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Total Eclipses of the Sun

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I

Total Eclipses of the Sun

THE

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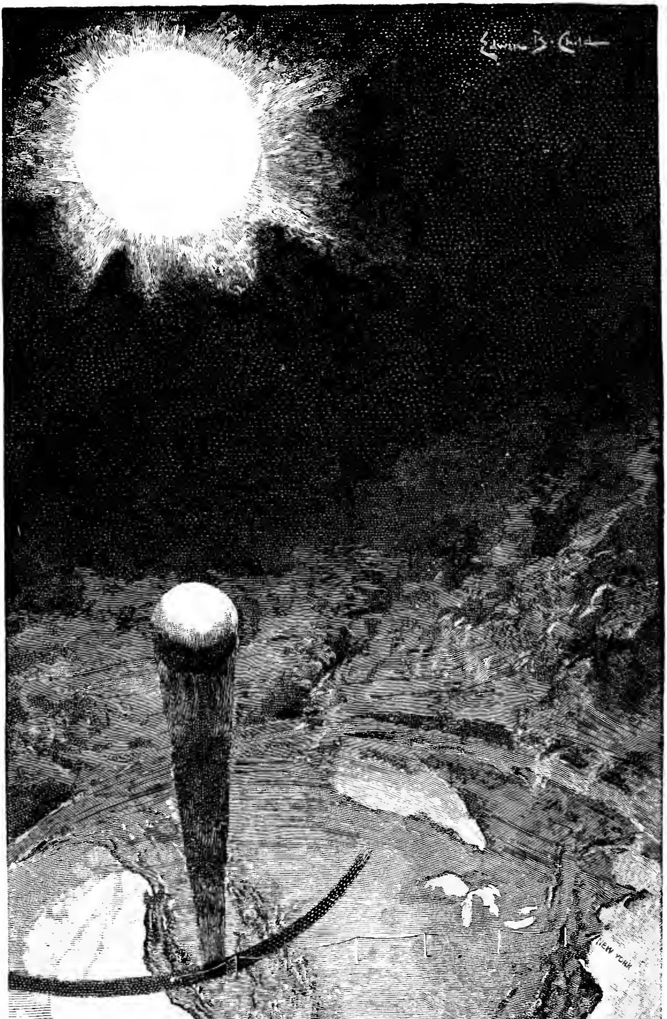

Moon's Shadow on the Earth

Knowledge the wing wherewith we fly to heaven
SHAKESPEARE

COLUMBIAN KNOWLEDGE SERIES
Edited by Professor TODD

NUMBER I

Total Eclipses of the Sun

BY

MABEL LOOMIS TODD

ILLUSTRATED

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EDITOR'S PREFACE

THE great eclipse of 1842 marked the dawn of a golden age of physical research upon the Sun, and the conclusion of a half-century of significant research forms a fitting epoch for summarizing salient results in review. Advantage has been taken of this opportunity to present the attractive features of remote eclipses; and the connection of those in early, mediæval, and later centuries with contemporary history will, it is hoped, add new interest to astronomical events already widely celebrated. The abundant references have been critically verified in the libraries of Amherst College, of the American Academy of Arts and Sciences, Boston, of Harvard College Observatory, and in the Newberry Library, Chicago.

Necessarily the ample illustrations have been chosen from a wide field. Particular attention is called to the collection of coronas of the different eclipses. Especial care has been bestowed upon the chart of eclipse tracks in the future. On pages 224–226 will be found biographic sketches of Sir

George Airy, F. W. Bessel, Father Perry, and Father Secchi, the distinguished astronomers whose portraits appear in the present volume.

Courteous acknowledgment is due The Century Company for the frontispiece, and the illustrations on pages 171, 177, 208, 209, and 211, and for permission to use portions of articles by the author and myself previously published in *St Nicholas* and *The Century Magazine*; to Sir Robert Ball's *Atlas of Astronomy*, for the excellent diagram of eclipses on page 15; to Professor Langley and the publishers of his *New Astronomy*, for the cuts of the corona on pages 53 and 60; to the editor of *The Forum*, for the use of my article on 'Modern Eclipse Problems' (July, 1890); to Professor Payne, editor of *Astronomy and Astro-Physics*, for a number of electrotypes kindly lent; and to Professor Holden, for the corona of 1893, on page 75.

Also I desire to thank Professor Young for examining the proof-sheets of the entire book, and making many valuable suggestions.

DAVID P. TODD.

Amherst College Observatory,
January 1894.

PREFATORY NOTE

TOTAL eclipses of the Sun, always occasions for stir in the astronomical world, have nowadays hardly less interest to people in general, though in a different way.

The present volume is not written for astronomers, much less for eclipse experts, but to give very unprofessional information to those without technical knowledge, who are yet curious as to these strangely impressive phenomena, — and with the hope, too, of creating farther intelligent interest.

Whatever in Professor TODD'S writing, published or unpublished, could serve my purpose, I have summarily appropriated, — pilfering generally confined to a paragraph merely, though occasionally more. As he must have recognized sentences of his own here and there while reading the proof with me, and has indulgently made no comment, I take this opportunity to tender him grateful appreciation for a silent generosity.

Also my thanks are due Dr WILLIAM HAYES WARD for numerous archæological references, and

Professor EDWIN A. GROSVENOR for kindly verifying historical allusions.

Nor is it less a pleasure to mention that, with her permission, the cover is ornamented with a charming design by my friend Mrs HUGGINS, the gifted wife of Dr WILLIAM HUGGINS, F. R. S., of London.

MABEL LOOMIS TODD.

AMHERST, MASSACHUSETTS,
October 1893.

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TOTAL ECLIPSES OF THE SUN

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ECLIPSES AND ECLIPSE TRACKS IN GENERAL

As when the Sun, a crescent of eclipse,
Dreams over lake and lawn, and isles and capes.
TENNYSON'S *Vision of Sin*.

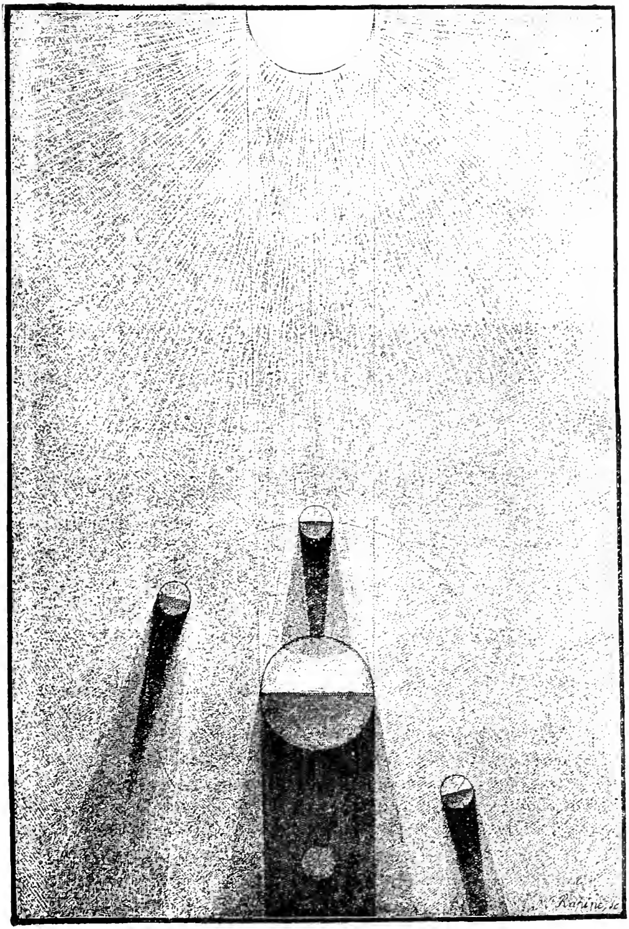
WHAT immortal schoolboy first noticed the curious fact that all the large rivers in his Geography flowed past the largest cities?

Rivers may have this obliging peculiarity, but the devious paths of total solar eclipses upon the Earth's surface do not follow so desirable a precedent. Indeed, it often seems that celestial happenings deign to be seen only from the most inaccessible parts of our globe.

Frequently the long tracks of eclipses lie almost wholly across oceans, touching no land except perhaps the outskirts of some barren or savage island; and no device for securing accurate astronomical observations from the deck of a ship has yet been perfected. Alaska, Labrador, West Africa, the summit of Pike's Peak, a coral atoll in the Pacific, are but a few of the remote localities whither astronomers have gone to view a total obscuration of the Sun.

The path of an eclipse, while thousands of miles long, is rarely over 140 miles wide, and can never be more than 167 miles in breadth. For the best observations of the total phase, one must place himself very nearly in the middle of this path; so with every eclipse there is a long line of points from which the Sun is seen to be exactly covered by the Moon, — not from all at the same time, but from one after the other, as the Moon's shadow trails easterly over the surface of the Earth. All along this narrow track of anticipated darkness assemble in our day astronomers of many nationalities, scattering throughout its land extent in picturesque precision. The regions of the world visited by the important eclipses of the last half-century are shown on page 221.

No indication of modern astronomical progress is more instructive than the change in the attitude of scientific men toward eclipses of the Sun. Little more than a half-century ago, astronomers rarely went from home for the observation of even a total solar eclipse; if the tracks of these phenomena happened to lie near at hand, the merely geometric phases were watched and measured, but that was all. The great revolution in the study of the heavens wrought by the introduction of spectroscope, camera, polariscope, and bolometer had not yet taken place; the science of astro-physics was hardly dreamed of. How different now! Rarely does a total eclipse take place without the notice of the chief governments of the world, which vie with one another in equipping expeditions with costly and specialized apparatus for attacking the great variety of problems pertaining to the Sun, his physical properties and surroundings. Formerly of use to the mathematical astronomer chiefly in correcting the tables of solar and lunar motions, or in evaluating unknown longi-



To show how Eclipses take Place

tudes of places on the Earth, solar eclipses are now observed for the most part by the astro-physicist for the knowledge afforded as to the Sun's constitution and radiations.

The wide utility of all this research, in its bearing upon meteorology and terrestrial physics, not to say ultimately upon the possible direct employ of solar heat for industrial purposes, is now so fully recognized that the astronomer devotes himself assiduously to the task of acquiring every possible fact about the Sun, and is rarely interrupted by the sordid inquiry, 'What 's the use?'

To realize how eclipses actually take place, it is only necessary to remember that, when walking along a shadeless country road some blazing August noon, one's shadow persistently follows. No less do all planets and satellites cast shadows in space which attend them as unerringly. The Sun being larger than these spherical bodies, their shadows are obviously conical, their length depending upon the size of the sphere and its distance from the Sun. 'If interplanetary space were slightly dusty,' says Professor Young, 'we should see, accompanying the Earth and Moon and each of the planets, a long black shadow projecting behind it and travelling with it.' But under existing conditions we are never conscious of it, except as the satellites occasionally drop into the shadow of their primary bodies, or when, perchance, a satellite, coming in between its primary and the Sun, projects its own shadow upon the planet itself.

To instance Jupiter: his moons frequently pass through the great shadow of the planet, and cause the lunar eclipses whose accurate observation enables the solution of many astronomical problems. When on the opposite side of the planet these little satellites are seen to cast their shadows upon his giant disk as minute dark spots, which, gradually moving across it, are called 'transits of the shadows.' Could the eye then be transported to Jupiter, exactly within this tiny spot there would be visible a total eclipse of the Sun.[1]

Bringing the illustration to our own Earth and Moon, it will easily be seen how eclipses actually occur from our terrestrial point of view. The lunar eclipse is due simply to the Moon's dropping into the Earth's shadow, and must therefore always take place at or near full moon; but the solar eclipse, occurring only at the time of new moon, is obviously caused by the direct physical intervention of our satellite, and is visible only in those regions where the Moon happens for the time to shut off the Sun's light. In both lunar and solar eclipses, Sun, Moon, and Earth are in line, or nearly so; but while in the former case the Earth is in the middle, in the latter the Moon occupies the intermediate position.

SOLAR ECLIPSE ON JUPITER, 18 Feb. 1874 (KNOBEL)

As one contemplates the relative size of Sun, Moon, and Earth, it may seem strange that a body so tiny as our satellite can completely blot out, even for a minute, an

[1] It is no unusual thing for two such solar eclipses to happen upon Jupiter at the same time (though of course not at the same place), caused by two different moons. Indeed, a double instance of this will occur in the forenoon, 5th April 1896. First, satellites II and IV are simultaneously eclipsing the Sun for 53 minutes, and shortly after, I and IV perform the same evolution for more than two hours together, — three separate total eclipses of the Sun completely taking place in seven hours, or less than one of Jupiter's days. How much the favored Jovians ought to know about the corona!

object so vast as the Sun; but while 400 times smaller in diameter, the Moon is almost 400 times nearer to us, so that both appear to be very nearly the same in size. Their distances as indicated in the opposite diagram are on precisely the same scale as the sizes of the bodies.

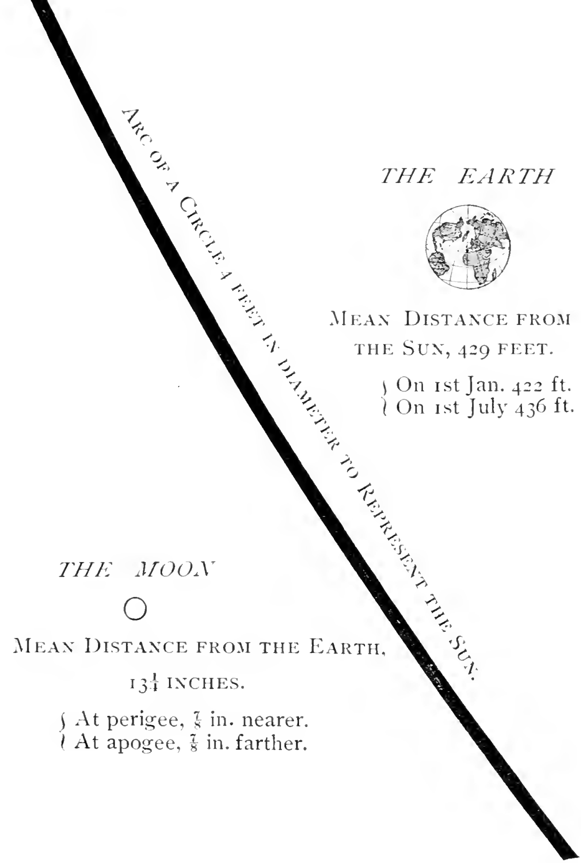
As the Moon moves in its orbit from west toward east, solar eclipses always begin on the west side of the Sun, where the 'first contact' must take place. It is, of course, not difficult to simulate mechanically, with reasonable precision, all the varied conditions of eclipses. Many such machines have been constructed to represent these phenomena and the manner of their occurrence, although the adjoining illustration of the relative distances and sizes of Sun, Moon, and Earth shows that a mechanical model in true proportion is wholly impossible.[2]

It matters little whether we regard the point of view of the savage, who is awe-struck because he does not know what terrific happenings such a spectacle may forebode, or that of the astronomer, who by dint of much travelling by sea and by land may many times have observed the Sun entirely obscured, and knows there is nothing to fear,

[2] The earliest was perhaps ROEMER'S 'Planisphere pour les éclipses, inventé par lui,' *Machines et Inventions approuvées par l'Académie des Sciences*, i. 85 (Paris, 1735). Then SEGNER'S 'Machina ad Eclipses Terræ repræsentandas,' *Philosophical Transactions*, 1741, p. 781; and FERGUSON'S 'Piece of Mechanism contrived for exhibiting the time, duration, and quantity of solar eclipse in all places of the Earth,' *Philosophical Transactions*, 1754, p. 520. The astronomical mechanicians of Italy, too, have toiled in this field, VENEZIANI, for example, describing his 'Macchina pel cui mezzo si predice l' avenimento di ecclissi del Sole e della Luna,' *Mem. di Matemat. e di Fisica Soc. Ital. Modena*, xiii. (1807), 9; and numerous others have applied their talents to this simple method of illustrating eclipses.

RELATIVE SIZE OF SUN, EARTH & MOON

(On scale of 18,000 miles = 1 inch.)



a total solar eclipse is a most imposing natural phenomenon. Neither does it occur with sufficient frequency to become at all monotonous. For the Earth generally, the number of total eclipses will average nearly 70 to the century. But an octogenarian stay-at-home may count himself fortunate if he sees even a single eclipse that is total, or nearly so. This, however, will depend very much upon where that home is. Should it have been the island of Blanquilla, off the northern coast of Venezuela, he might have seen two total eclipses in a little over three years (1886 and 1889 *b*); if the Yellowstone National Park, two within twelve years (1878 and 1889 *a*); but had he been born in Boston or New York in the latter part of the 18th century, he might live through the whole of the 19th and a long way into the 20th, and yet, so far as eclipse-seeing is concerned, have viewed but one; while in London in 1715 no total eclipse had been visible for nearly six centuries.

When, however, very long periods of time are considered, and large areas of the Earth's surface, like Australia or the North American continent, little difference is found in the number of total eclipses; one section of the globe is visited by the lunar shadow about as often as another, although the durations of totality will be quite various. Could the observer be ubiquitous, he might thus see the Sun's corona twice every three years; but taking general averages, and recalling the comparatively narrow belt of total eclipse, it will be found that every spot on the globe is likely to come within the range of the Moon's shadow but once in about three and one half centuries.

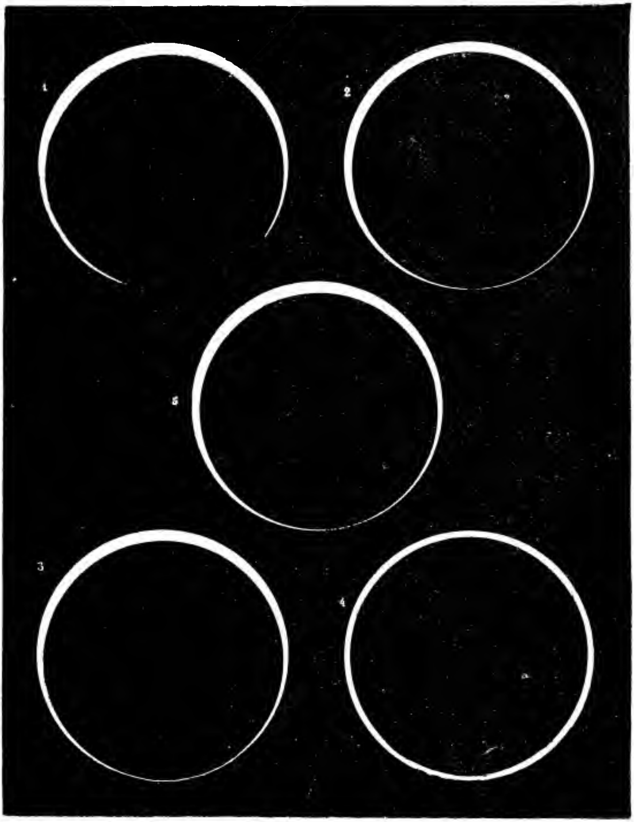
That circumstance of a solar eclipse most attractive to the astronomer of the present day is the length of total obscurity. By some celestial mishap this can never be so long as eight minutes. As an average, three minutes will more than cover the length of total phase; and for astronomers and physicists, who are perplexed in their attempts to unravel the labyrinth of mysteries surrounding the Sun which the kindly intervention of the dark Moon discloses, these brief moments are all too short. Unfortunately the best eclipses always occur near the Earth's equator; for while the lunar shadow sweeps easterly across our planet with a velocity somewhat exceeding 2,000 miles in a minute, an observer on the equator is, by the Earth's rotation, also carried eastward, but at a velocity about one half as great. The nearer he is to either terrestrial pole, the slower he goes, and thus the sooner will the Moon's shadow overtake and pass him by, and the shorter will be his time of viewing the Sun entirely covered.

A few figures will reveal something of the celestial odds with which the astronomer must contend. To save the accusation of taking unfair advantage of Earth and Moon, 5,000 miles may be allowed for the length of each eclipse track. Then, if this path be quite thickly strewn with astronomers and telescopes, at least one every hundred miles, scientific men would never be charged with wasting their opportunities. But how much solid watching of the corona would this ideal condition of things afford? A little more than one week's time in a whole century; while, as a matter of fact, if due allowance be made for the fondness of these tracks for lying across oceans, and the really small number of observers able to locate along any eclipse line and engage in effective research, a week of slender opportunities must be scaled down to something like a single day in the course of 100 years. Indeed, the accidents of cloud interference farther reduce this one half. Hence the importance of utilizing every such phenomenon to the utmost.

Before proceeding to the farther consideration of total eclipses, other solar obscurations by the Moon may be spoken of, but briefly. Most important of them are the annular eclipses, averaging seven in eight years. Recalling Jupiter again, and remembering that his satellites are about the same in size as our own Moon, the greater distance of these bodies from the Sun makes their shadows so much longer than our Moon's that they always reach far beyond Jupiter. Solar eclipses seen from the giant planet, therefore, are always total.

The average length of the Moon's shadow is 232,000 miles, varying $\frac{1}{60}$ part of this distance each way. But the lunar orbit is elliptical, not circular, and the distance of the Moon's centre from the surface of the Earth ranges between 218,000 and 249,000 miles. Now, if the Moon is at or near apogee, its shadow falls a little short of the Earth, its apparent diameter is less than the Sun's, and so does not quite cover it. Instead of dense darkness, then, a brilliant ring, or annulus, of true sunlight actually surrounds the lunar ball, making a beautiful and striking spectacle.

Very early accounts of such phenomena are of no special value, but three or four are worth a passing paragraph. Sir David Brewster found that an annular eclipse took place, 5th August 1263, which is picturesquely connected with an event in Scottish history. King Haco having sailed from Belgium with a Norse fleet to punish the King of Scotland, put in at Ronaldsvoe in Orkney, subject to him at that time. About one o'clock 'the sun appeared as a thin, bright ring,'—an evil portent for King Haco, as he was defeated two months later at Largo, and the Hebrides were annexed to Scotland.



THE SUN IN ANNULAR ECLIPSE, 1854
(*Daguerrotyped by* ALEXANDER)

An eclipse of this interesting type was widely observed throughout Europe, 7th September 1820, particularly by

Baily[3] and Nicolai.[4] It was during an annular eclipse, 15th May 1836, that Baily first vividly portrayed the 'beads' named for him, an appearance described in a subsequent chapter. Also Bessel made critical observations on this occasion at Königsberg.[5] An eclipse of the Sun, annular in a line from Ogdensburg, New York, to Boston, occurred 26th May 1854. Alexander of Princeton obtained fine daguerrotype impressions in several phases, reproduced on the preceding page, one showing the annulus practically perfect.[6]

Another eclipse of this nature occurred, 15th March 1858, the central line passing across England from Dorset to Lincoln. During the time of greatest obscuration the darkness was not very intense, though sufficiently marked to affect birds and animals, rooks and starlings taking flight in flocks to their night quarters, while the gloom and silence suggested an approaching thunder-storm. The annulus was very brief in duration, only ten seconds; but observations of the corona would perhaps have been possible had not the sky been densely clouded nearly everywhere. No one

[3] *Memoirs Royal Astronomical Society*, i. (1822), 135.

[4] Bode's *Jahrbuch*, 1823.

[5] *Astronomische Nachrichten*, No. 320.

[6] Gould's *Astronomical Journal*, iv. 15. It will be observed that annular eclipses, as well as total ones, have definite tracks of visibility, where the 'negative shadow' (or shadow produced by extending its lines beyond their intersection at the vertex of the true shadow) trails across the Earth. It may have a greater breadth than the true shadow, the diameter of its section by the Earth somewhat exceeding 200 miles in extreme cases. Exactly on the northern and southern limits of the annulus path, the greatest eclipse will appear like Nos. 2 and 5, while just outside this path the crescent is better shown by No. 3, or perhaps by No. 1.

examining Webber's account[7] of the 'luminous drops,' and Baily's exhaustive paper,[8] together with the testimony of more recent observers, can feel at all sure that Baily's Beads have no mystery inviting farther investigation. Here annular eclipses compete effectively with total ones, whose greater opportunities rarely admit that careful attention to minor phenomena, the full elucidation of which often requires the most critical observation. Annular eclipses, generally regarded as insignificant celestial phenomena, have received very little notice in the past. In comparison with the imposing spectacle of a total darkening of the Sun, the annulus seems entitled to interest the average observer but little; it is, however, quite possible that the rapid development of new methods in eclipse research may lead to the scientific observation of annular eclipses with that methodical care now bestowed upon total ones.[9]

[7] *Memoirs American Academy Arts and Sciences*, ii. (1793), 20. Account of the Annular Eclipse, 3d April 1791.

[8] *Memoirs Royal Astronomical Society*, x. (1838), 1.

[9] The notion that annular eclipses are indifferent affairs has certainly been helped along by the incorrect diagrams of them in many astronomical treatises, with semidiameters of Sun and Moon deceptively out of proportion. Sometimes the Moon is drawn only three quarters the diameter of the Sun, thus conveying the impression that a very large amount of sunlight is unextinguished along the path of central eclipse. In point of fact, the greatest breadth the annulus can have, under extreme circumstances, is only about a minute and a half of arc, or less than one twentieth the Sun's apparent diameter; while not infrequently the eclipse marked 'annular' in the almanacs barely escapes being total. It seems very possible that a strongly developed corona may be seen on such occasions; indeed, it is quite probable, if we regard the experience of many observers who have followed the corona after the total phase. At such times, the duration of the annulus is of course very short; but the doubling of opportunities for observing the solar

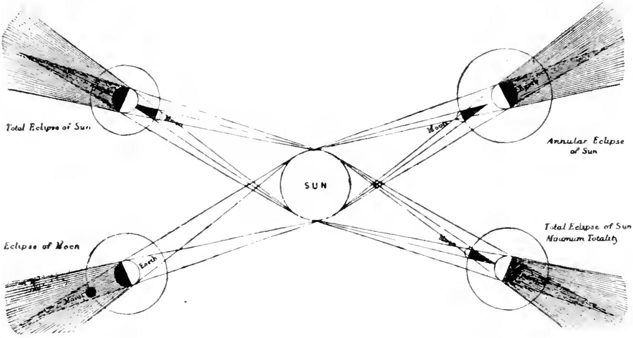
But there is a curious and rarer type of eclipse, a combination of the two already considered. Such an occurrence is peculiar enough to warrant a slight description. Phenomena of this character, heretofore rather useless, are worthy of more attention on the part of astronomers in the future. As already explained, when the size and distance of Sun and Moon happen to be so related that the vertex of the Moon's long conical shadow falls a little short of the Earth, the phenomena of the annular eclipse follow, confined to a terrestrial track much broader than a totality-path. Solar eclipses may of course take place at any distance of the Moon from the Earth. But the celestial mechanism is much more delicately adjusted than is perhaps usually imagined. On rare occasions that portion of the Earth nearest the Moon cuts off only a few hundred miles at the very apex of the lunar shadow. The diameter of our globe being thousands of miles, and its surface curv-

corona is worth striving for. Available annular eclipses near the present time occur as follow: —

1893, October 9, visible in the Andes of Peru, though near sunset;
1894, April 6, India (annulus 12^s duration), just east of Calcutta;
1897, February 1, Northwestern South America (Colombia);
1897, July 29, visible in the West Indies;
1900, November 22, South Africa, from Angola to Madagascar.

No annular eclipse visits the United States till 28th June 1908, when one may be well seen in Florida. The exact interposition of the Moon gives annular eclipses almost equal value with total ones, for research upon the varied conditions of solar radiations other than light and heat, — fields of investigation hardly yet entered. But in particular does the weakened illumination of the annulus afford favorable opportunity for testing a method (*vide* Chapter V.) like that of Dr Huggins, aiming to photograph the corona in full sunlight. — *D. P. T.*

ing rapidly away, there must evidently be points, both east and west of the middle eclipse, which the lunar shadow would fail to reach, — a relation of Sun, Moon, and Earth perfectly shown in the lower right-hand figure underneath. What results from such an unusual conjunction of circum-



(1) Moon's Shadow cut off by Earth (Total Solar Eclipse)
(2) Moon's Shadow does not reach Earth (Annular Eclipse)
(3) Moon in Earth's Shadow (Total Lunar Eclipse)
(4) Moon's Shadow just reaches Earth (*Total Solar Eclipse in Middle of Path, but Annular at both Ends*)

stances? An oddity in eclipses, indeed, — total in the middle of its track and annular at both ends. Such an event took place, 12th December 1890, called by the almanacs, for lack of a better name, a 'central eclipse.' From Madagascar, New Zealand, and the greater part of Australia the obscuration was only partial, and not different from the average occurrence of this character. But a little to the north of Mauritius began the annular phase. From this point southeasterly ran the track within which the solar ring was visible, the area becoming narrower and narrower, until a point was reached about 1600 miles west of Cape Leeuwin, Australia. Here the vertex of the shadow first impinged on the surface of the Earth; and an observer, had he been there when the shadow came along, would have seen the end of a total eclipse follow hard upon its beginning: the Moon would gradually have reduced the Sun to the darkness of late twilight, followed suddenly by an extraordinarily bright corona, though only for an instant, when its structure would have faded rapidly, obliterated by the returning effulgence of true sunlight.

Partial eclipses, though of little scientific value, have interesting features of their own, sometimes showing all the attendant phenomena of entire obscuration, except the total phase. If the Sun's disk is more than half covered, there is the same weird light, always wan and unnatural, of a quality quite different from mere twilight, and growing constantly duskier, — crescents underneath dense foliage, — half indifferent spectators gazing sunward through glass smoked to varying degrees of sootiness, — the crescentic Sun growing momentarily narrower, — a curious yet apathetic crowd surrounding the telescope-man in the public park: — to the casual eye, this is all.[10] At the

[10] In a paper communicated to the Royal Astronomical Society by WOLLASTON, giving observations of the partial eclipse of 26th April 1827, at Benares, the author says: 'I cannot avoid remarking how erroneous the Hindu calculations of this eclipse have proved in the time. Three Pundits in the town gave me diagrams of it, worked out, I believe, from the Grabalaghava rules; and from these it appears that the Hindu calculation places the eclipse half an hour too early. But the Pundits explained that this proceeds from their employing an abridged method of computation, instead

observatories within the wide area where the partial eclipse is visible, often 5,000 miles in breadth, the astronomers are recording the 'contacts,' perhaps optically, and with suitable eyepiece appliances viewing the Sun directly, or with its image projected upon a screen; or perhaps watching with a spectroscope at the critical point of the Sun's limb by Professor YOUNG's new method, to glimpse the first moment when the Moon's edge impinges upon it; or at intervals making photographs for subsequent measurement; or if there are spots, noting critically their occultation by the lunar disk, to see whether any distortion of the delicate details may not indicate slight trace of a lunar atmosphere.

But whether total, annular, or partial, no eclipse of the Sun is without its use to the astronomer, alert with eager apparatus to question the silent sky.

of going through the tedious process of the Surya Sidd'hanta, which would occupy 15 days.' — *Memoirs Royal Astronomical Society*, iii. (1829), 388.

CHAPTER II

DESCRIPTION OF A TOTAL ECLIPSE

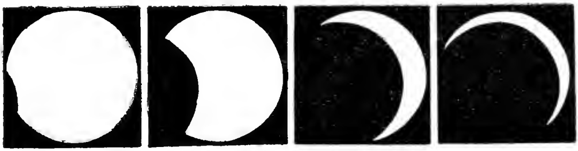
> Roses have thorns, and silver fountains mud;
> Clouds and eclipses stain both Moon and Sun.
>
> SHAKESPEARE'S *Sonnets*, xxxv.

ONCE I heard a distinguished astronomer say that he had never seen a total eclipse of the Sun, a statement difficult for me to understand, since within my own recollection he had been in charge of several expeditions for the express purpose of placing himself and his instruments well within the Moon's shadow. He must have seen my look of incredulity, for he continued quietly, 'Because I have always been too busy in observing them.'

The distinction is quite clear. To all spectators, civilized or savage, scientist or layman, a total eclipse is wonderful and most impressive. But the precise second of the 'contacts,' the photograph plates with their dark room, the telescopic search for intra-mercurian planets, and the score of other special points engrossing the astronomer's mind and eyes and fingers during the precious and far too brief moments of totality leave no time for the merely spectacular to enthral him. However, that even the professional astronomer might sometimes enjoy the opportunity to watch the unfolding glories of the corona from the standpoint of artist or poet, was perhaps implied by the late D^r PETERS of

Hamilton College, who, when asked what single instrument he would select for observing an eclipse, replied, 'A pillow.'

Astronomers have indeed little chance to appreciate the strange poetry of a world in ashy and unnatural shadow. Even the observer who has to draw the filmy streamers of the outer corona cannot be permitted to see too much; his



PHASES OF PARTIAL ECLIPSE
(*Photographed at the Lick Observatory*)

eyes must be bandaged for ten or twelve minutes before the total phase, that they may be acutely sensitive to the faintest ray from these airy, yet stupendously extended streamers of an unknown light.

As the dark body of the Moon gradually steals its silent way across the brilliant Sun, little effect is at first noticed. The light hardly diminishes, apparently, and birds and animals detect no change. During the partial phase a curious appearance may be noticed under any shady tree. Ordinarily, without an eclipse, the sunlight filters through the leaves in a series of tiny, overlapping disks on the ground, each of which is an image of the Sun.

This is matter of the commonest observation; and on noticing more closely it will be found that the luminous circles are larger in proportion to the height of the foliage, their diameter being about one inch for every ten feet. Clearly there would be no such phenomenon if the Sun's light all came from a star-like point instead of a disk; because the foliage would then be sharply outlined, in light and shade, as it is underneath a brilliant arc light. But when the partial phase of an eclipse is well advanced, these

CRESCENTS VISIBLE UNDER FOLIAGE DURING PARTIAL ECLIPSE

sunny spots become crescent in form, images of the now narrowing Sun; and there is, of course, the same appearance after totality also. The horns of each tiny crescent are turned opposite to the direction of the horns of the crescent Sun, the rays crossing as they pass through the foliage, just as if each minute, leafy aperture were actually a lens or an object glass.

As the entire duration of an eclipse, partial phases and all, embraces two or three hours, often for an hour after 'first contact' insects still chirp in the grass, birds sing, and animals quietly continue their grazing. But a sense of uneasiness seems gradually to steal over all life. Cows and horses feed intermittently, bird songs diminish, grasshoppers fall quiet, and a suggestion of chill crosses the air. Darker and darker grows the landscape. At this stage primitive peoples, particularly in parts of India and China, even now beat upon gongs, and, with wild shouts and savage uproar, endeavor to drive off the evil monster who is 'eating up the friendly Sun.'

So much as five minutes before the total obscurity it may be possible to detect strange wavering lines of light and shade dancing across the landscape — the 'shadow bands,' as they are called,— a curious and beautiful effect not yet fully understood.

Then, with frightful velocity, the actual shadow of the Moon is often seen approaching, a tangible darkness advancing almost like a wall, swift as imagination, silent as doom. The immensity of nature never comes quite so near as then, and strong must be the nerves not to quiver as this blue-black shadow rushes upon the spectator with incredible speed. A vast, palpable presence seems overwhelming the world. The blue sky changes to gray or dull purple, speedily becoming more dusky, and a death-like trance seizes upon everything earthly. Birds, with terrified cries, fly bewildered for a moment, and then silently seek their night quarters. Bats emerge stealthily. Sensitive flowers, the scarlet pimpernel, the African mimosa, close their delicate petals, and a sense of hushed expectancy deepens with the darkness. An assembled crowd is awed into absolute silence almost invariably. Trivial chatter and senseless joking cease. Sometimes the shadow engulfs the observer smoothly, sometimes apparently with jerks; but all the world might well be dead and cold and turned to ashes. Often the very air seems to hold its breath for sympathy; at other times a lull suddenly awakens into a strange wind. blowing with unnatural effect.

Then out upon the darkness, grewsome but sublime, flashes the glory of the incomparable corona, a silvery, soft, unearthly light, with radiant streamers, stretching at times millions of uncomprehended miles into space, while the rosy, flaming protuberances skirt the black rim of the Moon in ethereal splendor. It becomes curiously cold, dew frequently forms, and the chill is perhaps mental as well as physical.

Suddenly, instantaneous as a lightning flash, an arrow of actual sunlight strikes the landscape, and Earth comes to life again, while corona and protuberances melt into the returning brilliance, and occasionally the receding lunar shadow is glimpsed as it flies away with the tremendous speed of its approach.

The great opportunity has come and gone, and happy is the astronomer who has kept the poetry of his nature in such abeyance that the merely accurate and scientific work has been accomplished; but in executing his prescribed programme, the professional observer must exercise vast self-control. Professor LANGLEY says of this superb sight: 'The spectacle is one of which, though the man of science may prosaically state the facts, perhaps only the poet could render the impression.'

The effect of an eclipse shrouded in cloud is quite different. When the sky is overcast, total eclipses very often cause less darkness than in clear skies, because the clouds outside of the totality path — brilliantly illuminated by the Sun — reflect and diffuse their light throughout the shadow. This unique effect is excellently illustrated on page 123. But in the Japan eclipse of 1887 the sepulchral darkness was increased by the dense body of cloud which silently massed as totality approached. Clear and burning skies characterized the noon of 'the great, the important day.' Twenty or thirty native guards in snowy uniforms watched the castle where we lived, carefully reserving the entrances for specially invited guests. The instruments were adjusted for instant use, rehearsals of twenty observers, each with his telescope or other apparatus, having been daily conducted until the programme was safely familiar, and, in spite of the torrid heat, all were astir with eager anticipation.

But Nasu-take, a volcano to the west, whose most inopportune eruption had suddenly begun the night before, was still sending up volumes of white steam, inviting clouds, apparently, from every quarter. Quietly and simultaneously our 'massive enemies' collected, east and south and west. Finding that my drawing of the outer corona would be impossible, from the rapidly thickening sky, I left my appointed station behind the disk, and hastened to the upper castle wall to watch the changed landscape under its gray shroud. Even inanimate things are at times endowed with a terrible life of their own, and this deliberate, slow-moving pall of cloud seemed a malignant power not to be eluded.

Now and then a flood of sunlight fell upon the smoking and disastrous crater of Nasu-take, — a spectacle both aggravating and sublime.

Totality was announced, and, as if by two or three jerks, the darkness fell. Silence like death filled castle and town and all the country round. Except the feeble glimmer of a few lanterns in the town, eighty feet below, a streak of strange, sulphurous yellow in the southeast seemed to give out the only light in the world.

Not a word was spoken. Even the air was motionless, as if all nature sympathized with our pain and suspense. The useless instruments outlined their fantastic shapes dimly against the massing clouds, and a weird chill fell upon the earth. Mountains and rice fields became indistinguishable, the clouds above us turned nearly black, and a low roll of thunder muttered ominously on the horizon toward Kuroiso.

All trace of color fled from the world. Cold, dull, ashen gray covered the face of nature.

Even in that supreme moment my thoughts flew backward over the 8,000 miles of land and stormy ocean already travelled, the ton of telescopes brought with such care, the weeks of patient work and constant observation at the old castle in a remote Japanese town, — all the long journey and elaborate preparation, chiefly for just these three minutes of precious time, now slipping away so fast.

And already they are gone. The rare corona had wasted its ever new glories upon the hither side of uncaring cloud. We had trusted Nature; she had failed us, and the prevailing mood was a sense of overwhelming helplessness. The crowd of friends, Japanese, English, and American, breathed one mighty sigh, as from a universal heart just relieved of tension near to breaking. Then some one spoke, and so we faced common life again.

Repairing to the dark room, the astronomers found that a few valuable pictures of the partial phases had been obtained through breaks in the cloud, so that the expedition had been saved from entire wreck.

Since frequently nothing more tangible than the powers of the air can be held responsible for disaster, an astronomer must carry with him the potentiality of the hero. When Nature is pitiless, philosophy thrives.

I doubt if the effect of witnessing a total eclipse ever quite passes away. The impression is singularly vivid and quieting for days, and can never be wholly lost. A startling nearness to the gigantic forces of nature and their inconceivable operation seems to have been established. Personalities and towns and cities, and hates and jealousies, and even mundane hopes, grow very small and very far away.

THE AMERICAN ECLIPSE EXPEDITION TO JAPAN, 1887

CHAPTER III

MINOR PHENOMENA, AND INTRA-MERCURIAN PLANETS

Nature stands aghast;
And the fair light which gilds this new-made orb,
Shorn of his beams, shrinks in.

DRYDEN.

A FEW seconds before totality, when the narrowing crescent of the Sun is about to disappear, the slender curve of light is often seen to break into a number of rounded spots of brightness, now known as BAILY's Beads.

The earliest mention of this phenomenon is by HALLEY, in connection with the total eclipse of 3d May 1715.[1] According to descriptions by different writers, the beads are like drops of water drying up under a hot sun (1860), or a string of brilliants disappearing like snow under a white heat (1869). The formation of this curious chain of eight or ten separated points is so rapid that BAILY compares it to the 'ignition of a fine train of gunpowder.'[2] BAILY's Beads are commonly thought to be produced by irregularities

[1] Annular eclipses also reveal the beads, MACLAURIN first observing them during an eclipse of this character, 18th February 1737. CHAMBERS, *Handbook of Descriptive Astronomy*, i. 279.

[2] *Memoirs Royal Astronomical Society*, xli. (1879), 96.

upon the surface of the Moon at its edge or limb, the lunar mountains projected against the bright solar crescent causing divisions in its light. Seen so long as 15 seconds before totality, at dissolution they appear to run together like contiguous drops of water. Commonly visible during total eclipses, they are 'as plain, as distinct, and as well defined as the open fingers of the human hand held up to the light;' then trembling for an instant they suddenly disappear. Baily first described in full detail this curious phenomenon after the eclipse of 15th May 1836, annular in the north of England and south of Scotland, and in December of that year, as Vice-President of the Royal Astronomical Society, he presented a paper *On a Remarkable Phenomenon that occurs in Total and Annular Eclipses of the Sun*,[3] which is an elaborate discussion of the entire subject.

