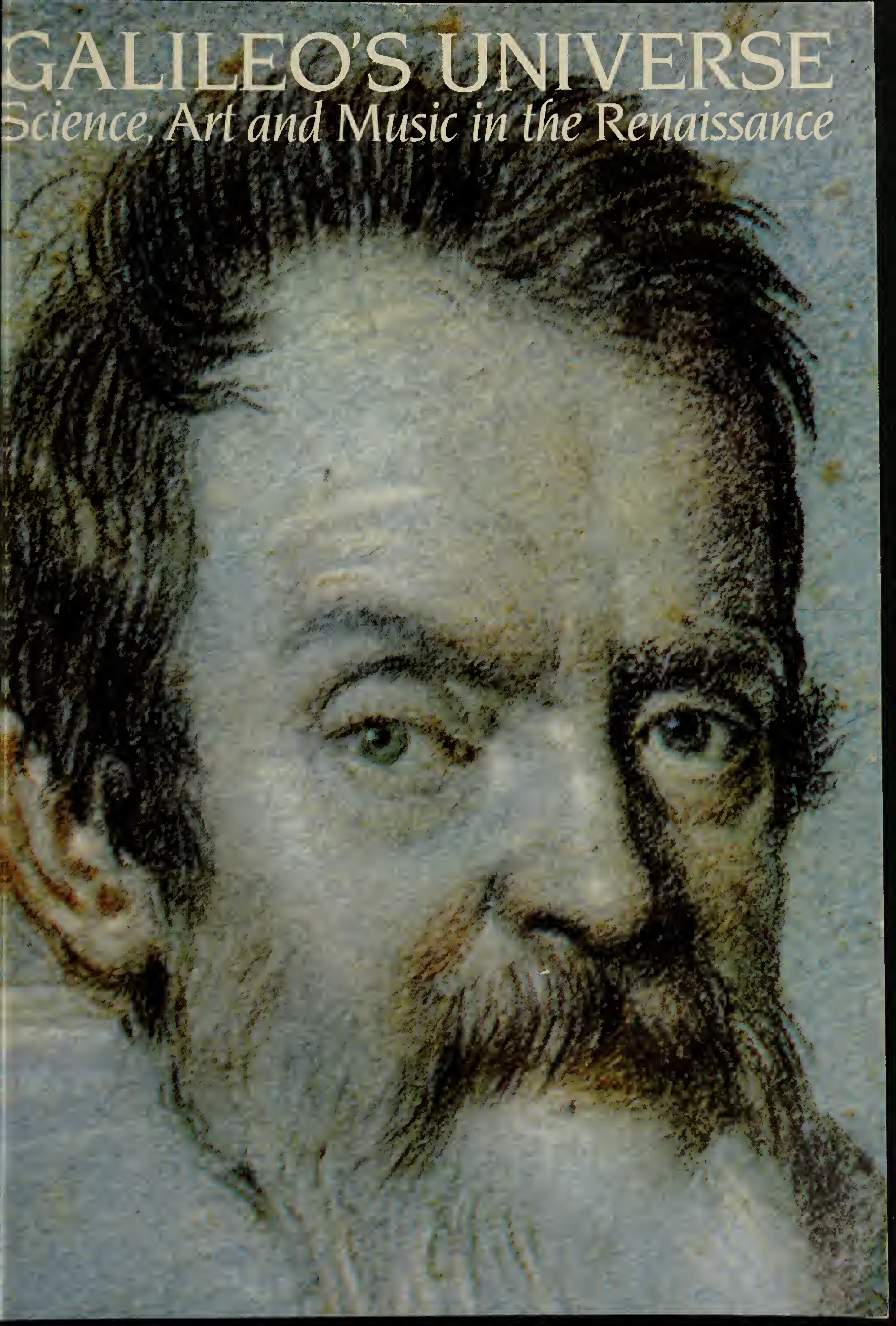
GALILEO'S UNIVERSE

Science, Art and Music in the Renaissance



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HUMANITIES WEST
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presents

GALILEO'S UNIVERSE
Science, Art and Music in the Renaissance

Contents

October 22 and 23, 1993
Herbst Theatre, San Francisco

Presented in cooperation with the
Astronomical Society of the Pacific
California Academy of Sciences
Consul General of Italy
Museo ItaloAmericano
Philharmonia Baroque

