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Human Skeletal Remains From Site OGSE-80, A Preceramic Site on the Sta. Elena Peninsula, Coastal Ecuador

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ABSTRACT

Recent excavations at a preceramic (6,000 B.C.) burial site on the coast of Ecuador discovered 65 burial features containing at least 192 individuals. These burials included complete articulated skeletons, as well as collections of non-articulated bones. Data are presented here on the skeletal content of each feature, demographic structure of the population, estimated living stature, artificial modifications of the skeleton, disease frequencies and morphological affinities with other Ecuadorean samples. Comparison with data from other sites shows little temporal change in living stature and in many skeletal measurements and observations. Temporal increases are revealed in the frequencies of many diseases, especially periosteal lesions, porotic hyperostosis, fractures, and dental disease, with related increases in mortality within most age groups. It is suggested that many of these temporal trends may be related to increased population density and to the increasing dependence on intensive agriculture.

Research in New World prehistoric skeletal biology increasingly calls for large, well documented skeletal samples to examine such important problems as the biological effects of intensive agriculture, prehistoric population relationships and evolution. Numerous large samples are now available for the early historic period and the recent prehistoric periods. Samples dating prior to 1,000 A.D. are much more uncommon and those that date from preceramic or preagricultural periods are quite rare, and are especially valuable in providing the early "link" in studies of biological temporal change.

Site 80, Vegas Complex, Sta. Elena Peninsula, coastal Ecuador has been identified as "preceramic" with radiocarbon dates clustering at about 6,000 B.C. (Stothert, 1977). Recent excavations at this site by Karen Stothert, sponsored by the Banco Central of Ecuador, identified 65 burial features concentrated within an approximately 200 square meter area. Analysis of these features reveals that at least 192 individuals are present; consequently the sample represents perhaps the oldest large human sample yet recovered in the New World. Excavation history and procedure, as well as preliminary interpretations of the site are presented by Stothert (1977). More detailed data are being assembled for a final report to be published by the Banco Central del Ecuador in Guayaquil. This report presents only biological information gleaned from analysis.

My involvement in this project began on July 18, 1978 when I was invited by Stothert and the Banco Central of Ecuador to immediately travel to Ecuador to advise on the further excavation and removal of the skeletons and to begin analysis. Due to the short notice of the invitation and previous commitments, I limited my participation at this time to about three weeks. With support from the Banco Central of Ecuador and the Smithsonian Institution, I travelled to Ecuador accompanied by my wife Maruja and Smithsonian research assistant Stephanie Damadio. During the 23 day period, from July 23 to August 15, we worked at the site and nearby laboratory, advising on the excavation and removal of the material, cleaning and restoring those skeletal materials which had been removed at that time, and taking initial data. After our departure, all additional skeletal material was sent to the Banco Central in Quito. It was then processed and examined by Maruja and me on two subsequent visits; December 20, 1978 to January 19, 1979 and June 21, 1979 to July 21, 1979. These research trips were also supported by the Banco Central of Ecuador and the Smithsonian Institution.

All of the bones were dry brushed until they were sufficiently clean to allow identification. Those that offered biological data were washed (water only) and reconstructed with an acetone soluble cement. Most bones were extremely fragmentary, which severely limited reconstruction and data collection.

When processing and data collection were complete, all material was placed in labeled plastic bags and packed within labeled cardboard cartons. At this time, the cartons are stored at the Banco Central in Quito, awaiting further curatorial attention and improved permanent storage.

Note that some skeletal material was removed from the site in 1971 and sent to the Smithsonian Institution. Site provenience was subsequently lost on this material, and now it can not be related spatially to the features reported here. For this reason data from this small sample are not included in the individual feature descriptions. Data on pathology from this material are included in the pathological section of this report.

Skeletal Inventory of Burial Features

The following is a detailed listing of the skeletal content of each burial feature. Numbers of each skeletal part present are only minimal determinations due to the fragmentary condition of the material. Whenever possible adult age estimates were made from the morphology of the pubic symphysis. When such observations were not possible, ages were estimated from dental attrition, cranial suture closure, and joint surface degeneration. Subadult ages were estimated from dental formation, utilizing the formation standards of Ubelaker (1978:112–113). When observations of dental formation were not possible, ages were estimated from long bone lengths or other size data. Estimates of sex were not attempted for subadults, but were made for adults whenever possible, using standard criteria. All methods used for sex and age estimation are summarized in Ubelaker (1978). Due to the fragmentation of most bones and considerable erosion on the periosteal surface of most long bones, it was not possible to utilize the microscopic method of estimating age at death.

The following description applies only to those burial features which were removed from the site for analysis. Complete information on all features will be presented by Stothert in a volume to be published in Ecuador.

Feature 1.—Large secondary burial. Adult bones present consist of six left and right humeri, six left and five right radii, five left and right ulnae, seven left and five right femora, four left and seven right tibiae, one left and four right fibulae, six left and five right clavicles, 10 left and nine right scapulae, six left and right temporals, four maxillae, six mandibles, six left and five right innominates, six first cervical vertebrae, six second cervicals, 13 other cervicals, 17 thoracic vertebrae, 17 lumbar vertebrae, one sacrum, one left capitate, six first metacarpals, four left and four right second metacarpals, one left and one right third metacarpal, 13 proximal hand phalanges, three middle hand phalanges, six left and four right calcanei, eight left and seven right tali, two left and one right cuboid, one left and one right foot navicular, two cuneiforms, two left and three right first metatarsals, four left and two right second metatarsals, three left and one right third metatarsals, three left and one right fourth metatarsals, three left and two right fifth metatarsals, four first foot phalanges and 36 ribs. The number of left scapulae indicates that at least 10 adults are present. Innominate morphology indicates that of these, at least two females and four males are present. Pubic symphysis morphology suggests ages at death of about 40 years for one male, and 35 years for two females.

Only the following subadult bones are present: right radius, left ulna, left femur, right temporal, and mandible. All bones probably originate from one individual. Dental formation data suggest an age at death of about nine months.

Feature 2.—According to field observations, this feature consists of a single primary skeleton, flexed on its right side. Detailed examination of the skeletal remains revealed that at least four adults and one child are present. The four adults are indicated by four right femora. Multiple adult individuals are also indicated by two left femora, two left and right tibiae, two mandibles, two innominates, two patellae, two left and three right tali and two adult crania. Both crania are male with estimated ages of 25 to 30 years and 35 to 45 years.

The subadult is represented by both humeri, the left ulna, both tibiae, one fibula, the right scapula, left ilium, right ischium, left pubis, right calcaneus and six vertebrae. Bone size suggests an age at death of about five years.

Feature 3.—This feature consists of an articulated adult and secondary, but tightly packed child. Both skeletons were left *in situ* for museum display. The secondary child appears to be relatively complete, except for the mandible. An isolated mandible was found nearby and removed for analysis. The mandible is very fragmentary with the following teeth present: right canine, left central incisor, left first molar and left third molar. The third molar had not reached the occlusal plane. The crown was complete, but the root was ¾ formed. One maxillary right central permanent incisor was present, displaying slight occlusal wear. The stage of formation of the third molar suggests an age at death of about 15 years.

Feature 4.—Flexed primary skeleton. The skeleton is generally complete, but missing both humeri, both clavicles and both scapulae. Long bone epiphyses are not united, indicating the individual is subadult. Dental formation data suggest an age at death of about 12 years.

Feature 5.—Flexed primary skeleton. Just the skull, mandible and rib fragments are present. Cranial morphology suggests female sex. Dental attrition data suggest an age at death of 30–35 years.

Feature 6.—Flexed primary skeleton. The skeleton is generally complete. Cranial and innominate morphology suggest male sex. The degree of dental attrition suggests an age at death of 25–30 years.

Feature 7.—Secondary burial. Two individuals are present: an adult and an adolescent. The adult is represented by both humeri, right ulna, left femur, both tibiae, both scapulae, both innominates, right patella, first cervical vertebra, second cervical vertebra, two 3–7 cervicals, four thoracics, three lumbars, sacrum, right hand navicular, both first metacarpals, six hand phalanges, four middle hand phalanges, one distal hand phalanx, left calcaneus, both tali, both cuboids, both naviculars, the first and second cuneiformes, the right fourth metatarsal, both proximal first foot phalanges, three 2–5 proximal foot phalanges and most of the skull. Cranial and pelvic morphology suggest male sex. Morphology of the pubic symphysis suggests an age at death of 40–45 years. An estimated maximum length of the right femur of 39.5 cm suggests a maximum living stature of 153 cm. The subadult is represented only by a right femur, the length of which suggests an age at death of 15 to 18 years.

Feature 8.—This is a very fragmentary skeleton found near the surface. Data are not available on position. Fragments of the following bones are present: right humerus, ulna, femur, right scapula and clavicle. No cranial fragments occur but the following teeth are present: mandibular right first, second and third molars, left canine, a premolar, second and third molars; maxillary right central incisor, one premolar, both second molars and both third molars. All teeth display slight occlusal wear, except the mandibular first molar which shows 50 percent dentin exposure. The extent of dental attrition generally suggests an age at death of 25 to 30 years. The robusticity of the femur suggests male sex. Some fragments show slight charring, indicative of exposure to fire.

Feature 9.—No bone preserved for analysis.

Feature 10.—Field notes describe one primary skeleton on its left side in flexed position. A concentration of human bones found 50 cm north of the skull of the primary skeleton is also included in this feature.

All bones are very fragmentary. The following is an inventory of bones present: one calvarium, two left humeri, one right humerus, one left and one right radius, two right ulnae (one large male?, one small female?), one left and one right femur, one left tibia, fibula fragments, one left scapula, one right maxilla, one left and one right mandible segments, hand and foot bone fragments and the following maxillary teeth: right lateral incisor, canine, both premolars, and all three molars; left canine, first premolar and all three molars. one molar of a second individual is present. The extent of dental attrition on the molars suggests an advanced age at death of 35 to 45 years. If field notes are correct, this would be the age of the primary skeleton. The other skeleton is adult, but no data are available for age determination.

One male and one female are present in this feature, as estimated from the comparative sizes of the left humeri and right ulnae. One femoral head displayed a maximum diameter of 39 mm, suggesting female sex. Since the skull is female also, it appears that the primary skeleton is female and the secondary deposit is male.

Feature 11.—Flexed primary skeleton. This skeleton is fragmentary, but generally complete. Innominate morphology suggests female sex. The extent of dental attrition suggests an age at death of 25 to 30 years. Maximum length of the right femur is 412 mm suggesting a living stature of 154 cm. An isolated right fourth metacarpal was found above the skull. This metacarpal and the right fifth metacarpal show unusual anterior curvature, and probably represent old healed fractures.

Feature 12.—Two primary skeletons. These young adult complete skeletons were not removed for analysis. Field examination revealed one is male and the other female.

Feature 13.—Flexed primary skeleton with secondary bone concentration. The articulated skeleton consists of the generally complete remains of a child. Of the major bones, only the left clavicle and left scapula are not present. Dental development suggests an age at death of about 11 years.

The secondary bone assemblage consists of the generally complete skeleton of an adult male. Of the major bones, only the left tibia is missing. Morphology of the pubic symphysis and the extent of vertebral osteophytosis and joint metamorphosis suggests an age at death of 40 to 45 years. A right tibia length of 400 mm suggests a living stature of 170 cm.

Feature 14.—Few isolated bones. No bones available for analysis.

Feature 15.—Few bones protruding from sidewall. No bones available for analysis.

Feature 16.—Flexed primary skeleton. This skeleton is fragmentary, but generally complete. Cranial morphology suggests female sex. Dental attrition suggests an age at death of greater than 40 years.

Feature 17.—Flexed primary skeleton. Cranial morphology of this generally complete skeleton suggests female sex. An age at death of 40 to 50 years is suggested by the stage of dental attrition and the union of cranial sutures. Estimated length of the left femur of 363 mm suggests a living stature of 141 cm.

Feature 18.—According to field notes, this feature represents a single skeleton, flexed on its right side. Fragments of nearly all bones of a single skeleton are present. All maxillary and mandibular teeth are present as well.

Cranial morphology suggests male sex, as does the robusticity of the long bones.

Attrition is advanced on most dental occlusal surfaces. On the central incisors through the first molars, dentin exposure is 100% of the crown surface. Dentin is exposed on 50% of the second molars. The vertebral bodies show no osteophytosis and the sagittal and lambdoidal sutures are open endocranially and ectocranially. Collectively, these data suggest an age at death of 35 to 40 years.

Four long bones were sufficiently complete for estimates of maximum length. The estimates are as follows: right humerus, 279 mm; left humerus, 270 mm; right ulna, 243 mm; right radius, 220 mm. The combined lengths of the right humerus and right ulna (52.2 cm) suggest a maximum living stature of about 159 cm, using Trotter and Gleser's formula for Mongoloid males (1958:120).

Feature 19.—Primary flexed skeleton. Adult skeleton not available for analysis.

Feature 20.—Field notes and a photograph indicate this feature consists of a single complete flexed primary skeleton on its right side. The material is very fragmentary but generally represents most bones of one adult. The skull was reconstructed and is complete except for the face. All maxillary teeth are present on the right side, but on the left, only the premolars and molars are present. The maxillary left canine and incisors are missing post-mortem. All mandibular teeth are present except the incisors, missing post-mortem and the right third molar, missing ante-mortem. Attrition is advanced with 100% dentin exposure on all teeth remaining, except the left maxillary third molar which shows only slight wear. The advanced attrition suggests an age at death of greater than 40 years. This age is also suggested by endocranial union of all vault sutures and ectocranial union of all, but part of the lambdoidal suture.

Cranial morphology suggests female sex.

The only pathological conditions observed were alveolar abscesses of the mandibular right first molar and the maxillary right first molar. The abscesses probably resulted from the excessive attrition of those teeth.

An estimated maximum length of the fibula of 316 mm suggests a living stature of about 154 cm using the formula of Trotter and Gleser for Mexican males (1958:120).

Feature 21.—Field observations record this feature as a single, flexed primary skeleton, on its left side. Laboratory analysis of the recovered bones reveals the extremely fragmentary, but generally complete remains of one adult. Teeth present are the following: mandibular right incisors; all left mandibular teeth; the maxillary right first incisor and canine; and all left maxillary teeth except the second premolar. The extent of dental attrition indicates an age at death of 35–40 years.

Male sex is suggested by cranial morphology and a femoral head diameter of 46 mm.

Feature 22.—Secondary burial. The following bones of a young adult female are present: right humerus, left radius, right ulna, right femur, left clavicle, first cervical vertebra, left fourth metacarpal, two proximal hand phalanges, right hand navicular, right second cuneiform, seven rib fragments, the skull and mandible. Cranial morphology suggests female sex. Lack of suture closure and dental attrition suggests an age at death of 20 to 30 years. An estimated length of the right femur of 350 mm suggests a living stature of 140 cm, using the formula of Genovés (1967:76).

Feature 23.—This feature represents a primary flexed adult skeleton lying on its left side. Most major bones of the skeleton are present, but all are very fragmentary. The only teeth present are the following: maxillary left canine, both premolars and the first molar; maxillary right canine and first molar. All display advanced attrition with 100% dentin exposure. The left second premolar displays an apical abscess and a carious lesion occurs on the left first premolar.

The reconstructed calvarium displays endocranial closure of all vault sutures, but little ectocranial closure. These data and the extent of dental attrition suggest an age at death of 35 to 45 years.

Cranial morphology and the size of the long bones suggest female sex.

An estimated length of a right tibia suggests a maximum living stature of 150 cm, using the formula of Genovés (1967:76) for Mexican females.

Except for the caries and dental abcess already mentioned, no pathological conditions were noted.

Feature 24.—This feature is described in field notes as a single primary skeleton flexed on its right side. All post-cranial remains were sent for radiocarbon analysis, after examination. The remaining skull is in poor condition but most of the skull, including the face was reconstructed. All teeth are present with no carious lesions. Alveolar abscesses occur with the mandibular right central and lateral incisors. Attrition is advanced, with 100% dentin exposure on all teeth from the central incisors through the first molars. The second molars display 75% dentin exposure and the third molars only 40%. The cranial vault shows endocranial fusion of the sagittal and lambdoidal sutures with partial ectocranial fusion of the sagittal suture. Collectively these data suggest an age at death of 40 to 45 years.

Cranial morphology suggests female sex.

An estimated right femur length of 413 mm suggests a living stature of about 154 cm, using the formulae of Genovés (1967:76).

Feature 25.—Large secondary burial containing some articulated skeletal parts and complete individuals. This feature number was assigned to a large collection of mostly disarticulated skeletal remains concentrated within an approximately 11 square meter area. Ten additional feature numbers were assigned to articulated skeletons, articulated parts of skeletons, or what appeared to be distinct groups of disarticulated bones. These features are 47, 49, 50, 54, 55, 56, 57, 58, 60, and 72 and are described separately under those numbers. Note also that since features 24, 39, 48, and 51 are located close to feature 25, some mixing of bones with feature 25 may have occurred.

Initially in the excavation, feature 25 was considered to be one large feature. Later a spatial division was detected within the feature and numbers 25a and 25b were assigned to the separated concentrations. In this analysis all material labeled as 25 was included in either 25a or 25b, as determined by the grid numbers (location) of the bones when they were removed. Analyses of these two units are presented separately.

25a.—This section of feature 25 (not including bones assigned to separate features) contained at least 17 adults and 21 subadults. Adult bones present consist of the following: 12 left and 13 right humeri, 14 left and 14 right radii, 11 left and 13 right ulnae, 10 left and 12 right femora, nine left and 11 right tibiae, three left and three right fibulae, 11 left and 14 right clavicles, nine left and nine right scapulae, 17 left and 16 right temporals, seven left and six right maxillae, 13 mandibles, one gladiolus, five left and five right innominates, seven left and eight right patellae, six first cervical vertebrae, four second cervical vertebrae, ten other cervical vertebrae, 30 thoracic vertebrae, 11 lumbar vertebrae, one sacrum, seven left and twelve right hand naviculars, three left and five right lunates, two pisiforms, two left and two right greater multangulars, one left lesser multangular, four left and four right capitates, three left and three right hamates, six left and five right first metacarpals, seven left and eight right second metacarpals, five left and five right third metacarpals, three left and four right fourth metacarpals, four left and three right fifth metacarpals, 69 proximal hand phalanges, 44 middle hand phalanges, 24 distal hand phalanges, two left and two right calcanea, four left and three right tali, two right cuboids, eight left and seven right foot naviculars, one right first cuneiform, two left and two right second cuneiforms, three left and three right third cuneiformes, eight left and eight right first metatarsals, six left and six right second metatarsals, four left and five right third metatarsals, five left and six right fourth metatarsals, eight left and five right fifth metatarsals, 15 first proximal foot phalanges, 33 other proximal foot phalanges, 13 middle foot phalanges, eight distal first foot phalanges, one other distal foot phalanx, two coccygeal vertebrae and 37 ribs.

Of the 17 adults present, at least five are males and five are females. Ages at death for the males are estimated from dental attrition and cranial suture closure to be as follows: 30–35, 30–40, 35–50, 40–45, and 40–50. By the same criteria, female estimates are 20–30, 30–35, 40–45, 40–50, and 45–55. One skull of undetermined sex was estimated to be between 30 and 35 years.

Stature estimates were possible for only one male and two females. One male left femur measured 420 mm which suggests a living stature of about 159 cm (Genovés, 1967:76). Female femora lengths of 380 mm and 400 mm suggest living statures of about 146 cm and 151 cm (Genovés, 1967:76).

Subadult remains from 25a consist of at least 21 individuals represented by the following bones: two left and one right humerus, three left and two right ulnae, two left and three right femora, two left and three right tibiae, one right clavicle, one left scapula, 21 left and 16 right temporals, one left and four right maxillae, five left and five right mandibles, one right ilium, one left ischium, one right pubis, one calcaneus, three ribs, 37 carpal and tarsal bones, and 43 vertebrae halves.

The following ages at death were assigned to the subadults based on observations of dental formation and temporal morphology: 11 individuals between birth and one year, five between one and two years, one at three years, one at four years, one at five years, one at seven years, and one at nine years.

25b.—At least 18 adults and 19 subadults are represented in this aspect of feature 25. Adult bones present are the following: 16 left and 16 right humeri, eight left and 10 right radii, seven left and 11 right ulnae, 13 left and 10 right femora, 10 left and 11 right tibiae, six fibulae, 13 left and 12 right clavicles, nine left and seven right scapulae, 18 left and 17 right temporals, three left and three right maxillae, 11 left and 10 right mandibles, three left and three right innominates, five left and six right patellae, two first cervical vertebrae, 10 second cervical vertebrae, five other cervical vertebrae, 13 thoracic vertebrae, 15 lumbar vertebrae, one sacrum, one left and three right hand naviculars, four left and two right lunates, one left and two right greater multangulars, one left and one right capitate, one right hamate, three left and two right first metacarpals, two left and three right second metacarpals, one left and one right third metacarpals, one left fourth metacarpal, two left and four right fifth metacarpals, 39 proximal hand phalanges, 23 middle hand phalanges, six distal hand phalanges, five left and five right calcanea, seven left and six right tali, one right cuboid, one left and one right navicular, three right second cuneiforms, one left third cuneiform, five left and four right first metatarsals, five left and two right second metatarsals, five left and two right third metatarsals, two left and one right fourth metatarsals, six left and 10 right fifth metatarsals, eight first proximal foot phalanges, 15 other proximal phalanges, six middle foot phalanges, three distal first foot phalanges and 26 ribs.

Cranial morphology indicates that at least five males and seven females are present. Dental attrition data suggest the following ages at death: seven between 20 and 30 years, three between 30 and 40 years and one between 40 and 50 years. No stature estimates are possible.

Nineteen subadults are represented in feature 25b by the following bones: three left humeri, two left and two right femora, one left tibia, 18 left and 19 right temporals, one left and two right maxillae, one mandible, one left ilium, one right ischium, one rib, seven carpal and tarsal bones, and 11 vertebrae.

The following ages at death are indicated by the morphology of temporals and long bones: 11 between birth and one year, four between one and two years, two between two and three years, one about four years and one between 13 and 16 years.

Feature 26.—Not a burial.

Feature 27.—According to field notes, this feature consists of a "pile of human hip bones." Analysis of the recovered material revealed the following adult bones: one left and one right clavicle, one left and two right innominates, and one left sacrum. All three innominates are from males. One pair of pubic bones is present. Analysis of the morphology of the pubic symphysis, using the system of McKern and Stewart (1957) suggests an age at death of about 21 years.

Subadult remains consist of one left and one right ilium. Estimated maximum diameters of 105 mm suggest an age at death of about 7.5 years, using the data of Merchant and Ubelaker (1977). No determination of sex can be made reliably.

Feature 28.—Primary flexed skeleton. Not available for analysis.

Feature 29.—This feature was found as a secondary bone assemblage with no apparent bone articulation. The following adult bones are present probably from a single individual: one left humerus, one left and one right radius, one left and one right ulna, one left and one right femur, one left and one right tibia, one right clavicle, one left and one right scapula, one mandible, one left innominate, one first cervical vertebra and fragments of other cervical vertebrae, one left calcaneus, one left and one right talus, one left first metatarsal, one right fourth metatarsal, many rib fragments, and many indistinguishable fragments. No cranial fragments are present. The following mandibular teeth are present: the three right molars, the right second premolar, right canine, right lateral incisor, right central incisor. Enamel exposure due to attrition is 100% on the incisors, canine, premolar and first molar; 40% on the second molar and slight on the third molar. This suggests an age at death of 35–40 years.

Morphology of the innominate and a maximum left femoral head diameter of 41 mm suggests female sex.

An estimated maximum length of the tibia of 34.5 cm suggests a maximum living stature of about 141 cm (Genovés, 1967:76).

No dental caries or other pathological conditions were observed.

The bone assemblage also contained the following subadult bones: one left and one right humerus, one left radius, one left and one right ulna, one left and one right femur, one left and one right tibia, left and right portions of a mandible and one left talus. Mandibular teeth present are the following: the left deciduous molars, one permanent right first molar, the permanent right central and lateral incisors, one permanent second molar (crown complete, root ¼) and one premolar (crown complete, root ¼). The stage of dental formation suggests an age at death of about eight years.

Feature 30.—This feature consists of a single adult primary skeleton, found on its right side in flexed position. The skeleton is fragmentary but generally complete.

Deep sciatic notches on the ilia, small mastoid processes of the temporals and other morphology suggests female sex.

Attrition is extreme on all teeth present, with most of the crowns worn away. The following mandibular teeth are present: right canine, premolars and part of the first molar; left canine, premolars and molars. Missing ante-mortem are the right ½ of the first molar, second molar and third molar; left incisors and ½ of the first molar. Maxillary teeth present are the following: left incisors, canine, and first premolar; right first and third molars. All left teeth not present are missing ante-mortem. Right maxillary teeth missing ante-mortem are the second premolar and second molar. The advanced attrition, cranial suture closure, and stage three (Ubelaker, 1978:60) osteophytic lipping on the cervical vertebrae suggest an age at death of greater than 45 years.

An estimated maximum length of the left tibia of 30.5 cm suggests a maximum living stature of 144 cm, using the formula of Genovés (1967:76).

Except for the teeth missing ante-mortem, no other pathological conditions were noted.

Feature 31.—Two isolated crania and one adult first proximal foot phalanx comprise this feature. The adult skull is relatively complete with the following maxillary teeth present: right lateral incisor, first premolar and second molar; left second and third molars. The teeth display no caries and no abscesses, but all have advanced attrition with 100% dentin exposure. The sagittal and lambdoidal sutures are closed endocranially and ectocranially while the coronal suture is open. The data on suture closure and attrition suggest an age at death of about 35–40 years.

Morphology of the adult skull suggests female sex.

The subadult skull consists only of vault fragments and one deciduous maxillary first molar. The crown is complete on this molar with no occlusal wear, suggesting an age at death of 12 to 18 months.

Feature 32.—Field notes indicate this feature contains one individual flexed on its right side. Skeletal analysis revealed one very fragmentary adult skeleton. The skull and mandible were reconstructed and contained the following teeth: maxillary right central incisor, left canine, and first premolar; mandibular right incisors, canine and premolars. Missing ante-mortem were the mandibular right molars; mandibular left lateral incisor, canine, first premolar and all three molars; maxillary right lateral incisor and first molar; and maxillary left second premolar and first molar. No caries and no abscesses were observed.

Morphology of the cranium and long bones suggests female sex.

An age at death of greater than 45 years is suggested by complete endocranial closure of all vault sutures, ectocranial closure of all vault sutures except part of the lambdoidal, and loss of nearly all tooth crowns due to attrition.

Feature 33.—Flexed primary skeleton with secondary burial.

The articulated skeleton is generally complete except for the clavicles, right scapula, skull and mandible. The large size of the skeleton suggests male sex. Extensive osteophytosis on the vertebrae suggests an age of 45 to 60 years.

The secondary skeleton is that of a young adult female. The following bones are present: both humeri, left radius, left ulna, both femora, left scapula, the skull and mandible, left patella, right calcaneus, left talus, right first metatarsal, and both fifth metatarsals. Some charring occurs on most bones.

A subadult skull was found with the remains of the articulated skeleton. No teeth are present but the size suggests an age between seven and 12 years.

Feature 34.—Secondary burial. The large secondary skeletal deposit was analyzed as one unit. At least 24 individuals are present: 18 adults and six subadults. The 18 adults are indicated by right humeri. Frequency of other adult bones varied considerably with 16 indicated by mandibles, 15 by temporals, 14 by femora, 14 by ulnae, 10 by tibiae, and only eight by radii. Morphology of the crania and innominates present suggests at least six males and six females are present. Two fifth metacarpals and two left radius fragments show red coloring. One long bone fragment shows evidence of post-mortem burning.

At least six subadults are represented, with temporals and mandibles occuring with greatest frequency. Dental data suggest the following ages: birth, 9 months, 3 years, 7 years, 8 years and 15 years.

Feature 35.—Flexed primary skeleton. Some cranial fragments were mistakenly sent to Florida with the faunal remains. All remaining skeletal materials are those of a single subadult skeleton. Bones present are the following: left and right humeri, right radius, left and right ulna, left femur, right clavicle, 16 ribs, 14 neural arches of vertebrae, one occipital fragment and one deciduous right lateral incisor showing slight wear. The incisor and an estimated maximum length of a left femur of 120 mm, suggest an age at death of about 18 months.

Feature 36.—Flexed primary skeleton. All bones present appear to belong to one subadult skeleton. Bones present are the following: both humeri, both radii, both femora, both tibiae, both fibulae, both maxillae and both sides of the mandible. All mandibular teeth are present except the third molars. Maxillary teeth present are the following: left lateral incisor (peg-shaped), canine, one premolar, first molar, and third molar; right central incisor, lateral incisor (peg-shaped) canine, one premolar, first molar, second molar and third molar. One deciduous maxillary second molar is also present, with extreme occlusal wear and nearly complete loss of roots. The dental calcification data suggest an age at death of 10 years. One maxillary canine shows hypoplasia at base of crown. No other pathological condition was noted.

Feature 37.—Flexed primary skeleton. This generally complete skeleton represents an adult. Female sex is suggested by innominate morphology. The extent of dental attrition suggests an age at death between 40 and 60 years. The estimated length of the left femur (39.4 cm) indicates a living stature of 149 cm (Genovés, 1967:76). A red stain occurs on both internal and external surfaces of the skull.

Feature 38.—Flexed primary skeleton. This skeleton is complete and relatively well preserved. Female sex is indicated by innominate morphology. Pubic symphysis morphology, cranial suture closure and the lack of joint arthritic change suggest an age at death of between 40 and 50 years. Maximum lengths of the right humerus (30.6 cm) and left radius (23.7 cm) indicate a living stature of about 165 cm using Trotter and Gleser's formulae for Mongoloids and Mexicans.

Feature 39.—Flexed primary skeleton. Two adults and one subadult are represented by skeletal remains labeled from this feature. Most of the adult remains are from an adult male. Extreme dental attrition suggests an age at death between 45 and 65 years. The estimated right femur length of 43.4 cm suggests a living stature of about 162 cm.

The second adult is represented only by a right ulna, right hand navicular, right capitate, right hamate, both tali, and a right foot navicular. Estimates of sex, age and stature cannot be made.

The subadult is represented only by one thoracic vertebra and one deciduous maxillary second molar with slight occlusal wear. These bones suggest an age between four and six years.

Feature 40.—No field notes available. Most bones present are from one infant skeleton. Several small adult bones are present as well. Subadult bones are the following: both humeri, right femur, both tibiae, one fibula, right clavicle, both temporals, both maxillae, fragments from both sides of the mandible, five neural arches of vertebrae and one carpal or tarsal.

Dental formation data suggest an age at death of one year.

The following adult bones are present: right capitate, one middle hand phalanx, one mandibular molar with crown nearly worn away, and several cranial fragments.

Feature 41.—Flexed primary skeleton. This complete skeleton consists of an adult female (cranial morphology). Union of cranial sutures and dental attrition suggest an age at death of 30 to 40 years. Estimated length of the right femur of 350 mm suggests a living stature of 138 cm. Red coloring occurs on the skull and some long bones.

Feature 42.—Secondary burial. This burial consists of the following bones of probably one adult: Left humerus, right ulna, both femora, tibia fragments, both temporals and four teeth. Small mastoid processes on the temporals suggest female sex. Dental attrition indicates an age between 35 and 45 years.

Feature 43.—Secondary burial. This secondary bone concentration contains at least one adult and one subadult. The adult consists of both humeri, both radii, left ulna, right femur, right tibia, both fibulae, left clavicle, both scapulae, mandible, left innominate, right patella, three thoracic vertebrae, left hand navicular, left first and second metatarsals, right calcaneus, left cuboid, right navicular, left second cuneiform, right third cuneiform, right fifth metatarsal and most of the cranial vault. Cranial morphology suggests male sex. Lack of union of cranial vault sutures indicates an age between 20 and 30 years. An estimated left fibula length of 34.5 cm suggests a stature of 163 cm, using Trotter and Gleser's 1958 formulae for Mongoloids and Mexicans.

The subadult is represented only by two thoracic vertebrae and one maxillary right permanent canine. The extent of development of the canine suggests an age of about six years.

Feature 44.—Secondary burial. Only fragments of an adult mandible and right innominate are present. Morphology of both bones suggests male sex. The extreme dental attrition suggests an age at death of 40 to 60 years.

Feature 45.—Secondary burial. The following bones of a single adult male are present: both scapulae, mandible, three vertebrae, five hand and foot bones and three ribs. An age of between 30 and 40 is suggested by dental attrition.

Feature 46.—Flexed primary skeleton. This skeleton is generally complete. Innominate morphology suggests male sex. Dental attrition and cranial suture closure suggests an age between 30 and 40 years. Maximum length of the left femur (43.7 cm) suggests a living stature of about 163 cm (Genovés, 1967:76).

Feature 47.—Articulated bones of thoracic area and other disarticulated bones. Two adults are represented by first cervical vertebrae. The following additional adult bones represent one adult: right humerus, right radius, left ulna, right femur, right tibia, left clavicle, right scapula, maxilla, mandible, gladiolus, right innominate, left patella, second cervical vertebra, four other cervical vertebrae, nine thoracics, three lumbars, 24 hand bones, 33 foot bones and 14 ribs. Age at death for one adult is estimated at 25–35 years. No estimates of sex or additional age estimates are possible.

One subadult is represented by one thoracic vertebra, one mandible and 11 teeth. Dental formation suggests an age at death of 1.5 years.

Feature 48.—Secondary burial. The following adult bones of probably one individual are present: left temporal, right innominate, and 15 hand and foot bones. Innominate morphology suggests male sex. Dental attrition suggests an age between 25 and 35 years.

Feature 49.—Flexed primary skeleton. Only both temporals, mandible and several long bone fragments are present. An estimated tibia maximum length of 75 mm suggests an age at death between birth and six months.

Feature 50.—Flexed primary skeleton. A nearly complete subadult skeleton is present. Dental formation data suggest an age at death of about eight years.

Feature 51.—Flexed primary skeleton. This feature represents a mostly complete skeleton with an estimated age at death of about 15 years. An adult right radius is also present. According to field notes a "finger bone" was found above the skull. The bone is a middle second, third, fourth or fifth hand phalanx.

Feature 52.—Not a burial.

Feature 53.—Not a burial.

Feature 54.—Flexed primary skeleton. The following bones of one subadult are present: right humerus, left and right radius, left femur, both tibiae, right fibula, right clavicle, both temporals, six ribs, five carpals and tarsals and four vertebrae. Dental formation data suggest an age at death of about nine years.

Feature 55.—Partially articulated skeleton. The following bones of this 28 to 30 year old male are present: right ulna, right femur, both tibiae, left fibula, both scapulae, both innominates, right patella, three lumbar vertebrae, right fourth metacarpal, four proximal hand phalanges, left calcaneus, left second metatarsal, right third metatarsal, right fifth metatarsal, one proximal first foot phalanx, and one middle foot phalanx.

Feature 56.—Group of disarticulated bones. At least three adults and one infant are represented within this group. Adult bones present include two left and two right humeri, one left and one right radius, one left and two right ulnae, one left and one right tibia, one left and one right fibula, one left and one right clavicle, two left and one right scapula, one left temporal, three mandibles, one left and one right innominate, three lumbar vertebrae, one sacrum, nine hand and foot bones and 15 ribs. At least one male and one female are present. Dental attrition on two mandibles suggests ages at death of 25 to 30 years and 28 to 33 years.

One right humerus length of 282 mm (probably from a male) suggests a living stature of about 159 cm, using the formulae of Trotter and Gleser (1958:120) for Mongoloid males. Using the same formulae, the estimated length of a probable female right humerus (273 mm) suggests a living stature of about 156 cm.

One infant right temporal is also present.

Feature 57.—Articulated thoracic area of skeleton. The following bones of a 25 to 30 year old male are present: right humerus, right radius, left ulna, left tibia, both temporals, the mandible, two lumbar vertebrae, one proximal and one middle hand phalanx and three ribs.

Feature 58.—Secondary bone deposit. The following bones of one 30 to 35 year old male are present: both humeri, both radii, both ulnae, both tibiae, one fibula, left clavicle, both scapulae, mandible, left innominate, left hand navicular, three proximal hand phalanges, one middle hand phalanx, one third metatarsal, one proximal first foot phalanx, one other proximal foot phalanx, and eight ribs.

Feature 59.—Primary skeleton. Only the following adult bones are present: one right radius, two right scapulae, one left lunate, one proximal hand phalanx, one distal hand phalanx, one left and one right talus, one left foot navicular and one middle foot phalanx. Attrition on teeth present suggests an age at death for one adult of 25 to 30 years.

Feature 60.—Possible articulated subadult skeleton. One infant temporal and the following adult bones are present: one left and one right humerus, one left femur, one left clavicle, one right scapula, one left and one right temporal, one left and one right maxilla and one mandible. Morphology of the skull suggests female sex. An age at death of 25 to 30 years is indicated by the dental attrition.

Features 61, 62, 63, and 64.—Not burials.

Feature 65.—Secondary burial. At least two individuals are represented by the following bones: left ulna, left femur, left and right tibia, left and right scapula, left and right temporal, left and right maxilla, a mandible, left and right innominate, right patella, 10 vertebrae, two left and one right calcaneus, and four other foot bones. Most bones are from an adolescent male, age 17 to 19 years. Epiphyses are not united on the proximal and distal left femur, but union does occur on the distal tibia.

The second individual is represented by the left calcaneus and maxilla.

Slight wear on a third molar suggests an age between 23 and 28 years.

Feature 66.—Secondary burial. The following bones of a single adult individual are present: left humerus, right femur, both tibiae, left scapula, both temporals, mandible, left fifth metacarpal, and left navicular. Cranial morphology suggests female sex. Dental attrition indicates an age at death between 45 and 60 years.

Feature 67.—Flexed primary skeleton. Innominate morphology indicates this generally complete skeleton is female. Dental attrition data suggest an age at death of 25 to 30 years.

Feature 68.—Flexed primary skeleton. This generally complete skeleton is that of a child of about eight years. No estimate of sex can be made.

Feature 69.—Not a burial.

Features 70 and 71.—Not excavated.

Feature 72.—Flexed primary skeleton. This fragmentary, but generally complete skeleton is adult. The small size of all bones suggests female sex. Dental attrition data suggest an age at death of between 40 and 60 years.

Features 73, 74 and 75.—Not burials.

Feature 76.—Secondary burial. Two individuals are represented: one adult and one child. The adult is represented by both humeri, the left ulna, both femora, both temporals, the mandible, and six vertebrae. The small size of the bone suggests female sex. Dental attrition data indicate an age at death of between 35 and 45 years.

The subadult is represented only by the left humerus, left femur, both temporals, the mandible and other long bone fragments. Dental development data indicate an age at death of about three years.

Feature 77.—Flexed primary skeleton. The incomplete skeleton of an adult female is present. Leg bones are missing. Dental attrition data indicate an age at death of between 40 and 60 years.

Bone Representation

The above described skeletal analysis of 61 burial features suggests that at least 192 individuals are represented. This tabulation assumes that individual skeletons are not represented in more than one feature. In fact, there probably has been some mixing, especially among those features associated with 25a and 25b. The effect of such possible comingling on bone counts is offset by the fact that due to excessive fragmentation, the individual bone counts are minimal. The data show that primary burials contained both sexes and all ages. Secondary burials ranged from several bones of single individuals to large communal burials of as many as 38 persons (feature 25a).

The pattern of bone representation within the secondary burials is similar to that reported for other large secondary burials (Ubelaker, 1974; Ubelaker, in press). Among adults, the temporal bone, particularly the durable petrous portion, is present in greatest frequency, followed by the largest long bones and the mandible. For the most part, these frequencies reflect the ability of the bone to survive, rather than cultural selection of bones to be buried, although the latter may also be a factor.

The subadult individual bone representation clearly reflects the effects of decomposition and fragmentation. Among subadult bones within feature 25 and 11 associated other features, 41 individuals are represented by the petrous portion of the temporal, while only seven are represented by other bones. Since the sample is so effected by preservation factors, the effects of cultural selection on the types of bones buried can not be detected.

Although numbers of specific bones have been effected by preservation, it does not appear that the sample is greatly biased. The sample contains both adults (122) and subadults (70). Adult skeletons that can be sexed show a relatively even representation of males (55) and females (63). As expected, ages of the subadult skeletons are mostly less than three years.

Artificial Modifications of the Skeleton

No examples of cranial deformation were found, although many skulls were so damaged that observations on cranial shape were not possible. At least 55 crania were reconstructed to the extent that such observations were possible and none of these show any evidence of deformation. This supports Munizaga's (1976) suggestion that artificial deformation did not begin in Ecuador until about 2000 B.C.

Examples of artificial dental modification and metatarsophalangeal alterations also were not found. The latter occurred with relatively high frequencies in Ayalán (coastal Ecuador) females (Ubelaker, 1979) and probably reflects habitual kneeling posture.

Living Stature

Estimates of living stature were made for 8 males and 14 females. When measurements of the femur and tibia were available, estimates were made using the formulae of Genovés (1967). Trotter and Gleser's 1958 formulae were employed when available measurements were from other long bones. Male statures range from 153 cm to 170 cm and average 161 cm. This is slightly taller than the 159 cm stature of the Late Integration Period Ayalán urn and non-urn features (Ubelaker, in press); but shorter than that recently suggested for a Valdivia sample from Real Alto (Klepinger, unpublished manuscript). Female statures ranged from 138 to 165 cm with a mean of 149 cm. The mean is the same as that found in both Ayalán samples and only one cm shorter than that of Valdivia.

Measurements and Observations

Non-metric observations were recorded on the crania and mandibles (Table 1) using the same techniques as employed in analyzing the Ayalán sample (Ubelaker, in press). Females show higher frequencies of frontal grooves, and supraorbital foramina, while males have more wormian bones. Other sex differences are not pronounced.

Interpopulation comparison is limited to the Ayalán sample, since data are not available for others. The Sta Elena sample shows a greater frequency of squamoparietal synostosis (9 percent) than found in the Ayalán urn (2 percent) or non-urn (0 percent) samples. The Ayalán urn sample shows a higher frequency of frontal grooves, infraorbital sutures, and wormian bones. Other differences between the samples are either negligible or are based on such small sample sizes that comparison is meaningless. The usefullness of these observations in assessing biological relationships within Ecuador and neighboring areas must await additional comparative data from other samples and larger sample sizes.

Summary statistics on cranial and mandibular measurements are presented in Table 2. As expected, most male measurements and indices are larger than those of females. Male and female mean cranial indices are mesocranic, although they range from dolichocranic to brachycranic in males and even hyperbrachycranic in females. The mean porion height index is well within the high range for both males and females.

Table 1.—Frequency of non-metric observations within the Sta. Elena sample.

	Males		Females		Both Sexes	
Observation	n	Percent present	n	Percent present	n	Percent present
Mylohyoid bridge	10	0	24	0	81	2
Accessory mental foramen	11	0	27	0	66	0
Frontal groove	31	0	42	17	83	8
Supraorbital foramen	29	31	39	41	88	30
Trochlear spur	9	0	17	0	26	0
Accessory optic canal	2	0	4	0	6	0
Infraorbital suture	0	0	4	0	4	0
Os Japonicum trace	0	0	2	0	2	0
Wormian bones	34	26	36	0	74	12
Parietal process of temporal squama	11	0	27	0	40	0
Squamoparietal synostosis	23	4	40	13	65	9
Auditory exotoses	16	0	39	0	109	0
Pharyngeal fossa	1	0	4	0	5	0
Paracondylar process	2	0	5	0	7	0
Intermediate condylar canal	2	0	3	0	5	0
Odonto-occipital articulation	1	0	3	0	4	0
Hypoglossal canal divided	2	0	2	0	4	0
Post condylar canal absent	2	0	4	0	6	0
Marginal foramen of tympanic plate	8	13	30	3	58	5
Tympanic plate dehiscence	10	20	37	16	85	24
Foramen in lateral pterygoid plate	0	0	4	0	4	0
Pterygobasal bridge	0	0	2	0	2	0
Foramen spinosum incomplete	0	0	2	0	2	0
Pterygospinous bridge	0	0	2	0	2	0
Maxillary third molar	9	78	10	100	31	94

Table 2.—Summary statistics of Sta. Elena cranial and mandibular measurements and indices.

	Males				Females			
Measurement or Index	n	Mean	S.D.	Range	n	Mean	S.D.	Range
Auricular height	6	121.7	5.7	112–128	17	117.2	6.2	100–127
Porion to bregma	6	120.5	6.5	111–128	16	113.2	6.9	94–124
Length	16	181.8	8.6	171–202	26	173.8	5.4	163–186
Breadth	15	140.7	7.2	130–156	24	138.0	7.0	125–152
Basion—bregma	1	139.0	—	—	3	130.7	9.5	120–138
Basion—porion	1	32.0	—	—	3	38.0	6.1	34–45
Minimum frontal breadth	12	94.6	5.5	84–104	20	89.8	4.6	83–95
Upper facial height	—	—	—	—	3	68.3	9.6	58–77
Facial width	—	—	—	—	5	129.4	3.5	125–133
Nasal height	—	—	—	—	2	46.0	5.7	42–50
Nasal breadth	—	—	—	—	4	28.3	6.3	22–37
Orbital height	—	—	—	—	4	35.5	6.6	31–45
Orbital breadth	—	—	—	—	5	38.2	1.6	36–40
Maxillo—alveolar length	—	—	—	—	5	53.2	3.3	48–57
Maxillo—alveolar breadth	—	—	—	—	6	56.2	4.8	52–64
Palatal length	—	—	—	—	5	43.0	4.7	38–48
Palatal breadth	—	-	—	—	6	38.5	1.5	37–41
Bicondylar breadth	1	115.0	—	—	5	117.4	4.1	112–120
Bigonial breadth	1	108.0	—	—	8	94.8	5.4	88–101
Height of ascending ramus	6	61.0	4.2	55–66	13	56.2	3.1	52–62
Minimum breadth ascending ramus	11	33.4	5.8	27–49	15	30.2	2.9	26–35
Height mandibular symphysis	7	34.6	3.7	30–41	10	32.9	2.3	29–36
Facial height	—	—	—	—	2	107.0	11.3	99–115
Cranial index	14	77.3	3.8	69–84	23	79.0	4.6	71–86
Mean porion height index	6	76.5	2.3	73–79	15	73.6	2.8	69–78

More data are available for interpopulation comparison using measurements than with non-metric observations, however small sample sizes and inconsistency in techniques limit any resulting conclusions regarding population affinities. Comparison (Table 3) is possible with the Real Alto Valdivia III phase sample, dating about 2920 B.C. to 2770 B.C. (Klepinger, 1979 and unpublished manuscript), Buena Vista, Valdivia C sample dating about 1400 to 2000 B.C. (Munizaga, 1965), the Ayalán non-urn sample (500 B.C.–A.D. 1155) and the Ayalán urn sample (A.D. 730–A.D. 1600), (Ubelaker, in press). Compared to these samples, Sta. Elena males show larger mean values for the mean porion height index, auricular height, porion-bregma height, cranial length, basion-bregma height, basion-porion height, minimum frontal breadth and bigonial breadth. Male crania from Sta. Elena have the smallest mean value in bicondylar breadth.

Sta. Elena females show the largest mean values for cranial length, bigonial breadth, height of the mandibular ascending ramus, and height of the mandibular symphysis. Females from Sta. Elena show the smallest mean values for the minimum breadth of the mandibular ascending ramus, auricular height; and porion-bregma height.

When the samples are arranged temporally, the data suggest a gradual increase in cranial width and a decrease in cranial length and height. This is especially apparent in males, but also detectable in females. Of course, confirmation of this trend must await larger, better preserved samples from other sites.

It is especially difficult to assess biological relationships from such small and incomplete samples. Mean values for only four measurements or indices (cranial length, cranial breadth, minimum frontal breadth, and cranial index) are available for all five of the coastal Ecuador samples discussed here. Since complete sets of data are not available for even these four variables, multivariate statistics are not applicable. A crude assessment of biological affini-

Table 3.—Comparison of mean values of cranial and mandibular measurements and indices among five skeletal samples from coastal Ecuador.

Measurement	Sta. Elena		Real Alto		Buena Vista		Ayalán Non-urn		Ayalán Urn	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Auricular height	122	117	—	—	—	—	120	120	121	118
Porion to bregma	121	113	—	—	120	114	117	116	117	114
Length	182	174	176	173	179	172	171	165	172	165
Breadth	141	138	140	133	145	146	143	142	148	143
Basion—bregma	139	131	134	127	—	—	—	—	131	130
Basion—porion	32	38	—	—	—	—	—	—	16	17
Minimum frontal breadth	95	90	92	89	91	94	93	93	92	89
Upper facial height	—	68	—	—	—	—	—	—	71	66
Facial width	—	129	—	—	—	—	—	—	136	130
Nasal height	—	46	—	—	—	—	—	—	51	49
Nasal breadth	—	28	—	—	—	—	—	—	24	24
Orbital height	—	36	—	—	—	—	—	—	35	35
Orbital breadth	—	38	—	—	—	—	—	—	39	40
Maxillo—aveolar length	—	53	—	—	—	—	52	57	53	50
Maxillo—aveolar breadth	—	56	—	—	—	—	—	—	66	60
Palatal length	—	43	—	—	—	—	—	—	49	43
Palatal breadth	—	39	—	—	—	—	—	—	40	39
Bicondylar breadth	115	117	123	115	—	—	120	110	121	120
Bigonial breadth	108	95	95	83	—	—	101	91	101	92
Height of ascending ramus	61	56	60	52	—	—	62	55	60	54
Minimum breadth of asc. ramus	33	30	—	—	—	—	34	33	34	32
Height of mandibular sym.	35	33	33	32	—	—	35	30	35	31
Facial height	—	107	—	—	—	—	116	—	121	107
Cranial index	77	79	81	77	80.7	84.8	87	85	86	87
Mean porion height index	77	74	—	—	76.0	71.5	75	75	74	74

ties among these samples can be made however, by calculating the percentage difference between the mean value of each variable in the Sta. Elena sample and the same variable for each of the other samples. For males, these differences total 12 for the Sta. Elena-Real Alto comparison; 14 for Sta. Elena-Buena Vista; 22 for Sta. Elena-Ayalán, non-urns; and 25 for Sta. Elena urns. The comparison of course does not consider sample size and variability around the mean, and thus is only a very crude and possibly inexact measure of sample relationships. The comparison does tentatively suggest closest affinity with Real Alto, followed closely by Buena Vista, and then the two Ayalán samples. Since this ordering also approximates the known temporal relationships, it may have meaning.

Females reveal the same pattern. Comparisons with the four other samples show the following differences: Real Alto 9, Buena Vista 19, Ayalán non-urns 20, and Ayalán urns 20.

Demography

Accurate demographic reconstruction from human skeletal remains is dependent upon adequate sampling of the prehistoric population described, and accurate age determination. This sample appears to contain individuals in all age categories and both sexes, however subtle sampling problems may exist, but remain undetected. The population may not have buried all types of individuals in the cemetery or in the excavated part of the cemetery. Preservation may have affected the proportions of subadults present. Erosion and non-professional excavation prior to 1971 may also have produced undetected sources of error. Age determination is accurate within this sample until the age of about 40 years. After that age, accuracy diminishes considerably, especially since estimates from cortical thin sections are not possible. Ages of old adults were estimated to be between 50 and 60 years, although it is certainly possible that some may be older.

Table 4.—Life table, reconstructed from the Sta. Elena skeletal sample.

x	Dx	dx	lx	qx	Lx	Tx	e^0x
0–.9	28	15	100	.150000	93	2538	25
1.0–4.9	19	10	85	.117647	320	2445	29
5.0–9.9	13	7	75	.093333	358	2125	28
10.0–14.9	5	2	68	.029412	335	1767	26
15.0–19.9	5	2	66	.030303	325	1432	22
20.0–24.9	5	2	64	.031250	315	1107	17
25.0–29.9	36	19	62	.306452	263	792	13
30.0–34.9	15	8	43	.186047	195	529	12
35.0–39.9	19	10	35	.285714	150	334	10
40.0–44.9	21	11	25	.440000	98	184	7
45.0–49.9	10	5	14	.357143	58	86	6
50.0–54.9	15	8	9	.888889	25	28	3
55.0–59.9	1	1	1	1.000000	3	3	3

With the above assumptions and limitations in consideration, age and sex data for this sample were compiled and arranged for standard demographic analysis. The data show that sex was estimated for 118 of the 122 adults, with both sexes present in nearly equal proportions (55 males and 63 females). Ages at death were estimated for only 30 males and 29 females. Mean female age at death (38 years) is slightly higher than the male value (34 years).

A life table (Table 4) was reconstructed using the methodology of Acsádi and Nemeskéri (1970) and Ubelaker (1974, 1978). Estimated ages at death are available for all 70 individuals less than 20 years at death, however ages at death were estimated for only 75 of the 122 adults. To insure that all adults are included in the life table, the number of adults in each five year age interval was multiplied by 1.63 and the resulting percentages of adults in each category were adjusted to equal 100. The factor of 1.63 reflects the ratio of adults with estimated ages to total adults in the sample. The resulting life table shows a life expectancy at birth of about 25 years, and at one year of about 29 years. The table suggests greater life expectancy at birth at this site than found at either Real Alto (Klepinger, 1979) or at Ayalán (Ubelaker, in press). Table 5 also compares adult life expectancy and longevity for these samples, with the adult life expectancy data showing little variability. The longevity data are difficult to interpret due to the difficulties in estimating age for adult skeletons with an age at death greater than 35 years.

Pathology

Skeletal evidence of disease in this sample is of three types; fractures resulting from trauma, periosteal lesions on long bone shafts, and dental disease (carious lesions, alveolar abscesses and antemortem tooth loss).

Some pathological lesions may have been overlooked due to the excessive fragmentation of the material. Consequently, the

Table 5.—Demographic comparison of the Sta. Elena, Real Alto, and Ayalán samples.

	Site and Approximate Date			
			Ayalán	
Statistic	Sta. Elena (7000 B.C.)	Real Alto (2,500 B.C.)	non-urn (A.D. 700)	urn (A.D. 1200)
Life expectancy (birth)	25	21	19	23
Life expectancy (age 20)	17	17	15	21
Maximum longevity	60	80	55	75

presented frequencies of lesions observed may be minimal, and examples of certain kinds of lesions may have gone unnoticed.

Trauma.—Skeletal evidence for trauma in this sample is confined to 11 examples from four features, all consisting of healed fractures. The following list describes these 11 examples, in the numerical order of the features they are associated with. All fractures are well remodeled and occur on adult bones.

Feature 11: midshaft of a right fourth metacarpal.

Feature 11: midshaft of a right fifth metacarpal.

Feature 25a: left clavicle, near the lateral end.

Fig. 1. Comparison of right radius segment from feature 25a displaying pseudoarthrosis (non-union fracture) with a modern normal right radius.

Feature 25a: right clavicle, near the lateral end.

Feature 25a: left ulna shaft; fracture occurred about 80 mm from distal end (Fig. 1).

Feature 25a: right fifth metatarsal; slightly misaligned.

Feature 25a: midshaft of proximal hand phalanx.

Feature 25a: compression fracture of left talus with considerable eburnation (indicative of cartilage destruction and direct bone contact) on the tibial articular surface.

Feature 25a: distal end of left humerus. Extreme distal end of bone is not present, but remodeling apparently involved most of the distal articular surface.

Feature 25a: unhealed (pseudoarthrosis) fracture in midshaft of right radius (Fig. 1). Only the distal segment (93 mm in length) is present, but it displays evidence of extensive remodeling and non-union of the two segments.

Feature 34: proximal third of radius shaft.

Note that most fractures (9 of 11) involve bones of the upper extremeties. Those involving the radius and ulna are midshaft fractures, rather than the Colles' fractures of the distal ends which were predominately found in the Ayalán samples (Ubelaker, in press). This indicates that the fractures more probably resulted from blows to the arms rather than falls. The number of fractures per adult individual is only .09. This is substantially less than the Ayalán figures of .13 (urn sample) and .18 (non-urn sample).

Infectious disease.—Skeletal evidence of infectious disease in this sample consists of well remodeled deposits of periosteal bone on nine long bone shafts. The bone locations of the lesions and the features they are from are as follows: distal fibula shaft from Feature 18; fibula midshaft, distal right radius shaft, and medial surface of a left third metatarsal from feature 25a (Fig. 2); midshaft area of two tibiae from Feature 25b; midshaft of right tibia and lateral surface of left metatarsal from feature 34; and the anterior midshaft of a left tibia from Feature 56.

Fig. 2. Lesion on medial surface of a left third metatarsal from feature 25a.

Ten of the 11 examples are from bones of the lower legs. This distribution is similar to that found in the Ayalán sample, where over 50 percent of 29 lesions present were found on lower leg bones. However in the Ayalán samples lesions occurred on the femur, ulna and vertebrae in addition to the ulna and lower leg bones.

The number of bones showing such lesions per each adult individual in the Sta. Elena sample is .09. One of the Ayalán examples is from an urn sample subadult. The remaining twenty-eight adult examples suggest that the number of bones with lesions per each adult individual is .14 in the urn sample and .04 in the non-urn sample, with a combined sample ratio of .13.

Dental disease.—Data were collected on three categories of dental disease: carious lesions, alveolar abscesses and non-congenital ante-mortem tooth loss. Once again these data are incomplete and subject to varied interpretation. Most teeth were separated from their mandibular or maxillary origins prior to analysis, thus it was not possible to discuss sex or age associations or even to assess complete dental disease in any one individual. Most of the maxillae and many of the mandibles were missing or incomplete, and those present frequently could not be associated with other cranial or post-cranial parts.

Table 6 summarizes data on the frequency of dental caries. Fifty-five (three

Table 6.—Frequency of carious lesions in permanent fully erupted teeth in the Sta. Elena sample.

Tooth Group	No. Present	No. Carious	% Carious
Maxillary			
incisors	164	1	<1
canines	126	4	3
premolars	251	6	2
molars	436	21	5
Mandibular			
incisors	124	0	0
canines	118	2	2
premolars	246	1	<1
molars	524	20	4
Total	1989	55	3

percent) of the 1,989 permanent teeth examined displayed some form of carious lesion. These lesions were evenly distributed between the upper and lower teeth, but were primarily concentrated in posterior teeth. The distribution of carious lesions within the mouth is nearly identical to that found in both Ayalán samples, although the overall frequency is much lower in Sta. Elena (three percent vs. 11 percent in Ayalán urns and eight percent in Ayalán non-urns). Note however, that the Sta. Elena frequency is higher than that found in the Buena Vista Valdivia sample (0 percent) or a Machalilla sample (2.2 percent), both reported by Turner (1978).

Only ten examples of active alveolar abscesses were found, six in the maxilla and four in the mandible. The maxillary abscesses were associated with four first molars, one first premolar and one second premolar. The four mandibular abscesses were associated with one right central incisor, one left central incisor, one left second premolar, and one right first molar. All of the abscesses were probably produced by attrition exposing the pulp cavity of the tooth. The percentage of teeth present which display associated alveolar abscesses is only one percent, compared to four percent of Ayalán urn teeth and three percent of Ayalán non-urn teeth.

At least 102 permanent teeth were missing antemortem. Twenty-one maxillary teeth were missing: one incisor, six premolars and 14 molars. Eighty-one mandibular teeth were missing: eight incisors, one canine, eight premolars, and 64 molars. The percentage of missing teeth in this sample is six, where n (1661) is equal to the number of teeth present (1559) and the number absent antemortem (102). This figure is substantially lower than the 15 percent and 13 percent documented for the Ayalán urn and non-urn samples (Ubelaker, in press).

Hypoplasia.—Only seven permanent teeth in this sample display enamel hypoplasia: one maxillary canine and one mandibular canine from features 25a and b, two maxillary canines from feature 36 and one maxillary incisor and two maxillary canines from material removed from the site in 1971. The location of the defects suggests they were formed at an age of about three years. Note that in the Ayalán study, six percent of the urn sample teeth and one percent of the non-urn sample teeth have hypoplastic defects, while less than one percent of the Sta. Elena teeth have them.

No other examples of pathology were noted in this sample. The absences of congenital disorders and porotic hyperostosis are especially noteworthy, in comparison with the Ayalán samples. Due to the fragmentary nature of much of this sample, data could not be collected on joint surface degeneration, lines of arrested growth in long bones, and other areas of pathology that would normally be of interest.

Summary

The above analysis is severely limited by the extreme bone fragmentation and bone surface erosion. The effect of this condition is especially apparent in the bone inventories of large secondary features, where the largest and most durable bones occur with greatest frequency.

In spite of this considerable limitation, the data do provide an important, initial look at the early skeletal biology on the coast of Ecuador and after comparison with later samples, allow for tenuous but illuminating suggestions of temporal trends in prehistoric Ecuadorean biology. As expected, no cranial deformation and no examples of artificial dental modification were found. The lack of metatarsophalangeal alterations in this sample probably indicates that a difference in postural habits existed between the Sta. Elena and Ayalán samples. Much of the Ayalán sample, especially females, displayed modifications of the foot bones which indicates habitual kneeling posture, with hyperdorsiflexion of the toes. Lack of these facets in the Sta. Elena sample suggests that habitual resting or work posture probably did not involve hyperdorsiflexion of the toes.

Estimates of living stature show little change through time. Statures estimated for the Late Integration Ayalán sample, Valdivia Real Alto sample and this preceramic sample all are about 160 cm for males and 150 cm for females.

Cranial and mandibular measurements, observations and indices are presented where possible, although the sophistication of comparison is limited because of the very small samples and incompleteness of the data. Metric univariate comparison with other coastal Ecuadorian samples, especially males, does suggest a temporal decrease in cranial length, cranial height, frontal breadth and the mandibular bigonial breadth. Cranial breadth and index appear to increase through time. Although cranial index is smaller than in the other samples, the mean Sta. Elena values are still classified within the mesocranic category. Interpopulation comparison within the Sta. Elena, Real Alto, Buena Vista and Ayalán samples was possible for only four measurements and indices which do not include any measure of height or any measurements of the face or cranial base. In a crude comparison of the means of these four measurements, the Sta. Elena sample shows a greater affinity for the Real Alto and Buena Vista samples than to Ayalán. This is expected since the Sta. Elena site is closer temporally and geographically to these sites than to Ayalán.

Demographic and pathological inferences from the Sta. Elena sample generally match with those expected from a pre-intensive-agriculture population. Comparison with the later samples generally reveals the expected deleterious effects of intensive agriculture on the population. Demographic reconstruction shows greater life expectancy at birth at Sta. Elena (25 years) than at any of the later sites, for which such information is available. Comparison with Ayalán reveals a substantial temporal increase in skeletal indications of infectious disease, fractures, and all aspects of dental disease. The number of periosteal lesions for each adult skeleton increased from .09 in the Sta. Elena sample to .13 in an Ayalán combined sample. The same ratio of fractures increased from .09 to .18 in the Ayalán urn sample. Caries frequency increased from three percent of all teeth examined in the Sta. Elena sample to about 11 percent in the Ayalán urn sample. Similarly in the same samples, frequencies of alveolar abscesses increased from one percent to four percent, antemortem tooth loss increased from six percent to 15 percent and dental hypoplasia increased from less than one percent to six percent. No examples of porotic hyperostosis were found, whereas in Ayalán, the ratio of bones showing such lesions to the total number of individuals in the sample was .07 in the urn sample and .08 in the non-urn sample. Munizaga (1965) also found evidence for it on four of ten Buena Vista crania. Numerous investigators have suggested that porotic hyperostosis in the New World probably results from vitamin deficiency anemia brought about by excessive dietary dependence upon maize. Therefore it is not surprising that it is absent in the Sta. Elena sample.

Due to the fragmentary condition of the sample, inferences from the Sta. Elena skeletons must be regarded as tenuous. Collectively however, in comparison with later samples, they seem to document the negative effects of a reliance upon intensive agriculture. The data suggest that effects of agriculture in prehistoric Ecuador may have been similar to those documented in other parts of the New World.

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Descriptions of new Tephritidae (Diptera) from Israel. II.

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ABSTRACT

Euarestella pninae n. sp., *Tephritis bimaculata* n. sp., *T. hurvitzi* n. sp. and *T. jabeliae* n. sp. are described from Israel and nearby areas. *T. hurvitzi* ranges from Greece to Israel and Uzbek S.S.R.

The present paper is the latest in a series of recent papers dealing with the taxonomy of Israeli Tephritidae (Freidberg, 1974, 1979a, 1979b, 1980; Kugler and Freidberg, 1975). This series serves as a preliminary study toward a comprehensive taxonomic treatment of the Israeli fauna (Freidberg and Kugler, in preparation). All the holotypes and most paratypes are deposited in the Department of Zoology, Tel Aviv University. Paratypes of the three *Tephritis* species will also be deposited in the British Museum (Natural History), London and the National Museum of Natural History, Washington, D.C.

Genus **Euarestella** Hendel

Euarestella Hendel 1927: 174. Type species, *Trypeta megacephala* Loew, by original designation.

In addition to the type species, *megacephala,* from Sicily, Hendel (1927) included in *Euarestella* an Egyptian species, *Euaresta iphionae* Efflatoun. Hering (1937: 260) described *Euarestella abyssinica* from Ethiopia, and Freidberg (1974: 56) described *Euarestella kugleri* from Israel and the Sinai.

The inclusion of the following new species in *Euarestella* broadens the concept of this already heterogeneous genus. The genus, as now recognized, comprises three elements. The type species plus the new species, *E. pninae,* are apparently closely related and form one group. The second group is made up of *E. iphionae* and *E. kugleri,* which are even more similar to each other than are the species of the first group; however, they are not too closely related to the type species and perhaps have greater affinities to *Goniurellia* Hendel. The third element is *E. abyssinica* by itself. Although its wing pattern is similar to that of *E. megacephala,* its longer and angular head and short lower squama detract from its congeneric status with the other species of the genus.

Euarestella pninae Freidberg, new species

(Fig. 1)

Head.–Length–height–width ratio 5.7:7.5:10.0. Frons convex, 2.9 times as wide as eye, ⅔ as long as width at vertex, slightly narrower anteriorly; frontal stripe bare or with few fine, yellowish, inconspicuous hairs at anterior margin; lunule large; parafacial almost linear; gena as wide as antenna; face slightly concave; epistome slightly or moderately projecting; antenna distinctly shorter than face, 3rd segment about 1.6 times as long as wide, rounded at apex; arista microscopically pubescent; proboscis capitate, palp normal; 2 upper, 3 lower fronto-orbital bristles; anterior lower fronto-orbital bristle about half as long as the other 2 and usually paler, but not distinctly lanceolate; ocellar bristle as long as anterior upper fronto-orbital bristle; ocellar, inner vertical, anterior upper fronto-orbital, lower fronto-orbital and genal bristles acuminate and brownish, the others lanceolate and whitish. Head yellowish to brownish, 3rd segment of antenna, proboscis and apex of palp sometimes brown; "V" marking on upper occiput, ocellar spot and slender part of arista dark brown to black; most parts very lightly pollinose; pubescence yellowish.

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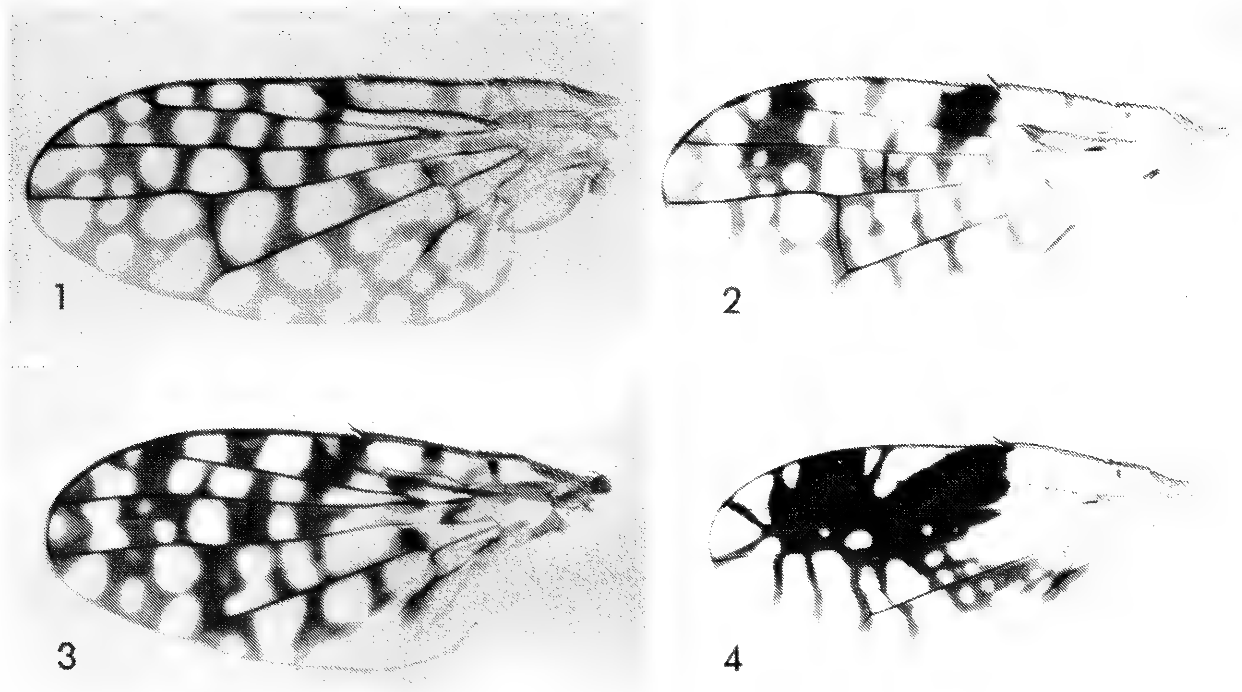

Figs. 1–4: Left wings of Tephritidae: 1, *Euarestella pninae* Freidberg, n. sp.; 2, *Tephritis bimaculata* Freidberg, n. sp.; 3, *T. jabeliae* Freidberg, n. sp.; 4, *T. hurvitzi* Freidberg, n. sp.

Thorax.—Mesonotum slightly wider than long; scutellum triangular, short and rather convex; chaetotaxy complete; bristles acuminate, brownish; posterior notopleural and pteropleural whitish; dorsocentrals situated on, or somewhat anterior to, line of anterior supra-alars. Only basal scutellar bristle present; pubescence whitish, coarse; pollinosity gray, with yellowish tinge, distinctly yellow on yellow parts: ground color of mesonotum, except more or less broad lateral margin, of scutellum, except margin and apex, and of large spots on pleura black; occasionally scutellum blackened only at extreme base, and only sternopleuron and hypopleuron with black spots; squamae white, with yellow margin; halter yellow.

Legs.—Normal in shape and bristling; yellow, with whitish to brownish pubescence and bristles.

Wing (Fig. 1).—Stigma about twice as long as wide; distance between crossveins slightly longer than r-m crossvein; vein r_{4+5} ending at wing apex, bare; cell CuP with a small point; costal spine very small. Pattern: almost uniform reticulation, more pronounced at anterior half of wing; stigma brown except at base; hyaline spots at anterior part of wing usually as wide as cells; cell R_1 with 3 hyaline spots, cell R_3 with 5–6 spots, cell BR with 2 spots in apical half, cell D with 3 spots, cell R_5 with 2 large spots in basal half, then 3–4 smaller spots in 2 rows and a large apical spot, the small spots sometimes united with each other or with 2nd basal spot; apical fork more or less developed; cell M usually with 5 spots in 2 rows, cell CuA_1 with 6–8 spots in 2 rows, axillary lobe completely reticulate.

Abdomen.—Subshiny, with light gray pollinosity, with whitish pubescence and brown bristles; terga vary from almost entirely black with narrow yellow posterior margin to mainly yellow with black spots at anterior and lateral margins; 6th tergum of female about as long as 5th. Genitalia: 9th tergum of male elongate oval; each twisted rod with 2 posterior spicules in addition to 2 inner prensisetae; phallotheca very short; vesica very long; oviscape shiny brownish yellow, with dark brown to black base, dorsum about as long as combined length of last 2 terga; pubescence brownish, fine and sparse, sometimes whitish at base.

Size.—Length of wing: 2.6–3.7 mm; length of oviscape (ventrally): 0.6–1.0 mm.

Material examined.—Holotype ♂, allotype ♀ and 1♂, 3♀♀ paratypes, Israel, Ein Feshkha, emerged on 27–28.III.1977 and 4–5.IV.1977 from *Pulicaria undulata* (L.) Kostel (Compositae), collected on 15. III.1977, M. Kaplan. Additional paratypes: Israel, Dead Sea Area, Kallia, 8.III.1976 (2♀♀), 25.III.1975 (1♀), 13.II.1975 (1♀), 30.III.1977, ex *P. undulata,* 9–10.IV.1977 (1♂, 1♀), Ras Feshkha, 22.XI.1976 (1♂), Nahal Qidron, 13.IV.1978 (1♂). Sinai Mountains, Moon Valley, 30. VIII. 1970 (1♂). The larvae of this species apparently feed in the stems of the host plant, as evidenced by puparia found in some stems.

Remarks.—*Euarestella pninae* is closely related to *E. megacephala,* differing from it by having 3 concolorous lower fronto-orbital bristles, frontal stripe usually bare, veins r_{4+5} and m parallel, the former vein bare, 6th tergum of female about as long as 5th, and 9th tergum of male on either side with 2 posterior spicules in addition to 2 prensisetae. *E. megacephala* usually has 4 lower fronto-orbital bristles, frontal stripe abundantly pubescent anteriorly, veins r_{4+5} and m divergent toward apex of wing, the former vein setulose along distal section, 6th tergum of female shorter than 5th, and 9th tergum of male only with 1 prensiseta on either side and without spicules. In addition, *E. pninae* is a smaller species, with the wing pattern more evenly reticulate and with more hyaline spots than in *E. megacephala.*

Etymology.—This species is named in honor of my wife, Pnina.

Genus **Tephritis** Latreille

Tephritis Latreille 1804: 196. Type species, *Musca arnicae* Linnaeus, designated by Cresson, 1914: 278.

The genus *Tephritis* contains about 100 species in the Palaearctic region alone. The three new species added here are closely related to other, known species, differing from them mainly by characters of the wing pattern. Within *Tephritis,* male genitalia are rather uniform, therefore of little taxonomic value. Female genitalia in this genus might be of more importance for the separation of species.

Tephritis bimaculata Freidberg, new species

(Fig. 2)

This species is similar to *T. dioscurea* (Loew), differing as follows:

Stigma mostly black (Fig. 2), with base and apex hyaline, but lacking an enclosed hyaline spot; two large square hyaline spots in cell R_1 almost equal in size; two hyaline spots in apical half of cell BR closer and larger, usually occupying entire width of cell; hyaline spots within range of large black preapical spot larger; as a consequence black spot on stigma and preapical spot relatively smaller. In *T. dioscurea* (see Hendel, 1927, Taf. XIV, Fig. 8) stigma black, with an enclosed hyaline spot; basal hyaline spot in cell R_1 distinctly larger than apical spot; hyaline spots in apical half of cell BR more distant and smaller; hyaline spots within large black preapical spot smaller; as a consequence large black spots of wing relatively larger.

Size.—Length of wing: 2.6–3.7 mm; length of oviscape (ventrally): 0.6–0.7 mm.

Material examined.—Holotype ♂, allotype ♀, 14♂♂, 24♀♀ paratypes, Mt. Hermon, 2000 m, 22.VI.1973, A. Freidberg. Additional 70 paratypes from Mt. Hermon, 1300–2000 m, Har Dov, Golan Heights (Kfar Nafech, Qusbiye, Merom Golan), Upper Galilee (Ha'Tanur), Mt. Carmel, Northern Negev (Mash'abei Sade, Qzi'ot), Sinai (St. Katharina, Mt. Abbas, Wadi Tlach, El Arba'in, Wadi Taiba, Qzaima), collected from March through September.

Etymology.—The specific epithet, *bimaculata,* refers to the two distinct brown spots on the wing.

Tephritis jabeliae Freidberg, new species

(Fig. 3)

This species is similar to *T. nigricauda* (Loew), differing from it as follows:

Brown spots on wing narrower (Fig. 3), resulting in more banded wing pattern; brown spots at apex of veins r_{4+5} and m together forming wide apical band, enclosing small hyaline spot in apex of cell R_5, usually narrower than half width of cell; brown spot on vein a_1 not connected to spots in cell CuA_1; distance between crossveins usually shorter than length of r-m crossvein; dorsum of oviscape slightly shorter than combined length of terga 5+6. In *T. nigricauda* (see Hendel, 1927, Taf. XIV, Fig. 7) brown spots on wing wider and pattern not appearing banded; hyaline spot in apex of cell R_5 large, wider than half width of cell; brown spot on vein a_1 connected to basal spot in cell CuA_1; distance between crossveins usually at least as long as r-m crossvein; dorsum of oviscape slightly longer than combined length of terga 5+6.

Size.—Length of wing: 3.3–3.8 mm; length of oviscape (ventrally): 0.6–0.8 mm.

Material examined.—Holotype ♂, allotype ♀, 50 paratypes, Sinai Mountains, Mt. Katharina, 2500 m, 13.VII.1974, F. Kaplan and A. Freidberg. Additional 50 paratypes from Sinai Mountains (Mt. Katharina, St. Katharina, Gabel [Mt.] Mussa, Mt. Abbas, Wadi Tlach, El Arba'in), collected from May through September. The host plant is suspected to be *Pyrethrum santolinoides* DC (Compositae). *T. jabeliae* as well as *Oxyna superflava* Freidberg (1974), which apparently feed on the same host plant, may be endemic to the Sinai Mts.

Etymology.—The name *jabeliae* refers to the mountains (of southern Sinai) and to the Bedouin tribe dwelling there.

Tephritis hurvitzi Freidberg, new species

(Fig. 4)

This species resembles *T. recurrens* Loew, differing as follows:

The part of the wing pattern behind vein r_{4+5}, which is less reticulate, having large hyaline spots and areas more united with each other, and brown rays to hind margin narrower and more distinct as rays: gray cloud crossing middle of cell D narrower than hyaline margin between it and hind margin of wing, not reaching wing margin and ending narrowly proximal to vein a_1; first three hyaline indentations distal to gray cloud (2 across apex of cell D and 1 beyond dm-cu crossvein) continuous, not crossed by brown bars. In *T. recurrens* (see Hendel, 1927, Taf. XV, Fig. 5) gray cloud crossing middle of cell D wider than hyaline margin between it and hind margin of wing, reaching hind margin at least beyond end of vein a_1 and extending proximally as far as longitudinal fold of axillary lobe; first three hyaline indentations distal to gray cloud usually broken by brown bars into rounded hyaline spots.

Size.—Length of wing: 3.6–4.9 mm; length of oviscape (ventrally): 1.1–1.4 mm.

Material examined.—Holotype ♂, allotype ♀, 19♂♂, 29♀♀ paratypes, Israel, Mt. Hermon, 1600 m, 27.VI.1977, emerged from stem galls on *Tragopogon longirostris* Sch. Bip. (Compositae) on 2–8.VII.1977, A. Freidberg. Additional 170 paratypes from Mt. Hermon, 1100–2000 m, Golan Heights (10 km S. Qunaitra, Kfar Nafech), Upper Galilee (Ha'Tanur, Mt. Meron) and Lower Galilee (Arbel), collected or reared from March through October. The species has also been reared from stem galls on *Scorzonera syriaca* Boiss et Bl. (Compositae). Additional paratypes were examined from the following localities outside Israel:
Turkey, 25 m S. W. Konya, 14.VIII.1974 (1♀), P. S. Cranston.
Cyprus, Mt. Trodos, 7.IX.1951 (4♂♂, 5♀♀), 28.VI.1937 (2♀♀), Pera Pedi, 8.VI.1937 (1♂), Marvomoustakis.
Iran, N. W. Persia, Kazim, 19.VII.1919 (1♂), Buxton.
U.S.S.R., Uzbek S.S.R., Chim Gand, 2000 m, 90 km NE Tashkent, 16.VIII.1968 (2♂♂, 2♀♀), C. Sabrosky.
A female from Greece, Athens, 1.IV.1980, Mathis & Freidberg, which shows some intermediate characters between *T. hurvitzi* and *T. recurrens,* is not included as a paratype.

Etymology.—This species is named in honor of Mr. E. Hurvitz of Kibbutz Dan, Director of the Beit Ussishkin Regional Museum, for his hospitality, assistance and encouragement during a survey of Mt. Hermon.

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The Taxonomy and Nomenclature of Some Palaearctic Tephritidae (Diptera)

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ABSTRACT

A new genus, *Capitites*, with *Trypeta ramulosa* Loew as type species, is described. *Trypanea dentiens* Bezzi, also assigned to *Capitites*, is a new combination. Previous erroneous type designations of several authors and the present correct ones are pointed out for the genera *Acinia, Aciura, Petalophora, Dacus, Ensina, Orellia, Carpomya, Carpomyia, Oxyna, Platyparea, Tephritis, Terellia, Trypeta,* and *Urophora* and the correct designations for *Icterica* and *Sinevra* are discussed. *Pseudonoeeta* is assigned as a new synonym of *Carphotricha, Siticola* of *Katonaia, Stephanaciura* of *Hypenidium, Squamensina* of *Orellia* and *Platyparella* of *Platyparea. Aciura powelli* is a new synonym of *A. coryli* (Rossi), and *Stephanaciura bipartita* Séguy and *Hemilea novakii* Strobl are new synonyms of *Hypenidium graecum* Loew. Type species are newly designated as follows: *scorzonerae* Robineau-Desvoidy for *Ensina, trotteriana* Bezzi for *Oedaspis* (*Melanoedaspis*), *villeneuvei* Bezzi for *Oedaspis* (*Dichoedaspis*), and *pyrethri* Robineau-Desvoidy for *Oxyphora.*

While clarifying the nomenclatural and taxonomic status of some names in the palaearctic Tephritidae, we noted a number of genera that lacked valid type designations. Other genera in the past had been given erroneous designations by various authors including Rondani (1856, 1870a, 1870b, 1871a, 1871b), principally because of their failure to cite an originally included species in conformance with the provisions of Article 69 of the International Code of Zoological Nomenclature. In every case we have pointed out or corrected these situations. Several previously unpublished or little-recognized synonymies and new combinations of names are also given. One new genus is described and discussed.

Genus **Acinia** Robineau-Desvoidy

Acinia Robineau-Desvoidy 1830: 775. Type species, *Acinia jaceae* Robineau-Desvoidy 1830: 776, designated by Rondani 1871a: 4 (1871b: 4) (= *corniculata* (Zetterstedt)).

Rondani's (1856: 113) designation of *corniculata* is invalidated by his failure to name an originally included species, but the concept of the genus would have remained the same had his 1856 designation been acceptable.

Genus **Aciura** Robineau-Desvoidy

Aciura Robineau-Desvoidy 1830: 773. Type species, *Aciura femoralis* Robineau-Desvoidy 1830: 773, designated by Rondani 1856: 113 (= *coryli* (Rossi)).

Rondani's (1870a: 9; 1870b: 9) and Hendel's (1914: 86; 1927: 108) designations of *Musca coryli* Rossi are invalid as the latter was not a name originally included by Robineau-Desvoidy.

No specific differences could be found between *Aciura powelli* Séguy (1930: 170) and *A. coryli* (Rossi). Consequently, the former name becomes a junior synonym of the latter (NEW SYNONYMY).

Genus **Capitites, new genus**

Type species, *Trypeta ramulosa* Loew 1944: 407, by present designation.

Hendel (1927: 202) described *Tephritomyia* as a subgenus of *Acanthiophilus* Becker 1908: 136 and placed *ramulosa* in *Acanthiophilus* s. str. Munro (1957: 1026) raised *Tephritomyia* to a genus, refined the distinction between it and *Acanthiophilus,* and described *Pherothrinax,* a third genus in the "*Acanthiophilus* series."

Capitites is distinguished from those three genera by the following combination of characters:

Anterior lower fronto-orbital bristle short, whitish, and lanceolate; frons slightly hairy at anterior border; proboscis spatulate; apical scutellar bristles more than half as long as basals; wing with dark and well defined, elongate, and radiate subapical spot, with distinct apical fork; aedeagus with complex sclerotization in basal part and rather voluminous vesica. The proboscis in the other three genera is short and capitate and the anterior lower fronto-orbital bristle is dark and acuminate.

Apart from *C. ramulosa,* a "Mediterranean" species, *Capitites* also includes *Trypanea dentiens* Bezzi (1924: 565) (NEW COMBINATION) and possibly other Afrotropical species.

Genus **Carphotricha** Loew

Carphotricha Loew 1862a: 77. Type species, *Trypeta strigilata* Loew 1855: 40, designated by Cresson 1914: 277.

Pseudonoeeta (subg. of *Noeeta*) Hering 1942: 4 (NEW SYNONYMY). Type species, *Noeeta crepidis* Hering 1936: 62, by original designation.

In the absence of any current taxonomic studies on this group of species, we accept Hering's concept of *Pseudonoeeta,* according to which *crepidis* and *strigilata* are congeneric. Obviously, Hering was entirely unaware of Cresson's previous designation of *strigilata* for *Carphotricha.*

Genus **Carpomya** A. Costa

Carpomya A. Costa 1854: 87. Type species, *Carpomya vesuviana* A. Costa 1854: 87, by monotypy.

Carpomyia Rondani 1870a: 6 (1870b: 6) (unjustified emendation). Type species, *Carpomya vesuviana* A. Costa 1854: 87, aut.

By citing Costa's paper under *Carpomyia,* Rondani (1870a: 22; 1870b: 22), obviously considered his *Carpomyia* (1870a: 6, 22; 1870b: 6, 22) equivalent to *Carpomya* A. Costa 1854. We consider this to be concrete evidence that, at least in 1870, his *Carpomyia* was an emendation of *Carpomya* A. Costa and that his designation (Rondani 1870a: 6; 1870b: 6) of *Trypeta signata* Meigen is invalidated by Costa's earlier monotypy. Although it might be argued that when Rondani (1856: 111) earlier used the name *Carpomya,* he erred in attributing the name to himself rather than to Costa, there is no truly objective evidence that *Carpomya* Rondani 1856, with *arctii* DeGeer as sole species, is anything but a synonym of *Orellia* Robineau-Desvoidy, especially since *arctii* is a generally accepted synonym of *Orellia tussilaginis* (Fabricius) and was assigned by Rondani himself (1870a: 7; 1870b, 7) to *Trypeta* Meigen. See the synonymy for and discussion of *Orellia* Robineau-Desvoidy.

Genus **Ceratitis** MacLeay

Ceratitis MacLeay 1829: 482. Type species, *Ceratitis citriperda* MacLeay 1829: 482, by monotypy (= *capitata* Wiedemann).

Petalophora Macquart 1835: 454. Type species, *Tephritis capitata* Wiedemann 1824: 55, by monotypy.

Rondani's (1870a: 7; 1870b: 7) designation of *hispanica* de Breme as the type species of *Petalophora* is invalidated by the monotypy. The name *Petalophora* is a widely accepted synonym of *Ceratitis.*

Genus **Dacus** Fabricius

Dacus Fabricius 1805: 272. Type species, *Dacus armatus* Fabricius 1805: 273, designated by Hendel 1927: 24.

Rondani's (1856: 114) and Hendel's (1914: 74) designations of *oleae* Gmelin are in error as not including an originally named species.

Genus **Ensina** Robineau-Desvoidy

Ensina Robineau-Desvoidy 1830: 751. Type species, *Ensina scorzonerae* Robineau-Desvoidy 1830: 753, by present designation (= *sonchi* (Linnaeus)).

Under the generic name *Ensina* Robineau-Desvoidy described six species—*chrysanthemi, herbarum, pratensis, linariae, doronici,* and *scorzonerae*—without indication of a type species. Most taxonomists since Rondani have recognized all six as being conspecific with *Musca sonchi* Linneaeus, but so far we have been unable to find a type designation that conforms to the letter of Article 69 of the Code. In several of the designations we have seen, more than one of the originally included species has been cited, either specifically or by indirect association (for example, Rondani (1870a: 45; 1870b: 119). Hence, the action taken here is merely in acknowledgment of the specific provision of the Code. We have chosen *scorzonerae* as the type because it is the only originally included species associated with *sonchi* by Robineau-Desvoidy ("C'est peut-être le véritable *Musca Sonchi* de Fabricius.").

Genus **Hypenidium** Loew

Hypenidium Loew 1862b: 87. Type species, *Hypenidium graecum* Loew 1862b: 88, by monotypy.
Stephanaciura Séguy 1930: 171 (NEW SYNONYMY). Type species, *Stephanaciura bipartita* Séguy 1930: 171, by original designation and monotypy (= *graecum* Loew (NEW SYNONYMY)).

We compared the holotype of *Stephanaciura bipartita* Séguy from Morocco with specimens from eastern Mediterranean countries. They all compared well with Loew's original (1862b) description of *graecum*. *S. bipartita* is therefore a synonym of *graecum*, as is *Hemilea novakii* Strobl (1893: 124) (NEW SYNONYMY).

Genus **Icterica** Loew

Icterica Loew, 1873: 287. Type species, *Trypeta seriata* Loew 1862c: 84, designated by Coquillett 1910: 555.

Hendel's (1927: 140) designation of *westermanni* Meigen as the type species of this genus is in error. Careful taxonomic studies are required to determine whether the palaearctic species currently assigned to *Icterica* are in fact congeneric with *seriata* Loew.

Genus **Katonaia** Munro

Katonaia Munro 1935: 142. Type species, *Katonaia arushae* Munro 1935: 142, by original designation and monotypy.
Siticola Hering 1947: 1 (NEW SYNONYMY). Type species, *Siticola hemileopsis* Hering 1947: 2, by original designation and monotypy.

We studied specimens of the three known species associated with these generic names—*arushae* Munro from East Africa, *hemileopsis* Hering from Crete, and *aida* Hering from Israel (*Siticola theodori* Hering was synonymized with the last-named species by Kugler and Freidberg (1975: 55))—and concluded that all three are congeneric.

Genus **Oedaspis** Loew

Subgenus **Melanoedaspis** Hendel

Oedaspis (*Melanoedaspis*) Hendel 1927: 83. Type species, *Oedaspis trotteriana* Bezzi 1913b: 151, by present designation.

Subgenus **Dichoedaspis** Hendel

Oedaspis (*Dichoedaspis*) Hendel 1927: 83. Type species, *Oedaspis villeneuvei* Bezzi 1913b: 149, by present designation.

Except for a reference to *Melanoedaspis* by Munro (1952: 218), these two subgenera have not been mentioned in the taxonomic literature since their original description. Further taxonomic studies will be required to determine whether the genus merits subdivision.

Genus **Orellia** Robineau-Desvoidy

Orellia Robineau-Desvoidy 1830: 765. Type species, *Orellia flavicans* Robineau-Desvoidy 1830: 765, by monotypy (= *punctata* (Schrank)).
Carpomya Rondani 1856: 111. Type species, *Musca arctii* DeGeer 1776: 42, by original designation and monotypy (= *Orellia tussilaginis* (Fabricius)). Preoccupied by *Carpomya* A. Costa 1854: 87.
Squamensina Hering 1938: 405 (NEW SYNONYMY). Type species, *Squamensina oasis* Hering 1938: 405, by original designation and monotypy.

The name *Carpomya* was first used by A. Costa in 1854 to provide a genus for *vesuviana*, its newly described and only included species. Two years later, Rondani used the same name (as "*Carpomya* mihi") for an entirely different generic concept without any reference whatever to A. Costa's publication. See our explanation for the use by Rondani of the names *Carpomya* and *Carpomyia* in the discussion of *Carpomya* A. Costa elsewhere in this paper.

We studied the holotype of *Squamensina oasis* Hering from Biskra, Algeria. It is either the same as *Orellia vectensis* Collin (1937: (2)) from England or *O. pseudovirens* Hering (1940: 7) from Cyprus, or very close to these species. In any case it is a typical *Orellia* sensu Hendel (1927). The specimen has only one upper fronto-orbital bristle, an aberrant condition also suggested by a second specimen from Tunisia, which is identical to it in all essential characters but has two upper fronto-orbital bristles as in all other *Orellia* species.

Genus **Oxyna** Robineau-Desvoidy

Oxyna Robineau-Desvoidy 1830: 755. Type species, *Oxyna flavescens* Robineau-Desvoidy 1830: 756, designated by Hendel 1914: 96 (= *flavipennis* (Loew)).

In transferring *Oxyna flavescens* Robineau-Desvoidy (1830: 756) to *Trypeta,* Loew (1844: 368) found it to be preoccupied by *flavescens* Fabricius (1798: 565) and renamed it *flavipennis.* Hendel (1914) was the first to unambiguously use an originally included name, and the designations for *Oxyna* of *parietina* Linnaeus by Rondani (1856: 110), of *punctella* Fallén by Rondani (1870a: 8; 1870b; 8), Foote (1965: 664; 1980: 39), and Hardy (1977: 126), and of *flavipennis* Loew by Hendel (1927: 164) are invalid in not citing the name of an originally included species.

Genus **Oxyphora** Robineau-Desvoidy

Oxyphora Robineau-Desvoidy, 1830: 757. Type species, *Oxyphora pyrethri* Robineau-Desvoidy, 1830: 757, by present designation.

Oxyphora pyrethri and *O. cardui* were the only species originally included in *Oxyphora* by Robineau-Desvoidy; we have been unable to find any type designation whatever in the literature available to us. *O. cardui* was synonymized without question by Loew in 1844 (p. 365) and 1862a (p. 80) with *westermanni* Meigen, now recognized as belonging to *Icterica* Loew (1873: 287) (see discussion of that genus). Our choice of *pyrethri* as the type species of *Oxyphora* avoids the necessity of changing the generic name *Icterica* but unfortunately it does not clarify the status of *Oxyphora* zoologically, as the Robineau-Desvoidy types are lost and *pyrethri* is unrecognizable from Robineau-Desvoidy's description.

Genus **Platyparea** Loew

Platyparea Loew 1862a: 25. Type species, *Musca discoidea* Fabricius 1787: 351, designated by Rondani 1870a: 9, 1870b: 9.

Platyparella Hendel 1914: 83 (NEW SYNONYMY). Type species, *Musca discoidea* Fabricius 1787: 351, by original designation and monotypy.

When Hendel described the genus *Platyparella* and subsequently discussed it in 1927 (p. 64), he was apparently unaware of Rondani's previous action with *Platyparea,* in which Loew had originally placed *poeciloptera* Schrank 1776, *caloptera* Loew 1850, and *discoidea* Fabricius. However, Rondani's action in 1870 fixed *discoidea* as the type of *Platyparea,* and Hendel's (1914: 84) designation of *poeciloptera* as the type species of *Platyparea* is thus invalid.

Genus **Sphenella** Robineau-Desvoidy

Sphenella Robineau-Desvoidy 1830: 773. Type species, *Sphenella linariae* Robineau-Desvoidy 1830: 774, by monotypy (= marginata Fallén).

Sinevra Lioy 1864: 1024. Type species, *Tephritis marginata* Fallén 1814: 165, designated by Hardy 1977: 130.

In his description of *Sinevra,* Lioy included *linariae* Robineau-Desvoidy, *septemmaculata* Macquart, *fasciata* Meigen, and *marginata* Fallén without an original type designation. Of these four names, *Sphenella linariae* Robineau-Desvoidy (1830: 774) (not *Ensina linariae* Robineau-Desvoidy 1830: 753) is a synonym of *marginata* Fallén, *septemmaculata* of *inulaedyssentericae* Blot, and *fasciata* appears not to be associated with the Tephritidae in any literature we have seen. The selection of *marginata* by Hardy is to be accepted as valid according to Article 69 (a) (iii) of the Code, although Hardy erred in stating the genus to have been originally monotypic.

Genus **Tephritis** Latreille

Tephritis Latreille 1804: 196. Type species, *Musca arnicae* Linnaeus 1758: 600, designated by Cresson 1914: 278.

The designations by Rondani (1856; 1870a: 8; 1870b: 8), Coquillett (1910: 613), and Bezzi (1913a: 162) are invalid as they do not cite an originally included name. See Cresson's (1914) discussion.

Genus **Terellia** Robineau-Desvoidy

Terellia Robineau-Desvoidy 1830: 758. Type species, *Terellia palpata* Robineau-Desvoidy 1830: 758, by designation of Cogan and Munro 1980 (= *serratulae* (Linnaeus)).

Rondani's (1856: 114), Coquillett's (1910: 613), and Hendel's (1914: 92; 1927: 126) indications of "*serratulae*" are invalidated by failure to mention either of Robineau-Desvoidy's originally included species.

Genus **Trypeta** Meigen

Trypeta Meigen 1803: 277. Type species, *Musca artemisiae* Fabricius 1794: 351, designated by Coquillett 1910: 618.

Rondani's (1870a: 7; 1870b: 7) designation of *Musca arctii* DeGeer is invalid because it is not an originally included species. Rondani considered *Orellia* to be synonymous with *Trypeta* Meigen, as evidenced by his notes (1870a: 24; 1870b: 24).

Genus **Urophora** Robineau-Desvoidy

Urophora Robineau-Desvoidy 1830: 769. Type species, *Musca cardui* Linnaeus 1758: 600, designated by Westwood 1840: 149.

The designation by Westwood precedes those of Rondani (1856: 110; 1870a: 6; 1870b: 6). Foote (1965: 658) and Hardy (1977: 86) have incorrectly cited *sonchi* the type species of *Urophora*.

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Comparative Rates of Predation on Northern and Southern Periwinkles

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Previous work has shown that predation by crushing predators is often more intense on tropical gastropods (snails) than on their northern counterparts (Vermeij, 1976). P. V. Hamilton (1976) has shown that *Callinectes sapidus* is an important predator on the periwinkle *Littorina irrorata.* Being interested in work done concerning the predation on temperate and tropical gastropods, we took the opportunity to examine specific cases. In this paper we discuss the relative rates of predation on two populations of periwinkles, *Littorina irrorata,* from a Florida saltmarsh, and *Littorina littorea* from a Massachusetts salt marsh.

The class collected 240 *Littorina littorea* from Little Sippiwisset Marsh, Woods Hole, Mass., and 235 living *L. irrorata* were sent from the marsh at Florida State University Marine Laboratory, Sopchoppy, Florida. Groups of investigators measured each shell using Vernier calipers, and recorded repaired injuries on the body whorl. Injuries were recognized as jagged, irregular scars not easily confused with growth lines. Any disagreements arising about the number of injuries were resolved by using a dissecting microscope.

The results of this experiment were as follows: On the 235 shells of *L. irrorata* we recorded 192 injuries. The 240 shells of *L. littorea* had 96 injuries; that is, exactly a 2:1 ratio occurred. The Chi-square test showed that the probability that this happened by chance was $< .005$.

After observing the preceding results, we have formulated three hypotheses to explain them; these are discussed in order of highest to lowest probability. An experiment which could be used to test these hypotheses will be presented later.

Our first hypothesis is that the southern predators are stronger than the northern ones. A stronger *Callinectes sapidus* (blue crab), for example, would be more successful in any given attack. This idea seems to be in agreement with those of other researchers (Vermeij, 1976).

A second hypothesis is that the northern periwinkle, which is more spherical and with a lower spire than the southern periwinkle, would be harder to grasp, and would thus elude a greater number of attacks. This hypothesis also agrees with previous work (Zipser and Vermeij, 1978).

Our last hypothesis is that the number of southern blue crabs or other predators could be greater than the number of northern ones, in our localities. This would allow more frequent attacks on each individual southern *Littorina.*

An experiment to help test these various hypotheses would be to collect both species of periwinkles, and both northern and southern blue crabs, and to put them in four separate tanks. The first would have a northern crab and northern periwinkles, the second a northern crab and southern periwinkles, the third a southern crab and northern periwinkles, and the fourth a southern crab and southern periwinkles. These would be observed for differences and similarities in the rates of predation.

[1] Bettina Dudley, teacher; Denise Mauzerall and Chris Cousins, assistants.

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Six New North American Species of Melanagromyza *Hendel (Diptera, Agromyzidae)*

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ABSTRACT

The following new species are described: *Melanagromyza hicksi* (Ontario; host, *Alcea rosea* L., Malvaceae), *M. lomatii* (Oregon; host, *Lomatium nudicaule* [Pursh] C. & R., Apiaceae), *M. panacis* (Indiana; host, *Panax quinquefolius* L., Araliaceae), *M. radicicola* (Maryland; host, presumably *Urtica dioica* L., Urticaceae), *M. vernoniae* (Maryland; host, *Vernonia noveboracensis* [L.] Michx.), and *M. vernoniana* (Maryland; host, *V. noveboracensis* [L.] Michx.). The latter two species were reared from the same plant in the same locality. Male postabdominal characters of *M. angelicae* (Frost) are figured for the first time for comparison with those of *M. hicksi.*

The descriptions here presented are part of the author's cooperation with Kenneth A. Spencer in the preparation of a manual of the Agromyzidae of the United States, and the species are described here in order to provide more complete description than would be proper to the Manual.

As with most species of *Melanagromyza,* the most distinctive characters are found in the male postabdomen (terminalia). Relationships will be brought out in the keys to be presented in the Manual, although the closest apparent relatives of each species are cited here. All species described herein belong to the major group of North American *Melanagromyza,* with wing vein C extending to M_{1+2} and with only 2 pairs of dorsocentral bristles, both postsutural.

Melanagromyza hicksi Steyskal, new species

(Figs. 1–3)

? "*Anthomyza*" *angelicae* Frost, Hansberry, 1940: 199.
Melanagromyza sp. (Steykal), Spencer, 1969: 78.

Male. Length of wing 3.0 to 3.2 mm.

Head as in Fig. 2; front matt black, at level of hindmost fronto-orbital bristle 0.43 to 0.46 of total head width (= head 2.12 to 2.22 times as wide as front); frontal orbits rather dull, sloping upward from eye margin, somewhat broadened anteriorly, with 4 or 5 lower inclinate bristles and numerous, rather irregularly disposed setulae, the lowermost proclinate; gena 0.18 of eye-height; antennae narrowly separated by low median keel; arista finely pubescent, 0.57 mm long; eye with sparse, short hairs in upper part.

Mesonotum metallic dark bluish black, shining laterally, dull mesally with minute, rather dense rugulosity; dorsocentral bristles 2, strong, anterior one slightly posterad of level of supra-alar bristle; acrostichal setulae in approximately 8 rows, a few extending posteriorly to scutellar suture.

Wing as in Fig. 3; last section of vein M_{3+4} 0.8 length of penultimate section; squamae and fringes whitish; halter with knob wholly black.

Foretibia without median bristle; midtibia with 2 median bristles, each shorter than tibial diameter.

Abdomen metallic greenish black; postabdomen as in Fig. 1; aedeagus with rounded subbasal swelling on anterior side, gap between U-shaped basiphallus and distiphallic complex about 0.6 length of latter; epandrium (Fig. 1D) in profile with ventral margin moderately but sharply offset at about 0.4 of distance from anterior margin.

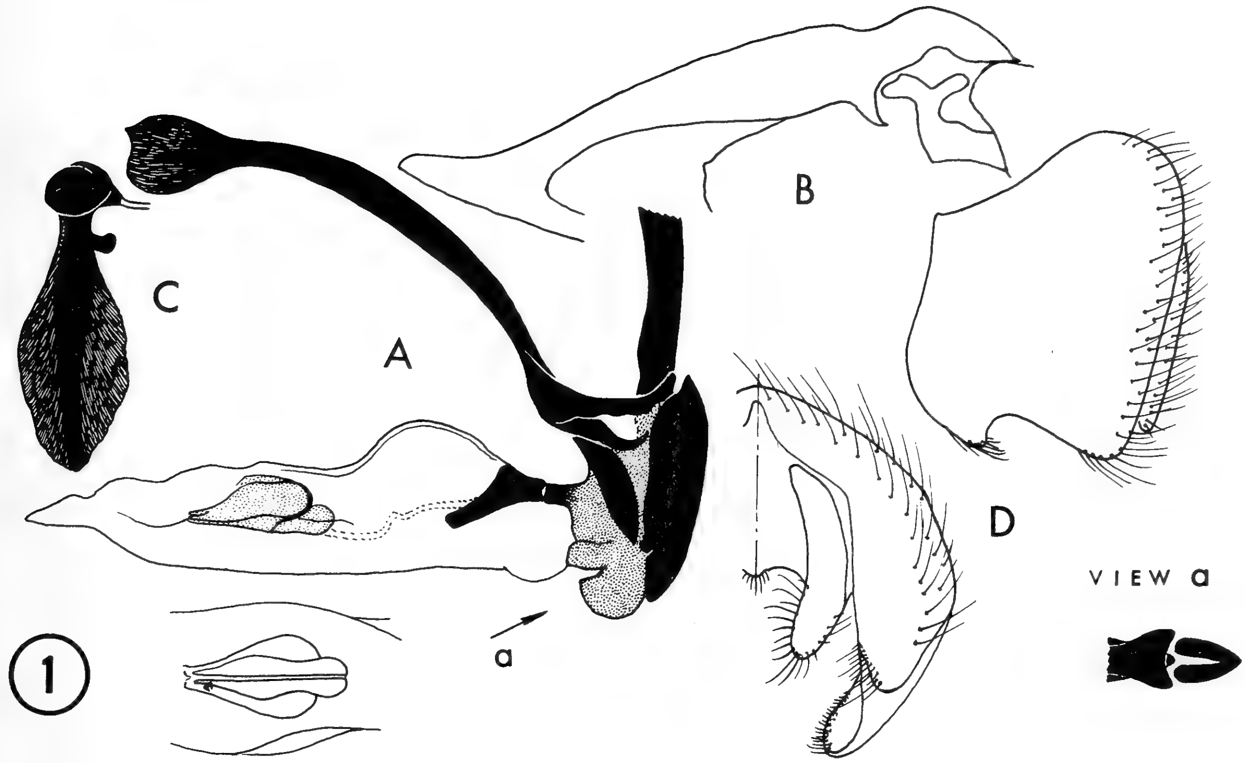

Fig. 1. *Melanagromyza hicksi* Steyskal. A, hypandrium and aedeagus, with ventral view of distiphallic complex; B, hypandrium, ventral view; C, sperm pump; D, epandrium, posterior (half) and profile view.

Female. Similar to male; front 0.42 to 0.44 of total head width; length of wing 3.1 to 3.4 mm; abdomen shining dark metallic bluish green; ovipositor sheath equal in length to last dorsal preabdominal tergum.

Types.—Holotype (♂), allotype, and 5 ♂ and 3 ♀ paratypes, Windsor, Ontario, Canada, 5 May 1946 (Stanton D. Hicks), reared from puparia found in pith near base of hollyhock (*Alcea rosea* L.; Malvaceae); in U.S. National Museum of Natural History.

Remarks.—This species is most closely related to a species to be described in the Manual by Spencer, but it is also related to another species described at this time, *M. panacis*. It is most decisively distinguished from its relatives by details of the male postabdomen. It is likely that *M. hicksi* is the species whose damage to hollyhock was noted by Hansberry (1940) at Ithaca, New York, as *Anthomyza* (sic) *angelicae* Frost. The postabdomen of a topotypical para-

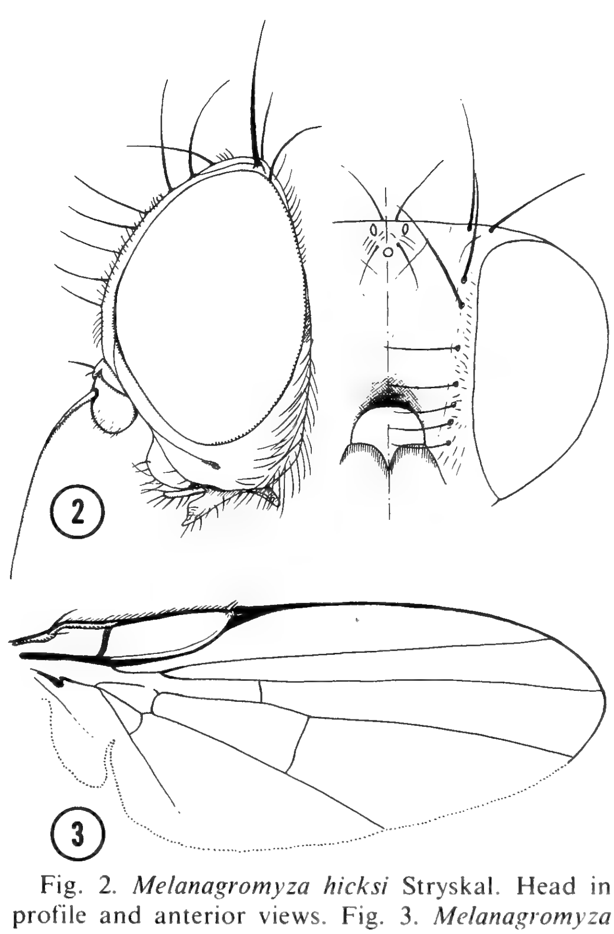

Fig. 2. *Melanagromyza hicksi* Stryskal. Head in profile and anterior views. Fig. 3. *Melanagromyza hicksi* Steyskal. Right wing.

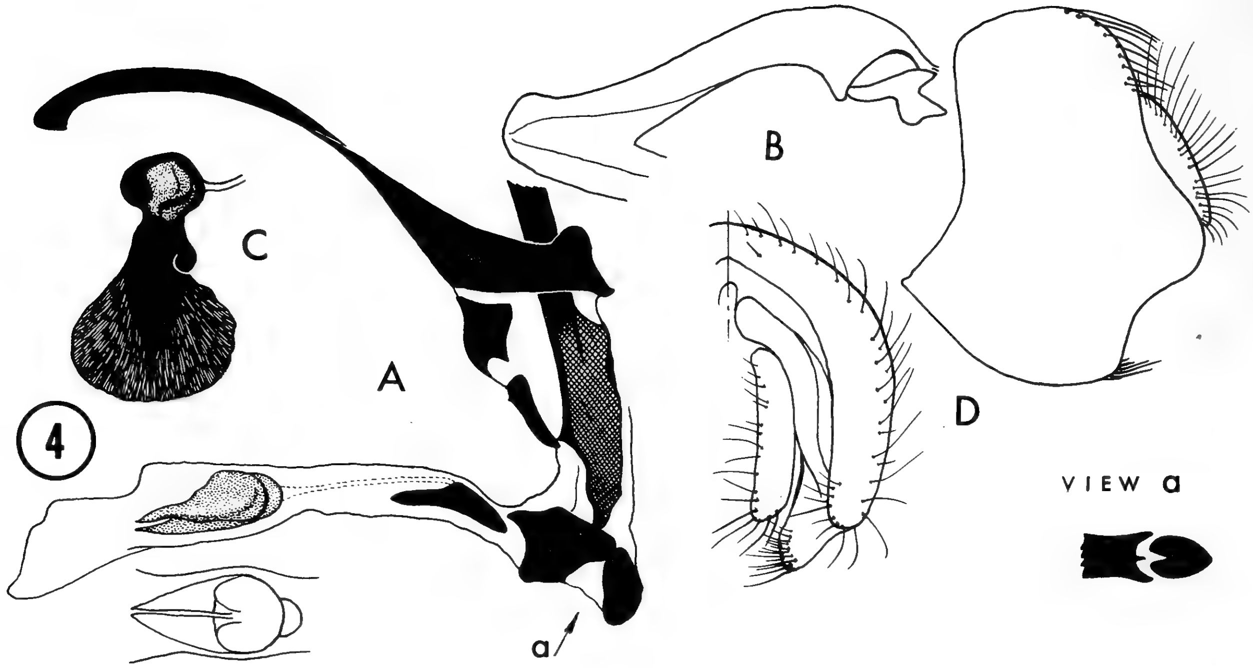

Fig. 4. *Melanagromyza angelicae* (Frost). A, aedeagus in profile, with details at right angle view; B, hypandrium, ventral view; C, sperm pump; D, posterior half (left) and profile (right) of epandrium.

type of *Melanagromyza angelicae* (Frost), originally described in *Agromyza*, and from Ithaca (S. A. Mills) as shown in detail in Fig. 4, wherein many differences from corresponding features of Fig. 1 may be seen.

I am pleased to name the species for my longtime friend Stanton D. Hicks, with apologies for taking so long to describe it.

Melanagromyza lomatii Steyskal, new species

(Fig. 5)

Male. Wing length 2.5 to 3.0 mm. Entire body and appendages black, mesonotum and abdomen with only slight bluish green metallic sheen.

Head with front at level of anterior *ors* 1.75 times as wide as an eye (0.47 of total width of head), cheek nearly half as high as eye; anterior front projecting

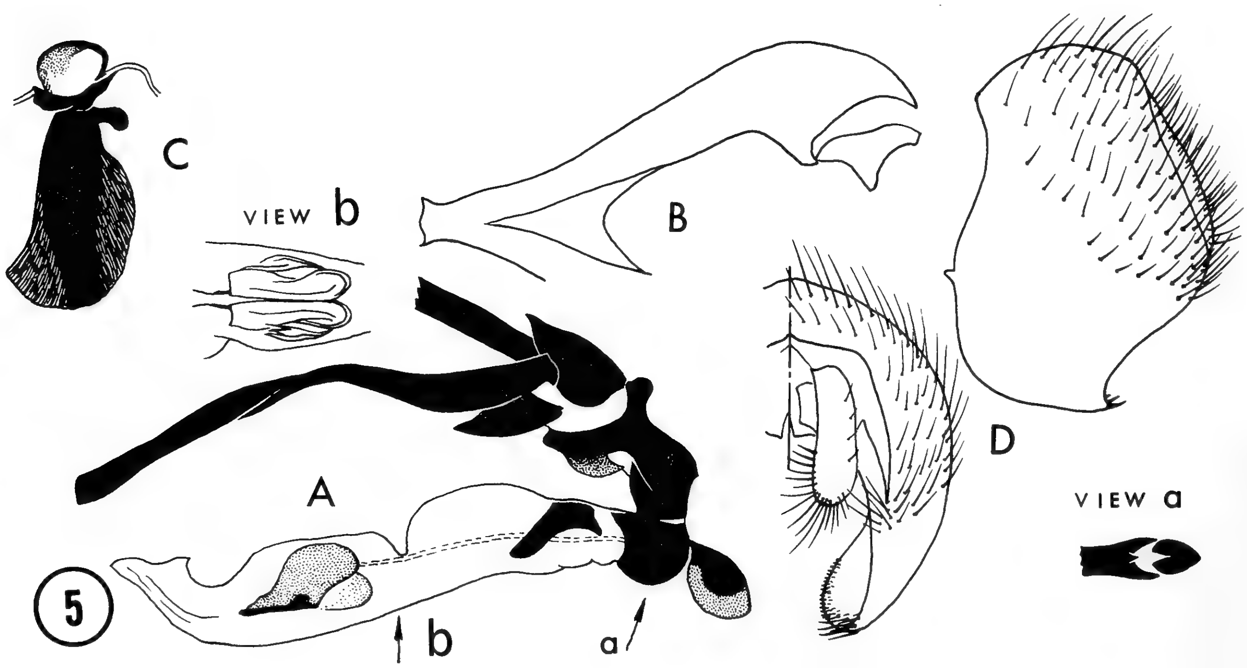

Fig. 5. *Melanagromyza lomatii* Steyskal. A, hypandrium and aedeagus, lateral view, with ventral view (b) of distiphallic complex; B, hypandrium, ventral view; C, sperm pump; D, epandrium, posterior (half) and profile views.

well before eye; parafrontal stripes dull, bearing 2 *ors*, 4 or 5 strong *ori*, and 2 rows of numerous setulae, mesal row proclinate; ocellar triangle lightly tomentose, subshining, apex about 60°; lunule semicircular, flat, grayish tomentose; facial carina broad, moderately raised, a little bent forward medially in profile; eye conspicuously hirsute above; antennae small, 3rd segment roundish, arista 0.45 mm long, apparently bare.

Mesonotum subshining, with about 8 rows of acrostichal setulae, several of which extend nearly to scutellar sulcus, and with 2 pairs of strong dc bristles, anterior pair at level of supra-alar bristles.

Wing very similar to that of *M. hicksi* (Fig. 3), 2.35 times as long as wide, distance between crossveins *ta* and *tp* about 1.25 times length of *tp*; squamae hyaline, marginal cord and fringe blackish; halter black.

Midtibia with 2 distinct medial bristles nearly as long as tibial diameter; foretibia without medial bristle.

Abdomen subshining; postabdomen as in Fig. 5, aedeagus with deep sulcus on anterior side between tumid basal half and apical half; basiphallic sclerite U-shaped, gap between it and distiphallic complex equal in length to latter; epandrium (Fig. 5D) in profile with midventral prong preceded by strongly arcuate free anterior margin and followed by sinuately sloping ventral margin.

Female. Similar to male; eye bare; length of wing 2.7 to 3.2 mm; abdomen with ovipositor sheath dorsally about as long as last preabdominal sclerite.

Types.—Holotype (♂), allotype, and 8 ♂ and 6 ♀ paratypes, La Grande, Union County, Oregon, 7 to 29 April 1964 (holotype, 22 April), reared from stems of bisquit root, *Lomatium nudicaule* (Pursh) C. & R. (Jon Skovlin); in U.S. National Museum of Natural History.

Remarks.—The fly is closely related to a Californian species being described elsewhere by Spencer; the host of that species is not known.

The name *lomatii* is the genitive case of the generic name of its host, *Lomatium nudicaule* (Pursh) C. & R., of the family Apiaceae or Umbelliferae. The habit of *M. lomatii* of boring in the upper half of the stem of its host plant was described in an unpublished report on file in the Portland, Oregon office of the Forest Insect and Watershed Management Research, Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture.

Melanagromyza panacis Steyskal, new species

(Fig. 6)

Male. Length of wing 2.4 to 2.8 mm.

Head with front matt black, at narrowest point 0.39 of total width of head; frontal orbit rather dull, parallel-sided, 0.08 mm wide, with hairs and conformation similar to that of *M. hicksi* (Fig. 1), but more of lower mesal hairs proclinate and with 3 or 4 inclinate bristles; ocellar triangle with minute, sparse tomentum; antennae narrowly separated by low median keel; arista finely pubescent (preserved, but in contorted condition, only in Wooster paratype); upper part of eye with long, rather numerous hairs.

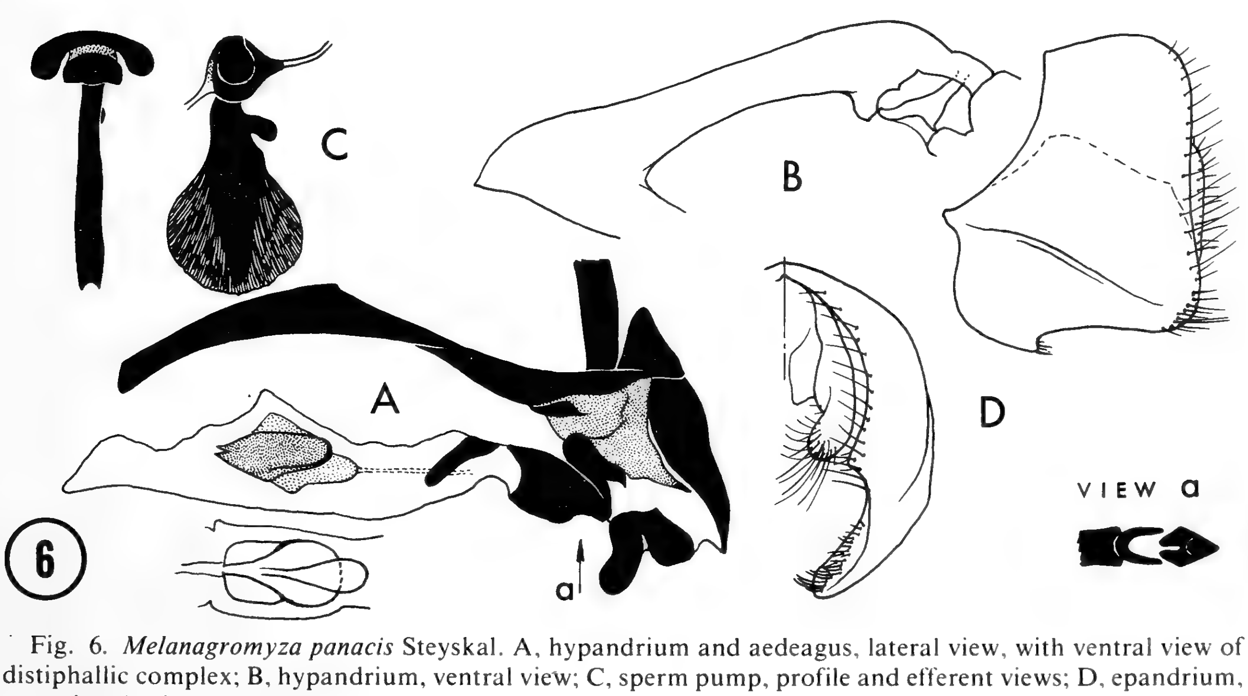

Fig. 6. *Melanagromyza panacis* Steyskal. A, hypandrium and aedeagus, lateral view, with ventral view of distiphallic complex; B, hypandrium, ventral view; C, sperm pump, profile and efferent views; D, epandrium, posterior (half) and profile views.

Mesonotum virtually black, with only slight metallic greenish tinge; subshining, with minute, rather sparse rugulosity; 2 strong dorsocentral bristles, anterior of which slightly posterad of supra-alar bristle; acrostichal hairs in about 8 rows, a few extending almost to scutellar sulcus.

Wing similar to that of *M. hicksi* (Fig. 3), but only 2.0 to 2.15 times as long as wide; squamae and fringes whitish; knob of halter wholly blackish.

Fore tibia with median bristles; midtibia with 2 such, each somewhat shorter than tibial diameter.

Abdomen shining, dark metallic greenish black; postabdomen as in Fig. 6; aedeagus with small anterior swelling near base, gap between U-shaped basiphallus and distiphallic complex 0.7 length of latter; epandrium (Fig. 6D) in profile with ventral margin sharply but very little offset.

Female. Similar to male; length of wing 2.7 to 2.9 mm; abdomen shining dark metallic green; ovipositor sheath as long as last dorsal preabdominal sclerite.

Types.—Holotype, allotype, and 1 ♂ and 3 ♀ paratypes, Washington Co., Indiana, April, 1966, boring in American ginseng (*Panax quinquefolius* L.; Araliaceae); 1 ♂ paratype, Wooster, Wayne County, Ohio, 3 April 1933, in stem of ginseng (Houser); in (U.S.) National Museum of Natural History.

Remarks.—*M. panacis* is very similar to *M. inornata* Spencer, differing in smaller size and green abdomen; it also resembles *M. angelicae* (Fig. 4) and *M. hicksi* (Fig. 1), the male terminalia showing distinct differences. The male terminalia of *M. inornata* was figured by Steyskal (1972: 3).

Melanagromyza radicicola Steyskal, new species

(Fig. 7)

Male. Length of wing 1.85 mm.

Head with front matt black, at narrowest point 0.37 of total width of head, at level of uppermost fronto-orbital bristles 1.35 times width of one eye; frontal orbit (Fig. 7D) dull, a little raised above eye, slightly wider at level of upper infraorbital seta (0.035 mm), and but little narrower posterad therefrom, but rapidly narrowing foreward to little more than half its width in the upper part; frontal orbit with 3 upper bristles (1 ifo and 2 sfo) equally spaced and 1 ifo nearly as far anterad of the other ifo as the latter is from the upper sfo, hairs short, scattered, erect or reclinate; ocellar triangle subshining, with sparse minute tomentum; gena 0.17 of eye height, deepest near middle; antennae separated by narrow flat strip not forming a keel; 3rd antennal segment (Fig. 7C) nearly round in profile, 0.12 mm broad, somewhat less in length; arista 0.39 mm long, appearing bare at 40× magnification, finely pubescent at 90×, evenly tapering from slightly enlarged base; most of eye with sparse, short hairs; ommatidia uniform in size; proboscis small, well retracted.

Mesonotum blackish with slight greenish tinge; 2 strong dorsocentral bristles, anterior of which slightly posterior to level of supra-alar bristle; acrostichal hairs in about 8 rows, a few extending as far back as to approach scutellar sulcus.

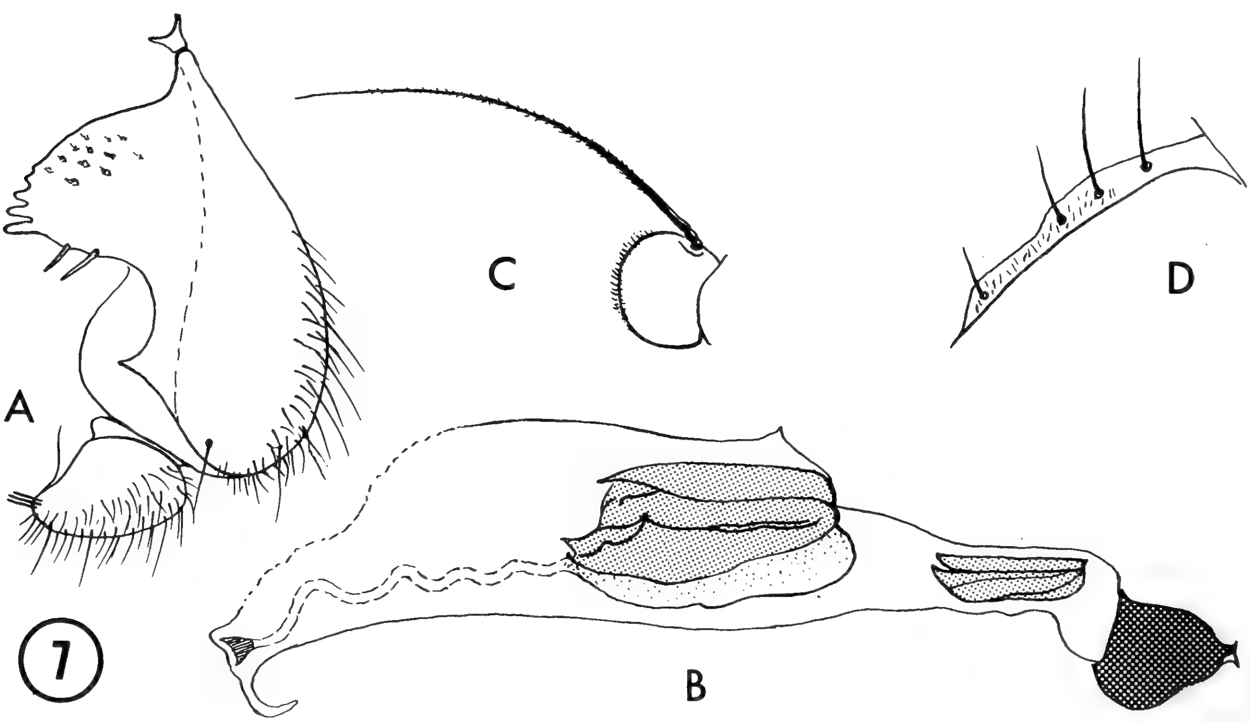

Fig. 7. *Melanagromyza radicicola* Steyskal. A, epandrium and cercus, sinistro-ventral view; B, aedeagus, lateral view; C, left antenna, profile; D, left frontal orbit, oblique dorsal view.

Wing 2.15× as long as wide; last section of vein M_{3+4} ⅔ as long as penultimate section; inner crossvein at 0.61 to 0.65 of length of discal cell (beyond middle); squamae pale yellowish, their fringe dark brown; knob of halter black.

Fore tibia without evident medial bristle; middle tibia with 1 posterior bristle almost as long as tibial diameter.

Abdomen shining, dark metallic greenish black; postabdomen as in Fig. 7; surstylus with lobe about as wide as long, bearing 2 thickened setae on posterior side and 3 digitate processes of decreasing length from rear forward as well as 2 small protrusions, all at apex, and several spicules on mesal surface; aedeagus (Fig. 7B) with long membranous apical extension ending in a hook; sperm duct within apical part of aedeagus ending in brownish infundibuliform orifice; cercus with apical group of 3 closely-spaced, equal-sized setae.

Female. Not known.

Types.—Holotype (♂), Bethesda, Montgomery County, Maryland, December, 1979, emerged indoors from root presumed to be of nettle, *Urtica dioica* L., collected a month previously. In U.S. National Museum of Natural History, with Spencer microslide no. 5089 attached to pin.

Remarks.—The closest relative of *M. radicicola* seems to be *M. minimoides* Spencer; however, the structure of the epandrial lobes or surstyli is quite characteristic and does not ally *M. radicicola* with any other North American species.

Two Species from **Vernonia noveboracensis**

In the course of the work by Donald M. Anderson (1970) on the simultaneous association of weevils of the genus *Smicronyx* (Curculionidae) with both dodder (*Cuscuta* spp.; Convolvulaceae) and its host ironweed (*Vernonia noveboracensis* [L.] Michx.; Asteraceae) 2 species of *Melanagromyza* were found that had bored in the stems of the *Vernonia* and had pupated in the lower end of their tunnels. The 2 species were twice found in the same host plant. They are very similar in general appearance but have a few distinctive characters, especially in the male postabdomen, that can only be specific.

Both species belong to a group of *Melanagromyza* distinguished by the following characters in addition to those common to all the species treated in this paper, viz., wing vein C attaining M_{1+2} and dorsocentral bristles in only 2 pairs, both postsutural: Squamae and fringe whitish; proboscis ordinary, short; ocellar triangle not brilliantly polished; eye of male with small patch of pilosity near frontal orbit; mesonotum and abdomen black, at least partly greenish, bluish or aeneous metallic; foretibia without well-developed medial bristle; wing at least 2.22 but less than 3.00 mm long; frons distinctly but not strongly projecting above eye; lower fronto-orbital bristles (ifo) in 2 pairs, widely separated; basiphallus U-shaped, close to distiphallic complex.

This group includes the European species *M. aeneoventris* (Fallén) and 2 Californian species in process of description by Spencer.

Melanagromyza vernoniae Steyskal, new species

(Fig. 8)

Male. Length of wing 2.82 to 2.91 mm; width of head 1.04 to 1.10 mm.

Front at level of anterior ocellus 0.43 to 0.46 mm wide; gena deepest in middle, 0.21 of height of eye; genal setae of approximately equal length.

Terminalia as in Fig. 8; epandrium in profile strongly swollen anteriorly, with 3 transverse ridges; ventral tip of epandrium rounded and bearing a few short, stout posterior setae; distiphallic complex with short apical arms and compact basal structures; extension of phallapodeme large, basally broad; sperm pump with comparatively thick subbasal projection on apodeme.

Types.—Holotype (♂), Washington, D.C., emerged indoors 19 December 1968 from puparium collected 18 October 1968; 1 ♂ paratype, same locality, emerged indoors 20 February 1970; 2 male paratypes, same locality, emerged indoors 28 March 1970; all collected by D. M. Anderson from stem of *Vernonia noveboracensis* (L.) Michx. and deposited in U.S. National Museum of Natural History.

Remarks.—One female, Washington, D.C., emerged 28 March 1970, is considered as possibly the female of *M. vernoniae* on the basis of the depth of the gena, but it is not designated a paratype.

Melanagromyza vernoniana Steyskal, new species

(Figure 9)

Male. Length of wing 2.28 to 2.52 mm; width of head 0.93 to 0.96 mm.

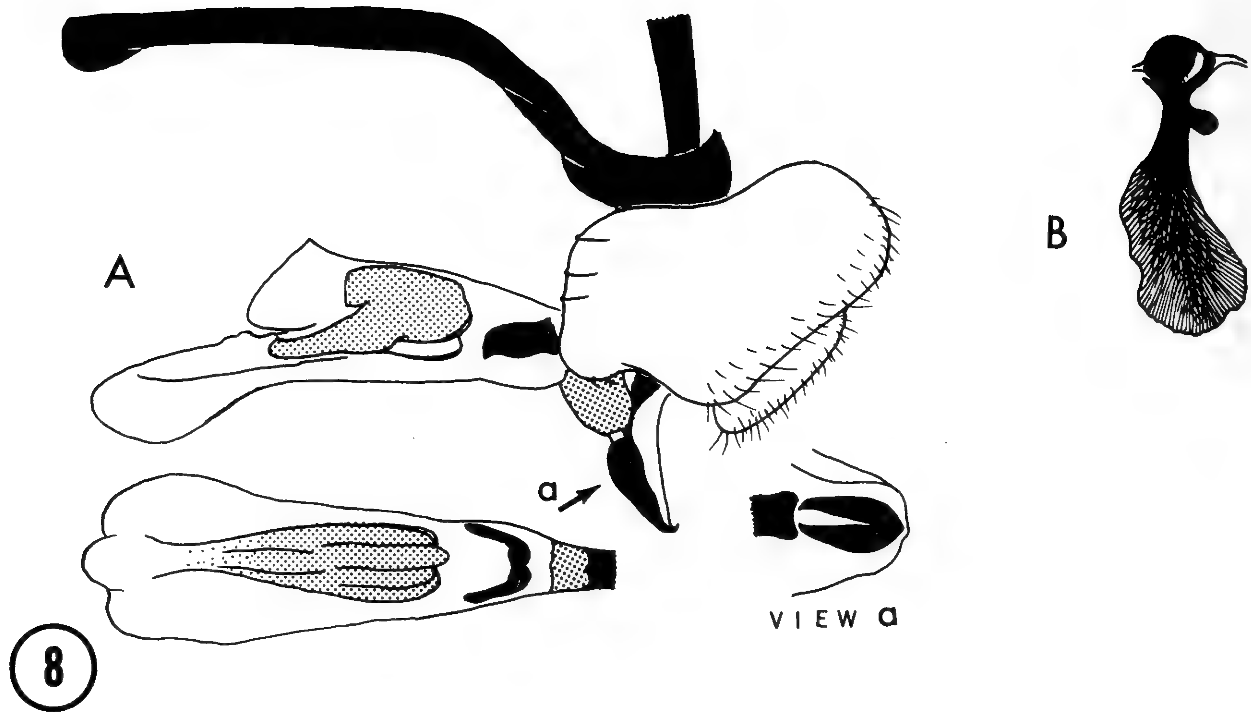

Fig. 8. *Melanagromyza vernoniae* Steyskal. A, postabdomen in profile, with ventral view of aedeagus and right angle view of phallapodemal extension; B, sperm pump.

Front at level of anterior ocellus 0.44 to 0.46 mm wide; gena deepest in middle, 0.14 of height of eye; genal setae with uppermost anterior seta (vibrissa) about twice as long as preceding setae.

Terminalia as in Fig. 9; epandrium in profile little swollen anteriorly, without ridges; ventral tip of epandrium angulate, with a few short stout posterior setae; distiphallic complex with long, arcuate apical arms and flared basal structures; extension of phallapodeme small, with slender apex; sperm pump with comparatively slender subbasal projection on apodeme.

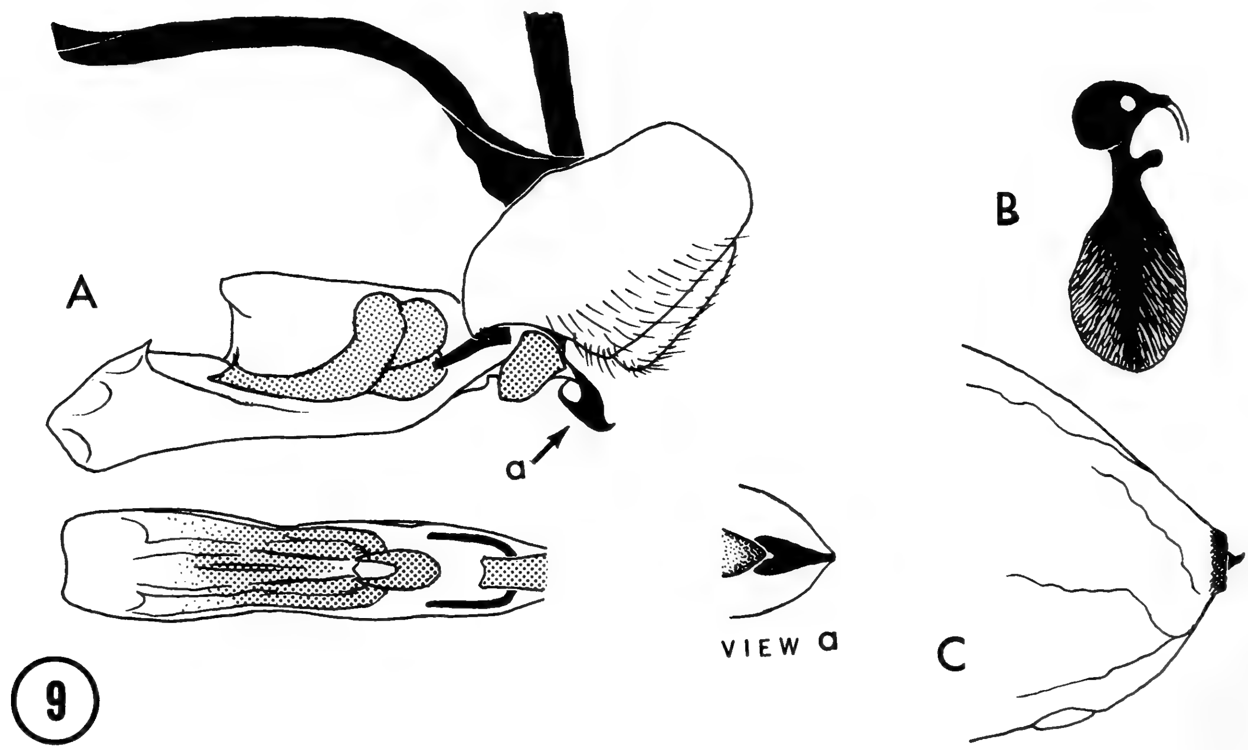

Fig. 9. *Melanagromyza vernoniana* Steyskal. A, postabdomen in profile, with ventral view of aedeagus and right angle view of phallapodemal extension; B, sperm pump; C, posterior end of putative puparium, profile view.

Types.—Holotype (♂), Cropley (on Potomac River 1.5 south of Great Falls), Montgomery County, Maryland, emerged indoors 11 February 1969 from puparium collected 20 October 1968; 1 ♂ paratype, Washington, D.C., emerged indoors 28 April 1970; both collected by D. M. Anderson from stem of *Vernonia noveboracensis* (L.) Michx. and deposited in U.S. National Museum of Natural History.

Remarks.—Five female specimens from the same locality and host as the male specimens are considered to be *M. vernoniana* because of the genal depth, but are not designated paratypes. A puparium is preserved with one of these females; it is pale tawny, 3.8 mm long by 1.3 mm in diameter, and has the posterior end as in Fig. 9C. Each stigmatophore has a circle of 16 pores.

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MEETING NOTES—BOARD OF MANAGERS

642nd Meeting—17 January 1980

The 642nd Meeting of the Board of Managers of the Washington Academy of Sciences was called to order by the President, Alfred Weissler at 7:30 P.M., at the Gillette Research Institute.

Minutes of Last Meeting: Corrections to minutes: In section 5b, change new member's name from Rosilind to Rosalind. The minutes were accepted as corrected.

Announcements: Grover Sherlin has been appointed chairman of an Ad Hoc Committee to prepare an information sheet for the affiliates. The new 1979 organization book was distributed. (Note: The Acoustical Society of America was omitted from the list of delegates.)

Report of the Secretary: There was no report.

Report of the Treasurer: The Annual Report was presented to the Board. Buras suggested that the Board of Managers request that the Executive Committee consider establishing a money market fund. The suggestion was approved with no dissenting vote.

Executive Committee: There was no report.

Membership Committee: The following new members have been elected: Mr. Lewis R. Townsend; Dr. Charles R. Townsend; Ms. Kay Test; and Dr. Barbara F. Howell. The Chairman complained that the secretarial service is so disorganized that it is hard to keep control of the membership process.

Policy Planning Committee: Two tasks are in progress—a book of SOP's, and a long-range planning document.

Ways and Means Committee: There has been no further action since the last report. The mailing list is still in error. President Townsend suggested that the Academy should permit members in arrears to become current by payment of current dues for this year only. It was agreed. Members will be notified.

Meetings Committee: O'Hare is planning for 100 people at the 26 February, 1980 meeting at the Cosmos Club. The 20 March, 1980 meeting will be held at Georgetown University. The 15 May, 1980 meeting will be held at the Cosmos Club.

Awards for Scientific Achievement: The six scientific panels have begun to function.

Grants-in-Aid for Research: There was no report.

Encouragement of Science Talent: There has been an active and varied program which has been quite successful. The Junior Academy has had division meetings; Christmas meetings; and Junior Science and Humanities Symposium. A representative of the Junior Academy will be invited to attend future Board meetings. Mrs. Shafrin was applauded by the Board for her work.

Public Information Committee: There was no report.

Policy for Academy Publications (O'Hare): A report (filed under committee's name) was submitted which recommended to Dr. K. Derucher or Dr. J. Fisher in that order. President Townsend moved that recommendation of the committee be accepted. The motion was unanamously approved.

Science, Engineering and Society (Abraham): It is possible to present topics on AM/FM radio if we prepare tapes. At present the committee is searching for funding.

Nominating (Aldridge): There was no report.

Auditing (Colwell): There was no report.

Report of the Editor: There was no report.

Report of the Joint Board on Science Education: There has been no new action since the last meeting of the Board.

Unfinished Business: There was no unfinished business.

New Business: There was no new business.

The meeting was adjourned at 10:32 P.M.

Respectfully submitted,

J. F. Goff, Secretary

643rd Meeting—21 February 1980

The 643rd Meeting of the Board of Managers was called to order by the President Alfred Weissler at 7:30 P.M. at the Gillette Research Institute.

Minutes of Last Meeting: The Treasurer's report was accepted as corrected.

Announcements: Dr. Derucher was introduced as the new editor. Dr. Foote was thanked by the President for his long and faithful service. Dr. James F. Schooley, 13700 Darnestown Rd, Gaithersburg, MD 20760, will be the delegate of the Philosophical Society of Washington. The National Association of Academies of Science has requested papers. President-elect Townsend will telephone E. Shafrin to see if there is any possible response by the Jr. Academy.

Report of the Secretary: There was no report.

Report of the Treasurer: The Treasurer's report was approved. It was suggested that the entry At Your Service be changed to Office Services.

Report of Standing Committees:

Executive: The committee met and considered the budget. A discussion of money market fund was conducted in concert with the board. The funds were viewed unfavorably because it was felt that capital would be mixed with cash. Also there was concern that losses incurred on the sale of bonds would not be offset by the increased interest. At Your Service was instructed to send third dues notices for the 1980's dues. Delinquents for '79 would be sent this notice with the advisory that they were to be given a one-time chance to become current by payment of only the 1980 dues. At Your Service was instructed to obtain FASEB's mailing list so that it could be photo-copied. FASEB would then be dismissed. At Your Service was instructed to report to the Board on its financial actions such as dues, page charges, and subscriptions. Specifically it is desired to know what mailings there have been, when they occurred, and what were the results.

Membership (Buras): The committee report was accepted. Mr. Jerome Robert Vetter was accepted for membership.

Policy Planning (Honig): There was no report.

Ways and Means (Stern): There was no report.

Meetings (Vila): It was moved that the supervisors of the recipients of the Awards for Scientific Achievement be invited to attend the dinner at their own expense at the 20 March meeting, Copley Lounge, Georgetown University. The motion was passed.

Awards for Scientific Achievement (Gray): At Your Service was directed to send a letter to the recipient, the nominator, and the head of laboratory or institution. Each letter was to be different as required.

Grants-In-Aid for Research (Long): There was no report.

Encouragement of Science Talent (Shafrin): There was no report.

Public Information (Parsons): There was no report.

Policy for Academy Publications (O'Hare): There was no report.

Science Engineering & Society (Abraham): There was no report.

Auditing (Colwell): There was no report.

Tellers (Rader/Buras): 596 letters were sent to members in good standing; 166 were returned. This percentage 28% is comparable to other organizations where numbers are available. Some ballots may have been delayed because of improper address. It was not felt to be necessary to redo the whole ballotting process. The Board accepted the results of the Tellers unanimously.

Report of the Editor: The September (79) and December (79) issues are almost ready for print.

Report of the Joint Board on Science Education (Sherlin): The Directory of the Joint Board of Science has been revised.

Unfinished Business: There was none.

New Business: There was none.

The next meeting of the Board will be held at the Graduate University, no fee, on Tuesday, March 18 at 7:30 P.M. The meeting was adjourned at 10:28 P.M.

Respectfully submitted,

J. F. Goff, Secretary

644th Meeting—March 18, 1980

The 644th Meeting of the Board of Managers was called to order at 7:30 P.M. at the National Graduate University on March 18, 1980. President Alfred Weissler thanked the University for its courtesy in having the meeting. He also noted that the Washington Academy of Sciences had its headquarters at the University and that there would be a tour of inspection of this after the meeting had adjourned.

Minutes of Last Meeting: Minutes of the previous meeting were corrected as follows: On page 3, 6. d. the word *results* in the final line of that paragraph should have read, *report*. Under 8 it should have been the Joint Board of Science and Engineering Education. The following line also should have had the words, *Engineering Education*, inserted. In the final paragraph the word, *National*, was to be inserted before Graduate University. On Attachment 3-2 under Disbursements of the Proposed 1980 Budget, the words, *Office Services*, was to substitute for *At Your Service*. On Attachment 4, last paragraph, it was *Mr.* James Glenn Moore, instead of *Dr.*, and elected to membership rather than fellowship. Dr. R. Landman observed that Maryland Withholding and IRS of $288.36 and $2,231.70 respectively had been paid by the WAS for the former office, which was unusual for an employer to do.

Announcements: The D.C. Institute of Chemists had elected a delegate as an alternate to Mr. Rechsigl, who is Dr. Edmund M. Buras, Jr. Dr. Ruth Landman, the new Delegate from the Anthropological Society of Washington, was introduced. A March 18, 1980 letter from At Your Service indicating their wishing to terminate their services to WAS on June 15, 1980.

Report on Secretarial Services: In the ensuing discussion of what to do about secretarial services, it was proposed that action be taken to set up services for the Academy. Dr. J. Boek presented two plans to begin in June 1980. One would be the normal services, the other would encompass a campaign for gaining new members of the Academy. Since the meeting lacked a quorum, it was decided that a vote would be taken on this at the next meeting. It was mentioned that it was not necessary to have the computer service at FASEB. It was also suggested that the minutes should be sent out as soon as possible and that the Executive Committee consider these budgets right away before the next Board meeting. When it was suggested that experience of other services be looked into, A. Weissler said he was not enthusiastic about Courtesy Associates because the Academy could not afford to pay more than at present.

Report of the Secretary: There was no report.

Report of the Treasurer: The Treasurer's Report from Dr. Rupp was accepted. The National Academy of Sciences has asked that WAS pay dues to it of 10¢ per member. The Treasurer had written to them. Last year the dues were $57.50. It was estimated that dues-paying members for this would be about $40.00. It was decided that this should be sent to them and handled as a routine expense of WAS. The NAS is a subsidiary of AAAS.

Reports of Standing Committees:

Membership (Buras): Chairman E. Buras absent.

Policy Planning (Honig): Chairman Dr. J. Honig absent.

Ways and Means (Stern): Chairman K. Stern absent.

Meetings (Vila): Chairman G. Vila absent. M. Townsend said the next WAS meeting was April 17.

Science Talent Awards: Chairman E. Shafrin reported by saying there was a need to enlarge this committee. The awards dinner was to be at Georgetown University for 10 recipients and their spouses. When Mrs. M. Townsend inquired about the possibility of having a combined awards dinner with the Joint Board on Science and Engineering Education, Mrs. Shafrin said the logistics would make that difficult, as there were so many awardees for both that the ceremony would be too lengthy. The Lamberton Award plaques were awarded to Stefan Prosky and Gonzaga High School. He will go to the International Science Fair. He is the winner of the Junior Academy of Sciences symposium and will go to St. Paul. An award on behalf of the WAS was given to Frank Lynn Brevard, a 12th grader of Ballou School, who had designed and built a hovercraft after seeing one at the David Taylor Model Basin.

The February meeting of the Junior Academy of Sciences was at the D.C. Mall in the Learning Center. Among the places they visited were the Luminist Exhibit at the National Gallery of Arts at which two of the Academy explained this to the others in the absence of a guide, which greatly impressed a ring of adults who surrounded the group to listen. They also visited the Naturalist Center, a place highly recommended, and visited the Einstein Exhibit and atom smashers at the Museum of History and Technology. Their next meeting is on March 29 at the Washington Cathedral, for which they are hoping to have an explanation of its structure by a liturgical architect. Dr. Shafrin expects to continue on the Committee for another year but not as its Chairman. She and Grover Sherlin have personally contributed substantial sums of their own money to the Junior Academy of Sciences to keep it operative. On the third Monday in May (19th) is the Awards Banquet for 40 high schoolers who placed first in the science fairs. This is at Georgetown University, with 100–200 persons expected. Six members of the Junior Academy were among the 300 selected of 10,000 entries in the United States. Among those in the local top 40, one was a Junior Academy member who won $500, another was not of the Academy who won a $10,000 scholarship.

Public Information (Parsons): Dr. Parsons reported with a prefatory question of whether behavioral sciences were represented at the science fairs. Dr. Shafren said there was one quasi-related one in which human traps were utilized for animals, which the person had patented. Dr. Parsons continued his report by stating that news releases for the Washington Academy of Sciences had been sent to all newspapers in the area. Mrs. Townsend said the *Washington Star* had hired a new person, and that if there was space, such notices would appear in columns about people in the area.

Report of the Special Committees:

Auditing (Colwell): Washington Academy of Sciences records were examined on March 11, 1980. Their report was accepted.

Report of the Editor: In the absence of the Journal Editor, Dr. Weissler said that the September (1979) and December (1979) issues were still underway.

Report of the Joint Board on Science Education (Sherlin): Mrs. Townsend gave the report in the absence of Mr. G. Sherlin. She said it had met the previous evening.

Unfinished Business: It was mentioned that At Your Service was sending third due notices.

New Business: There was none.

The next meeting of the Board of Managers is April 17 at 4:30 P.M. in Building 8, Room 400 of the Goddard Space Center, just prior to the monthly meeting. The meeting was adjourned at 9:35 P.M.

Respectfully submitted,

Jean Boek, Secretary Pro-Tem

645th Meeting—17 April 1980

The 645th Meeting of the Board of Managers of the Washington Academy of Sciences was called to order by the President, Alfred Weissler at 4:30 P.M., at the NASA/ Goddard Space Flight Center.

Minutes of Last Meeting: The minutes of the previous meeting were corrected as follows: In section 1, paragraph 1, line 11, the Maryland withholding was withheld from the secretaries salaries. In section 6f, paragraph 1, line 2, change *Dr.* Shafren to *Mrs.* Shafrin. Line 3, change human traps to humane traps. In section 10, paragraph 1, line 1, change *due* notices to *dues* notices. The minutes were accepted as corrected.

Announcements: Mr. Tony Nesky, President of the Jr. Academy of Sciences, discussed the purpose and condition of the Jr. Academy. The Jr. Academy provides access to facilities and personnel engaged in science for young people. It does this by tours and the publicizing of events. The Jr. Academy was founded in 1952 and is sponsored by the Senior Academy. For many years it was funded by Penn Central; but since that corporation foundered, the Jr. Academy has been on hard times. The current membership is about 150 to 200 members. The Jr. Academy plans to solicit funds and would like help in sending letters. It plans to send about 300 of them. M. Townsend offered to supply help by allowing the Jr. Academy the use of NASA automatic typewriters.

Dr. Weissler read the letter from Science 80 in which our mailing list was requested. It was moved that the Academy exchange mailing lists with Science 80. The motion passed with no dissent.

Report of the Secretary: The secretary delivered a letter from the AAAS to G. Sherlin in which the AAAS brought to our attention 2 student grant progams.

Report of the Treasurer: The treasurer's report was accepted subject to audit.

Report of Executive Committee: The Executive Committee considered a proposal by the National Graduate University to supply the secretarial services required by the Academy. There was considerable discussion over possible economies versus the merit of a close association of the service with the new secretary, Jean Boek. It was decided that the matter should be considered in more detail by an expanded Executive Committee consisting of: Present Committee (A. Weissler, M. Townsend, N. Rupp, J. Goff, M. Aldridge, and J. Boek), next year's committee (M. Townsend, L. S. Birks, J. Honig, J. Boek) and the Chairman of the Policy Planning Committee (J. Honig) and Ways & Means (K. Stern). The committee was charged to recommend alternatives by ballot to the Board of Managers at a meeting 2000 hrs. 29 April 1980 at Beeghly Hall, Room #102, American University.

The Executive Committee will meet at A. Weissler's house, 2000 hrs., 23 April 1980.

New Business: Dr. Weissler reported that Dr. Sawhill has been requested to speak at the retiring president's dinner. If he does not accept the invitation, Dr. Weissler will be forced to speak.

The meeting adjourned at 6:00 P.M.

Respectfully submitted,

J. F. Goff, Secretary

646th Meeting—29 April 1980

The 646th Meeting of the Board of Managers of the Washington Academy of Sciences was called to order by the President, Alfred Weissler at 8:01 P.M., at the American University.

Minutes of Last Meeting: Corrections to minutes of last meeting: Item 6: Dr. Weissler assured the Board of Managers that he would speak without being forced. The minutes were accepted as corrected.

Announcements: There were no announcements.

Report of the Secretary: There was no report.

Report of the Treasurer: The Treasurer's Report and comments were accepted. It was assured that the Treasurer's recommendation to pay $1,000 to the Lancaster Press be accepted. The motion was accepted without dissent. It was assured that the Executive Committee be authorized to borrow $5,000 if necessary to meet short-term expenses of the Academy. The motion was accepted without dissent.

Report of Standing Committees:

Executive Committee: The Executive Committee met to consider replacement of At-Your-Service. R. Cook inquired of the American Geophysical Union as to the possibility that they would provide our secretarial services. They declined. J. O'Hare reported that the D.C. Psychological Association declined also. The National Graduate University submitted a tentative contract. There were a number of comments such as the service should handle membership and fellow letters, notices should be sent in a timely manner (section III A-2) and so on. It was pointed out that any such contract should consider a statement to the effect that for any matters not specifically defined, it will be expected that they be handled in accordance with standard and reasonable accepted practice. As a result of these discussions, the following motion was passed unanimously: To authorize Executive Committee to negotiate a one-year contract with National Graduate University for office services subject to the following: Start date to be at end of arrangement with At-Your-Service; annual cost is to be $8,604 plus reimburseable expenses at cost, these expenses to include printing and postage; and use April 29, 1980 proposal as a basis subject to better definition by Executive Committee and agreed to by National Graduate University, including specific services for the Washington Junior Academy of Sciences.

Membership Committee (Buras): There was no report.

Policy Planning Committee (Honig): There was no report.

Ways and Means Committee (Stern): There was no report.

Committee on Meetings (Vila): There was no report.

Committee on Awards for Scientific Achievement (Gray): There was no report.

Committee on Grants-in-aid for Research (Long): There was no report.

Committee on Encouragement of Scientific Talent (Shafrin): Some forty may be honored at the Westinghouse Science Fair on Monday, 19 May 1980. It was moved that the Academy underwrite these awards in an amount not to exceed $400. The motion was passed unanimously.

Committee on Public Information (Parsons): There was no report.

Reports of the Special Committees: There were no reports of the following Special Committees: Auditing (Colwell), Bylaws and Board Rules (Wood), Nominating (Aldridge), Tellers (Rader), Science Engineering and Society (Abraham), or Publications Policies (O'Hare).