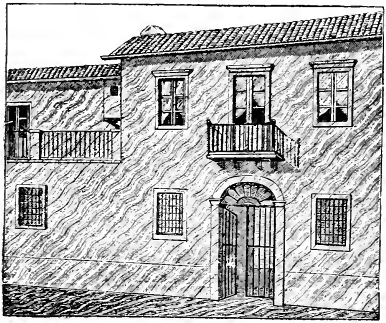
The first photographic record of Baily's Beads was obtained at Ottumwa, Illinois, during the eclipse of 1869; also they were seen by many observers, and the guides accompanying General Myer to the summit of White Top in Virginia called out that the Sun was 'breaking in pieces.' Mr Barnard of the Lick Observatory photographed them unintentionally in California on New Year's day, 1889, after the conclusion of totality, when the Sun began to emerge before the exposing cap could be replaced.

Phenomena perhaps not so obvious are the swiftly flying shadow bands. Seen by Goldschmidt in 1820, later observers have frequently identified them as rapidly moving (sometimes wavy) lines of light and shade, resembling sunlight reflected upon some adjacent wall from the rippling surface of water.

Thin, parallel lines of shadowy waves, they flit silently

[3] *Memoirs Royal Astronomical Society*, x. (1838), 1.

over the landscape, sometimes faster after totality than before, and indescribably light, airy, and evanescent. Apparently all the elements pertaining to the shadow bands vary from one eclipse to another, thus adding greatly to the intricacy of the puzzle. Perhaps at one time eight inches broad and two or three feet apart, at another only one or two inches broad and ten or twelve inches apart, they travel at one time about as fast as a man can run, and again with the velocity of an express-train. While visible at eclipses generally, just after totality as well as before, occasionally an eclipse occurs without any exhibition of shadow bands. Then again they have accompanied annular eclipses.



SHADOW BANDS OF 1870 ON AN ITALIAN DWELLING

As yet these impalpable shadows have not been sufficiently observed and studied to render possible more than a fair guess at their origin; but probably they are due to irregularities in atmospheric refraction of the slender beam of light from the waxing or waning crescent. Lying in general parallel to the nearest edge of the shadow-cone, the direction of the wind appears to coincide with, if not to control, the course of their travel; they have, indeed, been somewhat poetically described as 'visible wind.' During the more recent eclipses cameras have been at hand for obtaining instantaneous photographs of these nimble, shadowy fringes swiftly traversing a bright ground; and the attempt is worthy of repetition until success is attained. The greatest need, however, is a more highly sensitive film.

Professor William H. Pickering and others carefully observed the shadow bands, 29th August 1886, at Grenada. It is improbable that they can have anything to do with the lunar shadow, their speed, or lack of speed, proving their independence of it. In 1888 Professor Pickering made a series of valuable experiments,[4] related in his report on the eclipse of 1886, which appear to show that the shadow bands originate in the terrestrial atmosphere. Professor Upton in Russia attempted to photograph the shadowy lines of 1887, but without success; while in California in 1889 a repetition of this interesting attempt resulted in what may perhaps be called an encouraging failure. The bands were both faint and narrow during the first eclipse of that year, and although looking systematically Professor Keeler failed to detect even a trace of them.

The coming of the lunar shadow in all its startling velocity is often observed by the unprofessional spectator, as well as by the astronomer watching and waiting for its great approach.

Forbes, a fortunate observer, saw this phenomenon from the Superga at Turin, where the view itself is most magnificent. He alludes to the stupefaction produced by its terrifying advance. 'I felt,' he says, 'almost giddy for a moment, as if the massive building under me bowed on the side of the coming eclipse.' Frequently the effect upon the beholder is of something material sweeping over the Earth with incredible velocity. Another writes, 'I involuntarily listened for the rushing noise of a mighty wind.' It

[4] *Annals Harvard College Observatory*, xviii. 96.

is universally described as perhaps the most impressive feature of an eclipse. Often, however, expert observers do not see the almost tangible shadow, even when specially on the lookout. It is not strange, therefore, that different spectators describe it differently. To several observers the shadow seen in the distance resembled a dark storm upon the horizon. Some saw the shadow 'visible in the air'; one speaks of its 'gliding swiftly up over the heavens'; while another likens its passage to 'the lifting of a dark curtain.'

Those who have taken pains to note its color do not generally call it black, but deep violet or dark brown. One describes it as a 'wall of fog,' another as a 'vaporous shadow,' a third says it was 'like neither shadow nor vapor,' while no less careful observers than WINNECKE and Lady AIRY speak of the shadow as 'appearing like smoke.'

From their stations high above the valley of the Ebro, over which it swept, members of the *Himalaya* expedition of 1860 had exceptional opportunities for watching the approach and recession of the shadow, and many saw it. The speed is, in fact, so great that only observers upon considerable heights can satisfactorily follow its passage over the landscape, — it is more easily seen in the air, or upon clouds. While observers generally remark the 'frightful velocity' with which it travels, President HILL of Harvard, in Illinois in 1869, found the transit of the shadow much slower and more majestic and beautiful than he had been led to expect. 'A sweeping upward and eastward of a dense violet shadow' are his words.

General ABBOT, ascending Mount Ætna in 1870, wrote: 'At an elevation of 7,500 feet I was overtaken by the shadow, which swept with great rapidity over us, darkening the gloom to an awe-inspiring degree.' Professor LANGLEY speaks of the strange and distinct appearance of the advancing shadow, 29th July 1878, from the summit of Pike's Peak, — a stupendous vantage-ground, indeed, for a still more stupendous spectacle. Still another witness says it swept over the plains beneath 'like a rounded ball of darkness with an orange-yellow border.' But this majestic appearance presents little in the way of scientific conundrum.

Of course these are by no means all the minor phenomena of a total eclipse. Both before and after total obscurity the whole contour of the lunar disk is sometimes seen, and there are faint brushes of light raying out from the solar crescent. Occasionally there is a double observation of both beginning and end of totality, and the Moon has even appeared to jump forward at these critical instants 'as if it had made a jerk (stumbled against something).' The changing tints of the dark Moon while obscuration lasts, colors on the frequent clouds, the arcs of prismatic color and iridescent clouds, the pulsation of light as totality comes on, and the tremulous motion of the thin crescent, — these are not the half of the interesting phenomena accompanying a total eclipse of the Sun, all of which have been carefully summarized by Mr RANYARD.[5] The eclipse expert has always enough of them in mind to keep a score of people well occupied during the eclipse, and volunteer service must always be, as it has been in the past, an excellent assistance to the professional astronomer, who, absorbed with more important matters, has no opportunity to witness minor details, much less set down a record. But, if left to himself, the amateur is distracted in the attempt to

[5] *Memoirs Royal Astronomical Society*, xli. (1879).

choose what he will watch for. If he does not decide till the event, he is liable to see simply nothing, and will record even less.

Doubtless the long-suffering intra-mercurian planet (or planets) will continue to be looked for during many total eclipses in the future. The question has a fictitious importance due to the prestige of the name of LE VERRIER, who firmly asserted his belief in the existence of an intra-mercurian planet, the approximate elements of whose orbit he calculated, and to which he assigned the name Vulcan. But it is not difficult to convince one's self by argument that the existence of such bodies is next to impossible.[6] Some astronomers, however, continue to believe in the existence of intra-mercurian planets in the face of opposing evidence, and they find support for that belief in the fact that two astronomers reported observations of such objects during the total eclipse of 29th July 1878.

The late Professor WATSON of Ann Arbor, and Dr SWIFT of Rochester, set out from their respective stations in Separation, Wyoming, and on Capitol Hill in Denver, to entrap this elusive heavenly inhabitant. Both claimed to have seen interior neighbors of Mercury, so modest that they fly into hiding on mere mention of any attempt at discovery. WATSON's observations[7] were explained away by PETERS,[8] to the satisfaction of most astronomers; but WATSON, an excellent and critical observer, maintained to his death in 1880 the fullest belief in the new planets of his discovery. Neither these bodies, however, nor those

6 NEWCOMB, *Astronomical Papers of the American Ephemeris*, i. 474.

7 *American Journal of Science and Arts*, cxvi. (1878), 230, 310.

8 *Astronomische Nachrichten*, xciv. (1879), 321.

reported by Dr Swift[9] on the same occasion, have been observed at any subsequent eclipse, although persistently looked for.

Particularly was the optical search for this hypothetical planet systematically renewed at Caroline Island, 6th May 1883, by Professor Holden, M. Trouvelot, and Dr Palisa, and again by Professor W. H. Pickering in California in 1889, this time with the assistance of photography; but on both occasions the search was ineffectual. Also during the eclipse of 16th April 1893 no new object was seen near the Sun. The intra-mercurian planet question is a large one, and this is hardly the place for its farther treatment. The literature, too, is extensive.[10]

The astronomical Vulcan seems wellnigh as mythologic as the Vulcan of fable. It is, however, to be remarked that even the weight of negative evidence so far accumulated by no means disproves the existence of a body honestly seen and faithfully recorded by reputable astronomers; though it may thereby be rendered very doubtful. The reality of intra-mercurian planets is a mooted question, wherein photographic charting of the stars (now rendered easy) during the longer totalities of the future will alone afford the ultimate appeal.

9 *American Journal of Science and Arts*, cxvi. (1878), 313.

10 Houzeau *et* Lancaster, *Bibliographie Générale de l'Astronomie*, ii. 1090, contains nearly 150 entries.

CHAPTER IV

SOLAR PROMINENCES

> 'Void of light
> Save what the glimmering of these livid flames
> Cast pale and awful.'

WHEN totality is imminent, and expectation is becoming breathless, — when, though not yet visible, the noble corona seems all but hovering in the air, — suddenly at the edge of the dark Moon, flashing out into the gathering darkness, appear vivid, blood-red flames. Visible on one occasion so long as five minutes before the total obscuration, and again for six minutes after, they glow against the pure white of the corona with singular lustre.

The first allusion to prominences may have been made by FIRMICUS in connection with the eclipse of 17th July, A. D. 334. But the earliest authoritative account of their strange beauty was recorded by KEPLER during a partial eclipse in 1605. STANNYAN observed and gave a description of the red flames at Berne in 1706, and in 1715 they were seen by HALLEY, LOUVILLE, and HAYES.[1] Another early record occurs in observations of the eclipse of 24th June 1778, by D'ARANDA and ULLOA.[2] But their nature

[1] The first annular eclipse revealing the protuberances was observed in 1737 by MACLAURIN.

[2] HEIS, *Wochenschrift für Astron. Meteorol. und Geog.*, xviii. (Halle, 1875), 71.

was misunderstood for centuries. And this is not to be wondered at; for, as Proctor somewhere remarks, the same observer of the old eclipses describes the corona as well as the protuberances: to observe and record both accurately on the same occasion is manifestly beyond the power of the most skilful astronomer. Judging from the early accounts of Stannyan and others, they were at first supposed to belong to the Moon, probably indicating a lunar atmosphere.

Apparent on several subsequent occasions, the great eclipse of 1842 afforded the earliest substantial increase of our knowledge of the rose-colored prominences, then for the first time carefully observed. The descriptions were various, — 'Alpine mountains colored by the rising or setting Sun,' 'saw-teeth of a circular saw,' and 'a box of ebony garnished with rubies.' Littrow thought he saw them change from white to red, and from red to violet, and then back again in reverse order. Mauvais and Petit at Perpignan saw remarkable variations in the larger protuberances, which seemed to increase steadily in magnitude as if uncovered in consequence of the Moon's motion. But in spite of this convincing evidence, there was still much doubt as to their being a true solar appendage.

Astronomers looked forward eagerly to the next opportunity, the eclipse of 1851, when it was again carefully noted that the Moon gradually covered portions of the red protuberances, one after the other. Their solar origin and connection now seemed certain, because, as the black globe of the Moon passed over the Sun, not only did the flames on one side grow smaller, but those on the other became larger.

Strange to say, however, acceptance of this conclusion was not at once universal. After the eclipse of 1851 the prominences were fully described by DAWES, who speaks of their general rose-color, and says that the tint of the highest one was richer and far more vividly bright, reaching a height of 2′, or about 55,000 miles. In shape like a Turkish cimeter, its color was a deep carmine, which faded away only gradually after totality.

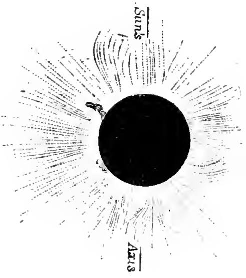
Professor G. P. BOND, after observing the eclipse of 1851 in Sweden, went to Chamounix,[3] where in September he made perhaps the first known attempt to see the protuberances under ordinary conditions by occulting all but the very edge of the Sun's disk upon one of the lofty peaks. He made the attempt at the edge of the shadow of the *Aiguille de Blettière*, a mass particularly well fitted for the purpose, but failed to see either corona or protuberances. He expressed, however, his faith in the ultimate success of the experiment, which AIRY, POWELL, and others also subsequently tried. During the autumn of 1851 and the summer of 1852, Professor PIAZZI SMYTH, acting on a suggestion by NASMYTH, made a strenuous attempt to capture the prominences on the uneclipsed Sun, but the results were discouraging;[4] LASSELL and some others accepted the evidence that these wonderful flames were truly solar appendages, but it remained for the eclipse of 1860 to prove indisputably their connection with the Sun. AIRY says their color on that occasion was not identical with those seen in 1842 and 1851, — the quality being the same, but apparently diluted with white, a faded lake. BRUHNS gives detailed descriptions of seven large protuberances, the first a bright rose at the base, but fading off at

[3] *American Journal of Science and Arts*, cx. (1875), 81.

[4] *Transactions Royal Society of Edinburgh*, xx. 509.

the top into the general white light of the corona ; while one of them remained visible more than six minutes after the total phase had passed.

De La Rue had now advanced celestial photography to such perfection that his efforts during this eclipse culminated in a splendid series of photographs of the solar prominences in all the different stages of obscuration behind the slowly moving Moon. He located at Rivabellosa ; and some distance away, at Desierto de las Palmas, Secchi too had equal success in the same direction. A comparison of the two series of photographs, with due allowance for parallactic change in the Moon's position, served to prove that the rosy flames, heretofore in debatable territory, were beyond a shadow of doubt a portion of the Sun. The name 'solar prominences' was now generally given. While in 1860 proof had been clear that the red flames belong to the Sun, the task of unravelling the mystery of their composition still appeared hopeless. But before the great eclipse of 1868, the spectroscope had been employed in chemical analysis, and the solution of this problem now seemed close at hand. With spectroscopy then for the first time scientifically applied, the composition of the glowing flames was no longer left in uncertainty. While undoubtedly gaseous, the characteristic bright line of hydrogen was thought to be surely detected, but it remained for a later eclipse to prove this conclusively.



Position of the 'Great Horn,'
(18th August 1868)

MM. Stephan and Rayet. 18th August in that year, were located at Wha-Tonne, on the coast of the Malay peninsula, with fine apparatus which enabled the latter to count nine bright lines in the prominence spectrum, due largely to hydrogen.[5] A striking protuberance, styled the 'Great Horn' was both observed and photographed during totality, and its spectrum showed that it contained the vapors of hydrogen, sodium, and magnesium. It appears to have been produced by the chance meeting of two jets of vapor, so colliding (about 16,000 miles above the Sun's surface) as to have generated the wonderful ascending spiral, so well shown in the drawing. It must have reached the enormous height of nearly 100,000 miles.

Solar Prominence, — 'Great Horn' of 1868 (*Height*, 100,000 *miles*)

An epoch-making discovery was achieved by M. Janssen at Guntoor. While carefully observing the unusual brightness and height of the protuberances during totality, the thought occurred to him that, as their light is mostly of a given wave-length (or nearly monochromatic), while the light of the sky background upon which they are projected is scattered throughout every part of the spectrum, an instrument of large dispersion ought to show the prominences at any time: while reducing the sky illumination very largely, it would affect the light of the protuberance only by separating its bright spectral lines

[5] The technical work of the expeditions is presented in the *Comptes Rendus de l'Académie des Sciences,* lxvii., and in the 17th volume of the *Proceedings of the Royal Society.*

farther from each other; so that when the light of both sky and prominence passed through the train of prisms, the difference of illumination would be sufficient to reveal the outlines of the prominence clearly. Most fortunately this proved the true solution of the problem, and M. JANSSEN had the satisfaction of continuing his spectroscopic observations of the protuberances for many days after the eclipse was over. But, waiting a fortnight to forward the news to France, the Secretary of the Paris Academy of Sciences announced at the same meeting that the identical result had been reached by Mr LOCKYER of England, — a brilliant discovery for each independently, and rewarded by a gold medal struck by the French government in honor of the two astronomers. The crimson shell in which these great prominences originate is estimated by Professor LANGLEY to be about 5,000 miles in thickness, while the uprising jets usually reach 20,000 miles, but often immensely more. LE VERRIER, in a paper upon the eclipse of 1860, had distinctly enunciated the idea of a continuous solar envelope, but his statement appears to have been forgotten. Similar conclusions, too, had been reached by ARAGO, GRANT, and SECCHI as well; the name chromosphere was at length given. But while seen spectroscopically under every-day conditions, the direct observation of the complete chromospheric ring has not yet been made during an eclipse, although it may be accomplished at some brief totality in the future, or perhaps with the annulus of exceeding narrowness. The total eclipse of 1927, visible in England, may afford such an opportunity.

An amazing quality of the prominences is the often tempestuous rapidity of their growth and decay. As Dr HUGGINS has so strikingly said, 'DANTE's and MILTON's poetic imaginings of Hades fall far below the commonplace scenes at the solar surface.' [6] Professor YOUNG has followed one to a height of 350,000 miles in an hour and a half, — when it faded entirely away in half an hour more.[7] Some protuberances are quiet and cloud-like; others resemble sudden eruptions from some vast and inconceivable solar volcano, a whirlwind of fire; accordingly, Professor YOUNG classifies them into eruptive and quiescent prominences.

A singular and mysterious connection appears to link them to auroral exhibitions, the 'northern lights' having been again and again noticed to dance in company with these solar displays.[8] M. TACCHINI also believes that electricity forms a large part of the prominence phenomena, and is in some way connected with our terrestrial magnetism.[9] RESPIGHI, however, thought differently.

The 'red flames' are not always red. POPE HENNESSY, describing them at length in connection with TENNANT'S expedition to Guntoor in 1868, speaks of a double-pointed protuberance whose left edge was a bright blue, 'like a brilliant sapphire with light thrown upon it.' Next

[6] *Proceedings Royal Society*, xxxix. (1885), 127.

[7] 'It is a demonstrated fact that masses of matter are from time to time ejected from the Sun with such velocities that they never return to him, but, unless perchance captured by one or other of his family of planets, pass away into interstellar space, visiting the domain of some other sun, and thence, unless captured there, passing away to another and another, flitting thus from sun to sun, until in the fulness of time they fall through some planet's atmosphere, and shining therein for a few seconds as falling stars, their careers as independent bodies are brought to a close.' — PROCTOR, *Old and New Astronomy* (New York, 1892), 405.

[8] LANGLEY, *The New Astronomy* (Boston, 1888), 67.

[9] *Reale Accademia dei Lincei*, S. N., i. (1885), 181.

to this came the sparkling ruby tint. In 1869 prominences of two sorts were reported by Messrs SHALER and PEIRCE, — some low, long, and yellow, while others were high, short, and red.

The eclipse of 22d December 1870 afforded farther observational proof that the prominences are largely composed of hydrogen; but such proof was no longer required.

To General TENNANT, in India in 1871, the protuberances and chromosphere seemed white at the beginning of total darkness, but passed almost immediately to rose, and then to their usual red. In this case there were certainly no red or blue tints either at the beginning or end of totality. In the Siam eclipse of 1875 two strong prominences in particular were seen close together during the first part of the obscuration, and their photographic spectra were carefully investigated by Dr SCHUSTER.[10] In some of the protuberances the lower edge seemed not to touch the body of the Moon, but to hang cloud-like in the corona.

Naturally, the successful observation of prominences in full sunlight led to their abandonment more and more during the totality of subsequent eclipses. While looked for in 1878, they were found to be generally inconspicuous. In Egypt, in 1882, the photograph with prismatic camera became important on making comparison of the spectra of different prominences giving lines with varying relative intensities, — probably caused by different degrees of temperature. Two prominent lines in the ultra-red were discovered. But although the energies of eclipse observers were focused more and more upon the increasing mysteries of the corona, M. TACCHINI has persistently followed them at later eclipses, observing at Caroline Island in 1883 the filamentous or so-called 'white prominences'; and at Grenada

[10] *Philosophical Transactions* (1878), p. 148.

in 1886 he showed that, while the protuberances may be studied without an eclipse, yet a given prominence observed before totality becomes a vastly more complex object if followed with the spectroscope into the period of complete obscuration; and farther, that the eclipse prominences are wholly or in part down-rushes of material relatively cool. The bearing of this important observation upon solar theories is so significant that prominence research ought again to be added to eclipse programmes.

One great protuberance in 1886, partly spiral and slightly resembling that of 1868, rose to a height of about 70,000 miles, where it split into three jets, two of which fell over upon the Sun, while the third or central one continued its eruptive course still outward from the Sun about 80,000 miles farther. This remarkable protuberance is well depicted in the photograph by Mr MAUNDER, of which the illustration is a faithful transcript.

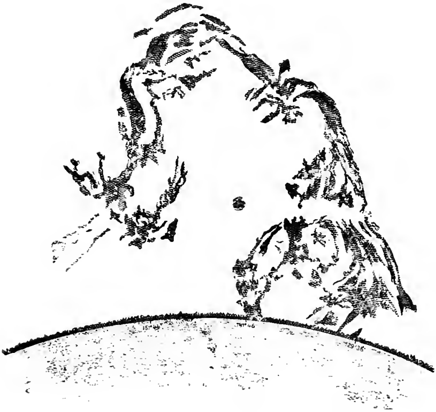
GREAT PROTUBERANCE
(29th August 1886)

There were many brilliant prominences, two especially large, photographed by Mr BARNARD in California during the New Year's day eclipse of 1889. They were exceedingly bright, and their light was strongly actinic. With slight magnifying power, one of the red protuberances was seen to have a large portion detached from the body of the chromosphere.

ERUPTIVE PROTUBERANCE
3d May 1892
(TROUVELOT)

Solar prominences without eclipse have now for many years been thor-

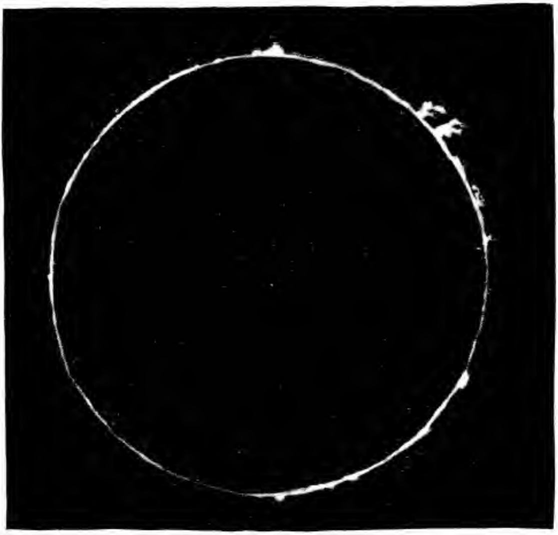
THE REVD FATHER ANGELO SECCHI (1818–1878) oughly investigated by leading astronomers. But it is rather aside from our present purpose to consider them in this aspect. Their detailed classification, periodicity, spectra, distribution on different parts of the Sun, and so on, are fully dealt with in works of a technical character. During the quarter-century that the protuberances have



SOLAR ERUPTION, 3d October 1892
(FÉNYI)

been the subjects of daily observation, their forms have been faithfully depicted by patient pencils at numerous observatories. The Revd W. SIDGREAVES, S. J., Director of Stonyhurst College Observatory, and his predecessor, the late Father PERRY, have pursued these researches with fidelity; while SECCHI, Director of the Observatory of the Collegio Romano, 1850 to 1878, and his indefatigable successor, M. TACCHINI, have observed the prominences most zealously. The work of TROUVELOT at Paris, and of RESPIGHI, RICCÒ, and others, at

Rome, Palermo, and elsewhere under favoring skies, must not be omitted. Also in Hungary, Dr Von Konkoly at Hereny has made their record a part of the routine of his observatory, and M. Fényi, Director of the Observatory at Kalocsa, is a constant observer, whose persistent



The Chromosphere and Protuberances
(*Photographed by Professor* Hale, 25th July 1892, *without an Eclipse*)

watching has been often rewarded by the discovery of striking eruptive prominences, a recent instance of which, rising to a height of 238,000 miles above the Sun, is well shown in the sketch on the opposite page, where the relative size of the Earth is indicated by the small black dot near the centre.

The field is a fertile one, and has been abundantly cultivated, particularly of late by Professor HALE of the University of Chicago, whose numerous and valuable papers report continual advance in these important lines.

The development of prominence observation may be succinctly outlined through all the stages from 1868 preceding the great Indian eclipse, when the flames could only be seen with the Sun totally obscured; through the earliest growth of the Janssen-Lockyer method, by which they were visible with the spectroscope in full sunlight, though at first only a portion of the protuberance could be seen at a time; then through the advance, simple but necessary, of Dr HUGGINS, which rendered it possible to observe an entire prominence in ordinary sunshine (the method in common use for the past twenty years); to the important stage where photography, first adapted by Professor YOUNG, enabled the photographing of a single protuberance entire; thence to the present day, when the ingenious spectroheliograph of Professor HALE enables him at any time without an eclipse to photograph on a single plate and with a single exposure beautiful representations of the chromosphere completely encircling the disk of the Sun.

For popular papers consult the full catalogues of POOLE'S *Index to Periodical Literature*, i. (1802–81), 1267–1269; ii. (1882–87), 424, 425; iii. (FLETCHER), (1887–92), 415. And FLETCHER'S *Index to General Literature* (Boston, 1893), 279.

Following is a list, by no means complete, of works partly of a technical character: —

SECCHI and others, *Atti dell' Accademia Pontificia dei Nuovi Lincei*, Rome, 1871 (and subsequently).

TACCHINI and others, *Memorie della Società degli Spettroscopisti Italiani*, Palermo and Rome, since 1872.
LOCKYER, *Contributions to Solar Physics*, London, 1874.
LOHSE, *Beobachtungen Sternwarte Bothkamp*, iii., Leipzig, 1875.
*SECCHI, *Le Soleil* (2 vols. and Atlas), Paris, 1875–77.
*WINLOCK, *Annals Harvard College Observatory*, viii., 1876.
PROCTOR, *The Sun: Ruler, Fire, Light, etc.*, London, 1876.
YOUNG, *The Sun*, New York, 1881.
*ZÖLLNER, *Wissenschaftliche Abhandlungen*, iv., Leipzig, 1881.
CLERKE, *A Popular History of Astronomy during the Nineteenth Century*, Edinburgh, 1885.
LOCKYER, *The Chemistry of the Sun*, London, 1887.
LANGLEY, *The New Astronomy*, Boston, 1888.
SCHEINER, *Die Spectralanalyse der Gestirne*, Leipzig, 1890.
HALE, Photography and the Invisible Solar Prominences, *Sidereal Messenger*, x. (1891), 257.
HALE, Photographic Investigation of the Solar Prominences and their Spectra, *American Journal of Science*, cxlii. (1891), 160, 459.
HALE, Recent Results in Solar Prominence Photography, *Astronomy and Astro-Physics*, xi. (1892), 70, and his subsequent papers in the same journal.
PROCTOR, *Old and New Astronomy*, London and New York, 1892.
VOGEL, *Populäre Astronomie* (NEWCOMB-ENGELMANN), Leipzig, 1892.
BRESTER, *Théorie du Soleil*, Amsterdam, 1892.

In the more advanced study of the prominences, the following special bibliographies will be found helpful: —

FIÉVEZ, Bibliographie des Ouvrages, etc., *Annuaire de l'Observatoire Royal de Bruxelles*, 1879.
DEWAR and others, *Reports British Association Advancement Science*, 1881, p. 370, and 1884, pp. 295 and 323.
HOUZEAU, *Vade Mecum de l'Astronome* (Brussels, 1882), 424.
HOUZEAU *et* LANCASTER, *Bibliographie Générale de l'Astronomie*, ii. (Brussels, 1882). 1036.
TUCKERMAN, Index to the Literature of the Spectroscope, *Smithsonian Miscellaneous Collections*, No. 658 (1888), 102.

* Finely illustrated with colored plates.

CHAPTER V

THE CORONA

Ce que nous connaissons est peu de chose, mais ce que nous ignorons est immense. — LAPLACE.

IT is told of the late Professor SNELL of Amherst College that he once asked for a definition of the solar corona from a member of his class in astronomy, who, after a good deal of hesitation, and feeling desperately on the brink of utter failure, finally plunged into the statement that he *did* know what the corona was, but had forgotten. 'What an incalculable loss to science!' said the Professor with characteristic humor; 'the only man who ever knew what the Sun's corona is, and he has forgotten!'

None the less true is it in our later day, that no one has yet entirely explained or analyzed this marvellous silvery halo surrounding the totally darkened Sun. Nature's most imposing phenomenon is perhaps the most mysterious. A suggestion of its general appearance may be gained by looking at the full Moon through a new wire window-screen, although the rays of light which then appear to point outward from the bright Moon are much more regular than the true corona, which varies greatly from one eclipse to another.

Thus far the corona has been seen only when the dark body of the Moon has intervened to occult the Sun completely; so that opportunities for studying it have resembled the visits of angels.

Naturally this superb spectacle of out-flashing glory must have been an amazing phenomenon to the beholders of antiquity; but historical references to the corona are meagre. Perhaps the earliest was by PLUTARCH,[1] about A. D. 100; and PHILOSTRATUS,[2] a century later, mentions that the death of the Emperor DOMITIAN at Ephesus was 'announced' by a total eclipse.

SCHMIDT, in 1870, directed attention to a record of the corona in the eclipse of 22d December 968, in Corfu.[3] But the corona seems first to have made a really strong impression on the spectators, 31st August 1030,[4] when a fierce battle took place at Stiklastad in Norway, between King OLAF, a Christian and subsequently the national saint, and his heathen subjects. While the battle was in progress the Sun became totally eclipsed, and a red light appeared around it. Not until the great eclipse of 1842 did men become really familiar with the corona and prominences, and HANSTEEN'S suggestion that the reddish appearance of 1030 was caused by the zodiacal light seemed to many not improbable.

CLAVIUS noticed the corona, 9th April 1567, at Rome, but supposed it merely an uncovered edge of the Sun. KEPLER showed, by computation of the relative apparent sizes of Sun and Moon, that this was impossible, and he

[1] Ἀλλὰ περιφαίνεταί τις αὐγὴ περὶ τὴν ἴτυν, οὐκ ἐῶσα βαθεῖαν γίνεσθαι τὴν σκιὰν καὶ ἄκρατον. — *Opera Mor. et Phil.*, ix. 682. (A radiance shone round the rim, and would not suffer darkness to become deep and intense.)

[2] *Life of Apollonius of Tyana*, viii. 23. (*Vide* p. 119.)

[3] *Nature*, xvii. (1877), 14.

[4] DREYER, *Nature*, xvi. (1877), 549.

regarded it as evidence of a lunar atmosphere. Clavius also observed the corona during a brief totality at Naples, 12th October 1605.[5]

Wyberd in 1652, and many others subsequently, have affirmed that the corona exhibited a rotary motion, catherine-wheel fashion, though slowly; and Ulloa wrote that the corona of 1778 'seemed to have a rapid circular motion, like an ignited wheel in fireworks, turning on its centre.' But no trustworthy observer in later times has reported such a startling phenomenon. Possibly the brushes of light sometimes seen to move radially about the cusps, just before and after totality, may have been mistaken for the corona itself. MM. Plantade and Capiés, who observed the total eclipse at Montpellier, 12th May 1706, give a distinct and accurate account of the corona.

It is interesting to observe the marked impulse in the development of eclipse astronomy afforded by Baily. As soon as the critical observation of Baily's Beads riveted attention upon the Sun's limb at the beginning and end of the total phase, the prominences were found worthy objects of investigation. Still later began research upon the corona, which, until 1851, was apparently regarded as a merely symmetric and structureless aureola encircling the eclipsing Moon. It is always first apparent on the side of the dark Moon farthest from the vanishing crescent; and there are well authenticated instances of its visibility during large partial eclipses. In 1842, at Alais, just without the belt of totality, it was clearly a 'circle of pale light which encompassed the Moon.'[6]

[5] *Vide* also Plassmann, Ueber eine alte Erwähnung der Sonnen-Corona, *Astronomische Nachrichten*, cxxxii. (1893), 205.

[6] Chambers, *Handbook of Descriptive and Practical Astronomy*, i. (London, 1889), 281.

Frequently the brighter regions of the corona have been detected both before and after the total obscurity, in some cases for several minutes. WINNECKE, at Santa Marina, near Pobes, caught the corona of 1860 a minute and a half before totality came on, and POLE at La Cantabria held it a like interval after this phase. Professor LANGLEY also, on the summit of Pike's Peak, observed that the remarkable corona of 1878 did not disappear entirely at the instant close of entire darkness.[7]

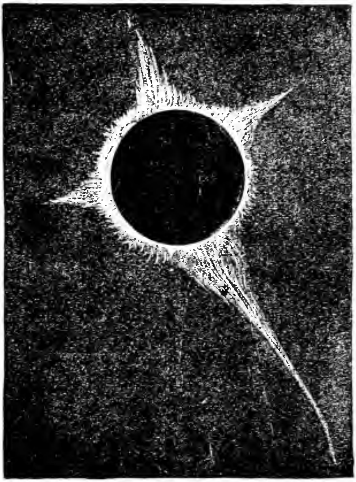
In the early observations of the corona, it was regarded as a halo merely, and so drawn. Its real structure was neither known, depicted, nor investigated. The earliest pictures all show this. Preconceived ideas prejudiced the observers, and their sketches were mostly structureless. In speaking of the superiority of the camera over hand-drawing, Professor LANGLEY says, 'It has no nerves, and what it sets down we may rely on.' It should not be forgotten that the coronal rays project outward into space from a spherical Sun, and do not lie in a plane as they appear to the eye and in photographs and drawings. Here is a fruitful source of material for generalizations as to the structure of the corona, and ultimately as to the law of energy distribution of the Sun itself. But pencil drawings, while ordinarily less trustworthy because involving the uncertain element of personal equation, are more valuable in delineating the finest and faintest detail of which the sensitive plate rarely takes note; the vast array of both, however, shows marked differences in the structure and form of the corona from one eclipse to another, though it has not yet revealed rapid changes during any one obscuration. This last interesting feature can be studied only by comparison of photo-

[7] LANGLEY, *The New Astronomy* (Boston, 1888), p. 56.

graphs near the beginning of an eclipse track and its end, two or three hours of absolute time apart. Such an investigation, first attempted in 1871, was planned for the eclipse of 1887, with Professor YOUNG near the western end in Russia, and Professor TODD several thousand miles farther east in Japan, their photographic equipments being identical. But the path of this ill-fated eclipse was shrouded in clouds for nearly its entire length; photographs of the corona were very few, and not favorably placed for the investigation referred to. Again in December 1889 the English parties at Cayenne and Angola were similarly fortified; but clouds obscured the corona at the African station. The eclipse of 1893 has yielded the first success. The photographs of the Harvard and Lick Observatory parties in Chile, and those of the English and French parties in Senegal, taken more than two hours of absolute time later, were all obtained under atmospheric conditions exceptionally fine; but minute comparison fails to indicate appreciable differences in the structure of the streamers. Research in this direction must be faithfully prosecuted in the future; but no opportunity so favorable occurs till 28th May 1900, our Southern States and Spain being then the available localities.

Special hand sketches of the complex filaments at the solar poles are exceedingly valuable. As yet, the photographs have by no means perfectly brought out the complicated rift-work visible with even very moderate optical means; though, with telescopes exceeding three inches in aperture, the magnifying power should never be less than 100. Good eyes and expert pencils have always a waiting future.

An excellent drawing of the corona was made in Spain in 1860 by Sir FRANCIS GALTON, who was one of the earliest observers to record that its long arms 'do not radiate strictly from the centre.' [8] While there was no actual pulsation, he thought the corona 'not absolutely constant.' That the rays are curved and far from radial was shown in drawings by MM. DALBIEZ and VILASÉCA in 1842, probably for the first time. But unfortunately ARAGO, who gives an account of this interesting observation, did not publish the drawings.

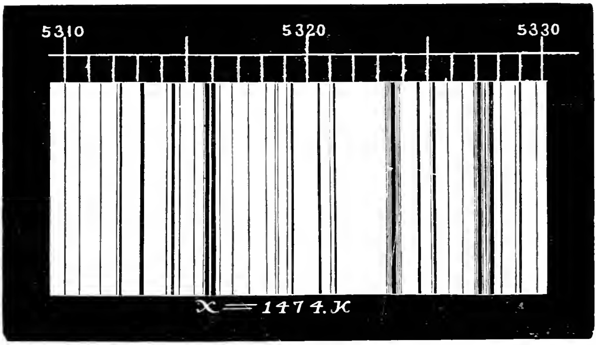


7th August 1869 (McLEOD)

An examination of other drawings of the eclipse of 1860, one of them by FEILITZSCH, showed that the corona is a truly solar appendage; and evidence on this point speedily became overwhelming. Before that date, some astronomical writers thought it due to causes perhaps residing in the terrestrial atmosphere. Of this theory Professor YOUNG remarks,[9] 'If its seat is in the Earth's atmosphere, it is of course an affair of little magnitude or importance; if, on the other hand, it is really at the Sun, it must be an object of enormous dimensions and of cosmical signifi-

[8] *Vacation Tourists*, i. (London, 1861), 441.
[9] *The Sun*, p. 222.

cance.' Refraction had been assigned as the cause, and reflection of solar rays from inequalities in the Moon's surface; but solar physics has now advanced beyond that stage, by pencil, camera, polariscope, and the variety of spectroscopes brought to bear upon the corona.



POSITION (AT *x* IN THE SOLAR SPECTRUM) OF THE BRIGHT LINE DUE TO CORONIUM

(*The numbers at the top indicate* ANGSTRÖM'S *scale*)

The first striking result was obtained 7th August 1869, when Professor HARKNESS at Des Moines and Professor YOUNG at Burlington, Iowa, found the coronal spectrum crossed by a bright green line coincident with 1474 of KIRCHHOFF'S scale, and due to incandescent vapor of some substance not as yet identified with anything terrestrial. So the name 'coronium' was evoked later, about 1882.

It is yet matter of doubt how far from the Sun's edge coronium in gaseous incandescence can be traced. In the outer corona of 1874, Mr STONE found Fraunhofer lines present, and traced the existence of the 1474 line to rather more than a degree from the Sun's centre (1,200,000 miles from the solar surface). Its spectrum was found to fade gradually as the visible limit was approached, and not to disappear sharply as if at its farthest extent. Other estimates, both earlier and later, assign a much lower limit.[10] In 1878 coronium reached a mean distance of 350,000 miles from the Sun's limb, and in January 1889 about 325,000 miles. Having no apparent physical connection with this substance, the outer corona appears rather to be due largely to inter-stellar dust, or meteoric matter in a comminuted state, possibly a reflection from shoals of meteors surrounding the Sun.

A line of green light appeared in the spectrum during the eclipse of 1869, near those in the spectra of the auroral and zodiacal lights, which has led to research into a possible connection between these strange varieties of mild radiance, though with inconclusive results.

Although brightest near the Sun, the conclusion reached by General Tennant in 1860, that the inner or lowest corona may be a sort of solar atmosphere, has not been borne out by subsequent research. His evidence that it shines by reflected light has, however, met with remarkable confirmation.

M. Janssen, at Caroline Island in 1883, devoted the opportunity largely to deciding whether the corona contains an important proportion of solar light, the result surpassing his expectations. He saw the Fraunhofer spectrum with great completeness, establishing the presence of an enormous quantity of reflected light; and as the coronal medium is very thin, he considers that cosmic matter exists in these regions as solid corpuscles.

[10] Ranyard, *Memoirs Royal Astronomical Society*, xli. (1879), 358.

Various opinions concerning the brightness of the corona have been entertained,[11] but from a careful consensus of

[11] The total brilliance of the corona, differently estimated by the earlier observers, has been pretty carefully measured at the later eclipses. The full Moon forms an excellent standard of reference: at one time the corona will exceed, at another fall short of, this standard. Variations in brilliancy from one eclipse to another were noticed by AIRY; the corona of 1869 was much brighter than that of 1870, which was carefully measured by Professor E. C. PICKERING; in 1878 the research of Professor HARKNESS made its brightness nearly four times that of the full Moon (about one seventh that of the corona of 1870); M. JANSSEN, in 1883, found it to exceed the full Moon in lustre; while for the results of more recent eclipses, consult ABNEY, *Philosophical Transactions*, 1889 (A), 363; W. H. PICKERING, *Annals Harvard College Observatory*, xviii. 100; and the *Contributions from the Lick Observatory*, Numbers 1 and 2, treating of the two total eclipses of 1889. It will be seen that much evidence has already accumulated on this important question; but whether the observed variations are real, or due chiefly to the varying relative sizes of Sun and Moon at different eclipses, is not yet known. The intermingling of visual and photographic data is of course to be regretted, and the influence of the greater intrinsic brilliancy of the prominences must be carefully excluded. More than this, the problem of extinction of the coronal light in the Earth's atmosphere has to be solved before the results can be set against each other in strict comparison. Some localities of observation have been lofty (Pike's Peak in 1878, elevation over 14,000 feet), while others have been at the sea level (Grenada, 1886); and the altitude of the eclipsed Sun above the horizon has varied 60° or more. These and other conditions render the problem one of unusual difficulty. But if the entire light of the corona (not as we see it at mid-totality, but as it actually exists in space) is to be determined from observational data, instead of mathematical inference, the opportunity of a total-annular eclipse must be embraced. Then, by locating just inside the points where the phase shifts from annular to total and back again, the full intensity of the inner corona may be satisfactorily evaluated, with that complete-

numerous observations. Mr Ranyard's conclusion[12] seems to be that its total illuminating power is considerably less than the full Moon's. This has of course nothing to do with the intrinsic brightness of limited areas, which often exceed many times that of a like portion of the Moon's surface. For example, Professor Harkness found that the most luminous part of the corona of 1878 was probably fifteen times brighter than the surface of the full Moon, or 37,000 times fainter than the surface of the Sun. Also his discussion of the photographs of the same eclipse showed that the coronal light varied inversely as the square of the distance from the Sun's limb, — a result disproved by Abney for the corona of 1886,[13] and by Professor Holden for that of January 1889.[14]

Professor C. Abbe in Colorado writes of 1878,[15] 'The illumination of surrounding objects due to the coronal light was so strong that the change from before to after second contact was, I thought, barely perceptible, the dark blue tint of the sky being only a few grades darker, and the diffused light from the corona being all-sufficient to read and write by, although it had nothing of the "body" that makes a bright full Moon so effective.'