GALILEO'S UNIVERSE:
SCIENCE, ART AND MUSIC IN THE RENAISSANCE

ROGER HAHN, *Moderator, UC Berkeley*

FRIDAY, OCTOBER 22, 8–10:15 PM

8:00 pm LECTURE: *Galileo and the Transformation of Europe*

THEODORE RABB, *Princeton University*

Professor Rabb depicts the sense of disorder in Galileo's time, how the rise of a new science helped to create a renewed sense of confidence, and why Galileo's role was pivotal in its transformation.

9:15 PM "Music From the Time of Galileo"
Arcadian Academy, NICHOLAS MCGEGAN, *Director*

Sonata ottava (Book II, 1639)	Marco Uccellini (c. 1603-1680)
Sonata a tre "Il Corisino" (Book I, 1621)	Francesco Turini (1589-1656)
Sonata quarta sopra l'Aria di Ruggiero (Book III, 1613)	Salamone Rossi (c. 1570-1630)
Sonata sesta in dialogo detta la Viena (Book III, 1613)	
Sonata quarta a 1 "per sonar con due corde" (Book VIII, 1626)	Biagio Marini (c. 1587-1663)
Ballo del Gran Duca (Book IV, 1626)	Giovanni Battista Buonamente (?-1643)
Sonata quarta (Book I, 1621)	Dario Castello (?-1644)
Sonata undecima	Giovanni Battista Fontana (?-1630)
Aria quinta sopra la Bergamasca	Marco Uccellini

ELIZABETH BLUMENSTOCK, *violin*
LISA WEISS, *violin*
DAVID BOWLES, *cello*
DAVID TAYLER, *lute, archlute and baroque guitar*
NICHOLAS MCGEGAN, *harpsichord and director*

SATURDAY, OCTOBER 23, 10 AM–4:00 PM

10:00 AM LECTURE: *Seeing and Believing:*
Galileo, the Telescope and the New Universe

ALBERT VAN HELDEN, *Rice University*

Galileo took up the newly invented telescope in 1609 and began turning it into an astronomical research instrument. His discoveries flew in the face of the old Aristotelian notions of the heavens and supported the Copernican heliocentric theory. This lecture will begin with a discussion of Galileo's place in the Scientific Revolution of the sixteenth and seventeenth centuries, and then will treat his celestial discoveries with the telescope, their reception, and the resulting change in world view. Professor Van Helden will then explore how, starting with Galileo's discoveries, astronomers had to develop a visual language for communicating their new knowledge about heavenly bodies.

11:05–11:15 AM BREAK

11:15 AM LECTURE/MUSICAL PRESENTATION: *Music in the Life and Ideas of Galileo*
VICTOR COELHO, *University of Calgary*

Galileo Galilei was the son of perhaps the most important musical theorist of late sixteenth-century Italy, Vincenzo Galilei, best known to musicians as one of the founders of opera. Galileo learned music theory and lute playing from his father, and this musical training was important in his own writings and experiments. Moreover, Galileo's training as a musician allowed him a greater breadth of expression than other scientists of the time. This led Galileo to develop theories about musical aesthetics and the role of the senses, and to seek a reconciliation between music theory and the beauty of heard sound. This talk will first provide a profile of Galileo as a musician: his musical training and influences from his father, and the use of music in his writings and experiments. Finally, this lecture, enhanced with live musical examples, will place Galileo's musical training within the larger context of the connections between music and science in the 17th century.

BREAK FOR LUNCH: 12:00–1:30 PM

1:30 PM LECTURE: *The Artistic World of Galileo's Rome*
VALERIE THORNHILL, *Independent Scholar, East Yorkshire, England*

The latter half of the 16th and the early part of the 17th centuries, spanning Galileo's life, was an immensely fertile period of intellectual conflict and inquiry in the visual arts as well as the sciences. This lecture will cover Pope Sixtus V's visionary town plan for Rome with its impressive vistas, fountains and obelisks. Special emphasis will also be given to some of the results of the Barberini Pope Urban VIII's patronage: the spectacular illusionistic ceiling paintings of Pietro da Cortona and the grandeur of Bemini's architecture and sculpture.