Report of the Editor: The editor was absent.

Report of the Joint Board on Science Education (Sherlin): M. Townsend announced that she was appointing the following new members to the Joint Board: Jo-Anne Jackson, Edythe Durie, and L. Douglas Ballard.

Unfinished Business: There was no additional unfinished business.

New Business: J. Wagner brought to the attention of the Board that Fidelity Cash & Reserve has a fund which pays interest and which can be used for checking. This information was given to M. Townsend. C. Creveling brought to the attention of the Board the fact that the D.C. Government has an office whose concern is Washington organizations which it can subsidize. He also asked whether the affiliates could be asked to contribute to the Academy. J. Goff suggested that all meetings should be joint with an affiliate in order to promote the sense of affiliation and reduce costs.

The next meeting will be held at the National Graduate University on Wednesday, June 4, 1980. The meeting was adjourned at 9:47 P.M.

Respectfully submitted,

J. F. Goff, Secretary

647th Meeting—June 4, 1980

The 647th Meeting of the Board of Managers of the Washington Academy of Sciences was called to order by the President, Mrs. Marjorie R. Townsend, at 7:30 P.M. in the Orange Room of National Graduate University. The following were either present or excused:

Officers:

Mrs. Marjorie R. Townsend (President)
Dr. Jean K. Boek (Secretary)
Mr. LaVerne S. Birks (Treasurer)
Dr. Alphonse Forziati (Past President, Nominating Committee Chairman)
Dr. Florence Forziati (Past President, Audit Committee Chairman)
Dr. John G. Honig (President Elect, Washington Operations Research Council)
Dr. Alfred Weissler (Past President)
Dr. Mary H. Aldridge (Past President)

Managers-at-large:

Dr. Conrad B. Link (Botanical Society of Washington)
Mrs. Elaine G. Shafrin (Washington Junior Academy of Sciences)
Dr. John J. O'Hare (District of Columbia Psychological Association)
Dr. Jo-Anne A. Jackson (Chemical Society of Washington)
Mr. Grover C. Sherlin (Membership Committee Chairman)

Committees:

Mr. Edward M. Buras, Jr. (Tellers Chairman)

Delegates and Alternates:

Dr. Charles E. Townsend (Medical Society of the District of Columbia)
Dr. Ronald W. Manderscheid (Society of General Systems Research)
Mr. William C. Prinz (Geological Society of Washington)
Dr. Lloyd G. Herman (American Society for Microbiology)
Mr. David Lewis (American Ceramic Society)
Dr. W. Ronald Heyer (Biological Society of Washington)
Dr. A. D. Berneking (Institute of Food Technologists)
Dr. Ruth H. Landman (Anthropological Society of Washington)
Mr. Paul H. Oehser (Columbia Historical Society)
Dr. Michael Chi (American Society of Mechanical Engineers)
Dr. George J. Simonis (Optical Society of America, National Capitol Section)

Excused:

Dr. H. McIlvaine Parsons (Human Factors Society, Public Information Committee Chairman)

Dr. Richard K. Cook (Acoustical Society of America)

The minutes of the April 29, 1980 meeting were approved.

The President then read names of Chairman of the Standing Committees:

Executive—Mrs. Marjorie R. Townsend
Membership—Mr. Grover C. Sherlin
Policy Planning—Dr. John G. Honig
Bylaws and Standing Rules—Dr. John G. Honig
Awards for Scientific Achievement—Dr. Sherman Ross
Ways and Means—Dr. Richard K. Cook
Grants-in-Aid for Research—Mr. Grover C. Sherlin
Encouragement of Science Talent—Mrs. Marjorie R. Townsend
Public Information—Dr. H. McIlvaine Parsons
Academy Contingent on the Joint Board on Science and Engineering Education—Dr. Jo-Anne Jackson
Audit—Dr. Florence H. Forziati
Nominating—Dr. Alphonse F. Forziati
Science, Engineering, and Society—Dr. George Abraham
Tellers—Mr. Edmund M. Buras, Jr.

Those in attendance at the meeting were next introduced. For new delegates, the purposes of the Academy and Board of Managers were explicated.

The Secretary reported that with the move of headquarters and operations to National Graduate University, the new phone number of the Washington Academy of Sciences, the Joint Board on Science and Engineering Education, and the Washington Junior Academy of Sciences is 703-347-3368.

The treasurer reported on a meeting with the President of National Graduate University in which they discussed the changeover of operations from At Your Service. It was recommended to the Academy that it adopt a system for its separate account in which automatic records in the account books are made as each check is written. It was moved and seconded, and passed that the $100–200 start-up cost of purchase of this system be authorized and that the Academy reimburse the University for the costs of the checks and account books.

The Board of Managers also moved, seconded and passed that the Academy bank account be transferred from American Security Bank, N. A. to the United Virginia Bank across the street from the University which pays interest on its checking account. It was further recommended by the Treasurer that consideration be given to putting cash accumulations beyond that needed for immediate checking account needs into a high interest-bearing ready-asset account at the brokerage firm of Thomas and McKinnon. The question was asked if this type of an account were insured by some agency like FDIC. It was also suggested that this matter be considered later if there were any surplus.

The Treasurer said that the University had also suggested a professional audit of the books at this time. It was moved and seconded that this be done. In the ensuing discussion, however, it was pointed out that because of the present state of the books that the Audit Committee chaired by Dr. Florence Forziati would have the burden of that audit anyway, that it would be very costly, and that the Board was satisfied that she and her committee would be able to do the job needed at this time. The motion was therefore defeated. Dr. Forziati indicated that she would be glad to undertake this task.

In the first report of the Standing Committees (as indicated on the Agenda appended to the minutes as E-1) Mrs. Townsend said that the Executive Committee had drafted the organization directory and had a meeting on May 21 in which substantial progress had been made on updating the Academy mailing list. During the June 18 meeting, the new list would be checked against the yellow cards. She also said that a contract for office services from June 1, 1980, through May 31, 1981, had been signed with National Graduate University. At Your Service files with exception of the account books and check book, had been moved on May 31 to the University at 1101 North Highland Street in Arlington by Mr.

Sherlin. At Your Service was using these to finish the May 15 report to the IRS. National Graduate University had made available a suite of rooms for the WAS, WJAS, and JBSEE where archives and furniture of the societies already had been placed.

Mr. Buras reported on nominations for Fellow of Dr. George F. Peiper and Dr. Peter F. Wiggens, whose qualifications had already been sent to the Board. It was moved, seconded, and passed that they be accepted as Fellows after this second reading. Mr. Buras also reported that two new members have been accepted and welcomed: Dr. Harold Berkson of the Naval Research Laboratory and Mrs. Carolyn C. Block.

For the Membership Committee, Mr. Sherlin said the seven or eight review committees according to scientific or engineering discipline would be reestablished for Fellowship nominations and a report given at the next Board meeting.

The Committee on Policy Planning under chairmanship of Dr. Honig had gone through long-range reports made through the years by various Academy presidents with an eye of how to increase activity of the society.

The Committee on Meetings said that monthly meetings of the Academy should be co-sponsored with affiliated societies. The Core Program for the year appended to these Minutes was used as a basis of decision of location of the meetings. Conversazione on Thursday, November 20, would be at National Graduate University, with the format being four or five tables set with wine and cheese, each headed by a well-known person in a different discipline to stimulate discussion. The Saturday, December 13, all-day meeting would be at Goddard Space Flight Center, with a full program of speakers, lunch, and use of the papers for the March 1981 issue of the *Journal.* Because this comes just before the week-long meeting of the astrophysics conference in Baltimore, notices of this would be mailed to that group as well. Conference registration would be $20–25, which includes lunch and proceedings. The high cost of previous conference proceedings was mentioned by Drs. Aldridge and Forziati. In view of this, the tendency was to favor incorporation of the papers in the Academy *Journal,* with perhaps extra copies in the number being printed for non-members who had attended. Cost of fliers for the meeting would be borne, in part, by Goddard.

In consideration of location of the meetings, Mrs. Sharin said if Dr. Finn would serve as sponsor for the Awards Banquet, we might consider having it at Georgetown University, as it has been satisfactory before. When Dr. O'Hare asked if any other arrangements had been made definite, Mrs. Townsend indicated that dates and speakers had been a first consideration. In the ensuing discussion about having dinner prior to meetings, Dr. Aldridge observed that attendance had been poor for many years at dinner meetings, except where there was co-sponsorship with another member society. Attendance was felt to depend on speakers as well as location. Dr. Simonis said the Optical Society has attendance of 20–50 at certain restaurants where dinner was $10. Dr. Chi said rotation of location for ASME meetings had brought in new faces each time, but not necessarily larger numbers. Attendance reasonable in size was considered to be 50–100. Kenwood Country Club was favored because of good parking, easy-to-reach location, and public transportation for the early evening. Dr. O'Hare said he would ask George Vila to reserve dates for the meetings.

Activities of the Committee on Grants-in-Aid for Research were reported by Mr. Sherlin. The Washington Academy of Sciences had an escrow account of $900 from former annual rebate from the American Association for the Advancement of Science. Now AAAS awards grants to groups within the United States who apply for this.

The next meeting of the Washington Junior Academy of Science was slated to be Saturday A.M. June 14, 1980 at National Graduate University. Mrs. Shafrin described one of their recent meetings at the National Presbyterian Church, attended by about 40, which featured take-offs on student papers. The Church charged $40 for several rooms and kitchen privileges. Balloting for their new officers is proceeding.

In discussing the report of the Archivist, Mr. Oehser said he was archivist for one group and was willing to help find one for WAS. Apparently WAS records were put in the Smithsonian Tower. He will investigate to learn what is there now.

The Joint Board will be meeting Monday, June 9 at the Patent Office.

Under New Business, the President asked each delegate to send information about his or her society to WAS at 1101 N. Highland Street in order to have it by the July meeting. This reminder was to be especially noted in the minutes (hence the underlining). It was also suggested that at least two prestigious members of each society be nominated for Fellow in WAS. Mr. Sherlin said two pink Fellow forms were needed for each. These, passed out. Members can apply on the green forms by themselves. Delegates who were not already Fellows could be sponsored. Dr. Simonis said it would be helpful to have a new brochure about WAS, but the present one has not been updated since this matter was discussed in the May 21 Executive Committee meeting. Mr. Sherlin said his wife was becoming a member.

When the difference between the $25 dues for Fellow and $20 for Member was noted, Dr. Alphonse Forziati said the original intent had been to have members as a support group for the Fellows who were the only ones permitted to vote and to hold office. There was no student membership because the WAS was for senior scientists and the Junior Academy for those younger. However, the hiatus existing for college-age students was noted.

The suggestion was made to co-sponsor the D.C. Forester's meeting in September.

The President asked those present how many had association newsletters, with half of those present indicating they did. This was prologue to the question of whether the WAS should have an umbrella newsletter. The American Chemical Society currently provides a list of all meetings in the city. Mrs. Shafrin said when the *WAS Journal* was issued 10 times a year, upcoming meetings were listed, so that function was fulfilled. It was noted that the Biological Society was having their centennial in December which WAS might wish to recognize. Dr. Landman suggested that WAS ask each affiliate society for the name of its newsletter and a list of members.

For the September 3 meeting of the Board of Managers, it was suggested to have a wine and cheese reception for the officers of all affiliated societies. Dr. Chi thought perhaps having the meeting first followed by a social hour afterward was a good idea. This underscored the importance of getting the list of members and officers from each society.

In a discussion of having an organizational emblem, Mrs. Townsend passed around samples of pins from other societies as examples. There would be a $35 set up cost plus purchase of 1000 of these to be underwritten by WAS, which would have to be recovered by the sale of these to members. The idea of having a $10 initiation fee to cover the cost of these, plus a certificate, was not received with much enthusiasm, as it was felt this might curtail increase in membership. The motion was made and seconded to offer a pin, plus a certificate for the $10 fee. In the discussion, Mrs. Shafrin said there was a Fellow certificate already in existence on which names could be placed, at a cost of about $2 each. The observation was made that with dues already high we would discourage new membership, as all scientific associations were becoming more expensive to belong to. Dr. Simonis objected to having such a large initiation fee. The motion was defeated.

Dr. Chi moved and Dr. Townsend seconded the motion to have an emblem available for sale for $5. This was amended to delete the $5. Discussion then centered on the design, with an indication that we already had one that was on the *Journal*. If there were to be others, Dr. O'Hare felt the members should approve of this. Dr. Aldridge said potential members or fellows ask what the society was going to do for them, and the extra expenses might inhibit their joining. On the vote for the motion, 8 were in favor, 5 opposed: motion carried. The motion to have the design approved by members was appended to the motion, but it was moved and seconded that the motion for consideration of design be tabled.

In discussion of affiliation with additional scientific societies, it was suggested that since the National Science Teacher's Association had headquarters in this area, they should be asked to become an affiliate. It was felt that because there were many association headquarters in the area that the Policy and Planning Committee should pursue this systematically. Sigma Xi was another group suggested to be asked to affiliate, especially as there were five chapters locally, according to Mr. Buras.

The AAAS had asked the Academy to send news. The $25 page charge for an author to publish in the journal was thought to dampen interest of potential contributors. There had been referee panels in different disciplines for the journal which Dr. Forziati was going to check on for future action.

The motion was then made, seconded and passed that the meeting be adjourned at 10:20 P.M.

Respectfully submitted,

Jean Boek, Secretary

APPENDIX A

From the Standing Rules, the regular order of business shall be:

A. Approval of the minutes of the last meeting.
B. Announcements, such as committee appointments.
C. Report of the Secretary.
D. Report of the Treasurer.
E. Reports of standing committees as follows:
   1. Executive Committee
      a. Draft organization directory.
      b. Meeting held on May 21, 1980.
      c. Contract for office services from June 1, 1980, through May 31, 1981, signed with National Graduate University.
      d. Closeout of activity with At Your Service effective May 31, 1980.
      e. Move of files to 1101 N. Highland Street.
      f. Activity to reestablish mailing list.
      g. Committee chairmen appointed.
   2. Committee on Membership
   3. Committee on Policy Planning
   4. Committee on Ways and Means
   5. Committee on Meetings
   6. Committee on Awards for Scientific Achievement
   7. Committee on Grants-in-aid for Research
   8. Committee on Encouragement of Science Talent
   9. Committee on Public Information
F. Reports on special committees.
G. Report of the Editor.
H. Report of the Archivist.
I. Report from the Joint Board on Science and Engineering Education.
J. Unfinished business.
K. New business.
   1. Action for delegates
      a. Obtain names, addresses, and term of office for officers for each affiliated society. Mail information to WAS office at 1101 N. Highland Street, Arlington, VA 22201, or bring to next meeting of the Board of Managers on Thursday, July 17, 1980, at 7:30 P.M.
      b. Arrange for the nomination of the two most prestigious members of your society to fellowship in the WAS.
      c. Determine whether any society meetings should be co-sponsored by the WAS.
   2. Possibility of wine and cheese reception for all Delegates and the Presidents/Chairmen of each affiliated society at the September 3, 1980, Board of Managers meeting.

3. Membership emblems.
4. Consideration of initiation fee to include emblem and certificate of membership.
5. Affiliation with additional scientific societies.

L. Adjournment

648th Meeting—July 17, 1980

The 648th Meeting of the Washington Academy of Sciences was called to order on Thursday, July 17, 1980 at 7:30 by President-Elect, John G. Honig. The minutes of the previous meeting were accepted as written.

The Secretary asked for Board opinion about having advertising in the WAS Journal, because the Smithsonian Institution had called to ask about this. The matter was referred to Dr. John O'Hare, Chairman of the Publications Committee. Since the Editor was not present, it was reported by Dr. Honig that Richard Foote, the previous editor, said that Dr. Kenneth N. Derucher had told him that he was waiting for one or two more articles before the first, 1980 Journal could go to press. Dr. Honig was not able to get any response from the Editor from his phone calls. It was pointed out that by having the journals late without giving a six-week notification to subscribers and members the Academy ran the risk of being cited for mail fraud, as another professional society had been. A letter from Mr. William H. Press, President of the Columbia Historical Society received on July 9, 1980 was read. It appealed for contributions to restore the Christian Heurich Mansion. It was decided to postpone action on this until the Academy's finances would be completely audited. In response to the request for the Board to act upon 1981 costs of library subscriptions for the journal, it was moved, seconded and passed that overseas library subscriptions would be raised from $20 to $22 and domestic subscriptions from $17 to $19 to meet the anticipated 10 percent increase in printing costs. The revision of the WAS flier was mentioned and deferred to a later time.

A new set of WAS directories were given to each person present. Dr. Parsons expressed the pleasure of the board in having these well-done in a timely fashion, credit that belongs to the President, Mrs. Marjorie Townsend and her husband, Dr. Charles Townsend, Delegate from the Medical Society of the District of Columbia. They were assisted in this work by Ms. Brenda Cullen, Mrs. Townsend's secretary.

The Treasurer said that from June 5 until July 15, 1980, WAS had an income of $1759 from its investments. During this time it paid out $1354, leaving a balance of $404.78 in the Virginia National Bank account.

The report of the Audit Committee was read by Dr. Forziati and written into the minutes as Exhibit A. They said there was $3,761.80 as of June 30 in the American Security Bank Account, which will be transferred to the Virginia National Bank account by the Treasurer during July. The auditors' suggestions for setting up the new bookkeeping system by National Graduate University for the Academy were found to coincide with categories that had already been set up by Mrs. Loreen McDaniel. The Lancaster Press was requested to reflect payment made to them of $1000 on the June account. The Academy also has a savings account in the Chevy Chase Savings and Loan of $267, as of September 26, 1979, which also will be transferred to the Virginia National Bank. It was moved, seconded and passed that all bills be paid except those of the Lancaster Press which currently exceed the amount in the accounts, and for a report about the investment assets being made. It was also moved, seconded and passed unanimously to accord the Forziatis a vote of thanks for the excellent and painstaking work they had done on the account books.

Mr. Buras reported that the WAS mailing list was partially worked through by the Executive working committee that had met several times at Mrs. Townsend's home to mesh the sources of names: the 1977, 1978, and 1979 Directories, the two 1980 printouts, and the active and inactive card files, with the goal of having one current, complete card file from which future mailings could be made. Mrs. Donna Smith's report was noted that savings could be made in mailing out the journals by having this done by National Graduate University instead of by the Lancaster Press.

The Committee on Policy Planning has put together reports of former presidents. Mr. Buras, Dr. Stern and Dr. Cook, as members of the committee suggested that four priorities be 1) to increase membership, 2) streamline management 3) have more joint activities with other societies and 4) put the Academy on a sound fiscal basis. It was also suggested that as a result of their July 3 meeting that three Vice Presidents be added to the Academy elected officers: 1) Membership to oversee mailing lists and promotion, 2) Programs and meeting support, and 3) Communication, journals, prizes and awards. This would require a change in the by-laws. It was also noted that there is now no special policy about new societies affiliating with WAS.

Dr. Cook, of Ways and Means asked to have an increase in dues for 1980 on. Discussion of the motion made and seconded to increase the dues included the observation that the Academy will not have a realistic budget based on actual membership, until the mailing list is completely corrected. Also, it was suggested that the Academy consider all financial problems together, that with the journal very behind schedule members were not getting what many join for, and that until the mailing list enabled the Academy to mail out dues notices to all members, it was best to keep them at the present rate of $20 for Members and $25 for Fellows. The vote was 6 to 4 in favor of tabling the motion in order that advance notice about dues increase in the future could be given to the Board as an agenda item.

Mr. Sherlin reported that there was no money for grants in aid from AAAS this year. Dr. Weissler said under the new rules that societies apply for these funds. It had been decided last fall to apply and that at present it was early enough to apply for this year, as this was the first year that no money was earmarked for WAS.

Dr. Parsons reporting on Public Information showed the Board an article from the July 4, 1980 LABSTRACTS Naval Laboratory featuring the work that Mrs. Elaine Shafrin had done for the Washington Junior Academy of Sciences.

Mr. Guy Hammer next reported on a proposal that had been written by Dr. George Abraham and himself as an activity of the Awards for Scientific Achievement Committee to apply to the National Science Foundation Science for Citizen program, as this was in line with WAS purpose. Discussion on the motion made and seconded to accept the report and to offer WAS support for this led to examination of the genesis of this and what next steps were. There was a vote of four against and five in favor of tabling the motion. However, Dr. Weissler said the Board thanked Mr. Hammer and Dr. Abraham for writing this proposal, and that it was well worth pushing ahead on this. This document represents a preliminary proposal which will be reviewed by NSF by September 15, so there will be another chance at the September 3 meeting to discuss it again.

Names of officers for affiliated societies are gradually being received for the Directory issue.

There being no other new business, the meeting was adjourned.

Respectfully submitted,
Jean K. Boek, Secretary

The date of publication of Vol. 70, No. 1 is February 16, 1981.

JOURNAL OF THE WASHINGTON ACADEMY OF SCIENCES

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National Geographical Society	T. Dale Stewart
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Columbia Historical Society	Paul H. Oehser
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Delegates continue in office until new selections are made by the representative societies.

Prehistoric Human Remains From The Cotocollao Site, Pichincha Province, Ecuador

Douglas H. Ubelaker

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ABSTRACT

Recent excavations by the Banco Central of Quito Ecuador at the Cotocollao site north of Quito recovered 199 human skeletons dating from about 540 B.C. and four skeletons dating from about 1100 B.C. Analysis reveals an estimated living stature of about 159 cm for males and 148 cm for females, several examples of cranial deformation, an equal representation of males and females, nearly a lack of infants younger than one year, comparatively low life expectancy and low frequencies of dental disease, infectious disease and examples of trauma. These data, as well as skeletal measurements and non-metric observations, are compared with those from coastal sites.

Large well-documented samples of prehistoric human skeletons offer important information regarding diet, demography, disease, population affinities and cultural practices that affect the skeleton. Such samples are now emerging in Latin America as physical anthropologists become more involved in excavation and archeologists increase awareness of the information to be gained in cemetery excavation.

In Ecuador, large well-documented samples have resulted from excavations at Ayalán (500 B.C. to A.D. 1600), Guayas Province (Ubelaker, 1981); Real Alto (2920 B.C. to 2770 B.C.), Guayas Province (Klepinger, 1979 and unpublished manuscript); Site OGSE-80, Sta. Elena Peninsula (6000 B.C.), Guayas Province (Stothert, 1977 and Ubelaker, 1980); and possibly Buena Vista (Valdivia C, 2000 B.C. to 1400 B.C.), Guayas Province (Munizaga, 1965). Published analysis of some of this material (Klepinger, 1979; Munizaga, 1965, 1976; Ubelaker, 1980, 1981) documents the variety of information gleaned from analysis and how it can be correlated with cultural variables. This report adds to this growing literature by presenting analysis of a new prehistoric human skeletal sample from Ecuador, that of the Cotocollao site (CO-1) near Quito.

Cotocollao represents a large prehistoric habitation site and associated cemetery located in the Ecuadorian highlands in the northwest suburbs of Quito. Recent intensive excavation sponsored by the Banco Central of Ecuador revealed a large cemetery containing at least two components: an early deposition of largely primary skeletons in clearly defined individual pits and a more recent deposit of a large group of skeletons, both primary and secondary with no discernible pit outlines. According to Project Director, Emil Petersen, (personal communication) radiocarbon dates average 1100 B.C. for the early sample and 540 B.C. for the later. All remains are covered with a thick layer of pumice and volcanic ash, believed to date from about 500 B.C.

My participation in the project began in August 1978, when my wife Maruja Andrade de Ubelaker, research assistant, Stephanie Damadio and I travelled to Ecuador at the invitation of the Banco Central to study skeletal materials from the Sta. Elena site (Ubelaker, 1980) and from Cotocollao. At the time of our arrival, all skeletal materials from Cotocollao had been removed from the site and were stored in a nearby laboratory. Some burials had been removed intact within large blocks of earth while most had been removed from the soil and were stored in individual boxes. All of the material was badly fragmented and some had been coated with glue. Most of the burials retained identification tags enabling correlation with field observations, location within the site, etc. During this initial visit, we located, cleaned and recorded data on human remains from 14 features and established procedures for the continued processing of the remaining features.

In December, 1979, Maruja Andrade de Ubelaker and I returned to Quito to continue the analysis. Following our August visit, processing of the material had continued through the able efforts of Peace Corps volunteer Petrova Ashby and others under her supervision. We returned to find that most of the material had been cleaned, labeled and placed in sealed cloth or plastic containers. With the continued assistance of Petrova Ashby, we completed data collection by January 1979.

The following presents detailed information on the skeletal content of each feature, as well as biological and cultural information gleaned from the complete sample. Individual bone counts and frequencies of observations and measurement must be regarded as minimal due to the extreme fragmentation and relatively poor preservation. Criteria for determining sex and age at death are summarized by Ubelaker (1978). All stature calculations were made utilizing the regression equations of Genovés or Trotter and Gleser (also summarized by Ubelaker, 1978). Note that data presented here are confined to biological information only. Information on burial location, position, associated artifacts, dating, stratigraphy and general site interpretations will be presented in a future publication planned by the Banco Central of Ecuador.

Site and feature terminology used here represents the system employed by Peterson (personal communication) in the excavation. Site features 19 and 38 refer to two large areas of the site that produced burials. Individual features and "tombs" within these areas refer to specific interments or groups of bones. According to Peterson's interpretation of the stratigraphy and radiocarbon dates, all burial features from site feature 38 and burial features 1 through 144 of site feature 19 represent the later component of about 540 B.C. Burial features 146 to 150 of site feature 19 represent the earlier component (1100 B.C.).

Site Feature 19

Feature 1:—One adult. Bones present: one left femur, one left clavicle, one left scapula, nine teeth, and several metatarsal fragments. Sex: unknown. Age: 25–35 years.

Feature 2:—Three adults and one subadult. Three adults are represented by crania and right femora. Other bones present include one left and one right humerus, one radius, one ulna, one left femur, one right tibia, one right patella. The skulls represent one male, age 20–30 years, one of unknown sex, age 25–35 years and one adult male of unknown age. One left femur appears to be female, thus the skull of unknown sex may be female. A living stature of about 142 cm is suggested by the femur. One subadult mandible is also present. Dental formation suggests an age of between 3 and 4 years.

Feature 3:—One complete adult skeleton. Sex: male. Age: 25–35 years. Stature estimated from left humerus using Trotter and Gleser's data is 167 cm.

Feature 4:—One adult and one subadult. Adult bones are the following: left radius, one ulna, one femur, one left tibia, one fibula, one right scapula, one first metacarpal and fragments of a left maxilla. No age and sex estimate can be made.

The subadult is represented only by one deciduous molar. Formation data suggest an age of about one year.

Feature 5:—One adult and one subadult. The adult consists only of femoral fragments and the acromial process from a left scapula. Resorption spaces in the femoral cortex suggest an age at death between 40 and 60 years. Sex: undetermined.

Two thoracic vertebrae are also present of a child between the ages of three and six years.

Feature 6:—One adolescent represented only by fragments from a left tibia, left temporal, maxilla and mandible. Dental formation suggests an age of about 15 years.

Feature 7:—Two adults and one subadult. Bones present are one right ulna, two left and two right tibiae, one left and one right temporal, one left and one right maxilla, one left calcaneus, one left talus, one left navicular, one right second metatarsal and teeth. One skull is fragmentary, but complete. It is male, 35–40 years in age. Extra teeth indicate the second adult may be 30 to 40 years in age. One maxillary incisor of a five year old child is also present.

Feature 8:—One young adult of undetermined sex. Bones present are both humerii, both femora, both tibiae, one fibula and the right clavicle. Lack of visible resorption spaces in the femoral cortex generally suggests an age between 20 and 40 years. An estimated right humerus length of 26.8 cm suggests a living stature of about 152 cm.

Feature 9:—Only a few adult long bone fragments. No estimate of sex and age.

Feature 10:—One young adult represented by 10 thoracic vertebrae, two lumbar vertebrae and 13 ribs. No estimate of sex or exact age.

Feature 11:—One adult of undetermined sex. Bones present are both humerii, one ulna, both femora, both tibiae, mandible and five thoracic vertebrae. An age of 25–35 is suggested by dental attrition.

Feature 12:—One adult. Bones present: right radius, left femur, right tibia, right scapula and teeth. Age: 20–25 years. Sex: undetermined.

Feature 14:—One young adult and one child. The adult is represented by the right humerus, one radius, the right femur, left temporal, one proximal hand phalanx and two teeth. Age: 20–25 years. Sex: undetermined.

The subadult is represented only by one permanent first molar. Formation data suggest an age of about three years.

Feature 15:—Three adults. Bones present: one left humerus, one left and one right radius, one ulna, one left and one right femur, two left and three right tibiae, three fibulae, one left and one right temporal, two left and two right maxillae and two cranial vaults. Both skulls are 25 to 30 year old males. A left tibia length of 37.0 cm suggests a living stature of 164 cm for one male.

Feature 16:—Two young adults. Fragments of a humerus, femur, fibula, patella and two mandibles are present. Both individuals are young adults, age 15–30 years. No estimate of sex can be made.

Feature 17:—One young adult. Only fragments of the skull, mandible, left humerus, femur, tibia, fibula, right clavicle, scapulae, one rib and three thoracic vertebrae are present. Sex: female. Age: 25–30 years.

Feature 18:—One adult. Fragments of the skull, mandible, femora, tibiae, clavicles, 11 ribs and 10 vertebrae are present. Sex: female. Age: 30–50 years.

Feature 19:—One adult. Bones present: left, humerus, right radius, both femora, left tibia, left scapula, right temporal and mandible. Sex: female. Age: unknown.

Feature 21:—One adult and one subadult. Bones present: both femora, both tibiae, right temporal, cranial fragments and teeth. Sex: undetermined. Age: 20–35 years. The subadult is represented only by one maxillary first molar. Estimated age: four years.

Feature 22:—One adult. Bones present: fragments of few long bones and skull. Sex: undetermined. Age: 23–30 years.

Feature 23:—One adult. Bones present: right scapula, right calcaneus, fragments of long bones, skull and teeth. Sex: undetermined. Age: 30–40 years.

Feature 26 (also features 59, 70, 81):—Two adults and one adolescent. Bones present: one left and one right humerus, one left and one right radius, one left and one right ulna, two left and three right femora, one left and one right tibia, one fibula, one left and one right clavicle, one right temporal, one right maxilla, one mandible, three vertebrae, six ribs, one right calcaneus, one right talus. Two individuals are adults of unknown sex and age. One of the right femora is from an adolescent, age 18–20 years.

Feature 27:—One adult. Bones present: cranial vault, teeth and right humerus. Sex: male. Age: 20–25 years.

Feature 28:—One adult. Bones present: left humerus, left femur, left tibia, teeth, and fragments from other long bones and the skull. Sex: female. Age: 20–30 years.

Feature 29:—Two adults. Generally complete skeleton with extra femora. Sex: female. Age: 30–40 years. Stature of complete skeleton: 138 cm. The extra femora are male, with stature estimated at 151 cm.

Feature 30:—One adult. Bones present: both humerii, both femora, left tibia, mandible, right innominate, long bone and cranial fragments. Sex: female. Age: 40–60 years.

Feature 31:—One adult. Only skull and two long bone fragments are present. Sex: female. Age: 40–60 years.

Feature 32:—One adult. Bones present: both humerii, both femora, right tibia, right scapula. Sex: male. Age: undetermined.

Feature 33:—One adult. Bones present: right humerus, both femora, mandible skull and long bone fragments. Sex: male. Age: 35–40 years.

Feature 34:—One adult. Bones present: right humerus, left femur, both tibiae and teeth. Sex: undetermined. Age: 25–35 years.

Feature 35 and 36:—Three adults. These two numbers were assigned to the same skeletal remains. Bones present: two left and three right humerii, one right radius, three left and three right femora, one left and one right tibia, two left and two right clavicles, one left and one right scapula, one right temporal, three left and three right maxillae, one mandible, two right innominates, several ribs and six thoracic vertebrae. Innominate morphology indicates at least one male and one female are present. Attrition data indicate that at least one male skull is 25 to 30 years. The other two skulls are aged at 35 to 60 years and 25 to 35 years.

Feature 37:—One adult and one adolescent. Most bones are from the nearly complete skeleton of a 16–19 year old, of undetermined sex. A right distal humerus is larger than the other bones and probably represents an adult of undetermined sex and age.

Feature 38:—One adult. Bones present: left humerus, both femora, both tibiae, the fibulae, left temporal, both maxillae and right hamate. Sex: male. Age: 25–35 years.

Feature 39:—Two adults. Bones present: right humerus, two left and two right femora, one left and two right tibiae, one left temporal, one left and one right maxilla, two mandibles and 18 hand and foot bones. The older individual is male, 25–35 years of age, with a living stature of about 157 cm. The younger individual is 18–21 years old and of undetermined sex.

Feature 40:—One adult. Bones present: right humerus, left femur, left fibula, right clavicle, right scapula, five ribs and one thoracic vertebra. Sex: female. Age: undetermined.

Feature 41:—One adult. Bones present: left femur, left fibula, both scapulae, left mandible, left patella, several ribs and six thoracic vertebrae. Sex: male. Age: 20–35 years.

Feature 42:—One adult. Bones present: both femora, left tibia, cranial fragments. Sex: undetermined. Age: undetermined.

Feature 43:—One adult. Bones present:

right femur, both tibiae, skull and mandible. Sex: female. Age: 40–60 years.

Feature 44:—One adult and one child. Adult bones present: left humerus, both ulnae, right femur, right clavicle, two vertebrae and several ribs. Sex: undetermined. Age: undetermined. The subadult is represented only by both femora, and the mandible. Age: 2 years.

Feature 46:—One adult and one adolescent. Bones present: one left and one right humerus, one right ulna, one left and two right femora, two left tibiae, one fibula, one right clavicle, one left and one right scapula, nine vertebrae and 15 ribs. The adult is of undetermined sex and age. The adolescent is probably between 15 and 18 years.

Feature 48:—Two adults and one subadult. Adult bones present: one left and two right femora, one left tibiae, one rib, and cranial fragments. Some cranial fragments show non-union of coronal and sagittal sutures, generally suggesting an age at death of less than 40 years for at least one adult. More exact age and sex determinations cannot be made.

The subadult is represented only by a right femur, about 175 mm in length. This length suggests an age at death of about 2.5 years.

Feature 49:—One adult and one child. Adult bones present: one right femur and one right tibia. Sex: undetermined. Age: undetermined.

The subadult is represented only by cranial fragments. Thickness of the fragments suggests an age less than five years.

Feature 50:—One adult. Bones present: left radius, both tibiae, left clavicle, both temporals. Sex: undetermined. Age: undetermined.

Feature 51:—One adult. Only fragmentary skull present. Sex: male. Age: 20–30 years.

Feature 52:—One adult. Bones present: both femora, right clavicle, right scapula, mandible and skull. Sex: undetermined. Age: 20–30 years.

Feature 53:—Only one subadult skull and mandible. Age: 13 years.

Feature 54 and 55:—Two fragmentary skulls. Sex: undetermined. Age: both 25–35 years.

Feature 56:—One adult. Bones present: right humerus, both radii, fibula. Sex: undetermined. Age: undetermined.

Feature 58:—One adult. Bones present: left scapula and mandible. Sex: undetermined. Age: undetermined.

Feature 60:—One adult. Bones present: right humerus, skull. Sex: female. Age: 20–30 years.

Feature 61:—Two adults. Bones present: left radius, left ulna, left femur, two left and two right tibiae, one fibula, one right clavicle, one right scapula, two mandibles, one right innominate, several ribs and vertebrae, 14 hand bones, and two skulls. One skeleton is male, age 45 years. The second skeleton is female, age 35 to 40 years.

Feature 62:—One adult. Bones present: one fifth metacarpal and one skull. Sex: male. Age: 20–35 years.

Feature 63:—One adult. Bones present: both femora, two cervical vertebrae, one third metacarpal, the skull and mandible. Sex: female. Age: 25–35 years.

Feature 64:—Three adults. Bones present: one left humerus, one left femur, three left and two right tibiae, one right clavicle, one left scapula, and one skull. Sex: the skull is female. Age: undetermined.

Feature 65:—One adult. Bones present: few long bone fragments and skull. Sex: undetermined. Age: undetermined.

Feature 66:—One adult. Bones present: both humerii, right femur, both tibiae, skull and mandible. Sex: male. Age: 35–40 years.

Feature 68:—One adult. Bones present: right femur, left clavicle, left temporal, mandible. Sex: undetermined. Age: 25–35 years.

Feature 69:—One adult. Bones present: left radius, both femora and other long bone fragments. Sex: undetermined. Age: undetermined.

Feature 71:—Two adults. Bones present: one left and two right humerii, one left radius, two left and one right femur, one left and one right tibia, one left scapula, one mandible, one left innominate, one left patella, 20 vertebrae, 10 hand and foot bones, several ribs, and one skull. Sex: one female, one undetermined. Age: one female, 35–60 years; other undetermined.

Feature 72:—One adult. Bones present: one left humerus, few cranial and long bone fragments. Sex: undetermined. Age: 18–25 years.

Feature 73:—One adult. Bones present: skull and mandible. Sex: female. Age: 40–60 years.

Feature 74:—One child. Bones present: left humerus, both tibiae, long bone and cranial fragments. Age: 8 years.

Feature 75:—One adult. Bones present: two cervical vertebrae, mandible and cranial fragments. Sex: undetermined. Age: 20–35 years.

Feature 76:—One adult. Bones present: both humerii, both femora, five hand and foot bones and cranial fragments. Sex: undetermined. Age: undetermined.

Feature 77:—Two adults. Bones present: left femur, left and right tibiae, left and right innominates, four lumbar vertebrae, sacrum, and skull. The skull is of undetermined sex, but between 35 and 60 years of age. The post-cranial skeleton is female, age 17 to 22 years.

Feature 78:—Two adults. Bones present: left humerus, both tibiae, left clavicle, two mandibles and one skull. One individual is male, age 25–30 years. The second individual is female, age undetermined.

Feature 79:—One adult. Bones present: left humerus, right radius, both femora, left tibia, fibula, right patella, seven hand and foot bones and the skull and mandible. Sex: female. Age: 23–30 years.

Feature 80:—One adult. Bones present: both femora, both tibiae, and fibula. Sex: undetermined. Age: 25–30 years.

Feature 82:—One adult. Bones present: left femur, left tibia, right scapula, mandible and cranial fragments. Sex: undetermined. Age: undetermined.

Feature 84:—One adult, one subadult. Adult bones present: left radius, both ulnae, right clavicle, four thoracic vertebrae, left talus, six ribs. Sex: male. Age: 20–40 years. Stature: 162 cm, calculated from a left radius length of 23.0 cm.

Subadult bones present consist of one right clavicle and one right tibia. Lengths of these bones suggest an age of 1.5 years.

Feature 86:—One adult. Bones present: few long bone fragments and nine teeth. Sex: undetermined. Age: 10–15 years.

Feature 87:—One adult. Bones present: right radius, both ulnae, right tibia, long bone fragments and teeth. Sex: undetermined. Age: 25–30 years.

Feature 88 and 89:—One adult. Bones present: left humerus, left clavicle, right scapula, both temporals, mandible, six thoracic vertebrae, and eight ribs. Sex: female. Age: 35–40 years.

Feature 90:—One adult. Bones present: both temporals, femoral fragments and teeth. Sex: undetermined. Age: 20–25 years.

Feature 92:—One adult, one subadult. Adult bones present: both humerii, left ulna, right femur, right clavicle, mandible, left innominate, six thoracic vertebrae, two lumbar vertebrae, five ribs. Sex: male. Age: 35–40 years.

Subadult bones present: left humerus, left femur, left tibia, left fibula, left scapula, both temporals, both maxillae, mandible, most ribs and vertebrae. Age: 2.5 years.

Feature 93:—One adult and one subadult. Adult bones present: right clavicle, right temporal, both maxillae, mandible and teeth. Sex: male. Age: 40–60 years.

Only one left femur represents the subadult. A length of 190 mm suggests an age at death of 3.5 years.

Feature 94:—One adult. Bones present: one mandible, skull and long bone fragments. Sex: undetermined. Age: 30–40 years.

Feature 95:—One adult. Bones present: left humerus, mandible, tibia fragments. Sex: female. Age: 20–35 years.

Feature 96:—One adult. Bones present: both humerii, radius, ulna, both femora, both tibiae, fibula, both clavicles, left scapula, mandible, right patella, eight hand and foot bones. Sex: male. Age: 35–60 years. Stature: 168 cm, calculated from a right femur length of 46.0 cm.

Feature 97:—One adult and one subadult. Adult bones present: all long bones, left clavicle, right scapula, mandible, left innominate, left patella, 10 vertebrae, sacrum, 18 foot bones and four ribs. Sex: female. Age: 35–45 years. Stature: 150 cm, calculated from a left femur length of 39.5 cm.

The subadult is represented only by one left humerus. Estimated length of 17.0 cm suggests an age at death of about six years.

Feature 98:—One adult. Bones present: both femora, both tibiae, both fibulae, both innominates, and six foot bones. Sex: male. Age: undetermined. Stature: 152 cm, calculated from a right femur length of 39.0 cm.

Feature 100:—One adult. Bones present: skull, mandible and four thoracic vertebrae. Sex: male. Age: 30–40 years.

Feature 101:—One adult. Bones present: left humerus, left radius, left ulna, right scapula, two thoracic vertebrae. Sex: undetermined. Age: 17–20 years.

Feature 102:—One adult. Bones present: right humerus, right ulna, left tibia, fibula, both clavicles, right scapula, right maxilla, and 10 ribs. Sex: female. Age: 25–35 years.

Feature 103:—One child. Bones present: both femora and teeth. Age: 4 years.

Feature 104:—One adult. Bones present: right temporal, teeth, cranial and long bone fragments. Sex: undetermined. Age: undetermined.

Feature 105:—One adult and one subadult. Adult bones present: left scapula, and teeth. Sex: undetermined. Age: 35–45 years.

The subadult is represented only by teeth. Age: about 4 years.

Feature 106:—One adult. Bones present: both humerii, left ulna, both femora, right tibia, left clavicle, left scapula. Sex: male. Age: 20–45 years.

Feature 107:—One adult. Articulated skeleton removed *in situ* within a block of soil. Skeleton is generally complete. Sex: male. Age: undetermined. Stature: 161 cm, calculated from a left femur length of 43.0 cm.

Feature 108:—One adolescent. Bones present: one left innominate and long bone and skull fragments covered with soil and glue. Age: 13 years.

Feature 109:—One adult. Bones present: both humerii, left radius, left femur, both tibiae, skull, mandible, both innominates, six thoracic vertebrae. Sex: female. Age: 30–40 years. Stature: 142 cm, calculated from a right tibia length of 29.5 cm.

Features 110 and 135:—One adult and one subadult. Adult bones present: both humerii, left radius, left femur, left scapula, both temporals, mandible. Sex: female. Age: 40–60 years. Stature: 151 cm, calculated from a left humerus length of 26.5 cm.

The subadult is represented by teeth only. Age: 10 years.

Feature 111:—One adult and one adolescent. Adult bones present: left humerus, left radius, left ulna, both femora, both tibiae, mandible, first cervical vertebra, one proximal hand phalanx, one right talus and skull. Sex: male. Age: 40–60 years. Stature: 159 cm, calculated from a right tibia length of 34.5 cm.

The subadult is represented only by a right clavicle and one thoracic vertebra. Age: 12–18 years.

Feature 112 and 121:—Two adults and two subadults. Adult bones present: one left and one right femur, two right tibia, one fibula, one mandible and teeth. Sex and Age: One adult is female, age 22–25 years. The other adult is of undetermined sex and age.

Subadult bones present: one left and one right temporal, one mandible and two groups of teeth. Ages: 10 and 4.5 years.

Feature 113:—One adult and one subadult. Adult bones present: cranial and long bone fragments and two teeth. Sex: undetermined. Age: 20–25 years.

The subadult is represented only by one tooth. Age: 4.5 years.

Feature 114:—One adult and one adolescent. Bones present: right temporal, mandible, proximal hand phalanx and two groups of teeth. Sex: the older individual is male, the younger undetermined. Age: 16–20 years and 30–50 years.

Feature 115:—One adult. Bones present:

cranial fragments only. Sex: undetermined. Age: 15–30 years.

Feature 116:—One adult. Bones present: generally complete skeleton moved *in situ* within block of soil. Sex: male. Age: 30–40 years. Stature: 161 cm, calculated from a left tibia length of 35.5 cm.

Feature 117:—One adult and one subadult. Adult bones present: both humerii, left radius, both femora, right tibia, fibula, right innominate, four thoracic vertebrae, one right calcaneus, seven metatarsals, and three ribs. Sex: male. Age: 20–40 years. Stature: 154 cm, calculated from a right tibia length of 32.0 cm.

The subadult is represented by one maxillary premolar. Age: 5 years.

Feature 118:—One subadult. Bones present: both clavicles, left scapula, right temporal, mandible, 11 ribs, 10 vertebrae and teeth. Age: 4 years.

Feature 119:—One subadult. Bones present: skull and teeth only. Age: 4.5 years.

Feature 120:—One adult. Bones present: skull fragments. Sex: undetermined. Age: 35–45 years.

Feature 122:—One adult and one subadult. Adult bones present: right humerus, left ulna, left tibia, left scapula, right temporal, both maxillae, left patella, innominate and teeth. Sex: female. Age: 35–60 years.

The subadult is represented by teeth only. Age: about 4 years.

Feature 123:—One adult. Bones present: right humerus, right ulna, both femora. Sex: undetermined. Age: undetermined.

Feature 124:—One adult. Bones present: Only adult-size long bone fragments. Sex: undetermined. Age: undetermined.

Feature 125:—One adult. Bones present: both femora and other long bone fragments, and teeth. Sex: undetermined. Age: undetermined.

Feature 126 and 127:—One adult and one subadult. Adult bones present: one left femur, one mandible, and skull. Sex: male. Age: 25–35 years.

The subadult is represented only by one tooth, age about 4 years.

Feature 128:—One adult. Bones present: one skeleton generally complete, removed intact within a large block of soil for museum display. Sex: female. Age: 35–40 years. Stature: 167 cm, calculated from a right tibia length of 38.8 cm.

Feature 129:—One adult. Bones present: right radius, right ulna, right clavicle, right scapula, two thoracic vertebrae, four hand bones, skull and mandible. Sex: male. Age: 30–40 years. Stature: 158 cm, calculated from a right ulna length of 23.5 cm.

Feature 130:—Two adults. Bones present: both clavicles, both scapulae, six cervical vertebrae, one rib, skull and mandible. Most represent a female age 35 to 45 years. Extra teeth represent an adult of undetermined sex, age 20 to 30 years.

Feature 131:—Two adults and two subadults. Bones present: one left and one right humerus, two left scapulae, two mandibles, two thoracic vertebrae, one second left metatarsal, 13 ribs and one skull. Sex: one male, one undetermined. Age: the male is 30–35 years. The other adult is of undetermined age.

The subadults are represented by one right femur and 27 teeth. Ages are estimated at 4.5 and 6.0 years.

Feature 132:—Two adults. Bones present: left humerus, left femur, both tibiae and two skulls. Sex: one male and one female. Age: both 20–30 years.

Feature 133:—One adult. Bones present: right tibia, skull and mandible. Sex: undetermined. Age: 30–35 years.

Feature 134:—One adult. Bones present: left femur, mandible and most of skull. Sex: undetermined. Age: 23–30 years.

Feature 136:—Two adults. Bones present: long bone fragments and teeth. Sex: both undetermined. Age: 18–25 years.

Feature 137:—One adult, one subadult. Adult bones present: left humerus, right femur and cranial fragments. Sex: female. Age: 20–30 years.

The subadult is represented only by one permanent and three deciduous teeth. Age: 3 years.

Feature 140:—One adult. Bones present: both humerii, left ulna, left femur, right scapula, skull and mandible. Sex: male.

Age: 30–35 years. Stature 149 cm, calculated from a left femur length of 37.5 cm.

Feature 141:—One adolescent. Bones present: right humerus, ten thoracic vertebrae, eight ribs, and cranial fragments. Sex: undetermined. Age: 15–18 years.

Feature 142:—One adult. Bones present: both tibae, skull and mandible. Sex: female. Age 40–60 years.

Feature 143:—Three adults. Bones present: three left humerii, three right humerii, one right radius, two left ulnae, one left femur, one right femur, one left and one right tibia, one fibula, and one left scapula, one mandible, and two cervical vertebrae. Sex: one male, two undetermined. Age: one 22–25 years, two undetermined.

Feature 144:—One adult, one subadult. Adult bones present: right humerus, left ulna, left scapula, mandible, two cervical and four thoracic vertebrae, eight ribs, and one skull. Sex: male. Age 25–30 years. Stature: 171 cm, calculated from a right humerus length of 33.3 cm.

The subadult is represented only by cranial fragments. Age: 5 to 15 years.

Feature 146 (*tomb burial*):—One adult. Bones present: one generally complete skeleton removed intact within a block of soil. Sex: male. Age: 30–40 years. Stature: 160 cm, calculated from a right femur length of 42.5 cm.

Feature 147 (*tomb burial*):—One adult. Bones present: right ulna, both femora, both tibiae, mandible and skull. Sex: male. Age: 30–40 years.

Feature 149 (*tomb burial*):—One adult. Bones present: teeth only. Sex: undetermined. Age: 22–25 years.

Feature 150 (*tomb burial*):—One adult. Bones present: teeth only. Sex: undetermined. Age: 20–25 years.

Site Feature 38

Tomb 1:—One adult. Bones present: left tibia, left clavicle, right scapula, long bone and cranial fragments. Sex: undetermined. Age: 15–25 years.

Tomb 3:—One adult. Bones present: left femur and cranial fragments. Sex: female. Age: 20–25 years.

Tomb 4:—Two adults. Bones present: right femur, two left fibulae, parts of two crania, and one right fifth metacarpal. Sex: one male, one female. Age: female, 30–35 years; male, undetermined.

Tomb 6:—Two adults. Bones present: both humerii, left radius, both femora, both tibiae, one fibula, both clavicles, both scapulae, one mandible, two left patellae and one right patella, six thoracic vertebrae, one hand phalanx, one right calcaneus, two metatarsals and 10 ribs. Sex: one male, one female. Age: one 30–35 years; other, undetermined. Stature of the male: 160 cm, calculated from a right humerus length of 29.5 cm.

Tomb 7:—One adult and two subadults. Adult bones present: both patellae, left femur and two thoracic vertebrae. Sex: male. Age: 40–60 years.

Subadult bones present: both humerii, both radii, both femora, both tibiae, both fibulae, both clavicles, both scapulae, both temporals, mandible, both patellae, and one metacarpal from one skeleton age 13 years. One deciduous mandibular second molar is also present, representing a 7 to 10 year old child.

Tomb 8:—One adult. Bones present: right humerus, left radius. Sex: female. Age: 35–45 years.

Tomb 9:—One adult. Bones present: one mandible. Sex: undetermined. Age: 25–30 years.

Tomb 10:—Two adults. Bones present: one right humerus, one right ulna, one left femur, two left and one right tibiae, one fibula, one right scapula, one left patella, and most of one skull. Sex: one female and probably one male. All remains but the extra tibia are female. Age: 40–45 years; male, undetermined.

Tomb 11:—One adult. Bones present: left humerus, right tibia, fibula, left clavicle, left scapula, mandible, seven cervical vertebrae, six hand phalanges, and two metatarsals. Sex: female. Age: 25–30 years.

Tomb 12:—One adult. Bones present:

fragmentary skull. Sex: undetermined. Age: 35–40 years.

Tomb 15:—One adult. Bones present: both humerii, left radius, both femora, right tibia, fibula fragments, skull, mandible and three foot bones. Sex: male. Age: 40–50 years.

Tomb 16:—Two adults. Bones present: two right humerii, one left and one right tibia, two right clavicles, one left scapula, two right scapulae, one mandible, one right patella, four cervical vertebrae, ten thoracic vertebrae, and one skull. The skull is female, age 20–25 years. Most long bones are male, age 40–60 years. Stature is 154 cm, calculated from a left fibula length of 31.5 cm.

Tomb 18:—One adult. Bones present: both humerii, right radius, both femora, left tibia, right fibula, right clavicle, right innominate, one vertebra, two foot bones and the skull. Sex: female. Age: 45–60 years.

Tomb 20:—One adult. Bones present: both humerii, both femora, both tibiae, one mandible, and 12 foot bones. Sex: female. Age: 25–30 years. Stature: 148 cm, calculated from a right femur length of 39.0 cm.

Tomb 22:—One adult. Bones present: cranial fragments and one tooth. Sex: undetermined. Age: 30–35 years.

Tomb 23:—One adult. Bones present: left femur, left tibia, right navicular, left talus, left first metatarsal. Sex: female. Age: undetermined.

The Total Sample

Note that each skeletal unit had been assigned at least one burial, tomb and/or feature number and during excavation some units had been assigned multiple numbers. Those numbers assigned to features in which no bone survived are not discussed here. This analysis assumes that each skeletal unit is of archeological/cultural significance and that single individuals are not represented in more than one burial unit. Note, also that all counts are minimal due to the fragmentary nature of the material.

The sample of human skeletons from the late component consist of 199 individuals from 137 burial units, an average of 1.5 individuals per unit. The earlier component is represented only by four adults from four tomb burials. Bone representation in both components varies from relatively complete skeletons to only a few bones or teeth. The varied representation represents mostly problems of preservation, but probably also some cultural selection of the kinds of bones buried. The large later sample contains nearly equal numbers of adults estimated to be males (42) and females (40), although sex could not be determined for a large number (73). Subadults appear to be under-represented in both the later and earlier samples since only 21 percent of the later sample are less than 20 years of age and no subadults are in the earlier sample.

Artificial Modifications of the Skeleton

Of the 27 crania from the later component that were sufficiently complete to allow observations of cranial deformation, only five (19 percent) showed such evidence. These five examples were all from feature 19, originating from three adult males, one adult female and one subadult. Four of these represent occipital flattening. The exception is a female skull from feature 132 that shows flattening above inion. Many other crania in this sample are deformed, but probably due to ground pressure, etc. rather than cultural practices while the individuals were alive. The five examples mentioned above may also have been influenced by soil pressures, but the appearance of the deformations indicates that cultural factors were involved. No examples of deformation were detected in the earlier sample.

Living Stature

Estimates of living stature were made for 17 males and seven females of the later sample and only for one male of the early sample. If tibiae or femora were available, statures were calculated using formulae of Genovés (1967), if not, those of Trotter and Gleser (1958) were used. For the late sample, male statures average 159 cm and range from 149 to 171 cm while female statures average 148 cm and range from 138 to 167 cm. The only male stature from the early sample is estimated at 160 cm. These mean values are nearly the same as those reported for the coastal samples of Ayalán, Real Alto and Sta. Elena (Ubelaker, 1980).

Measurements and Observations

Non-metric data were recorded on the crania and mandibles (Table 1) using the same techniques employed in the Ayalán (Ubelaker, 1981) and Sta. Elena (Ubelaker, 1980) analyses. The small sample sizes and incompleteness of the data limit interpretation, however, the data do suggest possible sex differences in several traits, especially supraorbital foramen, wormian bones, tympanic dehiscences. Most of these contrast with the sex differences noted in the Sta. Elena sample (Ubelaker, 1981). In the Sta. Elena sample, males show greater frequencies of wormian bones, marginal foramen of the tympanic plate, tympanic plate dehiscence while females showed more supraorbital foramen. In the Cotocollao sample, the exact reverse is the case. Not only do the frequencies vary but also the sex distribution of the frequencies. Comparison of the combined sex frequencies reveals that Cotocollao shows greater frequencies than Sta. Elena of nearly all traits.

Table 2 summarizes measurements and indices of the Cotocollao late sample. As expected most male measurements are greater than those of the females with bicondylar breadth and the cranial index showing the greatest sexual dimorphism. The male mean cranial index of 87 is equal to males of the non-urn component at Ayalán, coastal Ecuador, (500 B.C. to A.D. 1155) and females of the later Ayalán urn component (A.D. 730 to A.D. 1600), but larger than that found in all other Ecuadorian samples (Ubelaker, 1980). The female mean index of 75 is the smallest reported for all of these sites, although the sample size of cranial indices at Cotocollao is so small (2) that little significance can be attached to these observations. Compared to the other Ecuadorian samples, measurements of males in the Cotocollao material that are relatively large are cranial length, cranial breadth, minimum frontal breadth, orbital breadth, and bicondylar breadth. Values for the other measurements and indices fall within the range of those reported from the other sites. Overall, males show greatest similarity to the Buena Vista and the Ayalán urn samples while females are most similar to the Sta. Elena and Real Alto samples. Clarification

Table 1.—Frequency of non-metric observations within the Cotocollao sample, later component.

	Males		Females		Both sexes	
Observation	n.	Percent present	n.	Percent present	n.	Percent present
Mylohyoid bridge	17	12	11	27	28	18
Accessory mental foramen	18	0	18	0	36	0
Frontal groove	16	19	6	0	22	14
Supraorbital foramen	17	65	9	22	26	50
Wormian bones	13	54	8	100	21	71
Parietal process of temporal squama	7	0	4	0	11	0
Squamoparietal synostosis	13	0	15	7	28	3
Auditory exostoses	18	0	24	0	42	0
Marginal foramen of tympanic plate	10	0	17	12	27	7
Tympanic plate dehiscence	15	20	22	45	37	32
Maxillary third molar	10	100	3	100	13	100

Table 2.—Summary statistics of Cotocollao later component cranial and mandibular measurements and indices.

Measurement or Index	Males				Females			
	n.	Mean	S.D.	Range	n.	Mean	S.D.	Range
Auricular height	3	118	8	110–125	2	115	13	105–125
Porion to bregma	3	116	6	110–121	2	112	16	100–123
Length	4	181	4	178–187	3	182	7	174–187
Breadth	2	158	31	150–166	4	140	6	134–149
Basion-bregma	1	131	0	0	—	—	—	—
Basion-porion	1	43	0	0	—	—	—	—
Minimum frontal breadth	5	98	4	95–103	3	93	4	89–96
Upper facial height	1	70	0	0	1	67	0	0
Nasal height	1	51	0	0	1	49	0	0
Nasal breadth	1	28	0	0	1	25	0	0
Orbital height	2	38	4	35–40	1	34	0	0
Orbital breadth	1	43	0	0	1	40	0	0
Maxillo-alveolar length	3	52	6	46–58	4	50	5	45–55
Maxillo-alveolar breadth	3	67	3	64–70	3	64	4	60–67
Palatal length	3	39	6	34–46	4	34	2	32–35
Palatal breadth	3	41	6	34–46	3	40	1	39–41
Bicondylar breadth	3	127	9	118–136	2	107	11	99–115
Bigonial Breadth	4	110	10	100–119	2	98	8	92–103
Height of ascending ramus	8	61	4	53–65	5	53	3	47–56
Minimum breadth of ascending ramus	11	33	3	28–38	8	30	2	27–32
Height of mandibular symphysis	10	35	3	31–39	6	31	2	28–32
Cranial index	2	87	9	80–93	3	75	2	74–77

of the relationships must await larger, better preserved samples.

Demography

Accurate demographic reconstruction depends mostly upon accurate sampling and accurate estimation of sex and age of death. Both factors present problems for demographic analysis of these samples. The early component at Cotocallao is represented only by four incomplete adult skeletons, two males and two adults of undetermined sex. Ages of both males were estimated at between 30 and 40 years. The remaining two ages were 20–25 years and 22–25 years. The sample is too small to offer summary data on demographic structure.

The later sample consists of 199 individuals ranging in age from birth to greater than 50 years. Forty-two males and 40 females were recognized, although sex could not be determined for an additional 73 adults. Adult male ages at death averaged 35 years, while the female average value was 34. The average adult age at death (males and females combined) is also 34 years. Subadults are represented by nine individuals between ages 15 and 19, eight between 10 and 14, seven between 5 and 9, 19 between 2 and 4 and only one between birth and one year. The low figure for the youngest category may represent low mortality, but more probably represents burial practices that excluded the burial of young infants in the cemetery or such excessive decomposition and fragmentation of young infant bones that they either were not present in the final sample or were not recognized. Demographic information is summarized in the life table (Table 3), see Ubelaker (1978) for methodology used in calculation and for explanation of the symbols. To insure complete adult representation, the number and percent of individuals in each adult age interval was first calculated using only those adults whose ages were estimated. These figures were then adjusted proportionately upward so that their total equalled the total number of adults in the sample (155). The subadult figures (intervals below 20 years) are not adjusted. The life expectancy at birth figure

Table 3.—Life table, reconstructed from the later component, Cotocollao sample.

x	Dx	dx	lx	qx	Lx	Tx	e°x
.0– .9	1	1	100	.010	95	2824	28
1.0– 4.9	19	10	99	.096	379	2729	27
5.0– 9.9	7	4	90	.039	441	2350	26
10.0–14.9	8	4	86	.047	442	1909	22
15.0–19.9	9	5	82	.055	401	1487	18
20.0–24.9	19	10	78	.123	366	1087	14
25.0–29.9	40	20	68	.294	291	721	11
30.0–34.9	37	19	48	.385	195	430	9
35.0–39.9	22	11	30	.373	121	235	8
40.0–44.9	12	6	19	.324	78	114	6
45.0–49.9	23	12	13	.920	34	36	3
50.0–54.9	2	1	1	1.000	3	3	3

(28) is probably too high, due to the apparent loss of young infants from the sample. The remaining figures are similar to other data reported from prehistoric Ecuador (Ubelaker, 1980). Life expectancy at age one (27) is slightly lower than that derived from the Sta. Elena sample (29), and the Ayalán urn sample (29), but slightly higher than the 26 recorded for the Ayalán non-urn sample. Life expectancy at age 20 (14 years) is lower than that reported from Sta. Elena (17 years), Real Alto (17 years) Ayalán non-urns (15 years) and Ayalán urns (21 years). To some extent, this may reflect the difficulty in estimating adult age at death in the Cotocollao sample.

Pathology

Evidence for disease in the Cotocollao material all originates from the late sample and consists of three types; periosteal bone formation indicative of infectious disease, trauma, and dental disease. Frequencies are minimal since some lesions may have been overlooked due to the poor condition of the material.

Examples of infectious disease were found on seven lower leg bones (5 tibiae, 2 fibulae) of one male and four females from five features.

Feature 39.—25 to 35 year old male. Well remodeled periosteal bone formation with cloaca occurs on the medial midshaft area of a right tibia.

Feature 71.—35 to 60 year old female. A slight periosteal swelling is located on the medial midshaft area of a right tibia.

Feature 97.—35 to 45 year old female. Extensive periosteal lesions occur on much of the mid-shaft area of both fibulae and the left tibia. The lesions are well remodeled and probably invaded the medullary cavity.

Tomb 10.—40 to 45 year old female. Active periosteal lesions occur on the medial distal one half of a left tibia shaft.

Tomb 11.—25 to 30 year old female. A well remodeled periosteal lesion occurs on the proximal midshaft area of a tibia.

The location of lesions on the lower leg bones is most similar to that found in the Sta. Elena sample (Ubelaker, 1980), where 10 of the 11 examples are from lower legs. In the later Ayalán sample, lesions also occurred on the femur, ulna and vertebrae. The number of bones showing such lesions per each adult individual in the Cotocollao sample is .05 compared to .09 for Sta. Elena, .04 for Ayalán non-urn, and .14 for Ayalán urn.

Examples of trauma were found on only four individuals from Cotocollao. A 20 to 30 year old male from Feature 132 displayed a well remodeled depressed fracture of the right frontal. The fracture extends from glabella to the mid supraorbital margin of the right orbit. A 22 to 25 year old male from feature 143 displays a well remodeled fracture of a fibula. A 40 to 50 year old male from tomb 15 shows traumatic alteration of the distal end of the proximal second foot phalanx. A female of greater than 45 years from tomb 18 shows a well remodeled fracture of the left tibia midshaft and three small circular depressed fractures (15 mm deep) on the upper right frontal.

The depressed frontal fractures distinguish trauma at Cotocollao from that in the Ayalán and Sta. Elena samples. Fractures at Ayalán were mostly Colles fractures of the distal radius and ulna while those at Sta. Elena were mostly located in the midshafts of the upper arm bones. The Cotocollao fractures probably result from blows to the head, rather than falls. The number of fractures per adult individual is only .03, compared to .09 at Sta. Elena, .13 in the Ayalán urn sample and .18 in the non-urn sample.

Dental Disease

Permanent teeth in the Cotocollao sample number 1217, 60 from the early sample and 1157 from the late sample. Those in the early sample display no caries and no evidence of hypoplasia.

Adult teeth in the late sample consist of 474 from males, 327 from females and 356 that could not be related to skeletons of determined sex. Nineteen carious teeth were found associated with four females, two males and two skeletons of undetermined sex (Table 4). Eighteen of the carious teeth were molars (10 maxillary and 8 mandibular) and one was a mandibular right second incisor. The 19 carious teeth represent a frequency of only two percent, compared to the three percent found at Sta. Elena, eight percent in the Ayalán non-urn sample and 11 percent in the Ayalán urn sample.

At least 87 permanent teeth had been lost antemortem from the late sample. Twenty-four of these were maxillary; six incisors, four canines, seven premolars, and seven molars. The remaining 63 were mandibular; 17 incisors, two canines, 12 premolars, and 32 molars. The greater frequency of missing teeth in the mandible reflects to a considerable extent the greater frequency of that bone in the sample. The overall percentage of missing teeth is seven, where n (1244) is equal to the number of teeth present (1157) and the number absent antemortem (87). This figure is slightly higher than that reported for Sta. Elena (60 percent), but lower than Ayalán urn (15 percent) and non-urn (13 percent) (Ubelaker, 1980).

Table 4.—Frequency of carious lesions in permanent fully erupted teeth in the later component Cotocollao sample.

Tooth Group	No. Present	No. Carious	% Carious
Maxillary			
incisors	105	0	0
canines	70	0	0
premolars	170	0	0
molars	266	9	3
Mandibular			
incisors	74	1	1
canines	57	0	0
premolars	156	0	0
molars	259	9	3
Total	1184	19	2

Hypoplasia

Only three adult teeth show evidence of hypoplasia. These consist of a maxillary lateral incisor and maxillary right canine of a 10 year old subadult from feature 110/135 and a maxillary lateral incisor of a four year old from feature 122. Those of feature 110/135 formed at about five years, while that from feature 122 formed at about four years. The frequency of hypoplastic teeth is similar to that of the Sta. Elena sample (less than one percent) and less than the Ayalán urn sample (six percent) and Ayalán non-urn sample (one percent) (Ubelaker, 1980).

Just as in the Sta. Elena sample, no examples of congenital disorders, porotic hyperostosis or other pathological conditions were noted. Due to extreme bone fragmentation, data could not be collected on joint surface degeneration, lines of arrested growth in long bones and other types of data that normally would be of interest.

Summary

The fragmentary but relatively large sample of human skeletons recovered from excavations at Cotocollao, Ecuador provide important new data to the emerging picture of prehistoric Ecuadorian skeletal biology. Analysis of the large (199 individuals) from the later component (540 B.C.) reveals information on several biological variables that add "highland" perspective to previously published data from the coast. Analysis reveals that cranial deformation occurs among all age and sex groups and consists mostly of occipital flattening. Living stature averaged 159 cm for males and 148 cm for females, values nearly identical to those reported from coastal sites. Cranial measurements and observations generally fall within the range of those previously reported from the coast, although several male measurements are comparatively large. Demographic reconstruction for the later component reveals a life expectancy at age one year of 27 years, a figure slightly lower than those previously reported. Similarly the adult life expectancy of 14 years is lower than at the coastal sites.

Three types of pathology were noted; periosteal alterations, evidence of trauma and dental disease. Infectious disease was confined to the lower leg bones in contrast to the coastal sites, where more of the skeleton was involved. Evidence of trauma consists of fractures of the lower leg bones and toes and depressed fractures of the frontals. The depressed fractures of the skull must have resulted from blows to the head and have not been reported from the coastal sites. The frequencies of bones with evidence of infectious disease as well as trauma are lower than any of the coastal sites.

The frequency of dental caries (two percent) in the permanent dentition is lower than that reported for Ayalán or for Sta. Elena. This frequency is strikingly low considering the relatively late date of the sample. However, the frequency of teeth lost antemortem is intermediate between Sta. Elena and Ayalán. The frequency of hypoplastic teeth, a partial indicator of childhood morbidity, is similar to that of Sta. Elena and less than Ayalán.

All of this data is consistent with the suggested date (540 B.C.) except the somewhat low frequency of carious teeth. Clarification of all variables and a definitive assessment of population affinities must await analysis of additional samples with hopefully superior bone preservation.

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Caries and Elemental Composition of the Rhodesian Man Dentition

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ABSTRACT

The Rhodesian skull, BM(NH) 686, dated at around 100,000 B.P., has numerous carious teeth. Neither molar of the maxillary fragment (BM(NH) 687) from the same site, is carious. This study reports spectrographic analyses of enamel samples from these specimens, obtained by washing with distilled water (Rhodesian I^1, C, RM^1; maxilla M^2, M^3) and dilute acid (Rhodesian LM^1, RM^3).

The elements in acid etches of the carious LM^1 and caries-free RM^3 are virtually identical in concentration and rank. The elemental composition of the water wash of RM^1 differs from the acid etch of LM^1 in both concentration and rank, despite the fact that these two teeth formed and erupted about the same time. The water washes of the 5 teeth show both marked similarities and differences, suggesting that teeth in a single dentition may differ in caries susceptibility. Despite recovery from a lead-zinc mine, whether sampled by water or acid, neither specimen shows uniform or high concentrations of these elements.

The Rhodesian Man skull (BM(NH) #686) was recovered in 1921 from a lead-zinc mine site in present-day Zambia. The location in which this specimen was found had been the apex of a cave later filled in by natural forces. The rampant dental caries has been reported (Koritzer and St. Hoyme, 1977).

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In a previous study of archeologically recovered Potomac Creek, Virginia, Indian dental enamel inter-individual associations of elemental concentrations determined from water washings and caries were examined (Koritzer, 1977). Water washings and acid etching of Rhodesian dental enamel were analyzed using emission spectroscopy in a similar way. Caries degree varied in the Rhodesian dentition, as the central incisors were caries-free, the canines moderately affected, and the first molars severely damaged. In this intra-individual study we have looked at the relations of caries degree and elemental concentrations.

A maxillary fragment (BM(NH) #687) with several teeth was also found in the former cave but unassociated with the Rhodesian skull archeologically. The dental enamel of this early representative, though not contemporary with Rhodesian Man, was also analyzed. The dentition appeared, as far as could be seen, free of dental disease.

Methods and Data

Emission spectroscopy was done in the CAL laboratory of the Smithsonian Institution by Mr. Harold Westley with the kind cooperation of Drs. Olin and Organ. Water washings and acid etchings were collected on the oroginal specimens stored at the British Museum (Natural History) in London. The raw data and rank orders are presented in Table 1. A maximum of 23 elements was determined ranging from over 31 to as little as .04 parts per million. The central incisor, resistant to caries, was also least water soluble. The acid etches produced macro-quantities of calcium and phosphorous which could not be used in analysis as can be done with the parts-per-million quantities of these elements found in water washings. Interestingly cobalt and nickel, found readily in water washes, were absent in the acid etchings. On the other hand, barium, berylium, mercury, manganese, strontium, and titanium were found by acid etching only.

In the acid etches, the left, first molar

Table 1.—Dental enamel trace elements (ppm & rank: 1 = lowest).

	Rhodesian Man, BM(NH) 686										Rhodesian Man, BM(NH) 687			
	Acid etch				*Water wash*						*Water wash*			
	Ppm		Rank		Ppm			Rank			Ppm		Rank	
Element	LM^1*	M^3	LM^1	M^3	I^1	Can.*	RM^1**	I^1	Can.	RM^1	M^2	M^3	M^2	M^3
Al	9.70	10.2	17	17		.65	.7		9	12.5	.160	.630	8	11
As	.5	.5	3	2		.563	.7		8	12.5	.157	.734	7	12
Ba	2.22	2.54	10	10										
Be	.237	.266	1	1										
Ca					.970	1.97	.61	10	15	11	.711	2.34	17	17
Co						.087	.1		1	3	.310	.132	13	4
Cr	.998	.995	6	6		.825	.1		11	3	.240	.126	12	3
Cu	28.4	29.8	18	18	.04	.157	.2	6	3	6	.030	.112	2	1
F	.895	.932	8	5		.121	.087		2	1	.0001	.113	1	2
Fe	31.6	31.3	19	19		.691	1.0		10	15	.170	.830	9	13
Hg	.496	.465	2	3										
K	1.32	1.15	9	9		1.24	.2		13	6	.370	.230	14	8
Mg	6.14	7.02	14	13		.464	.1		7	3	.230	.152	11	5
Mn	1.15	.821	7	8										
Na	4.97	4.10	11	11	.065	.322	.8	7	4	14	.046	1.17	4	14
Ni						.398	.4		6	8.5	.052	.532	5	9
P						1.14	1.5		12	16	.190	2.16	20	16
Pb	1.02	.992	5	7		2.4	.5		16	10	.520	.562	15	10
Si	9.98	9.93	16	16	.085		.2	8		6		.169		6
Sn	4.92	6.14	13	12		1.4	.4		14	8.5	.550	1.73	16	15
Sr	8.53	9.23	15	15										
Ti	.502	.523	4	4										
Zn	6.84	4.43	12	14	.086	.375	.2	9	5	6	.041	.198	3	7

*Caries **Severe caries

	Rhodesian Skull BM(NH)686					Rhodesian Maxilla BM(NH)687	
	Acid Etch		Water Wash			Water Wash	
Rank	LM^1	M^3	1^1	C	RM^1	M^2	M^3
1	Be	Be					
				(Si)		(Si)	
2	As	Hg					
3	Hg	As			F		Cu
4	Ti	Ti		Co	Co	F	F
5	F	Pb		F	Cr	Cu	Cr
6	Cr	Cr	Cu	Cu	Mg	Zn	Co
7	Pb	Mn	Na	Na	Cu	Na	Mg
8	Mn	F	Si	Zn	Zn	Ni	Si
9	K	K	Zn	Ni	Si	As	Zn
10	Ba	Ba		Mg	K	Al	K
11	Na	Na		As	Ni	Fe	Ni
12	Sn	Zn		Al	Sn	P	Pb
13	Mg	Sn		Fe	Pb	Mg	Al
14	Zn	Mg		Cr	Ca	Cr	As
15	Sr	Sr		P	As	Co	Fe
16	Si	Si		K	Al	K	Na
17	Al	Al		Sn	Na	Pb	Sn
18	Cu	Cu		Ca	Fe	Sn	P
19	Fe	Fe	Ca	Pb	P	Ca	Ca

Fig. 1. Ranking of elemental concentrations (1 = least) in enamel samples from carious and non-carious teeth of Rhodesian Man, BM(NH) 686, and maxillary fragment, BM(NH) 687, from lead-zinc mine, dated about 100,000 B.P. Tied rankings are indicated by boxes.

Table 2.—Rhodesian teeth ratios.

	ppm			% Fe		% CO			% Ca		% Mg			% Na		% K	
Element	1	C	M[1]	C	M[1]	C	M[1]	1	C	M[1]	C	M[1]	1	C	M[1]	C	M[1]
Al		.065	.7	10.63	1.43	1.34	.14		.303	.871	.714	.143		.495	1.14	1.91	.286
As		.563	.7	1.23	1.43	.15	.14		3.49	.871	.824	.143		.572	1.14	2.20	.287
Ba																	
Be																	
Ca	.970	1.97	.61	1.13	1.64	.04	.163	.	.	.	.236	.167	.067	.163	1.33	.629	.33
Co		.087	.1	7.94	1.0	.	./.		22.6	6.1	5.33	1.0		3.7	8.0	14.25	2.0
Cr		.825	.1	.83	1.0	.105	.1		2.39	6.1	.562	1.0		.39	8.0	1.5	2.0
Cu	.04	.157	.2	4.40	5.0	.55	.5	24.25	12.54	3.05	2.96	.5	1.63	2.05	4.0	2.9	1.0
F		.121	.087	5.71	11.49	.72	1.15		16.28	7.01	3.84	1.15		2.66	9.2	10.25	2.3
Fe		.691	1.0			.125			2.85	.61	.671	.1		.466	.8	1.8	.2
Hg																	
K		1.24	.2	.55	5.0	.07	.5		1.59	3.05	.374	.5		.26	4.0	.	.
Mg		.464	.1	1.49	1.0	.19	.1		4.26	6.1	.	.		.694	8.0	2.67	2.0
Mn																	
Na	.065	.322	.8	2.14	1.25	.11	.125	14.92	6.12	.763	1.44	.125		.	.	3.85	.25
Ni		.398	.4	1.736	2.5	.22	.25		4.95	1.5	1.17	.25		.809	2.0	3.12	.5
P		1.14	1.5	.61	.67	.08	.067		.821	1.22	.193	.2		.134	1.6	.517	.4
Pb		2.4	.5	.29	2.0	.04	.2		1.73	.407	.407	.067		.282	.53	1.09	.133
Si	.085	.	.2	3.56	5.0	.	.5	11.41	.	3.05		.5	.765		4.0		1.0
Sn		1.4	.4	1.73	2.5	.06	.25		1.31	1.53	.309	.25		.215	2.0	.827	.5
Sr																	
Ti																	
Zn	.86	.375	.2	3.45	5.0	.23	.5	1.13	5.25	3.05	1.24	.5	.067	.163	1.33	.629	.33

(LM^1) carious area is compared with a caries free surface of the right third molar (M^3). Rank orders are seen to be almost identical with the exception of a slightly higher fluoride level in the caries-free surface.

Water washes of the caries-free central incisor (I^1), the moderately carious canine (can.) and the severely carious right, first molar (RM^1) resulted in elemental values with quite different rank orders. The fluoride in this case was, however, almost the same. Rank orders of chromium, iron, potassium, sodium, lead, silicon, and tin were markedly different between C and RM^1.

The second (M^2) and third (M^3) molars sampled from the maxillary fragment also resulted in marked difference and some similarity in rank orders. Arsenic, cobalt, chromium, potassium, magnesium, sodium, phosphorous, lead, and silicon were most varied. Calcium, copper, fluoride, and tin were most similar in rank order.

The elemental concentration rank orders were graphed (Fig. 1) comparing various tooth combinations for water washes and acid etches. Similarity of the acid etches is obvious. Comparison of the contralateral first molar water washes versus acid treatments evidences marked difference and little similarity. Comparison of RM^1 and C clearly separates these teeth. A limited comparison using all elements found in the I^1 is notable for a marked sodium variation.

The rank ordered graph of the maxillary fragment separates the teeth side by side in the same specimen subjected to identical long-term conditions of interment and storage. The moderately carious Rhodesian Man canine compared to the maxillary fragment M^2 and M^3 emphasizes some marked differences intra-individual for the latter.

In Table 2, elemental values as percentages of 6 selected elements are displayed for Rhodesian Man. The canine/molar percentages with sodium versus those for potassium are clearly reciprocal. The calcium/magnesium percentages have, on the other hand, the same directionality. Cal-

Table 3.—Maxillary fragment ratios.

	Ppm		% Fe		% Co		% Ca		% Mg		% Na		% K	
Element	M^2	M^3	M^2	M^3	M^2	M^3	M^2	M^3	M^2	M^3	M^2	M^3	M^2	M^3
Al	.160	.630	1.06	1.32	1.94	.21	4.44	3.71	1.44	.24	.29	1.86	2.31	.37
As	.157	.734	1.08	1.13	1.97	.18	4.53	3.19	1.46	.21	.29	1.59	2.36	.31
Ba														
Be														
Ca	.711	2.34	.24	.35	.44	.06	.	.	.32	.06	.06	5.0	.52	.1
Co	.310	.132	.54	6.29	.	.	2.29	17.73	.74	1.15	.15	8.86	1.19	1.74
Cr	.240	.126	.71	6.59	1.29	1.05	2.96	18.57	.96	1.21	.19	9.29	1.54	1.83
Cu	.030	.112	5.67	7.41	10.33	1.18	23.7	20.89	7.67	1.36	1.53	10.45	12.33	2.05
F		.113	.	7.35	.	1.17		20.71		1.35		10.35		2.04
Fe	.170	.83	.	.	1.82	.16	4.18	2.82	1.35	.18	.27	1.41	2.18	.28
Hg														
K	.370	.230	.46	3.61	.83	.58	1.92	10.17	.62	.66	.12	5.09	.	.
Mg	.230	.152	.739	5.46	1.35	.87	3.09	15.39	.	.	.2	7.70	1.61	1.51
Mn														
Na	.046	1.17	3.69	.71	6.74	.11	15.46	2.0	5.0	.13	.	.	8.04	.20
Ni	.052	.532	3.27	1.56	5.96	.25	13.67	4.4	4.42	.29	.88	2.20	7.12	.43
P	.520	.562	.327	1.48	.6	.23	1.37	4.16	.44	.27	.009	2.08	.71	.41
Pb	.190	2.16	.89	.38	1.63	.06	3.74	1.08	1.21	.007	.24	.54	1.95	.11
Si		.169		4.91		.78		13.85		.9		6.92		1.36
Sn	.550	1.73	.31	1.51	.56	.08	1.29	1.35	.42	.09	.08	68.0	.67	.13
Sr														
Ti														
Zn	.041	.198	4.15	20.2	7.56	.67	17.34	11.82	5.61	.77	1.12	5.91	9.02	1.16

cium magnitudes are greater than magnesium but calcium ratios for canine double those for M^1. The similar magnesium relation is more than triple.

For iron there is a notable reverse of relation between canine and M^1 for aluminum and fluoride. The cobalt relations for canine and M^1 are not remarkably different.

Table 3 gives ratios for the maxillary fragment. Sodium and potassium are reciprocal. Variation in the other ratios displayed clearly separate M^2 and M^3.

Discussion

Attempting to order such a large mass of data in a reasonable space is difficult. Only the most salient points can be considered. The first and most obvious fact is that determinations of this magnitude are obtainable at all from water-washings of enamel surfaces. The second important observation is that some degree of order exists in these values that patterns with caries.

Acid etching and water washing, clearly, give two quite different kinds of information. While acid etches supply data for enamel composition that may reflect the ecology in which the enamel formed and may differentiate populations (Koritzer, 1976; St. Hoyme and Koritzer, 1976), differences correlating with caries are obliterated. Water washes, which simulate oral environment more nearly than strong acids, reveal differences in general and specific solubility that do seem to relate to caries. This occurs inter-individually, as in the Potomac Creek study, and intra-individually, as in this study.

The generally reciprocal nature of sodium and potassium ratios for the canine and first molar of Rhodesian Man seems too orderly to occur by chance alone. Similarly the directional agreement of calcium and magnesium is striking. Without attempting to draw too much from the limited sample and data set, the behavior of these mono- and di-valent cations with caries degree arouses a high index of suspicion. Further study of this matter seems indicated.

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Haliday's Generic Names of Diptera First Published in Curtis' A Guide to . . . British Insects *(1837).*

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ABSTRACT

Seventeen generic names of mostly acalyptrate Diptera were first published in the addendum of Curtis' *A Guide to . . . British Insects.* Considerable confusion has existed as to author, date, type-species and current status of these names, largely due to an oversight that most of these names were first published in synonymy. We have re-examined each of the 17 names to determine its authorship, date, manner of type fixation, type-species and current status. As a result we have discovered three new synonyms and the need for one new name: *Napomyza* Haliday =*Phytomyza* Fallén (*Napomyza* of authors is *Dinevra* Lioy), ***Knutsonia*** Verbeke =*Ilione* Haliday (*Ilione* has been treated as a junior synonym of *Elgiva* of authors) and *Oecothea* Haliday=*Heleomyza* Fallén (*Oecothea* of authors is without a name). *Chione communis* Robineau-Desvoidy is designated the type-species of *Ilione* Haliday and *Leria subterranea* Robineau-Desvoidy the type-species of *Oecothea* Haliday.

In Curtis' *A Guide* to . . . *British Insects* (1837), 17 generic names of Diptera were published for the first time as part of an addendum. Most of these names figure prominently in subsequent literature, and some of them form the bases of familial names. Despite their prominence and frequent use, much confusion exists as to their authorship, date of publication and manner of type fixation as demonstrated by their citations in recent catalogs and in such basic references as Sherborn (1922), Neave (1939) and Schulze *et alia* (1928–1954). Our purpose is to review the pertinent portions of Curtis' publication, as well as other relevant literature, and to clarify usage of these names.

Haliday was an early Irish entomologist (1807–1870) who specialized in the systematics of Diptera and Hymenoptera. He was a generous correspondent (Osten Sacken 1978: 51–62, especially 56–57), and consequently many of his names and ideas appear first in the works of others. As a result, the treatment of these names has been different: Some authors have treated these names as Haliday's and dated them from their first appearance in the literature (e.g., *Atissa* Haliday in Curtis 1837 (Wirth 1965: 735)); others have dated them from their first appearance but considered them as those of the author in whose work they appeared (e.g., *Atissa* Curtis 1837 (Cogan 1980c: 657)); and a few dated them from their first appearance in Haliday's own works, regardless of their earlier appearance in the work of others (e.g., *Atissa* Haliday 1839 (Becker 1905: 191)). This variation is due to differences in various workers' diligence and interpretation of the rules of nomenclature, which over the years have also changed. Also, the preface of Curtis' *Guide* has been overlooked, although it contains information which bears directly on questions of authorship, date and type fixation.

The principal questions to be answered are those of availability, the date and place thereof, authorship and type-species. The conditions that determine availability can be grouped into three categories—publication, identification[1] and formation. A name must be published (articles 8–9), must be identified (articles 12–16), and must be properly formed (article 11, sections b–c & e–g). The Haliday names in Curtis were all (except *Camilla*) first published as synonyms, a fact previously overlooked. Curtis in his preface stated: "It need scarely be added that the generic and specific names without numbers are considered as synonyms . . . " (Curtis 1837: v–vi). Of the 17 dipteran names, only *Camilla* was given an unique number. For example, *Camilla* is numbered 1337[b] meaning that the name is valid and should be inserted after number 1337, the number for *Diastata* Meigen (p. 272). *Fucomyia* has the number 1320, but this number is the same as that of *Coelopa* (p. 270) of which Curtis considered *Fucomyia* to be a synonym. As these names were first published in synonymy, they come under a special section of Article 11 (section d) which states: "A name first published as a synonym is not thereby made available unless prior to 1961 it has been treated as an available name with its original date and authorship, and either adopted as the name of a taxon or used as a senior homonym." (I.C.Z.N. 1964: 11). The wording is poor as two interpretations are possible. Strictly interpreted, the *with* clause can be construed as part of the availability requirement such that the name must have been used *with* the particular date and author of its appearance in synonymy. A broader interpretation would require only that the name be used and thereafter becomes available ". . . with its original date and authorship." All of Haliday's names were first used within three years of their appearance in Curtis' *Guide.* These names were used in one or more of three publications. In two of the publications, 12 names meet the strict interpretation of Article 11 (d), and all the names meet the broad interpretation. In Haliday (1838), each name is followed by "C. Appl.," this being an explicit reference to Curtis' *Guide . . . , Appendix* [=Addenda] as is indicated both by the title of Haliday's paper (*New British Insects indicated in Mr. Curtis' Guide*) and his introduction. In Haliday (1839), each name is followed by "Curtis, Guide, App." which is likewise an explicit reference to Curtis. In Westwood (1840), the names are followed by simply "Hal." While most of these names are available from Haliday in Curtis 1837 under any interpretation of Article 11 (d), we feel that the broad interpretation is correct and therefore all the names are available from there. In support of this broad interpretation, we note that the proposed wording for this article in the draft version for a new edition of the Rules is in conformity to it: "A name first published as a junior synonym is not thereby made available unless prior to 1961 it has been treated as an available name and either adopted as the name of a taxon or treated as a senior homonym; such a name dates from its first publication as a synonym." (I.C.Z.N. 1977: 7).

Authorship is currently determined by article 50 ("The author (authors) of a scientific name is (are) the person (persons) who first publish(es) it [III] in a way that satisfies the criteria of availability [IV], unless it is clear from the contents of the publication that only one (or some) of the joint authors, or some other person (or persons), is alone responsible both for the name and the conditions that make it available." I.C.Z.N. 1964: 49). Again the wording is poor, as two interpretations are possible. Strictly interpreted, "the conditions" include all those mentioned above (publication, identification and formation), but a broader interpretation would include all except publication. Under a strict interpretation, all of the Haliday names in Curtis should be attributed to Curtis, but, under the broader interpretation, they would be accredited to Haliday. Curtis identified all these names

[1] Our use of the word "identification" here is slightly different from the conventional one. A name must have been accompanied by a diagnosis, description or indication that functions to "identify" the concept that the name denotes. Hence, we used the word "identification" for the process by which a name is tied to a concept, whereas the usual connotation of "identification" is tying a concept to a name.

(except *Napomyza*) with "Hal." and acknowledged Haliday " . . . for . . . kind assistance in rendering this Guide more complete than it otherwise could possibly have been." (Curtis 1837: vi). We feel that these facts along with a broad interpretation of Article 50 make Haliday the author of his names. This is also the opinion of the majority of workers who have used these names. We feel that our broad interpretation of the article is also correct as indicated by subsequent proposals to modify the Code (Sabrosky 1972a: 86, 1974: 206–208; I.C.Z.N. 1977: 34) and the proposed wording in the draft version which inserts the words "other than publication" after "conditions." Unfortunately, the draft version includes a new section of Article 50 (section g) to deal with the authorship of names proposed in synonymy (Sabrosky 1972a; I.C.Z.N. 1977: 35). Under this new section, which states that the author of this kind of name "is the person who publishes it as a synonym, even if he cited some other originator, and is not the person who subsequently adopted it," the author of the Haliday names would be Curtis. However, we feel that when and if this new section is adopted, at that time an application should be made to the International Commission on Zoological Nomenclature requesting the use of the plenary powers to validate Haliday as the author of his names. The case for such action could be based on present usage.

The manner of type fixation for names first proposed as synonyms is not covered by the present Code, as when that Code was prepared these names were not considered as available. Sabrosky (1972b) and the draft version (1977: 48, Art. 67 (m)) suggest that the type-species (or originally included species) of a genus-group name first published as a synonym is the species (or are the species) first directly associated with the synonym. Curtis wrote in his preface that " . . . although many of the former [=synonyms] which intersect long genera will most probably be eventually adopted, and it may often happen that *all* the species following such generic names would not be considered by the Author who proposed the name as belonging to his group, but the one *immediately* following is always a typical species . . ." (Curtis 1837: vi). Immediately following nearly all of the generic names are one to several species names. From one point of view, the first could be considered the type-species by original designation as stated by Curtis. However, Sabrosky and Blackwelder (1956) have argued that Curtis' statement does not constitute a valid type designation. In their point of view, the manner of type-fixation in these cases would be either by subsequent designation, if more than one species were listed, or by monotypy, if only one species is listed. We have accepted this latter viewpoint.

One final item from the preface relates to the names—the numbers used to identify species. For most previously described species listed under a genus, Curtis endeavored to use the same numbers as in his first edition of the guide (1829–1831). As Curtis stated (1837: v), " . . . but where the genera have received great additions, as in *Tachina* for instance, the numbers of Meigen have been substituted, by which means an easy reference may be made to his valuable Work." We have noted, with the appropriate species, where a Meigen number and name has been used in the original citations.

One last point needs to be made about Curtis' *Guide,* that is, its correct date of publication. Various dates, ranging from 1836 to 1838, have been assigned to this work. An extreme example of this is found in Neave and Sherborn where they cited all three years for the various names found on page 281. Curtis' second edition of his *Guide* was published as a whole in 1837, sometime after June, the date of the preface.

For each of the generic names treated we have used a standard format to enable more direct comparison. Information of a particular nature and other data of relevance are included in the appropriate remarks sections. The names are considered in alphabetical order. For the well-known references of Sherborn (1922–1923), Schutze *et alia* (1928–1954) and Neave (1939–1940), which are referred to in the remarks section of each generic name, we have not cited the year of publication nor given the full title and pagination in the reference section to save space.

Genus **Atissa** Haliday

Atissa Haliday, *in* Curtis 1837: 281 [published in synonymy; first made available by use in Haliday 1839:401, 404]. Type-species: *Ephydra pygmaea* Haliday 1833 by monotypy.

Atissa is a valid generic name in the family Ephydridae and is the basis for the tribal name Atissini. Most of the references we consulted dated *Atissa* to 1837 (Sherborn; Neave; Wirth 1965b, 1968; Cogan & Wirth 1977; Cogan 1980c) and credited authorship to Haliday, usually as Haliday in Curtis. The exceptions are Becker (1905, 1926), who dated the genus to 1839, and Cogan (1980c), who attributed the genus to Curtis.

Genus **Calliope** Haliday

Calliope Haliday, *in* Curtis 1837: 280 [published in synonymy; first made available by use in Westwood 1840:151]. Type-species: *Lauxania scutellata* Meigen 1826 by monotypy.
Calliopum Strand 1928:48 (new name for *Calliope* Haliday).

Calliope of Haliday is preoccupied (Gould 1836). The valid name for this group is *Calliopum* Strand 1928 in the family Lauxaniidae. The references we consulted consistently dated this genus as 1840 (Sherborn, Neave, Schulze *et alia,* Czerny 1932, Shewell 1965, and Miller 1980), but authorship was credited to either Haliday, usually as Haliday in Westwood (Sherborn, Neave, Czerny and Miller, *ibid.*), or to Westwood alone (Schulze *et alia* and Shewell 1965).

Genus **Camilla** Haliday

Camilla Haliday *in* Curtis 1837: 281 (*nomen nudum*).
Camilla Haliday 1838:188 (as a subgenus of *Diastata* Meigen 1830). Type-species: *Drosophila glabra* Fallén 1823 by monotypy.

Although *Camilla* Haliday is a valid generic name and is the basis for the familial name Camillidae, it neither dates to 1837 nor to Haliday in Curtis for authorship. *Camilla* was the only new Haliday name in Curtis' *Guide* that was not published in synonymy. Both the generic name and its listed type-species, *Camilla aerata* Haliday, as published in 1837, were *nomina nuda.* Consequently the generic name dates to Haliday 1838, when Haliday gave a diagnosis and included an available name in the genus.

All of the references consulted cited Haliday as author of *Camilla* but with varying dates and sources. Sherborn, Neave, and Schulze *et alia* cited Haliday in Curtis; however Sherborn and Neave dated the name to 1836, and Schulze *et alia* to 1837. Becker (1905), Duda (1934), McAlpine (1965) and Cogan (1980b) all date *Camilla* to Haliday 1838.

Genus **Canace** Haliday

Canace Haliday, *in* Curtis 1837: 281 [published in synonymy; first made available by use in Haliday 1839:411]. Type-species: *Ephydra nasica* Haliday 1839 by subsequent monotypy (Haliday 1839:411).

Canace is a valid generic name and is the basis for the familial name Canacidae. The references we consulted all credited *Canace* to Haliday, but dated it to either 1838 (Sherborn, Neave) or 1839 (Becker 1905, 1926; Wirth 1951, 1965a, 1975; Cogan 1980e; Mathis 1981).

Genus **Cleora** Haliday

Cleora Haliday, *in* Curtis 1837:282 [*nomen nudum;* published in synonymy but not subsequently made available by use].
Clusia Haliday 1838:188. Type-species: *Heteromyza flava* Meigen 1830 by monotypy.

Cleora of Haliday is preoccupied (Curtis 1825). Haliday (1838:188) synonymized his generic name *Cleora* under *Clusia* when he validated the latter name. Sherborn, Neave and Schulze *et alia* are the only references to cite an author and date for this generic name (as a *nomen nudum*). Sherborn and Neave dated it to 1836, but Schulze *et alia* as 1837.

Genus **Fucomyia** Haliday

Fucomyia Haliday, *in* Curtis 1837: 280 [published in synonymy; first made available by use in Haliday 1838:186]. Type-species: *Musca frigida* Fabricius 1805 by subsequent designation (Westwood 1840: 144).

Fucomyia Haliday is a valid genus-group name in the family Coelopidae. In Curtis, *Fucomyia* was listed as a synonym of *Coelopa, sensu stricto;* hence no typical species was indicated (i.e., this name did not "intersect" a large genus). Haliday (1838:186) when he validated the name, included three species (*frigida* Fabricius, *simplex* Haliday and *parvula* Haliday). Westwood designated *Musca frigida* as the type. In Neave, Sherborn, Schulze *et alia,* Becker (1905), Hennig (1937), and Vockeroth (1965a), this name is credited to Haliday, but with different dates and sources. Sherborn gave Haliday in Westwood (1840); Neave–Haliday in Curtis 1837; Schulze *et alia,* Hennig and Vockeroth–Haliday 1838; and Becker–Haliday 1839.

Genus **Halithea** Haliday

Halithea Haliday, *in* Curtis 1837:279 [published in synonymy; first made available by use in Haliday 1838:185]. Type-species: *Scatophaga maritima* Haliday 1838 by subsequent monotypy (Haliday 1838: 185).

Fucellia Robineau-Desvoidy 1842:269. Type-species: *Fucellia arenaria* Robineau-Desvoidy 1842 (=*Scatophaga maritima* Haliday 1838) by original designation and monotypy.

Halithea of Haliday is preoccupied (Savigny 1817). The valid name for this group is *Fucellia* Robineau-Desvoidy 1842 in the family Anthomyiidae. In Neave, Sherborn, Schulze *et alia* and Huckett (1965), this name is credited to Haliday, but with different dates and sources. Sherborn and Neave dated the genus as "1836," in Curtis, whereas Huckett dated it to Haliday 1838 (i.e., Haliday's publication).

Genus **Hecamede** Haliday

Hecamede Haliday, *in* Curtis 1837: 281 [published in synonymy; first made available by use in Haliday 1839:221, 224]. Type-species: *Notiphila albicans* Meigen 1830 by monotypy.

Hecamede is a valid generic name in the family Ephydridae. Use of this generic name has been confused both with respect to its date and author. Cogan (1980c) credited the generic name to Curtis, whereas the other references cited Haliday, usually as Haliday in Curtis (Becker 1905, 1926; Sherborn; Neave; Wirth 1965b, 1968; Cogan and Wirth 1977). Cogan (1980c), Wirth (1968), and Cogan and Wirth (1977) dated the genus to 1837; Sherborn and Neave dated it to 1838, and Wirth (1965b) and Becker (1905, 1926) dated it to 1839.

Genus **Hyadina** Haliday

Hyadina Haliday, *in* Curtis 1837: 282 [published in synonymy; first made available by use in Haliday 1839:404, 406]. Type-species: *Notiphila guttata* Fallén 1813 by subsequent designation (Westwood 1840:153).

Hyadina is a valid generic name in the family Ephydridae and is the basis for the tribal name Hyadinini. Sherborn and Neave both dated *Hyadina* to 1837 and credited it to Curtis. The other references we consulted consistently attributed the name to Haliday and dated it to 1839 (Becker 1905, 1926; Wirth 1965b, Cogan & Wirth 1977; Cogan 1980c).

Genus **Ilione** Haliday

Ilione Haliday, *in* Curtis 1837:280 [published in synonymy; first made available by use in Westwood 1840:146]. Type-species: *Chione communis* Robineau-Desvoidy 1830 (=*Musca albiseta* Scopoli 1763) by present designation.

Ilione is a valid genus-group name in the family Sciomyzidae. Neave and Steyskal (1965a) listed *Ilione* as a ***nomen nudum*** of Haliday in Curtis 1837. Sherborn, Becker (1905) and Sack (1939) all credited the name to Haliday but with some variation as to date and source. Sherborn cited Haliday in Curtis 1837, Becker listed Haliday in Westwood 1840, and Sack gave Haliday without citing a source. Schulze *et alia* credited the name to Curtis 1837 as a *nomen nudum.*

Curtis (1837) included two species under *Ilione, Chione communis* Robineau-Desvoidy and *C. sepedonidea* Robineau-Desvoidy. Westwood (1840) designated "*I. lineata Hal.*" as the type-species. The use of "Hal." as the authority for *lineata* has been considered an error, as the species involved is *Tetanocera lineata* Fallén 1820. Westwood's designation is invalid as *lineata* was not an originally included species. As we have not found any other type designation for *Ilione,* we here designate *communis* as type. All of these species—the two originally included and *lineata*—are now included in the genus *Knutsonia* Verbeke 1964. Consequently, with the correction in date and type-species, as indicated, *Ilione* becomes the senior synonym of *Knutsonia* (new synonym).

Genus **Ilythea** Haliday

Ilythea Haliday, *in* Curtis 1837:281 [published in synonymy; first made available by use in Haliday 1839:405, 408]. Type-species: *Ephydra spilota* Curtis 1832 by subsequent monotypy (Haliday 1839: 408).

Ilythea is a valid generic name of the family Ephydridae and is the basis of the tribal name Ilytheini. Sherborn, Neave and Schulze *et alia* gave authorship of *Ilythea* to Curtis, usually as a *nomen nudum,* and dated the name to 1837. The other references we consulted credited the genus to Haliday and dated it to 1839 (Becker 1905, 1926; Wirth 1965b, 1968; Cogan 1980c).

Genus **Malacomyza** Haliday

Malacomyza Haliday, *in* Curtis 1837:280 [published in synonymy; first made available by use in Haliday 1838:186]. Type-species: *Coelopa sciomyzina* Haliday 1833 by subsequent monotypy (Haliday 1838: 186).

Malacomyia Haliday, in Westwood 1840:144, Type-species: *Coelopa sciomyzina* Haliday 1833 by original designation.

Malacomyza of Haliday is preoccupied (Wesmael 1836). The valid name for this group is *Malacomyia* Haliday in the family Coelopidae. In Sherborn and Becker (1905: 21), this name is credited to Haliday, but with different dates and sources. Neave and Schulze *et alia* credited the name to Curtis. In Westwood, this name appears as "*Malacomyia* Hal.," a spelling which is not preoccupied. The status of this spelling is in question: is it an emendation, a new name or a proposal? Hennig (1937:29) considered it as a new name. Other workers used the spelling, accredited it to Haliday, but did not indicate its status. The present Code defines an emendation as an available name (I.C.Z.N. 1964: 19, Art. 19) and as "Any demonstrably intentional change in the original spelling." (I.C.Z.N. 1964:37, Art. 33). The Code does not clearly state the availability requirements for a replacement name, but one would expect a definite reference to the name being replaced to be one such requirement. The citation in Westwood does not include a reference to the original spelling, thus, it is clearly neither an emendation nor a new name. We consider it as a new proposal.

Genus **Napomyza** Haliday

Phytomyza Fallén 1810:21, 26. Type-species: *Phytomyza flaveola* Fallén 1810 by monotypy.

Napomyza Haliday, *in* Curtis 1837:282 [published in synonymy; first made available by use in Westwood 1840:152]. Type-species: *Phytomyza nigricornis* Macquart 1835 (=*Phytomyza affinis* Fallén 1823) by monotypy.

This is an available genus-group name and has been currently used at the generic and subgeneric level in the family Agromyzidae. The year 1840 is consistently published as the date of *Napomyza* in the references we consulted, but authorship has either been credited to Haliday (Sherborn, Neave, Hendel 1932) or to Westwood (Frick 1965, Spencer 1976, Cogan 1980a, Schulze *et alia*).

Napomyza appears without an authority. Most names in Curtis either have an authority or reference number to Curtis' *British Entomology.* The lack of an authority is clearly a *lapsus.* The name is attributed to Haliday by Westwood. This attribution by

Westwood as well as the large number of other names in the addenda of Curtis leads us to consider the author of *Napomyza* as Haliday.

Curtis (1837) included only *Phytomyza nigricornis* Macquart under *Napomyza.* Westwood (1840) cited *Phytomyza festiva* Meigen as the type-species of *Napomyza,* a designation accepted by all subsequent workers. Unfortunately, Westwood's designation is invalid and the correct type-species, *affinis* Fallén, is a species of *Phytomyza.* Thus, *Napomyza* becomes a synonym, and *Dinevra* Lioy 1864 (type-species *Phytomyza elegans* Meigen 1830 (senior synonym of *festiva* Meigen) is available for *Napomyza* of authors.

Genus **Oecothea** Haliday

Heleomyza Fallén 1810:19. Type-species. *Musca serrata* Linneaus 1758 by monotypy.
Oecothea Haliday, *in* Curtis 1837:280 [published in synonymy; first made available by use in Haliday 1838:187]. Type-species: *Leria subterranea* Robineau-Desvoidy 1830 by present designation.

Oecothea is a valid generic name in the family Heleomyzidae, although it was frequently listed as an emendation of *Aecothea* (Gill 1965, 1968). Just the opposite, however, is true—*Aecothea,* Haliday 1838, is an unjustified emendation of *Oecothea.*

Considerable confusion also exists regarding the type-species of *Oecothea.* Curtis (1837) included four species under *Oecothea: Helomyza* [*sic*] *pallescens* Meigen 1830 (now *Eccoptomera* Loew), *H. laeta* Meigen 1830 (now *Tephrochlamys* Fallén), *H. silvatica* Meigen 1830 (now *Eccoptomera* Loew) and *Leria subterranea* Robineau-Desvoidy 1830 (now *Heleomyza* Fallén). Haliday (1838), when he spelled this name as *Aecothea,* probably a *lapsus,* included only one British species, *Helomyza* [*sic*] *fenestralis* Fallén 1820, and most subsequent authors have listed that species as the type-species. Westwood (1840) listed *fenestralis* and "*pallescens* Mcq." as the "type" as well as using the correct spelling *Oecothea.* The designation of *fenestralis* as type-species cannot be valid, as it was not an originally included species, and as no other species has been designated, we have selected *subterranea,* the fourth species Curtis included under *Oecothea.* With the correction in the type-species, as listed, *Oecothea* is the junior synonym of *Heleomyza* Fallén 1810 (new synonym), leaving *Oecothea,* usually as *Aecothea,* of authors (Becker 1905:47; Czerny 1927:31; Gill 1962:518, 1965:811, 1968:2) as an unnamed genus.

Sherborn and Neave credited *Oecothea* to Curtis, whereas the other references we consulted listed Haliday. Dates for the genus varied from 1837 (Neave), to 1838 (Sherborn, Gill), to 1839 (Becker).

Genus **Pelina** Haliday

Pelina Haliday, *in* Curtis 1837:282 [published in synonymy; first made available by use in Haliday 1839:404, 407]. Type-species: *Notiphila aenea* Fallén by monotypy.

Pelina is a valid generic name in the family Ephydridae. The name is generally credited to Haliday (Becker 1905, 1926, Wirth 1965b, Cogan 1980c). The *Nomenclators* gave this as either "Curtis (ex Haliday)" (Sherborn, Neave) or "Curtis (Haliday MS)" (Schulze *et alia*). Dates varied from 1837 (Schulze *et alia*), to 1838 (Sherborn, Neave) and 1839 (Becker, Wirth, Cogan, *ibid.*).

Genus **Tethina** Haliday

Tethina Haliday, *in* Curtis 1837:293 [published in synonymy; first made abailable by use in Haliday 1838:188]. Type-species: *Opomyza illota* Haliday 1838 by subsequent monotypy (Haliday 1838:188).
Tethnia, Haliday *in* Curtis 1837:281 (incorrect original spelling by present revision).

Tethina is a valid generic name and is the basis for the familial name Tethinidae. In most of the references we examined *Tethina* is dated to 1838 and credited to Haliday (Sherborn, Neave, Vockeroth 1965b, Foster 1976, Steyskal and Sasakawa 1977, Cogan 1980d). Becker (1905) and Czerny (1928), however, dated the genus to 1839, but listed Haliday as the author.

Genus **Thais** Haliday

Tetanocera Duméril 1800:439 (as "Tétanocère"). Type-species, *Musca elata* Fabricius (I.C.Z.N. designation, and validation of this generic name from 1800 is required).

Thais Haliday, *in* Curtis 1837:280 [published in synonymy; first made available by use in Westwood 1840:146]. Type-species: *Tetanocera silvatica* Meigen 1830 (as "15. silvatica") by monotypy.

Thais of Haliday is preoccupied (Bolten 1798, Fabricius 1807 and Huebner 1820). The valid name for this group is *Tetanocera* Duméril 1800 in the family Sciomyzidae (for details of the history of *Tetanocera,* the reader is referred to Sabrosky 1952). *Thais* is listed only in Sherborn, Neave and Schulze *et alia,* where it is considered a *nomen nudum* and as Haliday in Curtis.

Acknowledgments

We thank Drs. Donald M. Anderson, Raymond J. Gagné, Paul R. Marsh and Curtis W. Sabrosky of the Systematic Entomology Laboratory, USDA, Washington; and Michael E. Faran, Walter Reed Army Medical Center, Washington, for their critical review of this manuscript.

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Identification of the Acordulecera *"Potato" Sawflies of Peru and Bolivia, with Descriptions of These and Related Species from South America (Hymenoptera: Pergidae)*

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ABSTRACT

Sawflies damaging potato foliage in Peru and Bolivia and previously recorded as *Acordulecera* sp. belong to three new species: *A. ducra* and *A. willei* from Peru and *A. munroi* from Bolivia. These species belong to a definable group within *Acordulecera* that also includes *A. ruficeps* (Konow), *A. schrottkyi* (Konow), and the following nine new species: *A. chilensis* from Chile and Argentina; *A. colombiana* from Colombia; *A. cretoa, A. nexa, A. porteri,* and *A. vikrea* from Argentina; *A. pyqua* from Argentina and Bolivia; and *A. karpa* and *A. schuhi* from Peru. A key is given to these 14 species, and each is described and illustrated.

Acordulecera is a large genus found only in the Western Hemisphere from southeastern Canada south to Tierra del Fuego. It is an especially large and diverse genus in the Neotropical Region and, as a whole, has never been studied. From south of the United States about 45 species have been described, but this is less than half of the actual number. Because the knowledge of the genus is restricted to inadequate descriptions of species published mostly before 1908, it is understandable that the sawflies reported as damaging potato foliage in Peru and Bolivia (Wille, 1943; Munro, 1954; Carrasco, 1967; Aréstegui, 1976) have been identified only as "*Acordulecera* sp."

During my investigations of Neotropical Symphyta, I have had the opportunity to study the types of all described species of *Acordulecera* except for five described by Enderlein from Santa Catarina, Brazil, the types of which cannot be located and may be lost. The *Acordulecera* from potato reported by the four authors mentioned above represent three new species, *A. ducra, A. willei,* and *A. munroi.* Furthermore, these taxa belong to a definable species group in *Acordulecera* involving 14 species distributed mainly in the Andes from Colombia south to northern Argentina, Paraguay, and in southern Argentina and southern Chile. Only two species in this group have been described, *A. ruficeps* (Konow) (1899) and *A. schrottkyi* (Konow) (1906); the other 12 are new. All 14 are described here.

The group of species of *Acordulecera*

treated here are separated from other species of the genus by the following combination of characters: (1) Head from above broadened behind eyes, with eyes small and removed from hindmargin of head (Figs. 1, 2); (2) distance between eyes below equal to or greater than eye length (Fig. 2); (3) clypeus truncate; (4) antenna (Fig. 1) 6-segmented, slender, its length subequal to or slightly shorter than head width, with only short hairs, shorter than width of the antenna; and with third and fourth segments about equal in length; (5) basal plates entire, emarginated for less than half their medial length and leaving a very small membranous area; and (6) mesoscutellum with strongly carinated margins, the margin usually produced into a thin flange and curved up (Fig. 3). Other species of *Acordulecera* commonly have large eyes that are very close to the hindmargin of the head, and the head in dorsal view narrows strongly behind the eyes; distance between eyes below commonly shorter than eye length; clypeus emarginated in a few species; antenna 6-segmented but of various lengths and shapes, commonly much shorter than head width ($\frac{2}{3}$ or less) with third segment usually longer than fourth segment, sometimes with long hairs, longer than width of antenna, and sometimes with several unusually long stiff hairs on apical segment; basal plates emarginated at center for more than half their medial length and commonly to base, leaving a large membranous area; and the margin of the mesoscutellum with an indistinct carina or short flange, but not strongly produced.

The following key will separate the species of *Acordulecera* treated here.

Even though coloration is used in the key, genitalia should always be checked and compared with the figures to avoid misidentification due to color variation not currently known.

1. Legs mostly black, at least femora black 2
   Legs all yellowish or yellow orange or only apices of tibiae and tarsi black 6
2. Head black with a reddish-brown spot on each side of postocellar area; lancet (Fig. 14) with large spurettes; sheath (Fig. 6) with short scopae, shorter than central portion of sheath (male unknown) .... *schuhi,* new species
   Head mostly reddish, sometimes with small black areas around ocelli and on or above clypeus; spurettes of lancet, if present, small and slender; sheath various 3
3. Sheath without lateral scopae (Fig. 5); lancet (Fig. 16) with small, slender spurettes (male unknown) .... *karpa,* new species
   Sheath with distinct, laterally projecting scopae 4
4. Tibiae and tarsi whitish; genitalia as in Fig. 23, harpe broader than long; Colombia (female unknown) .... *colombiana,* new species
   Tibiae and tarsi brownish to black; harpe of male genitalia at least as long as broad; Peru to northern Argentina 5
5. Sheath (Fig. 7) with scopae slightly shorter than central portion; male genitalia as in Fig. 22, with valve tapering to a narrowly rounded apex; lancet (Fig. 19) without spurettes .... *pyqua,* new species
   Sheath with scopae much longer than central portion (as in Fig. 9); male genitalia as in Fig. 24, with apex of valve broad (female lancet not examined) .... *ruficeps* (Konow) (in part)
6. Sheath without scopae, uniformly thick and blunt at apex in dorsal view (Fig. 10); lancet without spurettes (Fig. 21) (male unknown) .... *chilensis,* new species
   Sheath with laterally projecting scopae 7
7. Thorax mostly black, posterior margin of pronotum, tegula, areas on mesonotum, and/or spot on mesepisternum may be whitish, yellowish, or orange 8
   Thorax mostly yellowish to orange, mesosternum and lower portion of mesepisternum usually pale, if blackish as in some *vikrea,* the pronotum and tegulae all yellow orange 12
8. Sheath with scopae longer than central portion (Fig. 9); apex of hindtibia and hindtarsus blackish in female; male with orange spot on mesepisternum; male genitalia as in Fig. 25; lancet similar to Fig. 26 .... *schrottkyi* (Konow)
   Sheath with scopae slightly shorter than central portion; mesepisternum of male black; legs usually all pale 9

9. Head mostly reddish; male genitalia as in Fig. 25 .... *ruficeps* (Konow) (in part)
Head mostly black, usually a reddish-brown spot on each side of postocellar area 10

10. Male genitalia as in Fig. 28, with harpe as long as broad and apex of valve broad and without concave area (female unknown) (abdomen black with central portion of basal 3 or 4 terga yellow orange; reddish-brown area on postocellar area extends to inner margin of each eye) .... *willei,* new species
Male genitalia as in Figs. 27, 29 with harpe curved or longer than broad and apex of valve with concave area or narrowly rounded 11

11. Lancet (Fig. 12) with large, triangular spurettes; male genitalia (Fig. 29) with harpe curved and valve narrowly rounded at apex .... *munroi,* new species
Lancet (Fig. 15) with small, slender spurettes; male genitalia (Fig. 27) with harpe longer than broad and valve with concave area at apex .... *porteri,* new species

12. Lancet without spurettes (Fig. 20); male genitalia as in Fig. 26; head and commonly entire body orange, sometimes mesonotum and/or mesopleuron and mesoster num with black areas .... *vikrea,* new species
Lancet with spurettes; male genitalia as in Figs. 30, 31, valve with lobe on ventroapical margin or with two long dorsal lobes; usually some black on head, and mesopleuron commonly yellow orange with upper half or upper margin contrastingly black 13

13. Lancet (Fig. 13) with large, triangular spurettes, sometimes directed upwards; valve of male genitalia (Fig. 31) with ventroapical lobe .... *cretoa,* new species
Lancet with small, slender spurettes; valve of male genitalia with two long dorsal lobes 14

14. Underthorax all yellow or with only upper margin black; head largely black; lancet (Fig. 18) with short spurettes; male genitalia as in Fig. 30 ...... *ducra,* new species
Underthorax with upper third to half of mesopleuron black, lower portion orange yellow to white; head largely orange with ocellar and clypeal areas variously black; lancet (Fig. 17) with long spurettes (male unknown) .... *nexa,* new species

Acronyms for museums are given in the acknowledgments.

The species names *willei, munroi, schuhi,* and *porteri* are based on the collector of the types of those species; the names *chilensis* and *colombiana* are based on the country in which the type-locality is found; and the names *ducra, cretoa, nexa, vikrea, pyqua,* and *karpa* are arbitrary combinations of letters and are to be treated as nouns.

Acordulecera chilensis Smith, new species

Figs. 10, 21

Female.—Length, 3.5–4.0 mm. Antenna black to brownish. Head black, sometimes with postocellar area dark orange; clypeus, labrum, base of mandible, and palpi white; apex of mandible reddish brown. Thorax black with pronotum, tegula, mesoscutellum, and metanotum yellow orange; mesosternum and lower $\frac{1}{4}$ or less of mesepisternum reddish; mesonotum with prescutum and lateral lobes black or dark orange with center of each lobe black; anterior margin of mesoscutellum sometimes black. Abdominal terga black with central areas yellow orange, thus appearing black with longitudinal pale stripe; sterna and sheath yellow orange. Legs yellow orange, tarsi little darker. Wings hyaline, veins brown, costa and stigma yellowish. Length of antenna about $\frac{5}{6}$ head width; 3rd segment subequal in length to 4th segment. Postocellar area slightly broader than long. Hindbasitarsus subequal in length to following tarsal segments combined. Sheath (Fig. 10) truncate in lateral view, in dorsal view uniformly thick and blunt at apex, without scopae. Lancet (Fig. 21) without spurettes; each serrula with very fine subbasal teeth.

Male.—Unknown.

Holotype.—Female, "Chile: Prov. Magallanes, Rio Las Minas, 10, 15 Jan. 1966, Flint and Cekalovic" (USNM Type No. 76682).

Paratypes.—CHILE: Same data as for holotype (1♀); Prov. Magallanes, Chor. Las Piedras, 11 Jan. 1966, Flint and Cekalovic (1♀); Mt. Fenton, Pta Arenas, 9 Jan. 1952 (1♀); Puerto Eden, Isla Wellington, 49°S, 3.XII.1958, G. Kuschel (1♀). ARGENTINA: Bariloche, Rio Negro, Nov. 1926, R. and E. Shannon (2♀); Correntosa, Rio Negro, Nov. 1926, R. and E. Shannon (1♀). (USNM, BM)

Remarks.—The simple sheath, lacking scopae, and simple lancet, lacking spurettes, distinguish *chilensis.* The amount of black on the mesonotum varies, but the mesoscu-

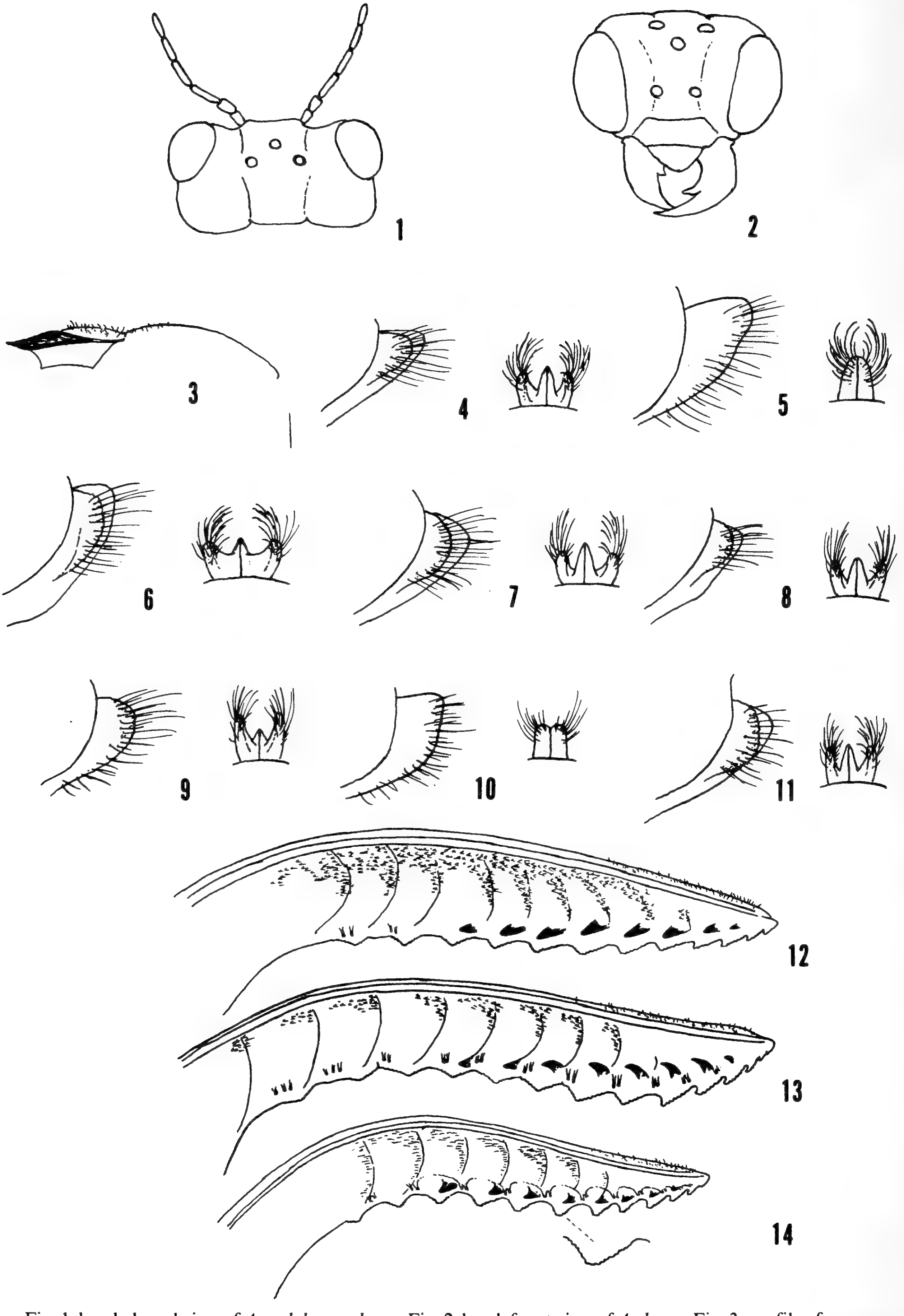
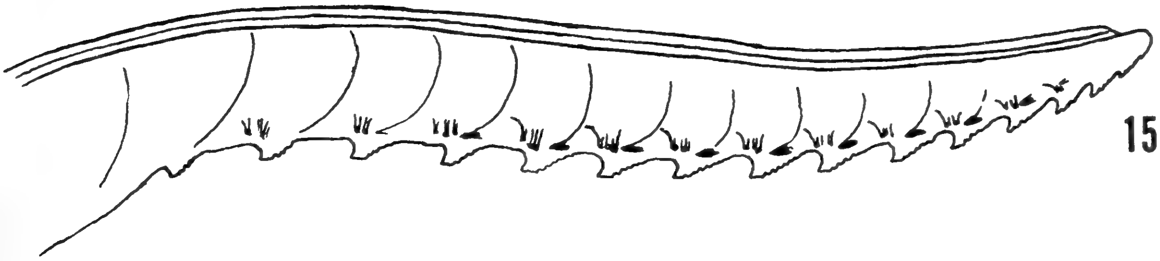


Fig. 1, head, dorsal view of *Acordulecera ducra.* Fig. 2, head, front view of *A. ducra.* Fig. 3, profile of mesonotum, scutellum at left, of *A. pyqua.* Figs. 4–11, female sheaths, lateral view at left, dorsal view at right: 4, *A. ducra;* 5, *A. karpa;* 6, *A. schuhi;* 7, *A. pyqua;* 8, *A. porteri;* 9, *A. schrottkyi;* 10, *A. chilensis;* 11, *A. munroi.* Figs. 12–14, female lancets: 12, *A. munroi;* 13, *A. cretoa;* 14, *A. schuhi.*



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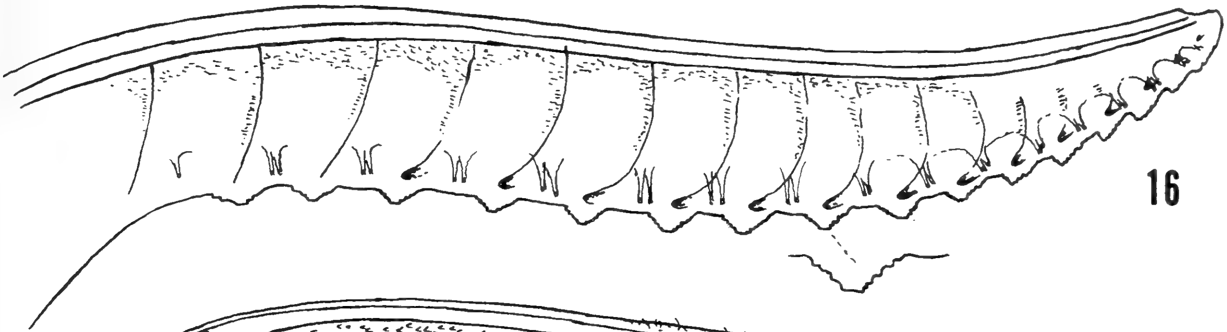

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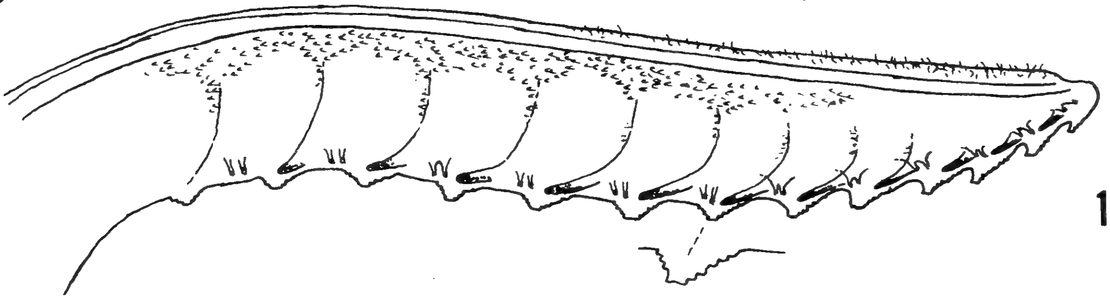

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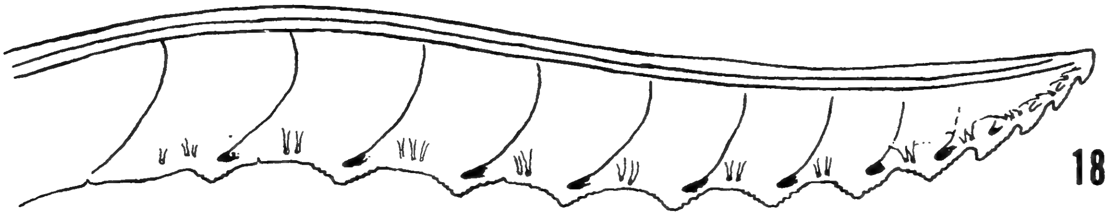

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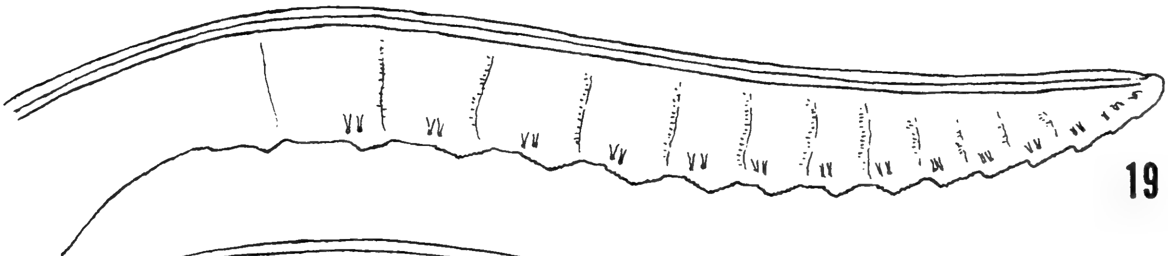

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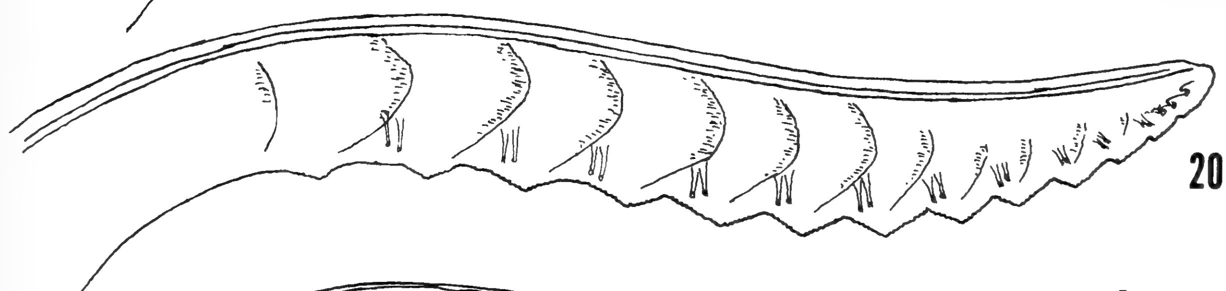

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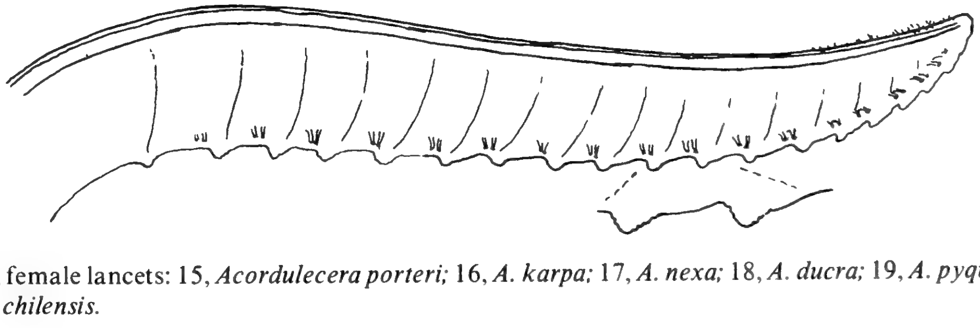

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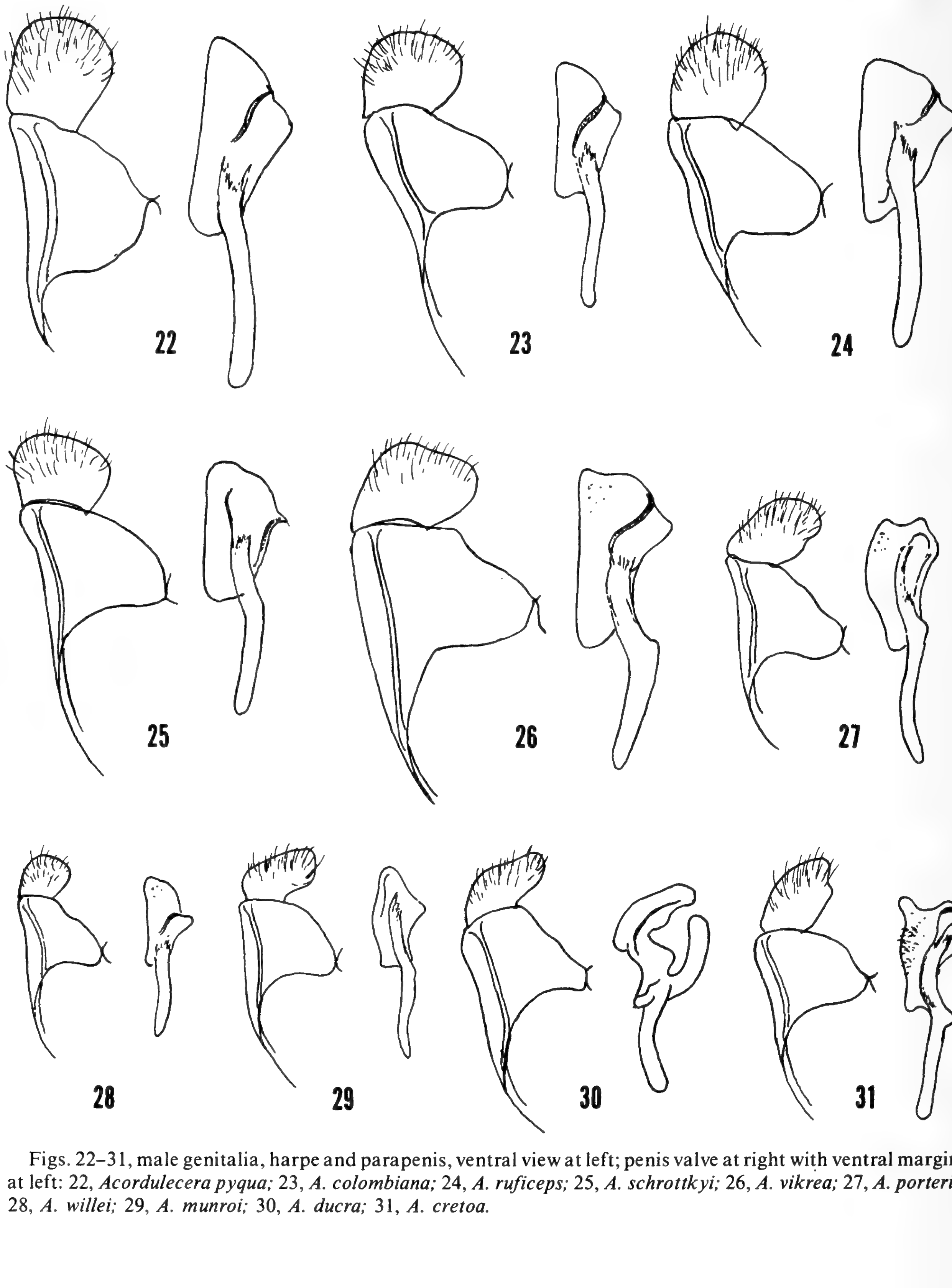
Figs. 15–21, female lancets: 15, *Acordulecera porteri;* 16, *A. karpa;* 17, *A. nexa;* 18, *A. ducra;* 19, *A. pyqua;* 20, *A. vikrea;* 21, *A. chilensis.*



22 23 24 25 26 27 28 29 30 31

Figs. 22–31, male genitalia, harpe and parapenis, ventral view at left; penis valve at right with ventral margin at left: 22, *Acordulecera pyqua;* 23, *A. colombiana;* 24, *A. ruficeps;* 25, *A. schrottkyi;* 26, *A. vikrea;* 27, *A. porteri;* 28, *A. willei;* 29, *A. munroi;* 30, *A. ducra;* 31, *A. cretoa.*

tellum is mostly yellow orange in all specimens examined. This is the southernmost species of *Acordulecera* and is the only species I have seen from southern Argentina and southern Chile.

Acordulecera colombiana Smith, new species

Fig. 23

Female.—Unknown.

Male.—Length, 4.0 mm. Antenna reddish, segments 1 and 2 black. Head dark reddish, ocellar area, clypeus, and labrum black; palpi and base of mandible brownish, apex of mandible dark red brown. Thorax black with posterior edge of pronotum brownish. Abdomen black, basal 2 or 3 sterna and terga 2 and 3 yellowish. Legs black with apices of femora and tibiae and tarsi whitish. Wings hyaline, veins brown, costa and stigma yellowish. Length of antenna about $\frac{5}{6}$ of head width; 3rd segment slightly longer than 4th segment. Postocellar area longer than broad. Hindbasitarsus subequal in length to remaining tarsal segments combined. Genitalia as in Fig. 23; harpe broader than long; apex of valve tapering to rounded apex at ventroapical corner.

Holotype.—Male, "Colombia: 11 mi. N. Popayana, Cauca, 1830 m, III-5-1955," "E. I. Schlinger and E. S. Ross, collectors" (CAS).

Paratypes.—COLOMBIA: Same data as for holotype (2♂) (CAS).

Remarks.—Due to the largely black coloration of the thorax, abdomen, and legs, reddish head, and structure of the genitalia, this species may be confused with *ruficeps* and *pyqua.* In *colombiana* the tibiae and tarsi are white, not brownish to black as in those species, and the genitalia differ (compare Figs. 22–24). In the genitalia of *colombiana,* the harpe is broader than long and the shape of the valve is slightly different.

Acordulecera cretoa Smith, new species

Figs. 13, 31

Female.—Length, 5.0–5.5 mm. Antenna brownish. Head yellow orange, blackish between antennae and on ocellar area; sometimes black extending laterally to eyes and sometimes black mark behind each eye extending downward on occipital margin. Thorax yellow orange with upper $\frac{1}{2}$ of mesopleuron, metapleuron, and prescutum and lateral lobes of mesonotum black, sometimes only black mark on lobes of mesonotum. Abdomen yellow orange with terga black, usually longitudinal pale mark medially on dorsum; apical 2 or 3 sterna with black spots; sheath yellow orange. Legs yellow orange with apical 2 or 3 tarsal segments blackish. Wings very lightly uniformly infuscated black; veins dark brown, costa and stigma yellowish. Length of antenna about $\frac{5}{6}$ head width; 3rd segment subequal in length to 4th segment. Postocellar area as long as broad. Hindbasitarsus subequal in length to remaining tarsal segments combined. Sheath (as in Fig. 8) with laterally projecting scopae which are slightly shorter than central portion of sheath. Lancet (Fig. 13) with large, triangular spurettes above serrulae 4–11, sometimes directed slightly upward; serrulae at center pointed at apices, each with an equal number, 5–7, of anterior and posterior subbasal teeth, serrulae at apex longer on posterior side than on anterior side.

Male.—Length, 4.5–5.5 mm. Coloration similar to that of female except head mainly yellow orange with ocellar area and marks extending part way to antennae black; usually less black on prescutum and lateral lobes of mesonotum. Genitalia as in Fig. 31; valve with short ventroapical lobe.

Holotype.—Female, "Horco Molle, Tuc., Arg., VII.10.31.66, L. Stange leg." (TUC).

Paratypes.—ARGENTINA: Same data as for holotype, VIII-1-20 (1♀, 1♂), VIII.30.31.66 (3♀), Jan. 23–Feb. 4, 66, C. C. Porter (1♀), IX-17-30-68, C. C. Porter (1♀), Mar. 25–Apr. 30, 66, C. C. Porter (1♂), 2–15 Nov. 1967, C. C. Porter (1♀), 9.14-V-1966, L. Stange (1♀), March 7–13, 1966, L. A. Stange (2♀, 2♂), Apr. 3–10, 1966, L. A. Stange (1♂); nr. Horco Molle, I-5-66, H. and M. Townes (1♂); Tucuman, Tafi-Quebrada Cainza, 19-XII-1950, R. Golbach (1♀); 10 mi. N. Trancas, Tucuman, II-13-51, Ross and Michelbacher (1♂); Salta, Rio Pescado, V-10-69, C. C. Porter (1♀); Jujuy, 29 Feb. 1920, Cornell University Expedit. (2♂); Jujuy, Posta Lozano, III-21-23-69, C. C. Porter (1♂), same, X-29-XI-4-68 (1♀), same, III-28-31-1968 (1♂), same X-27-XI-2-68 (2♀). (TUC, USNM, CU, MCZ, HKT)

Remarks.—The lancet of *cretoa* with the large spurettes resembles those of *munroi* and *schuhi,* but those species are mostly black, at least the head and thorax. The coloration of *cretoa* resembles *nexa* in that the thorax is mostly yellow orange with the upper half or so of the mesopleuron black, but *nexa* has rather long, slender spurettes on the lancet. The male is distinctive in that the valve (Fig. 31) has a rather long ventroapical lobe, not known in other species treated here.

The amount of black on the mesonotum varies, and the spurettes of the lancet are sometimes directed upward.

Acordulecera ducra Smith, new species

Figs. 1, 2, 4, 18, 30

Acordulecera sp.: Carrasco, 1967: 64–65, Figs. 2, 3; ? Aréstegui, 1976: 97.

Female.—Length, 5.0–5.5 mm. Antenna black, 1st segment brownish. Head black with orange spot on each side of postocellar area; clypeus, labrum, base of mandible, and palpi white; apex of mandible reddish brown. Thorax yellow with upper margins of meso- and metapleurae narrowly and mesonotum except scutellum black. Abdomen yellow orange, usually with 1st and 2nd terga black and black marks laterally on terga 3 to apex. Legs yellow orange, tarsi blackish. Wings hyaline; veins dark brown; costa and stigma yellowish. Length of antenna subequal to head width; 3rd segment slightly longer than 4th segment. Postocellar area about as long as broad. Hindbasitarsus slightly shorter than length of remaining tarsal segments combined. Sheath (Fig. 4) with lateral scopae which are shorter than central portion of sheath. Lancet (Fig. 18) with small spurettes above serrulae 2–12; each serrula with 4–5 anterior and 5–7 posterior fine subbasal teeth.

Male.—Length, 4.5–5.3 mm. Coloration similar to that of female except mesonotum sometimes black anteriorly; abdomen yellow orange with black laterally only on terga 1–3; and meso- and metapleurae with less black dorsally, sometimes black absent. Genitalia as in Fig. 30; harpe bent inward; valve with two long dorsal lobes.

Holotype:—Female, "Peru: Cusco, 1974, on potato, M. Delgado" (USNM Type No. 76684).

Paratypes.—PERU: Same data as for holotype (2♀, 1♂); Cuzco, F. Carrasco Z. (1♀, 1♂); Pisac, Cuzco, II-3-1968, A. Garcia and C. Porter (4♀); Urubamba, Cuzco, II-7-9-1968, A. Garcia and C. Porter (5♀, 5♂); Cuzco, I-31-1968, A. Garcia and C. Porter (1♀, 1♂); Ollantaitambo, Cuzco, Feb. 28, 1947, alt. 9200 ft., J. C. Pallister, coll. Donor Frank Johnson (1♀). (USNM, MCZ, AMNH)

Remarks.—The color of *ducra* is similar to that of *cretoa* and *nexa* in that the underthorax is yellow orange with the upper portion of the mesopleuron black, however the mesopleuron is at least half black in those two species and only the upper margin, at most, is black in *ducra.* Also, the spurettes of the lancet are smaller than those of *cretoa.* The lancet resembles those of *nexa, porteri,* and *karpa,* but the spurettes are longer in *nexa* and the mesopleuron is mostly black, *porteri* has the thorax mostly black, and *karpa* has a simple sheath, lacking scopae. The two lobes of the valve of the genitalia of the male are not found in other species in the group of *Acordulecera* treated here.

This is the species reported by Carrasco (1967) damaging potato foliage in the Department of Cuzco. He gave a short account of its biology and described the damage; the cocoons are illustrated. I have no specimens to verify the report by Aréstegui (1976) who recorded *Acordulecera* sp. feeding on potato foliage in the Department of Apurimac. Apurimac is adjacent to Cuzco, however, and Aréstegui's species may be *ducra.*

Acordulecera karpa Smith, new species

Figs. 5, 16

Female.—Length, 5.2 mm. Antenna dark red, segments 1 and 2 black. Head dark reddish; ocellar and most of central postocellar area, supraclypeal area, clypeus, and labrum black; palpi dark brown; mandible white at base, reddish brown at apex. Thorax black. Abdomen black, 2nd tergum and narrow posterior margins of terga 3–5 whitish. Legs black with apices of femora and inner surfaces of tibiae and tarsi pale brown. Wings hyaline; veins brown, costa and stigma more yellowish. Length of antenna slightly less than head width; 3rd segment slightly longer than 4th segment. Postocellar area longer than broad. Hindbasitarsus subequal in length to remaining tarsal segments combined. Sheath (Fig. 5) simple, without scopae; in lateral view rounded at apex; in dorsal view uniformly thick. Lancet with small spurettes above serrulae 3–16; central serrulae each with 3 or 4 anterior and 3 or 4 posterior subbasal teeth; apical serrulae longer on posterior margin than on anterior margin (Fig. 16).

Male.—Unknown.

Holotype.—Female, "Peru: 30 mi. NE Huanucho, 2500 m, IX-17-54, E. I. Schlinger and E. S. Ross collectors" (CAS).

Remarks.—The red head and black thorax, abdomen, and legs combined with the simple sheath separate *karpa* from other *Acordulecera.* With the small spurettes on the lancet, it resembles those of *nexa, cretoa,* and *ducra.* Those three species, however, have large scopae on the sheath and have considerable orange yellow coloration on the legs and body.

Acordulecera munroi Smith, new species

Figs. 11, 12, 29

Acordulecera sp.: Munro, 1954: 187.

Female.—Length, 4.5 mm. Antenna black. Head black with dark orange spot on each side of postocellar area; clypeus, labrum, base of mandible, and palpi white; apex of mandible reddish brown. Thorax black; pronotum except for lower lateral angles, tegula, inner margin of each lateral lobe of mesonotum narrowly, and mesoscutellum yellow orange. Abdomen yellow orange; usually most of 1st and 2nd terga black and lateral margin of 3rd tergum to apical tergum black; sheath black. Legs yellow orange, tarsi a little darker. Wings hyaline; veins, costa, and stigma dark brown; ventral margin of stigma pale brown. Length of antenna very slightly less than head width; 3rd segment slightly longer than 4th segment. Postocellar area as long as broad. Hindbasitarsus equal to length of remaining tarsal segments combined. Sheath (Fig. 11) with lateral projecting scopae which are slightly shorter than inner portion. Lancet (Fig. 12) with large, triangular spurette above serrulae 3–10; each serrula with 3 or 4 anterior and 6 to 8 posterior fine subbasal teeth; spinelike setae on annuli and near dorsal margin.

Male.—Length. 4.0 mm. Color similar to that of female except abdomen which is yellow with lateral areas of terga black, thus a broad longitudinal, medial pale stripe evident on length of abdomen; mesoscutellum with anterior $\frac{1}{2}$ or more black; and costa, stigma, and veins of wings amber. Genitalia as in Fig. 29; harpe bent; valve narrowly rounded at apex.

Holotype.—Female, "Sucre, Boliv., Feb. 25, 1954, potato, Munro, Nava" (USNM Type No. 76683).

Paratypes.—BOLIVIA: Same data as for holotype (1♀, 2♂); highlands, reared from potato, 1965, C. Montellano (4♀). (USNM)

Remarks.—*Acordulecera munroi* is distinguished by its mostly black head and thorax with the pronotum, tegula, and mesoscutellum yellow orange, its mostly yellow orange abdomen and legs, and by the presence of large, triangular spurettes on the lancet. The lancet resembles those of *cretoa* and *schuhi,* but *schuhi* has mostly black legs, and *cretoa* has the mesosternum and lower part of the mesopleurae orange yellow and has more extensive pale coloration on the head rather than only a small dark orange spot on each side of the postocellar area as in *munroi.*

Munro (1954) first reported this species from Bolivia as "*Acordulecera* sp.": "Adults of greenish, hymenopterous larvae which cause spectacular damage to potato foliage in south central Bolivia were identified . . . as *Acordulecera* sp. . . . In February, I saw potato plants in several fields badly defoliated by this pest . . ." He stated that, according to the identifier, these were the same as Wille's material from Peru (Wille, 1943), but they are different. See the description of *willei* and compare the genitalia in Figs. 28 and 29. The female of *willei* is not known, but the male genitalia are clearly different.

Acordulecera nexa Smith, new species

Fig. 17

Female.—Length, 5.5–6.0 mm. Antenna black. Head dark orange to reddish; clypeus, labrum, base of mandible, and palpi whitish; apex of mandible reddish brown; sometimes black areas between or just above antennae. Thorax orange on dorsum, sometimes anterior margin of mesoscutellum blackish; cervical sclerites, upper $\frac{2}{3}$ of mesopleuron, metapleuron, and lateral angles of pronotum black; whitish streak on lower margin of mesepisternum between black and yellow orange mesosternum. Abdomen black with basal sterna and center of basal 5 terga orange yellow. Legs whitish, extreme apex of hindtibia and tarsi dark brown. Wings subhyaline, veins and stigma brown. Length of antenna about $\frac{5}{6}$ of head width, 3rd segment longer than 4th segment. Postocellar area as long as broad. Hindbasitarsus equal to length of remaining tarsal segments combined. Sheath (as in Fig. 8) with lateral scopae which are slightly shorter than central portion. Lancet (Fig. 17) with rather long slender spurettes above serrulae 2–12; serrulae longer on posterior margin than on anterior margin, with 3 or 4 anterior and 5 or 6 posterior subbasal teeth.

Male.—Unknown.

Holotype.—Female, "Horco Molle, Tucuman, Argent., Mar. 25–Apr. 30, '66, C. C. Porter" (MCZ).

Paratypes.—ARGENTINA: same data as for holotype (1♀); Horco Molle, Tucuman, IV-24-V-9-68, C. C. Porter (1♀); Salta, 24 km O. Aguas Blancas, Cpto. Jakulica, 29-VI-1973, C. Porter and E. Demarest (1♀); Jujuy, Posta Lozano, X-27-XI-68, C. C. Porter (1♀). (MCZ, TUC)

Remarks:—The most distinctive feature of this species is the rather long, slender spurettes of the lancet, longer than those on the lancets of the related species *porteri, ducra,* and *karpa.* In *karpa* the female sheath is simple and the thorax, abdomen, and legs are mostly black; in *ducra* the thorax and abdomen are mostly orange yellow with the black on the thorax, if any, limited to only the upper margin; and in *porteri,* the thorax is mostly black underneath and there are more extensive black areas on the head. The coloration, especially the black upper half or more of the mesopleuron contrasting with the orange yellow coloration below it, resembles *cretoa,* but *cretoa* usually has more black on the head and has large, triangular spurettes on the lancet.

Acordulecera porteri Smith, new species

Figs. 8, 15, 27

Female.—Length, 5.0–5.5 mm. Antenna black. Head black with reddish brown U-shaped mark from posterior margin of postocellar area extending anterolaterally to inner margin of each eye, sometimes narrow line on inner margin of each eye, and stripe on gena from near top margin of eye increasing in width to malar area and touching eye only on lower outer margin; clypeus, labrum, base of mandible, and palpi white; apex of mandible reddish brown. Thorax black with posterior margin of pronotum, tegula, and posterior margin to posterior $\frac{1}{2}$ of mesoscutellum yellow orange. Abdomen black, sometimes yellowish areas at center of basal sterna and on anterior margin of basal terga. Legs orange yellow, apical tarsal segments infuscated blackish. Wings very lightly, uniformly infuscated blackish; veins dark brown, costa and stigma pale brown with apex of costa nearly whitish. Length of antenna slightly less than head width; 3rd segment subequal in length to 4th segment. Postocellar area about as long as broad. Hindbasitarsus equal to length of remaining tarsal segments combined. Sheath (Fig. 8) with scopae which are slightly shorter than inner portion. Lancet with small spurettes above serrulae 3–13; serrulae longer on posterior margin than on anterior margin, narrowly flattened at apices, and each with 3 or 4 anterior and 6 or 7 posterior fine subbasal teeth (Fig. 15).

Male.—Length, 4.5–5.5 mm. Color similar to that of female but generally paler, antenna usually reddish brown, reddish-brown areas on head usually broader, mesoscutellum and pronotum sometimes almost entirely reddish brown; lateral deflexed portions of lateral lobes of mesonotum reddish brown, and abdomen mostly yellowish to yellow orange with apical 3 or 4 terga and sometimes apical 2 or 3 sterna black. Genitalia as in Fig. 27; harpe longer than broad; valve with apical margin concave.

Holotype.—Female, "Jujuy, Posta Lozano, Argent., X-27-XI-2-68, C. C. Porter" (MCZ).

Paratypes.—ARGENTINA: Same data as for holotype (2♀, 10♂), same except X-29-XI-4-68 (1♀, 2♂); same except 26.X.1969 (1♀); Jujuy, I-14-66, H. and M. Townes (1♂); Tucumán, Tafí del Valle, 12–14 Nov. 1967, C. Porter, A. Garcia (1♂), same, March 3–12, 66, C. C. Porter (1♂), same, I-5-66, H. and M. Townes (1♀, 1♂), same I-4-66, H. and M. Townes (1♂); Villa Nogués, XII-24-65, H. and M. Townes (4♂), same, XII-26-65 (2♂); Tucuman, km 40 ruta a Tafi del Valle, 20-X-1971, C. Porter, L. Stange (2♂); Salta, Toldos, 2400 m, 19.21.II.1960, R. Golbach (1♂); Trancas, Tacanas, II-1953, coll. J. M. Arnau (1♂). (TUC, MCZ, HKT, USNM)

Remarks.—The small spurettes on the lancet resemble those of *karpa, nexa,* and *ducra,* but *karpa* has a simple sheath, mostly black thorax, abdomen, and legs, and a reddish head, and *nexa* and *ducra* each have a mostly yellow orange underthorax except for the upper half or upper margin of the mesopleuron. The valve of the male genitalia is distinctive in having the apical margin concave and lacking a rather long ventroapical lobe as is found in *ducra*. The coloration of *porteri*, especially the mostly black head and thorax, resembles that of *munroi*, but *munroi* has large, triangular spurettes on the lancet.

Acordulecera pyqua Smith, new species

Figs. 3, 7, 19, 22

Female.—Length, 5.5–6.0 mm. Antenna dark reddish, 1st and 2nd segments black. Head dark reddish, sometimes posterior margin of clypeus, labrum, and palpi black; mandible pale orange at base, reddish brown at apex. Thorax black; posterior margin of pronotum and tegula yellow orange. Abdomen black, 1st and usually part of 2nd terga and 2–3 basal sterna whitish to yellow orange. Legs black with tibiae and tarsi, especially those of forelegs, paler brownish. Wings subhyaline; veins dark brown, costa and stigma pale brown. Length of antenna about $\frac{2}{3}$ of head width; 3rd segment slightly longer than 4th segment. Postocellar area longer than broad. Hindbasitarsus equal to length of remaining tarsal segments combined. Sheath (Fig. 7) with scopae which are shorter than length of central portion. Lancet (Fig. 19) without spurettes; serrulae shallow, pointed at apices, each with about 5–6 anterior and 5–6 posterior fine subbasal teeth.

Male.—Length, 4.5–5.0 mm. Color similar to that of female except foretibia and foretarsus more whitish as are sometimes tibiae and tarsi of other legs; and basal 1–4 segments of abdomen mostly whitish to yellow. Genitalia as in Fig. 22; harpe slightly longer than broad; apex of valve narrowly rounded at apex.

Holotype.—Female, "R. A. Tucuman, Tafi-Lacavera, 28.XI.1951, coll. R. Golbach" (TUC).