If, however, the corona's light is sometimes inferior to the full Moon, its heat is far greater. Lord Kelvin's suggestions *On the Importance of making Observations on Thermal Radiation during the Coming Eclipse of the Sun* (1860) need

ness which can only be approached, but never quite attained, during any total eclipse. — *D. P. T.*

12 *Memoirs Royal Astronomical Society*, xli. (1879), 244.

13 *Philosophical Transactions*, 1889 (A), 380.

14 *Lick Observatory Report Eclipse of 1st January* 1889, p. 19.

15 *Professional Papers of the Signal Service*, No. I (Washington, 1881), p. 46.

to be followed up with the greatest care and painstaking.[16] Just before the eclipse of 1878, Mr Edison had devised his tasimeter, an instrument of extreme delicacy, employed in connection with a Thomson reflecting galvanometer. So sensitive was it that the heat from Arcturus was distinctly perceptible. In fact it proved too delicate for a successful measurement of the heat of the corona, which was sufficient to send the index beam of light entirely off the scale of the galvanometer.[17]

The fine quality of the photographs in December 1871 permits a better acquaintance with that corona than with any previous one, and even better than with many recorded later. It was nearly colorless, and faded off gradually, with numerous wedge-shaped portions of a gray tint, which formed the rifts and the separations of the rays. To General Tennant these rifts did not seem to extend down to the edge of the Moon, they were perfectly steady, and no changes in the corona were apparent.[18] His spectroscope was carefully arranged and manipulated, Captain Herschel assisting, and did excellent service; but the record is too technical for our purpose.[19]

16 *Monthly Notices Royal Astronomical Society*, xx. (1860), 317.

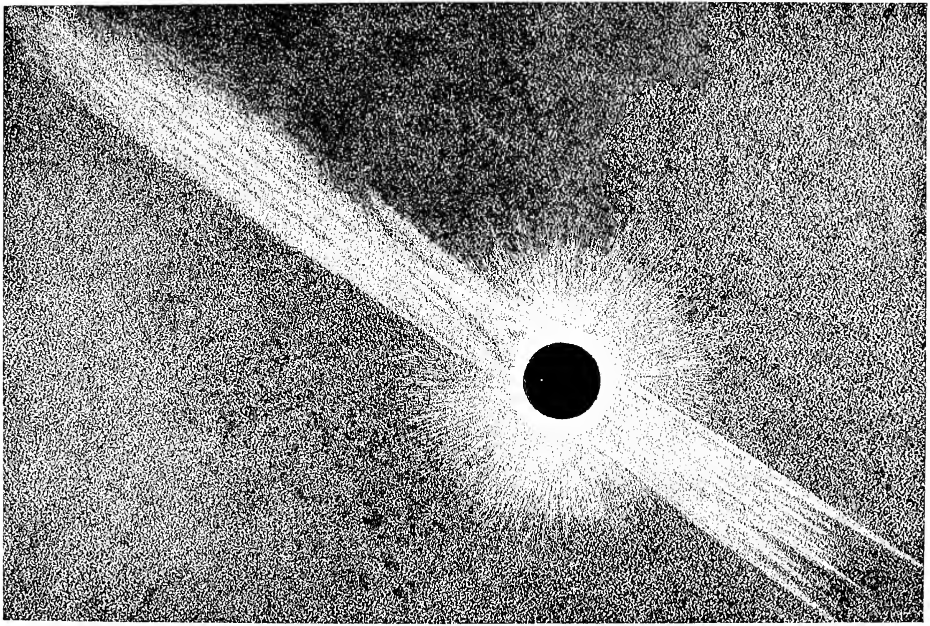
17 *American Journal of Science*, cxvii. (1879), 52. For farther considerations on the temperature of the corona, *vide* Ranyard, *Knowledge*, xiv. (1891), 28.

18 *Memoirs Royal Astronomical Society*, xlii. (1875), 6.

19 Captain Herschel's description of his naked-eye view of the corona is singularly clear and accurate for this early date; and had its indications been followed in photographing subsequent eclipses, our records would have been worth a thousand fold what they are. He says: 'The sight can never be forgotten; whether it was that my eyes had been *calmed* by looking into a nearly dark field, or that the short time — not more than a very few seconds — which was granted me, fixed the impression received very securely, I cannot

An enormous mass of material regarding the corona was accumulated in 1878; but this eclipse was remarkable chiefly for the discovery, by Professor NEWCOMB and Professor LANGLEY, independently, of the long streamers of the outer corona. Professor LANGLEY felt that he was witnessing a 'real phenomenon heretofore undescribed'; it did not vanish, but remained 'persistently visible.' But for an unfortunate exposure of his eye he would have seen it even farther than the observed prodigious extension of at least twelve solar diameters, or about eleven million miles. Visible for more than four minutes after totality, it seems possible that he might have continued to observe it in-

say, but the picture formed on my retina remains singularly clear and well defined. . . . The corona was evidently, to my eyes, an assemblage of distinct and well-defined groups of rays, of which the strongest ones seemed to start directly from the central disk, so that the so-called rifts were only the interstices between the bundles of rays. . . . I should add that the photographs which I have seen do not recall, in any satisfactory way, the impressions which I received during those three or four seconds, the individual separate character of the ray-groups being almost entirely lost.' Here are early and unmistakable indications that clock work of the utmost accuracy is absolutely necessary, if the minutely filamentous structure of the corona is to be caught on the plate as it exists in the sky. But the worthless photographs sometimes brought home by expeditions since that day show that Captain HERSCHEL'S specific statements have not always been sufficiently heeded. Four of the six photographs were carefully engraved (*Memoirs Royal Astronomical Society*, xlii. 32). Equally splendid pictures of this remarkable corona were also drawn by Messrs RANYARD and WESLEY from negatives taken at Baikul by Lord LINDSAY'S expedition (*Memoirs Royal Astronomical Society*, xli. 651), and an excellent Woodbury type is quite accessible in LEDGER'S *The Sun: its Planets and their Satellites* (London, 1882). In the process of reproduction on page 136 of the present volume, much of the beautiful structure is lost. — *D. P. T.*



Corona of 29th July 1878, observed by Professor Langley
from the Summit of Pike's Peak, 14,100 *feet Elevation*

definitely (page 60), had he been provided with specially devised apparatus. These vast outer streamers were of course the first to fade in the returning beams of actual sunlight.

If the extent and brilliancy of the corona are regarded as varying with the known period of sun-spot activity, it was to be supposed that the corona of 1878 would not be intensely marked. And so in reality it was found to be, Mr LOCKYER pronouncing it ten times fainter than it was during the Indian eclipse of 1871. But the complexity of the phenomenon was very noticeable, and appears in many cases to have completely baffled the hurried attempts of those who sought to depict it. M. TROUVELOT, widely known for his admirable pictures, made a suggestive and artistic sketch of this elusive object, and his verbal description [20] is extended to the minutest detail, including the complex tangential filaments which had been quite unknown before the eclipse of 1871. Professor Boss devoted himself to a particular part of the polar corona. which he drew effectively with the aid of a telescope, and described most accurately in his report.[21] The corona was not so dazzling, to be sure, as on some other occasions; but in most of the sketches the pencils of the artists appear to have been agitated by something more trustworthy than their imaginations.[22] The corona of 1878 was certainly

[20] *Washington Observations*, 1876 (Appendix iii.), 85.

[21] *Washington Observations*, 1876 (Appendix iii.), 312.

[22] The frequent and extraordinary variations in the drawings of a given corona is perhaps best explained by Professor EDDY, who directs attention to the fact that its light falls so near the limit of visibility at the violet end of the spectrum as to excite the retina in different persons unequally. He says, 'I would have each observer tested for color-blindness in the part of the spectrum

22d December 1870
(Becker)

22d December 1870
(Iglesius)

22d December 1870
(A Lady at Cadiz)

22d December 1870
(Lassaletta)

22d December 1870
(E Thuillier)

attacked in the right way, and great advances were made. With specially constructed portrait lenses by DALLMEYER, a remarkable series of eleven photographs was taken, exhibiting a great mass of structural detail of the inner corona, although failing to show the outer streamers. By good fortune, however, a photograph taken by one of Professor HOLDEN'S party represents them in great perfection, its outlines beginning just where the details of the other photographs end; and from the twelve an extraordinarily fine representation of the corona was drawn by Professor HARKNESS (page 141).

A very complete photographic record of the polarization of coronal light was made by Professor HARKNESS, and Professor WRIGHT of Yale College.[23] The late Dr DRAPER and his party at Rawlins[24] also devoted themselves to the corona. The photographic and photo-spectroscopic work and the eye slitless spectroscope were in charge of Dr and Mrs DRAPER, the analyzing slit spectroscope was operated by Professor BARKER, who aimed to ascertain the presence of bright lines, or perhaps dark Fraunhofer lines, in the corona, and the polariscope by Professor MORTON. Dr DRAPER found the photographed spectrum of the corona the same in character as that of the Sun, and not

between G and H; and no doubt as great differences would be found in the sensitiveness of different eyes near the upper limits of visibility as is known to exist in different ears in perceiving sounds near the upper limit of audibility. Only those sketches of the corona could be properly compared with each other which were made by observers to whom the relative intensity of the various parts of the spectrum appeared approximately the same.'—*Science*, i. (1883), 169. Average variations are shown on page 62.

[23] *Washington Observations*, 1876 (Appendix iii.), 278.

[24] *American Journal of Science and Arts*, cxvi. (1878), 227.

due to a special incandescent gas; the Fraunhofer lines were abundantly observed, and the polarization of the corona answered to reflected solar light.

The Egyptian corona of 1882 was in general a repetition of that of 1871, but the distinctive features of 1878 were not apparent. While devoid of structure near the poles, the filamentous character of the streamers was not so marked as in 1871. The duration of totality was only seventy seconds, but into that brief interval was crowded much active research, with many important results.[25] Photographs of the corona and its complete spectrum were obtained by Dr Schuster on Captain Abney's plates, H and K being the most intense lines. A study of the red end of the spectrum of the corona and prominences was made by M. Tacchini. An absolute determination of the place of the coronal line at 1474 (Kirchhoff) was made by two of the French observers, Thollon and Trépied. The absence of dark lines in the coronal spectrum was noted by Tacchini and Thollon with different dispersions. But according to the report of Abney and Schuster,[25] the corona was specially rich in lines, the fact that part of the outer corona shines by reflected light being proved by the presence of the dark Fraunhofer lines. Many bright lines in the violet, observed in the spectrum by Thollon, were photographed by Schuster. The coronal and hydrogen lines were studied in a grating spectroscope by Puiseux, and with a direct vision prism by Thollon. The continuous spectrum seemed fainter, relatively, than in 1878, but stronger than in 1871. The intensification of absorption was observed in group A at the edge of the Moon by Trépied and Thollon.

[25] *Philosophical Transactions* (1884), 253.

The photographs of the spectra of the corona and prominences yielded an abundant harvest.[26] In part the interest attaching to the direct photographs of the corona is due to the fact that they were taken during a sun-spot maximum, that they extended farther than any previous ones, and that by their aid the position of the corona was fixed to the fraction of a degree.

The best pictorial representations of the corona of 1883 are by Mr Wesley, Assistant Secretary of the Royal Astronomical Society, in engraved plates collated from the excellent photographs taken at Caroline Island by Mr Lawrance and Mr Ray Woods. In comparing the eclipse of 1883 with the Egyptian eclipse of 1882, the most striking feature is the entire absence of hydrogen lines; but as the prominences in the former were very marked, and were extremely small in the latter, this result is not perhaps to be wondered at. Possibly the corona of 1882 was illuminated more or less by prominence light.[27] It is matter of necessity to separate all such illumination from coronal light, as it tends to mask the spectrum of the latter.

The brilliant corona of 1886 appeared at least seven seconds before totality began, and was extensively photographed in the West Indies. The late Father Perry's research was chiefly spectroscopic, and directed toward a search for the carbon bands glimpsed by M. Tacchini in 1883, who had himself joined the British expedition to Grenada, hoping to settle this question beyond doubt. Mr Maunder's photographic plates were very successfully

[26] Abney and Schuster, *Philosophical Transactions* (1884), 270.
[27] Abney, *Philosophical Transactions*, 1889 (A), 123.

utilized on his return by Mr WESLEY, whom we have again to thank for collating the series into a splendid engraving, scarcely surpassed by the photographs of 1871, and reproduced below. Dr SCHUSTER'S work related exclusively to the coronal spectrum, and his drawing from the photographic plates is on the next page. His catalogue of the lines recorded is exceedingly full;[28] also the lines in the Egyptian corona of the year previous are set beside in comparison. To summarize his 'summary of results' is not easy, but they are too important to be omitted. First, the continuous coronal spectrum having the maximum actinic intensity considerably displaced toward the red (when compared with the spectrum of sunlight), proves that the corona can only be partly due to light scattered by small particles. The continuous spectrum, then, would appear to be caused principally by incandescent matter of a lower temperature than that of the Sun. Calcium and hydrogen do *not* form part of its normal spectrum. The line most strongly marked in the 1886 corona was probably identical with the line 4233.0, often observed by Professor YOUNG in the chromosphere. As to the comparison of coronal lines with the lines of terrestrial elements, only negative results were forthcoming.

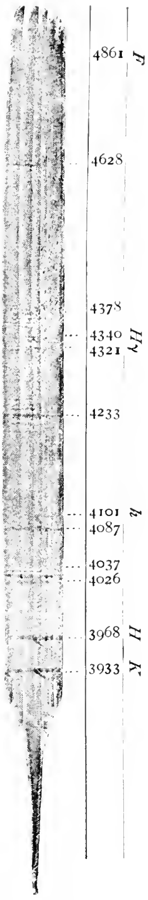
THE CORONA OF 29TH AUGUST 1886
(WESLEY, *from* MAUNDER'S *plates*)

Passing over the few fine photographs of the corona of

[28] *Philosophical Transactions*, 1889 (A), 335.

1887 (all taken between clouds), by Herr Chamantoff at Krasnoiarsk, at Jurjewetz by M. Niesten, and by Mr Arai, near Niigata, Japan, none of which reveal unusual features, the next full and perfect record of the corona was secured in California, 1st January 1889. The Harvard apparatus included every part of the coronal spectrum with completeness, and the Lick Observatory results were no less significant. Also both these expeditions secured pictorial representations of the corona by photography of the first order for purposes of scientific study.

Mr Ranyard was the first to suggest the probable variation of the gaseous part of the corona with the spots on the Sun,[29] and the eclipse of 1889 strengthened this view very greatly. The coronas of 1867 and 1878 had both been characterized by remarkable ecliptic streamers; and then followed the eclipse of 1889, also nearly coincident with the minimum of sun-spots, exhibiting similar prodigious extensions.[30]

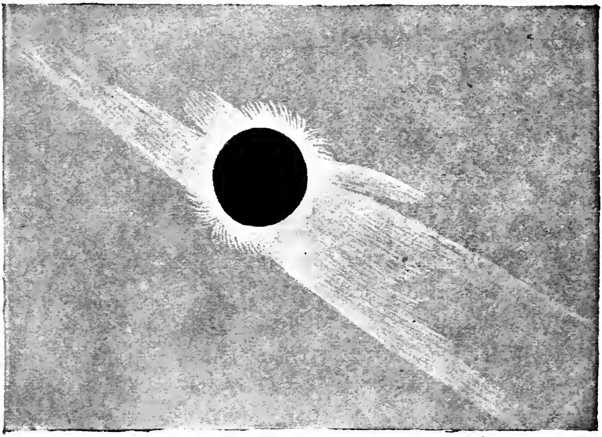


The Spectrum of the Corona, 29th August 1886 (Schuster)

[29] *The Athenæum* (12 and 19 October 1878). Also, *The Astronomical Register*, xvi. (1878), 281.

[30] Although successfully photographed, they are better shown in a composite drawing by Mrs Todd, embodying a multitude of hand sketches made under my instructions by volunteer observers all along the totality path from California to Manitoba. Also, the entire collection of drawings was combined by

The conclusion seemed well fortified, that these greatly elongated coronas are characteristic of epochs of very few sun-spots. This result, however, ought not to be accepted without reserve, until the total eclipse of 1900 is found to reveal a corona of the same type. There is



THE CORONA OF 1ST JANUARY 1889
(M^rs TODD, *Composite from* 100 *sketches*)

much reason for supposing that periodicity in the corona may depend on the time of the year when the eclipse takes place, and D^r SCHUSTER has collected the evidence on this point [31] from the photographed coronas of 1870 to 1886.

The corona of 1889 showed an intricacy of structure at the solar poles exceeding anything before observed, and

photography, and presented to the National Academy of Sciences, 19th April 1889, in a paper *On Composite Coronagraphy.* — *D. P. T.*

[31] *Philosophical Transactions*, 1889 (A), 305.

many of the dark rifts between the luminous filaments were strongly marked to the very edge of the Moon itself. Professor HOLDEN has discussed this corona in ample detail,[32] derived from the very excellent photographs by Mr BARNARD and others; and Mr KEELER'S spectroscopic observations show conclusively that the length of a coronal line is not always an indication of the depth of the gaseous coronal atmosphere of the Sun at that point. The true atmosphere of the Sun, then, may be comparatively shallow.

The scientific data respecting the corona of 22d December 1889, obtained by the lamented Father PERRY and Comte DE LA BAUME PLUVINEL at Iles du Salut, and by Mr BURNHAM and Mr SCHAEBERLE of the Lick Observatory expedition to Cayenne, French Guiana, have not yet been fully discussed, so that all presentation of them is omitted here. Also, the extensive results of the numerous expeditions to observe the recent total eclipse of 16th April 1893, — English, French, American, and other, — obtained on the South American continent in Chile, Argentina, and Brazil, and in Senegal on the west coast of Africa, cannot of course be fully known until the photographic plates have been critically investigated.

The true corona appears to be a triple phenomenon. First, there are the polar rays, nearly straight throughout their visible extent. Gradually, as these rays start out from points on the solar disk farther and farther removed from the poles, they acquire increasing curvature, and very probably extend into the equatorial regions, but are with great difficulty traceable there, because projected upon and confused with the filaments having their origin remote from

[32] *Lick Observatory Reports on the Total Eclipse of 1st January 1889*, p. 3.

the poles. Then there is the inner equatorial corona, apparently connected intimately with truly solar phenomena, quite like the polar rays; while the third element in the composite is the outer equatorial corona, made up of the long ecliptic streamers, for the most part visible only to the naked eye, also existing as a solar appendage, and possibly merging into the zodiacal light.

The total eclipses of a half-century have cleared up a few obscurities, and added many perplexities. There is little or no doubt about the substantial, if not entire, reality of the corona as a truly solar phenomenon. The Moon, if it has anything at all to do with the corona, aside from the fact of its coming in conveniently between Sun and Earth so as to allow a brief glimpse of something startlingly beautiful which otherwise could never have been known, is probably responsible for only a very narrow ring of the inner radiance, of pretty even breadth all round. This diffraction effect is accepted; but the problem still remains how wide this annulus may be, and whether it may vary in width from one eclipse to another. These questions once settled, the spurious structure may then be excerpted from the true. Indeed, the coronal streamers, delicately curving and interlacing, may tell the whole story of the Sun's radiant energy.[33]

[33] Perhaps the most striking fact developed by research upon the phenomena of mid-totality is that the axis of symmetry of the corona does not coincide with the Sun's axis of revolution as determined by long observation of the solar spots. This might have been expected, but astronomers were a long time in getting at it. Then the question arises, What is the angle of divergence of these two axes? which Professor BIGELOW has competently answered. (*American Journal of Science*, cxlii. (1891), 1.) If we regard the Earth as a great magnet, may not the poles of the corona mark the position of the magnetic poles of the Sun? ZÖLLNER was

This is hardly the place to speak at length of electrical theories of the corona, although they are coming more and more to the front. There are, of course, vague suggestions earlier, but REYNOLDS was among the first to treat of the corona as an electric phenomenon,[34] following up the subject a few years later, and generalizing his theory by including the aurora and cometary tails.[35] ZÖLLNER'S speculations, too, are worthy of note.[36] Dr HUGGINS dwells lucidly upon this interesting phase of the corona problem in his Bakerian lecture of 1885, where the consequences of granting the existence of a high electric potential of the solar surface are fully followed out.[37] The possible effect of the electric con-

probably the first to guess this relation, and the idea is far from wild. But the eclipse part of the problem — the actual determination of the solar co-ordinates of this possible 'magnetic pole,'— would be sufficiently easy, only that observers in the past have too often paid little regard to precise orientation in pictures of the corona otherwise unexceptionable. All that is needed is the geometric means of drawing the Sun's axis across the photograph, and the required datum for each picture is then had at once, by direct measurement of the angle it makes with the coronal axis. Nor must it be forgotten that the centre of the Moon will rarely coincide exactly with the centre of the Sun; consequently the full discussion of coronal photographs implies correct knowledge of the longitude and latitude of the place where they were taken, and of the local time of mid-exposure. Also the distortion of the corona by atmospheric refraction becomes appreciable at low altitudes. These matters have too often been treated with indifference; but the eclipses of another decennary will perhaps provide the full data for this fundamental discussion. — *D. P. T.*

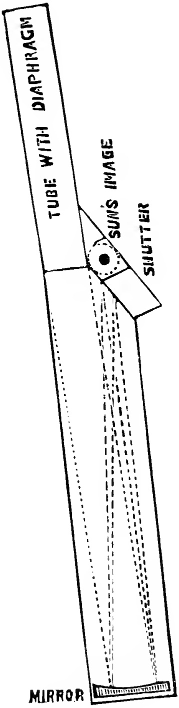
34 *Chemical News*, xxii. (1870), 294.

35 *Memoirs Literary and Philosophical Society of Manchester*, xxv. (1876), 44, 53, 202.

36 ZÖLLNER, *Ueber die Natur der Cometen* (Leipzig, 1872), p. 127.

37 *Proceedings Royal Society*, xxxix. (1885), 126.

dition of the nearer planets may influence the direction and magnitude of the longer streamers, although observation on this point is not yet definite.[38] Also, electrical discharges through poor vacua appear to be worthy of farther investigation.[39]



The brighter streamers of the corona may yet be recorded in full sunlight; and the problem is so important that hope should never be abandoned. Soon after the eclipse of 1882, it occurred to Dr Huggins of London that a photographic method of his own devising might secure this result, and he lost little time in trying it. The arrangement of his apparatus is here shown, — a long tube carefully diaphragmed, admitting the Sun's rays to a mirror which forms by reflection an image of the uneclipsed Sun and the sky immediately surrounding it. Theoretically, the sky against which the corona is projected must be a little brighter than that immediately adjoining, which has no corona upon it. Delicate photographic manipulation appeared to be sufficient to bring out this minute difference, while the eye is powerless to detect it; and success in the early attempts seemed most hopeful. In particular, some

38 *Proceedings Royal Society*, xxxix (1885), 132.

39 Pupin, *Astronomy and Astro-Physics*, xi. (1892), 483.

London photographs of the corona near the time of the great eclipse of 1883 were found to reveal a structure similar to that shown upon the eclipse plates taken in the Caroline Islands, 6th May. But later attempts were most disappointing, and the careful work of M^r^ RAY WOODS on the Riffelberg in 1884 under the direction of D^r^ HUGGINS, and afterward at Cape Town, came to naught.

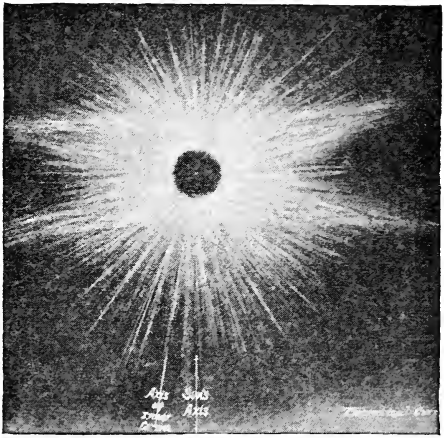
Again was the method put to a more crucial test during the eclipse of 1886, when two coronagraphs constructed by D^r^ HUGGINS were in the field, the one used by Captain DARWIN[40] at Prickly Point, Grenada, and the other at the Royal Observatory, Cape Town, by D^r^ GILL. As seen from the latter place, the eclipse culminated in a large partial phase; so that if the corona were actually depicted on the plate, that part of the black Moon not projected upon the Sun ought to have cut a crescent out of the inner corona. Also at Grenada, both before and after totality, under similar conditions of partial phase, a like experiment was tried; but from both these widely separate localities came disheartening news, — the real corona had not been photographed at all, only a spurious atmospheric one.

Also D^r^ WRIGHT of Yale University has attempted to observe the corona optically without an eclipse. using a variety of suitably colored media; while at great elevations, D^r^ COPELAND in the Andes (1883), Professor TODD on Fuji-san (1887), Professor HALE on Pike's Peak (1893), and others elsewhere, have made serious efforts to do away in part with the necessity for eclipse expeditions in the future; but so far without avail.

Coronal theories abound, — that the corona is a gaseous atmosphere carried round with the Sun,— that it is gaseous

[40] *Philosophical Transactions*, 1889 (A), 306.

matter ejected from the Sun or received by it, in motion from the forces of ejection, gravity, solar rotation, or perhaps repulsion of some kind, — that, like the ring of Saturn, it consists of swarms of meteoric particles too swiftly revolving to fall into the Sun, — or again, that it is due to the ceaseless downfall of meteoric matter, and the *débris* of disinte-



CORONA OF 16TH APRIL 1893, AS PREDICTED BY SCHAEBERLE

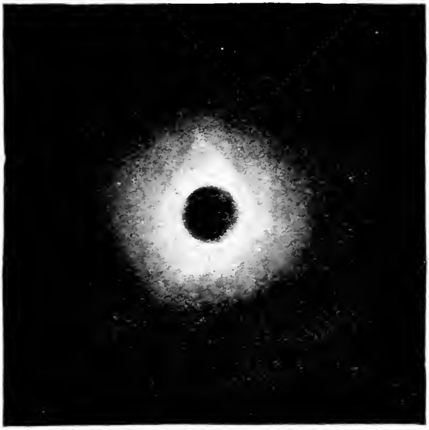
grating comets.[41] Professor NEWTON, first authority in matters meteoric, considers it not at all probable that meteors may account for the long streamers of the corona.[42]

Other theories are advocated, — a mechanical one by Mr SCHAEBERLE, and Professor BIGELOW's magnetic theory,—

[41] HUGGINS, *Proceedings Royal Society*, xxxix. (1885), 120.

[42] *Proceedings American Association Advancement of Science*, xxxv. (1886), 9.

neither of which, however, has yet stood the ultimate test of predicting fully and correctly the configuration of the coronal streamers. The mechanical theory assumes that the corona is caused by light emitted and reflected from streams of matter ejected from the Sun by forces which act in general along lines normal to the solar surface.



CORONA OF 16TH APRIL 1893, AS PHOTOGRAPHED BY SCHAEBERLE

As is known, these forces are most active near the middle of each sun-spot zone, and mere perspective thus plays a large part. Comparison of M[r] SCHAEBERLE'S predicted corona (on the opposite page) with the actual corona of 1893 (shown above) unfortunately does not seem to sustain this theory.

According to Professor BIGELOW'S theory, the coronal light is merely a phenomenon of the Sun's magnetism, which determines the position and direction of the luminous filaments composing the corona. Somewhat the relation existing between the streamers of the aurora and the Earth may thus connect the coronal streamers with the Sun.

Dr Schuster agrees with Dr Huggins in the idea that the brighter filaments of the corona are probably due to electric discharges;[43] but it seems unlikely that any single hypothesis will completely account for a phenomenon so complex.

Meanwhile, to sum up in a few words, the corona is to be described as a truly solar appendage (as proved anew at the eclipse of 1893 by the research of M. Deslandres, which shows that it rotates with the Sun on its axis); a small percentage of its light in the lowest regions may be due to diffraction at the edge of the Moon; the innermost portions have perhaps in part the nature of a solar atmosphere; the middle regions the spectroscope shows to be due in great part to incandescent matter (of a lower temperature than the Sun's surface), and the polariscope in part to light reflected from dark particles possibly meteoric, but more likely dust particles or fog of some sort; while the enormous extensions along the ecliptic (most strikingly developed coincidently with the sun-spot minimum) are possibly connected in origin with the zodiacal light. But the mystery of the corona is by no means solved, and the entire subject will require many years of patient and critical investigation in the future.

Dr Huggins has suggested the striking thought that the corona must have been much more brilliant and extended in early geologic time than now; so that if the skies were then as clear as at present, not impossibly the corona may

[43] *Philosophical Transactions*, 1889 (A), 304.

still have been faintly visible during the far-away infancy of the human race. He adds, 'Are there any philological traces of it in the earliest words and ideas connected with the Sun?' In the next chapter we shall look backward toward those ages, and find perhaps a suggestion of the corona in the sculptures of prehistoric peoples.

Whatever its cause and meaning, the corona must always continue to absorb the deepest attention during eclipses. At some remote epoch, however, — perhaps millions of years hence, though really but a step astronomically, — our great Sun, already on his decline, will have so shrunken that there will be no corona. In the picturesque language of Dr HUGGINS, 'The candle of the Sun is burning down, and so far as we can see, must at last reach the socket. Then will begin a total eclipse which will have no end:

Dies illa
Solvet sæclum in favilla.'

*** Titles of early papers will be found in HOUZEAU *et* LANCASTER, *Bibliographie Générale de l'Astronomie*, ii. 1041.

The lists already cited on page 46 will be found ample for popular papers. In the *Smithsonian Reports* Mr W. C. WINLOCK gives excellent technical summaries from time to time. Following are important references to modern literature of the corona: —

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CHAPTER VI

ECLIPSES IN THE REMOTE PAST

What glory 's like to thee?
Soule of this world, this universe's eye,
No wonder some made thee a deity.
ANNE BRADSTREET, *Contemplations.*

TO a fabulous age all nature was mystery. In our own day, with superstition far in the background, and with clear scientific explanation for nearly all natural phenomena, the prodigious effect of a solar eclipse upon primal races is hard to apprehend. Indeed, the derivation of the word from the Greek (ἐκλείπειν, to relinquish or abandon) itself indicates the ancient idea; sometimes expressed as a swooning or fainting of the Sun (ἔκλειψις ἡλίου, or *defectus solis*), or leaving his accustomed place and brightness in the heavens.

Fragmentary accounts still extant teem with terror at the wrath of the gods, — stories of strange darkness coming on solely to prevent or suspend battles, or portending speedy death to some potentate; of a gigantic monster devouring the kindly Sun as penalty perchance for insufficient offering. On the occasion of an eclipse in China clouds once covered the sky, preventing observations. The courtiers joyfully repaired to the Emperor to felicitate him that Heaven, touched by his virtues, had spared him the pain of witnessing the 'eating of the Sun.'[1]

[1] WELLS WILLIAMS, *Middle Kingdom*, ii. 73.

'All over India they believe that when the Sun and Moon are eclipsed, the phenomenon is occasioned by a certain dragon with very black claws, which extends them, and thus wants to seize those two bodies, wherefore at such times the rivers are seen covered with human heads, the Indians immersing themselves up to their necks, which they look upon as a most devout position, and most suitable to induce the Sun and Moon to defend themselves well against the dragon. In America the aboriginal inhabitants are convinced that the Sun and Moon are angry when they are eclipsed, and it is difficult to state what they would not do to obtain favor from them. But did not the Greeks, who were so refined, believe for a long time that the Moon was under the influence of sorcery, and that the magicians made her descend from heaven to throw a certain injurious froth upon herbs? And, as for ourselves, were we not mightily afraid in 1654 of a solar eclipse, which indeed was total? Did not a multitude of people shut themselves up in cellars?'[2]

European science has thus far produced little effect upon the masses of superstitious natives of India; for even as late as 1868 they verily believed the great eclipse of that year to have been caused by the huge dragon Rahu endeavoring to swallow up the lord of day. An interesting article in *Chambers's Journal* about this time gives accounts of the singular customs still observed on such occasions.[3] The

[2] FONTENELLE, *Entretiens sur la Pluralité des Mondes*, 2me soir.

[3] 'It easily appears that the dragons Rahu and Ketu are personifications of the nodes, ascending and descending. The astrologers of Europe seem to have inherited the tradition from their Aryan progenitors, for, strangely enough, the astrological name of the ascending node is *Caput Draconis*, and of the descending, *Cauda Draconis*. In like manner, it may be noted, we, as well as the Greeks and Romans, have inherited the Indian names of the constellations

Japanese cover their wells during an eclipse, to prevent poison from dropping into them from the sky.[4]

A Mongolian myth relates how the gods determined to punish ARAKHO for some misdeeds, but he hid from them. Asking his hiding place of the Sun, his answer was evasive; applying to the Moon, she told its location. So ARAKHO was dragged out and punished; and now, in revenge, he pursues both Sun and Moon, and whenever he approaches sufficiently near, an eclipse occurs. To help Sun and Moon in this sad catastrophe a great noise is made, and finally ARAKHO is frightened away.[5]

The Sun himself was for ages an object of worship, and a favorite representation of the Sun-god among Egyptians, Phœnicians, Assyrians, Persians, and Hittites was the 'winged disk.'[6]

and of the days of the week. Darkness is the most fitting emblem of evil; while light symbolizes the truthful and good. As MAX MÜLLER has shown, in most of the Aryan myths the hero represents the Sun, while darkness is generally personified as a snake or a dragon lying coiled around the dawn.' — *Chambers's Journal*, xlv. (1868), 676.

[4] GRIFFIS, *The Mikado's Empire* (New York, 1883), p. 471.

[5] *Knowledge*, xi. (1888), 51.

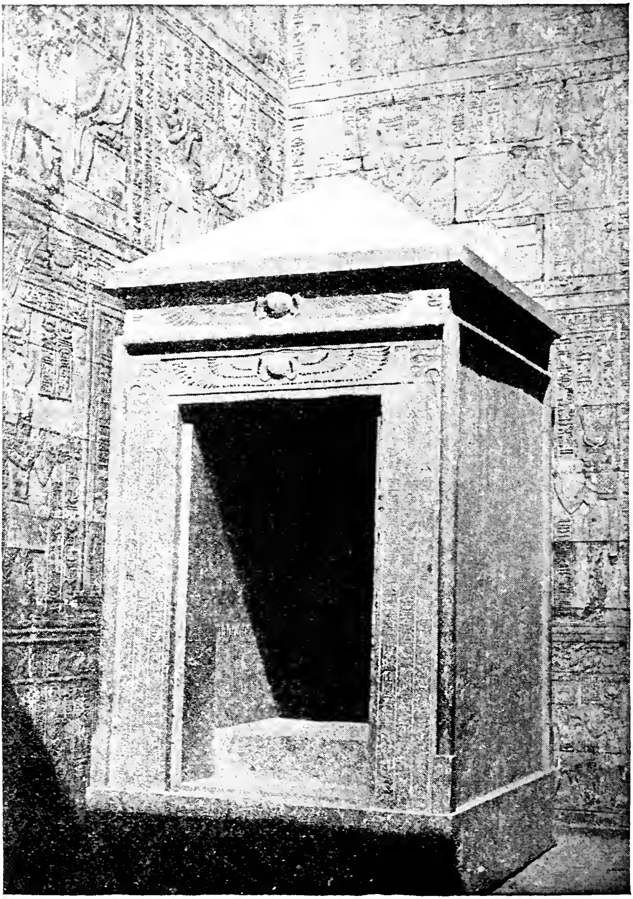
[6] In effect very like the long streamers of the solar corona, were not the 'wings' first suggested to the ancient and childlike peoples by viewing prehistoric eclipses? The Sun's corona, majestic and impressive to our beholding, must have been to them a spectacle even more imposing. That they sought to record, and did record, though crudely, these phenomena of the sky is plausible; but, like the other evidences of early civilizations, these records for the most part are either no longer extant, or remain buried for subsequent generations to unearth. From the slender allusions to the corona by PLUTARCH and PHILOSTRATUS, backward to the epoch of the earliest races, is an interval of many centuries, yielding apparently no reference to that wonderful phenomenon of totality characterized by a 'solemn steadiness,' as Sir FRANCIS GALTON has fittingly said.

In the books of Scripture are repeated allusions to the protecting wings of the Deity, referring to this design.

But from investigations of the motion of the Moon, with modern data so accurate that the early paths of its shadow across those ancient countries can be assigned with confidence, it appears that Egypt and Western Asia were favored by repeated total eclipses.

To primitive races the Sun was, naturally enough, the supreme deity; but, equally naturally, one might conjecture that the Sun-god of their worship would be symbolically expressed by a symmetrical radiance, completely enveloping him. What, however, are the earliest glyptic representations of the solar deity? Certainly among them are the Egyptian, Assyrian, Babylonian, and Hittite monuments, upon which, repeated again and again, may be seen the famous 'winged globe,' or 'winged solar disk,' whose origin is so remote that archæologists assign no date. BRUGSCH Bey has, however, investigated the history and significance of the symbol, in his 'Die Sage von der geflügelten Sonnenscheibe nach alt Aegyptischen Quellen dargestellt' (*Abhandlung der k. Gesellschaft der Wissenschaften zu Göttingen*, xiv., 1868–69, Hist. Phil. Classe, 173). Doubtless originating in Egypt, this symbol of the Sun-god is diversely represented in these early monuments, Egyptian, Chaldean, Assyrian, Babylonian, Phœnician, Hittite, Persian, and other; but the wide variations from the primitive type, in order to adapt it to intaglios, cylinders, seals, tablets, and architectural monuments, are aside from my present purpose, and need not now be farther alluded to. I desire only to direct attention to the fact that modern eclipse research has developed a type of corona, recurring coincidently with the minimum of solar spots, which suggests at once an explanation of the wings accompanying this prehistoric symbol of the Sun-god.

Pending publication of a memoir on the subject, it is only desirable to present here two or three illustrations of the winged solar disk or globe. On the following page is an illustration from a photograph of early Egyptian architecture (on which the winged globe forms the chief decoration over gateways), in this case a double carving of the constantly recurring symbol, over the entrance to a granite shrine in the sanctuary at Edfou. Another adorns the entrance to PHARAOH's Bed at Philæ, where the symbol is now cut in



Granite Shrine in Sanctuary at Edfou
(*Showing the Winged Solar Globe*)

Another figure often recurring upon the small carved cylinders of hematite or lapis-lazuli, between B. C. 2500 and

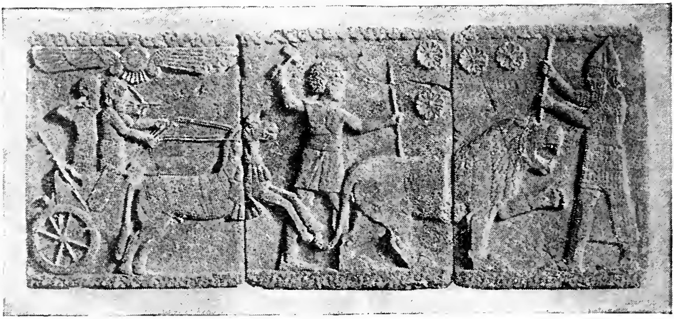
two by the breaking of the lintel (shown below) Likewise at Luxor, Karnak, and other well known Egyptian localities, the winged solar globe has been architecturally sculptured. In the Boston Museum

PHARAOH'S BED AT PHILÆ
(*Showing the Winged Solar Globe*)

1500, represents the Sun in the arms of the Moon, with pointed lines meaning rays, and straight ones streams of

of Fine Arts may be seen excellent representations of the winged disk, — on both sides of the pylon which divides the Egyptian room; also just above the middle of the sarcophagus lid (the last one on the left) standing on top of the case in the same room.

A well preserved Hittite figure occurs at Saktsche-gözü (latitude 37° 10′ North, longitude 36° 55′ East of Greenwich). Three tablets

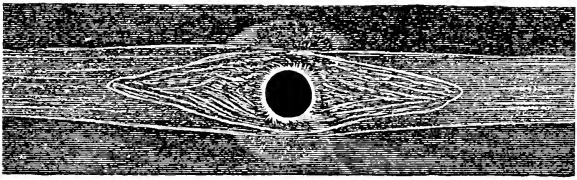


HITTITE MONUMENT AT SAKTSCHE-GÖZÜ
(*Showing the Winged Solar Disk*)

commemorate the lion hunt; at the top of the left-hand one (here reproduced from HUMANN and PUCHSTEIN, *Reisen in Klein Asien und Nord Syrien*, Berlin, 1890, Atlas, Tafel xlvi.), is a conventionalized winged disk, doubtless to show that the King is under the protection of the Supreme Deity. I have to thank D^r STERRETT for reference to this work. Less perfect representations are seen at Boghaz-Köi, well known to archæologists; while at El-Flatûn-Puñar D^r STERRETT photographed a monument bearing a triple representation of this favorite symbol, reproduced, with a description of the monument by D^r WARD, in *The American Journal of Archæology*, ii. 49.