2:15–2:20 BREAK

2:20 PM LECTURE: *Framing Galileo's Trial*
MARIO BIAGIOLI, UCLA

Very few events in the history of science have received more attention than Galileo's trial of 1633. However, while much literature has focused on its conceptual dimensions and on the specific personal interactions between Galileo and his friends and foes, it was only recently that scholars have begun to consider the role patronage may have played in the events of 1633. Given the major gaps in the available documentary evidence, Professor Biagioli will offer a possible framework for understanding the trial based on an analysis of patronage and court dynamics. He will then argue that Galileo's career was propelled and then undone by the same patronage system. The very dynamics that led to Galileo's troubles were possibly quite typical of a princely court: they resembled what was known as "the fall of the favorite."

3:05–3:10 BREAK

3:10 PM ROGER HAHN, UC *Berkeley, The Trials of Galileo*

3:20 PM *Panel with the speakers, moderated by* ROGER HAHN.

PARTICIPANTS' BIOGRAPHIES

MARIO BIAGIOLI has studied computer science at the University of Pisa in Italy, the history of photography at the Rochester Institute of Technology, the history and philosophy of science at the University of Rochester, and has received a Ph.D. in the History of Science from the University of California at Berkeley in 1989. He is currently Associate Professor of the History of Early Modern Science at UCLA, and has been Visiting Professor of the History of Science at Stanford. His publications include articles on Galileo and the relationship between science and court culture. His book, *Galileo, Courtier* is being published by the University of Chicago press in 1993.

ELIZABETH BLUMENSTOCK, violin, has been a member of Philharmonia Baroque Orchestra since its first season and serves often as concertmaster or soloist. She is also founding member of Concerto Amabile and the Artaria Quartet, and has performed with the Boston Early Music Festival Orchestra, American Bach Soloists, the Mostly Mozart Festival, the Bach Ensemble, the Santa Fe Chamber Music Festival, the Rotterdam Philharmonic and the Oakland Symphony. She has recorded for Harmonia Mundi U.S.A. and Koch International and is also organist and choir director at Holy Trinity Church in Richmond, California.

DAVID BOWLES, cello, received B.M. and M.M. degrees from The Juilliard School, and received a Certificate in baroque music performance practice from the Royal Conservatory in The Hague, Netherlands. He is currently a member of Philharmonia Baroque Orchestra, and serves often as principal and continuo cellist. He has also played continuo cello for the Gottingen Handel Festival, the baroque orchestra of St. Luke's and Capella Savaria and has performed with the Boston Early Music Festival Orchestra and the Handel and Haydn Society. He has recorded for Harmonia Mundi U.S.A., Teldec, Newport Classics and Hungaroton.

VICTOR COELHO, Associate Professor of Music History at the University of Calgary, was educated at Berkeley (B.A.) and UCLA (M.A., Ph.D), and has taught at the University of Wisconsin-Madison, the Ecole Normale Supérieure in Paris, and the University of Melbourne, Australia. Dr. Coelho is a specialist in late 16th and early 17th-century Italian music and culture, with a particular interest in interdisciplinary studies. This has led to a volume of essays entitled *Music and Science in the Age of Galileo* (Dordrecht, 1992). He is also the author of *The Manuscript Sources of 17th- Century Italian Lute Music* (Garland), and a forthcoming volume for the *Cambridge Studies in Performance Practice* series. Dr. Coelho is Editor-in-Chief of the *Journal of the Lute Society of America.*

ROGER HAHN is an internationally prominent cultural historian of science who has taught history at UC Berkeley for the last thirty years. Born in Paris, he holds a B.A. and M.A. T. from Harvard and a Ph.D. from Cornell University. He has lectured widely in various languages, including at Milan, Bologna, Florence, Rome and Erice. He is the author of books and articles on scientific institutions of the 17th and 18th centuries, the French Revolution and the history of the physical sciences. Currently he is working on a biography of the astronomer Pierre Simon Laplace.