Paratypes.—ARGENTINA: Same data as for holotype (3♂); Tucuman, Dpto: Burruyaui, Rio Calera, 26-X-1971, col: Porter, Fidalao (15♂); Tucuman, San Javier, 10.XII.1950, coll. R. Golbach (1♂); Horco Molle, Tucuman, Mar. 25–Apr. 30, 1966, C. C. Porter (2♂, 1♀); Tucuman, Tafi-Lacavera, 16–31 Oct. 1967, C. C. Porter (1♀); Tucuman, X-19-72, G. E. Bohart (1♂); Jujuy, Alto La Viña, Mar. 13–20, 1966, C. C. Porter (1♂); Jujuy, Posta Lozano, X-29-XI-4-68, C. C. Porter (1♂); Jujuy, I-4-66, H. and M. Townes (1♂); Salta, Rio Pescado, ca. Oran, 22°53′S-64°27′O., 26-V-1970, col. C. Porter (1♀, 3♂), same, 27-V-1970 (1♀); Villa Nogués, XII-23-65, H. and M. Townes (1♂). BOLIVIA: Yungas (1♂). (TUC, USNM, MCZ, USU, HKT, LEI)

Remarks.—This is a mostly black species with a reddish head and is closest to *ruficeps*, *karpa*, and *colombiana*. From both *karpa* and *ruficeps*, *pyqua* can be separated by the female lancet and sheath. In *karpa*, the sheath is simple and the lancet has spurettes above the serrulae; in *ruficeps*, the scopae of the sheath are much longer than the central portion of the sheath. The male genitalia of *colombiana*, *ruficeps*, and *pyqua* are very similar, but *colombiana* has the harpe broader than long, and the shape of the valve differs between *pyqua* and *ruficeps* as shown in Figs. 22, 24.

Acordulecera ruficeps (Konow)

Fig. 24

Acorduleceros ruficeps Konow, 1899: 308 (♀, ♂); Konow, 1905: 32.

Acordulecera ruficeps: Smith, 1978: 179.

Female.—Length, 5.0 mm. Antenna yellow orange, segments 1 and 2 black. Head dark reddish, area around and below antennae more yellow orange as are bases of mandible and palpi; apex of mandible reddish brown. Thorax black, narrow posterior margin of pronotum brownish. Abdomen black; apical 2 or 3 segments more brownish. Legs with coxae black, apices of coxae and trochanters whitish, remaining parts of legs mostly dark brown on outer surfaces, whitish on inner surfaces. Wings with yellowish tinge to subhyaline; veins and stigma yellow orange. Length of antenna about $\frac{5}{6}$ of head width; 3rd segment slightly longer than 4th segment. Postocellar area longer than broad. Hindbasitarsis subequal in length to remaining tarsal segments combined. Sheath with posteriorly projecting scopae, rounded in lateral view, and much longer than central portion of sheath (as in Fig. 9).

Male.—Length, 4.5–5.0 mm. Similar in color to female but in general paler with posterior margin of pronotum and tegula brownish, abdomen with basal 3–4 segments whitish and apical segments black, and legs yellow orange with coxae except extreme apices, sometimes part of femora, and apical tarsal segments black. Genitalia as in Fig. 24; harpe round; apex of valve rather blunt.

Types.—The type-series of *ruficeps* is at Eberswalde; 3♂ and 1♀ labeled types were sent to me; all are labeled "Callanga, Cuczo, Peru," the locality as stated by Konow (1899). The female is hereby designated lectotype; the 3 males, paralectotypes. The specimens have been labeled as such.

Records.—PERU: Callanga, Cuczo (lectotype and paralectotypes); 50 mi. S. Tingo Maria, Carpish Creek, XII-28-1954; E. side Carpish Mts., 2800 m, 40 mi. SW Tingo Maria, X-17-1954; Machu Picchu, XII-1-65, XI-27-65.

Remarks.—The red head and mostly black coloration of *ruficeps* resemble that of *pyqua, colombiana,* and *karpa.* The female is separated from those of *pyqua* and *karpa* by the sheath, which has the central portion much shorter than the scopae and not visible in lateral view; in *karpa* the sheath is simple, and in *pyqua* the sheath has the scopae shorter than the inner portion and consequently the inner portion is visible in lateral view. The male is separated from those of *pyqua* and *colombiana* by having paler legs (in some specimens the legs are mostly entirely yellow orange) and by the genitalia as compared in Figs. 22–24. The harpe of the genitalia of *ruficeps* is as long as broad and the apex of the valve is not as narrow as in *pyqua* and *colombiana.*

The female lectotype is the only female I have seen, and I did not examine the lancet before returning it.

Acordulecera schuhi, Smith, new species

Figs. 6, 14

Female.—Length, 5.0 mm. Antenna dark brown. Head black with a reddish brown spot on each side of postocellar area; apical margin of clypeus, labrum, base of mandible, and palpi white; apex of mandible reddish brown. Thorax black, narrow posterior margin of pronotum whitish. Abdomen black, very narrow margin of each segment whitish. Legs mostly black to dark brown with extreme apices of coxae, trochanters, apical $\frac{1}{4}$ and inner surface of forefemur, apical $\frac{1}{5}$ of mid- and hindfemora, and most of inner surfaces of tibiae and tarsi pale brown to whitish. Wings hyaline, veins and stigma dark brown, costa paler brown. Length of antennae slightly greater than head width; 3rd segment subequal in length to 4th segment. Postocellar area slightly longer than broad. Hindbasitarsus subequal in length to remaining tarsal segments combined. Sheath (Fig. 6) with scopae which are shorter than inner portion. Lancet (Fig. 14) short, with large triangular spurettes above serrulae 3–10; serrulae slightly flattened at apices, each with about 7 or 8 anterior and posterior subbasal teeth except apical serrulae, which are longer on posterior margin than on anterior margin.

Male.—Unknown.

Holotype.—Female, "Peru: Amazonas: Molinopampa, 43 km E. Chachapoyas, 2300 m, July 11, 1972, R. T. and J. C. Schuh" (AMNH).

Remarks.—The coloration, especially the mostly black thorax, abdomen, and legs, are similar to *ruficeps, colombiana, pyqua,* and *karpa;* however, *schuhi* has a mostly black head, not red as in these other species. Also the lancet of *schuhi* has large triangular spurettes which are either absent or small in the other species of which the female is known. The scopae of the sheath separate *schuhi* from *ruficeps* and *karpa;* in *ruficeps* the central portion is shorter than the scopae and in *karpa* the sheath is simple.

The large spurettes of the lancet resemble those of *munroi* and *cretoa,* but those species have yellow-orange legs and usually much more extensive yellow-orange coloration on the thorax and/or abdomen.

Acordulecera schrottkyi (Konow)

Figs. 9, 25

Acorduleceros schrottkyi Konow, 1906: 345–346 (♀).

Acordulecera schrottkyi: Smith, 1978: 179.

Female.—Length, 4.3 mm. Antenna black. Head black with reddish brown spot on each side of postocellar area; apical margin of clypeus, labrum, palpi, and base of mandible white; apex of mandible reddish brown. Thorax black with pronotum except for lower lateral angles, tegula, and apical margin of mesoscutellum yellow orange. Abdomen black with apical $\frac{1}{2}$ of 2nd tergum and terga 3 and 4 yellow orange. Legs with coxae black, whitish at extreme apices, femora mostly yellow orange with black mark at bases on inner surfaces, tibiae whitish on basal $\frac{1}{4}$, blackish on apical $\frac{3}{4}$, and tarsi dark brown. Wings very lightly, uniformly infuscated blackish to hyaline; veins and stigma dark brown, posterior margin of stigma paler brown. Length of antenna about $\frac{3}{4}$ of head width; 3rd segment longer than 4th segment. Postocellar area as long as broad. Hindbasitarsus slightly shorter than length of remaining tarsal segments combined. Sheath (Fig. 9) with scopae longer than inner portion; rounded in lateral view. Lancet (similar to Fig. 20) lacking spurettes; annuli nearly straight and perpendicular to ventral margin; annular hairs nearly as long as width of segments.

Male.—Length, 3.5 mm. Antenna brownish. Head color as for female but clypeus all white. Thorax black with pronotum, tegula, inner margins of mesoprescutum, all mesoscutellum, and a large central area on mesepisternum orange. Abdomen black with yellow orange laterally. Legs yellow orange with black spot at base of each coxa and extreme apices of tibiae and apical 1 or 2 tarsal segments black. Wings with slight yellow tinge, veins brown, costa and stigma yellowish. Genitalia as in Fig. 25; harpe broader than long; valve rounded at apex, with short spine on dorsal margin.

Type.—Konow (1906) described the female; after the description he described a male from the same locality that he thought might be the male of *schrottkyi,* but he was not certain. A male and female were sent to me from Eberswalde; both are labeled types and both are labeled "Villa Encarnac., Paraguay." Konow stated "Paraguay (Villa Encarnación)" in the original description. The female must be the holotype of *schrottkyi;* the male agrees with the description of the male by Konow, and I treat it as the male above, but I do not regard it as part of the type-series.

Records.—PARAGUAY: Villa Encarnación (type and male described above).

Remarks.—The black head, underthorax, and abdomen resemble the color of *munroi, willei,* and *porteri,* but the females of *munroi* and *porteri* have small or large spurettes on the lancet and each has the inner portion of the sheath slightly longer than the scopae. The male genitalia also differ as shown in the illustrations. Although the lancet of *schrottkyi* lacks spurettes as in *pyqua* and *vikrea,* the heads of those species are reddish to orange, and the sheaths of those species have the scopae shorter than the central portion.

Acordulecera vikrea Smith, new species

Figs. 20, 26

Female.—Length, 4.5–5.5 mm. Entirely yellow orange or with some or all of following brownish to black: postocellar area, anterior margin of pronotum, all or part of mesonotum, underthorax, apical 2 or 3 terga, outer surface of hindtibia, and tarsi; intermediate colorations and variations of these extremes exist. Clypeus, labrum, base of mandible, and palpi whitish; apex of mandible reddish brown. Wings with yellowish tinge to subhyaline; veins brown, costa and stigma yellowish. Length of antenna about $\frac{5}{6}$ of head width; 3rd segment slightly longer than 4th segment. Postocellar area slightly longer than broad. Hindbasitarsus subequal in length to remaining tarsal segments combined. Sheath (as in Fig. 8) with scopae slightly shorter than inner portion. Lancet (Fig. 20) without spurettes; serrulae pointed at apices, each with about 5–7 anterior and posterior fine subbasal teeth except those at apex, which are longer on posterior margin than on anterior margin.

Male.—Length, 4.5–5.0 mm. Coloration similar to and as variable as that for female. Genitalia as in Fig. 26; harpe broader than long; valve broad at apex.

Holotype.—Female, "Argentina, Tucuman, Depto. Tafi, Quebrado Cainzo, 19-XII-1950, R. Golbach" (TUC).

Paratypes.—ARGENTINA: Same data as for holotype (14♀, 6♂); Tucuman, Parque Aconquija, 22-1-1971 (1♂); Tucuman, Tafi Lacavera, 28.XI.1951, R. Golbach (1♀, 1♂); Tucuman, Alrededores Ciudad, I.1956., col. R. Golbach (1♂); Tucuman, S. M. de Tucuman, Mayo 1977, Trampa Moericke, col. P. Fidalgo (1♀); Tucuman, Dpto Burrayacu, Rio Calaza, 26-X-1971, Porter-Fidalgo (1♂); Tucuman, Horco Molle, IV-9-30-1968, C. C. Porter (1♀); same, Jan. 23–Feb. 4, 66 (4♀, 5♂), same 16–31 Oct. 1967 (2♂), same, Mar. 25–Apr. 30, 66 (4♀, 10♂), same, Jan. 15–19, 1966, L. A. Stange (1♂), same, Mar. 7–13, 1966, L. A. Stange (1♀); Horco Molle, nr. Tucuman, I-18-66, H. and M. Townes (1♀); Salta, 24 km O. Aguas Blancas, Cpto. Jakulica, 29-VI-1973, C. Porter and E. Demarest (1♀, 1♂); Salta, Orán, Abra Grande, IV-18-V-5-69, C. Porter (1♀); Jujuy, Posta Lozano, X-27-XI-2-68, C. C. Porter (1♂); Jujuy, I-14-66, H. and M. Townes (1♂), same, I-15-66 (2♂), same, I-8-66 (2♂), same I-13-66 (1♀). (TUC, USNM, HKT, MCZ)

Remarks.—Most specimens are entirely yellow orange, but some in the same series have the underthorax brownish to black and have other blackish markings in various combinations as given in the description. The head is always yellow orange to orange with at most the postocellar area blackish. This species is distinguished by this coloration, by the lack of spurettes on the lancet, by the sheath which has the scopae slightly shorter than the inner portion, and by the male genitalia. Both *schrottkyi* and *pyqua* have no spurettes on the lancet, but those species are mostly black except for the reddish head in *pyqua,* and *schrottkyi* has the scopae of the sheath much longer than the central portion.

Acordulecera willei Smith, new species

Fig. 28

Acordulecera sp.: Wille, 1943: 325.

Female.—Unknown.

Male.—Length, 4.0–4.5 mm. Antennal segments 1 and 2 reddish brown (flagellum in all specimens missing). Head black with broad stripe on posterior margin of postocellar area extending on each side anterolaterally to each eye, clypeus, labrum, base of mandible, and palpi reddish brown; apex of mandible dark red brown. Thorax black with pronotum except laterally, tegula, spot on each anterolateral corner of mesoprescutum, spot on posterolaterial corner of each lateral lobe of mesonotum, broad posterior margin of mesoscutellum, and metanotum yellow orange. Abdomen black with terga 1–3 and part of 4 dorsally yellow orange. Legs yellow orange with apical tarsal segments darker. Wings subhyaline, veins and stigma yellow orange. Postocellar area slightly broader than long. Apical hindtarsal segments missing in all specimens. Genitalia as in Fig. 28; harpe as long as broad; valve with apex rounded and with lobe on dorsal margin.

Holotype.—Male, "No. 19–38, Huaras [Department of Ancash, Peru], 3.II.1938," "S. P. Vallejos and J. E. Wille coll" (USNM Type No. 76685).

Paratypes.—PERU: each labeled "No. 19–38," though locality data probably same as holotype (3♂). One paratype with whitish, papery cocoon attached to portion of a leaf. (USNM)

Remarks.—Though only the male is known, this species is separated by the mostly black coloration of the head, thorax, and abdomen, and by the genitalia. The coloration is similar to that of males of *porteri* and *munroi,* but *porteri* has the abdomen mostly orange with only the apical terga blackish and the valve of the genitalia is concave at its apex and lacks a dorsal lobe, and *munroi* has most of the sterna of the abdomen yellow orange and the harpe of the genitalia is strongly bent.

This is the species reported by Wille (1943) as defoliating potato in the Department of Ancash. He gave a very brief description of the larva and described its damage.

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Obtainable from the Academy office (address at bottom of opposite column): **Proceedings:** Vols. 1–13 (1898–1910) **Index:** To Vols. 1–13 of the *Proceedings* and Vols. 1–40 of the *Journal* **Journal:** Back issues, volumes, and sets (Vols. 1–62, 1911–1972) and all current issues.

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DELEGATES TO THE WASHINGTON ACADEMY OF SCIENCES, REPRESENTING THE LOCAL AFFILIATED SOCIETIES

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Anthropological Society of Washington	Ruth H. Landman
Biological Society of Washington	William R. Heyer
Chemical Society of Washington	Barbara Howell
Entomological Society of Washington	Donald R. Davis
National Geographical Society	T. Dale Stewart
Geological Society of Washington	William C. Prinz
Medical Society of the District of Columbia	James E. Boland
Columbia Historical Society	Paul H. Oehser
Botanical Society of Washington	Conrad B. Link
Society of American Foresters	Boyd W. Post
Washington Society of Engineers	George Abraham
Institute of Electrical and Electronics Engineers	George Abraham
American Society of Mechanical Engineers	Michael Chi
Helminthological Society of Washington	Robert S. Isenstein
American Society for Microbiology	Frank M. Hetrick
Society of American Military Engineers	H. P. Demuth
American Society of Civil Engineers	Algis A. Lukas
Society for Experimental Biology and Medicine	Cyrus R. Creveling
American Society for Metals	Charles G. Interrante
American Association of Dental Research	W. V. Loebenstein
American Institute of Aeronautics and Astronautics	Richard P. Hallion
American Meteorological Society	A. James Wagner
Insecticide Society of Washington	Jack R. Plimmer
Acoustical Society of America	Richard K. Cook
American Nuclear Society	C. Bornscheuer
Institute of Food Technologists	A. D. Berneking
American Ceramic Society	Edwin R. Fuller, Jr.
Electrochemical Society	David R. Flinn
Washington History of Science Club	Deborah J. Warner
American Association of Physics Teachers	Peggy A. Dixon
Optical Society of America	George J. Simonis
American Society of Plant Physiologists	Walter Shropshire
Washington Operations Research Council	Jay Mandelbaum
Instrument Society of America	Jewel B. Barlow
American Institute of Mining, Metallurgical and Petroleum Engineers	Garrett R. Hyde
National Capitol Astronomers	Benson J. Simon
Mathematical Association of America	Howard Penn
D.C. Institute of Chemists	Fred Ordway
D.C. Psychological Association	John O'Hare
The Washington Paint Technical Group	Paul G. Campbell
American Phytopathological Society	Howard E. Waterworth
Society for General Systems Research	Ronald W. Manderscheid
Human Factors Society	H. McIlvaine Parsons
American Fisheries Society	Irwin M. Alperin

Delegates continue in office until new selections are made by the representative societies.

THE DIRECTORY OF THE ACADEMY FOR 1980

Foreword

The present, 55th issue of the Academy's directory is again this year issued as part of the September number of the Journal. As in previous years, the alphabetical listing is based on a postcard questionnaire sent to the Academy membership. Members were asked to update the data concerning address. In cases in which cards were not received, the address appears as it was used during 1980, and the remaining data were taken from the directory for 1979. Corrections should be called to the attention of the Academy office.

Code for Affiliated Societies, and Society Officers

1 The Philosophical Society of Washington (1898)

President:	James F. Goff (1980), 3405 34th Pl. N.W., Washington, D.C. 20016
1st Vice-President:	Donald H. Tsai (1980), 10400 Lloyd Road, Potomac, MD 20854
2nd Vice President:	A. Fred Spilhaus, 10900 Picasso Lane, Potomac, MD 20854
Recording Secretary:	Dirse Sallet (1979–1980), 12440 Old Flechertown Rd., Bowie, MD 20715
Corresponding Secretary:	Paul A. Willis (1980–1981), 2824 West George Mason Dr., Falls Church, VA 22042
Treasurer:	L. Douglas Ballard (1980), 7823 Mineral Springs Dr., Gaithersburg, MD 20760
Delegate:	Mr. James F. Schooley, Chief, Temperature Div., Natl. Bureau of Standards, D.C. 20234

2 Anthropological Society of Washington (1898)

President:	Dr. Michael Kenny, Dept. Anthro., CU, D.C. 20064
President-elect:	Dr. William Fitzhugh, Dept. Anthro., U.S. Nat. Mus., Smithsonian Institution, D.C. 20560
Secretary:	Dr. John L. Landgraf, 2423 Eye St. N.W., D.C. 20037
Treasurer:	Dr. Beatrice Hackett, D.C. Communities Humanities Council, 1341 G St. N.W., D.C. 20006
Delegate:	Dr. Ruth H. Landman, Professor & Chairman, Dept. of Anthropology, American Univ., D.C. 20016

3 Biological Society of Washington (1898)

President:	Richard Banks, Bird & Mammal Labs., Fish and Wildlife Div., U.S. Dept. of Interior, Smithsonian Institution, Washington, D.C. 20560
Vice-President:	Raymond B. Manning, Dept. of Invertebrate Zoology, Nat. Mus. Nat. Hist., Smithsonian Institution, Washington, D.C. 30560
Secretary:	Michael A. Bogan, Bird & Mammal Labs., Fish and Wildlife Div., U.S. Dept. of Interior, Smithsonian Institution, Washington, D.C. 20560
Treasurer:	David L. Pawson, Dept. of Invertebrate Zoology, Nat. Mus. Nat. Hist., Smithsonian Institution, Washington, D.C. 20560
Delegate:	W. Ronald Heyer, Dept. of Vertebrate Zoology, Nat. Mus. Nat. Hist., Smithsonian Institution, Washington, D.C. 20560

4 Chemical Society of Washington (1898)

President:	Dr. Walter Benson, FDA, HFD 420, 200 C St. S.W., Washington, D.C. 20204
President-elect:	Dr. George Mushrush, Chem. Dept. George Mason Univ., 4400 University Dr., Fairfax, VA 22030
Secretary:	Dr. Jo-Anne Jackson, Natl. Bureau of Stds., Bg. 223, Rm. A329, Washington, D.C. 20234
Delegate:	Dr. Barbara Howell, Natl. Bureau of Stds., Bg. 222, Rm. A367, Washington, D.C. 20234

5 Entomological Society of Washington (1898)

President:	Donald R. Davis, Dept. of Entomology, NHB 105, Smithsonian Institution, Washington, D.C. 20560
Vice-President:	T. J. Spilman, Dept. of Entomology, NHB 169, Smithsonian Institution, Washington, D.C. 20560
Secretary:	Wayne N. Mathis, Dept. of Entomology, NHB 169, Smithsonian Institution, Washington, D.C. 20560
Delegate:	Donald R. Davis, see above

6 National Geographic Society (1898)

President:	Gilbert M. Grosvernor, 1145 17th St. N.W. Washington, D.C. 20036
Chairman:	Dr. Melvin M. Payne, 1145 17th St. N.W. Washington, D.C. 20036
Secretary:	Dr. Edwin W. Snider, 1145 17th St. N.W. Washington, D.C. 20036
Delegate:	Dr. Dale Stewart, 1145 17th St. N.W. Washington, D.C. 20036

7 Geological Society of Washington (1898)

President:	Francis R. Boyd, Jr., Carnegie Institution of Washington, Geophysical Lab., 2801 Upton St., N.W., Washington, D.C. 20008
Vice-President:	J. Thomas Dutro, U.S. Geological Survey, Branch of Paleontology and Stratigraphy, U.S. National Museum, Washington, D.C. 20560
Secretary:	William E. Davies, U.S. Geological Survey, Reston, VA 22092, Mail Stop 973
Delegate:	Not appointed

8 Medical Society of the District of Columbia (1898)

President:	Dr. Dort
President-elect:	Dr. Lewis H. Biben
Secretary:	Mr. Frank T. Forraraccio
Delegate:	Dr. James E. Boland, Dr. Raymond Scalettar

9 Columbia Historical Society (1899)

President:	William H. Press, 1646 32nd St. N.W. Washington, D.C. 20007
Vice-Presidents:	Francis C. Rosenberger, 6809 Melrose Dr. McLean, VA 22101
	John N. Pearce, 122 11th St., SE, Washington, D.C. 20003
Secretary:	Marcellina Hummer, 2006 Columbia Rd. NW, Washington, D.C. 20009
Treasurer:	William L. Ellis, 1307 New Hampshire Ave. N.W. Washington, D.C. 20036
Delegate:	Mr. Paul H. Oehser, 9012 Old Dominion Dr., McLean, VA 22102

10 Botanical Society of Washington (1902)

President:	Kittie Parker, Dept. of Botany, George Wash. Univ., 2029 G. St. N.W. Washington, D.C. 20052
Vice-President:	Ted R. Bradley, Dept. of Biology, George Mason Univ., Fairfax, VA 22030
Secretary:	Antoinette Frederick, Dept. of Botany, Howard Univ., Washington, D.C. 20059
Treasurer:	Deborah Bell, Dept. of Botany, Smithsonian Institution, Washington, D.C. 20560
Delegate:	Conrad B. Link, Dept. of Horticulture, Univ. of Maryland, College Park, MD 20742

11 Society of American Foresters, Washington Section (1904)

President:	Stephen H. Spurr
Vice-President:	Thomas B. Borden
Second Vice-President:	John C. Barber

12 Washington Society of Engineers (1907)

President:	Gerald S. McKenna, 9520 Bulls Run Parkway, Chevy Chase, Maryland 20034
Vice-President:	Michael W. Werth, 14 Grafton Street, Chevy Chase, Maryland 20034
Secretary:	Charles E. Remington, 2005 Columbia Pike Arlington, Virginia 22204
Delegate:	Dr. George Abraham, 3107 Westover Drive, SE Washington, D.C. 20020

13 Institute of Electrical & Electronics Engineers, Washington Section (1912)

Chairman:	Dr. Sajjad H. Durrani, 1753 Lafayette Drive, Olney, Maryland, 20832
Vice-Chairman:	Dr. Gideon Kantor, 1702 Kenilworth Avenue, Garrett Park, Maryland, 20766
Secretary:	James C. Arnold, Jr., Rural Electrification Administration, USDA, 14th and Independence Ave., Washington, D.C.
Delegate:	Dr. George Abraham, 3107 Westover Drive, S.E., Washington, D.C., 20020

14 American Society of Mechanical Engineers, Washington Section (1923)

President:	Mark Au, P.E., 8800 Fox Hills Trail, Potomac, MD 20854
Vice-President:	John Fairbanks, P.E., 4717 Jasmine Drive, Rockville, MD 20853
Secretary:	Thomas C. Tang, P.E., 8350 Greensboro Drive, Unit No. 1-524, McLean, VA 22102
Treasurer:	Jawahar L. Chandary, 11813 Randy Lane, Laurel, MD 20811
Delegate:	Dr. Michael Chi, 2721 N. 24th Street, Arlington, VA 22207

15 Helminthological Society of Washington (1923)

President:	J. Ralph Lichtenfels, Animal Parasitology Institute, Bldg 1080' BARC-East, USDA, Beltsville, MD 20705
Vice-President:	Nancy D. Pacheco, Department of Immunoparasitology, Naval Medical Research Institute, Bethesda, MD 20014
Secretary-Treasurer:	Sherman S. Hendrix, Chairman, Department of Biology, Gettysburg College, Gettysburg, PA 17325
Delegate:	Robert S. Isenstein, Food Safety and Quality Service, USDA, Building 318C, Beltsville, MD 20705

16 American Society for Microbiology, Washington Branch (1923)

President:	George G. Royal, Jr. (PhD), Dept. of Microbiology Howard University, College of Medicine, Washington, D.C. 20001
Vice-President:	Thomas B. Elliot (PhD), 126 Moore Ave. S.W. Vienna, VA 22180
Secretary:	Robert G. Loon, PhD, FDA, Extramural Research Coordination Staff, Rm 6504 (HFF-9), 200 C St., S.W. Washington, D.C. 20204
Treasurer:	Elizabeth Von Kaenel, Microbiological Associates, Inc., 5221 River Road, Bethesda, Maryland 20016
Councilor:	Frank M. Hetrick, PhD, Dept. of Microbiology, University of Maryland, College Park, MD 20742

17 Society of American Military Engineers, Washington Post (1927)

President:	Col. Edwin P. Geesey, DAEN-FEZ-B, Washington, D.C. 20314
Vice-President:	R.Adm. H. R. Lippold, NOAA, Washington, D.C. 20233
Secretary:	William I. Jacob, DAEN-FER-P, Washington, D.C. 20314
Delegate:	Hal P. Demuth, 4025 Pine Brook Rd., Alexandria, VA 22310

18 American Society of Civil Engineers, National Capital Section (1942)

President:	David Harland, c/o De Leuw, Cather & Co., 1201 Connecticut Ave., Suite 500, Washington, D.C. 20036
Vice-President:	Neal Fitzsimons, 10408 Montgomery Ave., Kensington, MD 20795
Secretary:	Chris Collver, 12615 Sayler's Creek Lane, Herndon, VA 22070
Treasurer:	Charles Smith, 9792 Oleander Ave., Vienna, VA 22180
Delegate:	Algis A. Lukas, Lukas, Henningson, Duram & Richardson, 5454 Wisconsin Ave., Chevy Chase, MD

19 Society for Experimental Biology & Medicine, D.C. Section (1952)

President:	Elise A. Brown, USDA, Washington, D.C. 20750
Vice-President:	Ariel Hollinshead, G. W. Univ., Warwick Cancer Clinic, Washington, D.C. 20052
Recording Secretary:	Jocelyn Stewart, Food & Drug Adm., Rockville, MD 20204
Corresponding Secretary:	William Von Arsdel, Food & Drug Adm., Bureau of Drugs, Rockville, MD 20204
Treasurer:	Margaret Davison, Dept. of Defense, Defense Fuel Supplies, Washington, D.C.
President Emeritus:	Arthur Wykes, Natl. Library of Medicine, Bethesda, MD 20014
Delegate:	Dr. Cyrus R. Creveling, Laboratory of Bio-organic Chemistry, NIAMDD, NIH, Bethesda, MD 20205

20 American Society for Metals, Washington Chapter (1953)

Chairperson:	Anna C. Fraker, B-264, Materials Building 223, National Bureau of Standards, Washington, D.C. 20234
Vice-Chairperson:	Joseph R. Crisci, David W. Taylor Naval Ship R&D Center, Code 282, Annapolis, MD 21402
Secretary:	Henry Hahn, Artech Corp., 2901 Telestar Court, Falls Church, VA 22042
Treasurer:	James R. Ward, VSE Comp., 2550 Huntington Avenue, Alexandria, VA 22303
Delegate:	Dr. Charles G. Interrante, B120 Materials Bldg. (562), Natl. Bureau of Stds., Washington, D.C. 20234

21 American Association for Dental Research, Washington Section (1953)

President:	John D. Termine, Natl. Institute of Dental Research, Bethesda, MD 20014
Vice-President:	William R. Cotton, Naval Medical Research Institute, Bethesda, MD 20014
Secretary:	Stanley Vermilyea, Walter Reed Army Inst. of Res., Washington, D.C. 20012
Delegate:	William V. Loebenstein, National Bureau of Standards, Washington, D.C. 20234

22 American Institute of Aeronautics and Astronautics, National Capital Section (1953)

Chairman:	George J. Vila, General Dynamics, 1745 Jefferson Davis Highway, Suite 1000, Arlington, VA 22202
Vice-Chairman:	Dr. Richard Hallion, Smithsonian Institution, National Air & Space Museum, 7th & Independence Ave., Washington, D.C. 20560
Secretary:	Dr. Frederick L. Schuyler, Department of Energy, MS C-448 Washington, D.C. 20560
Delegate:	Dr. Richard Hallion, Smithsonian Institution, National Air & Space Museum, 7th & Independence Ave., Washington, D.C. 20560

23 American Meteorological Society, D.C. Chapter (1954)

Chairman:	Harold A. Bedient, 645 Walnut Ave., Rosehaven, MD 20831
Vice-Chairman:	Dale A. Lowry, Techniques Development Lab., Gramax Bldg., Room 802, Silver Spring, MD 20910
Corresponding Secretary:	Gary Ellrod, Satellite Field Ser. Station, 5139 Stop G, WWB, Camp Springs, MD
Delegate:	A. James Wagner, Climate Analysis Center W351, NMC, NWS, NOAA, Room 604, WWB, 5200 Auth Road, Washington, D.C. 20233

24 Insecticide Society of Washington (1959)

Chairman:	W. Hollis, National Agricultural Chemicals Assoc., 1155 15th St. N.W., Suite 514, Washington, D.C. 20005
Chairman-elect:	D. H. Hayes USDA, SEA, AR, BARC, AEQI, Livestock Insects Lab., Office of Pesticides Programs, Beltsville, MD 20705
Secretary:	J. O. Nelson, University of Maryland, Dept. of Entomology, College Park, MD 20742
Delegate:	J. R. Plimmer, 11078 Berrypick Lane, Columbia, MD 21044

25 Acoustical Society of America (1959)

Chairman:	Edith L. Corliss, National Bureau of Standards, Washington, D.C. 20234
Vice-Chairman:	James M. Pickett, Gallaudet College, 7th and Florida Aves. N.E., Washington, D.C. 20002
Secretary:	William K. Blake, The David W. Taylor Naval Ship RND Center, Bethesda, MD 20084
Delegate:	Dr. Richard K. Cook, 8517 Milford Ave., Silver Spring, MD 20910

26 American Nuclear Society, Washington Section (1960)

Chairman:	R. W. Durante, 1801 K St. N.W., Washington, D.C. 20006
Secretary:	Clyde Jupiter, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555
Treasurer:	C. Bornscheuer, 1850 K St. N.W., Suite 220, Washington, D.C. 20006

27 Institute of Food Technologists, Washington Section (1961)

Chairman:	Dr. Prince G. Harrill, FDA, 200 C St. S.W., Washington, D.C. 20204
Chairman-elect:	Dr. Allen W. Matthys, National Food Processors Association, 1133 20th St. N.W., Washington, D.C. 20036
Treasurer:	Mrs. Catherine R. Calvert, Bureau of Foods (HFF414), FDA, 200 C St. S.W., Washington, D.C. 20204
Secretary:	Dr. Richard A. Hagen, National Food Processors Association, 1133 20th St. N.W., Washington, D.C. 20036
Delegate:	Dr. A. D. Berneking, Director, Division of Food Technology, Bureau of Foods, FDA, 200 C St. S.W., Washington, D.C. 20204

28 American Ceramic Society, Baltimore–Washington Section (1962)

Chairman:	Subatra Banerjee, General Refractories Research Center, P.O. Box 1673, Baltimore, MD 21203
Chairman-elect:	Ed Fuller, Fracture & Deformation Division, National Bureau of Standards, Washington, D.C. 20234
Vice-Chairman:	Merrill Wood, General Refractories Research Center, P.O. Box 1673, Baltimore, MD 21203
Secretary/ Treasurer:	Connie Moynihan, Catholic University of America, Chemical Engineering Dept., Washington, D.C. 20064

29 Electrochemical Society, National Capital Section (1963)

Chairman:	David R. Flinn, Bureau of Mines, College Park Research Center, College Park, MD 20740
Vice-Chairman:	John R. Ambrose, National Bureau of Standards, Bldg. 223, Rm. B254, Washington, D.C. 20234
Secretary:	George Marinenko, National Bureau of Standards, Bldg. 222, Rm. A217, Washington, D.C. 20234
Delegate:	David R. Flinn, see above

30 Washington History of Science Club (1965)

Chairman:	Richard G. Hewlett, Atomic Energy Comm.
Vice-Chairman:	Deborah Warner, Smithsonian Institution
Secretary:	Dean C. Allard
Delegate:	None appointed

31 American Association of Physics Teachers, Chesapeake Section (1965)

President:	Morton Rubin, University of Maryland, Baltimore County
Vice-President:	Eugenie V. Mielczarek, George Mason Univ., 4400 University Dr., Fairfax, VA 22030
Secretary:	Roberta Stoney, Langley High School
Delegate:	Peggy A. Dixon, Montgomery College, Takoma Park Campus

32 Optical Society of America, National Capitol Section (1966)

President:	Robert L. Denningham, Naval Research Lab.
1st Vice-President:	William R. Graver, Riverside Research Institute
2nd Vice-President:	Louis Sica, Jr., Naval Research Laboratory
Secretary:	Eugene A. Margerum, U.S. Army Engineer Topographic Lab.
Treasurer:	Sandford W. Hinkal, Goddard Space Flight Center
Delegate:	Dr. George J. Simonis, 13609 Russett Terrace, Rockville, MD 20853

33 American Society of Plant Physiologists, Washington Section (1966)

Chairman:	Dr. Charles R. Cleland, Smithsonian Radiation Laboratory, 12441 Parklawn Drive, Rockville, MD 20852
Vice-Chairman:	Dr. William VanDerWoude, Seed Research Laboratory B-006, USDA, ARC-W, Beltsville, MD 20705
Secretary/ Treasurer:	Dr. Gerald Deitzer, Smithsonian Radiation Biology, 12441 Parklawn Drive, Rockville, MD 20852
Delegate:	Dr. W. Shropshire, Jr., Smithsonian Radiation Biology Laboratory, 12441 Parklawn Drive, Rockville, MD 20852

34 Washington Operations Research/Management Science Council (1966)

President:	Gary Sorrell, Management Consulting & Research, Inc., Falls Church, VA
President-elect:	Eloise Brooks, Federal Aviation Administration, Washington, D.C.
Secretary:	Mary J. Hutzler, Department of Energy, Washington, D.C.
Treasurer:	Jay Mandelbaum, Federal Railroad Administration, Washington, D.C.

35 Instrument Society of America, Washington Section (1967)

President:	Francis C. Quinn
President-elect:	John I. Peterson
Secretary:	Frank L. Carou
Delegate:	None appointed

36 American Institute of Mining, Metallurgical & Petroleum Engineers (1968)

Chairman:	L. Michael Kaas, Bureau of Mines, 2401 E. St. N.W., Washington, D.C. 20241
Vice-Chairman:	Ronald A. Munson, Bureau of Mines, 2401 E. St. N.W., Washington, D.C. 20241
Secretary/ Treasurer:	Daniel R. Walton, 12536 Arnsley Court, Herndon, VA 22070
Delegate:	Dr. Garrett R. Hyde, Bureau of Mines, 2401 E. St. N.W., Washington, D.C. 20241

37 National Capital Astronomers (1969)

President:	Mary Ellen Simon, 8704 Royal Ridge Lane, Laurel, MD 20811
Vice-President:	Wolfgang Schubert, 7906 Gosport Lane, Springfield, VA 22151
Secretary:	Sharon Edmonds, 11322 Cherry Hill Road, Beltsville, MD 20705
Delegate:	Benson J. Simon, 8704 Royal Ridge Lane, Laurel, MD 20811

38 Mathematical Association of America, Maryland, D.C., and Virginia Section (1971)

Chairman:	John Smith, George Washington Univ., Dept. of Mathematics, Fairfax, VA
Vice-Chairman for Membership:	Howard Penn, Dept. of Mathematics, George Washington Univ., Fairfax, VA

39 The District of Columbia Institute of Chemists (1973)

President:	Carolyn E. Damon, 3100 S. Manchester St., Aprt. #540, Falls Church, VA 22044
President-elect:	Winston R. Demonsabert, 604 Cobblestone Court, Silver Spring, MD 20904
Secretary-Treasurer:	James E. Whitney, 7700 Lakecrest Dr., Greenbelt, MD 20770
Councilor:	Fred Ordway, Artech Corporation, 2901 Telstar Court, Falls Church, VA 22042

40 The D.C. Psychological Association (1975)

President:	Alfred M. Wellner, Council for the Natl. Regis., Health Serv., Prov. in Psych., 1200 17th Street N.W., Suite 106, Washington, D.C. 20036
President-elect:	Barbara Hammer, 5225 Connecticut Ave. N.W., Washington, D.C. 20015
Secretary:	Jane F. Allen, 9001 Congressional Parkway, Potomac, MD 20850
Delegate:	Dr. John J. O'Hare, 301 G Streets S.W. #824, Washington, D.C. 20024

41 The Washington Paint Technical Group (1976)

President:	Robert F. Brady, Jr., GSA
Vice-President:	Mildred A. Post, National Bureau of Standards, Bldg. 226, Rm. B-348, Washington, D.C. 20234
Secretary:	William Allanach, International Paint, Harve de Grace, MD
Delegate:	Paul G. Campbell, National Bureau of Standards, B-348, Br., Washington, D.C. 20234

42 American Phytopathological Society, Potomac Division (1977)

President:	Lawrence H. Perdy, Plant Pathology, Univ. of Florida, Gainesville, Florida 32611
Executive Vice-President:	Raymond Tarleton, 3340 Pilot Knob Road, St. Paul, MN 55121
Vice-President:	J. Arty Browning, Dept. of Plant Pathology, Seed and Weed Science, Iowa State Univ., Ames, IA 50011
Secretary:	Daryl A. Slack, Dept. of Plant Pathology, Univ. of Arkansas, Fayetteville, AK 72701
Treasurer:	Edgar L. Kendricks, Agricultural Research, SEA-USDA, PO Box 53326, New Orleans, LA 70153
Delegate:	Dr. Howard E. Waterworth, USDA, Plant Introduction Station, Glenn Dale, MD 20769

43 Society for General Systems Research, Metropolitan Washington Chapter (1977)

Chairman:	Ronald W. Manderscheid, PhD, 6 Monument Court, Rockville, MD 20850 (home) 301-762-3388 (office) 301-436-6274
Secretary:	Helen Griffin Tibbitts, 4105 Montpelier Road, Rockville, MD 20852 (home) 301-871-6853
Delegate:	Ronald W. Manderscheid, PhD, 6 Monument Court, Rockville, MD 20850 (home) 301-762-3388 (office) 301-436-6274

44 Human Factors Society, Potomac Chapter (1977)

President:	E. Ralph Dusek
President-elect:	Ted Post
Secretary:	Stephen C. Merriman
Treasurer:	Thomas M. Granda
Delegate:	Dr. H. Mcilvaine Parsons, Human Resources Research Organ., 300 N. Washington Street, Alexandria, VA 22314

45 American Fisheries Society, Potomac Chapter (1978)

President:	Norville S. Prosser, Sport Fishing Institute, 608 13th St., N.W., Suite 801, Washington, D.C. 20005
President-elect:	Richard H. Schaefer, National Marine Fisheries Service, 3300 Whitehaven Drive, N.W., Washington, D.C. 20235
Secretary:	Stephanie D. Story, Federal Energy Regulatory Commission, 825 N. Capitol St., N.E., Washington, D.C. 20426
Treasurer:	Donald J. Leedy, 2825 Yeonas Drive, Vienna, VA 22180
Delegate:	Irwin M. Alperin, Atlantic States Marine Fisheries Commission, 1717 Massachusetts Avenue, N.W. Washington, D.C. 20036

Alphabetical List of Members

M = Member; F = Fellow; E = Emeritus member; L = Life Member or Fellow.

A

ABDULNUR, SUHEIL F. (Dr), Chemistry Dept., American Univ., Washington, D.C. 20016 (F)

ABELSON, PHILIP H. (Dr), Editor, AAAS, 1550 Massachusetts Ave., N.W., Washington, D.C. 20005 (F)

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ALDRICH, JOHN W. (Dr), 6324 Lakeview Dr., Falls Church, Va. 22041 (F)

ALDRIDGE, MARY H. (Dr), 2930 45th St., N.W., Washington, D.C. 20016 (F)

ALEXANDER, ALLEN L. (Dr), 4216 Sleepy Hollow Rd., Annandale, Va. 22003 (E)

ALEXANDER, BENJAMIN H. (Dr), Pres., Chicago State Univ., 95th St. at King Dr., Chicago, Ill. 60628 (F)

ALLEN, ANTON M. (Dr), 11718 Lakeway Dr., Manassas, Va. 22110 (F)

ALLEN, J. FRANCES, 7507 23rd Ave., Hyattesville, Md. 20783 (F)

ANDERSON, JOHN D. (Dr), Dept. of Aerospace Engrg., Univ. of Maryland, College Park, Md. 20742 (F)

ANDERSON, MYRON S. (Dr), 1433 Manchester La., N.W., Washington, D.C. 20011 (E)

ANDERSON, WENDELL L. (Mr), RR 4, Box 4172, La Plata, Md. 20646 (F)

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The Integrals $\int$ sec x dx *and* $\int$ csc x dx *Revisited*

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ABSTRACT

This paper summarizes techniques used to evaluate the indefinite trigonometric integrals $\int$ sec x dx and $\int$ csc x dx, and describes an alternative procedure which takes advantage of the Euler identities.

Essentially all serious mathematics problems that arise in the physical sciences require integration.[24] The integral is in fact a basic tool for solving a great many problems of the sciences and is one of the central ideas of mathematics. One of the important types of integrals studied in an elementary calculus course is that involving trigonometric functions. These functions are extremely important in the study of periodic phenomena.[25] Additionally, the integration of certain algebraic expressions (quadratic irrationalities in the integrand) may often be simplified by introducing trigonometric substitution based on elementary trigonometric identities.[11, 18, 22, 23, 28, 35, 37, 38]

The present paper is concerned with 2 of the 6 basic indefinite trigonometric integrals, $\int$ sec x dx and $\int$ csc x dx, whose solutions may be expressed in the form[32]

$$\int \sec x dx = \ln|\sec x + \tan x| + C \quad (\sec x + \tan x > 0 \quad \text{or} \quad < 0), \qquad (1)$$

and

$$\int \csc x dx = -\ln|\csc x + \cot x| + C \quad (\csc x + \cot x > 0 \quad \text{or} \quad < 0), \qquad (2)$$

respectively, where C is an integration constant. These solutions may also be expressed in other equivalent forms (see, for example, references 2, 3, 8, 28, 40).

To help put the above integrals in proper perspective, the following observations are made relative to the evaluation of the integrals of the 6 basic trigonometric functions (sin x, cos x, tan x, cot x, sec x, and csc x): The formulas for differentiation of sin x and cos x, derived in the study of differential calculus, can be immediately reformulated as formulas of integration.[35] The integrals for tan x and cot x can be readily solved by expressing the integrands in terms of sin x and cos x. What makes the integrals $\int$ sec xdx and $\int$ csc xdx different, and hence interesting and challenging, is that when their evaluation is first attempted in an elementary calculus course, it becomes clear that these quantities are not the end products of differentiating any simple functions the student has yet encountered (see Hellman in reference 20, page 158). It turns out that the evaluation of each of these 2 integrals involves a more subtle approach than that used for the other 4 basic trigonometric integrals.[35] As correctly observed by Thomas,[44] the integral $\int \sec x dx$ is hard to evaluate unless one has seen the trick of converting this integral into one of a perfect differential. In this connection, Moise[32] states "by an ingenious and rather obscure device, we find $\int \sec x dx$—". The remarks of Thomas and Moise are also applicable to $\int \csc x dx$.

A perusal of a relatively large number of mathematics books (mostly calculus textbooks) which discuss the integrals $\int \sec x dx$ and $\int \csc x dx$[1–4, 6–47] further indicates that when the evaluation of these integrals is first attempted, it is accomplished by resorting to a "trick solution". As the student progresses in the study of integral calculus, other techniques for deriving equations (1) and (2) (or for obtaining equivalent solutions) are usually presented. For some students, however, the "trick solution" is either the only one to which they are exposed or is the only one which they associate with these integrals. The objectives of the present paper are to (a) provide a summary of techniques used to evaluate the indefinite trigonometric integrals $\int \sec x dx$ and $\int \csc x dx$, and (b) describe an alternative procedure which takes advantage of the Euler identities[5] coupled with elementary properties of complex numbers. The substance of the present paper should be of particular interest to the undergraduate student encountering for the first time trigonometric integrals in general and equations (1) and (2) in particular.

Summary of Existing Methods of Solution

I. $\int \sec x \, dx$

A. The following trick (or minor variants of it) is usually used to evaluate this integral when it is first encountered in the study of elementary calculus[2, 11, 19, 21, 23, 25, 28, 31, 32, 35–39, 41, 43, 44–46].

$$\int \sec x dx = \int \sec x \left(\frac{\sec x + \tan x}{\sec x + \tan x}\right) dx \quad (3)$$

$$= \int \frac{du}{u} \quad (u = \sec x + \tan x) \quad (4)$$

$$= \ln|u| + C \quad (5)$$

$$= \ln|\sec x + \tan x| + C. \quad (6)$$

The trick employed was, of course, to multiply and divide the integrand by sec x + tan x. A possible rationale for this approach is the following: Although we do not have a trigonometric function whose derivative is sec x, there are trigonometric functions whose derivative contains sec x. Thus

$$\frac{d}{dx}(\sec x) = \tan x \sec x \quad (7)$$

and,

$$\frac{d}{dx}(\tan x) = \sec^2 x. \quad (8)$$

Neither of these relations alone enables us to evaluate $\int \sec x dx$. The existence of these relations does, however, suggest that some combination of (7) and (8) might be worthwhile to pursue. The simplest combinations are, of course, sum and difference. Adding (7) and (8), we obtain

$$\frac{d}{dx}(\sec x + \tan x)$$

$$= \sec^2 x + \sec x \tan x \quad (9)$$

$$= \sec x (\sec x + \tan x). \quad (10)$$

From (10), it follows that

$$\frac{d}{dx}(\ln|\sec x + \tan x|) = \sec x \quad (11)$$

or

$$\int \sec x dx = \ln|\sec x + \tan x| + C. \quad (12)$$

Equation (12) could also have been obtained by subtracting (8) from (7) and proceeding as above. From equation (10), it becomes quite apparent how one might deduce the trick used in equation (3). It should be noted that the integration of $\int \sec x dx$ could have been accomplished by multiplying and dividing the integrand by sec x − tan x (instead of by sec x + tan x).

B. (40, 42, 44, for example)

$$\int \sec x dx = \int \frac{dx}{\cos x} = \int \frac{\cos x dx}{\cos^2 x} \quad (13)$$

$$= \frac{dz}{z} = \frac{1}{2} \ln \left| \frac{1+z}{1-z} \right| + C$$

$$(z = \sin x). \quad (14)$$

Replacing z by sin x and simplifying, yields the right hand side of equation (6). If we now replace cos x by its equivalent sine function, sin [(π/2) + (x)], in ∫ (dx/cos x) and then express sin [(π/2) + (x)] as 2 sin [(π/4) + (x/2)] cos [(π/4) + (x/2)], the following alternative solution is readily obtainable[40]:

$$\int \sec x dx = \ln \left| \tan\left(\frac{\pi}{4} + \frac{x}{2}\right) \right| + C. \quad (15)$$

C. In a variant to the approach used in equation (13), the substitution of z = sin x (see, for example, reference (6)) is applied to the integral ∫ (dx/cos x)(= ∫ sec xdx). The steps in the solution are:

$$\int \frac{dx}{\cos x} = \int \frac{dz}{\cos^2 x} = \int \frac{dz}{1 - \sin^2 x}$$

$$= \int \frac{dz}{1 - z^2}, \quad (16)$$

which appears in equation (14), and from which the solution is readily obtainable.

D. (see Hellman in (20)).

Hellman starts with the easily derivable trigonometric identity

$$\sec x - \tan x = \frac{\cos x}{1 + \sin x}. \quad (17)$$

It follows that

$$\int \sec x dx$$

$$= \int \tan x dx + \int \frac{\cos x}{1 + \sin x} dx \quad (18)$$

$$= \ln \left| \frac{1 + \sin x}{\cos x} \right| + C \quad (19)$$

$$= \ln|\sec x + \tan x| + C. \quad (20)$$

E. Use of the half angle formula tan (x/2) = z (8, 12, 22, 24, 28, 33, 44, for example). This substitution enables the transformation of the integral of any rational function of the trigonometric functions sin x and cos x into an integral of a rational function of x. Applying this substitution to the integral ∫ sec xdx [= ∫ (dx/cos x)], we obtain, after simplification,

$$\int \sec x dx = 2 \int \frac{dz}{1 - z^2} \quad (21)$$

$$= \ln \left| \frac{1 + z}{1 - z} \right| + C$$

$$= \ln \left| \frac{1 + \tan (x/2)}{1 - \tan (x/2)} \right| + C. \quad (22)$$

By replacing tan (x/2) in (22) by its trigonometric ratio [sin (x/2)/cos (x/2)] and simplifying the result (see, for example, Morrill (33)), equations (19) and (20) are readily obtained. The right hand side of equation (22) can be transformed into equation (15) (see, for example, references (28) and (44)) by observing that 1 = tan [(π/4)] and using the trigonometric identity

$$\tan (m + p) = \frac{\tan m + \tan p}{1 - \tan m \tan p}. \quad (23)$$

We obtain

$$\int \sec x dx$$

$$= \ln \left| \frac{\tan (\pi/4) + \tan (x/2)}{1 - \tan (\pi/4) \tan (x/2)} \right| + C, \quad (24)$$

$$= \ln \left| \tan\left(\frac{\pi}{4} + \frac{x}{2}\right) \right| + C. \quad (25)$$

F. A variant of E(4).

$$\int \frac{dx}{\cos x} = \int \frac{dx}{\cos^2 (x/2) - \sin^2 (x/2)}$$

$$= \int \frac{\sec^2 (x/2) \, dx}{1 - \tan^2 (x/2)} \quad (26)$$

$$= 2 \int \frac{d[\tan (x/2)]}{1 - \tan^2 (x/2)} \quad (27)$$

$$= \ln\left|\frac{1 + \tan(x/2)}{1 - \tan(x/2)}\right| + C, \quad (28)$$

which is the same as equation (22). For those familiar with hyperbolic functions, equation (21) can be integrated to give, after replacing z by tan (x/2),

$$\int \sec x dx = 2 \tanh^{-1} [\tan(x/2)] + C, \quad (29)$$

which is another acceptable solution (see reference (4)). Equation (29) can easily be shown to be equivalent to equation (28) (see, for example, reference (33) in which the relationship between the inverse hyperbolic tangent and its logarithmic equivalent is discussed).

G. Evaluation of $\int \sec x dx$ derived from the solution of $\int \csc x dx$[3, 7, 9, 10] which may be expressed as (see B. below for details)

$$\int \csc x \, dx \left(= \int \frac{dx}{\sin x}\right) = \ln \tan\left(\frac{x}{2}\right) + C. \quad (30)$$

If we replace x by $[(\pi/2) + (x)]$ in the integrals in (30), we get

$$\int \frac{dx}{\sin[(\pi/2) + (x)]} = \int \frac{dx}{\cos x} = \int \sec x dx$$

$$= \ln\left|\tan\left(\frac{\pi}{4} + \frac{x}{2}\right)\right| + C, \quad (31)$$

which is the same as equation (15).

H. Two rather interesting substitutions (see Viertel in reference (1) for details) which have been used to facilitate the integration of $\int \sec x dx$ are $\tan x = \sinh \theta$ and $\tan x = i \sin \theta$. These substitutions lead to the form of the solution given in equation (6).

II. $\int \csc x \, dx$

A. Probably the most common approach used is similar to that shown in section IA.[19, 28, 31, 32, 35, 37, 38, 41, 43, 45, 46] In the present case the integrand is multiplied and divided by csc x + cot x (or by csc x − cot x). Either of these substitutions readily enables the integration to be completed, and the result is equation (2). A possible rationale for the use of this approach would be very similar to that presented in section IA. We would start with the observations that $d/dx (\csc x) = -\csc x \cot x$; $d/dx (\cot x) = -\csc^2 x$, and then proceed as we did in IA.

B. Use of a simple trigonometric identity.[2,7,10,17,19,30,42]

$$\int \csc x dx = \int \frac{dx}{\sin x}$$

$$= \int \frac{dx}{2 \sin(x/2) \cos(x/2)} \quad (32)$$

$$= \int \frac{\sec^2 (x/2) \, d(x/2)}{\tan(x/2)} \quad (33)$$

$$= \int \frac{du}{u} \quad \left(u = \tan\left(\frac{x}{2}\right)\right) \quad (34)$$

$$= \ln\left|\tan\left(\frac{x}{2}\right)\right| + C. \quad (35)$$

C. Use of the half angle formula $\tan(x/2) = z$.[3, 8, 9, 12, 16, 26, 27, 28, 29, 44] The approach is similar to that described in IE and yields

$$\int \csc x dx = \int \frac{dx}{\sin x} = \int \frac{dz}{z} \quad \left(z = \tan\left(\frac{x}{2}\right)\right) \quad (36)$$

$$= \ln\left|\tan\left(\frac{x}{2}\right)\right| + C. \quad (37)$$

D. Evaluation of $\int \csc x dx$ from a knowledge of the solution of $\int \sec x dx$.[1, 9]

$$\int \csc x dx = \int \sec\left(\frac{\pi}{2} - x\right) dx \quad (38)$$

$$= -\ln\left|\sec\left(\frac{\pi}{2} - x\right) + \tan\left(\frac{\pi}{2} - x\right)\right| + C \quad (39)$$

$$= -\ln|\csc x + \cot x| + C. \quad (40)$$

E. Starting with an easily derivable trigonometric identity (Hellman in reference (20)). The steps in the solution are:

$$\csc x - \cot x = \frac{\sin x}{1 + \cos x} \quad (41)$$

$$\int \csc x dx$$

$$= \int \cot x dx + \int \frac{\sin x dx}{1 + \cos x} \quad (42)$$

$$= \ln\left|\frac{\sin x}{1 + \cos x}\right| + C \quad (43)$$

$$= -\ln|\csc x + \cot x| + C. \quad (44)$$

F. The substitution of $\cot x = \sinh \theta$ has been used to evaluate $\int \csc x dx$ (see Viertel in reference (1)) for details. This integral has also been evaluated by using the substitution $\cot x = i \sin \theta$ (see reference (21) for details), or $z = \cos x$[6] (approach is similar to that in IC).

Application of the Euler Identities

Integration of the hyperbolic functions sech x and csch x may be readily accomplished by replacing each of these two functions by their real exponential equivalents.[15] This suggests that the integration of the trigonometric functions sec x and csc x should be facilitated by expressing these quantities in terms of their complex exponential equivalents. The Euler identities,[5] which may be expressed as $e^{(\pm ix)} = \cos x \pm i \sin x$ (where $i = \sqrt{-1}$) enables us to accomplish the appropriate transformation. Although the complex exponential function has been used to evaluate such quantities as $\int \sin^5 x dx$ ((24), for example) or $\int e^{ax} \cos x dx$ ((34), for example), standard calculus textbooks do not use such an approach to evaluate $\int \sec x dx$ and $\int \csc x dx$. We shall take advantage of the Euler identities coupled with elementary properties of complex numbers to evaluate these two trigonometric integrals.

Applying the Euler identities to $\int \sec x dx$, gives, after simplification,

$$\int \sec x dx = \text{Re}\left[-2i \int \frac{dm}{1 + m^2}\right]$$

$$(m = e^{ix}), \quad (45)$$

where Re indicates that we desire the real part of the solution. Since $1 + m^2$ may be expressed as the product $(m + i)(m - i)$, we can apply the method of partial fractions to obtain

$$-2 \int \frac{dm}{1 + m^2}$$

$$= \int \frac{dm}{m + i} - \int \frac{dm}{m - i} \quad (46)$$

$$= \ln\left|\frac{m + i}{m - i}\right| + C + iK, \quad (47)$$

where $C + iK$ is a complex integration constant. We now replace m in (47) by $\cos x + i \sin x$, multiply and divide the resulting fraction in the logarithmic term by the conjugate of the denominator, simplify, and obtain

$$-2i \int \frac{dm}{1 + m^2}$$

$$= \ln\left|\frac{i \cos x}{1 - \sin x}\right| + C + iK. \quad (48)$$

Keeping in mind that the logarithm of a product is equal to the sum of the logarithms of the factors of the product, and, as indicated in equation (45), we desire only the real part of the solution, we obtain

$$\int \sec x dx = \text{Re}\left[-2i \int \frac{dm}{1 + m^2}\right] \quad (49)$$

$$= \ln\left|\frac{\cos x}{1 - \sin x}\right| + C \quad (50)$$

$$= \ln|\sec x + \tan x| + C, \quad (51)$$

which is equation (1). Equation (51) was obtained from equation (50) by multiplying and dividing the fraction of the logarithmic term by $1 + \sin x$, and simplifying the result.

The evaluation of $\int \csc xdx$ can be accomplished in a manner similar to that shown above for $\int \sec xdx$. Let us, however, use a variant of this approach to evaluate $\int \csc xdx$. We shall transform the integrand to the complex exponential form, and then reduce it to a readily integrable trigonometric form before performing the actual integration. The steps in the solution are:

$$\int \csc xdx = 2\int \frac{ie^{ix}dx}{e^{2ix} - 1}. \qquad (52)$$

$$\frac{ie^{ix}}{e^{2ix} - 1}$$

$$= \left[\frac{-\sin x + i \cos x}{(-1 + \cos 2x) + i \sin 2x}\right]. \qquad (53)$$

We now multiply the numerator and denominator of the fraction on the right hand side of (53) by the conjugate of the denominator, simplify, and obtain

$$\int \csc xdx = 2\int \frac{\sin xdx}{1 - \cos 2x} \qquad (54)$$

$$= -\int \frac{d (\cos x)}{1 - \cos^2 x} \qquad (55)$$

$$= -\int \frac{dn}{(1 + n)(1 - n)} \quad (n = \cos x) \qquad (56)$$

$$= \frac{1}{2} \ln\left|\frac{1 - n}{1 + n}\right| + C. \qquad (57)$$

Replacing n by cos x and then multiplying and dividing the resulting fraction of the logarithmic term by 1 − cos x, gives, after simplification

$$\int \csc xdx$$

$$= \ln\left|\frac{1 - \cos x}{\sin x}\right| + C \qquad (58)$$

$$= \ln|\csc x - \cot x| + C \qquad (59)$$

$$= -\ln|\csc x + \cot x| + C, \qquad (60)$$

which is equation (2).

Concluding Remarks

As indicated in the introductory remarks, one of the two objectives of the present paper was to provide a summary of techniques used to evaluate the indefinite trigonometric integrals $\int \sec xdx$ and $\int \csc xdx$. Although the summary presented is fairly extensive, it is not (nor was it intended to be) exhaustive in coverage. Those individuals who are familiar with trigonometric identities and are adept in their manipulation will, no doubt, be able to come up with other suitable identities as starting points for the evaluation of these two integrals. Starting, for example, with the trigonometric identity $\csc x = \cot (x/2) - \cot x$, the integral $\int \csc xdx = \int \cot (x/2)\, dx - \int \cot xdx$ can readily be shown to yield equation (35) as the solution. Some students might even find it an interesting challenge to search for and/or derive other trigonometric identities (as well as techniques) which could be used to facilitate the evaluation of $\int \sec xdx$, $\int \csc xdx$ and more complicated integrals.

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Review of Vrilletta, *With Two New Species and a Key (Coleoptera: Anobiidae)*

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ABSTRACT

Two new species of *Vrilletta* are described from California: *bicolor* and *pectinicornis*. Notes are given for distinguishing these from closely related species, illustrations are included, and a key to the 10 North American species of *Vrilletta* is presented. Two species names are of uncertain status, and their probable status is discussed.

Recently I have tried to assign all names for species of *Vrilletta* and thereby settle the disposition of apparently undescribed species held from collections sent to me. Descriptions by Maurice Pic of two North American species that evidently belong in *Vrilletta* have complicated my work.

In March of 1977 I visited the Museum National d'Histoire Naturelle in Paris to study the Pic types of American Anobiidae species. Unfortunately, some of the types had been loaned 13 years previously and were never returned. Two that I did not see were of *Vrilletta fulvolineata* (Pic) and *V. nigra* Pic, so I cannot now assign these names with certainty. However, rather than abandon my work because of this problem, it would better serve advancement of our knowledge to present my data and provisionally assign Pic's names.

Following is a diagnosis of the genus *Vrilletta:* antennal segments 4 through 8 strongly serrate to pectinate, length of last 3 segments combined almost as great as to greater than that of all preceding segments. Elytral striae distinct throughout, usually finely, strongly impressed, but sometimes punctate; intervals convex. Outer face of front and middle tibiae concave. Body length 3.5–8.4 mm.

Vrilletta bicolor, new species

Figs. 4, 5, 6, 8

General.—Body elongate-robust, 2.3 times as long as wide; elytral sides subparallel in basal 3/5. Elytra orange brown, suture and often lateral margins narrowly dark brown to black; scutellum black; pronotum mostly orange or red brown, at base brown to nearly black; head and ventral surface black, antenna dark brown to black; femora mostly dark brown, remainder of legs mostly red-brown. Pubescence very short, fine, not obscuring surface, dull white.

Head.—Front weakly, longitudinally carinate at middle, nearly evenly convex side to side, weakly convex front to back; surface minutely punctate-granulate. Eyes small, separated by about 5 times frontal width of an eye, not varying in sexes. Antenna of male (Fig. 4) nearly 1/2 as long as body, that of female (Fig. 5) nearly 1/3 as long as body; 2nd antennal segment of male a little wider than long, 3rd segment about 1.5 times as wide as long, segments 4–8 each 3 to 4 times as wide as long, ramus of 9th segment 2 times as long as segment, ramus of 10th segment nearly 2 times as long as segment, 11th segment arcuate and about 7 times as long as wide. Last segment of maxillary palpus subtriangular, about 2 times as long as wide, widest before middle; last segment of labial palpus subtriangular, about 2 times as long as wide, widest at middle.

Dorsal surface.—Pronotal disk and sides nearly evenly convex, but at extreme side shallowly concave; lateral margin produced, complete, and explanate, most produced at hind angle; surface throughout minutely granulate and obscurely punctate. Scutellum width about equal to length, apex broadly rounded. Elytra with distinct, complete, impressed striae, most striae with distinct punctures; surface throughout with minute, dense punctures, usually transversely aligned, causing a finely rugose appearance; intervals moderately convex, more distinctly convex apically; elytral apex truncate.

Ventral surface.—Outer face of anterior tibia concave nearly throughout; outer face of middle tibia concave apically; outer face of hind tibia weekly flattened. Metasternal surface finely, densely punctate and granulate, granules most distinct near base. Abdominal surface finely, densely punctate.

Length.—7.2–7.7 mm.

The male holotype (in CASC) bears the data: Fairfax, Marin Co., California, 4/24/49; D. Giuliani Collector; Derham Giuliani Collection, Calif. Acad. Sci., Accession 1967. One female paraytpe (in CASC) bears essentially the same data except for the date 4/15/50. Two female paratypes (in USNM) bear the data—11074a' Hopk. US; Apr. 24/15, Reared; Harvey BT Colr; Ashland, Oregon; Alnus rhombifolia.

The species name refers to the body color: the ventral surface and head are black and the dorsal surface is mostly orange or red-brown. Typically, species of *Vrilletta* exhibit much variation in color, but these 4 specimens are almost identical to one another in this regard.

Vrilletta bicolor is most similar to *V. convexa* LeConte, but they differ in characters of color, antennae, and male genitalia. No members of *convexa* match the color of *bicolor* (see above). The color of *convexa* varies from black throughout to black or dark brown nearly throughout and with elytra orange-brown except for darkened margins, to brown or red-brown nearly throughout. Antennal segments 9 and 10 of both sexes of *bicolor* (Figs. 4, 5) are more strongly serrate than these segments of *convexa* (Figs. 2, 3). The male genitalia of *bicolor* (Fig. 8) has the palp-like object of a lateral lobe widest near the base, while that of *convexa* (Fig. 9) has the palp-like object of a lateral lobe widest apically. Finally, there are differences in the shapes of the median lobes and their internal processes. In *bicolor,* the median lobe is narrower than in *convexa,* and the internal processes are much stouter than those of *convexa.*

Vrilletta pectinicornis, new species

Fig. 1

General.—Body elongate-robust, 2.3–2.4 times as long as wide, elytral sides subparallel in basal 3/5. Body and appendages mostly black, following parts brownish: apex of last antennal segment, apex of tibiae, tarsi. Pubescence fine, short, appressed, not obscuring surface, dull white.

Head.—Front nearly evenly convex side to side, weakly convex front to back; surface finely punctate-granulate. Eyes small, separated by 4.5 times frontal width of an eye. Antenna of female (Fig. 1) about 1/3 as long as body, 2nd segment a little wider than long, 3rd segment as wide as long, 4th segment a little wider than long, 5th segment about 1.5 times as wide as long, segment 6 and 7 each a little over 2 times as wide as long, segment 8 nearly 4 times as wide as long, 9th segment nearly 3 times as wide as long, 10th segment over 2 times as wide as long, 11th segment about 4 times as long as wide, weakly arcuate, widest before apex. Last segment of maxillary palpus subtriangular, widest before middle, 2 times as long as wide; last segment of labial palpus subtriangular, widest at middle, 2 times as long as wide.

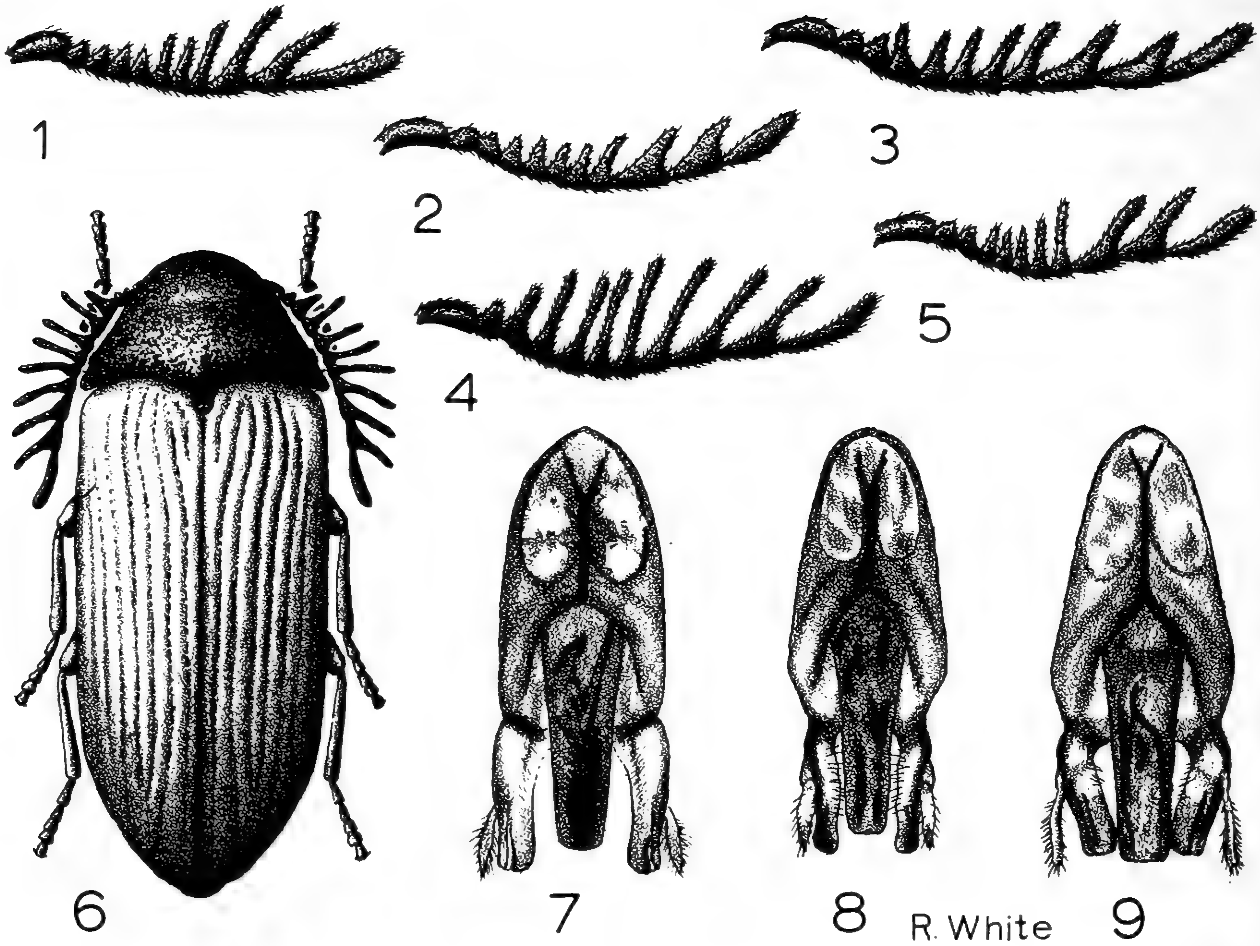
Dorsal surface.—Pronotal disk unevenly convex, sides nearly evenly convex, but shallowly depressed above anterior angle; lateral margin produced, complete, explanate, most produced at hind angle; disk finely punctate-granulate, surface at side with obscurely dual granulation. Scrutellum about as wide as long, apex broadly rounded. Elytra with more or less distinct, impressed striae, generally vague on disk, striae at sides with weak punctures; intervals convex; surface minutely, transversely rugose; apex narrowly truncate.

Ventral surface.—Outer face of anterior tibia concave nearly throughout, outer face of middle tibia concave apically, outer face of hind tibia weakly flattened. Metasternal surface finely, densely punctate, punctures dual, small punctures denser than larger, rimmed punctures. Abdominal surface sculpture of fine, dense punctures.

Length.—7.7–8.0 mm.

The female holoytpe (USNM No. 76536) bears the data: Glenwood Rd., Santa Cruz Co., California, 12-III-1966, reared from tanbark oak, W. H. Tyson, Collector. The single paratype (also a female in USNM) bears the data: Ben Lomond, 4.10.1930, L. W. Saylor Collector. This is a California locality.

Vrilletta pectinicornis (the name refers to the antenna) differs from the other two species of *Vrilletta* with pectinate or subpectinate antennae (i.e., *bicolor* White and *convexa* LeConte) in that each ramus of segments 9 and 10 is 2–3 times as long as its segment, whereas in *bicolor* and *convexa* a



Figs. 1–5, *Vrilletta* antennae: 1, *V. pectinicornis*, female; 2, *V. convexa*, female; 3, *V. convexa*, male; 4, *V. bicolor*, male; 5, *V. bicolor*, female; 6, *V. bicolor*, male holotype. Figs. 7–9, male genitalia: 7, *V. decorata;* 8, *V. bicolor;* 9, *V. convexa.*

ramus is never more than 2 times as long as its segment, usually much less. Typically in species of *Vrilletta,* the serration or pectination of an antenna is more developed in the male than in the female. If that is also the case in this species, then the male antenna of *pectinicornis* will be even more developed than is the male antenna of *bicolor.*

Pic species of *Vrilletta*

I have tried to assign the names *Vrilletta fulvolineata* (Pic), 1903 and *V. nigra* Pic, 1905. Due to the brevity and superficiality of most of Pic's descriptions, they usually provide little useful data for assigning names. However, meaningful characters in these two descriptions allow some conclusions to be drawn.

The length of *V. nigra* (7 mm) and reference to convex elytral intervals make it likely that Pic did have a species of *Vrilletta* before him. He described the antenna as greatly pectinate starting from the 3rd segment. This narrows the possibilities among known species of *Vrilletta* to only *convexa* LeConte, *pectinicornis* White, and *bicolor* White. The color given for *nigra*—black with tibiae and tarsi reddish—immediately excludes *bicolor.* The distributions of *convexa* and *pectinicornis* place them near the locality of Mariposa, California, which is given for *nigra.* The antennal form described for *nigra* does not agree with the female antenna of *convexa* nor the female (and only specimen) of *pectinicornis;* however, it does agree with the male antenna of *convexa,* and it is possible that it also conforms with the male antenna of *pectinicornis.* A single male of the color-variable *convexa* in the USNM series of 12 specimens agrees with the color given for *nigra.* Also, the color of *nigra* agrees well with that of the female of *pectinicornis.* Pic, in his description for *nigra,* compared his species with *convexa* and presented a character that he believed separated them ("Voisin de *V. convexa* Lec., distinct de cette espèce (2) par la structure des antennes, notamment par la forme triangulaire du 2″ article"). I doubt that there is any value to this character, but, of course, it is possible that the two are actually distinct. For the present I will regard *nigra* as possibly synonymic with either *convexa* or *pectinicornis.*

The Pic description of *fulvolineata* allows probable assignment (see below) of this name to the same species that VanDyke described (1918) as *V. decorata.* If *decorata* is synonymized with *fulvolineata,* that change should come only after examination of Pic's type so his name can be assigned with certainty.

The length given for *fulvolineata* (7 mm) is a little large for *decorata;* the 72 specimens in the USNM series of *decorata* range in length from 5.2–6.9 mm. The meaningful color characters for *fulvolineata* presented by Pic follow: he described the underside of the body as black, the upper part as dark in the middle of the prothorax and on the elytra, the periphery of these parts as reddish, and the legs and antennae as obscurely reddish. Pic also stated that each elytron had basally 3 light longitudinal lines, the first being the longest. Certain individuals of the highly color variable *decorata* agree well with these characters, and comparison of the other species of *Vrilletta* with the characters shows that none of these does agree. As is mentioned by VanDyke, 1918, p. 8, *decorata* is the most common species of the genus. The meaning of the locality data given by Pic for his *fulvolineata* "l'Amerique Sle" is obscure. However, in his catalog of Anobiidae (Pic, 1912, p. 46), he gave the locality as "U.S. America". I have illustrated the male genitalia of *decorata* (Fig. 7).

Key to species of *Vrilletta*

1. Antenna with segments 9 and 10 strongly, acutely produced in both sexes (Figs. 1–6) 2
   Antenna with segments 9 and 10 not strongly produced 4

2(1). Female with ramus of 9th antennal segment 3 times as long as segment, ramus of 10th segment over 2 times as long as segment (Fig. 1); body black nearly throughout .... *pectinicornis,* n. sp.
   Antennal rami not as elongated as above; body usually with orange-brown or red-brown 3

3(2). Antenna more strongly pectinate (Figs. 4, 5, 6); dorsal surface orange-brown to red-brown with base of pronotum dark and elytral margins usually black; ventral surface and head black to dark brown .... *bicolor,* n. sp.
   Antenna less strongly pectinate (Figs. 2, 3); color never exactly as above .... *convexa* LeConte

4(1). Pubescence dense, whitish, largely concealing surface, somewhat reflective, changing in direction .... *californica* Fisher
   Pubescence never exactly as above, always less dense 5

5(4). Occurring in Pennsylvania, Quebec, and Ontario .... *laurentina* Fall
   Occurring on Pacific coast 6

6(5). Basal 2/3 of pronotum orange to orange brown and apex more or less distinctly darker; elytra clearly darker than base of pronotum, elytron usually with an orange spot before middle .... *murrayi* LeConte
   Pronotal and elytral color never exactly as above 7

7(6). Elytra bicolored, primarily dark but with orange to orange-brown spots or stripes 8
   Elytra not bicolored, of same color throughout, or primarily light 9

8(7). Elytron before middle with orange markings less extensive, only on interval 7, sometimes also on 6, or 5 and 6 .... *blaisdelli* Fall
   Elytral markings much more extensive than above .... *decorata* VanDyke

9(7). Pronotum with dense, dual punctation (large, rimmed punctures and small dot-like punctures) and fine granules; dorsal surface with feeble luster; discal invervals not or feebly convex .... *plumbea* Fall

Pronotum granulate and with fine punctation, with few to no large punctures; dorsal surface with moderate luster; discal intervals more or less clearly convex .... *expansa* LeConte

Checklist of species of *Vrilletta*

Vrilletta LeConte, 1874, p. 64
  Pseudoxyletinus Pic, 1903, p. 182.
    bicolor White
    blaisdelli Fall, 1905, p. 194
    californica Fisher, 1939, p. 175
    convexa LeConte, 1874, p. 65
    decorata VanDyke, 1918, p. 7
    expansa LeConte, 1874, p. 64
    laurentina Fall, 1905, p. 195
    murrayi LeConte, 1874, p. 64
    pectinicornis White
    plumbea Fall, 1905, p. 196
Uncertain status
  fulvolineata (Pic), 1903, p. 182 (probably *decorata*)
  nigra Pic, 1905, p. 171 (possibly *convexa* or *pectinicornis*)

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Studies of Neotropical Caddisflies, XXIX: The Genus Polycentropus *(Trichoptera: Psychomyiidae)*

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ABSTRACT

Fifteen new species of the genus *Polycentropus* are described and the male genitalia figured. The holotypes are from Belize (1 species), Ecuador (2), El Salvador (1), Guatemala (1), Mexico (6), Panama (3), and Venezuela (1).

Collections made in recent years in Mexico, Central America, and northern South America have revealed an unexpected specific diversity in the genus *Polycentropus.* Yet, although the genus is often taken at light, it is rarely abundant and most species are encountered very infrequently. Within the area in consideration only three species

(*P. altmani* Yam., *P. guatemalensis* Flint, and *P. picana* Ross) have been collected at more than three localities. As a consequence most species, including the majority of those herein described, are known from a single collection, often from only one specimen, or a very few collections generally from nearby localities.

The species here described fall into two major groups, the *insularis* and *gertschi* groups. A third, the *arizonensis* group, also occurs in Mexico, but no undescribed species of this group are at hand.

Acknowledgments

I express my gratitude to those who have collected and donated this material to the National Collection: Dr. Joaquin Bueno Soria, Universidad Nacional Autonoma de Mexico, Mexico City (UNAM); Dr. Hindrik Wolda, Smithsonian Tropical Research Institute, Balboa, Panama, through Dr. Vincent Resh and Mr. Eric McElravy, University of California, Berkeley (UC-B); Dr. Yale Sedman, Western Illinois University, Macomb; Mr. Stephen R. Steinhauser, Sarasota, Florida; and especially to my coworkers at the National Museum of Natural History, Terry L. Erwin, Gary F. Hevel, John B. Heppner, and Paul J. Spangler who have collected so much of this and other valuable material over the years.

The **insularis** group

In addition to *P. insularis* Bks. (known from Grenada and Dominica), I also place *P. altmani* Yam. (Costa Rica, Nicaragua, Panama, Ecuador, Venezuela), *P. biappendiculatus* Flint (Surinam), and *P. surinamensis* Flint in the group. The form of the cercus is very characteristic: a long dorsomesal process first directed anteriad then curving mesad and posteriad, and a dorsolateral lobe which usually bears a small mesal lobe. The aedeagus bears apically a ventromesal liplike lobe and the claspers usually are formed of an erect, dorsolateral lobe basally and a more elongate apical lobe. The new species *P. cuspidatus* is clearly a member of the group. The known distribution of this group is from Nicaragua south to Ecuador, east across northern South America to Surinam, and north into the Lesser Antilles to Dominica.

Polycentropus cuspidatus, new species

Figures 1–4

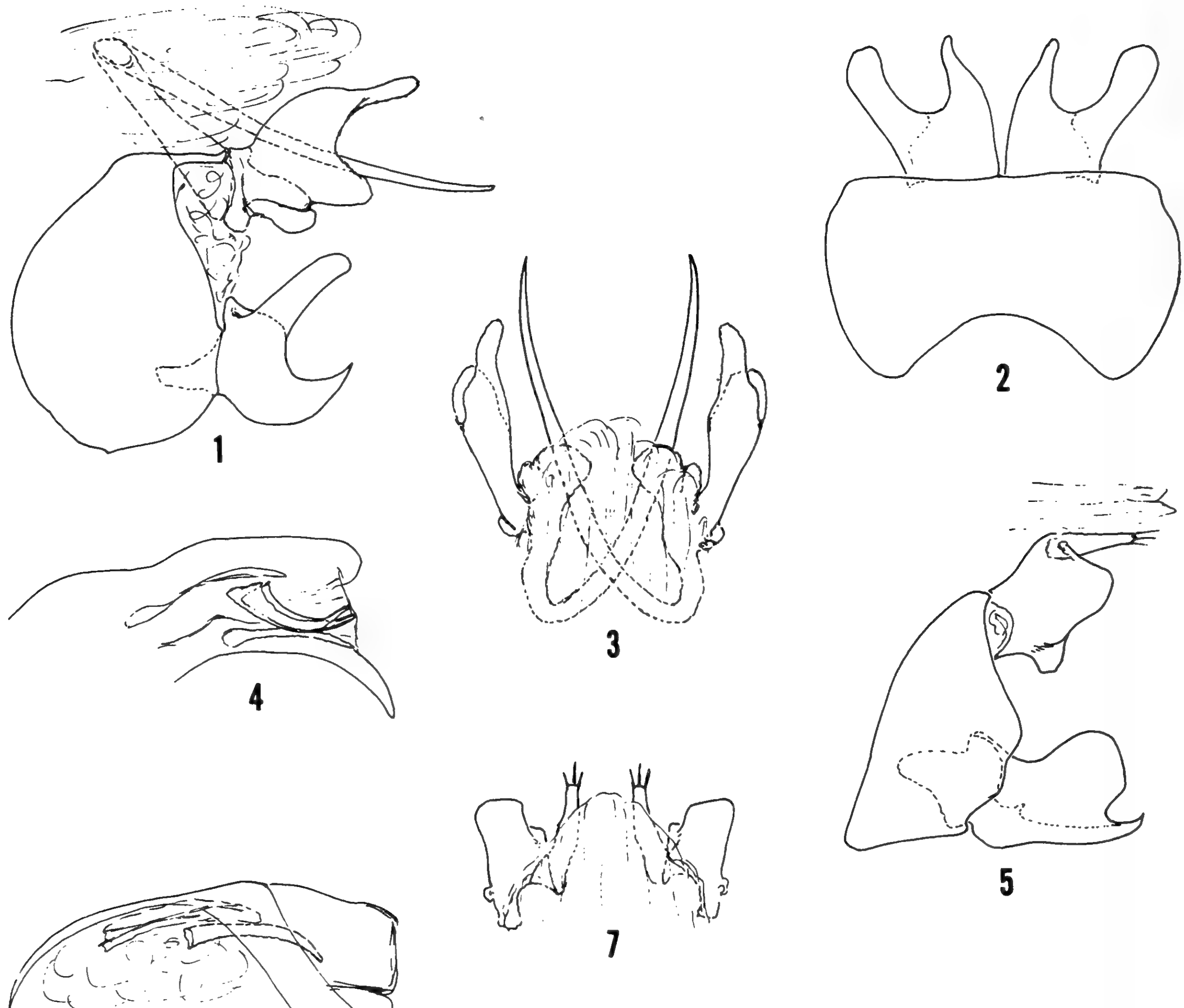
The species is closely related to *P. altmani* Yam., but is easily distinguished by the bifid dorsolateral lobe of the cercus, and the shorter, narrower lobes of the claspers which are of nearly equal size.

Adult.—Length of forewing, 6 mm. Color brown; antennae, legs and body ventrally, stramineous; forewing brown, densely maculate with golden hairs. Forewing with R_2 present (hindwings completely cleared and venation invisible). Male genitalia: Ninth segment with anterior margin evenly rounded; posterior margin cut-away dorsally. Tenth tergum membranous. Cercus with dorsolateral lobe elongate, posterior margin bifid; mesal lobe elongate, small; dorsomesal process very long, slender, directed first basad then curving apicad. Clasper with an elongate, narrow, dorsolateral lobe and a ventromesal pointed lobe. Aedeagus with a small apicoventral lip; internally with a pair of curved apicodorsal spines and a broad, flat ventral plate whose apex is bilobed in dorsal aspect, and a lightly sclerotized tubular structure.

Material.—Holotype, male: Ecuador, Prov. Pastaza, 16 kms. west of Puyo, 3 Feb 1976, Spangler, *et. al.,* at blacklight. USNM Type 76857.

The **gertschi** group

This is an extremely large group of species found from the southwestern United States south throughout Mexico and Central America at least as far as Ecuador and east to Venezuela. The characteristics of the group are rather difficult to define without finding some species that violates some part of the definition; the following is therefore a general statement. The clasper has a thin, erect dorsolateral lobe that joins a thicker ventromesal region which is delimited by a sharp mesal shelf or carina that bears one or two sharp toothlike projections. The cercus is typically composed of three parts: a slender rodlike dorsomesal lobe, a broader usually elongate or quadrate dorsolateral lobe (densely setate), and a ventral and slightly more mesal lobe usu-



Figs. 1–12. *Polycentropus cuspidatus:* 1, male genitalia, lateral; 2, ninth sternum and claspers, ventral; 3, cerci, dorsal; 4, aedeagus, lateral. *P. azulus:* 5, male genitalia, lateral; 6, ninth sternum and claspers, ventral; 7, cerci, dorsal; 8, aedeagus, lateral. *P. mayanus:* 9, male genitalia, lateral; 10, ninth sternum and claspers, ventral; 11, cerci, dorsal; 12, aedeagus, lateral.

ally broadly joined to the dorsolateral lobe. These three lobes are very variable in shape, manner of union, and often one will be reduced or lost. The aedeagus has an apical, liplike projection.

Polycentropus azulus, new species

Figures 5–8

P. dentoides Yam., *P. mayanus* n.sp. and this one form a very closely knit assemblage of species. There are rather small differences in the shape of the lobes of the cerci between the three, but the shape of the clasper is more distinctive. The large apicomesal and small basomesal teeth are distinctive in *azulus* as is the shape and position of the dorsolateral lobe.

Adult.—Length of forewing, 4.5 mm. Color pale brown in alcohol. Fore and hindwing with R_2 present; hindwing lacking crossvein between R_3 and R_4. Male genitalia: Ninth segment with anterior margin nearly vertical; hind margin slightly produced at midlength. Tenth tergum membranous. Cercus with a broad dorsolateral lobe, bearing a small ventral lobe; with a short, tubular dorsomesal lobe. Clasper with a thin, rounded, dorsolateral lobe; mesoventral shelf with a small basal tooth and a large apical tooth. Aedeagus with a recurved apicoventral lip; apically with a pair of lateral plates; internally with a single long spine and an indistinct tubular structure.

Material.—Holotype, male: Mexico, Edo. Chiapas, Agua Azul, 1 May 1978, H. Brailovsky. USNM Type 76858.

Polycentropus mayanus, new species

Figures 9–12

As stated under *azulus* n.sp., this species and *P. dentoides* are closely related. The shape of the clasper, especially the large, rounded dorsolateral lobe, and mesal shelf ending in an apical tooth, is distinctive.

Adult.—Length of forewing, 5–7 mm. Color dark brown; antennae, legs and body ventrally stramineous; forewing covered with dark brown hairs with numerous interspersed flecks of golden hair. Fore and hindwings with R_2; hindwing lacking crossvein between R_3 and R_4. Male genitalia: Ninth segment with anterior margin slightly oblique, posterior margin produced posteriad. Tenth tergum membranous. Cercus with a spinelike dorsomesal lobe, curved mesad; lateral lobe rounded, grading into a poorly differentiated ventromesal lobe. Clasper rounded, higher than long; mesal shelf well developed, ending in a well developed apical tooth. Aedeagus produced into a long, slender, pointed apicoventral lip; apex with thin lateral plates; internally with a basal tubular structure, and a single long spine.

Material.—Holotype, male: Mexico, Edo. Chiapas, Rió Chacamax, Palenque, 6 Dec 1975, C.M. & O.S. Flint, Jr., USNM Type 76859. Paratypes: Same data, 1♀.

Polycentropus lingulatus, new species

Figures 13–16

Polycentropus undescribed sp. "B": McElravy, *et al.*, in press, Table 1.

This species is closest to *P. digitus* Yam. with which it shares the well developed ventromesal lobe of the cercus. However, the clasper of *lingulatus* which is shorter and higher in outline and the mesal shelf which ends in a tooth is distinctive.

Adult.—Length of forewing, 5.5 mm. Color in alcohol, brown. Fore and hindwings with R_2 present; hindwing lacking crossvein between R_3 and R_4. Male genitalia: Ninth segment with anterior margin slightly oblique, posterior margin produced posteriad. Tenth tergum membranous. Cercus with a spinelike dorsomesal lobe whose apex bears 2 spiniform setae; lateral lobe simple, platelike, apex rounded; with a mesoventral plate developed into a small apicoventral point, with a vertical posterior margin extending as far posteriad as lateral lobe. Clasper with a large, rounded, dorsolateral lobe; mesal shelf produced into a sharp apical tooth. Aedeagus produced into a long, slender apical lip; apex with thin, lateral plates; internally with a basal tubular structure and six small spines.

Material.—Holotype, male: Panama, Prov. Chiriqui, Fortuna, 24–30 Nov. 76, H. Wolda (OTU #32). USNM Type 76860. Paratypes: Same, but taken between 24 Nov 1976 and 3 Jan 1978, 42♂. (USNM, UC-B).

Polycentropus veracruzensis, new species

Figures 17–21

This species is yet another member of the *gertschi* group, closely related to *P. picana* Ross. From the latter, and all other known species of the group it is easily recognized by the claspers which are longer than high, bear a small apicomesal lobe, and a pair of basal teeth which are united for their basal halves.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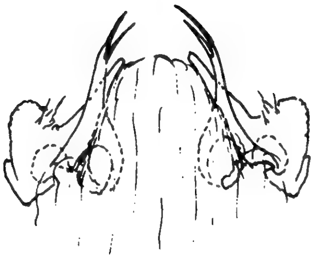
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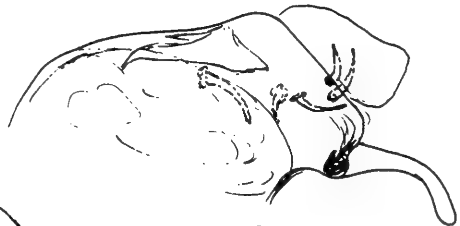
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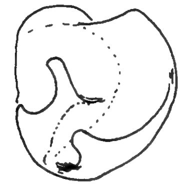
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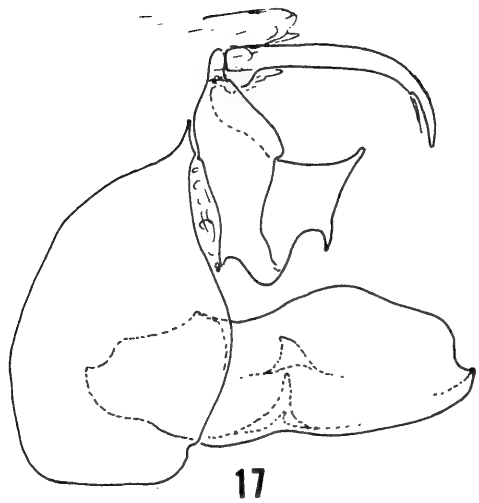
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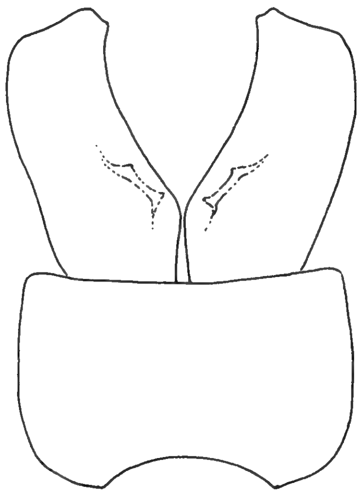
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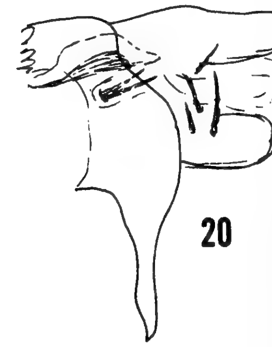
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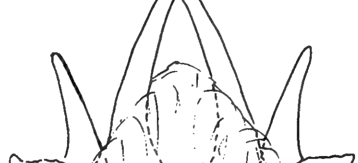
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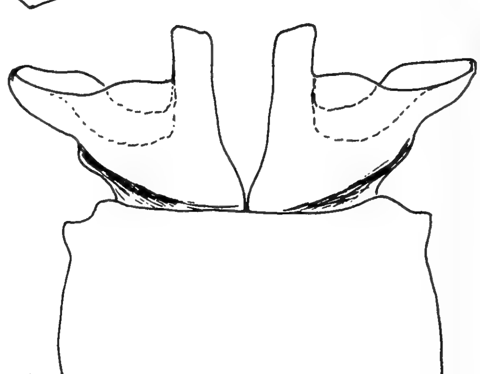
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Adult.—Length of forewing, 6–7.5 mm. Color dark brown, antennae, legs and body ventrally stramineous; forewing covered with dark brown hairs with numerous interspersed flecks of golden hair. Fore and hindwings with R_2 present; hindwing lacking crossvein between R_3 and R_4. Male genitalia: Ninth segment with anterior margin oblique, posterior margin sinuate. Tenth tergum membranous. Cercus with dorsomesal lobe elongate, spinelike, apex curved ventrad and mesad; lateral lobe small and barely developed, mesoventral lobe twice as long as lateral lobe and apicodorsal and ventral angles developed into short points. Clasper longer than high; mesal shelf poorly developed, with a short rounded apical tooth, and more basad a pair of teeth which are united basally. Aedeagus produced into a long, pointed ventral lip; apex with thin, lightly sclerotized lateral plates; internally with a basal tubular structure and 2 small groups of 2 or 4 short spines each.

Material.—Holotype, male: Mexico, Edo. Veracruz, near Huatusco, 25–26 July 1965, Flint & Ortiz. USNM Type 76861. Paratypes: Same data, 1♀; Metlac, near Fortin de las Flores, 30 June 1976, J. Bueno, 1♂ (UNAM). Las Minas, (near Perote), 3 Jan 1978, J. Bueno, 1♂ (UNAM); same, but 9 Sept 1977, 4♂ (USNM, UNAM).

Polycentropus hamiferus, new species

Figures 22–25

Although clearly a member of the *gertschi* group, this species does not seem to have any close relatives. The dorsomesal lobe of the cercus which is short, broad, and hooked apically, together with the very long lip of the aedeagus, are distinctive.

Adult.—Length of forewing, 9 mm. Color brown; antennae, legs and body ventrally, stramineous; forewing dark brown with numerous flecks of golden hair. Fore and hindwings with R_2 present; hindwing lacking crossvein between R_3 and R_4. Male genitalia: Ninth segment with anterior and posterior margins nearly vertical. Tenth tergum lightly sclerotized and setate dorsally. Cercus with an elongate, clavate dorsolateral lobe, an elongate, apically rounded ventromesal lobe, and a short dorsomesal lobe ending in an upturned hook. Clasper with a thin, rounded dorsolateral lobe, and a strong mesal shelf bearing an apical tooth, blunt in ventral aspect. Aedeagus produced into a long, attenuate apicoventral lip; apicolateral plates weakly developed; internally with a complex, lightly sclerotized, basal structure roughly tubular in outline.

Material.—Holotype, male: El Salvador [Dept. Santa Ana] north of Metapan [Cerro Miramundo], 2300 m., 17 May 1969, S. Steinhauser. USNM Type 76862. Paratype: Same, but 23 Jan 1971, 1♀.

Polycentropus meridiensis, new species

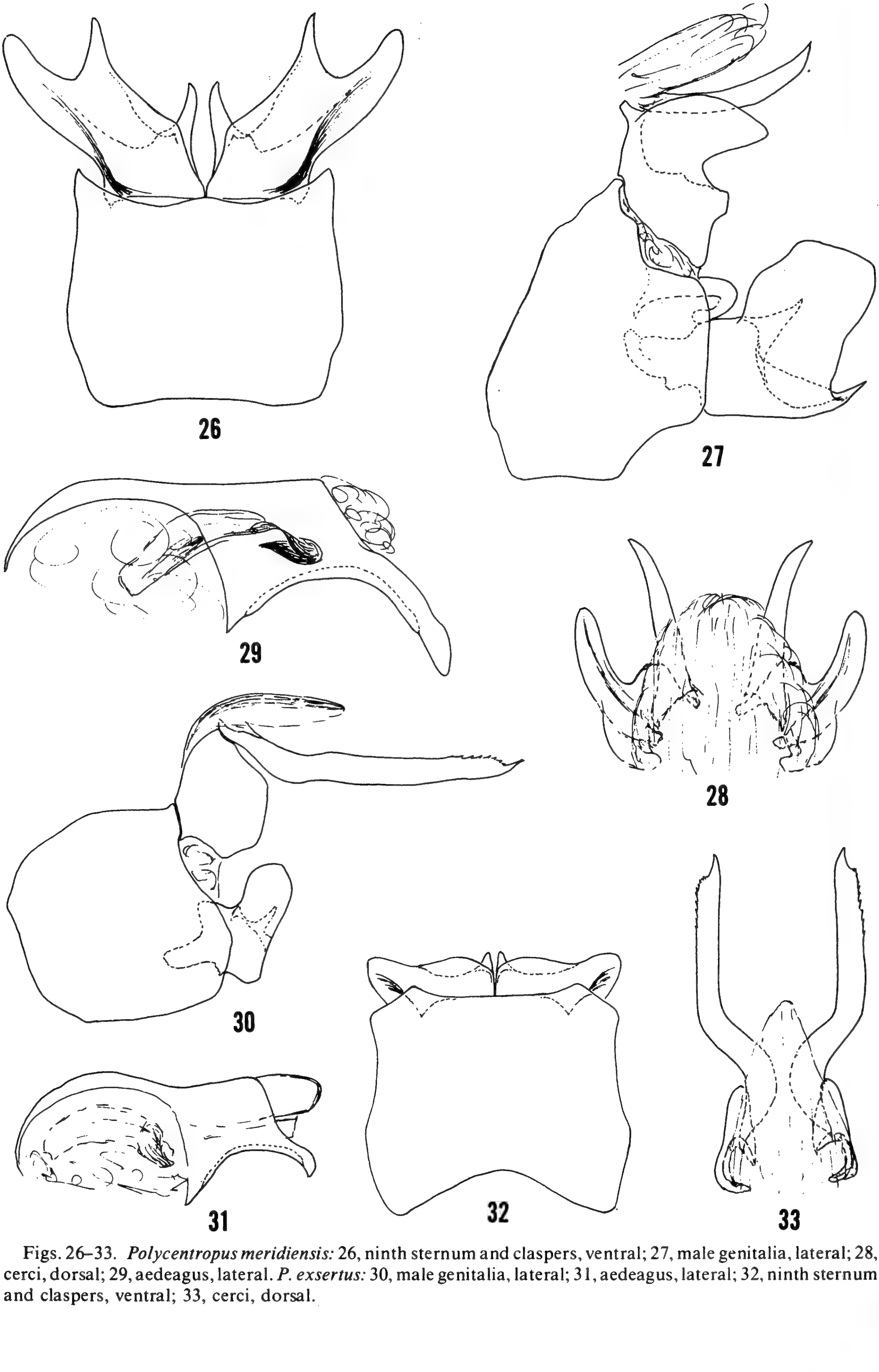
Figures 26–29

This species appears to be related to *P. connatus* Flint, also known from Venezuela. The shape of the clasper is virtually identical in the two, but the cerci are quite different. In *connatus* the dorsomesal lobe is united to the dorsolateral lobe, but in *meridiensis* it is, as usual, loosely associated to it.

Adult.—Length of forewing, 9–10 mm. Color brown, antennae, legs and body ventrally stramineous; forewing dark brown, with many flecks of golden hairs. Fore and hindwings with R_2 present; hindwing lacking crossvein between R_3 and R_4. Male genitalia: Ninth segment with anterior margin slightly oblique, posterior margin vertical. Tenth tergum membranous. Cercus with an elongate, clavate, dorsolateral lobe, produced ventrally into a strongly sclerotized lobe whose posterior margin bears a small lobe; with a free dorsomesal, slightly curved, pointed process. Clasper with a thin, apicodorsal lobe, mesal shelf with a strong spine basally, and ending in another spine projecting from posterior margin. Aedeagus with an elongate apicoventral lip; internally with a lightly sclerotized tubular structure ending in a darkened apical structure.

Material.—Holotype, male: Venezuela, Edo. Merida, 4 km. south of Santo Domingo, 19–23 Feb 1976, C.M. & O.S. Flint, Jr. USNM Type 76863. Paratypes: Same data, 3♂. Rio Santo Domingo, 5 km. northwest of Santo Domingo, 19 Feb 1976, C.M. & O.S. Flint, Jr., 3♂. Mucuy Fish Hatchery, 7 km. east of Tabay, 6600 ft., 10–13 Feb 1978, J. B. Heppner, 3♂ 1♀.

Figs. 13–25. *Polycentropus lingulatus:* 13, male genitalia, lateral; 14, cerci, dorsal; 15, ninth sternum and claspers, ventral; 16, aedeagus, lateral. *P. veracruzensis:* 17, male genitalia, lateral; 18, ninth sternum and claspers, ventral; 19, clasper, posterior; 20, aedeagus, lateral; 21 cerci, dorsal. *P. hamiferus:* 22, male genitalia, lateral; 23, ninth sternum and claspers, ventral; 24, cerci, dorsal; 25, aedeagus, lateral.



Figs. 26–33. *Polycentropus meridiensis:* 26, ninth sternum and claspers, ventral; 27, male genitalia, lateral; 28, cerci, dorsal; 29, aedeagus, lateral. *P. exsertus:* 30, male genitalia, lateral; 31, aedeagus, lateral; 32, ninth sternum and claspers, ventral; 33, cerci, dorsal.

Polycentropus exsertus, new species

Figures 30–33

This is a very distinctive species, readily distinguished from its congeners by the exserted dorsomesal lobes of the cerci and the very narrow claspers.

Adult.—Length of forewing, 7 mm. Color brown; body ventrally and basal halves of legs, stramineous; forewing dark brown with scattered spots of golden hairs. Fore and hindwings with R_2 present; hindwing lacking crossvein between R_3 and R_4. Male genitalia: Ninth segment with anterior margin evenly rounded; posterior margin irregularly oblique. Tenth tergum with dorsal surface weakly sclerotized. Cercus with a platelike lateral lobe, and a long dorsal process distinctly angled in dorsal aspect. Clasper short, with a thin, narrow, rounded dorsolateral lobe; mesal shelf short with a distinct spine. Aedeagus with a short apicoventral lip; lightly sclerotized eversible plates apically; internally with a lightly sclerotized tubular structure.

Material.—Holotype, male: Ecudador, Prov. Pastaza, 16 kms. west of Puyo, 3 Feb 1976, Spangler, et al., at blacklight. USNM Type 76864. Paratypes: Same data, 1♂ 5♀.

Polycentropus zanclus, new species

Figures 34–37

This species and the following, *P. bellus,* are closely related, and easily recognized by the apparent loss of the dorsomesal lobe of the cercus, and great elongation of the clasper. The long, slender ventromesal lobe, and the short dorsolateral lobe are distinctive in *zanclus.*

Adult.—Length of forewing, 8 mm. Color brown, legs and body ventrally, stramineous; forewings dark brown, spotted with golden hairs. Fore and hindwings with R_2 present; hindwing lacking crossvein between R_3 and R_4. Male genitalia: Ninth segment with anterior margin broadly rounded, posterior margin slightly produced. Tenth tergum membranous. Cercus with a small dorsolateral lobe, broadly united to a long slender, sicklelike apicoventral lobe; dorsomesally with a small, rounded lobe. Clasper with a narrow, erect, thin basodorsal lobe, and a long, slender apical lobe; mesal shelf short, produced into a basodorsal hook. Aedeagus with apicoventral lip trifid, with short pointed submesal lobes and a longer, decurved mesal lobe; lateral plates apically; internally with a basodorsal, lightly sclerotized, roughly tubular structure, and 10 short ventral spines.

Material.—Holotype, male: Guatemala, [Dept. Quiche], El Quiche, 7.3 km. south of Chichicastenago (15° 54′ N, 91° 07′ W), 2400 m., 28 May 1973, Erwin & Hevel. USNM Type 76865. Paratype: Same data, 1♂.

Polycentropus bellus, new species

Figures 38–41

This species and *P. zanclus* form a closely related pair of species. They are easily distinguished by the shape of the claspers and especially the cerci, which in *bellus* apparently consist of a long lobe, ending in a ventral tooth.

Adult.—Length of forewing, 8 mm. Color in alcohol, brown. Fore and hindwings with R_2; hindwing lacking crossvein between R_3 and R_4. Male genitalia: Ninth segment with anterior margin produced ventrally; posterior margin nearly vertical. Tenth tergum membranous. Cercus with dorsolateral and lateroventral lobes broadly joined, elongate, ending in a decurved hook; dorsomesal lobe lacking. Clasper with a narrow, erect, thin basodorsal lobe, and a long, slender apical lobe with a strong subbasal tooth. Aedeagus with apicoventral lip trifid, submesal lobes short and pointed, mesal lobe long and decurved; lateral plates apically; internally with a basodorsal, elongate, lightly sclerotized tubular structure, and 12 short ventral spines.

Material.—Holotype, male: Mexico, Edo. Chiapas, Santa Elena, Rio Santo Domingo (39 km. east of Lagunas Montebello), 9 Apr 1979, Barrera. USNM Type 76866. Paratype: Same, but 6 Apr 1979, J. Bueno S., 1♂ (UNAM).

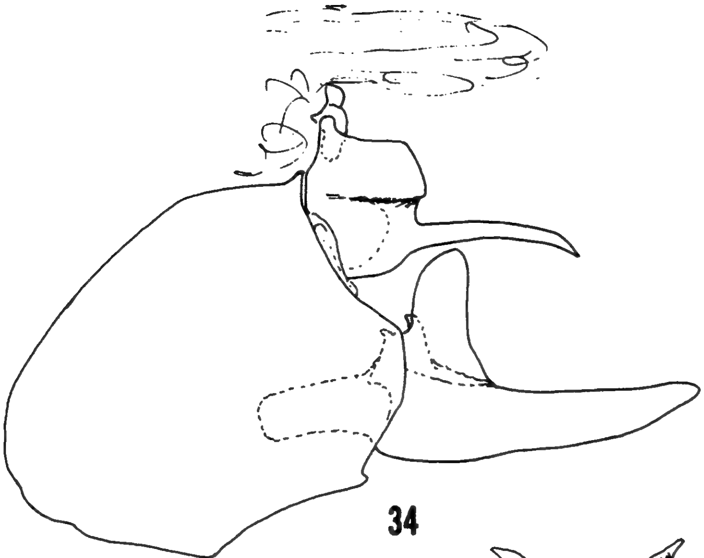
Polycentropus fortunus, new species

Figures 42–45

Polycentropus undescribed sp. "A": McElravy, *et al.,* Table 1.

This and the following new species, *P. acanthogaster,* appear to be slightly related. In both species the cercus is reduced to only two lobes, in *fortunus* there are clearly the dosomesal and lateral lobes. In addition the elongate, rather triangular outline of the clasper in this species is distinctive.

Adult.—Length of forewing, 6 mm. Color in alcohol, brown. Fore and hindwings with R_2 present; hindwing lacking crossvein between R_3 and R_4. Male genitalia: Ninth segment with anterior margin nearly vertical, posterior margin produced posteriad. Tenth tergum membranous. Cercus with an elongate spine-



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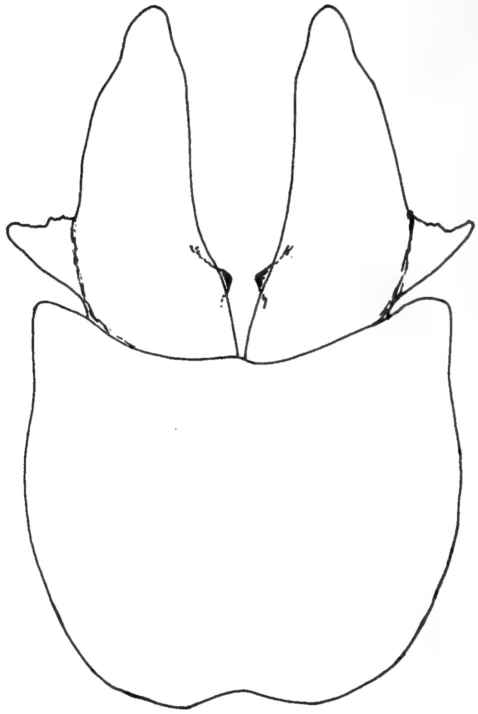

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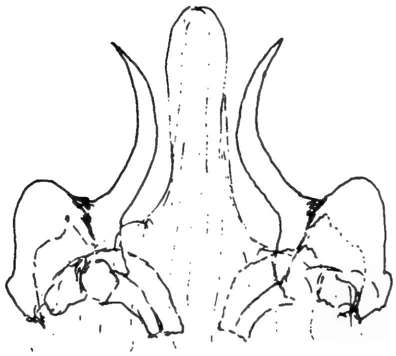

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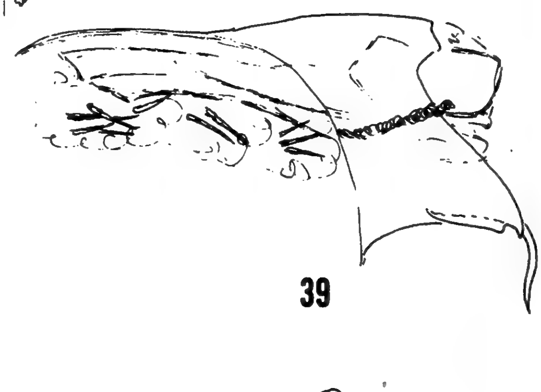

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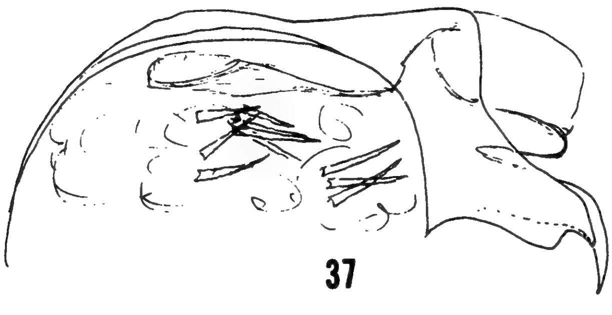

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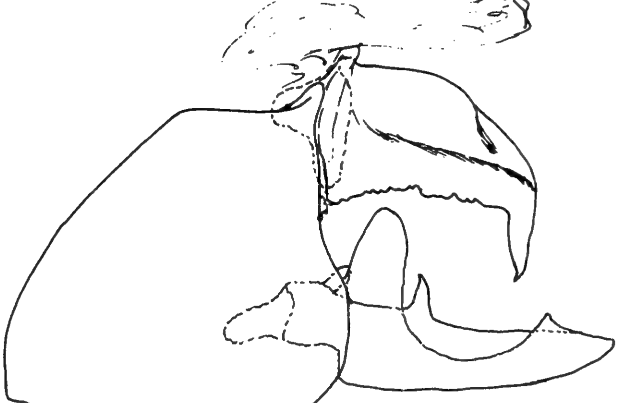

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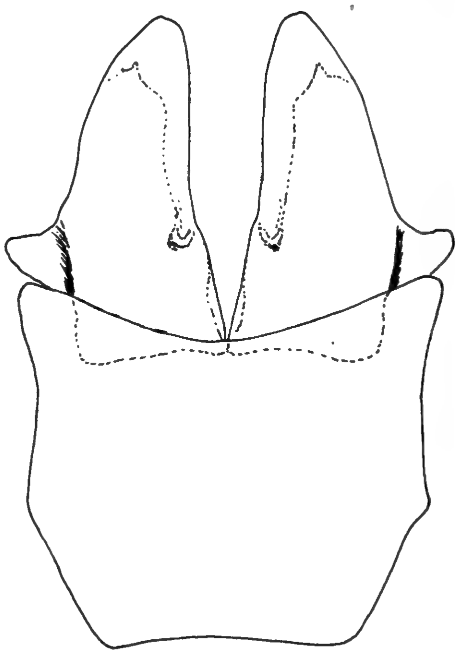

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like dorsomesal lobe whose apex is sharply curved ventrad and mesad; lateral lobe simple, platelike, apex rounded. Clasper with a broad, slightly produced dorsolateral margin; mesal shelf narrow, ending in a sharp spine at its apex, with a basomesal pad of spinelike setae. Aedeagus produced into a long, slender apicoventral lip; thin, lateral plates apically; internally with a basal tubular structure surmounting a single spine.

Material.—Holotype, male: Panama, Prov. Chiriqui, Fortuna, 10–16 Nov 1976, H. Wolda (OTU #7). USNM Type 76867. Paratypes: Same, but taken between 10 Nov 1976 to 13 Dec 1977, 39♂ (USNM, UC-B).

Polycentropus acanthogaster, new species

Figures 46–49

Polycentropus undescribed sp. "C": McElravy, *et al.*, in press, Table 1.

Although the clasper and aedeagus of this species are absolutely typical of the *gertschi* group, the cercus is quite different. Both this species and the preceeding have two-parted cerci, but in *acanthogaster* it is not clear which lobe is present in addition to the lateral one. The position is that of the ventromesal lobe, but the shape is more typical of the dorsomesal lobe. Although this species lacks the small, dorsomesal, digitate process of the cercus of the following species, the ventral lobe of *acanthogaster* may represent a further development of the ventral process of *bonus.*

Adult.—Length of forewing, 5 mm. Specimen completely cleared, in alcohol. Fore and hindwings with R_2 present; hindwing lacking crossvein between R_3 and R_4. Male genitalia: Ninth segment with anterior margin strongly rounded ventrally, posterior margin vertical. Tenth tergum membranous. Cercus lacking dorsomesal lobe; lateral lobe simple, platelike, apex oblique; with a strong spinelike process from ventromesal margin, sharply curved dorsad. Clasper with a thin, dorsolateral lobe, and a strong mesal shelf bearing a sharp tooth. Aedeagus produced into a short apicoventral lip ending in a pair of short lateral lobes and a short, pale, mesal process; apex with thin lateral plates; internally with a pair of slender spines attached to an irregular base.

Material.—Holotype, male: Panama, Prov. Chiriqui, Fortuna, 1–7 June 1977, H. Wolda (OTU #55). USNM Type 76868. Paratypes: Same, but 17–23 Nov 1976, 1♂; same, but 5–11 June 1977, 1♂; same, but 4–10 May 1977, 1♂; same, but 18–24 May 1977, 1♂; same, but 5–11 Oct 1977, 1♂ (USNM, UC-B).

Polycentropus bonus, new species

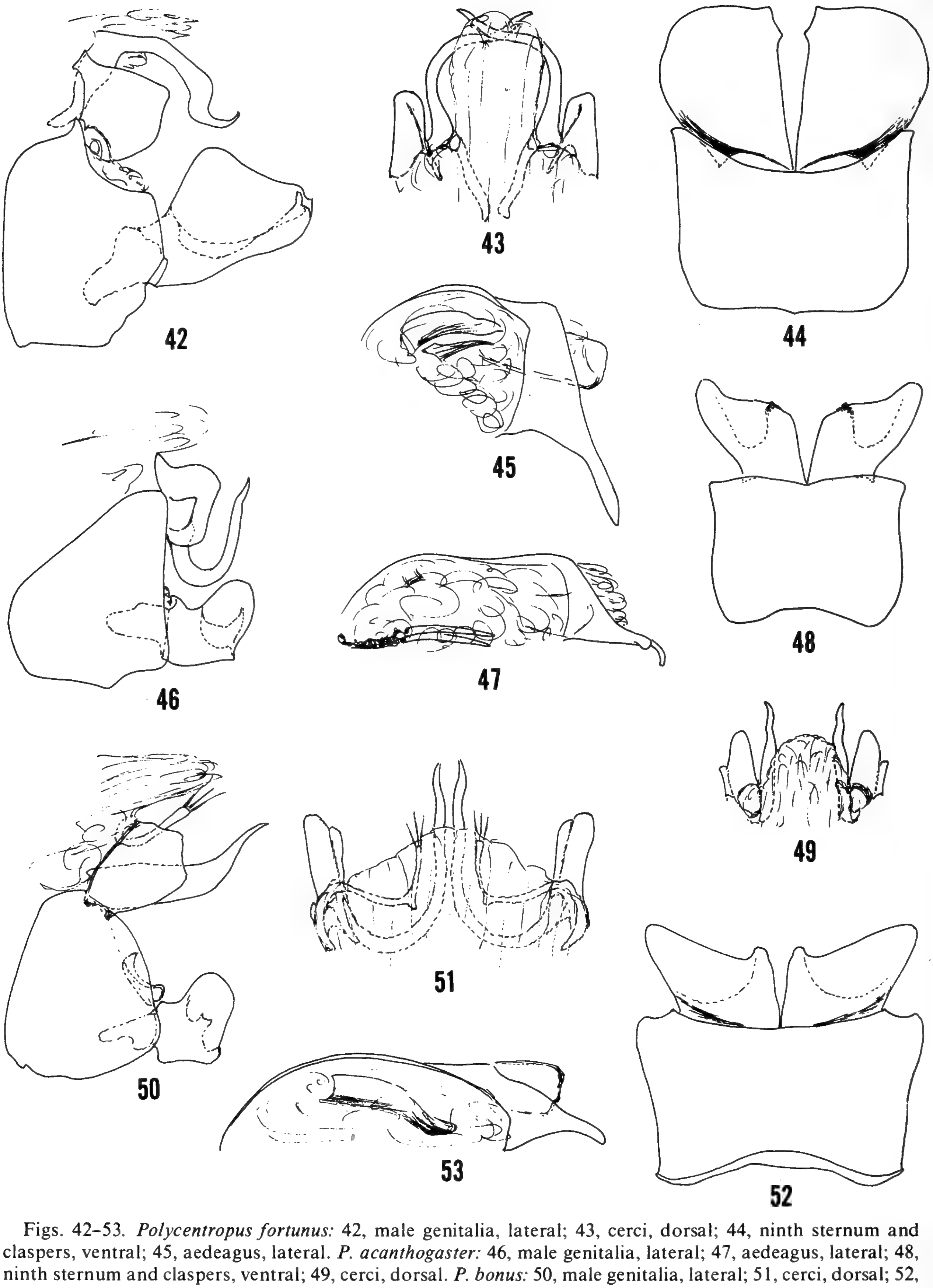
Figures 50–53

Belonging to the *gertschi* group this species is related to *P. acanthogaster, clarus* and *alatus.* With *acanthogaster* it shares the general structure and shape of the claspers, and with *clarus* and *alatus* the possession of a lightly sclerotized, process-bearing structure from the inner face of the cercus and strongly sclerotized ventral support for the aedeagus. It differs from each species in the precise shape of claspers, cerci, and aedeagus.

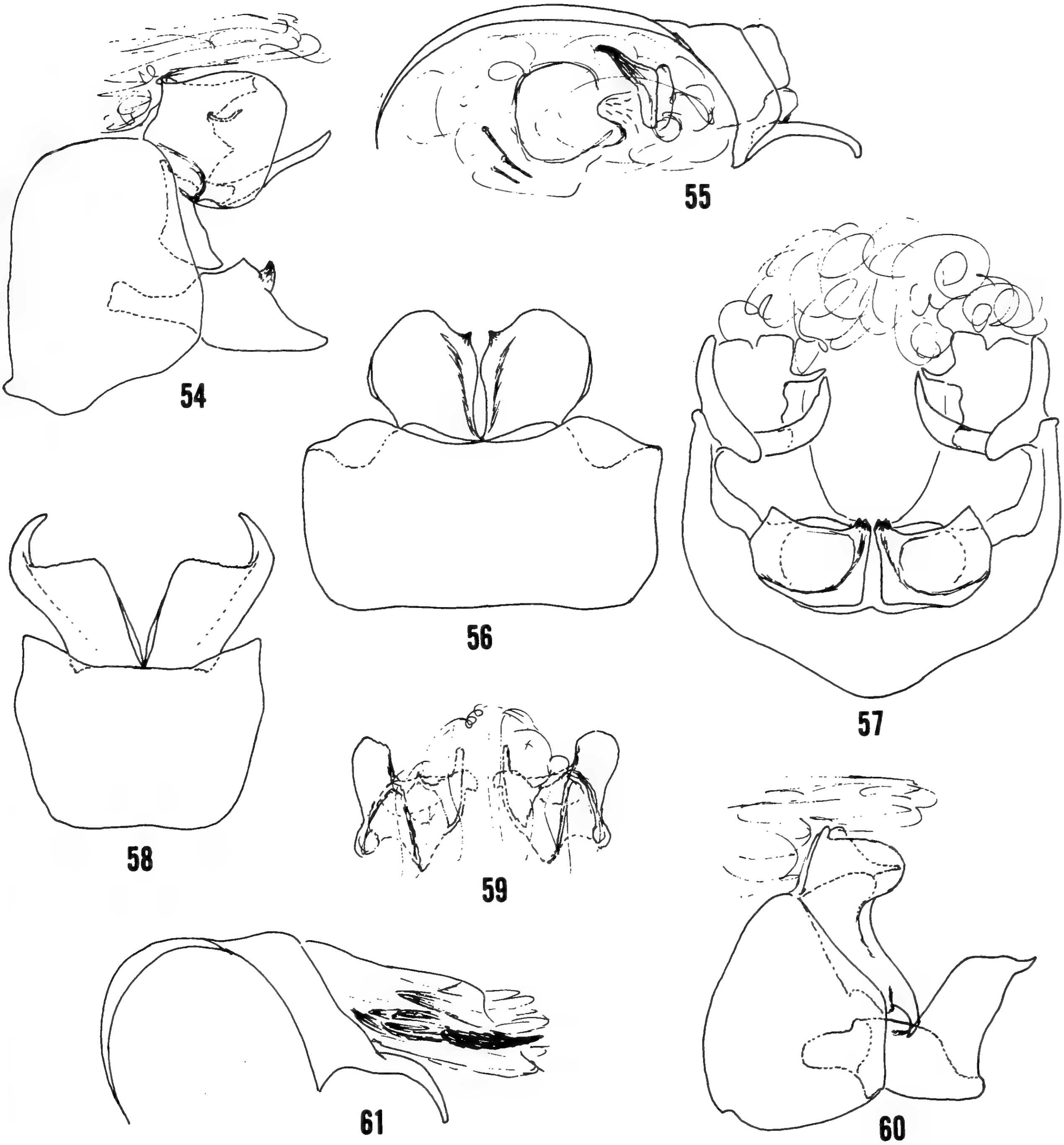
Adult.—Length of forewing, 5–5.5 mm. Specimen in alcohol, brown. Fore and hindwings with R_2 present; hindwing lacking crossvein between R_3 and R_4. Male genitalia: Ninth segment with anterior and posterior margins slightly expanded ventrad. Tenth tergum membranous. Cercus with a thin, lateral lobe, about as long as broad; ventrobasally giving rise to a long, curved spinelike process; inner face developed into a slender sclerotized area bearing a slender digitate lobe near the midline. A platelike sclerite surrounding aedeagus laterally and ventrally. Clasper with a thin, rounded dorsolateral lobe; mesal shelf bearing a blunt tooth at midlength. Aedeagus produced into a short, pointed, mesoventral lip; thin, lateral plates apically; internally with a tubular lightly sclerotized structure (paratype also contains a cluster of 9 short spines).

Material.—Holotype, male: Belize, Cayo Dist., Rió Privassion, Blancaneaux Lodge, 9–11 July 1973, Y. Sedman. USNM Type 76869. Paratypes: Same data, 1♀. Mexico, Edo. Chiapas, Bonampak, 3 May 1978, E. Barrera, 1♂ (UNAM).

Figs. 34–41. *Polycentropus zanclus:* 34, male genitalia, lateral; 35, ninth sternum and claspers, ventral; 36 cerci, dorsal; 37, aedeagus, lateral. *P. bellus:* 38, cerci, dorsal; 39, aedeagus, lateral; 40, male genitalia, lateral; 41, ninth sternum and claspers, ventral.



Figs. 42–53. *Polycentropus fortunus:* 42, male genitalia, lateral; 43, cerci, dorsal; 44, ninth sternum and claspers, ventral; 45, aedeagus, lateral. *P. acanthogaster:* 46, male genitalia, lateral; 47, aedeagus, lateral; 48, ninth sternum and claspers, ventral; 49, cerci, dorsal. *P. bonus:* 50, male genitalia, lateral; 51, cerci, dorsal; 52, ninth sternum and claspers, ventral; 53, aedeagus, lateral.



Figs. 54–61. *Polycentropus clarus:* 54, male genitalia, lateral; 55, aedeagus, lateral; 56, ninth sternum and claspers, ventral; 57, male genitalia, less aedeagus, posterior. *P. alatus:* 58, ninth sternum and claspers, ventral; 59, cerci, dorsal; 60, male genitalia, lateral; 61, aedeagus, lateral.

Polycentropus clarus, new species

Figures 54–57

Although this species lacks most of the distinctive characters of the *gertschi* group, it is placed in the group because it seems to represent an extreme development of some of the tendencies apparent in *P. bonus* which is more clearly a member of the group. The shapes of the clasper and cercus are unique in *clarus.*

Adult.—Length of forewing, 6.5 mm. Color in alcohol, brown, appearing speckled with paler marks. Fore and hindwings with R_2 present; hindwing lacking crossvein between R_3 and R_4. Male genitalia: Ninth segment with anterior and posterior margins nearly vertical. Tenth tergum membranous. Cercus with a rounded outer lobe, and a platelike mesal lobe bearing a slender process at midlength and a longer, stouter process ventrally, a flattened sclerite between cercus and clasper. Clasper trianguloid in lateral aspect, with dark, erect dorsomesal and broader dorsolateral points. Aedeagus produced into a long, slender apicoventral lip; thin lateral plates apically; internally with a pointed, tubular structure, and 3 small spines.

Material.—Holotype, male: Mexico, Edo. Veracruz, Arroyo Claro, Sierra Sta. Marta, Los Tuxtlas, 18 Dec 1976, J. Bueno S. USNM Type 76870.

Polycentropus alatus, new species

Figures 58–61

This species apparently is related to the preceeding two species on the basis of the presence of a small digitate lobe borne from the inner face of the cercus. However, the shape of ventromesal lobe of the cercus and the clasper is distinctive.

Adult.—Length of forewing, 5.5 mm. Color in alcohol brown. Fore and hindwings with R_2 present; hindwing lacking crossvein between R_3 and R_4. Male genitalia: Ninth segment with anterior and posterior margins slightly expanded ventrad. Tenth tergum membranous. Cercus, with dorsolateral lobe small, rounded apically, united to a long, declivious ventral lobe which ends in a short hook; dorsomesally with a lightly sclerotized area bearing a slender digitate lobe near midline. Clasper with a thin, erect lateral lobe ending in a spinelike process; mesal shelf unornamented. Aedeagus with a apicoventral lip produced into a slender process; thin lateral plates apically; internally with a single large spine and a complex of lightly sclerotized ill-defined structures.

Material.—Holotype, male: Mexico, Edo. Chiapas, Colon (Lagartero), (30 km. northeast of Ciudad Cuauhtemoc), 8 Apr 1979, J. Bueno. USNM Type 76871. Paratypes: Same data 7♂ 1♀ (USNM, UNAM).

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Nesting Behavior and Prey of Argogorytes *Ashmead (Hymenoptera: Sphecidae)*

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ABSTRACT

The nesting behavior and prey of 4 species of *Argogorytes,* a primitive gorytine genus in the sphecid subfamily Nyssoninae, are reviewed. The wasps nest in the ground and dig relatively shallow, multicellular nests, provisioning the cells with 3 to 30 homopterous prey. The Palaearctic *A. mystaceus* and *A. fargeii* prey on nymphs of the genus *Aphrophora* (Aphrophoridae). *A. carbonarius,* endemic to New Zealand, preys on nymphs of the genus *Carystoterpa* (Aphrophoridae). The European *A. hispanicus* preys on adults of the genus *Hysteropterum* (Issidae). The nesting behavior of *Argogorytes* is discussed and compared with that of related gorytine genera.

The genus *Argogorytes* was established by Ashmead (1899) for those gorytine wasps with a broad head, well developed epicnemium (prepectus), strong oblique groove on the mesopleuron, and other features. Bohart & Menke (1976) gave a full generic diagnosis and considered subgeneric divisions to be unjustified. *Argogorytes* is undoubtedly one of the most primitive gorytine genera and is nearly worldwide in distribution, being absent only from the Afrotropical (Ethiopian) region.

Nothing significant is known of the biology of the 2 North American or 4 Australian species, nor of most of the 18 other members of the genus. Both sexes of the Australian *A. rufomixtus* (Turner) have been reared from cocoons dug out of a sandy bank near Brisbane, Queensland, but the prey is unknown. However, some information on the nesting behavior and prey of 4 species of *Argogorytes* is now available. Three Palaearctic species have been studied in Europe and Japan, and meager observations made on 1 species in New Zealand.

The three European species are readily separable by keys given by Beaumont (1964), and Lomholdt (1976) re-described the 2 better known species that reach Scandinavia. Benno (1977) discussed these 2 species in the Netherlands with special reference to ecological preferences and the host associations of their cleptoparasites.

Argogorytes mystaceus mystaceus (Linnaeus)

Originally described in *Sphex,* the nominate subspecies is the best known and most widely distributed *Argogorytes,* ranging through the Palaearctic region. Bohart & Menke (1976) gave a full synonymy. It is a common wasp in Europe and occurs also in North Africa, but no recent observations have been found on its nesting habits. Shuckard (1837) was probably one of the first to note that it was common in Britain on Umbelliferae in June and July, and to report capturing it with prey, the nymph of *Aphrophora* sp., entering a sandbank.

Hamm & Richards (1930) referred to earlier work on its biology, recording nymphs of the spittlebug (froghopper) *Aphrophora spumaria* (Linnaeus) (Aphrophoridae) as prey, and *Nysson spinosus* (J. Forster) as a cleptoparasite. The female wasp was reported to fly to the nest carrying the prey by her mid-legs after extracting it from the spittle-mass. According to one account, the wasp inserted her legs and sting into the froth, and according to another she plunged her head in to effect capture of the prey.

Evans & Eberhard (1970) mentioned pseudocopulation of males with the flowers of the orchid *Ophrys insectifera* (Linnaeus) whereby the latter are pollinated. Lomholdt (1976) also referred to this and the classic experiments of Kullenberg (1961) in Sweden on the subject.

Argogorytes mystaceus grandis (Gussakovskij)

This subspecies was described from Ussuri district, Eastern Siberia, U.S.S.R. by Gussakovskij (1933) and occurs also in Japan and Korea. Tsuneki (1965) observed its nesting behavior near Lake Suganuma in the Nikko region of Honshu, Japan. The burrows of the nests were 8–12 cm in length and 4–4.5 mm across. In a unicellular nest the cell was at a vertical depth of 7 cm and in a bicellular nest cells were 2.5 and 3.7 cm deep, the cells lying horizontally and measuring 17 mm by 10 mm.

Tsuneki reported that the burrows were closed with sand in the absence of the wasp, and noted that the prey-laden wasp opened the closed entrance with the fore legs without relinquishing the prey. When the wasp entered the nest the prey was left in the entrance of the burrow, being visible from outside, and then disappeared down the burrow. Presumably the wasp turned around within the nest, because the prey was dragged down the burrow from inside. The wasp was observed to capture *Aphrophora* spp. (Aphrophoridae) carried venter to venter and head to head, but it was not explicitly stated whether the prey comprised nymphs or adults. A completed cell contained 4 prey placed in the cell head inwards and venter uppermost. The egg measured 2.8 mm by 1.0 mm and was laid on the prey lying innermost in the cell. It was attached by the caudal end to one of the hind coxae of the prey and the cephalic end reached the fore coxa.

Argogorytes fargeii (Shuckard)

This Palaearctic species is widespread but is less widely distributed than *A. mystaceus* and not as well known. Shuckard (1837), who described it in *Gorytes,* noted that it was not uncommon in July on Umbelliferae in the London area and stated that he captured a female carrying the nymph of *Aphrophora spumaria* (Aphrophoridae). No recent observations seem to have been published on its nesting behavior.

Hamm & Richards (1930) summarized the observations of Adlerz (1906) in southern Sweden, who reported that the prey of this species (as *campestris* Mueller) comprised spittlebug nymphs of the genus *Aphrophora.* Adlerz stated that the wasp plunged legs and sting into the spittlemass to remove the prey, which was carried in flight by the midlegs to the nest. Burrows penetrated 10 cm vertically and the same distance horizontally into bare slopes of clay or gravel and were always left open. Nests were multicellular with 6–9 cells. In one nest 19–27 prey were found in each cell, but in a unicellular nest the cell contained 30 prey. In all cells the prey lay with heads pointing inwards, but neither egg nor larva was found.

Malyshev (1968) made some interesting comments on the absence of the egg in this and other instances, suggesting that it might be insecurely attached to the prey and fall off or be destroyed by the larva of an inquiline miltogrammine fly.

Nysson spinosus (see under *A. mystaceus*) has been recorded as a cleptoparasite of *A. fargeii,* but Benno (1977) has shown in the Netherlands that *N. spinosus* is restricted to *A. mystaceus* and *N. interruptus* Fabricius is a cleptoparasite of *A. fargeii.*

Argogorytes hispanicus (Mercet)

This species is known only from southern and central Europe. It was described in *Gorytes* from near Madrid by Mercet (1906) and has since been found in various other parts of Spain. Beaumont (1945) first recorded *A. hispanicus* from Switzerland, where it occurs in the Alps up to 1,800 m, and it has apparently been found in southern France. It is a little known species, and Beaumont suggested that it has probably been confused with its congeners and may range more widely.

The nesting behavior and prey of *A. hispanicus* were unknown until Janvier (1974)[1] studied a colony nesting at Málaga in southern Spain. Janvier reported colonies containing several tens of individuals, described digging, provisioning and nest structure, oviposition, structural features of the larva and its development, and cocoon formation. A nest with 6 cells and the mature larva with relevant structures were figured. The nest had burrows 10–20 cm long, and were multicellular with 5–7 cells, 15 mm long and 8–9 mm wide. The incubation period of the egg was said to be 4–5 days and the larval feeding period took a week. The ovoid cocoon was 11–12 mm long and 5 mm wide.

Janvier found that on hot days female wasps were active from 9000 to 2000 hours, alternating nesting activities with visits to the flowers of Umbelliferae to feed and with basking in the sun. No observations were made on males. Females explored vegetation for prey, which, when captured successfully, was taken to a nearby shrub and stung. In returning to the nest the wasp flew heavily with the prey held by the midlegs and landed a short distance from the entrance. Without releasing the prey, the wasp walked to the next, and, supported by the hind legs, used the fore legs to enlarge the entrance and took the prey down the burrow to the cell. The wasp returned repeatedly to the nest to deposit additional prey in the cell, the entrance being evidently left open during provisioning.

In excavating a nest, Janvier located a cell at the end of a burrow 14 cm long and within it found 8 paralyzed prey with the heads directed inwards. All the prey were *Hysteropterum reticulatum* (Herrich-Schaeffer). *Hysteropterum* is a widespread Holarctic genus with numerous species and belongs to the homopterous family Issidae. *H. reticulatum* is a well-known central and southern European species ranging from Germany to Sicily and Spain. One of the

[1] Janvier's paper was published in 1974 and is correctly cited by Bohart & Menke (1976), but appeared in *Graellsia,* 27, 1971 and this year is given in *Zoological Record, Insecta, Part E, Hymenoptera,* 110(13): 21.

first prey placed in the cell bore a minute larva. A second cell in the same nest contained 4 prey, the first one deposited having an egg attached to the upper mesopleuron. The egg was whitish, 2 mm long, somewhat curved, with the cephalic end directed towards the neck of the prey.

Janvier emphasized that the first prey placed in the cell was used for oviposition, stating that the wasp positions the prey on its side with the fore wings slightly apart to facilitate applying the egg lengthwise along the upper mesopleuron. After oviposition the wasp captures further prey, 6 to 10 journeys over several days being required to complete provisioning. The fully stored cell is closed with loose sand and an inner closure of the cell burrow made before the wasp digs the next cell. It was concluded that it required 4 or 5 weeks for a wasp to construct and provision the 5–7 cells in its nest with 40 to 50 adults of *H. reticulatum.* Wasps were said to spend the night in their burrows.

Argogorytes carbonarius (F. Smith)

This is the type species of the genus as designated by Ashmead (1899), and a series of the generotype was studied by Bohart & Menke (1976). *A carbonarius* is endemic to New Zealand and I recently discussed what is known of its biology (Callan, 1979). Gourlay (1930) was apparently the first to report this species (as *Gorytes*) preying on nymphs of the spittlebug *Carystoterpa fingens* (Walker) (Aphrophoridae). The prey was recorded as *Philaenus trimaculatus* White. Gourlay (1964) gave a brief account of the wasp provisioning its nest in the soil of garden beds at Nelson with late nymphal spittlebugs. Although he noted the source of the prey on young shoots of Meyer lemon trees, it was not stated how the nymphs were extracted from the frothy spittlemass surrounding them. The name of the prey was given by Gourlay in this paper as *Carystoterpa trimaculata* (Butler), which is a synonym of *C. fingens.*

The Aphrophoridae are represented by 2 species only in New Zealand and both belong to endemic genera. *C. fingens* was originally described in the genus *Ptyelus* and is a highly variable species. It is the more abundant and widely distributed of the 2 New Zealand aphrophorids and is found on various shrubs.

Gourlay did not record the length of the burrow of the wasp nor the number of cells constructed, mentioning only that up to 3 spittlebug nymphs were placed "in each burrow." Adult females of *C. fingens* vary in length from 7–9 mm, and the relatively large size of the late nymphs accounts no doubt for the small number of prey stored. Gourlay stated that on one of the prey "a single egg is deposited longitudinally between the rudimentary wings and the legs." He did not record whether the nest entrance was closed or left open in the absence of the wasp. In view of the fragmentary nature of these observations, it would be interesting to learn more of the nesting behavior of this New Zealand species.

Discussion

1. Species of *Argogorytes* nest in small colonies in the ground, usually in bare, flat, sandy soil, but also on slopes of clay or gravel, in sandbanks and in garden beds.

2. Adults of *A. mystaceus, A. fargeii* and *A. hispanicus* are reported to visit flowers of Umbelliferae.

3. Little is known of the behavior of male gorytine wasps, and no observations seem to have been made on the males of *Argogorytes,* except for those of *A. mystaceus,* which are remarkable in being attracted to and pollinating orchids.

4. Most Gorytini apparently spend the night on vegetation, but a few are thought to sleep in their burrows. Females of *A. hispanicus* are said to spend the night in their nests. Janvier (1928) reported that both sexes of *Clitemnestra* in Chile spend the night in the burrows.

5. *Argogorytes* females dig relatively shallow, multicellular nests with the fore legs, which have no tarsal comb or pecten. Burrows are reported to be 8–20 cm in length and 2.5–10 cm in vertical depth with

up to 9 cells measuring about 15–17 mm by 8–10 mm.

6. The nest entrance is closed in *A. mystaceus* but left open in *A. fargeii* in the absence of the female. In *A. hispanicus* the female on arrival with prey is said to enlarge the entrance, so it is presumably left at least partly open. Janvier (1974) used the verb "ensanchar" in his account of nesting in this species, and would surely have used "abrir" had the nest been closed. Most gorytine wasps close the nest entrance, but a few species, such as *Clitemnestra* in Chile (Janvier, 1928) and in Australia (Evans & Matthews, 1971), *Dienoplus* in Britain (Bristowe, 1948), and a species of *Hoplisoides* in Argentina (Evans & Matthews, 1973), are reported to leave it open.

7. In provisioning the nest, the prey is carried in flight by the female *Argogorytes*, using the legs to clasp it tightly venter to venter and head foremost. Several days are said to be required to complete mass provisioning a cell in *A. hispanicus* and the incubation period of the egg is 4–5 days, which is reminiscent of *Clitemnestra*. In *Argogorytes* the number of prey ranges from 3–30, placed in the cell with the head in and venter uppermost.

8. The prey in *A. mystaceus, A. fargeii* and *A. carbonarius* comprises nymphs of the family Aphrophoridae in the genera *Aphrophora* and *Carystoterpa*. In *A. hispanicus* the prey comprises adults of the family Issidae in the genus *Hysteropterum*. Both prey families are Homoptera Auchenorhyncha but pertain to different superfamilies—Aphrophoridae to Cercopoidea and Issidae to Fulgoroidea. *Argogorytes* was formerly thought to be exceptional in specializing on nymphal Aphrophoridae until the discovery of adult Issidae used as prey by the genus. Most gorytine wasps provision their nests with one or several homopterous families; *Ochleroptera* is reported to prey on 5 families and *Sagenista* preys on 6 families (Callan, 1977). By contrast, some *Hoplisoides* prey on numerous species of the single family Membracidae, and Evans & Matthews (1971) reported *Austrogorytes* in Australia preying on 7 species of one endemic family Eurymelidae. *Pseudoplisus* seems to be one of the few gorytine genera exhibiting a high degree of prey specificity, storing its nests exclusively with adult Aphrophoridae, one species of wasp restricting itself to a single species of prey. In South Africa numerous prey records from widely disparate areas indicate that *P. natalensis* (F. Smith) preys only on *Ptyelus grossus* (Fabricius), and *P. ranosahae* (Arnold) in Malagasy apparently preys only on *Ptyelus goudoti* (Bennett) (Callan, unpublished observations).

9. In most gorytine wasps, the egg is laid on the last prey deposited in the cell, being attached longitudinally on the ventral side of the thorax alongside the coxae (Evans, 1966). The egg is reported to be laid on the first prey placed in the cell in *A. mystaceus* and *A. hispanicus*, in the former species attached to the outside of one of the hind coxae and in the latter to the mesopleuron of the thorax. In *A. carbonarius* the egg is said to be laid between the wing-buds and the legs. In *Clitemnestra* in Chile the first prey is also reported to bear the egg, which is apparently attached to one of the midlegs (Janvier, 1928), and in *Dienoplus* in U.S.S.R. the egg is also evidently on the first prey deposited in the cell (Malyshev, 1968).

10. Cocoons in *Argogorytes*, as in related genera, are hard and ovoid, more pointed posteriorly, incorporating sand grains in the walls, but without mural pores. In *A. hispanicus* cocoons are reported to be 11 to 12 mm long and 5 mm wide.

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BOARD OF MANAGERS MEETING NOTES

649th Meeting—September 3, 1980

The 649th meeting of the Board of Managers of the Washington Academy of Sciences was called to order at 7:30 PM on Wednesday, September 3, 1980 by President Marjorie R. Townsend. The meeting followed a reception that had been arranged by the Board for delegates and presidents of affiliated societies. After corrections were suggested and made, the minutes of the previous meeting were approved.

In considering the minutes of the previous meeting, Dr. Honig and Dr. Alfred Weissler reaffirmed that there was not an automatic annual grant from the American Association for the Advancement of Science as there had been in the past, but rather that it was necessary for each society to apply for these for particular purposes each year. Dr. Richard Cook added that it was up to the Board of Managers to apply on the basis of its decision of what had to be done. Mr. Grover Sherlin had said during the previous meeting that we had not applied for the money this year.

The Secretary reported that Mrs. Donna E. Smith had worked virtually full time during most of the summer uncovering and answering correspondence dating back through the last two years about nonreceipt of the Journal and other matters to bring affairs of the Academy up to date. Mrs. Loreen McDaniel had also spent time setting up the Washington Academy of Sciences' accounts and setting up the Washington Junior Academy of Sciences' accounts to get those bills paid, and working with Drs. Florence and Alphonse Forziati as they spent days in their auditing of income and expenditures.

The Academy had been sent the *Records of the Columbia Historical Society,* the Fiftieth Volume for 1980. The Secretary indicated she would write the Society a letter of thanks from the Academy.

The resignation of Dr. Kenneth N. Derucher as Journal Editor was accepted.

In discussion of potential affiliation of the Academy, it was mentioned that there were 20 Sigma Xi chapters in the Washington area. Although the Academy Board is composed of representatives both of local and national associations, Dr. Honig mentioned that so far no association with more than one local chapter has applied or been invited for affiliation.

The Treasurer's report was presented. Dr. Al Forziati said the audit was continuing. Dr. Ronald W. Manderscheid moved, and it was seconded and passed, that the Treasurer's report be accepted.

Dr. Honig passed around to the Board an interim report of the Policy Planning Committee, entitled a "Progress Report of the Long Range Planning Committee." Participants in this have been Mr. E. M. Buras, Jr., Dr. R. K. Cook and Dr. K. Stern. Top priorities stemming from their June 11, 1980 meeting were: 1) to increase membership; 2) to streamline the management process; 3) to have more joint activities and meetings; and 4) to put the Academy on a sound financial basis. Lowest priorities were to raise prestige and public stature of the Academy and to present prizes and awards. Recommendations from the July 3, 1980 meeting were: 1) to reactive the Membership Promotions Committee separate from the current Membership Committee to disseminate membership formation and actively seek out potential new members; 2) to have a new, updated brochure to attract new members; 3) to look at potential sources of new members including local universities, governmental institutions, foreign scientific missions and attaches, and affiliated societies; 4) listing committee chairman in the Journal so readers can contact them; 5) encouragement of more joint activities; election of three new vice presidents: a. Membership, b. Programs, encompassing meetings, symposia and the Joint Board, and c. Communications for oversight of the Journal, encouragement of Science Talent, awards for Scientific Achievement, grants in aid, and public information. The three elected vice presidents would become members of the Executive Committee. Dr. Honig concluded with the statement that additional meetings of the Committee will be held this fall.

Dr. Cook, Chairman of the Ways and Means Committee, said the issue of raising fellow dues from $25 to $30, tabled since the last meeting, could now be discussed. The motion to raise them was moved by Dr. Cook and seconded by Mr. James Wagner. In the ensuing discussion, Dr. Cook said this took inflation into account. Dr. Honig said it had been tabled the last time because we did not have a budget, nor will we have one until we know the size of the dues-paying membership. Dr. Ruth Landman pointed out that AAAS dues were only $40 which included 52 issues of SCIENCE. After the question, the motion was defeated. Dues for 1981 will remain $20 for members, $25 for fellows.

Mr. Verne Birks pointed out that the Journal was both expensive and, at this juncture, not of the highest caliber. It was also pointed out, whereas it formerly had come out 11 or 12 times a year, it now was a quarterly. Dr. Honig said we were still paying old bills of the Academy in the painful process of changing the business management and office support, and that we no longer were paying for a full-time office manager or rent to save expenses. Dr. Cook added that the Ways and Means Committee was seeking ideas for more sources of income.

In reporting on the Committee on Meetings, Mrs. Townsend said that Dr. Richard P. Hallion had arranged the October and January monthly meetings of WAS to be co-sponsored with the Society of Biology and Medicine. The October 16 meeting was being co-sponsored by the Association of Plant Physiologists. The meetings list had also been sent to the Capitol chemists association. The Uhuru Memorial Symposium on December 13 follows a week-long meeting of the Tenth Annual Meeting of the Texas Astrophysics Association in Baltimore to be attended by an estimated 1200 from the United States and 600 from overseas, including a Chinese delegation.

Registration for the Uhuru meeting was to be $20 before December, $25 after that. This included lunch and the Proceedings. Name badges, mailing of proceedings to participants, and brochure expenses were being underwritten by the Goddard Space Flight Center. Dr. John Naugle, recently retired as Chief Scientist of NASA, would be guest editor, and page charges would not be asked of contributors.

Mrs. Townsend then reported on the Encouragement of Science Talent Committee, indicating that the president of WAS had been away much of the summer.

Dr. H. McIlvaine Parsons, reporting for the Public Information Committee, said announcements of WAS programs for the year had been sent to 21 newsletters of affiliated societies. One notice appeared in the July 18, 1980 *Labstracts,* cited information provided by Mr. Birks (Naval Research Laboratory, Washington, D.C., Vol. XX, No. 29, P. 4.) Mr. James Wagner included an invitation to all WAS Board members to all meetings of the American Meteorological Society, D.C. Chapter.

Dr. Florence Forziati, reporting for the

Audit Committee for the WAS, said they had gone back to 1977. Mrs. Elaine Shafrin, who had paid all expenses of the WJAS from July 1977 to April 15, 1980, was going to be reimbursed for this $1767.86, leaving $218 in the WJAS account. Dr. Forziati were thanked by Mrs. Townsend for their careful attention to a very difficult undertaking.

The report of the Bylaws and Standing Rules Committee will be discussed at the next meeting of the Board.

Dr. Alfred Weissler reported for the Interdisciplinary Cooperation Committee. Discussion of the Journal noted that although nothing had been published as yet, Dr. Richard Foote was taking over as Editor pro-tem for the next four issues, with his former compensation, and was intending to send the material to the printers on September 8. Dr. Weissler said Mrs. Donna Smith was preparing the committee lists. Names of officers of affiliated societies had been received and were being filed.

For the Science, Engineering and Society Committee, it was noted that Dr. Abraham had lost his wife the week before and that the Secretary had sent him an expression of sympathy from the Academy. Discussion then centered on the National Science Foundation proposal which NSF had indicated could not be funded in its present form. Dr. John O'Hare had written to Dr. George Abraham and Mr. Guy Hammer about the proposal, suggesting that it be conceptually and methodologically tightened. In essence, Dr. O'Hare said that the proposal work plan was vague and loose, an inadequate response to the problem. There were no fresh concepts, precision, or specifics about methods to be used, but these things could be corrected. Mr. Hammer said he appreciated the excellent suggestions of Dr. O'Hare, and indicated that the proposal could be resubmitted. It was also noted that before the WAS could completely endorse a project, it had to have sufficient details of its content and budget, which should include some overhead for the Academy, such as the 10% received by the American Association of Medical Instrumentation which had supported a proposal. Development of support for the Academy could take cognizance of the many retired persons in the area, as the Joint Board had. It was further mentioned that the Joint Board had had a NSF grant in 1967 for science teacher educational programs which Mr. Grover Sherlin and Dr. Jean Boek had largely administered. Although the proposed project did not indicate how it would have been monitored, this should be done by the WAS Treasurer. Mr. Hammer said for the preliminary proposal NSF had specified that the entire project had to be described in five pages and that the comments were very valid. Because various Board members stated that there was not enough time to get enough members of the Academy involved in this project for the September 30, 1980 proposal deadline, that consideration might be given to getting ready for the next one. Dr. James Schooley proposed that encouragement be given to this and other proposals that were in accord with the WAS bylaws, which indicate that this organization is dedicated to the diffusion of scientific knowledge. Since this proposal was designed to involve populations not ordinarily reached by scientists, it seemed congruent with the WAS purpose. The problem for most learned societies, he added, was the inability to gain a great deal of public support. His comments were endorsed by Mr. Buras.

Dr. Schooley went on to move that WAS lend its support to the generation of a proposal along the lines embodied in the proposal that was sent out with the last WAS minutes. This was seconded by Mr. Buras. In the discussion it was asked by Dr. Honig if the proposal had been rewritten. Mr. Hammer replied that he was waiting to see if he had WAS encouragement to do so. Dr. Schooley indicated that if his motion succeeded that a committee could be deputized to assist with this. Dr. Landman said that as a departmental chairman at her university, signing a proposal was done as a responsible member of the faculty who endorsed the content and purpose of this. Mr. Hammer said under the NSF Guide for

Science and Citizen Planning Studies the next proposal deadline was January 15, followed by a March 15 final proposal deadline. Dr. Honig said that if the Board became involved with a proposal it would place its confidence in Mr. Hammer and Dr. Abraham who would provide oversight. Before the Board did so, however, Mrs. Townsend stated that it should have sufficient details of content of the proposed project. It was further pointed out that the final proposal should incorporate suggestions of Dr. O'Hare. At the question, the vote by raised hands was seven for and nine against the motion.

In reporting for the Ad Hoc Journal Committee, Dr. O'Hare noted that committee's tenure ended in October 1980. There had been a problem of collecting factual data on which the committee could act. During the years the Journal had changed in frequency of issuance, price of editorship. In January of 1960, Chester Page had been editor and he had had a Managing Editor, a Board of Associate Editors, and an Editorial Review Board composed of a consultant from every affiliated society. When Dr. Foote became editor in 1970, none of this had been continued. There had been no control during the past decade on the number of pages printed each year. The Ad Hoc Committee's plan, therefore, was to come up with a rational plan for managing the Journal by the next meeting of the Board for its consideration. In light of Dr. Derucher's resignation as editor, Dr. O'Hare said they wondered if Dr. Joel Fisher were still amenable to becoming editor. Dr. Alphonse Forziati said he would but with his new post at the State Department he could not do this at present since he would be going overseas. However, he was willing to do what he could even now.

Dr. JoAnne Jackson reported for the Joint Board on Science and Engineering Education that there were three new members. Re-publishing the Blue Book now would be much easier than when Mr. Sherlin had to do it from the beginning each year, since now the data had been put on a floppy-disk. Their present theme: Energy—Key to the Future.

Revision of the WAS flier was discussed, with Dr. Honig saying it no longer was responsibility of the Committee on Policy Planning. Mrs. Townsend has identified 100 staffers of NASA as potential Academy members to whom she is writing an invitation letter. She asked for volunteers to work on an ad hoc membership committee for working on the flier. Mr. Birks said we had to be discreet about who was being nominated for fellow. Others of the Board agreed, but indicated that personal knowledge of a nominee by a WAS fellow had virtually always been the best guide.

For Old Business, Mrs. Townsend said for this year's meeting she had tried to vary the night of the week to accommodate those who had to teach or had other commitments on specific evenings.

The meeting was adjourned at 9:30 P.M.

Respectfully submitted,

Jean K. Boek, Ph.D., Secretary

650th Meeting—October 30, 1980

The 650th meeting of the Board of Managers of the Washington Academy of Sciences was called to order at 7:35 P.M. on Thursday, October 30, 1980, by President Marjorie R. Townsend. After corrections were suggested and adopted, the minutes of the previous meeting were approved.