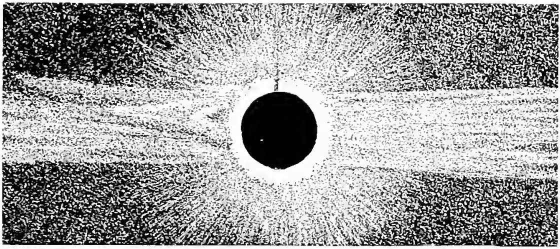
But the point I desire specially to emphasize is that the origin water, — not impossibly suggesting an eclipse, although the connection is rather vague.[7]

of the wings should be sought, not in the Oriental imagination, but in a celestial phenomenon which the ancient peoples could hardly



THE CORONAL STREAMERS OF 1878 (NEWCOMB)

have failed to observe; that is, the Sun's corona of the precise type discovered during the eclipse of 1878 by Professor NEWCOMB in Wyoming, and a few moments later by Professor LANGLEY from



THE CORONAL STREAMERS OF 1878 (LANGLEY)

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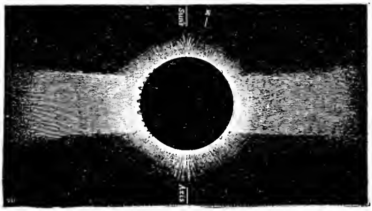
[7] The cylinders were often made of chalcedony and jasper as well, but this special design is not found upon these materials so frequently. Continually unearthed in Babylonia and its general region, how much of quaint and valuable information has come to us on these wonderful stones, — seals used to stamp with authenticity the epistles written upon tablets of clay.

While the Egyptians worshipped chiefly animals, the Semitic religions were largely based upon reverence for astronomical objects. Hence the Sun-god SHAMASH and his wife AA appear in various forms upon most of these ancient cylinders, even as remotely as B. C. 3000. The Babylonian VENUS, ISHTAR (biblically ESTHER), also occurs frequently.

Perhaps the oldest design on the cylinders represents the Sun-god coming out of the door of sunrise, while the 'gate of the East' is being opened by a porter. From his shoulders stream rays, a weapon with a saw-edge is in his hand, and one foot rests on the top of a mountain, an attitude frequently spoken of in the old Babylonian hymns. A representation of the Sun-god of Sippara found at Abu-habba shows him seated, with three persons advancing in a pro-

the summit of Pike's Peak. Other coronas exhibiting a recurrence of this type are those drawn by GROSCH (1867), and by M[rs] TODD (1889 *a*) from many sketches of the ecliptic streamers (page 68). On comparing the much extended coronas of these modern eclipses with the conventionalized symbol of the ancient Sun-god, one is strongly tempted to ask, Did not these primitive peoples, seeing this type of banded corona during total eclipses of the Sun, naturally infer that the coronal extensions were the wings by which the Sun-god flew, as they supposed, from one part of the heavens to the other in his daily round? Absolute demonstration may be impossible, but the identity is promising. — *D. P. T.*



CORONA OF 1867 (GROSCH)

cession,[8] while near by upon an altar is a great sun with rays which two creatures aloft in the air are pulling along by a rope. SAMSON, Hebrew for sun, may possibly have indicated the Sun-god of the Hebrews; while the Phœnician BAAL, or deity, was a sun-god under different designations.[9] At the time of the Shepherd Kings, about B. C. 1500, during the Hyksos dynasty, a peculiar circle was sometimes used for the solar deity, showing the disk with long rays ending in hands.

Unfortunately, of the oldest known work on astronomy — written about B. C. 3800 by SARGON the First, King of Agade in Babylonia — only the merest fragments have survived. It is significant that he also wrote a work upon 'Omens.' Thus early had begun that intimate relationship of astronomy to mysticism and superstitious worship which persisted almost to our own century.

Naturally, then, a darkening of this great and beneficent Sun-god — light, life, ruler of the world — brought consternation to the breasts of all beholders; neither is it strange that extant descriptions of the earlier eclipses are vague and unsatisfactory. Accuracy in minutiæ, like noting the beginning and end, precise date and duration, and locality of observation, seems to be a modern attribute. If these early peoples recorded any natural phenomenon within several years of the actual time, one must be well content.

Can anything different be said of the ancient battles? In Persian or Arabic history prior to the fifth century, a divergence of twenty-five years is considered of trivial conse-

8 The Arabs called it NOAH, with SHEM, HAM, and JAPHET approaching.

9 In Phœnicia, BAAL was known as HADAD, in Babylonia as TAMMUZ, and in Cilicia as SANDAN.

quence. Even in the case of eclipses, mere differences of two or three years do not seem in the least to disturb the old chroniclers.[10]

The earliest known record of an eclipse occurs, though imperfectly, in that ancient Chinese work, the *Shu-king*. Visible at Tay-Kang-Kien during the reign of CHUNG KANG, the fourth emperor of the Hea dynasty, calculations from modern times backward through these dim ages show that it may have occurred as early as the autumn of B. C. 2158.[11] COCHOU-KING, the greatest astronomer of China, who flour-

[10] It should be remembered, too, that while the astronomical reckoning of the years of the Christian era is identical with the ordinary or chronological system, astronomers differ from chronologists in their numeration of the years preceding that era. The simple relation of the two systems is apparent from the following:—

Chronological		Astronomical
Year B. C. 3	=	Year −2
B. C. 2	=	−1
B. C. 1	=	0
A. D. 1	=	+1
A. D. 2	=	+2
A. D. 3	=	+3

As the astronomical system recognizes a year 0, while the other does not, the ordinary or chronological numbers of the years designated by the letters B. C. are arithmetically one greater than the same years designated in astronomical records by the sign *minus*.

[11] The Chinese characters representing this bit of history are literally translated by WILLIAMS in the *Monthly Notices Royal Astronomical Society*, xxiii. (1863), 239, as follows: 'In the last month of the autumn, the first day of the Moon, the heavenly bodies were not in agreement in Fang,' that asterism being part of our constellation Scorpio. The visible heavens were divided by the Chinese into thirty-one parts, of which Fang is a very small one. Its determining group consists of certain stars in Scorpio, and a few small

ished about A. D. 1280, admitted this eclipse.[12] Another is spoken of in *Shi-king* as occurring B. C. 776 (the year when authentic history began in another land with the running of the foot-race in Olympia by CHOREBOS, from which event the Olympiads were counted).

In *Chun Tsew*, one of the *Vu-king* or canonical books of the Chinese ascribed to CONFUCIUS, is given a short review of the most remarkable events taking place from B. C. 721 to B. C. 480 at the court of the principality of Lu. Chun Tsew means 'Spring and Harvest,' which according to one of the peculiarities of the Chinese language may be considered as merely an abbreviation of spring, summer, autumn, and winter, and translated as 'Annals.' In the Chinese canonical books thirty-eight eclipses are mentioned. Of these, eighteen agree with PINGRÉ'S list, but many of the others have some error, either in month or year. This, however, may perhaps come from our defective knowledge of the ancient Chinese calendar, particularly with reference to intercalation and the beginning of the year, which were probably subject to irregularities. But always the day is correct, showing that the records were reliable. Three of these described as total SCHJELLERUP has selected for scientific discussion in a paper[13] published in the *Proceedings of the Royal Danish Society of Sciences*. These took place 16th July, B. C. 708, 19th September, B. C. 600, and 18th June, B. C. 548. CONFUCIUS was three years old at the time the last occurred. Quite probably the eclipses

stars in Libra, Ophiuchus, and Lupus. The exact place in the sky where the eclipse occurred is thus pointed out. Consult also *Nature*, xxxii. (1885), 276.

[12] *Memoirs Royal Astronomical Society*, xi. (1840), 49.

[13] *Copernicus*, i. (Dublin, 1881), 41.

were not mentioned with scientific intent, but because they were bad omens.

A fragment from ARCHILOCHUS describes ZEUS as once turning mid-day into night, an event so remarkable that 'no one ought in future to be surprised at anything.' While OPPOLZER thought this referred to the eclipse of 6th April, B. C. 648, his map seemed to carry the Moon's shadow too far to the north of the Ægean Sea. Professor MILLOSEVICH, however, reinvestigated the question, examining all the solar eclipses occurring in the seventh century B. C., and found but two which at all corresponded to that mentioned by ARCHILOCHUS, one of which, 15th April, B. C. 657, although a large eclipse, was not quite total. The other, on the date given by OPPOLZER, was found to have been total at ten o'clock in the morning at Thasos and in the northern part of the Ægean Sea. Answering well to the poet's description, this eclipse was without much doubt the one referred to. Grecian chronology prior to the Persian wars was so uncertain, that there is really no reason for not accepting this eclipse merely because the date at which ARCHILOCHUS flourished is thus carried down nearly a half-century later than that generally supposed.[14]

To the burning of all native scientific books (except those on agriculture, medicine, and astrology) by TSIN-CHI-HWANG-TI, B. C. 221, the Chinese attribute the loss of a precious mass of astronomical learning, the accumulation of long ages. Notices of 460 solar eclipses have been collected by DE MAILLA, extending from B. C. 2159 to A. D. 1699; and WYLIE gives a careful list of 925 solar and 574 lunar eclipses ob-

[14] MILLOSEVICH, On the eclipse of ARCHILOCHUS and the iconography in OPPOLZER'S 'Canon of Solar Eclipses,' *Memorie della Società degli Spettroscopisti Italiani*, xxii. (1893), 70.

served between B. C. 2150 and A. D. 1785; while this mysterious nation is said by WILLIAMS to have observed 600 solar eclipses between B. C. 2159 and A. D. 1223. What was known in the early part of the present century relating to the Chinese eclipses is presented with great completeness by DELAMBRE in his somewhat sombre *Histoire de l'Astronomie Ancienne.*[15]

One of the Nineveh slabs representing an Assyrian king, ASSURNAZIRPAL, supposably pointing at an eclipse as a happy omen of his coronation, about B. C. 900, was formerly quoted as evidence of one of the oldest eclipses. But unfortunately it must collapse, the interpretation having been based upon an early and erroneous translation.

The Nineveh eclipse, B. C. 763, ten years before the founding of Rome, is the first in which the description really approaches clearness. Discovered on the Assyrian Eponym tablets in the British Museum,[16] its underlined record would seem to indicate something especially noteworthy,—probably a total obscuration. Also this eclipse appears to have been noticed in Palestine, and Mr J. W. BOSANQUET connects it with a passage in Amos viii. 9, and perhaps also in v. 8.[17] The first of these verses reads, 'And it shall come to pass in that day, saith the LORD God, that I will cause the Sun to go down at noon, and I will darken the Earth in the clear day.'

According to SIMPLICIUS and PORPHYRY, a catalogue of eclipses recorded on tablets of baked clay was discovered by CALLISTHENES, who accompanied ALEXANDER the Great

15 Vol. i. (Paris, 1817), p. 347.

16 'Revolt in the city of Assur, in month Sivan, Sun was eclipsed.' SMITH, *The Assyrian Eponym Canon*, p. 63.

17 *Ibid.*, p. 183.

to Babylon on his expedition of conquest. The earliest of these dated from B. C. 2233, only a few years after the death of YAO, and ALEXANDER ordered the tablets sent to ARISTOTLE.[18] Except six preserved by PTOLEMY, the oldest of which is dated B. C. 720, and is one of the first reliable observations extant, these tablets are now all lost. A less important eclipse is mentioned by writers in the fabulous ages as coincident with the death of ROMULUS, B. C. 715.

While the famous series of ancient eclipses, beginning with that of THALES,[19] 28th May, B. C. 585, is full of interest, viewed from our age, even through the imperfect records, it must be confessed that modern astronomers have derived little satisfaction and utility from erudite discussion of them in the hope of determining the motions of the Moon. Numerous German mathematicians, among them HARTWIG, ZECH, and GINZEL,[20] together with AIRY in England and SCHJELLERUP in Denmark, and others, have nearly exhausted the subject; but their labors appear to have given lunar places less trustworthy than those which Professor NEWCOMB has derived from the Ptolemaic eclipses of the Moon recorded in the *Almagest*.[21] A number of valuable communications relating to ancient eclipses have been made

18 WELLS WILLIAMS, *The Middle Kingdom* (New York, 1883), ii. 68.

19 An account of this eclipse is given by STUKELY, *Philosophical Transactions*, 1753, p. 221.

20 Astronomische Untersuchungen über Finsternisse, *Sitz. der k. Akademie*, lxxxix. (Wien, 1884).

21 This subject is pursued farther in Professor NEWCOMB's *Popular Astronomy*, p. 100, and *in extenso* in his *Researches on the Motion of the Moon* (Washington Observations, 1875). An ample list of titles of original papers on the ancient eclipses is given by HOUZEAU et LANCASTER, *Bibliographie Générale de l'Astronomie*, ii. 25.

BATTLE BETWEEN THE LYDIANS AND MEDES ARRESTED BY THE TOTAL ECLIPSE OF THE SUN, 28th May, B.C. 585

to *The Observatory* in recent years by Mr Lynn, formerly of the Royal Observatory at Greenwich.

The eclipse of B. C. 585 is famous chiefly because it is the first one known to have been foretold. This mathematical feat, wonderful for that early time, was performed by Thales of Miletus, one of the acutest philosophers of antiquity. He did not, of course, predict it with modern precision, for he had neither the tools for doing this, nor the materials for making those tools. But Thales was keen enough to employ a periodicity in eclipses known as the Saros, reference to which will be made in a subsequent chapter; and it was this cycle, the result of fortuitous relations of Sun and Moon and their motions, which necessarily brought about the happy verification of his forecast. Herodotus in his oft-mentioned description of a war carried on for years between the Lydians and the Medes, assigns as cause for its sudden cessation an instant turning of day into night. So affected were the contending parties in a great battle then in progress that they ceased fighting, and at once concluded a peace, cemented by two marriages. And this although Thales had predicted an eclipse even so closely as 'this very year in which it did actually occur,'— a fact, however, possibly unknown to the combatants. Cicero and Pliny make like statements. Although this is perhaps the most famous eclipse of antiquity, some authorities nevertheless fail to find convincing proof of the reality of connection between the above mentioned battle and an eclipse whose track is known to have crossed Asia Minor about that time. The illustration on the preceding page, from a well known French source, is inserted more for picturesqueness than for precision.

Xenophon mentions the supposed eclipse of 19th May,

B. C. 557, in a passage in his *Anabasis*, of which the following is a literal translation: — 'They [the soldiers of Cyrus] came to the river Tigris. There was a deserted city, large, the name to which was Larissa.[22] Formerly Medes inhabited it. The width of its wall was twenty-five feet and the height one hundred.' Then follows a brief description of the manner of its construction. 'The king of the Persians, besieging this city at the time when the Persians were seizing the power from the Medes, was in no way able to take it.' The nine following words are very obscure, and capable of several renderings, of which one may be, 'But the Sun disappeared, having covered itself as with a cloud until the men lost heart.' Then, 'And thus the city was taken.'[23]

The next of the famous ancient series is called the eclipse of XERXES, 17th February, B. C. 478, which took place during the memorable expedition against Greece; but the concession of this date, in the attempt to reconcile chronology with the known occurrence of an annular eclipse, would place the battle of Salamis two years later than the generally received date.[24]

[22] Not to be confused with the Thessalian Larissa.

[23] Referring to this questionable eclipse, Mr LYNN remarks: 'I cannot refrain from expressing my concurrence with Professor NEWCOMB in doubting very much whether the phenomenon stated by XENOPHON (*Anabasis*, iii. 4) to have taken place when the Persians took Larissa (the modern Nimrûd) from the Medes, was really an eclipse of the Sun, as has been supposed.'— *The Observatory*, vii. (1884), 381.

[24] The interesting questions arising from utilizing eclipses of both Sun and Moon for verifying ancient dates, and the rectification of chronology, are too complex and unwieldy for treatment here. PINGRÉ, in the latter part of the 18th century, published several great works which deal with these matters. In his *L'Art*

The eclipse of Athens, 3d August, B. C. 431, occurred in the first year of the Peloponnesian war, which resulted (B. C. 404) in the overthrow of Athens by Sparta, the subsequent tyrant of all Greece. Of an eclipse, 21st June, B. C. 400, ENNIUS writes, 'During the nones of June, the Moon and the night stood over against the Sun,' or, 'the Moon stood over against the Sun and there was night.' Nearly forty years later, Thebes aroused herself against Sparta, under the leadership of PELOPIDAS, from whom is named another eclipse, 13th July, B. C. 364.

The great Greek commander, AGATHOCLES, intimately connected with the struggle between the Carthaginians and the Greeks of Sicily, has an eclipse named for him, of which the totality is perhaps best established of all the early list, 14th August, B. C. 310. Eight or ten unimportant obscurations are mentioned between B. C. 463 and B. C. 104, while the great annular eclipse, well known as having occurred when JULIUS CÆSAR crossed the Rubicon, brings down to B. C. 49 the list of what may by courtesy be called authentic ancient eclipses.

How the astronomers of that early time, HIPPARCHUS for example, observed and recorded an eclipse is a fascinating subject, of which our limits unfortunately forbid an extensive study. It must suffice to say that from the comparison of a great number of very circumstantial and accurate observations of eclipses recorded by the Chaldeans, HIPPARCHUS

de Vérifier les Dates des Faits Historiques (Paris, 1770, 1783, 1818) is a chronology of solar and lunar eclipses from the beginning of the Christian era to 1900 (subsequently extended an additional century); and in 1787 he published a similar work to include the eclipses of the ten centuries preceding the Christian era. Also the recent papers by Mr STOCKWELL in GOULD'S *Astronomical Journal* have occasioned much discussion.

was enabled to determine the period of the Moon's motion relatively to the stars, the Sun, her nodes, and her apogee. These are among the most valuable results of the old astronomy. While the ancients had neither telescope nor clock nor camera, their few simple instruments were constructed on principles essentially identical with those embodied in the fundamental equipment of a modern observatory; and this subject will be found attractively treated by Mr LOCKYER in the initial chapters of his *Stargazing*.[25]

With the crudest apparatus, or none whatever, inexact historians, and battles and eclipses liable in any one of several years, a certain haziness not altogether of poetry is scarcely matter for wonder. But may we not safely allow the questionable ancient darkenings of the Sun to remain as the dramatic interference with affairs of state, rather than suggest some suddenly heavy cloud, or the unnoticed approach of normal nightfall? It has, to be sure, remained for modern astronomers to calculate backward, and reduce the dim and imperfect accounts to conformity with known dates, whereby, unhappily, the terrible battles, deaths, and other inevitable accompaniments or results of these far away celestial adventures must too often be relieved of their supernatural connection, and brought into practical daylight, where the inaccurate but poetic view becomes far more prosaic if exact in proportion. While perhaps of slight astronomical value, these remote observations afford picturesque and almost indispensable glimpses into the misty past.

[25] Also PROCTOR, *Old and New Astronomy* (New York, 1892), p. 36.

CHAPTER VII

EARLY, MEDIÆVAL, AND LATER ECLIPSES (A. D. 5 TO 1842)

As when the Sun, new risen,
Looks through the horizontal misty air,
Shorn of his beams; or from behind the Moon,
In dim eclipse, disastrous twilight sheds
On half the nations, and with fear of change
Perplexes monarchs.

MILTON, *Paradise Lost*, i. 594.

IN the Teynkirche at Prague, made illustrious by the sermons of HUSS, lie the remains of TYCHO BRAHÉ,[1] the great Danish astronomer. Born in 1546 in Skaane, the most southern province of Scandinavia, then a part of Denmark, his interest as a young student at the University was greatly excited by an eclipse of the Sun, 21st August 1560, although it was only slightly visible at Copenhagen; and it struck him as 'something divine' that such happenings could actually be foretold. Thenceforth his studies turned permanently toward mathematics and astronomy, resulting in the *Historia Cœlestis*, a magnificent work, in which appears a long list of eclipses within historic times. The first is a small one, 28th March, A. D. 5, visible at Rome.

The final eclipses of PTOLEMY were observed in the

[1] DREYER, *Tycho Brahé: A Picture of Scientific Life and Work in the 16th Century* (Edinburgh, 1890), p. 310.

second century of our era. Mankind had advanced from the earliest and rudest mythologic speculation as to the Sun's darkening, but the phenomenon continued to inspire unreasoning terror.

Comets have sometimes owed their discovery to eclipses, one having been detected, 19th July, A. D. 418, during an obscuration of the Sun, probably total slightly south of Constantinople. And even before this a similar case had been mentioned by SENECA.

The first eclipse seen in England is alluded to in *The Saxon Chronicle* as occurring 15th February, A. D. 538. The accounts, however, are greatly confused and uncertain, as would perhaps be natural fully 60 years before the advent of Saint AUGUSTINE, and when Britain was helplessly harassed with its continual struggle in the fierce hands of West Saxons and East Saxons, of Picts and conquering Angles. Men have little time to record celestial happenings clearly, much less to indulge in scientific comment and theorizing upon natural phenomena, when the history of a nation sways to and fro with the tide of battle, and what is gained to-day may be fatally lost to-morrow. And so there is little said about this eclipse, and that little is more vague and uncertain even than the monotonous plaints of GILDAS,— the one writer whom Britain has left us,— in his meagre accounts of the conquest of Kent, and the forsaken walls and violated shrines of this early epoch.

Two famous eclipses occurred in Europe during the unrest of the ninth century, A. D. 840 and 885. In the first, totality lasted five minutes in Bavaria, probably causing the death from fright of the Emperor LOUIS,— his three sons at once proceeding to fight over the succession, and tearing in pieces the unhappy country, all of which turmoil resulted finally in the great treaty of Verdun, signed in 843, when the three countries comprising the great empire of CHARLEMAGNE were definitely separated, — originating the France, Italy, and Germany of to-day. Here in Bavaria as well as Saxony lay the centre of CHARLEMAGNE'S power. It was during this eclipse, fatal to the timid LOUIS, that a change of color was first noticed on terrestrial objects because of the lunar shadow. The second was also nearly five minutes total, and, though visible in Ireland, must have been at its best in Scotland.

Bagdad, in all the glory of the Arabian Nights epoch, witnessed several eclipses, — in November 829, November 923, and August 928. While nothing of great historical interest accompanies this period. — associated in the minds of Arabic scholars with the Fatimite and Abassid dynasties,— it was yet the gorgeous scene of the wonderful fables clustering about the good Caliph HAROUN ALRASCHID; and who can say that one of these eclipses may not have taken place on the very day when that monarch was diverting himself with the stories of BABA ABDALLAH, SIDI NOUMAN, and COGIA HASSAN.

During the next hundred years a number of eclipses were visible in Cairo, and recorded with sufficient accuracy to form the basis of computation. LA PLACE has called attention to the important observations of eclipses made by EBN-JOUNIS, the astronomer of HAKEM, Caliph of Egypt A. D. 1000.[2] Nine of his eclipses, from 829 to 1004, at Bagdad and Cairo, are discussed by Professor NEWCOMB.[3]

[2] LA PLACE, *The System of the World*, translated by J. POND, F.R.S. (London, 1809), ii. 289.

[3] NEWCOMB, *Researches on the Motion of the Moon* (Washington, 1878), p. 44.

The battle of Stiklastad occurred on 31st August 1030, during which took place the total eclipse of the Sun mentioned in a previous chapter.

One of the most famous mediæval eclipses was seen on 2d August 1133, although some confusion among old historians seems to have resulted from their attempts to connect it with the death of HENRY the First. There was no eclipse in August 1135, the year when HENRY died; but the writers of that period speak of the 'Sun on that day' being shrouded in 'hideous darkness,' thus showing Nature's sorrow at 'this great man's last departure.' So that HENRY must have died in 1133, which he *did* not, or else there must have been an eclipse in 1135, which there *was* not.[4] But this is not the only labyrinth into which chronology and old eclipses, imagination and computation, lead the unwary searcher. An eclipse of the Moon in the year of HENRY's death can hardly account for the 'darkness.'

HALLEY alludes in not very explicit terms to an eclipse occurring in London, 20th March 1140. Neither KEPLER nor RICCIOLI alludes to it, but in *The Saxon Chronicle* (which became a valuable and well written record from the time good King ALFRED took it in hand, about 887), the following account relative to 1140 is found: 'In the Lent the Sun and the day darkened about the noontide of the day, when men were eating; and they lighted candles

[4] The Rev[d] S. J. JOHNSON remarks, with reference to these irreconcilable dates: 'There is a mistake about the date the translations have given. HENRY I. died in 1135; but at the new Moon, in August of that year, I find there was no eclipse. On August 2, the day after Lammas, 1133, an eclipse took place which thoroughly answers the conditions.'— *Eclipses, Past and Future* (London, 1874), p. 47. But see also LYNN, *The Observatory*, xv. (1892), 225.

to eat by. That was the 13th day before the calends of April. Men were very much struck with wonder.'[5]

An eclipse of some sort, 26th January 1153, seems to have been dimly suggested by one of the old historians, who remarks naïvely, 'Something singular happened to the Sun, the day after the Conversion of Saint PAUL.'

Also a total eclipse is recorded 4th September 1187, during which the stars were said to have been seen at Jerusalem, where perhaps SALADIN may have watched with wonder. Fifteen years after the signing of Magna Charta a great solar eclipse occurred about sunrise, 14th May 1230, and was quaintly said by CALVISIUS to have 'prolonged the night.'

Two total eclipses, 3d June 1239, and 6th October 1241, have been carefully discussed by Professor CELORIA of Milan, affording correction to certain mathematical elements of the lunar tables. Of the second of these, TYCHO BRAHÉ says, 'A few stars appeared about noonday, and the Sun was hidden from sight in a clear sky.'[6]

An early morning eclipse, 16th June 1406, three years before the supposed date of the birth of JOAN of Arc, passed in its total phase slightly south of England, bringing very great darkness, so that persons could scarcely recognize one another. The famous eclipse, 17th June 1433, total across Scotland, was long remembered by the people as

[5] GRANT, *History of Physical Astronomy* (London, 1852), p. 364.

[6] A supposed solar obscuration at the battle of Cressy, 26th August 1346, was, according to Mr JOHNSON, nothing more than an unusually heavy cloud, or some other meteorological phenomenon; since, on calculating the two eclipses of that year, 21st February and 17th August, he finds that neither was even visible in Europe.

the *Black Friday*, a term applied, I have been told, in our own century to a day of shadow even more melancholy. The Scotch accounts speak of darkness so deep, at three o'clock in the afternoon, that nothing could be seen. According to GRANT,[7] this report is manifestly an exaggeration; but it must have been a remarkable occurrence, for the apparent diameter of the Moon was very large, and that of the Sun near its smallest. Other things being equal, summer eclipses are longer than winter ones, for the Earth is then farther from the Sun, thus making its diameter appear smaller, so that the Moon can cover it longer.

Of course eclipses are the earliest astronomical events recorded, being far more impressive than anything else taking place in the sky. The Aztecs had begun, some time before the arrival of Europeans, to record the principal astronomical phenomena. In the LE TELLIER manuscript in the National Library at Paris, are accounts of the eclipses (total or annular) of 25th February 1476, 8th August 1496, 13th January 1507, and 8th May 1510; also an account of the comet of 1490, and mention of the zodiacal light of 1509. All these dates belong to the half-century preceding the Conquest, but the observations were continued for a time after the establishment of Spanish rule. The Incas, less exact, noticed eclipses, but did not record particular ones. When the Sun was eclipsed they imagined that it showed his anger, proving that they had offended him. It was to them the forerunner of veritable punishment.[8] The astronomy of the Incas and Aztecs had not the precision

[7] *History of Physical Astronomy* (London, 1852), p. 365.

[8] HOUZEAU, *Bibliographie Générale de l'Astronomie*, i. (Bruxelles, 1887), p. 60. An indispensable book for consultation.

of that pertaining to the early peoples of the ancient Orient, — classic Greece, India, or China.

REGIOMONTANUS in his *Kalendarium* gives diagrams of eclipses from 1475 to 1530, in which the exposed or un-eclipsed portion of the Sun is hand-colored in yellow.

Two years after the birth of LUTHER, RABELAIS, and RAPHAEL, and the very year in which RICHARD the Third was slain at the battle of Bosworth Field, a famous eclipse occurred, 16th March 1485. The great Spanish Inquisitor TORQUEMADA had been appointed the year before: how could Nature more fitly celebrate such an event? The intense gloom of this eclipse caused fowls, wild birds, and animals to betake themselves to night quarters (their immemorial custom), and in Nuremberg candles were lighted.

LALANDE gives abundant references to the observations of solar eclipses in the 16th, 17th, and 18th centuries,[9] and CASSINI[10] was among the first to indicate their applicability for determining longitudes on the Earth. This was, in fact, the chief use of an eclipse until the middle of the 19th century, when the rapidly increasing telegraph lines made it possible to accomplish the same result more rapidly, and with far greater precision. Also Professor NEWCOMB'S *Researches on the Motion of the Moon*[11] contains a transcript of numerous observations of mediæval and later eclipses; and from this elaborate paper knowledge may be obtained of the way in which the modern astronomer utilizes the results of these ancient records. With him, of course, the problem is the converse one: assuming that the posi-

9 *Bibliographie Astronomique* (Paris, An XI, 1803), p. 938.

10 *Tables Astronomiques du Soleil, de la Lune*, etc. (Paris, MDCCXL).

11 *Washington Observations for* 1875, Appendix ii.

tions of the oldest observatories on the face of the Earth are sufficiently well known, he determines the errors of the Moon's position at the times when the several eclipses were observed.

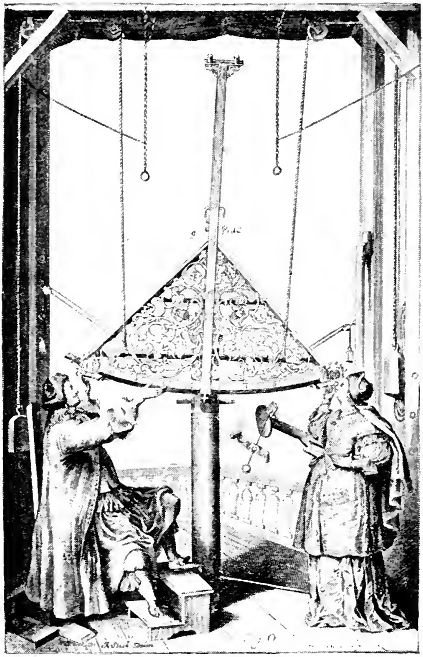
Following this come numerous accounts of well known eclipses, among them that of 24th January 1544, the year before the Council of Trent, and three years before the death of FRANCIS the First of France and HENRY the Eighth of England. Again birds ceased singing, and the astrology still so intimately interwoven with all astronomical work peeps out in the account of LEOVITIUS, an old monkish historian, who announced that this eclipse presaged famine, pestilence, and wars in Germany; and that in 1551 would occur 'dangerous changes in religion, the death of Pope PAUL, and other events, as many know.'

The years 1560 and 1567 each witnessed fine solar eclipses, when women screamed and fainted, birds fell to the ground with fright, no one could see his path, and the stars appeared.

Ten years after the destruction of the Spanish Armada, and while SHAKESPEARE was just in his prime, 25th February 1598 was known for generations as 'The Black Saturday,' an eclipse being total in the border counties of Scotland and England, while Edinburgh lay within the belt of entire obscurity.

It is interesting to read that the eclipse of 30th May 1612 was the first seen 'through a tube.' And Scotland again became the scene of a total eclipse, 8th April 1652, which was visible in Ireland also, originating the expression 'Mirk Monday.' Canny Scotland, rather exceptionally favored by these celestial spectacles in the past, has from 1652 had a long immunity, which will continue until the 22d century.

In early years there were no clocks to facilitate astronomical observation, and HEVELIUS (1611–1687) was the first to utilize HUYGENS's adaptation of the pendulum for this purpose, about 1650. This industrious astronomer, together with his consort and companion in the observatory, are here 'taking sights for time,' — possibly just before or after some solar eclipse the contacts of which had been accurately recorded.



HEVELIUS AND HIS CONSORT MAKING AN OBSERVATION

GASSENDI, an acute philosopher and diligent astronomer of the 17th century, has published a mass of observations, many of solar eclipses, in the fourth volume of his works,[12] where they are recorded in the quaint method of that day.

[12] PETRI GASSENDI *Diniensis Ecclesiæ præpositi, et in Academia Parisiensi Matheseos Regii Professoris Astronomica.* Tomvs Qvartvs. Lvgdvni M. DC. LVIII.

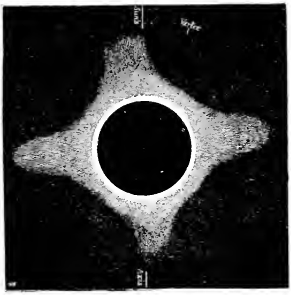
Although the passage at the beginning of this chapter has been so often quoted as to become almost hackneyed, a fact in connection with it may not be so generally familiar: the entire suppression of the great poem was almost accomplished by means of these lines. *Paradise Lost* was begun probably in 1658,[13] although not finished until 1663, nor its thorough revision completed until 1665. The censorship still existed, and TOMKYNS (one of the chaplains through whom the Archbishop gave or refused license), although a broader-minded man than many of his day, found this passage especially objectionable. The poem was allowed to see the light only through the interposition of a friend of MILTON. Upon such slender chances may hang the life of an incomparable work of art! But it is easy to see that in the turbulent days when CHARLES the Second had returned to power after the death of CROMWELL, these lines should have been deemed dangerously suggestive, in imputing to monarchs 'perplexity' and 'fear of change.'

While the accounts of mediæval eclipses are in a sense historic, no one would claim for them scientific fulness or precision. The first to exhibit a suggestion of these qualities was observed at Geneva, Nuremberg, and elsewhere, 12th May 1706, with mention of the corona, and an excellent account of the 'red flames.' Again we read of closing flowers, bewildered bats, amazed swallows, — and some one took the pains to record that of caged birds parrots were more affected than canaries, — of persons prostrate on the ground praying for deliverance from the 'last day'; and of the Geneva Council in full session ad-

[13] GARNETT, *Life of Milton* (London, 1890), p. 147.

journing from inability to see to read or write during the greatest obscuration.[14] This was also the occasion when, if DUILLIER's account is to be trusted, the Moon's shadow was first seen in its swift approach.

London, after its long rest from eclipses, was favored with an outflashing corona, 3d May 1715. A pamphlet published in that city predicting this event is entitled *The Black Day, or a Prospect of Doomsday. Exemplified in the great and terrible Eclipse, Which will happen on the 22nd April* 1715. Another 'black day' occurred 22d May 1724, London just escaping the total phase, and of which STUKELY and others wrote interesting accounts, both before and after. One was called *Speculum Mundi: or, an Exact Account of the Great and Formidable Eclipse of the Sun, Which will be Visible, Total and Central, in England, 11th May* 1724. The discrepancy of dates in both the titles quoted is of course due simply to the difference between Old Style and New Style reckoning, which amounted to eleven days in the 18th century.



3d May 1715 (AT CAMBRIDGE, ENGLAND)

An eclipse in 1733 was well observed at Catherinesholm in Sweden. The year before had been born, not far from Philadelphia, one of the earliest American astronomers, DAVID RITTENHOUSE, who, when a boy on his father's farm,

14 GRANT, *History of Physical Astronomy*, p. 366.

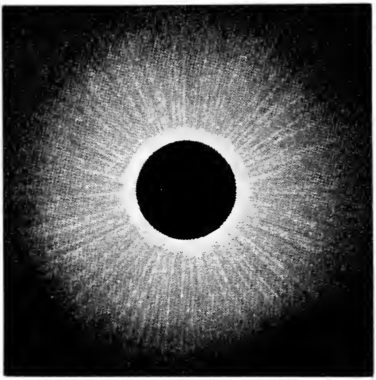
used to cover his plough-handles with computations of eclipses, and even the fences at the head of the furrows were thus distinguished.[15] Rittenhouse observed whatever celestial happenings of interest occurred in his firmament for many years. Between 1761 and 1784 many astronomical phenomena, solar and lunar eclipses, a transit of Mercury, and so forth, were recorded by others as well in this country. Among them were the Revd Phillips Payson, President Joseph Willard of Harvard College, Joseph Brown, Benjamin West, and M. de Grandchain. Indeed, the early Memoirs of the American Academy are in large part taken up with the quaint reports of such observations.

9th February 1766 (Officers *Comte d'Artois*)

Don Antonio Ulloa observed a total eclipse at sea, 24th June 1778; and from him 'trou d'Ulloa' has come to be recognized as meaning an apparent hole through the disk of the Moon during an eclipse. No such hole or even spot of light has since been authoritatively seen, and what he observed was without doubt a red protuberance. Although his 1778 corona is evidently conventionalized, it is remarkable that the pairing of the coronal rays was even

[15] *Memoirs of the Life of David Rittenhouse* (Philadelphia, 1813), p. 97.

then noticed, exactly as the polar streamers are now shown on the latest and best photographs. This eclipse was observed by RITTENHOUSE and two friends, SMITH and LUKENS.[16] Total as well in some of the Southern States, attempts at careful observation were made in Massachusetts by Professor WILLIAMS at Bradford. Clouds prevented great accuracy, but the change in color of the sky, and the chill and dampness of the air, were very marked. Professor WILLIAMS says, 'The dew fell fo faft as to wet the paper we were ufing to a confiderable degree.'[17]



24th June 1778 (ULLOA)

But of special interest to Americans is the eclipse of 27th October 1780, for it was the occasion of the first American eclipse expedition, destined to be followed in after years by a noble array of brilliant and thoroughly equipped expeditions to all parts of the world. Professor SAMUEL WILLIAMS was despatched from Cambridge to Penobscot, with a few simple instruments belonging to the University. He begins his account, from which a few extracts are given below, 'A total eclipfe of the fun is a curious and uncommon phenome-

[16] RENWICK'S *Life of David Rittenhouse*, in *American Biography Series*, conducted by JARED SPARKS, vii. 375.

[17] *Memoirs American Academy of Arts and Sciences*, i. (1783), 84.

non.'[18] It would appear that the Penobscot party just failed to reach a suitable position in the path of totality, probably owing to the unreliable condition of the Tables, for he says:[19] 'Immediately after the laſt obſervation, the ſun's limb became ſo ſmall as to appear like a circular thread, or rather like a very fine horn. Both the ends loſt their acuteneſs, and ſeemed to break off in the form of ſmall drops or ſtars; ſome of which were round, and others of an oblong figure. They would ſeparate to a ſmall diſtance: Some would appear to run together again, and others diminiſh until they wholly diſappeared. Finding it very difficult to meaſure the lucid part any longer, I obſerved again in the larger teleſcope, looking out for the

[18] 'From the principles of aſtronomy, it is certain that a central eclipſe will happen, in ſome part of the earth, in the courſe of every year: But it is but ſeldom that a total eclipſe of the ſun is ſeen in any particular place. A favourable opportunity preſenting for viewing one of theſe eclipſes on October 27, 1780, the American Academy of Arts and Sciences, and the Univerſity at Cambridge, were deſirous to have it properly obſerved in the eaſtern parts of the State, where, by calculation, it was expected it would be total. With this view they ſolicited the government of the Commonwealth, that a veſſel might be prepared to convey proper obſervers to *Penobſcot-Bay;* and that application might be made to the officer who commanded the *Britiſh* garriſon there, for leave to take a ſituation convenient for this purpoſe.

'Though involved in all the calamities and diſtreſſes of a ſevere war, the government diſcovered all the attention and readineſs to promote the cauſe of ſcience, which could have been expected in the moſt peaceable and proſperous times; and paſſed a reſolve, directing the Board of War to fit out the Lincoln galley to convey me to *Penobſcot,* or any other port at the eaſtward, with ſuch aſſiſtants as I ſhould judge neceſſary.

'Accordingly, I embarked October 9.'—*Ibid.*, p. 86.

[19] *Ibid.*, p. 93.

total immerfion. After viewing the fun's limb about a minute, I found almoft the whole of it thus broken or feparated in drops, a fmall part only in the middle remaining connected.' This would seem to indicate the 'BAILY'S Beads' of a later epoch. Immediately after this the light increased, the 'total immerfion' not having been visible to Professor WILLIAMS. President WILLARD observed this eclipse at Beverly, the 'Revd Profeffor WIGGLESWORTH' and others at Cambridge, while Dr CLARKE and Mr WRIGHT watched it at '*Charlotte-town*, on the ifland of *St. John*, in the gulph of *St. Laurence*.' The apparatus there was painfully meagre, as the communication in response to a request for observations, the previous summer, reads, 'I am fo unfortunate as not to have any kind of apparatus for obfervations of that fort; nor is there, that I know of, in this place, any thing of the kind,—thefe things, however ufeful, as well as pleafing, being very little attended to in this place.'[20] The eclipse seems to have been total at '*Yarmouth-Jebouge-Harbour*' on the western coast, 'for a momentary fpace.'

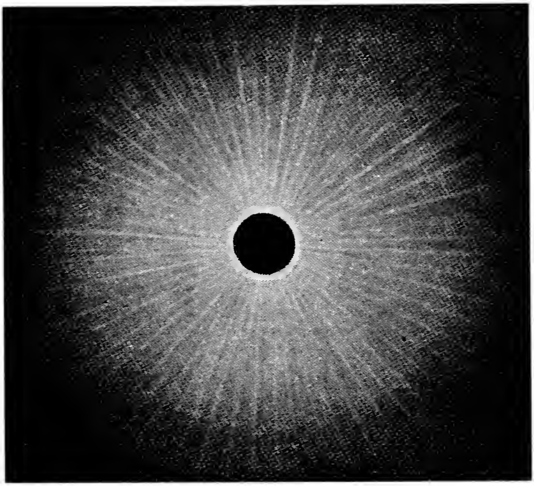
WEBBER, Hollis Professor at Harvard, observed the annular eclipse of 3d April 1791.[21] His clock unfortunately stopping the day before the eclipse, he writes: 'The failure of my clock being known to the Reverend Prefident of the Univerfity, he, with his ufual goodnefs, invited me to obferve with him; as his clock was good, and regulated for the purpofe.' The sky was perfectly clear, and observations were not interrupted by the intervention of a single cloud, while the annulus was visible for 4^m 49^s. WEBBER was himself afterward President; and if he was promoted also to the

20 *Memoirs American Academy of Arts and Sciences*, i. (1783), 143.

21 *Ibid.*, ii. (1793), 20.

better clock, it is to be hoped that he kept it always regulated to help out future unfortunate professors.