NICHOLAS McGEGAN, harpsichord and director, was born in England, trained at Cambridge and Oxford universities as musicologist and performer, and has been Music Director of Philharmonia Baroque Orchestra since 1985. In 1990, he assumed artistic directorship of the Gottingen Handel Festival in Germany and was recently appointed Principal Conductor of the famous Drottingholm Court Theatre in Sweden. He regularly conducts orchestras such as those of San Francisco, Minnesota, St. Louis and Houston. Projects in the next season include English National Opera, Scottish Opera, the Halle Orchestra, and the City of Birmingham Symphony Orchestra. He records exclusively for Harmonia Mundi U.S.A., and with them he has directed prize-winning recordings with both Philharmonia Baroque Orchestra and the Arcadian Academy.

THEODORE K. RABB is Professor of History at Princeton University. He received his Ph.D. from Princeton, and subsequently taught at Stanford, Northwestern, Harvard and Johns

Hopkins Universities. He is the author of numerous articles and reviews, and has been editor of *The Journal of Interdisciplinary History* since its foundation. Among the books he has written or edited are *The Struggle for Stability in Early Modern Europe*, *The New History*, and *Renaissance Lives*. Professor Rabb has held offices in various national organizations, including the American Historical Association and the Social Science History Association, and has been the principal historian for a PBS multi-part television series on Renaissance history.

DAVID TAYLER, lute, archlute and baroque guitar, received his B.A. in music and interdisciplinary studies from Hunter College, and his M.A. and Ph.D. in musicology from the University of California at Berkeley. He is a member of Philharmonia Baroque Orchestra and has appeared with numerous ensembles in the United States and Europe. He is director of the U.C. Berkeley Collegium Musicum, assistant director of Amherst Early Music, Inc., and has recorded with Harmonia Mundi U.S.A., ORF, Koch International, Background Music and Arabesque.

VALERIE RALEIGH THORNHILL studied at Newnham College, Cambridge, and at the Sorbonne. After teaching for eight years in Rome, she returned to Britain in 1970 to lecture in the Italian departments at Nottingham and Warwick Universities. Besides directing summer schools at Cambridge University for UCLA and the University of Texas at Austin, she has lectured widely in the United States, Italy and Japan, and is currently leading an annual study tour on the Renaissance in Tuscany for UC Berkeley. She edited and translated the catalogue for the "Horses of San Marco" exhibition and co-founded and chairs the East Yorkshire Association of the National Trust.

ALBERT VAN HELDEN came to the United States from the Netherlands at age 15. He studied engineering at Stevens Institute of Technology, and received a Ph.D. from Imperial College, University of London. Since 1970 he has taught at Rice University where he is the Lynette S. Autrey Professor of History and where he served as chairman of the History Department from 1987-90. His research area is the history of astronomy; his major publications in this area are *The Invention of the Telescope*, *Measuring the Universe: Cosmic Dimensions from Aristarchus to Halley*, and a translation of Galileo's *Sidereus Nuncius or the Sidereal Messenger*. He is currently writing a book on the first century of telescopic astronomy.

LISA WEISS, violin, completed her undergraduate studies at the University of California at Santa Cruz and earned the first M.M. in chamber music from the San Francisco Conservatory of Music. She has received numerous awards and scholarships for chamber music performance, and has appeared at the Marlboro and Cabrillo festivals, Chamber Music West, and Monadnock Music. At home in the Bay Area, Ms. Weiss is a frequent guest artist with local early music ensembles and is a member of Philharmonia Baroque Orchestra and American Bach Soloists. She has recorded for Harmonia Mundi U.S.A., Sonic Arts and Folkways.

The ARCADIAN ACADEMY (Accademia dell 'Arcadia) was founded in Rome in 1690 as a society of artists, musicians, scholars and writers dedicated to the reform of Italian culture. The Academy grew out of the circle surrounding the flamboyant Queen Christina of Sweden, who, following her abdication from the throne in 1654, took up residence at the Palazzo Riaro in Rome, living in the greatest of style from 1659 until her death in 1680. Following her death, this brilliant circle formalized the society and became an intellectual community that was the envy of Europe.