As the first item on the Agenda provided by the President, there was note of the new delegate from the Geological Society of Washington, Dr. James V. O'Connor, Physical Scientist, U.S. Geological Survey, National Center, Mail Stop 109, Reston, Virginia 22092. Another new delegate for the American Association for Dental Research is Captain W. R. Cotton, Director, Casualty Care Research Program, Naval Medical Institute, National Naval Medical Center, Bethesda, Maryland 20012. The former delegate had been Dr. Donald W. Turner.

Mr. Grover Sherlin for the Membership Committee reported that five persons have been appointed to each of ten panels for evaluating applicants for Fellow in the Washington Academy of Sciences in 1) Agricultural Sciences, 2) Behavioral Sciences, 3) Biological Sciences, 4) Chemistry, 5) Earth and Space Sciences, 6) Engineering, 7) Mathematics, 8) Medical Sciences, 9) Physics, and 10) Science Education. On each panel there are five positions labeled A to E. The full term for each member is six years. In setting these panels up, however, the terms are staggered in order that only one or two members have to be reappointed during any one year.

The first reading or evaluation of qualifications of Dr. Charles Townsend was done by the Board. It was moved, seconded and unanimously passed that he be approved. Article II, Section 7 of the Bylaws stipulates that:

> An individual of unquestioned eminence may be recommended by vote of the Committee on Membership Promotion for immediate election to fellowship by the Board of Managers, without the necessity for compliance with the provisions of Sections 4 and 5.

It was moved, seconded and passed unanimously that Mr. A. Thomas as Director of the Goddard Space Flight Center (NASA) and Dr. John H. McElroy as Deputy Director of Goddard be elected as Fellows of the Academy. For other nominees, three out of five panel recommendations are necessary in addition to the two readings by the Board of Managers.

The report of the Policy Planning Committee presented by Dr. John Honig is Exhibit A. In addition to these suggested changes to the Bylaws, it was noted that delegates to the Academy for affiliated societies should be members or elected to Fellow, if they are qualified, as they had been before 1966. It was also emphasized that more business could be handled by the Executive Committee than is presently done. The proposed changes will again be discussed during the December 4 meeting.

Dr. Richard Cook, Chairman of the Ways and Means Standing Committee, said he had no report at this time.

Mrs. Townsend in reporting for the Committee on Meetings said the Philosophical Society was mailing out notices for the November 21 meeting at the Cosmos Club at which Dr. Donald Chalkley would be speaking on "Fetal Medicine: Research Imperatives, Ethical Risks." For the December 13 Uhuru Memorial Symposium, the Goddard Space Flight Center will open the auditorium and cafeteria. Registration before December 1 is $20, after that date $25 to pay for the lunch and other incidentals. In addition to the 58 registrations already received, 50 are expected to come from NASA staff members. The brochure will be mailed to all members in early November. Exhibit B shows the program for the rest of the year, as well as details of the Symposium. This had earlier been sent to all members (except for locations of the meetings) with their dues notices.

The Washington Junior Academy of Sciences will meet in one of the main floor lecture rooms in the Old Dominion Building of National Graduate University on Saturday, November 22. Mr. Paul Young of the WJAS Executive Committee is arranging this.

Dr. H. McIlvaine Parsons in reporting for the Public Information Committee said that the IEEE journal will carry a notice of the January 14 meeting, which is in the Officers Club and Research Laboratory Auditorium of the Bethesda Naval Medical Research Center. The Medical Society of Washington, D.C. declined to co-sponsor a meeting because it does not have a continuing education program.

Dr. Florence Forziati, Chairman of the special committee on audit, gave the following report: The Committee completed IRS Form 990, Return of Organization Exempt form Income Tax, which was due May 15, 1980 but had not been done by the secretarial service previously employed. The form was mailed to the IRS with a covering letter explaining the circumstances that led to the delay and requesting that the return be accepted without penalty. (The penalty is figured at $10 per day from May 15 to the date received by IRS, amounting to $1,200 in our case.) The Committee is glad to report that IRS has accepted the return without penalty.

The Nominating Committee consisted of five past WAS presidents: Dr. Mary Aldridge, Dr. Florence Forziati, Mr. Grover Sherlin, Dr. Alfred Weissler, and Dr. Al Forziati. The final ballot, including write-in nominations from Fellows, will be mailed before December 15, 1980.

The Ad Hoc Journal Committee report was presented to the Board. Discussion also centered on nomination of Dr. Irving Gray, Professor of Biology of Georgetown University and Dr. Joseph H. Neale, Assistant Professor of Biology at Georgetown. Their full curriculum vitae were given to each Board member present and are on file in the Academy office. Both have impressive research records. It was moved and seconded that they be appointed as Co-Editors by the President for an indefinite period beginning January 1, 1981, and that this appointment be reviewed annually. After a discussion, the motion was withdrawn. Instead, the Board recommended to the President that she appoint Dr. Gray as Editor and Dr. Neale as Co-Editor. This was accepted.

Mr. Sherlin in reporting for the Joint Board on Science and Engineering Education said that they had had two meetings this year and that revisions were being made for the blue directory, detailing projects and programs, and school liaison and administrative officers for public, Catholic, and independent schools in the District of Columbia, Prince George's County, Alexandria, Falls Church, Fairfax, and Prince William County in Virginia (public schools only).

A letter has been drafted to be sent to all affiliated societies of the WAS indicating purpose of the Joint Board and asking for a contribution.

Dr. Jean Boek reported that bids are being received for printing the revised WAS flier.

In accordance with item 7(b) of the Standing Rules of the Board of Managers, the request for affiliation by the Association for Science, Technology and Innovation was considered by the Committee on Policy Planning. After its report to the Board, it was moved, seconded and passed with one dissenting vote that the Fellows of the Academy have an opportunity to approve or disapprove affiliation of the association on the December, 1980, ballot.

The meeting adjourned at 9:40 P.M., followed by an Executive Committee meeting.

Respectfully submitted,

Jean K. Boek, Ph.D., Secretary

Exhibit A

Proposed Changes to the By-Laws

Article IV. Section 1.

Change to read:

. . . a President, a President-Elect, three Vice Presidents, a Secretary . . . Article IV. Insert new Section 3 (between Section 2 and old Section 3.)

New Section 3.

The three elected vice-presidents shall coordinate groups of committees in selected areas as follows:

Vice President for Membership
- Membership Committee
- Membership Promotion Committee

Vice President for Programs
- Meetings Committee
- Symposium Committee
- Joint Board of Science and Engineering
- Junior Academy of Sciences

Vice President for Communications
- Public Information
- Encouragement for Scientific Talent
- Awards for Scientific Achievement
- Grants-in-Aid
- Journal Policy Committee
- Journal Editor

Committee chairmen shall report directly to their respective vice-presidents who shall coordinate their committee activities and represent them on the Executive Committee. Committee chairmen will continue to submit individual reports to the Board as required.

Renumber remaining sections.

Article IV. Section 9.

Change to read:

. . . President-Elect, of each Vice President, of Secretary and of Treasurer, . . .

Article V. Section 3.

Change to read:

The Board of Managers shall formulate Academy policy and transact all business of the Academy . . . shall be twelve of its members.

Article VI. Section 1. COMMITTEES

The Executive Committee, consisting of three Presidents, President-Elect, the three elected Vice-Presidents, Secretary, Treasurer, and two members appointed annually by the President from the membership of the Board, shall be responsible for conducting the Academy's business, guided by policies developed by the Board of Managers.

As part of these duties the Executive Committee shall have general supervision of Academy finances, approve the selection of a depository for the current funds, and direct the investment of the permanent funds. At the beginning of the year it shall present to the Board of Managers an itemized statement of receipts and expenditures of the preceding year and a budget based on the estimated receipts and disbursements of the coming year, with such recommendations as may seem desirable. It shall be charged with the duty of considering all activities of the Academy which may tend to maintain and promotion relations with the affiliated societies, and with any other business which may be assigned to it by the Board.

Exhibit B

Program Remaining for 1980–1981

Thursday, February 19, 1981—"Prospects for Solar Energy in the 80's," Dr. Peter Varadi, Kenwood Country Club

Thursday, March 19, 1981—Awards Banquet, Georgetown University Cafeteria

Thursday, April 16, 1981—"Human Performance within Modern Technology," Dr. Richard W. Pew, Kenwood Country Club

Thursday, May 21, 1981—"Space Systems for the 80's," Marjorie R. Townsend, Kenwood Country Club

651st Meeting—December 4, 1980

The 651st meeting of the Board of Managers of the Academy was called to order at 7:30 P.M. on Thursday, December 4, 1980 by President Marjorie R. Townsend. After corrections were offered, the motion was made, seconded, and carried to approve the minutes.

In reporting on the Academy's office management, the Secretary said that the costs for staff time to write letters in response to complaints about the tardiness of the JOURNAL, to straighten out and keep updated the mailing lists for the JOURNAL, WAS members, WJAS and Joint Board, to answer requests for information from the JOURNAL and records, to get the files in order and to maintain them, to answer other correspondence, to type and send out minutes, to make arrangement for monthly dinner meetings, and to serve the membership and other committees greatly exceed the monthly amount that the Washington Academy of Sciences was able to pay to National Graduate University. The total cost for staff salary and wage work of the Academy from June to the end of November, 1980, was $6,916, whereas reimbursement by the Academy was $4,302, which meant that the University had subsidized Academy activities in the amount of $2,613 for this period. On an annual basis, the subsidy would be expected to be $5,226. The non-recurring items of this total amounted to $1,630 for setting up the mailing list after the Executive Committee had worked for some 75 person hours at Mrs. Townsend's home, and answering correspondence from the United States and abroad about the non-appearance of the JOURNAL. However, this amount was more than matched by the work contributed to the Academy by the President this year in arranging the December 13 Uhuru Symposium, and in compiling, printing and putting out and keeping current the Directory of the Board of Managers. Mrs. Townsend further has taken full responsibility for having her own letters typed and sent to elected fellows and members, as well as to more than 100 prospective members of WAS. The Secretary also pointed out that 1980 was the first year in a long time in which the Academy did not have to borrow money to maintain cash flow during the summer, thereby saving the Academy interest costs. Further economies in the current management were brought about by transferring the mailing lists to labels that could be xeroxed instead of continuing the expensive computorized lists, and by the office arranging to send out the *Journal* to save another $200 that the printer would have charged. Also, this year the Academy has not had to pay for its office and meeting room space.

The Treasurer has been working with Mrs. Loreen McDaniel at National Graduate University to summarize income and disbursements, assets and liabilities of the Academy as the basis for next year's budget. At present there is enough in the bank account to pay publication of the 1980 JOURNAL.

Mrs. Townsend noted that Dr. Paul Oehser had given a fine talk the previous evening to the Biological Society of Washington.

Mr. Grover Sherlin in reporting for the Committee on Membership said the first reading for nominated fellows had been done in the previous meeting. The persons had also been listed in the minutes that had been sent to all members of the Board. It was moved and seconded that persons who had first been presented during the October 4, 1980 Board meeting be elected as fellows. These included Mr. Jeremiah J. Madden, Dr. Thomas J. Lynch, Mr. Robert C. Baumann, Dr. Siegfried J. Bauer, Dr. Robert D. Chapman, Dr. Harold Glaser, Dr. Thomas L. Cline, Mr. Harry A. Taylor, Dr. William P. Bishop, Dr. Michael J. Mumma, Dr. Charles J. Pellerin, Jr., Dr. Werner M. Neupert, Dr. Rudolf A. Hanel, Dr. Albert Rango, Dr. Vincent V. Salomonson, Dr. Charles E. Townsend, Dr. Lowell Thomas Harmison, Dr. Bernhard Edward Keiser, Dr. Lawrence Martin Leibowtiz, Dr. Edward James Martin, Dr. Joseph W. Ray, Dr. Vera R. Usdin, Mr. Roderick Sotelo Quiroz, Dr. Coryl LaRue Jones, Dr. Thomas B. Malone, Dr. Robert William Swezey, Dr. Robert Flanders Clarke, Dr. Jo-Anne Alice Jackson, Mrs. Betty Jane Long, Dr. Miklos M. Breuer, Dr. Robert Franklin Farmer, III, Dr. Stephen Krop, and Dr. Lucy B. Hagan. The first reading was then done for Dr. Dudley G. McConnell, Mr. Robert O. Aller, Mr. John J. Quann, and Mr. Gilbert Ousley, Sr. Upon election to the Academy, each has been receiving a letter from Mrs. Townsend. Then Mrs. Donna Smith in the office has been adding their names to the mailing list and card file and billing them for 1981 dues.

Dr. Richard Cook in reporting for the Ways and Means Committee recommended that the Academy reestablish a Committee on Membership Promotion.

For the Committee on Meetings, Mrs. Townsend said that 167 were presently registered for the Uhuru Memorial Symposium, with 18 being from abroad. A total of 95 checks have been received. The countries represented are Switzerland, Australia, Ireland, United Kingdom, Italy, Japan, India, Holland, Germany, Sweden, Israel, Hong Kong, China (Peking), Turkey, Philippine Islands, Canada, Belgium and Austria. Uhuru is the Swahili word for freedom. Speakers have been requested to arrive with their manuscripts in ahead of time in order that the Proceedings can be published in the March, 1981, *Journal* of the Academy.

In discussing the January 17 monthly meeting notices sent to all members together with their ballots, it was suggested that signs be posted on the Bethesda Naval Medical Center Grounds for location of the lecture.

Announcements for the Awards Committee have been mailed out.

The new Chairman for the Encouragement of Science Talent is Dr. Jerry Baruch. The November 22 meeting of the Washington Junior Academy of Sciences at National Graduate University had been well attended.

The Nominating Committee Chairman showed the sample ballot to the Board which, together with an envelop to be signed, was in the mail to all members. When each is received, Mrs. Donna Smith then checks to see if dues have been paid, checks off their name on an alphabetical listing of members, takes the ballot out of the envelop and places it in the ballot box for the tellers to count.

No one was present who planned to attend the American Association for the Advancement of Science meeting in Toronto on January 3, 1981.

Dr. John O'Hare passed out copies of the report of the Ad Hoc Committee on Policies for Academy Publications (Exhibit A). In discussing this, he suggested that the Sigma Xi format be used in the future for having more broadly focused review articles, with a total of 128 pages for the year. The usefulness of the Directory issue was reaffirmed, but the recommendation was that it be made a fifth issue in a less expensive format. The additional cost even of a xeroxed list was mentioned, as well as the fact that this type of issuance would not be included in the bound library copies of the *Journals*. It was moved and seconded that the directory of members and fellows be a separate publication in addition to the four issues of the *Journal* published each year and that this not be the responsibility of the Editor of the *Journal*. This was defeated by a vote of 6 to 4. Dr. Joseph Neale, as Co-Editor then suggested that the Directory be published every alternate year in September, but Dr. O'Hare felt that this should be an annual issue in view of addresses and other changes that occur.

The 128 pages per annum were based on a multiple of 32. The 1979 total had been 188 pages, with the Directory being 29 pages. There appeared to be no estimations from printers on the cost per page. However, it was suggested on the basis of this amount that bids be obtained from various printers. Bids already received by Mrs. Smith were given to Dr. Neale. Mr. Sherlin said in the past the *Journal* had had its own Treasurer and its separate budget. Neale said he preferred that system, as that would permit them to know what funds were available to work with. Mr. O'Hare suggested not having more than 157 pages a year. Mrs. Townsend asked the Editors to come to the next Board meeting with a proposal. Dr. Al Forziati thought that past costs could be one guide. Dr. Ronald Manderscheid observed that in view of the rapid advances in technology we should investigate how the quality of the *Journal* could be maintained with even lower costs than at present, such as having the authors responsible for typing the manuscript in a certain pattern that could be directly photographed. Dr. Neale said there should be no page charges to authors unless an author had funds for this in a research or other budget. The motion was made and seconded that page charges to authors not be mandatory but rather requested of an author only on the basis of ability to pay. In the ensuing discussion, Dr. Neale said that they would like to be in a position of being able to solicit manuscripts from authors without adding the stipulation of their paying $25 per page. The motion was carried.

In reviewing the eighth point of the report about format, Dr. Manderscheid thought the *Psychological Bulletin* might be examined as an example. There might also be an occasional monograph or special issues on a specific topic. It was moved by Dr. O'Hare and seconded by Richard Cook that papers from the WAS sponsored symposia be published in a separate monograph. In the discussion, Mr. Sherlin said these symposia had been very important to the Academy *Journal* and that he was confident that the new editors could get the manuscript from the December 13 symposium to have the issue out on time. Dr. Manderscheid reflected that special issues may be more viable than the *Journal* itself. Dr. O'Hare noted, however, that in the past these issues had been left over. Mrs. Townsend said that for the December 13 Uhuru Symposium on the Past, Present and Future of X-ray Astronomy that we would know exactly how many attended and therefore how many to print. The additional costs of a special issue were also considered. The motion was defeated.

For Point 10 of the Ad Hoc Committee's report, organization of the editorial staff, it was noted that although the WAS *Journal* editor for the previous decade had been alone in this job, in the past there had been many associate editors to obtain and screen manuscripts. The appointment of a managing editor was strongly recommended by Dr. O'Hare for handling advertising, printing bids, bill payment and the like. Mrs. Townsend stated that after hearing these discussions, the present editors should tell the Board how they wished to operate. The motion to create a managing editor was tabled. Mrs. Townsend on behalf of the Board thanked the Ad Hoc Committee for a job well done.

In discussion of the publication schedule of the 1980 *Journal,* Dr. Al Forziati indicated that Dr. Richard Foote had accepted responsibility for getting them out. Dr. Neale thought they were to be out by December, 1980.

The status of revision of flier is that only one bid had been received from the 10 printers to whom the flier had been sent for a price estimation.

Under new business, Mrs. Townsend reported on a suggested by Dr. Lloyd Church, Chairman of the Board of the Great Oaks Center. He is anxious to sponsor a symposium on a problem faced by mental institutions of every state of sexual relations in homes for the mentally retarded. Since this was an issue that could not be handled by governmental units, he thought it would attract people from around the nation. Mrs. Townsend had talked with Dr. Manderscheid and another person about the Academy sponsoring the symposium. Dr. O'Hare suggested consulting the Psychological Association and then Academy affiliates such as the Washington Psychiatric Society which might consider being co-sponsors. Mr. Sherlin counted at least five societies that might be interested in co-sponsoring a conference of this type. Mr. Cook thought there might be professional societies specifically interested in this topic in addition to this that might be involved. Dr. O'Hare volunteered to contact the clinical psychologists about this in order to get informed people involved in this.

The last item of new business was consideration of Academy membership of delegates to the Board of Managers from affiliated societies. Before 1966 the bylaws had stipulated that delegates were to be fellows. Dr. Jean Boek stated that if a delegate were not a member or fellow there would not necessarily be any commitment to the Academy. Dr. Al Forziati asked if it were not strange that people would be allowed to vote on the fate of an organization without having even the commitment to it of being a member. The point to be made was that sitting as delegates to the Board should have a connection to it that would commit them to the organization. The meeting adjourned at 9:55 P.M.

Respectfully submitted,

Jean K. Boek, Ph.D. Secretary

Exhibit A

4 December 1980

To: Marjorie R. Townsend
President, WAS

From: Ad hoc Committee on Policies for Academy Publications
W. M. Benson
L. S. Birks
R. R. Colwell
J. H. Howard, Jr.
J. J. O'Hare (Chair)

Subj: Summary of recommendations

1. *Continuance.* No arguments were advanced to discontinue the publication of the *Journal of the Washington Academy of Sciences* whose first issue appeared in July 1911. A *Proceedings of the WAS* made its first appearance in 1899 and a *Directory* was published in 1889; both of these, of course, have been discontinued.

2. *Content.* It is recommended that the *Journal* structure revert to the practices in effect prior to 1970, i.e. publication of primary research reports should not be encouraged. Instead, a preference should be given to articles that review or trace the development of important scientific events and that no more than one such paper appear in each issue. The remainder of the publication should reflect Academy news, events, personalities and local activities of interest to members.

3. *Directory.* It is recommended that the *Directory* be a separate publication that is not the responsibility of the Editor of the *Journal.* This publication should appear annually around 15 September.

4. *Schedule.* It is recommended that a quarterly publication schedule be followed: 15 March; 15 June; 15 September; and 15 December.

5. *Page allocation.* The number of pages should be costed out for the year in conjunction with the budget of the Treasurer; the allocation should be voted upon each year by the Board of Managers. As a first approximation it is recommended that the *Journal* be allocated 128 pages per annum.

6. *Press run.* The press run should be costed out for the year in conjunction with the budget of the Treasurer; the total will be determined by the number of members predicted for the year, the subscription list, and an over-run that should not exceed 5% of the run for that issue, for later sales.

7. *Page charges.* Charges shall not be mandatory but requested on the ability to pay. Exceptions may be made when there is an excessive use of figures, tables, and photos; and that would a judgment of the Editor.

8. *Format.* It is recommended that the division of the Journal into three sections be continued: feature articles, research reports, and Academy news. Indexing of each volume ceased in 1960 and need not be resumed.

9. *Other publications.* The publication of papers that are given at WAS sponsored symposia should appear as a separate monograph, with its own editor, and costed out separately, with a publication date determined by the symposium organizers. The *Journal* should not be expected to be the natural outlet for such events.

10. *Organization of editorial staff.* The Editor of the *Journal* would be expected to recruit an editorial staff to consist of up to 6 Associate Editors from diverse fields represented by the affiliated societies, and up to 11 members of an Editorial Board to act as reviewers and solicitors of articles for the Journal.

11. *Management of publications.* It is recommended that the Editor of the *Journal* be charged exclusively with the selection, editing, and transmittal of the copy to the printer; the imposition of the task of management and administration shall be assigned to a Managing Editor to oversee production of the *Journal* and any other WAS publications. The Managing Editor shall assume responsibility for these functions: recruitment of editors, recommendations for honoraria, set prices and subscription rates, prepare publication manuals, submission of annual report, submission of annual budget, determination of press run per issue, negotiate publication contracts, accept advertising copy and set advertising rates, assume responsibility for copyrighting, assume responsibility for reprint permission, processing of subscription lists, and assist in the production of each issue.

12. *Implementation.* It is recommended that these changes be put into effect as soon as possible.

It is further recommended that the Ad hoc Committee on Policies for Academy Publications be discharged with the receipt of this report.

Respectfully submitted,

John J. O'Hare, Chair

The date of publication of Vol. 70, No. 4 is May 14, 1981.

JOURNAL OF THE WASHINGTON ACADEMY OF SCIENCES

Instructions to Contributors

General

Type manuscripts on white bond paper either 8½ by 11 or 8 by 10½ inches. Double space all lines, including those in abstracts, tables, legends, quoted matter, acknowledgments, and references cited. Number pages consecutively. Place your name and complete address in the upper right hand corner of the title page.

Title, Author, and Affiliation

Page 1 of your manuscript should contain only this information and your name and address. Choose a concise but complete and meaningful title. In research papers concerning biological subjects, include an indication of the order and family of the taxa discussed. Academic degrees will not normally be included unless the author so specifies. If possible, combine your affiliation and mailing address (including Zip) so that readers can write to you directly.

Abstract

Type on a separate sheet at the end of the manuscript. Make the abstract intelligible without reference to the text of the paper. Write an informative digest of the significant content and conclusions, not a mere description. Generally, the abstract should not exceed 3% of the text.

Footnotes

Use footnotes as sparingly as possible. Number text footnotes consecutively with Arabic numerals and type them on a separate sheet of paper at the end of the manuscript. Type table footnotes, if any, below each pertinent table on the same page.

Illustrations and Legends

The quality of all original illustrations must be high enough to facilitate good offset reproduction. They should have ample margins and be drawn on heavy stock or fastened to stiff cardboard to prevent bending. They should be proportioned to column (1 x 3) or page (2 x 3) type-dimensions, leaving space for legend material. Photographs should have a glossy finish. They reproduce best when the contrast is fairly high. Identify each illustration with number and author in light pencil marks on the reverse side. Submit all illustrations separately – please do not glue or clip them to the pages of the manuscript.

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Tables

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PROCEEDINGS

of the

UHURU MEMORIAL SYMPOSIUM

The Past, Present and Future of X-RAY ASTRONOMY

HELD AT

**Goddard Space Flight Center
Greenbelt, Maryland USA
December 13, 1980**

PART I THE PAST

Washington Academy of Sciences

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UHURU Part I

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INTRODUCTION

MARJORIE R. TOWNSEND

President
Washington Academy of Sciences
(1980–1981)

The Uhuru Memorial Symposium on December 13, 1980, meant far more to me than an important opportunity to review the state of the art in X-ray astronomy. It was the culmination of my 21 years at NASA's Goddard Space Flight Center and an outstanding chance to see again so many of the friends I made as Project Manager of the series of Small Astronomy Satellites (SAS) that have contributed significantly to high-energy astronomy.

In reviewing scenes of the San Marco Range, from which all three SAS spacecraft were launched for the United States by the Italian Government, memories of equatorial Africa came flooding back, including the reason for the nickname, "Uhuru". SAS-1 was launched in 1970 on Kenya's Independence Day, December 12th. It seemed to me to be appropriate that the United States recognize that fact in some way. Therefore, with approvals from all of the necessary government entities and the blessing of Riccardo Giacconi, the Principal Investigator, SAS-1's name became "Uhuru", the Swahili word for "Freedom". The freedom extended beyond that of Kenya to the satellite itself. For the proportional counters on board, whose purpose was to detect X-rays, the equatorial orbit meant freedom from the background noise from charged particles to which they would have been exposed in a standard 28° orbit.

I would like to dedicate these Proceedings of the Uhuru Memorial Symposium (if anything survived cremation upon reentering the atmosphere, it was buried at sea) to all of the dedicated scientists, engineers and technicians who made Uhuru possible by conceiving of it, funding it, building it, operating it and last, but not least, keeping its memory ever alive by continuing to analyze and use the data which it returned.

1962–1972 (Up Through UHURU)

Riccardo Giacconi

Harvard/Smithsonian Center for Astrophysics
Cambridge, MA. USA 02138

Marjorie Townsend and John Naugle have brought us together today on the happy occasion of the 10th Anniversary of the launch of UHURU. It is an opportunity for us to meet old friends, to remember the not-so-remote beginnings of X-ray astronomy, to rejoice in its accomplishments to date, and to contemplate with hope its future potential. I am most grateful to the organizers and to our hosts here at Goddard Space Flight Center for making this meeting possible.

Extrasolar X-ray astronomy is less than 20 years old. Yet to discuss adequately its development in the first ten years and the wealth of discoveries it has brought about is an almost impossible task in the space of half an hour. In choosing the material to discuss today, I found myself forced to leave out large and important areas of research and the contributions of many scientists, for which I apologize in advance. Furthermore, since I believe that X-ray astronomy did not start in a vacuum, I felt it incumbent upon me, as the first speaker at this meeting, to at least mention some of the events that preceded the discovery of the first extrasolar X-ray source in 1962.[1]

Reflecting upon the course of events, I think we can recognize at least two major factors that led to the development of X-ray astronomy: one is the interest in ionospheric phenomena and their causes, and the suggestion by Edward O. Hulburt[2] and Lars Vegard[3] in 1938 that solar X-ray radiation might be the cause of the ionization in the E region. This, in turn, led to the series of post-war experiments by the Naval Research Laboratory (NRL) group which established the existence of X-ray emission from the Sun. Starting in 1948, Herb Friedman[4] and his collaborators at NRL studied solar X-ray emission over an entire solar cycle by means of rocket experiments carrying ever more sophisticated instruments. The thin window counters developed by the NRL group for this work furnished the technical basis for their own work in UV astronomy and the starting point for other groups interested in X-ray astronomy.

After the formation of the National Aeronautics and Space Administration (NASA) in July 1958, Jim Kupperian left the NRL group to become head of the Astronomy Branch of Goddard Space Flight Center (GSFC) in early 1959.[5] Kupperian had become quite interested in the possible detection of X-ray sources in the night sky after obtaining some suggestive indication of non-solar X-ray flux in a 1957 rocket flight. In his new position he was able to interest Savedoff[6] of Cornell (June 1959) and Fisher[7] of Lockheed (December 1960) in initiating programs of detector development and rocket flights to search for extrasolar X-ray sources.

The second major factor which led to the development of X-ray astronomy was the early interest of the National Academy of Sciences' Space Science Board (formed in June 1958) in surveying the sky in all spectral ranges. In an interim report of the Space Science Board's Committee on Physics of Fields and Particles in Space, J. A. Simpson, the Chairman, suggested gamma- and X-ray mapping of the sky.[8] Lawrence Aller, a member of the Committee on Optical and Radio Astronomy, pointed out the fact that interstellar absorption would be a severe handicap for stellar observations at energies greater than 13.6 eV (the ionization potential of hydrogen), but that many stars and nebulas would become observable at $\lambda < 20A$.[9] Similarly, Leo Goldberg[10] in the summary report of the same Committee, advocated the development of X-ray instrumentation in view of its potential benefits to astronomy.

Above and beyond sharing in this general recognition of the potential of X-ray astronomy, B. Rossi, also a member of the Space Science Board, provided the immediate stimulus to the work of my group at American Science & Engineering, Inc., (AS&E), which eventually led to the detection of Sco X-1 in 1962. He not only provided the initial impetus for this research, but by his presence in Cambridge, his continued interest and enthusiasm in high energy astrophysics, contributed greatly to create the climate of intellectual fervor and discussion in which further advances took place.

When we first attempted to review the status of knowledge in late 1959, and predict expected fluxes, we obtained the estimates shown in Table 1. It was evident that detectors at least 50 times more sensitive than those available at the time had to be developed in order to detect such small fluxes. We then embarked on two parallel efforts: one directed to the long-range development of imaging telescopes which came to fruition in the late 1960's,[11] the other directed to the development of an improved non-imaging detector for immediate use in rocket scanning experiments.[12]

R. GIACCONI, G. W. CLARK AND B. B. ROSSI
ASE-TN-49 15 JANUARY 1960

SUN	< 20A	CORONAL EMISSION	$\sim 10^6$ CM^{-2} S^{-1}
SUN AT 8 LIGHT YEARS	< 20A	CORONAL EMISSION	2.5×10^{-4} CM^{-2} S^{-1}
SIRIUS IF $L_X \sim L_{OPT}$	< 20A	? NO CONVECTIVE ZONE	0.25 CM^{-2} S^{-1}
FLARE STARS	< 20A	SUNLIKE FLARES ?	?
PECULIAR A STARS	< 20A	B $\sim 10^4$ GAUSS LARGE B PARTICLE ACCELERATION	?
CRAB NEBULA	$\sim$ 25A	SYNCHROTRON $E_E \geq 10^{13}$ eV IN B=10^{-4} GAUSS LIFETIMES?	?
MOON	< 23A	FLUORESCENCE	0.4 CM^{-2}S^{-1}
MOON	$\sim$ 20A	IMPACT FROM SOLAR WIND ELECTRONS $\phi_E = 0 - 10^{13}$ CM^{-2} S^{-1}	$0-1.6\times10^3$ CM^{-2} S^{-1}
SCO X-1	2-8A	?	28 ± 1.2 CM^{-2}S^{-1}

Table 1.—Abstracted from ASE document ASE-TN-49, "A Brief Review of Experimental and Theoretical Progress in X-ray Astronomy", R. Giacconi, G. W. Clark and B. B. Rossi, 15 January 1960.

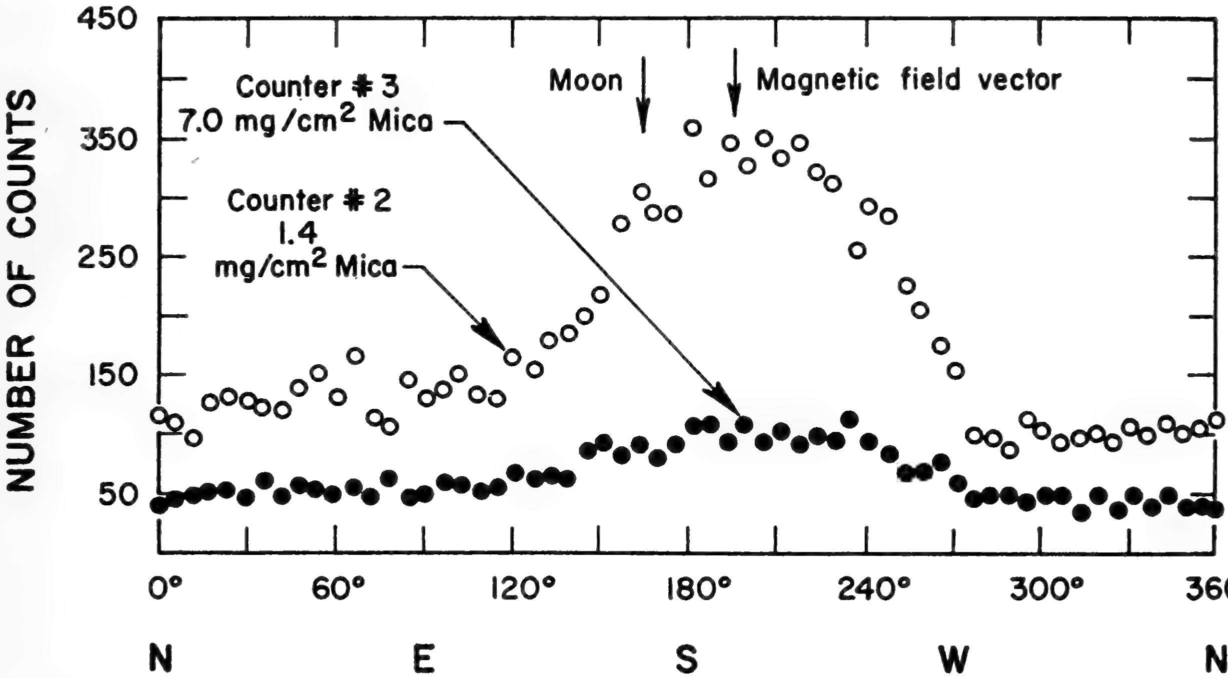

Fig. 1. Azimuthal distributions of recorded counts from Geiger counters flown during June 1962.

It was by use of this new detector system, approximately 100 times more sensitive than any previously flown, that in June 1962 we discovered the existence of a strong extrasolar source, Sco X-1 (Figures 1 and 2). The most surprising aspect of this flight was not the hoped-for detection of an X-ray star, but the discovery of a new class of celestial objects, whose existence was unsuspected and whose X-ray emission was orders of magnitude greater than that expected from any previously known stellar object. If Sco X-1 had the same L_x/L_{opt} ratio as the Sun, it should appear in visible light brighter than the Moon!

It was later found that in fact most of the energy loss in Sco X-1 and similar systems occurs by X-ray emission with $L_x/L_{opt} \sim 10^3$, whereas in the Sun $L_x/L_{opt} \sim 10^{-6}$, where L_x and L_{opt} are the absolute X-ray and optical luminosities. Also, the absolute luminosity of Sco X-1 in X-rays was some 10^3 times greater than that of the Sun at all wavelengths making it one of the brightest stars in the galaxy. Sco X-1 was so strong that it could be seen directly in the telemetry strip charts (Figure 3).

The April 1963 rocket flight by NRL[13] and the flights of my group at AS&E in October 1962 and June 1963[14] not only provided confirmation of this finding, but revealed the existence of additional sources. Furthermore, the NRL flight demonstrated that Sco X-1 had finite sizes (<10°) and was not coincident with the galactic center. It also confirmed the finding of the June 1962 flight of a diffuse isotropic X-ray background of mysterious origin.

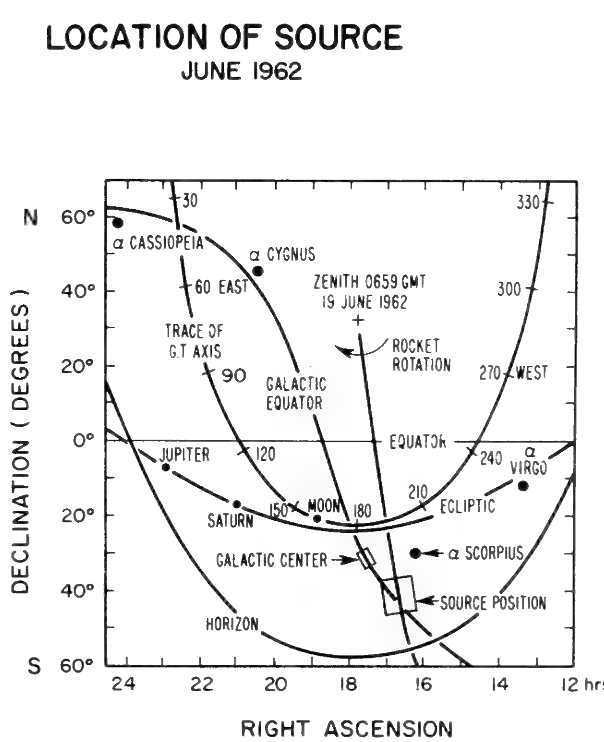

Fig. 2. Location of the Sco X-1 source.

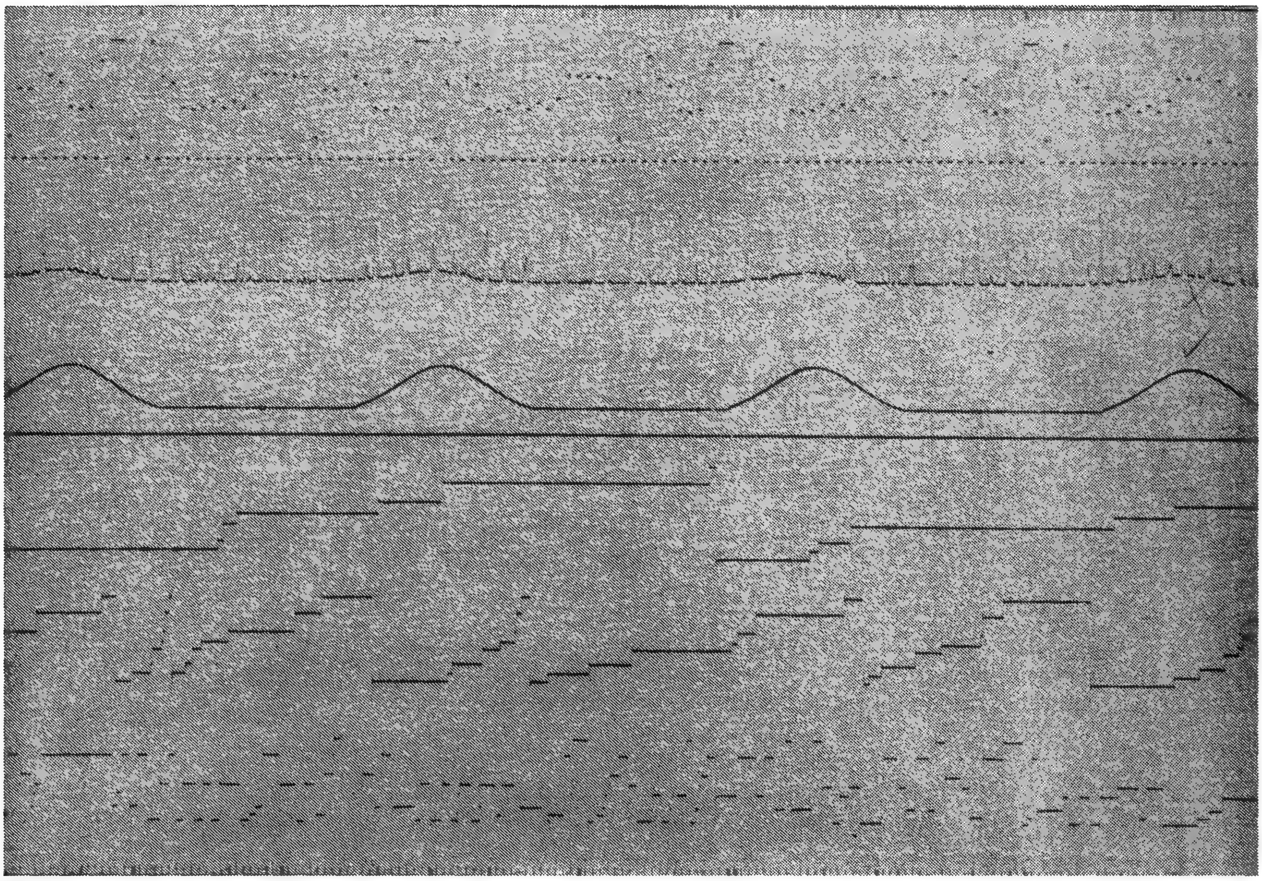

Fig. 3. Photograph of the strip chart record of the June 1962 flight. The upper two traces are housekeeping and a star sensor output. The third trace is the output of a photoelectric cell showing the maximum of light when coming to the point of closest approach to the Moon. The bottom 3 traces show the output of the 3 Geiger counters which were flown. One of the counters is in discharge; the other two are working properly. The upper one has a thicker mica window than the lower one. Each step corresponds to the detection of one photon. Several steps occurring one near the other indicate higher counting rates at that position in the spin. The detection of Sco X-1 can be seen.

After this initial discovery phase, there followed a number of rocket and balloon experiments by many groups. Due to time limitations, I can mention only a few which had either particular scientific significance or opened new avenues of research.

1. The detection of the Crab Nebula X-ray source by Bowyer *et al.*,[15] in 1964 was the result of an imaginative experiment utilizing lunar occultation, which first identified an extrasolar X-ray source with a known celestial object (Figure 4).

2. The slow-scan survey by Fisher and his colleagues at Lockheed,[16] in 1964 introduced the controlled study of small regions of the sky with fine, one-dimensional angular resolution—a technique immediately adopted by most groups.

3. The extension of X-ray observations of Crab Nebula to the 50 keV range, accomplished by G. Clark, of Massachusetts Institute of Technology (MIT), with a balloon-borne detector in 1965,[17] was the forerunner of a number of balloon experiments by W. Lewin and others at MIT, and L. Peterson and others at UCSD[18] which greatly enriched our knowledge of the X-ray sky at higher energies.

4. The measurement of the Sco X-1 spectrum by Giacconi *et al.*,[19] in 1964 excluded black-body radiation, and that by Chodil *et al.*[20] definitively established its thermal bremsstrahlung nature.

5. The discovery of the first extragalactic source, M87, was made by Byram and his colleagues in 1966.[21]

6. The measurement of the angular size and location of Sco X-1 in 1966 by H. Gursky and M. Oda and their colleagues at MIT and AS&E[22] groups, led to its iden-

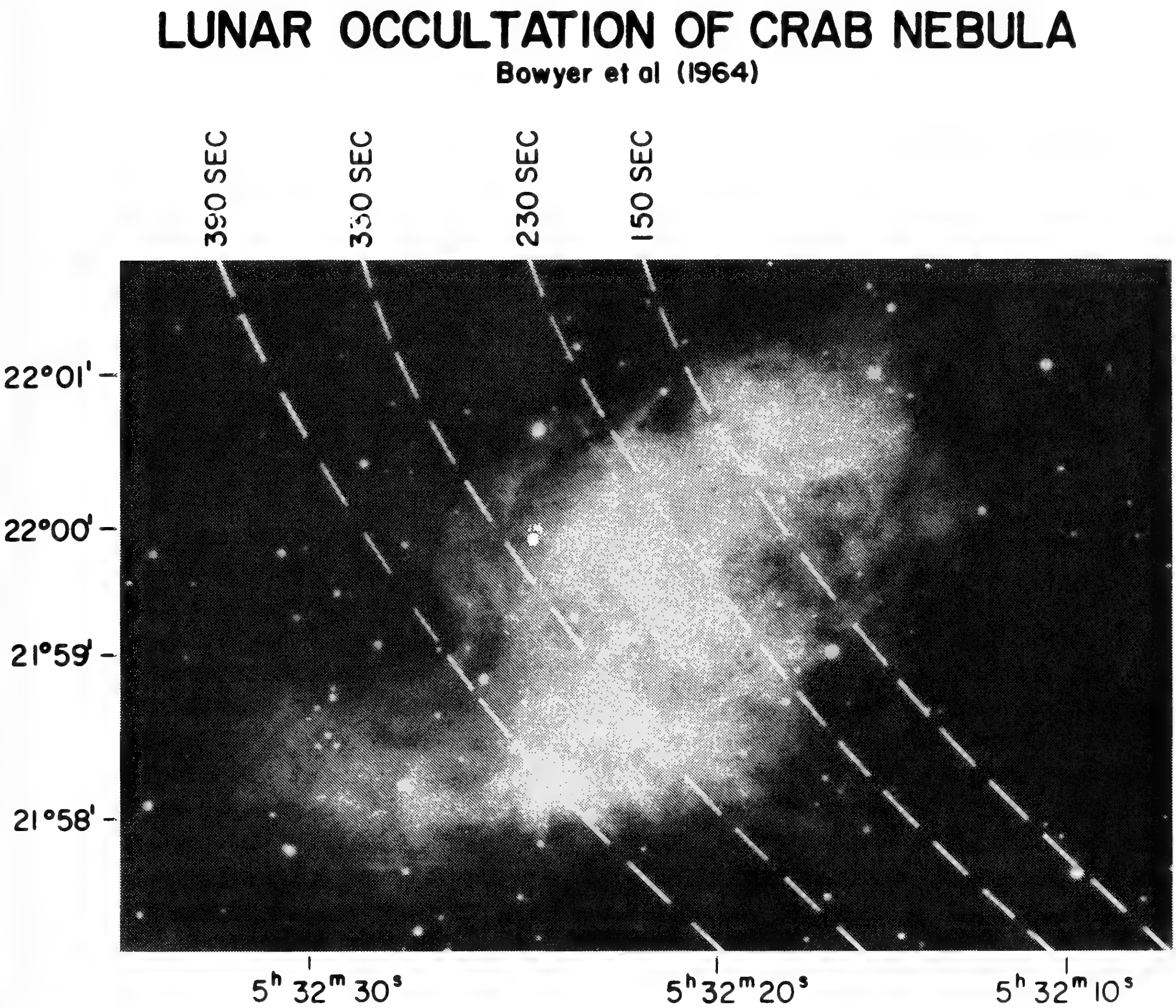

Fig. 4. Position of Moon with respect to the Crab Nebula during the 1964 rocket experiment is indicated by the dashed lines.

tification with a faint blue 13th M star by Ichimura[23] and Sandage[24] (Figure 5). The old nova-like spectrum of the object gave the first experimental clue to the understanding of galactic X-ray sources other than supernovas. The determination of the optically thick nature of the source by the IR measurement of Garmire and his colleagues placed several constraints on the nature of the source.[25]

7. The measurement of the location and spectra of Cyg X-1, Cyg X-2, Cyg X-3 by Giacconi *et al.*[26] led to the identification of Cyg X-2 by Sandage and his colleagues,[27] and to the recognition of the spectral peculiarities of Cyg X-2 and Cyg X-3.

8. The discovery of pulsed X-ray emission from the pulsar NP 0532 by Friedman and his colleagues at NRL,[28] and by H. Bradt and his colleagues at MIT[29] in the spring of 1969, was made within a few weeks of each other.

Although many important experiments have been omitted in this brief summary, even these few examples indicate the pace of discovery by rocket and balloon experiments in the 1964–1969 period. A catalog of X-ray sources which was current in September 1969, shows several dozen sources, six of which are identified (Figure 6). They included the Crab, Tycho, and Cas A supernova remnants; one certainly identified extragalactic object, M87, and two identified with blue, faint, starlike optical counterparts Sco X-1 and Cyg X-2 (and possibly GX 3 + 1 and Cen XR-2).

PORTION OF SKY CONTAINING ScoX-1

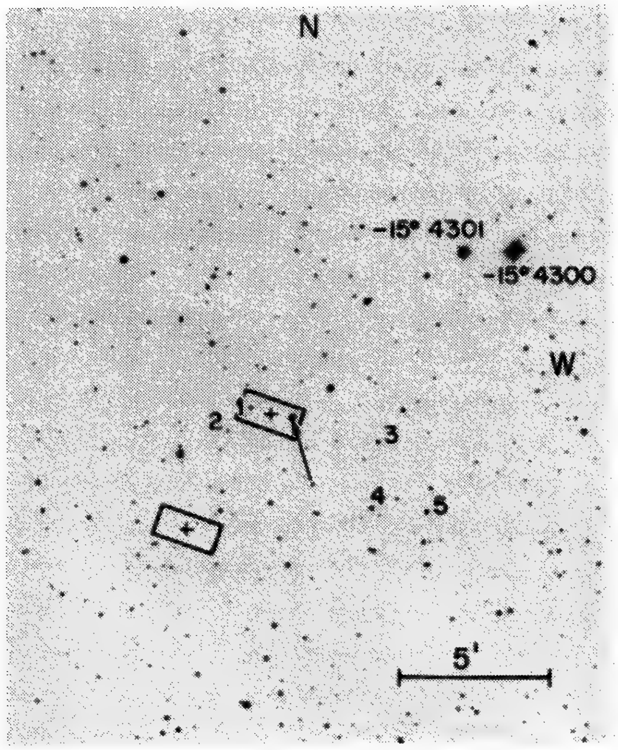

Fig. 5. Photograph of the region containing the new X-ray position of Sco X-1, reproduced from the Palomar Sky Survey prints. The two equally probable X-ray positions are marked by crosses surrounded by a rectangle of 1 by 2 arc min. The object described in the text is marked with an arrow. The identifications of other stars for which photoelectric photometry exists are also marked.

The discovery by Hewish and Bell in 1967[30] of a neutron star in the Crab Nebula solved the long-standing problem of the energy source of the short-lived high energy electrons producing the visible light and X-ray continuum in the Nebula by synchrotron emission. The energy comes from the conversion of rotational energy of the pulsar in particle acceleration. Interaction of the expanding shell of supernovas and the interstellar medium was proposed to explain the emission from other supernova remnants. The source of the energy and the process of X-ray production for Sco X-1 like sources (and, as it later turned out, most of the remaining galactic X-ray sources), however, remained a mystery.

Early suggestions by Matsuoka and Hayakawa in 1964[31] that mass accretion in a binary system could produce the observed X-ray by shock heating of the gas, lay dormant because of lack of any observational support. Black-body emission from the million-degree surface of a neutron star could be excluded on observational grounds. The identification in 1966 of Sco X-1 with an object resembling old novas which were known to consist of binary stellar systems, rekindled interest in the mass exchange binary model which was re-proposed by Shklovsky[32] and by Burbidge and Prendergast[33] in 1968. Again, no observational evidence could be found to support this model, since most old novas were not detected as X-ray emitters and alternate models based on emission from pulsars with or without coccoons were introduced by many theorists.

It remained for UHURU to solve this important question. UHURU was the first of a series of satellite experiments which revolutionized X-ray astronomy in the 1970's.[34] It had been conceived and proposed to NASA in September 1963[35] as part of a long-range plan of rocket and satellite X-ray astronomy research by the AS&E group when only three extrasolar X-ray sources were known: Sco X-1, Crab, and the Diffuse Background. Scientific objectives of the X-ray Explorer, shown in Table 2, have been abstracted from a more detailed proposal for an "X-ray Explorer to Survey Galactic and Extragalactic Sources", submitted in April 1964. After some delay, the program started in earnest in late 1966 as the first in the series of Small Astronomy Satellites so capably managed by Marjorie Townsend. Since several descriptions of the UHURU complement of instruments and its operations exist in the literature, I do not believe it necessary to repeat the details. I would, however, like to acknowledge the extraordinary scientific and technical contributions of H. Tananbaum and E. Kellogg to all phases of the program; of J. Waters to the design and construction of the experiment, and of H. Gursky, E. Schreier, S. Murray, C. Jones and W. Forman to the data analysis.

Launched from the San Marco Platform off the coast of Kenya on their Independ-

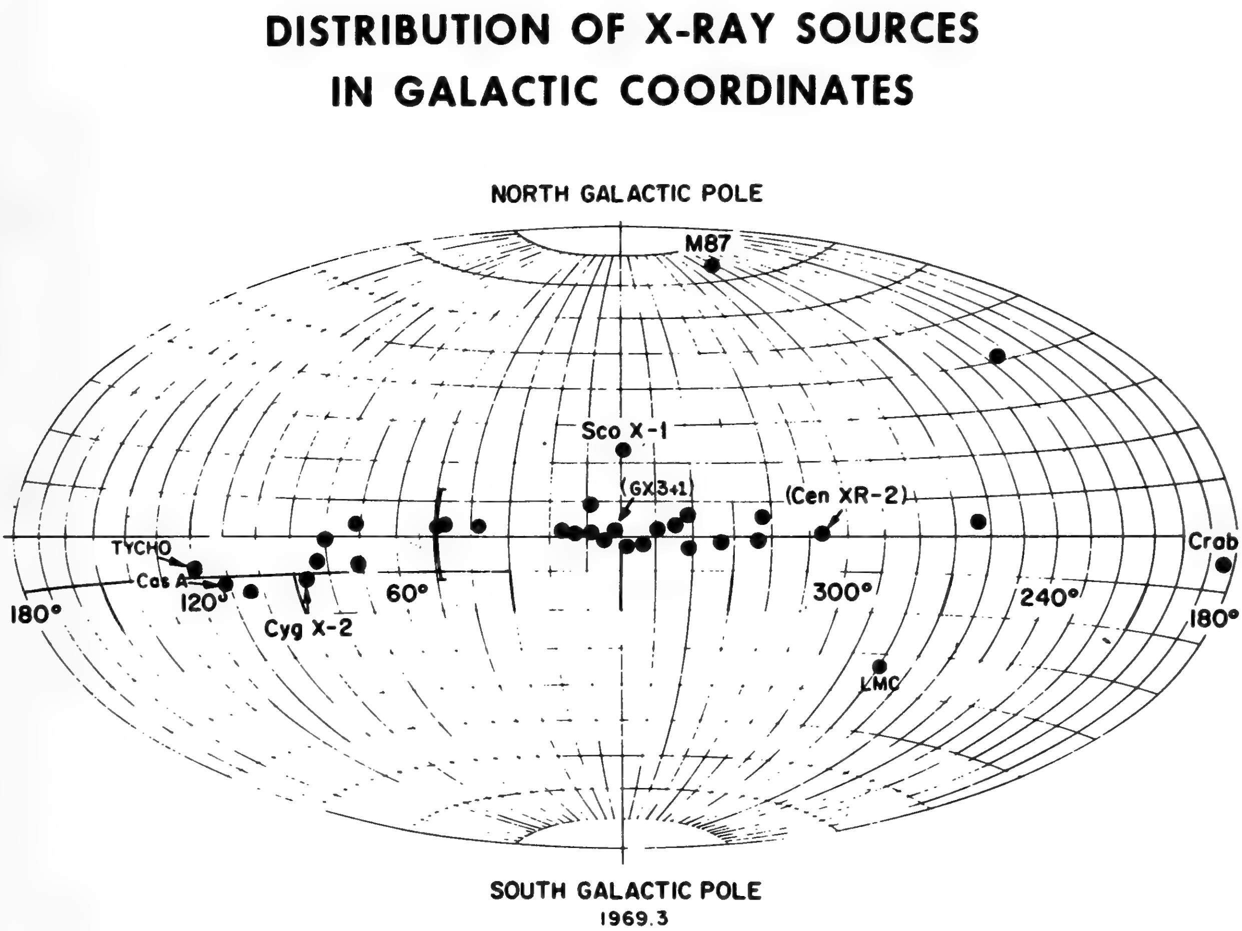

Fig. 6. The distribution of X-ray sources on a galactic coordinate system (from "Properties of Individual X-ray Sources" by R. Giacconi, in *Non-Solar X- and Gama-ray Astronomy"*, Proceedings of the IAU; (ed. L. Gratton), D. Reidel Pub. Co., Dordrecht, Holland, 1970, p. 108).

ence Day (UHURU), December 12, 1970, UHURU was a remarkably simple, relatively low-cost and long-lived satellite (Figure 7). It met or exceeded all of our expectations with regard to all-sky surveys, detecting some 339 discrete sources in its 2-1/4 year life span (Figure 8). Its major scientific achievements came, however, from unforeseen discoveries. I will mention only two: (a) the discovery that most galactic X-ray sources were mass exchange binaries containing a collapsed star (neutron star or black hole), primarily through the work of H. Tananbaum, E. Schrier and myself, and (b) the discovery of diffused X-ray emission from high temperature intergalactic gas in clusters of galaxies primarily through the work of H. Gursky, E. Kellogg and W. Forman.

The first finding solved a long-standing riddle of X-ray astronomy and provided the intellectual framework to understand many of the subsequent discoveries in galactic X-ray astronomy.

The second was the discovery of matter in a form detectable only to X-ray observations. Although the intercluster gas is extremely thin, it fills such huge volumes that its total mass equals that in the visible galaxies. The study of the temperature and distribution of this gas gives us a powerful new tool with which to probe the evolution of clusters, the largest aggregate of matter in the known universe.

To expand on the first point, UHURU observations revealed the existence of rapid intensity fluctuations in some of the galactic sources. While several rocket and balloon flights had established that some variability existed in galactic sources, the long-term monitoring capabilities of a satellite instrument permitted us to study this phenomenon in detail over long terms (months) and with time resolutions of order of 0.1 sec-

SCIENTIFIC OBJECTIVES OF X-RAY EXPLORER
(FROM ASE-578 APRIL 8, 1964)

ALL SKY SURVEY

POSITIONS TO 0.1° FOR KNOWN SOURCES

STRUCTURE

NEW SOURCES

ANISOTROPY OF BACKGROUND

SPECTRAL COMPOSITION

CORRELATION WITH OPTICAL AND RADIO

TEMPORAL VARIATIONS OVER MONTHS

Table 2.—Scientific Objectives of X-ray Explorer, abstracted from ASE document ASE-578, April 8, 1964 "A Proposal for an X-ray Explorer to Survey Galactic and Extragalactic Sources."

onds. Use of this capability led us to the discovery of the first regularly pulsing X-ray sources, Cen X-3 and Her X-1, and of the erratically flickering behavior of Cyg X-1. As soon as we discovered pulsations in Cen X-3 (Figure 9), we slowed down the spacecraft spin to examine the source in greater detail. We found that regular pulsations persisted with a period of 4.8 seconds (Figure 10). As we continued to monitor the source, we observed gradual changes in the period of pulsation as well as changes in the total intensity (Figure 11).[36] The changes in period were regularly occurring according to a sinusoidal law whose period coincided with the periodic waxing and waning of the intensity (Figure 12). We concluded that we were observing a pulsating X-ray source in orbit about an occulting companion whose frequency was Doppler shifted by its motion about the companion (Figure 13).[37]

But how were the X-rays produced? Could they be due to a pulsar mechanism? Long-term monitoring of the period revealed (Figure 14) that it was decreasing rather than increasing in time, thus the star was acquiring rather than losing energy. The only plausible explanation was that the energy was released by the infall of material in the deep potential well of a compact object. The pulsations were due to the preferential accretion of material at the poles of a highly magnetized star (Figure 15). Although in principle white dwarfs or neutron stars could be candidates for the regularly pulsating X-ray emitting objects, subsequent studies of the response of the accreting object to variable accretion torques led us to the conclusion that the compact objects in Her X-1 and Cen X-3 were neutron stars.[38] Following identification of their optical counterparts, the X-ray Doppler measurement and radial velocity measurements in the visible led to the first independent mass determination for neutron stars. Thus was solved the riddle of the energy source for galactic X-ray sources! Most of them, including the mysterious Sco X-1, appear to be variations on this basic model.

There is one variation which UHURU also discovered which is of particular interest. I refer, of course, to the detection of the first black hole candidate, Cyg X-1. In a mass accreting binary system a black hole can provide the deep potential well for accelerating material and heating it to high temperatures. Its emission cannot, however, be regularly pulsed since no asymmetries are allowed outside the black hole horizon. The discovery of erratic pulsations from Cyg X-1[39,40] (Figure 16) and the better positional accuracy available through UHURU[41] and rocket measurements by the MIT[42] group (Figure 17) spurred new efforts to identify the optical and radio counterparts of this source. Braes and Miley,[43] and Hjellming and Wade[44] soon thereafter (1971) discovered a radio counterpart. It is the precise radio location which then led to the identification by Webster and Murdin[45] in 1972, and by Bolton

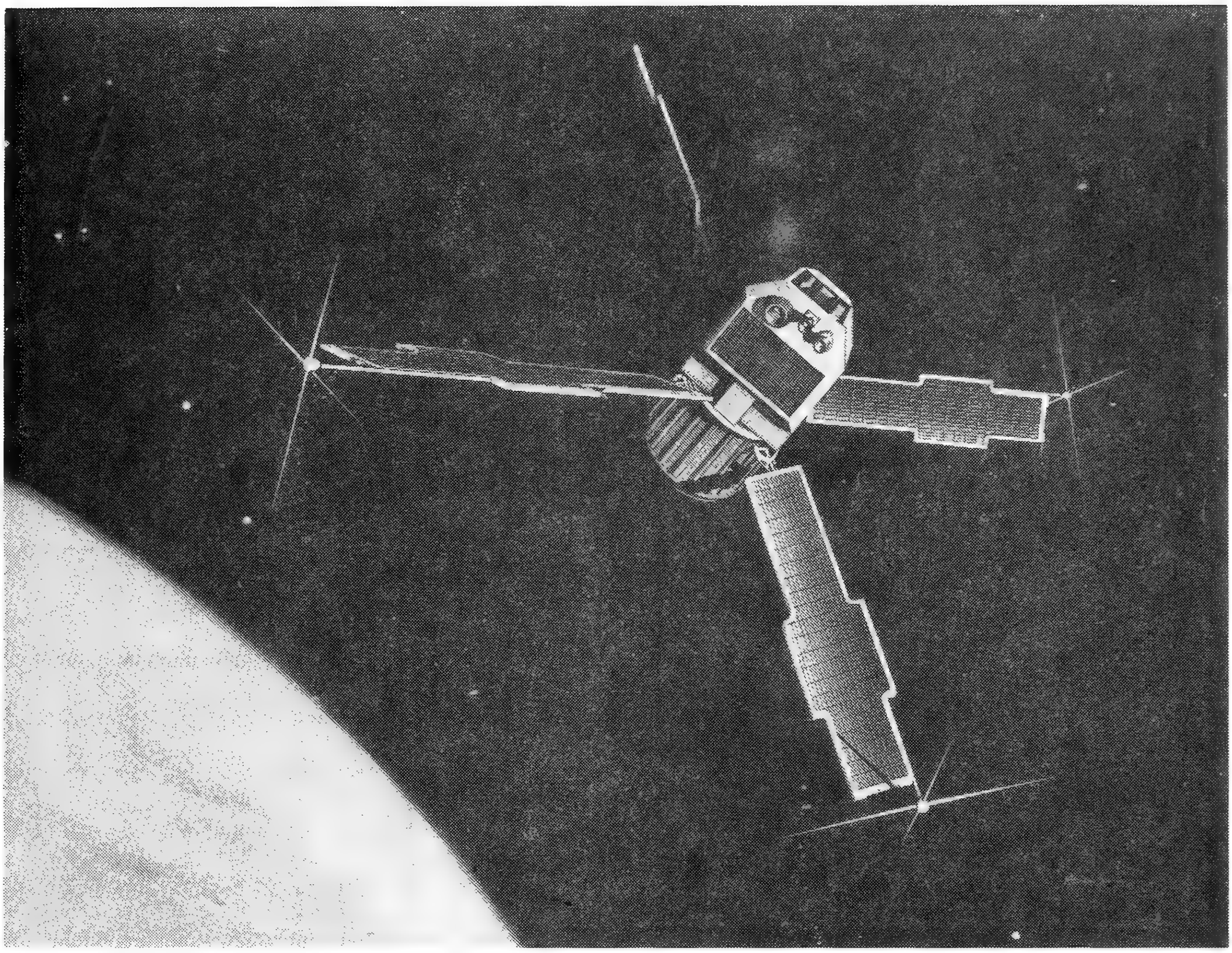

Fig. 7. An artist's concept of the UHURU spacecraft.

(1972)[46] of Cyg X-1 with the 5.6 day spectroscopic binary system HDE 226868, consisting of a massive 9th magnitude Bo supergiant of more than 20 $M_{\odot}$ and unseen companion of several solar masses. The X-ray transitions in Cyg X-1 observed by UHURU to coincide with radio transition established this identification beyond doubt (Figure 18).[47] The rocket experiments by Rappaport and others at MIT,[48] and by Holt and others at GSFC,[49] confirmed the rapid variability of the X-ray source first discovered by UHURU and compelled us to consider source regions of 10^9 cm or less. The mass determination of the X-ray emitting secondary star by Bolton[50] and by Kristian and Brucato[51] yielded a mass of more than 5 $M_{\odot}$.

Theoretical computations by Ruffini[52] and Hartle[53] determined that under the most general assumptions masses of neutron stars could not exceed 5 $M_{\odot}$. A star of 10^9 cm radius and Mass >5 $M_{\odot}$ would therefore collapse indefinitely and become the black hole predicted by general relativity. It is for this reason that we have concluded that Cyg X-1 is the best existing candidate for a black hole.

In the years since they were discovered, X-ray binary systems have become a veritable astrophysical laboratory whose use enables us to test the laws of matter at densities unachievable in the laboratory and to study the effects of general relativity under conditions in which they become of major significance. X-ray observations of extragalactic sources which UHURU initiated in earnest, have become one of the most powerful tools for astronomical investigation of the most distant objects known in the universe. UHURU was a happy child. I feel both privileged and grateful to have been allowed the opportunity to bring it into the world.

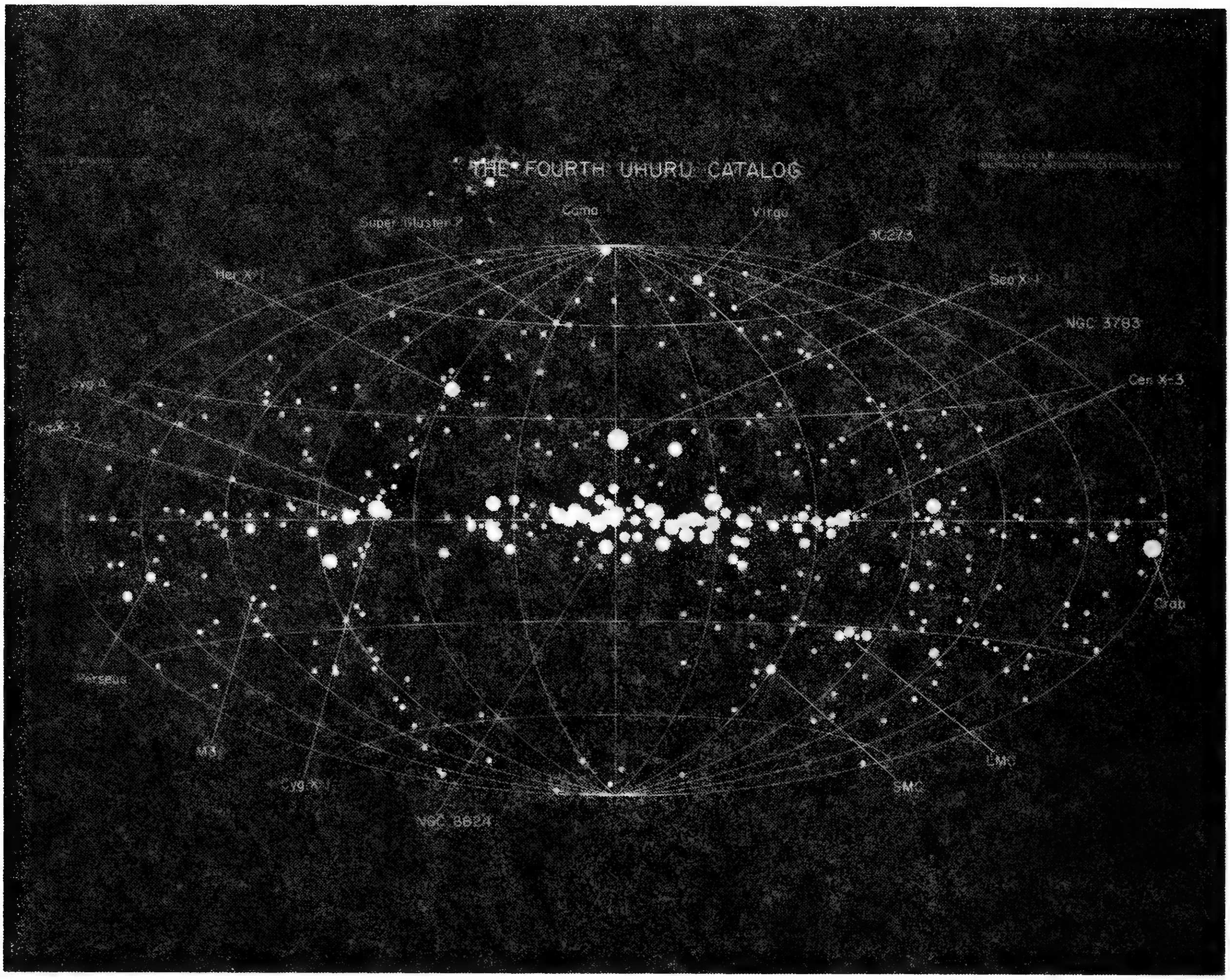

Fig. 8. "The Fourth UHURU Catalog of X-ray Sources", W. Forman, C. Jones, L. Cominsky, P. Julien, S. Murray, G. Peters, H. Tananbaum and R. Giacconi, Astrophys. J. **38,** No. 4 (Suppl. Series), 1978.

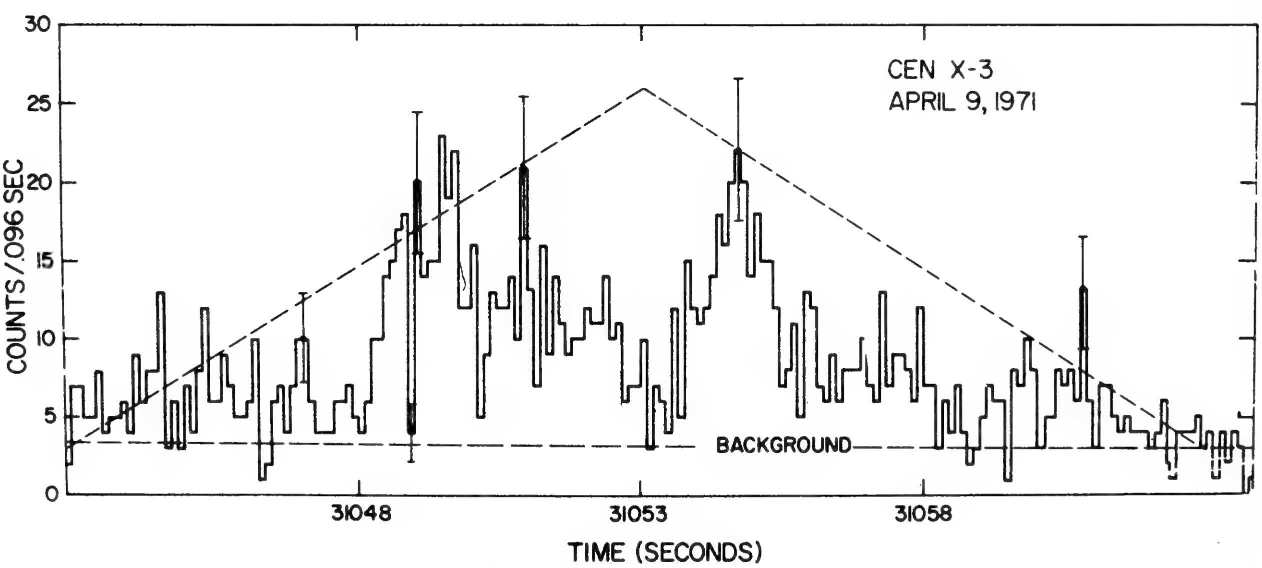

Fig. 9. Cen X-3 April 9, 1971

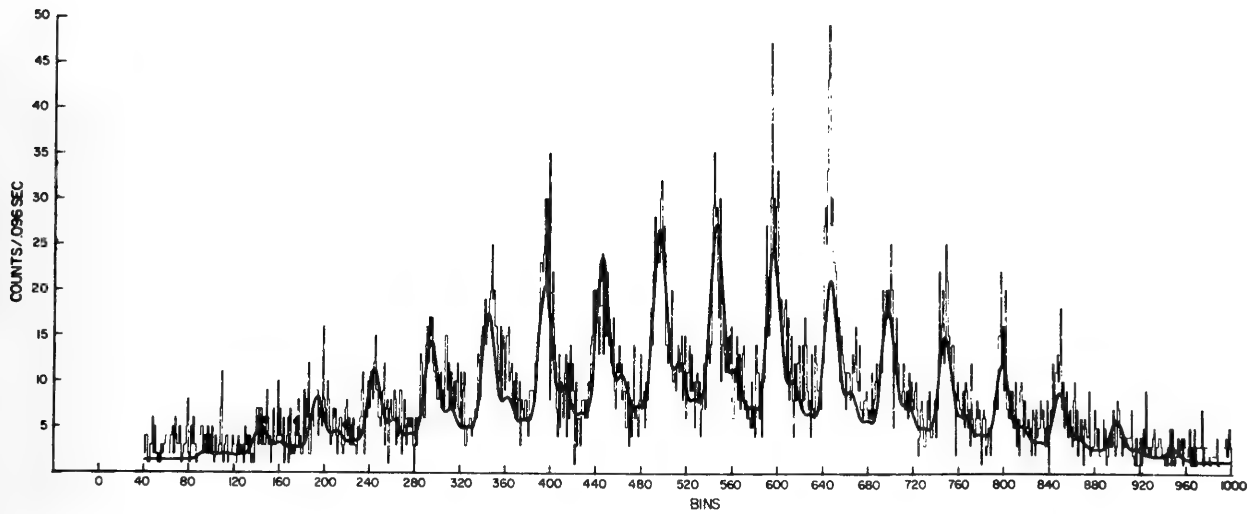

Fig. 10. Cen X-3 May 7, 1971

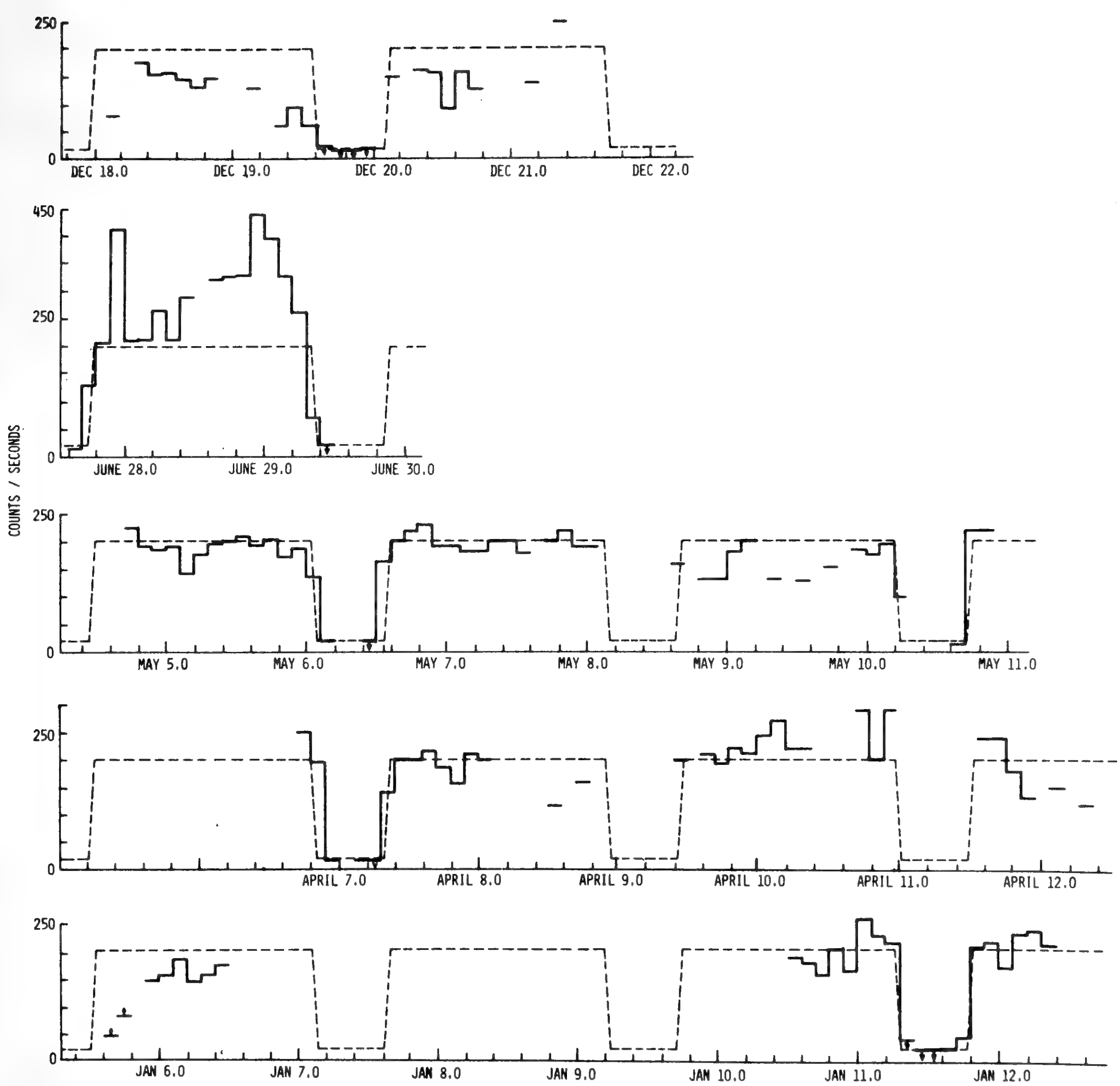

Fig. 11. Cen X-3 Changes in period of pulsation/total intensity

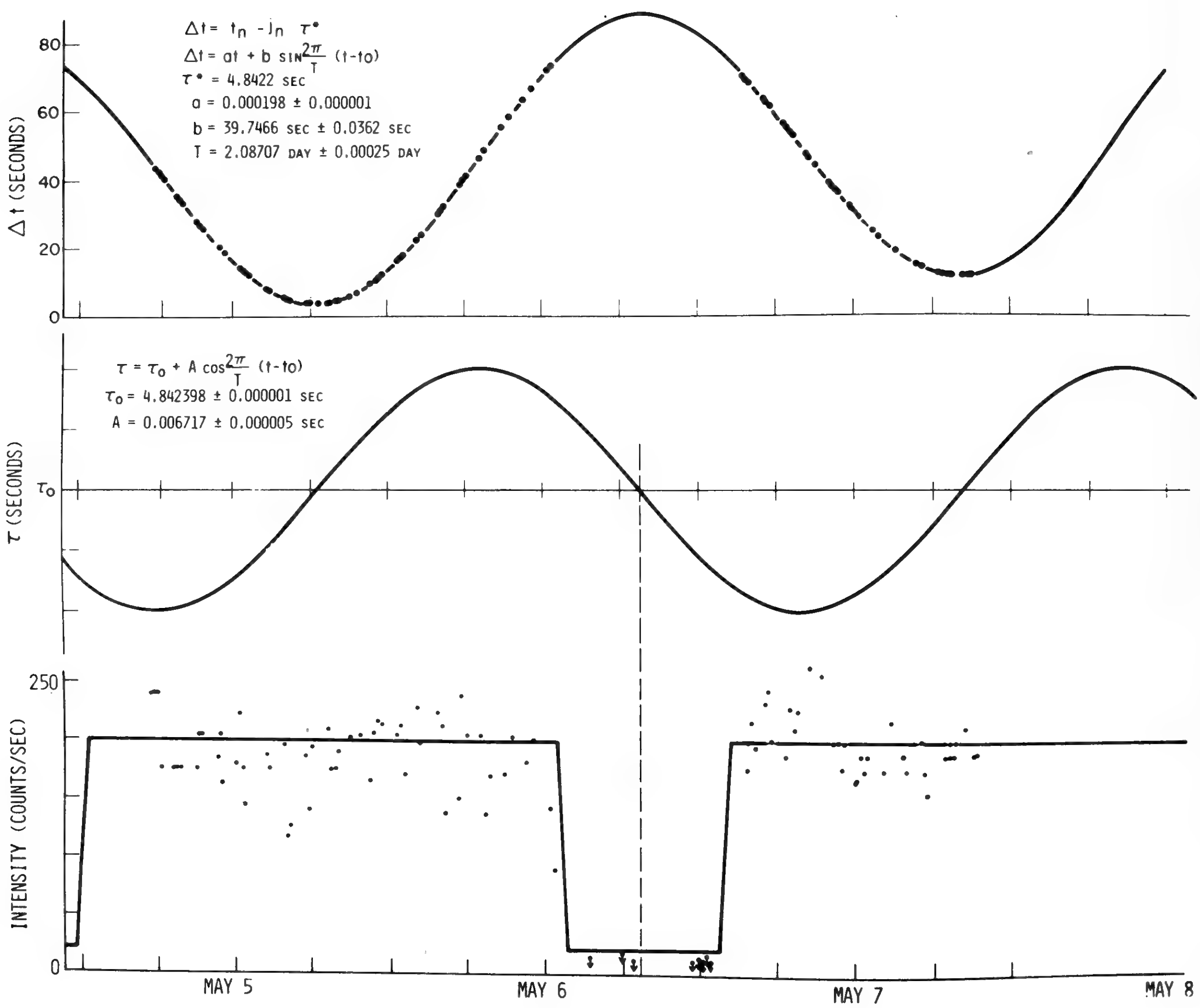

Fig. 12. Intensity observed from Cen X-3

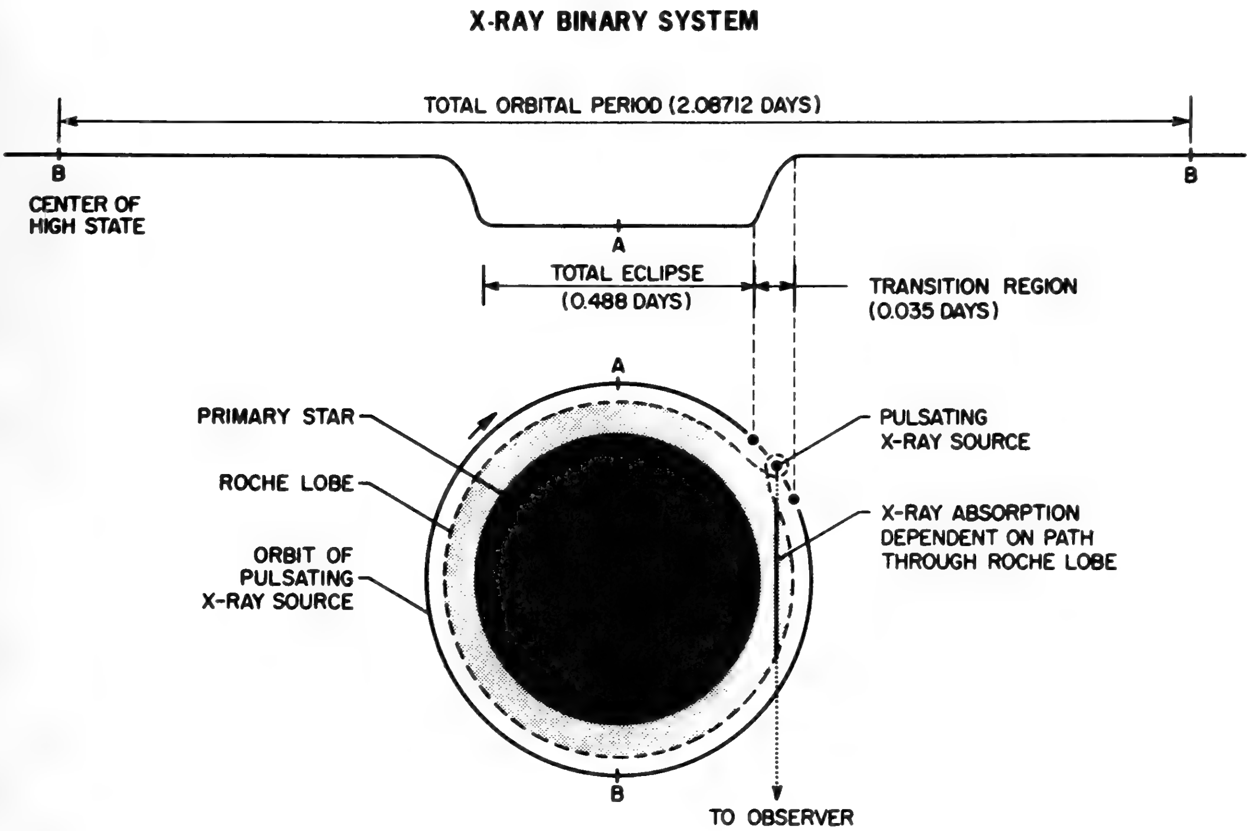

Fig. 13. Schematic representation of occulting binary X-ray system.

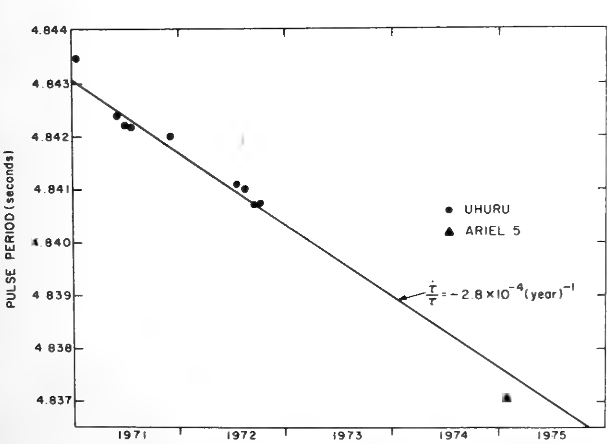

Fig. 14. The long-term behavior of the pulsation period of Cen X-3 (from G. Fabbiano and E. Schreier, Astrophys. J. **214,** 235, 1977).

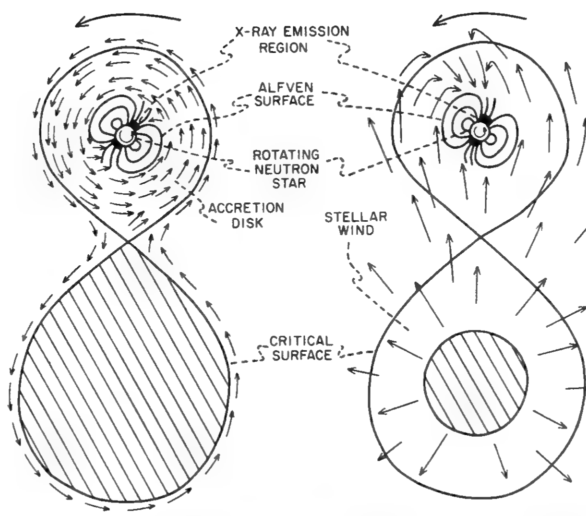

Fig. 15. Schematic representation of the rotating neutron star model for pulsating X-ray stars. Both accretion disk and stellar wind cases are shown (from *X-ray Astronomy* (eds. R. Giacconi and H. Gursky), D. Reidel Pub. Co., Dordrecht, The Netherlands, 1974

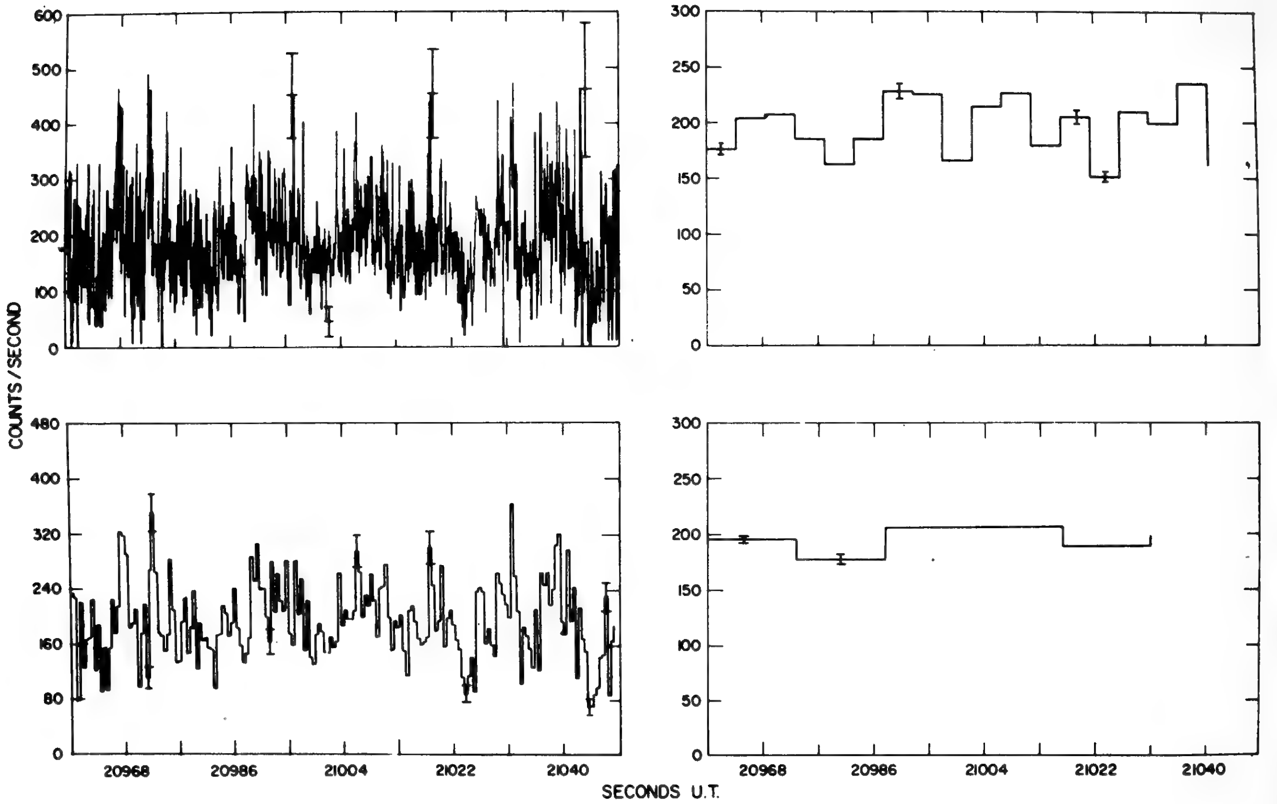

Fig. 16. Observation of Cyg X-1 on 1971 June 10 (from *X- and Gamma-ray Astronomy,* (eds. H. Bradt and R. Giacconi), IAU Symposium #55, D. Reidel Pub. Co., Dordrecht, The Netherlands, 1973).

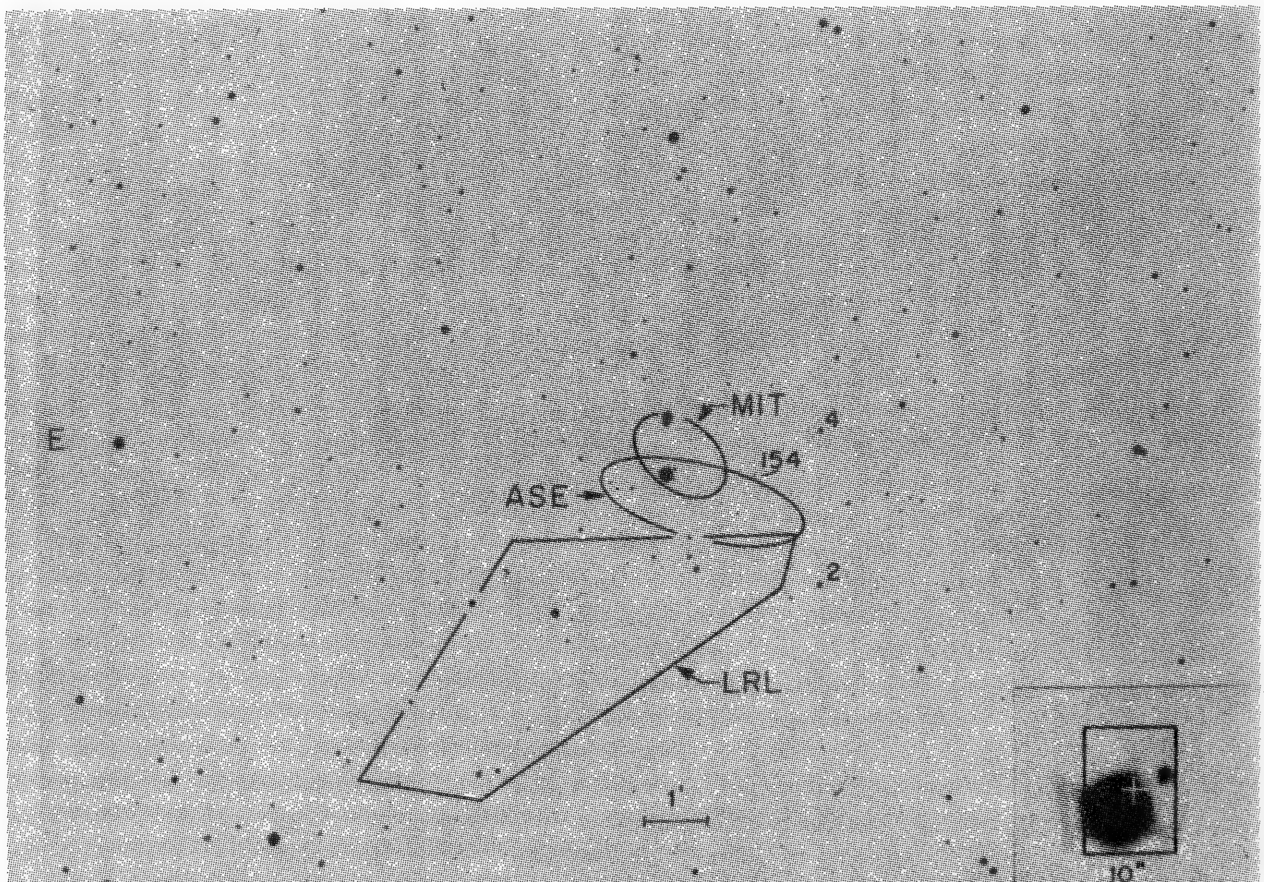

Fig. 17. X-ray location of Cyg X-1 (ibid)

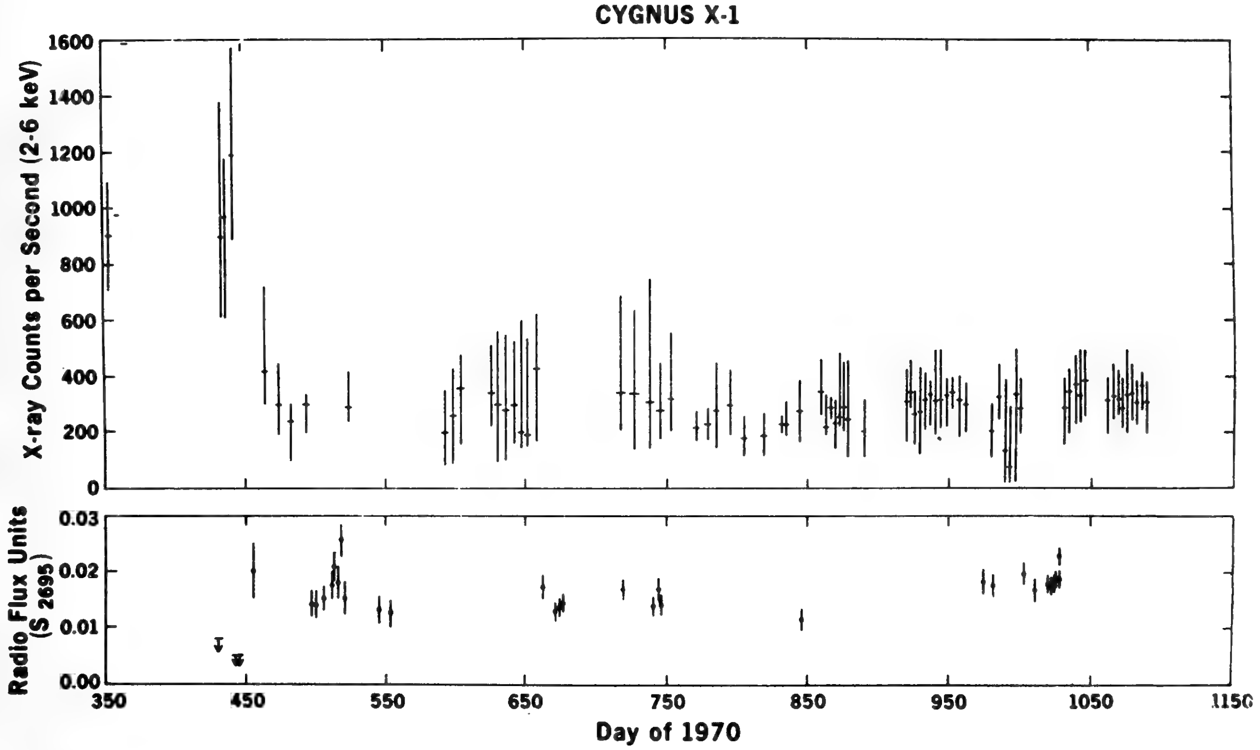

Fig. 18. Cygnus X-1. Sixteen months of observation; X-ray data for 2–6 keV energy band plotted vs. day of 1970. Radio data shown at bottom of figure (from *X-ray Astronomy* (eds. R. Giacconi and H. Gursky), D. Reidel Pub. Co., Dordrecht, The Netherlands, 1974)

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X-Ray Astronomy From Uhuru to HEAO-1

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Introduction

Seven satellites with X-ray detectors operated during various portions of the seven years between the launches of Uhuru and HEAO-1. Six were operating at the same time for several months in 1975 and 1976. Throughout the decade of the 70's many balloon and rocket experiments were also carried out. These missions, building on the foundation laid by Uhuru, extended the range of spectral measurements to higher and lower energies. Some achieved higher spectral resolution with improved detectors and multichannel analysis of the sizes of pulses from proportional detectors. Modulation collimators were used to measure positions with uncertainty areas 30 times smaller than Uhuru. Some satellites had three axis stabalization which facilitated long-term pointed-mode observations of variable sources.

The hundreds of galactic and extragalactic X-ray sources accessible for study with the instruments on these missions consist of a wide variety of stars, supernova remnants, the interstellar medium, active galactic nuclei of various types, and clusters of galaxies. I will try to convey a sense of the progress made toward understanding their X-ray phenomena by focussing on a few key questions in the legacy of Uhuru. References to the work of the many scientists responsible for this progress can be found in the review articles cited.

1. Are X-ray pulsars neutron stars or white dwarfs?

The discovery and detailed study with Uhuru of pulsations and eclipses in several of the bright X-ray stars confirmed the hypothesis, put forward by a number of theorists in the 1960's, that these objects are close binary systems in which matter, drawn from a nuclear burning star, falls onto the surface of a compact companion in the form of a white dwarf or neutron star. In this process, the gravitational energy of the falling matter is converted into heat and radiated as X-rays. With the discovery of regular pulsations in Cen X-3 and Her X-1 it became clear that if the compact star has a strong dipole magnetic field, the flow of hot and highly ionized matter is channeled into narrow accretion columns at the magnetic poles, and that the X-rays are emitted anisotropically from the polar regions. If the dipole is not aligned with the rotation axis, then rotation of the compact star, like the rotation of a coastal beacon, causes pulsations in the flux of radiation recorded by a distant observer.

The observable phenomena of pulsating X-ray binaries offer opportunities for measurements which can, under favorable circumstances, yield precise determinations of the orbital elements of the binary system and significant limits on the masses and sizes of its stars. Most important of these favorable circumstances is the identification of the optical counterpart of the X-ray binary and the presence of measurable lines in the optical spectrum of the nuclear burning star. Then measurements of the Doppler effect of orbital motion on the period of the X-ray pulsations and on the wavelengths of the optical features can be analyzed, as in a "double-line" binary, to obtain the two masses within a factor that depends only on the inclination of the orbit to the line of sight. Limits on the inclination can be derived from the observed duration of the eclipse of the X-ray pulsar by the optical companion. The latter's size is known from the requirement that it must nearly fill its critical potential lobe in order for its outer layer to flow over to the pulsar. And finally, measurements of the spectrum and magnitude of the optical counterpart and, if possible, of nearby stellar associates can provide an estimate of the distance which permits one to derive the absolute X-ray luminosity from the measured X-ray flux.

According to the accretion model, incoming material spirals inward in an accretion disc to the radius where it is captured by the magnetic field of the pulsar and forced to corotate with the pulsar. In this process, the accretion flow exerts a torque on the pulsar which accelerates the rotation at a rate that depends on the rate of accretion and the moment of inertia of the pulsar. The luminosity also depends on the rate of accretion. Thus, a relation exists between the luminosity of an X-ray pulsar and the rate at which its period decreases, and this relation depends on the pulsar's moment of inertia.

With these concepts and consequences of the accretion model of X-ray pulsars in mind, what do the observations tell us about the nature of pulsars themselves? Are they white dwarfs or neutron stars?

After Uhuru, more than a dozen new binary pulsars were discovered by Ariel-V, SAS-3, OSO-8 and an NRL (Naval Research Laboratory) rocket, thereby adding much to the variety of systems and circumstances available for study. Long-term pointed-mode observations yielded extremely precise measurements of Doppler variations of the pulsar periods. Precise position determinations led to identification and detiled study of the optical counterparts. By the time of HEAO-1 a good understanding of the nature of X-ray pulsars had been achieved.

The periods of the known pulsars range from nearly 15 minutes down to 0.71 seconds. This shortest period, discovered in an NRL rocket observation, is of special interest because it places a lower limit on the mean density of the X-ray star which exceeds that of the densest possible white dwarf. An elementary calculation shows that matter riding on the equator of a spinning sphere will be restrained by gravity from flying off only if the mean density of the sphere is greater than $(11860/P)^2$ g cm^{-3} where P is the period of rotation in seconds. Putting $P = 0.71$ seconds, one finds the density is greater than 2.8×10^8 g cm^{-3}, a result that proves SMC X-1 is denser than a white dwarf and is therefore a neutron star.

Detailed analysis of several well-measured X-ray pulsers (see Rappaport and Joss, 1981) yielded a set of results in which the lowest lower limit on the pulsar mass is approximately 0.3 M_0 (M_0 = one solar mass), the highest upper limit 3 M_0, and all the limits are consistent with a single mass in a narrow range about 1.4 M_0, the Chandrasekhar upper limit on the mass of a degenerate dwarf. Since the masses of known white dwarfs in wide binary systems are generally less than 1.0 M_0, the facts that some of the lower limits on masses of X-ray pulsars are greater than 1.0 M_0 and all measurements are consistent with 1.4 M_0 support the idea that the X-ray pulsars are not white dwarfs but are neutron stars formed by the collapse of overweight degenerate stellar cores.

The X-ray luminosity of a typical X-ray binary is highly variable, ranging from a "saturated" value corresponding to an accretion rate limited by radiation pressure, to zero when the supply of accretion material is interrupted by some change in the binary system. When a pulsar is "ON" its period generally decreases, evidently due to torques exerted on the pulsar by the accretion flow. The rates of decrease are remarkably large—in some cases the characteristic spin up times are of the order of only hundreds or thousands of years. Clearly, to avoid a spin-up catastrophe, one must assume that pulsars spin *down* during their "OFF" periods due to braking torques caused by interaction of their magnetic fields with plasma in the binary system. In any event, a comparison of the spin up rates during "ON" periods with the accretion torques derived from the observed X-ray luminosities shows that the moments of inertia of X-ray pulsars are much less than those of white dwarfs and are, in fact, consistent with the values calculated for a sphere of mass 1.4 M_0 and radius 7 km, which implies a mean density of about 2×10^{15} g cm^{-3}. These are the specifications of a neutron star.

The estimate of accretion torque from the luminosity of a given pulsar depends on the value assumed for the strength of the magnetic dipole since it determines the distance at which the accretion flow is captured and, consequently, the specific angular momentum of the accreted material at the moment of capture. On rather general grounds it was assumed that compression of the magnetic field of the precursor star during its collapse into a neutron star would lead to surface fields of the order of 10^{12} gauss. Direct evidence for the existence of such a field in Her X-1 was discovered in a MPI (Max Planck Institute) balloon observation which detected a spectral feature in the X-ray spectrum at about 60 keV attributed to cyclotron resonance of electrons in a field of 6×10^{12} gauss.

Thus, it became clear in the period between Uhuru and HEAO-1 that X-ray pulsars are strongly magnetized neutron stars. The fact that their companions are generally massive, short-lived nuclear burning stars has led to the conclusion, now well supported by computer modeling, that they are formed in the evolution of massive primordial close binaries.

2. What is the Nature of the Population II X-Ray Stars?

The Uhuru sky survey, as represented in the famous 3U Catalogue, provided evidence for the division of high luminosity X-ray stars into two classes, one associated with young stars in the spiral arms (Population I), and consisting mostly of the massive binaries with magnetic neutron stars that pulse, and, in some cases, eclipse as described above, and another class associated with old stars in the central regions or "bulge" of the galaxy (Population II). The survey of positions, spectra and variability carried out with the OSO-7 satellite, launched one year after Uhuru, provided additional evidence for such a distinction.

The "bulge" X-ray sources, are in regions where no stars have formed for billions of years. With certain notable exceptions, these X-ray stars, though variable, do not pulse or eclipse, and they have softer spectra than the binary X-ray pulsars. Of special significance in the recognition of this distinct class of Population II objects was the discovery of X-ray stars in globular clusters—three by Uhuru, two by OSO-7 and several more by Ariel-V, SAS-3, and most recently by the Einstein Observatory. The globular clusters were formed over 10 billion years ago, and no star formation has apparently taken place in them since then. They therefore contain only the remnants of very ancient stars. The visible remnants are slowly evolving nuclear burning dwarfs and red giants with masses up to about 0.8 M_0. Undoubtedly, there are faint remnants in the form of degenerate dwarfs whose progenitors were stars with masses in the range from about 0.8 M_0 to 4 M_0 which completed their nuclear burning phases during the past 99 percent of the cluster age. And finally, there are probably some remnants in the form of neutron stars, and possibly black holes, that were produced within the first few millions of years of the cluster life in supernova explosions of stars with masses greater than about 4 M_0. Some of these may have escaped being ejected by the explosions from the shallow gravitational wells of their clusters, and thereafter settled into the cluster cores. It is from these various remnants or their combinations that the globular cluster X-ray stars probably formed. The similarity of their X-ray phenomena to those of the Population II X-ray stars found outside globular clusters leads one to suspect that they are similar in nature.

A vital clue to the nature of the Population II X-ray stars was provided by the discovery in observations by ANS in 1975 of X-ray bursts from the X-ray star 3U1820-30 in the globular cluster NGC6624. Within a few months Vela-5A, SAS-3, Ariel-V and OSO-8 had discovered similar X-ray bursts from about three dozen other Population II X-ray stars both inside and outside of globular clusters. In addition, with accurate positions obtained by SAS-3, the optical counterparts of several bursters outside of globular clusters were identified and studied. The X-ray bursters turned out to be typical Population II X-ray stars with high (greater than 10^{36} ergs sec^{-1}) persistent X-ray luminosities, soft spectra, and high variability without pulses or eclipses. Their optical counterparts are faint blue objects whose optical radiation is caused mostly by X-ray heating of material in their accretion discs or in the outer envelopes of dwarf nuclear-burning companions.

The bursts themselves are a remarkable phenomenon (see Lewin and Joss, 1981). In a typical burst of so called type I, the X-ray luminosity rises in less than 1 second to a peak luminosity of about 2×10^{38} erg s^{-1} (the approximate luminosity at which radiation pressure balances the gravitational attraction on material above the surface of a 1.4 M_0 star) and then decays over 10 to 100 seconds. A typical burster produces one burst every few hours during burst-active periods, and ceases bursting if its persistent luminosity exceeds a certain critical value.

Soon after their discovery, two ideas as to the cause of bursts were put forward. One was that they are the result of instabilities in the accretion flow onto a neutron star or black hole. The other was that they are thermal radiation from the surface of a neutron star which has been suddenly heated to X-ray incandescence by a thermonuclear flash burning of accreted material drawn from a close binary companion. Strong evidence in favor of the thermonuclear flash model was soon found in a measurement of variations in the spectrum of a burst by OSO-8, and then in extensive studies of burst characteristics by SAS-3. The luminosity and spectra of bursts were found to vary during the decay phase like that of an optically thick radiator cooling from a temperature of 30 million degrees and with an area equal to that of a neutron star. Also, the ratio of persistent X-ray flux to average burst flux of typical bursters was found to be approximately equal to the ratio of gravitational energy to thermonuclear energy of material accreted by a neutron star.

Discovery and detailed study with SAS-3 of one remarkable and unique object, the Rapid Burster, yielded decisive confirmation of the thermonuclear flash model of X-ray bursts. Located at the center of a highly obscured and previously unknown globular cluster, the Rapid Burster turns "on" every few months for a period of several weeks during which it emits a machine-gun fire of X-ray bursts that recur at intervals that are sometimes as short as 20 seconds, and have spectra that show no evidence of cooling during the decay phase. The observed upper limit on the flux of persistent emission between bursts is much less than 100 times the average burst flux. Thus the rapid bursts are clearly of a different kind and were dubbed type II. Then it was discovered that in the midst of the crowd of type II bursts an occasional type I occurs, and that the mean flux in type II's is about 100 times that in type I's. Suddenly it was clear that the Rapid Burster does it both ways, making type II bursts by instabilities in the accretion flow, and type I bursts by thermonuclear flash burning of the accreted material.

Theoretical calculations of thermonuclear flashes on the surfaces of non-magnetic neutron stars predict X-ray bursts with temporal and spectral characteristics that match well those observed in type II bursts. Thus, it seems that the Population II X-ray stars that burst are weakly or non-magnetic neutron stars with low-mass companions. The calculations show that if the accretion rate is too high or the magnetic field too strong, then thermonuclear burning is continuous, and bursting ceases. This result is consistent with the fact that most of the brightest Population II X-ray stars don't burst. Pulsars apparently never burst because the high magnetic fields and high temperatures in their polar regions cause continuous thermonuclear burning of the accreted material.

The persistent emissions of bursters and of non-bursting, non-pulsing Population II X-ray stars are similar in the softness of their spectra, in the absence of periodicities in their variations, and in the characteristics of their optical counterparts which are faint blue stars with spectral features attributed to the effects of X-ray heating. In view of these similarities it is now generally believed that all non-pulsing Population II X-ray stars are of a similar nature, namely, weakly or non-magnetic neutron stars with low-mass companions in close, mass-transfer binary systems. The weakness of the magnetic field also allows the accretion disc to extend inward to near the neutron star's surface so that it casts a deep X-ray shadow in the equatorial plane of the system, thereby preventing the observation of X-ray eclipses.

Finally, a word about the origins of Population II X-ray stars. Their relatively frequent occurrence in the cores of centrally condensed globular clusters is evidence in favor of the idea that they are formed through capture of nuclear burning companions by old neutron stars lurking in those regions of very high star density. Population II X-ray stars outside of globular clusters may be formed by evolution of close binary systems with white dwarfs that accrete matter until they exceed the Chandrasekhar limit and collapse into neutron stars. In either case the resulting X-ray stars are very long-lived systems that may last billions of years as their neutron stars gradually swallow the substance of their companions. Their very low production rate multiplied by their very long life equals the hundred or so objects we see, a number quite comparable to the much higher production rate of the Population I X-ray stars multiplied by their much shorter life.

3. Are There Lower Luminosity X-Ray Stars?

The frequency distribution of the maximum luminosities of the X-ray stars in the Uhuru survey exhibited a broad peak in the range from 10^{36} to 10^{38} erg s^{-1}. This fact found a natural explanation in the framework of the standard model of binary X-ray stars described previously. The upper luminosity limit is set by the effect of radiation pressure on limiting the accretion flow. For spherically symmetric accretion, this limit is 1.7×10^{38} erg s^{-1} for a 1.4 M_0 star. Actual accretion flows are radiation limited at generally lower values. As for the lower limit, accretion onto a neutron star is an enormously efficient source of heat energy, yielding about 0.3 c^2 per unit mass of accreted material. A very low accretion rate, amounting to only 10^{-9} M_0 per year, is sufficient to generate a typical "saturated" luminosity of 1.7×10^{37} ergs s^{-1}. Thus, the luminosities of X-ray binaries are easily driven to their limits by modest rates of mass transfer, which accounts for the clustering of maximum luminosities in the 10^{36} to 10^{38} erg s^{-1} range. UHURU was sensitive enough to detect such sources anywhere in the galaxy. It could also, of course, detect weaker sources nearby. However, for lack of identifications of possible nearby weak X-ray stars it was not posssible to determine whether there exists a class of X-ray stars with peak luminosities between that of the sun and the lower limit of the neutron stars in mass-transfer binaries.

Then, a Lockheed rocket observation detected soft X-rays from Capella, a wide non-degenerate binary and the first of what has since come to be recognized as the class of RS CVn-type coronal X-ray emitters. An MIT rocket observation detected soft X-rays from the cataclysmic variable SS Cygni, a white dwarf in a close binary. SAS-3 detected HZ43, an isolated hot white dwarf; AM Her, a magnetic white dwarf in a close binary; Algol, a non-degenerate eclipsing binary of which one component is a coronal X-ray emitter; the Orion Trapezium, a cluster of young massive stars; and Gamma Cas, a Be star.

All these lower luminosity sources had peak values in the range from 10^{31} to 10^{33} erg s^{-1}, substantially less than the peak luminosities of neutron stars in mass exchange binaries. The trail was thereby blazed to the promised land where X-ray observations were to play a vital role in general stellar astronomy.

4. What is the Nature of the Diffuse X-Ray Emission from Clusters of Galaxies?

Two entirely different interpretations of the diffuse X-ray emission from clusters of galaxies were put forward shortly after the phenomenon was discovered by Uhuru. One was that it is X-rays produced by inverse Compton scattering of microwave photons by high energy electrons. The other was that it is thermal emission of hot intergalactic gas. If the latter is correct, then the question arises as to whether the gas is primordial material left behind when the galaxies of the cluster condensed and formed stars, or is material that has been processed in stars in galaxies and then swept out of the galaxies to form an intracluster medium trapped in the gravitational potential well of the cluster. Clearly, the answer to this question has profound implications for our understanding of the origin and evolution of clusters and galaxies.

The decisive discovery was made with Ariel-V which revealed the presence of iron K-line emission in the X-ray spectrum of the Perseus cluster. OSO-8 confirmed this result and also found K-line emission in the spectra of the Virgo and Coma clusters. The abundances of iron relative to hydrogen implied by the data were close to those found in the sun and other objects composed of material that has been processed in stars and ejected by supernovae. The conclusion was clear that the diffuse emission from clusters of galaxies is thermal bremstrahlung of hot matter that has been processed in stars in galaxies and subsequently swept out, apparently by the ram pressure exerted by the intergalactic gas itself on the processed gas in galaxies as the galaxies move in their orbits through the cluster (see Culhane, 1979).

5. What are the Unidentified High Galactic Latitude Sources?

An NRL rocket observation before Uhuru detected X-ray emissions from the giant elliptical galaxy M87, and the Seyfert galaxy NGC1275. The multiple-lobed radio galaxy Cen A and the quasar 3C273 were detected in Berkeley rocket observations, also just before the launch of UHURU. The X-ray luminosities of these extragalactic sources exceeded by far the combined luminosities of the X-ray stars in their associated galaxies. It then seemed likely that this small set of extragalactic sources was the tip of an iceberg of distant extragalactic X-ray sources of great luminosity that would be detectable with more sensitive instruments.

Uhuru observations confirmed and extended these results with the discovery of diffuse X-ray emission from galaxy clusters and from several additional identified Seyfert galaxies. OSO-7, launched ten months after Uhuru, discovered variability on a time scale of days in Cen A, proving thereby that the emission comes from an active compact source in the nucleus of the galaxy. Many faint sources were found at high galactic latitude in the surveys of Uhuru and OSO-7, but only a few were identified with known optical or radio objects on account of large uncertainties in their positions. Thus, a key question confronting the observers preparing to use the facilities of the next generation of X-ray satellites was the nature of the "UHGLS"—the unidentified high galactic latitude sources.

Ariel-V carried out an extensive survey at high galactic latitudes with improved positional accuracy and demonstrated that many of these sources are the active nuclei of Seyfert galaxies. SAS-3 measured the positions of galactic and extragalactic sources to within uncertainties of 20 arc seconds and thereby facilitated the identification of numerous extragalactic objects. Among these were additional clusters and active galactic nuclei including Cd galaxies, Seyfert nuclei, BL Lac objects and two additional quasars. Thus, by the time that HEAO-1 was launched, it appeared likely that most, and perhaps all, of the "UHGLS" in the Uhuru and subsequent sky surveys are active nuclei of galaxies or clusters of galaxies (see Wilson, 1979).

6. What is the Nature of the Unresolved X-Ray Background?

Above 1 keV there exists a highly isotropic, apparently diffuse X-ray background noted and measured in the 1962 rocket survey that discovered the first X-ray star, Sco X-1. At each stage of refinement in X-ray surveys some portion of the previously unresolved "background" has been analyzed into three components—newly resolved discrete sources, an unresolved component attributable to distant objects of a kind and spatial density deduced from detailed study of resolved objects, and an unresolved component of unknown nature that may be emission from faint discrete objects or a diffuse extragalactic medium.

The identifications of many of the "UHGLS" with specific active galactic nuclei and galaxy clusters at known distances and the discovery of additional X-ray emitting QSO's permitted a further refinement of this background analysis with the result that it was possible to account for about one-third of the unresolved and highly uniform background above 1 keV in terms of distant members of the classes of known extragalactic sources.

Below 1 keV, the X-ray background rises rapidly in intensity with decreasing energy and becomes highly anisotropic. Rocket surveys with large-area gas-flow detectors proved to be the most effective means for exploring the origins of this radiation which was below the threshold of the Uhuru counters. A scan of the small Magellanic cloud in a Wisconsin rocket observation showed no evidence of a shadow in the soft X-ray background due to absorption by the diffuse matter in the SMC of soft X-rays from sources beyond the SMC. This result demonstrated that some, or possibly all, of the soft X-ray backgrond originates in front of the SMC, presumably in our own galaxy. Maps made from various rocket surveys show correlations between soft X-ray intensity contours and radio intensity contours that lead to the conclusion that the soft X-ray background is emission from a hot component of the interstellar medium, probably the product of old supernova remnants that have expanded and merged into a network of plasma clouds with temperatures of the order of 10^6 degrees Kelvin (see Kraushaar, 1979).

Conclusion

The period from Uhuru to HEAO-1 was the heyday of exploratory satellite X-ray observations which consolidated and extended the great leap forward achieved by Uhuru. An invigorating spirit of competition and cooperation was felt in the scientific groups responsible for the various missions. Many of the observers had a kind of hands on experience with their instruments in Earth orbit that may never be known again. It was indeed an exciting and rewarding time for X-ray astronomers.

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The High Energy Astronomy Observatory: HEAO-1

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The HEAO-1 mission, launched seven years after Uhuru, is really a direct outgrowth of that original all-sky X-ray survey, and is based upon the same principals, greatly expanded. As I mentioned to the HEAO-1 project scientist (Frank McDonald) at the beginning of its development, HEAO-1 could be viewed as the dinosaur of X-ray astronomy, but the kind of mission that is vital for the proper evolution of the field. I am now convinced that it was a critical mission and I hope this will be evident from what follows.

First, let's examine how the Uhuru scheme was applied to HEAO-1; this is shown in Table 1. As I view it, the Uhuru scheme is one that emphasizes an all-sky survey using mechanical collimation. Such an all-sky scheme establishes classes of sources by detecting the brightest members and is generally more efficient in this respect than surveys concentrated over small regions. These sources are then characterized further by non-dispersive spectroscopy and timing measurements. Hence, we use the headings "All-Sky Survey", "Non-dispersive Spectroscopy", "Timing" and "Mechanical Collimation" (see Table 1). For Uhuru the all-sky survey was carried out with a detector area of about 0.08 m^2, where the scan mode was one of great circles. As applied to HEAO-1 the great-circle scans were such that the corresponding spin-axis always pointed to the sun whereby a rather uniform all-sky scan was relentlessly carried out in six months and then repeated. This relatively rapid sort of all-sky survey was nevertheless carried out with high effective exposure because of the large detector area involved, an order of magnitude more than Uhuru. By non-dispersive spectroscopy we mean measuring the energy of each photon individually via the photo-electric effect. For Uhuru this was done for the 2-20 keV band by using argon gas proportional counters. For HEAO-1 the bandwidth was vastly expanded to cover 0.1 keV to about 10 MeV. This called for several different kinds of gas proportional counters and scintillators, each optimized for a special portion of the overall band. Spectroscopy was now emphasized. Rather than 8 pulse-height analyzer channels for the entire band, the experiments were designed to provide an order of magnitude better resolution by

Table 1

UHURU SCHEME

	ALL-SKY SURVEY		NON-DISPERSIVE SPECTROSCOPY		TIMING	MECHANICAL COLLIMATION
	SCAN MODE	EFFECTIVE AREA	ΔE	PHA CHANNELS		
UHURU	GREAT CIRCLES	0.08 m^2	2 KeV-20 KeV	8	INTENSITY	CELLULAR COLLIMATORS
HEAO-1	SIX-MONTH CYCLE	1.1 m^2	0.1 KeV-10 MeV	64/DECADE	SPECTRUM	• MULTIPLE FIELDS • MODULATION COLLIMATOR

using 64 PHA channels for each decade in energy. Timing measurements were no longer restricted to intensity variations for a few colors. The pioneering measurments with Uhuru of pulsations from sources such as Her X-1 and chaotic variability of other objects such as Cyg X-1 could now be extended to spectroscopy. For pulsars we call this "pulse-phase spectroscopy".[1] The mechanical collimation for Uhuru involved a cellular structure optimized for isolating individual sources of emission. The same sort of principal was applied to the large area survey modules of HEAO-1. In addition, however, multiple fields of view were incorporated into other modules which were optimized for measurements of the surface brightness of the X-ray background and large-scale features. Finally, modulation collimators were incorporated into some modules covering the Uhuru band so that the HEAO-1 mission could be used to locate sources to a precision of about half an arc minute and thereby provide opportunities for optically identifying a substantial number of objects. All-sky coverage along with simultaneous spectroscopy at energies extending from well below the Uhuru band to well above have made this identification aspect of the HEAO-1 program particularly powerful and unique in providing essential links to the rest of astronomy.

The various institutions directly involved with HEAO-1 are listed in Table 2. Project management was handled at Marshall Space Flight Center. The project scientist is at Goddard. The responsibilities for the principal investigations are summarized in Table 2. The modules devoted to the large area sky survey and microsecond timing are associated with NRL. Non-dispersive spectroscopy and surface brightness measurements were carried out with modules especially developed for the minimization of extraneous background and its quantitative evaluation. These were divided into three bands. The soft X-ray modules were handled by CalTech, JPL and Berkeley, mid-band modules by Goddard and hard X-ray scintillators by MIT and UCSD. The modulation collimator portion of HEAO-1 was shared by the Smithsonian at Harvard and MIT. Several other institutions are also involved, mainly in connection with guest investigators. The HEAO-1 mission was carried out with a great degree of coordination among the various experiments and the investigators associated with them. This applied not only to initial planning and operations but to data analysis, interpretation of results and their joint publication.

Figure 1 gives some idea of the size of HEAO-1. This photograph was taken at TRW during the integration of the large

Table 2

HEAO - 1

PROJECT MANAGEMENT: MARSHALL SPACE FLIGHT CENTER – F. SPEER

PROJECT SCIENTIST: F. McDONALD – GODDARD SPACE FLIGHT CENTER

PRINCIPAL INVESTIGATIONS

□ LARGE AREA ($1.1m^2$) SKY SURVEY (0.5 - 20 KeV)

□ RAPID TIMING (μ sec.)

- O NAVAL RESEARCH LABORATORY – H. FRIEDMAN

□ NON-DISPERSIVE SPECTROSCOPY

□ SURFACE BRIGHTNESS OF LARGE-SCALE FEATURES AND ISOTROPIC BACKGROUND

- Δ SOFT X-RAYS (0.1 - 3 KeV):
  - O CALIFORNIA INSTITUTE OF TECHNOLOGY – G. GARMIRE
  - O JET PROPULSION LABORATORY – G. RIEGLER
  - O UNIVERSITY OF CALIFORNIA (BERKELEY) – S. BOWYER
- Δ MEDIUM BAND (2 - 60 KeV):
  - O GODDARD SPACE FLIGHT CENTER – E. BOLDT
- Δ HARD X-RAYS (.01 - 10 MeV):
  - O MASSACHUSETTS INSTITUTE OF TECHNOLOGY – W. LEWIN
  - O UNIVERSITY OF CALIFORNIA (SAN DIEGO) – L. PETERSON

□ MODULATION COLLIMATOR IDENTIFICATION OF SOURCES (1.5 - 13 KeV):

- O CENTER FOR ASTROPHYSICS (HARVARD) – D. SCHWARTZ (H. GURSKY)
- O MASSACHUSETTS INSTITUTE OF TECHNOLOGY – H. BRADT

area NRL sky survey modules, shown here with protective covers. The other modules devoted to non-dispersive spectroscopy, surface brightness and modulation collimator studies are on the opposite side. The large solar panels are along the left side of the observatory.

Now to some of the results being obtained from the analysis of HEAO-1 data. First of all, let's address integral properties of the X-ray sky, something that this broad-band all-sky mission could do particularly well. Considering a band of energies that overlaps significantly with Uhuru but is generally higher than energies examined with the Einstein Observatory, we can construct a map of surface brightness in which some gross aspects of the Uhuru sky become quite evident. This was done by DeAnn Iwan from the all-sky data base associated with one of the Goddard modules; the resulting map is shown in Figure 2.

The all-sky map exhibited here (Figure 2) is an equal area projection of the celestial sphere in galactic coordinates. The longitude is zero at the center and increases to the left. Since the map is in galactic coordinates, the equator and center of the galaxy are quite evident. The data were obtained from a Goddard module called High Energy Detector #1 (HED-1). The counts recorded were simply assigned to $3° \times 3°$ pixels. This was done with all sources included. The resulting intensities for the pixels are color coded. Those intensities within 3% of a constant sky background are blue. Intensities lower than this are shown as black, higher are shown as red. Within each color code, the lines per pixel provide a vernier on the numerical intensity. This particular map saturates at a surface brightness about 40% above that of the diffuse background. In terms of source intensity it is equivalent to the brightest isolated galaxy, which is Cen A. A few clusters of galaxies exceed this saturation limit; many galactic sources do, of course. For the present discussion, the main thing to notice is that most of this map is blue, indicating that the associated cosmic background is a well-defined dominant aspect of the X-ray sky in the Uhuru band and somewhat higher. We now know quite precisely what there is in toto that needs to be explained. It turns out that spectroscopy has become an important part of this picture, and we will come back to the cosmic X-ray background in this context later on.

By lowering the photon threshold energy by an order of magnitude to below 1/4 keV we enter a source regime now studied with the imaging devices of the Einstein Observatory. Gordon Garmire and the Caltech group have done this using HEAO-1 data from the soft X-ray modules and thereby constructed a similar surface brightness map to the one shown, but corresponding to much lower energies. Here again the X-ray sky is dominated by a background, but this time it's a highly anisotropic one associated with large-scale galactic effects. In general these are related to diffuse emission by extensive interstellar plasmas at temperatures of a few million degrees.

In order to examine possible structure in galactic emission in the Uhuru band (both resolved and unresolved) we have made another map concentrating on latitudes within 45° of the plane and using $1° \times 1°$ pixels. This was done by Frank Marshall from the data base associated with Goddard's medium energy module (MED) and is shown in Figure 3. The gradations in color-coded intensity are described by the

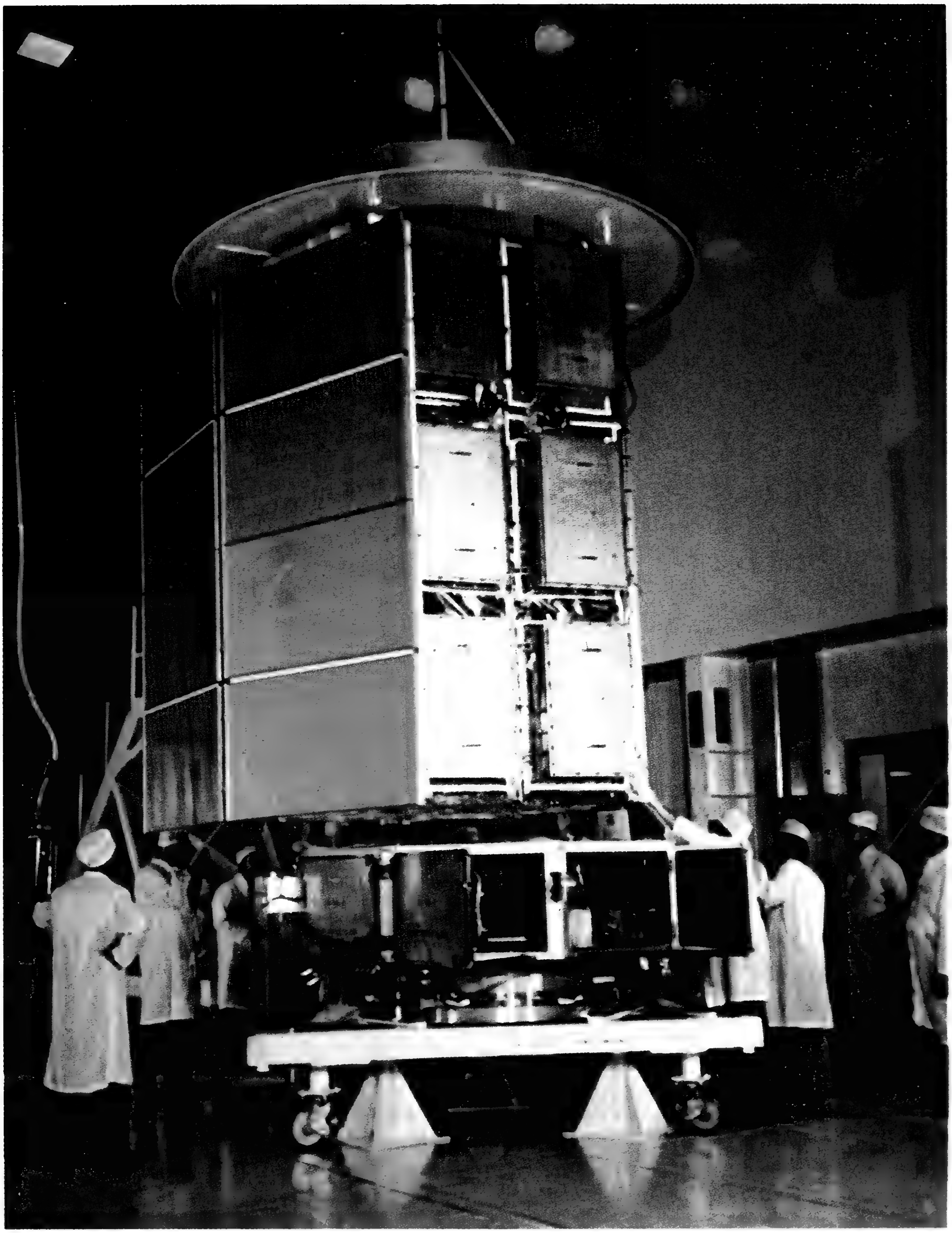

Fig. 1. The HEAO-1 payload as photographed at TRW during integration of the NRL sky-survey modules.

strip at the bottom; high intensities saturate at red. Here again the counts recorded were simply assigned to the appropriate pixels and the resulting intensities color coded as indicated. A point source appears in several pixels because no attempt was made to remove collimator response. Source confusion is evident, especially towards the galactic center but several bright Uhuru sources are easily identified. The three brightest sources in the longitude band 70°–90° are Cygnus X1, X3 and X2. We

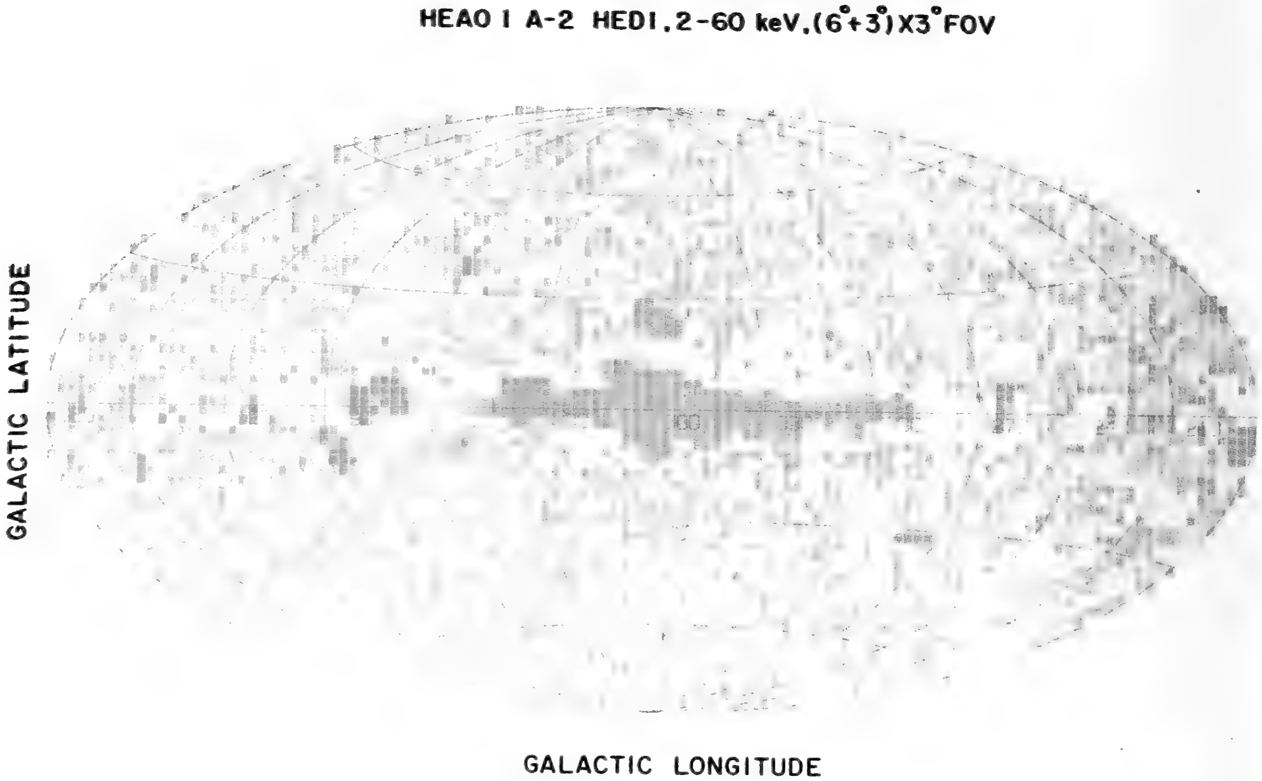

Fig. 2. The surface brightness of the entire X-ray sky (in 3° × 3° pixels) as obtained with the combined 3° × 3° and 6° × 3° collimator sections of a GSFC high energy detector (HED-1) over the band 2–60 keV. The map is presented in galactic coordinates. Intensity gradations are color-coded in the order black, blue and red (highest).

note the concentration of sources towards the center and the relative absence of resolved sources in the interarm region at longtitudes near 60° adjacent to the Cygnus sources. There is also some galactic emission that can not be attributed to specific sources and which, at this level, we call unresolved. One such component has a scale height of about 200 pc and is, for example, related to the greenish haze exhibited in the interarm region at $l \sim 60°$. Diana Worrall *et al.*[2] have modelled this further and find that the entire galactic emission from this thin unresolved disk is about a tenth of that from all bright galactic sources already detected. There is also a general enhancement at higher galactic latitudes and this can be seen here by the increased blueness within ~20° of the plane. DeAnn Iwan *et al.*[3] have modelled this and conclude that the scale height involved is about 3 kpc. The total luminosity is comparable to that of the thin disk. At this stage it appears that unresolved stellar emission from low luminosity X-ray sources at effective temperatures corresponding to several keV could dominate at least one of these two components, but more studies are needed.

One effective way to investigate low luminosity source populations within our galaxy is to examine objects detected at high galactic latitudes. This minimizes source confusion and, for galactic sources, maximizes apparent intensities. As a matter of fact the unidentified high latitude Uhuru sources constitute one of the major challenges of X-ray astronomy to be addressed by HEAO-1. The total number of Uhuru sources at high galactic latitudes is about a hundred. However, many of these are asso-

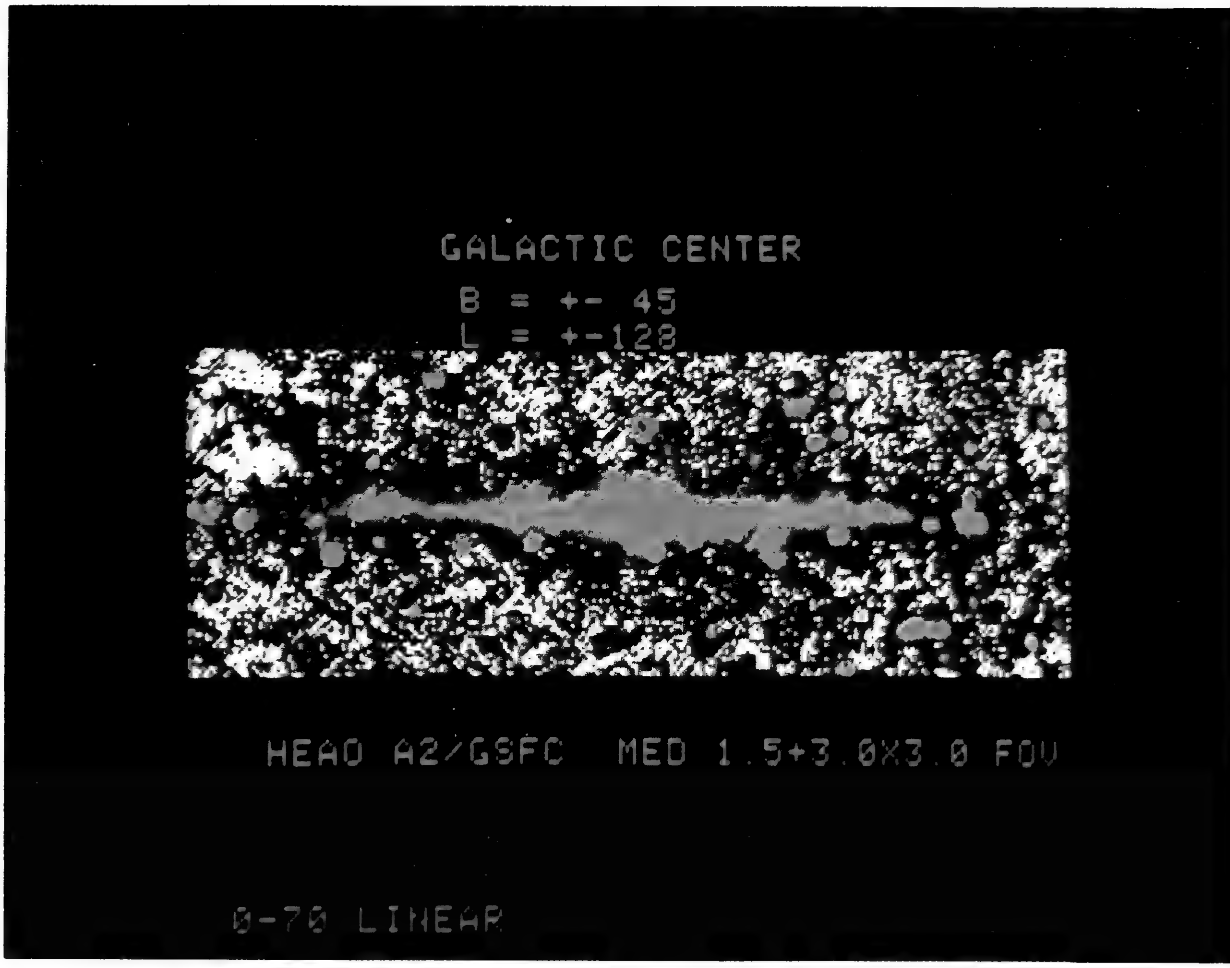

Fig. 3. The surface brightness of the X-ray sky (in 1° × 1° pixels) associated with the Milky Way as obtained from the 1 1/2° × 3° collimator portion of Goddard's Medium Energy detector (MED) over the band 1.5–20 keV. The map is presented in galactic coordinates. Intensity gradations, indicated by the strip at the bottom, are color coded in the order white, blue to red (highest). Galactic coordinates are restricted to $|b| < 45°$, $|l| < 128°$.

ciated with special non-stellar objects such as clusters of galaxies and active galaxies. About two-thirds of them were identified as extragalactic based on data from Uhuru and subsequent missions. However, the other high-latitude sources remained mainly for HEAO-1, which has now established the major classes of objects involved. These previously unidentified sources were always particularly fascinating and prompted early speculation that they were a new class of extragalactic objects. The HEAO-1 data base can be used to establish those high latitude sources that exceeded 1 Uhuru flux unit during the time they were observed within the all-sky scan. Excluding sources identified with non-stellar objects we are left with 21 objects. Of these, 14 are now identified with stellar objects within our galaxy. A galactic plot of these 14 high latitude Uhuru sources identified as stellar is shown in Figure 4. Three of the 14 stellar X-ray sources plotted (Figure 4) were identified prior to HEAO-1; they are Sco X-1, Her X-1 and AM Her. Sco X-1 is of course the first and brightest X-ray star in the sky. It's a low mass binary with a period of ~ 0.8 days established from optical observations alone. The X-ray source is a degenerate star (either a neutron star or white dwarf). Richard Rothschild *et al.*,[4] have used HEAO-1 scintillator observations to determine that a 5 keV thermal bremsstrahlung spectrum provides a good fit to the high energy data up to at least 70 keV although Peter Serlemitsos and Jean Swank[5] are investigating a possible low temperature component in this and similar sources. Her X-1 is also associated with a low mass binary and is one of the major triumphs of

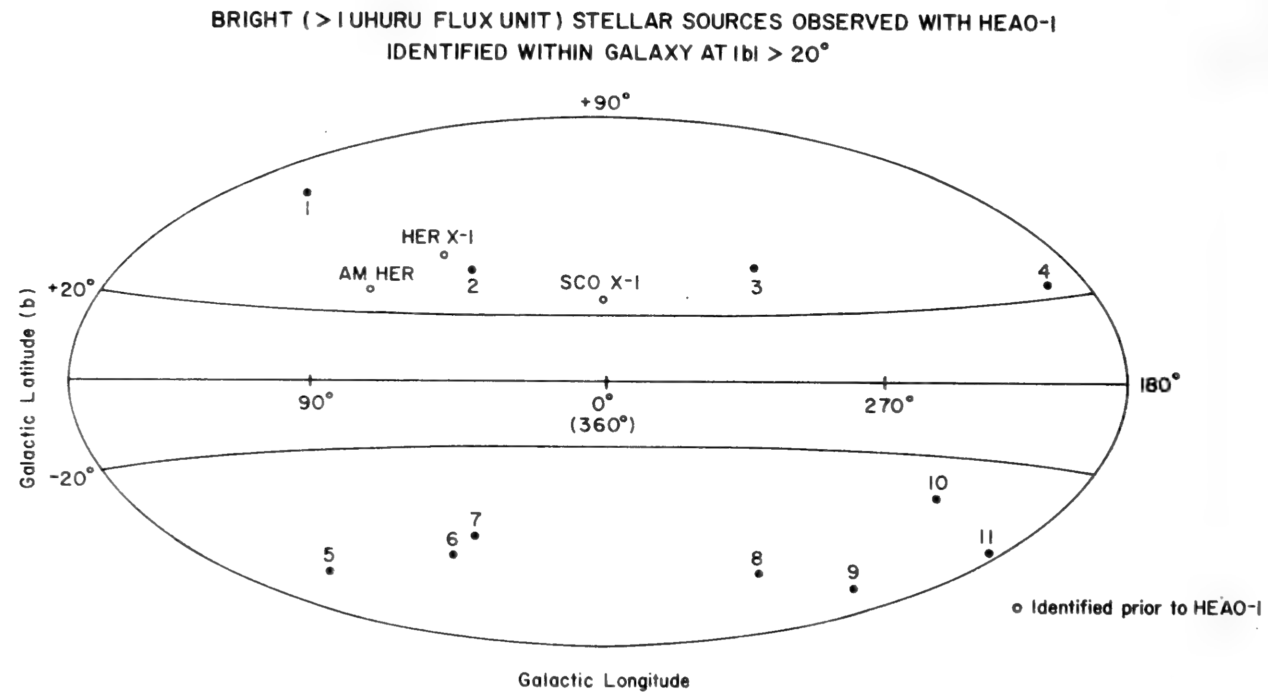

Fig. 4. Bright (> 1 Uhuru flux unit) stellar X-ray sources observed with HEAO-1 identified within the galaxy at |b| > 20°. Positions are plotted in galactic coordinates. Source numbers indicated are identified as follows: 1) 2A1052 + 60 (BD61 + 1211) 2) 2A1704 + 24 3) 2A1249 − 28 (EX Hya) 4) H 0751 + 22 (U Gem) 5) H 0123 + 070 6) H 2252 − 035 7) H 2215 − 08 (Wolf 1561) 8) 2A0235 − 52 9) 2A0311 − 22 10) 2A0526 − 32 11) 4U0336 + 01 (HR 1099).

Uhuru. Studies of the X-ray pulsar involved with this system have been remarkably fruitful indicating a neutron star X-ray source with a normal companion of about 2 solar masses. Balloon observations by Trumper *et al.*[6] suggesting cyclotron spectral structure have been elaborated upon by Duane Gruber *et al.*[7] using the HEAO-1 scintillator data.

AM Her was first detected as a soft X-ray source by Hearn *et al.*,[8] with SAS-3 and is now known as a hard X-ray source as well from OSO-8[9] and HEAO-1[10] (see Figure 5). This low mass binary has a 3.1 hour period and involves a magnetic white dwarf phase-locked with a dwarf M star companion. Another such system is number 9 (2A0311-22). The HEAO modulation collimator location of this Ariel 5 source by Griffiths *et al.*,[11] matched well with optical studies that found an 81 minute binary system similar to AM Her. Using HEAO-1 proportional counter data White[12] has found this period in the X-ray source as well. Number 6 is a HEAO-1 source (H2252-035) that precipitated the optical discovery[13] of a white dwarf binary with some particularly interesting properties. The binary period here is 3.6 hours but in this situation the magnetized white dwarf is not yet phase locked and appears as an X-ray pulsar[14] with a period of 14 minutes. Number 3 (2A1249-28) was identified with the dwarf nova EX Hydra by France Cordova and Guenter Riegler[15] based on HEAO-1 soft X-ray data and firmly established as such by the modulation collimator[16] at higher energies. In this case the binary period is 98 minutes and the white dwarf does not have a strong magnetic field. Number 4 (H0751 + 22) is an example of impulsive accretion onto a white dwarf. This source is identified with the dwarf nova U Geminorum and was discovered by Keith Mason *et al.*,[17] with the HEAO-1 soft X-ray detectors during outburst of the source. A survey by France Cordoval *et al.*,[18] of 20 dwarf novae in outburst yielded positive detections only for UGem and SS Cygni. The HEAO-1 discovery of quasi-coherent pulsations[19] for SS Cygni and for U Gem is probably a direct measure of the Keplerian periods at the surface of these accreting white dwarfs. Number 10 (2A0526-32) is a cataclysmic

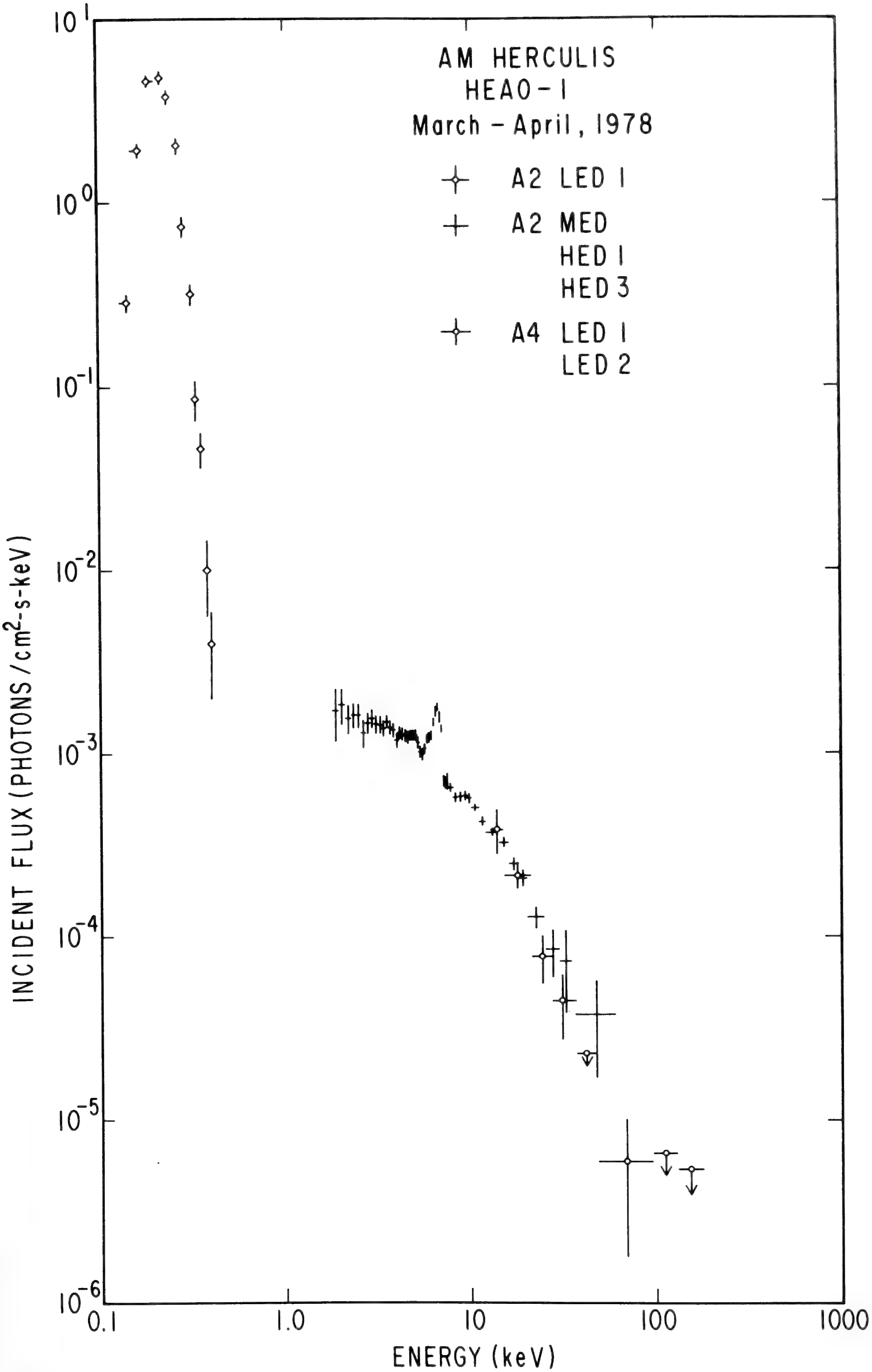

Fig. 5. Composite spectrum for AM Herculis obtained by combining data from several different modules, as indicated. The two distinct components (soft and hard) are evident as is the iron K line emission in the 6–7 keV band.

variable discovered in the optical[20] as a direct consequence of the HEAO-1 modulation collimator location[21] of this Ariel 5 source. For all of these sources the X-ray luminosity involved is on the order of 10^{32} erg s^{-1}, several orders of magnitude lower than the X-ray luminosities associated with known X-ray binaries involving neutron stars.

Low mass binaries where the X-ray source is a white dwarf appear to account for a substantial fraction of our high-latitude Uhuru sources. What else is there? Number 7 (H2215-08) is associated with a flare star (Wolf 1561).[22] Number 1 (2A1052 + 60), number 5 (H0123 + 070) and number 11 (4U0336 + 01) are stars with very active coronae associated with the type RS CVn. Numbers 1 and 5 are new RS CVn systems [23–25] arising from the identification of sources located with the modulation collimator. Phil Charles *et al.*,[23] observed number 1 during a large flare of soft X-rays amounting to more than 10^{37} erg within about 2 days. However, displaying these RS CVn systems is just scratching the surface. With the HEAO-1 soft X-ray data Frederick Walter and colleagues[26] spearheaded this work and found that most RS CVn systems within ~100 pc are strong X-ray emitters, at least by solar standards. In particular, HEAO-1 data have been used to discover 15 RS CVn objects with X-ray luminosities on the order of 10^{31} erg s^{-1} at temperatures on the order of 10^7 degrees. The thermal spectra measured with HEAO-1 for Capella exhibits iron line emission[27] indicating that, at least for some of these objects, the abundances involved in the emitting plasma could be close to solar. The relatively high temperature of these stellar coronae suggests that the magnetic loop confinement model of Rosner *et al.*,[28] developed to explain observations of the solar corona over active regions is operative here as well. However, the luminosity is relatively high for these sources indicating that RS CVn stars involve active regions over a large fraction of their surface. These RS CVn systems are the most luminous nondegenerate late type stellar X-ray sources known. This pioneering work based on HEAO-1 showed that these systems are a natural place to test theories and models of late type stellar coronae, and such studies are now well along.

In addition to studies of stellar galactic sources, HEAO-1 also was used for the study of supernova remnants and their effects on the interstellar medium. To exhibit this we examine the Cygnus region. Figure 6 displays a map constructed by Frederick Walter and Webster Cash based on soft X-ray data in the 1/4 keV band. The field here is ~20° in diameter. Black pixels indicate that data were excluded because of some problem or because of overflow. The intensity increases from blue to yellow. The galactic plane is along a diagonal from the upper left to the bottom right. The obvious enhancement near the bottom is the Cygnus Loop, an old supernova remnant measured by Steve Kahn *et al.*,[29] to be a 3×10^6 °K thermal source with oxygen K and iron L lines. The weaker source to the right was identified by Mason *et al.*,[30] with G65.2 + 5.7, another old supernova remnant exhibiting a thermal spectrum with line structure similar to that of the Cygnus Loop. Altogether there was a dozen new soft X-ray sources discovered[31] which are associated with supernova remnants. Since this picture is based on 1/4 keV data we are restricted to sources within a few hundred parsecs. In fact we are looking in the direction of the Great Rift of Cygnus, a large region of dust and gas extending along much of the diagonal representing the galactic plane. Sources within the galactic disk at distances greater than a kpc or so would be highly obscured, even at harder X-ray energies. Now what happens if we construct a similar map, but with data at somewhat more penetrating X-ray energies $\gtrsim$1/2 keV? This is displayed in Figure 7.