A partial eclipse, 5th September 1793, was carefully observed by Sir WILLIAM HERSCHEL, who measured the height



THE CORONA OF 16th June 1806 (FERRER)

of several mountains on the Moon,[22] a task to which he had previously been much accustomed.

Totality of the splendid eclipse. 16th June 1806, was observed for 4^m 51^s by DE WITT at Albany, and at Kinderhook for 4^m 37^s by a Spanish astronomer, Don JOAQUIN DE FERRER.[23] The path of complete obscuration

[22] *Philosophical Transactions* (1794), part i. p. 39.

[23] *Transactions American Philosophical Society*, vi. (1809), 264, 293, 362.

did not extend as far north as Rutland, nor as far south as Philadelphia.[24] NATHANIEL BOWDITCH, the distinguished translator of the *Mécanique Céleste*,[25] saw it at Salem; but interested as he was in precise observations and what could be deduced from them, he merely says, 'The whole of the Moon was then seen surrounded by a luminous appearance of considerable extent, such as has generally been taken notice of in total eclipses of the Sun.'

An eclipse track crossed the Southern States, 30th November 1834, and NICOLLET at Milledgeville, Georgia, seems to have observed the totality, but he says nothing about corona or protuberances.[26] It was watched by a number of observers in Philadelphia and elsewhere north of the line of totality.

Early in the century an Eclipse Committee from the American Philosophical Society made full reports upon all such phenomena, in particular the eclipse 15th May 1836, which, however, was not total.

Of the earlier eclipses in our century, that of 8th July 1842 is perhaps the most famous. Total in some of the populous districts of Europe — southern France, northern Italy, Germany, and Russia — this great eclipse kindled the present fire of scientific enthusiasm.

With celebrated astronomers like ARAGO and LAUGIER at Perpignan,[27] VALZ at Marseilles, FLAUGERGUES at Toulon,

[24] An old work upon this eclipse may be found in the library of the Antiquarian Society at Worcester, and the Boston Athenæum: *Darkness at Noon: or the Great Solar Eclipse of* 16 *June* 1806. *By an inhabitant of Boston.* (Boston, 1806.)

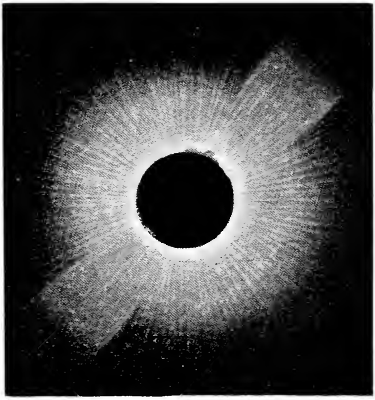
[25] *Memoirs American Academy of Arts and Sciences*, iii. (1809), 18.

[26] *Transactions American Philosophical Society*, viii. (1843), 309.

[27] *Annuaire du Bureau des Longitudes pour* 1846.

AIRY at Turin, BAILY at Pavia, LITTROW and SCHUMACHER at Vienna,[28] STRUVE at Lipetsk, with SANTINI, QUETELET,[29] and scores of others in the field, the opportunities of 1842 were by no means neglected.

Several observers saw the corona four to six seconds in advance of the total obscurity, and AIRY, from the Church of the Superga, near Turin, recorded a strange, double observation of the beginning of totality. The Sun was completely hidden for two minutes, deeply impressing the most stolid witnesses; even the soldiers and villagers of the Alps and Pyrenees.



THE CORONA OF 8th July 1842
(ARAGO)

At that early time, in non-telegraphing days, the main idea in observing eclipses was to correct the longitude; or, in case that was well known, to correct the Moon's place among the stars. For that purpose a partial eclipse was nearly as effective as a total or annular one, so that the long journeys to see an entire obscuration were rarely taken. Onward from 1842, however, total eclipses have contributed rather to solar physics than to astronomy of

[28] *Annalen der k. k. Sternwarte in Wien*, xxii.
[29] *Bulletins de l' Académie Royale de Bruxelles*, ix.

precision, — to the new astronomy rather than the old. Indeed, the wonderful recent developments of the new astronomy may be directly traced to the increasing importance accorded to physical observations of total eclipses of the Sun.

CHAPTER VIII

MODERN ECLIPSES (1842–1880)

Περὶ δὲ τὸν χρόνον, ὃν τῇ Ἑλλάδι ἐνεσπούδαζεν, ἐπεῖχε τον οὐρανὸν διοσημία τοιαύτη· τὸν τοῦ ἡλίου κύκλον περιελθὼν στέφανος ἐοικὼς ἴριδι τὴν ἀκτῖνα ἠμαύρου.[1]

PHILOSTRATUS, *Life of Apollonius of Tyana*, viii. 23.

WHILE the eclipse of 1842 marks the dawn of a golden age of physical research upon the Sun, investigation necessarily proceeded slowly, because for several succeeding years there were few available eclipses. The tracks of all those actually observed are indicated on the illustrative map on page 221. CALDECOTT, at Parratt on the Malabar coast, 21st December 1843, may have seen the corona as indicated by his drawing,[2] though he says that 'the Sun wanted the smallest imaginable quantity of being *totally* eclipsed.' The fine opportunity of 7th August 1850 was nearly completely lost on the Pacific, only KUTCZYCKI observing it at Honolulu, and recording both corona and prominences.[3]

With the great eclipse of 28th July 1851 methodical observation began in earnest. Seen to fine advantage in

[1] (About this time, while he [APOLLONIUS] was pursuing his studies in Greece, such an omen was observable in the heavens. A crown resembling iris surrounded the disk of the Sun, and darkened its rays.)

[2] *Memoirs Royal Astronomical Society*, xv. (1846), 173.

[3] *Comptes Rendus*, xxxii. (1851), 577.

Sweden, ADAMS, AIRY,[4] G. P. BOND, CARRINGTON, DAWES,[5] DUNKIN, FEARNLEY,[6] HIND, LASSELL, ROBINSON, PIAZZI SMYTH, and OTTO STRUVE were among the many prominent astronomers despatched thither for its observation.[7] The younger BOND, perhaps the first American to visit Europe for the purpose of witnessing a total eclipse, took up his station at Lilla Edet.[8] As the total phase was coming on, he noticed particularly the shortening of one of the solar cusps by division into beads of light which seemed to move slowly toward the point and then disappear. He speaks of his 'inexpressible admiration at the glorious spectacle of the corona, and the prominences of rose-colored flame which surrounded the Moon.' CARRINGTON'S comparison to flames bursting through the roof of a house was thought to be very exact, except that the motion was not rapid. BOND saw the corona very plainly even after totality was over.

The earliest photograph of a total eclipse was made at Königsberg on this occasion by BUSCH, whose daguerrotype (an enlarged copy of which was exhibited at the World's Fair, 1893) is a valuable record of the corona of 1851. Also SECCHI conducted photographic experiments. AIRY, then Astronomer Royal, observed at Göteborg; and his account not only adds greatly to our scientific data, but abounds in careful description of impressive and spectacular aspects, the approach of totality being accompanied

[4] Numerous reports of this eclipse are embodied in *Astronomische Nachrichten*, xxxiii., and *Comptes Rendus*, xxxiii.

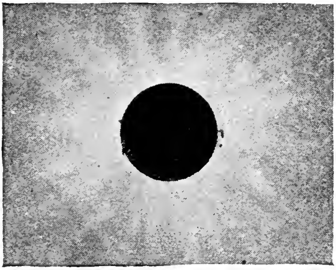
[5] *Astronomische Nachrichten*, xxxiii. (1852), 151.

[6] *Königsberg Astronomische Beobachtungen*, xxvi. (1854).

[7] *Memoirs Royal Astronomical Society*, xxi. (1852), 1.

[8] GOULD'S *Astronomical Journal*, ii. 49.

with 'that indescribably mysterious and gloomy appearance' which he remembers from the previous eclipse. The sudden and appalling darkness seemed to him much more striking than in 1842, and his descriptions of the corona and prominences were most discriminating. Indeed, his drawing of this corona is one of the first wherein a particular and definite radial structure is delineated.[9] 'Its outline was very irregular, . . . the whole was beamy, radiated in structure, and terminated (though very indefinitely) in a way which reminded me of the ornament frequently placed round a mariner's compass. . . . I saw no flickering or unsteadiness of light. . . . It looked like a radiating luminous cloud behind the Moon.' The wonderful rosiness of the clear northern sky was especially remarked, and the Astronomer Royal speaks picturesquely of the rapid yet 'half unwilling' return of the surrounding country to its normal cheerfulness.



28th July 1851 (Airy)

Many observers looked for the Moon's limb externally to that of the Sun, all failing to see it except Dembowski at Cremano. Before the total obscuration the Moon was seen red by a number of observers, and Airy saw Venus for a quarter of an hour before mid-totality.

[9] At a distance of about three feet from the normal eye, the engraving gives more nearly the effect of the original.

The Moon's shadow advances so swiftly that only those situate upon high ground can follow its passage over the Earth. But for fully six seconds after totality the Astronomer Royal and other observers saw the enormous lunar shadow speeding off through the air. The prospect of this eclipse had occasioned much alarm, and some of the farmers near Lilla Edet had not planted their lands in the spring, thinking, no doubt, that death and chaos were bound to reap the harvest. At Lilla Edet most of the people were dressed in their best clothes; apropos of which CARRINGTON dryly remarks: 'Whether the quotation from the loss of the Abergavenny, "Some appeared perfectly resigned . . . but the most prominent idea was that of putting on their best and cleanest clothes," is at all to the point, or too fanciful an explanation, others can judge for themselves.'

Professor PIAZZI SMYTH located on Bue Island, off the west coast of Norway; but as thick clouds precluded his accomplishing anything in the line of exact measurement, he devoted himself to a careful delineation of landscape effects during totality, which are capitally depicted in the beautiful though sombre engraving on the following page.[10]

Total eclipses occurred 11th December 1852 in China, 5th April 1856 in Australia, and 25th March 1857 in Mexico; but, excepting the totality of 30th November 1853, depicted by MOESTA of Santiago,[11] that of 7th September 1858 seems to have been the next observed. GILLISS settled near Olmos, Peru;[12] his sketches were completed

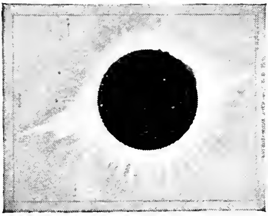
[10] *Transactions Royal Society of Edinburgh*, xx., plate xiv.

[11] GOULD'S *Astronomical Journal*, iii 145.

[12] *Smithsonian Contributions to Knowledge*, xi. (1859), Art. iii.

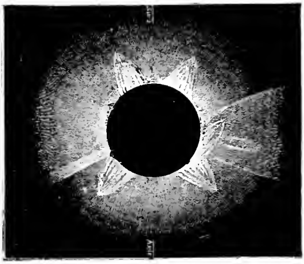
LANDSCAPE EFFECTS OF TOTALITY, 28th July 1851 (PIAZZI SMYTH)
Bue Island, Coast of Norway

during totality without artificial light, although his assistant found a candle necessary in reading the seconds dial of the chronometer. But the obscuration was certainly inferior to that of many eclipses. Superstition was still rife in this region, and during totality the solemn tolling of a church bell did its utmost to ward off the evil spirits of darkness, though the inhabitants probably did not (as they have been known to do since in regions less civilized) consider the foreign visitors entirely responsible for the Sun's withdrawal.



30th November 1853 (Moesta)

The Imperial Government of Brazil provided for an expedition at Paranagua under the direction of Liais,[13] which secured excellent results, among them a pictorial representation of the corona with the 'Gothic' structure for the first time strongly marked.



7th September 1858 (Liais)

The first total eclipse to visit North America, since astronomy had begun to be scientifically cultivated in the United States, took place 18th July 1860.

Its track passed over the northwest corner of the Pacific

[13] *Comptes Rendus*, xlvii. (1858), 786; *Astronomische Nachrichten*, xlix. (1859), 273.

States, thence northeasterly through British America and Labrador, crossing the Atlantic Ocean to traverse the Spanish peninsula southeasterly; and while not quite total at Madrid, the central line left the coast of Spain about fifty miles northeast of Valencia.

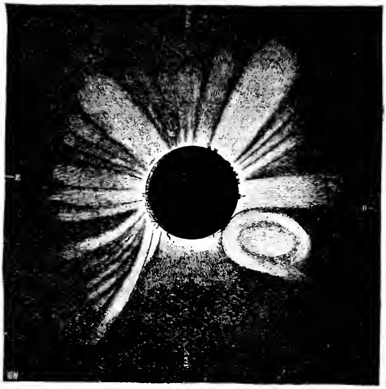
Long before the days of trans-continental railroads, an overland journey from the Eastern States to the Pacific coast was not to be essayed; and GILLISS, again in the field, set out for his observing post near Steilacoom, Washington Territory, via Panama. He was rewarded by fine views of the corona and prominences, but confined himself almost wholly to the latter.

An enthusiastic party of three Americans, the late Professor FERREL, Professor NEWCOMB, and M^r SCUDDER, forced its way into the wilds of British America, finally occupying a station on the banks of the Saskatchewan[14] in north latitude nearly 54°.

But there was still another American expedition, sent out under the auspices of the United States Coast Survey, in charge of ALEXANDER of Princeton, associated with whom were the late President BARNARD, Professor VENABLE, and others. Aulezavik Island, off the coast of Labrador, was their inhospitable destination, and a thorough eclipse programme was mapped out for the entire expedition, including

[14] The weather, however, was unpropitious; and the historian of the expedition, whose facile pencil lends added interest to his narrative, wrote: 'This, then, is our success. Three thousand miles of constant travel occupying five weeks, to reach by heroic endeavor the outer edge of the belt of totality; to sit in a marsh, and view the eclipse through the clouds!'— *The Winnipeg Country, or Roughing it with an Eclipse Party*, by A Rochester Fellow [M^r SAMUEL H. SCUDDER], Boston, 1886.

something for every one to do, even officers and seamen.[15] But the sky was nine tenths overcast at the critical moments, and only one of the astronomers (Lieutenant Ashe, Royal Navy, Director of the Observatory at Quebec) caught a glimpse of any portion of the corona; between clouds he saw a single 'white flame shooting up to a considerable distance.' The expedition can scarcely be called successful; and indeed there was still dearth of knowledge as to just what ought to be observed.



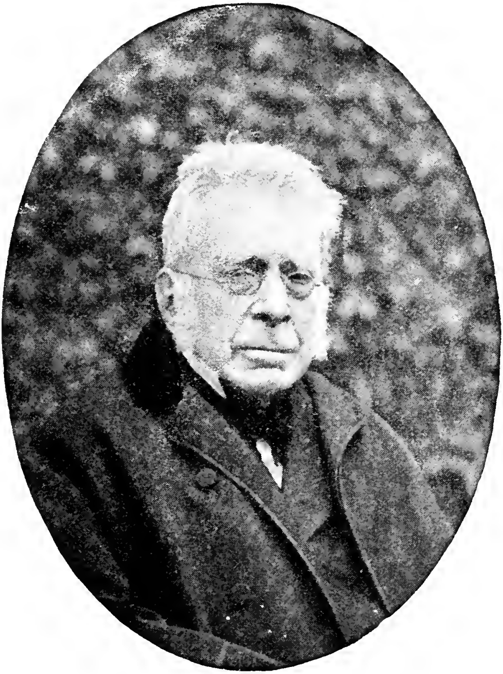
18th July 1860 (Tempel)

Spain, so frequently the scene of total eclipses, again offered an advantageous site, and thither a large observing party from England was transported in H. M. S. *Himalaya*. This eclipse will be forever memorable as the earliest in which the camera was systematically applied. It is, indeed, generally regarded as the actual beginning of eclipse photography.

Tempel, whose familiarity with nebular and cometary light and forms stood him in fine stead in depicting the similar streamers of the corona, executed the wonderful drawing shown above,— the first to indicate that amazing complexity of recurving structure which continues to puzzle astronomers to the present day.

[15] *Report United States Coast Survey*, 1860, Appendix 21.

AIRY, indefatigable, was at Pobes in the north of Spain. The general light appeared much greater than during the eclipses of 1842 and 1851, perhaps ten times as great.



SIR GEORGE AIRY (1801–1892)

One luckless photographer (not of the *Himalaya* party) went enthusiastically to work, but when the eclipse was over he discovered that he had forgotten to put any plate in his camera slide. As careful training and experience multiply with the years, such accidents become rarer.

The phenomena of this fine eclipse were very fully recorded by most competent astronomers, the bare list of whose names would fill a page. D'ABBADIE, BRUHNS, DONATI,[16] GAUTIER, MAEDLER,[17] PLANTAMOUR, SECCHI who took admirable photographs of the corona, OTTO STRUVE,[18] VILLARCEAU,[19] and WINNECKE were but a few of this distinguished array. A very full and interesting, as well as extremely valuable, account of this eclipse is given by DE LA RUE in the Bakerian Lecture, read 10th April 1862.[20] Established at Rivabellosa, near Miranda de Ebro, DE LA RUE employed the Kew photo-heliograph during the eclipse with collodion plates, and succeeded in obtaining about forty photographs, two of them during totality, though fully eighty seconds were required to protect and take out one plate, place another in the instrument, draw back the slide which covered it, allow time for the vibrations to cease, and remove the temporary cap from the telescope. It is recommended in this paper that no fewer than four persons ought to accompany each telescope, two of them accomplished photographers. The morning of eclipse day was thickly clouded, but this effect gradually disappeared, leaving clear skies for the critical time. The colors of sky and horizon during totality were very brilliant, and the whole effect most striking, affecting in a marked manner the crowd of bystanders as well as the observing party.

The eclipse of 31st December 1861, visible in Guiana and Northern Africa, was not especially noteworthy. At

16 *Annali del R. Museo Fiorentino*, i. 21.

17 *Transactions of the Academy of Jena*, xxviii.–ix. (1861–62).

18 *Mémoires de l'Académie Impériale de St Pétersbourg*, iv (1861).

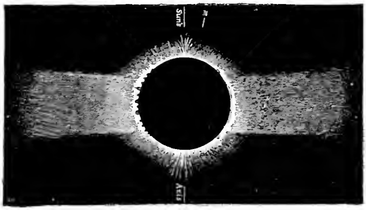
19 *Comptes Rendus*, lxvii. (1868), 270.

20 *Philosophical Transactions*, 1863, p. 333.

Goree, the fringes of light were observed by M. POULAIN. The coronas of 25th April 1865 and 29th August 1867 were sketched, the former by CAPPELLETTI in Chile (*Bull. Met. Coll. Rom.*, iv. 89), and the latter at Santiago by GROSCH, whose drawing appears

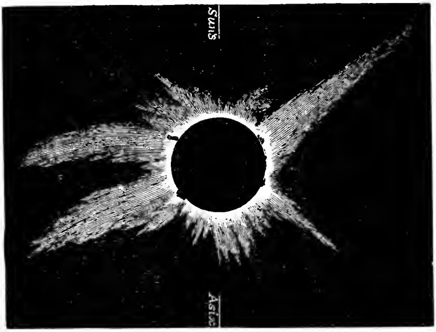
25th April 1865 (CAPPELLETTI)

to be the earliest published one to show the curved filaments adjacent to the solar poles.



29th August 1867 (GROSCH)

But when the lunar shadow traversed the Indian and Malay peninsulas, 18th August 1868, total obscuration lasted over five minutes and a half, forming the longest eclipse ever observed. Then the history of eclipse spectroscopy made a vigorous beginning. Four expeditions were sent out, two each from England and France, with highly gratifying results as to the composition of some heretofore mysteriously constructed solar envelopes; another expedition of Jesuits was despatched from Manila. Great variations in the darkness were reported in different places. At Beejapoor and at Vumpurthy it seems to have been as dark as any clear starlight night, while observers at Wha-Tonne remark their ability to read print in the open air, — although candles were necessary for reading the micrometer-head in the telescope-house. This great eclipse was also observed at Guntoor by General TENNANT,[21] under instructions from the Right Honorable the Secretary of State for India. BULLOCK made this excellent drawing of the corona; the work of RAYET and the great discovery of JANSSEN have already been referred to; while among other astronomers of note were ENGELMANN,[22] OPPOLZER,[23]



18th August 1868 (BULLOCK)

OUDEMANS, who advanced a novel hypothesis regarding the corona,[24] POGSON, POPE HENNESSY,[25] SPORER, STEPHAN, VOGEL, and WEISS, who published an elaborate account of the Aden expedition, with a full discussion of results.[26]

The track of the eclipse of 7th August 1869 lay almost centrally over Mount Saint Elias, thence diagonally across

21 *Memoirs Royal Astronomical Society*, xxxvii. (1869), 37.

22 *Vierteljahrsschrift der Astronomischen Gesellschaft*, vii. (1872), 181, 245.

23 *Sitzungsberichte der k. Akad. der Wissenschaften*, lix. (1869), ii.

24 *Nature*, iii. (1870), 25.

25 *Proceedings Royal Society*, xvii. (1869), 81.

26 *Sitzungsberichte der k. Akad. der Wissenschaften Wien*, lxii. (1870), Abth. ii. 873.

North America from Behring's Straits through Iowa, Illinois, Indiana, and Kentucky to the coast of North Carolina, where the shadow rushed off upon the ocean and vanished.

Assistant GEORGE DAVIDSON of the United States Coast Survey took up his station at Kohklux on the Chilkaht River, Alaska, where good fortune favored him. He says: 'About the time the Sun was half obscured the chief Koh-klūx and all the Indians had disappeared from around the observing-tent; they left off fishing on the river banks; all employments were discontinued; and every soul disappeared; nor was a sound heard throughout the village of fifty-three houses. . . . The natives had been warned of what would take place, but doubted the prediction. When it did occur they looked upon me as the cause of the Sun's being "very sick and going to bed." They were thoroughly alarmed, and overwhelmed with an undefinable dread.'[27]

Professors LANGLEY, WINLOCK, C. S. PEIRCE, SHALER, ARTHUR SEARLE, and G. M. SEARLE, Mr ALVAN G. CLARK, and the late Mr J. I. BOWDITCH were located at Shelbyville, Kentucky, where also WHIPPLE directed very successful photographic operations, taking fine pictures of the corona, the first in America. WINLOCK, aiming to secure good coronal photographs, achieved very satisfactory results, seven exposures being made during the total phase.

7th August 1869 (WINLOCK, *from photograph*)

Other work of the Coast Survey officers related largely to observations of precision for fixing the Moon's position. Professor HOUGH,

[27] *Report U. S. Coast Survey* (1869), p. 179.

then Director of the Dudley Observatory at Albany, was stationed at Mattoon, Illinois. Associated with him were Professor MURRAY, Dr SWIFT, and Dr THOMAS HILL.[28]

Although 'beset with observers,' perhaps the most effective work upon this eclipse was done in Iowa. Nearly all the astronomers of the Naval Observatory were in the field, one journeying to Plover Bay on the west side of Behring Straits, while the main station was at Des Moines, Iowa.[29] The favorable locality of Tennessee, too, was not forgotten. Professor NEWCOMB searched for intra-mercurian planets, and arranged for a series of observations by amateurs located near the limits of the totality-belt, which afford precise corrections to the lunar elements. All the photographic work was conducted with the greatest success by Dr EDWARD CURTIS, United States Army. LANE devoted his attention to coronal details, and GILMAN sketched the corona in rather amazing colors. But Professor HARKNESS was the hero at Des Moines, making the significant observation of the bright coronal line which was also seen and correctly identified by Professor YOUNG.

In response to representations of the American Academy of Arts and Sciences, and of the American Philosophical Society and the Franklin Institute in Philadelphia, Congress appropriated $5,000 for observing this eclipse under the direction of the Superintendent of the Nautical Almanac Office, and Burlington, Iowa, was selected as the principal station.

28 *Transactions Albany Institute*, vi. (1870), 177, where an excellent drawing of this corona by MURRAY is given.

29 A curious sight was noticed by one observer in Cedar Falls. Being near the northern limit of totality, he saw trees at Janesville (toward the northeast and eight or ten miles distant), basking in dim sunlight through a lurid haze, while he himself was in the deep shadow.

Associated with Professor COFFIN were Professor YOUNG, D^r GOULD of Cambridge, who devoted himself to the corona and the search for intra-mercurian planets, D^r MAYER in charge of the photographic party, and Miss MITCHELL. D^r MORTON was appointed chief of the Philadelphia photographic expedition. At Mount Pleasant, 28 miles west of Burlington, were Professor WATSON of Ann Arbor, conducting general astronomical observations, Professor VAN VLECK of Middletown pursuing spectroscopic work, and Professor EDWARD C. PICKERING, then of the Massachusetts Institute of Technology, making physical observations with the spectroscope and polariscope, while ALEXANDER of Princeton, M^r STOCKWELL, and several others, were on hand for both astronomical and physical research.

These expeditions garnered a rich harvest. D^r GOULD'S studies of the còrona, and Professor YOUNG'S novel method of observing the contacts by means of a spectroscope, were specially significant. The photographic expeditions made a variety of experiments with particularly good effect, some of their photographs of the partial phases being unsurpassed to the present time. But the signal success of the day was Professor YOUNG'S discovery of 'coronium.'[30]

General MYER, United States Army, observed this eclipse from the summit of White Top Mountain in Virginia, 5,530 feet above the sea, through an atmosphere of crystal clearness.

The variety and importance of these eclipse results rendered it desirable to make immediate use of the experience

[30] Consult the original reports published by the Navy Department; also, *Journal Franklin Institute*, lviii. (1869), and a significant paper by PICKERING, On Photograping the Corona, *Ibid.*, lxii (1871), 54.

gained, and American parties were accordingly despatched to Gibraltar and Syracuse in 1870 for the eclipse of 22d December. In general, the weather was unfavorable along the shores of the Mediterranean where totality should have been seen. BROTHERS of Manchester was also at Syracuse, and managed to photograph the corona with much detail of rift structure. (*Mem. R. A. S.*, xli. plate vi).

22d December 1870
(A. THUILLIER)

Observers from Washington located in Sicily, but owing to cloud their success was only partial. The observations made, however, tended to confirm conclusions reached in 1869, and form interesting additions to that work. Captain TUPMAN, R. M. A., made a sketch of the corona, besides assisting Professor HARKNESS at Syracuse in spectroscopic researches under difficulties.

Professor NEWCOMB, established near Gibraltar at a station known as Buena Vista, made the physical constitution of the corona his especial study, and was fortunate enough to obtain clear views through a break in the prevailing cloud.[31]

Italian astronomers were not slow to embrace the rare opportunity of an eclipse crossing Calabria, and their researches were most complete and significant. SANTINI was President of the Eclipse Commission, and among the observers were many well-known names, — SECCHI, DONATI, CACCIATORE, DENZA, LORENZONI, NOBILE, SERPIERI, and TACCHINI, the last contributing a fine drawing of the corona,

[31] *Washington Observations for* 1869, Appendix i.

together with other rich materials relating chiefly to the solar prominences, which greatly embellish the splendid volume published by the Commission.[32]

M. Janssen, ever devoted, left besieged Paris in a balloon, 2d December, taking with him the essential parts of a reflecting telescope; with a strong young sailor as his assistant, he descended near the mouth of the Loire, and obtaining an interview with M. Gambetta, who gave friendly aid and encouragement, he prepared to observe the eclipse at Oran. Nature, however, ignored his faithfulness. Clouds covered the sky, and observation was hopeless. The late Professor Tyndall also settled with Dr Huggins, near Oran, intending to note all phenomena; but he too was defeated.

Despite an overcast sky, however, much information was obtained at the numerous stations, notably Professor Young's discovery of the 'reversing layer.' He describes this beautiful phenomenon, superbly seen for the first time at Jerez de la Frontera in Spain, as follows: —

'As the Moon advances, making narrower and narrower the remaining sickle of the solar disk, the dark lines of the spectrum for the most part remain sensibly unchanged, though becoming somewhat more intense. A few, however, begin to fade out, and some even turn palely bright a minute or two before the totality begins. But the moment the Sun is hidden, through the whole length of the spectrum, in the red, the green, the violet, the bright lines flash out by hundreds and thousands, almost startlingly; as suddenly as stars from a bursting rocket-head, and as evanescent, for the whole thing is over within two or three

[32] *Rapporti sulle Osservazioni dell' Ecclisse Totale di Sole* (Palermo, 1872).

seconds. The layer seems to be only something under a thousand miles in thickness, and the Moon's motion covers it very quickly.'[33]

The eclipse of 12th December 1871 is worthy of more extended notice, because, in addition to what was accomplished with spectroscope and polariscope, the photographs afford most excellent representations of the corona. The Government of India having sanctioned the expense, General TENNANT, Royal Engineers, made very valuable observations from his station in the Nilgherries, at Dodabetta, 8,600 feet above the sea. Many negatives were obtained on the Malabar coast by the English parties, and also at Baikul by Lord LINDSAY's expedition. A very remarkable structure was visible upon the photographs. which may have been due to a comet.[34] Captain MACLEAR's narrative, Mr LOCKYER's account, M. JANSSEN's results, and RESPIGHI's observations are full of interest,[35] and deserve much more than passing reference; not to mention also Mr LOCKYER's lecture before the Royal Institution, admirably summarizing the entire work.[36] In Java the shadow

12th December 1871
(From Lord LINDSAY's Photographs)

[33] YOUNG, *The Sun* (New York, 1881), p. 83.

[34] RANYARD, *Monthly Notices Roy. Ast. Society*, xxxiv. (1874), 365.

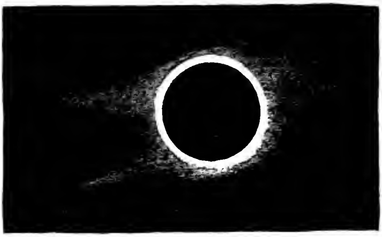
[35] *Nature*, v. (1872), 163, 217, 219, 237, 259.

[36] *Ibid.*, vii. (1873), 57, 92.

bands were remarkable, seen for three minutes before totality, and traced for nearly five minutes afterward. In Australia the weather was unpropitious.

At the eclipse of 16th April 1874, total throughout the northern portions of Cape Colony, M^r^ E. J. Stone, then her Majesty's Astronomer at the Cape, who located at Klipfontein, Namaqualand, addressed himself chiefly to an estimate of the extent and spectroscopic constitution of the outer corona. In addition to the clear, dry atmosphere of Namaqualand, Klipfontein presented the farther advantage of an elevation 3,000 feet above sea-level. During the partial eclipse, and before the approach of totality, M^r^ Stone failed to detect additional absorption lines in the Sun's spectrum near the edge of the Moon, nor was there any sensible change in the appearance of the Fraunhofer lines near the Moon's limb from that presented at considerable distances. His observations afforded a farther accumulation of negative evidence of a lunar atmosphere, and appear to indicate that no modification of the visible corona can be attributed to the refraction of solar or coronal rays at the edge of the Moon.

But M^r^ Stone's most important observation relates to the reversal of the Fraunhofer lines at the edge of the Sun on the approach of totality. Carefully holding the diminishing segment of the Sun's disk upon the centre of the slit, 'the field appeared to be full of bright lines of very different lengths. My impression was that all the Fraunhofer lines were seen reversed, but this is, of course, only an impression. I can only state as a matter of fact that a very large number indeed of bright lines were seen. . . . It is difficult for me to form any correct idea of the time during which the general reversion, or what I assumed to be the general reversion, of the Fraunhofer lines lasted; but I should hardly consider that it could have been longer than a second!' No effort was made to observe this remarkable reversion at the end of totality, as Mr Stone was fully absorbed with spectroscopic work on the outer corona. Photographs were not attempted; but a few good drawings show the general extent of that corona, one of which, by Mr Bright, is here reproduced.

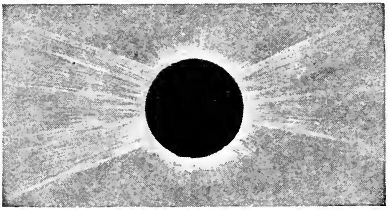


16th April 1874 (Bright)

The English expedition to observe the Siam eclipse, 6th April 1875, was in charge of Dr Schuster, who was joined at Suez by Dr H. W. Vogel of Berlin. The linguistic experts of the party must have had excellent practice, in calls of state 'upon his Excellency Chau Phya Sri Surawongse Way Wadhn-Kalahome (the Minister of War), his Excellency Chau Phya Bhanuwongse Kromatah (the Minister of Foreign Affairs), and his Excellency Phya Bashakarawongse (Private Secretary to his Majesty).'[37] Indeed, the expedition had an audience with the King, whose father had died some years previously, in consequence of a fever contracted on a journey made to the

[37] *Philosophical Transactions* (1878), 143.

southern parts of his kingdom to observe the total eclipse of 1868. Not only did his Majesty take great interest in the objects of Dr Schuster's visit to Siam and give orders that every possible help should be afforded him, but he even observed totality himself, and contributed a good drawing of the solar prominences; and by order of his Majesty, Prince Tong made this excellent sketch of the corona. Of the prominence spectra Dr Schuster did not obtain photographs as he hoped, but the photographs of the corona were as successful as possible without clockwork.



6th April 1875 (Prince Tong)

The corona was nearly a duplicate of that observed a year previously in South Africa. Dr Vogel had joined the expedition at Suez, leaving it at Galle in order to accompany that sent out from India in charge of Captain Waterhouse, and with M. Tacchini he located at Camorta, where clouds completely frustrated their endeavors. Dr Schuster found the light of the prominences due in part to the bright lines $H\beta$ and $H\gamma$, but the strongest protuberance line was in the ultra-violet. The inferior corona gave a strong continuous spectrum.

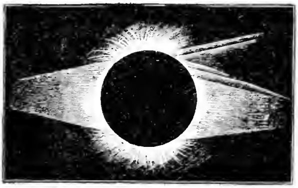
The eclipse in this decade which brought the most far-reaching results occurred 29th July 1878. Observing parties were scattered all along its line in the United States, where, above the Rocky Mountains, hung skies of such limpid clearness that on several evenings Jupiter's satellites were seen with the naked eye.

General MYER's impromptu observations from White Top in 1869 had been so interesting that he was greatly inclined to confirm and enlarge them from the summits of other mountains whenever occasion should offer. To this warm personal interest is partly due the organization of the expedition to Pike's Peak. Here totality lasted for two minutes and a half, and more than 14,000 feet above sea-level the thin air contributed wonderfully to the fine results, in particular the unparalleled coronal observations of Professor LANGLEY already described (page 59). Those who delight in the adventures of astronomical expeditions will find little on record to rival the fascination of Professor LANGLEY's story of his life and work on the summit of Pike's Peak.

An observer much lower down, at the Lake House, 10,230 feet elevation, saw few red flames, and none whatever until just before the close of totality; but the delicate coronal streamers or rays, of gauze-like texture, were apparently mingled with the atmospheric blue.

Professor NEWCOMB, at Separation, Wyoming, though at a far inferior elevation, nearly 8,000 feet, made also striking researches upon the same phenomenon. His drawing of this corona has already been given on page 87, with the streamers much curtailed, however. The ingenious but simple device for rendering the outer streamers visible should be tried at all future eclipses. After setting up the opaque disk for occulting the bright inner corona, especial care should be taken to fix the exact point where the eye must be placed from time to time during totality, in order that the corona may be centrally obscured, or nearly so.

D[r] and M[rs] HENRY DRAPER were at Rawlins, Wyoming, 6,730 feet above sea-level, and associated with them were Mr Edison, Dr Morton, and Professor Barker. Mr Ranyard, located at Cherry Creek Camp, near Denver, with Professor Young,[38] prepared to take photographs with a 13-inch objective, on a scale much larger than usual at that time. He saw no branching coronal structure like that in 1871, but noticed the great inclination to the radial of the rays forming the boundaries of the great northern and southern rifts, which were themselves much broader than in 1871.[39]



29th July 1878 (Harkness)
(*From photographs*)

From twelve photographs of the totality of 1878, Professor Harkness has delineated with great care a drawing which holds high rank among trustworthy representations of the corona.[40]

[38] *American Journal of Science and Arts*, cxvi. (1878), 242, 279.

[39] *Memoirs Royal Astronomical Society*, xlvi. (1881), 213.

[40] A resident of Fort Sill, Indian Territory, wrote an account of the effect of this eclipse upon the neighboring Indians. He says: 'On Monday last we were permitted to see the eclipse of the Sun in a beautiful bright sky. Not a cloud was visible. We had made ample preparation, laying in a stock of smoked glass several days in advance. It was the grandest sight I ever beheld, but it frightened the Indians badly. Some of them threw themselves upon their knees and invoked the Divine blessing; others flung themselves flat on the ground, face downward; others cried and yelled in frantic excitement and terror. Finally one old fellow stepped from the door of his lodge, pistol in hand, and, fixing his eyes on the darkened Sun, mumbled a few unintelligible words and raising his arm took direct aim at the luminary, fired off his pistol, and after throwing his arms about his head in a series of extraordinary

With this eclipse the scientific world was fully launched upon the most approved modern methods of attacking the great problems of the Sun, many of which must wait years for these fleeting minutes to afford the necessary opportunity for their complete solution.

The eclipse of 11th January 1880, visible for 32 seconds in California, contributed little advance, though the sky was cloudless. Lieutenant CHRISTOPHER, United States Navy, and Professor FRISBY, observed from Santa Lucia Mountain, 6,000 feet above sea-level; but the protuberances were not seen, and the corona was rather indefinite, although the Sun had an elevation of 11° at totality. Professor FRISBY remarks the amazement of the Indians, — their especial wonder being how the observing party could have known that the sky was going to be clear.[41]

Here, then, may properly end the account of merely modern eclipses. The more recent ones present also a brilliant array of well equipped expeditions and significant results.

gesticulations retreated to his own quarters. As it happened, that very instant was the conclusion of totality. The Indians beheld the glorious orb of day once more peep forth, and it was unanimously voted that the timely discharge of that pistol was the only thing that drove away the shadow and saved them from the public inconvenience that would have certainly resulted from the entire extinction of the Sun.'

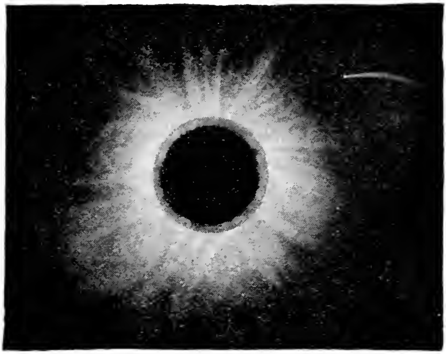
[41] *Washington Observations for* 1876, Appendix iii., p. 398. Also DAVIDSON, *Report of U. S. Coast and Geodetic Survey*, 1882, Appendix 20.

CHAPTER IX

RECENT ECLIPSES (1882-1893)

Come like shadows, so depart.
SHAKESPEARE, *Macbeth*, iv. 1.

A SPLENDIDLY observed eclipse occurred 17th May 1882. Although its duration was less than a minute and a quarter, astronomers gathered along the track where



CORONA OF 17th May 1882
(WESLEY, *from* SCHUSTER'S *photographs*)

it intersected the Nile in Upper Egypt. All the great problems were attacked again, with systematic artillery.[1]

[1] In thorough study of the eclipses preceding 1882, no bibliography will be found more helpful than LINDEMANN, *Librorum in Bibliotheca Speculæ Pulcovensis . . . Catalogus*, pars secunda, (Petropoli, 1880,) p. 282.

What new thing would be unveiled about the yet mysterious corona? How would the rose-red protuberances develop under the novel apparatus brought to bear? And the physical constitution of the Sun, — what fresh light would be thrown back upon its own incomparable brightness? All the old questions were asked, with many new ones; and observers and instruments made careful preparations to answer them.

Very fine photographs were taken by Dr SCHUSTER, who was successful for the first time in obtaining the spectrum of the corona with an ordinary slit spectroscope. A unique feature of the pictorial photographs (preceding page) consisted in the momentary imprisonment of an unwilling comet, very near the Sun, airy and graceful, and never seen again. Though discovered before by means of eclipses, no comet was ever thus caught photographically until 1882; and this one was observed with the naked eye also.

Government officials are almost invariably generous and appreciative in their treatment of scientific expeditions, affording every possible help and encouragement. Particularly was this the case in 1882. Leaving England the 19th April, the members of the expedition reached Suez a fortnight later, and were received on behalf of the Khedive by ESMATT Effendi and the Governor of Suez. The French expedition was sent out and its expenses defrayed by M. BISCHOFFSHEIM, the generous founder of the great observatory at Nice; and it consisted of the late M. THOLLON, M. TRÉPIED, Director of the Observatory at Algiers, and M. PUISEUX. The Italian expedition was in charge of M. TACCHINI of Rome.[2] All the expeditions were the guests of the Khedive; because of this courtesy, and to occasion as

[2] *Comptes Rendus*, xcv. (1882), 896.

little inconvenience as possible to their imperial host, all located together at Sohag; but this proved no disadvantage, for the weather was fine. STONE Pasha, chief of staff, was unwearied in his thoughtfulness and consideration for the astronomers. The Observatory was close to the Nile,[3] and surrounded by a double wall of sugar-canes to keep out dust, still farther subdued by the daily labors of the watermen. A telegraphic report,[4] signed by LOCKYER, TACCHINI, and THOLLON, begins: 'Unprecedented facilites afforded by Egyptian Government for observation of the eclipse. The plan carried out was agreed upon by the members of the English, French, and Italian expeditions. The accord among the results is very satisfactory.' It was reported that 'the spectroscopic and eye observations just before and during the period of totality gave most valuable results, the darkening of the lines observed by the French astronomers indicating a lunar atmosphere.'[5] THOLLON and TRÉPIED outdistanced all their *confrères*, each having the most powerful form of Thollon spectroscope yet constructed.[6] Bright lines were observed, before and after totality, of different heights by Mr LOCKYER, and with intensities differing from the Fraunhofer lines by Mr LOCKYER and M. TRÉPIED. The rings were observed of the first, second, and third orders, with a grating, or diffraction spectroscope. The work of Mr RAY WOODS, with that of Mr LAWRANCE, Mr LOCKYER'S assistant, was of especial value in carrying out the photographic programme.