The Academy took its name from the ancient Greek Arcadia, which had become synonymous with pastoral contentment, innocence, peace and simplicity — an environment in which music and poetry could flourish. Members took Pan pipes for their emblem, the late Queen Christina for their empress, and the baby Jesus for their protector, humble shepherds having been the first to learn of the nativity. The Arcadian Academy of the 1990's dedicates itself to the performance of the original Academy and their contemporaries.

SEEING AND BELIEVING: GALILEO, THE TELESCOPE, AND THE NEW UNIVERSE

Albert *Van* *Helden*

1. *One of Galileo's wash drawings of the* Moon; Le opere di Galileo Galilei, *ed. by* A. *Favaro* (*Florence,* 1890-1909), *vol.* 3, *part* 1, *p.* 48.

Galileo did not invent the telescope. He did something much more interesting: he turned it into a high-powered research instrument and with it made discoveries that changed the terms of the cosmological debate between the followers of Aristotle and Copernicus. It was Galileo who with his discoveries brought the so-called Great Debate to a head, and if in the short run he lost the battle against the forces of orthodoxy, he and his followers eventually won the war.

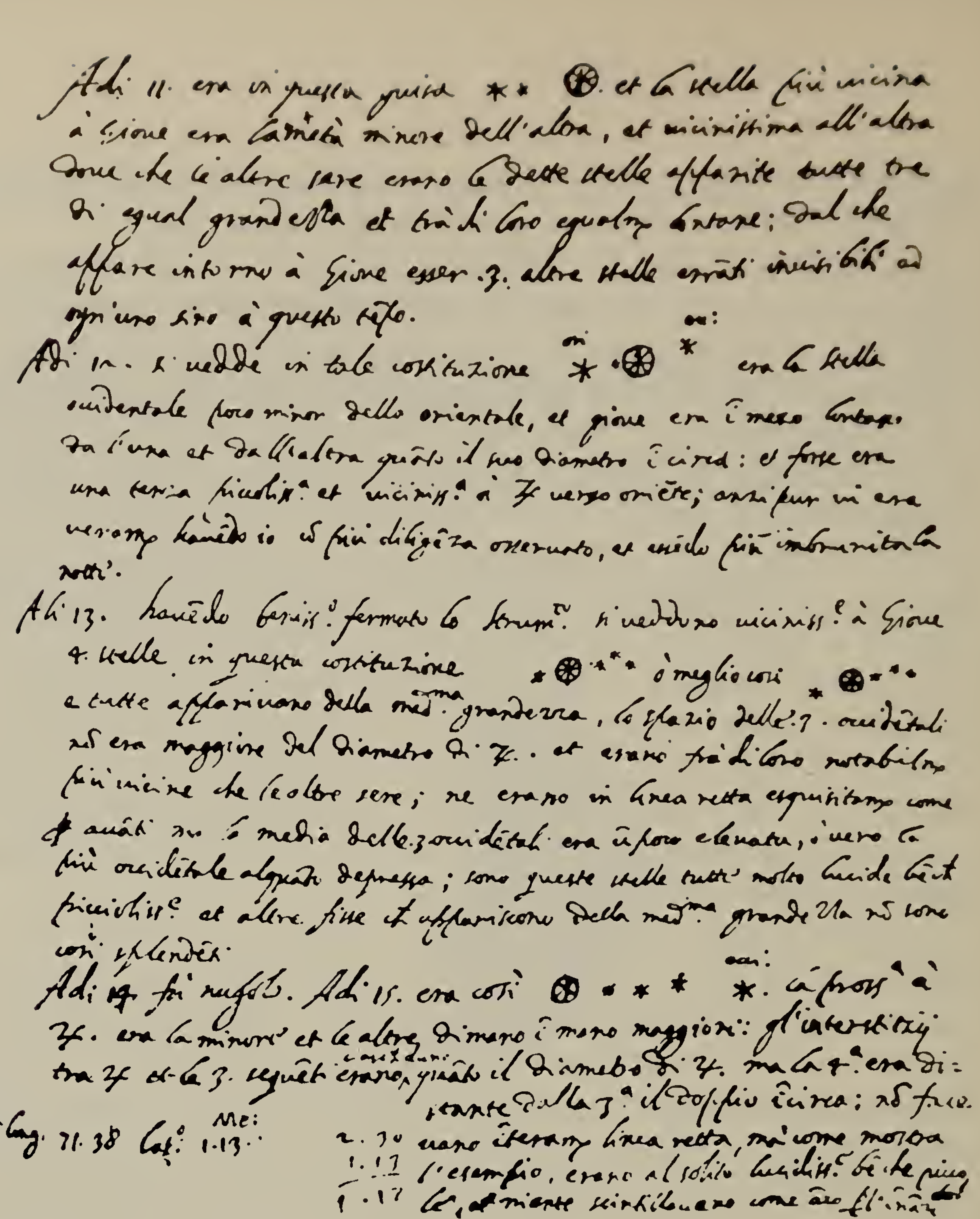
Galileo was a fairly well known professor of mathematics at the University of Padua when, in 1609, he heard that in the Netherlands artisans had invented a device for seeing faraway things as though nearby. The news intrigued him, and he set out to make such a device for himself. As a rule, university professors were not interested in the world of craft, but Galileo was an exception: he was one of the first intellectuals who was good with his hands. Since the telescope made of a concave eye-lens and a convex object-lens is rather obvious, once one begins to play with lenses of the requisite strengths, it did not take Galileo very long to make a three-powered spyglass. But whereas the spectacle-makers saw their profit in mass producing these gadgets, Galileo saw his advantage in making a more powerful device. He quickly figured out what was required, weaker convex lenses or stronger concave ones, but these were not available from the spectacle-makers. He therefore learned how to grind his own lenses, and between June and August progressed from spyglasses that magnified three times to instruments that magnified eight or nine times. At the end of August he presented such an instrument to the Senate of Venice (Padua had been incorporated into the Venetian Republic). The advantages of this device were obvious: from the towers of Venice the senators could identify ships two hours before they were visible with the naked eye.