Except for the Great Rift of Cygnus, the map exhibited in Figure 7 is lit up with X-rays. This giant X-ray ring of Cygnus as analyzed by Webster Cash *et al.*,[32] was one of the most spectacular objects discovered with HEAO-1. Subtending almost 20° it is intermediate in size between the North

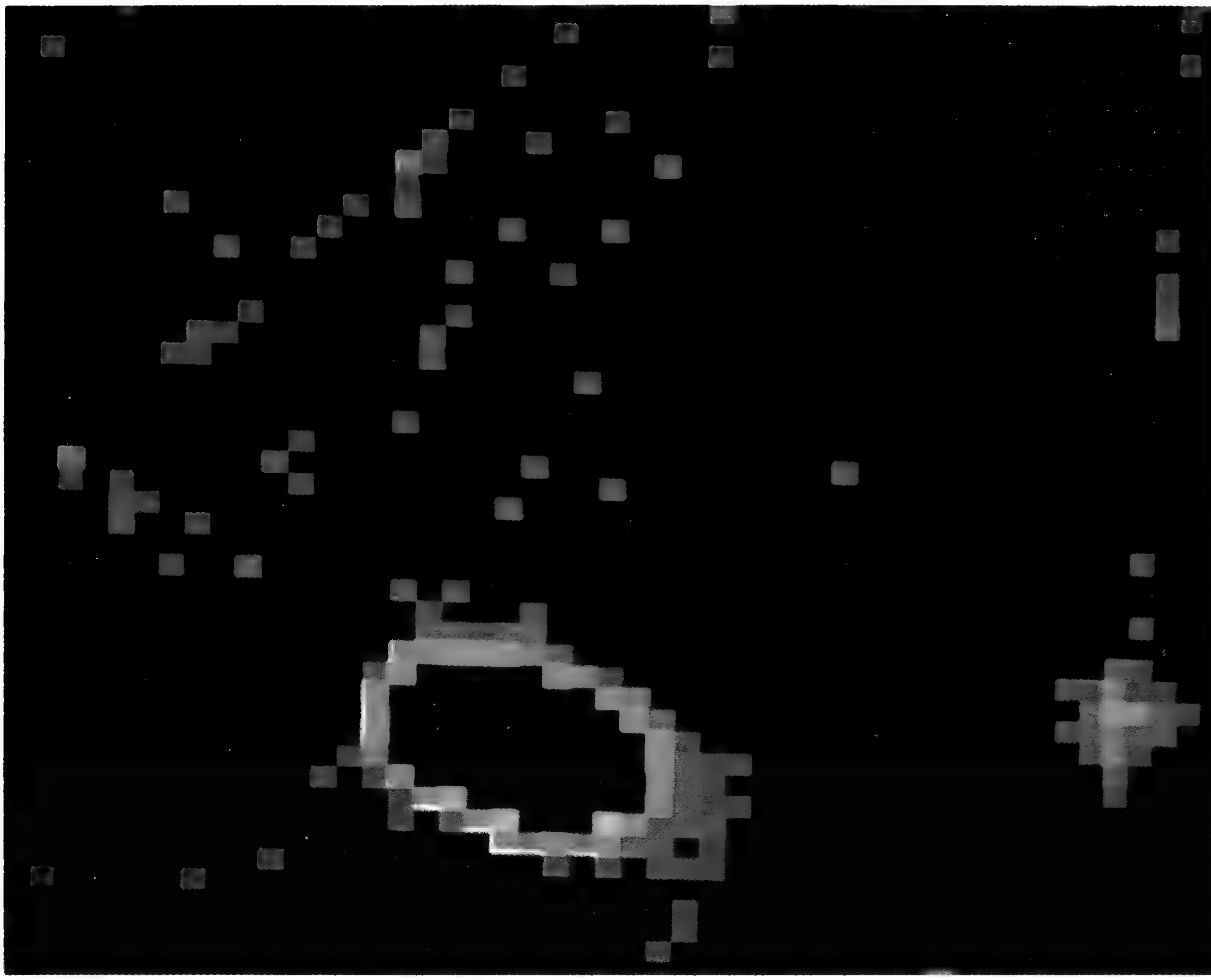

Fig. 6. An intensity map of the Cygnus region in the 1/4 keV soft X-ray band. Color represents the average counting rate while the collimator of the low energy detector (LED of HEAO-1 A2) was centered on the 0.5° pixel. Black indicates rejected data (e.g. due to saturation, contamination, loss). The color code for accepted data goes from blue (lowest) to yellow (highest).

Polar Spur and large supernova remnants. Without the full sky coverage of HEAO-1 this could not have been mapped. The radiating electrons of the 2×10^6 K plasma associated with this structure have an energy content exceeding 10^{52} erg. Cash postulates that "superbubbles" such as this are commonplace, the result of the large number of supernovae associated with the early evolutionary stages of large O-B associations. Such objects may encompass about a tenth of the galactic disk and play a major role in the energetics of the interstellar medium.

Now let's increase our effective threshold energy to about 1 keV so as to lessen our efficiency for detecting the softer radiation from a 2×10^6 K plasma such as the Cygnus Superbubble. The map obtained for this same region with this somewhat higher threshold is shown in Figure 8. As expected, the superbubble has essentially disappeared. The Cygnus Loop at the bottom is still visible because it is a brighter source. The source up to the left of the Cygnus Loop is Cyg X-2. The bright source to the right is Cyg X-1, which has been extensively studied with HEAO-1 over a broad spectral-temporal domain. Based on data from the NRL models and the modulation collimator a source similar to Cyg X-1 has been identified;[33] it is GX339-04. The source immediately up towards the left of Cyg X-1, indicated by the small greenish patch, is Cygnus X-3, one of the brightest sources in the Uhuru band. However, it is estimated to be at a distance of 10 kpc within the galactic disk and is therefore

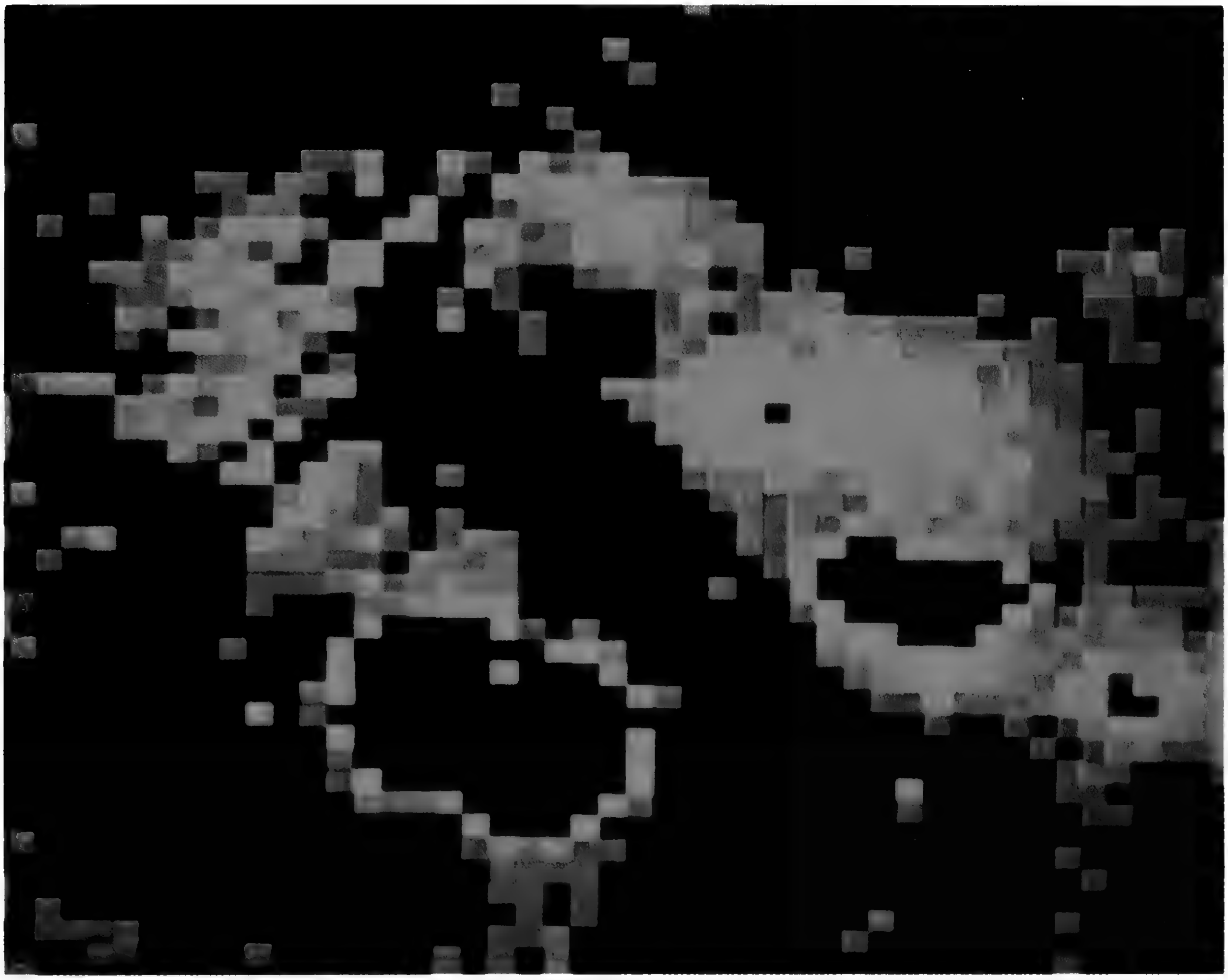

Fig. 7. An intensity map of the Cygnus region in the 1/2 keV X-ray band, constructed exactly as for Figure 6.

barely visible at the 1 keV band effective for this map. If we were to increase our threshold and bandwidth beyond several keV, Cyg X-3 would appear very bright on this map and the Cygnus Loop would disappear. Quite generally, the temperatures associated with the X-ray emission by supernova remnants are less than about 10^7 K. However, the kinetic temperatures of expansion associated with young remnants such as Cas A and Tycho are greater than about 10^8 K. Using HEAO-1 data for these sources Pravdo and Smith[34] have determined that, although most of the X-ray emission is associated with cooler electrons not yet in equilibrium with the much hotter ions, there is significant emission up to 25 keV indicating the presence of a substantial electron-ion component that is at temperature equilibrium in the expanding shell of such young remnants.

In taking this updated tour of the Uhuru sky we must eventually leave our galaxy. And in doing this it's most appropriate that we first consider the emission from clusters of galaxies since it was with Uhuru that they were established as a major new class of strong X-ray sources. Subsequent observations with Ariel 5 and OSO-8 showed the importance of iron K line emission for these objects, pointing to an extensive thermal plasma as the main source of X-radiation. The Perseus cluster is the brightest extragalactic source; it's spectrum in the Uhuru band is shown in Figure 9. This spectrum is that characteristic of a thermal plasma at about 80 million degrees and shows how well one can do with multichannel analysis. The X-ray luminosity of this source is about a million times that of our galaxy. In addition to the fact that this GSFC measurement has such fine statistics

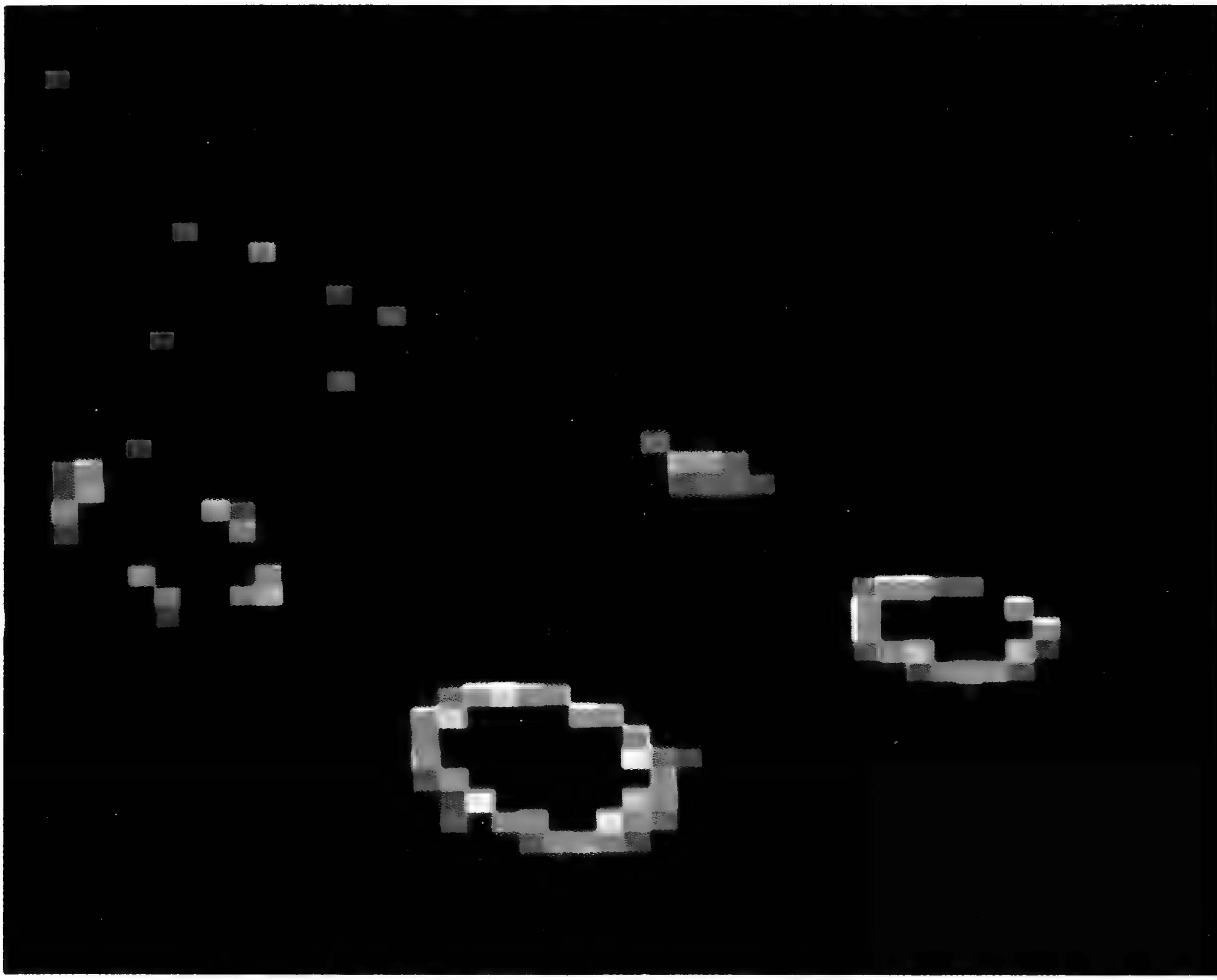

Fig. 8. An intensity map of the Cygnus region in the 1 keV X-ray band, constructed exactly as for Figure 6.

and provides such a good thermal fit, we have here finally found direct evidence for a higher energy transition to the K electron shell of iron in a cluster source. These lines correspond to both Kα and Kβ transitions. L shell iron lines were detected from Virgo by Susan Lea *et al.*[35] There are now 18 cluster spectra from HEAO-1 exhibiting clear iron K line emission.[26] Two-thirds of these have been well fit with an isothermal model and may be used to determine iron abundance in the emitting plasma. As pointed out by Richard Mushotzky,[36] a remarkable outcome of these determinations is that all these clusters have the same abundance of iron and that it's half solar. The luminosity function for these clusters has now been determined with HEAO-1 data in three different ways that converge to the same answer. John McKee *et al.*,[37] have used as their basis an optically complete sample of Abell clusters of distance class up through 4. Mel Ulmer *et al.*,[38] have considered a more restricted angular region of the sky but include all Abell clusters up through distance class 6. Giuseppi Piccinotti *et al.*,[39] have considered an X-ray complete sample of X-ray sources exceeding 1 Uhuru flux unit to search for clusters used in their sample. A useful way to express these three results is to give the corresponding cluster contribution to the cosmic X-ray background in the Uhuru band. The value 4% matches well with all three determinations and is considerably less than some of the much earlier estimates from previous experiments.

In addition to the sort of rich clusters identified with Uhuru, the HEAO-1 modulation collimator data have been used by Dan Schwartz *et al.*,[40] to exhibit that poor clusters can also be strong thermal X-ray

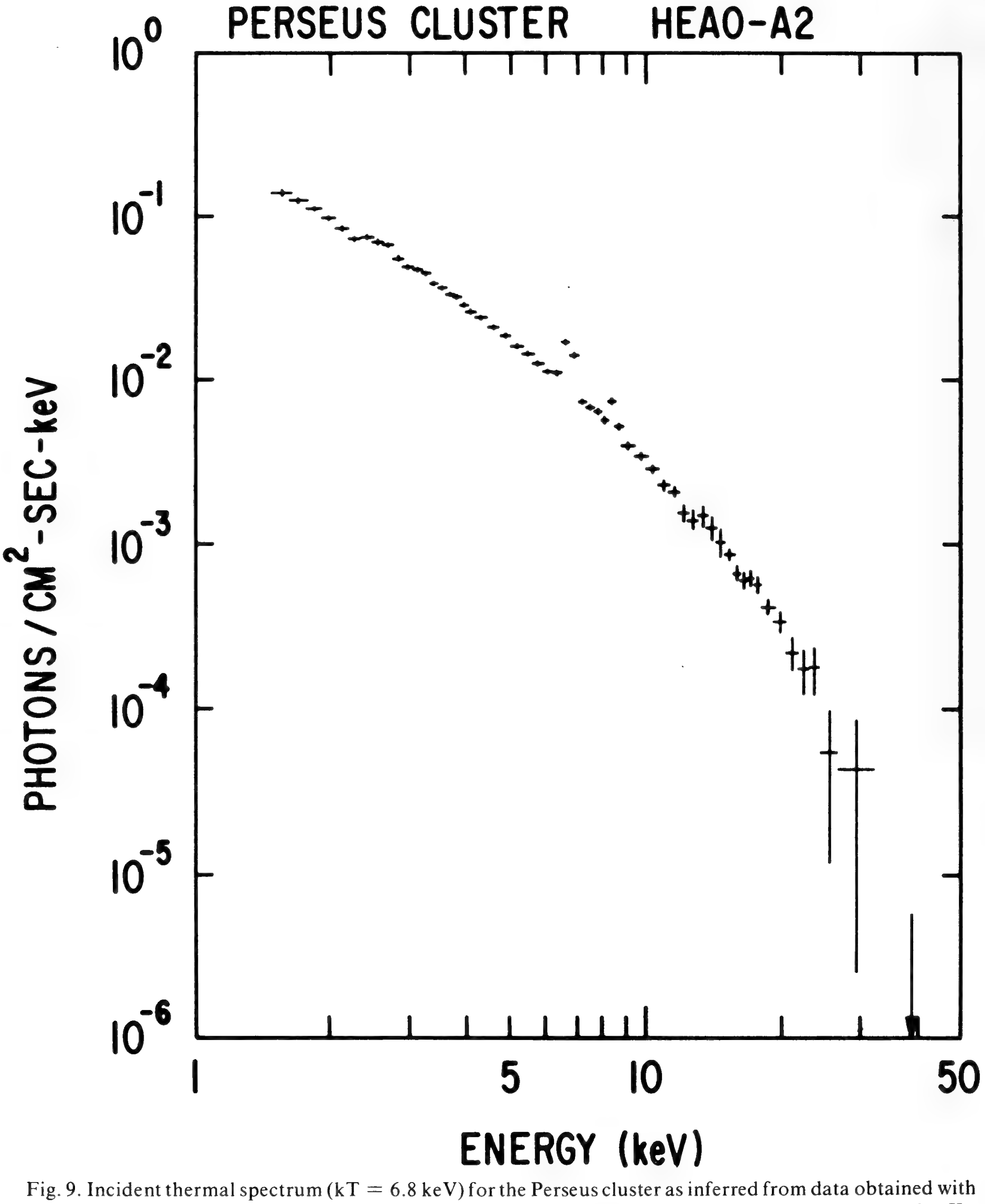

Fig. 9. Incident thermal spectrum (kT = 6.8 keV) for the Perseus cluster as inferred from data obtained with argon (MED) and xenon (HED) proportional counters. Prominent lines in the 5–10 keV band correspond to Kα and Kβ transitions in iron ions having only K shell electrons.

sources. Comparing data from the Goddard modules with modulation collimator results, Joe Schwartz *et al.*,[41] have identified several clusters with condensed cores, cD clusters.

As far as important classes of new sources established with HEAO-1, the extragalactic counterpart of RS CVn stars within our galaxy would have to be the so-called BL Lac type objects, comparable in luminosity to the most powerful cluster X-ray sources. Four such objects are exhib-

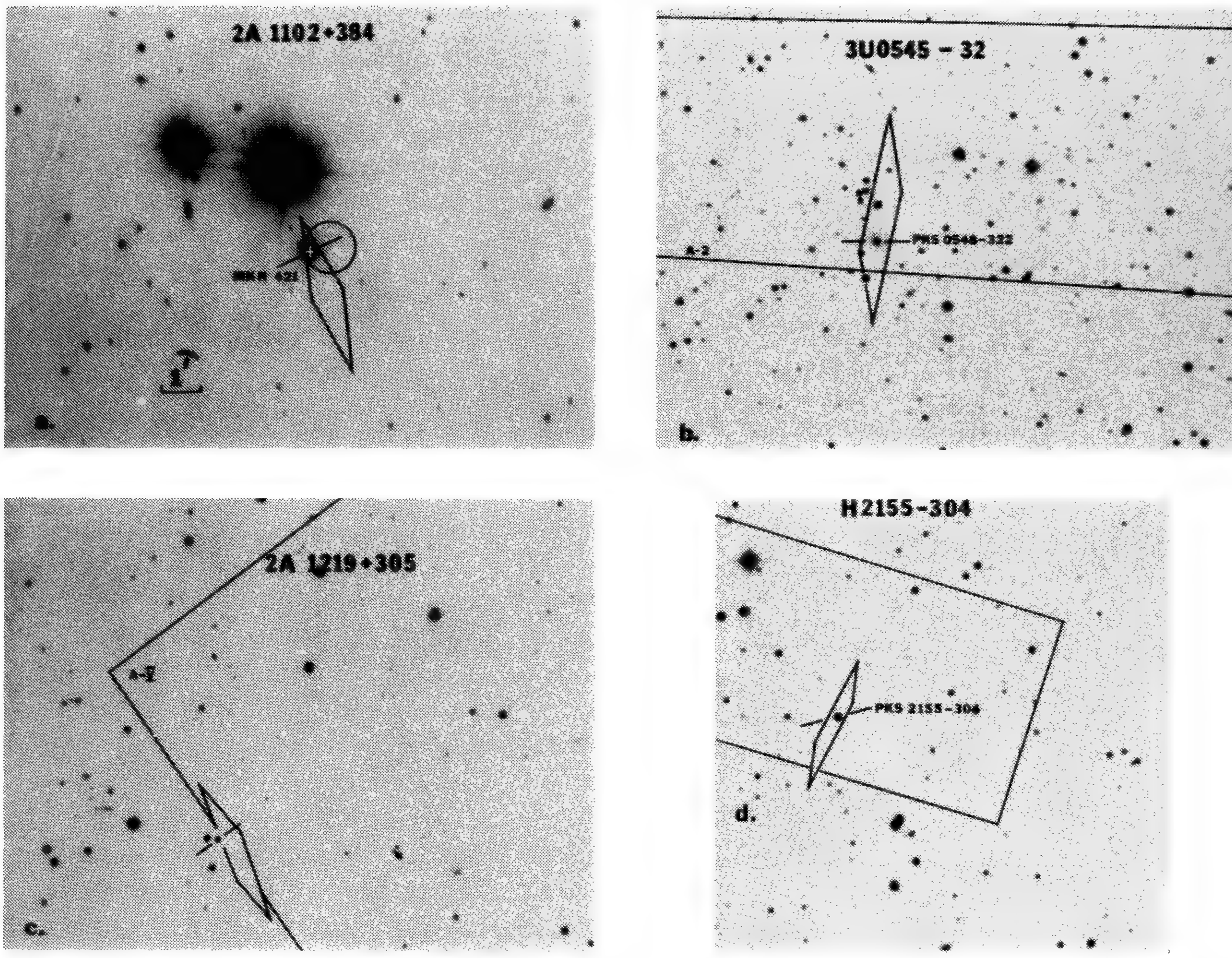

Fig. 10. HEAO-1 modulation collimator locations of four X-ray emitting BL Lac type objects, viz a) MKN421 b) PKS 0548 − 322 c) 2A1219 + 305 d) PKS 2155 − 304. Portions of previous X-ray locations are also shown.

ited in Figure 10. These four optical fields were used to locate the indicated BL Lac type objects with the modulation collimator in terms of various larger X-ray position limits. The objects at the top (a: MKN421 and b: PKS 0548-322) are of particular interest because they are in elliptical galaxies with measured redshift. The Ariel 5 source in the lower left (c: 2A1219 + 305) was the first BL Lac type object to be found as a result of its X-ray detection; this suggested association was established as correct by the HEAO-1 modulation collimator.[16] Soft X-ray detection by Prahlad Agrawal and Guenter Riegler[42] along with modulation collimator location[43] led to the identification of PKS2155-304 with the HEAO-1 object in the lower right (d: H2155-304).

The spectrum of PKS2155-304 obtained by the JPL and Goddard groups is displayed in Figure 11; it shows the steep power-law component that seems to be present to varying degrees in all the BL Lac spectra observed. For this object, ~90% of the luminosity resides below 2 keV. The contribution of such objects to the cosmic X-ray background would necessarily be most evident in soft X-rays, such as now readily resolved with the Einstein Observatory. If the redshift of this is as high as estimated by Charles *et al.*,[44] then its X-ray luminosity alone exceeds 10^{46} ergs s^{-1}. And it is a highly variable source, as shown in Figure 12; the intensities plotted here were observed by Snyder *et al.*,[45] with the NRL modules from scan data obtained over the course of a week. Variations over time scales as short as 6 hours are evident. By considering this temporal variability in conjunction with the overall spectral behavior from the radio to hard X-rays, Meg

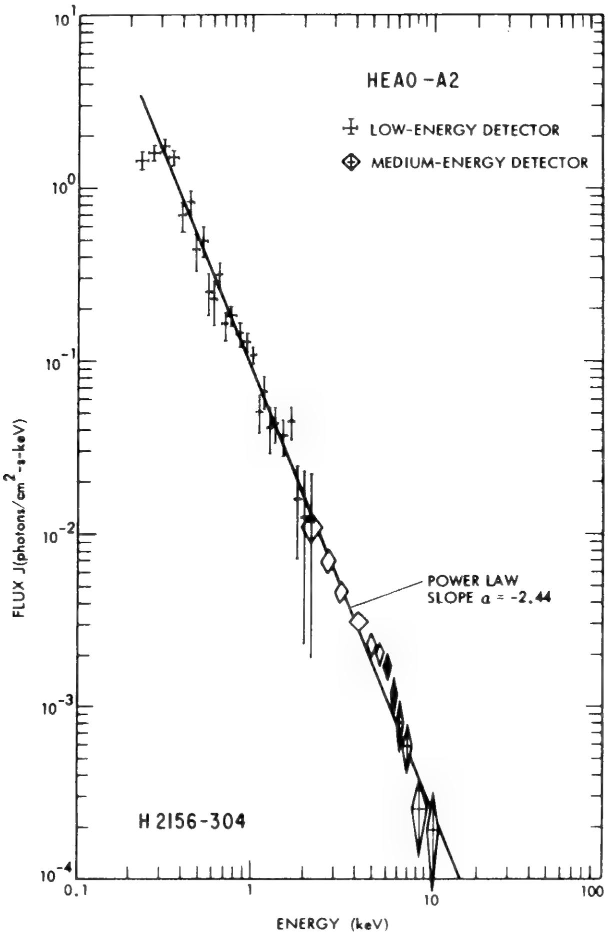

Fig. 11. The X-ray spectrum for the BL Lac type object PKS 2155-304 as inferred from data obtained with a low energy detector (LED results from JPL indicated by crosses) and a medium energy detector (MED results from GSFC indicated by diamonds).

Urry and Richard Mushotzky[46] conclude that a synchrotron model provides a good description, but only if there is significant beaming of the radiating electrons.

Apart from BL Lac type objects and possibly quasars, where our spectral knowledge is still meager, active galaxies exhibit spectra that are surprisingly uniform. First of all, we consider the spectrum of the brightest X-ray galaxy, Centaurus A (see Figure 13). This spectrum was compiled by William Baity *et al.*,[47] from both scintillator and proportional counter data. Cen A is bright mainly because it is relatively nearby; it is less luminous than most of the active galaxies identified. The spectrum is clearly non-thermal. Below a few keV, it shows the pronounced effect of absorption by a large amount of matter. At higher energies, though, a power-law of number index $\Gamma = 1.6–1.7$ provides a good fit up to a few hundred keV. In addition to the spectrum for Cen A, HEAO-1 has provided broad-band spectra for 18 Seyfert galaxies. While all have power-law spectra similar to Cen A, most fail to exhibit the sort of low-energy absorption indicated here; none of the highest luminosity Seyferts show any self-absorption. The broad-band spectrum for a typical Seyfert (NGC 5548) is shown in Figure 14. Here again, we have combined gas proportional counter data with scintillator data to obtain a broad-band spectrum.[48] A single power-law fit with a number index $\Gamma \approx 1.7$ is obviously valid

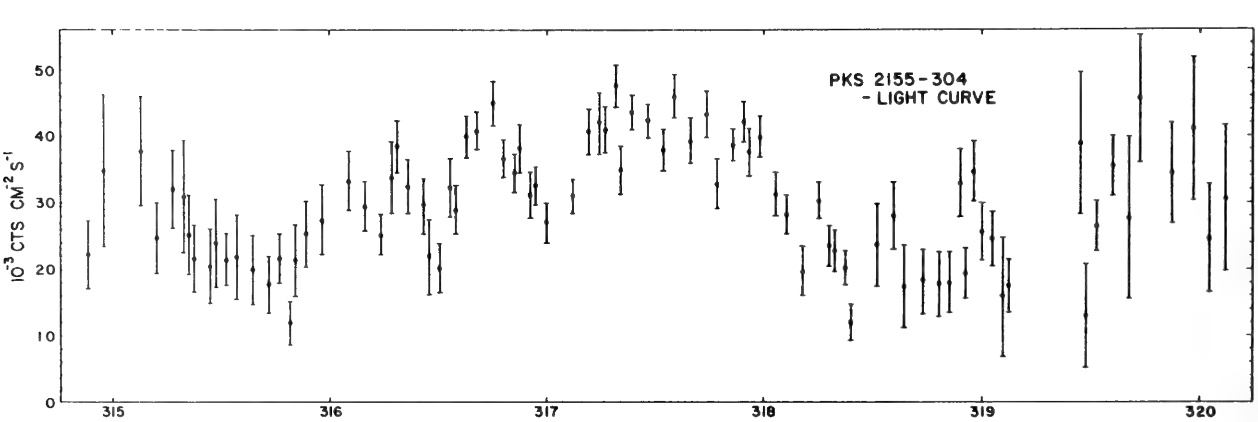

Fig. 12. Light curve obtained[45] from single scan observations with the NRL modules in the 0.5–20 keV energy range. Each observation lasts 10 seconds. High background and earth occulted data have been excluded. The abscissa is day of 1977.

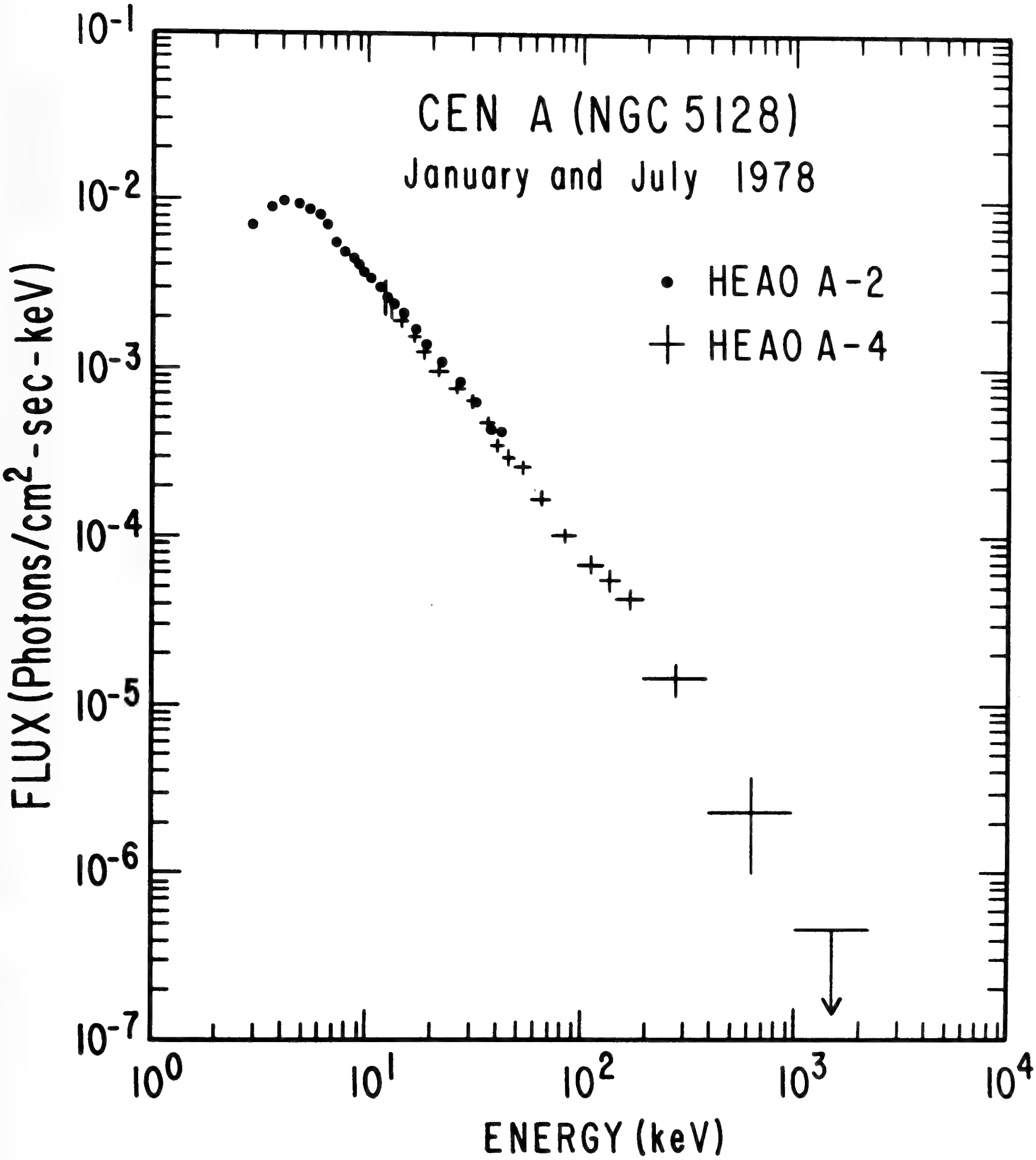

Fig. 13. The X-ray spectrum for Cen A as inferred from data obtained with a xenon proportional counter (HEAO A-2 experiment) and alkali halide scintillators (HEAO A-4 experiment), using the model of a power-law spectrum at the source absorbed by surrounding non-ionized matter exhibiting iron K absorption and fluorescence. Data obtained in July 1978 were renormalized[47] (by a factor of 1.45) to the data obtained in January 1978. The statistical errors associated with the A2 data below 30 keV are smaller than the dots indicated.

over more than a decade. A thermal spectrum is definitely ruled out for this source as well as for several other Seyferts.

The power-law spectral indices for the 18 Seyferts discussed here are displayed in Figure 15. The dots correspond to Seyferts with broad optical emission lines, the crosses show those with narrow lines. The coordinates here are luminosity (L) and the energy spectral index α offset by one unit from the photon number index Γ. Since most objects fall within the vertical dashed lines, regardless of luminosity or type, we conclude that one can define an effective

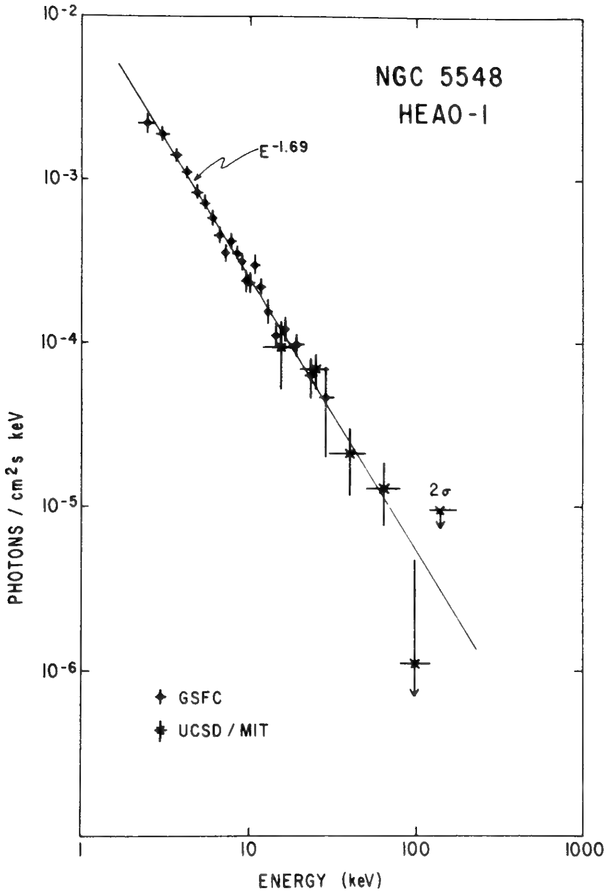

Fig. 14. Incident power-law spectrum inferred[48] for NGC 5548 by combining data from xenon gas counters (GSFC) and scintillators (UCSD/MIT).

typical spectrum for a Seyfert galaxy and that this spectrum is a power-law with $\alpha \approx 0.7$.

Can power-law sources such as the Seyferts discussed here make much of a contribution to the cosmic X-ray background? To examine this we have tried power-law fits to the observed background spectrum, and two such are shown in Figure 16. We have here plotted the ratio (R) of the observed flux to that predicted by the model considered as a function of energy. The bottom graph shows the fit for $\Gamma = 1.7$ associated with Seyfert galaxies. It's clearly unacceptable. The top graph for $\Gamma = 1.4$ exhibits that the fit is fairly decent at the lowest energies and then falls away exponentially with a characteristic energy of ~40 keV. This is the sort of behavior expected for an optically thin thermal spectrum with kT ~40 keV. Hence, we tried fitting the data with thermal models, and the results[49] are shown in Figure 17. Here again we have plotted the ratio (R) of the observed flux to that predicted by the model considered. As shown, we tried three different temperatures. The correct temperature is about a half-billion degrees, corresponding to kT = 40 keV. Up to about 20 keV the statistical errors are smaller than the size of the symbols used and deviations from unity for the best fit are generally less than ~1%. As recently pointed out by Gianfranco De Zotti,[50] we can conclude that the portion of the X-ray background spectrum represented here is known much better than the spectrum of the 2.7 K cosmic microwave background. If one tries to fit this X-ray background spectrum with two components, one thermal and the other a power-law suitable for Seyferts, the nonthermal component can not exceed a third of the total.

We now know that the portion of the X-ray background associated with galaxies in the present epoch is dominated by Seyferts. The luminosity function for the present epoch is well fixed[39] with HEAO-1. If we

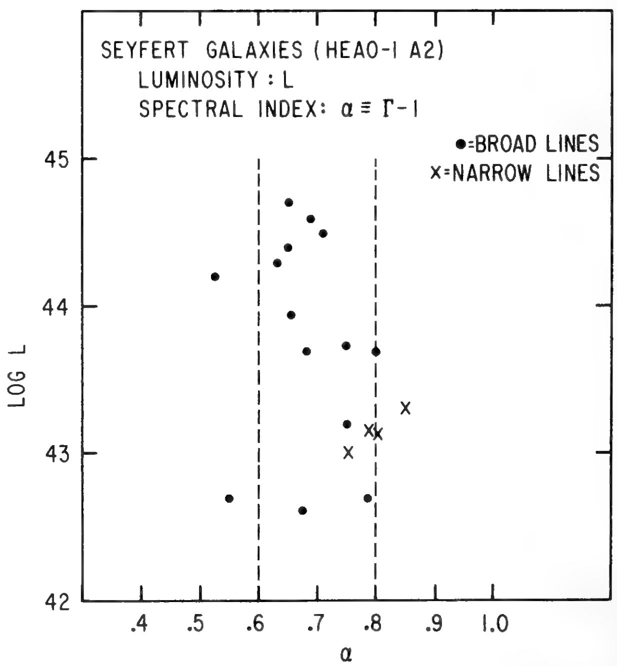

Fig. 15. Seyfert galaxies measured with HEAO-1 A2 xenon gas counters (GSFC) are plotted as regards luminosity (Log L) and inferred energy spectral index ($\alpha \equiv \Gamma - 1$). Separate symbols are used to designate their optical emission lines as broad or narrow. Vertical dashed lines define $\bar{\alpha} \pm 0.1$.

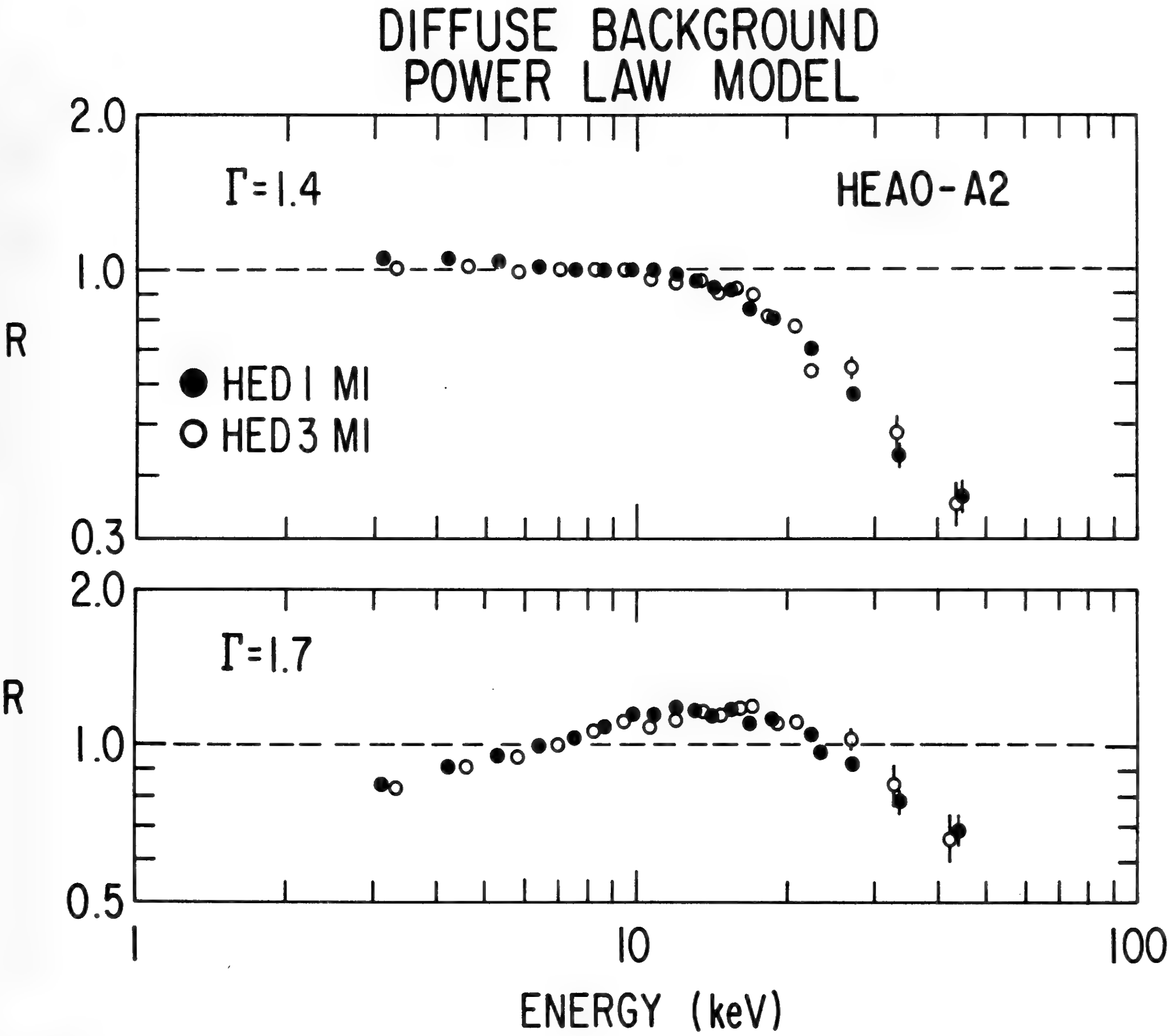

Fig. 16. The ratio (R) as a function of X-ray energy of the counts observed[49] for the X-ray background to that predicted by convolving with the detector response function power-law spectra (characterized by $\Gamma = 1.4$, $\Gamma = 1.7$). Different symbols are used to represent the first layer of the MED and both layers of HED 1 and HED 3. Statistical errors are shown when larger than the size of the symbols.

assume that the X-ray source populations during all epochs since galaxy formation are similar to the present one, we can make a good estimate of their total contribution to the cosmic X-ray background. As shown in Figure 18, the total Seyfert contribution falls far short of the X-ray background in the region below ~50 keV. However, there's HEAO-1 scintillation data[51] for the background at higher energies, and the extrapolation of the Seyfert contribution exhibited here indicates that at energies much above 100 keV Seyferts in fact dominate the background. Most of this Seyfert background comes from objects with $z < .5$. The number of these relatively nearby sources visible above the deep survey limit for the Einstein Observatory[52] should be at least 5 deg^{-2} and therefore a substantial fraction of the total number of sources detected.

Where is the rest of the background coming from? DeZotti, Cavaliere, and colleagues[53] are examing HEAO-1 data within the context of a model based on evolving non-thermal spectra which, in toto, mimic a thermal spectrum. Darryl Leiter and I are considering the thermal component as basic and examining possible evolutionary tracks for active galaxies whereby they switch from thermal emitters at an early epoch to non-thermal at later epochs.[54] If

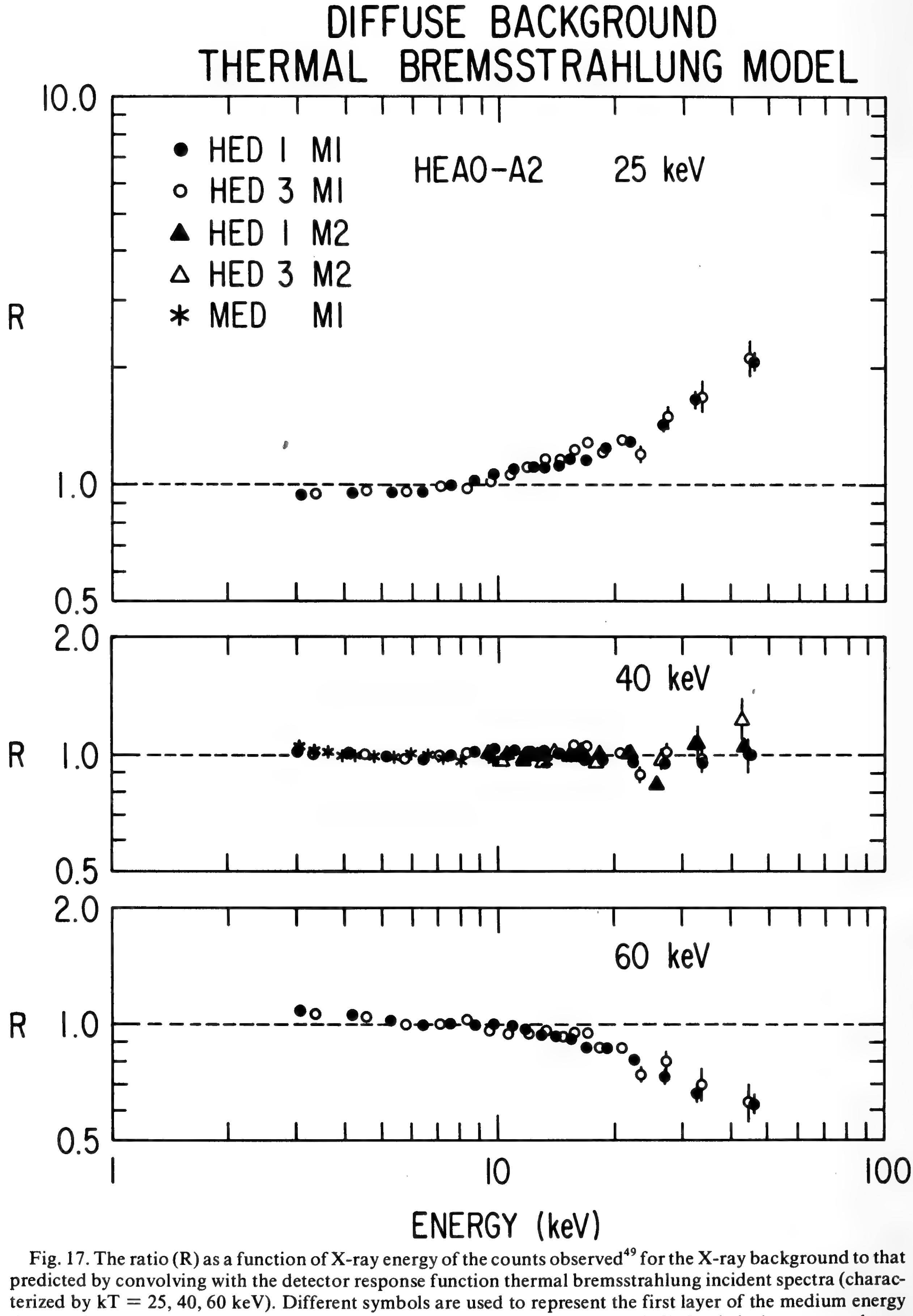

Fig. 17. The ratio (R) as a function of X-ray energy of the counts observed[49] for the X-ray background to that predicted by convolving with the detector response function thermal bremsstrahlung incident spectra (characterized by kT = 25, 40, 60 keV). Different symbols are used to represent the first layer of the medium energy detector (MED) and both layers of the high energy detectors (HED 1 and HED 3). Statistical errors are shown when larger than the size of the symbols.

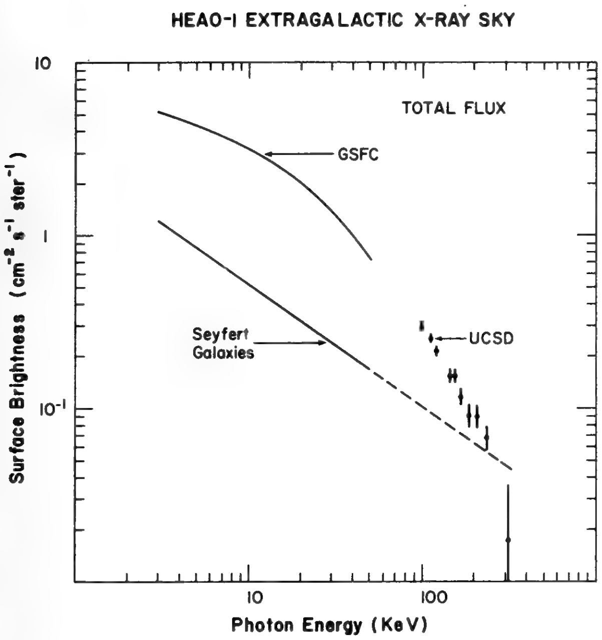

Fig. 18. Surface brightness of the extragalactic X-ray sky as a function of photon energy. The curve indicating total flux is the best-fit thermal spectrum ($kT = 40$ keV) for the background measured[47] with the GSFC instrument. The power-law represents the composite flux from Seyfert galaxies for $z \leqslant 1$, based on the luminosity function[39] determined with HEAO-1 A2 and assuming no evolution. The dashed line is an extrapolation of this power law to higher energies for comparison with HEAO-1 scintillator data (UCSD) on the background.[51]

such schemes fail, we will have to look for a new origin, possibly involving diffuse emission from the intergalactic medium.[49,55,56]

In preparing this presentation I benefitted from the cooperation of many of my HEAO-1 associates, particularly Stu Bowyer, Webster Cash, Gordon Garmire, Walter Lewin, Rich Mushotzky, Rick Rothschild, Dan Schwartz, and Nick White.

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"Netherlands Foundation for Radio Astronomy"

X-Ray Astronomy with the Einstein Observatory

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Introduction

The Einstein Observatory (HEAO-B before its launch) represents a major departure in observing technique by virtue of its use of focussing X-ray optics. Figure 1 is a schematic representation showing the glancing or grazing incidence nature of the two reflections that use total external reflection of photons at angles less than the critical angle to produce a high quality X-ray image. The major benefit beyond direct imaging or picture-taking is that the signal is focussed onto a very small detector area thereby reducing background. As a result, the Einstein imaging detectors are approximately 1000 times more sensitive than Uhuru for detecting faint X-ray sources. To increase the total collecting area four nearly cylindrical mirrors are nested one inside another. The observatory makes use of two imaging instruments and two spectrometers, which can be interchanged at the telescope focus. The experiment was developed by a scientific consortium involving our group at the Harvard-Smith-

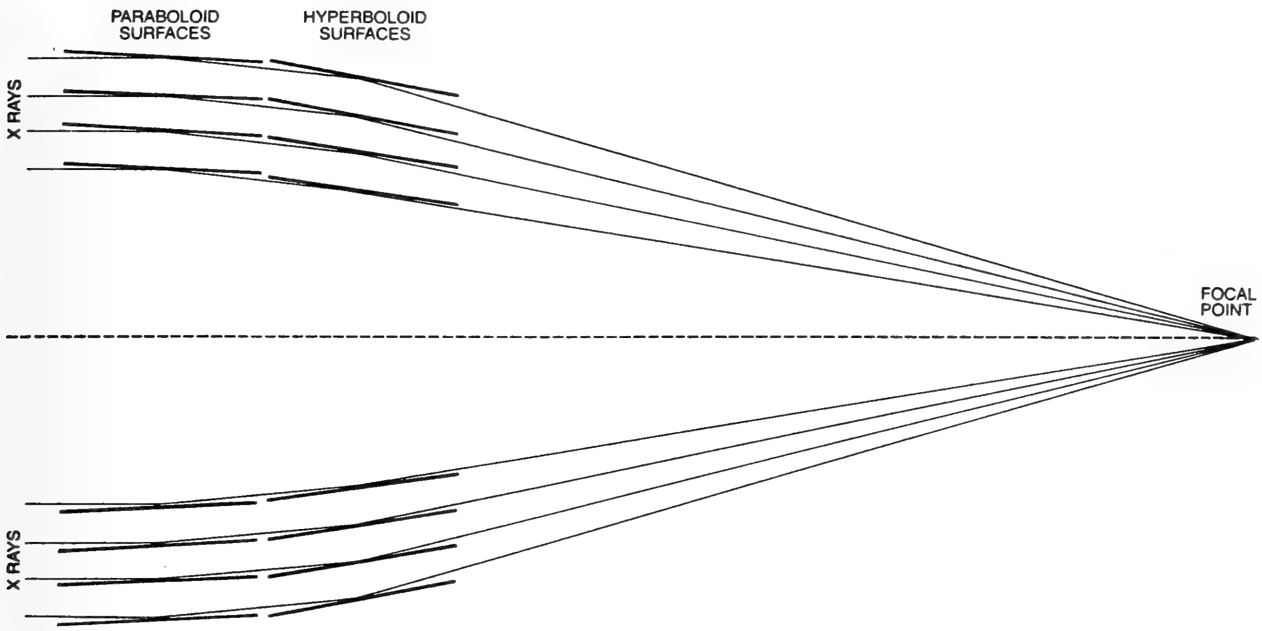

Fig. 1. In an X-ray telescope the rays are reflected first from a paraboloidal surface and then from a hyperboloidal one. The Einstein Observatory telescope has four nested surfaces of each type.

sonian Center for Astrophysics and the X-ray groups at Goddard Space Flight Center, MIT, and Columbia. R. Giacconi is the Principal Investigator, and Principal Scientists include E. Boldt, S. Holt, G. Clark, R. Novick, H. Gursky and H. Tananbaum. Much of the experiment was built by AS&E and the spacecraft was developed by TRW, all under the direction of Marshall Space Flight Center. Flight operations are carried out by a joint NASA, TRW, SAO team at Goddard Space Flight Center.

Figure 2 shows the payload just before its launch with an Atlas-Centaur rocket on November 13, 1978. The satellite operated very well until late August of 1980 when hardware failure left only 2 gyros working which threatened to end operations. In December 1980 one gyro was restarted successfully. We now expect to carry out 4 or 5 more months of science observations before the small amount of remaining RCS propellant is expended. One measure of the overall interest in X-ray astronomy is the fact that more than 400 Guest Observers have used the Observatory in its first two years accounting for approximately 2000 of the 5000 total targets observed.

1. Observations of Galactic Sources

One of the earliest discoveries with the Observatory was the pervasiveness of X-ray emission from stars. Figure 3 is an Imaging Proportional Counter (IPC) X-ray image of the field containing η-Carinae, the variable star which erupted so spectacularly in the 1800's. η-Car is detected in X-rays as the central source in this picture (Seward *et al.,* 1979). Several additional sources are also seen and identified with massive, hot O stars. Observations of O and B stars (early type stars) show X-ray luminosities ranging from 10^{31} to 10^{34} ergs s^{-1} (Seward *et al.,* 1979, Harnden *et al.,* 1979).

Figure 4 shows a High Resolution Imager (HRI) image used to resolve our stellar neighbors α-Centauri A and B. Following models describing the X-ray emission from the solar corona we would have expected the more massive and hotter sun-like G2 star to be a much stronger X-ray source than its companion K1-star. In this X-ray image, however, the K1 star is almost twice as bright. X-ray luminosities ranging from 10^{26} to 10^{31} erg s^{-1} have now

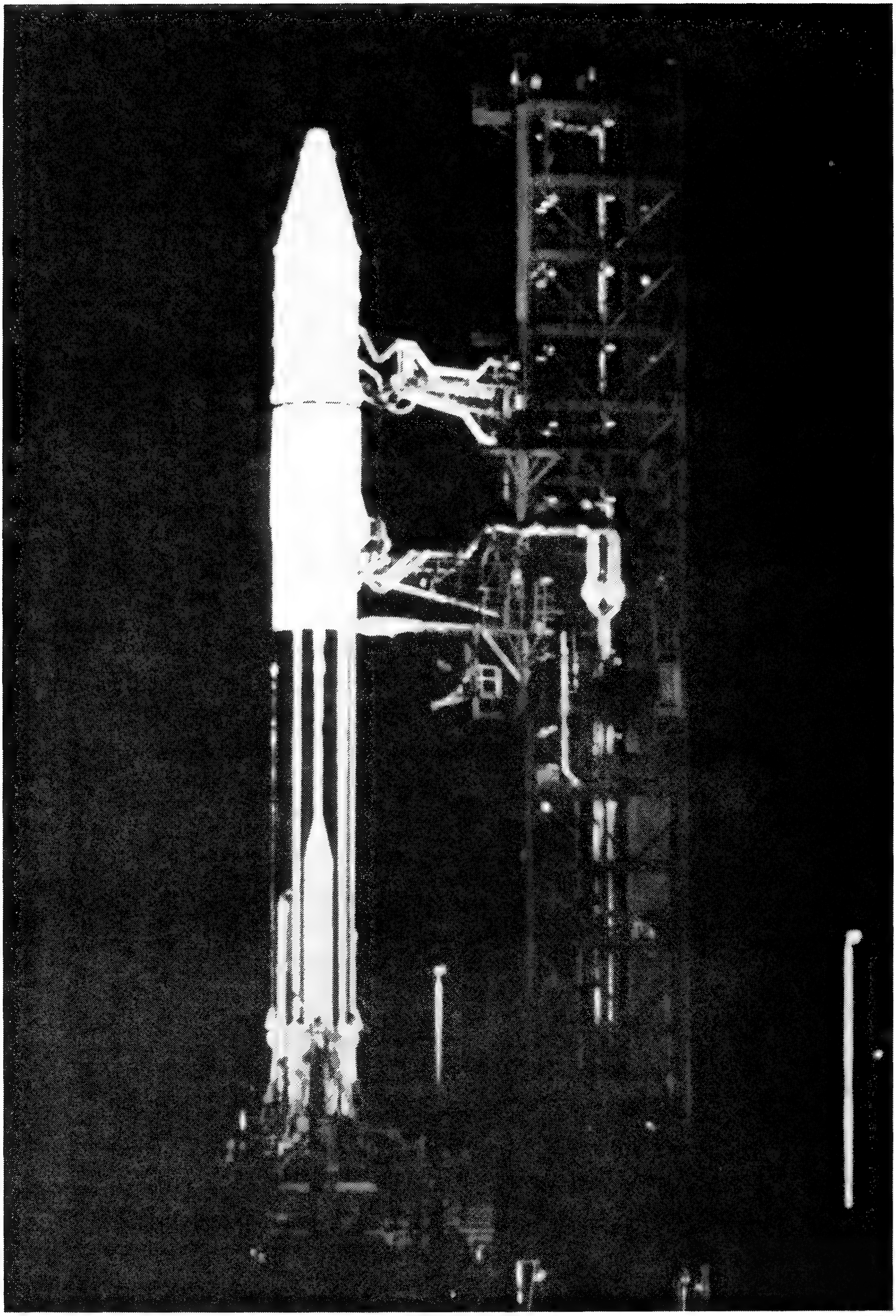

Fig. 2. The payload just before its launch with an Atlas-Centaur Rocket on November 13, 1978.

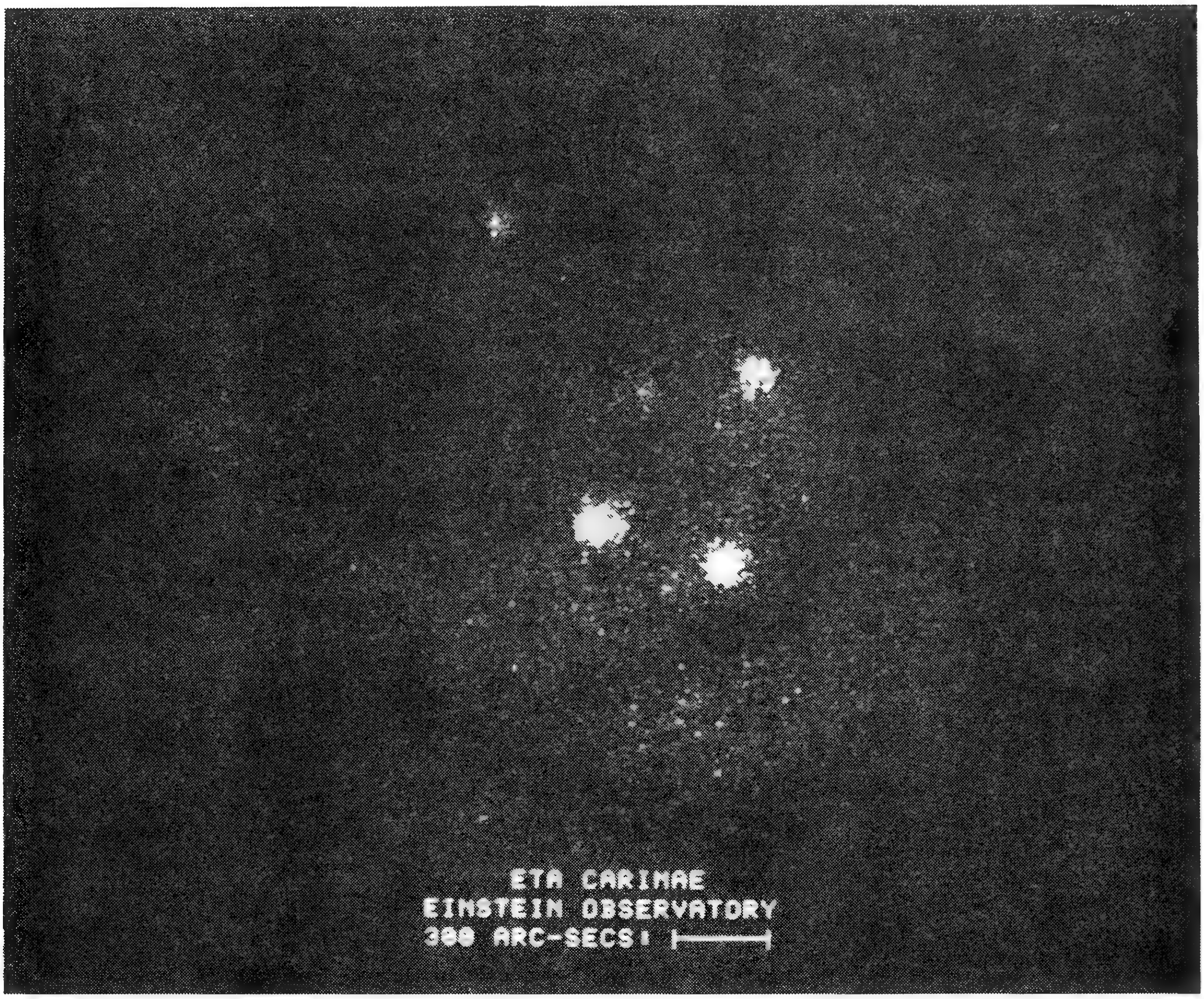

Fig. 3. Picture of the Eta Carinae region taken with the IPC.

been detected from later-type stars (F, G, K, and M), indicating that these stars all possess a hot corona (Vaiana *et al.*, 1981).

This situation is summarized in Figure 5 taken from the paper by Vaiana *et al.* (1981). The figure shows the median X-ray luminosity and with the heavy dots the relatively large range of stellar X-ray luminosity observed as a function of spectral type from O to M. The top panel shows data obtained for main sequence stars and the bottom for giants and supergiants. The data show that the X-ray luminosity of a star cannot be determined in a simple way from its surface temperature or surface gravity. The dotted and dashed lines show the coronal X-ray emission that might have been predicted from acoustical heating models based on solar observations. The hotter stars (O and B) are expected to radiate energy rather easily and therefore be unlikely candidates to develop the vigorous convection zones required to acoustically heat a corona. Lower mass (K and M) stars should have too little energy generated in their core to produce the turbulence required to heat a corona to X-ray temperature. It seems likely that new models presently being developed to explain the observed X-ray emission from all stars will involve magnetic fields to channel energy to the corona and to confine hot plasma. Surface turbulence and stellar rotation also will play key roles in stressing and modulating surface magnetic fields, thereby affecting the intensity of the X-ray emission.

The upper half of Figure 6 is a 10-hour HRI exposure obtained by Gorenstein, Seward, and Tucker (1981), for the remnant of the supernova observed by Tycho Brahe in 1572. The visible light curve was typical of a Type 1 supernova. The appear-

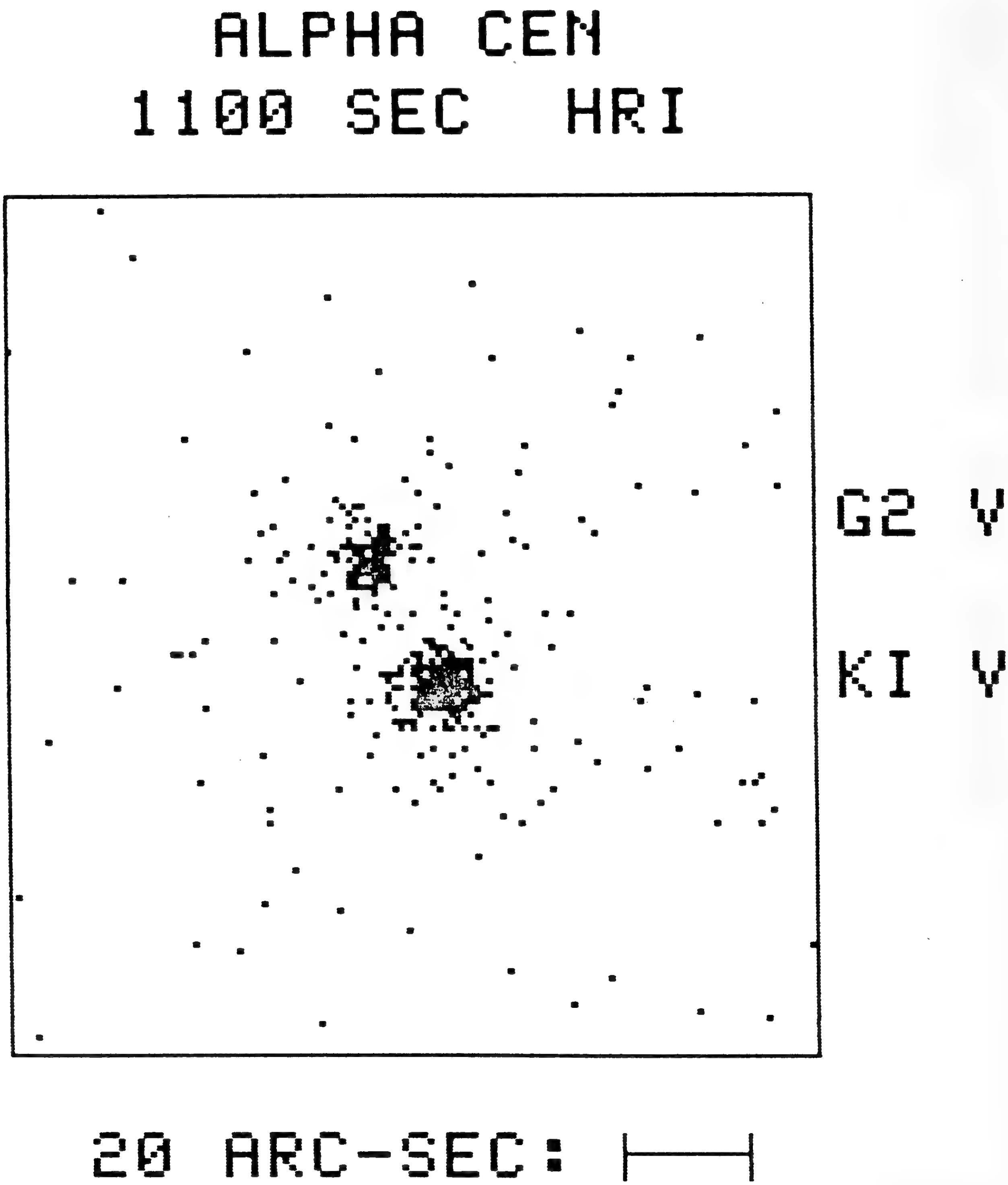

Fig. 4. High-resolution X-ray photograph of nearby binary star system, Alpha Centauri. The brighter X-ray source corresponds to the K star and the other X-ray source to the G star, contrary to theoretical expectations for the relative X-ray emission from these two different classes of stars.

ance of the remnant in X-rays is an almost circular shell with diameter 8 arc minutes. It shows limb brightening varying from a maximum in the northwest to a minimum in the southeast. In many but not all details, the X-ray image of the shell is quite similar to the high resolution radio map of Duin and Strom (1975), shown in the lower half of Figure 6.

The X-ray shell can be resolved in the HRI picture and has a thickness which averages 30 percent of the radius. The structure suggests we are seeing ejected material expanding into the interstellar medium,

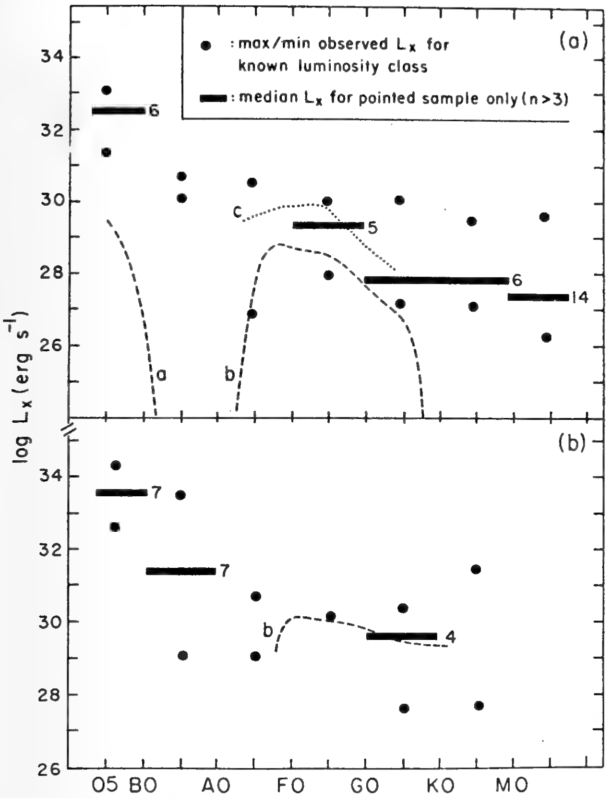

Fig. 5. Variation in X-ray luminosity L_x vs. spectral type (a) main sequence, (b) giants and supergiants. Circles indicate the maximum and minimum value of L_x found for each subclass in this optically well-classified sample. Horizontal bars indicate the median value of L_x for each subset containing more than three stars of a given spectral type. The number of stars which entered into the median computation is also indicated. For comparison, we also plot as dashed and dotted curves, several theoretical predictions of X-ray emission levels.

possibly immersed in a blast wave. Asymmetries are probably due to density variations in the interstellar medium. The observations can be used to estimate the electron density in the shell, the thermal energy in hot gas, and the total mass of the shell (3–6 $M_{\odot}$). In spite of the presence of patches or knots of X-ray emission within the shell, there is no evidence for a pulsar or hot neutron star remnant from the explosion.

Figure 7 shows the spectrum obtained by Becker *et al.,* (1980), summing 5 Solid State Spectrometer observations covering Tycho. Counts/sec-keV are plotted versus energy as horizontal dashes with measurement error bars shown, and the continuous histogram represents the best fit model spectrum. The two strongest emission lines at 1.85 and 2.45 keV correspond to transitions in helium-like silicon and sulfur. The lower dashed curve represents the emission from all $z \leq 10$ elements. Other lines due to argon and calcium are readily apparent, and emissions from magnesium and iron are also required to fit the data. Abundance fits show Si, S and Ar are clearly overabundant relative to Mg, Fe, and low z elements, by factors of 10 to 100 compared to solar abundances. One model of a type 1 supernova by Arnett (1979), shows that the light curves could result from the explosion of a low mass helium star. Such an event would eject ~0.3 $M_{\odot}$ of iron. Mixing 0.3 $M_{\odot}$ of iron with 3 $M_{\odot}$ of swept up material in Tycho would lead to an iron overabundance of ~60 relative to low z elements.

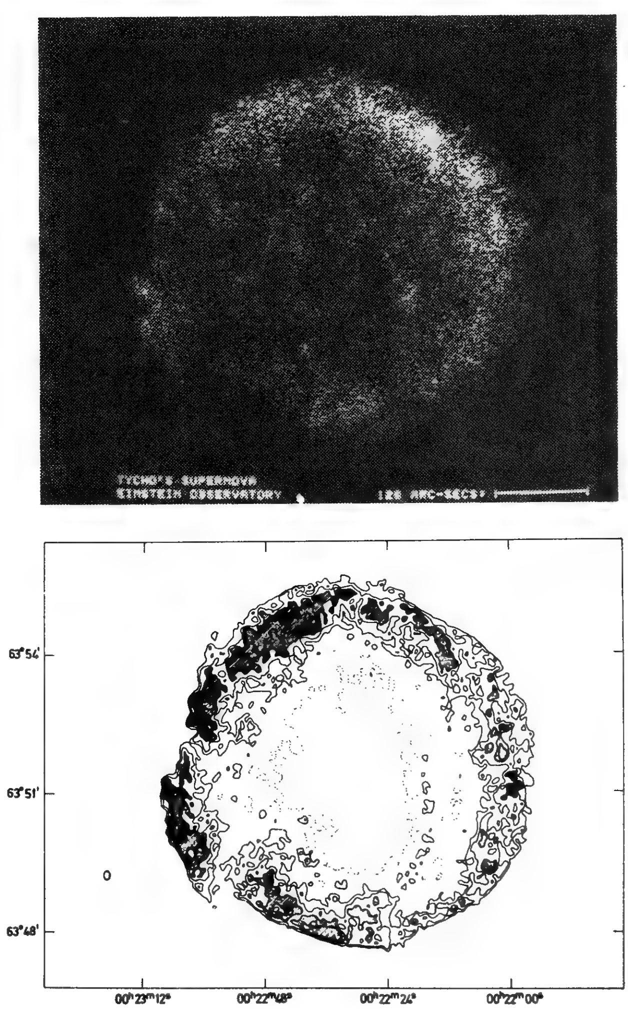

Fig. 6. Top—HRI picture of Tycho SNR. Bottom—Tycho SNR—6cm radio map from Duin and Strom (1975).

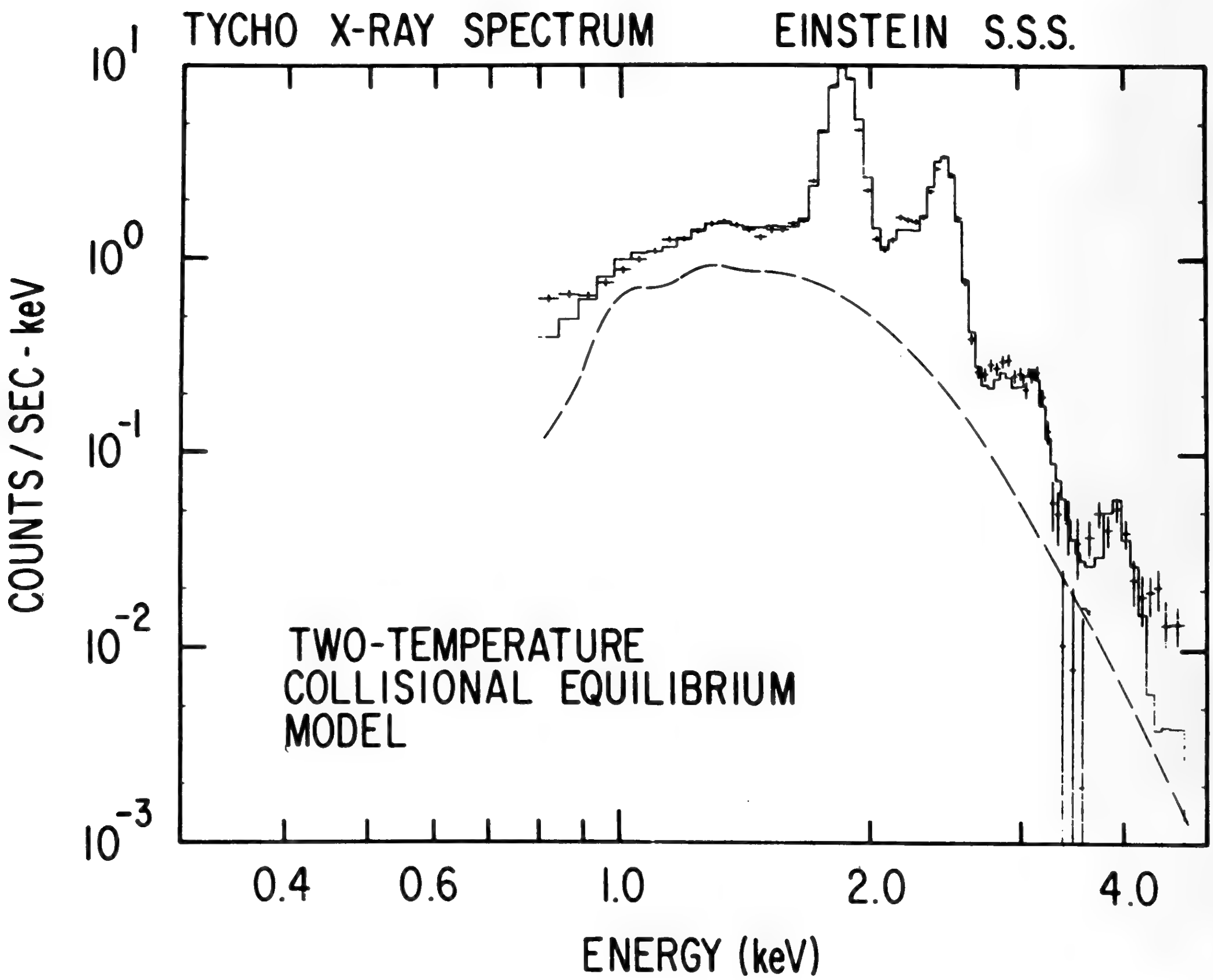

Fig. 7. Pulse height spectrum of Tycho's SNR as observed by the SSS on the Einstein Observatory. Superimposed upon the data is the best fit two-temperature collisional equilibrium model. The lower trace is the estimated underlying X-ray continuum. (Courtesy of Becker *et al.*, 1980.)

The SSS X-ray data do not support such a model, particularly if instabilities remove any stratification of the ejected elements after a few hundred years. This still leaves open the question of the nature of the progenitors of type 1 supernovae such as Tycho. Successful models will have to account for the X-ray observed overabundance of Si, S, and Ar.

Figure 8 is an HRI picture of a much older supernova remnant—Puppis A. This picture obtained by Petre, Winkler, and Kriss (1980), is a composite of 11 separate exposures covering the entire supernova remnant. All of the sharp edges are real; many of the features correlate well with radio observations of the remnant shell. The complex internal structure has little correlation with radio or optical features, except for one X-ray bright spot just behind the eastern shock front, which coincides with faint optical filaments from which intense Fe XIV λ5303 Å coronal lines have been observed. The data suggest that this bright X-ray emission results from a collision between the supernova remnant blast wave and a cloud in the interstellar medium. With a distance of 1 kpc for Puppis A, such a cloud would have a diameter of $\sim$1 pc, electron density of $\sim$17, and mass of $\sim$1 $M_\odot$.

Winkler *et al.* (1980), have reported a high resolution spectrum of Puppis A from the Einstein Focal Plane Crystal Spectrometer (FPCS). The data were obtained with a $3' \times 30'$ aperture centered on the X-ray bright northeast portion of the remnant. Figure 9 shows the counting rate spectrum

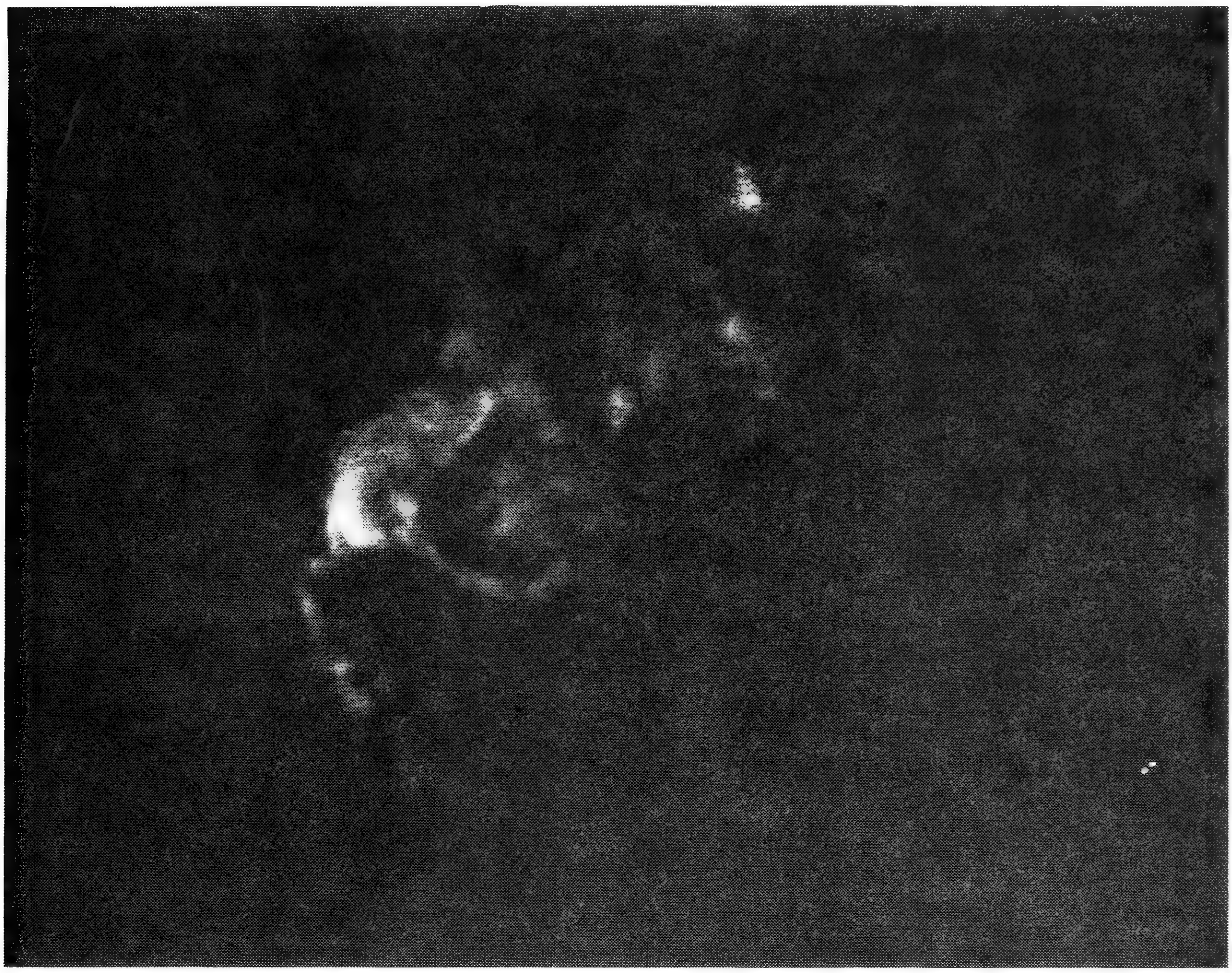

Fig. 8. HRI picture of Puppis A. (Courtesy of Petre, Winkler, and Kriss 1980.)

from 490 to 680 eV with lines seen from N VII, O VII, O VIII, and O VII again. A detailed analysis of the oxygen lines indicates that the O VIII population is $\sim 1.5 \pm 0.5$ times O VII and that electron collisions are the dominant excitation mechanism in the plasma. Figure 10 shows the counting rate spectrum from 700 to 1100 eV, with lines from Fe XVII, O VIII, Ne IX, and Ne X, among others. The most prominent lines seen in these figures are those of hydrogen and helium-like ions of oxygen and neon. The observations of these lines require a range of temperatures from ~ 2 to 5×10^6 °K. The data show Ne lines comparable in strength to O lines. After the data have been corrected for interstellar absorption, the Ne to O strength exceeds solar by a factor of about 2. Also the Fe XVII lines are relatively weaker than oxygen lines by a factor of 5 compared to the solar corona.

For a distance of 1 kpc one can determine an oxygen mass of at least 2 $M_\odot$ in the entire Puppis A remnant. This suggests a Type II supernova from a 25 $M_\odot$ star, which would have ejected 3–4 $M_\odot$ of oxygen, and produced the observed overabundance of neon (primarily through carbon burning in the presupernova star).

2. Observations of Normal Galaxies

A composite of 3 IPC images obtained by Van Speybroeck *et al.*, (1981), for our twin galaxy, M31 or Andromeda,is shown in Figure 11. The picture shows a number of bright sources that follow the spiral arm structure of the galaxy as well as a region of

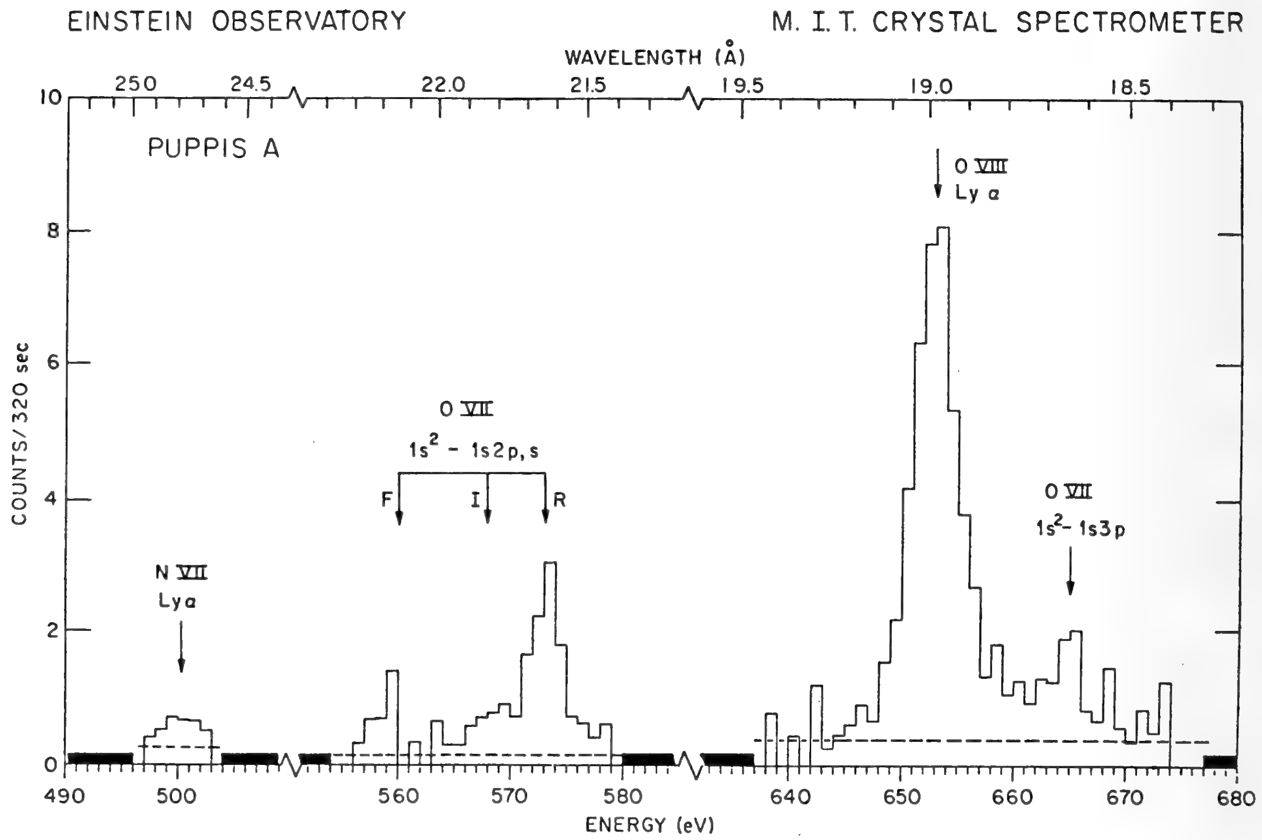

Fig. 9. X-ray spectrum (500–700 eV) of the Puppis A SNR as observed by the Einstein FPCS, using the RAP crystal. Heavy lines along the energy axis indicate regions with no exposure. Background levels are indicated by the dashed lines. (Courtesy of Winkler *et al.*, 1980.)

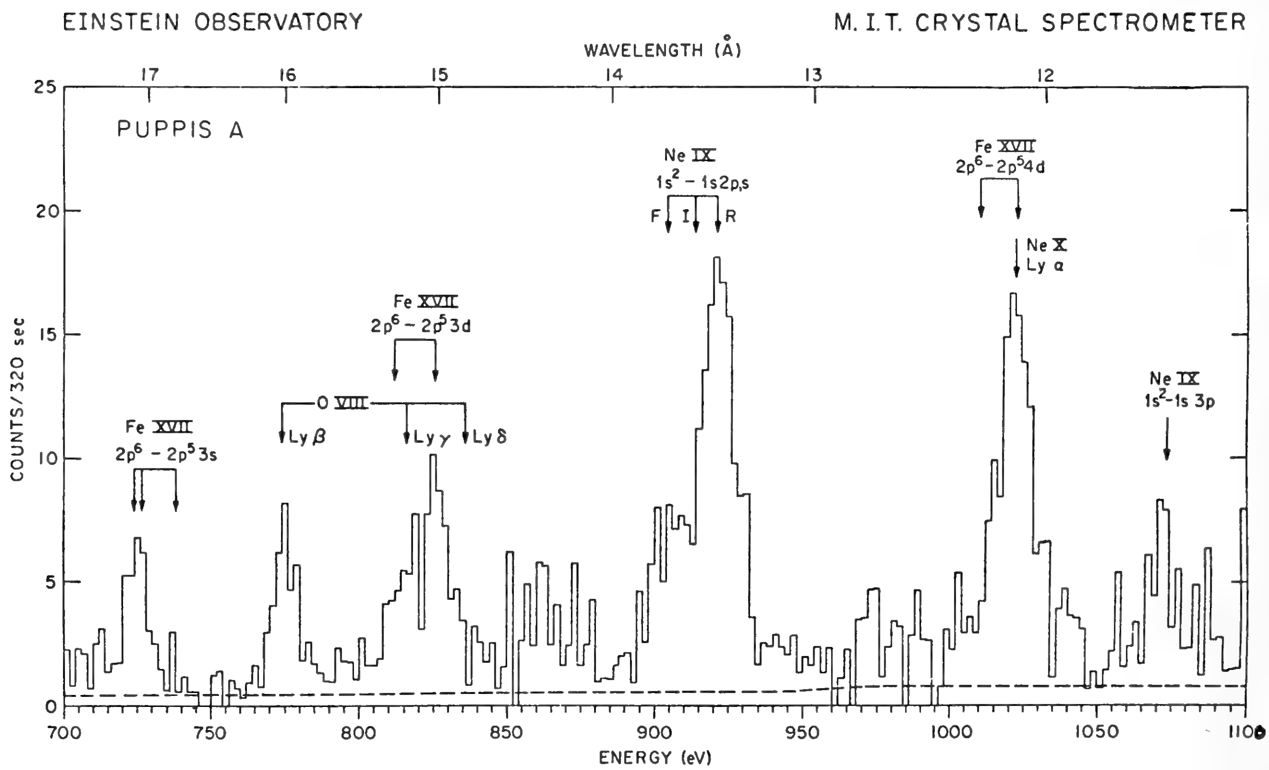

Fig. 10. X-ray spectrum (700–1100 eV) of Puppis A as observed by the Einstein FPCS. Data from 14 scans with the TAP crystal are combined. The dashed line indicates the background level. (Courtesy of Winkler *et al.*, 1980.)

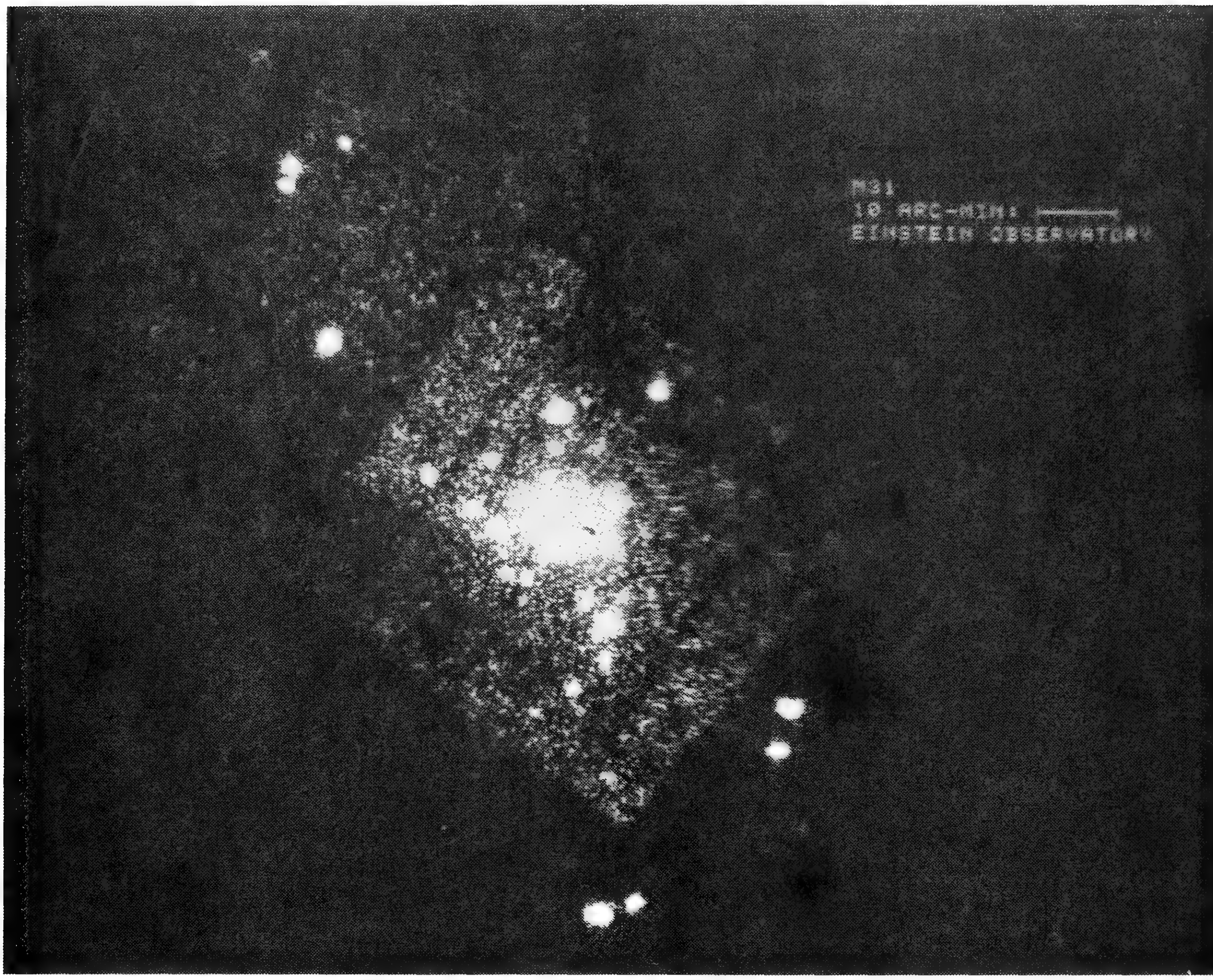

Fig. 11. A composite of 3 IPC images for our twin galaxy—M31 or Andromeda.

extended emission in the center of the galaxy. A part of the central region is shown as an expanded HRI picture in Figure 12. The extended region is resolved into a large number of point sources. Two HRI exposures, taken approximately 6 months apart are shown. A number of sources are seen to be highly variable. In particular, the source identified with the nucleus of M31 and radiating at $\sim 10^{38}$ erg s^{-1} in the January 1979 image is at least 10 times fainter in the second picture. In a third observation, not shown, the source reappeared with a luminosity of $\sim 5 \times 10^{37}$ erg s^{-1}. At maximum observed brightness the nucleus of M31 is $\sim 10^3$ times brighter than our own Galactic nucleus, but it still accounts for no more than 5 percent of the total 0.5–4.5 keV luminosity of M31. Overall, 88 sources have been observed by Van Speybroeck *et al.* (1981), in M31 above a threshold of $\sim 4 \times 10^{36}$ erg s^{-1}, most of which are probably binary systems with accreting compact stars. Figure 13 shows a histogram of the overall luminosity distribution for these 88 sources, a histogram for a subset of 16 sources identified with globular clusters in M31, a histogram for 53 others more than 2′ from the nucleus, and a histogram for 19 within 2′ of the nucleus. Since the M31 sources are all at approximately the same distance from the Earth, it is possible to construct distributions such as these to search for differences in distribution means and widths which might be due to differences in stellar populations, for example. For similar sources in our own Galaxy, significant uncertainties in distances make such calculations difficult if not impossible. The mean luminosities suggest that the globular cluster X-ray sources and the galactic center X-ray sources in M31 may be

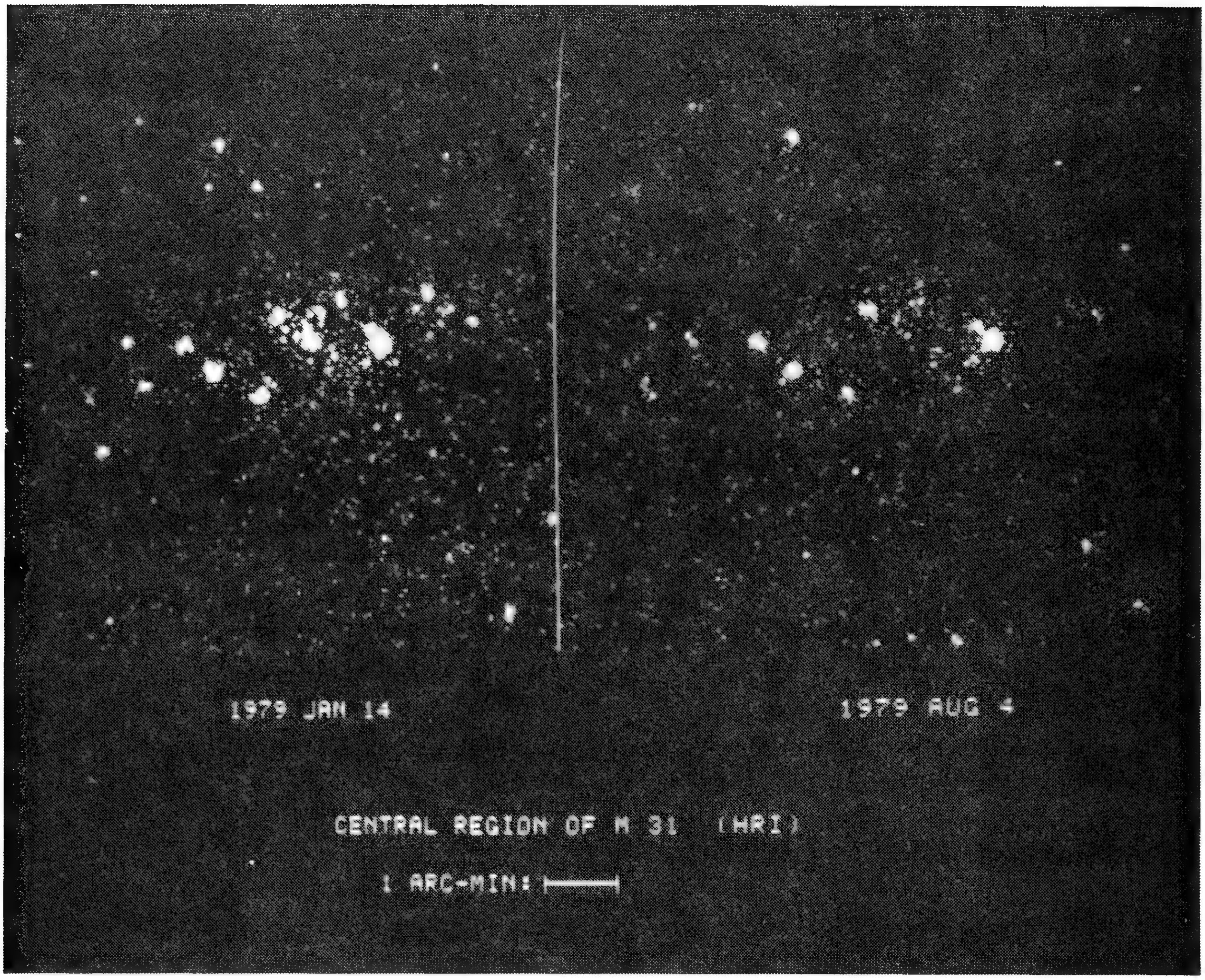

Fig. 12. Expanded HRI picture showing a part of the central region of M31.

twice as luminous as the outer (spiral-arm) sources. These more luminous sources may contain low mass binary systems accreting via Roche lobe overflow, while the spiral arm sources may be mostly high mass binaries powered by stellar wind mass transfer. It is noteworthy that the 19 sources within 2′ or 400 pc of the nucleus of M31 account for $\sim 1/3$ of the X-ray emission from this galaxy while this region contains only about 1 1/2 percent of the mass of M31. No such similar concentration is observed for our own Galactic center.

To explore questions such as these, groups at both Columbia and CfA are carrying out surveys of "normal" galaxies. Helfand and Long (1980 and private communication), have detected over 150 sources from the Large Magellanic Cloud of which as many as 25 may be supernova remnants. For individual galaxies, a wide range of nuclear X-ray emissions has been observed. In one case, Elvis *et al.* (1980), have reported an X-ray luminosity on the order of 10^{42} erg s^{-1} from the nucleus of NGC 4156, an otherwise undistinguished looking spiral galaxy. As we shall see next, the nuclear emission and the emission from supernova remnants and mass transfer binaries are only part of the picture when we examine galaxies in clusters.

3. Observations of Clusters of Galaxies

Figure 14 shows an updated version of the IPC X-ray contours obtained by Forman *et al.* (1979), superimposed on an optical photograph containing the galaxies

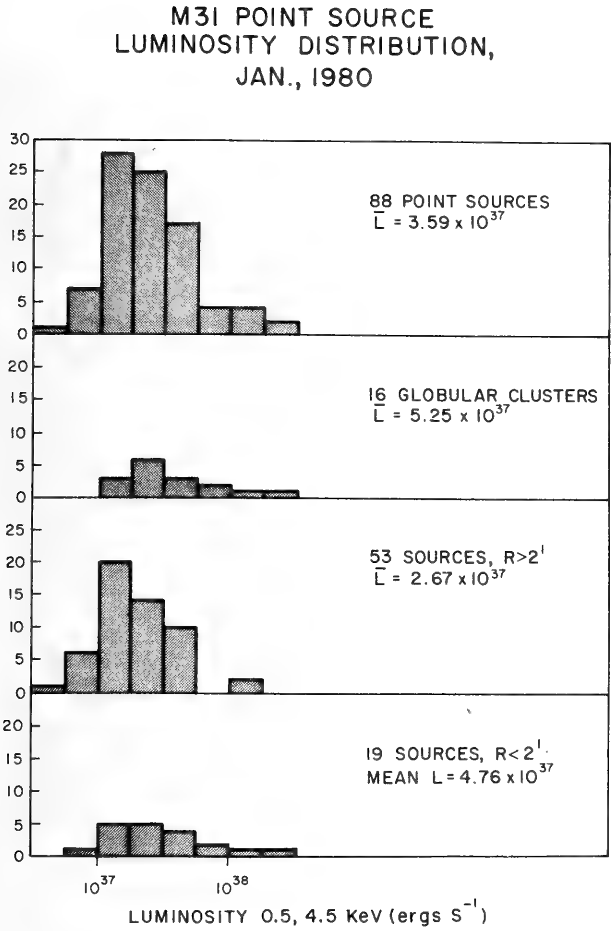

Fig. 13. Histogram of the overall luminosity distribution for 88 objects observed in M31 above a threshold of 4×10^{36} erg s^{-1}.

M86 and M84 in the Virgo cluster. Note the asymmetric very extended plume associated with M86 in the center of the picture and the extended emission associated with M84 as well. HRI data provide no evidence for a point source associated with either of these galaxies. The total 0.5–3 keV X-ray luminosity of M86 is $\sim 2 \times 10^{41}$ ergs s^{-1}; that of M84 is $\sim 3 \times 10^{40}$ erg s^{-1}. Interpretation of these results involves understanding the environment around the galaxies. This is indicated schematically in Figure 15 which shows M84 being a well-bound member of the cluster core (on the basis of its radial velocity), while M86 based on its radial velocity of 1500 km s^{-1} relative to the cluster is likely to be in an eccentric orbit bound to the cluster, but not to the cluster core. A thermal origin for the X-ray emission from M86 requires a gas mass of several $\times 10^9 M_\odot$, which may be comparable to that lost by stars within M86 during the time of 5×10^9 years while M86 is away from the core. The extended trailing plume suggests that M86 has recently moved well into the cluster core and has had much of its gas stripped by ram pressure. Calculations by Fabian, Schwarz, and Forman (1980), suggest that a massive dark halo with at least 10 times the mass of the luminous galaxy would be required to gravitationally bind the halo gas until ram pressure stripping occurs. Alternatively the gas may be pressure confined by the hot, tenuous cluster medium. In contrast, M84 probably spends most of its time moving at a relatively high velocity in the denser cluster core regions with the consequence that all but its inner regions remain ram pressure stripped of gas.

This figure also shows M87 as a large, static galaxy near the center of the cluster core. Such a galaxy can retain all of its gas and must eventually be subject to cooling which can initiate pressure-driven accretion flows. The IPC contours for M87 obtained and analyzed by Fabricant, Lecar, and Gorenstein (1980), are shown in Figure 16. The approximate spherical symmetry of this extended bright X-ray source is apparent. The 0.2–3.0 keV X-ray luminosity of M87 is $\sim 1.6 \times 10^{43}$ erg sec^{-1} or almost 100 times that of M86. Analysis of the IPC spectral data indicates a gas temperature which is approximately constant between radii of 6 and 20 arc minutes, but which decreases in the innermost 6 arc minutes. Beyond 20 arc minutes the gas temperature probably begins to increase. Because the X-ray emitting gas responds to the gravitational potential of M87, these X-ray observations can be used to measure the radial mass distribution of M87. Fabricant, Gorenstein, and Lecar (1980), assumed hydrostatic equilibrium with gas pressure balancing gravitational forces and then determined the overall halo mass distribution from the gas density and temperature profiles measured by the X-ray observations. Figure 17 shows the radial dependence of the mass density for the visible galaxy matter in the central 5 arc minutes, for the

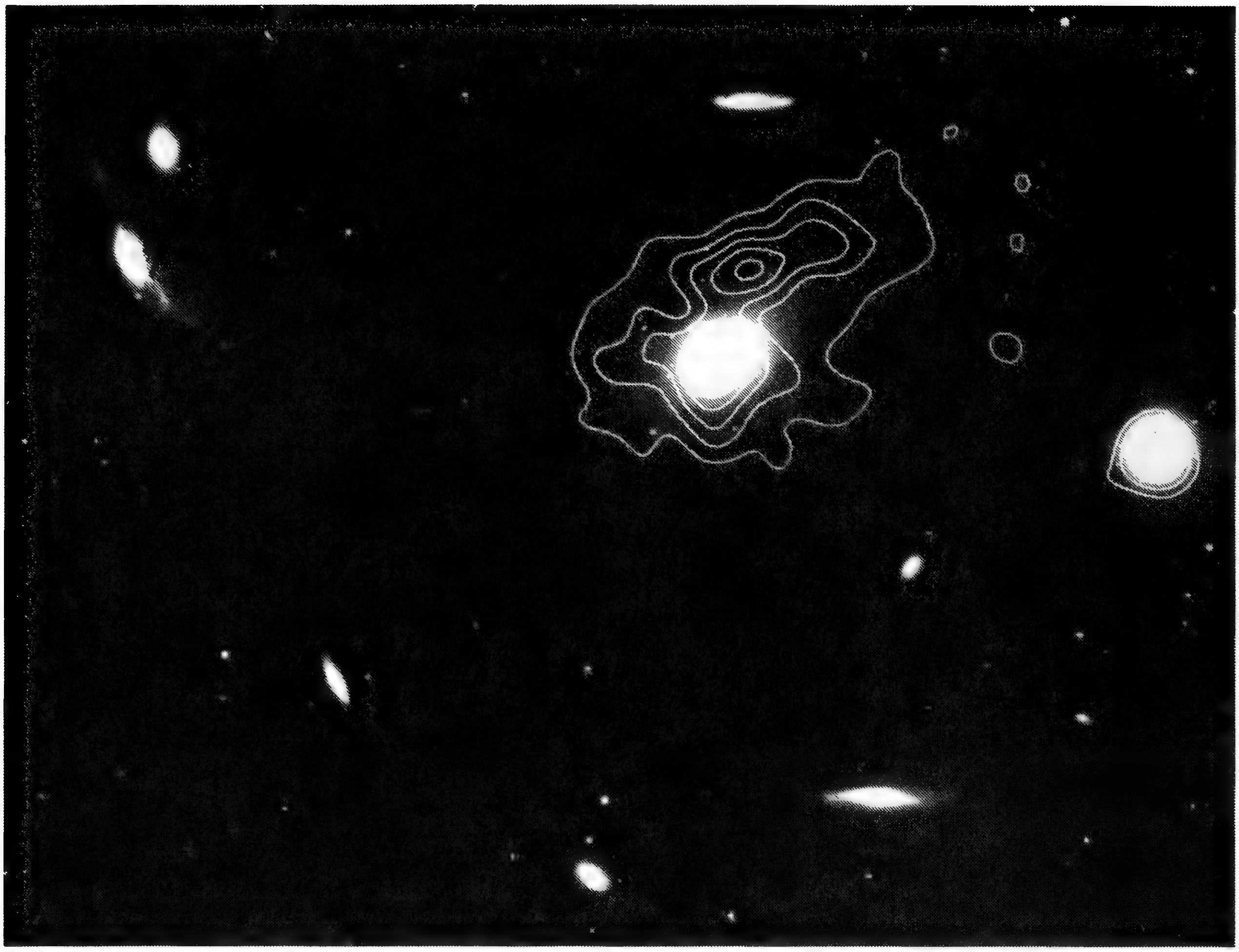

Fig. 14. IPC X-ray contours superimposed on an optical photograph (from the Kitt Peak 4m telescope) containing the galaxies M86 and M84 in the Virgo Cluster.

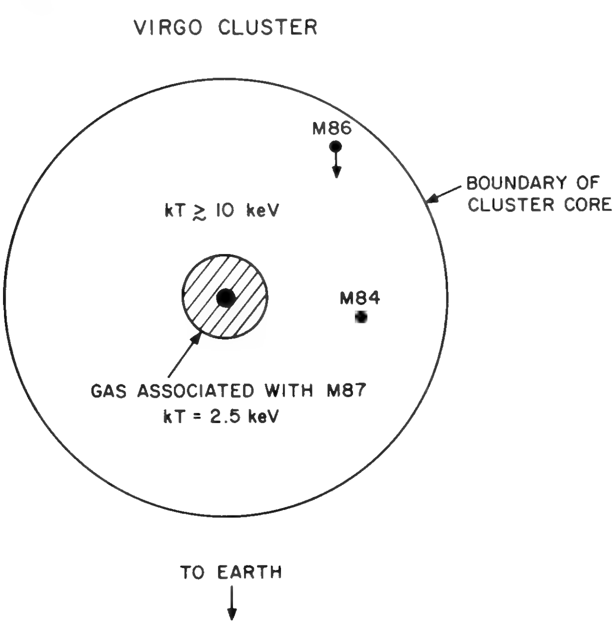

Fig. 15. Virgo Schematic which shows M84 being a well bound member of the cluster core, while M86 based on its radial velocity of 1500 km S^{-1} relative to the cluster is likely to be in an eccentric orbit bound to the cluster, but not to the cluster core.

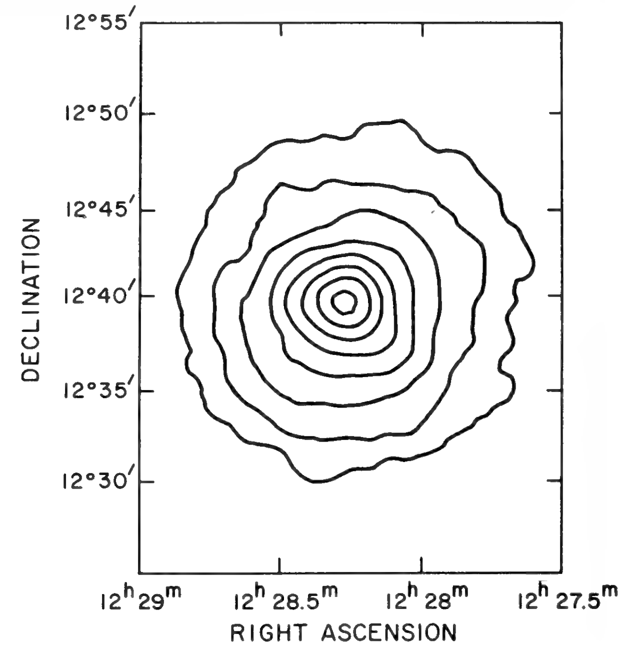

Fig. 16. A 0.7 to 3.0 keV contour plot of M87. The data have been smoothed with a 2 arcminute (FWHM) gaussian weighting function. The contour levels are separated by a factor of 1.5 in surface brightness.

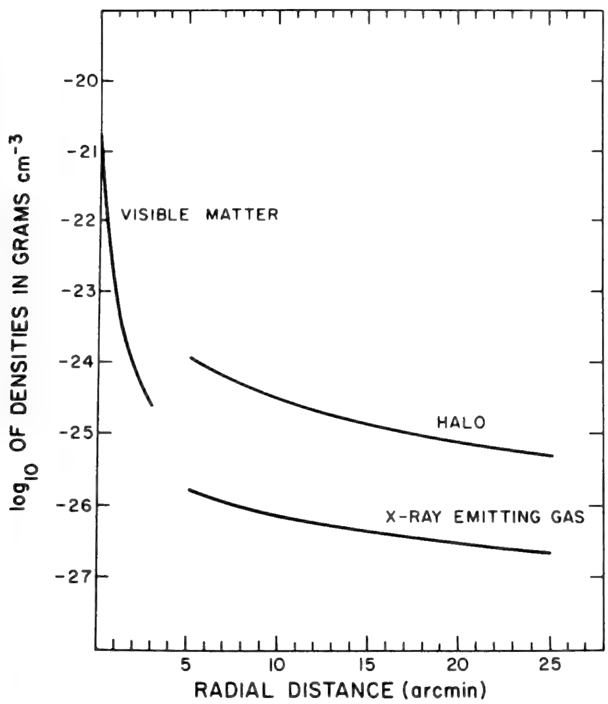

Fig. 17. The approximate density profiles of the halo, X-ray emitting gas, and visible matter in M87.

X-ray emitting gas from 5 to 25 arc minutes, and for the massive, dark halo required to establish hydrostatic equilibrium. Allowing for a positive temperature gradient beyond 20 arc minutes and extending the calculation over the 50 arc minutes for which the source is observed results in a halo mass between 1.7 and 4×10^{13} $M_{\odot}$. This is more than 10 times the mass actually detected in hot gas or in the visible light galaxy. Note that this massive dark halo is not really a missing mass but rather it is the light accompanying the matter that is missing. Neutrinos with non-zero mass might be one way of explaining observations such as these.

A further example of the study of galaxies in clusters is seen in Figure 18 which is an HRI image obtained by Jones *et al.* (1981), for the cluster A1367. An earlier IPC picture had shown a very extended, irregular, clumped X-ray emission, and this

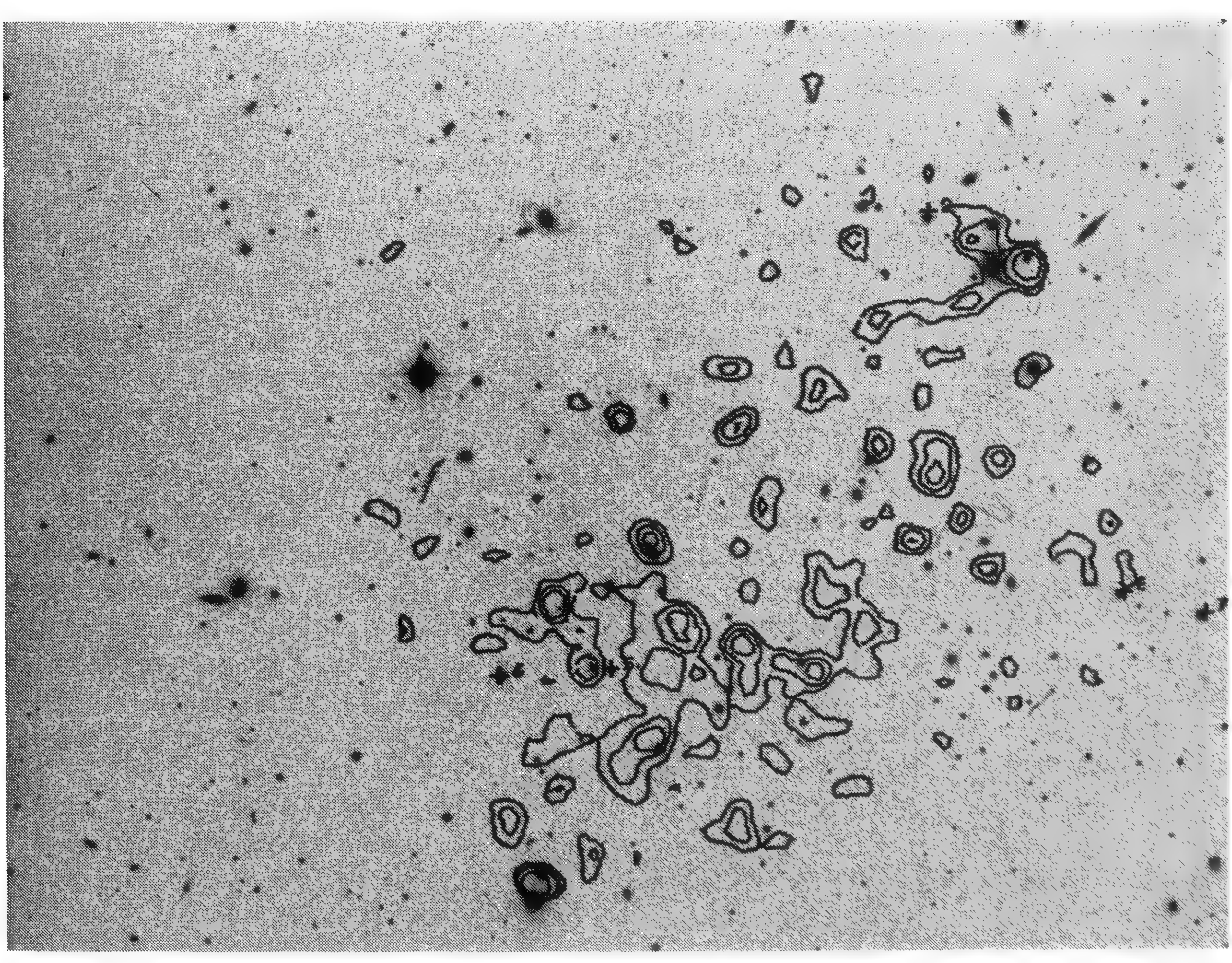

Fig. 18. HRI image for cluster A1367 superposed on Palomar Sky Survey optical photograph.

HRI exposure of the central cluster region confirms that result. X-ray contours shown in this figure start with 3σ upward deviations and increase inward. At least 10 sources are detected above the 3σ level; of these, 7 are near bright galaxies and 3 are not. These sources are typically extended with diameter of order 1 arc minute (or ~40 kpc at the distance of A1367). The extended sources each have an X-ray luminosity of a few times 10^{41} erg s^{-1}, and their total emission is about 5 percent of the cluster X-ray luminosity. The sizes and luminosities are comparable to those observed for M86 in the Virgo cluster as discussed earlier. For the gas responsible for the extended X-ray emission associated with these galaxies the relative importance of pressure confinement by hot cluster gas and gravitational binding by dark galactic halos is not yet known. We hope to advance our understanding in this area by observing a number of such clusters to develop more data on galaxies at various cluster locations with a range of relative velocities. HRI observations will be required to distinguish between point nuclear sources and extended X-ray halos.

Jones *et al.* (1981), have also used the X-ray images of clusters to compare observations with theoretical models of cluster dynamics such as those computed by Peebles (1970), by Aarseth (1969), and by White (1976), among others. Figure 19 is

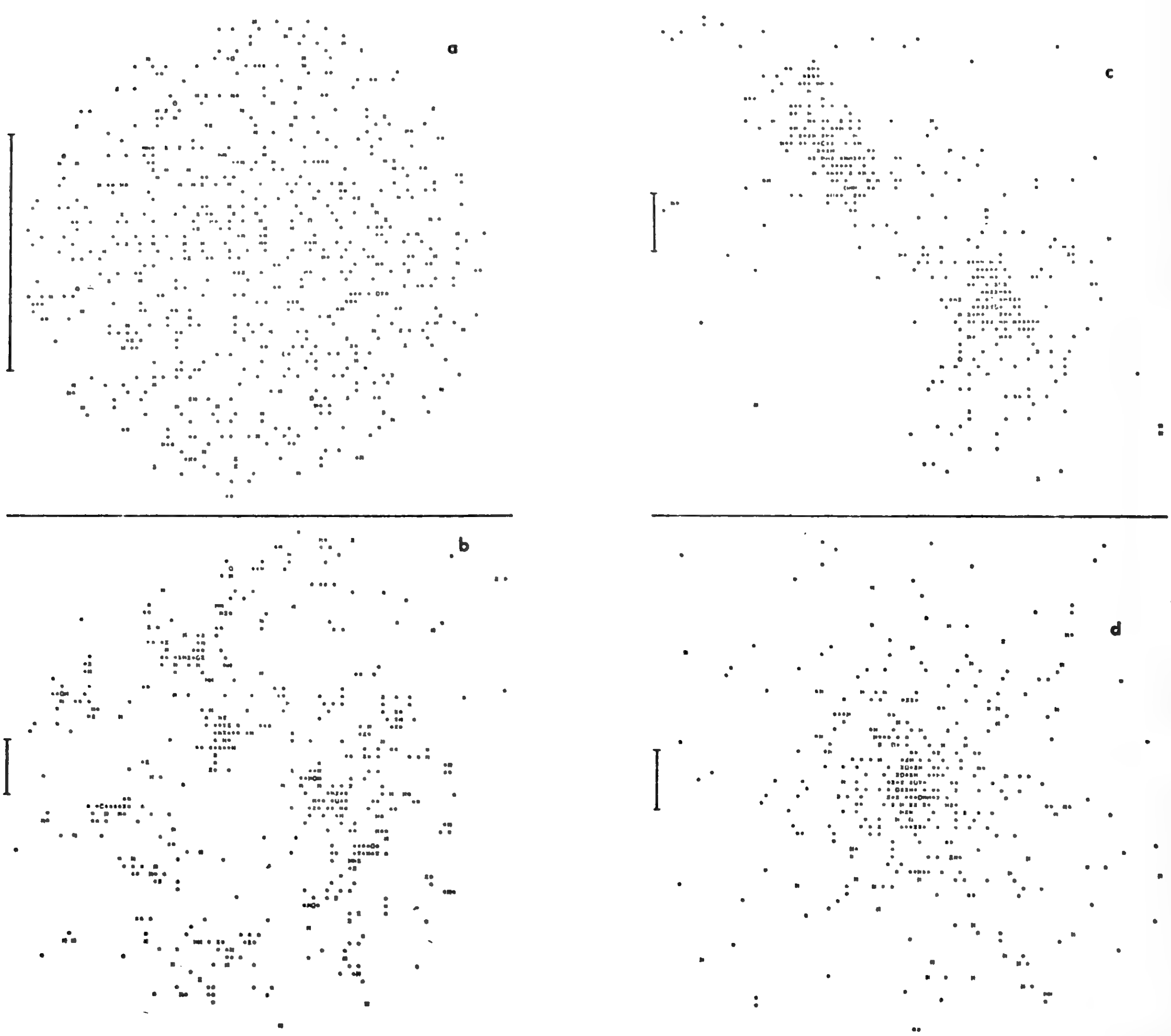

Fig. 19. The projected distribution of particles in the model cluster at four times: (a) t = 0, (b) t = 1.4×10^9 years, (c) t = 6.8×10^9 years, and (d) t = 18.7×10^9 years. (Courtesy of White and the Royal Astronomical Society, 1976.)

taken from a numerical calculation made by White (1976). The galaxies—each represented by a dot—first separate out from the general Hubble expansion as shown in the upper left and form into groups as shown in the lower left. The groups merge into a few large groups as seen in the upper right, and finally a relaxed cluster, dominated by the overall cluster gravitational potential, is shown in the lower right. The vertical bar at the left of each panel indicates a scale of about 1 Mpc. This evolutionary scenario is based on hierarchical clustering in which relaxation occurs first on the smallest mass scales due to the largest overdensities. Developments on larger scales can then be modelled by N-body gravitational interactions.

Clusters such as A1367 and Virgo would probably correspond to a stage such as that shown in the lower left where the overall cluster potential is poorly developed and substantial gas is still associated with individual galaxies. The presence of a massive central galaxy such as M87 probably means that the Virgo evolution will not follow the rest of the scenario, since White's calculations do not allow for galactic cannibalism or for tidal disruption of massive galactic halos. On the other hand, as shown in Figure 20, Forman *et al.* (1981), have discovered 4 clusters which appear very similar to the double cluster stage predicted by White's simulations. Observed subcluster separations and core radii are in good agreement with the model calculations.

X-ray observations are particularly useful for generating cluster classification schemes since the hot X-ray emitting gas provides a sensitive map of the cluster mass distribution. Figure 21 (Jones *et al.*, 1981) summarizes progress to date in this area. Clusters are divided into two groups—those with dominant centrally located galaxies characterized by centrally peaked X-ray surface brightness distributions (shown to the right) and those with no strong central X-ray concentration shown to the left. These clusters without strong central X-ray concentration evolve along the scenario described by White and others. A relatively early stage is typified by A1367 with broad emissions clumped around galaxies. An intermediate stage is typified by SC0627-54 whose double X-ray structure is indicated in the middle panel on the left. A final, relaxed stage is indicated by the IPC contours for A2256. Although we do not yet have statistically complete samples, the data indicate that the large majority of the non centrally peaked X-ray dominant clusters are in the A1367 stage, with about 10 percent in the double cluster stage, and another 10 percent in the relaxed A2256 or Coma stage. If selection biases are not a problem, these percentages can be used to calculate the amount of time clusters spend in various stages of evolution.

Clusters with peaking due to dominant central X-ray galaxies evolve somewhat differently. The upper right shows the centrally peaked IPC contours for A262, an unevolved cluster similar to Virgo with M87. A2199 may represent an intermediate stage of evolution and A85 a still more evolved state with both having smoother, more symmetrical X-ray distributions than A262 and Virgo. The primary observable difference between the second and third stage may be an increase in the temperature of the X-ray emitting gas.

Table 1 is organized in parallel with the contours seen in Figure 21. The data show how parameters other than the X-ray structure change as the clusters evolve. Relevant parameters include the X-ray gas temperature, galaxy velocity dispersion, and probably X-ray luminosity which increase as the cluster potential becomes dominant. X-ray observations by Henry *et al.* (1979), and Perrenod and Henry (1980), for clusters over a range of redshifts support this picture. Optical data also show that the fraction of spiral galaxies decreases with time presumably due to the stripping of the gas by the cluster medium.

4. Observations of Active Galaxies and Quasars

An updated picture of the HRI exposure for the radio galaxy Centaurus A obtained

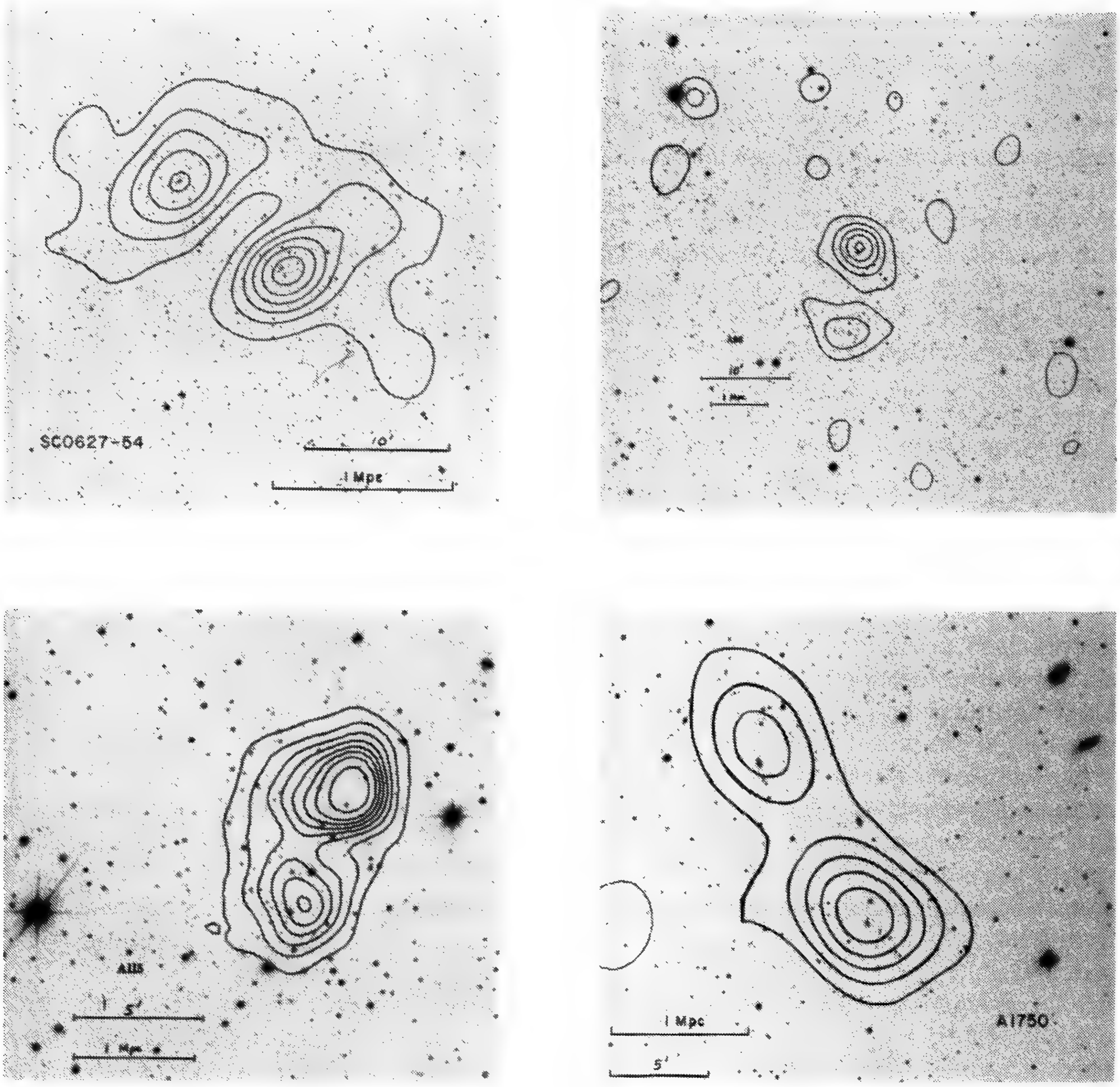

Fig. 20. The X-ray iso-intensity contours are shown superposed on the Palomar Sky Survey Prints (A98, A115, A1750) and on the European Southern Observatory Print (SC0627-54). The X-ray contours have been generated by deconvolving the image data with a Weiner filter, which smooths on a scale comparable to the detector's resolution. The contour levels are given below as the number of counts in each 64 × 64 square arcsecond bin: SC0627-54—12.0, 21.4, 30.2, 39.1, 48.5, 57.3 A98—5.2, 7.0, 8.8, 10.8, 12.6 A115—5.3, 7.7, 10.5, 13.3, 16.1, 18.9, 22.1, 27.3 A1750—3.9, 6.8, 9.6, 12.6, 15.5. The background levels in the fields in the same units are 2.0, 1.1, 5.5, and 0.6 respectively.

by Schreier *et al.* (1979), is shown in Figure 22. The image shows the point source associated with the nucleus of the galaxy NGC 5128 and a jet-like structure extending several arc minutes from the nucleus towards one of a pair of inner radio lobes associated with this source. This jet coincides in part with an inner optical jet observed by Dufour and van den Bergh (1978). Both thermal and synchrotron models have been used to explain the X-ray emission from the jet. Radio observations recently made at the VLA should allow us to choose between the two mechanisms. It is likely that this jet is capable of transporting the energy needed to replenish the inner radio lobe.

Figure 23 is an SSS spectrum of the Seyfert galaxy NGC 4151 obtained by Holt *et al.* (1980). The crosses indicate the observed counts s^{-1} keV^{-1} versus energy from

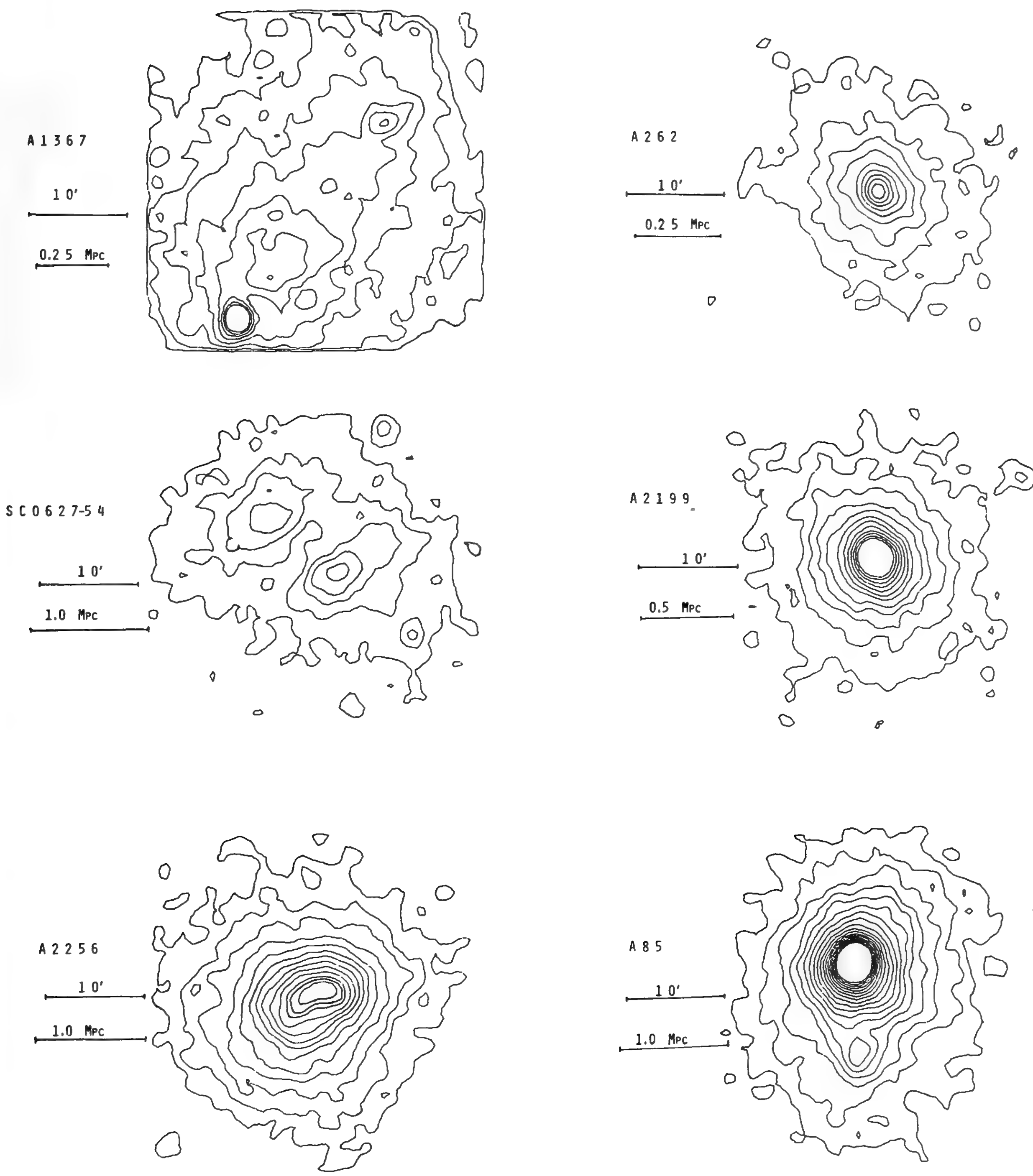

Fig. 21. Six contours showing non XD and XD cluster evolution.

0.5 to 4.5 keV. The existence of a significant number of counts below 2 keV is very surprising in view of higher energy measurements of a low energy cutoff of order 3 keV for this source. IPC and HRI data indicate that the low energy excess is in fact coming from NGC 4151. The top panel shows a smooth curve fit to the data above 2 keV with a solar abundance column density of $N_H \sim 5 \times 10^{22}$ H-atoms cm^{-2}. The middle panel shows a fit above 1.5 keV including an overabundance of silicon relative to oxygen of a factor of 4. Neither of these models fits the low energy data satisfactorily. A reasonable fit is shown in the bottom panel where a power law of energy index 0.55 is used (as for the top 2 panels) together with an absorbing column with solar abundances and $N_H \sim 6 \times 10^{22}$ cm^{-2} covering 94 percent of the source. This non-uniform

Table 1.—Cluster Classification.

NON XD SYSTEMS			*X-RAY DOMINANT (XD)* SYSTEMS		
A1367	Cool X-ray Gas	2.8 ± 1.0 keV	A262	Cool X-ray Gas	2.4 ± 0.8 keV
	Emission Around Galaxies			Emission Around Single Galaxy	
	Low Velocity Dispersion	694 ± 75 km/sec		Low Velocity Dispersion	478^{+183}_{-110}
	High Spiral Fraction	40%		High Spiral Fraction	45%
SC0627-54	Double X-ray Structure		A2199	Two-Component X-ray Spectrum	1.8, > 9 keV
A2256	Hot X-ray Gas	7^{+3}_{-2} keV		High Velocity Dispersion	843 ± 110
	High Velocity Dispersion	1274 ± 250		Low-Intermediate Spiral Fraction	24%
	Low Spiral Fraction	21%	A85	Hot X-ray Gas	6.8 ± 0.5 keV
				Low Spiral Fraction	$\leq$22%

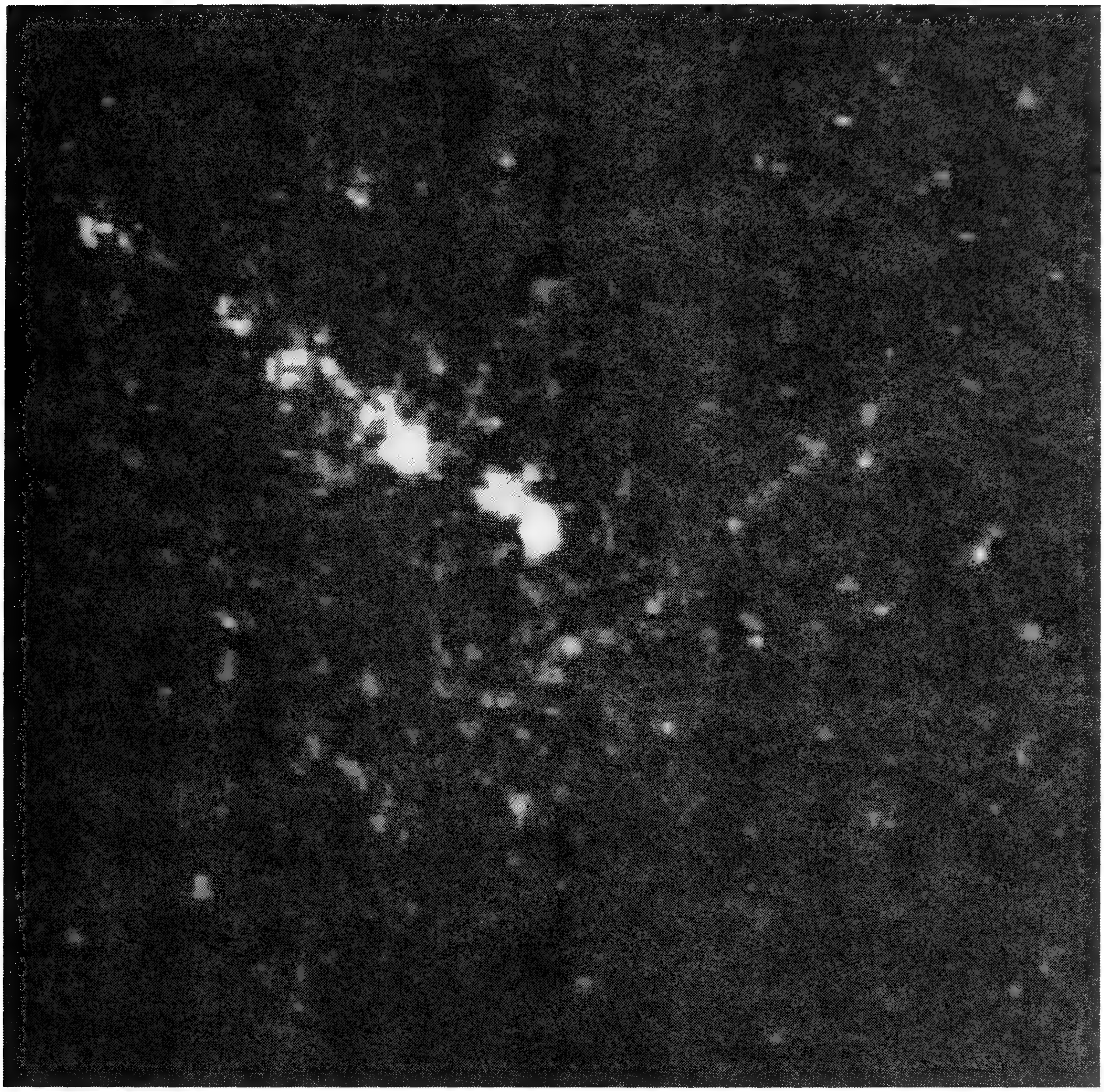

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Fig. 22. An HRI exposure of the radio galaxy, Centaurus A.

leaky absorber results in an acceptable fit to all of the data. These data suggest that the absorption arises in the relatively cold clouds responsible for the broad optical line emission. If the cloud dimensions are small compared to the X-ray source region, for example if 2 clouds typically cover 5 percent of the source area, then statistical fluctuations could leave an uncovered fraction of the order observed.

Extensive surveys of quasars have been carried out at CFA (cf. Tananbaum *et al.*, 1979, and Zamorani *et al.*, 1981) and at Columbia (cf. Ku, Helfand, and Lucy 1980). We find that quasars as a class are luminous X-ray emitters with some objects radiating more than 10^{47} ergs s^{-1}. Data also show that radio-emitting quasars on the average are more luminous X-ray emitters than radio quiet quasars. The ratios of

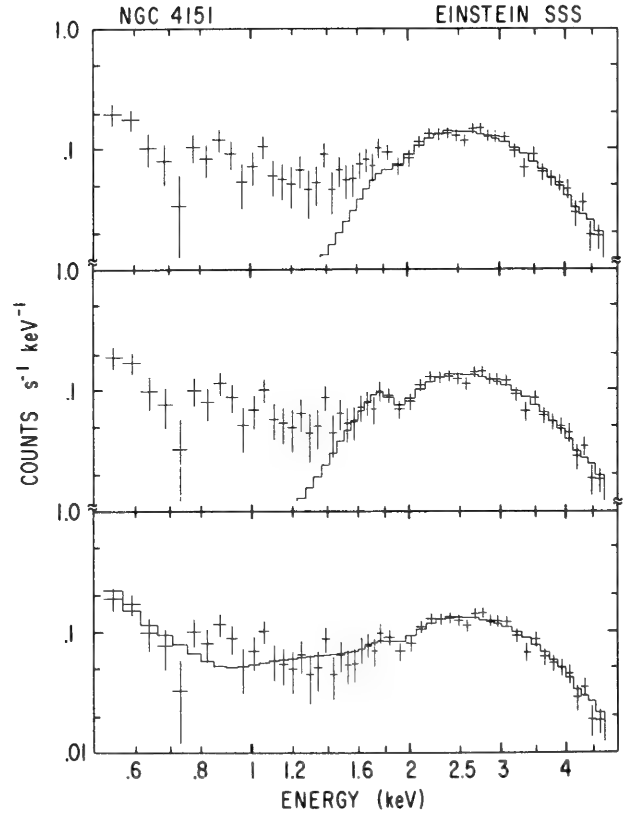

Fig. 23. NGC4151 SSS Spectrum. Raw (background-subtracted) pulse height spectrum from SSS exposure to NGC 4151 fitted with 3 trial spectra, each of which have the same power-law index $\alpha = 0.55$ with a best-fit normalization of $.024 \pm .002$ $cm^{-2}s^{-1}keV^{-1}$. a) Data above 2 keV fit with a solar abundance column density of $N_H = 4.9 \times 10^{22}$ H-atoms cm^{-2}. b) Data above 1.5 keV fit with a uniform column density of $N_H = 3.9 \times 10^{22}$ H-atoms cm^{-2} with an overabundance of silicon (relative to solar oxygen) of a factor of 4. c) Data above 500 eV fit with a solar abundance column density of $N_H = 6.1 \times 10^{22}$ H-atoms cm^{-2} over .94 of the source. (Courtesy of Holt *et al.*, 1980.)

X-ray to optical emission and optical source counts have been used to estimate the contribution of quasars to the extragalactic, diffuse X-ray background with interesting implications. This situation is illustrated in Figure 24. Here we show the number of optically observed quasars per square degree brighter than blue magnitude m_β as a function of magnitude. The solid line represents a power law of slope 2.16 fit to these optical source counts from 15.5 to 21.4 magnitude. Combining these data with our X-ray observations, Zamorani *et al.* (1981), concluded that quasars brighter than $21^m.2$ would produce 100 percent of the extragalactic diffuse X-ray background at 2 keV. At the same time, such quasars should account for ~65% of the diffuse background via discrete sources above the limit of the Einstein deep surveys. However, as we shall see, actual discrete source detections account for approximately 30 percent of the background at the Einstein limit. To overcome this problem, Zamorani *et al.*, concluded that the optical source counts must flatten above 20th magnitude. Recently Bonoli *et al.* (1979), have determined that a significant fraction (~2/3) of the ultraviolet excess objects in the Braccesi samples at 20^m are in fact slightly extended and therefore not quasars. Also, Kron (1980), has obtained data which may be used to set a limit on the number of very faint quasars at $23^m.5$. As a result the dotted line shown in Figure 24 better represents the quasar number counts. This flattening of the source counts agrees with that required by our X-ray data and in combination with the redshift distributions indicates that luminosity evolution rather than density evolution better describes the qua-

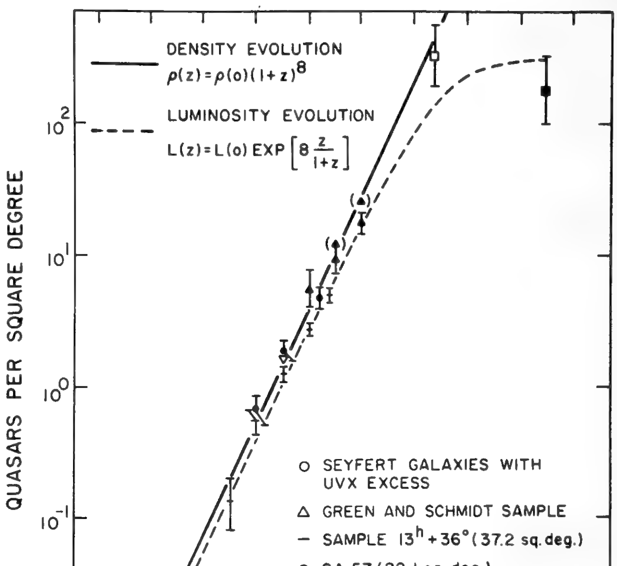

Fig. 24. Optical number counts versus blue magnitude for quasars.

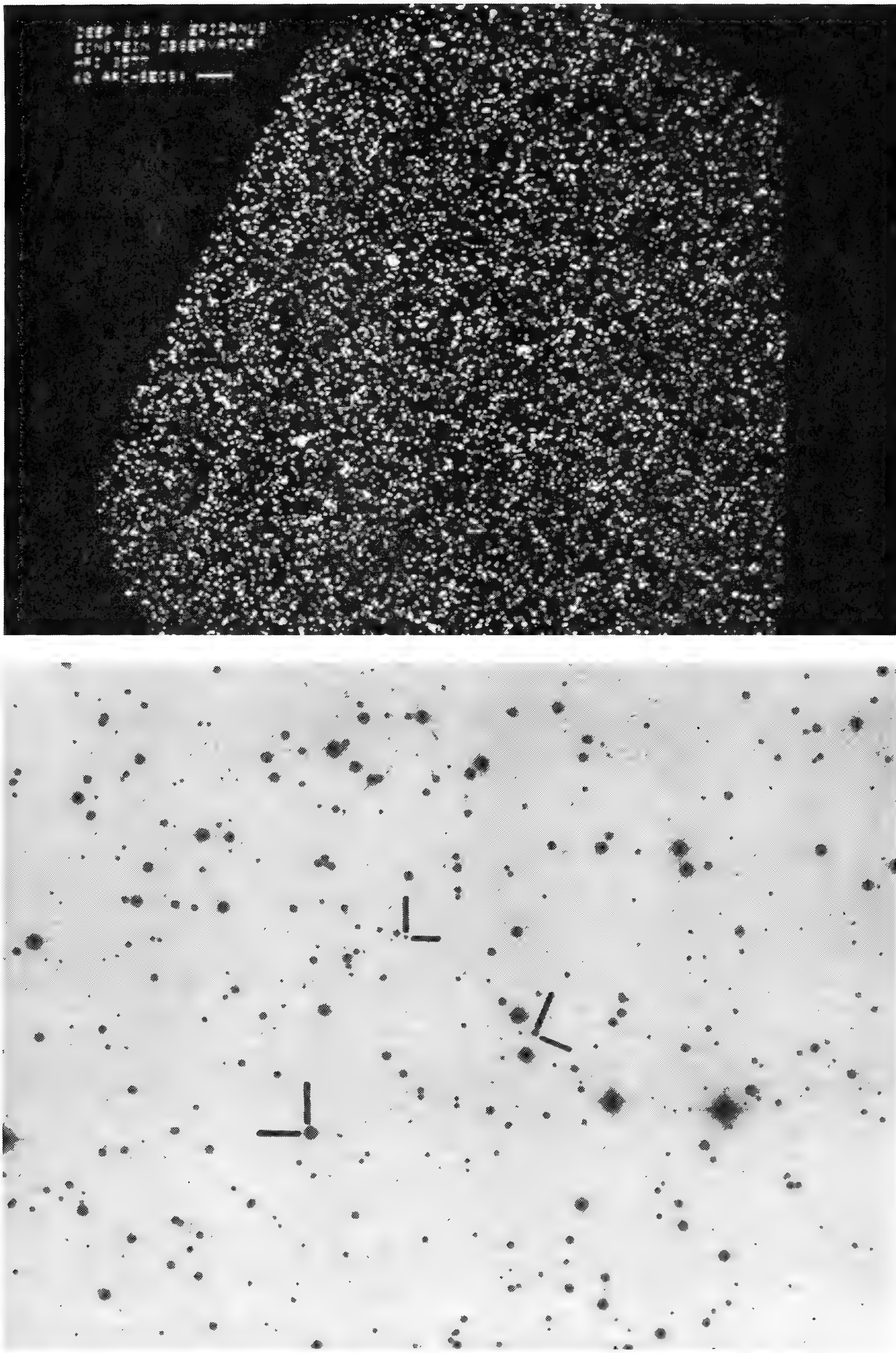

Fig. 25. Top—An HRI image obtained during Einstein deep X-ray survey of field in Eridanus. Three sources—two quasars and one star—are visible in the X-ray data. Bottom—Forty-eight inch Schmidt plate showing the visible light photograph corresponding to the X-ray exposure of the top figure. The optical counterparts of the three X-ray sources are indicated.

sar luminosity function. This suggests that the typical quasar at redshift 2 is approximately 100 times more luminous than the same quasar at redshift zero.