The eclipse of 6th May 1883 was total for five minutes and twenty-four seconds. After the frequent manner of its

[3] *Philosophical Transactions* (1884), p. 254.

[4] *Nature,* xxvi. (1882), 100. [5] *Ibid.*, p. 52. [6] *Ibid.*, p. 100.

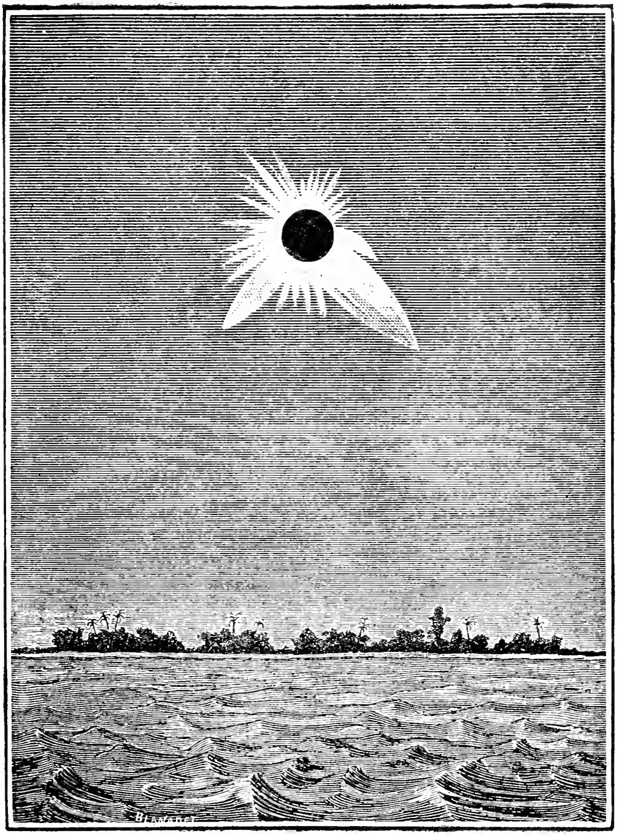
kind, the path lay where it would be least useful, — across the wind-swept wastes of the Pacific. But, fortunately, one of a small group of coral islands lay quite in its line, and, nothing daunted, the brave scientific men set their faces toward this friendly cluster, in cheerful faith that they could locate there. Directed to take up their abode somewhere on a diminutive island about which nothing could be ascertained beforehand, save the bare fact of its existence at a known spot in mid-ocean, the American observers were absent from the United States more than three months, most of which time was spent in travelling, 15,000 miles in all, with ten full weeks at sea. Their tiny foothold in the Pacific was the Caroline Island, a coral atoll on the outskirts of the Marquesas group, shown in TROUVELOT's pictorial sketch on the opposite page.

The American party, under the auspices of a committee of the National Academy of Sciences, with Professor YOUNG as Chairman,[7] was followed shortly by a company of astronomers from France, Italy, and Austria, led by M. JANSSEN,[8] whose work was both optical and photographic. England was again represented by Mr LAWRANCE and Mr RAY WOODS.[9]

[7] It should be remarked that the real originator of this project was Mr CHARLES H. ROCKWELL, of Tarrytown, New York, who persistently followed the matter up, and was himself an important member of the expedition. Among other members achieving significant results were Dr HASTINGS, then of the Johns Hopkins University, whose excellent summary of research on the corona has already been alluded to; Professor UPTON, now of Brown University, in charge of the meteorological work; and Mr PRESTON, of the United States Coast and Geodetic Survey, who determined the force of gravity at several stations, Caroline Island among them.

[8] *Annuaire du Bureau des Longitudes pour* 1884, p. 847. Also, *Comptes Rendus*, xcvii. (1883), 586.

[9] *Nature*, xxviii. (1883), 145.

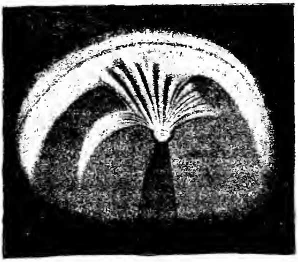


6th May 1883 (Trouvelot)
(*Showing also Caroline Island Atoll*)

Although showers came up in the morning of eclipse-day, the clouds broke just in time to leave totality clear, and the observations of all were brilliant and successful.

The Caroline Island seemed to possess only three houses and two sheds, and was rather sparsely inhabited by four native men, one woman, and two children; but a good many graves were discovered in which the former owners of the island were said to have found stone axes and other relics of early residents long since departed. The native Kanakas tended a sickly plantation of cocoa-palms, living an absolutely eventless life, except when once a year the 'blig' anchors with their annual store of ship biscuit and molasses. What unprecedented excitement must have arrived with the two men-of-war, the energetic astronomers, and the jovial sailors! But the island was dreamy, tropical, and beautiful, with wonderful color effects in water like emerald and lapis-lazuli, softly meeting coral beaches of dazzling white.

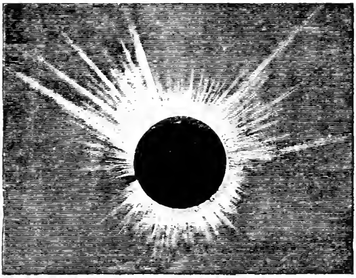
The eclipse of 8th September 1885 was total in New Zealand, the observations being of slight importance, although a photograph was made at Nelson, showing two remarkable sets of prominences at exactly opposite points from each other. Mr GRAYDON made the opposite sketch of the outer corona,[10] remarkable for the breadth of a characteristic dark rift extending outward from the very limb of the Moon, and strongly suggesting the black belt following the nucleus in many comets, as for example COGGIA's comet of 1874, or the great comet of 1861, the head of which is here reproduced from SECCHI's drawing. But on 29th August



HEAD OF COMET OF 1861
(SECCHI)

10 *Nature*, xxxii. (1885), 632.

1886, an eclipse was total for four minutes at Grenada in the West Indies, enabling results of great significance. While the maximum totality was 6 minutes 34 seconds, it was, most unfortunately, again an ocean track throughout nearly its whole length. In the little island, however, congregated English, Italian, and American observers. The operations of the several expeditions were greatly facilitated by Sir WALTER SENDALL, then Governor of Grenada, who four years later, as Governor of Barbados, again afforded kindly courtesy and helpful interest in the scientific work of the United States Eclipse Expedition to West Africa, which on its homeward voyage put in at Bridgetown to determine the force of gravity. The late Father PERRY and M^r^ MAUNDER were conveyed to the island of Carriacou, D^r^ SCHUSTER and Captain DARWIN located at Prickly Point, and M^r^ TURNER, Chief Assistant to the Astronomer Royal, and M. TACCHINI took up their station at Grenville.



8th September 1885 (GRAYDON)

Eclipse research had already become in the main photographic, and Professor W. H. PICKERING was in charge of the Harvard expedition, the work of which was chiefly of this character.[11] Extraordinary features of his corona are the narrow jets, one rising to a height of 1,300,000 miles, where it divides into three parts. Two of these curve to the right

[11] His detailed research upon the corona of 1886 is amply presented in the *Harvard Observatory Annals*, xviii. 100.

and left, while the third keeps on to a height of 1,600,000 miles, when it also begins to fall over. These unique effects, intensified in the accompanying illustration, are nevertheless clearly visible in the original negative. 'The whole appearance,' he says, 'is as if vast quantities of heated matter

29th August 1886 (PICKERING)
(*From photographs*)

were rising over the hydrogen protuberances to the south of the solar equator. This matter cooled as it rose, and again became heated as it condensed and fell back upon the solar surface to the north of the equator.'

On the West Coast of Africa, this totality was visible for four and a half minutes at Benguela in a cloudless sky, and the Revd Mr WALTER speaks of its wonderful effect, and of his great regret that neither astronomers nor instruments were there to record a corona so exceptionally displayed.

Astronomers had for so many years looked forward to the great eclipse of 1886, that, when the occasion had come and gone, with its splendid totality squandered for the most part on the ocean, and with disappointing weather at one of the two available stations, they naturally turned with zest toward the next opportunity, which was not a full year distant. On 19th August 1887, the Sun rose totally eclipsed at Berlin, whence the shadow trailed easterly and slightly north over Russia and Western Siberia, thence southeasterly through the farther region of that country, crossing Lake Baikal, and finally in mid-afternoon presenting the spectacle of total obscurity to Dai Nippon, in the land of the Rising Sun.

19th August 1887 (NIESTEN)
(*From photographs*)

All along the line were scores of trained observers and costly instruments, assembled from the scientific centres of all nations: at Rshev, Professors YOUNG, MCNEILL, and LIBBEY from Princeton;[12] at Savidoro, Padre FERRARI from Rome; at Schipulino, Dr HASSELBERG of Pulkowa and Drs MÜLLER and SCHEINER of Potsdam; at Wissokofsky, Mr TURNER of Greenwich and Comte DE LA BAUME PLUVINEL of Paris; at Petrovsk, Professor GLASENAPP of St Petersburg;[13] at Jvanova, Professor UPTON of Providence and Mr ROTCH of Boston; at Kineshma, Dr BREDICHIN of Moscow, Father PERRY of Stonyhurst, and Dr COPELAND of Dun Echt; at Jurjewetz, Dr VOGEL of Berlin and M. NIESTEN

[12] YOUNG, 'An Astronomer's Summer Trip,' *Scribner's Magazine*, iv. (1888), 82.

[13] Петровская Экспедиція для Наблюденія Полнаго Солнечнаго Затменія 18 Августа 1887 Года. Отчетъ С. П. Глазенапа. (Санктпетербургъ, 1888.)

of Brussels;[14] at Viatka, MM. TACCHINI of Rome, RICCÒ of Palermo, and DUBIAGO of Kazan; at Krasnoiarsk, Siberia, M. CHAMANTOFF; at Sanjo (near Niigata), Japan, Professor ARAI; at Kuroiso, Professor TERAO; and at Shirakawa, Professor TODD,[15] assisted by Dr HOLLAND of Pittsburgh, Lieutenant SOUTHERLAND, United States Navy, Passed Assistant Engineer PEMBERTON, United States Navy, Mr NAKAGAWA and Mr OGAWA of Tōkyō, the last as photographer, — a long list, but by no means complete. Numbers, however, did not insure favorable skies; and never was the disappointment so appalling. Here and there a few pictures of the corona were caught between clouds, and other observations of importance made.[16] But in general, from Germany to Japan, the track of the eclipse was clouded, and failure was the order of the day.[17] A wag in Berlin, undoubtedly not an astronomer, is said to have posted a public notice that on account of the weather the eclipse had been postponed to another day.

The exceptional advantages of similar instrumental equipment at two widely separate localities and careful arrangements for detecting any rapid changes in the corona were thus of no avail, through Nature's indifference. But if astronomers had lost an opportunity to advance their own science, they had a noble chance to cultivate a practical philosophy.

14 *L'Éclipse Totale de Soleil du* 19 *Aout* 1887, *observée a Jurjewetz (Russie), par* L. NIESTEN (Bruxelles, 1888).

15 'The Total Eclipse in Japan,' *The Observatory*, x. (1887), 371.

16 Among them, drawings by M. BELOPOLSKY, *Annales de l'Observatoire de Moscou*. Consult also Mr TURNER'S 'Notes on some Total Solar Eclipses,' *The Observatory*, xii (1889), 65.

17 Professor HARKNESS has outlined the fate of all these expeditions in *The Sidereal Messenger*, vii. (1888), 1.

In Russia Professor Mendeleef determined to rise above the accidents of meteorological circumstance, and so engaged a balloon to transport him thither. He got beyond the clouds, but almost in a double sense ; for, the balloon refusing to ascend with both Professor Mendeleef and his aeronaut, the latter was left behind, accidentally or otherwise, and the astronomer shot up alone into space, reaching an altitude of 11,500 feet, — over two miles above the Earth. Here, to be sure, he had a fine and unobstructed view of the marvellous corona, but the imminent duties attending his novel conveyance must have allowed but divided attention for solar glories.

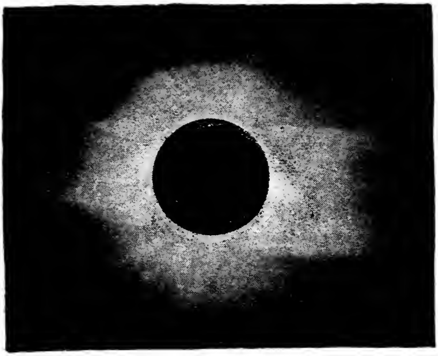
Shortly after his return to Italy, that veteran observer, M. Tacchini, published a very readable account of the varied experiences on his numerous expeditions to all parts of the world in the interests of solar physics.[18]

Miss Brown, an amateur of England, also went to Russia for this eclipse, but, in common with nearly all other travellers into the dark pathway, met with grievous disappointment at Kineshma. An entertaining little volume, however, is the result of her adventures, picturesquely entitled *In Pursuit of a Shadow*; and *Caught in the Tropics* is the sequel, — a happier outcome of December 1889.

The first eclipse of 1889, on New Year's day, afforded a capital opportunity for retrieving the losses of 1887. The lunar shadow traversed the United States in a northeasterly direction, from California and Nevada, through Idaho, Montana, and North Dakota, to Manitoba, as depicted in the frontispiece. The skies nearly everywhere were clear,

[18] *Eclissi Totali di Sole del* 1870, 1882, 1883, 1886 *e* 1887. *Relazioni e Note.* (Roma, 1888.)

and observers and instruments thickly dotted the path. Negatives and drawings were made in abundance, and the record of this eclipse is one of the most complete ever secured.



1st January 1889 (ENGLER, *from photographs*)

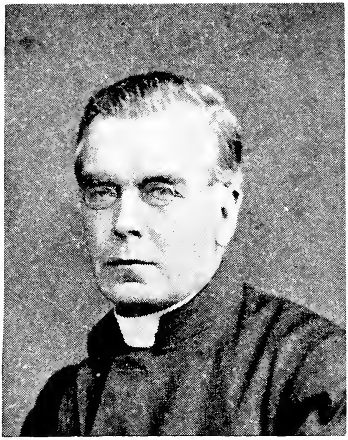
The Harvard expedition to Willows, California, in charge of Professor W. H. PICKERING, had a large equipment of telescopes, cameras, spectroscopes, and photometers, which were successfully operated, nearly 60 photographs being taken. Professor UPTON of Providence, and Mr ROTCH, the well-known meteorologist of the Blue Hill Observatory near Boston, were in an adjoining part of the town with a fine collection of meteorological instruments. No fluctuation of the barometer was caused by the passage of the Moon's shadow, but the air temperature fell 6°, reaching the minimum ten minutes after close of totality. The solar radiation thermometers showed that some heat was received throughout the total phase, and the wind died down to a calm, from an hourly velocity of twelve miles, showing a slight westerly fluctuation in direction which may with some plausibility be referred to the eclipse.[19]

Professor KEELER, Mr BARNARD, and others of the Lick Observatory party, located at Bartlett Springs, California, and did excellent work.[20] The fine photographs formed a large accumulation for studying the actinic brightness of the corona in every part. The picture on the opposite page is reproduced from the Report of the Washington University eclipse party. A multitude of drawings, forwarded to Professor TODD, gave the needed evidence as to the ecliptic streamers of the outer corona, and these have been embodied in two composite pictures; the first a hand composite (page 68) showing with much accuracy the extent to which the faint filaments were traced by those who had taken the greatest care to look for them, and the second a photographic composite made by Professor STODDARD from groups of carefully executed drawings.

22 December 1889 (PERRY)
(*From photographs*)

A second eclipse in the year 1889 occurred 22d December, total off the northern coast of South America and on the west coast of Africa. Again clouds interfered, and one of the most elaborate equipments of fine instruments ever collected for such work was rendered powerless by the misty veil. The expeditions were English and American. The

19 *Annals Harvard College Observatory*, xxix 20.
20 TURNER, *The Observatory*, xii. (1889), 106.



The R^T^ Rev^D^ Stephen J. Perry, S. J. (1833–1889)

late Father Perry, Director of the Stonyhurst Observatory, and the hero of many astronomical enterprises, was located at Cayenne. The eclipse taking place in the early morning hours, the interference of clouds was only partial, and Father Perry was enabled to secure valuable photographs,[21] although exposure and overwork on this occasion cost him his life. Always a cheerful sufferer in the cause of science, Father Perry had been a member of more astronomical expeditions than any man now living.

The Lick Observatory party was provided for by the generosity of the Hon. C. F. Crocker of San Francisco, who sent M^r^ Burnham and M^r^ Schaeberle to Cayenne, where their labors were crowned with success.[22]

[21] Rarely do the photographs of an eclipse lend themselves suitably to direct process or even lithographic reproduction, and the corona of December 1889 is no exception. Either a silver print or a careful drawing of the filaments is necessary to show that detailed structure which the eye readily recognizes on the photographic plates — *D. P. T.*

[22] Their excellent pictures, together with some discussion of them and suggestions bearing on future eclipse work, are to be found in *Reports on the Observations of the Total Eclipse of the Sun, 22d December* 1889 (Sacramento, 1891).

The cameras of the English expedition in West Africa, employed by Mr Taylor, were quite similar to those of Father Perry, but were rendered inoperative through the accident of clouds at the critical moment.[23] In the same region, at Cape Ledo, Angola, was located the United States expedition in charge of Professor Todd, who, with the assistance of Professor Bigelow and many others, had prepared to carry out a programme of operations on a scale never before attempted.[24] The unique collection of automatic apparatus is described in a subsequent chapter; but clouds covered the Sun during the entire totality.

Sunday, 16th April 1893, witnessed a darkening of the Sun whose track was favored by clear skies throughout very nearly its entire length. Perhaps for the first time in the history of eclipse observation, only a single party failed of its results because of clouds. As usual, several expeditions were despatched from various countries, American astronomers locating at the beginning or western end of the totality-belt. Harvard University, with its Boyden Observatory at Arequipa, Peru, was represented by Professor W. H. Pickering, who, already not far from the field, took up his station in Chile, where also Mr Schaeberle of the Lick Observatory established himself. To the northeast, in Argentina, an expedition in charge of Professor Thome, Director of the National Observatory at Cordoba, watched for the Sun's obscuration, but had unfavorable weather. Still farther northeast, and near Ceara, at Pará Curu in the Brazilian region where the path of totality left the American conti-

[23] Turner, *Monthly Notices Royal Astronomical Society*, l. (1890), 2, 265. Also Wesley, *The Observatory*, xiii. (1890), 105, and Taylor, *Ibid.*, 153.

[24] *Nature*, xli. (1890), 379.

nent, the English astronomers had a well-equipped expedition in charge of Mr Taylor, who had served in similar capacity in West Africa during the second eclipse of 1889.

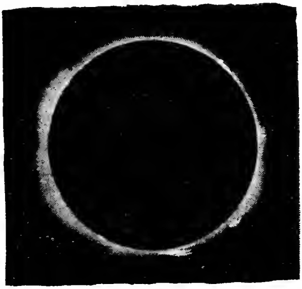
On crossing the Atlantic Ocean to North Africa, in the region of Bathurst and Senegal, the Moon's shadow was met by still other expeditions, two under French auspices, MM. Bigourdan and Deslandres of the Paris Observatory in one locality, and Comte de la Baume Pluvinel in another. In a third region of the African belt, and at some distance up the Salum River, Professor Thorpe led an English expedition, with apparatus quite similar to that which Mr Taylor employed on the Brazilian coast. A study of relatively rapid variations in coronal light and streamers was thus made possible. But in addition to this, the other problems presented by the corona were not neglected, and the customary observations with spectroscope and photometer were amply undertaken.[25]

The Chilean parties were located in one of the driest climates on the globe. Professor Pickering had associated with him Mr Rotch, and Mr Douglas of the Observatory at Arequipa. Establishing the station at a silver mine known as Mina Aris in the district of Agua Amarga, near Valleñar, the party received many courtesies and helpful facilities from railroad and government officials. Volunteer assistants came from Valparaiso and Huasco, and rehearsals of the eclipse programme occupied two days before the event. The skies were brilliantly clear, and at the beginning of totality a solemn silence fell upon the

[25] Thorpe, *The Fortnightly Review*, liv. (1893), 55. This discourse, delivered at the Royal Institution 9th June 1893, combines a readable summary of the results of the eclipse with a delightful narrative of the African Expedition.

scene. Shadow bands were observed to some extent, but their presence 900 feet higher up the hill than the station could barely be detected. The corona seemed very white, with four extended streamers, which, however, do not appear upon any photograph. A combination of the coronas of 1871 and 1858 seems best to describe the phenomena of this latest totality. The protuberances were a pale pink, some reaching a height of 90,000 miles. Many photographs were taken, those with the differential spectroscope giving 20 lines in the reversing layer, three or four seconds before totality. While the existence of the reversing layer has been contested by Mr Lockyer ever since the remarkable observation by Professor Young in 1870, it is gratifying to find that this most recent eclipse has afforded evidence sufficient to establish its entire reality. With the integrating spectroscope, one red and one yellow line, two green lines, and one blue line in the corona were shown. All the observations pointed conclusively to the condition of the Sun as one of great disturbance; and while a network of fine filaments was seen, and the four long streamers, two of more than 435,000 miles in length, upon the whole that uniform distribution so characteristic of eclipses during periods of maximum solar disturbance was exhibited.

Mr Schaeberle arrived early in March, and settled at Mina Bronces. His work was altogether photographic, with five cameras in all; and bringing no scientific assistants with him, he enlisted the services of intelligent persons near at hand to aid him on eclipse-day. Mr John King accompanied him from Carrizal Bajo, and practice drill occupied the previous day. On the approach of total eclipse, the dark shadow could be seen on the hills opposite, coming nearer and nearer, until with a mighty shiver the Sun was obscured from sight. Eyes shielded before totality were then fitted to see the corona properly. In a private letter Mr King writes of its 'beauty and brightness; and the amount of light it gave out was equal to four or six full moons, but a much more beautiful light. It was very little dark, there was light enough for all outdoor work; even railway signalling could have been carried on in the light.' The corona was seen for a few seconds, both before and after totality. Three planets only, Venus, Jupiter, and Mercury, were seen in the region of the Sun. Nearer the sea it was darker, and the corona neither so bright nor so wide as at Mina Bronces, where, 6,700 feet above the sea, an exceptionally fine morning shone in that land of clear skies. Fifty photographs were secured with the three telescopes used. Mr Schaeberle attended the 40-foot camera himself, which was built on a hill-side,[26] the Sun being kept in a given position on the great plate, 18 × 22 inches, by means of a clock-arrangement, facetiously called a 'Joshua.' These photographs are wonderfully fine, and the illustration is an unsatisfactory reproduction of one of them. In the original negative, the Moon's diameter is nearly five times as great as it is here; so that the large scale, with the fine definition, will afford exceptional facilities for accurate measurement.



Prominences and Inner Corona
16th April 1893
(*Photographed by* Schaeberle)

26 *Popular Astronomy*, i. (1893), 72.

M^r^ TAYLOR'S party at Pará Curu, with M^r^ SHACKLETON assisting, did good work under favoring skies. At Fundium, the Salum River station, Professor THORPE and M^r^ GRAY made photometric measures of the intensity of the coronal light, by the same method used in Grenada in 1886, while Sergeant KEARNEY, Royal Engineers, took several good coronal photographs. Also the exposures made by M^r^ FOWLER with the prismatic camera are particularly valuable, providing a large amount of material. At the signal of the beginning of totality, when the last trace of bright sunlight disappeared, out flashed a magnificent corona of silvery light, as well as numerous red and white prominences. Professor THORPE'S party testify also to the disturbed state of the Sun, and report the corona just what they had expected from this condition, the eleven-year series of sun-spots being then well advanced toward its maximum. The outer corona was carefully observed by Captain LANG, Royal Navy, by covering the inner and brighter ring with a disk, after the manner adopted by Professor NEWCOMB in 1878; but no great equatorial extensions like those of 1878 and 1889 were discovered. The periodicity of the corona coincidently with sun-spot epochs thus receives additional confirmation.

M^r^ WESLEY'S skill in drawing will soon produce a fine combination of the double series of photographs taken by the two expeditions sent out by the English Committee. Professor PICKERING has also left in M^r^ WESLEY'S hands some of his own photographs taken in Chile, both with the Harvard instruments and with M^r^ COMMON'S 20-inch mirror, for comparison with the English negatives, and these are said to show more detail in the inner corona than those obtained by the English observers. Much of interest has been revealed by the scrutiny, and the plates are still being studied and compared. While at first Mr Wesley was inclined to think that there was evidence of possible change in the corona as shown in the three sets of plates from the widely separate regions of Chile, Brazil, and Senegal, he writes in a private letter that, after farther and careful comparison, he is 'convinced that the apparent differences were due to other causes than real change in the corona,' though he would not wish to be understood as speaking with entire decision of the matter until this critical research shall have been concluded.

Two French expeditions were despatched to Senegal for observations upon astronomy of position, or precision, as well as upon physical astronomy. The photographic apparatus of the first was sent out by Comte de la Baume Pluvinel,[27] in charge of M. Pasteur, and consisted of nine cameras, the lenses of which varied in diameter from 6½ inches to about ¼ inch, but with 60 inches as their common focal length. Mounted at Joal on the coast, these were exposed as a single instrument as long as the corona was visible. While all the pictures were thus of the same size, their quality and intensity were very different, and the lens of about one inch in diameter produced the most satisfactory plates. Two photographic spectroscopes were also exposed throughout totality, but while the more powerful one was not successful, the other, of low dispersion, gave surprisingly fine results. Its spectrum shows the dark Fraunhofer lines, thus putting beyond question the presence of reflected sunlight in the corona.

M. Deslandres, in charge of the second French expedi-

[27] *Comptes Rendus*, cxvii. (1893), 24.

tion,[28] proposed specially to study the general motions of the corona, and to measure its rotation, —a delicate experiment, but of great interest, since it may throw much light on the vexed question of what the corona is. By means of that technicality known as DÖPPLER'S principle, and photographing on a single plate the spectrum of the corona on opposite sides of the Sun, the displacement of the lines shows the eastern filaments to be approaching the Earth and the western receding from it. And farther, the velocity of approach and recession indicates that the corona revolves in the same period that the Sun itself does. Twenty-two photographs were obtained, some showing especially the external portion, others only the more brilliant interior filaments and the protuberances. The study of the chemical composition in a hitherto unexplored part of the coronal light was satistactory, and will disclose the existence of additional elements within the regions of this luminous appendage of the Sun.

So carefully were all the instruments and observers marshalled along the line of this totality, so critical had been their preparations, so successful were the observations under most propitious skies, and so significant the results, that the eclipse of 1893 is already accorded high rank in the annals of solar investigation.

[28] *Ibid.*, cxvi. (1893), 1108; *L'Astronomie*, xii (1893), 246.

CHAPTER X

ECLIPSES AND THE ELECTRIC TELEGRAPH

Eclipses suns imply.
EMILY DICKINSON.

THE velocity of celestial motions is wellnigh inconceivable. On the approach of total eclipse the fearful rush of the Moon's deep shadow affords opportunity for an unmistakable comparison between the swiftness of heavenly movements and the sluggishness of most terrestrial operations. Man has, however, for his own uses, broken in harness a super-earthly power, so that it may vie with its own untamed kindred of space.

Can this fleet Mercury, the telegraph, outstrip the rushing shadow? And will any advantage result if it can?

Evidently the odds are largely in favor of the electric messenger, as the actual speed is many thousandfold greater than the lunar velocity. But while the Moon moves steadily onward, telegraphic despatches are often subject to sundry and irregular detentions; so there may well be doubt as to which may outstrip the other, when both are matched together on the airy highway of space. If the telegraph can win the race, many possible benefits are obvious on slight consideration.

It is already apparent that no eclipse can be total at the same time everywhere along its track; as the Moon journeys eastward, its shadow following it, totality near the west end of the trail may occur more than two hours (world time) before it comes on at the eastern extremity. If the astronomers near both ends of the shadow-track are in telegraphic communication, these may become moments of supreme significance.

An important observation, a discovery possibly, may be made by an observer whom the shadow first meets; it may be months, perhaps years, before another eclipse will present all conditions favorable for the verification of that discovery. But if the telegraph is called in as an adjunct, new light may be available at once, and without waiting for another eclipse. By telegraphing the nature of the observation eastward to a fellow observer, the discovery may be confirmed forthwith, or the observation, if doubtful, may be rejected.

So long ago as 1878 a young astronomer first brought this novel project to the notice of his colleagues,[1] during the eclipse when the Moon's shadow swept southeasterly across Wyoming and Texas, Professor NEWCOMB observing in the former, and Professor TODD having a station in the latter State. Intra-mercurian planets were then favorite objects of search, and these observers had concluded an arrangement with the Western Union Telegraph Company to forward any message from the northern station to the southern one with all possible despatch. But no opportunity for the practical test offered on that occasion. Three years later, the general conception of the scheme proposed was outlined to the American Academy of Arts and Sciences at Boston.[2]

[1] *Washington Observations*, 1876, Appendix iii., p. 354.

[2] TODD, On the Use of the Electric Telegraph during Total Solar Eclipses, *Proceedings American Academy*, xvi. (1881), 359.

A year afterward a case not wholly supposititious arose. The astronomers who went to Egypt in 1882 to observe the total eclipse in May of that year took a photograph of the region surrounding the Sun. To their great surprise, on developing the negative, a small, bright comet made its appearance alongside the corona, as depicted at the beginning of the previous chapter. This object had never been seen before, nor has it ever been seen since; so that nothing is known of its orbit, or whether the comet will ever return to the Sun or not. But it is easy to see how the telegraph may render important service on a similar occasion in the future. By telegraphing eastward to an astronomer where to find it, an observation of the comet two or three hours later may readily furnish data sufficient to indicate where to look for the stranger as it recedes into space. Subsequent observations may then enable the determination of all the elements of its orbit with precision. Again in 1887 all conditions were favorable for practically testing the new method,[3] but dense clouds intervened to thwart the attempt.

Any one acquainted with the conditions of this double problem of astronomy and telegraphy will at once recognize the practicability of the project of telegraphing ahead of the Moon; and this was demonstrated at the total eclipse of New Year's day, 1889.

The eclipse began in the wastes of the Pacific, somewhat as shown in the frontispiece, and one of the first stations to be covered by the shadow was that occupied by the Harvard Observatory party at Willows, California. Had the limits of the page permitted accurate drawing, a line joining the centres of Sun and Moon during this

[3] Todd, *American Journal of Science*, cxxxiii. (1887), 226

eclipse would have been a tangent to the Earth's surface at that point in the British Possessions where the eclipse trail ends. This line, then, becomes less and less inclined to the totality path as the end of it is approached; consequently the apparent velocity of the shadow is all the time increasing until it leaves the Earth. Over the plains of Manitoba its speed was no less than five times that of a rifle-shot.

At Willows was located a very complete collection of photographic apparatus, — cameras for photographing the corona on every scale, spectroscopes for a thorough analysis of the coronal light, photometers for measuring its intensity, and a large camera for charting all the stars in the neighborhood of the Sun, so as to detect if possible the suspected intra-mercurian planet.

The immediate reporting of the eclipse observations at Willows and elsewhere was a matter of great scientific interest to astronomers in both hemispheres. It could not, however, be successfully accomplished without very careful pre-arrangement with the observers themselves; while the enterprise of Mr James Gordon Bennett of the *New York Herald* (represented by Mr Maurice Minton, then City Editor in charge) was invoked in executing the comprehensive plans.

First, a complete list of the instruments of every observer, and the work proposed to be done with them, had to be prepared. Weather probabilities were everywhere very unsatisfactory, and there was a possibility of all degrees of success or failure. Accordingly the problem was to arrange for each station a cipher code which should include as minutely as possible all the likely combinations of instruments, weather, and results on eclipse-day.

About one hundred words were found sufficient to embrace a complete cipher. A part of the code for Willows is given here: —

Africa,	Perfectly clear throughout the whole eclipse.
Alaska,	Perfectly clear during totality.
Belgium,	Clear sky for the partial phases, but cloudy for totality.
Bolivia,	Entirely cloudy throughout the whole eclipse.
Brazil,	Observed all the contacts.
Bremen,	Observed three of the contacts.
Ceylon,	Made observations on the shadow-bands.
Chili,	Observed lines of the reversing layer visually.
China,	The corona showed great detail.
Cork,	Obtained 40–50 negatives during totality.
Corsica,	Obtained 50–60 negatives during totality.
Crimea,	Obtained 60–70 negatives during totality.
Cuba,	Observed a comet.

And so on through a great variety of detail, not the least of which was the capability of the cipher to indicate with sufficient accuracy the position of any intra-mercurian planet which the photographs might disclose.

Between 20 and 30 codes had been prepared on a like plan for as many stations, and the observers were instructed to report the results of their work in cipher at the earliest available moment, employing the ordinary telegraphic facilities. On rehearsing the programme, the thought occurred that in receiving so many cipher despatches great delays, through no fault of the telegraph company, were at least possible. In only a single way could the arrangements be improved: were a special wire available in direct circuit from New York to the eclipse stations in turn, the chances of success would surely be bettered, not only in gathering the reports, but also in proving the practicability of telegraphing ahead of the Moon.

Upon outlining his plans to the Western Union Telegraph Company, and asking for the use of a special wire to the more important stations for the purpose of immediate and rapid transmission of the observations, Professor Todd received from the manager a hearty response. A New York and San Francisco wire was placed at his disposal, and a loop, as it is called, or branch wire, was led across Broadway from the Western Union building to the editorial rooms of the *Herald*.

From San Francisco every California observer was within easy telegraphic reach, and the wire thus extended by direct circuit to each eclipse station in turn. From the editorial rooms of the *Herald*, Professor Todd was in immediate communication with any observers whom he chose to call. As previously intimated, arrangements had been made with the Harvard astronomers at Willows to receive their message first and with the utmost despatch, in order to test the feasibility of outstripping the Moon.

Shortly before five o'clock in the afternoon despatches began to come in. Of course a slight delay was unavoidable, as the observers at the various stations were some rods distant from the local telegraph offices, and it would take a few minutes after the eclipse was over to prepare the suitable message from the cipher code. On the astronomer's table in the *Herald* office were a large map and a chronometer. The latter indicated exact Greenwich time, and the former showed the correct position of the Moon's shadow at the beginning of every minute by the chronometer. In this way it was possible to follow readily the precise phase of the eclipse at every station. About the rooms and accessible for immediate use were arranged the cipher codes pertaining to the several stations, and other papers necessary in preparing the reports for the press.

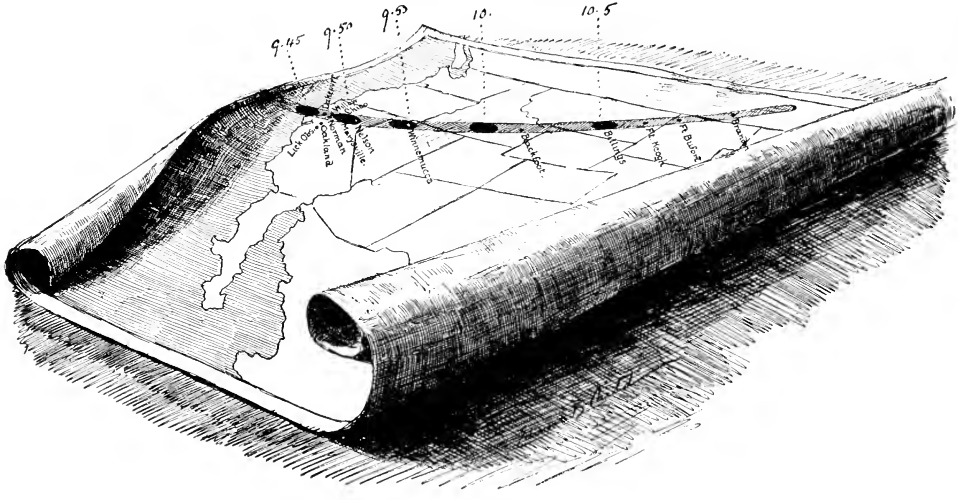
On the opposite page is a sketch of the map showing the eclipse track, with the position of the Moon's shadow at intervals of five minutes of Greenwich time. The location of many of the observers who had been requested to transmit their reports is also indicated. As the lunar shadow fell upon the Earth obliquely, its dark section is elliptical, not circular.

The eclipse was to become total at Willows at 9^h 48^m Greenwich time.[4] The direct wire had been fully tested an hour before. At about 9^h 30^m the operator at Willows was asked the state of the weather. He replied that it was already getting quite dark, that the sky was perfectly clear toward the southwest, and that no cloud was anywhere near the Sun. So that in New York, 3,000 miles away, the success of the Harvard party was regarded as a foregone conclusion.

At that time the Moon's shadow lay out on the Pacific Ocean. Rapidly it rushed along, the total obscurity came on at Willows, the corona flashed out for nearly two minutes, and then disappeared. Totality was over at 9^h 50^m, and the shadow swept swiftly eastward, affording other astronomers a brief glimpse of the Sun's surroundings.

After a short interval, Professor Pickering, chief of the Harvard party, came to the telegraph office and began to send a despatch announcing the general success of the entire expedition. The first three words of the cipher despatch — *Alaska*, *China*, *Corsica* — came quickly over the line; then the circuit of the wire was lost! Meanwhile

[4] This was 4^h 48^m Eastern standard time, and 1^h 48^m Pacific time.



TRACK OF THE NEW YEAR'S DAY ECLIPSE, 1889

(From California to Manitoba)

the Moon was getting a long way the start in the race,— the eclipse was already total in Idaho. The break in the long line was soon located somewhere between Utah and California, but more than half an hour elapsed before the circuit was re-established and the remainder of the despatch could be received.

During this interval, the lunar shadow, advancing over Montana and Dakota, had left the earth entirely, sweeping off again into space. Still, however, the prospect that the telegraph might win the race was hopeful. Had New York been located in the eclipse-path as well as Willows, with both stations symmetrically placed, the total eclipse would have become visible at New York about an hour and a quarter after the shadow had left California.

Thus there was time to spare. Having recovered the wire, Professor PICKERING'S message was completed at 10^h 36^m, the cipher translated, and the stenographer's notes were written out and despatched to the composing-room six minutes later.

The 'copy' was quickly put in type, and the hurried proof handed to Professor TODD at 10^h 50^m, exactly an hour of absolute time after the observations were concluded.

Had the Moon's shadow been advancing from California toward New York, there was still a margin of several minutes before the eclipse could become total at the latter place. In point of fact, while the proof-sheet of the first message was being read, the lunar shadow would have been loitering among the Alleghanies.

Man's messenger had thus outrun the Moon.

The telegraphic reports of the other astronomers were gradually gathered and put in type, and the forms of the *Herald* were ready for the stereotyper at the proper time, some two hours after midnight. At 3 o'clock A. M. the European mails closed, and the pouches put on board the steamship *Aller* carried the usual copies for the foreign circulation. Within twenty-four hours after the observations of the eclipse were made near the Pacific coast, the results had been telegraphed to the Atlantic seaboard, collated and printed, and the papers were well out on their journey to European readers.

An eclipse-track covering an extensive region accessible by telegraph; costly and delicate instruments; a multitude of trained observers; liberal officials willing to afford every facility of a vast telegraph system; enterprising journalists ready to undertake a unique piece of news-gathering, and withal skies everywhere propitious, — these are conditions never before met, and which only the rarest of fortune can completely fulfil.[5]

[5] What may come of the application of the telegraph to future eclipses can hardly be predicted with safety. Possibilities readily suggest themselves, while comparison of the map of future eclipses (shown on page 223) with a map of the land and cable lines of the world enables one to distinguish at a glance between the eclipses available for the telegraphic method and those which are not. Many things need to be considered: east and west stations widely separate, though not too near the end of totality-path; the chance of good weather; and the feasibility of telegraphic connection of the stations with comparative directness. The eclipse track of 28th May 1900 will meet these conditions perhaps the best of all in the near future. To connect stations in Mexico or Southern Texas with those in Spain on that occasion would appear to be entirely practicable; and it is hoped that a definitive test may then be made of the capabilities of the telegraph as a helpful adjunct in eclipse research. — *D. P. T.*

CHAPTER XI

AUTOMATIC INSTRUMENTS FOR ECLIPSE PHOTOGRAPHY

> As doth the blushing discontented Sun
> From out the fiery portal of the east,
> When he perceives the envious clouds are bent
> To dim his glory, and to stain the track
> Of his bright passage to the occident.
>
> SHAKESPEARE, *King Richard the Second*, iii. 3.

AS long ago as 1852 Professor PIAZZI SMYTH wrote of the overwhelming effect of a total eclipse upon the observer, and its distracting power for confusing the best laid programme of work. 'Although it is not impossible,' he says, 'but that some frigid man of metal nerve may be found capable of resisting the temptation, yet certain it is that no man of ordinary feelings and human heart and soul can withstand it. In the eclipse of 1842, it was not only the volatile Frenchman who was carried away in the impulses of the moment, and had afterwards to plead his being no more than a man, as an excuse for his unfulfilled part in the observations, — but the same was the case with the staid Englishman, and the stolid German. . . . In fact, the general scene of a total eclipse is a potent Siren's song, which no human mind can withstand: and the only way in which its witcheries can be guarded against, is that by which ULYSSES passed the fatal shore in safety. Let, then, those who on a future occasion have to make the more accurate telescopic observations, surround themselves by some high wall, which shall prevent their seeing anything but a very small portion of the sky round about the Sun and Moon.'[1]

Perhaps in more modern days the astronomer would not admit the strength of this pictorial effect upon his nerves; he certainly would not allow it to interfere with his plan of operations. But he has now in some degree surrounded himself with the high wall recommended by Professor SMYTH, in the dark rooms and photograph-house, where the camera, having no nerves, plays the largest part in eclipse observation.

Prominent among the obstacles to recent research upon the corona has been the fact that only a small number of pictures can be taken in the available moments. Some appearance, perhaps new and significant, may have been a mere peculiarity in the plate, and the few exposures made may not suffice to correct this impression.