Galileo's reward for this presentation was a doubling of his salary, which made him one of the highest paid professors of the university, and the granting of life-tenure. He was, however, not yet satisfied and carried on with his experiments in lens grinding. By the end of November of 1609 he had instruments with magnifications of up to twenty, and now he turned away from earthly matters and directed his instruments to the heavens. In the beginning of December he started his first research project in telescopic astronomy, observing the Moon through half a lunation and preparing his argument that our nearest neighbor is not perfectly smooth and spherical, as the followers of Aristotle claimed all heavenly bodies to be, but has a rough surface, marked by mountains and valleys (fig. 1). During his youth in Florence Galileo had received formal training in drawing and perspective—*disegno*—, and there is little doubt that this training allowed him to make sense out of the varying shadow patterns on the surface of the Moon.

Early in January 1610 Galileo pointed his telescope to the planet Jupiter, which was then in the best position for observations, and saw what he thought to be three little stars aligned with it. As Jupiter moved with respect to the fixed stars over the next few days, the little stars seemed to move with, but also with respect to, the planet. It took Galileo perhaps a week to figure out that he was looking at four moons of Jupiter (fig. 2). This was an amazing discovery. Since the dawn of history there had been seven planetary bodies—the Sun, the Moon, Saturn, Jupiter, Mars, Venus, and Mercury—and now here were four more, never before seen by the human eye. And if anti-Copernicans argued that the heliocentric hypothesis was absurd because it would make the Earth the only planet with a secondary planet and required two centers of rotation, it was now clear that no matter what cosmological system one believed in there were at least two centers of motion (Sun or Earth and Jupiter). Moreover, if one wanted to believe in the heliocentric cosmology the question of why the Earth was the only planet with a moon was now answered: it was not, Jupiter had four.

If Galileo had his eyes on the stars during this period, we must not think that he was an absent-minded professor. First, he realized that others might catch up to his lead, and therefore he rushed into print: by the middle of March 1610 his little book, *Sidereus nuncius* (The Sidereal Messenger, or Message, fig. 3) had been printed. Second, he named the new moons after the Medici family—the Medicean Stars—and dedicated his book to Cosimo de' Medici, the current Grand Duke of Tuscany. As a result he was appointed Mathematician and Philosopher of the Grand Duke and became one of the ten highest paid officials in Tuscany.