5. The X-Ray Background

This revised set of optical source counts indicates that quasars brighter than 22^m can account for about 60 percent of the X-ray background. Seyfert galaxies and clusters may account for another 20 percent leaving about 20 percent for new categories of sources such as young galaxies or for a small diffuse component at our observing energy of 2 keV. Direct studies of the source counts are typified by the HRI deep survey in Eridanus obtained by Giacconi *et al.* (1979), as shown in the top half of Figure 25. Three sources are clearly seen in this HRI exposure and are indicated by the hatch marks. The bottom half of Figure 25 shows the optical counterparts for these sources. The eastern most and brightest corresponds to a 13th magnitude G-star. The northern most is a $19^m.8$, z = 0.5 quasar and the western most is a $17^m.8$, z = 2 quasar. This result is somewhat typical in that approximately 1/3 of the deep survey sources are identified as stars and eliminated from further studies of the extragalactic background. Of the remaining sources the most frequently identified to date are previously uncatalogued QSO's.

Figure 26 provided by Giacconi, Murray, and Maccacaro (1980), shows the number of X-ray sources brighter than a given intensity S as a function of S. Uhuru and Ariel V data are indicated as is an extrapolated 3/2 power law expected for nonevolving sources in a Euclidean universe. Only 5 sigma source detections are used to determine these Einstein deep survey and medium survey data points. Note that the Einstein deep surveys reach a factor of almost 1000 beyond Uhuru and Ariel V. For the 15 deep survey sources seen above 5σ, 7 are identified—4 with previously unknown quasars and 3 with faint galaxies of which 2 are also radio sources. Most of the 8 un-

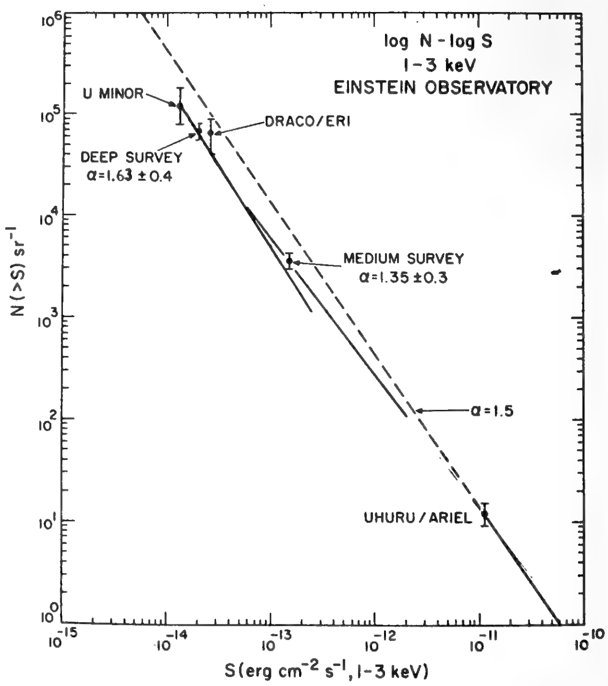

Fig. 26. The number of X-ray sources brighter than a given intensity S as a function of S.

identified sources have optical counterparts fainter than 19^m and spectrographic observations of candidates are still required. Our quasar X-ray results and the optical source counts suggest that many of these unidentified sources will be 20 and 21^m quasars.

The present data are not yet of sufficient statistical precision to test whether the intermediate survey source counts turn over due to effects of cosmological expansion and whether the deep survey source counts steepen again due to the contribution of a rapidly evolving population such as the quasars. Of course, ultimately, the source counts must turn over to avoid exceeding the background, but, when and how this will happen and how much, if any, diffuse background will remain will require AXAF for an answer.

Acknowledgments

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of the

UHURU MEMORIAL SYMPOSIUM

The Past, Present and Future of X-RAY ASTRONOMY

HELD AT

Goddard Space Flight Center
Greenbelt, Maryland USA
December 13, 1980

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The Advanced X-Ray Astrophysics Facility

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Introduction

The HEAO-2/Einstein Observatory employed for the first time in satellite X-ray astronomy, the technology of imaging optics in the direct study of galactic and extragalactic X-ray sources. The increase in sensitivity (a factor of 1000 for the detection of point sources) over UHURU only hints at the tremendous advance in observational capability that focussing optics has provided to X-ray astronomy. The results presented by Dr. Tananbaum elsewhere in these proceedings have clearly demonstrated the importance and significance of imaging X-ray optics and the field of X-ray astronomy. It is because of the success of the HEAO-2/Einstein, both technical and scientific, that the next major program, the Advanced X-Ray Astrophysics Facility (AXAF), is readily identified and well defined. In what follows I will briefly summarize the planned capability of this observatory and indicate some of the astrophysical problems that AXAF will be well suited to address.

1. The Observatory

The AXAF will be an X-ray observatory built around a large-area, high-resolution, grazing incidence X-ray telescope. Designed to operate in space for 10 to 15 years, the AXAF will be operated as a major national facility with the majority of the observing time set aside for guest investigators. An artist's conception of the AXAF in orbit is shown in Figure 1, and the major elements of the AXAF are identified in Figure 2. Also shown in Figure 1 is the Space Shuttle which will be used to place the AXAF in orbit and revisit the observatory at approximately 3-year intervals for the purpose of refurbishing and/or replacing instruments.

The long lifetime of AXAF will provide us with a facility not only capable of performing the observations now known to be necessary because of previous investigations and the questions raised by them, but also to follow up, in coordinated observing programs, those new discoveries which AXAF will surely make.

The heart of the AXAF is an X-ray telescope made up of six nested Wolter type I paraboloid-hyperboloid pairs ranging in diameter from 0.6 to 1.2 meters. The geometric collecting area will be 1700 cm^2, and the focal length will be 10 meters. The energy response will extend to well above 8 keV. The telescope will have angular resolution of better than 0.5 arc-second on axis and independent of energy, and a significant (but energy dependent) fraction of the reflected flux within the central core.

The baseline design of the AXAF has evolved from an interaction between the scientific requirements and engineering

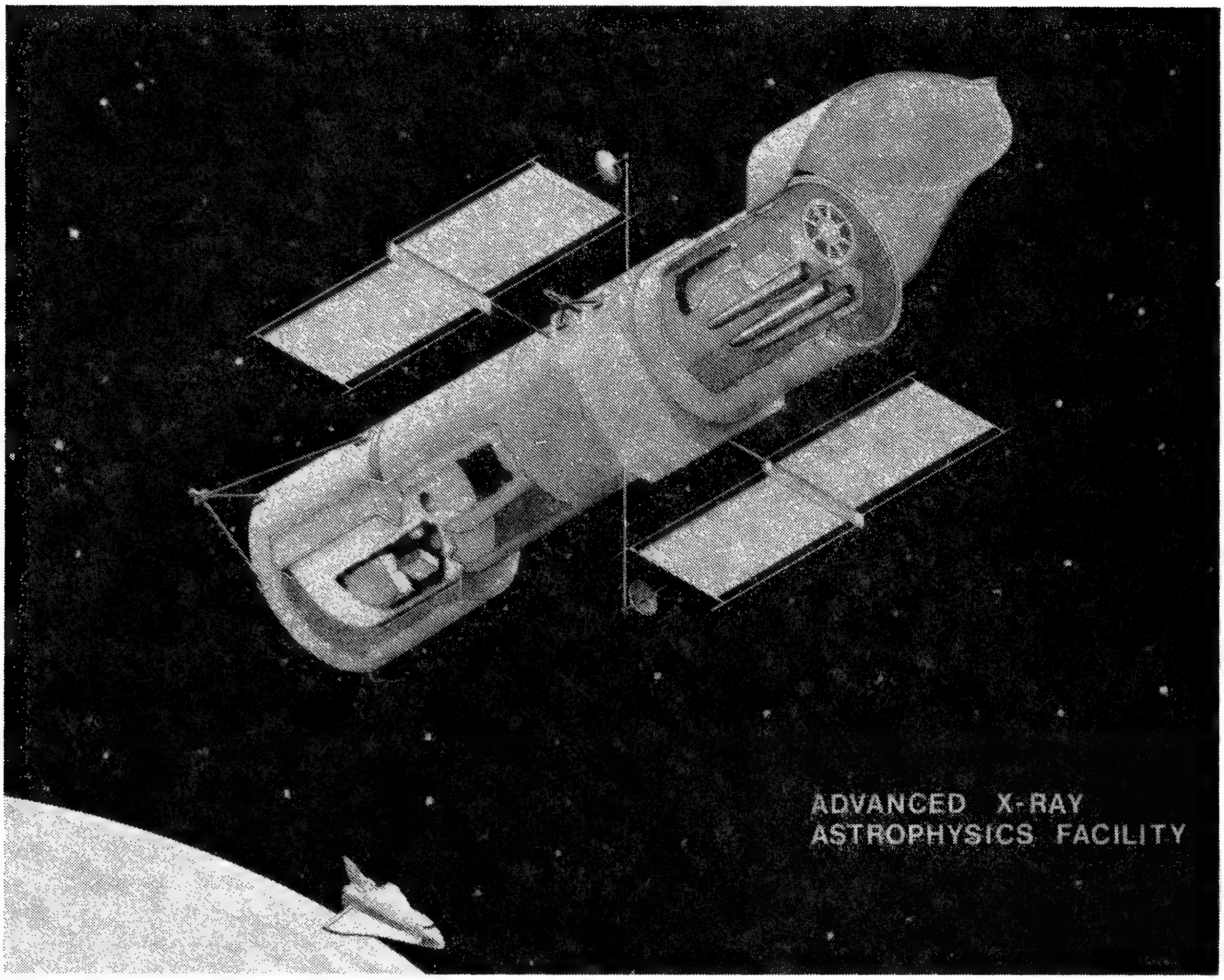

Fig. 1. An artist's conception of the AXAF in orbit.

constraints. It has been enhanced as a result of the experience gained in the design, fabrication, assembly, test and performance of the HEAO-2/Einstein telescope. The AXAF telescope parameters are summarized in Table 1, where they are also compared to those of the Einstein Observatory. There are several important differences between the two telescopes, and these are only partially apparent from the factor four increase in geometric area and the factor eight goal for the improvement in angular resolution listed in the table.

Certainly the larger geometric collecting area will make the AXAF far more efficient than the Einstein telescope over the energy bandwidth that the two observatories have in common. Furthermore, the range of grazing angles permitted by the AXAF design allows the response of the telescope to extend to energies well beyond 7 keV. The total (on-axis) effective collecting areas are compared in Figure 3. The extension of X-ray imaging to the energies shown in the figure will have important consequences. This response includes the complex of lines due to highly ionized iron and permits such studies as the iron line spectroscopy of nearby supernova remnants and also the direct measurement of redshifts from clusters of galaxies where we know, from UHURU and its successors, that emission from highly ionized iron exists. Of equal significance, however, are not the observations in this new wavelength range we can now point to, but the fact that we will have available to us a new region of the spectrum for imaging studies. Both UHURU and especially the HEAO-2/Einstein have demonstrated the importance of increasing the wavelength sensitivity, and one can only speculate now as to what surprises await us.

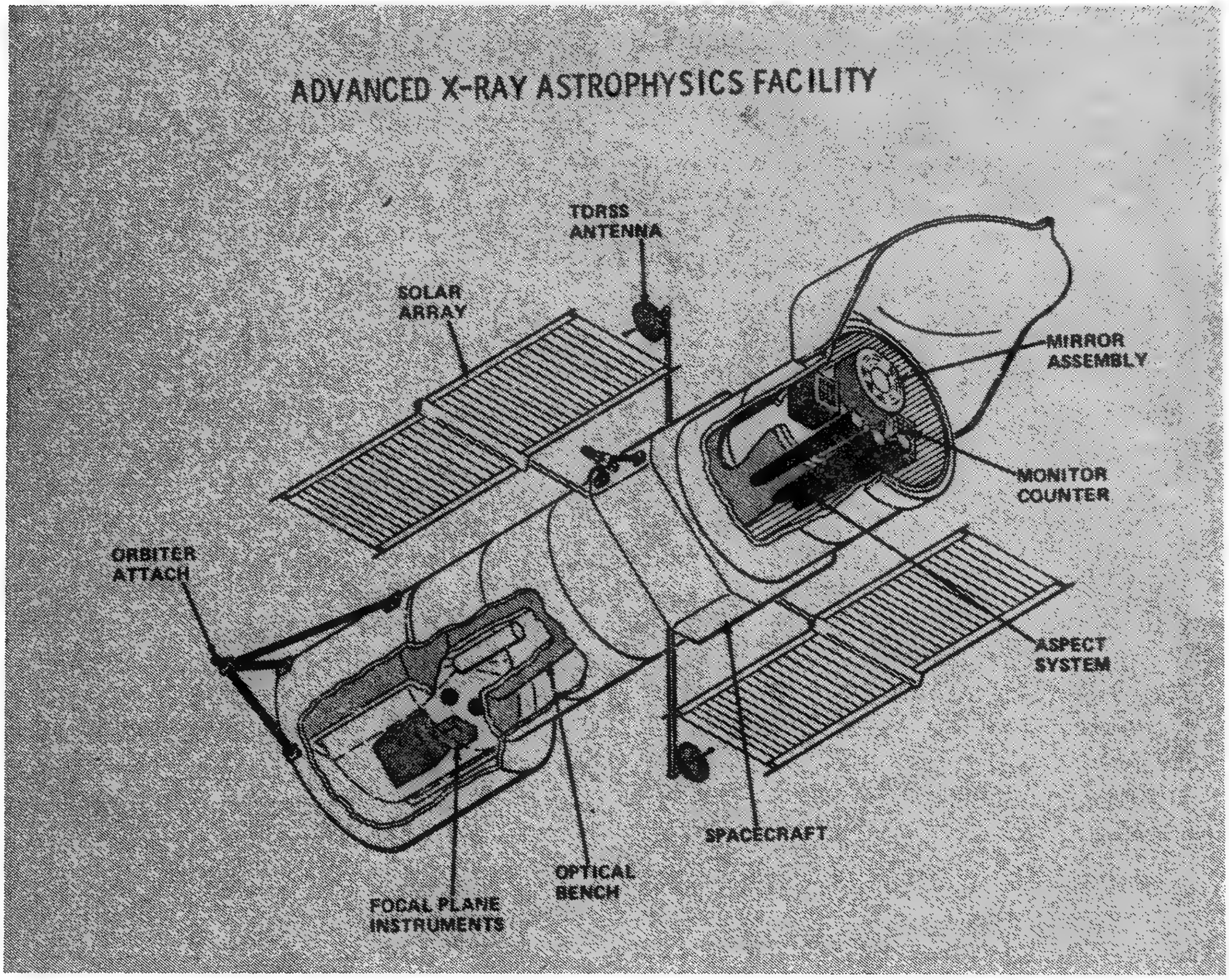

Fig. 2. Cutaway showing the major elements of the AXAF.

The most important and significant difference between the AXAF and its prototype is the imaging quality. This is illustrated in Figure 4 where the fraction of on-axis reflected flux at 2.5 keV is shown as a function of the radius of a perfect detector. In general, the imaging performance of an X-ray telescope is not limited by diffraction but by the geometrical figure, the alignment, and the surface finish of the reflecting elements. The figure and alignment determine the full-width-half-maximum of the response function and is independent of energy. The surface finish, primarily microscopic surface roughness, determines the fraction of the reflected flux that remains within any given radius about the center of an X-ray image. Thus, figure and

Table 1—A Comparison of Telescope Parameters.

	HEAO-2/Einstein	AXAF
No. of Elements	4 Nested Pairs	6 Nested Pairs
Outer Diameter (m)	0.58	1.2
Focal Length (m)	3.44	10.0
Geometric Area (cm^2)	460	1700
Inner Grazing Angle (°)	0.68	0.45
Outer Grazing Angle (°)	1.17	0.85
Resolution (arc-sec)	4.0	0.5
Field of View (°)	1	1

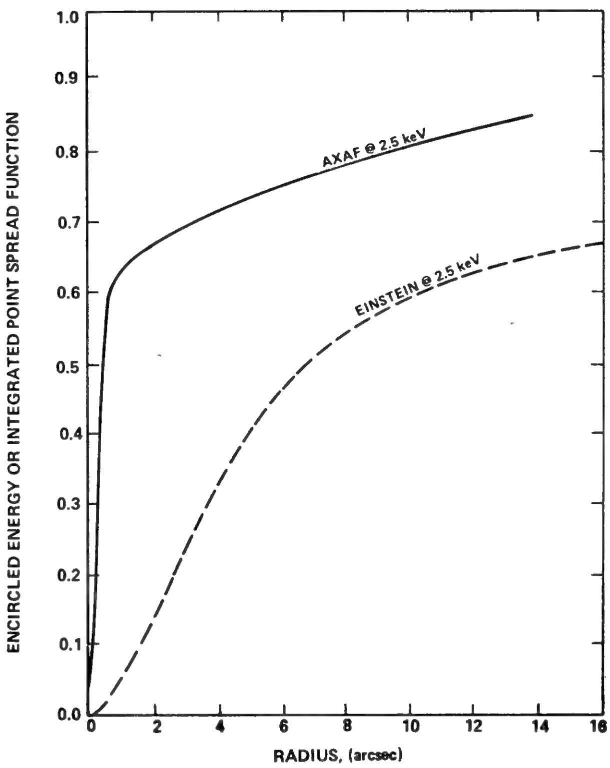

Fig. 3. The AXAF and Einstein on-axis effective areas as a function of energy.

alignment establish the rapidly rising portions of the response curves shown in Figure 4, whereas the amount of scatter from the reflecting surfaces limits the efficiency and the ability to resolve low contrast features. Figure 5 demonstrates the anticipated AXAF performance as a function of energy for resolution elements of 1 and 20 arc-second diameters. The significant improvement of the AXAF imaging quality over that achieved by the HEAO-2/Einstein is based, for the most part, on a modest extension of the Einstein tolerances and a much better understanding of the contributions to X-ray scatter that have taken place in the years since the HEAO-2/Einstein was fabricated.

Before I discuss the types of instruments one might expect to see aboard the AXAF, it is important to note that the AXAF's improved angular resolution and low scatter are absolutely necessary to attack a large number of astrophysical problems which simply cannot be done at the Einstein level of performance. These include, for example, the "weighing" of X-ray sources in globular clusters where even a three solar mass binary system could be expected to be no more than 1 arc-second from the center of a typical centrally condensed cluster. Both low scatter and high angular resolution are musts for the search for, and study of, low contrast features such as jets near nuclei of active galaxies.

2. Instrumentation

The instrumentation for the AXAF will be selected through a series of Announcements of Opportunity (AO), and the AO for the first instrument complement is currently scheduled to be released in 1981. Tables 2 and 3 list a number of instruments that have been identified by the members of the AXAF Science Working Group. This group, whose members are listed in Table 4, was established in 1977 to advise NASA on the scientific requirements for AXAF and the possible instrumentation that might be flown. I won't dwell on these instruments except to point out that, first, the longer focal length and, thus, the increased plate scale have resulted in an immediate

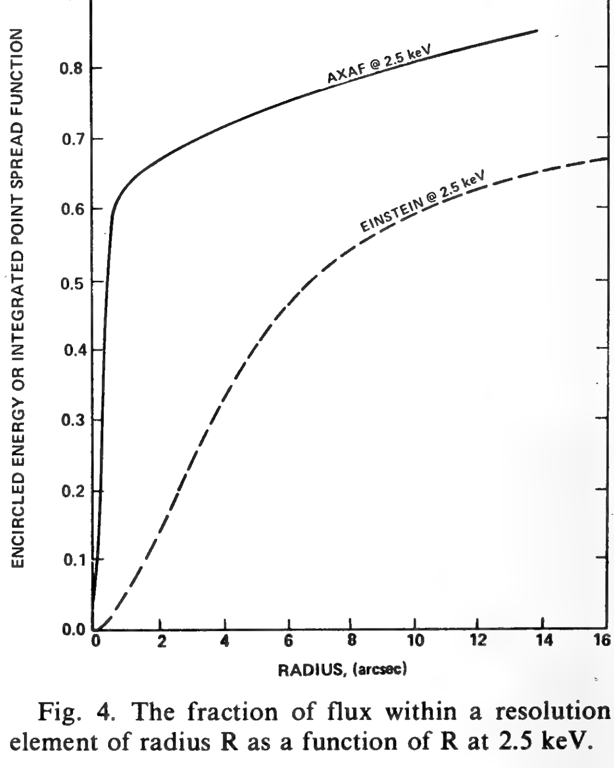

Fig. 4. The fraction of flux within a resolution element of radius R as a function of R at 2.5 keV.

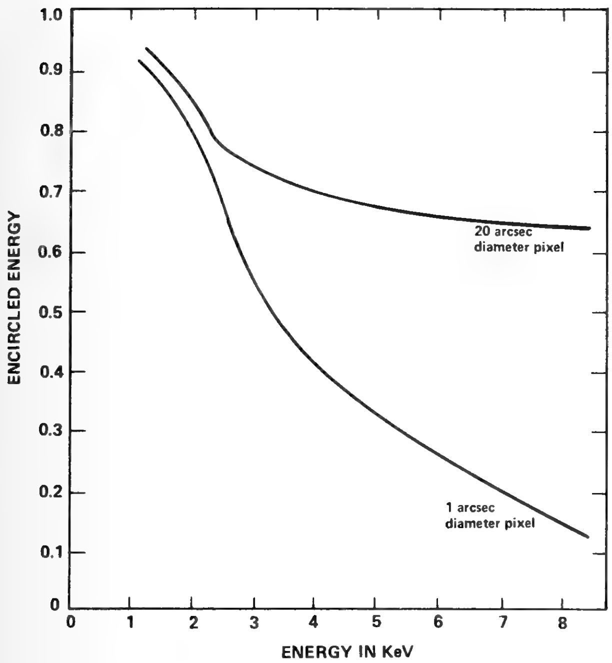

Fig. 5. The fraction of reflected flux within resolution elements of 1 and 20 arc-seconds diameter as a function of energy.

improvement in the angular resolution of even the HEAO generation of imaging detectors by a factor of three. Second, more recent developments in instrumentation technology offer the exciting prospect of performing spatially resolved, high quantum efficiency, reasonable energy resolution spectroscopy. Indeed, detailed spectroscopic studies with AXAF will encompass a wide range of objectives, and instruments, such as those listed in Tables 2 and 3, will be well suited to accomplish these studies. For example, with an objective grating and a high resolution imaging detector in the focal plane, the spectra of faint compact sources could be obtained with an energy resolution (E/ΔE) of order 100 and, thanks to improvements in grating technology and the AXAF's collecting area, effective areas a factor of a hundred or more over the equivalent HEAO-2/Einstein instrument are possible.

3. Potential Investigations

Figure 6 shows the potential sensitivity of AXAF for the detection of point sources as compared to the HEAO-2/Einstein performance with the High Resolution Imager (HRI) and the Imaging Proportional Counter (IPC) in the focal plane. The AXAF sensitivity is based on the use of a high-resolution imaging detector with the efficiency of a charge-coupled solid state detector. The sensitivity shown in Figure 6 is placed in perspective in Table 5, which lists the minimum detectable luminosity as

Table 2—Imaging X-Ray Detectors.

Detector	Size (Field of View)	Spatial Resolution	Quantum Efficiency	E/ΔE @1 keV	E/ΔE @6 keV
Charge Coupled Device	>25 mm × 25 mm (≥8 × 8 arc min)	15–25 μm (0.3–0.5 arc sec)	high	5	30
Negative Electron Affinity Detector	>25 mm diameter (≥8 arc min)	15 μm (0.3 arc sec)	high	5	1
Microchannel Plate	≥85 mm diameter (≥30 arc min)	15 μm (0.3 arc sec)	low	none	
Imaging Proportional Counter	180 mm × 180 mm (1° × 1°)	<0.5 mm (<10 arc sec)	high	2	5
Gas Scintillating Imaging Proportional Counter	180 mm × 180 mm (1° × 1°)	<0.5 mm (<10 arc sec)	high	10	12

Table 3—X-Ray Spectrometers and Polarimeters.

Instrument	Energy Range (keV)	Energy Resolution (E/ΔE)	Location
Filter Wheel	0.1–8	3	in front of detector
Transmission Grating	0.1–4	100–200	behind mirrors
Solid State Detector	0.4–8	15–50	in focal plane
Objective Crystal	0.5–8	500–10,000	in front of mirrors
Focal Plane Crystal	0.5–8	500–3,000	in focal plane
Focal Plane Concave Grating Spectrometer	0.1–1	500	in focal plane
Gas Scintillation Proportional Counter	0.1–8	10–15	in focal plane
Bragg Crystal Polarimeter	2.6, 5.2	N/A	in focal plane

Table 4—Members of the AXAF Science Working Group.

Professor Riccardo Giacconi—Harvard University—Chairman
Dr. Martin C. Weisskopf—Marshall Space Flight Center—Vice Chairman
Dr. Elihu Boldt—Goddard Space Flight Center
Professor Stuart Bowyer—University of California, Berkeley
Professor George Clark—Massachusetts Institute of Technology
Professor Arthur Davidson—Johns Hopkins University
Professor Gordon Garmire—California Institute of Technology
Professor William Kraushaar—University of Wisconsin
Professor Robert Novick—Columbia University
Dr. Albert Opp—NASA Headquarters—ex officio
Professor Minoru Oda—Tokyo University, Japan
Professor Kenneth Pounds—University of Leicester, United Kingdom
Dr. Seth Shulman—Naval Research Laboratory
Dr. Harvey Tananbaum—Harvard/Smithsonian Center for Astrophysics
Dr. Joachim Truemper, Max-Planck Institute, Germany
Professor Arthur Walker—Stanford University

Table 5—Minimum Detectable Luminosities for 10^5 Seconds of Observation.

Luminosity-Distance	Object	L_{min} (ergs/s)	Linear-Dimension (per arc-second)
150 pc	star	10^{27}	50 Au
0.7 Mpc	point source in M31	2×10^{34}	3.5 pc
19 Mpc	point source in Virgo Cluster	10^{37}	100 pc
300 Mpc	normal spiral galaxy	3×10^{39}	1.5 Kpc
1000 Mpc	active galaxy in Hydra	3×10^{40}	5 Kpc
2×10^5 Mpc	quasar	10^{45}	1 Mpc

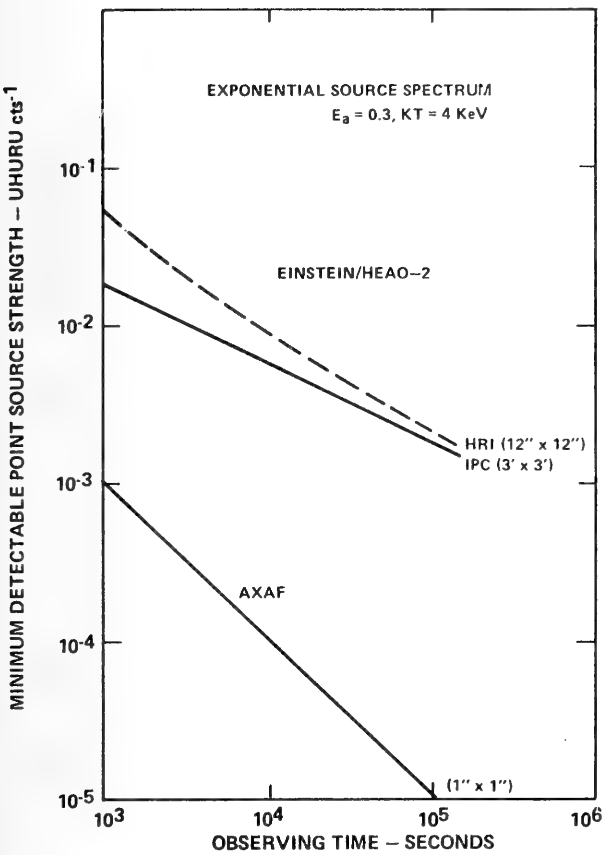

Fig. 6. The sensitivity of the AXAF for the detection of point sources as a function of observing time as compared to the Einstein Observatory. The calculation is based on a moderately efficient charge-coupled imaging detector in the focal plane.

a function of the luminosity-distance for several characteristic distances and objects. The usefulness of this sensitivity is indicated in Table 6, which lists the known luminosity of several categories of X-ray sources.

Such sensitivity clearly opens the door for many avenues of research. Consider, for example, the study of normal stars. Based on the (unexpected) Einstein results, we now know that stars throughout the H-R diagram will lie well within AXAF's observational capability. By the end of its mission, the HEAO-2/Einstein will have observed only approximately 500 stars and, of these, probably less than half of the observations will have obtained even low resolution spectra with the IPC. Thus, only statistically limited spectral classifications will be completed, and one will be restricted, for the most part, to relatively crude correlation studies with optical data. Taking the one-hundred-fold increase in the sensitivity of AXAF into account, all of the more than 6000 stars in principle accessible to the Einstein (but not observed) could be studied in a relatively short time. The total number of stars accessible to AXAF is, of course, vastly larger, and the available volume of space for sampling will increase by a factor of a thousand.

The promise of AXAF is perhaps more colorfully illustrated in Figure 7, which shows the HEAO-2/Einstein images of M31. The AXAF would add a third image, further resolving the galactic nucleus and, in clarity, would be to the HRI image shown, as the HRI image is to the IPC image. Furthermore, with the AXAF the study of discrete sources in normal galaxies will be extended to objects with much lower luminosity than was possible with the HEAO-2/Einstein. Sources as weak as 5×10^{34} ergs/s could be detected in Andromeda, and the coronae of O and B stars would be visible in the Magellanic Clouds. The study of individual high-luminosity (10^{37} ergs/s) sources, now only possible for M31, will be extended to galaxies at distances up to 20 Mpc. Thus, all 2500 galaxies in the Virgo Cluster will be amenable to the type of observation illustrated in Figure 7. With such data one will be able to study the spatial

Table 6—Examples of Known X-Ray Luminosities.

Object	Luminosity (ergs/s)
Sun	5×10^{27}
Cen X-3	2×10^{37}
Milky Way	5×10^{39}
M87	3×10^{43}
3C273	5×10^{45}

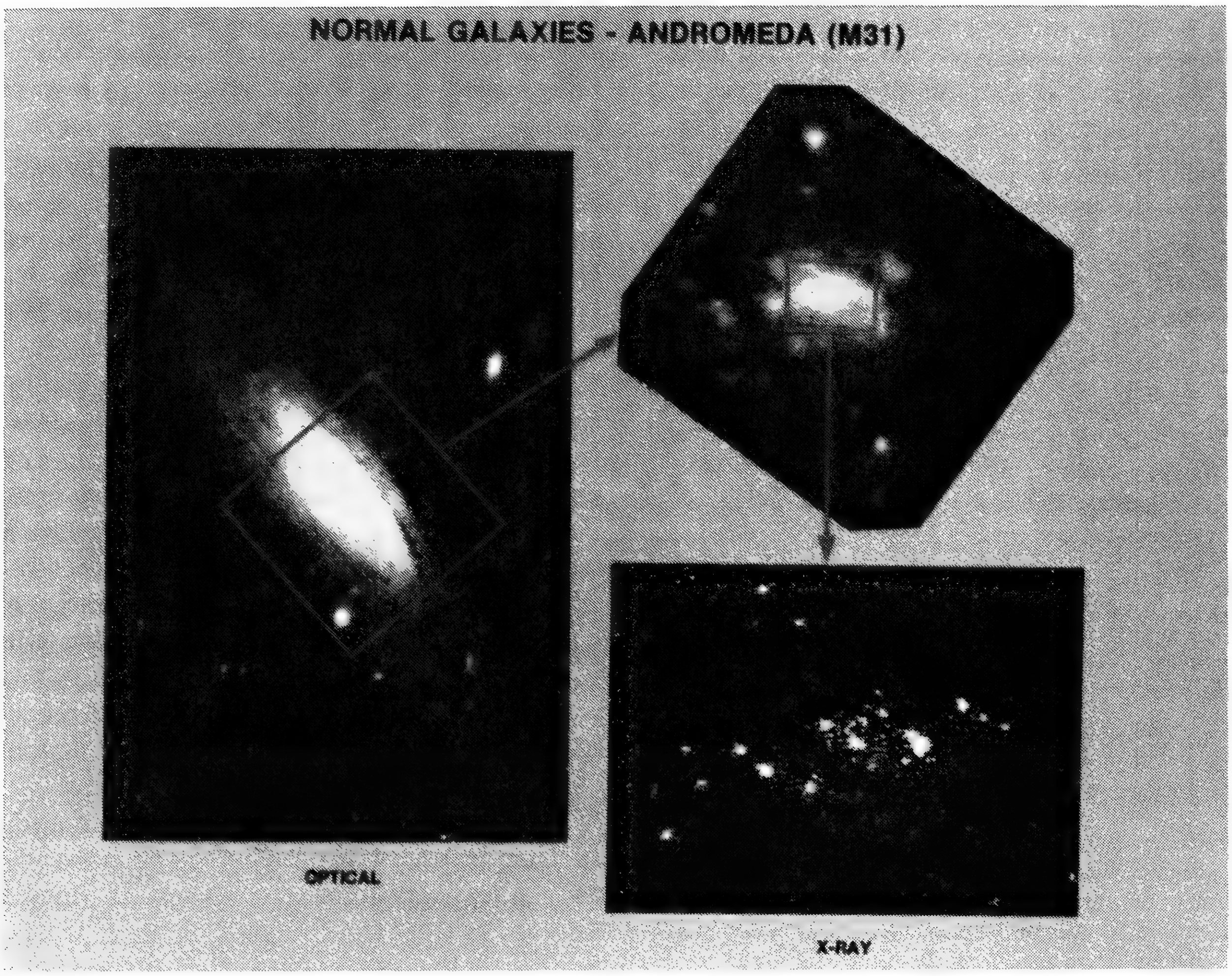

Fig. 7. Optical and X-ray picture of M31 (Andromeda). IPC observation (upper right). HRI observation (lower right).

and luminosity distributions with an angular resolution which can distinguish between bulge, disc and nuclear components and can correlate these distributions to galaxy properties: morphology, metallicity, etc. Insofar as the integrated emission of galaxies is concerned, the sensitivity of AXAF will increase the sample from approximately 1 normal galaxy/1° field to as many as 1000/1° field. Among other things, these observations can be used to determine whether high-luminosity activity in the galactic nucleus is confined to a small fraction of all galaxies or whether all galaxies spend a small fraction of their life in a highly active state. Clearly such observations can also shed some light on the relationship between normal and active galaxies.

Another area of research in which the AXAF is prepared to provide unique and significant advances is in the study of clusters of galaxies. This follows directly from the existence of the hot intra-cluster gas first detected by UHURU; the importance of this gas has been emphasized by many of the results presented earlier today. X-ray imaging with the HEAO-2/Einstein has begun the detailed study of cluster morphology, so important since the gas is invisible at longer wavelengths. Yet, these observations are sensitive only to the cooler gas because of a limited energy response. Furthermore, detailed mapping and spectroscopy with the HEAO-2/Einstein are limited by the spatial sensitivity. With the AXAF, spectrally resolved high-resolution maps of a statistically significant sample of clusters will be possible. Based on a 6-month observing program and an assumed density of 10^{-6} cluster sources/Mpc^3 ($L_x \geq 10^{44}$ ergs/s), 800 sources could be detected in a survey of one hundred square degrees. Moreover, the AXAF should allow for: (1) the detection of the integrated emission from clusters at redshifts up to one and possibly as large as four, depending on their epoch of formation and early evolution; (2) the detection and spatial resolution for clusters as distant as $Z = 1$ to 3; and (3) the detailed mapping and spectroscopy, including X-ray measurements of the redshift for Z as large as 0.5 to 1. Observations such as these will allow for the detailed study of the formation and evolution of the clusters, the origin and heating mechanisms of the intra-cluster medium and the matter content, with emphasis on the hot gas. X-ray observations of clusters with the AXAF should also provide the basis for at least two tests of cosmological models: the first through the differential number counts of X-ray clusters at large redshifts and the second (described in more detail by Dr. Fabian elsewhere in these proceedings) combining X-ray and microwave measurements to determine the deacceleration parameter in an almost assumption-independent way.

Conclusions

I have only touched upon the capabilities of the AXAF and some of the types of studies which could be carried out with this observatory. A far more detailed description of the AXAF, its scientific objectives and its potential for accomplishing these objectives may be found in the report of the AXAF Science Working Group (NASA TM-78285, May 1980).

In conclusion, I believe it is adamantly clear from the results we have heard today that X-ray astronomy has come of age. The tremendous success of the last X-ray astronomy mission, the HEAO-2/Einstein, is underscored by the far greater number of astrophysical questions which now confront us, as opposed to what we knew before that mission began. An essential point in charting the future course of our field is that AXAF is not only necessary to perform the required observational tasks to answer these questions, but that AXAF alone has the capability to carry out the majority of the major research goals before us. With the AXAF, X-ray astronomy will be able to take its place, along with radio and optical astronomy, as one of the major probes of the Universe.

Large Area Modular Array Of Reflectors (LAMAR)

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LAMAR

Introduction

The central role to be played by imaging optics in the future development of X-ray astronomy has recently been re-emphasized by the outstanding results of the Einstein Observatory. In considering the major thrust in X-ray telescope development over the next decade an analogy with optical astronomy is apparent. The established requirement of complementary instruments of extreme resolution (e.g. the Space Telescope) and large collecting area (multi-mirror telescope, new large 10 m design, etc.) finds a parallel in X-ray stronomy, where again a facility of large photon collection capability will be needed to complement AXAF. While AXAF will provide an extremely high point source sensitivity and sub-arc sec angular resolution for the detection, location and imaging of faint sources, a second 'World Class' facility will be necessary in many photon-limited situations, such as imaging extended objects of low surface brightness, spectroscopy and time-variability studies. Also, the potential of a very deep, all-sky survey is obvious from the outstanding success of Uhuru and Ariel-5 and the primary importance in other wavebands of, for example, the Palomar Schmidt and Cambridge 3C radio surveys. Gorenstein (1973) first proposed to NASA a mission to tackle these objectives; this was named the *L*arge *A*rea *M*odular *A*rray of *R*eflectors (LAMAR) and I intend in this short review to take a further look at the need for and possible progress towards the realisation of such a LAMAR. It seems clear that the dominant criteria for realising LAMAR relate to the ability to construct and pay for the very large area of mirrors required. In this regard, a modular approach and moderate angular resolution are likely to be key factors.

1. Elements of a LAMAR

The essential requirements of a LAMAR are that it provides a large photon collection area, combined with 'adequate' angular resolution. Considerations of the positional accuracy needed to identify sources detected by such a sensitive instrument and of the effects of source confusion lead to an angular resolution requirement which, in turn, makes the use of imaging optics essential to LAMAR.

The initial LAMAR concept (Figure 1) envisaged a spacecraft launched by Shuttle with the following major parameters:—

effective photon collection area (at .28 keV)	$\sim 2 \times 10^4$ cm^2
angular resolution	$\sim$20 arc sec
field of view	$\sim$2 deg^2
energy range	$\sim$0.15–6 keV

The photon collection area is thus $\sim 50 \times$ Einstein and $\sim 15 \times$ AXAF, but with a specified angular resolution that is substantially less stringent. It is useful to re-

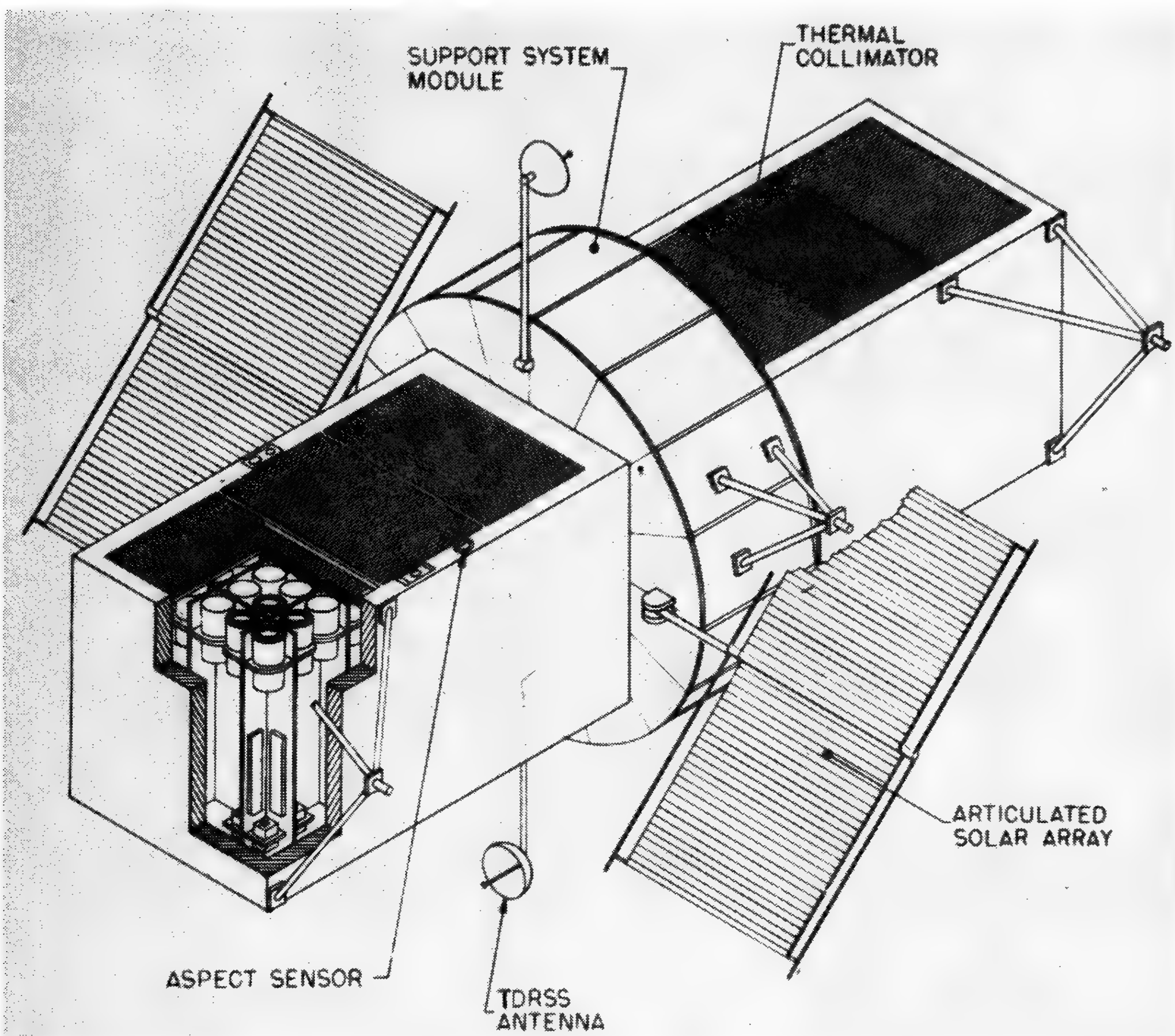

Fig. 1. Conceptual drawing of a LAMAR facility for long term orbital observations (from Gorenstein, 1979, SPIE, *184*, 63).

examine these parameters in the light of actual results from the Einstein Observatory.

2. Sky Survey

One important task for LAMAR will be to carry out a very deep all-sky survey. Uhuru and Ariel-5 covered the whole sky (at 2–10 keV) to a limit of $\sim 1.5 \times 10^{-3}$ Crab and HEAO-1 is likely to improve on this by a factor ~3. The Einstein medium and deep surveys will reach $10^{-5} - 10^{-6}$ Crab, but will cover less than one percent of the celestial sphere. The German ROSAT should extend the *all-sky* cover to $\sim 10^{-5}$ Crab (at $E \leq 2$ keV).

A 12-months uniform sky survey by the above LAMAR payload would give a mean exposure time $\sim 3 \times 10^7$ (sec) $\times$ 0.6 (coverage) $\times 5 \times 10^{-5}$ (ster) $\simeq$ *1000 sec.* Making reasonable assumptions for the effective area versus energy response for a combination of LAMAR optics and conventional IPC detectors, the count rate from a source of strength 1 mCrab is estimated to be ~75 sec^{-1}. Neglecting background,* this gives a limiting source detection (10 cts) in 10^3 sec of $S_{min} \sim 1.3 \times 10^{-7}$ Crab.

* Assuming 50 telescope modules are used to give the prescribed LAMAR, the 50 focal plane IPC's will yield a particle background rate of $\sim 3 \times 10^{-3}$ cts sec^{-1} per $20'' \times 20''$ pixel in the 0.15–6 keV band. The estimated cosmic X-ray background rate is comparable. Hence, $\sim 10^3$ sec is also about the upper limit for a photon-limited exposure.

Extrapolating the Uhuru/Ariel-5 source count relation to this level predicts a total of $\sim 10^8$ sources, the integrated flux of which would be equivalent to the observed X-ray sky background (out of the galactic plane). Indications from the Einstein deep survey work are that many of these sources will be distant QSO's, whilst a probable decrease in the slope of the source count function at small S may give an actual yield (for LAMAR) of $\sim 10^7$ sources. Even so, this represents an average of 250 sources deg^{-2} and—with a minimum requirement of 40 pixels per source—sets an upper limit of *~30 arc sec* to a pixel, i.e., to the necessary angular resolution of LAMAR.

On the separate question of source identification, the Einstein Observatory experience may be the most directly relevant. In the Einstein DRACO and ERIDANUS deep field surveys (Giacconi *et al.,* 1979), 43 objects were detected down to a level $\sim 10^{-6}$ Crab. Position accuracies varied from ~5 arc sec (HRI) to ~1 arc min (IPC). For all 16 sources located to ~1 arc min only, multiple candidates were found. At the other extreme, 3 sources determined to ~5 − 10 arc sec had 'empty fields', i.e., no optical counterpart brighter than $M_B \sim 23$ in the error boxes. Only for the 21 sources located by the HRI, with uncertainties in the range ~5 − 20 arc sec, were likely or near-certain identifications possible. Since the LAMAR survey will reach a depth ~10× lower than the Einstein deep fields, it is clear that many sources may *not* be readily identified at a typical LAMAR positional accuracy of, say, 10 arc sec.

From the above general considerations it follows that the nominal 20 arc sec resolution is only barely adequate *in the survey mode* for a LAMAR of the prescribed aperture. Improved resolution will clearly be most valuable if it can be achieved within the real confines of cost and mass production of the X-ray optics. This point may be made again by taking another Einstein example. Figure 2 shows the IPC field around the bright Seyfert I galaxy NGC 4151. In all, 8 sources were detected in this 2.7×10^4 sec exposure, including 3 within ~5 arc min of the bright nucleus of NGC 4151 itself. These are believed to be entirely separate objects, being identified with a field galaxy (No. 7), a distant QSO (No. 8) and (probably) an intermediate-distance active galaxy (No. 5). In a LAMAR survey, such a field would be detected ~5 times further away, i.e. with 4 sources within ~1 arc min.

3. Use of LAMAR in individual source observations

As noted in the introduction, the large photon 'throughput' of LAMAR makes it especially powerful in the study of time variability, in the imaging of diffuse X-ray sources and in X-ray spectroscopy. These aspects are briefly examined in this section. The angular resolution requirement will generally be less severe here.

Time variability Variability has long been a key feature in the properties of X-ray sources. Perhaps the outstanding discovery of Uhuru—and one of the most important results of space science to date—was the powerful X-ray binaries. These are now known to dominate the X-ray emission of the Galaxy and provide, in practice and potentially, unique information on stellar evolution, on mass transfer and radiation in extreme gravity and magnetic fields, and on the properties and structure of white dwarf and neutron stars, black holes, etc. LAMAR will have the sensitivity *and* resolution to extend such studies to external galaxies. For example, a source of $L_x \sim 10^{38}$ erg sec^{-1} in M31 would yield ~300 cts/10^3 sec in LAMAR. An observation over several days could establish accurate pulse periods, orbital characteristics, etc. for many such sources in a LAMAR field. Of still greater scientific potential would be the LAMAR study of extragalactic variability. Figure 3 shows a recent Ariel-5 detection of a sharp increase in the X-ray luminosity of the bright QSO 3C 273. This event, a doubling of the X-ray emission in ≤0.5 day, reveals directly the small scale of the emitting region and implies a remarkably high efficiency of mass-to-radiation

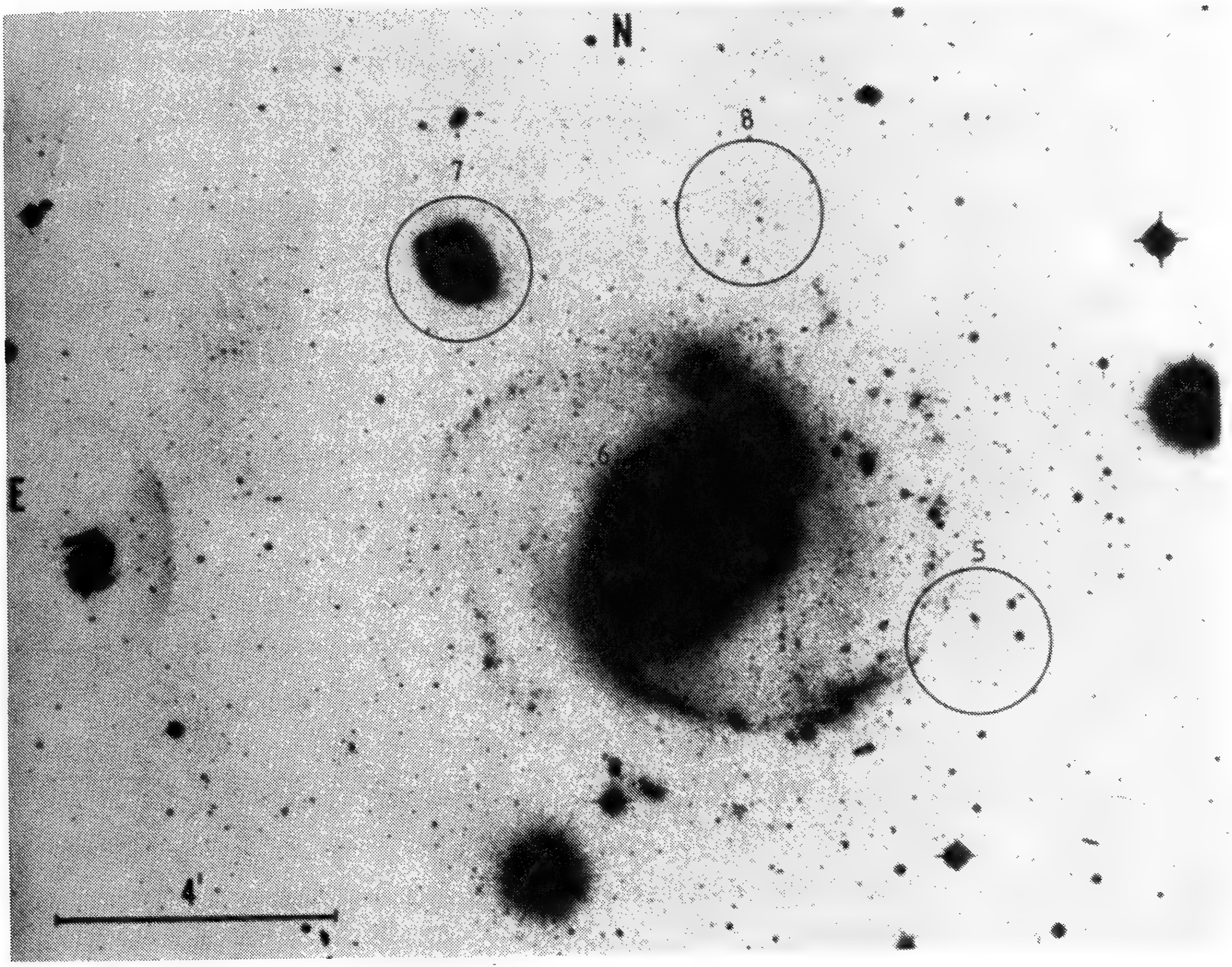

Fig. 2. Einstein Observatory field near the Seyfert galaxy NGC 4151.

conversion (≥10%), which in turn is strongly suggestive of a massive black hole as the ultimate source of power in 3C 273 (Pounds, 1980). Evidence has accumulated over the past 2–3 years that such short-term variability is a common feature of X-ray active galaxies (Marshall *et al.*, 1981) and LAMAR offers the exciting prospect of examining this possibility for a wide range of active galaxies out to quite high red shifts. In this application the large photon collection area, low background per pixel and angular resolution sufficient to separate individual faint sources are all crucial. For example, a source a thousand times fainter than 3C 273 (i.e. 3C 273 at Z ~2–4) would give a signal count of ~0.5 ct sec^{-1} in LAMAR. With an overall particle and X-ray background of $\sim 6 \times 10^{-3}$ $pixel^{-1}$ sec^{-1} a 20% increase in flux would readily be detected in 1000 secs.

Diffuse objects Implicit in the estimate that the X-ray background is comparable to the particle-induced background in a 20 × 20 $(arc\ sec)^2$ pixel is the ability to study spatial features in this background. Recent studies on a quite crude spatial scale (tens of deg^2) have shown a galactic enhancement of several percent at E > 2 keV (Ariel-5, Warwick *et al.*, 1980; Uhuru, Protheroe *et al.*, 1980), together with a marginal effect compatible with the Compton-Getting enhancement of the microwave background (Smoot *et al.*, 1977). LAMAR may, of course, resolve most of the galactic component as individual stellar sources, but a diffuse part must exist at some level. Observations below ~1 keV (Sanders *et al.*, 1977) have also indicated the great potential of a detailed study of the softer X-ray background structure, containing information on the hot component of the interstellar medium.

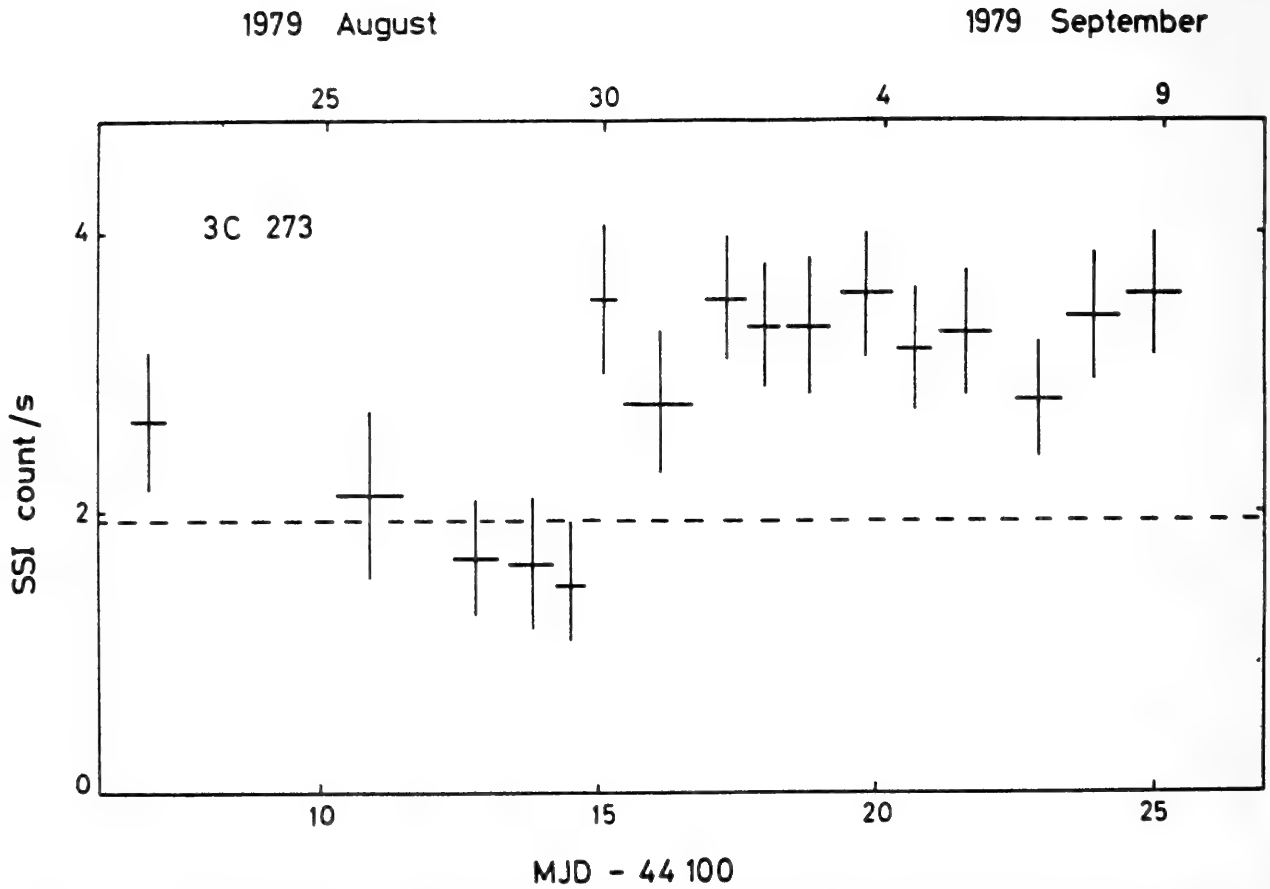

Fig. 3. Ariel-5 X-ray light curve of the quasar 3C 273 showing a rapid increase in the (2–10 keV) luminosity. 1 SSI count/s ≃ 2.5 milliCrabs.

As just one example, a map of the X-ray background could be produced by LAMAR on an arc min angular scale, comparable to current 21 cm radio maps, at ~8% contrast level with 10^4 sec exposure per field. In 1 year 10% of the sky could be sampled at this exposure.

Individual diffuse sources, such as supernova remnants and galaxy clusters, may have an X-ray surface brightness 10 to 100 times greater than the average X-ray background; clearly these objects are very well suited to detailed study by LAMAR. For example, a cluster such as A 1367 (see Einstein X-ray image in paper by Dr. Tananbaum) would be imaged by LAMAR with an effective surface brightness ~50 times that recorded with the Einstein IPC. The detail on the spatial distribution of the hot gas in this and many fainter clusters would be extremely important in studying such questions as the source of the gas, the heating process and even the evolution of clusters of galaxies.

Spectroscopy The spectroscopic capability of LAMAR will depend critically on the type of detectors employed. If these are conventional IPC's, which are well matched to the spatial resolution, bandwidth and high efficiency requirements of LAMAR, the spectra obtained will benefit directly from the high photon rates (again this will be very beneficial in the study of extended objects of low surface brightness), but the spectral resolution will be limited to the typical $E/\Delta E$ ~3–10 intrinsic to the gas proportional counter. The use of CCD's, if then available with adequate area and low noise, could offer spectral resolutions 1–2 orders of magnitude better, allowing well-resolved X-ray spectra to be obtained, with all the wide benefits that spectroscopy has provided in optical astronomy.

4. Summary and current status

At present LAMAR is not an approved mission. However, NASA is currently supporting two separate design studies in which groups led by Gorenstein (CFA) and Catura (Lockheed) are evaluating LAMAR modules for flight on Shuttle/Spacelab ~1985. Although they have interesting scientific possibilities, these studies are principally aimed at establishing the feasibility of building the sort of LAMAR facility discussed in this paper. Weighing its great scientific potential against the major task involved in producing such a free-flier LAMAR, it seems clear that a long-term, coordinated (and probably international) effort should be organized as soon as practicable if this potential is to begin to be realized much before the end of the second post-Uhuru decade.

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X-Ray Timing Explorer (XTE)

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I am sure that most of this audience was aware, even before hearing the excellent reviews this morning, that the large fraction of the brightest X-ray sources in the sky are binary stellar systems in our own galaxy which contain neutron stars. Their spatial distribution alone allowed us to guess, without knowing what they were, that they were at average distances of several kpc, so that their luminosities had to be within an order-of-magnitude-or-so of 10^{37} erg s^{-1}. Most of the real progress that we made in understanding their fundamental nature, however, came out of what might be termed "timing" measurements. The discovery, from UHURU, of at least two reproducible variability timescales from sources like Cen X-3 and Her X-1 turned out to be what might very appropriately be called the Rosetta Stone.

We now know that the pulsing periodicities on timescales of seconds are the rotation periods of neutron stars, and the periodicities on timescales of days are eclipsing effects at the rotation periods of the whole binary systems. Timing measurements allowed us to see the two effects separately, but the additional timing analyses which revealed that the pulsing was Doppler shifted at precisely the eclipse period virtually forced the realization that we were seeing the first detected examples of neutron stars in binary systems. Just as important were the longer-term timing measurements which demonstrated the secular speed-up of the pulsars, since these ultimately reconciled the energy source with the conversion

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of gravitational energy—very different than either the nuclear energy source in stars or the kinetic energy source for contemporary X-ray production in conventional SNR's.

Once we had the basic model laid out, other aspects of the timing measurements were readily interpretable: system eccentricities from departures from purely sinusoidal Doppler curves, for example, and mass limits on the stellar components. Some aspects of the timing measurements were less obviously interpretable, however, especially when we were able to combine timing with a modest spectroscopic capability in an attempt to investigate X-ray production and X-ray transport mechanisms in the sources.

Figure 1 exhibits some rudimentary examples of this "pulse phase spectroscopy." In the lower left are the pulse profiles of the three best-studied pulsars, where the shaded regions indicate those portions of the light curve where the X-ray spectrum is hardest: the presumption is that transport out of the source will tend to soften the emergent spectrum, so that the shaded parts probably represent our least obscured view of the primarily-produced X-radiation. In the upper left is one of the more pedestrian cases: in all three colors, the pulse profile looks about the same. The 7-second pulsar, on the right, is at the other extreme: the pulse phase seems to change by 180° between 1 and 5 keV, and then change by 180° again above 14 keV. If we slice the pulse into 10 phase intervals and look at the spectra of the individual slices, we can get a different perspective. Spectrum 8 looks like an "average" pulsar spectrum: flat power law with a cutoff; while spectrum 3 looks like it might be the same with the addition of a broad, possibly cyclotron, feature near 20 keV.

It is important to appreciate that the sources from which we can presently measure regular periodicities like these constitute a small fraction of those which we think contain neutron stars. But *all* galactic X-ray binaries, including those which we presently believe to contain black holes or white dwarfs instead of neutron stars, exhibit *irregular* temporal variations, on a variety of timescales.

Figure 2 illustrates some rather pronounced examples of this irregular variability. In each of these three cases, the panel on the right represents a small portion of the panel of the left with the temporal scale expanded. The first two exhibit our best galactic black hole candidate, Cyg X-1, on two very different timescales. The obvious variability in the 20 ms accumulations in data from a rocket flight indicate, when this flare is expanded to .64 ms resolution, that there might be variability all the way down to the submillisecond timescale which should be characteristic of the innermost Keplerian orbit around the candidate black hole. The data in the middle pair represent weekly averages for the source intensity over almost five years, and the source sometimes jumps to about three times its usual output and maintains that level for weeks or even months at a time. The half-day averages on the right for the first of these increases indicate that the change of state takes place in a time much less than one day.

Finally, the traces on the bottom are from a source which has been named the Rapid Burster. Because the amplitude of these bursts depends on the time between bursts, we think that this kind of behavior reflects some sort of a regulating mechanism in the mass accretion process in this source. The annotated peculiar-looking longer decay-time burst probably has a different origin; we think that it represents some sort of a thermonuclear flash on the surface of the neutron star. It is this latter kind of burst, and not the rapid bursting, which is typical of all the other X-ray burst sources.

In order to further pursue the study of temporal variations from X-ray sources, we require not only more exposure, but more of each of the two parameters, area and time, which multiply together to give exposure. We require more time on sources in order to investigate longer timescale ef-

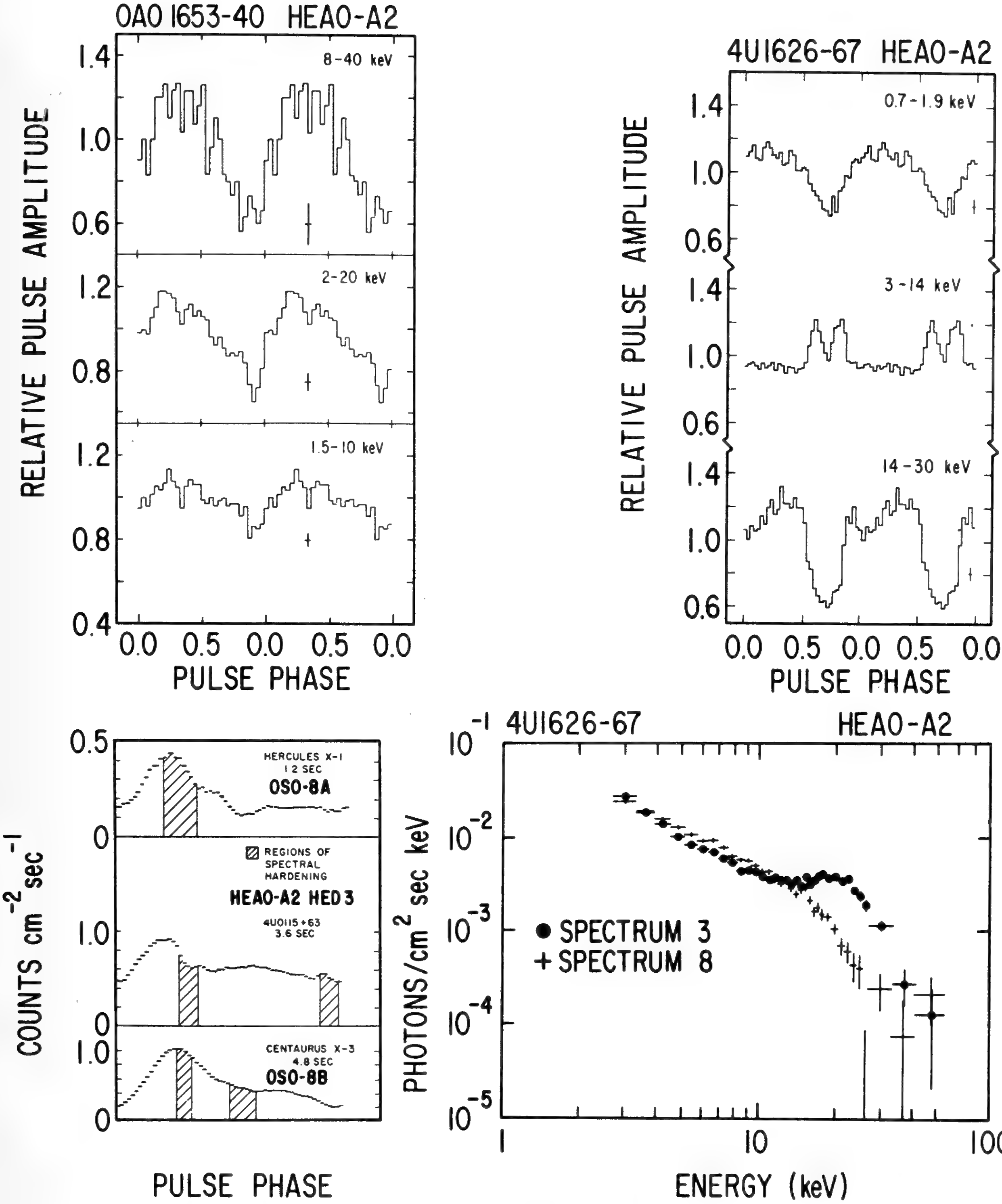

Fig. 1. Examples of pulse-phase spectroscopy. The top two examples are data folded at the pulse periods in three energy windows, with representative errors indicated. The shaded areas in the lower left are those phases of the pulse where the spectra are harder than the phase-averaged spectra. In the lower right, the spectra for two out of ten phase intervals for 4U1626-67 are displayed explicitly.

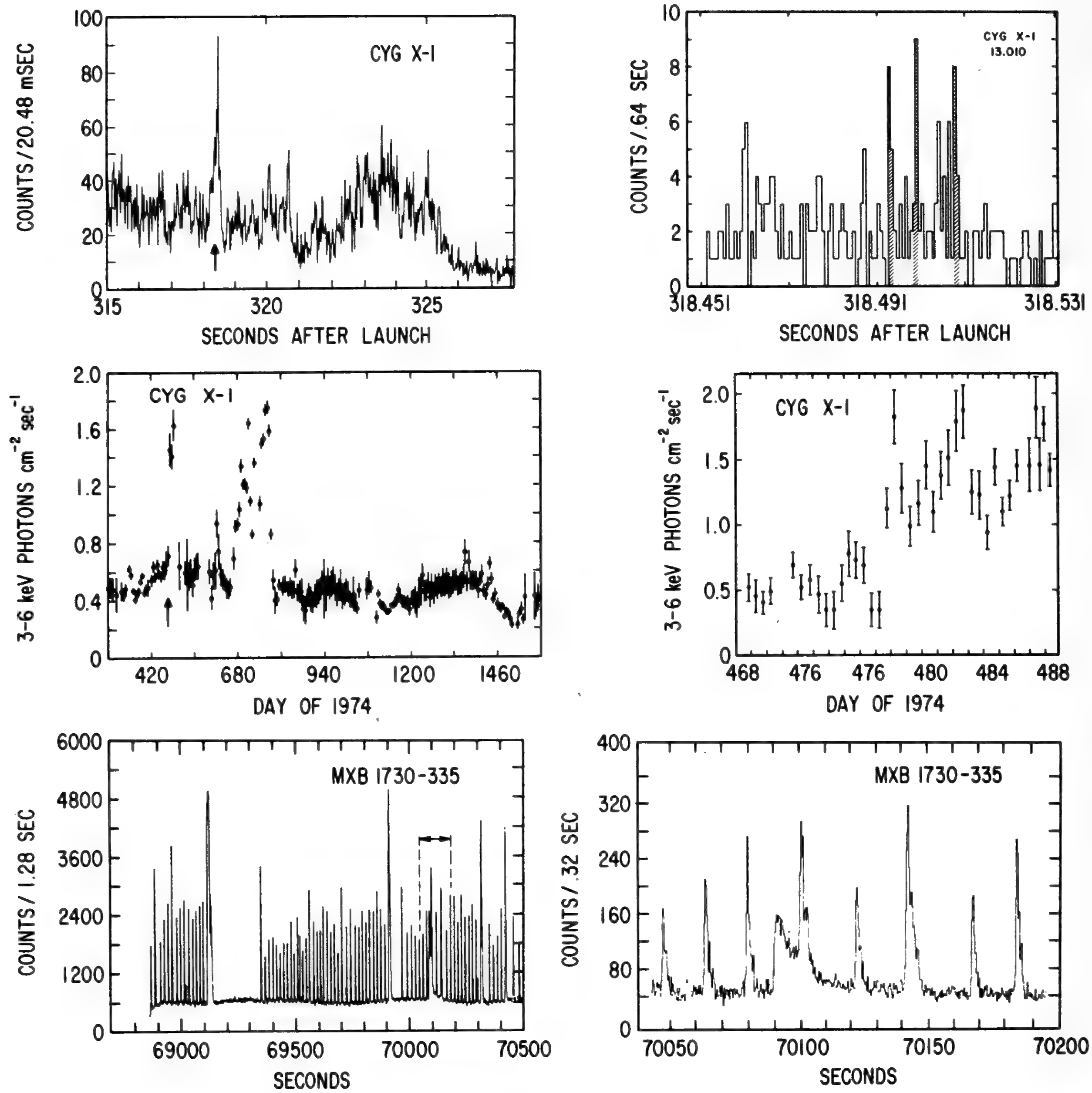

Fig. 2. Examples of non-periodic variability. The top two traces are for Cyg X-1 on short timescales, with the trace on the right an expanded view of the time interval indicated by an arrow on the left. The middle two traces are similar views of Cyg X-1 on much longer timescales. The bottom two traces are for the Rapid Burster, MXB 1730-335.

fects, including gradients in shorter-timescale variability, and more area to allow the detailed investigation of shorter samples, particularly with regard to non-periodic or non-reproducible variability.

The collective realization of the whole community that the mother lode of temporal X-ray astronomy was not going to be tapped by approved NASA missions led to a number of proposals for timing experiments in response to NASA AO 6 & 7 about six years ago. Several received category 1 endorsement, including one from our group at Goddard and SAO, from MIT and from NRL. All of us were put together on a study mission named ATREX which, unfortunately, never got off the drawing board, but it did serve as the first real demonstration of community enthusiasm which eventually was transferred to its second coming as XTE.

In the intervening time, the justification for such a mission has only been heightened by new experimental and theoretical results. Interestingly, the increased sensitivity of later missions, especially HEAO-2, detected very different kinds of X-ray sources: much weaker, more traditional stellar systems, and much more powerful and more distant active galactic nuclei. But both of these newer classes of X-ray emitters also exhibit temporal variability, so that their systematic study affords even more possibilities for fruitful timing research.

Two years ago, David Pines and Fred Lamb organized a Workshop, with both theoreticians and experimenters participating, devoted to the definition of an Explorer-class X-ray timing mission. The Proceedings stressed the maturation of the theory over the last few years, particularly in regard to the use of timing measurements to probe the physics laboratory available in the interiors of neutron stars. Briefly, the consensus recommendation of the Workshop for instrumentation was for some sort of a large area pointed proportional counter array, with the possible provision of some X-ray peripheral vision for it. At the same time, our colleagues outside the US were considering X-ray timing missions of their own. One scenario for a collaborative mission which has received some publicity is with the Dutch; their primary interest is the detailed study of bursters with a wide-angle X-ray camera system, and a NASA AO issued last summer noted the possibility of such a collaborative arrangement.

The observational and scientific objectives listed in the NASA AO represent a straightforward tabulation of the application of timing measurements to all varieties of X-ray sources. Responses to this AO are presently under evaluation, so that a detailed characterization of the payload is not possible at this time. The only certainty is that the AO requirements will be satisfied. This means that the selected instrument or instruments will be true to the spirit of the observational requirements, and also means that the participation of the whole scientific community will be guaranteed by a guest investigator program that will get the major fraction of the observing time.

The Extreme Ultraviolet Explorer

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Introduction

The extreme ultraviolet (EUV) spectral region from 100–912 Å is one of the last bands of the spectrum to be explored. Since the discovery of the first EUV star in 1975, rapid developments in this field have occurred even though no dedicated orbiting experiments have been launched. New sources have been reported from the Soviet Soyuz spacecraft (Sagdeev, 1979) and by an experiment on the Voyager mission (Holberg *et al.,* 1980a). The first spectroscopic observations have been carried out from sounding rockets (Malina, 1979) and from Voyager (Holberg *et al.,* 1980b). Within the next few years several new sounding rocket payloads developed in both Europe and the

USA will be launched both as searches for new sources and for high resolution EUV spectroscopy. Detailed studies have been carried out or are now underway for EUV all sky satellite surveys by ESA, NASA, the Netherlands and the United Kingdom. Limited searches in the hard EUV shortward of 200 Å will be carried out by ESA's EXOSAT observatory in 1982. This initial exploration phase of EUV astronomy will end with the launch of NASA's Extreme Ultraviolet Explorer in 1985. This mission will carry out the first systematic all sky EUV survey in three spectral bandpasses covering the whole EUV, with sensitivities 10–100 times greater than existing measurements.

1. Astrophysical Interest of EUV Observations of Extra-Solar Objects

Dupree (1981) has recently reviewed the various areas of astrophysical interest that are already known to be best elucidated through EUV data. It now seems clear that many astronomical objects radiate strongly in the EUV and that they will be visible at earth. Early attempts to look for EUV sources were hampered by two principal considerations. Firstly, instrumental difficulties were severe because large grazing incidence optics and efficient photon-counting detectors are necessary to obtain sufficient sensitivity. These difficulties were surmounted in the instrumentation flown on the Apollo-Soyuz Test Project (Bowyer *et al.,* 1977) and have been further improved with the realization of full imaging (cf. Lampton *et al.,* 1977; Malina *et al.,* 1980). Secondly, the pre-existing theoretical pessimism about the high opacity of the local interstellar medium (ISM) diverted experimenters' interest. This pessimism proved to be overstated.

The Interstellar Medium

It is now known primarily from direct UV spectroscopic measurements of nearby stars that column densities can be quite low, in some view directions as low as .005 cm^{-3} (Anderson and Weiler, 1978). For distances within 100 pc of the sun, the column densities of hydrogen range from a few times 10^{17} cm^{-2} to 10^{20} cm^{-2}, with variations of an order of magnitude for view directions separated by only tens of degrees (Cash *et al.,* 1979a; Dupree, 1981). The EUV horizon for this range of column densities varies from tens of parsecs to several hundred parsecs at the shorter wavelengths (cf. Cruddace *et al.,* 1974). This will permit extragalactic observations in selected areas at 100 Å; this concept was implausible only five years ago. The local ISM is however highly clumpy, so that it is relatively difficult to predict accurately the opacity to individual proposed EUV sources. One of the primary goals of an all sky survey is thus to catalog comprehensively the observable EUV sources so that pointed follow on missions can be carried out efficiently. In turn such a catalog will provide a detailed mapping of the local ISM, a subject of interest in itself.

Follow on spectroscopic missions will have a further profound impact on our understanding of the ISM. Moderate resolution spectroscopy ($\Delta\lambda \sim 5$ Å) of bright continuum EUV sources will measure the neutral helium and singly ionized helium column densities from observations of the absorption jumps at 504 Å and 228 Å. For example the jump at 228 Å has already been measured in HZ43 (Malina, 1979) with coarse resolution and is attributed primarily to photospheric absorption. Higher resolution will allow both the pressure broadened photospheric and narrow interstellar components to be measured simultaneously. High resolution ($\Delta\lambda \leq .1$ Å) spectroscopy will measure transitions from neutral at 584 Å and 304 Å giving for the first time a direct measure of the total helium abundance (Dupree, 1981). Observations of higher temperature species will complement those obtained in the ultraviolet and permit the study of the hot component of the ISM as well as local shocks such as that expected at the interface with the solar wind (Raymond, 1980).

Sources

The first type of EUV source to be discovered was the hot white dwarf HZ43 (Lampton *et al.* 1976). To date two others Feige 24 (Margon *et al.*, 1976) and G191-B2B (Holberg *et al.*, 1980a) have been reported. A preliminary report attributes observed 500 Å flux to Feige 4 (Sagdeev *et al.*, 1979). Observations of individual white dwarfs will continue to be of interest for studies of the atmospheric structure and physics of element separation in high gravity atmospheres. However the complete survey to be provided by EUVE will be essential to unravel the evolutionary history and cooling rates of these objects.

A second class of strong EUV emitters consists of stellar chromospheres and coronae. The first member of this class to be detected in the EUV was Proxima Centauri (Haisch *et al.*, 1977). Observations from IUE, HEAO-1 and the Einstein Observatory reveal that hot chromospheres and coronae are a common feature of almost all stellar types. In addition, the solar UV luminosity is not typical with many common classes such as the RS CVn stars being much more luminous. Since the EUV contains atomic and ionic lines indicative of plasmas with energies from 1 to 3000 eV (Dupree, 1981; Stern *et al.*, 1978), EUV observations allow critical plasma parameters to be measured simultaneously over a wide energy range. The sensitivity of EUV observations to the physical processes involved has been repeatedly demonstrated in solar observations such as those carried out on the Solar Maximum Mission. In spite of the accumulated X-ray and UV data, current understanding of the heating and energy transport in solar and stellar chromospheres is rudimentary. EUV observations will extend our perspective and identify the determinants of coronal structures (Dupree, 1981).

Several other classes of objects are expected to be strong EUV sources (Paresce, 1977). SS Cygni, a member of the class of cataclysmic variables, was detected in the EUV (Margon *et al.*, 1978) and HEAO-1 has shown that a number of these are soft X-ray sources (Cordova *et al.*, 1981). Theoretical studies (e.g. Kylafis and Lamb, 1979) predict that a major component of the emission lies in the EUV and that only the high and low energy tails are being observed in the UV and X-ray. The EUV flux has expected contributions from cyclotron cooling of the shock heated accretion flow, radiation from the accretion disk and from the heated stellar photosphere. An intriguing possibility is an observable contribution from steady nuclear burning on the white dwarf (Weast *et al.*, 1979).

Other potential classes of EUV sources include accreting neutron stars and hot subdwarfs. Several sources of diffuse interstellar emission have also been suggested. The exploration of other regions of the spectrum encourage the speculation that new serendipitous sources of EUV emission will be uncovered during an unbiased all sky survey.

2. Investigative Approach

The spacecraft concept, as originally proposed (Bowyer *et al.*, 1975) is that of a simple free-flying spin-stabilized satellite comparable in concept to that used for the Uhuru X-ray all sky survey. The mission concept is being designed in detail by the Jet Propulsion Laboratory (McLaughlin *et al.*, 1980).

The spacecraft will be spun-up to several rpm after being launched from the Shuttle and will be placed in a 500 Km orbit. The design altitude has been selected in consideration of detector background, residual atmospheric absorption, and satellite lifetime due to orbital decay. Once in its final orbit the spacecraft will be oriented so that the orbital geometry is as shown in Figure 1. The spin-vector will be pointed along the Earth/Sun line, thus insuring that the solar panels always face the sun and providing a simple thermal control geometry. Three telescopes are arranged with their viewing direction perpendicular to the Sun-Earth line and sweep out great circles in the sky with each spacecraft revolution. As the

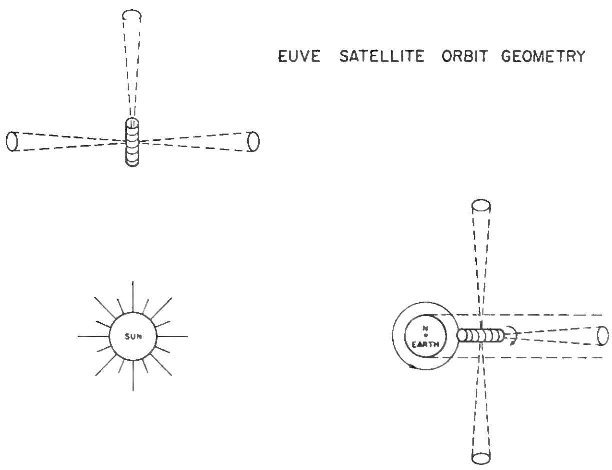

Fig. 1. The EUV Explorer orbit geometry. The satellite spin axis is pointed at the sun. The three telescopes pointed normal to the Sun-Earth line carry out an all sky survey in six months. The fourth, pointed along the anti-sun line, will make a deep survey along the ecliptic.

earth moves around the sun in its yearly orbit, this circle will gradually move through the sky, covering the entire celestial sphere in six months. Three different fixed EUV filters will be used to provide sky maps with 0.1° pixels in each of the three different colors. Since the EUV background radiation is many orders of magnitude larger in daytime than at night, data is only taken at night. this dictates an orbit with large nightime residence; such orbits are easily provided by the Shuttle.

At night the primary diffuse background is at 304 Å, the result of sunlight resonantly scattered from singly ionized helium trapped in the Earth's plasmasphere (Paresce *et al.,* 1974a) and at 584 Å, the result of sunlight resonantly scattered from neutral helium in the local interstellar medium (Paresce *et al.,* 1974b). In the anti-solar direction, however, the HeII 304 Å background is almost completely absent (Paresce *et al.,* 1981). Hence a telescope pointed along the anti-sun vector will have far more sensitivity for point sources. Such an alignment is presented naturally in the adopted geometry by pointing a fourth telescope along the spacecraft spin axis. Although this telescope will scan only a small part of the sky in the ecliptic plane, the lower background and longer observing times will allow a higher sensitivity to be achieved and will provide a valuable insight into the types of sources which might be discovered in a higher sensitivity follow up mission. For example, if no new classes of sources were discovered in this representative sample and if effectively the EUV horizon has been reached in the less sensitive all sky survey, then it would be fairly argued that a follow up higher sensitivity all sky search would be of less importance than detailed studies of the sources found in the first survey.

To achieve maximum sensitivity for point sources, measures must be taken to reduce the remaining nighttime background. In addition, every care must be taken to exclude the geocoronal Lyman alpha line at 1216 Å. One approach would have been to use a high altitude orbit as proposed by ESA (ESA Report, 1979). The cheaper approach which has been adopted is to use thin film filters which will, in addition, provide spectral information on sources. The complete EUV band can be divided into specific bandpasses through the use of thin metallic and plastic filters. The specific choice of filters will be made based on scientific usefulness, space-qualified filter materials, as well as the available spacecraft telemetry rate. The survey sensitivity is a direct function of this telemetry rate since it dictates the amount of acceptable geocoronal background leakage through non-ideal filters. In principle, one could employ a single telescope with a wheel with numerous filters in front of a single focal plane detector as is being used on ESA's EXOSAT detector. A major problem, however, is ensuring a reliable free-turning wheel which provides a mechanical barrier to all forms of charged particles. As a consequence, we have opted to employ three separate telescopes each with a fixed different EUV filter. A magnetic broom is used to reject higher energy particles which are transmitted by the filters. A wide bandpass filter will be used for the higher sensitivity spin-asis telescope. This multiple telescope design provides a great deal of inherent redundancy ensuring that single point failures will not completely disable the mission.

3. Status of EUVE Development

EUVE science instrumentation has reached a high level of maturity with the completion of a full-scale engineering model of the telescope. A schematic of this telescope is provided in Figure 2 (Bowyer *et al.*, 1981a) and a picture of the mirror with its metering structure is shown in Figure 3. This instrument is currently undergoing full environmental testing to verify the configuration.

The primary result of the development program is that no major instrumentation changes have resulted; each of the four EUVE telescopes is essentially identical to those originally proposed for AO 6/7 (Bowyer *et al.*, 1975). All fabrication processes and vendors have now been identified for critical components. As was expected, no new technology will be required. The development study has resulted in several improvements in instrumentation, discussed below, which will increase the reliability and sensitivity of the telescopes as well as ensure the rapid development of flight instrumentation.

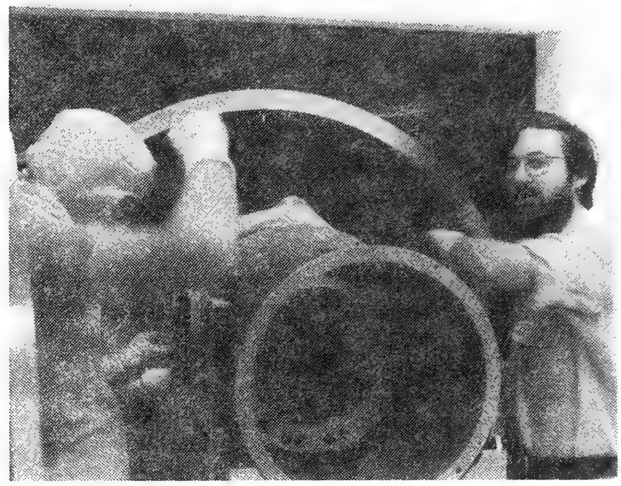

Fig. 3. Prototype optics and center tube being installed in calibration tank.

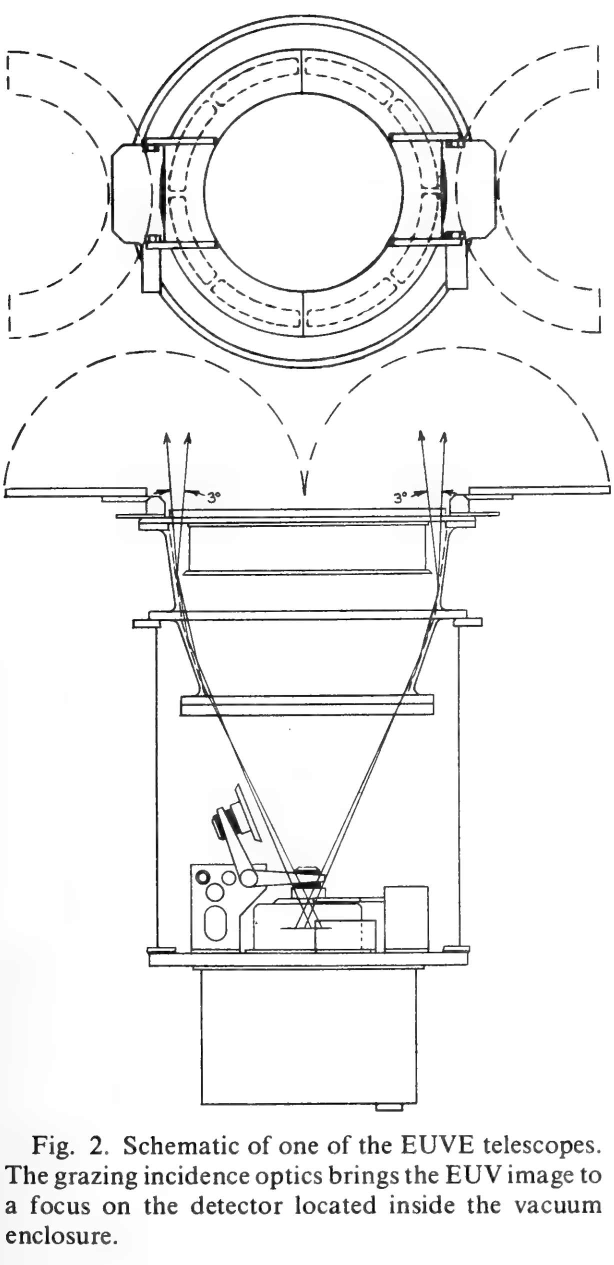

Fig. 2. Schematic of one of the EUVE telescopes. The grazing incidence optics brings the EUV image to a focus on the detector located inside the vacuum enclosure.

Optics

The instrument includes a 40cm diameter grazing incidence optic. The types of optics which could be used for this mission, the theoretical rationale for the final choice and practical fabrication details have been examined and discussed in detail (see Malina *et al.*, 1980). An intensive study of possible new surface equations concluded that the originally proposed Wolter-Schwarzschild designs are best suited to the EUVE goals (Cash *et al.*, 1979b). A prototype mirror has been fabricated. Detailed testing has verified that it meets the design specifications. The fabrication process consists of diamond-turning a forged aluminum blank to obtain a mirror figure accurate to ± 10 micrometers. The diamond-turning has been carried out at Lawrence Livermore Laboratories (Byran *et al.*, 1973).

Based on the success of this prototype, the flight instruments will be figured in a similar way. Following figuring, the mirror is plated with .15 mil of nickel and lapped to achieve a low-scatter surface. This lapping is rapid and inexpensive since it involves no refiguring.

Several materials have been considered for the final mirror surface (Malina *et al.,* 1978). Nickel has been found to be preferable at the shorter wavelengths while gold enhances the reflectivity at the longer ones. One thousand angstroms of gold has been electroplated onto the existing proto-optic. The optic is equipped with strip heaters which will be used to warm the mirrors during an initial spacecraft outgassing period to minimize condensation of volatiles.

Detectors

As originally proposed, the detectors will be large microchannel plate (MCP) arrays used in a chevron configuration. This type of detector was flown on a Berkeley airglow spectrometer on the P78-1 mission (Bowyer *et al.,* 1981b) and is similar to those used in the High Resolution Imager on the Einstein Observatory. The development program has consisted of the fabrication of a prototype detector, while, in parallel, a lifetesting study of MCP's has led to final specification of the MCP's and selection of vendors. The MCP is coupled to a two-dimensional imaging anode. As part of this study, two types of anodes have been fully developed. The first of these is the ranicon (Lampton and Paresce, 1974) where the MCP's are proximity coupled to a two dimensional resistive anode. In operation the electron cloud from a detected MCP event is intercepted by the anode; the charge drains off the anode into four amplifiers connected to each of the four corners. The x and y position of each event is then determined by the relative charge on each of the amplifiers. Anodes with a variety of geometries have been fabricated in house and with commercial vendors. The associated electronics consists of four low noise charge amplifiers developed for the HEAO A-2 cosmic X-ray experiment and pulse position analysis circuits. The system can be view real-time on a CRT screen or fed directly into a computer.

One disadvantage of the ranicon is that the use of uniform square or rectangular resistors leads to inherent image distortion. Although this distortion is fixed for a given anode geometry and can be removed in subsequent post processing, this is an expensive and time consuming step. An improved version of the resistive anode which reduces this problem has been developed by us (Lampton and Carlson, 1979) and is based on rectifying the equipotential surfaces by controlled resistive termination of the edges of the anode.

An alternative to the distortionless anode discussed above has been developed in our laboratory and has now been qualified for flight. (Martin *et al.,* 1981). In this anode the position encoding is carried out by charge division of charges collected by a series of wedge-and-strip conductors. This system has the advantage of requiring only three amplifiers, is inherently distortionless and can be fabricated by standard circuit board techniques. There is no thermal noise associated with resistive elements, allowing rapid charge collection to be carried out with high resolution. For the EUVE application, with a low count rate and modest pixel requirement, the choice between the resistive anode and the wedge-and-strip will be made on the basis of reliability, availability of vendors, overall performance and cost.

Filters

A full development program of the flight complement of filters is underway. Selected filters have been drawn from commercially available and space qualified materials used in various solar, atmospheric and celestial experiments. In addition, a restricted number of new filter combinations which offer substantially increased sensitivity have been studied. Prototype filter holders have been designed, built and qualified. The three filters for flight are expected to be:

1. Parylene: Parylene N is a plastic material which is vacuum deposited like a metal. Its thickness has been optimized using a computer modelling of the EUV background. The effective bandpass is in the hard EUV which is excellent in the study of sources in the transition region between soft X-rays and the EUV. This is the bandpass with the largest visibility through the ISM. The turn-on wavelength is determined by the design of the optics.

2. Aluminum: Aluminum has been the workhorse of EUV astronomy; it is sensitive from 180 to 600 Å, yet opaque to the ultraviolet. When used in combination with a thin layer of carbon, the 304 Å throughput can be reduced thereby increasing the overall signal to noise.

3. Tin: Tin has an excellent window from 500–750 Å. Its largest drawback is the presence in the center of the bandpass of the strong 585 Å background line.

The most striking failing of the filter complement described above is the lack of a filter to cover the 350–500 Å band with high sensitivity. This central region of the EUV has great scientific potential because it is at a sufficiently short wavelength to allow reasonable visibility through the ISM. A study of potential new filter materials has resulted in the selection of antimony and titanium as useful materials. An optimized sandwich combination of these has been developed which excludes both the 304 Å and 584 Å lines and provides a strong filter which is resistant to degradation. Several of these filters have been fabricated are are being qualified.

A plot of the overall effective area of the telescopes with the filters discussed above is shown in Figure 4. The exact effective area will be determined by the final calibration of the engineering model, together with the filter thicknesses optimized for the telemetry rate.

Mechanical Elements

In addition to the optical elements of the instrument, engineering units of all electromechanical components have been developed. The front aperture is protected by a

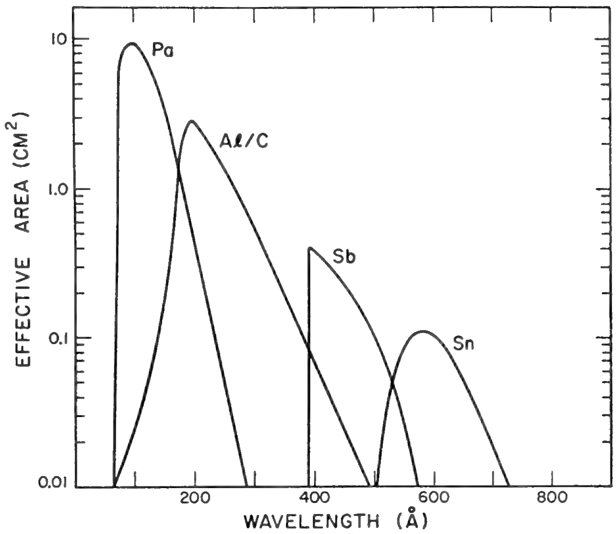

Fig. 4. Effective area of scanning telescopes with several possible thin film bandpasses. The deep survey telescope uses an aluminum filter optimized to view down the earth's shadow cone.

two segment dust cover which will be kept closed during the initial outgassing period and allows the optics cavity to be kept purged during all ground operations. The detector and filters are housed in an evacuated box with a motorized door. This box allows the detectors to be operated during all ground operations, ensures the calibration stability of the filters and photocathode and eliminates accoustic loads on the fragile detector elements during launch. Finally, a sun shutter has been developed which covers the detector in case of loss of spacecraft pointing and exposure to solar flux. This shutter will also be used for carrying out measurements of the internal background of the detector. Figure 5 shows the assembled focal plane assembly.

Mission Sensitivity

We can compute the overall sensitivity of the telescope with a fair assurance of accuracy. For this computation we have assumed 5000 seconds of exposure time to each point on the sky. This exposure would be achieved in an average sky location in a one-year mission in which 40% of each orbit was useful for EUV data collection. Due to the motion of the spacecraft spin plane, the exposure coverage is not entirely uniform; the exposure would be somewhat less than 5000 seconds in the ecliptic plane

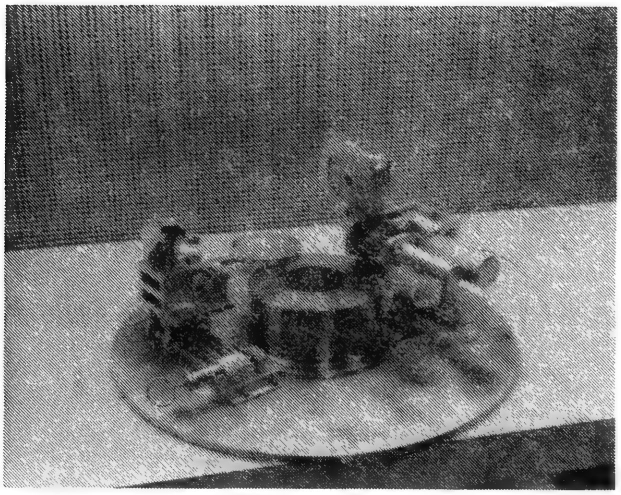

Fig. 5. Focal plane assembly including vacuum enclosure, vacuum box door and sun shutter.

and substantially greater at the ecliptic poles. The spin axis directed telescope would accumulate about 50,000 seconds on field points near the ecliptic plane.

These fluxes have been plotted in Figure 6 as functions of wavelength or photon energy. There the curve marked "all-sky scan" spans the three EUV bands defined by filters of Sb, Al-C, and Pa; the curve marked "deep survey" is the spin axis telescope. It is clear that the proposed instrument's all-sky sensitivity is between 100 and 3000 times greater than would be required to detect HZ43.

The nominal sensitivity of the Berkeley Apollo-Soyuz instrument also has been sketched in Figure 6. The sensitivities of the three scanning telescopes range from over ten to over one hundred times that of the Apollo-Soyuz instrument. The spin axis telescope will survey about 7% of the sky with about one thousand times the sensitivity of the Apollo-Soyuz instrument.

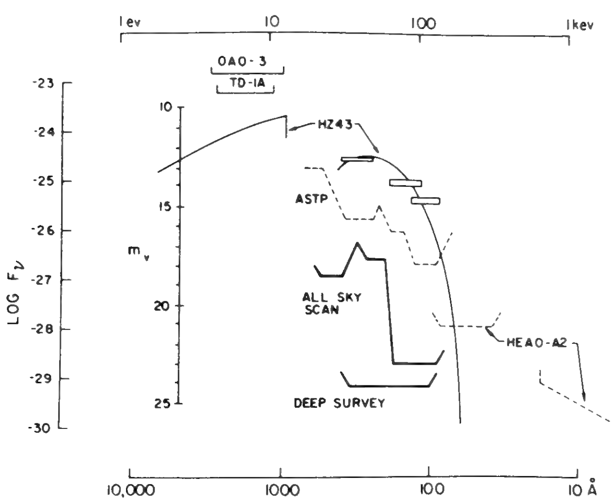

Fig. 6. Overall sensitivity of the EUV Explorer all sky survey compared with various other missions.

It is also of interest to compare the baseline configuration's minimum detectable fluxes with measurements which are carried out in contiguous portions of the spectrum. In the ultraviolet band (1000–3000 Å) the Princeton Experiment Package on board OAO-3 is indicated as is that of the TD-1A satellite. The IUE sensitivity is comparable to that of the long wavelength EUVE bandpass.

In the soft X-ray band (10–100 Å), the HEAO-1 spacecraft has furnished high sensitivity sky survey data. The corresponding minimum detectable flux is shown in Figure 6; it is comparable to the minimum detectable flux values for the EUVE survey.

The largest ground-based optical observatories can reach objects as faint as $m_V = 22$ to 23. It is remarkable that the proposed EUV survey will reach comparable flux levels of the order 10^{-28} to 10^{-29} erg/cm^2 sec Å. Consequently, the proposed EUV observatory is comparable with the National Geographic/Palomar Sky Survey.

4. Future Prospects

The first priority in EUV Astronomy is the completion of the all sky survey to be performed by the EUVE. The systematic catalog resulting from this survey will provide the necessary data for targeting and designing follow on missions. In addition, the study of the collective parameters of the observed sources will permit analysis of the various types of emission processes involved. The direct comparison is the crucial role that the Uhuru satellite is playing in X-ray astronomy.

The next important step is spectroscopy of individual sources. The Berkeley group has reported spectroscopic observations of the white dwarf HZ43 with 15 Å resolution from 170 to 500 Å (Malina, 1979; Bowyer, 1979); this observation resulted in a positive detection of the 228 Å absorption edge of HeII. Additional spectroscopic observations longward of 500 Å with 5 Å resolution have been made by the Voyager spacecraft of the hot white dwarfs HZ43 and G191-B2B (Holberg *et al.,* 1980a, 1980b). Several other spectroscopic instruments have been built or are under development for sounding rocket experiments. Dr. G. Garmire of Penn State has recently launched a transmission grating EUV spectrometer to observe shortward of 200 Å. A large (1m class) normal incidence mirror and spectrometer for high resolution observation longward of 500 Å is under development by Dr. M. Grewing and coworkers at the University of Tubingen. For high resolution observations shortward of 500 Å, a large grazing incidence instrument is being built by P. Sanford and L. Culhane of University College London together with Dr. A. C. Brinkman of Utrecht. Proposals for carrying out EUV spectroscopy have included using the proposed solar GRIST instrument for stellar EUV observations (ESA Report, 1978), and extending the range of a proposed Far Ultraviolet Explorer (FUSE) through the EUV.

Other EUVE follow up missions have also been proposed including deep survey work, polarization studies and timing studies. For example, Dr. S. Rappaport of MIT in collaboration with Dr. K. Pounds of the University of Leicester is currently readying for launch a sounding rocket for deep survey work in the EUV band. Such experiments would be well suited to limited sortie missions by the Space Shuttle or Spacelab.

Acknowledgments

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Stellar Coronal Explorer

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I. Overview: The Present Status of Stellar X-ray Astronomy

This is an opportune time to examine the status of stellar X-ray astronomy. The end of the Einstein stellar surveys is in sight, and we are now in a position to evaluate their overall content. It is already clear that what one means by galactic X-ray astronomy has dramatically changed as a result of the Einstein surveys. No longer is galactic X-ray astronomy a study of relatively unusual and rare objects; instead, its purview has expanded to include virtually all astronomical objects commonly studied by our optical, radio, or infrared astronomy colleagues.

In the following, I would like to briefly recap the major results of the Einstein stellar surveys, with an eye towards what now seem to be the crucial unanswered questions and then sketch for you the outlines of an explorer-class instrument, called STCO-EX by us, which we believe will allow stellar astronomers access to the necessary observations. The key hallmarks of STCO-EX are an emphasis upon spectroscopy in the 6–200 Å range, and dedication in its observing schedule. One should be aware, of course, that AXAF will have far superior sensitivity and spectral resolution; but because of its power, one expects that stellar dedicated time will be optionally used to exploit its unique capabilities, such as very deep probing and very high-resolution spectroscopy.

Let me begin by showing you what kinds of stellar objects have now been seen as X-ray sources. Figure 1 shows an H-R diagram of stars observed as X-ray sources by

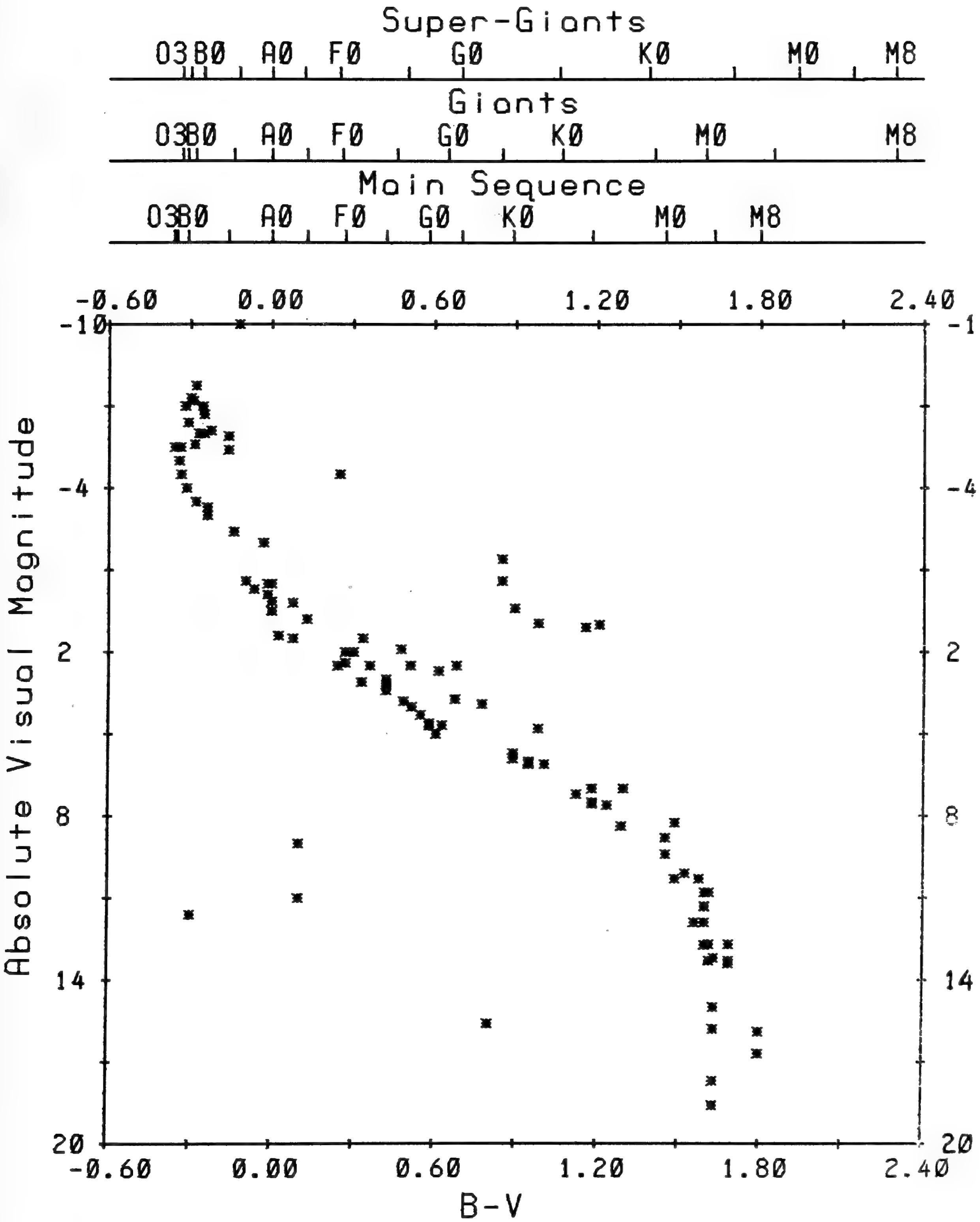

Fig. 1. H-R diagram for stars observed in the CfA Stellar Survey. (From Vaiana *et al.* 1981; see also Harnden *et al.* 1980 and Ku and Chanan 1979).

Einstein. Note that one sees the entire main sequence, much of the giant branch, and the supergiant branch up to roughly spectral type G. Thus, not only are solar-type stars X-ray emitters, but so are early-type stars, well-evolved stars and very young, pre-main sequence stars.

Looking at the overall behavior of X-ray emission throughout the H-R diagram, it appears that essentially all stars emit in the range of 10^{26} to 10^{33} erg s^{-1}; and that there is no discernible difference in X-ray luminosity behavior between stars of similar spectral type but different luminosity class. What difference there does exist appears to be tied to spectral type, but only in a gross sense. That is, there is a distinct difference in behavior between early-type and late-type stars, but relatively little difference within these two very general categories.

What general conclusions can we draw from these data? It is evident that X-ray emission is a common (in fact, universal) stellar attribute; its presence points to the existence of non-thermal processes in the outer atmospheres of essentially all stars, and serves as an essential diagnostic for these processes. For example, comparison with published coronal heating models for late-type stars has led to negative results, and in the case of acoustic heating, I believe it is fair to say that Einstein data, in conjunction with recent OSO-8 solar observations, exclude such heating as a viable coronal heating process in late-type stars.

What does stellar X-ray emission correlate with? Recent studies by Ayres and Linsky (1980), Walter and Bowyer (1981) and by Pallavicini *et al.* (1981) show that for late-type stars, there is considerable correlation between X-ray emission and stellar rotation rate (Figure 2), a correlation consistent with the Ca II rotation rate correlation found many years ago by Skumanich. Our group has also examined the variation of X-ray emission levels with age and we do in fact discern a general decrease of emission levels as late-type stars evolve, from the T Tauri stage through main-sequence life. This work is still in progress.

If one attempts to correlate X-ray emission levels with the presence (or absence) of stellar winds, a perhaps surprising result emerges. Early-type and very young (e.g. T Tauri) stars, which are known to have large mass loss rates and associated with extremely fast winds (of order 2000 km/sec), are powerful stellar X-ray emitters (Figure 3). In contrast, late-type giants and supergiants, which also can have large mass loss rates (but associated with relatively low terminal velocities) are weak sources comparable to the low-mass loss late-type, main-sequence stars. In the first case, it appears that X-ray emission may occur *because* of the presence of mass loss; in the

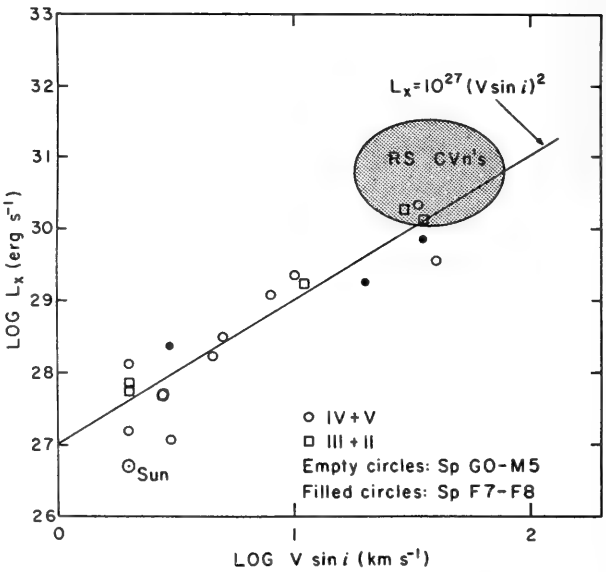

Fig. 2. Scatter diagram of X-ray luminosities *vs.* projected rotational velocities for stars of spectral type F7-M5; different symbols indicate different luminosity class. (From Pallavicini *et al.* 1981).

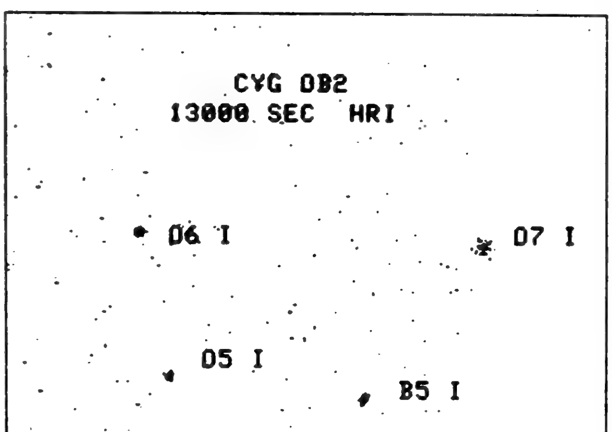

Fig. 3. High Resolution Imager observation of the Cygnus OB2 association, showing the power of the HRI in resolving and detecting stellar X-ray sources.

latter case, it has been argued that X-ray emission occurs in spite of mass loss.

To summarize, Einstein will soon have completed the exploratory or discovery phase of stellar X-ray astronomy. Briefly put, all stars are X-ray sources; *why* they are sources remains unknown.

In the course of this discovery program, Einstein has managed to awaken great interest in X-ray astronomy throughout the stellar astronomy community. The Einstein guest observer catalog reads like a Who's Who in stellar astronomy and includes over 110 separate observing programs; we find UV, optical, radio and IR stellar observers, as well as theorists, all now appearing in the guise of X-ray astronomers. Clearly, X-ray astronomy has joined the main stream of stellar astronomy, and has become one of its powerful observational tools.

Now, why should stellar astronomers look towards the X-ray domain? First, and most obviously, the non-thermal processes which led to a hot circumstellar or coronal stellar envelope produce material which dominantly emits at soft X-ray wavelengths; in order to observe coronae, one might as well look at them in the appropriate wavelength region. Second, for many kinds of stars (particularly the early-type and very young stars), one can use X-ray emission as a probe of a much cooler ambient gas by means of soft X-ray absorption studies. Such studies have in fact been attempted with Einstein using the IPC, OGS and S^3. Third, one can show that of all the possible diagnostics of non-thermal stellar emission, the greatest dynamic range is found at X-ray wavelengths and, furthermore, present instrumentation gives sufficient sensitivity to study very large, volume-limited, samples of stars.

II. The Future: New Directions for Stellar X-ray Astronomy

What then ought to be our next goals in stellar X-ray astronomy? Now that we know X-ray emission is common, we seek to understand its origins; and the hallowed way of dealing with this problem is to look towards spectroscopy. We want to carry out emission measure analyses for coronae of late-type stars, similar to work in the solar area; such studies require sufficient spectral resolution that temperature-sensitive line ratios can be used as detailed coronal thermometers. I have already mentioned studies of X-ray absorption by cold plasma, as for example by cool wind material in early-type stars; here we can investigate the ionization structure of the cold phase by its absorption effects. Given observations which can yield estimates of coronal temperatures and emission measures, one can then carry out correlative studies: how do coronal properties vary with luminosity class (effective gravity), rotation rate, spectral type, age? Spectrally resolved observations also allow access to abundance analysis. One can then study the differences between coronal and photospheric abundances (as observed in the solar case) throughout the H-R diagram and in particular study the effects of stellar age and spectral type on such differences.

Spectroscopic studies are, of course, not the only type of work that is now of interest. Einstein observations such as that of Prox Cen (Haisch *et al.* 1980; Figure 4) have already given a hint of the usefulness of coordinated studies of transients in various wavelength regimes; such studies represent a valuable future research direction. Another example is the observation of activity-generated flux modulation on rotational or larger time scales. Such studies were first carried out by Wilson and coworkers, who used Ca II emission and its modulation as a tracer of stellar surface activity. The large dynamic range of stellar X-ray emission suggests that similar studies of, for example, rotational modulation of stellar X-ray emission, may provide a powerful tool of stellar rotation rates for slowly rotating late-type stars. Such studies would not be hampered by difficulties such as variable visibility as a function of spectral type.

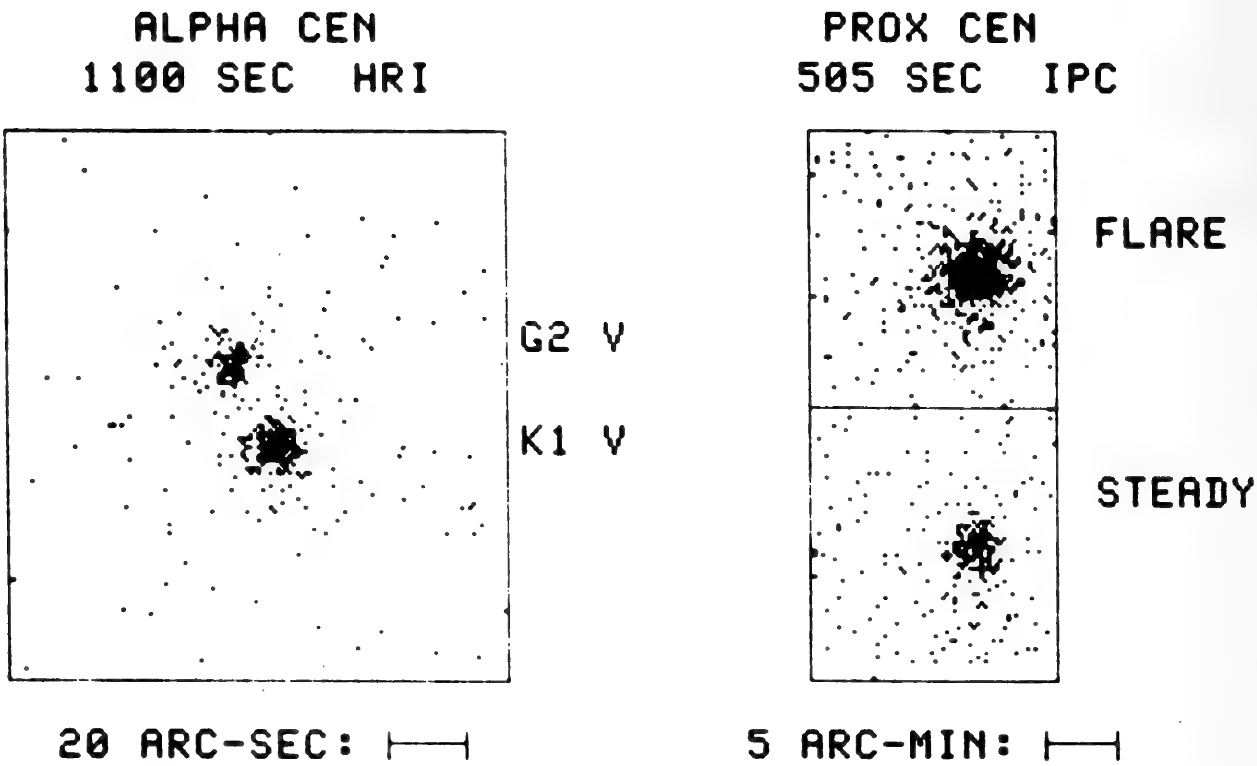

Fig. 4. (Right) A solar-like flare was observed on Prox Cen using the Einstein Imaging Proportional Counter (Haisch *et al.* 1980). The peak temperature of $\sim 2 \times 10^7$ K and X-ray luminosity of $\sim 7 \times 10^{27}$ erg s^{-1} are comparable to those observed in solar flares in the same passband. (Left) The solar-type stars Alpha Cen A/B are both resolved as X-ray sources by the Einstein HRI (From Golub *et al.* 1981).

III. A Stellar Coronal Explorer

We have used these fairly ambitious observing goals to define the requirements of a simple, cost-effective dedicated X-ray instrument capable of carrying out such studies. In the space remaining, I present the results of our analysis and our suggestions for future stellar X-ray instrumentation.

1. Instrument Description: STCO-EX

First, the demands of temperature and abundance analysis call for wavelength resolution of order $\lambda/\Delta\lambda \sim 50\text{–}200$. A study of the plasma emissivity function shows that essentially all strong lines from plasmas at temperatures above $\sim 10^6$ K fall short of 200 Å; we thus require wide spectral coverage, ranging from 6 to 200 Å.

Second, because high spectral resolution is obtained at the expense of sensitivity, one needs long exposure times; and therefore it is important that spectroscopic studies not be faced by constant competition with low (if any) resolution short exposure observations characteristic of, for example, detection surveys. This lesson, gained from Einstein experience, implies an *observatory dedicated to spectroscopic studies.* Dedication is also crucial for coordinated observations with ground-based or other instruments; again, as Einstein has shown, the ready possibility for observing flexibility is essential for carrying out such studies successfully.

Finally, one may ask for the optimal spectroscopic technique. The goal is highest efficiency for a given resolution. In the resolution range just discussed, we believe that transmission grating technology now provides the optimal solution. First, as has been shown in actual flight by the Max Planck group, one can achieve high transmission efficiencies even at high dispersions. Second, transmission gratings allow one to obtain simultaneous dispersed spectra for several point sources in the field-of-view; and as stars are effectively X-ray point sources, transmission gratings can be very effectively used in fields such as the Hyades, Orion, etc.

Figure 5 shows the arrangement of the major system components of the STCO-EX spectroscopic telescope. These include a nested pair of grazing incidence mirrors, followed immediately by a movable coma-corrected transmission grating. In the focal plane there is a translation stage, on which are mounted the focal plane instruments. For the baseline design these include a High Resolution Imager of the HEAO-2 type and an optional Position-Sensitive Proportional Counter.

The effective area of the STCO-EX mirrors as a function of wavelength is shown in Figure 6. The two curves show the results to be expected with either gold or nickel coatings and they show the relative benefits of both. We are also looking into the feasibility of mixed coatings which would provide the best qualities of both; this will be one of our early phase B studies.

If we now look more closely at the telescope resolving power as a function of wavelength, we see that the quantity $\lambda/\Delta\lambda$ is at least 50 at short wavelengths and reaches a broad maximum of about 200 near 50 Å for the 2000 line grating and near 110 Å for the 1000 line grating (Figure 7). We thus have excellent spectral capability

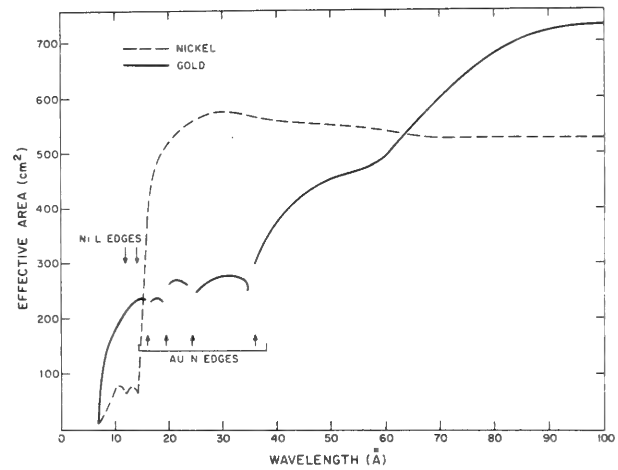

Fig. 6. Effective area of the STCOEX mirrors (2-mirror configuration); combined Ni/Au coatings could provide an ideal combination of both surfaces' beneficial properties.

over most of the instrument's full spectral range, with the implied scientific advantages already discussed earlier.

A summary description of this instrument is provided in Table 1.

2. Scientific Program of STCO-EX

What sorts of things can be done with this instrument? To appreciate its power, I've chosen a particularly well-studied star, Capella (Cash *et al.* 1978; Haisch & Linsky 1976). The low-resolution IPC spectrum shows Capella to be fairly unexceptional; with this resolution, one can only attempt a single-temperature fit. Capella has also been extensively observed by the Einstein Objective Grating Spectrometer (OGS);

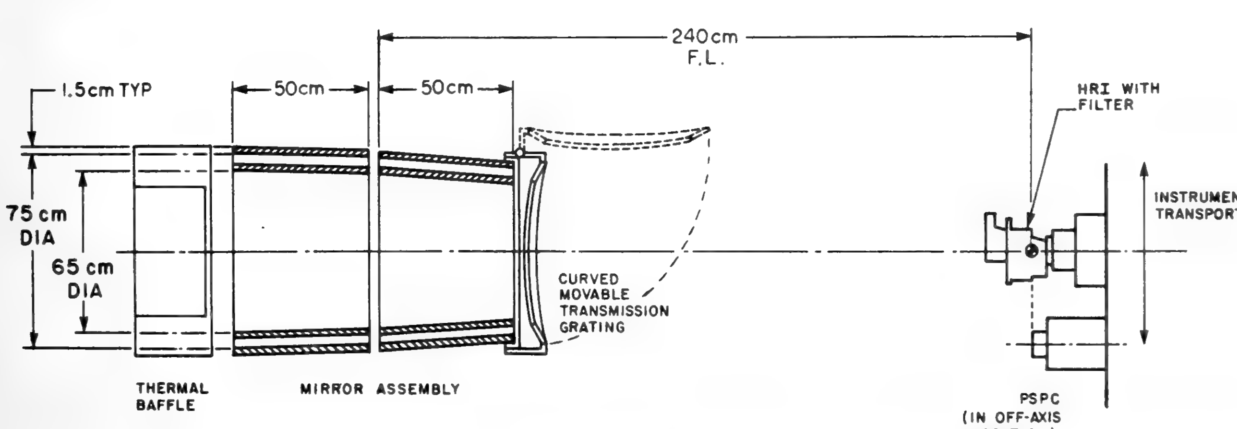

Fig. 5. Schematic outline of the major STCOEX system components. The HRI is of the type used by Einstein and the design allows for the addition of both an inner and an outer mirror.

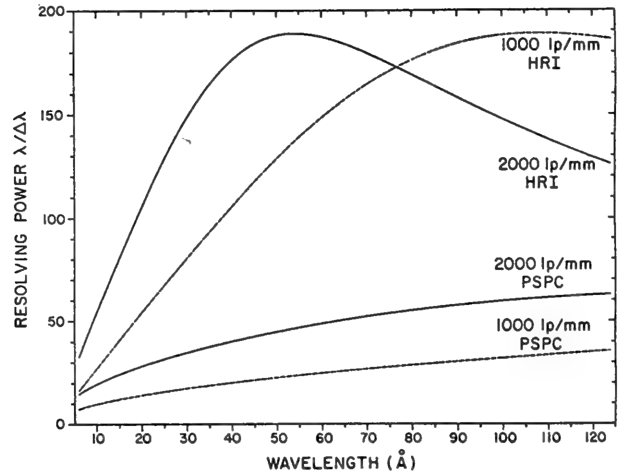

Fig. 7. Effective resolving power of the STCOEX using either a 1000 1p/mm or 2000 1p/mm grating and an HRI.

the total system efficiency is not high, so that the spectrum is fairly noisy.

A substantial improvement in sensitivity is provided by the Einstein Solid State Spectrometer (S^3); this spectrum is of sufficient quality that a two-temperature component model can be fit; and in fact Holt *et al.* 1981 have shown that such a fit gives a significantly better account of Capella's spectrum than the aforementioned single-temperature models. Their derived best-fit temperatures are $T \cong 6 \times 10^6$K and $T \cong 4.6 \times 10^7$ K.

How does the performance of the proposed instrument, using a 2000 1pm grating, compare? Figure 8 shows the calculated Capella spectrum due only to the low-temperature component for an exposure time of 10^4 seconds. This calculation takes into account the telescope effective area and resolution, the measured transmission efficiency of gratings presently available, and the efficiency of presently available HRI detectors. It is interesting to note that wavelength resolution at high energies ($\lambda \lesssim 30$ Å) is limited primarily by the telescope resolution, rather than by the grating; for example, below 25 Å, one requires better than 1″ spatial resolution to attain the wavelength resolution of a 2000 1 pm grating at a typical 32″/Å dispersion. Note also that if one wishes to do spectroscopy at wavelengths longer than ~100 Å, it is convenient to use a 1000 1pm grating, rather than the one shown previously.

Table 2 summarizes the kinds of studies one can conduct at this sensitivity and resolution. Finally, we mention the number of stars which can actually be observed at this

Table 1.—Instrument Summary

OPTICAL SYSTEM: Wolter Type I Grazing-Incidence	
MIRROR APERTURES	65, 75 cm
COLLECTING AREA	550 cm² at 44 Å
SEGMENT LENGTH	50 cm
GRAZING ANGLE	2°
SPATIAL RESOLUTION	4 arcseconds
FOCAL PLANE DETECTORS:	
High Resolution Imager-(HRI)	
PIXEL SIZE	15 μm (1.4 arcsec)
FIELD OF VIEW	38 arcmin
Position-Sensitive Proportional Counter—(PSPC)	
SPATIAL RESOLUTION	0.2–0.5 mm.
ENERGY RESOLUTION	50% at 1 keV.
FIELD OF VIEW	2°
TRANSMISSION GRATINGS:	
GRATING PERIODS	1000 lp/mm 2000 lp/mm
DISPERSION	16 arcsec/ Å = 0.2 mm/ Å 32 arcsec/ Å = 0.4 mm/ Å
SPECTRAL RESOLUTION	200 at 44 Å
SPECTRAL RANGE	6–200 Å with HRI 6–100 Å with PSPC

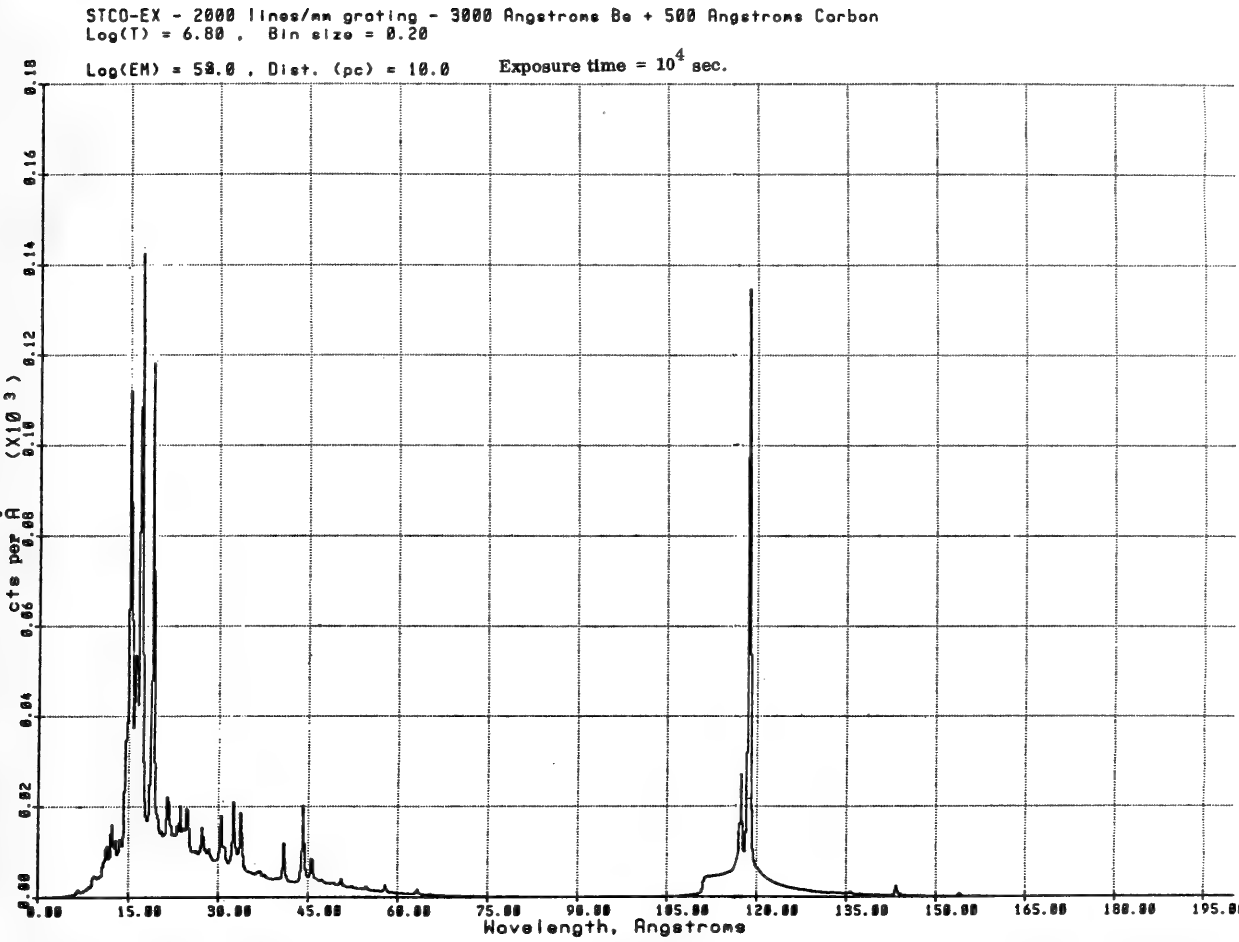

Fig. 8. Calculated observed spectrum for Capella using the STCOEX transmission grating and taking into account the mirror, filter and detector responses. We have taken the conservative assumption of a grating transmission equal to that now available and already proven in existing instruments.

Table 2.—Stellar X-Ray Spectroscopy from STCO-EX.

GENERAL OBSERVATIONAL OBJECTIVES:

1. Plasma parameter determination of hot plasma associated with stars throughout the H-R diagram: temperature, density, abundances.
2. Correlation studies of—
   a) Plasma temperature and spectral type, luminosity class, rotation rate, age, mass loss rate.
   b) Variability of high and low temperature components with luminosity and parameters of "underlying" star.

SCIENTIFIC OBJECTIVES:

1. To understand the dependence of coronal plasma parameters on the parameters of the "underlying" star as a test for theories of coronal formation.
2. To understand the relation between coronal formation, mass loss and stellar despinning.
3. To understand the elemental abundance contribution of stellar mass loss to the ISM.
4. To obtain the spectral dependence of the stellar contribution to the soft x-ray background.

sensitivity and resolution. Assuming a point source line sensitivity of $\sim 10^{-14}$ erg s^{-1} cm^{-2}, well within STCO-EX's capability, the weakest solar-type stars can be seen out to ~ 5 pc, so that the volume (rather than flux) limited sample would contain ~ 60 stars. The total number of stars which are accessible for spectroscopic studies is, of course, far larger, in fact is in excess of 1000 stars; this sample will be biased towards the brighter sources. Thus STCOEX would, for example, be able to carry out spectroscopic observations of the Hyades at exposure times of 3×10^4 sec.

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The European Programme in X-Ray Astronomy

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Introduction

An active interest in the study of non-solar sources of X-rays by scientists in several European countries dates back to the early sixties. In late 1961—before the discovery of Sco X-1—a proposal was made to NASA by the University College London and Leicester University groups, to fly a set of small non-imaging X-ray telescopes on OAO-C (later to become the Copernicus satellite). Several rocket-borne payloads were successfully flown from 1967 onwards by the two British groups, mainly in Australia, and by scientists from Utrecht and Leiden. In 1968/9 plans were agreed, in collaboration with NASA, to build the British Ariel-5 and Dutch ANS satellites, the former being entirely devoted to X-ray astronomy and the latter being a joint X-ray and UV astronomy payload. Reference to the successful outcome of Copernicus, Ariel-5 and ANS may be found in the accompanying paper by Professor Clark. Now, in 1980, X-ray astronomy remains a major interest in Britain and Holland, while an impressive programme has been developed in Germany (ref. paper by Professor Trümper) and strong scientific interest exists elsewhere, particularly in Italy.

At present, the British Ariel-6 satellite is the only operational X-ray astronomy mission from Europe. In addition to a large cosmic ray experiment, Ariel-6 carries X-ray detectors from UCL and Leicester which cover the energy bands 0.15–1.5

keV and 1.5–50 keV respectively. Despite an unusual number of spacecraft problems, both experiments are functioning correctly and have so far provided timing and spectral data on a variety of galactic and extragalactic sources. Many of these results will be published over the next few months, and I intend to spend my limited time describing the next mission in X-ray astronomy from Europe—indeed the first from the European Space Agency (ESA)—namely, EXOSAT. This mission, approved in 1974, evolved from the HELOS proposal to fly an X-ray detector in a highly eccentric orbit to observe the lunar occultation of specific X-ray sources. This evolution has seen a substantial development of the payload which now will emphasize the non-occultation observations, while retaining the choice of orbit and occultation capability.

1. EXOSAT. Spacecraft and payload

Figure 1 shows an artist's impression of EXOSAT and Figure 2 an exploded view of the spacecraft and payload elements. Evident are the rotatable solar array, antennae and the X-ray instruments. The main features of the spacecraft are a precise 3-axis attitude control system and a hydrazine thruster for orbital adjustment to optimise occultation observations. The principal characteristics of the spacecraft systems are outlined in Table 1.

The experiment payload is designed to be effective in both occultation and 'offset pointing' observations. The *Medium Energy Detector Array* (MEDA) is a set of eight proportional counters with ~ 1800 cm^2 post-collimator area. The detectors are mounted in four pairs, each quadrant being adjustable in relative alignment to give a flat-topped field of view (for occultation observations) or independent off-source background measurement at any time. The latter facility is considered particularly desirable in view of the high and variable particle rates that will be encountered in parts of the chosen orbit. Since the MEDA sensitivity for observing faint sources, particularly in positioning them from an occultation detection, is strongly dependent on the background count rates, both 5-sided anti-coincidence and rise-time discrimination have been included in the detector design. Each detector is of multi-anode construction with a front cell filled with Ar/CO_2 and separated by a Be window from a rear Xe/CO_2 cell. These cells respond respectively over the energy bands 1.5–15 keV and 6–60 keV. Field collimators of 45 $\times$ 45 arc min (square, FWHM) in front of each detector are made from specially moulded microchannel plate arrays, with the inner surfaces etched to remove reflection effects.

The *Low Energy Imaging Telescope* (LEIT) is in fact two identical Wolter I type reflecting telescopes, each having two nested sets of paraboloid-hyperboloid mirrors. The basic parameters of each telescope are listed in Table 2. A severe payload weight restriction led to development of lightweight mirrors and those for EXOSAT are made of Be and weigh only 7 kg per telescope. The technique of manufacture is by replication in which a polished master surface is gold coated and transferred onto the Be substrate via an adhesive epoxy layer. This method has been described earlier (De Korte, 1979) and X-ray tests on the EXOSAT qualification model have given encouraging results. Further tests to be carried out early in 1981 at the PANTER X-ray facility in Germany will determine the performance of the flight mirrors. The results are not expected to differ substantially from those given in Table 2 and used in Figures 10–12, which are based on the earlier QM data.

The *Gas Scintillation proportional Counter* (GSPC) is included in the EXOSAT payload to provide an improved spectroscopic capability for bright sources. Although the GSPC has an effective, post-collimator area of only ~ 165 cm^2 it has approximately a factor of two better energy resolution than the MEDA. Measured values include 11% (FWHM) at 6 keV and 3.5% at 60 keV.

The GSPC has an identical 45 $\times$ 45 arc min (FWHM) field collimator to the MEDA and has a sensitive bandwidth of 2–80 keV.

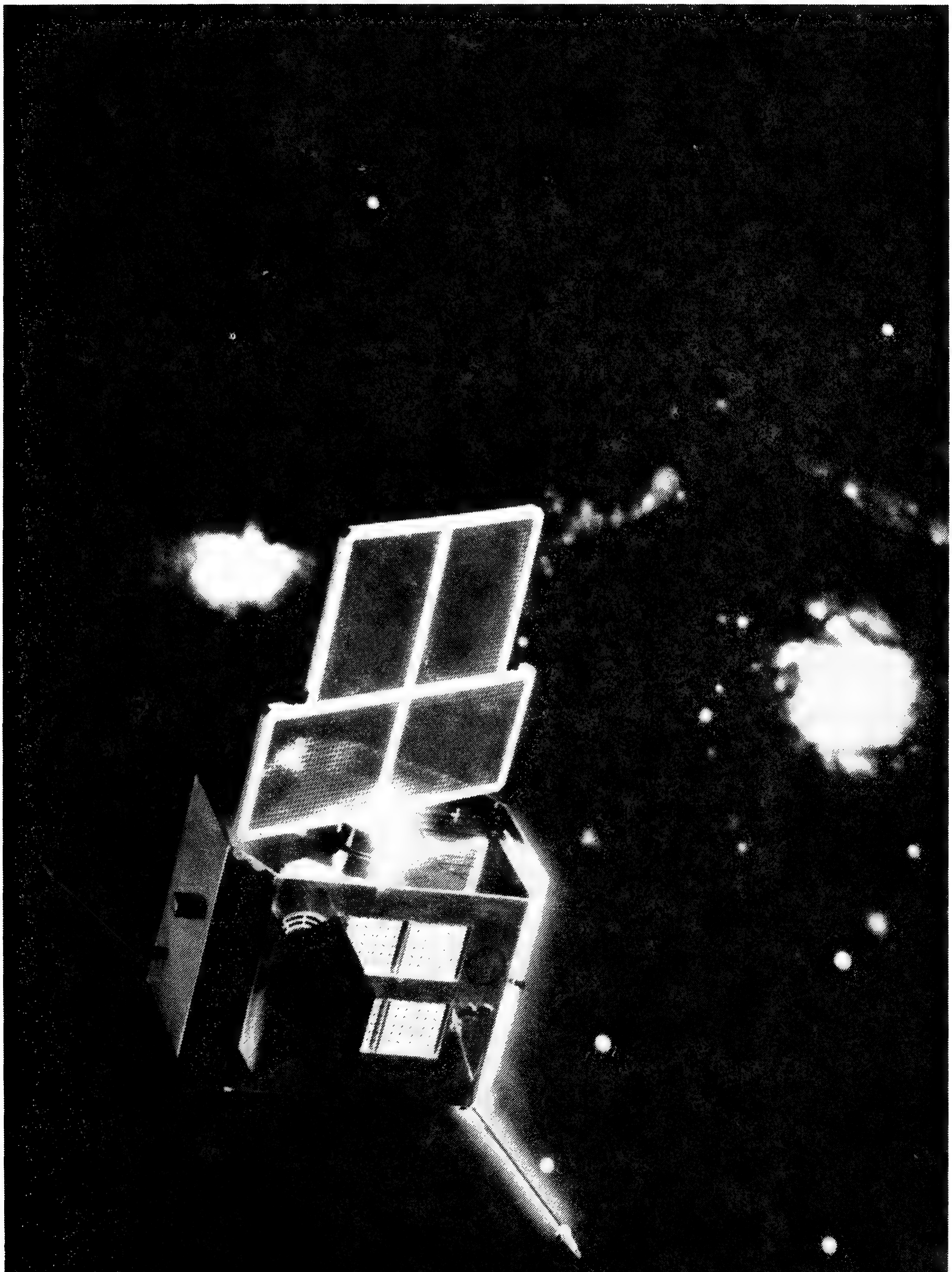

Fig. 1. Artist's impression of EXOSAT in its orbital configuration.

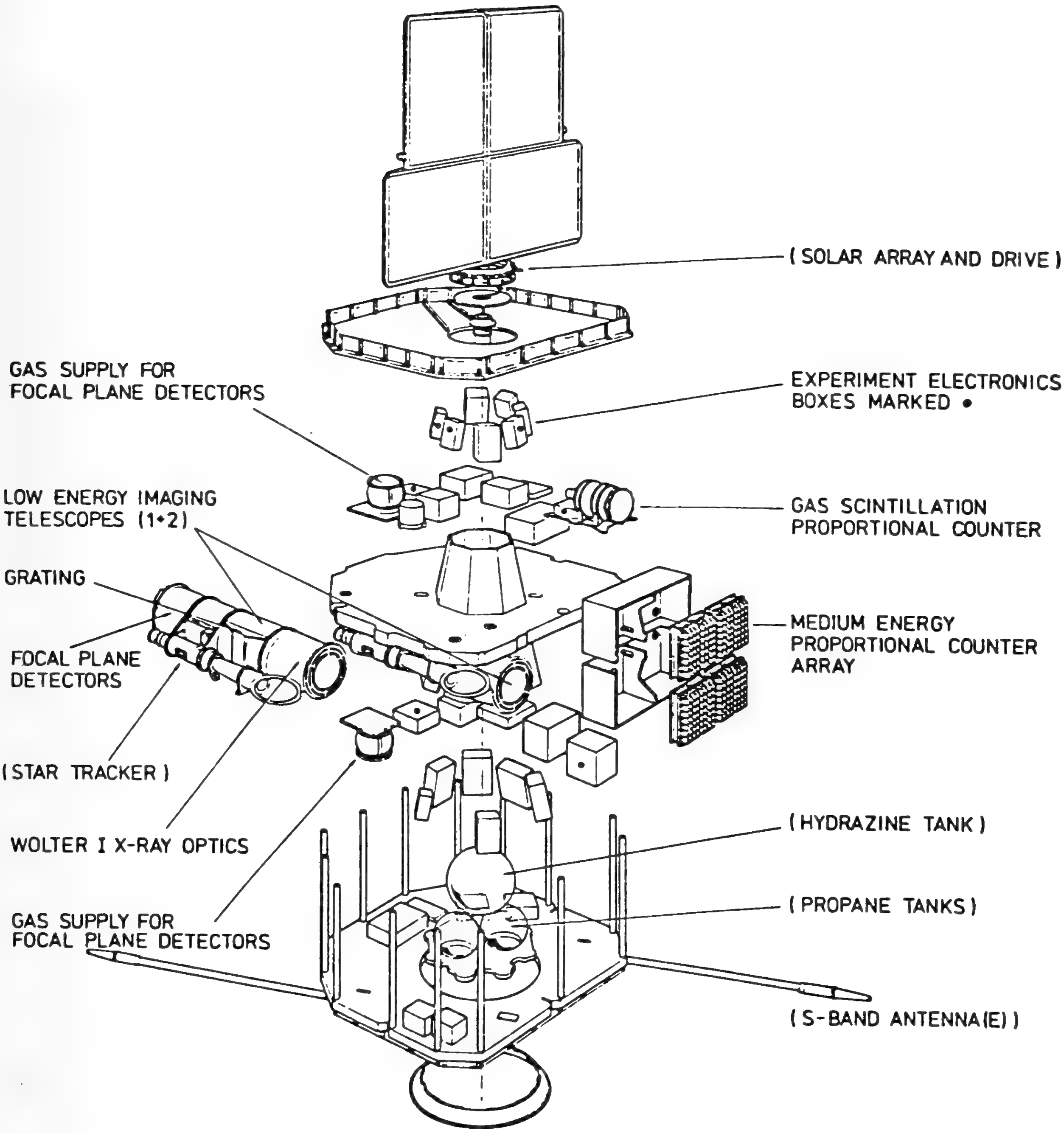

Fig. 2. Exploded view of EXOSAT showing carbon fibre/aluminium honeycomb structure and main payload and spacecraft elements.

2. EXOSAT performance capabilities

2.1 Occultation mode. The chosen orbit allows EXOSAT to observe lunar occultations over ~20 percent of the celestial sphere, including the galactic centre region. The occultation mode is shown schematically in Figure 3. Prior to an occultation observation, the hydrazine thruster is used with the spacecraft near perigee to optimise the lunar latitude of the subsequent X-ray source passage; the case of 45 degrees is shown in the figure.

Because of its larger photon collection area the MEDA will be the most useful instrument in occultation observations. For a point source flux of S (1–15 keV) and a corresponding background count rate of B,

Table 1.—The EXOSAT spacecraft

- 380 kg space craft due for launch in 1982 with an Ariane (or Delta) launcher.
- Orbit perpendicular to ecliptic plane with apogee 2×10^5 km, perigee 500 km and period 4.125 days (99 hours).
- S-band telemetry with 8 kb/s data rate in direct contact with Villafranca ground station (up to 80 hours per orbit).
- 3-axis attitude control, using propane gas, sun sensors, and gyro reference with star tracker up-dating:

gyro drift	0.0005 deg/hr (used in occultations)
star tracker	~2 arc sec (40 arc sec on Moon)
limit cycle	±5 arc sec

Slew rates 42 deg/hr (and ×2, ×4, ×8). Propane gas (13 kg) adequate for up to 2×10^4 targets.

- Orbit control with hydrazine thruster. Adequate for up to 90 occultations.
- On board computer (OBC) serves spacecraft and payload.

Table 2.—Basic parameters of each imaging telescope.

Geometric area	90 cm^2
Focal length	109 cm
Field of view	2 deg (FWHM)
On-axis resolution	~5 arc sec (FWHM)
	~10 arc sec (HEW)

- Average grazing angles of the inner (1.5 deg) and outer (1.8 deg) mirror shells yield an upper energy cut-off ~2 keV.
- Each focal plane contains:
  - a position sensitive proportional counter giving (FWHM) resolution ~45 arc sec at 1.5 keV and ~180 arc sec at 0.28 keV.
  - a channel multiplier array giving (FWHM) resolution ~10 arc sec, independent of energy.
  - a filter wheel with 4 filters and 1 open position provide observing bands between ~0.04 – 2 keV.
- A transmission grating (500 or 1000 lines/mm) may be swung behind the mirrors for spectroscopy of strong sources.
- A fixed UV filter is available to determine possible contamination at $\lambda \geq 1100$ Å.

the position determination of the source in eclipse by the moon is determined (at 5 sigma) by the relation

$$S\, t^{1/2} \gtrsim 5\, (S + 2B)^{1/2}$$

where t is the interval taken to detect the source eclipse. Since for observations near apogee the moon's relative velocity is ~0.5 arc sec/sec the positional accuracy θ is given by

$$\theta = \frac{12.5\,(S + 2B)}{S^2} \text{ arc sec}$$

or

$$\theta = \frac{0.98\,(3.57\,f + 47)}{f^2} \text{ arc sec}$$

where the source has a Crab-like spectrum and a 2–6 keV flux of f milliCrabs. Figure 4 shows the resulting occultation performance for a predicted value of B ~ 200 cts/sec, based on Apollo and COS-B measured particle rates and the ~99% rejection efficiency of the EXOSAT prototype detectors.

2.2 Offset pointing mode. In this mode all three detector arrays will view a source or source field continuously for up to 80 hours. Alternatively, rapid slewing can facilitate observation of many separate sources in a single EXOSAT orbit (up to an average of 10 per orbit for a 2.5 year mission duration).

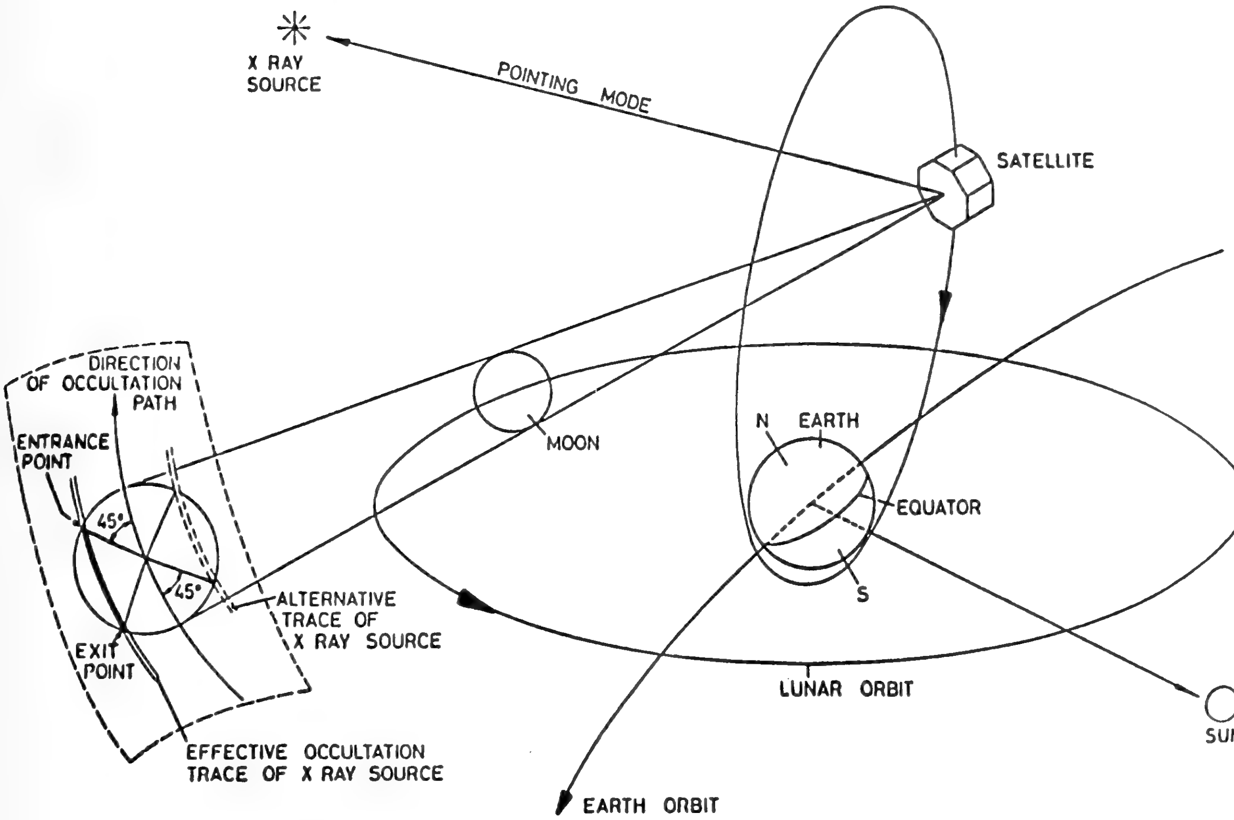

Fig. 3. Schematic of the lunar occultation observing mode for EXOSAT.

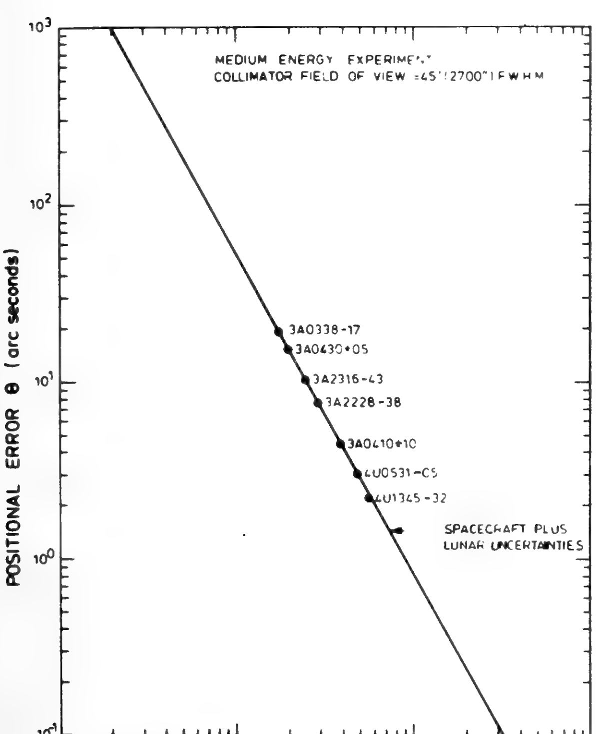

Fig. 4. Source location accuracy determined by the MEDA from observation of lunar occultation.

It is likely the MEDA will be mainly employed in the measurement of spectra and variability of known sources, although the somewhat lower confusion limit than Uhuru, Ariel-5 and HEAO-1 will allow useful search or survey studies of selected optical, IR and radio objects. Figures 5 and 6 indicate the predicted MEDA sensitivities for source detection and variability measurement in the two main energy bands. It is clear that the available sensitivity, combined with the long uninterrupted viewing capability of EXOSAT, offers a powerful facility for the study of all types of galactic and extragalactic X-ray source brighter than a few tenths of a mCrab.

The MEDA is also valuable in the measurement of of X-ray lines and edges, having a factor-of-two greater sensitivity for their detection compared with the GSPC. This factor arises simply from the tenfold larger area of the MEDA, partly counterbalanced by the factor-of-two inferior spec-

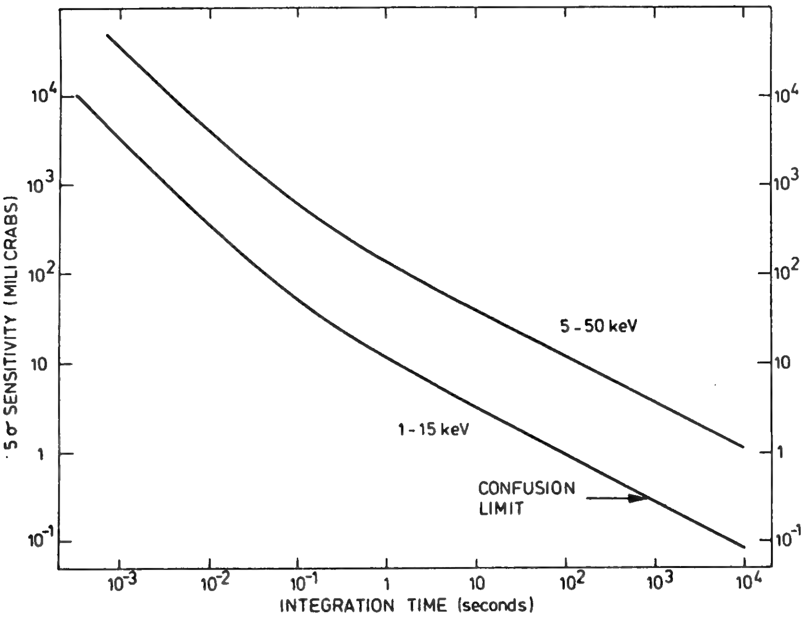

Fig. 5. MEDA source detection sensitivity versus integration time.