The photometry of the corona, or the detailed measurement of its light in every part, is a problem requiring much critically arranged apparatus, and is now nearly all accomplished in the most satisfactory way photographically. While the eye can record the spectrum of the corona in only limited regions, a multiple spectroscope making a photographic record might give the composition of its light in a multitude of regions. And there are many other problems of size and form of apparatus still awaiting solution. What size of lens is best adapted to photograph specific parts of the corona? Should the full aperture be used, or

[1] *Transactions Royal Society of Edinburgh*, xx. (1852), 504.

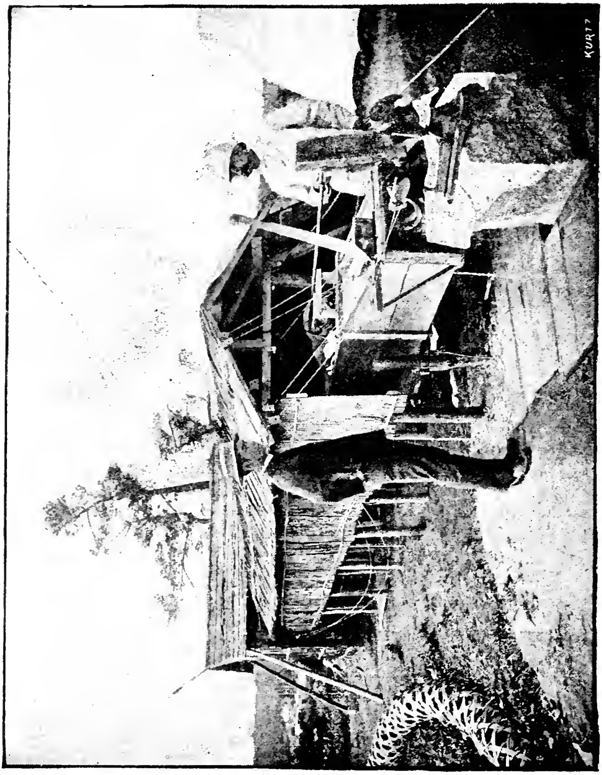
should it be reduced? Do lenses figured for the actinic rays offer great advantages over those not so figured? Are not reflecting telescopes with metallic specula in every way better adapted to coronal photography than refractors? Much light is still demanded upon these and other matters governing the proper outfit of eclipse expeditions.

Obviously the early attainment of this information can come only through a large increase of apparatus. But here arise difficulties: to take out the exposed plate, lay it down, place another in the focus, expose and take that away, — all are time-consuming operations, and the mere changing of plates ordinarily occupies a large part of the entire period of totality. Manifestly, only a few plates can be exposed with a single instrument during the average three minutes.

An automatic apparatus was devised and employed by Professor TODD during the eclipse of 22d December 1889 (by which several hundred plates were exposed during the 190 seconds of the total phase), which is entirely novel, and worked so flawlessly that I am sure it will be of interest to describe it here.

Suppose twenty telescopes or fifty telescopes could all be brought to bear upon the corona, with means at hand for each to make its individual record: evidently the gain would be enormous, because telescope, spectroscope, and camera would then be available for a great variety of experiments; in fact, the most effective way to use certain of these instruments has yet to be found out by repeated trial, with many variations of the mechanical, optical, and photographic circumstances of each.

Photography supplies the means of unimpeachable record, to be sure; but obstacles, mainly mechanical, have always hampered its application. Of course, each sepa-



THE PHOTO-HELIOGRAPH, SHIRAKAWA, JAPAN, 1887

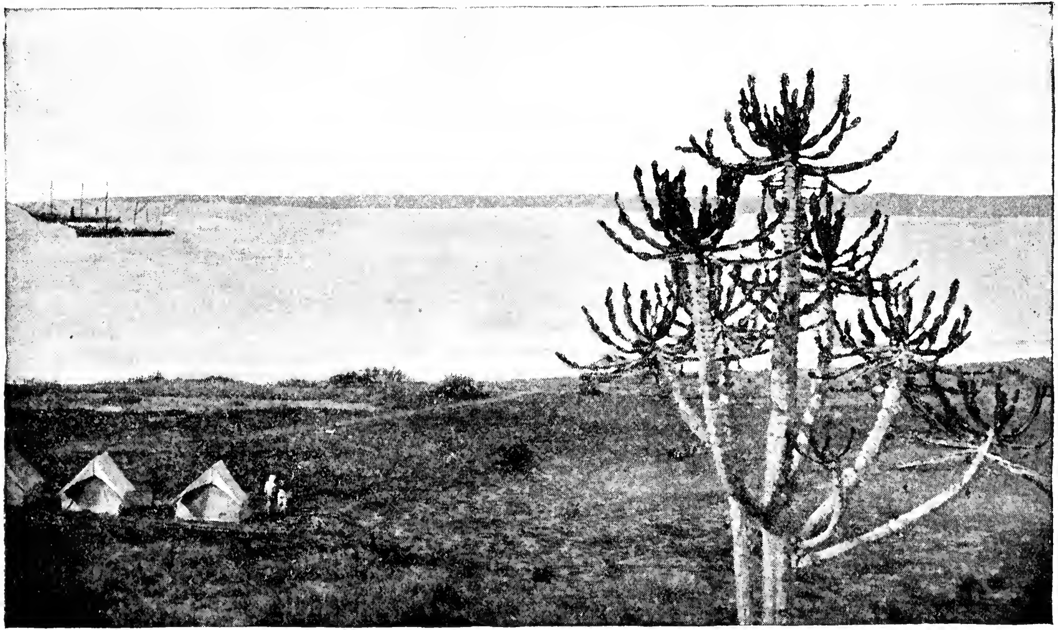
rate instrument requires a delicate adjustment to point it directly at the Sun; then a clock-work must maintain it accurately pointed; exposing shutters must open and close at times which are rarely identical for any two telescopes; and withal the sensitive photographic plates must be changed at frequent and irregular intervals, if each instrument is employed to its fullest capacity.

Heretofore these operations, often rather complex, had always been made by hand. In extreme cases, one astronomer may attend two or three photographic telescopes; but in moments of high tension he is always liable to forget some part of his programme, and ruin a corresponding part of the results. The more complicated instruments have often required the exclusive attention of two persons, and sometimes four, during the hurried and always too brief moments of total obscuration.

Why should it not all be done automatically? Coming home from the Japan eclipse in 1887 this significant question occurred. No answer came. A number of crude appliances, partly shown on page 177, had been employed, but on experimenting some months with curious combinations of apparatus, electric, pneumatic, and other, a general solution of the problem was reached. The principles employed in the action of automatic musical instruments are well known and successfully applied; by adapting them to the requirements of astronomical photographic apparatus, the necessary mechanical movements were clearly feasible.

Mr Gally, the eminent inventor, giving his authorization to the use of the pneumatic valve system covered by his letters patent, the necessary apparatus was immediately begun for the United States Eclipse Expedition to West Africa in 1889, in charge of Professor Todd.[2]

[2] This expedition was provided for by act of Congress, approved 2d March 1889, appropriating $5,000 for expenditure under the



U. S. S. *Pensacola* } MEN-OF-WAR ATTENDING THE ECLIPSE EXPEDITIONS TO WEST AFRICA, DECEMBER, 1889
H. M. S. *Bramble* }

The optical preparations were unusual. Spectroscopes and photometers were supplied from the Harvard Observatory; polariscopes from Yale; photographic telescopes, both reflecting and refracting, by the United States Naval Observatory and Mr SAEGMÜLLER, the well-known instrument-maker at Washington; large photographic lenses by the Gundlach Optical Company of Rochester; while the observatories of Princeton and Amherst also made contributions of useful apparatus. In all there were twenty-three object-glasses and two reflectors,[3] every one adapted to a special problem.

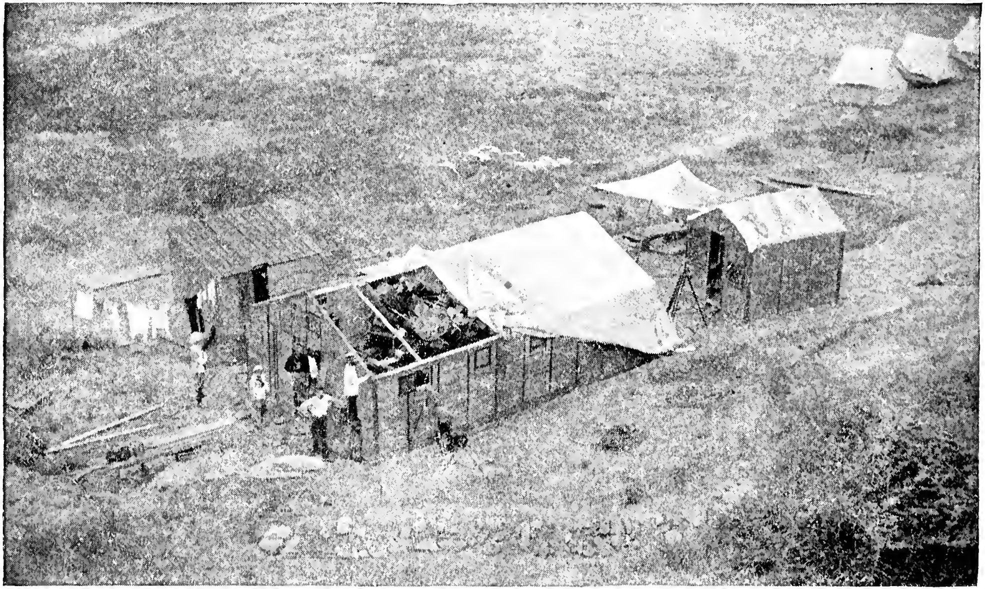
Naturally, each instrument could not have its individual clock-work and mounting; so the emergency was met by building an axis to revolve equatorially, and large enough to accommodate the entire photographic apparatus. This was not so difficult as the more important matter of clock-work sufficiently powerful to move this great mounting with the requisite degree of precision.

The illustration on the opposite page shows a general view of the camp on the African coast, while the page following gives a nearer view of the automatic instruments described. A skeleton axis was mounted upon massive piers

direction of the Hon. BENJAMIN F. TRACY, then the Secretary of the Navy, who assigned the U. S. S. *Pensacola* for this special service. In addition to the scientific *personnel* of the expedition, many officers of the navy loyally promoted its interests, chief among them Admiral WALKER, who perfected the naval organization; the late Captain YATES, in command of the *Pensacola* during her African cruise, who devoted himself with the utmost faithfulness to the furtherance of all the objects of the expedition; and Passed Assistant Engineer TOBIN, whose ready expedients on several occasions were of invaluable service.

[3] *Monthly Notices Royal Astronomical Society*, l. (1890), 382.

MASTOTE BAY, ANGOLA, WEST AFRICA (40 *ft Telescope in the Foreground*)



General View of the Automatic Instruments, U. S. Eclipse Expediton to West Africa, 1889 of stone and iron, which were in a north and south line, the south one being elevated so that the axis should point directly toward the south pole of the heavens. At the top of the iron cap-pieces were the heavy brass bearings in which the axis turned; and these could be moved either up and down, or to the right and left, until the smallest deviation from the true pole was corrected.

Then all the foregoing instruments were rigidly secured in the duplex revolving frame, and pointed upon the Sun.

Other piers were built alongside to support powerful clock-work geared upon one end of the polar axis, and a weight of nearly half a ton was required to drive it. Then, as the Sun moved downward in the west, all the telescopes, once directed upon it, followed with the necessary accuracy.

Next, the photographic part of the programme — and farther difficulties. Some of the sensitive plates were very small, an inch by $2\frac{1}{4}$ inches; some very large, 17 inches by 20. In order that the plates should be changeable by simple pneumatic movements, it was generally found best to attach them to revolving barrels, as large and as many-sided as the number and size of the plates for each particular instrument might require. Attaching a pulley to one end of the barrel, and winding upon it a cord with a weight attached, the necessary means of turning the plate-barrels was at hand. Several metallic pins, equal to the number of photographic plates, were then inserted in the pulley as detents; and thus the motion of each barrel was entirely under the control of a small bellows attachment, operated by the air current of the pneumatic commutator.

Where the plates were few and small, they were moved along in grooves by means of minute organ-bellows, rigged with suitable ratchet movements. In another form of automatic plate-holder, the plate was secured in a light frame, moving laterally in a second frame, which again moved longitudinally in a shallow box about four times as large as the plate. The movements of the frames were readily accomplished by pneumatic bellows, and so it was possible to bring every part of the plate to that position where the image of the corona should fall upon it suitably for exposure. Twenty-five pictures on a single plate were within easy reach of this mechanism.

In still another form, the plates were double-hinged together into an endless chain, by means of pairs of flexible tapes, cemented on the ends. These ran round square axles like a belt, and the motion of the axles was effected in the way previously indicated for the plate-barrels.

In an extreme case, a combination of the barrel and ratchet movement was devised by Professor Bigelow, to test the utmost rapidity of working. It is rather intricate for description here, but a hundred exposures during the 190 seconds of totality were found to be well within its capacity.

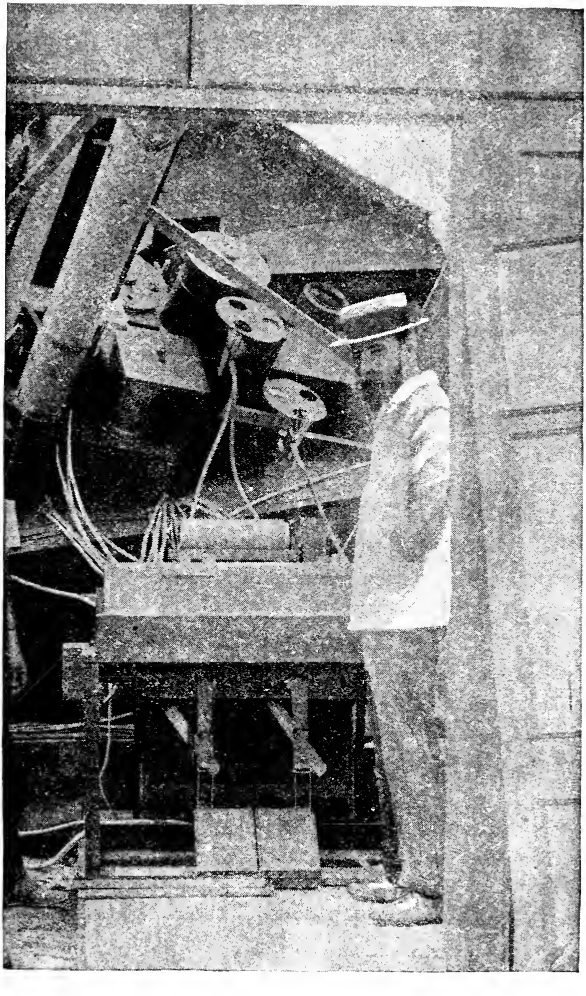
Although the photographic plates were to be used only during the total eclipse, when it would be quite dark, it was still necessary to provide for their protection from the impress of diffused light, which might ruin the sensitive surfaces for recording the delicate filaments of the corona.

But there was not time to make a dark box to cover the plates for every instrument, even if there had been room on the great polar axis to accommodate them all. This obstacle was overcome by erecting a large Ducker portable house above the entire collection of apparatus, and dividing it in two compartments, as shown on page 182, — the light half toward the Sun, with a removable roof, while the other part formed an extensive dark room, into which the telescopes all projected. Flexible diaphragms of opaque cloth bridged over the spaces between the partition and the cameras, and sufficient slack was left in the cloth so that the clock movement of the frame, with its entire cluster of instruments, should meet with no obstruction.

And, lastly, the pneumatic apparatus. Any one in the least degree familiar with the construction and working of the ordinary automatic organ will have little difficulty in following this description. The automatic valve system is a device, simple as it is ingenious, by which a very small current of air becomes competent to control the movement of another current relatively large. To all intents and purposes, the action of the large current resembles the explosive of a fire-arm, while the action of the small current may be likened to that of a trigger. Then, the number of valves in the system must equal the number of mechanical movements required for shifting photographic plates, opening and closing shutters, and performing the varied sorts of work required in operating eclipse instruments. Also, there must be as many triggers, or control currents, as there are valves.

The pneumatic commutator, as built for the expedition by Mr Gally, looks much like a medium-sized cabinet organ with the case off (page 186). Underneath are the two feeders of an exhaust bellows, operated by ordinary pedals. On top of the exhaust chamber are the chest and valve action, and the ports where the air-tubes leading to all the different parts of the photographic apparatus were connected.

Still above, and on the left, is the 'tracker,' or system of control-apertures. This is a small box with a curved top having in it forty-eight holes, six to the inch, leading each

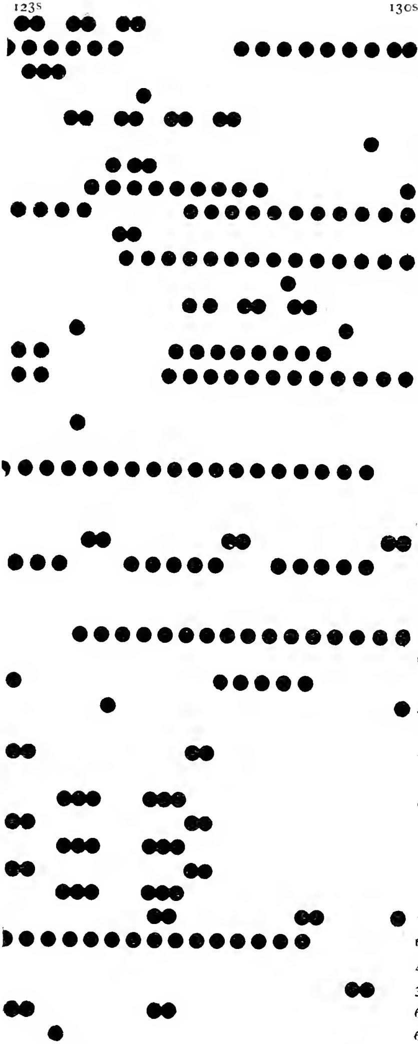


THE PNEUMATIC COMMUTATOR AND PHOTOGRAPHIC INSTRUMENTS IN PART to its appropriate valve in the chest below. When all the apertures of the tracker are closed, and the pedals are operated to exhaust the air strongly from the bellows, the commutator may then be said to be loaded. But the instant one of the small holes is uncovered, the atmospheric equilibrium is disturbed beneath, and a powerful exhaust current is set in motion through the corresponding valve-port, and through the pipe leading to the little exhaust bellows which has been suitably attached to some piece or other of the photographic apparatus. And this exhaust current continues so long as the pedals are operated and the tiny hole in the tracker remains uncapped.

Now to operate the instruments, a ribbon of paper nine inches wide and of proper length is so perforated that, when it is drawn along over the tracker, its apertures shall come opposite the appropriate holes at the proper times. To make this commutator sheet move with perfect uniformity, it was all wound upon the barrel of an ordinary chronograph, as shown in the engraving on page 182, at the right of the valve-chest. As the chronograph barrel revolves, the control-sheet unwinds, passes out to the left, and up over the tracker, after which it winds upon a small roller turned by a cord attached to a weight just heavy enough to hold the paper at the right tension.

On the next page is a reproduction of a portion of the control-sheet actually employed in operating all the automatic instruments during the total eclipse of 22d December 1889, at the station in West Africa.

The camp selected by Professor Todd for the installation of this apparatus was established at Cape Ledo, 60 miles from Loanda, and about 250 miles below the mouth of the Congo. When the *Pensacola* came to anchor, there was



Polariscope 1, shutter and nicol.
6 in. DALLMEYER, 38 focus, shutter.
Polariscope 1, plate.
6 in. DALLMEYER, 38 focus, plate.
Polariscope 2, shutter and nicol.
6 in. DALLMEYER, 24 focus, plate.
Polariscope 2, plate.
5 in. ROSS, shutter.
Harvard 8 in. doublet, shutter.
Harvard 8 in. doublet, plate.
Harvard 8 in. doublet, orthochrom. screen.
5 in. ROSS, plate.
Duplex photometer, plate.
8 in. mirror, 33 focus, plate.
8 in. mirror, 33 focus, shutter.
8 in. mirror, 72 focus, shutter.
3.5 in. CLARK, frame A to right.
8 in. mirror, 72 focus, plate.
3.5 in. CLARK, shifts frame B.
3.5 in. CLARK, shutter.
6 in. SCHROEDER, plate-barrel to right.
6 in. SCHROEDER, barrel-escapement.
6 in. SCHROEDER, plate-barrel to left
6 in. SCHROEDER, shutter.
4 in. GUNDLACH, shutter.
4 in. GUNDLACH, plate.
5 in. CLARK, shutter.
5 in. CLARK, plate.
4 in. SPENCER, shutter.
4 in. SPENCER, plate.
Reversing-layer spectroscope, shutter.
Quartz spectroscope, shutter.
Reversing-layer spectroscope, plate-trail.
Quartz spectroscope, plate.
Flint spectroscope 1, shutter.
Flint spectroscope 1, plate.
Flint spectroscope 2, shutter.
Flint spectroscope 2, plate.
Duplex photometer, shutter.
6 in. DALLMEYER, 24 focus, shutter.
4 in. SPENCER, aperture-diaphragm.
3.5 in. CLARK, frame A to left.
6.4 in. MERZ-CLARK, aperture-diaphragm.
6.4 in. MERZ-CLARK, plate.
6.4 in. MERZ-CLARK, shutter.

CONTROL-SHEET (123s to 130s of Totality) WITH KEY TO AUTOMATIC MOVEMENTS just a fortnight to the day of the eclipse. The time was short, but faithful workers were not a few. Cape Ledo itself is a bold and rocky headland about 300 feet in height, in parts nearly perpendicular. The entire region is totally uninhabited, although visits from various cannibal chiefs with their staffs from some distance inland varied the monotony of days devoted entirely to work and preparation. Representatives of the Quissama tribe made a number of calls, their firm white teeth chipped to sharp points for the better appreciation of their favorite delicacy. The surf, breaking continually upon the beaches near Cape Ledo, was at no time heavy enough entirely to prevent landing, though sudden overturns were occasionally threatened. Fine oysters and game abounded; while palms, the cactus-like euphorbias (page 179), and the gigantic baobab gave a tropical effect to the scenery, in general less luxuriant than might have been anticipated from the latitude.

Two days before the eclipse, affairs were rapidly converging toward complete readiness. There was the best of reason for satisfaction with the station meteorologically, for friendly clouds had veiled the morning skies, allowing the work to go on with minimum fatigue, while the afternoons had delighted every one with their transparency.

The forenoon of eclipse-day, too, was thickly overcast; and the early afternoon showed the most encouraging signs of a clear totality. Breaks in the clouds permitted excellent pictures of the partial eclipse. Shortly before the total phase, darkness covered the station, and soon the ashen shadow of the Moon was seen, sweeping in from the ocean.

The critical moment had arrived, the chronographic governor was started, and the control-paper began to unroll with unerring precision. One aperture after another passed its appointed place at the appointed instant, and hundreds of mechanical movements took place, — exposing-shutters opened and closed, apertures of the lenses varied, Nicol prisms revolved, and fresh plates came promptly into the proper focal planes, to replace those just exposed.

All this went on as if by magic: no hand anywhere touched or offered assistance; but seated before the pneumatic commutator was one man exercising as energetically as if performing the pedal voice of BACH'S G-minor fugue.

The programme had been fully carried out, and over three hundred exposures made. Prism, lens, and mirror, mechanical devices and sensitized surfaces had done everything they could, but not a trace of the corona was recorded.

Totality had been cloudy.[4]

[4] It will be remarked that this 'accident of the day,' unfortunate in so far as that particular eclipse is concerned, in no wise affects the application of this new method to future obscurations of the Sun. The feasibility of operating a large cluster of instruments automatically has been demonstrated; and the apparatus must now be rebuilt with such modifications as the experience with provisional mechanism may have suggested. It is to be hoped that a generous patron of science may be found to provide the means for carrying out these plans in ample time for the next total eclipse, which may be well observed in Norway and Japan, 9th August 1896. — *D. P. T.*

CHAPTER XII

THE RECURRENCE AND PREDICTION OF ECLIPSES —SELECTING STATIONS—FUTURE ECLIPSES

> Eclipses are predicted,
> And science bows them in.
>
> EMILY DICKINSON.

POETS usually care little for the *modus operandi* of scientific phenomena; the lines above embrace the fact, the result, the gist of the whole matter, and that ought to be sufficient.

But many will desire to know more of detail, for instance, how it is possible that eclipses can be predicted. This forms a recondite portion of our subject, lightly touched upon here, but a general outline will serve to indicate in some measure how it is accomplished.

Simple methods of predicting these astronomical happenings would seem to have been in common use in China more than 2,000 years before our era. The eclipse already mentioned on page 90 as occurring B. C. 2158 is said to have appeared unexpectedly during the reign of CHUNG KANG, who was thereby so greatly irritated against HO and HI, two important officers of state, perhaps astronomers royal, that he had them at once put to death for failing to foretell it. This legend, illustrating the danger of allowing eclipses to spring upon monarchs unawares, is an interesting indication that their prediction in some sort was expected, and so probably customary.

Eclipses are roughly predictable by means of the Saros, known since the time of THALES, in the seventh century before Christ, and probably discovered by the Chaldeans, the greatest astronomers of antiquity.[1] The Saros is a period of $6585\frac{1}{3}$ days,[2] at the conclusion of which the centres of

[1] For historical references on the periodicity of eclipses, consult HOUZEAU *et* LANCASTER, *Bibliographie Générale de l'Astronomie*, i. 181. Among others, the Arabian astronomers were familiar with the principles of forecasting eclipses of the Sun, as is evident from LEE'S 'Notice of the Astronomical Tables of MOHAMMED ABIBEKER AL FARSI,' two copies of which are preserved in the Public Library of the University of Cambridge (*Transactions Cambridge Philosophical Society*, i. (1821), 262.) D^{r} WOLF, in his excellent *Handbuch der Astronomie, ihrer Geschichte und Litteratur* (Zurich, 1893, ii. 291), gives a concise summary of ancient methods of predicting eclipses; and M. TANNERY, in his *Recherches sur l'Histoire de l'Astronomie Ancienne* (Paris, 1893, p. 231), deals particularly with the insufficient methods of HIPPARCHUS and PTOLEMY. — *D. P. T.*

[2] More exactly $6585^{d}.32116$, at the epoch 1900. This period is equivalent to 18 years $11\frac{1}{3}$ days; or 18 years $10\frac{1}{3}$ days, if five leap years have intervened. In one complete Saros, 41 solar eclipses will ordinarily occur, but only about ten of them will be total, the remainder being of the types mentioned near the end of Chapter I. (14 partial and 17 annular).

In every calendar year there must be two solar eclipses of some type or other; often there will be three, and occasionally four. As many as five in a single year are possible, but this happens very rarely; the last occasion was early in the present century, and it occurs only once (1935) in the next two and a half centuries. If a total eclipse takes place very early in the year, it is not impossible that another should happen before the end of the year, as actually did happen in 1889 (1st January and 22d December); but this coincidence will not again occur until the year 2057, with total eclipses on 5th January and 26th December. If the Moon travelled

Sun and Moon return very nearly to their relative positions at the beginning of the cycle, and certain orbital conditions essential to the accuracy of the Saros are fulfilled.[3] Thus, in general, the eclipse of any year will be a repetition of a similar phenomenon which took place 18 years previously, and in like manner there will be a recurrence 18 years later. The eclipse of 1896, for example, is a return of the famous ones of 1878, 1860, and 1842; and there will be other repetitions in 1914 and 1932.

But the fractional part of a day in the Saros, combined with the rotation of the Earth on its axis, makes any given total eclipse fall about 120° of longtitude (or one third the way round the globe) farther west at each return. The maps on pages 221 and 223 will show this. So that when three

round the Earth in the same plane as the Earth moves round the Sun, a solar eclipse would take place every month. But as the orbits of Earth and Moon are somewhat inclined to each other, our satellite in passing by the Sun each month generally goes above or below it; and all degrees of solar eclipse are evidently possible. The two opposite points where the Moon's path intersects the plane of the Earth's are called the nodes; and these are not stationary, but move continually toward the west, going all the way round the sky in about $18\frac{3}{5}$ years. Only when the Sun is near one of these nodes can an eclipse of that body take place, and the interval during which an eclipse may occur is about five weeks in duration, and is called an eclipse season. Obviously there must be two such seasons in every year, and the average interval between them is $173^{d}.3$. Falling in the months of April and October for 1893, they come about 20 days earlier each succeeding year. For detailed explanation of ecliptic limits, and the theory of eclipses, reference must be had to astronomical treatises and the encyclopædias. — *D. P. T.*

[3] Professor Newcomb sets forth all these relations very lucidly in his work *On the Recurrence of Solar Eclipses* (Washington, 1879), p. 7.

periods (about 54 years, 1 month) have passed, an eclipse ordinarily returns to the same general region on the Earth, in so far as longitude is concerned; but as the track will lie about 600 miles either north or south of the one 54 years before, the narrowness of the shadow path (usually less than 100 miles wide) will nearly always preclude a return of totality precisely at a specified place. The tracks of the eclipses of 1901 and 1955 through Malay and China are a case in point. That the paths of eclipses belonging to different series often intersect, is also apparent from the maps. For example, those of 29th July 1878 and 1st January 1889 both passed almost centrally over the Yellowstone National Park; and in like manner, if larger areas are considered, Spain is perhaps the most favored spot within modern days, total eclipses occurring in that country in 1842, 1860, 1870, 1900, and 1905.

It is already clear that all eclipses may be classified in series, the eclipses in each of which are separated by 18-year intervals. But while, in relatively brief periods of time, 'eclipses run their steady cycle,' the cycles themselves are not indefinite in duration. Ordinarily the individual series will embrace about 64 returns of a particular eclipse, that is, the length of the solar eclipse cycle is not far from 1150 years.

To understand the progression of such a series across our globe is not difficult. The advent of a slight partial eclipse near either pole of the Earth will herald the beginning of the new series.[4] At each succeeding return conformably to the Saros, the partial eclipse will move a little

[4] On the average, new cycles will begin at intervals of thirty years. Consult Mr MAUNDER's 'Life-history of a Solar Eclipse,' *Knowledge*, xvi. (1893), 181.

farther toward the opposite pole, its magnitude gradually increasing for about 200 years, but during all this time only the lunar penumbra (*vide* page 3) will impinge upon the Earth. But when the true shadow begins to touch, the obscuration will have become annular or total near the pole where it first appeared. The eclipse has now acquired a track, which will cross the Earth slightly farther from that pole every time it returns, for about 750 years. At the conclusion of this interval, the shadow path will have reached the opposite pole; the eclipse will then become partial again, and continue to grow smaller and smaller for about 200 years additional. The series then ceases to exist, its entire duration having been about 1150 years.

To refer to the maps again (pp. 221 and 223), which, although covering a period not much exceeding a single century, suffice for abundant illustration. The series of 'great eclipses,' of which two occurred in 1865 and 1883, while others will happen in 1901, 1919, 1937, 1955, and 1973, affords an excellent instance of the northward progression of eclipse tracks; and another series, with totality nearly as great (1850, 1868, 1886, 1904, and 1922), is progressing slowly southward.

It is evident that the Saros is useful for predicting eclipses only in the crudest fashion. If there were no other method at our disposal, it would be impossible for a modern eclipse expedition to locate itself where the totality could be certainly observed, although a chance hit might place it within the region traversed by the lunar shadow.

Kepler was perhaps the first astronomer to develop a method, exemplified in his Rudolphine Tables, of computing eclipses with some approach to scientific form.[5] It

[5] Kepler, *Opera Omnia*, iii. (1860), 525; vi. (1866), 503.

was, however, only graphical. In the fifteenth and sixteenth centuries predictions of eclipses were issued much farther ahead than now, with all the accuracy possible at that time. The instruments and methods of the astronomy of that day were such that eclipses could be predicted with nearly the same degree of precision as it was possible to observe and record them. LEADBETTER published in 1731 his *Treatise of Eclipses*, and afterward amply set forth KEPLER'S method as improved by FLAMSTEED.[6] LA GRANGE, whose refined analysis effected great advances, appears to have given the first development of a method for calculating the circumstances of an eclipse for any specified place on the surface of the Earth.[7]

[6] LEADBETTER, *Uranoscopia: or, the Contemplation of the Heavens* (London, M DCC XXXV).

[7] *Astronomisches Jahrbuch*, 1782. In the latter part of the eighteenth century, and the beginning of the nineteenth, LEXELL, LAMBERT, and GOUDIN made important contributions to this problem, the last publishing a memoir on eclipses of the Sun in the new edition of his works (Paris, 1803). The method of the 'nonagesimal,' as it is termed, referring Sun and Moon to the ecliptic, was generally employed, and is fully explained by HALLASCHKA (*Elementa Eclipsium*, Prague, 1816), who gives also the method of prediction for the Earth generally, on the orthographic projection, explained as well in the astronomical treatises of DELAMBRE and LALANDE. MONTEIRO DA ROCHA gives additional details more accurately (*Mémoires sur l'Astronomie Pratique*, Paris, 1808).

LALANDE, in his magnificently printed collection of titles of astronomical works (*Bibliographie Astronomique*, Paris, An XI = 1803), gives about eighty titles of papers dealing with the theory of eclipses, by PURBACH, KEPLER, WALTHERUS, LA HIRE, DE LISLE, MAYER, GOUDIN, LE MONNIER, PINGRÉ, and others. More generally available is the fine list of works relating to the general theory of eclipses, given in that treatise of incalculable benefit to the astronomer, and to which frequent reference has already been made

Hansen printed his first paper on eclipses in 1837,[8] but it was reserved for the great Bessel to bestow the final precision in his *Analyse der Finsternisse*,[9] where he develops the fundamental equations upon which the occurrence of

(Houzeau *et* Lancaster, *Bibliographie Générale de l'Astronomie*, i. 1330; also ii. 482). There are in all about one hundred and fifty entries, which will enable any one to trace the subject in all phases of its development, from the crude methods of the seventeenth century, through the intermediate stages imposed by Lalande, Du Séjour, Euler, and Lexell, to the elegant conceptions of La Grange, the adaptations of Woolhouse (*Appendix to the British Nautical Almanac*, 1836) and Souchon (*Traité d'Astronomie Pratique*, Paris, 1883), and the finished product exemplified in the available formulæ of Bessel and Hansen, the latter of whom furnished a set of ecliptic tables (Ecliptische Tafeln für die Conjunctionen des Mondes und der Sonne, *Berichte der k. Sächs. Gesellschaft*, ix. 1857, p. 75). Littrow published in 1821 his *Beiträge zur Berechnung der Finsternisse*, and Sir John Lubbock, in 1835, *An Elementary Treatise on the Computation of Eclipses and Occultations*. Watt's quaint list of eclipse literature (*Bibliotheca Britannica*, iii., Edinburgh, 1824) includes many early papers on the prediction and calculation of these phenomena; and very useful also to the thorough student will be found Struve, *Librorum in Bibliotheca Speculæ Pulcovensis . . . Catalogus* (Petropoli, 1860). Reference should be made to Penrose, *On a Method of Predicting by Graphical Construction . . . Solar Eclipses for any given Place* (London, 1869). Professor Cayley's later additions to the subject are accessible in the *Memoirs of the Royal Astronomical Society*, xxxix. (1871), 1, and the *Monthly Notices*, xxxi. (1871), 39; nor should the paper of Grunert, published by the Vienna Academy in 1854, be omitted. — *D. P. T.*

[8] *Astronomische Nachrichten*, No. 339. Hansen returned to the subject, publishing in 1859 his 'Theorie der Sonnenfinsternisse und Verwandten Erscheinungen,' *Abhandlungen der k. Sächs. Gesellschaft*, iv.

[9] *Untersuchungen*, ii. (1842), and Engelmann's Bessel's *Abhandlungen*, iii. (Leipzig, 1876), 369.

solar eclipses depends for the Earth generally, and presents in convenient shape the necessary formulæ for computing

FRIEDRICH WILHELM BESSEL (1784–1846)

the precise instants of beginning and ending of the eclipse at any place whatever on the surface of the globe.[10] The theory of BESSEL, a thorough exposition from the mathe-

[10] Consult also *De Calculo Eclipsium Besseliano Commentatio.* Auctore D^r GUSTAVO ADOLPHO JAHN (Lipsiæ, 1848). *Transactions American Philosophical Society*, x. (1853), 183.

matician's point of view, is fully presented by CHAUVENET[11] and other writers on spherical and practical astronomy.

It is not now necessary, however, to employ these refinements to secure a fairly exact knowledge of the circumstances of a future eclipse, — the time and place of its visibility, the length of the total phase, and so on.[12] These impressive celestial phenomena may be determined for all regions of the globe, and with accuracy sufficient for most purposes, from Professor NEWCOMB'S *Tables of Solar Eclipses from* B. C. 700 *to* A. D. 2300.[13] No maps are presented in this work, but in his *Canon der Finsternisse*[14] OPPOLZER gives approximate calculations for the visibility of 8,000 solar eclipses for a period of 3,370 years (B. C. 1208 to A. D. 2162), accompanied by 160 charts containing the tracks of all the principal ones.[15]

[11] CHAUVENET, *Spherical and Practical Astronomy*, i. 439.

[12] Supplementary to his *Eclipses, Past and Future* (Oxford and London, 1874), the Revd S. J. JOHNSON published in 1889 a pamphlet containing dates of eclipses, both solar and lunar, visible in England from A. D. 1700 to 2000, with those of the Sun for the two centuries following, and the larger solar eclipses to 2500. His projections and diagrams of the eclipses were presented to the Royal Astronomical Society in a large MS. volume. Mr JOHNSON has made much use of the expeditious tables for calculating eclipses in *The Encyclopædia Britannica*, 8th edition, iv. (1854), 120.

[13] *Astronomical Papers of the American Ephemeris and Nautical Almanac*, i. (1882), 29. Also OPPOLZER'S 'Syzygien-tafeln für den Mond' (*Publication der Astronomischen Gesellschaft*, xvi., Leipzig, 1881) is serviceable for the same purpose.

[14] *Denkschriften der k. Akademie der Wissenschaften*, lii. (Wien 1887).

[15] The approximate methods employed by OPPOLZER in constructing his charts render the eclipse tracks frequently erroneous, except at their beginning, middle, and end. Consult Dr SCHRAM'S

But if the utmost exactitude of eclipse prediction is sought, recourse must be had to the fundamental data derived directly from HANSEN'S *Tables du Soleil*, and his *Tables de la Lune*, with Professor NEWCOMB'S system of corrections to the latter.[16]

These definite positions of Sun and Moon, with other appropriate quantities, form part of those mathematical data known as the 'elements' of an eclipse; and by employing them according to the methods of HANSEN and BESSEL already mentioned, the computer derives other and

Reductionstafeln für den Oppolzer'schen Finsterniss-canon zum übergang auf die Ginzel'schen empirischen correctionen. Ibid., lvi. (1889), 187.

[16] The accuracy of this prediction depends, of course, upon the degree of perfection of the Tables; and even their present precision has only been attained as a result of mathematical researches of the highest type, developing the equations of motion of the Moon to the last degree of accuracy, in accordance with the Newtonian law of gravitation. This mathematical theory is then compared with all the observations in the past, including ancient eclipses both lunar and solar, and the results of this comparison are finally incorporated in the permanent Tables in such form that they may be used for evaluating the positions of Sun and Moon in the sky for all past and future time.

Foremost in prosecuting these researches during the last half-century have been HANSEN in Germany, PONTÉCOULANT and DELAUNAY in France, AIRY and ADAMS in England, and Professor NEWCOMB and Mr G. W. HILL in America. HANSEN, DELAUNAY, and AIRY spent a goodly portion of their lives upon the intricate mathematics of the 'lunar theory,' as it is termed. However, the formation of final Tables for predicting the Moon's motion is a task so prodigious that only one of these investigators (HANSEN) arrived at the complete solution of the problem, publishing at London, in 1857, his *Tables de la Lune, construites d'après le Principe Newtonien de la Gravitation Universelle.—D. P. T.*

especial elements which render easy the calculation of all the circumstances of an eclipse for any terrestrial locality. The Nautical Almanacs of the leading nations give such elements for all the eclipses occurring each year, together with data for charting the shadow path accurately, the duration of the total phase on the central line of that path, and maps showing the geographical regions of visibility.[17]

These elements, in turn, are directly of service in deducing the particular circumstances of an eclipse by the computational methods indicated in the Ephemeris; and so conveniently arranged are they, that for an expert computer the calculation of beginning and end of an eclipse, for any place on the Earth, with the utmost accuracy, becomes only the work of an hour or two. The elements form, indeed, the intermediary link between the general tables of Sun 'and Moon, and the specific calculations

[17] In preparing the 'elements,' the German and French Ephemerides employ the method of HANSEN, the English that of WOOLHOUSE, and the American that of BESSEL. But, as the *Berliner Jahrbuch*, the *Connaissance des Temps*, the *British Nautical Almanac*, and the *American Ephemeris* are at present all founded on HANSEN'S *Tables de la Lune*, their predictions of any eclipse for a particular point on the Earth's surface are practically identical. Of these four national annuals, the English is issued earliest, nearly four years in advance, the American follows it in about six months, and the French and German ordinarily appear between two and three years in advance. When the elements are known, a machine like FERGUSON'S eclipsareon, mentioned on page 6, and described and figured in his *Astronomy*, is of use in roughly illustrating a solar eclipse. In the practical construction of eclipse charts, Mr BUCHANAN'S *Treatise on the Projection of the Sphere* (Washington, 1890) will be found helpful, and in Dr CRAIG'S *Treatise on Projections* (U. S. Coast and Geodetic Survey, 1882) is a complete presentation of mathematical methods. — *D. P. T.*

which determine the absolute hour, minute, and second at which any eclipse will begin or end at any especial locality.