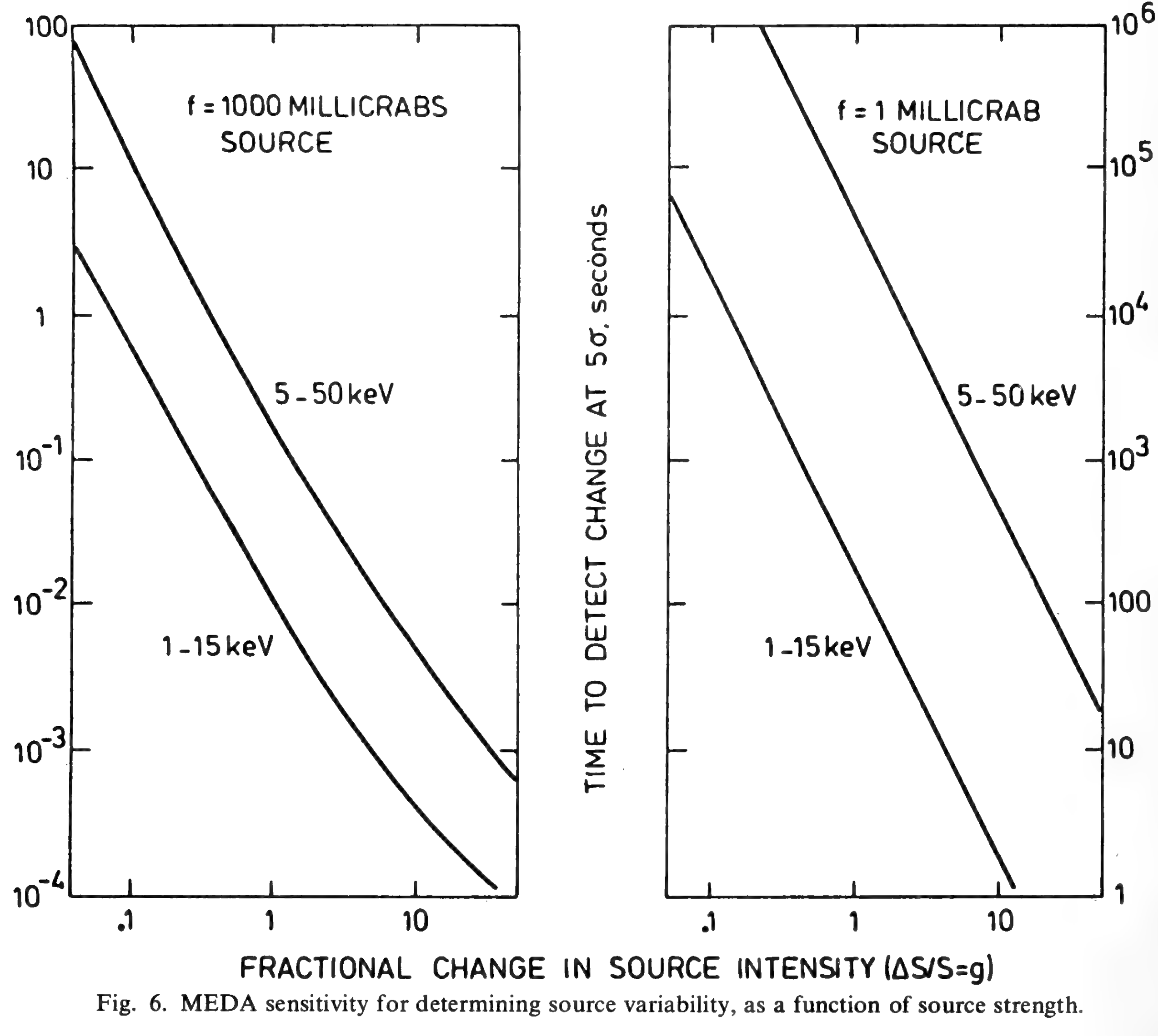

Fig. 6. MEDA sensitivity for determining source variability, as a function of source strength.

tral resolution. For example, the minimum detectable line strength of iron emission at ~6 keV can be written as:

$$I_L = 0.29 \left(\frac{I_c + 0.0092}{t} \right)^{1/2} \text{ ph cm}^{-2} \text{ sec}^{-1}$$

where I_c is the local continuum intensity (ph cm^{-2} sec^{-1} keV^{-1}) and t the exposure (sec).

Predicted values of I_c are plotted against a range of continuum intensities in Figure 7. Also shown are previously reported values for several well known X-ray sources. A comparison with the GSPC sensitivity for iron line detection may be made by reference to Figure 8. The great value of the GSPC is, of course, in its better resolution which is of direct benefit for all but the faintest detectable sources. Figure 9 illustrates the point in comparable simulations of a bright source spectrum, with iron line, measured with both the MEDA and GSPC.

The angular resolution versus energy and for off-axis rays for the LEIT are shown in Figures 10 and 11. In essence the scientific potential of the LEIT in the offset pointing mode can perhaps best be emphasized by noting its comparable performance to the highly successful Einstein Observatory (see chapter by Dr Tananbaum). Figure 12 shows the point source sensitivities of the EXOSAT and Einstein moderate resolution (PSD and IPC) and high resolution (CMA and HRI) image detectors. The two missions are seen to be similar in sensitivity for the assumed input spectrum (4 keV thermal bremsstrahlung, with hydrogen column density $N_H = 4.2 \times 10^{20} cm^{-2}$). It should be noted, however, that the somewhat different energy responses of the two optical systems give the Einstein Observatory a strong advantage for hotter, harder or more cut-off spectra, whilst EXOSAT becomes the more sensitive for cooler or softer spectra than that used in deriving Figure 12. On the above basis, it may be anticipated that the strongest potential of the LEIT will lie in the detection of soft stellar sources, cooler material in clusters or galactic nebulae and

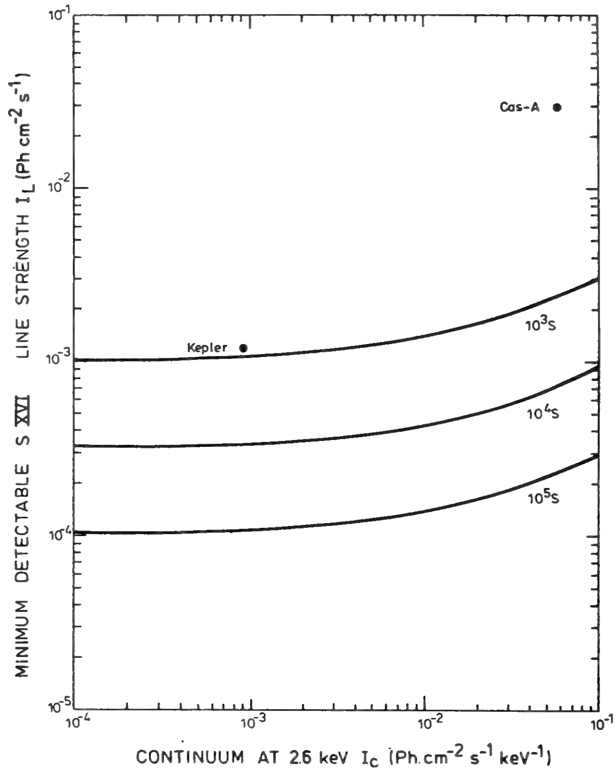

Fig. 8. GSPC sensitivity for iron-K line detection, as a function of continuum intensity.

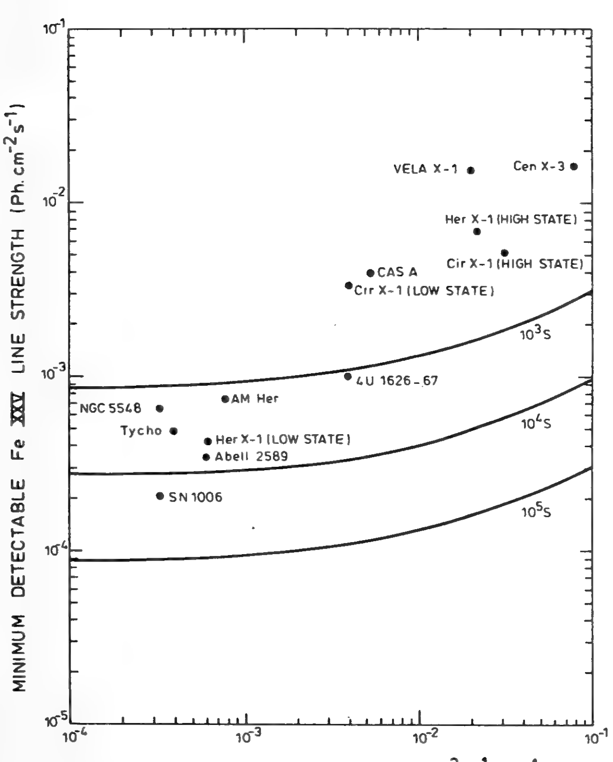

Fig. 7. MEDA sensitivity for iron-K line detection, as a function of continuum intensity.

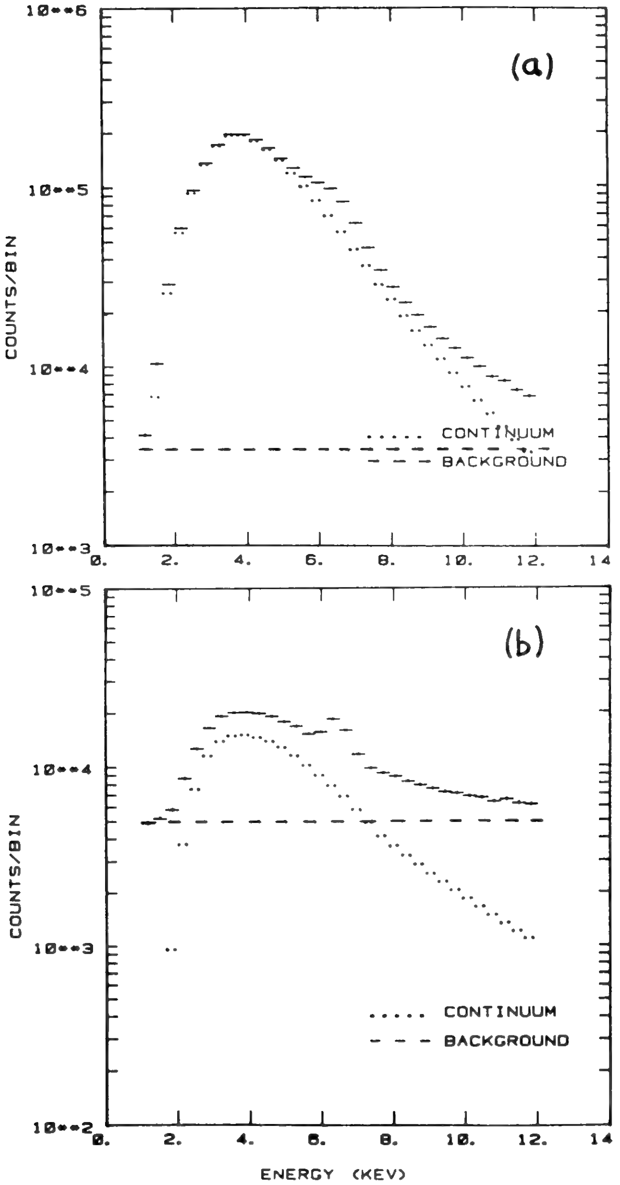

Fig. 9. Comparison of a spectral simulation of the bright galactic X-ray source Cygnus X-3 using (a) the MEDA and (b) the GSPC.

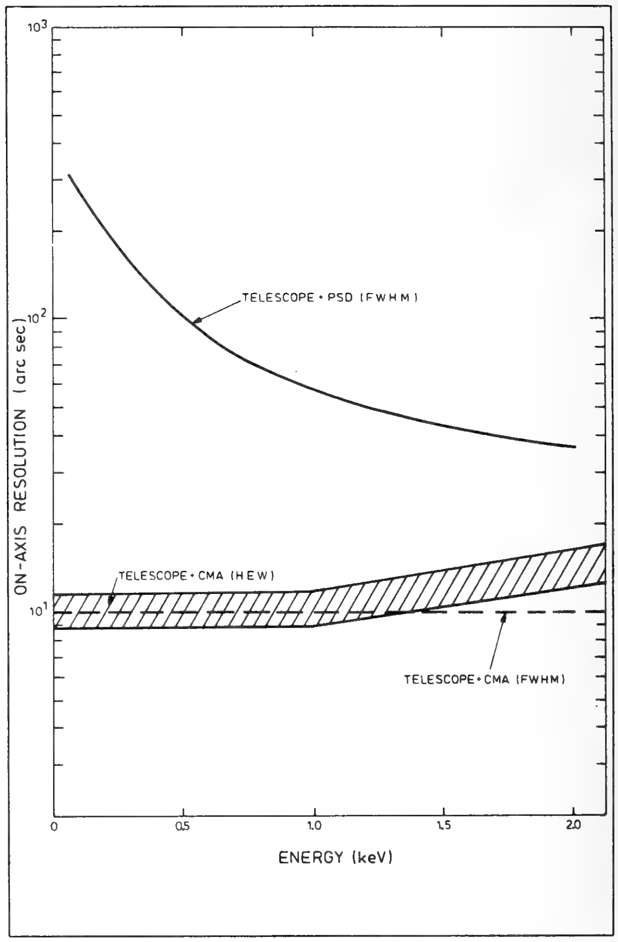

Fig. 10. On-axis resolution of the LEIT versus photon energy. For the PSD the detector resolution dominates while the mirror properties are dominant when the CMA is being used; note the effect of mirror scattering on the half energy width above ~0.7 keV.

active galaxies without a strong intrinsic low energy cut-off.

The transmission gratings on EXOSAT have higher efficiencies than those on Einstein and are expected to be more effective, particularly for the study of the softer X-ray sources. Nevertheless, the relatively small effective area of the mirror grating combination (Figure 13) will restrict their use to the brightest sources.

3. EXOSAT mission operations

The present schedule for EXOSAT has a January 1982 launch date, but this now seems likely to be delayed ~6 months. Preparations for mission operations are proceeding in two areas. First, ESA have established a *C*omittee for *O*bserving *P*rogramme *S*election (COPS) and the A/O inviting observing proposals for the first six months of full operation will be issued in the Spring. This first announcement will be restricted to ESA member states, but thereafter it is intended to invite proposals worldwide. A detailed description of EXOSAT, its payload, in-orbit calibration data (when available) and a listing of previous and currently approved observing programmes will be issued with each A/O (at 6 or 9 monthly intervals to the end of the mission). Secondly, work is in hand at ESOC in Darmstadt, W. Germany, to prepare mission operations and data reduc-

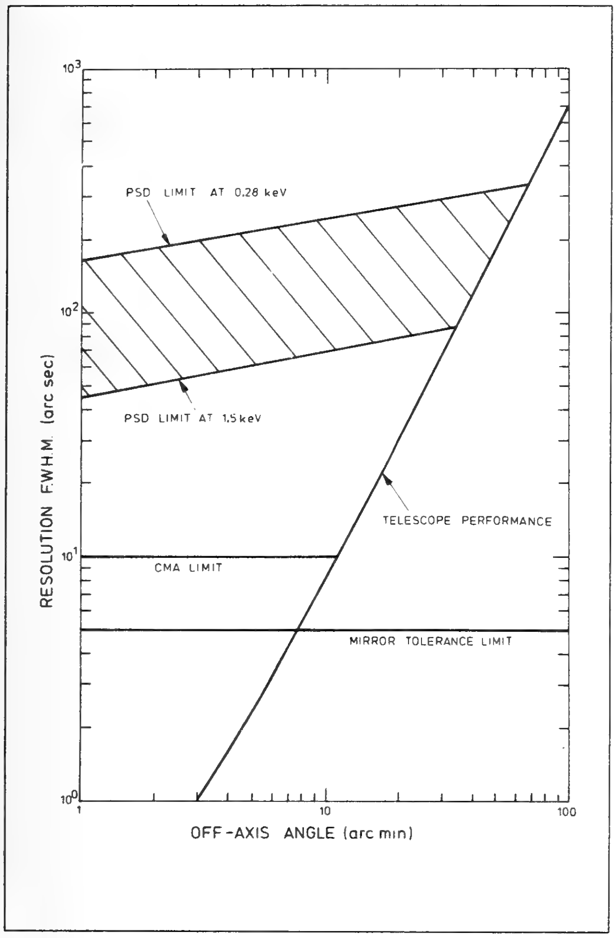

Fig. 11. Off-axis resolution of the LEIT at 0.28 keV and 1.5 keV.

tion software. A preliminary analysis of data will also be available in near real-time (observers will generally be advised to attend at ESOC during their observations, in the pattern now successfully established for the IUE mission) and a final observations tape (FOT) containing all scientific data, up-to-date calibrations and necessary housekeeping data approximately 5 weeks later. Details of these arrangements will also be issued by ESA at the time of the observing proposal A/O. On behalf of my fellow European X-ray astronomers, I can say that we look forward to EXOSAT marking the successful entry of Europe as a whole into this exciting field and to fruitful participation by our colleagues in the United States, Japan and elsewhere, many of whom are joining with us now in celebrating the pioneering success of Uhuru a decade ago.

Reference

de Korte, P. A. J. (1979) *S.P.I.E.* **184**, 189.

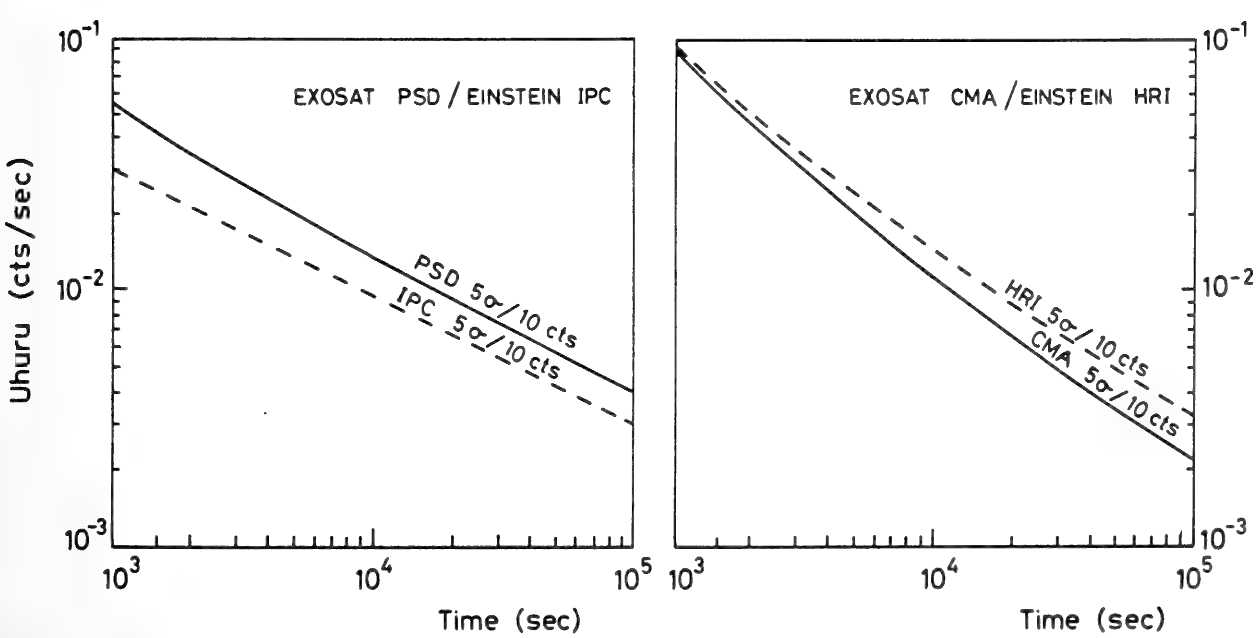

Fig. 12. Comparison of the EXOSAT and Einstein Observatory point source sensitivities as a function of integration time and for an assumed thermal bremsstrahlung input spectrum with $kT = 4$ keV and $N_H = 4.2 \times 10^{20}$ cm^{-2}. 1 Uhuru (cts/s) $\simeq$ 1.1 milliCrab.

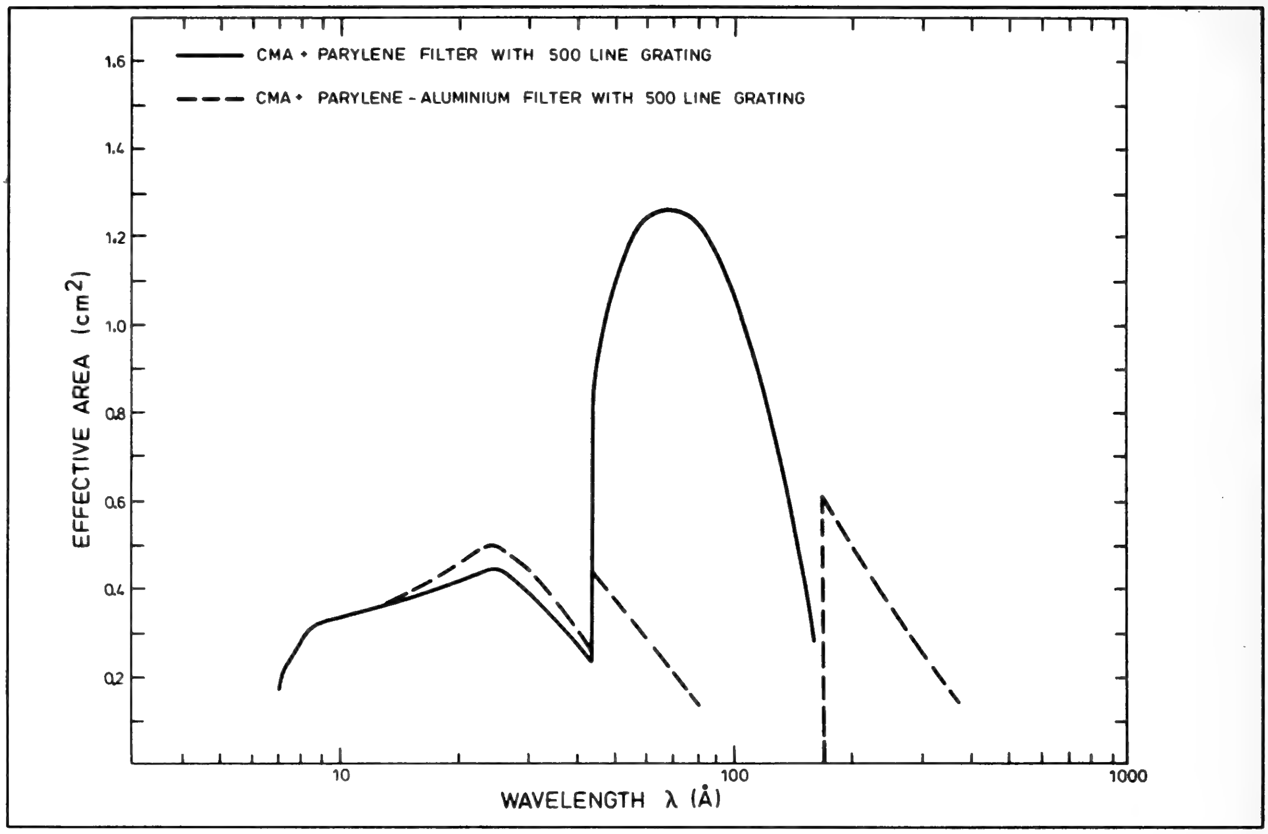

Fig. 13. Effective area of LEIT mirror and transmission grating combination versus photon energy.

The Röntgen Satellite

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Introduction

X-ray astronomy is rather young in Germany—actually we began thinking about a research programme in this field only just before the launch of the Uhuru satellite.

As a first step we initiated in 1971 a balloon programme in hard X-ray astronomy ($E \geq 20$ keV) which is an ongoing collaborative effort of the Astronomisches Institut Tübingen and MPI Garching. Numerous results on compact galactic and extragalactic active X-ray sources have been obtained during ten successful balloon flights launched during the period 1973–1980, from Palestine and Alice Springs, using pointed instruments of increasing size and complexity. A highlight of this programme was the discovery of features in the spectrum of the mass accreting neutron star Her X-1 which are interpreted in terms of electron cyclotron resonance effects. This provided for the first time a direct determination of the magnetic field strength at the surface of a neutron star (1).

In 1980 we had the first flight of a new balloon payload combining the sensitivity of a very large Phoswich detector (2400 cm^2) with the spectral resolution of a cooled Germanium spectrometer (114 cm^2). We hope to fly this powerful instrument several times over the next few years.

Another project in which we are involved since its beginnings in the late 1960's, is EXOSAT which has been described by K. Pounds at this meeting (2). In EXOSAT we are collaborating with the University of Leicester and the University of Tübingen on the large area proportional counters. In addition, we will take part in the flight qualification of the 27 cm imaging telescopes to be carried out in our long beam X-ray test facility in Munich.

By far our largest effort in X-ray astronomy, however, is devoted to a project called ROSAT (Röntgen Satellite, formerly ROBISAT) and its description will form the main subject of this talk.

1. Prehistory of the ROSAT project

With the realization of the enormous scientific potential of imaging X-ray astronomy, we started a telescope development program around 1974/75. The first step was to build large paraboloidal concentrators with low background focal plane detectors and Ross filters. A very large payload (1200 cm^2 mirror area) was flown in 1977 on one of the first Aries flights in order to perform spectral studies of the supernova remnants Vela and Puppis A (3).

As the next step we turned our attention to truly imaging systems. Several Wolter type I mirror systems of 32 cm aperture were built for us by Carl Zeiss (4), while MPI Garching, developed the corresponding imaging proportional counters. The first rocket flight of this "32 cm telescope" from Woomera in early 1979 was successful and yielded spectrally resolved images of the supernova remnants Puppis A and Crab Nebula.

Figure 1 shows the image of Puppis A having 1.2 arcmin resolution in which the photons are tagged by colour according to their energy. In general the measured bright ness distribution agrees well with that of the Einstein HRI images of Puppis A which have better angular, but no spectral resolution. A detailed analysis of our Puppis A picture reveals spectral variations across the supernova remnant (5).

A second rocket flight with an improved version of the imaging proportional counter is scheduled for summer 1981, and there may be a third one in 1982/83 as part of the ROSAT instrument development program.

2. The ROSAT project

Up to the mid 1970's we were involved in two X-ray telescope satellite projects studied by European and US-European collaborations, both of which were unsuccessful because of their complexity and costs. We therefore thought of a rather simple, but nevertheless very powerful instrument which could be realized at comparatively low costs. The result is ROSAT which, in its baseline version, consists of a big X-ray mirror system and imaging proportional counters (IPC) in the focal plane. In its simplicity, it actually can be considered as a translation of Uhuru into the X-ray telescope era (collimator → mirror, proportional counter → IPC).

The main objective of ROSAT will be to perform the first all sky survey with an imaging telescope, providing a gain in sensitivity of about a thousand times that of Uhuru. Since both the Einstein and EXOSAT telescopes are pointing onto selected sources and "see" only a few percent of the whole sky, ROSAT will provide an enormous amount of information from regions which have not been explored with the sensitivity of X-ray telescopes. After completion of the sky survey which will take fully half a year, ROSAT will be used for detailed follow-up studies of individual sources. In this mode it will provide a gain

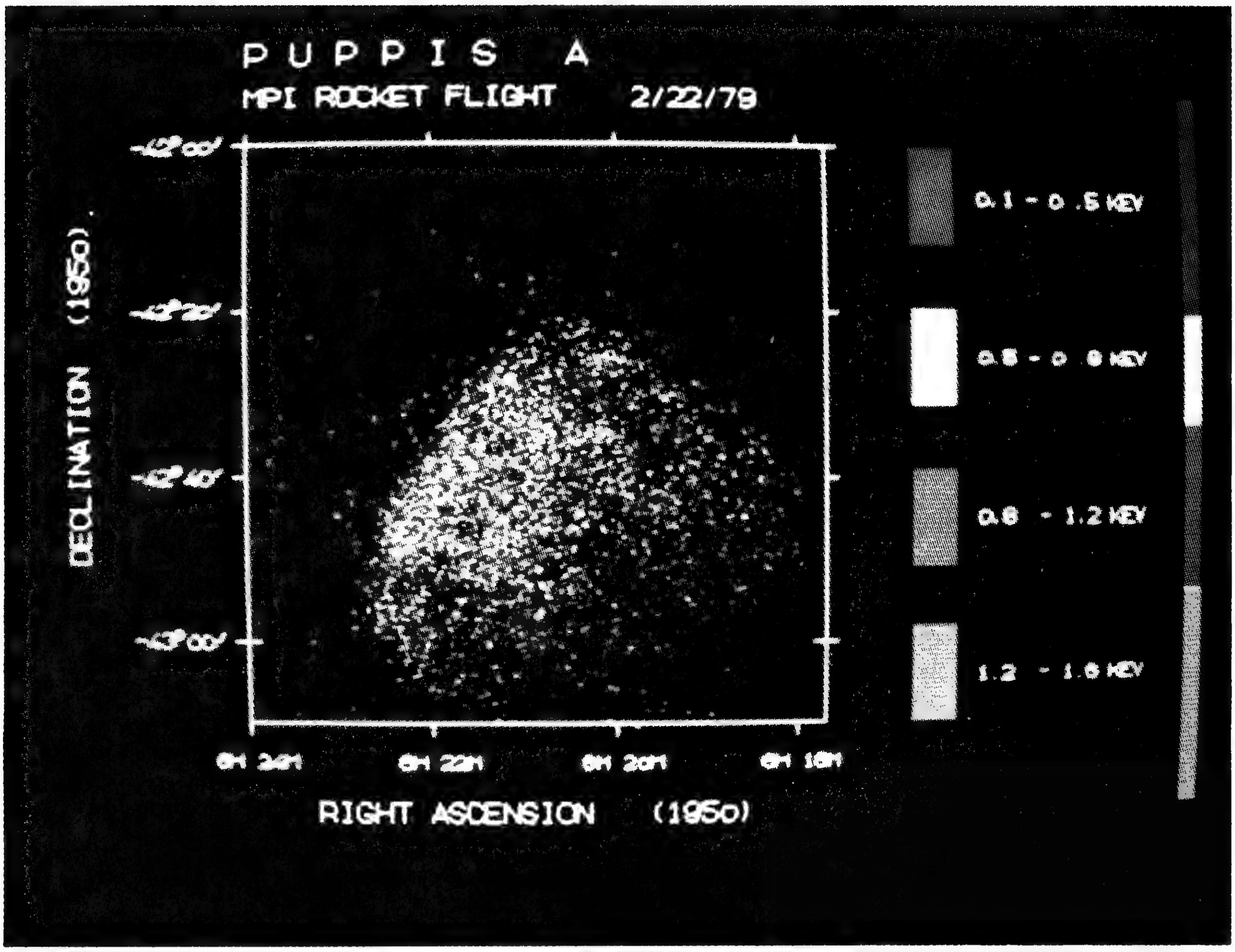


Fig. 1. Image of Puppis A, taken with the MPI 32 cm telescope during a rocket flight on Feb. 22, 1979 from Woomera.

in sensitivity by a factor of about three compared to the Einstein IPC observations.

3. The ROSAT spacecraft and payload (baseline concept)

ROSAT is a three-axis stabilized spacecraft to be launched by the shuttle into a 56° inclination orbit at 430 km height. Figure 2 shows the satellite configuration which is dominated by the large cylindrical tube housing the telescope. The mechanical structure around it supports a fixed solar array and the other spacecraft subsystems. Furthermore it has the task to fix the telescope in a transverse position during shuttle launch. The three-axis stabilization is achieved by momentum wheels which are desaturated by magnetic torquers. On board data storage will be on magnetic tapes with data dump to Weilheim, the German satellite ground station located near Munich. The design life time of the satellite is 1.5 years, while the lifetime of the orbit and of the instrument consumables (counter gas) will be 2.5 years. The first part of the mission will be devoted to the all-sky survey which is achieved by a slow scan of the telescope over the sky. With a progression of ~1° ecliptical longitude per day and a telescope field of view of 2°, every source in the sky will be visible for at least 2 days (~32 orbits). The complete sky survey will take 6 months. In this mode the instrument will be oriented perpendicular to the solar direction looking away from the earth all the time (spin period equal to the orbital period).

Later in the mission observations of particular sources can be made in the pointing

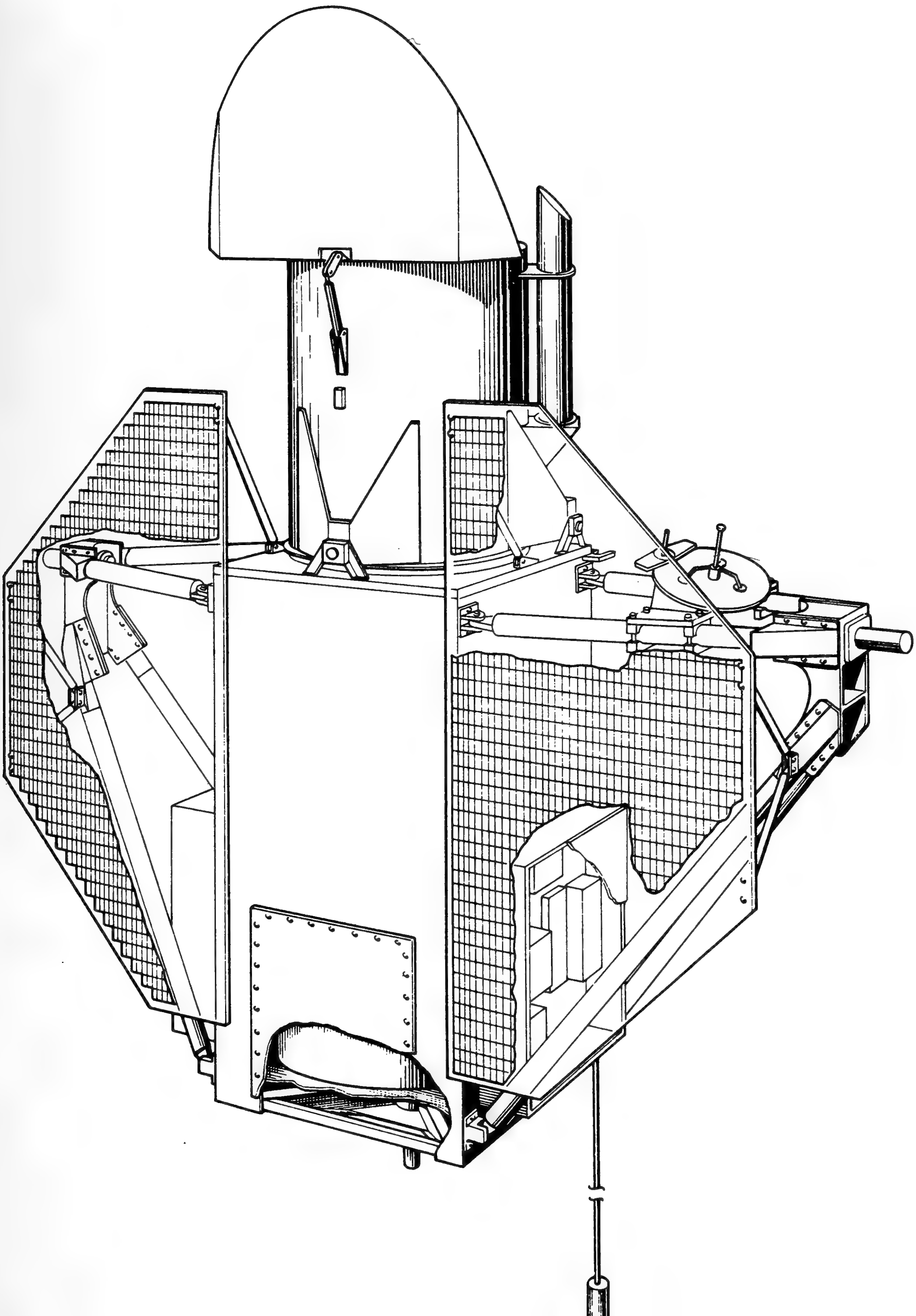


Fig. 2. The ROSAT spacecraft configuration according to the Phase B concept proposed by Dornier System.

mode for durations up to ~40 minutes (half an orbit). In this mode the off-sun angle restriction will be relaxed to ±15° in order to provide more flexibility for the observational program.

The X-ray telescope is shown in Figure 3. It consists of a fourfold nested Wolter type I mirror system with 80 cm aperture and 240 cm focal length which is optimized with respect to survey sensitivity and on-axis collecting area at ~1 keV. A carousel in the focal plane assembly carries three imaging proportional counters, which are almost identical apart from differences in window thickness. Each counter has its own filter wheel with four positions. We have summarized in Table 1 a few key data of the telescope.

4. ROSAT scientific objectives

The main scientific objective of ROSAT will be to perform the first *X-ray sky survey* with an imaging telescope. Compared with the "counter surveys" of Uhuru and HEAO-1 the increase in sensitivity will be enormous, namely, by a factor of ~1000 and 100 respectively (c.f. Table 2). These figures have been calculated for a uniform coverage during a 6 month period. The angular resolution of the survey will be ≤1 arcmin which is good enough to avoid source confusion and to enable the identification of many sources.

Using the log N- log S distributions obtained by earlier missions, in particular by the Einstein observatory (6) one can estimate that the total number of sources to be discovered will be a few hundred thousands. It is evident from the Einstein observations that the ROSAT sky survey will comprise almost all astronomical objects, from nearby "normal stars" to the very distant quasars at the edge of the known universe. Figures 4, 5, and 6 illustrate the sensitivity of the ROSAT sky survey with respect to observations of galactic, extragalactic and cosmological realm.

Since it is not possible to discuss all the various scientific objectives here in detail, we wish to stress a few general points:

- results of the ROSAT sky survey will become standard astronomical tools like the Palomar and ESO optical surveys and the 3C/4C catalogues of radio astronomy.
- obviously the scope of this mission is complementary to other telescope missions like Einstein, EXOSAT and AXAF which point onto selected objects. An unbiased sky survey has the

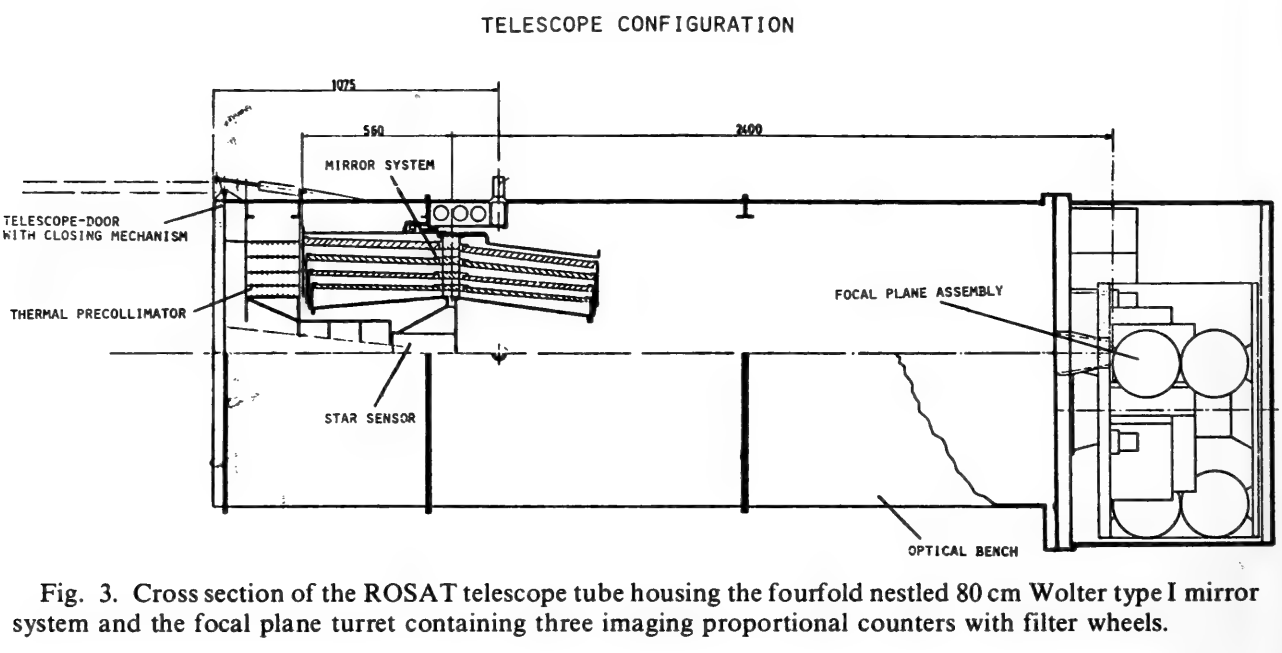


Fig. 3. Cross section of the ROSAT telescope tube housing the fourfold nestled 80 cm Wolter type I mirror system and the focal plane turret containing three imaging proportional counters with filter wheels.

Table 1

Mirror system	
mirror material	Zerodur, gold coated
aperture of outermost mirror	83 cm
innermost mirror	47 cm
geometrical collecting area	1200 cm^2
focal length	240 cm
mean grazing angle	2°
on-axis resolution	5″ (half power circle)
Imaging proportional counters	
size	8 cm × 8 cm
gas filling	argon/xenon/methan
background reduction	5 side anticoincidences and pulse shape dicrimination
energy resolution at 1 keV	50% FWHM
Telescope	
field of view	2° × 2°
effective collecting area at 1 keV	420 cm^2
at 0.28 keV	470 cm^2
on axis angular resolution at 1 keV	~20 arcsec (FWHM)
at 0.28 keV	~1 arcmin (FWHM)

Table 2

Comparison with *survey* performance of previous experiments:

Experiment	Point source sensitivity (erg/cm^2s)	Energy range (keV)
Uhuru	2×10^{-11}	2–6
HEAO A-1	5×10^{-12}	0.5–2
HEAO A-2	8×10^{-12}	0.5–3
Einstein Observatory* deep surveys	1×10^{-14}	0.5–4
ROSAT	6×10^{-14}	0.5–2
	2×10^{-14}	0.1–3

*The Einstein deep surveys cover in total a few square degrees.

potential to discover unexpected, rare and unusual objects.

— another aspect is that studies of classes of objects can be made on the basis of large unbiased samples, e.g. L_x/L_{opt} distributions for various types of stars, galaxies and quasars.

— in particular the results of the ROSAT survey may provide a valuable guide for the AXAF mission which aims at detailed studies of selected objects.

The *pointed observations* planned for the later part of the mission can be considered as a follow up to the Einstein IPC observations, with some improvements in angular resolution (1′ → 20″) and spectral resolution ($\Delta E/E \sim 0.5$ FWHM at 1 keV). Owing to the large collecting area of the ROSAT telescope the sensitivity for a given observation time will be about three times that of Einstein.

These features allow a large number of interesting scientific problems to be tackled which relate to almost all fields of astronomy. In total there may be $\sim 10^4$ pointings of ~2000 sec duration, in which a wide scientific community can participate by

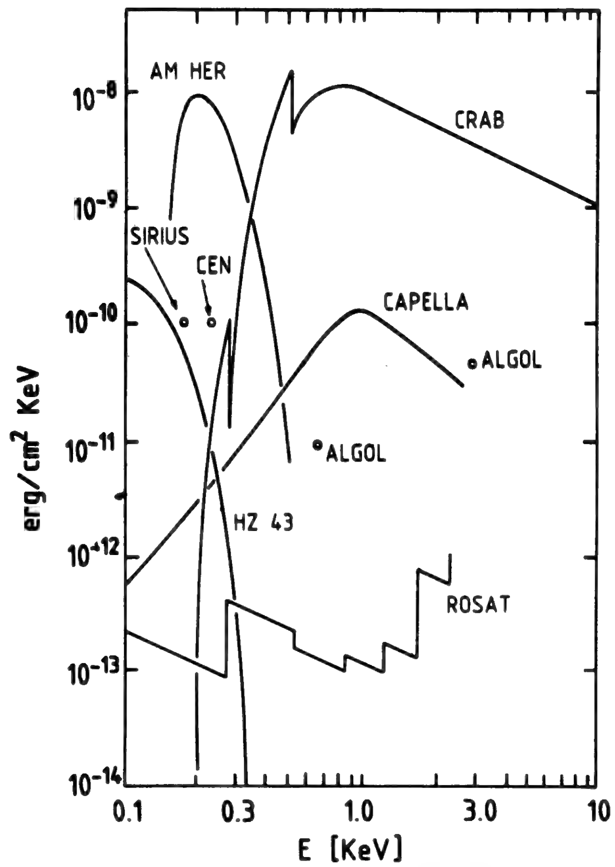


Fig. 4. Energy spectra of a few selected, galactic X-ray sources compared with the detectability limit of ROSAT for a uniform, all-sky *survey* of half a year.

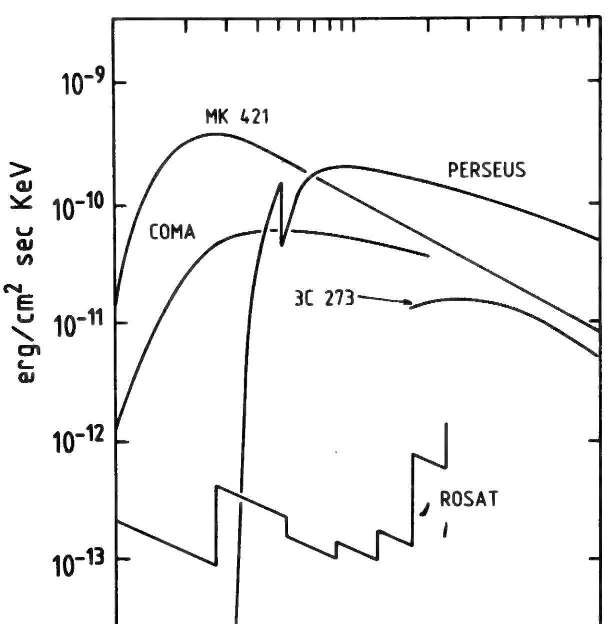


Fig. 5. Energy spectra of a few selected extragalactic X-ray sources compared with the detectability limit of ROSAT for a uniform, all-sky *survey* of half a year.

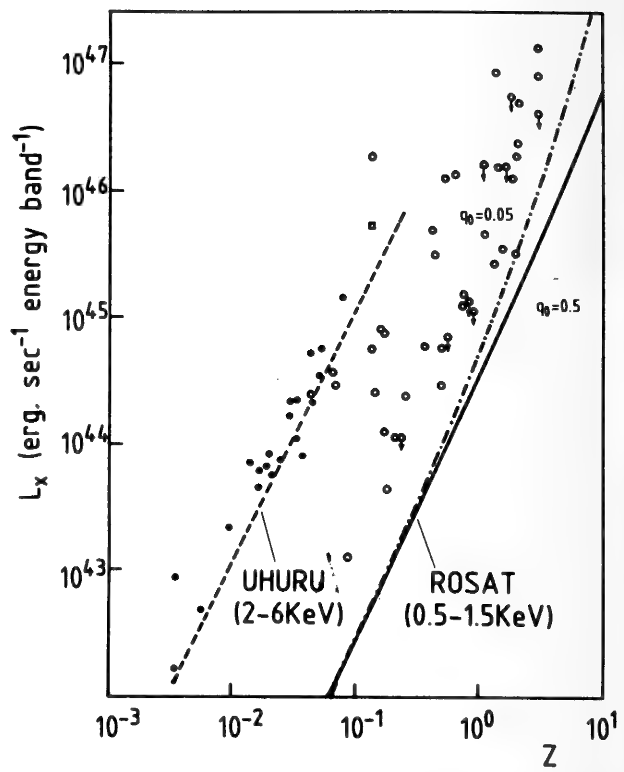


Fig. 6. Luminosity vs redshift diagram for Seyfert type I galaxies (●) and quasars (○). Data on Seyferts are from pre-Einstein-observatory experiments; data on quasars are from the Einstein observatory ($q_0 = 0$, $\Delta E = 0.5$–4.5 keV). The dashed line indicates the detectability limit of Uhuru. The dashed-dotted line and the solid lines indicate the detectability of the ROSAT all-sky survey for cosmological deceleration parameters $q_0 = 0.05$ and 0.5, respectively.

means of a guest investigator program. It is clear that the results of the sky survey would provide very important guidance for the ROSAT pointed observations. Therefore it is planned to generate a raw version of the sky survey maps in almost real time.

In summary, there is a large amount of new and excellent science which can be done with ROSAT both in the survey and the pointing mode. In the following we list a number of scientific objectives:

Galactic Astronomy

— study of coronal emission from stars of all spectral types

— measurement of X-ray luminosity functions of stars of all spectral types on the basis of complete samples

— study of correlations of L_x with L_{op}, magnetic fields and rotational periods for stars

- detection of X-ray time variability of flare stars
- study of outbursts of dwarf novae
- detection of thermal emission from isolated neutron stars
- study of soft X-ray emission from hot white dwarfs
- detection of X-ray emission from binary systems containing accreting white dwarfs, neutron stars and black holes
- mapping of extended sources like supernova remnants and galactic loops
- study of the large scale distribution of the diffuse galactic X-ray emission
- study of bright X-ray sources in nearby galaxies

Extragalactic Astronomy

- study in detail of various populations of extragalactic sources: i.e. Seyfert Type 1 and Type 2 galaxies, BL Lacertae objects, quasars, cluster of galaxies, young galaxies, radio galaxies
- measurement of luminosity function of above listed sources on the basis of large samples
- study of evolutionary effects back to $z \gtrsim 1$ on both population and luminosity functions
- unbiased search for ultra-high luminosity sources e.g. quasars or new classes of objects out to $z \lesssim 10$. These are most likely to be found in all-sky survey!
- morphological study of extended sources on a few arcmin scale. How and when do clusters form? Clusters of typically 500 kpc linear size can be detected as extended sources out to $z \lesssim 0.3$.
- search of the entire sky for supercluster formation. Do they provide the missing mass in order to close the universe?

5. Possible foreign participation

The baseline mission described above has been designed in such a way that it can be carried out as a national German project. However, as the satellite will be launched by the space shuttle, it is natural to consider a collaboration with NASA. Two possibilities have been discussed in this context, which differ not only in their scientific potential but also in their technical and financial implications.

1. The easiest possibility would be to leave ROSAT as described above and to consider participation of US scientists in the pointed mode observations.

2. A more involved participation would be the addition of a NASA high resolution instrument (HRI) in the focal plane, which would replace one of the three MPI imaging proportional counters thereby improving the angular resolution from 20 arcsec to better than 10 arcsec. This has no impact on the mirror system, since the design goal is 5 arcsec, anyway. But, it requires improved versions of the optical trackers, as well as additional complexity of the focal plane assembly.

In both versions it may be useful to change the orbital inclination from 56° to 28° and to use NASA facilities instead of the ones at Weilheim for telemetry. The technical and cost implications of a NASA participation are studied as options in our present phase B1 in order to provide the basis for further discussions and program decisions to be made after the completion of phase B1 in summer 1981.

Another possibility of foreign participation is the addition of a comparatively small, autonomous free standing instrument to the ROSAT spacecraft. A corresponding Announcement of Flight Opportunity was released by the Bundesminister für Forschung und Technologie within ESA in late 1979. This led to a very interesting proposal for a wide field soft X-ray camera, made by the University of Leicester through SRC, which is presently being studied in Phase B. Looking parallel to the main telescope this instrument would extend the useful energy range considerably beyond the low energy limit of ROSAT.

6. Possible evolution of the program—ROSAT 2

Being a shuttle launched satellite ROSAT may be retrieved by the shuttle and brought back to earth for refurbishment and relaunch. A particularly interesting possibility is to add a high efficiency transmission grating behind the telescope in order to perform soft X-ray spectroscopy in a second mission.

During the last two years, free standing gold transmission gratings with 1000 and 2000 lines/mm have been developed in Germany with a performance very close to the theoretical optimum (7). A transmission grating behind the ROSAT 80 cm telescope would be curved in order to avoid coma aberrations as shown in Figure 7. Table 3 summarizes the performance to be achieved with different combinations of gratings and focal plane instruments.

The main aim of ROSAT 2 would be to perform detailed spectroscopic studies of objects discovered by the ROSAT sky survey. A rich field would be furnished by the spectroscopy of stellar coronae. The Einstein photometric observations have shown that stellar coronal X-ray emission is a rather abundant phenomenon for stars of all spectral types (8, 9). Detailed spectroscopic studies with ROSAT 2 would yield invaluable plasma diagnostic information on these objects and enable corona temperatures and element abundances to be determined. This is illustrated in Figure 8 which shows the count rate spectrum calculated for a 10^5 sec observation of a thermal source of 5.1×10^6 K and an intensity which corresponds to ζ Puppis. Such spectrum contains a large number of detectable lines, predominantly from highly ionized states of oxygen and iron (10). A more detailed discussion of such a mission is given

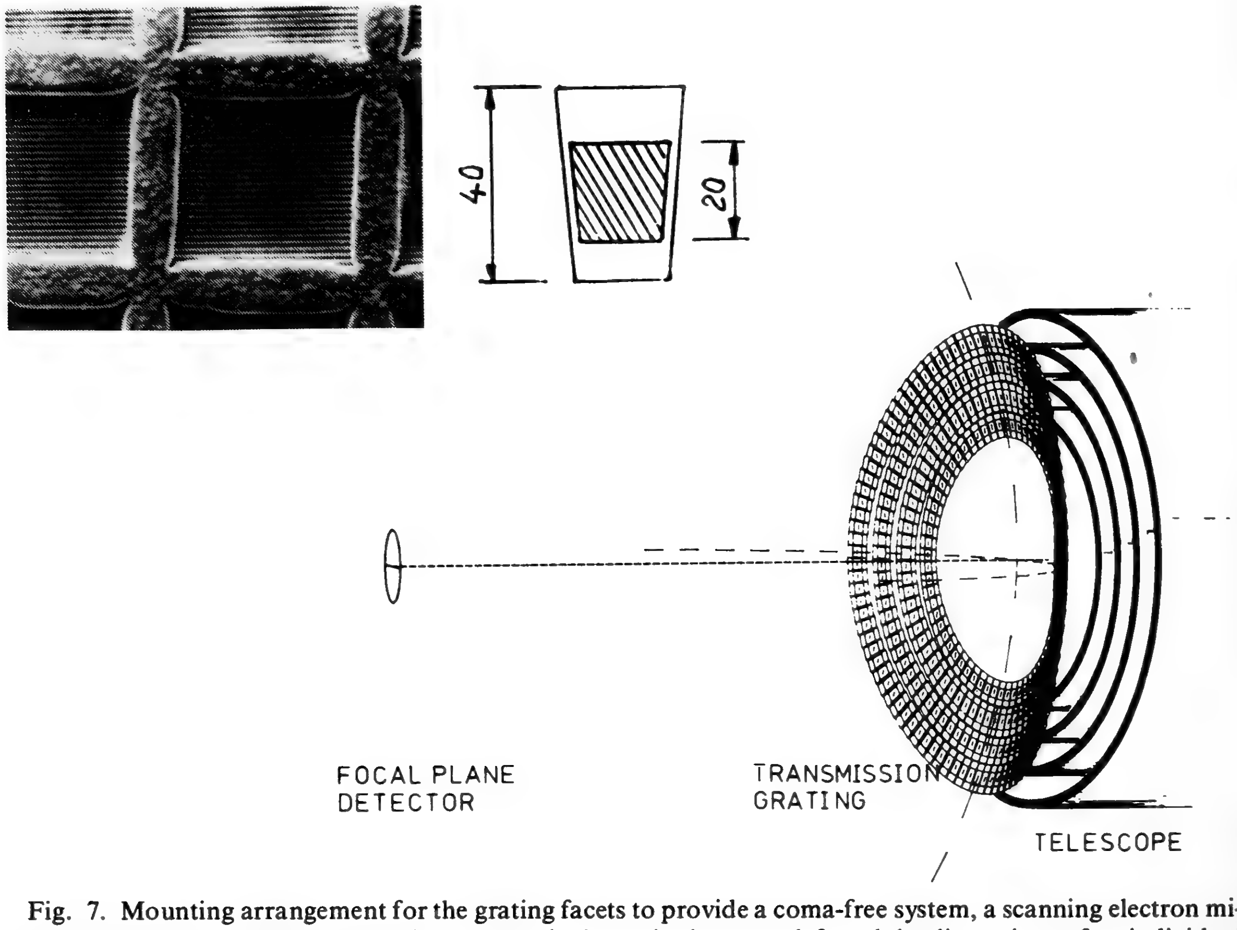


Fig. 7. Mounting arrangement for the grating facets to provide a coma-free system, a scanning electron microphotograph of a 1000 1/mm grating element is shown in the upper left and the dimensions of an individual facet are shown in the upper right.

Table 3.—Performance of ROSAT 2 Transmission grating spectroscopy

	focal instrument	
effective area	*HRI* ~5 cm^2	*IPC* ~50 cm^2
1000 1/mm grating		
wavelength range	8–200 Å	8–80 Å
Δλ (FWHM)	0.2 Å at 12 Å 0.4 Å at 80 Å 1.3 Å at 200 Å	1.5 Å at 12 Å 5 Å at 80 Å
2000 1/mm grating		
wavelength range	8–100 Å	8–80 Å
Δλ (FWHM)	0.1 Å at 12 Å 0.4 Å at 80 Å	0.8 Å at 12 Å 2.5 Å at 80 Å

by G. Vaiana in his talk on "Stellar X-ray Coronal Explorer" at this meeting (11). This project would actually be very similar to what is envisaged for ROSAT 2. Finally we note that a mission devoted to soft X-ray stellar spectroscopy would be largely complementary to AXAF which is optimized for high energies (up to 7 keV) and will concentrate on extragalactic and cosmological objects.

7. Present status and time schedule

At present, a team of 23 scientists, engineers and technicians is working at MPI on the development of the ROSAT focal plane

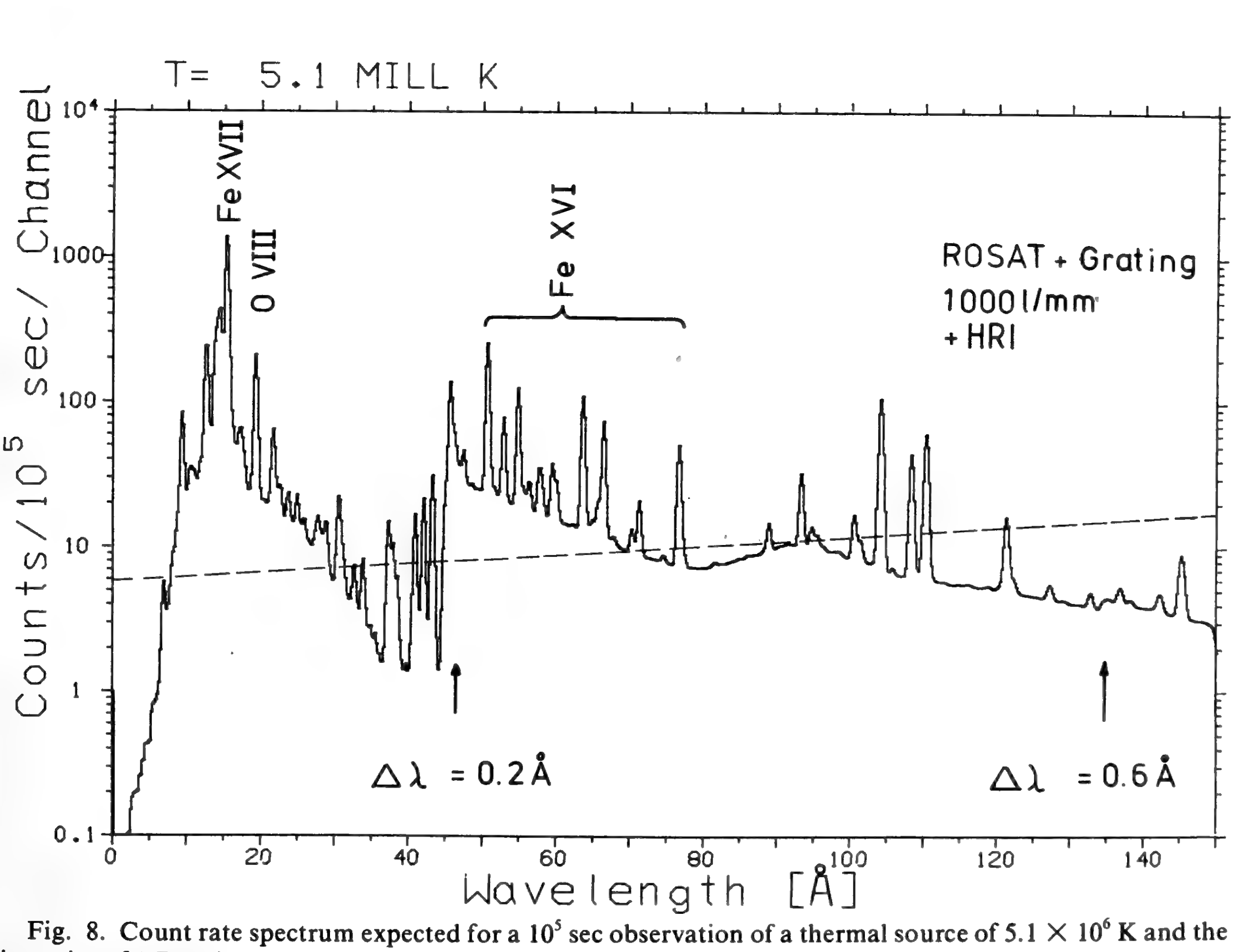
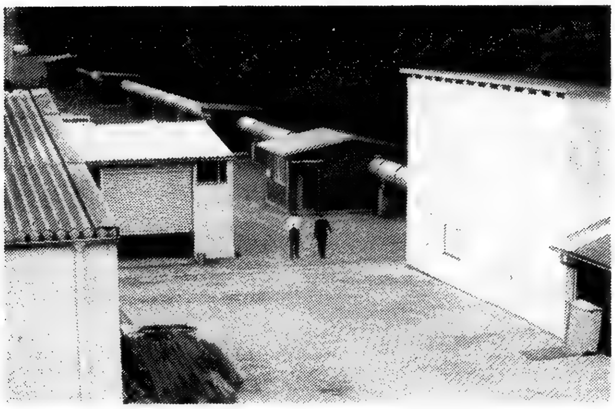


Fig. 8. Count rate spectrum expected for a 10^5 sec observation of a thermal source of 5.1×10^6 K and the intensity of ζ Puppis. The channel plate background is indicated by a dashed line.

instruments and various aspects of the mission, including preparations for the science data analysis. A 130 m long beam X-ray test facility has been built by MPI in Munich-Neuried whose major task is to support the ROSAT mirror development and qualification program and to make the X-ray calibrations of the flight telescope (12). Figure 9 shows a view of this facility which has been in operation since the fall of 1980.

At the Carl Zeiss Company the machines for figuring and polishing of the large mirror shells as well as instruments for measuring the surface figure and microroughness have been constructed. The mounting table to be used for the assembly of the mirror system is in the design phase. It is hoped that the first paraboloidal—hyperboloidal shell of the 80 cm telescope can be exposed to X-rays in our long beam facility early in 1982.

The current phase B1 study performed by Dornier System with Messerschmidt-Bölkow-Blohm and Carl Zeiss as subcontractors will end in the summer of 1981. The present schedule foresees a launch of ROSAT in 1986. A mission duration of 2 to 2.5 years would indicate a possible launch date of ROSAT 2 in the early 1990's.



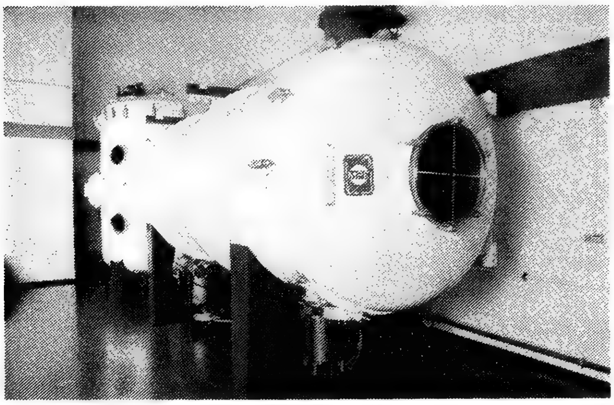


Fig. 9. View of the 130 m X-ray test facility of MPI Garching (top). The big vacuum chamber of the facility will take up the ROSAT telescopes for X-ray testing (bottom).

Acknowledgment

This project is a joint effort of the Deutsche Versuchsanstalt für Luft- und Raumfahrt, Dornier Systems, Messerschmitt-Bölkow-Blohm, Carl Zeiss—Oberkochen und MPI Garching. The Project management is conducted by a team of DFVLR-BPT under Dr. Pfeiffer on behalf of BMFT. The author is indebted to many people for useful discussions.

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Strategy of X-Ray Astronomy in Japan

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Japan's space program for the forthcoming 10 years will be briefly described. Here I will remain in rather technical and even superficial description, and not discuss much about physics assuming that physics rationale of each project in the program is almost obvious to today's audiences.

First, Figure 1 shows the Japanese 10-year plan or calendar of space science in general. The backbone of space science activities in Japan is the "small" satellite with the pace of approximately one per year. The square in the figure indicates the satellite: the upstairs shows the mission and the downstairs indicates the rocket. The definition of "small" may be somewhat misleading: the satellite which we can launch by ourselves with the solid propellant launcher developed in the university is called "small." Thus, the size of the spacecraft is not fixed. As our in-house rocket technology develops, it has grown from several 10 kg in weight to ~200 kg and will grow to approximately 700 kg in 10 years. In addition to this series of the small satellite, we hope to have one large satellite per, say, 5 years.

Unlike the US, before the details of the spacecraft are defined and proposed, the schedule of each discipline being given the chance of the spacecraft is discussed and determined. Therefore we know when we will have the spacecraft before it is designed in detail. For example, we know that we will conduct the Comet Halley mission whose objectives are not yet finally defined.

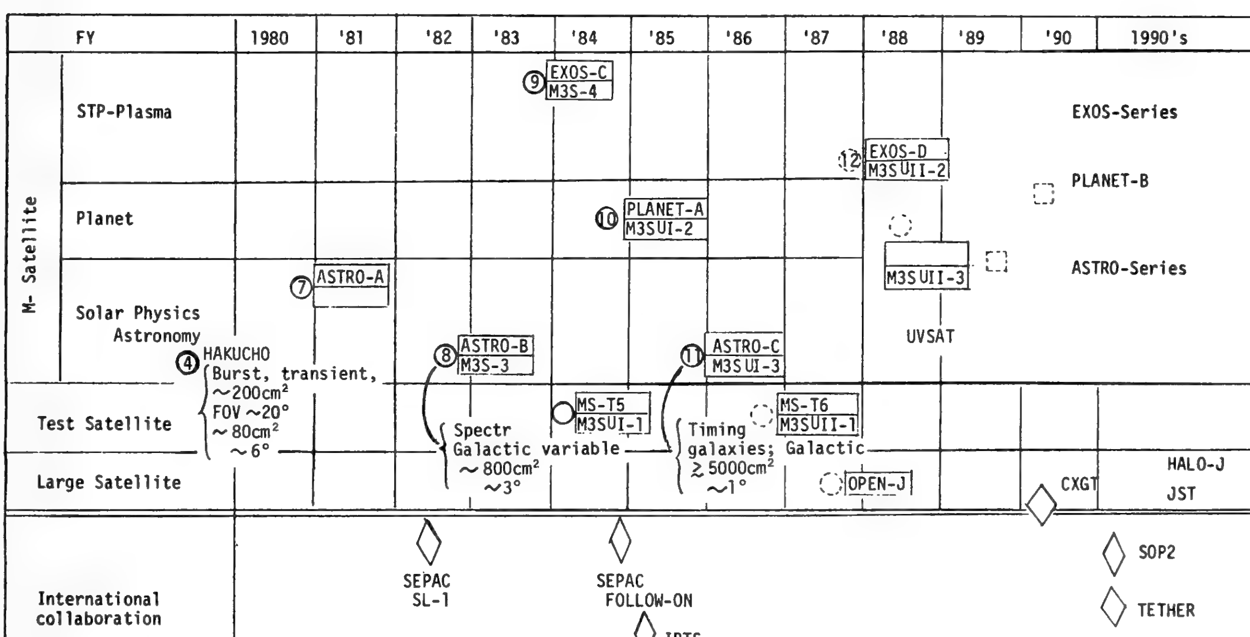

Fig. 1. Ten year program of Japan's space science.

The mission definition will be continually revised, reviewing the development of the rocketry. However, whether the observational programs on this spacecraft will be sufficiently funded or not is the different story.

Now, as for X-ray astronomy, currently we have "HAKUCHO" satellite in operation for almost 2 years and we hope to have it for at least another year. Following "HAKUCHO," two more X-ray satellites are scheduled in 1980's. We will have ASTRO-B in 1983 and then we are going to have another X-ray satellite which has been approved by the Space Activities Commission but not yet by the Ministry of Finance. Around 1990 or a little later the X-ray community will be given a chance of launching a large satellite.

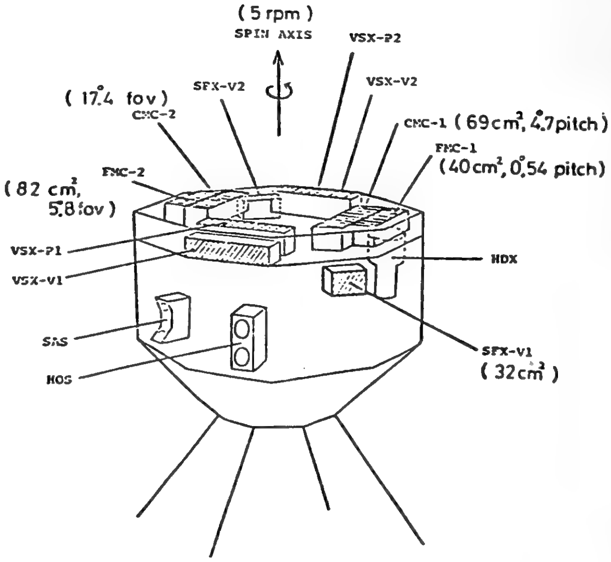

Fig. 2. Configuration of X-ray counters and aspect sensors of "HAKUCHO": SAS abbreviates the sun aspect sensor and HOS is the horizon sensor.

I will not come into the details but quickly go through specifications and guidelines of these satellites. In Table I, specifications of "HAKUCHO" are indicated. Most emphasized objectives are wide field of view watch and observations of X-ray burst sources, pulsars and other variable sources. Crude descriptions of three band detectors are presented. Proportional counters of wide field of view with modulation collimators watch a pointed region of the sky for bursts and other bright X-ray sources: locations of the objects are determined to the accuracy of ~0.5°. A proportional counter equipped with a fine modulation collimator is capable of determining the location to ~0.05°. Figure 2 shows the configuration of various counters. Observational results will not be given here but presented at the Workshop of the Tenth Texas Symposium.

Next, Table II indicates ASTRO-B which is due for launch in February 1983. Note that the weight is twice that of HAKUCHO. Emphasis is placed on the array of the scintillation proportional counter (gas scintillation counter) of reasonably large

Table 1.—"HAKUCHO": Feb 1979 → > Dec 1981: 96 Kg.

	1 ~ 30 keV pc				
Wide FOV burst obs.	CMC-1, 2	~70cm^2 × 2	with RMC	Spin-axis	sensitive to
	FMC-2	~40cm^2 × 1		pointing	0.1 Crab burst
	FMC-1	~80cm^2 × 1		Scanning	location to
Pulsars, other variables	SFXV	~30cm^2 × 2			~0.5/~0.05°
Transients	0.1 ~ 2.5 KeV				Time
	(1.5 μm pp	VSX-P	80cm^2 × 2	Pointing	0.01/0.1/0.75 sec
Wide band Spectr of strong sources	window)	VSX-V	80cm^2 × 2	Scanning	~1° $\gtrsim$5 sec
Sottransients	10 ~ 100 KeV				
	sc HDX	55cm^2		Pointing	~1°
				real time 5.461 kbps	
				storage 6.5 Mb	

Table II.—"ASTRO-B": Feb 1983: ~210 Kg, 0.137 rpm (×1/2, ×4).

Temporal-Spectral study of Galactic sources: Pulsar, burster, bulge source, other variables	large area SPC $100cm^2 \times (8–10)$ 2–60 KeV	Spin-axis pointing	FOV (3° dia FWHM) ΔE ~ 10% at 6 KeV Δt ~ 0.5/0.06/0.016 sec 0.01 Crab source per 1000 sec 0.001 Crab source per day
WideFOV watch: burst & other transients	Transient Source Monitor (TSM) a) One dimensional Hadamard-Transform Telescope: 1 ~ 30 KeV IPC $146cm^2 \times 2$		<30° from Z-axis 10 σ for 1 Crab burst 10 σ for 0.1 Crab source for 10 min. obs
	b) Scanning slats collimator counter: 1 ~ 30 KeV PC: $100cm^2 \times 2$		<60° from Z-axis ~0.1 Crab source per 5.5 sec obs
1 KeV range diffuse source	XFC one dimensional reflective collector. $20cm^2 \times 2$ f = 585mm		0.2° × 5° FOV × 8 cell
			real time 8.192 kbps storage 19.66 Mb

area provided by 10 counters of ~100 cm^2 each. Objectives are to study the time variability of X-ray spectra of some selected sources with a better energy resolution compared to the conventional proportional counter.

In addition, we plan a wide field of view watch for burst sources and other transient sources. For this purpose we have two instruments: one is the one-dimensional Hadamard-transform (or coded mask) telescope with the imaging proportional counter and the other is the scanning slats collimator counter. With all these instruments together, the sky within ≲ 60° from the direction of the spinning axis of the spacecraft will be scanned.

Further we have an additional instrument that is the one-dimensional reflective collector of two of 20 cm^2 area each. This is to exercise the technology of the reflective mirror and to study the spatial structure of diffuse sources over the ≲ keV range. The flight unit is being manufactured and will be assembled for the first time by the end of this fiscal year; i.e. April, 1981.

So much for the X-ray astronomy satellite in operation and in preparation. Next, as for ASTRO-C, again note that the weight will be increased. Launch date will be February, 1986, if the program will be hopefully approved by the Ministry of Finance in time. The concept of this mission is rather crude at the moment. Besides, technological constraints are not yet clear: e.g. the trade-off between the pointing accuracy of the spacecraft and the necessary weight for the aspect control has not been completely studied.

At present the basic idea is as indicated in Table III. The objectives are the high sensitivity observation of compact extragalactic sources and galactic sources. Particularly, the time variability of the nuclei of the extragalactic sources or long term monitoring of the sources will be emphasized. With a tentatively planned area of the proportional counters, ~5000 cm^2, the sensitivities may be calculated in a straightforward way as indicated.

In addition, again we feel that monitoring transient sources will be important.

Table III.—"ASTRO-C": FEB 1986 (?): ~400 Kg approved by Space Activities Commission, not yet by M. O. Finance.

High Sensitivity observations	Y-axis pointing $\gtrsim$5,000cm^{2}P.C. F.O.V. ~1° × 1°	~0.1°
Compact extraga. sources τ min. long term monitor X/opt	1 UFU detection or 1 UFU variation	in ≤ 100 sec.
Galactic sources	For 100 UFU source	
transients	1% var.	~100 sec.
pulsars	10% var.	~ 1 sec.
aperiodic	100% var.	~ 10 msec.
Transient Source Monitor (Status monitor of X-ray sky)		
	$\gtrsim$100 UFU source survey several times/day? Hadamard telescope or pin-hole camera) ?	

However, we are not yet sure whether we shall just watch for occurrence of the transient sources as the candidate object of the variability study or stress physical significance of the long term watch of some number of selected objects. Still, there is space for revision of the concept.

Finally, I come to the subject of a large X-ray satellite vaguely planned for around 1990. Original concept was produced as early as 1975. It was then a multi-purpose complex for X-ray and perhaps gamma ray observations. It was considered to be large, from our standard of that time, and hoped to be launched in mid-1980's. We hoped this would be included in the space programs under the US-Japanese collaboration which had been under discussion between NASA and the Space Activities Commission of Japan. However, the great success of the "Einstein," our own experiences with "HAKUCHO" and also discussions in an international symposium on the future prospect of Japanese X-ray astronomy held in the Summer of 1979 strongly affected our plan. Then, the value of the focussing mirror telescope in 1990 and on, even if it would be much smaller than AXAF, became more and more recognized. So the original concept evolved to the ASTRO-C in mid-1980's and the large satellite which is to be postponed to ~1990. At the moment the guideline of the CXGT is the mirror telescope. Everything is vague but we still hope this to be under the US-Japan cooperation.

X-Rays and Cosmology

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Introduction

Many cosmological tests have been devised to discriminate between the various cosmological models proposed over the past 60 years. These tests have almost exclusively made use of optical and radio observations. At the present time, the hot Big Bang model appears to be in excellent agreement with these observations, although it is still uncertain whether the Universe is open or closed.

X-ray observations may be applied to existing tests (number counts, angular diameter—redshift etc.) and may even be of advantage owing to greater and more uniform sky-coverage and perhaps to ease of discriminating galactic objects. Cosmic evolution of the sources is again likely to dominate the uncertainties. In order to predict how many sources there should be at a given redshift above a given flux level in a given waveband requires a theoretical model not only of the Universe, but of the source spectra and of their evolution with time. It may prove to be fortunate that most distant X-ray sources observed above a few keV are unlikely to show much in the way of line features. The form of source evolution is still unknown, but if, as appears to be the case in many galactic nuclei, the major energy loss is in X-rays, then it might be hoped that it is relatively simple.

The X-ray waveband also reveals a background radiation that is fairly well determined. The origin of this background is a matter for debate but is likely to lie within a redshift of about 3. If even a small part of it is due to hot intergalactic gas, then that may be the major matter constituent of the Universe and thus of q_0 and will be only detectable by X-rays. Whatever its origin, the isotropy of the background limits the lumpiness of the Universe on scales for which the X-ray sources are similarly clumped. Indeed current measurements from the Uhuru and Ariel 5 satellites provide the best limit on the lumpiness of the Universe on the scales of 100–1000 Mpc (Rees 1980).

1. Measurements of H_0 and q_0 from X-rays

The Hubble constant H_0 is currently uncertain to within a factor of two (50–100 km s^{-1} Mpc^{-1}) and its rate of change—the deceleration parameter, q_0—may lie anywhere between $\lesssim 0$ and $\gtrsim 0.5$. One way to constrain H_0 is to use a 'standard candle.' Such a device may emerge from X-ray observations of the luminosity function of binary X-ray sources (Margon & Ostriker 1973). The lack of sources brighter than 10^{39} $ergs^{-1}$ is possibly due to the Eddington limit, and is likely to be independent of distance. The actual shape of the luminosity function may vary with the Hubble type of the underlying galaxy, but it seems reasonable to suppose that X-ray distance measurements relying on fits to this function within the Virgo cluster will be possible with AXAF and LAMAR. Measurements of L to better than a factor of 4 will make this approach competitive with existing methods (at least at the present time).

Variability of the X-ray emission from active galactic nuclei, and quasars, may provide a method for greater distances. Electron scattering in matter being converted to energy with an efficiency of $0.1\eta_{0.1}$ constrains the emergent luminosity variation ΔL to occur on a timescale Δt such that

$$\Delta L \lesssim 2.10^{41}\ \eta_{0.1}\ \Delta t \text{ erg s}^{-1}$$

(Cavallo & Rees 1978, Fabian 1979). An efficiency of 0.1 is unlikely to be exceeded unless relativistic expansion or some special geometry is involved. A measurement of a variation in the flux of $10^{-10}\ \Delta S_{-10}$ erg cm^{-2} s^{-1} on a timescale 100 Δt_2 s thus constrains the distance to the source to be less than 42 $\Delta S_{-10}{}^{1/2}\ \Delta t_2{}^{1/2}$ Mpc. This approach has been applied to the 100s variations in NGC 6814 observed by the A-2 experiment on HEAO-1 by Tennant *et al.* (1981). The measured redshift of that galaxy is ~1400 km s^{-1}, which then implies that H_0 must be greater than 50 km s^{-1} Mpc^{-1}. Variations in quasars at a redshift of ~2, on timescales of days, can be used to limit $H_{z=2}$, and thus q_0. (The distance limit derived is then the 'luminosity distance' divided by $\sqrt{1+z}$.) This method will, of course, require the application of a statistical sample and can be used at any waveband if the scattering cross-section is appropriately modified.

A particularly interesting method for obtaining H_0 and q_0 from X-ray observations of clusters of galaxies has been suggested by Silk & White (1978), Gunn (1978), Cavaliere *et al.* (1979), Birkenshaw (1979) and Boynton & Murray (1978). The X-ray flux due to thermal bremsstrahlung from a spherical cloud of gas subtending an angle of 2Θ at a distance D is

$$S_x = C_x\, n_e^2\, T_e^{1/2}\, D\Theta^3,$$

where n_e and T_e are the electron density and temperature of the gas and C_x is a constant. Compton scattering of microwave background photons in the gas produces a decrease in the measured temperatures of the microwave background in that direction, longward of the blackbody peak (Sunyaev & Zel'dovich 1972)

$$\frac{\Delta T\mu}{T\mu} = C n_e T_e D\theta$$

where $C\mu$ is another constant. (The hard X-ray background could be used here if detectors were enormously more sensitive.) This combines to give D entirely in measurable quantities,

$$D = \frac{C_{x\mu}\theta}{T_e{}^{3/2} S_x}\left(\frac{\Delta T\mu}{T\mu}\right)^2,$$

and thus gives H_0 with the measured value of z for the cluster. Just two clusters at different distances give q_0. This method generalizes to any form of spherical distribution but requires accurate knowledge of the X-ray profile. Unfortunately, the reported microwave dips may not be due to Comptonization in the observed gas. White & Silk (1980) formally derive a value of only 1.5 km s^{-1} Mpc^{-1} for A576, and the error is at present ~±50 km s^{-1} Mpc^{-1}. Gas temperatures are in general too low to produce a measurable microwave dip, and most clusters are not spherically symmetric.

2. The Isotropy of the X-ray Background

The X-ray background in the 2–10 keV range is very isotropic. The observed small-scale fluctuations (~3°–10°) are completely explained as due to unresolved sources of the type already detected (Fabian 1975, Schwartz, Murray & Gursky 1976, Pye & Warwick 1979), and any residual fluction must be less than about 1 percent (Fabian & Rees 1978, Schwartz 1980). This gives us a powerful constraint on the lumpiness of matter in the Universe on scales of 100–1000 Mpc (Fabian, Warwick & Pye 1980, Rees 1980). If the Universe is perturbed by a ripple of amplitude $\delta\rho/\rho$ on a scale, then any anisotropy is dominated by the nearest lump, which will be $\sim\ell$ away. Then

$$\frac{\delta I}{I} \simeq f\left(\frac{\delta\rho}{\rho}\right)\left(\frac{\ell}{\ell_H}\right)$$

where ℓ_H is a Hubble radius, and f is the fraction of the background due to sources similarly perturbed. If most of the background is due to quasars, say, at redshifts ~2, then we again get another limit, which is diluted by the number of cells within our beam. Constraints produced in this way are shown in Figure 1. A more complete de-

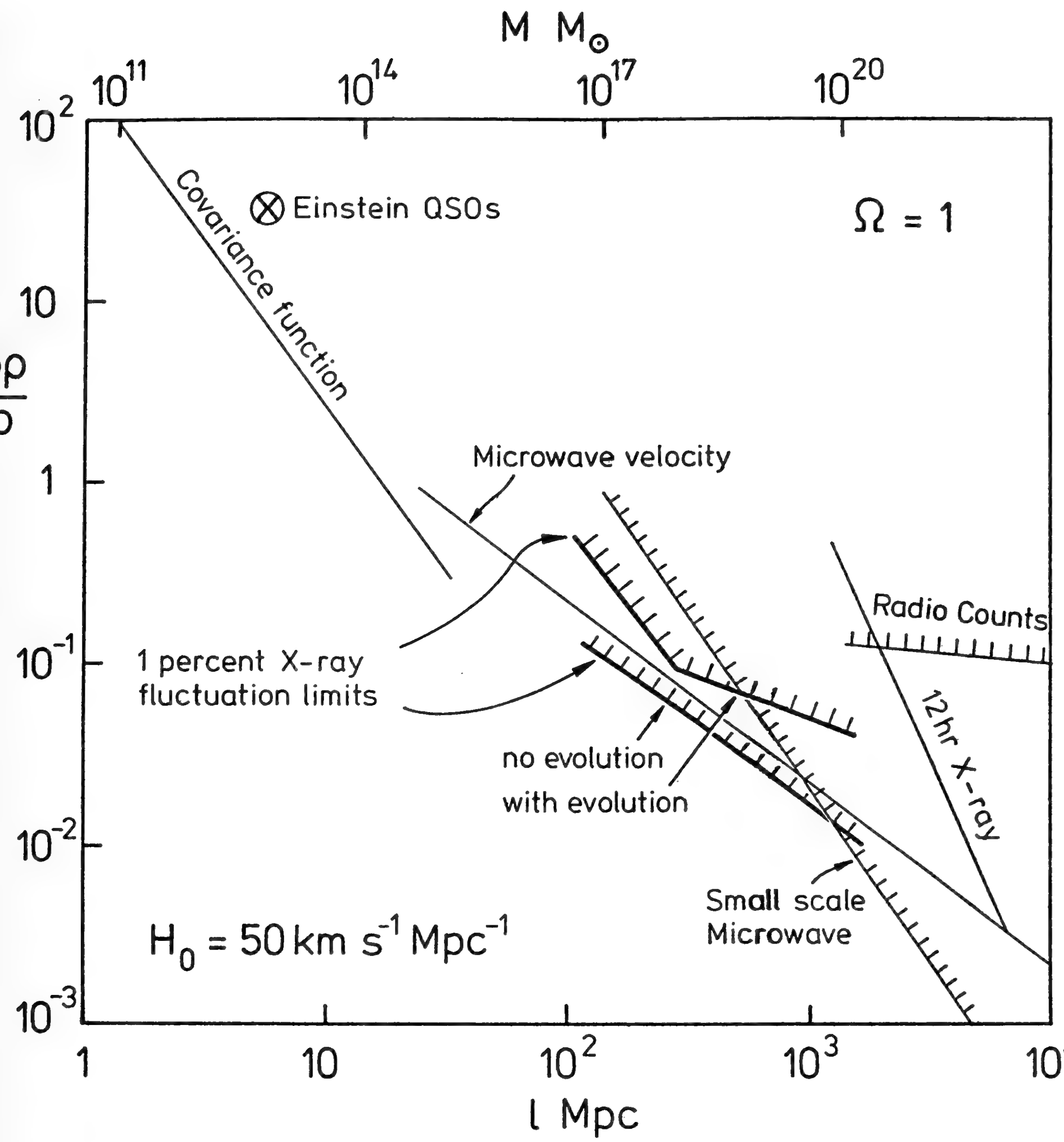

Fig. 1(a). Matter fluctuations ($\delta\rho/\rho$) at the current epoch on various length scales, for Ω ($=2q_0$) $= 1$. The covariance function line and X-ray limits assume that the galaxy and X-ray source distributions follow the underlying mass distribution. The small-scale microwave limit is for $\Delta T/T < 6.10^{-4}$ (see Partridge 1980) due to gravitational perturbations at the epoch of the last-scattering surface (Sachs & Wolfe 1967).

scription of the derivation of this figure is given in my Texas talk (Fabian 1981).

The X-ray background does show large-scale anisotropies due to our galaxy (Warwick, Pye & Fabian 1979, Schwartz 1980, Boldt 1980), and significant (but small) large-scale effects remain when a first-order galactic fit is removed from the Ariel-5 data. These could well be reflecting the complex structure of the galactic emission, but it is possible that they indicate very large scale motions in the Universe (Fabian & Warwick 1979). The comparison of large-scale X-ray and microwave anisotropies then leads to a measure of q_0 (Warwick, Pye & Fabian 1980).

The X-ray background offers us the only means yet of sampling the total emission in the Universe out to redshifts of ~3. With future X-ray studies it should be possible to

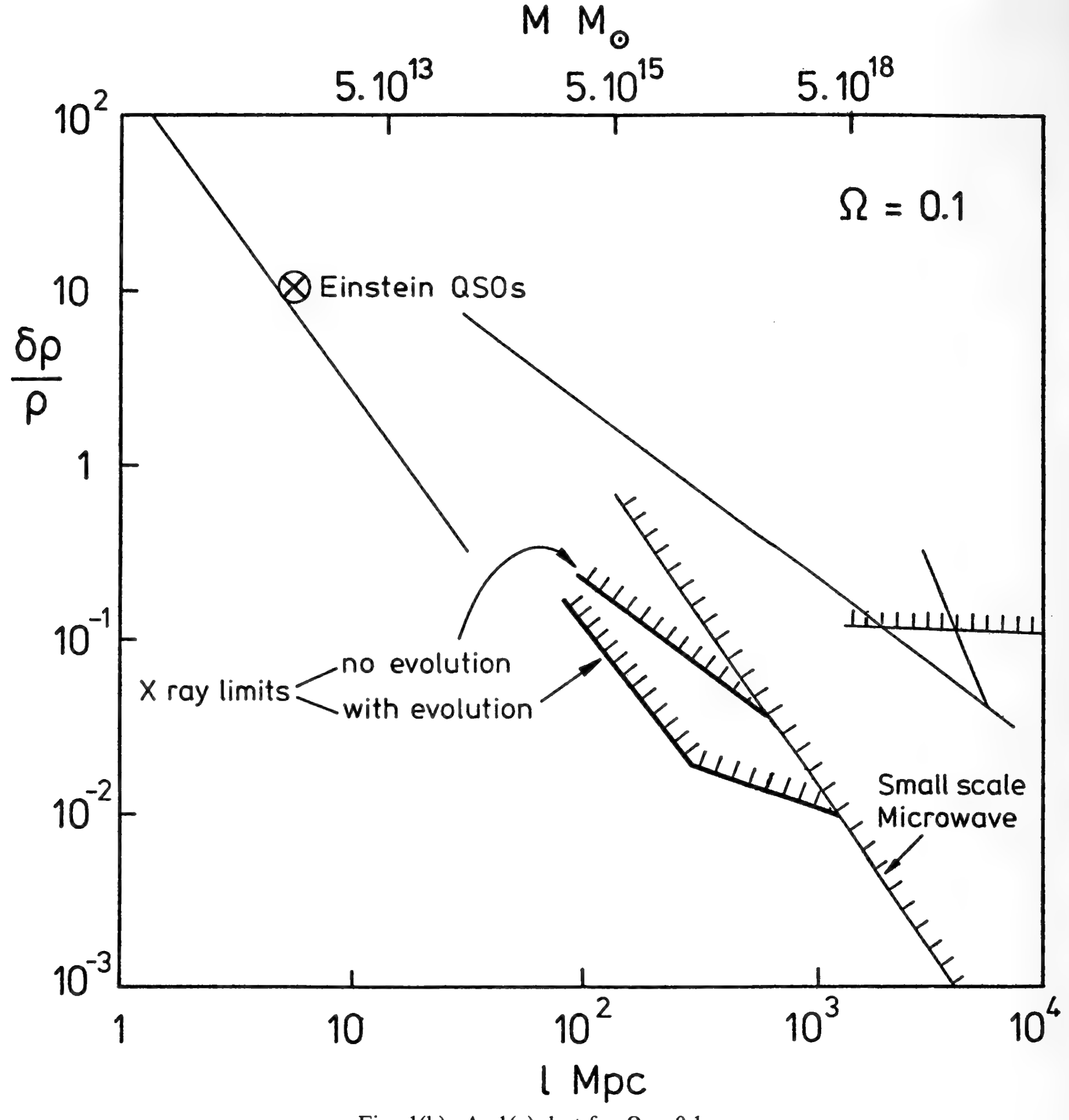

Fig. 1(b). As 1(a), but for $\Omega = 0.1$.

define the structure of the Universe on scales of ~50 Mpc to 2000 Mpc and beyond.

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A Sea of Carcinogens

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ABSTRACT

The human race is exposed to carcinogens of varying potencies by both occupational and environmental means. Exposure to occupational carcinogens can be controlled through regulatory agencies. Individuals have a responsibility to themselves to decrease their exposure to known carcinogenic factors that are involved in lifestyle.

Statements have been made that man is living in a sea of carcinogens or untested chemicals that may be carcinogens.[1–3] Certain groups claim that this has been so for ages; others attribute this "sea" to modern technology. Certainly, tumors—probably osteosarcomas—have been identified in the bones of dinosaurs that existed long before man as such appeared on earth. Furthermore, examination of Egyptian and Peruvian mummies from about 3000 years ago, has revealed the presences of various types of cancer, some of which are still prevalent in those parts of the world. Writings of ancient physicians and Egyptian papyruses all comment on diseases which obviously were cancers.[4] Thus, cancer in man is not a recent phenomemon at all.

Cancer, however, is difficult to define since it can be any of many diseases, characterized by uncontrolled growth of cells. Tumors are also divided into benign and maligant types, with widely differing characteristics. Thus, the cells in benign tumors have normal chromosomes, divide rarely and maintain relatively normal function. Cells from malignant tumors show abnormal chromosomes, divide frequently and often do not function normally.[5] As an example, in a benign tumor of the thyroid induced by feeding 2,4-diaminoanisole in a rat there is a sharp demarcation between tumor and normal tissue. However, in a malignant tumor such as that induced in the stomach of a rat by 1,2-dibromoethane or 1,2-dibromo-3-chloropropane, the tumor actively invades the adjacent cell layers. This example illustrates the difficulty of controlling and removing malignant tumors.

Even occupational cancer in man is not a recent development. In 1531 Paracelsus described a disease, now recognized as lung cancer, among the silver and cobalt miners of Germany. In 1700, Ramazzini wrote on cancer as a consequence of one's occupation—especially breast cancer in nuns.[6] However, the most widely known correlation was that made in 1775 by P. Pott between development of cancer of the scrotum in chimney sweeps due to exposure to soot. English chimney sweeps generally were young boys who were exposed all day and night to soot, since they slept in their clothes and bathing was unfashiona-

[1] Based on the Hillebrand Award Address before the Chemical Society of Washington, March 12, 1981.

ble. Thus, it is not surprising that cancer developed after 10–20 years of exposure. The disease was relatively uncommon on Continental Europe where bathing and protective clothing were required.

Many new industries developed in Europe in the late 1800's, largely as a result of dyestuff manufacture. Eventually it was realized that some of the products made or used were carcinogenic for workers. Examples were benzidine and 2-naphthylamine in the dyestuff industry and shale oil in machine operations.[7] Within the last 10 years, it was discovered that vinyl chloride led to an unusual type of liver tumor. In the USA alone, 78 billion lbs. of vinyl chloride have been produced since 1952; over 6 billion lbs. in 1979. Thus far, at least 84 cases of liver tumors have been noted in exposed U.S. workers.[8,9].

Epidemiologic or retrospective studies on various groups of people have led to the conclusion that certain compounds are carcinogenic in humans. These include polycyclic aromatic hydrocarbons, con-

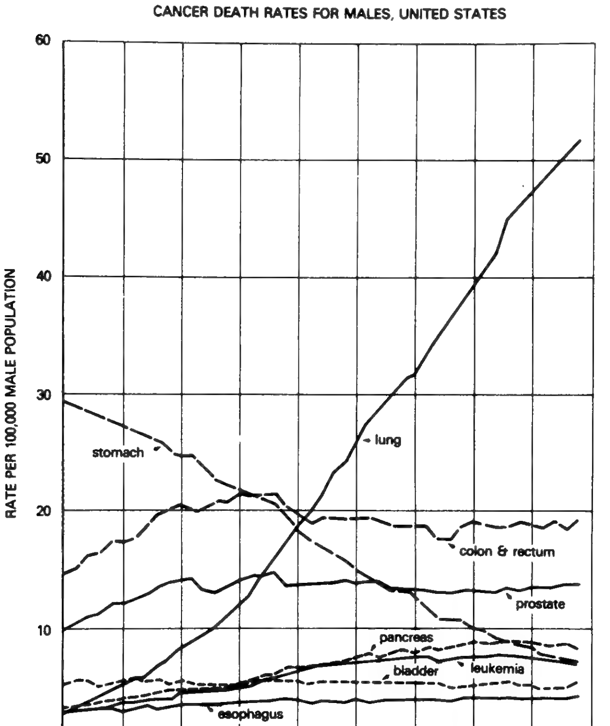

Fig. 1. Time trends in cancer mortality rates for U.S. males.

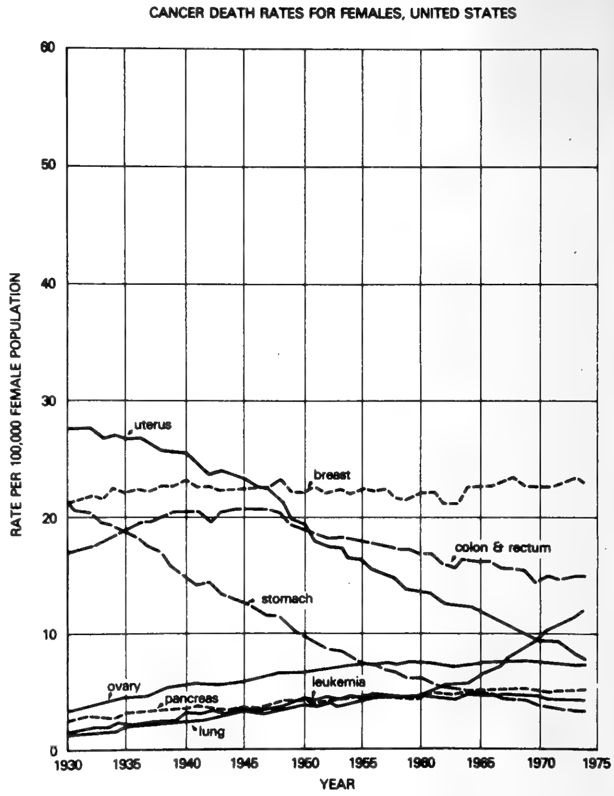

Fig. 2. Time trends in cancer mortality rates for U.S. females.

tained in soots, tars and the like, some aromatic amines, alkylating agents, nickel carbonyl, asbestos, radioactive elements, diethylstilbestrol, and others.[10]

Epidemiologic studies are complicated by the fact that cancer rates differ with the years and for various organs. Furthermore, one of the greatest risks from cancer is old age. Since infectious diseases such as tuberculosis, small pox, cholera, etc., have largely been eliminated, people live longer and have a greater probability of developing cancer. For U.S. males, stomach cancer is decreasing, probably as a result of better diet, but lung cancer is increasing rapidly (Figure 1). Similarly, in U.S. females, stomach cancer is decreasing; breast cancer remains almost constant; but lung cancer is beginning to increase (Figure 2). Furthermore, cancer rates differ from country to country. Despite the high lung cancer rate in the U.S.A., several other countries (i.e., Scotland, England and Wales, France) all have higher rates than does the U.S.A. With respect to stomach cancer, Japan has the lead, followed by Chile, while the rate in the U.S.A. is among the lowest.[11]

The problem is what can we do about preventing cancer?

One approach—that taken by the government or the country as a whole, is not to allow the indiscriminate use of carcinogenic chemicals, to regulate the exposure, and to require testing of new products or chemicals before introduction into the marketplace. Government is moving in this direction with the Toxic Substances Control Act. However, throughout the ages, new compounds and processes have been introduced without regard for some of their consequences. An early example was that of Prometheus, who according to Greek mythology, stole fire from the gods and gave it to man. Without fire or energy, technological development would be nil. But as a result of fire or pyrolytic processes, benzo[a]pyrene and related polycyclic aromatic hydrocarbons are formed. These compounds occur in soots, highly roasted food, charcoal broiled steaks, some crude oils, and around highways, airports, factories, in relatively higher concentrations. But benzo[a]pyrene is also present in forest soils, made by some algae in culture, expelled by volcanoes, and it even occurs in the deeper soil layers in permafrost regions, as in Siberia.[12] Thus, it is an environmental carcinogen to which everyone has some exposure.

Of course, if the government or industry are to know what is a carcinogen, then new compounds must be tested to determine whether they can induce tumors in animals. The National Toxicology Program, which evolved largely from the National Cancer Institute Bioassay Program, is charged with coordinating such efforts. The testing of any one compound is a long and expensive process. Compounds are tested by any of several routes, usually in rats and mice, but hamsters are also useful. Application may be by cutaneous, oral, injection, implantation and respiratory routes.

The initial phase of a bioassay includes acute toxicity tests, then repeated dose studies, then subchronic tests and finally a two-year chronic study in 2 species, with at least 50 males and 50 females of each species at each of several dose levels.[13]

The process requires teams of analytical chemists (to determine stability, purity, identify impurities, uniformity of mixing, etc), veterinarians, animal husbandry experts, histologists, pathologists, statisticians, data handling and computer experts. Furthermore, many factors can influence the outcome of a bioassay in animals. These include species, strain, sex, age, diet, presence of enzyme inducers in the diet, such as traces of pesticides or vegetable material, and the spontaneous incidence in the type of animal.[14]

The code of good laboratory practice, initiated by FDA, to increase confidence in results of tests on new drugs, also enters. Thus, tests of a new compound can well cost $500,000–$750,000, and last for 3–5 years.

One may well ask are there no cheaper and shorter tests. Much effort has gone into this area lately. One of the more widely publicized is the so-called Ames test in selected strains of the bacterium *Salmonella typhimurium*.[15] These bacteria have been developed to be especially sensitive (i.e., loss of their polysaccharide coats, the ability to repair themselves). But the test is very simple—a histidine requiring mutant is grown in presence of a trace of histidine plus the test compound. If the test compound mutates the bacteria to a form that doesn't require histidine, then the bacteria will grow and form colonies. To ensure that the test compounds will be activated or metabolized to their active forms, a fraction from mammalian liver (usually rat) called S-9 is often added.

Results are read in 24 to 48 hours. The premise is that a compound which can mutate bacteria, that is, cause a heritable change in their DNA, would mutate DNA of mammals and probably cause cancer. Thus the test is really a prescreen. In fact, EPA under the Toxic Substances Control Act now asks that eight assorted short term tests be done on new compounds. Three tests to detect gene mutations are required: either in bacteria, eukaryotic microorganisms, insects (fruit flies), mammalian somatic cells in culture, or the mouse specific locus test. Three tests to determine chromosomal aberrations can be selected from: cytogenetic tests in animals, insects (fruit flies), dominant lethal effects in rodents, or heritable translocation tests in rodents. At least 2 tests to detect DNA damage are required: DNA repair in bacteria, unscheduled DNA repair synthesis in mammalian cells; mitotic recombination in yeast and sister-chromatid exchange in mammalian cells.[16]

Why not use such tests entirely? There are discrepancies with the Ames tests. In a series of aromatic diamines, the Ames test showed too many false positives. Again the Ames test is negative for other compounds, some of which are animal and possibly even human carcinogens, procarbazine for example. Certain types of compounds, such as nitrosamines are not detected readily by the Ames tests.[17]

Other peculiar results have come from these types of studies since the cells are isolated, without aid from the detoxication and immunological resources of whole organisms. Vitamin C, and vitamin pills, for example, have caused chromosomal aberrations in Chinese hamster ovary cells, one of the generally accepted short term tests.[18] Thus, one cannot rely entirely on short term tests. The need for animal tests of very important new compounds will continue, although the short term methods will furnish some information on their mode of action and give valuable clues as to their degree of suspicion.

What else can be done about reducing the exposure to carcinogens? Individual efforts are needed and probably are more important overall than governmental attempts to reduce occupational exposure. This is especially important to chemists—note that they are at higher risk for developing certain types of cancer. A study by Li and associates[19] reported American male chemists had a higher than expected risk of death due to malignant neoplasms, including those of the pancreas and lymphatic and hematopoietic systems. Similar data have now been reported for Swedish and British chemist. Thus, one should use chemicals wisely and in a safe fashion, either in the laboratory, in industry, in hobbies, or other situations.

One can decrease or cut out exposure to other factors which are carcinogenic. One of the most important is smoking, a habit popularized in Europe by Sir Walter Raleigh, which led to the extensive cultivation of tobacco, an important crop in nearby Maryland.

The American Cancer Society estimates there will be 325,000 premature deaths in 1981 from smoking, about 120,000 from heart disease; about 105,000 from lung cancer, some from throat, bladder and pancreas cancer, the rest from emphysema, bronchitis, etc.[20] In view of the many compounds in tobacco smoke, this is not surprising. These include the toxins: CO, NH_3, nitrogen oxides, HCN, aldehydes, dialkylnitrosamines, hydrazine, and vinyl chloride. The particulate phase of tobacco smoke contains various nitrosamines, ^{210}Po, nickel compounds, cadmium compounds as well as numerous carcinogenic polycyclic aromatic hydrocarbons and analogs such as dibenzoacridines.[21] Even unburned tobacco contains carcinogenic nitrosamines, most derived from the nicotine.[22] Furthermore, use of tobacco along with alcohol increases the risk of certain types of tumors, especially of the throat. Smoking and exposure to asbestos increases the risk 90-fold.

Another important component is sunlight—where it is estimated that 10% of cancers in males and females result from overexposure to this natural factor. Some sunlight is needed to allow our bodies to make vitamin D, but an excess is harmful.

Radiation—from cosmic, x-rays, or

other sources, is only a small component. However, living at high elevations or flying in jet airplanes does increase risk. Uranium miners are a class at greater risk of developing lung tumors because of the radon gas inhaled. Smoking likewise increases the effect over that of uranium mining alone.[23]

The variety of possible carcinogens to which people are exposed through diet is amazing. People eat mushrooms such as the false morel, a delicious but expensive item, which contain hydrazines. Among spices and flavorings, the tarragon plant contains estragole which led to liver tumors in young male mice. Safrole, a minute component of many spices, but an appreciable component of sassafras root is also carcinogenic in rats and mice.[24–26] However, occasional use of spices is probably not harmful, but overabuse might be. In Hawaii certain seaweeds are used as flavorings; these contain various halogenated compounds, many related to toxic or carcinogenic substances.[27] Cooking, especially broiling or frying, yields traces of compounds in the dark portions of the cooked meat or fish, which are very mutagenic and transform cells in culture.[28,29] There are traces of benzene in foods such as eggs, cooked fish or meat, vegetables, the aroma of fruits, dairy products.[30] Benzene was even a minor component of the 228 flavor constituents of baked potatoes.[31]

Exposure also occurs in herb teas and home remedies: comfrey used in teas; coltsfoot used as a vegetable and to make cough syrup; tansy ragwort, a contaminant of grain, milk, honey and also a herbal medicine. All these contain pyrrolizidine alkaloids similar to retrorsine which was carcinogenic in rats.[32]

One could eat moldy peanuts and be exposed to aflatoxin, the most potent liver carcinogen known, from *Aspergillus flavus*. The fiddleheads or croziers of bracken fern, are also eaten as a vegetable in Canada, Japan and parts of the U.S.A. This plant is carcinogenic to rats, mice and cattle.[33] Ethyl carbamate may be formed from ethanol and carbamyl phosphate during fermentation processes.[34] Nitrosamines may be formed endogenously from nitrite and amines.[35]

Thus, people are indeed exposed to many carcinogens, of which only some prominent examples have been mentioned.[36] Some of these compounds are used industrially where all efforts should be made to limit exposure. Some carcinogenic factors are inevitable—cosmic radiation, for example, about which we can do little in a reasonable fashion. As individuals we can do something about others—avoid or cut down exposure, live a moderate lifestyle, eat varied but adequate diets, lower in red meat and fats, but including certain vegetables and fruits which contain protective factors.[37] Remember that *man* and *woman* have evolved over a long time and have developed many defenses against toxic substances, including carcinogens. Human cells in culture have much higher capacity to repair damage to DNA than cells from other mammals. It helps too, to have chosen good ancestors. Let your motto be: Ask not only what the government can do to prevent cancer, but ask also what one can do individually to decrease the probability of becoming a cancer patient.

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Recombinant DNA and the NIH Guidelines

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ABSTRACT

Recombinant DNA is a technique of major importance in basic biomedical research and increasingly in industrial applications. The National Institutes of Health Guidelines for Research Involving Recombinant DNA Molecules are a widely accepted, evolving set of safety standards.

Deoxyribonucleic acid (DNA) exists within all cells and determines hereditary characteristics. Chromosomes contain genes and genes are made up of DNA.

Recombinant DNA is a technique that allows a piece of DNA from one organism to be joined to a piece of DNA from another organism in a test tube, after which the DNA is inserted back into a living cell.[1,2] That is, this technique allows the transfer of genes from cells of one species to cells of another species.

By introducing a particular piece of DNA into a bacterium, and then growing up the bacterial cells, one can produce large amounts of the desired DNA segments for study. This had been, and continues to be, widely used, in thousands of laboratories throughout the world, to produce DNA which is then analyzed to determine the precise structure of specific genes.[a] This has led to a major finding about the organization of DNA in eukaryotic cells, namely the existence of "intervening," or "intron," sequences.[3–5] Much new information is arising from recombinant DNA experiments, some of which may be important in ultimately understanding why a cancer cell is different from a normal cell.

If the inserted recombinant DNA in the cell is transcribed into messenger RNA and then translated into protein, a whole new range of possibilities opens up. Major successes have been reported in the past years leading to the production by bacteria of mammalian proteins such as somatostatin,[6] insulin,[7,8] growth hormone,[9] and interferon.[10,11] Techniques are being perfected to increase the yields of bacterial production of such proteins. Theoretically, any protein can be made in bacteria; recombinant DNA promises to yield scarce biological products such as biologically active peptides[12] and hormones,[13] and viral antigens to use as vaccines[14–16] in huge amounts, at a much lower cost than they are today.

[a] An entire recent issue (Volume 209, Number 4463, September 19, 1980) of the journal *Science* is devoted to recombinant DNA experiments.

Outside the pharmaceutical industry, many other uses are being explored.[a] Among these are:

Chemical production—inserting genes into bacteria so that they can synthesize organic chemicals, such as ethylene oxide used in making plastics, or ethylene glycol.

Energy production—inserting genes into bacteria to enable them to convert plants or sewage into methane, methanol, ethanol, hydrogen, or other compounds that can be burned as fuels.

Metal-extracting bacteria—inserting genes into bacteria so that the bacteria can eat away impurities, allowing the extraction of desired metals from ores.

All these uses of recombinant DNA involve inserting recombinant DNA into microorganisms. Another class of uses, just beginning to be explored, involves the insertion of recombinant DNA into higher organisms. There have already been numerous instances of recombinant DNA being added to, and expressing protein products in, the cells of higher organisms in tissue culture. A future goal would be the insertion of nitrogen fixation genes into agriculturally important plants, eliminating the need for fertilizers. Ultimately, it should be possible to alter the genetic constitution of higher animals and man to cure inherited disorders.

There are already many benefits of recombinant DNA research and they will surely grow in the coming years. The risks remain hypothetical. Recombinant DNA experiments have now been performed for over 8 years, with millions of recombinant DNA clones produced in thousands of laboratories throughout the world, and to date, no actual hazard has been demonstrated. However, because of concern about possible dangers of recombinant DNA molecules, scientists working in this field spearheaded discussions of safety.

Both the promise and possible hazards of recombinant DNA experiments were discussed at a 1973 Gordon Conference. Those present voted that a letter be sent to the National Academy of Sciences, and be published suggesting that the Academy "consider this problem and recommend specific actions or guidelines."[17]

In response, the Academy formed a distinguished committee which proposed[18] "First, and most important, that until the potential hazards of such recombinant DNA molecules have been better evaluated or until adequate methods are developed for preventing their spread, scientists throughout the world join with the members of this committee in voluntarily deferring [certain] experiments." (This request was widely hailed in the press as a historical occurrence of scientists calling for a voluntary "moratorium" on certain experiments while questions of public safety were further evaluated.)

Second, the committee called for the National Institutes of Health (NIH) to establish an Advisory Committee for ". . . devising guidelines to be followed by investigators working with potentially hazardous recombinant DNA molecules."

Third, the committee called for an international conference. This was held in February 1975 at the Asilomar Conference Center.[b] There were 150 attendees from 15 countries (plus many members of the press, who gave the meeting wide coverage). The final report of the Conference recommended proceeding with most recombinant DNA experiments using appropriate "physical containment" and "biological containment."[19]

[a] Recent articles describing industrial uses of microorganisms into which recombinant DNA has been inserted include: a cover story in *Time*, March 9, 1981, "Shaping Life in the Lab"; a cover story in *Newsweek*, March 17, 1980, "DNA's New Miracles"; a cover story in *Life*, May 1980, "Weaving New Life in the Lab"; *Science*, May 16, 1980, "Cloning Gold Rush Turns Basic Biology into Big Business"; *Chemical Week*, October 8, 1980, "Biotechnology: Research That Could Remake Industries"; *Fortune*, June 16, 1980, "DNA Can Build Companies, Too" and the *New York Times Magazine*, February 17, 1980, "On the Brink of Altering Life."

[b] Two books describing the Asilomar Conference are: *The Ultimate Experiment* by Nicholas Wade, Walker and Company, 1977; and *Biohazard* by Michael Rogers, Alfred A. Knopf, 1977.

The NIH Recombinant DNA Advisory Committee (RAC) was formed in response to the request in the 1974 Berg *et al.* letter. The first RAC meeting[a] was held the day after the Asilomar Conference. After a series of meetings, the RAC, in December 1975, adopted its proposed Guidelines for Recombinant DNA Research. When NIH Director Donald Fredrickson received these proposed Guidelines from the RAC, he called a meeting of his Director's Advisory Committee in February 1976, to which he invited many distinguished scientific and public representatives. (The full transcript of this February 1976 meeting, and all letters received on the proposed Guidelines, form the bulk of Volume One of what is now a five-volume massive public record of the history of the NIH Guidelines.)[b] Following changes based on the suggestions received at the February 1976 meeting and afterwards, the original NIH Guidelines were made final and released in June 1976.

The original 1976 NIH Guidelines[c] included a list of prohibited experiments. The Guidelines then described in great detail four sets of special practices, equipment, and laboratory installations that defined four levels of physical containment, called P1, P2, P3, and P4. P1 corresponds to the microbiology diagnostic laboratories existing in all hospitals where infectious microorganisms isolated from patients are grown and analyzed. P2 adds more practices and equipment—most important, the use of biological safety cabinets for certain operations. P3 adds still more special practices, equipment, and laboratory installations—most important, the entire laboratory is operated with an inward air flow, like a giant hood. P4 laboratories have many special engineering features. All experiments are confined to Class III air-tight biological safety cabinets, working through glove ports. An entire set of secondary barriers exist.

P1 and P4 are levels of physical containment. A major advance coming out of the Asilomar Conference was the concept of biological containment. Biological containment is defined as the use of organisms with limited ability to survive outside of the laboratory. Most recombinant DNA experiments at present are being done with the harmless bacterium *Escherichia coli* strain K-12. Its use, together with certain specified plasmid or bacteriophage vectors, constitutes what is called the EK1 level of biological containment. By further modifying *E. coli* K-12 to render the bacteria much less likely to survive, were they to escape from the laboratory (for example, by making them dependent for survival on certain nutrients which are supplied in the laboratory, but which do not occur in significant concentrations in nature, and by making the modified bacteria sensitive to sunlight and to bile acids), and by requiring data on the survivability to be submitted to NIH, and approved by the RAC, one finally arrived at what were called the EK2 and EK3 levels of biological containment.

The Guidelines, having defined four levels of physical containment—P1, P2, P3 and P4—and three levels of biological containment—EK1, EK2, and EK3—went on to specify a specific level of physical containment and of biological containment for each of many different kinds of experiments.

Finally, the Guidelines discussed the roles and responsibilities of the scientist, his university, its institutional biosafety committee, and the NIH.

In July 1976, Senators Javits and Kennedy wrote to President Ford urging

[a] Minutes of all RAC meetings are available from the Office of Recombinant DNA Activities, Building 31, Room 4A52, National Institutes of Health, Bethesda, Maryland.

[b] The volumes in this series may be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, or viewed in some 600 public libraries of the GPO depository system. The GPO stock number of Volume 1 is 017-040-00398-6; Volume 2, 017-040-00422-2 and (supplement: Environmental Impact Statement) 017-040-00413-3; Volume 3, 017-040-00429-0 and (appendices) 017-040-00430-3; Volume 4, 017-040-00443-5 and (appendices) 017-040-00442-7; and Volume 5, 017-040-00470-2.

[c] Federal Register, July 7, 1976, Volume 41, pp. 27902–27943.

that "every possible measure be explored for assuring that the NIH Guidelines are adhered to in all sectors of the research community." In his reply to the two Senators, President Ford described the creation of the Federal Interagency Advisory Committee on Recombinant DNA Research. This Committee has met periodically since 1976.[a] It consists of members from all Federal agencies which either fund or might regulate recombinant DNA research. In 1977, it recommended new national legislation to extend the NIH Guidelines by law to private industry.

In the first session of the 95th Congress, which lasted through 1977, many different bills on the topic of recombinant DNA were introduced. Extensive hearings were held. Over 100 witnesses appeared before the Senate Subcommittee on Health and Scientific Research[b] (Edward Kennedy, Chairman): the Senate Subcommittee on Science, Technology and Space[c] (Adlai Stevenson, Chairman); the House Subcommittee on Health and Environment[d] (Paul Rogers, Chairman); and the House Subcommittee on Science, Research and Technology[e] (Ray Thornton, Chairman).

There was great disagreement on a number of provisions of the proposed recombinant DNA bills, and none ever reached the floor of the full House or Senate for a vote. There is, therefore, no national law making the NIH Guidelines mandatory for private industry.

In the absence of national legislation, a number of states and localities have acted. In Cambridge, Massachusetts, in 1976, the City Council called for a six-month moratorium on all P3 and P4 research by Harvard University and the Massachusetts Institute of Technology while an appointed Cambridge Experimental Review Board studied the situation. The Board consisted of a former Cambridge mayor and owner of a heating oil business, a community worker, a hospital nurse, an engineer, a practicing physician, a social worker, and a professor of urban policy. None of the members knew anything about recombinant DNA before they were appointed; they heard over 75 hours of testimony, and finally issued their report recommending that recombinant DNA research be allowed in Cambridge, basically under the NIH Guidelines with a few added restrictions. This was adopted by the Cambridge City Council in February 1977. Other local jurisdictions which have made the NIH Guidelines mandatory are: Princeton, New Jersey; Amherst, Massachusetts; Waltham, Massachusetts; Berkeley, California; and Emeryville, California. Two states have enacted such legislation—New York and Maryland.

Internationally, guidelines either identical, or similar, to the NIH Guidelines have been adopted in many countries. The national committees monitoring this research communicate regularly with each other, freely exchanging information on their rules.

Two and a half years elapsed between the issuance of the original NIH Guidelines in June 1976 and the issuance of revised Guidelines in December 1978. Many steps were involved in the revision. First, the RAC worked during the spring of 1977, at a number of meetings, to produce draft revisions. A workshop held in Falmouth, Massachusetts, in June 1977,[f] led to a consensus of experts that *E. coli* K-12 is a harmless organism and cannot be converted into a pathogen by the insertion of recombinant DNA. Revised Guidelines as proposed by the RAC were published in the *Federal Register* in September 1977[g] and sent out widely for public comment. At the NIH Director's

[a] Minutes of all meetings of the Federal Interagency Advisory Committee on Recombinant DNA Research are available from the Committee Executive Secretary, Building 1, Room 137, National Institutes of Health, Bethesda, Maryland, 20205.

[b] Hearing held on April 6, 1977.

[c] Hearings held on November 2, 8, and 10, 1977.

[d] Hearings held on March 15, 16, and 17, 1977.

[e] Hearings held on March 29, 30, 31; April 27, 28; May 3, 4, 5, 25, 26; and September 7 and 8, 1977.

[f] The procedings of the Falmouth Workshop were published (1978) in the Journal of Infectious Diseases **137**: 613–714.

[g] Federal Register, September 27, 1977, Volume 42, pp. 49596–49609.

Advisory Committee meeting in December 1977, many witnesses spoke about their views of the proposed revisions.[a] Additional scientific meetings were held, focusing especially on the risks of recombinant DNA experiments involving viruses[b] and plant pathogens.[c] Then, after much further analysis, a new set of proposed revised Guidelines was published in July 1978. This document,[d] which amounted to 136 pages in the *Federal Register*, actually consisted of three parts: the new proposed Guidelines; a "Decision Document" explaining in great detail the proposed changes and the reasons for them, as well as why certain suggested changes were not adopted; and an Environmental Impact Assessment. It was mailed to over 2,500 individuals who had communicated their interest in this issue to NIH, with a 60-day period allowed for public comment; 170 responses were received. In addition, a public hearing was held in September 1978, chaired by the General Counsel of the Department of Health, Education, and Welfare.[e]

After careful analysis of all comments received, final revised Guidelines were issued on December 22, 1978, accompanied by a new Decision Document and Environmental Impact Assessment.[f] Some of the major changes in the new December 1978 Guidelines, as compared with the original 1976 Guidelines, were:

1. In general, experiments were assigned lower levels of required containment.
2. Certain classes of experiments deemed of the lowest potential hazard were exempted entirely from the Guidelines.
3. Increased representation was mandated on local institutional biosafety committees and on the RAC.
4. Built into the Guidelines were procedures to change them in the future.

The RAC was originally a 14-member committee, composed entirely of scientists. At the RAC's own suggestion, two laymen were added to the Committee in 1976, a professor of government and a bioethicist. At the time of the Guidelines revision in December 1978, the RAC was expanded to 25 voting members, at least six of whom were required to "be persons knowledgeable in applicable law, standards of professional conduct and practice, public attitudes, the environment, public health, occupational health, or related fields." Also, scientists representing many different backgrounds were added as members, and all relevant Federal agencies were given nonvoting membership. There are currently 15 agencies so represented. Since July 1980, the Chairman of the RAC has been Ray Thornton, former Congressman and currently President of Arkansas State University.

Another change in the 1978 Guidelines, as compared with the 1976 Guidelines, was the requirement that local institutional biosafety committees, which oversee the work at each institution, must contain at least two members, at least 20% of their membership, who are not affiliated with the institution and who represent the interest of the surrounding community with respect to health and protection of the environment.

Perhaps the major change in the December 1978 Guidelines compared with the original 1976 Guidelines was that a process was built into the Guidelines for further incrementally changing them. Anyone wishing to suggest a Guideline revision may submit such to NIH. It is published in the *Federal*

[a] The transcript of the December 15–16, 1977, meeting of the NIH Director's Advisory Committee appears in Volume 3 of the documents cited in footnote b, p. 3 of this manuscript.

[b] The report of the US—EMBO Workshop to Assess Risks for Recombinant DNA Experiments Involving the Genomes of Animal, Plant and Insect Viruses appears in the Federal Register, March 31, 1978, Volume 43, pp. 13748–13755, and again July 28, 1978, Volume 43, pp. 33159–33167.

[c] The report of the Workshop on Risk Assessment of Agricultural Pathogens appears in the Federal Register, July 28, 1978, Volume 43, pp. 33174–33178.

[d] Federal Register, July 28, 1978, Volume 43, pp. 33042–33178.

[e] The transcript of the September 15, 1978, hearing appears in Volume 4 of the documents cited in footnote b, p. 3 of this manuscript.

[f] Federal Register, December 22, 1978, Volume 43, pp. 60080–60131.

Register for public comment at least 30 days prior to a regular quarterly meeting of the RAC. The suggested revision, together with all written comments received, is then considered by the RAC at its open meeting; members of the public wishing to speak on the subject are given an opportunity. Following the discussion, the RAC votes on whether to recommend the Guideline revision. After the meeting, the Director, NIH, promulgates in the *Federal Register* his final decision on the RAC recommendations. In this fashion, the Guidelines have been incrementally modified essentially every three months since December 1978.[a]

The original 1976 NIH Guidelines said nothing about the private sector. They dealt only with those receiving Federal funds for recombinant DNA research. In the absence of legislation mandating industry compliance with the Guidelines, NIH recently provided a means for voluntary industry compliance. Part VI, entitled "Voluntary Compliance," was formally added to the NIH Guidelines on January 29, 1980.[a] It encourages voluntary compliance by the private sector and specifies how NIH will protect proprietary information voluntarily submitted.

Private companies may voluntarily submit information about the membership of their Institutional Biosafety Committees to NIH, which will verify that they meet the requirements of the NIH Guidelines. They may register experiments with NIH, seek clarification of the Guidelines, and receive NIH certification of new host-vector systems.

The Guidelines state that all recombinant DNA experiments over 10 liters in volume require prior approval by the Director, NIH. A number of proposals to exceed 10 liters have been submitted voluntarily to NIH by industry, have been recommended for approval by the RAC after careful review, and finally have been approved by NIH. These proposals include large-scale production of human insulin, growth hormone, somatostatin, and interferon.

Recombinant DNA techniques are a major advance, used widely in biomedical research, and increasingly in industrial applications. The benefits are coming out of thousands of laboratories throughout the world; scientific data along a number of lines indicate that the potential hazards were initially overestimated. The NIH Guidelines for Recombinant DNA Research provide widely accepted safety standards for the work, continously evolving, based on the input of scientists and laymen.

[a] Federal Register, April 11, 1979, Volume 44, pp. 21730–21736; July 20, 1979, Volume 44, pp. 42914–42917; January 17, 1980, Volume 45, pp. 3552–3556; January 29, 1980, Volume 45, pp. 6718–6749; April 14, 1980, Volume 45, pp. 25366–25370; July 29, 1980, Volume 45, pp. 50524–50531; November 21, 1980, Volume 45, pp. 77372–77409; March 12, 1981, Volume 46, pp. 16452–16457.

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On Immortality

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ABSTRACT

This essay discusses the question of immortality—both biological and extrabiological—and concludes that immortality is relative.

"It can be proved by The Law, The Prophets, and The Writings that a man is led along the road he wishes to follow."

Talmud

With a gasp of air and a loud scream we are ushered into the world carrying the burden of all of the hopes and unfulfilled dreams of our parents, our ancestors, the whole human race. With luck we shall be educated, taught about the good things in life. We learn to work hard to get a good job, live an exemplary life, and contribute in a small or larger way to the betterment of mankind. Our failures and unfinished business will be passed on to our children, and in turn to theirs.

We appear on the earthly scene for only a brief moment in the whole of eternity. Most people are content to work, eat, rest, enjoy a few pleasurable moments, and, perhaps, do their small share to improve the lot of their fellow humans. A few people are driven by some unpredictable force to devote a larger share of their earthly goods (time, of course, being the most important) to altruistic activities. They derive adequate payment in emotional satisfaction from these virtuous actions. All of the people so far discussed take a back seat to another group which is the major subject of this essay: those people who desire and actively seek immortality. We will pass quickly over those who actually wish to live forever to those who desire to be remembered as a means of attaining immortality.

Upon reflection, it appears to me that immortality is relative. Thus, for human tribes without a written history, immortality might represent remembrances of several generations, or at most, until the last member of the tribe is seduced by the progress of "civilization", and becomes assimilated, thereby leaving in the dim reaches of his memory the immortality of the greats of his tribe. When this last Mohican dies, the "immortals" of his tribe die with him, their memory erased as quickly as the tracks in the desert are forever removed by the dust storm that obliterates all traces of previous happenings.

In a "civilized" society, we have famous warriors, politicians, philosophers, noblemen, artists, athletes, scientists, and businessmen. Many of the famous hope that they will be remembered forever. Some may be expected by historians to live on, even if the famous themselves did not have such expectations. Moreover, many people who ultimately achieve fame that lasts more than several generations may not have been motivated by the desire for fame. Many will have done science because they were curious, or painted to satisfy some psychological drive. Others will have hungered for power or glory. (Ironically many of the people who have achieved recognition by later generations were ignored by their own.) Nevertheless, due to my inability to dissect motives, all of these people will be considered together.

A few great artists (writers, sculptors), scientists, philosophers and politicians who lived 2,500 years ago in ancient Greece are still remembered. Egyptian, Jewish and Chinese history go back even further. Although most of the casts of characters do not represent household names, some have lived on in our writings, and some in our memories. One could go back further and cite a skeleton (usually a part thereof) from one or three million years ago, carefully studied and preserved in a museum, as an example of long-term remembrance; however, without the deeds or thoughts, the essence of the owner's personality, there is little to recommend it as an example of immortality.

What are our chances of immortality? As I mentioned earlier, immortality appears to be relative. It is relative at least two ways: (1) the length of time one is remembered; (2) the number (or percentage) of people alive at a given time who remember. I will concentrate on the first, but the second will be lurking as an unstated corollary. Short-term immortality in athletics is possible for superstars. Babe Ruth, Ty Cobb, Lou Gerigh, and Cy Young are living legends for American baseball fans. That very few Chinese, Indonesians, or Russians know of them appears irrelevant in the center of North America where the names of soccer stars of South America of the same period, or the best cricket players of Great Britain, would summon up not the slightest cord of recognition. Over longer periods of time, athletics appears to be a limited vehicle for attaining immortality. The olympic medal winner's names will be preserved, but without biographical recollections, this seems an empty feat. Artists may fare somewhat better; hundreds of millions of people know of Leonardo da Vinci (more than all of the people alive when he painted).

However, some of the most popular and famous painters of 17th, 18th, and 19th century France are virtually unknown today. They and Bruce Jenner (no offense intended) will have a limited hold upon human memories.

Writers (novelists, poets, playwrights, essayists and philosophers) have done a little better, probably because of the ease of reproduction of their work. Nevertheless, most college graduates would have difficulty naming five writers of the seventeenth century. And that is only three hundred years ago, less than an instant in the five billion years of the Earth's history between the seventeenth century and the time the sun will cease to support life on earth.

Leaders of countries have achieved relative immortality of many generations because school children are forced to learn their names. However, when the list gets very long, only the names are remembered (and those only by the diligent). Thus, the kings and queens of England, presidents of the United States, and leaders of the Communist Party in the U.S.S.R. will, with a few exceptions, become names in a list like the names in the telephone directory. Future Americans will remember some details about Washington, Jefferson (well they should), and Jackson; but, what did Tyler do? What kind of person was Polk? With the passage of time, history books will devote less and less space to each until they remain only names. Will Harding be remembered 500 years from now? 5,000? 50,000? Microstorage systems may preserve biographies in library vaults: however, if unread, they constitute a shallow form of immortality.

How about antisocial behavior? Hijacking planes, holding hostages, murders (or political assasinations), and other forms of antisocial behavior rarely lead to immortality. An occasional act will confer upon the criminal decades or even centuries of immortality (e.g., John Wilkes Booth, Benedict Arnold). The longest-lived antisocial characters are those who have plotted against a race, religion or nationality. These people are remembered best when used in special stories or holidays, usually to stir group unity. Thus, Hayman, who plotted against the Jews 3,000 years ago, and was outwitted by Esther, is remembered in the Jewish story of the holiday of Purim.

Perhaps the best way to be remembered is to be the figurehead of a religion. Budda, Mohammed, and Jesus Christ are well remembered. Roger Smith is somewhat less well known as are Martin Luther and Abraham who have not been assigned divine attributes. Although many religions (or sects) have been studied in the last 500 years, very few of their leaders are known world-wide. Thus, in religion, as in art, one has to be a superstar to achieve widespread recognition and relatively long-lived immortality.

Let us now turn to a greater scale of time: Can anyone be remembered forever? Assuming continued "civilization" and "progress", extrabiological information transfer should remain at least as good as it is today, and it probably will improve considerably. Thus, Hamlet should be available 500 million years from now. That represents a period of time one million times as great as the period between the present and the time Shakespeare wrote. In that long period of time, many great writers may come along; Shakespeare may go out of fashion; life may become so different that his plays may appear irrelevant. Nevertheless, let us assume that Shakespeare will always be deemed a great writer by all civilizations. Is there a limit to his relatively long immortality? With regard to our solar system, the limit is imposed by the sun which gives us the energy by which to live. Without life, Shakespeare's words would die like the rest of the millions of words printed and discarded every day. It is likely that humans will manage to colonize another solar system before the sun burns out. (Alternatively, we could transmit the information to another civilization.) They could take Shakespeare along for another ten billion years, giving him a total survival of fifteen billion years. Thus, Shakespeare's warmth could outlive that of our solar system by billions of years.

However, approximately fifteen billion years from now, even Shakespeare's immortality would be in jeopardy. At that time the continuation of life in the universe we know will be tenuous. Two possibilities for the end of life are currently in vogue. The first, presently considered likely, points to an ever-expanding universe. All cosmic bodies will continue to drift farther and farther apart; eventually all stars will lose their life-giving warmth, and all planets will cease to support life. Artificial support systems ultimately will run out of adequate raw materials as a temperature close to absolute zero pervades the universe. Moreover, with increasing distances between cosmic bodies, especially in the absence of stellar power, inhabitants of one world would find it increasingly difficult to travel to other cosmic bodies, and eventually, all life in the universe would cease. At that time, despite the likely preservation of records never again to be deciphered, no one would be remembered by anyone—no one would be immortal. The second possibility for the universe (currently considered less likely than the first) is that it is oscillating, expanding now, but scheduled to reverse its course some day. After that, heavenly bodies will speed toward a central point in the universe. When they all meet there, some fifteen billion years hence, all matter will be converted into energy. All people, all records, all living things, all thought will be destroyed. No one will be immortal.

Thus, immortality appears to be relative. In biological life we must all die; similarly, in extrabiological life we must also die. When the last thinking being dies, there will be no more recollections of the names, thoughts, or deeds of anything. No person will be remembered forever.

Alas, immortality appears to be relative with regard to duration. Most people are remembered by their children or grandchildren. Most are not remembered by their great-great grandchildren (or their contemporaries' great-great grandchildren). Very few people indeed are remembered for ten generations (150 to 400 years). Will anyone remember Mickey Mantle or Willie Mays 1,000 years from now? Will Gerald Ford be a household word in 100,000 years? Who will remember the author of the Gettysburg Address a million years into the future? Napoleon, Constantine, William the Conqueror, Julius Caesar, Hitler, Chou En Lai, and other major political figures who influenced the course of our culture will belong to primitive fables 10,000,000 years from now, remembered only by computer storage devices. Perhaps Michaelangelo's David (albeit in replica) will last 10,000,000 years. The works of Bach, Beethoven, Homer and Sophocles have a chance of being remembered 100,000,000 years from now. That is about as immortal as most of us can conceive, and is only a factor of about 150 from the upper limit of immortality anyway, so let's be gracious and give them the full 15,000,000,000 years. By contrast, it is a bit humbling to realize that this essay will probably not outlast its author.

Similarly, it is humbling to realize that as the inventions of the past become obsolete, their creators no longer occupy a prominent place in our minds. The memory of Eli Whitney has been fading during the period of my life; Marconi and A.G. Bell will meet similar fates someday. Will the memory of Thomas Edison last 10,000 years? Scientists, especially if a constant is named after them, will probably be remembered longer than will inventors. Avagadro, at least in name, if not in personality, appears destined for relatively long human memory. Outstanding scientists who established new fields, such as Darwin, or who established important theoretical principles, such as Newton and Einstein, will live on. However, with the passage of time, Volta and Ampere may fade as personalities, as will the discoverers of planets and subatomic particles.

Explorers have been remembered well in the past few hundred years; however, it seems unlikely that ten thousand years from now Magellan and Columbus will be deemed very courageous. Even having a place named after yourself is no guarantee of even 100 years of prominence. Street names, airports (Idelwild), towns, and even countries are subject to name changes for a variety of reasons. Over longer periods of time, continents will shift enough to make irrelevant explorations, cities, and bays, and other geographical features we hold so dear. How many people living today can name, let alone describe, the seven wonders of the ancient world (2,000–4,000 years later). Will they have any meaning in 100,000 years?

I have emphasized works of writing and music and art as candidates for relatively long immortality. Will the poems of Robert Frost lose all meaning in urban societies 10,000 years into the future? Will Donatelli's sculptures seem distasteful? I hope not. What better way will there be to help a young person embark upon a career in politics or the social sciences 10,000 years from now than by engaging him in a thorough analysis of Plato's Republic?

Many years in the future, society may become intellectually more sophisticated, or may achieve a more widespread appreciation of relatively unpopular fields such as mathematics and philosophy. People who have remained relatively unknown, except to a few specialists in the field, may become uniformly acknowledged. Thus, in addition to Archimedes, Descartes, Pythagorous and Euclid, such mathematicians as Georg Cantor, Bernhard Bolzano, John Napir, Fermat, Gauss, Euler, Reimann, Bolyai and Lobachevsky may be better known a thousand years from now than they are today.

Now that the argument has been presented, it seems appropriate to return to those people who paint or write or do science not so much for the vanity of recognition by society, or peer approval, but rather as an attempt to leave one's stamp on the world; to leave something behind; to achieve relative immortality. Such activity may be motivated by a desire to trick nature, and avoid the death dictated by our biology, through the extremely efficient extrabiological information system the human race has evolved. This possibility is strengthened by the realization that biological information transfer is capricious at best. Having children is an uncertain avenue to immortality. Genes are subject to dilution and change. Offspring may not chose to reproduce. A Hitler or Amin may decide that your family does not deserve its small niche in the world. Finally, the future may bring human reproduction to the level of bovine reproduction as practiced at the end of the Twentieth Century. This practice consists of using sperm from the "best bulls" to artificially inseminate promising cows. Leaving aside other aspects of such a practice for humans, it would leave most people without a chance for genetic immortality of even the most limited sort. Total *in vitro* reproduction would further reduce genetic immortality for most people, and genetic manipulation would essentially eliminate it altogether. Thus, many people instinctively, if not conciously, have recognized that immortality may be on safer ground elsewhere; that achievements may lead to immortality through extrabiological information transfer. However, it appears that such immortality is relative, only a few people living today will be remembered 500 years from now. Perhaps none will be remembered 500,000 years from now. Moreover, it could be argued that there is so much to be discovered and written and composed and painted that our current "immortals" may be replaced. This would put an even greater restriction upon achieving long-term immortality. However, it is easier to point to the discoverer of elements in general, or to the discoverer of the first element, than to the discoverers of the next one hundred and fifty elements. Similarly, the first discoverers of a subatomic particle will probably be remembered better than the discoverer of the thirteenth. In a sense, as time goes on, it may become harder and harder to achieve long lasting fame or relatively long immortality. Thus, the earlier one lives in the history of a civilization, the better the chance of achieving relatively long-lasting immortality. This is especially true if one considers the proportionate increase in population, and in educated population, that has occurred during recorded human history to the present.

Mark Twain recognized this aspect of the human condition when he remarked that Adam (the first man) was lucky because he knew that when he said a good thought no one had ever said it before. Therefore, we are lucky relative to the billions of people who are destined to follow us, since we have a better chance of achieving relatively long-lived immortality than they. It could also be argued that we also have the advantage, over those who lived long ago, of living in an age of efficient extrabiological information storage and transfer. Moreover, we have the opportunity to enjoy the labors of Tschaikovsky, Mozart, Picasso, Neruda, Poe, and Rodin in those spare moments that we set aside as rest periods in our pursuit of relatively long immortality.

Radiation Risk: A Problem in Assessment and Perception

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Introduction

Ever since the beginning of time, life on earth has evolved in a sea of radiations from naturally occurring radioactive materials on the earth and from cosmic rays from outer space. Since the beginning of this century, man-made radiations such as X-rays from medical X-ray equipment and radionuclides from nuclear power plants have provided additional radiation exposures above and beyond that which is received naturally. There is no question that these man-made radiations have provided and will continue to provide tremendous benefits for society. For instance, X-rays and radioactive materials have revolutionized diagnostic medicine; nuclear power plants now provide nearly 10% of the electric power in the United States.[1.]

The widespread uses of radiations are not without hazards. Depending on dose, radiations can be lethal, cause cancer and developmental anomalies, and induce mutations which may be passed on to our descendants. Of considerable concern to society is the balance of these hazards against the potential benefits. How much risk is society willing to accept at the price of a given amount of benefit? What is excessive radiation exposure? Are there safe dose limits for radiation exposure? The magnitude of risk that society is willing to accept depends on numerous factors including the size of the population exposed, the magnitude and nature of other risks that the population is also subjected to, and economic and political factors. Assessment of benefits by society must also include consideration of similar factors. In the most fundamental case, it is desirable to adjust benefits and risks so that the benefits to risks ratio is greater than one. However, in most situations, benefits and risks are interrelated in a complex fashion such that the best that can be done is to maximize the ratio of the sum of all the benefits to the sum of all the risks. Such a task is much easier said than done. Maximizing the benefit/risk ratio for one individual or group of individuals may reduce the ratio for another segment of the population. As a simple example, radiation workers in a nuclear power plant may greatly benefit from the small radiation exposures that are usually received at work and the radioactive materials leaked into the environment because they have well-paying, secure jobs. On the other hand, people living near the power plant may contend that they get no benefit from the radiation exposures received from the plant. Thus, the people subject to the risks are not always the ones realizing the benefits.

In this paper I consider the complex problem of assessment and perception of radiation risk, particularly with regard to nuclear power. Assessment and perception are two components of the overall determination of risk acceptability. For technologies such as nuclear power, which pervade major segments of our society and economy, determining the acceptability of risk is an issue of national concern.[2]

Risk Assessment

Assessment of radiation risk involves (a) identification of radioactive materials and radiations, (b) determination of the dose and dose distribution within the affected population and, (c) prediction of the health effects. Identification of the radionuclides and radiations is usually a straightforward procedure. For instance, in nuclear power plants, knowledge of the various radiochemical processes and some samples of contaminated material for analysis of the radionuclide content are usually all that is needed.[3] The problem of measuring the dose to the population is considerably more complex and requires knowledge about the quantity and quality of radiations emitted, pathways of exposure (e.g., air transport), metabolic pathways of radionuclide contamination, etc. Complex mathematical models of the behavior of radionuclides in the atmosphere and biosphere are usually used to assist in predicting dose.[3]

The major problems in risk assessment are the quantification of radiation risk and prediction of health effects. Quantification of radiation risks is not precisely known at low doses of radiation. Risk estimates must be extrapolated from the well-known effects at high doses that have been obtained from studies of the Japanese survivors of the atomic bombings, studies of radiotherapy patients and other sources.[4] The prevailing view among radiation scientists has been that the risk is directly proportional to the radiation dose, even at low doses and that any dose, no matter how small, potentially may be damaging (linear, no threshold model). Some scientists postulate a threshold dose below which the risk is zero, while others contend that the risks are disproportionately lower or higher than expected from the linear, no threshold model. Distinguishing among these models is made difficult by the fact that the effects predicted by each theory are small, and insufficient data have been collected or can expect to be collected at low doses making it almost impossible to verify which model is correct. This is illustrated in Figure 1, in which the mortality ratio (ratio of observed to expected mortality rates) for leukemia in Japanese atom bomb victims has been plotted against the radiation dose. In part (A) of the figure, the data points with 80% confidence limits have been redrawn from Jablon and Kato.[5] In part (B), I have drawn by eye three possible models that may be fitted to these data. The data do not allow distinction between a straight line or curvilinear relation or between the occurrence of a threshold or nonthreshold at low doses.

For radiation protection purposes and setting exposure standards the linear, no threshold model has frequently been adopted to evaluate radiation risk at low doses of radiation. Other models such as the quadratic and linear quadratic have also been used to predict risk.[4,6,7] Table 1 lists risk estimates for the major low dose radiation effects. For cancer, the estimation of risk is facilitated by the fact that the number of deaths provides a rough measure of the im-

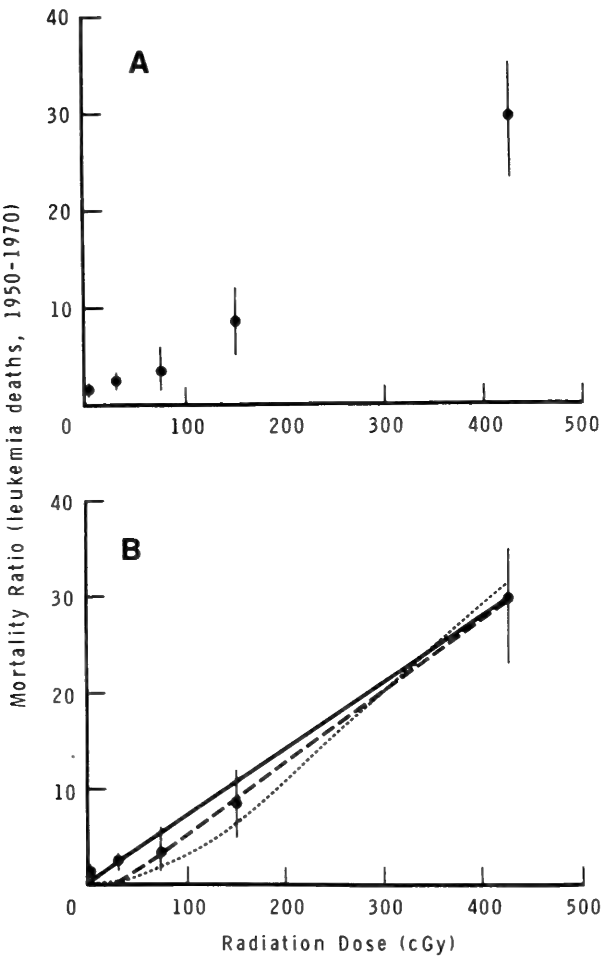

Fig. 1. Leukemia in Japanese atom bomb victims versus radiation dose. The mortality ratio (80% confidence intervals) for leukemia (ratio of observed to expected leukemia deaths) from 1950–1970 has been plotted against the radiation dose (in centigray). Part (A), redrawn from Jablon and Kato (5). In part (B), the same data points with three possible models to predict effect of low doses—linear, no threshold (-), linear threshold (--) and curvilinear (. . . .).

pact of the disease. However, for genetic and teratogenic effects, no single index can be used since these effects may be described by a great range of conditions. For usual medical radiation exposure and population exposures from nuclear power plant emissions, health risks are minimal. In diagnostic X-ray, whole body doses <0.1 cGy (rad) are commonly delivered for many procedures[4] resulting in radiation-induced cancer death or genetic effect risks $<10^{-5}$. For nuclear power, radiation releases to the environment are typically orders of magnitude less than this. At Three Mile Island, the accident resulted in an average whole body dose of about 0.001 cGy to the 2 million people within a 50-mile radius of the accident site.[8] Consequently, the risk for radiation induced cancer for this population would be about 10^{-7}. Under normal conditions from nuclear reactor operations, radiation exposures and risks would be even less than this.

The question of risk at low doses of radiation is a highly controversial issue. Risk estimation usually involves significant judgmental inputs. There may be substantial disagreements over risk estimates, the methods used to calculate estimates, and the competency, integrity and motivation of the experts providing the estimates.[2] Some of these problems are illustrated in the recent controversy over the latest report of the National Academy of Sciences Advisory Committee on the Biological Effects of Ionizing Radiation (BIER III) which was recently published but had a long and troubled history because of the inability of the Committee members themselves to reach a consensus.[9–11]

Risk Perception

At present there are no criteria for determining what levels of risk may be acceptable. Risks of the order of 10^{-6} per lifetime may be considered insignificant, whereas risks greater than 10^{-4} per year are probably unacceptable.[12] The radiation risks as discussed in the preceding section probably lie between these extremes. However, quantitation of risk is not the only determinant of acceptability. How the risk is perceived by the public is also a critical factor.

Perceptions of the severity of risk by ordinary people are usually different from the actual, measured hazard. Paul Slovic of Decision Research conducted a survey

Table 1—Radiation Risks at Low Doses.

Effect	Risk Estimate	Reference
Carcinogenic: Lifetime cancer mortality from radiation exposure (e.g., X-ray) including leukemia, breast cancer, thyroid cancer, etc.	10^{-4} per cGy*	4, 6
Mutagenic: Autosomal recessive autosomal dominant multifactorial disorders chromosome aberrations	10^{-4} per cGy*	4, 6
Teratogenic: Serious malformations and cancer induction in prenatal exposure	$10^{-4} - 10^{-3}$ per cGy*	4, 7

* 1 centigray (1 cGy) = 1 rad

among various groups to determine how risks are perceived.[13] Individuals from the League of Women Voters, college students, and a professional group were asked to rank 30 activities in order of most hazardous to least hazardous. As shown in Figure 2 the perceived ranking bears no relation to the actual hazards ranking of the activities. The solid line in the figure represents the position of points if perceived and actual ranks correlated perfectly. Points above this line suggest that activities are perceived to be less hazardous than they really are. Points below the line would suggest that activities are perceived as more hazardous than they really are. Of interest is a comparison of the two radiation technologies—medical X-rays and nuclear power. Nuclear power was perceived as far more hazardous than actual hazard measurements would suggest; medical X-rays were perceived as less hazardous.[13] In order to identify factors which may influence perception of risk, Slovic and co-workers surveyed the same people as above and found that the charcteristics listed in Table 2 strongly determined how risks were perceived. The risk profile for nuclear power indicated high risk scores for nearly all characteristics. Risks were seen to be invol-

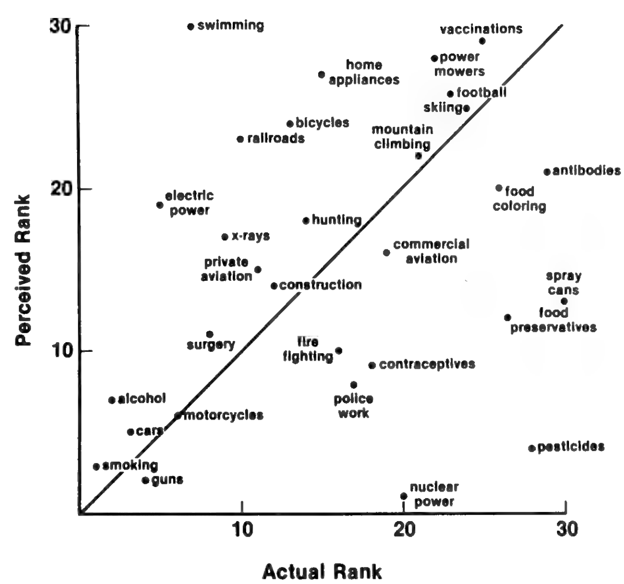

Fig. 2. Lack of correlation between actual and perceived risks. A college student group was asked to rank 30 activities from most to least risky. The abscissa is the actual ranking; the ordinate is the ranking by the group. The solid line represents the position of points if there were perfect correlation. Points above the line were perceived as less hazardous than they really are; points below the line were perceived as more hazardous. The scatter of points in the plot obviously shows the lack of correlation between perceived and actual risks. Data from reference 13.

Table 2—Risk Profiles for Nuclear Power and Medical X ray.*

Characteristic of Risk	Nuclear Power	Diagnostic X Ray
Voluntariness	risks are viewed as highly involuntary	risks may be voluntary or involuntary
Catastrophic	catastrophic—can kill many people at once	non-catastrophic—may kill people one at a time
Dread Factor	dreaded risks	reasonable calm about risks
Security of Consequences	consequence of accident likely to be fatal	consequence of accident may or may not be fatal
Knowledge about Risk	risks not known by public	risks not known by public
Immediacy about effects	effects are delayed	effects are delayed
Control over risk	people have no control over risks	people have no control over risks
Novelty of risk	risks are new and novel	risks are familiar

* Source, Reference 14.

untary, unknown to those exposed or to science, uncontrollable, unfamiliar, potentially castastrophic, severe and dreaded. On the other hand, medical X-rays were judged to have much lower risks and consequently a much less spectacular risk profile.[14] The public's difficulty in assessing risks may also stem from an inability to grasp the likelihood of an event occurring although the consequences of an event (such as lung cancer from cigarette smoking) may be fully comprehended.[2] Most people may normally assess risk by using an "availability heuristic"[15] which suggests that the assessment of probability of an event occurring depends on the extent to which the event is remembered.[15] As an example, one may assess the risk of a car accident by recalling such events among acquaintances. Other heuristics may also be employed in making judgments under uncertainity.[15]

Problems in public perception present an obstacle to the acceptance of various technologies such as nuclear power. The perception problem may be resolved by a better understanding of risk profiles[14] and of "heuristics and of the biases to which they lead"[15] and by improving quantitation of risk estimations and using comparative risk methodology.[12]

Summary

Society is becoming increasingly well-informed about technology associated risks.[16] Evaluation of risk may be defined as a two-stage process: the first stage is the scientific determination of the risk; the second stage is the much more complex issue of risk assessment which involves exploration of societal values and subjective estimation of probability. In this paper, we have discussed some of the problems of risk estimation and risk perception in radiation technologies. Only a few of the many issues and problems have been addressed. The ultimate acceptability of a particular technology risk will depend on refinement of risk estimations and the development and implementation of methods to improve risk perception.

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Thermoelectricity: The New Transport Phenomenon

James F. Goff

Address of the Retiring President of The Philosophical Society of Washington, January 9, 1981

ABSTRACT

In which the Author pursues TRUTH in diverse ways and places and finally glimpses it dimly shortly before he expires.

I. Introduction

Thermoelectricity is an enigma. It was one of the great discoveries of the early Nineteenth Century, one that in the context of the time would have been of Nobel quality; yet, 160 years later there is still no Handbuch der Physik article on the subject. Monographs have begun to appear only within the last fifteen years and serious use, other than thermocouples, has begun only in the last twenty or so years.

It is a simple measurement involving thermal and electrical parameters that can be made easily during the course of other transport measurements by the addition of a switch. It requires neither thermal equilibrium nor steady state conditions, but only sensitivity and precision, and not any great experimental complexity.

Nonetheless, the results usually are startling. The theory is simple and very easily understood, but the data almost never are in agreement with it. When the physical situation is well understood, theory and experiment are quite compatible; and so the inference is that some component of the physical situation is being ignored in the application of the theory. I shall argue and adduce evidence that the complexity of the distribution of states in solids is not being taken into account.

To begin, the discovery of thermoelectricity will be placed in its historical context. This discovery will then be considered from a modern point-of-view so that its fundamental nature can be appreciated. Theory and experiment will be discussed to illustrate their disagreement in such a way that the source of these differences will be indicated. There will be some discussion of the problem of utilizing the phenomenon for practical devices. Finally, there will be some comment and summary of problems and direction of research needed.