Of course, then, these accurate predictions of eclipses are immediately available only so far in the future as the national Ephemerides, or Nautical Almanacs, have been prepared and published; ordinarily, they are issued two or three years in advance. If the precise conditions of an eclipse farther in the future are desired, the task is a more laborious one, because the computer must first prepare essentially all the eclipse elements which the Ephemeris gives. This, however, is by no means difficult for the professional astronomer or computer. For a quarter of a century in advance the error in the instant of beginning and ending of the eclipse will be only a few seconds, and deviation of the shadow path to the north or south of its theoretical location ought not to exceed three or four miles. But although this high degree of accuracy is remarkable, and entirely sufficient for all purposes of usual prediction, it cannot be said that absolute precision has been attained. The 'contacts' of an eclipse can be observed much more accurately than they can be predicted with our present facilities; while no astronomer would be willing to assert that the time of an eclipse a century or more in the future can be predicted within four or five seconds of the truth.

Foremost among considerations influencing the choice of eclipse stations is, of course, the geographical area within which the eclipse is visible. Ordinarily the Nautical Almanac will indicate this with sufficient accuracy two or three years in advance, as has been said; and the astronomer will have time to ascertain in part the nature of the remote localities which he may be called upon to visit. But in all those land regions of the globe which the lunar shadow trails across, perhaps 5,000 miles in extent, there will usually be wide variation in the condition of the sky on the day when the eclipse occurs: at some stations it will be filled with cloud,[18] at others there may be only slight interference, while on rare occasions almost the entire track of totality will traverse an area of complete cloudlessness.

[18] This suggests the query frequently heard whether an eclipse coming on may not produce the clouds which sometimes work the astronomer's defeat. The answer is, that, as yet, no reason is apparent why the advent of the lunar shadow should cause the formation of visible cloud. A portion of the direct solar heat is withdrawn, to be sure, from a comparatively small volume of the atmosphere, having the shape of a slightly flaring cylinder about a hundred miles in diameter. The air temperature falls a few degrees only, the direction of the wind may change several points, and there is usually a slight deposition of dew. The barometer does not often fluctuate appreciably.

An equally unsatisfactory answer appears on referring to the cloud records of past eclipses. If there were anything in the thought that the obscuration itself may bring on a thickening of the atmosphere, evidently we should expect to find more cloudy eclipses than clear ones. The data are not at hand for showing the state of the sky all along the track of every total eclipse; and our only present means of judging is the success or failure of the parties of observers situate at particular points here and there along the line. The expeditions of 1878, 1880, 1882, and 1883 were generally successful, although the last, at Caroline Island, in the remote South Pacific, came very near losing the total eclipse by reason of thick skies, which prevailed except at the critical moments. The eclipse of 1885 was clear in New Zealand; and that of 1886, while partially obscured in the West Indies, where the astronomers were all located, was perfectly clear in Benguela, West Africa, as already mentioned. Then followed the eclipse of 1887, remarkable for the defeat of expeditions everywhere, from Russia to Japan. But the

While many eclipses approaching the maximum duration, being visible only within the tropics, are unavailing because the land localities are few, it very often happens that the meteorological conditions are everywhere so unfavorable that these opportunities for solar research are lost. In selecting stations, then, the necessity of systematic examination of the cloud conditions in eclipse localities must be apparent. Only thus can the best observing points be known, and the eclipse utilized to the utmost.

If the shadow chances to cross many inhabited countries, where meteorological observations may have been made for years, the astronomer never fails to profit by their valuable indications, as a matter of course. This, however, very infrequently happens; almost always the eclipse path will traverse regions very sparsely settled, and the ordinary occupations of the few inhabitants will be quite other than meteorological. More often than not, their memory of what the weather was in previous years will lead to the

next darkening of the Sun in total eclipse, on New Year's day, 1889, was equally memorable for transparent skies almost all the way from California to Manitoba; while the second eclipse of 1889, which passed for the most part in clouds in the Eastern hemisphere, favored the observers with clear skies in the Western. And that of 16th April 1893 was nearly everywhere clear. As the data are insufficient for a scientific opinion, every one is at liberty to judge for himself.

Other terrestrial effects of eclipses are suspected, although the mechanism of the connection may be unknown. For example, D[r] GINZEL finds a score of coincidences between solar eclipses and California earthquakes from 1850 to 1888, which seem remarkable, even if merely accidental. There were, of course, many eclipses unaccompanied by earthquakes, and many earthquakes occurring independently of eclipses; still, the research is not without interest. (*Himmel und Erde*, ii. 1890, 255, 309.) — *D. P. T.*

belief that the sky will certainly be clear when the eclipse comes on.

As already pointed out, the Ephemeris tells just where the eclipse is to be total four years in advance; evidently this intervening time may be employed to great advantage. Why not have cloud observations carefully made at all the available localities during these years, and for the specific purpose of determining what stations will be likely to afford the best weather?

For the first time this was done for the total eclipse of 16th April 1893, with some approach to comprehensiveness. The aim was to secure, in so far as possible, cloud observations at or near all advantageous positions in the shadow path, throughout the month of April, 1890, 1891, and 1892, at or near the particular time of day when the eclipse should take place at each station. In some regions it was, of course, impracticable to do this; for these, the best available data were collated, however meagre. The map on page 221 represents the entire line of visibility of this eclipse through South America, the Atlantic Ocean, and Africa. The particular localities available were (in the order of absolute time) Chile, Argentine Republic, Paraguay, Brazil, Senegal, and Sahara.

Any one interested in this novel research must consult the original paper;[19] but the result of the whole inquiry was, that the Desert of Atacama, Chile, would be by far the best station if clear skies alone were to be regarded. On passing to the east of the Andes, the meteorological conditions might be rather less favorable, even on the great mountain

[19] Todd, 'Data (chiefly Meteorological) bearing upon the Selection of Stations for observing the Total Eclipse of 1893, April 16,' *American Meteorological Journal*, ix. (1893), 379.

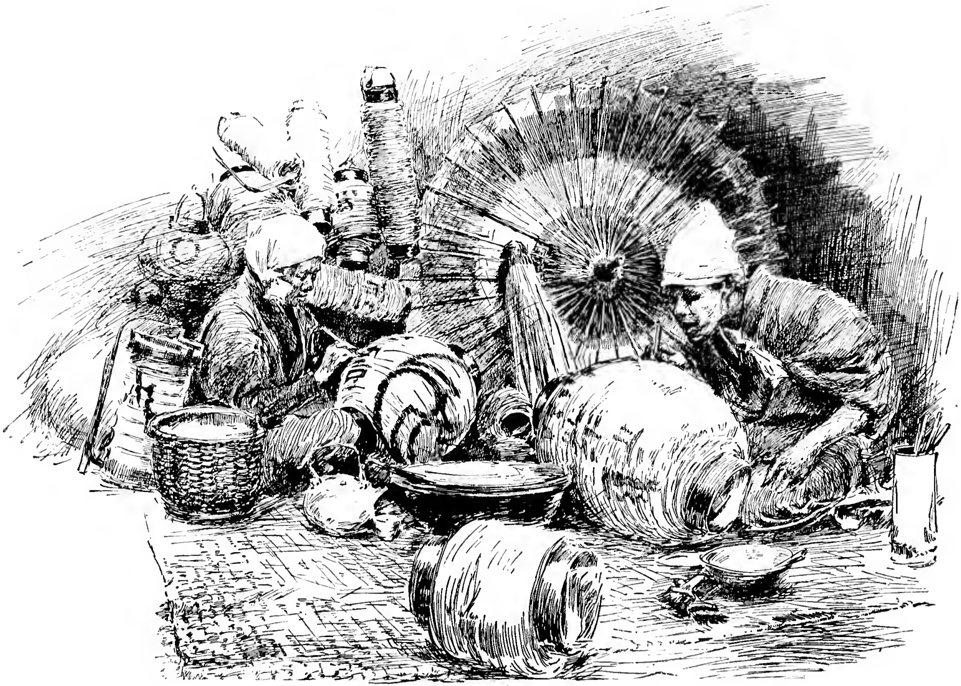
elevations which intersected the path of totality. Still farther to the northeast, and in the very accessible region of Tucuman, reached by rail from Buenos Ayres, the chances of a cloudy sky were found near the maximum. Coming next to northeastern Brazil, in the neighborhood of Ceará, a locality easy to reach, and with all the astronomical conditions most favorable (the Sun being near the zenith, and the total eclipse approaching five minutes in duration), clouds, most unfortunately, were to be expected. But in Africa, the chances were greatly improved, and the eclipse was thought likely to be seen in cloudless skies, though the indications regarding haze (a great foe to observation of the corona) were not hopeful. This is sufficient to indicate the general process of such investigation, and the results of the actual observations of the eclipse eminently justified this preliminary research.

The selection of sites for observation involves a good deal in addition to mere meteorology. The station ought not to be more than eight or ten miles from the middle of the belt of totality, and many an unimportant hamlet which would otherwise slumber peacefully through all time in its native oblivion has thus been raised into fleeting glory; it should be sufficiently elevated to escape low-lying river or marsh mists (which not only thicken the atmosphere, but in some localities would endanger the health of the expedition); because of the exceeding weight of apparatus and supplies, it should be comparatively easy of access by steamer, train, good wagon road, or mule path; an abundant supply of fresh water is necessary for photographic purposes, and within the tropics it must be artificially cooled; while the chief of a large expedition has always to weigh carefully the advantage of locating near a populous town, in order to insure the readiness of native workmen in abundance for the characteristic service of the region,[20] and particularly for all the heavier labor. If, in addition to these essentials, a few comforts in living can be secured for the astronomer and his followers, they will not be accepted otherwise than gratefully; but, contrary to the usual notion, any one adopting the astronomer's profession must be ready to eschew personal luxury.

Our selection of an observing station in Japan in 1887 was at first a difficult matter.[21] The consequences to an expedition are so momentous, that, in considering the several points geographically possible, the greatest care must be exercised. If any locality that was available prove clear on the important day, while that actually occupied is cloudy, endless regret must follow. And so, many days of deliberation followed our arrival in the 'Land of the Rising Sun.' Nikko, the beautiful summer resort, among mountains, groves, and temples, was the most attractive from a personal standpoint, but as a daily afternoon thunder-storm was the usual programme during August, it was reluctantly abandoned. The frequent sight of coolies in their rainy-day dress (shown on page 209) was not particularly reassuring for any locality. The city of Niigata on the west coast was considered, but its selection involved either several

[20] To instance the lantern makers of Japan, — shown at their work on the following page, — whose deft fingers and airy constructions were repeatedly serviceable in a variety of optical and photographic experiments conducted by our expedition.

[21] For the most part, the stations of the Japanese weather service, at which cloud observations had been made in previous years, were on the coast, where it seemed undesirable to locate on account of the great probability of thick haze on August afternoons.



Japanese decorating Lanterns

days at sea, or a long overland journey by pack-horse and *kuruma*, with a ton or two of instruments. That

Japanese Coolie in Rainy-Day Costume

locality, however, was weighed in the balance for several days against Shirakawa, an inland city but 113 miles from Tōkyō by rail, and which was finally selected after full consultation with Dr Knipping, then Meteorologist of the Imperial Weather Service. Here, by permission of His Excellency, Count Oyama, Secretary of War, the instruments were mounted at the top of the old castle. The dwellings had been burned in the revolution of 1868, but three tiers of stone embankments surrounded by a moat rose picturesquely nearly a hundred feet above the town, — an ideal situation, combining nearly all the advantages an astronomical observer could desire.

Strolling up the grassy path, with insects humming and buzzing all about, the peaceful sunshine lying silently over the grim stone walls, and the lotus dreaming in the moat, it was hard to imagine that only twenty years before had been fought here a bloody battle, as this last stronghold of the once all-powerful Shoguns fell before the Mikado's conquering forces. But so it was, — and now these same stone embankments were crowned by the houses and white tents of an American eclipse expedition, while gnarled pines were picturesquely rooted here and there, and over all the ruin climbed ivy and swinging festoons of white roses.

All scientific expeditions have indeed two sides, — the detail and accomplishment of noble work, and the practical and sometimes adventurous experiences of those concerned in it. Often the latter read like a veritable romance.

A popular and entertaining account of the Spanish eclipse of 1860 is given by Sir Francis Galton,[22] who accompanied the English expedition on the *Himalaya*, and settled at the village of La Guardia, near Logroño. With the intention of measuring the coronal heat, he had

[22] *Vacation Tourists*, i. (London, 1861), 422.

Eclipse-camp in the Old Castle, Shirakawa, Japan, 1887 taken an actinometer; but finding that its thermometer was broken, he speaks of 'a rising feeling of exultation' that there was now no reason why he should be obliged to spend the precious three minutes of totality 'in poring on an ascending column of blue fluid in a graduated stem, and noting down the results by a feeble lamplight.' Instead, he was free to enjoy the glories of the spectacle, to sketch the corona, and to note the color of the eclipse-light. So impressive was the whole phenomenon that he forgot to record the beginning of totality. The entire narrative is well worth the reading; and equally another attractively written account of an eclipse expedition, by the late Professor TYNDALL,[23] who went to Algeria in 1870, and established himself at Oran. It is perhaps none the less entertaining because of the clouds which at intervals covered 'the silver sickle' of the Sun, and finally shrouded the total phase in a darkness which the coronal rays were too feeble to penetrate.[24] The narratives of modern expeditions form a voluminous literature, confined for the most part to the periodicals of the day.[25]

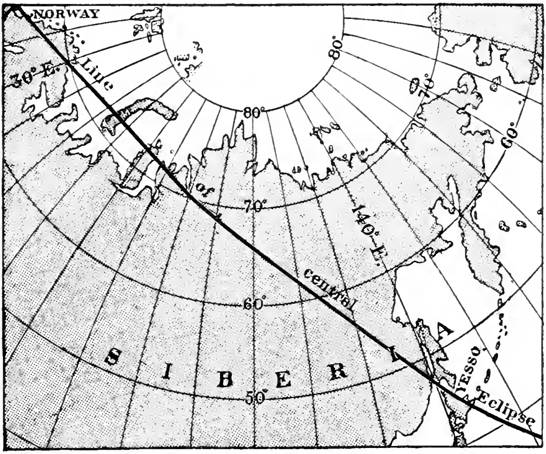
[23] *Hours of Exercise in the Alps* (New York, 1873), p. 429.

[24] In his willing exile for a half-year on the island of Ascension, observing the opposition of Mars in 1877, (one of the most favorable opportunities of the century for determining the Sun's parallax,) D^r GILL, now her Majesty's Astronomer at the Cape, had the good fortune to be accompanied by his wife; and M^rs GILL's delightful book, relating all the varied adventures in her charming style, and entitled *Six Months in Ascension, an Unscientific Account of a Scientific Expedition* (London, 1880), is a model narrative. The occasion was not, indeed, an eclipse expedition; but, in their outward aspect, all such trips, whether for eclipses, transits of Venus, or an opposition of Mars, have much in common.

[25] Consult (under the heading *Eclipse*) the lists already cited on page 46.

The eclipses of the future will prove no less interesting than those of the past have been. If only the approximate track of any totality during the next forty years is desired, the map on page 223 will amply suffice, while the table preceding it shows the length of the total phase, and the years in which the eclipses of the same Saros-series fall.

Great interest already attaches to the next total obscuration of the Sun, occurring 9th August 1896, and visible in



PATH OF THE NEXT TOTAL ECLIPSE, 9th August 1896

Norway and Sweden, Nova Zembla, northern and eastern Siberia, and Yesso, the northern island of Japan. Totality lasts nearly three minutes, and the adjacent map shows the path of the lunar shadow in all necessary detail. The most accessible station will be on the west coast of Norway, which the path of central eclipse intersects at latitude 67°, and where the duration of total phase will be about $1^m\ 35^s$. The eclipse, however, will be total very soon after sunrise; but, if accessible, the ice-fields of Sulitjelma, 6,200 feet elevation, and about thirty miles inland, may afford a good station, although rather remote from the central line. Other localities, favorably placed geographically, have been selected for computation by Mr Downing, Superintendent of the British Nautical Almanac, with the results embodied in the following table.

STATIONS FOR OBSERVING THE TOTAL ECLIPSE

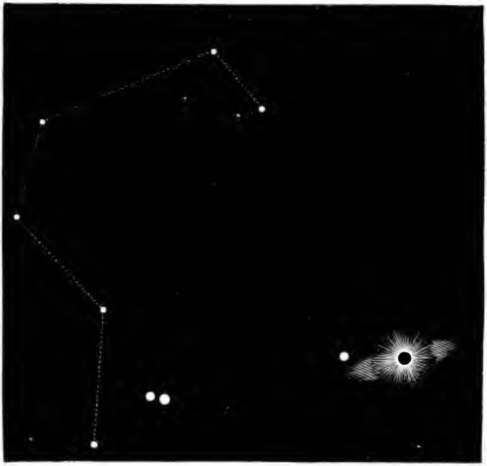
SUNDAY, 9TH AUGUST 1896

Locality on Line of Central Eclipse	Longitude (East of Greenwich)		Latitude (North)		Total Eclipse begins (Local Mean Time)				Duration of Total Eclipse		Sun's Altitude
	°	′	°	′	h	m	s		m	s	°
Varanger Fjord, near Vadsö	29	45	69	52	5	55	37	A. M.	1	46.4	15
West coast of Nova Zembla	51	30	72	1	7	28	59	A. M.	1	59.9	22
East Siberia, River Amur .	137	0	50	12	2	27	31	P. M.	2	45.9	46
East Siberia, Fish River . .	139	30	48	0	2	43	47	P. M.	2	44.2	45
Yesso, near Horonai	142	45	44	47	3	5	36	P. M.	2	40.3	43

As is usual, much of the land region of this eclipse track is of doubtful accessibility (in Eastern Siberia); but all the foregoing stations seem to be within easy reach, also many additional ones in the island of Yesso. Meteorological observations are in progress to determine the most favorable localities in that island, and already astronomers in Europe and America are beginning their best plans for the thorough observation of this totality.

The spectacular appearance of the heavens around the Sun will vary greatly from one obscuration to another. Sometimes no stars will be seen without a telescope, while again bright stars and planets will abound, wonderfully enhancing the beauty and magnificence of the corona. In so far as stellar objects alone are concerned, total eclipses occurring in June are the most brilliant, because the bright stars of Taurus, Gemini, and Orion will generally be visible near the Sun. Often, however, the configurations of the more conspicuous planets will have more to do with this element of totality than all the fixed stars put together.[26]

[26] The eclipse of 1896 is a case in point, as the accompanying picture clearly shows. The direction *up* is toward the north pole of the heavens, and toward the left is east. About 10° east of the



Bright Stars and Planets near the Sun
at Mid-Eclipse, 9th August 1896

Sun will be Regulus (α Leonis), and above it the well-known asterism of 'the Sickle.' Then to the right, and very close together, will be Mercury and Venus in order; and quite near the Sun, Jupiter will appear, almost within the streamers of the outer corona.

Magnificent India will be the scene of an eclipse lasting two minutes, 22d January 1898; and our own country will again be traversed by the lunar shadow, 28th May 1900, when the Southern States will be the two minutes' Mecca for scientific pilgrims. An unusually long eclipse, six minutes in duration, may be seen from Sumatra, Borneo, and Celebes, 18th May 1901; and another track crosses the Atlantic Ocean from Labrador to Spain, Egypt, and Arabia, 30th August 1905, with totality lasting for four minutes. From Russia and Persia two fine ones will be observable, 14th January 1907, and 21st August 1914; while the intermediate eclipse of 10th October 1912 may be witnessed for one minute in South America, and another two minutes in duration will visit the same general region, 3d February 1916. Then comes the return of the American eclipse of 1900, when the United States from Oregon to Florida will again be favored by the shadow path for two minutes, 8th June 1918; and South America, apparently taking the giant's share of daytime darkness, will be shrouded for six minutes, 29th May 1919, — a second return of the totality so successfully observed at Caroline Island in 1883. An eclipse will be visible in California and Mexico, 10th September 1923, which may possibly be total at San Francisco and the Lick Observatory.

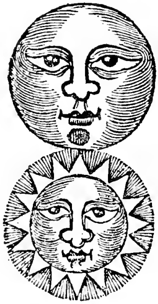
From the chart of future shadow paths on page 223, it will be seen that no total eclipse is visible in New England or the Middle States until 24th January 1925. The totality belts of the great eclipse of 1904, and of the eclipses of 1908 and 1911, unfortunately lie for the most part over the unavailable wastes of the Pacific. To avoid confusion on the map, the paths of future eclipses are not all given after the year 1937.

As for eclipses beyond this date and visible in the eastern part of the United States, they are few and unimportant for the next century. The Sun may rise entirely eclipsed at Boston, 2d October 1959, but totality will be very short. On 7th March 1970, there will be another brief totality, this time in Florida. But not until early in the twenty-first century will the path of any total eclipse traverse a large area of the United States: then, if the charts of OPPOLZER can be trusted, two totalities near midday will occur in the region of the Mississippi; the first of them. 21st August 2017, with a line from Oregon to South Carolina; and the second, 8th April 2024, with a track passing northeasterly from Austin, Texas, to the city of Washington, almost duplicating the path of the eclipse of 1900, and perhaps again exhibiting the spectacle of the corona at Boston. But present enthusiasm for these far-away darkenings of the Sun is naturally feeble.

In spite of the number constantly occurring, certain regions of our globe must wait a long time for a total eclipse to visit them. Scotland, for instance, will not see another until the twenty-second century, and London must possess itself in patience for nearly five hundred years. There will, however, be a very short obscuration in England, 29th June 1927, the track lying from the Isle of Anglesey across Northumberland, and thence through Norway and Sweden. The briefness of totality constitutes its particular interest, for the apparent diameters of Sun and Moon will be so nearly equal that the red prominences may appear, not as disconnected jets of brilliant flame, but the chromosphere may be visible as a continuous ring of rosy light encircling the dark Moon with a novel glory.

Totality of the Saros series of 1883 and 1901 increases in duration with each return until the middle of the twentieth century; and the great eclipses of 20th June 1955 (visible in India, Siam, and Luzon), and 30th June 1973 (in Sahara, Abyssinia, and Somali, as the chart shows), will doubtless exhibit a longer totality than any others during the thousand years preceding.

An eclipse, occurring 11th August 1999, will be visible and total in England, the path crossing Cornwall and Devonshire. By that remote epoch, at least, when the generation now intently watching the final eclipses of the nineteenth century may have penetrated farther mysteries of space and time, I faintly indulge the hope that a new and current edition of *Total Eclipses* may be forthcoming. But, be that as it may, one can be sure that always 'the same eclipses run their steady cycle'; that eager eyes will await them in the future as in the past; and that constantly improving facilities will continue to question problems yet unsolved, so long as 'the blue sky bends over all.'



LIST

OF PAST AND FUTURE

TOTAL ECLIPSES OF THE SUN

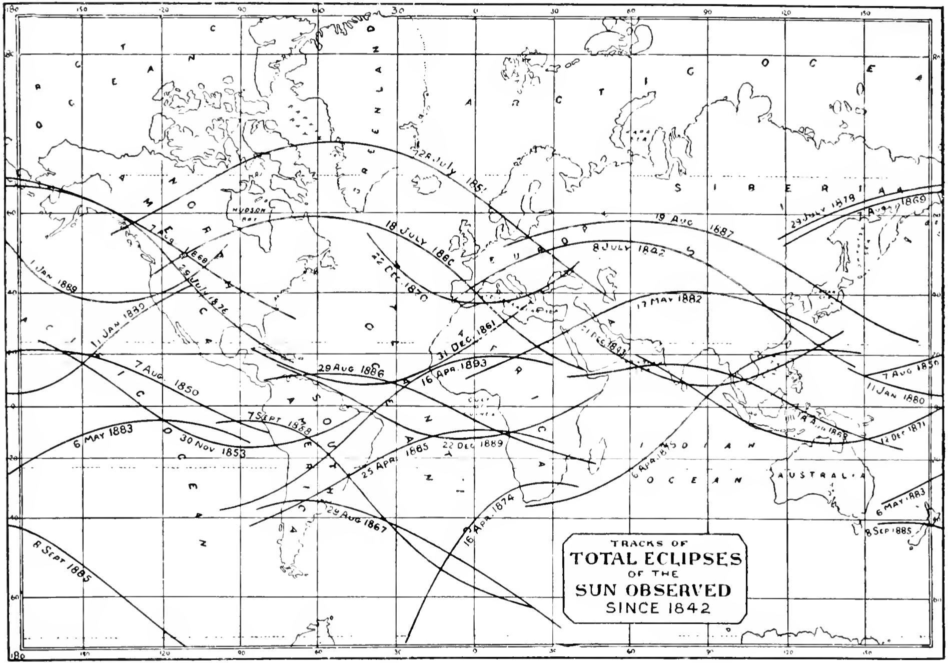
WITH CHARTS OF THE SAME

A. D. 1842–1973

TOTAL ECLIPSES OF THE SUN OBSERVED SINCE 1842

DATE (Civil)	Greenwich Hour	Maximum Totality	SAROS-RETURNS											
	h	m s												
1842, July 8	6.9 A.M.		{1806} 1842											
1843, Dec. 21	5.1 A.M.			1843										
1850, Aug. 7	9.5 P.M.				1850									
1851, July 28	2.4 P.M.					1851								
1853, Nov. 30	7.2 P.M.						1853							
1858, Sept. 7	2.7 P.M.							1858						
1860, July 18	2.1 P.M.	3 50	1860											
1861, Dec. 31	2.0 P.M.			1861										
1865, Apr. 25	1.9 P.M.								1865					
1867, Aug. 29	1.6 P.M.									1867				
1868, Aug. 18	5.2 A.M.	6 46			1868									
1869, Aug. 7	9.8 P.M.	3 47				1869								
1870, Dec. 22	0.3 P.M.	2 15									1870			
1871, Dec. 12	4.0 A.M.	4 25					1871							
1874, Apr. 16	1.3 P.M.	4 10										1874		
1875, Apr. 6	6.5 A.M.	4 38											1875	
1878, July 29	9.4 P.M.	3 12	1878											
1880, Jan. 11	10.8 P.M.	2 10		1880										
1882, May 17	7.7 A.M.	1 48												1882
1883, May 6	9.8 P.M.	5 56							1883					
1885, Sept. 8	9.3 P.M.	2 30								1885				
1886, Aug. 29	1.0 P.M.	6 34			1886									
1887, Aug. 19	5.3 A.M.	3 48				1887								
1889, Jan. 1	9.3 P.M.	2,15									1889*a*			
1889, Dec. 22	0.9 P.M.	4 15					1889*b*							
1893, Apr. 16	2.5 P.M.	4 46											1893	
			{1896, 1914, 1932}	{1898, 1916, 1934}	{1904, 1922}	{1905, 1923}	{1908, 1926}	{1894, 1912, 1930}	{1901, 1919, 1937, 1955, 1973}	{1903, 1921}	{1907, 1925}	{1910, 1928}	{1911, 1929}	{1900, 1918, 1936}

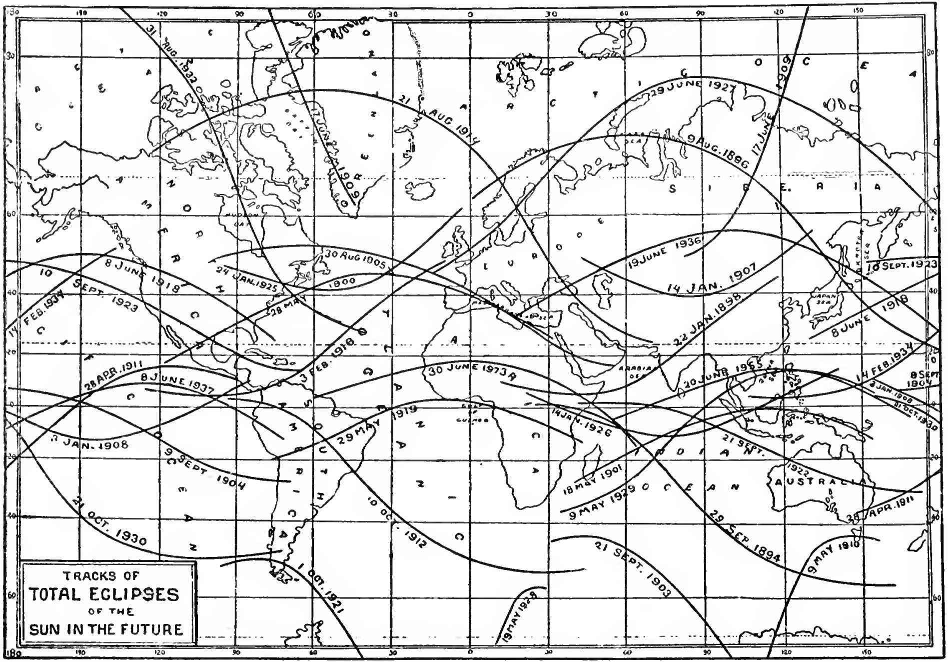
N. B. — Follow across the page horizontally until a repetition of the year in the first column is met; then eclipses of that series occur in all years found in the same vertical column with the repeated year.


TRACKS OF
TOTAL ECLIPSES
OF THE
SUN OBSERVED
SINCE 1842
28 July 1851
18 July 1860
19 Aug 1887
8 July 1842
29 July 1878
7 Aug 1869
1 Jan 1889
11 Jan 1880
7 Aug 1850
29 Aug 1886
16 Apr. 1893
31 Dec. 1861
22 Dec. 1870
17 May 1882
7 Sept 1858
30 Nov 1853
6 May 1883
25 Apr. 1865
22 Dec 1889
29 Aug 1867
16 Apr. 1874
6 Apr. 1875
12 Dec 1871
8 Sept 1885
HUDSON BAY
GREENLAND
SIBERIA
AUSTRALIA

TOTAL ECLIPSES OF THE SUN IN THE FUTURE

DATE (Civil)	Green-wich Hour	Dura-tion of Totality	SAROS-RETURNS											
			1858	{ 1842 1860 1878 }	{ 1843 1861 1880 }	1882	{ 1865 1883 }	{ 1867 1885 }	{ 1850 1868 1886 }	{ 1851 1869 1887 }	{ 1870 1889*a* }	{ 1853 1871 1889*b* }	{ 1874 1892 }	{ 1875 1893 }
	h	m s												
1894, Sept. 29	5.7 A.M.	0 11	1894											
1896, Aug. 9	5.0 A.M.	2 47		1896										
1898, Jan. 22	7.4 A.M.	2			1898									
1900, May 28	2.8 P.M.	2				1900								
1901, May 18	5.6 A.M.	6					1901							
1903, Sept. 21	4.5 A.M.	2						1903						
1904, Sept. 9	8.7 P.M.	6							1904					
1905, Aug. 30	1.2 P.M.	4								1905				
1907, Jan. 14	6.0 A.M.	2									1907			
1908, Jan. 3	9.7 P.M.	4										1908		
1909, June 17	11.5 P.M.	1												
1910, May 9	5.6 A.M.	4											1910	
1911, Apr. 28	10.4 P.M.	5												1911
1912, Oct. 10	1.7 P.M.	1	1912											
1914, Aug. 21	0.4 P.M.	2		1914										
1916, Feb. 3	4.1 P.M.	2			1916									
1918, June 8	10.1 P.M.	2				1918								
1919, May 29	1.2 P.M.	6					1919							
1921, Oct. 1	0.4 P.M.	2						1921						
1922, Sept. 21	4.6 A.M.	6							1922					
1923, Sept. 10	8.9 P.M.	4								1923				
1925, Jan. 24	2.8 P.M.	2									1925			
1926, Jan. 14	6.6 A.M.	4										1926		
1927, June 29	6.5 A.M.	1												
1928, May 19	1.2 P.M.	3											1928	
1929, May 9	6.1 A.M.	5												1929
1930, Oct. 21	9.8 P.M.	1	1930											
1932, Aug. 31	7.9 P.M.	2		1932										
1934, Feb. 14	0.7 A.M.	2			1934									
1936, June 19	5.3 A.M.	3				1936								
1937, June 8	8.7 P.M.	6					1937							
1955, June 20	4.2 A.M.	7					1955							
1973, June 30	11.7 A.M.	7					1973							

N. B. — Follow across the page horizontally until a repetition of the year in the first column is met; then eclipses of that series occur in all years found in the same vertical column with the repeated year.


TRACKS OF
TOTAL ECLIPSES
OF THE
SUN IN THE FUTURE
31 AUG. 1932
17 JUNE 1909
21 AUG. 1914
29 JUNE 1927
9 AUG. 1896
17 JUNE 1909
30 AUG. 1905
24 JAN. 1925
1900
28 MAY
8 JUNE 1918
10 SEPT. 1923
14 FEB. 1934
19 JUNE 1936
14 JAN. 1907
22 JAN. 1898
16 SEPT. 1923
8 JUNE 1918
3 FEB. 1916
28 APR. 1911
8 JUNE 1937
30 JUNE 1973
20 JUNE 1955
14 FEB. 1934
8 SEPT. 1904
3 JAN. 1908
21 OCT. 1930
29 MAY 1919
14 JAN. 1926
21 SEPT. 1922
3 JAN. 1908
9 SEPT. 1904
18 MAY 1901
9 MAY 1929
21 OCT. 1930
10 OCT. 1912
29 SEP. 1894
28 APR. 1911
1 OCT. 1921
21 SEPT. 1903
9 MAY 1910
19 MAY 1928
ARCTIC OCEAN
NORTH AMERICA
GREENLAND
EUROPE
SIBERIA
PACIFIC
ATLANTIC OCEAN
AFRICA
SOUTH AMERICA
INDIAN OCEAN
AUSTRALIA
HUDSON BAY
JAPAN SEA

BIOGRAPHIC SKETCHES OF ASTRONOMERS WHOSE PORTRAITS APPEAR IN THIS BOOK

Sir **George Biddell Airy**, K. C. B., F. R. S., LL. D., D. C. L., (page 127,) seventh Astronomer Royal, and one of England's most eminent astronomers. Born at Alnwick, 27th July 1801, and Senior Wrangler at Cambridge in 1823, he was appointed three years later to the Lucasian Chair of Mathematics, rendered illustrious by Sir ISAAC NEWTON, one of its first occupants. In 1828 he resigned to become Plumian Professor of Astronomy and Superintendent of the Cambridge Observatory, an appointment which marked an epoch in modern astronomy; for AIRY, never content to follow in the routine footsteps of any predecessor, established methods of his own, to the great advance of the science. In the summer of 1835, the post of Astronomer Royal becoming vacant, he succeeded to this high office, which he held for 46 years; and under his direction the scientific usefulness of the Royal Observatory was greatly amplified. While his observations of the total eclipses of 1842, 1851, and 1860 were of the first order, his reductions of the Greenwich lunar and planetary observations since the time of BRADLEY in 1750, and his researches on the lunar theory (page 200), form his greatest contributions to astronomy. The titles of his published works exceed five hundred, embracing every section of astronomical and optical research; also he was an extensive author in literary and historical subjects. Elected a Fellow of the Royal Society in 1836, he was its President in 1871, and Foreign Associate of the Institute of France and of the Dutch Academy of Sciences. The gold medals and honorary titles conferred upon him, and his election to foreign academies and societies, indicate the high appreciation of his eminent worth. AIRY was President of the British Association at Ipswich, 1851; five times President of the Royal Astronomical Society; he received the Albert Medal of the Society of Arts, presented to him by the Prince of Wales; he was decorated by the Emperor of Brazil and the Emperor NICHOLAS of Russia; he belonged to the Legion of Honor of France, had decorations from Sweden, and was Chevalier of the Order 'Pour le Mérite' of Prussia. The portrait in this volume was taken on his 90th birthday. An accidental fall shortly after hastened his death, 2d January 1892. — *The Athenæum*, 1892, i. 55; *Nature*, xviii. (1878), 689, and xlv. (1892), 232; *Proceedings American Academy of Arts and Sciences*, xxvii. (1892), 446; T. COOPER, *Men of Mark*, ii. 15; E. H. YATES, *Celebrities at Home*, iii. 15; *The Observatory*, xv. (1892), 74; *Proceedings Royal Society*, li. (1892), p. i.

Friedrich Wilhelm Bessel (page 198), Director of the Königsberg Observatory, and foremost among practical astronomers. Born at Minden, 22d July 1784, he was apprenticed to a Bremen commercial house at fifteen. Anticipating a long voyage in the interest of his employers, he studied French, Spanish, and navigation assiduously, the latter turning him toward astronomy with an all-absorbing delight, as one treatise after another was mastered and a course of mathematical reading begun. His development was astonishingly swift, and original research occupied him incessantly. So brilliant and masterly had been his achievements that he soon attained the first rank as an astronomer, assisting SCHROETER at Lilienthal, and was called to the directorship of the observatory established at Königsberg in 1810 by the King of Prussia. This eminent institution and the classic work he did there form BESSEL'S greatest monument. While still young he completed his famous *Fundamenta Astronomiæ*, published in 1818, and twelve years later the *Tabulæ Regiomontanæ*, supplementary to it. Another very important result of the indefatigable activity of BESSEL was the *Gradmessung in Ost-Preussen*, published in 1838, which did for geodesy what the *Fundamenta* had accomplished for astronomy. He derived the size and figure of the earth with exceedingly close approximation; and his investigation of the distance of 61 Cygni is a classic. BESSEL contributed to every department of astronomy, and nothing passed through his hands without receiving extension or improvement. The titles of his published papers are very nearly 400 in number. The delicacy, finish, and precision of all his work are amazing. As mathematician he was of the first order; as physical experimenter in geodetic measurements, determinations of standards of weight and length, pendulum researches, and the like, his skill was not less consummate; and as astronomer, he was model and guide for all Europe. He was elected a Foreign Member of the Royal Society in 1825. A member of almost every known academy and learned society, BESSEL in 1842 visited England for the only time, and was received with distinction appropriate to his unquestioned eminence. His charming personality and his richly stored mind lent added pain to the news of his death, 17th March 1846. — Sir J. F. W. HERSCHEL, *Essays*, pp. 507, 532; *Memoirs Royal Astronomical Society*, iv. (1831), 217; xii. (1842), 442; xvi. (1847), 512; *The American Journal of Science and Arts*, iv. (1847), 305; *The Philosophical Magazine*, xxx. (1847), 201; *Literatur über* BESSEL, ENGELMANN'S BESSEL'S *Abhandlungen*, iii. (Leipzig, 1876), 504; CLERKE, *History of Astronomy* (London, 1893), p. 34.

The R^t Rev^d **Stephen Joseph Perry**, S. J., F. R. S., (page 156.) Director of Stonyhurst College Observatory, and Roman Catholic Bishop of Guiana. Born in London, 26th August 1833, and having decided upon the priesthood, his early years were spent in the Benedictine College at Douai, at Rome, and in the studies of his novitiate. Not until 1868 was he able to undertake permanently the duties which really began his scientific career. Father PERRY observed the total eclipses of 1870, 1886, 1887, and 1889*b*; and these phenomena, together with the recent transits of Venus, gave opportunity for the exercise of his remarkable powers. After the first transit of Venus trip, to Kerguelen Island in 1874, he came into prominence as a popular expounder of astronomical subjects, lecturing on several occasions at the Royal Institution, and never failing to draw large and deeply interested audiences. He observed the transit of 1882 in Madagascar. As Director of the Stonyhurst Observatory he inaugurated and maintained important observations for the advance of solar physics. Also he had charge of the teaching of mathematics, which during the last few years of his life left little time for preaching; but his earnestness and simplicity made him always impressive in the pulpit. Father PERRY was elected a Fellow of the Royal Society in 1874, was President of the Liverpool Astronomical Society, and a member of many other learned bodies. His personality was winning and lovable; his industry untiring; and to his complete devotion to the duty at hand was due his death at his post while faithfully attending to the details of observing the eclipse of 22d December 1889 at Îles du Salut. His hearty response, whenever a volunteer was called on for some difficult scientific enterprise, was ready and never-failing. 'Like the fighting bishops of old he was always eager to gird on his armor in the sacred name of Science: the discomforts and anxieties, nay the real dangers of the crusade never daunted him for a moment; and we can claim for him all the laurels due to the soldier who pays for victory with his life, and dies bravely, cheerfully, nobly at the moment of success.' Father PERRY died 27th December 1889.—*Nature*, xli. (1890), 279, 301; *The Observatory*, xiii. (1890), 81; *The Sidereal Messenger*, ix. (1890), 197; *Proceedings Royal Society*, xlviii. (1890), p. xii.

The Rev[d] Father **Pietro Angelo Secchi**, S. J., (page 43,) Director of the Observatory of the Collegio Romano. Born at Reggio in Emilia, 29th June 1818, he joined the Order of Jesuits at 15, and was two years a professor at Georgetown College, D. C. While at this post his permanent interest in solar physics was aroused by assisting Professor HENRY in the first experiments on the heat radiated by different portions of the Sun's disk. Recalled to Rome in 1850, he was made Director of the Observatory there, and so remained until his death. His interest in spectroscopy dates from M. JANSSEN's visit to Rome; and in the varied departments of research upon the Sun he was an ardent observer and voluminous writer. The literary assiduity of Father SECCHI is quite unparalleled, the list of his published papers reaching 600, many of which exhibit great originality and penetration. Besides his great work *Le Soleil*, two others may be mentioned here,—*Les Étoiles*, and *L'Unité des Forces Physiques*. He observed the eclipses of 1851, 1860, and 1870. Father SECCHI was prominent in many official commissions, holding among them an appointment by Pope PIUS the Ninth to complete the trigonometric survey of the Papal States begun by BOSCOVICH. He was Corresponding Member of the Paris Academy of Sciences; of the Royal Society of London, and a member of almost all other scientific societies and academies. So great was the public appreciation of his attainments that when the Roman College was closed, and the edict expelling the Jesuits promulgated, in October 1873, Father SECCHI was permitted to remain. He founded the famous *Società degli Spettroscopisti Italiani*. In 1867 farther distinction was conferred upon him with the award of a great French prize for his meteorograph; the Emperor NAPOLEON the Third decorated him with the Cross of the Legion of Honor, and the Emperor of Brazil bestowed upon him the Imperial Order of the Golden Rose. Father SECCHI died 26th February 1878.—*The Popular Science Monthly*, xii. (1878), 742; *Nature*, xvii. (1878), 370; *Le Révérend Père* SECCHI, *par M. l'Abbé* MOIGNO (Paris, 1879).

INDEX

*** Numbers in parentheses are dates (A. D.) of eclipses.

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