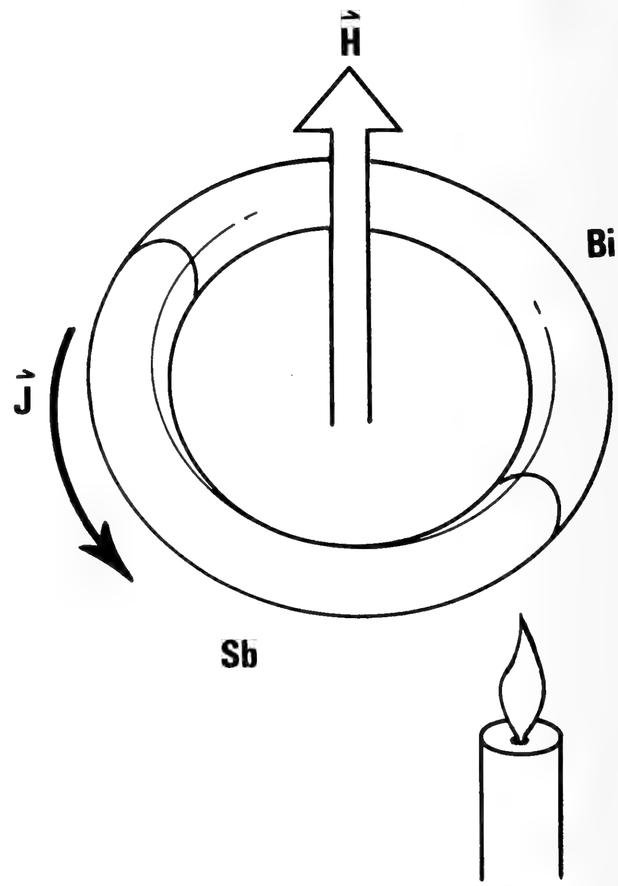

Fig. 1. Seebeck's ring of dissimilar metals which was used to demonstrate thermomagnetism.

II. Historical Perspective

Solids have two great uses: they serve as structures, and they transport energy. The first use makes life possible; but if it were not for the second, our civilization would not exist.

In the absence of a magnetic field, the transport of energy and charge is defined completely by three transport coefficients: κ, the thermal conductivity; σ, the electrical conductivity; and S, the Seebeck coefficient. Heat and thermal conduction were discovered in prehistoric times, and the first application was probably the cooking pot. The discovery of electricity occurred in ancient times and is attributed to Thales or "someone associated with him" about 600 BC.[1] Probably one of his graduate students. Thermoelectricity was discovered about 1822 by Thomas Johann Seebeck.[2]

Seebeck was born in Tallinn, Estonia in 1770. As a young man he studied medicine at Berlin and Gottingen and received his M.D. in 1802. He considered himself a natural philosopher. His field of interest was optics, and he shared the Paris Academy of Science's annual prize in 1816 for work on polarization in stressed glasses.

By 1820 he had become interested in magnetism, the mystery of the age, which was beginning to captivate our own Joseph Henry about the same time. His work involving the flow of current through the electrochemical series led him to observe irregularities at the junctions which he attributed to temperature. Reasoning from these observations, he was led to construct a ring as shown in Figure 1 of the most opposite metals, bisimuth and antimony. When he heated one junction, he observed a deflection on a nearby compass, and so decided that he had discovered thermomagnetism. He persisted in this belief for the rest of his life.

Today we would say that he had set up a thermoelectric current as a result of a difference of temperature between the junctions of two dissimilar metals. The current in turn, of course, causes a magnetic field which deflects the compass.

III. The Modern View

In modern terms we would say that the energy flux **U** and the current flux **J** are linear functions of the electric field **ε** and the temperature gradient ∇T:

$$\mathbf{U} = L_{TE}\boldsymbol{\varepsilon} + L_{TT}\nabla T \quad (1a)$$

$$\mathbf{J} = L_{EE}\boldsymbol{\varepsilon} + L_{ET}\nabla T. \quad (1b)$$

The L_{ij} are the so-called macroscopic transport coefficients. It will be seen when we come to the discussion of the applications of thermoelectricity that these are the fundamental quantities; however, one generally discusses the microscopic coefficients instead.

The microscopic coefficients are related to the L_{ij} for specific conditions imposed on Eq. (1):

$$\mathbf{J} = \sigma\boldsymbol{\varepsilon} \quad (\nabla T = 0) \quad (2a)$$

$$\mathbf{U} = \kappa\nabla T \quad (\mathbf{J} = 0) \quad (2b)$$

$$\boldsymbol{\varepsilon} = S\nabla T \quad (\mathbf{J} = 0) \quad (2c)$$

$$\mathbf{U} = \Pi\mathbf{J} \quad (\nabla T = 0) \quad (2d)$$

where the microscopic coefficients are the electrical conductivity σ, the thermal conductivity κ, the thermoelectric power (Seebeck coefficient) S, and the Peltier coefficient Π. Thus,

$$\sigma = L_{EE} \quad (3a)$$

$$\kappa = -\left(L_{TT} - \frac{L_{TE}L_{ET}}{L_{EE}}\right) \quad (3b)$$

$$S = -\frac{L_{ET}}{L_{EE}} \quad (3c)$$

$$\Pi = \frac{L_{TE}}{L_{EE}} \quad (3d)$$

so that the microscopic coefficients completely define the macroscopic ones, and Seebeck's discovery is fundamentally necessary.

It was shown by Lord Kelvin that in the absence of a magnetic field, Π and S are simply related (the Kelvin relation):

$$S = \frac{\Pi}{T} \quad (4)$$

where T is the temperature in degrees Kelvin. As a consequence, Π is an extremely important quantity theoretically and conceptually. As can be seen from the definitions (Eqs. (2c) and (2d)), Π is an isothermal quantity while S is not. Further, Π is the energy flow per unit current; and consequently, by Eq. (4) S is the entropy flow per unit current. It is usually simpler theoretically to work with isothermal conditions than with temperature gradients, and it is easier to conceive of energy fluxes than of entropy ones.

IV. Thermolectric Power

Phenomenologically, the Seebeck effect is very simple. Consider the ring shown in Figure 1 to be split apart so that one of its metallic elements is a bar as shown in Figure 2. Further, suppose this bar is a positive semiconductor so that the current is carried by positive charges. Now, if one end of the bar is heated, those charges diffuse to the

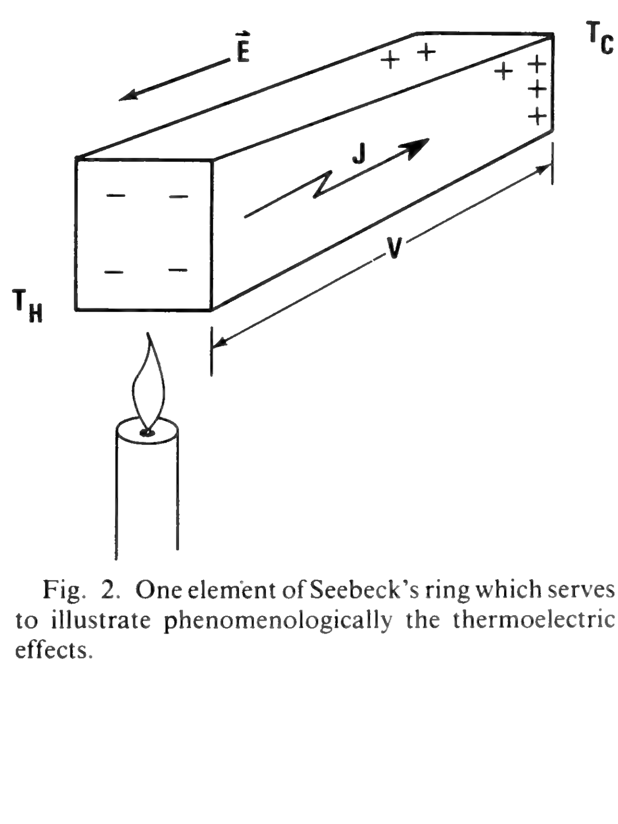

Fig. 2. One element of Seebeck's ring which serves to illustrate phenomenologically the thermoelectric effects.

cold end of the bar and set up an electric field ε which opposes the diffusion. Thus, the Seebeck coefficient is

$$S = \frac{\varepsilon}{\nabla T} = \lim_{\Delta T \to 0} \frac{V}{\Delta T} \quad (J = 0) \quad (5)$$

where V is the potential difference, which is chosen so that diffusion by positive charges gives a positive S and diffusion by negative charges gives a negative S.

Now the potential difference V is measured by wires attached to each end of the bar. Clearly such wires are just the other metallic element of Seebeck's ring. If those wires are connected to a potentiometer so that the circuit is open, then the measured S is called the thermoelectric power. If the wires are connected to an ammeter, then one can measure the thermoelectric current. Thus, the thermoelectric element shown in Figure 2 is like an electric cell. The study of the thermoelectric power is the study of the mechanisms in the solid that produce a thermal potential difference. The study of thermoelectricity is the study of the internal mechanisms that affect the thermoelectric cell under load conditions.

There are two further points to be derived from Figure 2. First, S or the thermoelectric power is a bulk phenomenon that occurs in the bulk of the solid and not at the junctions as is often presumed. Second, S is always measured relative to another metal. The obtaining of S for a single metal, the so-called absolute thermoelectric power, is complicated and beyond this paper. Extensive work has obtained the absolute S for Pb which can be used as a reference metal to obtain the absolute values of S for other metals.[3]

Typical values of S for various classes of solids are as follows: noble metals (1–2 μV/K); transition metals (10–20 μU/K); semiconductors (100–1000 μV/K).

Now, according to equations (2d) and (4), the thermoelectric power S is related to the flow of energy per unit current in the solid. The carrier of this energy has not been specified. Until about thirty years ago, it was assumed that the only carrier of energy was the electron system. However, Frederikse showed that significant energy was also carried by the crystal lattice.[4]

A solid can be considered as composed of two systems as shown in Figure 3: an itinerant electron system and a phonon system (the quantized vibrations of the atomic lattice). Under an applied field ε, the elec-

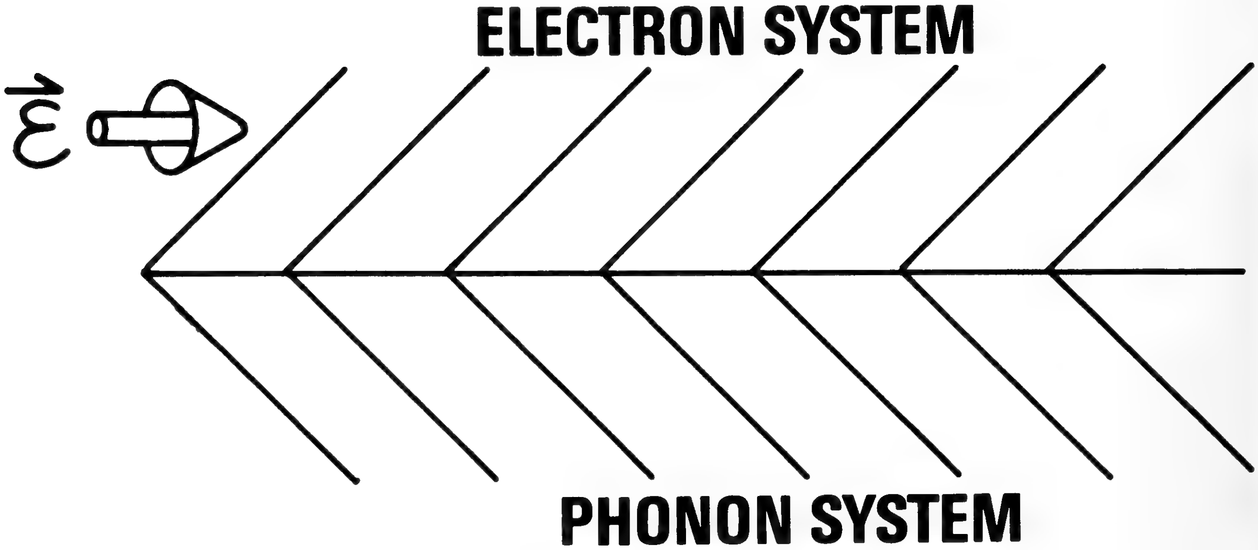

Fig. 3. The interaction of the electron and phonon systems.

tron system flows and drags the phonon system with it. Thus,

$$\Pi = \frac{U}{J} = \frac{U_{electron} = U_{phonon}}{J} = \Pi_e + \Pi_g \quad (6)$$

and by Eq. (4),

$$S = S_e + S_g. \quad (7)$$

These components are called the diffusion and the phonon drag components, respectively.

The interaction of these two systems is somewhat complicated and depends upon whether the solid contains a few or many itinerant electrons; that is, whether it is a semiconductor or a metal, respectively. Herring first treated the problem quantitatively from the point-of-view of a semiconductor.[5] Figure 4a shows Herring's phenomenological description of his model.

The essential element of model is that the electrons of the electron system are described by wave numbers $k = 1/\lambda$ and the phonons of the phonon system by wave number $q = 1/\lambda$ where λ is the wavelength, respectively. The electron-phonon interaction occurs for $k \simeq q$; that is, for approximately equal wavelengths. As a consequence, whenever the number of itinerant electrons is less than 25% of the

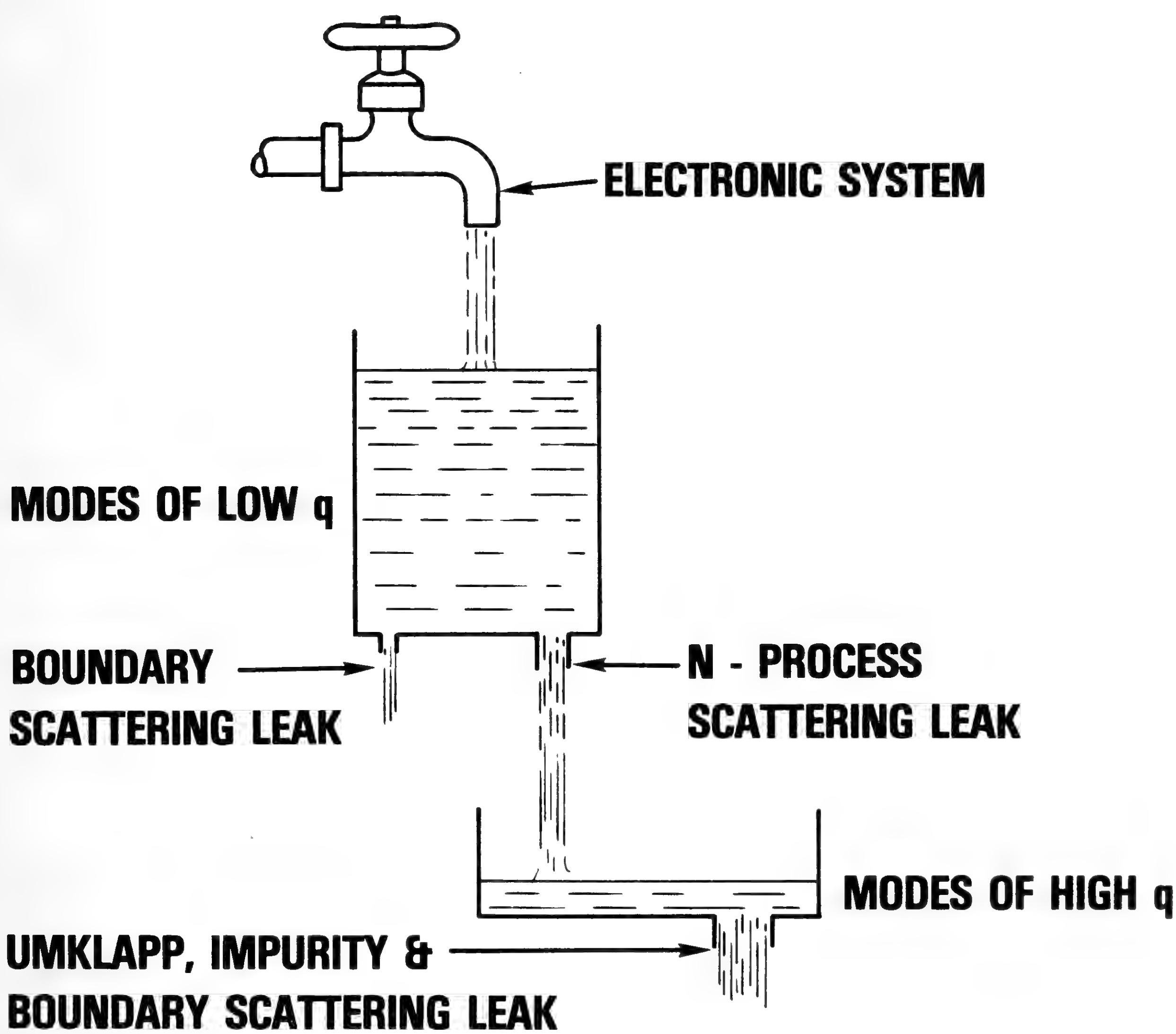

Fig. 4a. Herring's hydraulic model of phonon drag (5).

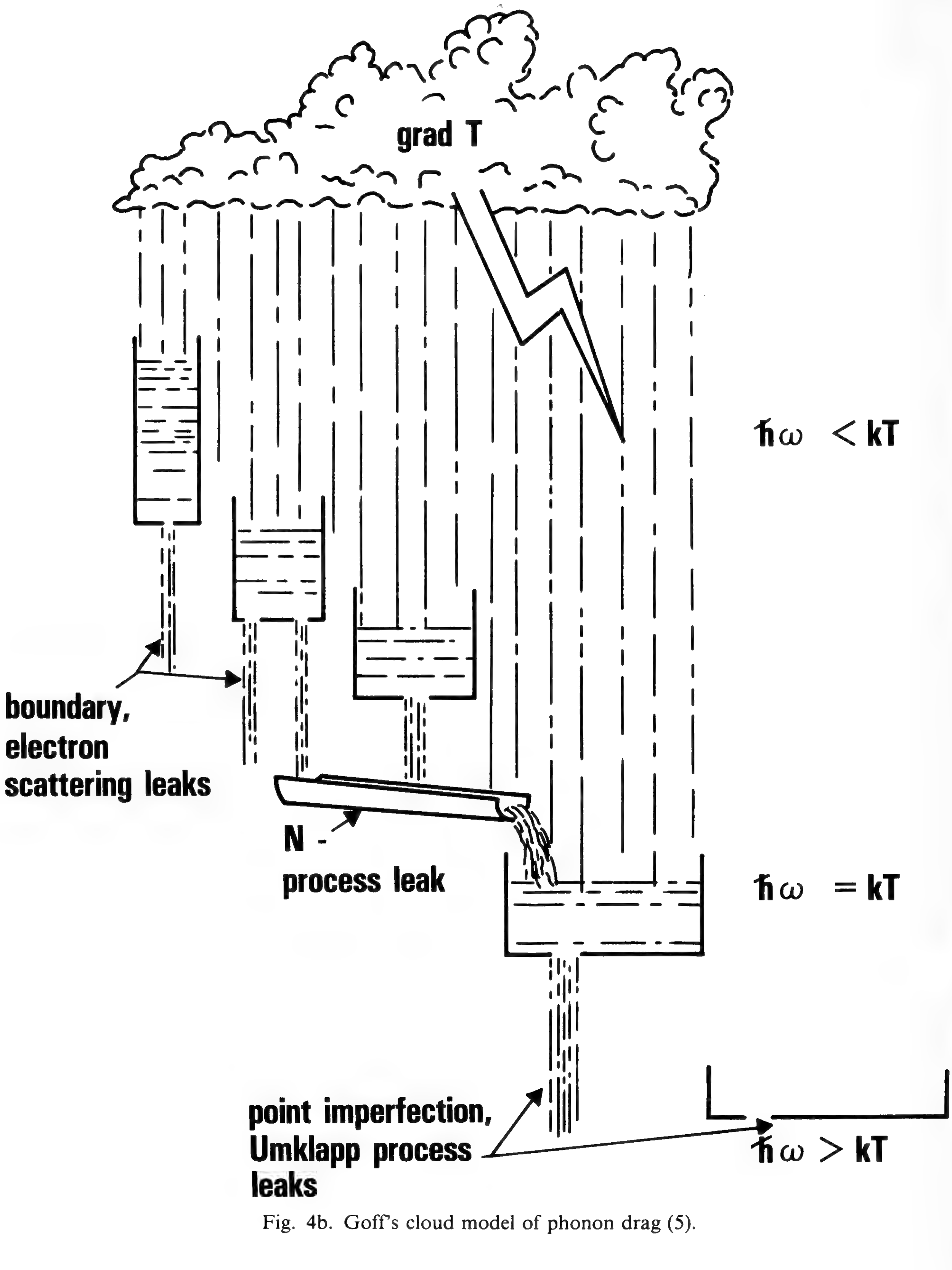

Fig. 4b. Goff's cloud model of phonon drag (5).

number of atoms they cannot interact with the whole phonon system, but only with the lower energy, longer wavelength ones.[6]

Since in a semiconductor the ratio of itinerant electrons to atoms is less than approximately $10^{18}/10^{23} = 10^{-5}$, the electron system interacts with the long wavelength, low q portion of the phonon system; it is necessary to divide the phonon system dichotomously into phonons that interact with the electrons and those which do not. Therefore, from the point of view of the Π approach, Herring depicts the electron system as a faucet which feeds crystal momentum into the low q portion of the phonon system.

These low **q** phonons dissipate this momentum in two ways: directly by interactions with crystaline boundaries, or indirectly by phonon-phonon interactions (N-process leak) which transfer it to modes of high q where it is dissipated by several other mechanisms such as non-momentum conserving phonon interactions (Umklapp), impurity interactions, or boundary interactions. The efficiency of these interactions varies. Boundary interactions are inefficient, while the efficiency of N-processes is low but increases with temperature and wavenumber. Thus, momentum is trapped in the low q phonon system until the dissipation rate of the N-process leak comes into equilibrium with the input from the electron system.

Figure 5 shows data for Sb-doped (N-type, electron conducting) Ge with carrier concentrations ranging from $2 \times 10^{16}\ cm^{-3}$ (Sb172) to $1 \times 10^{18}\ cm^{-3}$ (As222/Sb30).[7] The behavior of these data with temperature and carrier concentration can be understood on the basis of the Herring model. Consider first one of the lower carrier concentration samples.

As the temperature is raised, the phonon system is excited and S_g increases with the lattice heat capacity C_g (The whole matter is complicated in this case because at temperatures on the order of 50K the electrons begin to drop into impurity states.

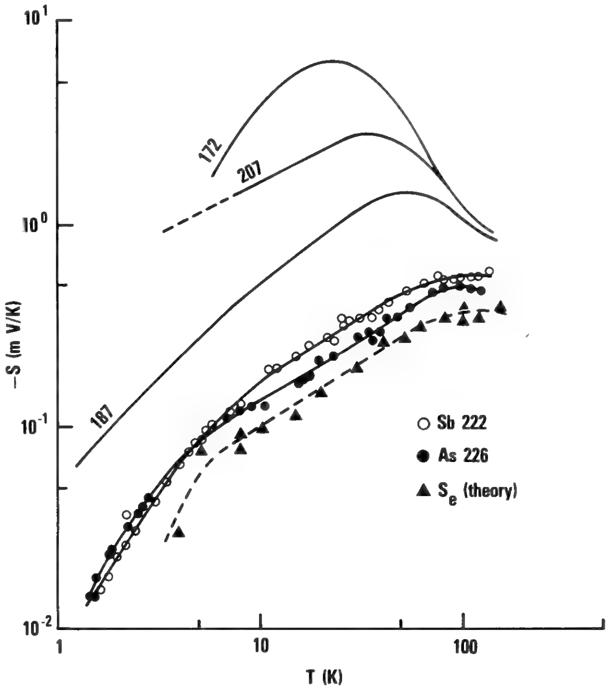

Fig. 5. Thermoelectric power for N-type Ge.

This decrease in the effective electron concentration should cause the S_g to appear to increases less fast than C_g). Simultaneously, the N-process leak begins to transfer momentum to the high q phonons with increasing effectiveness. When the effectiveness of this process becomes great enough to overcome the input from the faucet, S_g begins to decrease, as is seen.

As the carrier concentration is increased, the electron system interacts with higher q modes which have more effective N-processes. Thus, one would expect S_g to decrease as is seen (Note: in addition there are other considerations beyond the scope of this paper).

Figure 4b shows the same interaction from the point-of-view of the S approach.[8] The temperature gradient is portrayed as a storm cloud that rains crystal momentum into the phonon system. As temperature is increased, the rain front moves to the right and fills the buckets whose size increases as the phonon energy increases (or momentum since $\omega/q = v_g$ the phonon velocity). The momentum from the lower q buckets is fed into the electron system that picks up an extra drift which is seen as a contribution to S.

In the above discussion of phonon drag, the phonon system has been discussed in more detail than the electric one. Up to this point, it has been implicitly assumed that the simple description of the thermoelectric effect given by Figure 2 is adequate; however, it is not at all sufficient in order to quantitatively formulate S_e.

As is well known, electrons are fermions which occupy quantum mechanical states in **k** space. As such, only two electrons can occupy each state (Δk_x, Δk_y, Δk_z). These states are filled from the origin $\mathbf{k} = 0$ so that in the beginning they fill a sphere, called the Fermi sphere, such as shown in Figure 6. Under the effect of an electric field ε, this sphere moves a distance $\Delta k = (dk/dt)\tau$ where τ is the relaxation time of the scattering process that tries to return the electron system to its original position. The conductivity σ of a conductor is just a measure of how far the Fermi sphere can move before scattering processes set up a steady state position.

There are three factors that affect the magnitude and temperature dependence of S_e: scattering processes, shape of the Fermi surface, and the distribution of electronic states above and below the surface. Although most attempts to explain the peculiar behavior of S_e have evoked scattering processes, they have not been successful (see for example reference 9), and it is the purpose of the following portion of this paper to adduce that Fermi surface shape and the distribution of states about it are of more importance.

If one treats the problem in the standard way, he obtains what will be called the classical formula[10]

$$S_e = \frac{1}{eT}\left(\frac{K_1}{K_0} - \zeta\right) \tag{8}$$

where

$$K_n = -\frac{1}{(2\pi)^3 e^2}\int \sigma(E)\, E^n \frac{\partial f_0}{\partial E}\, dE$$

and ζ is the Fermi energy, f_0 is the equilibrium Fermi function, E is the energy of the carriers in state **k** as measured from the bottom of the energy band, and σ (E) is their conductivity. The important point to notice is that K_1/K_0 is a normalized energy. Thus, S_e is related to the difference between the carrier energy and the Fermi energy. S_e is the difference of two large numbers and so involves a balance of contributions.

This equation was applied in the case of degenerate Ge (samples Sb 222 and As 226) in Figure 5 (see reference 7). The value of ζ was determined by measurements of the Hall coefficient on the same samples while the ratio of K_1/K_0 was taken from theory.[11] The agreement between theory and experiment was considered quite good, the criterion being that temperature dependences are considered more significant than magnitudes in solid state transport theory. From this agreement it was apparent that the theory gives good agreement with experiment whenever the physical situation is understood.

Semiconductors have low degeneracy temperatures; that is, the temperature T_D where $kT_D \simeq \zeta$. Metals are much more degenerate with T_D on the order of 50,000K for the noble metals, although transition metals may be on the order of 1000K in some cases. Mott showed that in the case of infinite degeneracy ($T_D = \infty$), Eq. (8) had a very simple form:

$$\lim_{\zeta\to\infty} S = \frac{\pi^2}{3}\frac{kT}{e}\frac{\partial}{\partial E}\left(\ln \sigma(E)\right) E = \zeta \tag{9}$$

Thus, the Mott formula considers the extreme case wherein only the derivatives of

Table 1

Sample	Impurity	Carrier Concentration	Degeneracy Temperature
Sb222	Sb	$1.1 \times 10^{18}\,cm^{-3}$	75K
AS226	As	$8.8 \times 10^{17}\,cm^{-3}$	75K

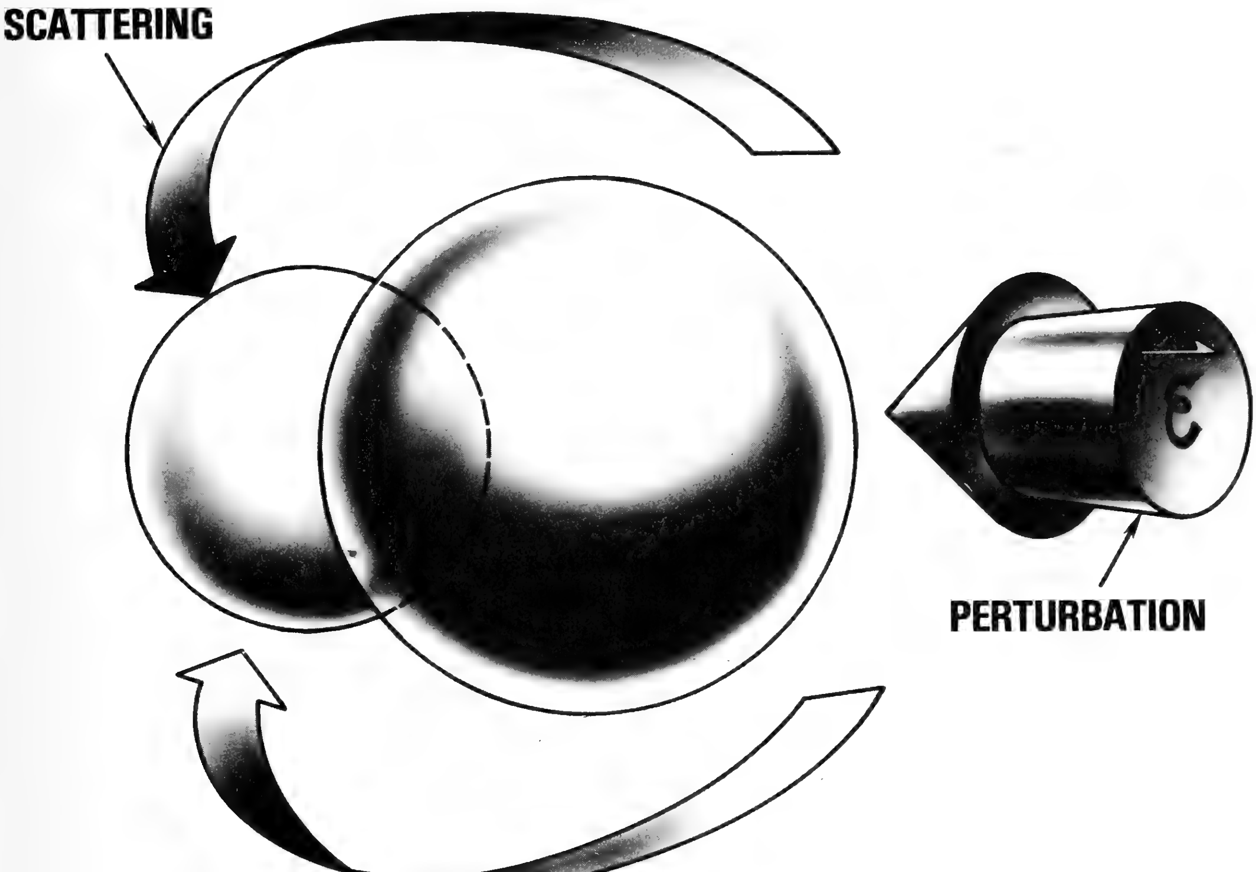

Fig. 6. The perturbation of a Fermi sphere by an electric field.

scattering processes and state distribution at the Fermi surface ($E = \zeta$) are important. In that extreme, $S \propto T$.

Figure 7 shows data for Cu and Cu_3Au.[12] The Cu_3Au gold system undergoes an ordering transformation at $T = 663K$ which greatly affects S. To begin, $S(Cu) \propto T$ in no part of the measured temperature range. Additionally, it is positive over most of the temperature range even though Cu has a negative Hall coefficient and thus electronic conduction. It is interesting therefore that $S(Cu_3Au/disorder)$, which should be a metal very similar to Cu, shows features that resemble S(Cu), such as a low temperature negative value and a higher temperature positive one. Further, $S(Cu_3Au/partial\ order)$ is negative.

The significance of the ordering experiment arises from the effect of ordering on the Fermi surface. The Fermi surface of Cu, shown in Figure 8, is not quite spherical but

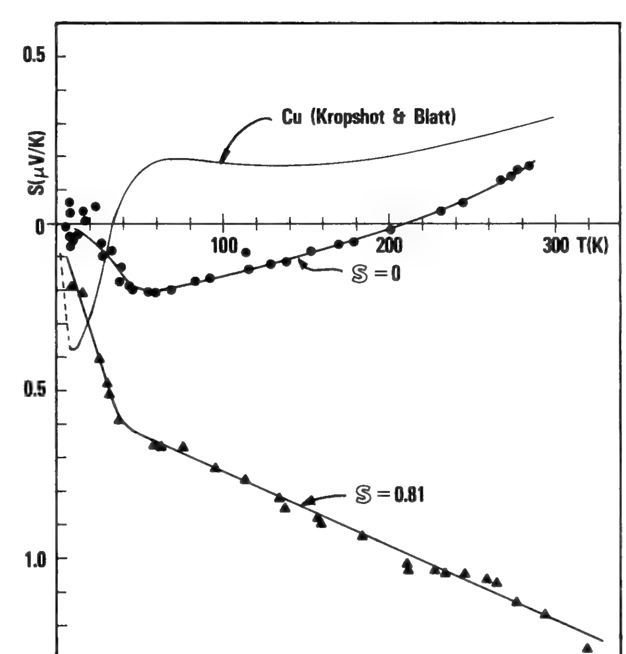

Fig. 7. Cu and Cu_3An thermoelectric power for two states of order S.

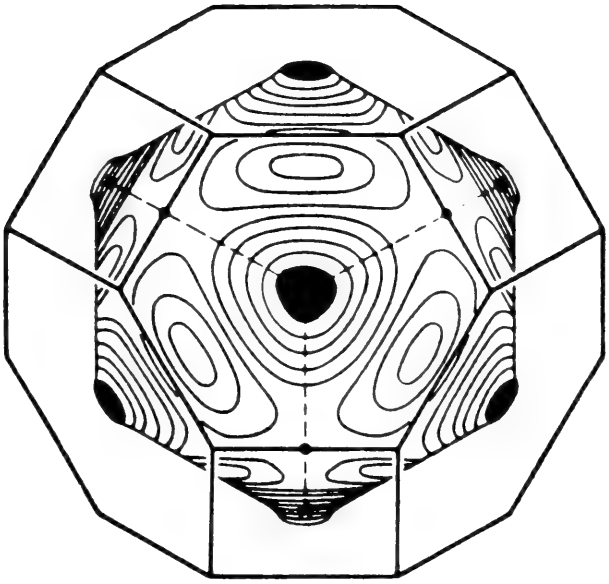

Fig. 8. The Fermi surface of Cu.

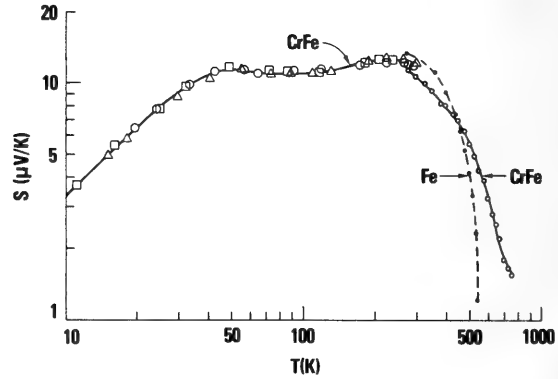

Fig. 9. The thermoelectric power of CrFe shown compared with that of Fe. Below 300K, data are shown for three samples which differ stoichiometrically by ±1%. The data above 300K were measured by Lucke and Cox (private communication) for the same samples but by a different apparatus. Representative data for Fe is shown for comparison.

rather consists of three features: a spherical body, necks in the [111] directions, and slight mounds on the belly of the spherical portion in the (110) direction.[13] Cu_3Au/disordered has a similar surface with some modification of the dimensions of the necks and mounds. The effect of ordering is to create a basis for the crystal lattice that causes portions of this surface to disappear. Clearly, such changes have a great effect on S. This experiment suggests that S is made up of contributions of different portions of the Fermi surface, some of which are positive and some of which are negative.

Figure 9 gives another example of data for a real metal system, the transition metal alloy CrFe.[14] These data are very enigmatic in that the low temperature portion vary as T, as the Mott equation requires for extreme degeneracy, but at about 30K the data become almost temperature independent as would be expected for zero degeneracy. At still higher temperatures, the data show a decrease. This decrease occurs at a temperature where both Cr and Fe show decreases.

The purpose of these two examples is to show that Eq. (9) does not explain the data in any satisfying way. Usually, $\sigma(\zeta)$ is defined in an ad hoc manner to explain the actual S(T)'s observed. It would seem to be a sounder approach to consider the effect of the actual finite degeneracies found in metals. After all, Eq. (8) does give good agreement with the data while Eq. (9) essentially never does.

It is customary to state that all conduction processes of the sphere shown in Figure 6 occur within ±2kT of the surface. However, if one calculates the integrals involved as a function of the limits of integration, he finds that, depending on the order of the integral, the energy spread for three figure accuracy may be ±10kT or somewhat more.[15] At 1000K, such energy spreads are several electron volts, a significant portion of the energies available for conduction processes.

Figure 10 shows the paramagnetic Cr surface which consists of a large and a small pocket of positive carriers and a similar pair of negative ones.[16,17] This surface should resemble those of Mo and W which are in the same chemical group V1B. Indeed, Vedernikov and Burkov have pointed out that S for these elements is similar except at low temperatures where Cr is antiferromagnetic.[18]

One would expect that the distribution of states about this Fermi surface would be

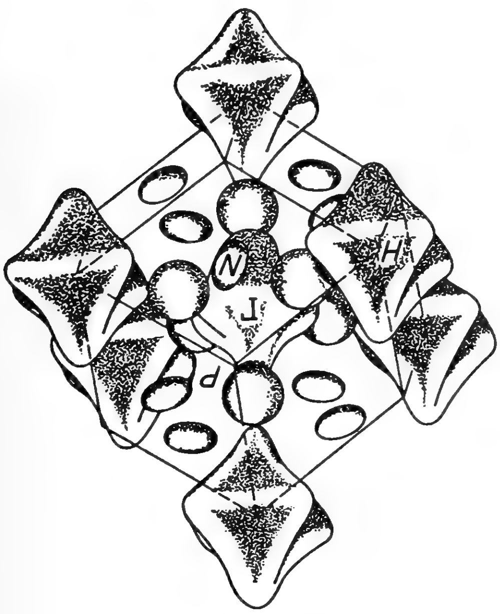

Fig. 10. The Cr Fermi surface.

unusual and indeed calculations shown in Figure 11 are quite different from the more usual distributions which vary as $E^{1/2}$.[19] In order to treat such cases, integral formulations of Eq. (8) must be used. Klemens reformulated Eq. (8) in a moments form where the Fermi energy is taken as the fiducial zero:[20]

$$S = \frac{k}{e} \frac{M_1}{M_0} \qquad (10a)$$

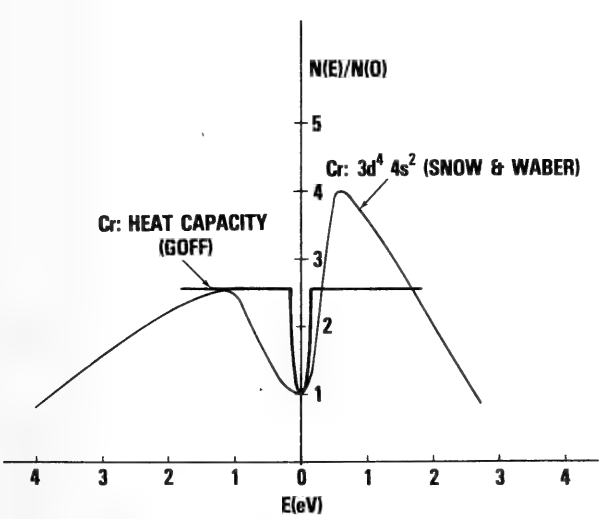

Fig. 11. The distribution of states which were derived experimentally from the analysis of the high temperature conductivities of Cr shown compared with the theoretical values of Snow and Waber.

where

$$M_n = - \int \sigma(\epsilon)\epsilon^n \frac{\partial f_0}{\partial \epsilon} d\epsilon \qquad (10b)$$

The current concern is to understand the implications of Eq. (10). For example it should be noted that M_1 is an odd integral while M_0 is even. Since it is unlikely that the distributions of states about all the pieces of the Fermi surface shown in Figure 10 have the same symmetry, it is possible that the different pieces give different contributions to the numerator and the denominator. For example the electrical conductivity $\sigma = M_0$. It has been possible to analyze[21] the conductivity data to obtain the experimental distribution of states shown in Figure 11. However, such a model contains no S whatsoever. Similar analysis of the conductivities of Fe have yielded values of S which are quite encouraging.[22]

V. Thermoelectricity

As was pointed out in Section IV, the thermoelectric element shown in Figure 2 is similar to an electric cell. The study of the thermoelectric power is the study of the internal mechanisms that produce a thermal potential difference for an open circuit; the study of thermoelectricity is the study of the internal mechanisms that affect the behavior of this cell under closed circuit conditions.

In practice, these thermoelectric elements are connected in couples as shown in Figure 12. The two elements are selected to be as nearly alike as possible but with opposite signs of the thermoelectric power. Such couples can be run in either direction; that is, they can be used to generate a current from heat or they can be driven by a current to refrigerate.

The advantages of such devices are threefold: simplicity (no moving parts), reliability (mean time before failure approaches thirty years), reversibility (power generation or cooling with the same device). They also, of course, use low grade energy such

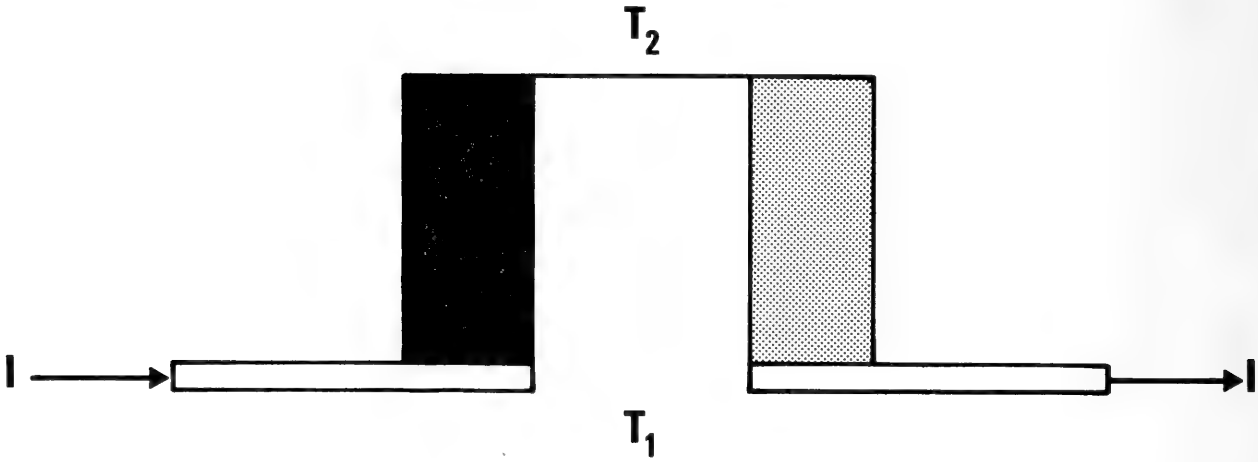

Fig. 12. Thermoelectric module used to construct thermoelectric devices.

as heat rather than light. Thus, in the sphere of solar energy, the solar collectors could be used dirty and could be ballasted to smooth out the effects of cloud shadows.

The behavior of a thermoelectric element is described by the Figure-of-merit Z where

$$ZT = \frac{S^2\sigma T}{\kappa_e + \Sigma\kappa_j} = \frac{S^2\sigma T}{\kappa_e(\Sigma\kappa_j/\kappa_e + 1)} \quad (11)$$

where all the quantites have been defined. κ_e is the thermal conductivity for electronic conduction and $\Sigma\kappa_j$ is the sum of all other thermal conduction mechanisms such as the lattice κ_g, infrared radiation κ_r, and any other loss mechanisms. Since the $\Sigma\kappa_j$ is considered as a parasitic loss, it has been collected into a degradation term $(\Sigma\kappa_j/\kappa_e + 1)$. It should be noted that the principal driving term

$$\frac{S^2\sigma T}{\kappa_e} = \frac{S^2}{L} \quad (12)$$

where L is the Lorenz number.

ZT is unitless. Eq. (11) with Eq. (3) shows that there is quite a bit of redundancy in Eq. (11) that makes it difficult to conceptualize. If Eqs. (3) and (4) were combined, then

$$\sigma = L_{EE} \quad (13a)$$

$$S = \frac{L_{ET}}{\sigma} \quad (13b)$$

$$\kappa = -(L_{TT} + \sigma TS^2). \quad (13c)$$

Substitution of these equations into Eq. (11) yields a non-redundant formulation

$$ZT = \frac{1}{\dfrac{L_{TT}L_{EE}}{L_{ET}^2} + 1}. \quad (14)$$

The value of ZT is a simple ratio of the macroscopic coefficients. Eq. (14) can be expressed in terms of moment integrals:[23]

$$ZT = \frac{1}{p(e^2T\,\Sigma\kappa_j/M_2 + 1) - 1} \quad (15a)$$

where

$$p = M_0M_2/M_1^2 \quad (15b)$$

and the M's have been defined by Eq. (10b). These equations have been applied to a PbTe three band model shown in Figure 13 to calculate the value of ZT shown, compared with the data in Figures 14 and 14b. The agreement is within 20% and is sensitive enough to band parameters that some experimental quandaries can be resolved.

VI. Conclusions

It has been argued that the thermoelectric effects: thermoelectric power and thermoelectricity are just now being understood—some 150 or so years after their discovery. It appears that the thermoelec-

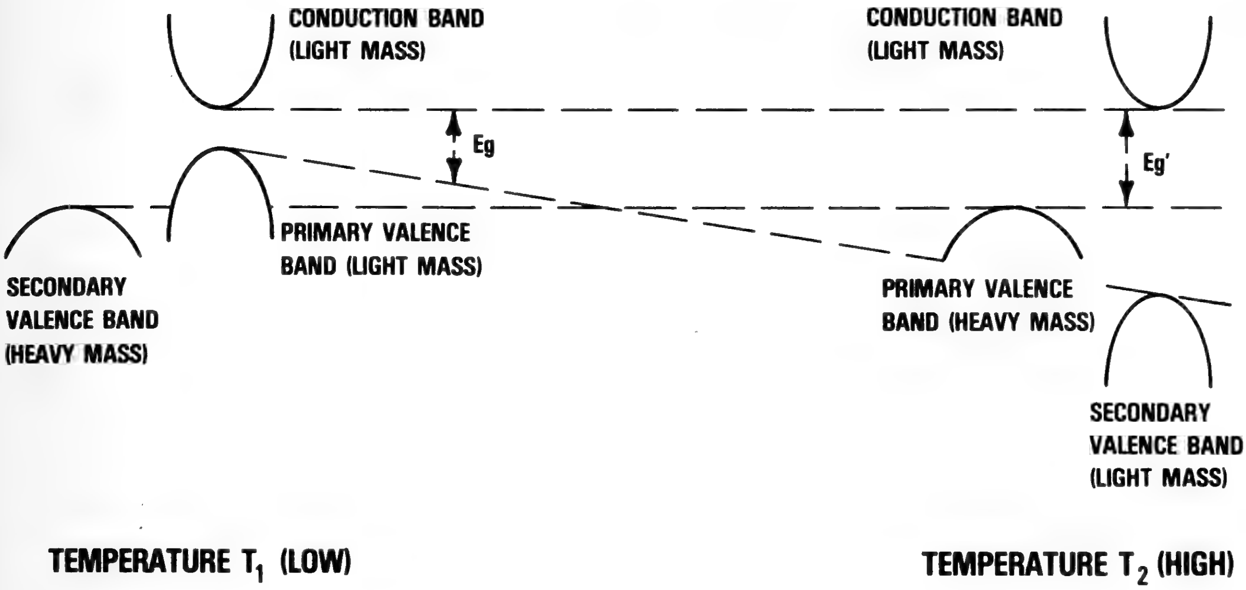

Fig. 13. The three band model of PbTe used to analyze the figure-of-merit.

tric power depends strongly on the distribution of states in the Brillouin zone and their distribution about the Fermi surface. These distributions appear to be of more import than scattering processes, although scattering is undoubtedly a consideration. In order to take such distributions into account, it is necessary to use integral forms rather than the more usual Mott expression for a derivative form.

It would help markedly in these analyses if the theoretical calculations of the density of states; that is, the distributions of states about the Fermi surface, were computed for the principal directions of the Brillouin zone so that the individual contributions

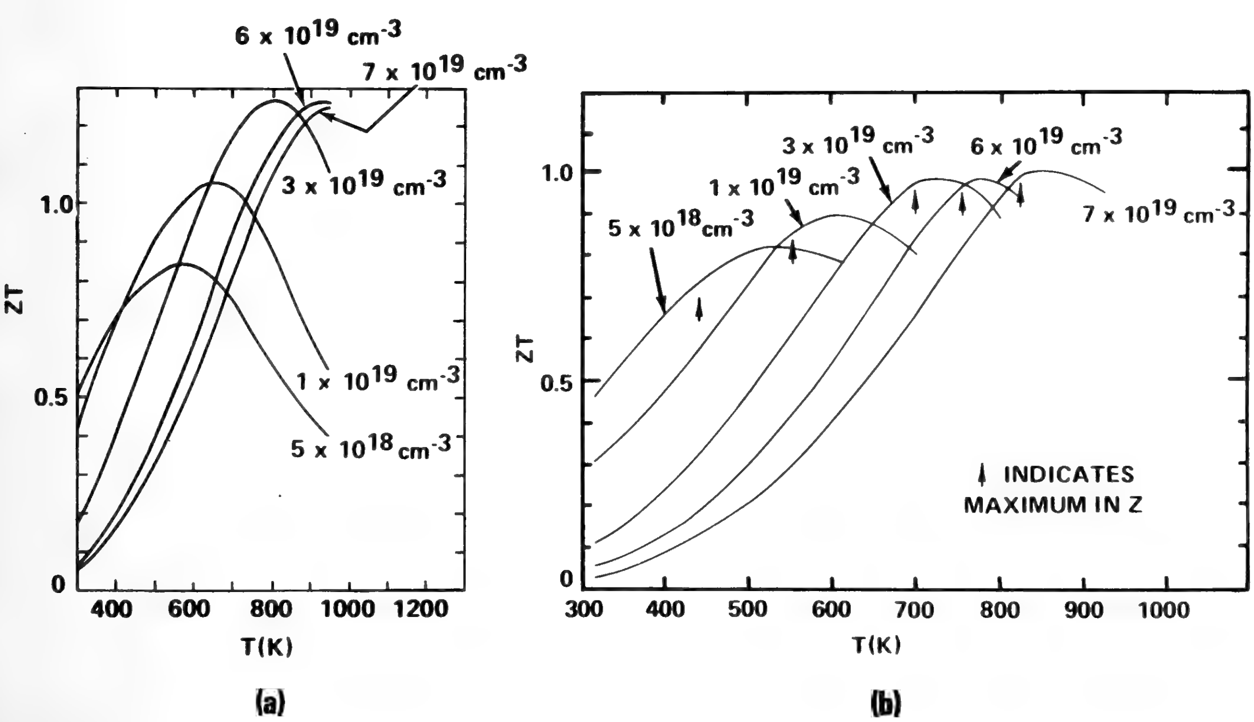

Fig. 14a. The figure-of-merit of N-type Pbte. 14b. The calculated figure-of-merit of N-type PbTe.

of the various carrier pockets could be analyzed.

Finally the author would like to acknowledge the following coworkers over the many years: N. Pearlman, M. Cole, A. Verbalis, M. Mitchell, J. Lowney, P. Hsiung, and P. Klemens.

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An Editor's Guide to Rejection Letters

Lawrence D. Grouse, M.D., Ph.D.

Senior Editor, Journal of the American Medical Association,
535 North Dearborn, Chicago, Illinois 60610

My detractors have accused me of becoming an editor as the only means of giving out more letters of rejection than I was receiving when I was engaged in full-time research. The same individuals also believe that I take sadistic pleasure in sending out letters of rejection for scientific manuscripts.I can assure you that this is not usually the case. Often, rejections provoke an instant or two of remorse, although by far the most common emotion is one of relief. It feels good to see another bad, bulky manuscript leave my desk.

No one likes to send a letter of rejection, but, matters of scientific and literary merit aside, skyrocketing publishing costs make it increasingly difficult to publish half-baked articles purely out of pity. Greater than 80% of the manuscripts submitted to our journal must be rejected. Thus, there must be a certain amount of unpleasantness as eager authors receive their letters of rejection.

I attempt to be diplomatic. I try not to reject a manuscript within one minute of its being placed on my desk, although sometimes this is impossible. I try to soften the pain produced by a cruel or sarcastic reviewer's critique. I will sometimes inform the author when I am interested in one of the less bad aspects of the manuscript and encourage him not to leave science right away, but to try again. It is a mistake for an editor to include bits of advice or homely philosophy into a rejection letter. The author does not want to hear that a revised manuscript might be more appropriately sent to the *Balkan Journal of Poultry Science.* He may not appreciate the editor's assessment, "It appears that the reviewer had not had any red meat to eat on the day that he reviewed your manuscript."

Rejection letters may have no redeeming value to authors, but good scientific reviews can prove valuable. Unfortunately, it is not sufficient to send a referee's savage comments and let the authors guess that their manuscript has been rejected; the letter of rejection must be included.

My favorite letter from an author who received a rejection contains the following passage:

"On February 3, 1981, I received the notice that my manuscript had been rejected. I can't say that I was terribly happy about it, but after reviewing both your letter and the comments made by your consultants it became painfully obvious that you had made the correct decision. As written, it really was a piece of garbage that had more scientific holes than a piece of Swiss cheese. God, the damned thing seemed so good as I was writing it! So much for objectivity."

If his original scientific communication had contained ideas as true and important as these, I not only would have accepted the manuscript, I would have nominated him for the Nobel Prize.

Decriminalization of Marijuana—A Brief Overview of Research-Relevant Policy Issues

Robert C. Petersen, Ph.D.

Division of Research, National Institute on Drug Abuse, Rockville, Maryland 20857

Having been involved with the marijuana issue virtually from the inception of NIDA's high priority research effort in 1967, I feel a little like an usher in a theater with a long-run play. The actors may change, but the plot is strangely familiar! I'm pleased to have the opportunity to provide an overview of research-relevant policy issues concerning the decriminalization of marijuana. Since the problem of developing a rational approach toward marijuana goes considerably beyond the legal issue of decriminalization, I hope I may be forgiven for encouraging all of us to think about the larger question of researchable issues around social control of marijuana use. The law is, after all, but one small part.

In essence we are asking the question, just how can we as researchers provide guidance—a data base—for the development of more rational approaches to drug policy? Just how do we minimize the social and individual costs of drug abuse while at the same time minimizing the injury to the individual and society resulting from whatever legal strictures are employed? Perhaps we should acknowledge at the outset that, while we may be able to develop more rational approaches, we probably cannot be, nor need we be, altogether consistent. To expect society to handle such diverse drugs as alcohol, tobacco, and marijuana with utter consistency is to ignore important differences in their patterns of use and social acceptance. It is easy to outlaw a substance without a long tradition of acceptance. Conversely, it is very difficult to outlaw one well-embedded in our social mores. As the Volstead Act demonstrated, eliminating the availability of alcohol in our country was impossible, despite the many pious declarations against it. But in a Mohammedan country such a law may be both acceptable and effective. The legal dictum, "Prevalency of a crime is no excuse for legalizing it," cannot be successfully followed when sufficiently large numbers insist on ignoring the law and on "committing" the crime.

Superficially, the problem of assessing the impact of decriminalizing marijuana seems simple. You locate two adjacent geographical areas with similar demographic characteristics, in one of which the law has been changed, and compare rates and patterns of use following the change. But the apparently simple is often in reality quite complex. In States with draconian penalties, district attorneys may be understandably reluctant to press for conviction because the penalties are so obviously disproportionate to the crime. And, if the district attorneys and courts are reluctant to exact these penalties, the police may be equally reluctant to make arrests. When marijuana use becomes widespread among the sons and daughters of the "establishment," including those involved in law enforcement and the courts, an added dimension of reluctance to exact harsh penalties is introduced. Even when the law is applied impartially and consistently, which is probably rare, its deterrent value is dependent on the user's subjective assessment of the probabilities of getting caught and being successfully prosecuted. It's probably safe to say that the largest increases in marijuana use occurred at a time when the legal penalties for personal possession were hardly lenient and certainly far harsher than they are today.

When Oregon decriminalized marijuana in 1973, becoming the first State to do so, several studies were conducted to determine what, if any, were the consequences of the legal change. Attempts were made there, and later elsewhere, to assess the number of arrests and convictions and costs to the taxpayer related to enforcement, as well as to assess the reported levels and patterns of use before and after enactment of the new law. There are, of course, other, less tangible aspects of decriminalization that are less readily assessed. These might include increased respect for the law and for law enforcement efforts, greater trust of the "establishment," decreased fear and suspicion of the authorities, and reduced incentive to use that may be based on defying what is seen as irrational authority.

Even when studies of use and decriminalization are conducted with punctilious care, their interpretation is fraught with difficulty. The viewer-with-alarm may take quite a different view from the sanguine. For example, in Oregon, research indicated no substantial change in the two years subsequent to enactment of decriminalization. However, between 1975 and 1976 the number of those who had ever used jumped by 20 percent (from 20 to 24 percent) and current users increased by 50 percent (from 8 to 12 percent).[1] One interpretation of this is that the legal change was perceived as indicating marijuana was safer than earlier supposed, and that use was therefore less of a source of health concern to the user. An indication of this is that the percentage of nonusers who described "possible health dangers" as the basis for their nonuse dropped dramatically from 28 percent in 1975 to 7 percent in 1976.[1] Indeed, it is the belief that decriminalization is very likely to be so interpreted that has led some decriminalization advocates to abandon that position, although they still do not believe severe penalties for use or possession are justified on other grounds.[1]

With respect to criminal justice costs, what evidence there is strongly supports the belief that decriminalization substantially decreases the costs to the taxpayer of arrests, trial procedures, incarceration, probation and the like.[2] But there are other problems to complicate this apparently optimistic picture.

In California, which decriminalized marijuana as of January 1, 1976, there was a marked increase in the number of arrests for driving under the influence of a drug in the 6 months following decriminalization as compared with a like period a year earlier. The number of adults (over 18) arrested under those circumstances went up by nearly 50 percent and the number of juveniles by over 70 percent.[3] While such an increase may not reflect a simple cause and effect relationship to the legal change, it does indicate the possibility that legal change may have unexpected consequences apart from simply increased marijuana use. While it is, of course, possible that the increase noted may have resulted from a shift in law enforcement emphasis, one more parsimonious explanation is that faced with less severe penalties, more drivers were willing to drive stoned than previously. Such an explanation has been adduced to explain the much higher rates of driving while intoxicated in the United States as compared to Scandinavian countries, where the penalties are much more severe.

In looking at the possible effects of decriminalization, it is also important to realize that the law may not have an equally deterrent effect on all segments of the society. In California, for example, a study done prior to decriminalization as well as subsequent to it found an increase in the number of those who had ever used marijuana and who currently used it nearly a year after passage of the law. However, among adults between 30 and 39 years old and between 40 and 49 years old, the increases noted were much larger than in the 18- to 29-year-old group. Current use increased by about 30 percent among the young adult group, but it tripled in the 30- to 39-year-old group (from 5 to 16 percent), and quadrupled in the 40- to 49-year-old group (from 1 to 4 percent).[3] Thus, the deterrent effect of criminal penalties may well be greater on older, more established members of the community who presumably have more to lose by potential arrest. While overall changes in adult patterns of use were interpreted as having been little affected by decriminalization, this may not be true of all segments of the population.

When one turns to the perception of the effects legal change is believed to have had, marked differences of opinion are to be found among various segments of the population. For example, Blachly sent a questionnaire to 186 persons in the police-judicial-parole system 2 years after Oregon changed its law. He sent a similar questionnaire to 157 educators who headed the colleges and universities in the State, as well as to principals of all high schools with more than 500 students. While nearly nine out of ten (86 percent) of the police felt that marijuana problems had increased, only one in four (24 percent) judges noted a similar increase. Nearly half the educators felt that the numbers of students who had school problems involving marijuana use had increased since the legal change, although the number having other drug-related problems was believed to have decreased.[4] While this study hardly "proves" that changes in the law do, in fact, alter behavior, it does demonstrate how different the view of a problem can be, depending on one's priorities and vantage point.

Overall, then, depending on one's selection of data, one can make use of what research has been done to "prove": (1) that decriminalization has had little or no effect on patterns and extent of marijuana use, (2) that marijuana use has significantly increased among some segments of the population as a result of or coincidentally with decriminalization, (3) that the social problem caused by marijuana abuse, at least as reflected in law enforcement costs, has decreased following legal change, or (4) that the public health costs of marijuana may have markedly increased as a result of decriminalization, if drug-related erratic driving is taken into account. I am reminded of the story of the Rabbi who, in counseling a couple with diametrically opposed views of their marital difficulties, told each, "You're right." When confronted by his assistant who said such contradictory views could not possibly both be right, he again replied, "You're right!"

Perhaps the hardiest perennial in the Garden of Marijuana Beliefs is that our problems of public policy would be solved if only our scientific data were adequate to define the parameters of risk. As one medical editorial writer nearly a decade ago put it, "Since the warning signals that marijuana use can be harmful are numerous, widespread, and apparently increasing, it would seem to be sound social policy to discourage its use by all reasonable methods until or unless future research proves it has no deleterious effects."[5] Whatever one may feel about the soundness of the author's general observation, a moment's reflection makes it clear that research can never "prove" that marijuana, or any other drug, for that matter, has no deleterious effects. Conversely, "proving," or at least providing evidence, that marijuana has deleterious effects on health, however horrendous, does not in itself automatically adduce a sound legal or social policy. Like such other recreational substances as alcohol and tobacco, marijuana's health risks are likely to vary with amounts taken, the susceptibility of the user, and the circumstances of use. At one extreme, it is unlikely that the one-joint-per-month recreational user who is otherwise in good health is likely to suffer serious adverse consequences of use. At the other, it is unlikely that the user who is characteristically marijuana-intoxicated is likely to escape consequences, perhaps combining some of the unhappy health implications of both alcohol and tobacco use. As with alcohol and tobacco, we are faced with the question of how users collectively reckon the cost-benefit ratio in their personal decision to use and at what level.

Having said this much, is anything possible? Can the researcher, in fact, make a meaningful contribution? Is drug policy research feasible? I believe it is, but not in the sense that one can do a piece of research from which improved policy automatically flows. As my brief examples and the others that will be discussed in greater detail later illustrate, research on the outcomes of legal change is fraught with difficulty. There is also the very real possibility that it is not the legal change *per se* that is most significant, but rather a whole set of other variables that may interact with it or completely overshadow its importance. Realistically, the law, in combination with many other factors, such as law enforcement policy, drug availability, age of the user, and self-perceived benefits or risks, has a complex effect on use patterns. These may range from virtually no effect on some consequences to a profound effect on others.

Depending on what is measured or valued, it can be argued that the effects of a change in drug policy are desirable or undesirable. Moreover, the perceived implications of legal change may alter markedly over time. For example, at some point in the future, when the parameters of risk associated with marijuana use are better defined, decriminalization may say no more about marijuana's safety than does the legal availability of cigarettes. At present, we are confronted with a kind of cultural lag in which some of the important changes in the marijuana use picture have not yet become common knowledge. It is probably safe to say that the public and even legislators are not generally aware of the marked increase in the frequency of use of a much more potent material at a much earlier age. For this much younger group, the law may be far less relevant than parental attitudes and school policies.

If we are not to overinterpret the influence of the law itself, it is important that we also adequately assess enforcement policy prior to and after legal change. If the law simply codifies what has already been informal law enforcement and judicial custom, its effect may be very modest indeed. Or, if the typical user, for whatever reason, feels that legal consequences are unlikely to ensue, his or her behavior is not likely to be markedly affected—regardless of the law's severity. It is doubtful, for example, that the laws concerning fornication which existed in many States until comparatively recently inhibited most individual's sexual behavior.

Unfortunately for our attempts at drug policy research, we are confronted not with a stable drug scene, but with an ever-changing one. Our American experience has largely been confined to the use of relatively small amounts of low potency materials used by the healthiest segment of the population on an occasional, rather than on a chronic, basis. Like the Alcoholic Beverage Control laws, the effects of the law are likely to profoundly interact with emerging social custom, the ways in which recreational drug use is "regulated" by user and group attitudes. The shift to younger age use already may have resulted in a stiffening of attitudes toward marijuana use that might not have occurred had use continued to be largely restricted to young adults. The emergence of a paraphernalia industry and the backlash that has resulted in consequence also may have important unforeseen consequences for general acceptance of marijuana use. If the possible increase in numbers driving while high is shown to be inversely correlated with the severity of marijuana possession penalties, this too may alter markedly the public attitudes toward use and toward drug legislation.

To the extent that drug laws are even partially successful in reducing drug supply or markedly increasing price, harsher penalties for selling also may alter use patterns in ways that are not altogether predictable.

There has been very little, if any, research exploring the economics of the illicit drug marketplace as they affect consumption patterns. From what is known about alcohol consumption, such relationships may prove to be complex.

Another aspect of the drug scene that intrigues me personally is the impact of changing economic conditions, or more generally, the influence of a psychology of scarcity or of a less permissive orientation. The influence of the youth culture, that strange product of a bumper crop of children from post-World War II era, has now peaked and is in decline. With the greying of America, one might well expect a considerably more conservative approach to drug use with or without changes in the law. There is some evidence that as people go on to adult life, taking on more traditional vocational and marital responsibilities and roles, use of illicit drugs, including marijuana, drops.[6] If economic conditions, worsen, not only may there be less discretionary income available for drugs, there also may be a greater need to work harder in ways inimical to drug use; for goals that have previously been taken for granted.

By now you may have begun to suspect that "drug policy research," even if we confine ourselves to the issue of decriminalization, is, by my lights at least, anything but simple. We are increasingly aware, for example, that our earlier ways of looking at marijuana consumption in terms of *frequency* of use rather than at the quantity and quality consumed were misleadingly simplistic. It is also evident that the circumstances and pattern of consumption, as with alcohol, are important. In the absence of simple, reliable means of measuring marijuana intoxication in a manner analogous to alcohol consumption and of correlating it with performance, the legal picture is still further complicated.

Let me briefly summarize my baker's dozen of what are important researchable issues around marijuana policy for me:

1. What, in fact, is the interpretation of decriminalization by the general public and by various subsamples of it? Is the belief that such a move signifies marijuana is a "safe" drug warranted?
2. How are legal penalties perceived by user groups? Under what circumstances do users see them as deterring them from use?
3. What is the relationship of legal penalties to the willingness to take such risks as driving while high, using marijuana in the work place, or otherwise jeopardizing oneself and others' safety?
4. How do changes in legal penalties affect other aspects of drug use, such as the amounts of marijuana used, degree of acceptance of use, and the circumstances of use?
5. To what extent do the law and law enforcement policy affect the behavior of what may be the most vulnerable segment of the population—younger users?
6. To what extent do changes in the marijuana law affect public attitudes toward the use of other illicit drugs? Is the present upsurge in cocaine and PCP use related to marijuana laws?
7. How do changes in the laws governing possession impact on the seller and the general acceptance of illicit drug traffic?
8. How do changes in the law affect the behavior of those charged with law enforcement? Does a reduction in penalties result in an increased reluctance to enforce the law? Does it result in a greater tolerance for drug selling on the part of law enforcement personnel?
9. What has been the impact of the court decisions in Alaska, which went considerably beyond simple decriminalization?
10. To what extent is decriminalization perceived as a way station en route to ultimate legalization of marijuana use?

11. What other social forces, group norms, and emerging social customs around marijuana use serve to moderate or to control use?
12. Does a reduction in penalties significantly alter the attitudes and behavior of educators and others in ways that encourage greater youthful use?
13. How does a change in law affect the way in which the convicted user views himself or herself, and what is its impact on his or her future behavior?

This brief review has explored the promise and the problems of doing policy-relevant research. If the problems are formidable, so too is the promise of the researcher making a difference, helping the policymaker to develop a more rational, more workable approach to limiting the social and individual disruption related to marijuana use.

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Early Women Chemists of the Northeast[1]

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ABSTRACT

Few women chemists in the early part of the twentieth century followed what would be considered traditional courses in chemistry or biochemistry. The lives and careers of women from the Northeast who followed different pathways to success are discussed.

The women from Mt. Holyoke are considered, including Emma Perry Carr, Mary Lura Sherrill, and Lucy Pickett who formed one of the early research groups in order to achieve success and recognition for their work. Other women who followed a variety of routes included Pauline Beery Mack at Penn State, Mary Petermann at Sloan Kettering, Mary Caldwell at Columbia, and Helen Dyer at NIH. Katherine B. Blodgett, the first woman to get a Ph.D. in Physics at Cambridge and whose lifetime was spent working on physical chemical problems at General Electric is also discussed.

Contributions and accomplishments of several other women chemists from the Northeast, who were also recipients of the Garvan Medal, are discussed.

In the early part of this century, chemistry was basically a man's discipline. It was not a field in which women were expected or allowed to excel. A few very talented women, however, struggled to become successful chemists and biochemists, and won. Their advances have opened the way for the aspiring women chemists of today. These women, coming from different backgrounds, discovered very different routes to success and recognition. Although talented women were working nationwide, some of the greatest advances were made in the Northeast.

One of the most successful of the early research groups was that formed by the women of Mt. Holyoke, including Emma Perry Carr, Mary Lura Sherrill, and Lucy W. Pickett.

Emma Perry Carr received most of her undergraduate and graduate instruction at the University of Chicago and graduated in 1905 with a B.S. in Chemistry. She earned her Ph.D five years later and immediately began a long teaching career at Mt. Holyoke College, including 33 years as chairman of the Chemistry Department. During these years, her emphasis on group research gained for her department, as well as herself, a reputation of excellence among women's schools.[2]

Her research was concentrated in the field of physical chemistry. The research that earned for her in 1937 the first Garvan Medal ever awarded was her study of the electronic spectra of aliphatic hydrocarbons through the use of absorption studies in the far ultraviolet. After her first work appeared in 1929, she gained the support of the National Research Council and the Rockefeller Foundation. The research group that she put together, utilizing the work of other professors and a long progression of students, became one of the best models of this type of group research. Even more significant is the fact that it was achieved at an institution concentrating on undergraduate study. The work of the Mt. Holyoke research group contributed to a better theoretical basis of the energy relationships involved in ethylenic unsaturation. Her advances were later applied by petroleum chemists.[3]

Dr. Carr received many honors for her work, including four honorary degrees. The Northeastern Section of the American Chemical Society recognized her exemplary teaching career with the James Flack Norris Award in 1957. She was an active member of Phi Beta Kappa, Sigma Xi, an honorary member of Sigma Delta Epsilon and Iota Sigma Pi, and many other professional organizations. She was also a delegate to the International Chemical Union in 1925, 1926, and 1936. Dr. Carr remained active in Mt. Holyoke's program long after her retirement. She died in 1972 at the age of 92.[3]

Mary Lura Sherrill was a colleague of Dr. Carr at Mt. Holyoke and in the research group there. She received her B.A. and M.A. at Randolph–Macon Women's College in 1909 and immediately began teaching there. In 1918, she went to the Woman's College of the University of North Carolina and in 1920, she became a chemist at the Edgewood Arsenal for the Chemical Warfare Service. Finally, in 1921, she embarked on her long teaching career at Mt. Holyoke College where she remained for 34 years. She participated in the group research which studied ultraviolet absorption spectra of unsaturated hydrocarbons. This work required a high standard of sample purity. The accuracy of her work was later upheld by spectra prepared by the American Petroleum Institute.[3]

World War II was Mary Lura Sherrill's next opportunity to gain recognition for her work. Supported by the Office of Research and Development, she and her students initiated research on new antimalarial drugs. The synthesis of aminobenzothiazole derivatives became more important in the 1970's during research aimed at the drug-resistant malarias of Southeast Asia. This type of group research which involved faculty colleagues, and especially students, was typical of Mary Lura Sherrill's career. Among her many honors were the James Flack Norris Award for outstanding achievement in the teaching of

Chemistry, awarded by the Northeastern Section of the American Chemical Society in 1957, and the Garvan Medal, awarded by the ACS in 1947. She died in 1968 at the age of 80.[3]

Lucy W. Pickett was the third member of the Mt. Holyoke research group. She received her A.B. and M.A. from Mt. Holyoke College in 1925 and 1927 and received her doctorate from the University of Illinois in 1930. She immediately began teaching at Mt. Holyoke where she remained until 1968 when she was designated an emeritus professor. She served six years as chairman of the Chemistry Department.[4]

Dr. Pickett worked with Dr. Carr and Dr. Sherrill on vacuum ultraviolet techniques of analyzing simple organic compounds, a process that has become important in the petroleum industry. Dr. Pickett received the Garvan Medal for her work on far ultraviolet spectroscopy in 1957.[4]

The Mt. Holyoke research proved that group research was a very efficient use of the scarce resources of time and money. By working together, these women were able to gain recognition for their research and advances, as well as continue and further their teaching careers. Together they made Mt. Holyoke an outstanding research institution in Chemistry.

Pauline Beery Mack gained recognition for her outstanding work in the field of nutrition. She received her undergraduate training at Missouri State University where she also received her first research experience. She then went on to get a master's at Columbia University in 1919 and her doctorate in 1932 at Pennsylvania State University where she began her career in education. During her first 15 years, she taught elementary chemistry courses for home economics majors. Her goal was a research/teaching position in physical chemistry but because she was a woman, most universities would not even consider that. In this period, her reputation for teaching excellence grew.[5]

Dr. Mack's main research centered on the calcium chemistry of bone. In 1927, she began research that she would continue for 23 years on a method of measuring the density of calcium in the bone structure of living subjects through the use of x-rays. She then used this process to study the retention of calcium in the human body and in other animals. In 1940, Dr. Mack was made the first director of the newly formed Ellen H. Richards Institute, a departmental research group named for the first woman graduate in chemistry from the Massachusetts Institute of Technology. This institute studied the chemistry of nutrition, textiles, and household materials. The Pennsylvania Mass Studies in Human Nutrition, begun in 1935 and supported by the state of Pennsylvania since 1936, is said to be the longest running research project in nutrition.[5]

Pauline Beery Mack became Dean of the College of Household Arts and Sciences of the Texas State College for Women in 1952 and Director of its Nelda C. Stark Research Foundation in 1966. She was a member of many professional societies, including Iota Sigma Pi, in which she served as National President; the American Chemical Society, from which she received the Garvan Medal in 1950; and Phi Beta Kappa Associates. She also received the "Silver Snoopy" from the American Astronauts in 1970. She died in 1974.[5]

Mary Locke Petermann received recognition as the first woman member of the Sloan–Kettering Institute for Cancer Research. She received her undergraduate training at Smith College, graduating in 1929. Her doctoral degree was earned at the University of Wisconsin in 1939, where she then became the first woman chemist on the staff of the University of Wisconsin. During World War II, under the auspices of the National Defense Research Council's Committee on Medical Research, she researched the properties of human serum albumin and discovered methods of purifying it for use as a substitute for blood. She also found a method for the purification of immunoglobulins which is now a treatment for mumps. In 1945, Dr. Petermann began work at Sloan–Kettering in New York in nucleoprotein research.[6] She became the first to isolate, characterize, and measure the ribosome. For a short time, they were even called "Petermann particles" before they were formally named. Using ultracentrifugal analysis and electrophoretic analysis, she showed that the ribosomes of normal and abnormal mammalian tissues differed in some ways.[7] In 1966, Dr. Petermann became a full Professor of Biochemistry at Sloan–Kettering Institute Graduate School of Medical Sciences at Cornell University where she worked until her retirement in 1973.[6]

Dr. Petermann received the Garvan Medal in 1966 for her work in cellular chemistry. She also received the Alfred P. Sloan Award in Cancer Research in 1964 for her work linking ribosomes to cancer. In 1974, Dr. Petermann formed the Memorial Sloan–Kettering Organization for Professional Women. She died in 1975 at the age of 67.[6]

Mary Letitia Caldwell has been recognized for her work in carbohydrate enzymology. She received her A.B. from Western College for Women in 1913 and her A.M. and Ph.D. from Columbia University in 1919 and 1921 respectively. She began a teaching career at Columbia in 1922 that continued until her death in 1972.[3]

Dr. Caldwell began her research on malt amylase in 1918—research that was to take her a lifetime. She used group research, including the work of many graduate students, which was paid for by foundation and industrial grants. Enzymology has been changed radically by her research. Many of her techniques are now standard practice in universities and industry. She studied the properties and reactions of highly purified amylases, becoming the first to prepare crystalline pancreatic amylase. The research group also showed that amylases were proteins, and identified what triggered their activity. Finally, they demonstrated that all alpha-amylases do not have the same action mechanism. Mary Caldwell received the Garvan Medal in 1960 for her outstanding contributions in the field of enzymology.[3]

In reality, Dr. Caldwell had two careers. One was her research; the other was her dedication to the administrative duties of the Chemistry Department at Columbia. She served for over thirty years as an adviser in charge of assigning teaching assistants and guiding graduate admissions and research. At the same time, Dr. Caldwell served as secretary of the department and as a financial adviser to graduate students.[8]

Katherine Burr Blodgett earned her B.S. from Bryn Mawr in 1917 and her M.S. from the University of Chicago in 1918. In 1926, she became the first woman to receive a Ph.D. in Physics from Cambridge. She began her research career as the first woman at General Electric research laboratories in 1918. She got this position with the help of friends in GE and the labor shortage caused by World War I. She assisted Dr. Irving Langmuir in his work on monomolecular films. This group research, including several other prominent chemists at GE, resulted in the production of "invisible" glass in 1938, a product now standard in all cameras and optical equipment.[9] Successive one-molecule thick layers of transparent soap are applied to a lens in order to cut down on reflection. She then devised a method and a gauge to measure the thickness to one microinch of films based on color comparisons. Other research included the improvement of tungsten filaments in electric lights, ridding airplane wings of ice, and developing a new smoke screen during the second World War.[10]

Katherine Blodgett received the American Association of University Women Achievement Award in 1945 and the Garvan Medal in 1951 for her work with monomolecular films. She died at the age of 81 in 1979.[10]

Gertrude B. Elion made advances in Biochemistry and Pharmacology. She received her A.B. at Hunter College in 1937 and her M.S. at New York University. After a few years of shifting from company to company in menial jobs, she found her place at the Burroughs Wellcome Research Laboratories in New York in 1944. The wartime manpower shortage was the boost that she needed to land a good research job.

At Burroughs Wellcome, she synthesized Allopurinol (Zyloprim) which reduces the formation of uric acid. This drug is effective against gout and other diseases.

Azathioprine (Imuran), another of her drugs, is an immunosuppressant used in organ transplants. In fact, it was utilized in the first human heart transplant. She also synthesized 6-mercaptopurine which is used to treat children with leukemia. She was the recipient of the Garvan Medal in 1968 for her advances in pharmacology and chemotherapy.[11]

Sarah Ratner received her A.B. and M.A. at Cornell University in 1924 and 1927 and her Ph.D. at Columbia University in 1937. She began teaching at Long Island College of Medicine in 1926. In 1930, she moved to Columbia University's College of Physicians and Surgeons. She went to New York University's College of Medicine in 1946 where she was appointed adjunct associate professor of biochemistry in 1954. That same year, she joined the Public Health Research Institute of New York City.[12]

Dr. Ratner's research in the area of amino acids metabolism has gained recognition for her as well as her colleagues. Her first work studied the reaction of cysteine and formaldehyde. Later she applied isotopes to research in amino acid metabolism. In 1945, she initiated research in the utilization of enzymes in this process. This was a great step toward the eventual discovery of the mechanism of urea synthesis. As part of this research, she helped to study a children's mental deficiency associated with one of these enzymes.[12]

Dr. Ratner received the Carl Neuberg Medal of the Society of European Chemists in 1959. She was also the recipient of the Garvan Medal in 1961 for her research on the effect of enzymes on protein production.[12]

Gertrude Erika Perlmann received her D.Sc. in chemistry and physics from the German University of Prague in 1936. In 1939, she came to the United States, joined the staff at Harvard Medical School, and in 1945 became a naturalized citizen. She joined the Rockefeller Institute in New York that same year where she remained until her death in 1974 at the age of 62.[13]

She used electrophoresis in several research projects on proteins. She was the first to link phosphate with the stabilization of protein structures, showing that the phosphate group in pepsin forms a diester in the polypeptide chain, creating a loop. She then thoroughly researched the structure of pepsin. She described its atomic arrangement, its use in digestion, and the structure and properties of pepsinogen when it is activated.[14]

She authored many publications on protein and enzyme chemistry. Dr. Perlmann received the Garvan Medal in 1965 for these studies on protein structures.[14]

Mary Engle Pennington was one of the first chemists to study the structures and reactions of perishable foods. She received her Ph.D. at the University of Pennsylvania in 1895. In 1898, she began teaching at Women's Medical College, specializing in bacteriology. She was consulted by doctors nationwide, and by the city of Philadelphia, on the care of perishable foods, including the refrigeration of milk. In 1908, Dr. Pennington helped to implement the Federal Food and Drug Act by setting up and directing a laboratory for the Department of Agriculture. This installation researched methods of ascertaining the quality of such perishables as eggs, poultry, and fish. This work led to many improvements in the food storage and transportation industries. Dr. Pennington was a U.S. delegate to the first three meetings of the International Congress of Refrigeration.[3]

In 1919, she became the manager of the research and development division of the American Balsa Company in New York. Finally, in 1923, she established her own office in New York City as a private consultant on the bacteriology of perishables. She maintained this office until her death in 1952. During World War II, she was called in by the War Shipping Administration. As Director of the Household Refrigeration Bureau of the National Association of Ice Industries, she did research on frozen foods.[3]

Mary Pennington was a member of numerous professional societies and the author of many publications. She was the recipient of the Garvan Medal in 1940.[3]

Helen M. Dyer has made startling advances in the field of cancer causation and nutrition. She earned her B.A. from Goucher

College in 1917 and her M.S. and Ph.D. from George Washington University in 1929 and 1935 respectively. Her first teaching experience was at the Mt. Holyoke College in 1919 and 1920 where she taught physiology. She then returned to Washington, D.C. and went to work at the Hygienic Laboratory in its department of Chemotherapy under Dr. Carl Voegtlin. After a few years, she left the laboratory to study at George Washington University where she began to teach in 1930. In 1942, she rejoined Dr. Voegtlin, then at the National Cancer Institute where she helped with the establishment of its chemotherapy program.[15]

Her research work has laid the groundwork for other research projects. She showed the relationship between vitamin B_6 and N-2-fluroenylacitamide in the production of abnormal tryptophan metabolites. This research led to various studies into the carcinogenic effects of this reaction. In 1938, Dr. Dyer made a breakthrough in biochemistry by synthesizing the ethyl analog of methionine expecting to find a methionine dietary substitute. Instead, she found that the analog is extremely toxic. This discovery added a new field in medical research and pharmacology. In 1949, Dr. Dyer collected and reduced a tremendous amount of literature into an index of tumor chemotherapy. More recently she has shown that there is an inverse relationship between the level of serum glutamic-oxalacetic transaminase (GOT) and the growth rate of liver tumors.[15]

The result of Dr. Helen Dyer's research has been over sixty publications. Today she is working as a consultant in the Washington D.C. area. She is a fellow of the AAAS, and a member of the ACS, Sigma Xi, Iota Sigma Pi, and other professional societies.[13]

The lives and careers of these women have inspired other talented women to enter a field that was once closed to them. Although their careers were very different, some similarities are apparent in their different paths to recognition. First, the influence of the two world wars on the supply of talented men and on the supply of good research jobs seems to have been a crucial factor in many of these women's "first break" and added new opportunities for others who already had distinguished themselves in chemistry. Among these women were Mary Petermann, Katherine Blodgett, Gertrude Elion, Gertrude Perlmann, and Mary Pennington. Another similarity is the use of group research. The women of Mt. Holyoke College are perhaps the best but not the only example.

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The Scientific Awards of the Academy: 1981

Sherman Ross

General Chairman

The Annual Awards Dinner meeting of the Academy for 1981 was held on March 15 at Georgetown University. Four awards were made for significant contributions to research, and two awards for science teaching. This program was started in 1939 to recognize young scientists for " . . . noteworthy discovery, accomplishment, or publication in the Biological, Physical, and Engineering Sciences." An award for Outstanding Teaching was added in 1955 (renamed in 1979 as the Leo Schubert Award), and in Mathematics in 1959. In 1975 the award for the Behavioral Sciences and the Berenice G. Lambert award for Teaching of High School Science were made.

Behavioral Sciences

Dr. Frank R. Yekovich is Assistant Professor of Educational/Psychology, School of Education, The Catholic University of America. He was born in Colorado, and received the bachelor's degree from the University of Colorado. His graduate study was at Arizona State University (M.A. 1975, Ph.D. 1977). He served in 1978–79 as research psychologist with the U. S. Army Research Institute, and in 1977–78 as a research scientist with the Seville Research Corporation.

Dr. Yekovich's research deals broadly with language comprehension and memory for written text. Unlike the traditional wordlist research of the 1960s, he has studied how people acquire and remember complex written materials (both sentence and prose memory). Dr. Yekovich's projects have spanned both basic and applied research. His work on feedback procedures in programmed text has attempted to isolate the learner and the text variables responsible for influencing the acquisition and retention of classroom materials. He has started identifying the linguistic factors (i.e., the structural characteristics) that define the semantic representation of text. By identifying and manipulating these rules, psychologists have been able to trace what and how people learn from written texts. This work has relevance for developing theories about text structure and human memory. In addition, the research provides a base for investigating why "poor" readers are poor, and what can be done to make them better readers.

Dr. Yekovich currently is engaged in four research efforts. The first deals with deriving a hypothetical framework for representing knowledge of expository text materials. The second is a project aimed at characterizing the linguistic differences between certain types of oral and written discourse, and then measuring the effects of these differences on learning and retention. The third project investigates similarities and differences in the knowledge structures that hearing and deaf people use to process and remember simple stories. Finally, he is doing pilot work on how previously acquired knowledge becomes activated and used during the comprehension of text materials.

Engineering Sciences

Dr. Robert M. Williams is Technical Manager of the X-Wing Program, David Taylor Naval Ship Research & Development Center. He was born in Washington D.C. and received a bachelor's degree in Engineering Mechanics from the Virginia Polytechnic Institute. With some post graduate study at the University of Maryland, he completed his research leading to the Ph.D. in Aerospace Engineering at the University of Southampton (England) in 1977.

Dr. Williams began his DTNSRDC career as a co-op student in 1963. As a junior engineer in 1967, he examined the feasibility of an idea for a V/STOL aircraft employing a single 2-bladed rotor, that could be stopped in flight and stowed along the top of the fuselage on a sparetime basis.

On his recommendations, and with his technical participation, a highly successful circulation control airfoil research program was carried out at DTNSRDC in 1968-1970. In the ensuing years, Mr. Williams contributed substantially to the technical development of helicopter applications of circulation control. At the same time, he provided the creative spark and technical rationale for a number of new projects involving circulation control applications. These included applications to fixed wing high lift systems, Surface Effect Ship lift fans, submarine control surfaces and marine propellers.

In an informal competition at DTNSRDC in 1975 for development of a V/STOL Remotely Piloted Vehicle concept, Dr. Williams submitted a stopped-rotor vehicle concept, which he called an "X-Wing" vehicle. The X-Wing derived its name from the appearance of the wing when stopped with two blades swept forward by 45 degrees and two swept aft. In the fixed wing mode, the vehicle would have the potential for flight up to transonic speeds. In the rotary wing mode, it would provide helicopter-like capabilities from small ships. Dr. Williams' analyses of the potential of the X-Wing were so appealing that a preliminary design of a manned X-Wing aircraft was started. After six months, a full scale flight demonstration air-craft was started under his technical management. In 1979 a full scale wind tunnel test at NASA Ames confirmed that the rotor could be stopped and restarted without loss of lift, and without significant vibration at the high forward speeds at which rotary to fixed wing conversion is planned. All other aspects of these critical tests either met or exceeded expectations. The X-Wing aircraft appears to be the compelling choice to meet the Navy's evolving small-ship VTOL requirements. It promises triple the range at triple the speed in comparison to helicopters, and superior compatibility with small ships with respect to space requirements, environmental considerations and reliability/maintainability considerations. It could well prove to be the most significant contribution to Navy sea control capability in decades.

Mathematics & Computer Sciences

Dr. James A. Yorke is Professor, Institute for Physical Science and Technology, and the Department of Mathematics at the University of Maryland, College Park. He received the A.B. degree from Columbia University (1963), and a Ph.D. from the University of Maryland (1966). Dr. Yorke served as Assistant Professor (1967–69), as Research Associate Professor at the University of Maryland. He was a Guggenheim Fellow in 1980–81.

Dr. Yorke's mathematical achievements incorporate an intuition in topology, geometry and dynamics with a striving for applied results. His recent efforts toward "applied topology", and his striking ideas have reached and influenced a broad audience, including both biological and physical scientists. The common element throughout his work is the application of the methods of global analysis.

Topologists have long used global methods for proving that systems of equations possess certain properties. Dr. Yorke's principal contribution has been to convert these global methods into a numerical feasible form. His paper: "Period Three Implies Chaos" has become well known in Ecology and Physics. He has investigated "chaotic" phenomena, which behave chaotically for some time period, exhibit a half life, and finally decay to a more regular behavior.

Dr. Yorke developed a proof that there is a gradually attracting stationary solution to certain types of equations. He was then able to examine how these stationary solutions vary as various control procedures and strategies are applied. He has been involved with the modeling of gonorrhea in the U.S. He also has produced an analysis of measles outbreaks in the U.S., and indicated how measles might be eradicated.

Physical Sciences

Dr. Daniel T. Pierce, National Bureau of Standards was born in Los Angeles, California. He completed his undergraduate work at Stanford, received an M.S. at Wesleyan College, and his doctorate from Stanford—all in Physics. He served as a Peace Corps lecturer in Nepal and briefly as a physicist in Thailand. He was a research assistant at Wesleyan and at Stanford, where he also served as a Research Associate. He spent three years as a physicist at the Swiss Federal Institute of Technology (E.T.H.) in Zurich, before taking on his current work at the Bureau. He has been awarded the Department of Commerce Silver Medal, and was the Co-Winner of Industrial Research Magazine's IR-100 award, as well as the E. A. Condon Award of the N.B.S. Dr. Pierce was an active worker on the first measurements of the magnetization of the surface layer of nickel using a polarized electron beam. Of crucial importance to the success of this experiment was a method of scattering low energy electrons from magnetic materials that are at their saturation magnetization. Dr. Pierce developed an elegant way of capturing the stray flux that not only permits electron scattering, but is now being used in spin polarized photomission. Dr. Pierce's work on photoemission with W. E. Spicer at Stanford University was the basis for his early reputation. His later work on electron spin polarization phenomena has gained him substantial recognition. Electron scattering experiments are used widely to investigate the physics of atoms, molecules and materials. Although two parameters are available in such experiments (momentum and spin polarization of the scattered beam), only the momentum variable usually is used. This is due to the cumbersome and inefficient nature of the devices used to produce and detect the spin polarization in free electron beams. While at the E.T.H., Dr. Pierce began a program of improving spin polarization measurement, and applying the more efficient techniques to problems of fundamental importance.

His work at E.T.H. concentrated on the study of surfaces through the measurement of the polarization (the degree of alignment of electron spins in a preferred direction) of electrons ejected from both magnetic and nonmagnetic materials. The electrons were photoemitted from a clean surface, and their spin polarization analyzed by high energy Mott detection. Dr. Pierce brought his expertise in photoemission and the ability to make complex experimental systems work.

At E.T.H., Dr. Pierce showed that it was possible to obtain polarized electrons from a semiconductor (GaAs) by treating it to obtain a negative electron affinity and illuminating it with circularly polarized light. This proved to be a major breakthrough because of the high efficiency of the process. At the National Bureau of Standards he worked on the development of a practical source of polarized electrons based on photoemission. Dr. Pierce made major contributions to the development in the area of the surface physics of the negative electron affinity system and the photoemission process. This device produces, in most cases, as intense a beam of polarized electrons as the unpolarized beam it replaces. It provides a typical improvement of three orders of magnitude in available polarized electron current. The first application of this new technology demonstrated the usefulness of polarization measurements in surface structure determinations. Next came the start of a study of surface magnetism.

The Leo Schubert Award for Teaching of Science

Dr. George W. Gokel, Associate Professor of Chemistry, University of Maryland, College Park, was born in New York City, and did his undergraduate work in Chemistry at Tulane University. In 1971 he received a Ph.D. from the University of Southern California, and then spent two postdoctoral years at UCLA. From 1974–78 he was an Assistant Professor of Chemistry at the Pennsylvania State University. He came to the University of Maryland in 1978.

Dr. Gokel's work has been in the fields of synthetic and physical organic chemistry. His studies have been characterized by a concentration on fundamentally new and broadly important phenomena. His investigations of the synthesis, chemistry, and catalytic behavior of the class of macrocyclic organic substances known as "Crown Ethers" have provided fundamental knowledge to this remarkably interesting and scientifically important area. The significance of his contributions are demonstrated by the large number of invited lectures he has delivered before national and international audiences. More recent experimental studies carried out in Professor Gokel's laboratory have been targeted at the development of new synthetic methodology. In a very brief time period, this adventure has produced results which have advanced the fundamental knowledge of synthetic organic chemistry. His use of sulfur containing heterocyclic compounds in sequences to prepare biochemically and industrially important substances serves to exemplify this point. His contributions have been not only through his research activities and his teaching responsibilities, but include books and chapters in books, which summarize major accomplishments from his studies and those of his colleagues. He has co-authored a textbook on experimental techniques in organic chemistry for the undergraduate level. His brief career in chemical research and education has been extremely productive and influential.

The Berenice G. Lamberton Award for Teaching of High School Science

Dr. Maria Penny is a member of the Science faculty at Walter Johnson High School, Bethesda, Maryland. She was born in Madrid, Spain, and did her undergraduate work at New York University, and elected to Phi Beta Kappa. Her master's degree was from the Case-Western Reserve University, and she received a Ph.D. from the University of Maryland. After teaching in Florida for one year, she spent 1970–78 in the Howard County (Wilde Lake) school system. She has been at Walter Johnson since 1978 teaching Physics, Algebra, and Spanish.

She is an excellent teacher, hardworking, compassionate, friendly and knowledgeable. She is dedicated to her students, has developed new approaches, new methods and new courses in Physics. Her efforts and her contributions are exceptional, and have been recognized by the Distinguished Service Award of the American Association of Physics Teachers.

Acknowledgements

The contributions of the chairmen of the various panels and their colleagues, who carried out the difficult task of making the selections, are acknowledged with sincere thanks. The chairmen were:

Dr. John J. O'Hare	—Behavioral Sciences
Dr. Kun-Yen Huang	—Biological Sciences
Dr. John D. Anderson, Jr.	—Engineering Sciences
Dr. Joan Rosenblatt	—Mathematical & Computer Sciences
Dr. Mary H. Aldridge	—Physical Sciences
Dr. Joseph B. Morris	—Teaching of Science*

*Leo Schubert and Berenice G. Lamberton Awards

Thanks are due to the nominators and to the sponsors of all the candidates. The aid of Dr. Jean Boek, Secretary of the Academy, and Mrs. Donna Smith of the Central Office was timely and effective in the completion of the competition. On behalf of the Academy we commend the individuals, whose work is honored, and we wish them continued productive careers.

Gradient Device for the Study of Temperature Effects on Biological Systems[1]

W. Drost-Hansen

Laboratory for Water Research, Department of Chemistry, University of Miami, Coral Gables, Florida 33124

Introduction

Need for Closely Spaced Measurements

Over a period of about two decades in the early part of this century a fundamental change in attitude occurred regarding experimental work in the natural sciences. Profound insight was being made possible with the advance of atomic and molecular theories. The scope of possible research was expanded almost beyond imagination. Vast new areas of science became accessible and to advance over such a broad front dictated a philosophy of experimentation which did not permit each phenomenon to be subject to intense, detailed study. The "romance of the next digit" faded. As an example, in studies of thermal properties of matter it became possible at this time to extend measurements from very close to the absolute zero to very high temperatures and few researchers saw the need to measure, for instance, surface tension of water at one degree intervals. This attitude persisted and by the middle of the century the introduction of computers dealt the final blow to "closely spaced measurements": it seemed more appropriate to make measurements with the highest possible precision at a smaller number of points and let the computer provide best fit to the data for interpolation- and extrapolation-purposes.

Unfortunately, it is not always realized that failure to make measurements at closely spaced intervals of the independent variable tacitly implies that the dependent variable is a relatively slowly varying, continuous, monotone function of the independent variable. This (unstated) assumption is frequently fully justified. However, it remains nonetheless an assumption and at least in studies where water at interfaces (vicinal water) is involved, the assumption of a simple dependency on temperature of the parameters observed is not obeyed.

In this paper is described a device—based on maintaining a thermal gradient in a metal block—which facilitates making measurements at closely spaced temperature intervals. In addition, some of the types of results obtained with a "gradient incubator" in our laboratory will be discussed. The studies range from measurements of physicochemical properties of relatively well-defined, simple systems to the study of complex biochemical and physiological processes.

A Classical Example: Viscosity

In 1936, Magat[1] proposed that unexpected, relatively abrupt changes occur in the properties of water (and aqueous solutions) around 40 to 50°C. Among the properties reported to be "unusual" was the viscosity (of pure water) and also surface tension.[2] On this basis, Magat inferred that a change occurs in the structure of water in this temperature range. A number of authors expanded on this notion, including the late J. D. Bernal in whose laboratories measurements of the viscosity of pure water were carried out at closely spaced temperature intervals. Many papers, some quite controversial, were published on this

[1] Contribution #28 LWR

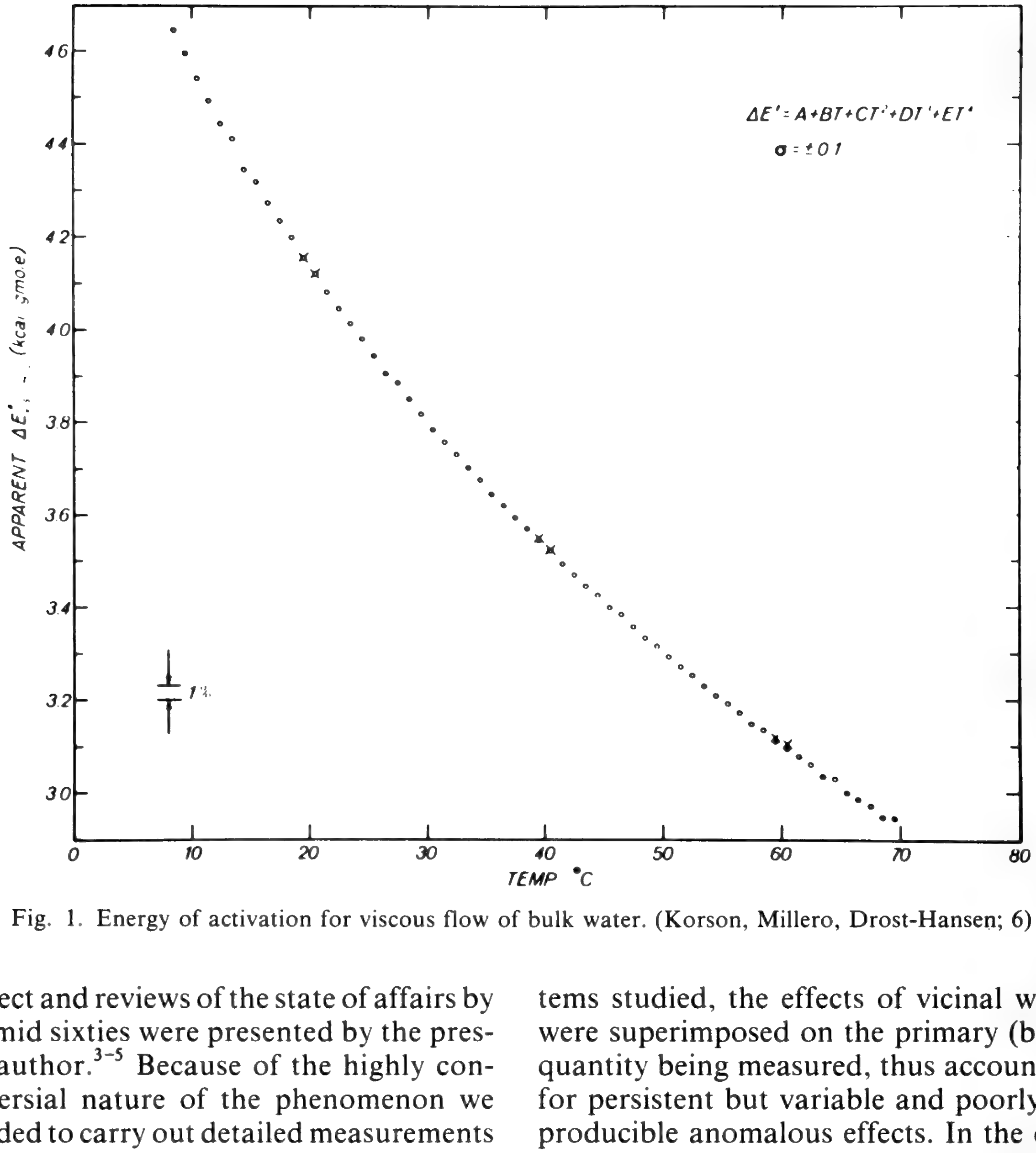

Fig. 1. Energy of activation for viscous flow of bulk water. (Korson, Millero, Drost-Hansen; 6)

subject and reviews of the state of affairs by the mid sixties were presented by the present author.[3–5] Because of the highly controversial nature of the phenomenon we decided to carry out detailed measurements of the viscosity of water using the highest precision attainable at closely spaced intervals. The results[6] clearly demonstrated that no unusual temperature effects existed in the viscosity data for bulk water. Yet enough reliable measurements had been reported by a large number of authors of anomalous properties of water to warrant a detailed search for the origin of these anomalies. The result of this effort was the suggestion[7] that bulk water does *not* exhibit any anomalous changes with temperature but that the properties of *vicinal water* (i.e., water at interfaces, particularly near solid surfaces) indeed *undergoes abrupt changes as a function of temperature* at various temperature intervals. In many of the systems studied, the effects of vicinal water were superimposed on the primary (bulk) quantity being measured, thus accounting for persistent but variable and poorly reproducible anomalous effects. In the case of viscosity measurements this was demonstrated particularly well by the results obtained by Peschel and Adlfinger.[8] Figure 1 shows the entirely "normal" temperature dependence of the apparent energy of activation for bulk water,[6] while Figure 2 shows the unusual viscosity of vicinal water as reported by Peschel and Adlfinger. Note that closely spaced measurements were made in both our own measurements and in those of Peschel and Adlfinger.

In connection with closely spaced measurements of viscosity, it is also of interest to note the study by Plötze, *et al.*[9] on the viscosity of kaolin suspensions. Their results are shown in Figure 3. Again, an anomaly is observed—in this case as a

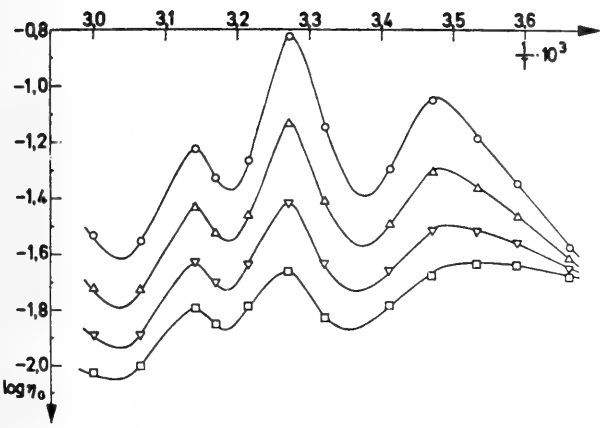

Fig. 2. Arrhenius plot of viscosity of water between two quartz plates. Distance between plates: (bottom to top) 900, 700, 500 and 300 Å. (Peschel and Adlfinger, 8)

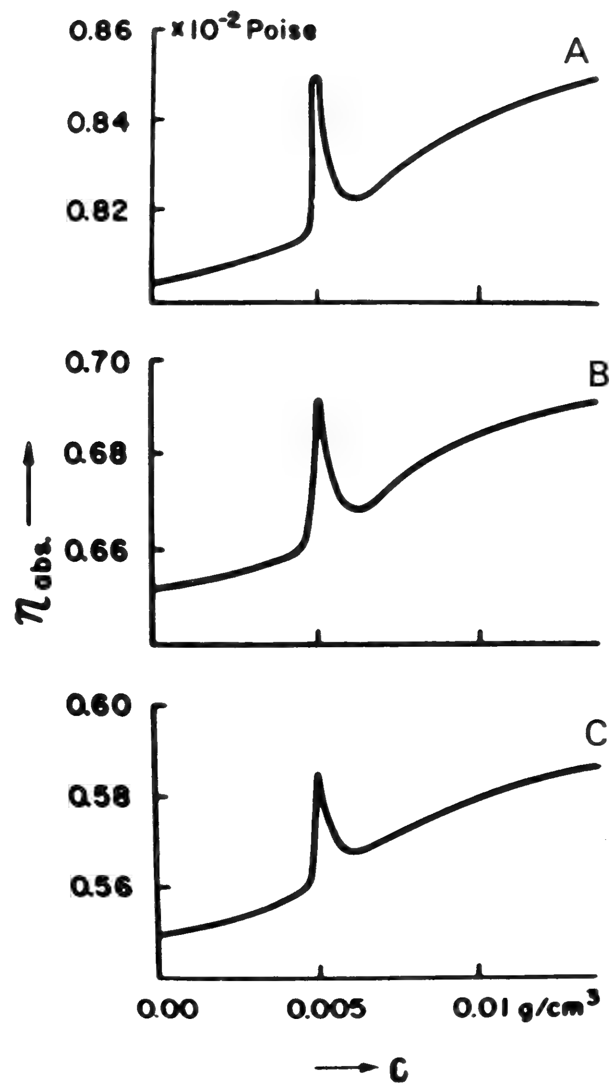

Fig. 3. Apparent viscosity of dilute kaolin suspensions, at three different temperatures: A) 30°C; B) 40°C; C) 50°C. (Plötze *et al.*, 9)

function of concentration. Whether or not the anomaly reflects effects of vicinal water (such as overlap of "hydration hulls" of the clay platelets) is not of primary importance here. Suffice it to point out that this anomaly is so "sharp" that it was observed only by virtue of the very closely spaced measurements carried out.

Thermal Gradient Devices

Historical Note

One of the first uses of a thermal gradient device appears to have been reported by Herter (see reference 10, pages 148–149). His gradient block consisted of a massive metal bar, heated in one end (by a Bunsen burner) and cooled at the other end, apparently with no automatic control device but relying on manual regulation. While the instrument was lacking in sophistication, Herter nonetheless deserves credit for the first use of such a gradient approach in ecological laboratory studies (thermotaxis of insects).

The use of gradient devices—especially for the study of ecological effects of chemicals on aquatic organisms—goes back more than 60 years, to Shelford and Allee.[11] A review of early work can be found in a paper by Höglund[12] from 1951 who introduced an improved design of a chemical gradient device, referred to as a "fluviarium".

In the same decade, at least three thermal gradient devices were constructed. Scott and Jones at Scripps Institution of Oceanography (in California) in 1958 described a temperature gradient incubator in a relatively inaccessible ONR report.[13] Halldal and French,[14] also in 1958, described an ingeneous "cross gradient culture chamber" in which (continuous) gradients of temperature and light intensity were maintained. The device was used for the study of growth of algae. Finally, Oppenheimer and Drost-Hansen[15]—somewhat earlier but unaware at the time of the previous work by Herter—constructed a "polythermostat", originally intended primarily for bacterial growth experiments. It is this device which will be

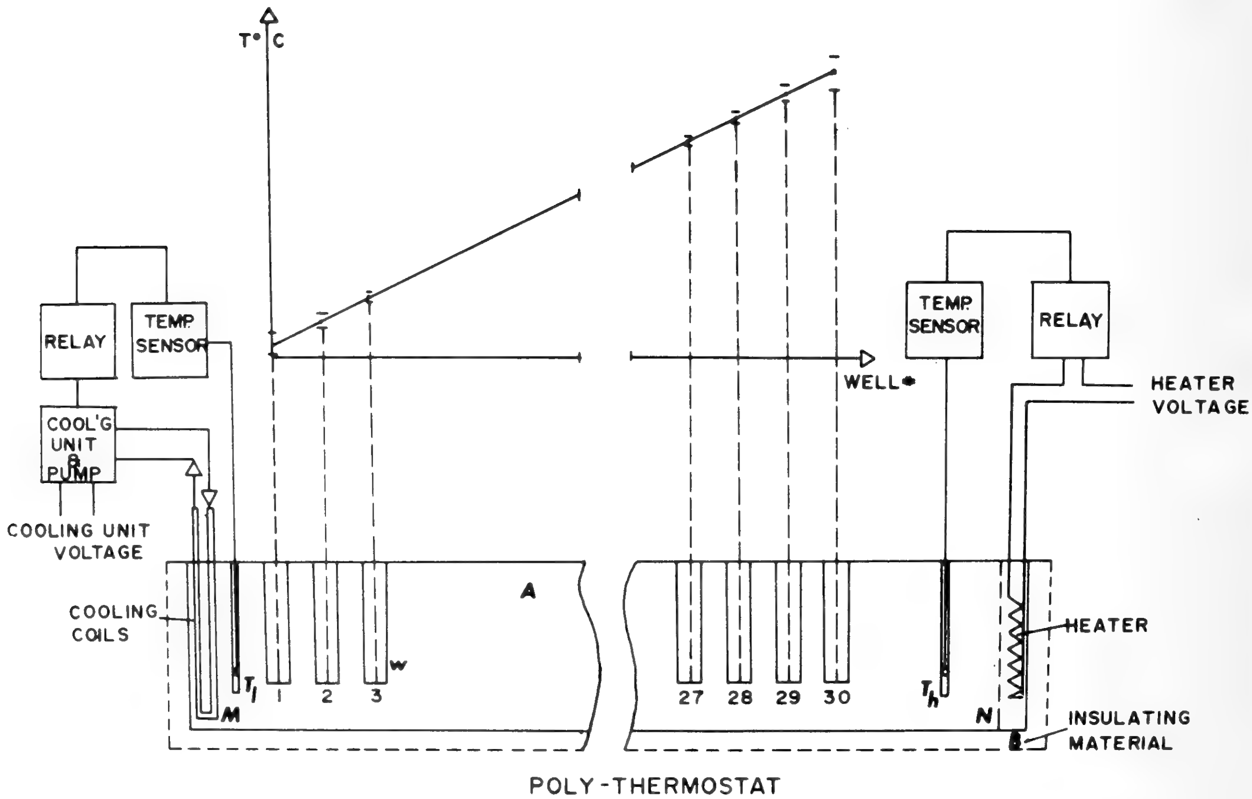

Fig. 4. Polythermostat (Temperature Gradient Incubator); schematic. See text for details.

discussed in the present paper. However, attention is called as well to a number of papers by other authors in which polythermostats have also been described.[16]

Instrument Design

Oppenheimer and Drost-Hansen first constructed the thermal gradient device for bacteriological studies in 1956.[15] The principle used is simple. In general, temperature gradient bars (and gradient plates) depend on the high heat conductivity of a suitable metal block, insulated on the sides and maintained at fixed constant temperatures at opposite ends (or sides). Figure 4 shows schematically the principle usually employed in the construction of temperature gradient bars. *A* is the heat conducting metal block, usually aluminum (the heat conductivity of aluminum being very high). The gradient bar is provided with wells (usually two rows arranged symmetrically) to accommodate culture tubes or test tubes. *C* and *D* are, respectively, a heating element and a heat exchanger, such as cooling coils. The entire assembly is covered on all sides (except possibly for the top, or "working side") with suitable insulation material such as polystyrene foam (or other materials; for instance, Bakelite, for working at higher temperatures).

The temperatures at each end are maintained constant by the use of two temperature controllers such as mercury on/off switches, platinum resistance sensors, thermistors or (in earlier versions) bimetalic contacts. The cooling is usually provided by circulating a cold liquid either from an external constant-temperature cooling unit or from a built-in refrigeration unit (in some commercial models). For certain operations where very low temperatures are not required, cold tap water may suffice to maintain a fixed (low) temperature.

Temperature linearity and fluctuations in the gradient bar are determined by the sensitivity of the thermoregulators at the hot and cold ends and by any spurious heat transfer to or from the surroundings (due to imperfect insulation). In our own experience the gradient is usually quite linear; however, for other reasons (to be discussed below), the actual gradient is normally determined from a calibration run prior to (or simultaneously with) actual experimentation.

In many applications, particularly those involving sample containers other than test tubes or culture tubes (which are completely contained within the sample wells) it is necessary to perform a calibration. In our own experiments we have usually also maintained two or three wells without samples to spot-check for temperature constancy during individual experiments. Using L-shaped tubes or Thunberg tubes a significant amount of the tube extends beyond the thermally conducting, temperature regulated, part of the aluminum bar. In these cases, a measurement of the actual temperature of the tube is necessary as the final temperature is somewhat different from the calculated temperature (due to the gradient itself) as it is influenced by the ambient temperature (say, within ±1 to 3°C); the constancy of the tubes is satisfactory.

The overall temperature constancy is determined primarily by the temperature regulation at the ends of the bar. The temperature fluctuations depend critically on the relative locations of the temperature sensors with respect to the heaters and cooling coils. The tendency is for the temperatures at the extremes—in Figure 4, well number 1 and to a lesser extent number 2, and well number 30 (and number 29)—to vary within some tenths (to one) degree. For the majority of the wells (say, numbers 3–28), the temperature variations are usually within 0.2 degrees, or better. For special applications, greater temperature constancies may be required. In those cases it is necessary to use highly sensitive thermo-regulators (such as mercury-in-glass metastatic on/off controllers, sensitive to 0.005°C or better). It is possible to bring the temperature variations of the major part of the bar to ±0.02 (to 0.05°C). For most purposes this appears to be sufficient.

Sample Containers

A variety of sample containers have been described in the literature and various types have been developed in our laboratory.

Ordinary test tubes, usually stoppered with cork or rubber stoppers, have frequently been employed and have proven highly versatile. In work with bacterial cultures, standard screw cap culture tubes have been used. Available commercially are also various types of "L-shaped" tubes. Some slightly curved "L-shaped" tubes have been used in the author's laboratory, but are primarily useful only for specialty applications. The use of culture flasks in thermal gradient devices have been described by Miller and co-workers.

Commercial temperature gradient incubators are available with provisions for culture trays (made of stainless steel) or long glass tubes which can be filled with the inoculated medium. In principle, such tubes may be monitored either visually or by passing through a spectrophotometer with a suitably modified sample holder design. The use of sample trays is particularly employed in temperature gradient plates; for instance, for determination of seed germination or growth plants.

For bacterial growth experiments as well as for some enzyme reactions, the classical Thunberg tubes have been employed in our laboratory. Using such tubes it is obviously possible to study the growth of anerobic organisms. However, one experimental difficulty is frequently encountered; namely evaporation of the medium and condensation of the liquid in the part of the tube not contained within the temperature controlled portion of the gradient bar.

Agitation of Samples

In the original version of the temperature gradient device, constructed by Oppenheimer and Drost-Hansen, the samples were contained in vertical wells in the bar. To agitate the contents of the tubes the entire unit was mounted on a sieve-shaker. While this approach offered some agitation in the tubes, it was noted that in some cases standing waves resulted with "nodes" with no or little agitation compared to the tubes in other wells. (A commercial model was available some years ago with a built-in eccentric motor also serving to shake the entire bar with its auxiliary instrumentation).

In two currently available models of the gradient device the samples are contained in horizontal wells in the gradient bar. In this case the same samples can be left at rest or tilted at a certain angle. The samples can also be tilted with a variable period around a horizontal axis through the length of the aluminum bar. In this case effective agitation is obtained; the amplitude and frequency of the rocking motion may be adjusted by changing the point of attachment of the bar to an eccentric wheel-and-cam arrangement.

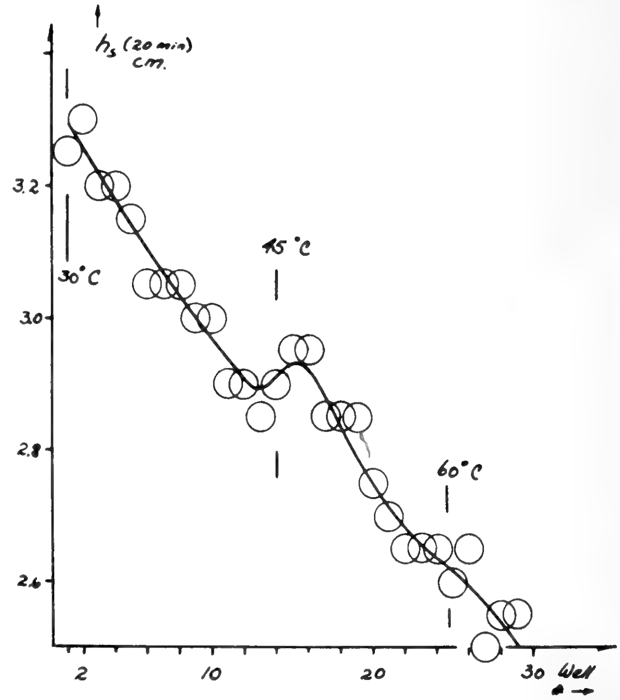

Fig. 5. Sediment height in 10% kaolin suspension (after 20 min.) as function of temperature. (Drost-Hansen, 17)

Temperature Ranges

One of the commercially available models (manufactured by Scientific Industries, Inc., of Bohemia, New York) is designed for use over a relatively wide temperature range. Thus, the temperature of the cold end may be selected in the range between —5° and about 20°, while the temperature at the hot end may be set between approximately room temperature and 105°C. The model employs a total of two horizontal rows of 30 wells each. The access to the two sets of 30 samples are from opposite sides of the gradient bar. At operations (of the low end) below the dew-point in the laboratory, ice tends to form on the exposed filling part for the circulating coolant liquid; however, this does not seem to affect the operation of the instrument significantly. The instrument is highly versatile and one such unit has been operating nearly continuously in the author's laboratory for three years.

Applications

Physico-chemical Systems

Sedimentation Studies

Using a polythermostat in which the samples are contained in vertical test tubes, rates of sedimentation and compaction of dispersed solids have been measured. So far measurements have been made primarily on kaolin and on suspensions of polystyrene spheres (of uniform diameter, produced by Dow Chemical Co.).

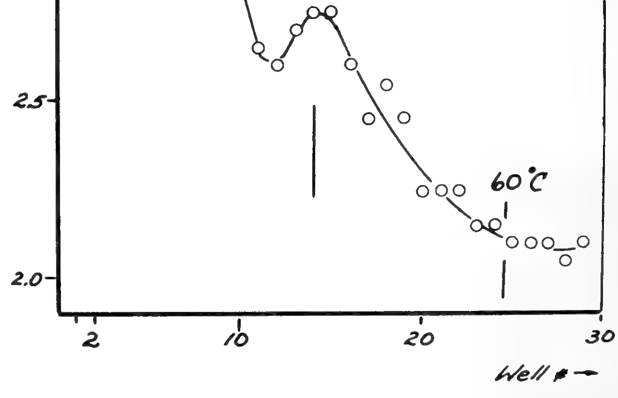

Fig. 6. Sediment height in 10% kaolin suspension (after 7 hours) as function of temperature. (Drost-Hansen, 17)

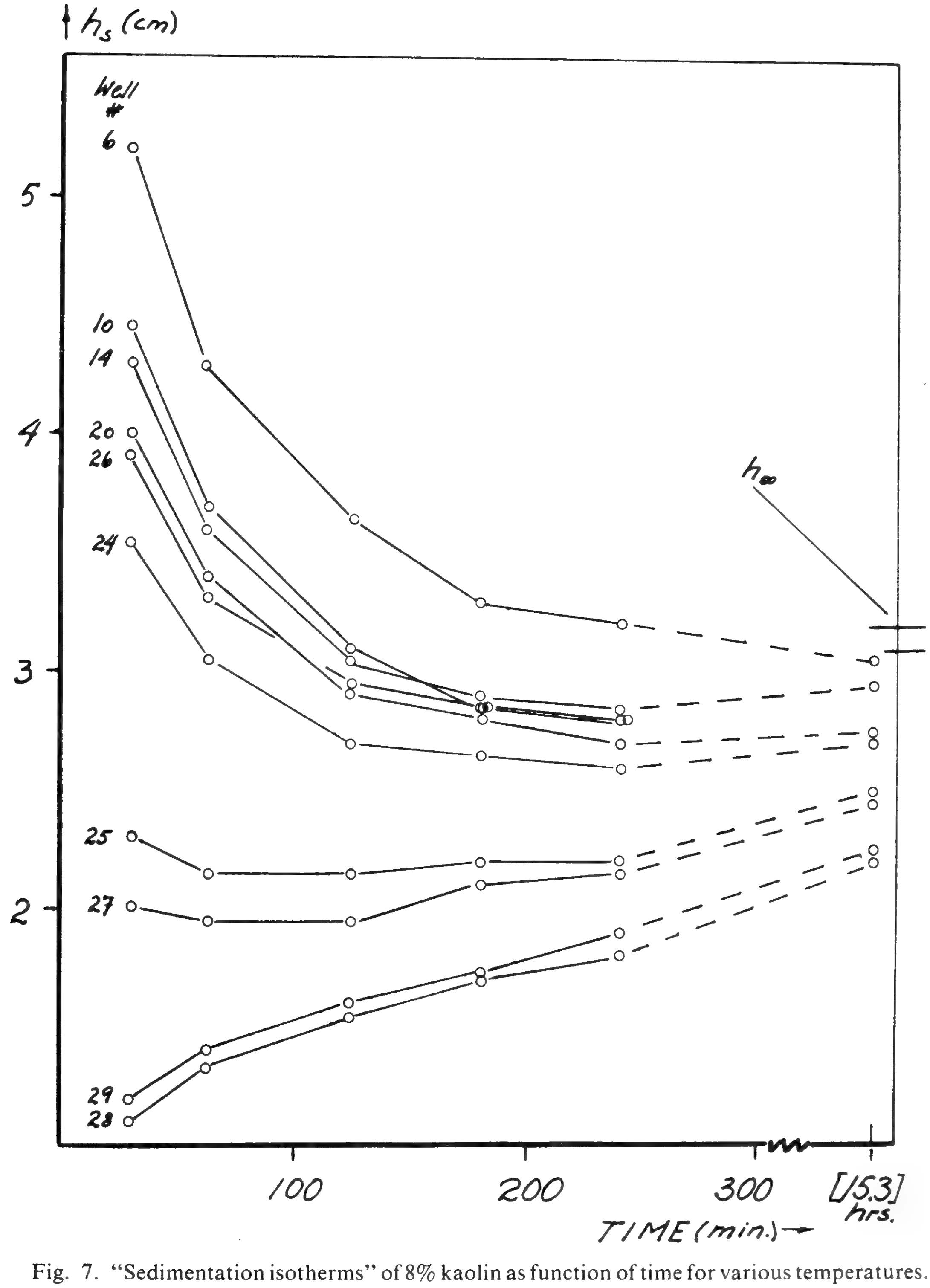

Fig. 7. "Sedimentation isotherms" of 8% kaolin as function of time for various temperatures. (approx. temperatures, for well #6; 10; 14; 20, and 25 are, respectively, 36; 40.5; 45; 53 and 60°C)

The study of the sedimentation of kaolin has been made by simply measuring the height of the sediment in each test tube with a ruler. Two typical sets of data are shown in Figures 5 and 6. In the first of these illustrations is shown the sediment height 20 minutes after the samples had been thoroughly agitated; in the second illustration, after seven hours of sedimentation. Note in Figure 5 (a) the decrease in sediment volume with increasing temperature, and (b) the anomaly around 45°C (confer Figure 2 in which an anomaly exists in the viscosity of vicinal water at this temperature). For comments on these data and implications of vicinal water for colloidal stability, see

(17). The process of sedimentation and compaction of natural kaolin appear to be more complex than originally expected. Figure 7 shows some "sedimentation isotherms" (all conveniently obtained simultaneously in a single run). The data are somewhat unexpected, no doubt due in part to notably different rates of actual sedimentation and subsequent compaction. An analysis of the data in terms of the individual contributions is not possible without additional information, but the results of the experiment suggest that further study may be highly worthwhile and such work is in progress in our laboratory.

Ion Distribution

In 1975 Wiggins[18] in New Zealand reported on measurements of the distribution of sodium and potassium ions from equimolar sodium-potassium salt solutions in contact with a highly porous quartz gel. Wiggins' results are shown in Figure 8. The

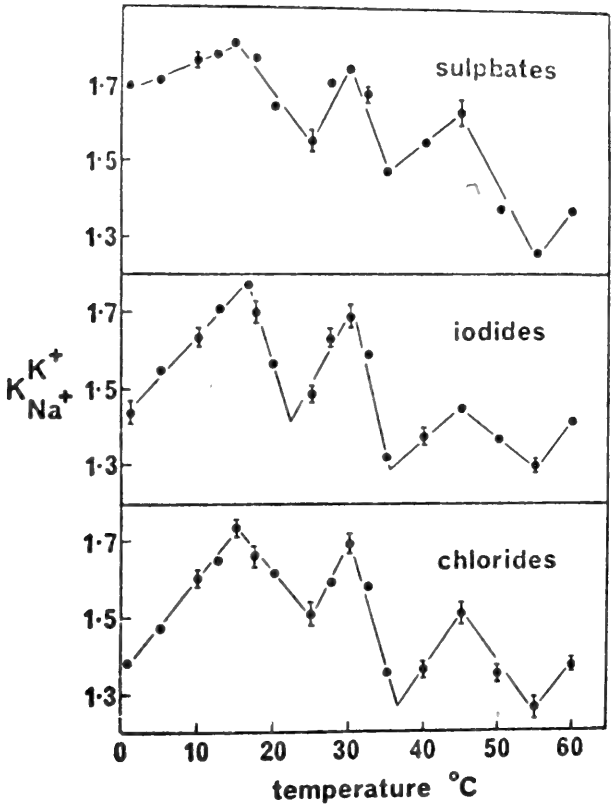

Fig. 8. Potassium/sodium ion distribution in silica pores (from equimolar mixture of Na^+ and K^+) as function of temperature. Top to bottom: sulfates; iodides; chlorides. (Wiggins, 18)

partition coefficient, K, is defined by the equations:

$$\lambda_{K^+} = \frac{[K^+]_i}{[K^+]_\sigma} \qquad \lambda_{Na^+} = \frac{[Na^+]_i}{[Na^+]_\sigma}$$

where $[\ ]_i$ and $[\ ]_\sigma$ are, respectively, the ion concentrations inside and outside the pores of the gel. Hence,

$$K = \frac{\lambda_{K^+}}{\lambda_{Na^+}}$$

The values for K were calculated for potassium and sodium sulfate, iodide, and chloride. As can be seen from Figure 8, potassium ions tend to exclude sodium ions, the value of K ranging from 1.3 to 1.7. The distribution is seen to be highly nonlinear with sharp peaks near 15, 30 and 45°. These temperatures are in excellent agreement with the temperatures at which the present author has demonstrated that the structure of interfacial (vicinal) water undergoes some type of change, most likely a higher-order phase transition. (Note also the results are essentially independent of the nature of the anion present).

In view of the significance of the results obtained by Wiggins, Hurtado and the present author have repeated such experiments on a similar type porous media (Davison gel, #950) using a temperature gradient device (Scientific Industries, Inc., Model 675). Because of the availability of the gradient incubator it was possible for us to make measurements at more closely spaced intervals than had been possible for Wiggins. The results obtained agree quantitatively with the results obtained by Wiggins. (These data are discussed in a recent volume.[19])

Enzyme Kinetics

The polythermostat is uniquely well suited to measurements of the effects of temperature on rates of reaction, especially enzyme reactions. This is particularly true for reactions which can be followed spectrophotometrically: the sample tube is transferred directly from the gradient device to the spectrophotometer. As each reading can usually be made in a matter of a minute or so, nearly simultaneous measurements are possible, and variability due to need for different stock solutions (which may "age" from one day to another) is eliminated. Besides the use of screw-cap culture tubes (or L-shaped tubes) Thunberg tubes can be used in gradient devices with vertical sample wells. Using such techniques we have made a preliminary investigation of the effects of temperature on the alkaline phosphatase reaction.[20]

Other Studies

Polythermostats have been used in the author's laboratory for measurements of the effects of temperature on: (a) solubility (and mutual solubility of partially immiscible liquids); (b) partition of organic solutes between aqueous phase and an immiscible, organic liquid; and (c) equilibrium constants.

Biological Systems

Germination Studies

Polythermostats have been used in the present author's laboratory for the study of effects of temperature on rates (and extent) of germination.

Figure 9 shows the percent germination of turnip seeds as a function of time (in hours) measured at 19.9°. Similar germination curves were obtained in experiments at each of the 30 available, different temperatures (wherever germination occurred). In Figure 9 the maximum germination rate (α) is defined as the maximum slope (indicated by the dotted line). This parameter is similar to the intrinsic germination rate, determined by the logistics equation generally used in population studies. Other measures of the rate of germination used are the reciprocal of the time to reach either 16% or 50% germination.

Figures 10 and 11 show the log germination rates, respectively, for the 16 and 50%

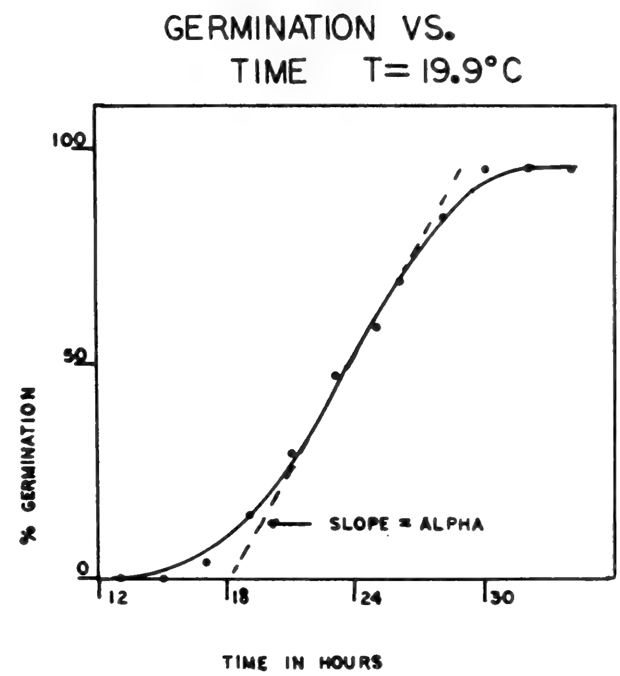

Fig. 9. Percent germination of turnip seeds as function of time. (Etzler and Drost-Hansen, *29*)

germination plotted vs. reciprocal absolute temperature (in a standard type Arrhenius graph). As seen from Figures 10 and 11, it appears that changes in slope occur near 15 and 30°C. For a discussion of the kinetic interpretation of these data, see the paper by Etzler and Drost-Hansen.[29] Finally, Figure 12 shows the maximum rate of germination (α, defined above) in an Arrhenius plot. A notable anomaly occurs near 30°C—again one of the temperatures at which vicinal water appears to undergo a marked change in structure.

In a separate series of experiments we have determined the effects of H_2O replacement by D_2O on the temperature dependence of the germination rate.[21] As the available polythermostats all have provisions for two samples at each of 30 different temperatures, one set of samples can be used as "control" (in this case, germination in pure H_2O) while the other set of wells was used for measurement of germination in the presence of D_2O. A total of three different D_2O concentrations were investigated; 33, 67 and 98 mole-percent.

Figure 13 shows the amount of germination after 14 hours, for 67 mole-percent D_2O. At low temperatures D_2O notably in-

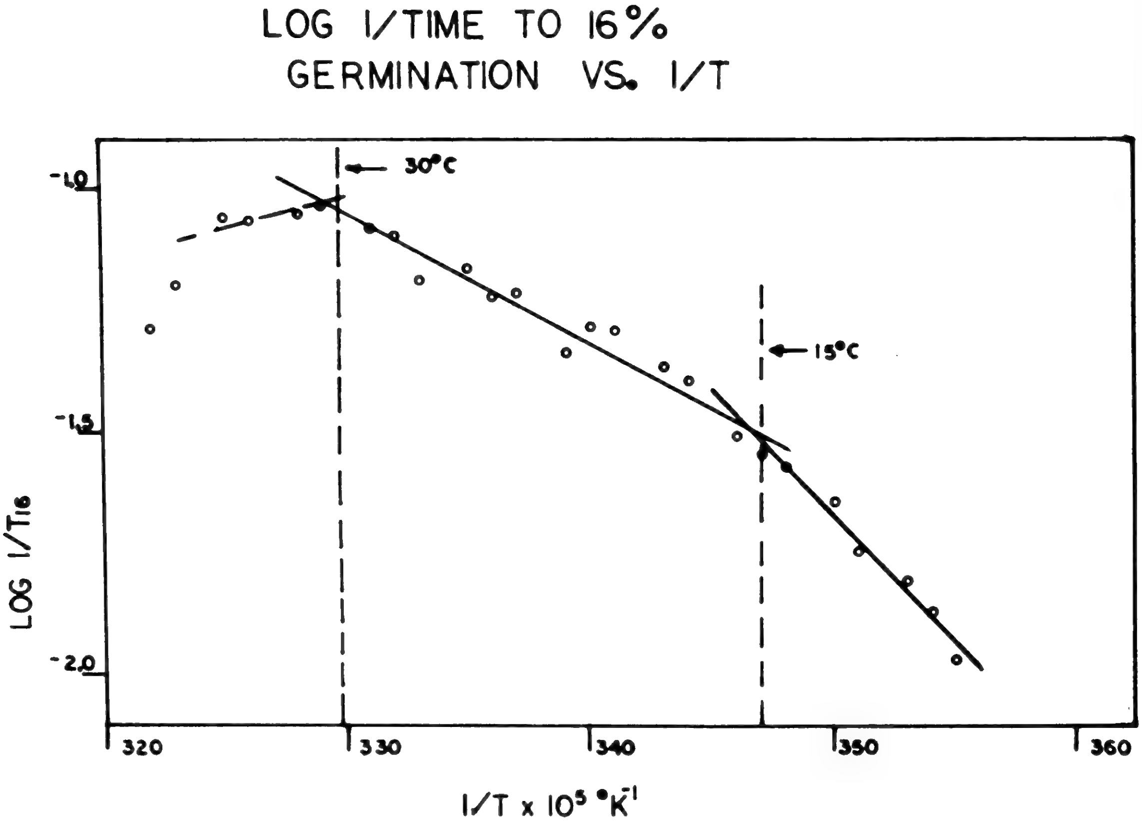

Fig. 10. Log germination rate for 16% germination of turnip seeds as function of reciprocal, absolute temperature. (Etzler and Drost-Hansen, *29*)

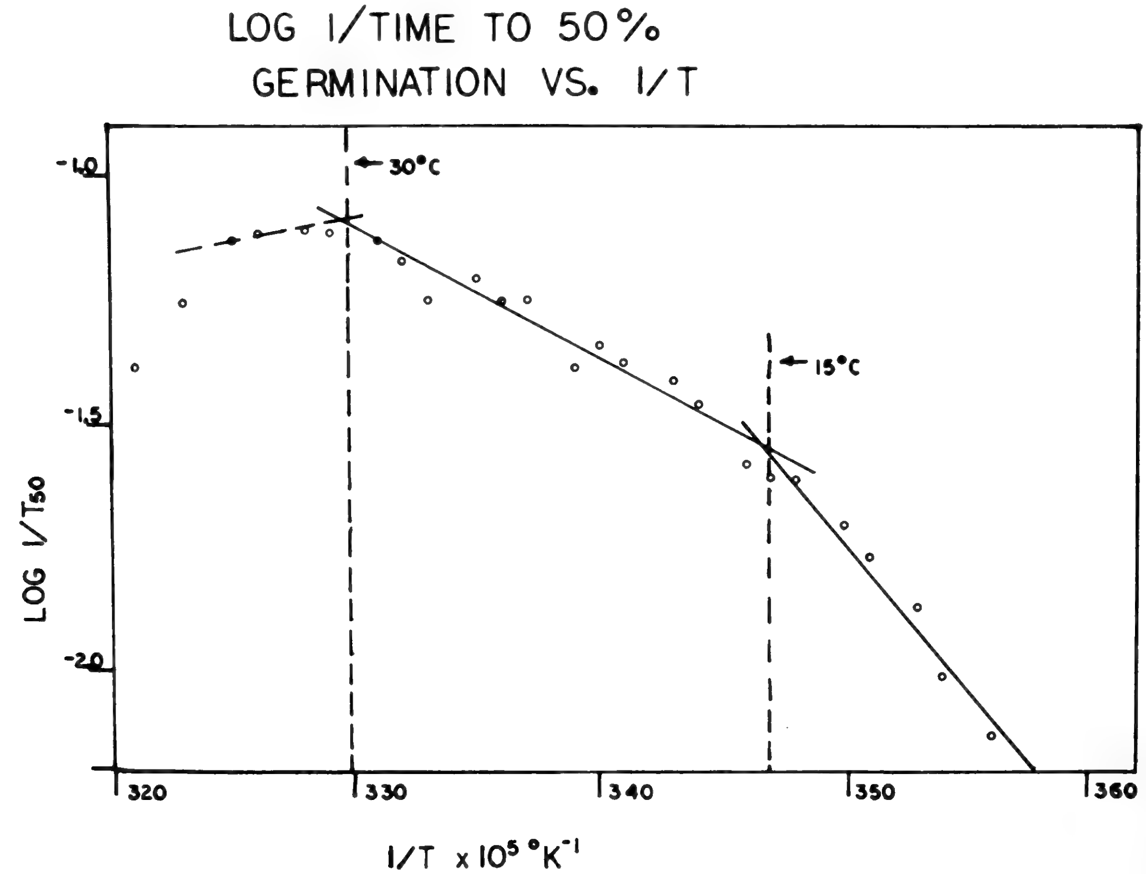

Fig. 11. Log germination rate for 50% germination of turnip seeds as function of reciprocal, absolute temperature. (Etzler and Drost-Hansen, *29*)

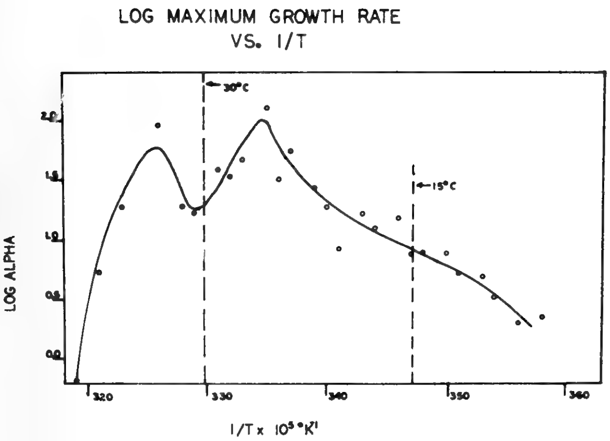

Fig. 12. Log maximum germination rate of turnip seeds as function of reciprocal, absolute temperature. (Etzler and Drost-Hansen, *29*)

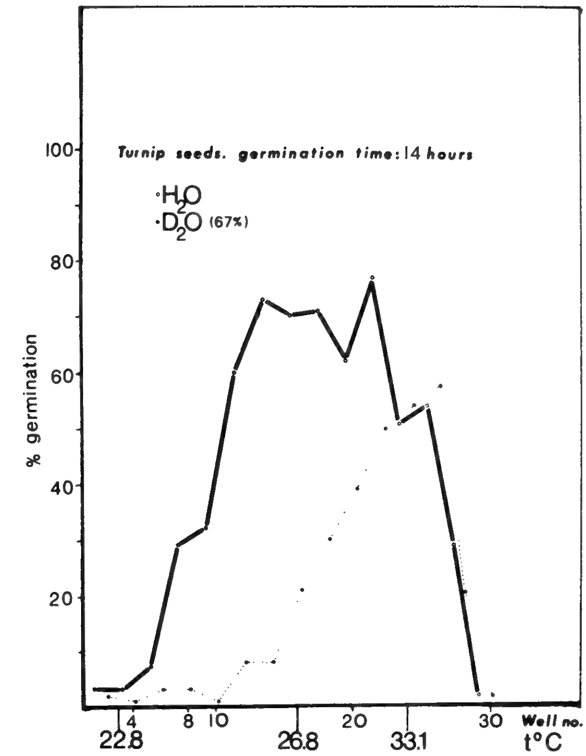

Fig. 13. Percent germination of turnip seeds in 67 mole-percent D_2O as function of temperature after 14 hours. (Bee Drost-Hansen and W. Drost-Hansen, unpublished)

hibits the germination (reduces the rate of germination). However, at higher temperatures the effect of D_2O replacement disappears; in fact, it appears that D_2O may actually increase the rate of germination. We define an inhibition coefficient, I, as

$$I = 1 - \frac{(\%\ \text{germinated in } H_2O\text{-}D_2O)\ \text{at time } t}{(\%\ \text{germinated in } H_2O)\ \text{at time } t}$$

For zero percent germination in an H_2O-D_2O mixture (when some germination has occurred in pure water), I is one. If no effect due to D_2O is observed (i.e., identical amounts of germination), I is zero. If the percent of seeds germinated in D_2O exceeds the percent germinated in H_2O, I is negative and corresponds to a relative enhancement of germination. Figure 14 shows a graph of I as a function of temperature. Nearly complete inhibition is observed below ~26°C, but above this temperature the inhibition due to D_2O decreases and at higher temperatures in a rather narrow range around 35 to 37°C) it appears that germination is actually facilitated by D_2O, however, this enhancement is not statistically significant.

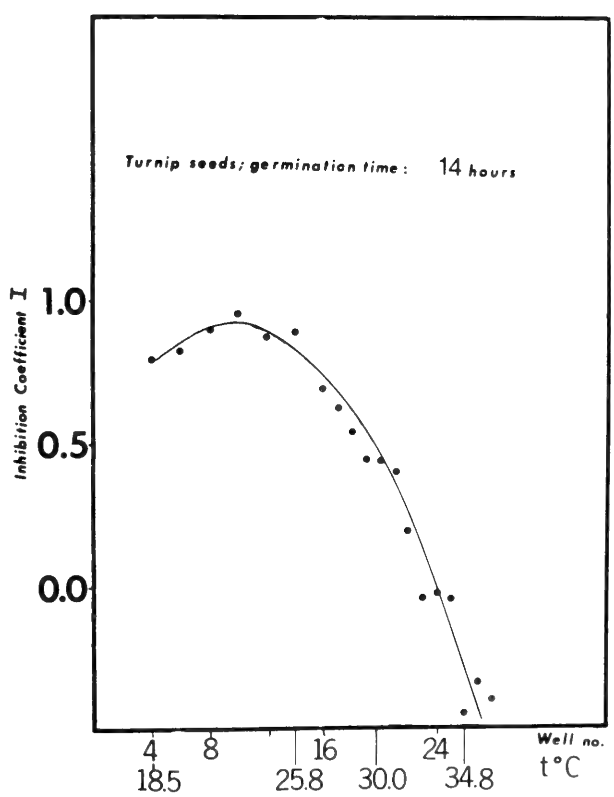

Fig. 14. Inhibition coefficient, I, (of germination) of turnip seeds as function of temperature. (Bee Drost-Hansen and W. Drost-Hansen, unpublished)

Algal Studies

Thorhaug, working in the author's laboratory a number of years ago, used a

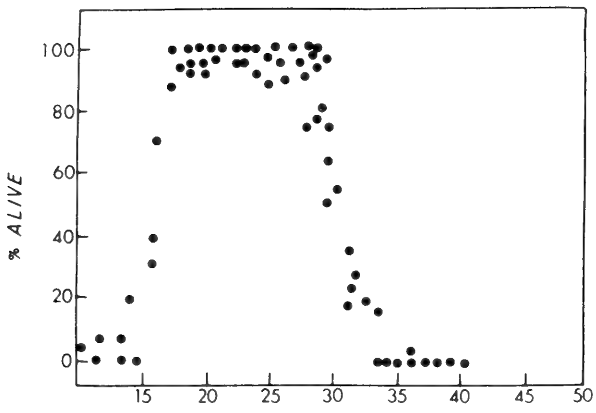

Fig. 15. Percent survival of *Valonia macrophysa* after 3 days exposure. (Thorhaug, 22)

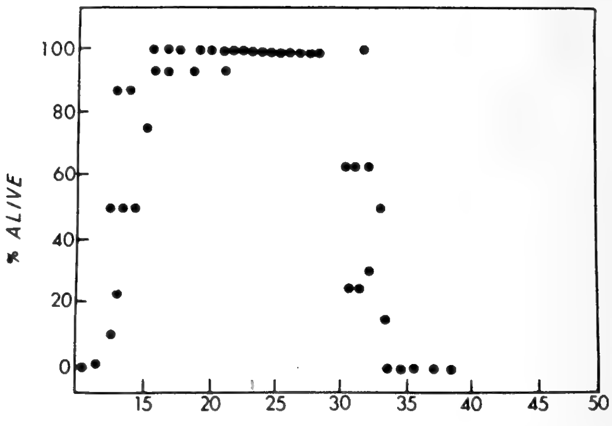

Fig. 17. Percent survival of *Valonia ventricosa* after 3 days of exposure. (Thorhaug, 22)

polythermostat to determine the effects of temperature on several species of algae, particularly *Valonia.*

In a series of experiments, Thorhaug[22] subjected three species of Valonia to temperatures ranging from 10°C to about 40°C. This study was undertaken in connection with our research on the possible existence of sharp upper thermal limits. The results of exposures of this alga to a wide range of temperatures, are shown in Figures 15, 16 and 17. The abruptness of the onset of irreversible plasmolysis is striking, both at the upper and lower ends of the temperature ranges (22; see also 23 and particularly 24).

Thermal Limits for Some Marine Organisms

Thorhaug[22] has reported data on the survival of a number of marine organisms exposed to thermal stresses. A total of 27 different species and life stages were studied. Some of Thorhaug's results are shown in Figures 18, 19 and 20. In all cases shown, abrupt changes in survival occur near 15 ± 1°C and near 30 ± 2°C. The results are in excellent agreement with expectations based on the temperatures of changes in vicinal water structure.[24,25,26,27]

Microbial Growth Studies. Clostridium

The first use of the Oppenheimer/Drost-Hansen Polythermostat was to study the effects of temperature on the growth of a sulfate-reducing bacterium, probably a *clostridium.*[16] Notable growth optima were recorded at 12, 25 and 38°C with pronounced minima at 16, 31 and 45°C. These results were, however, obtained using an

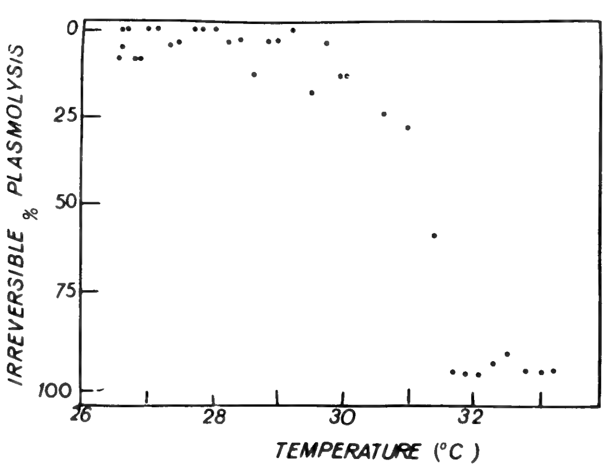

Fig. 16. Percent survival of *Valonia utricularis* after 3 days exposure. (Thorhaug, 22)

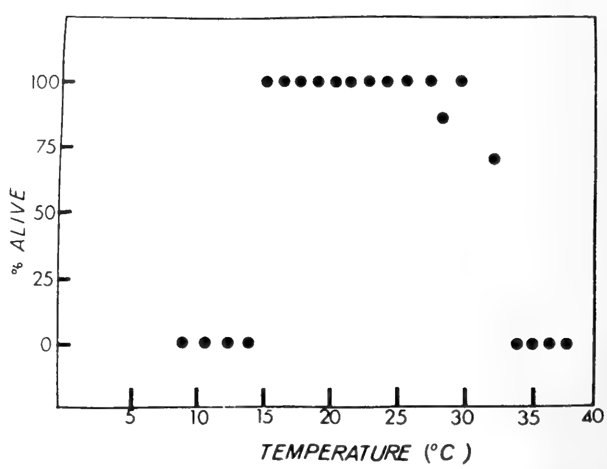

Fig. 18. Percent survival of *Penicillus capitatus* after 8 to 10 days exposure. (Thorhaug, 22)

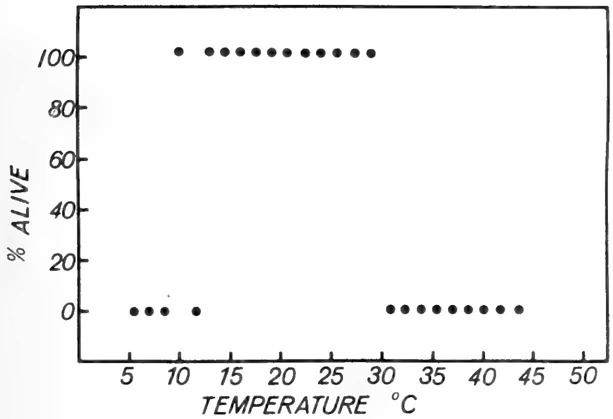

Fig. 19. Percent survival of *Menippe mercenaria* after 24 hours exposure. (Thorhaug, 22)

extremely simple approach (amounts of growth estimated only visually). For this reason, Schmidt and Drost-Hansen repeated the study more carefully and again observed growth opinion near 24 and 40°C with a broad, somewhat asymmetric minimum near 31–33°C.[28] Schmidt and Drost-Hansen also measured the growth of a stain of *E. coli,* a strain of *Aerobacter* and *Serratia marcesence.* Again, multiple growth optima and minima were discovered especially where the organisms were grown on minimal media.

Multiple Growth Optima

In the original publication[16] Oppenheimer and Drost-Hansen proposed that the multiple growth optima might reveal the operation of two (or more) different metabolic pathways, for instance, above or below 31°C, somehow imposed by more or less abrupt changes in water structure. This

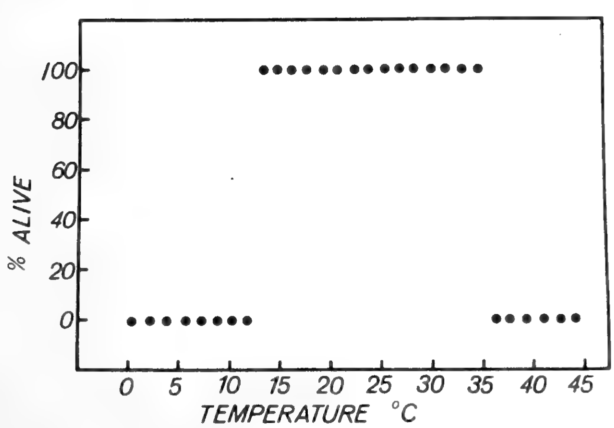

Fig. 20. Percent survival of *Periclimenes* sp. after 168 hours exposure. (Thorhaug, 22)

idea was also discussed by Drost-Hansen,[26] but little progress was made at the time; this was, in part, due to the mistaken notion that bulk water structure underwent structural changes near the observed transition temperatures. First by 1968 did it become obvious[7] that bulk water does not change, but the structure of vicinal water does. More recently the problem has been taken up again by Etzler and Drost-Hansen; the results of these studies have appeared recently.[29,30]

In passing, it should be noted that many other authors have reported multiple optima for growth and other biological processes. (Some of the pertinent papers are listed in 24). Only one other example of multiple growth optima will be mentioned briefly here. Etzler and Drost-Hansen[30] studied the growth of a green photosynthesizing thermophilic alga, *Cyanidium caldarium.* A typical growth curve is shown in Figure 21. No less than three optima have been observed (repeatedly) in these experiments. The optima occur near 28, 37 and 48°C, with the growth minima near 32 and 43°C—again in excellent agreement with the temperatures at which the thermal transitions are observed in vicinal water (near 14 to 16°; 29 to 32°; 44 to 46°C).

Summary and Discussion

Through measurements at closely spaced temperature intervals anomalous properties have been observed in a large number of aqueous interfacial systems, ranging from dispersed clays and highly porous silica gels to living (cellular) systems. A convenient device is described for studies at closely spaced temperatures. The anomalous effects observed are explained (in part) in terms of structural changes in vicinal (interfacial) water.

Acknowledgment

The author wishes to express his gratitude to the Environmental Protection

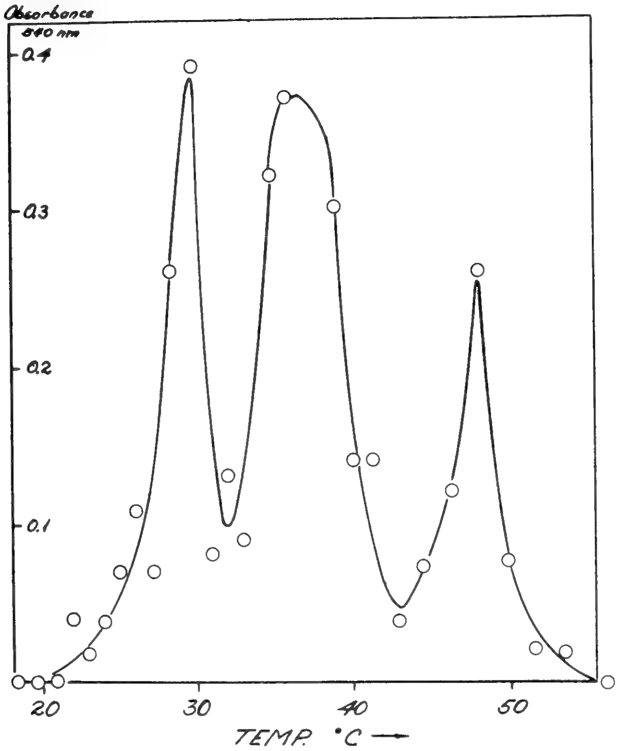

Fig. 21. Growth (as measured by optical density) of *Cyanidium caldarium* (a green, thermophilic alga) as function of temperature. (Etzler and Drost-Hansen, 30)

Agency (EPA) for its extended support of his research on aqueous systems. Thanks are also due to Scientific Industries, Inc. (Bohemia, New York) for donating a commercial model of its Temperature Gradient Incubator. Dr. James Clegg has greatly helped the author on innumerable occasions through advice, discussions and encouragement. Dr. Robert Cunnion conducted the enzyme experiments; Mrs. B. Drost-Hansen assisted with some of the germination studies, and Dr. Frank Etzler has contributed significantly through his work on seed germination and algal growth studies. My sincere thanks to all of these investigators.

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