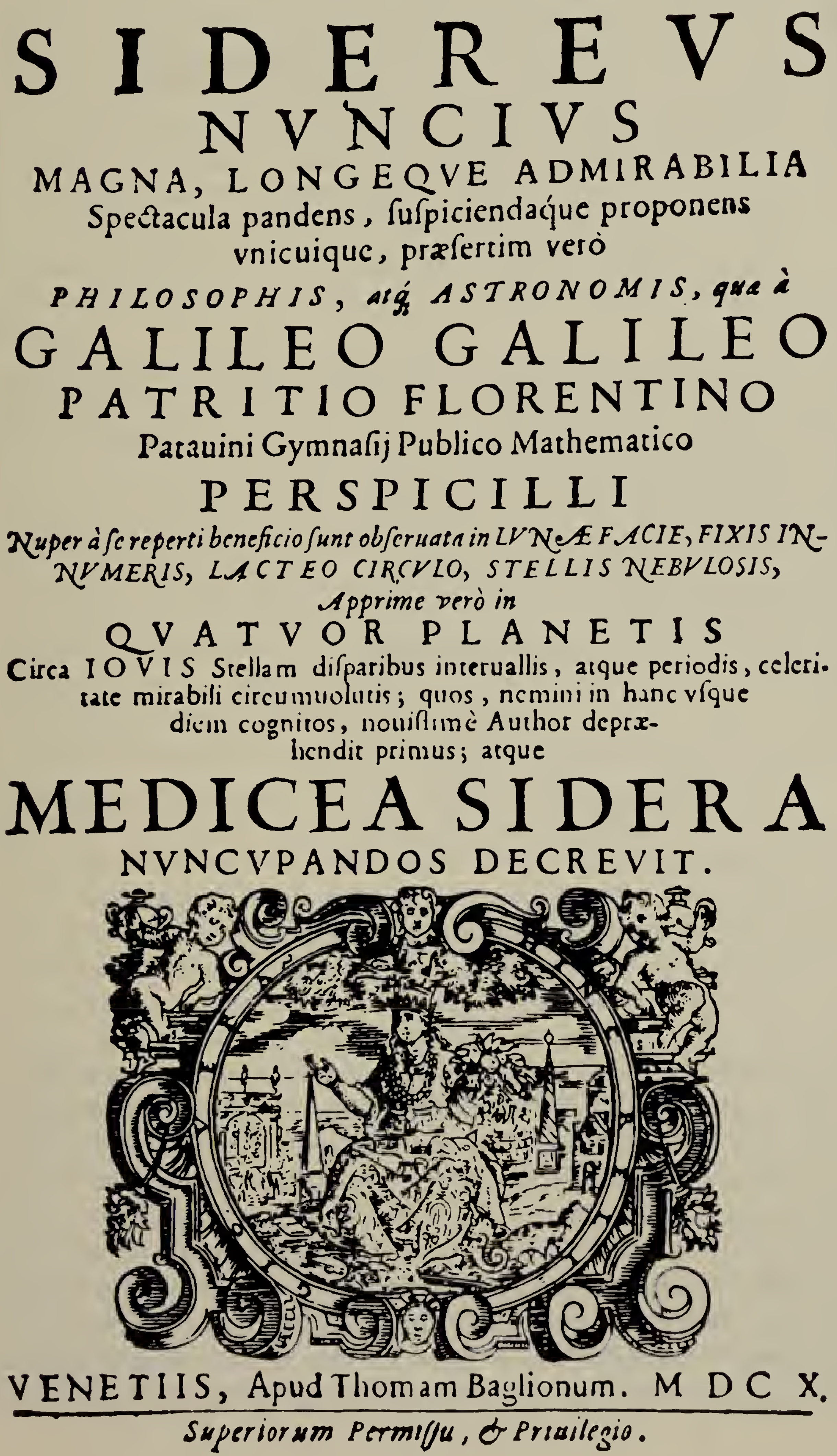
There were two aspects to the novelty of Galileo's discoveries. The first was the instrument. One could verify that on earth the telescope showed things the way they really were, but whether or



2. *Galileo's observations of Jupiter's satellites,* January 1610; Le opere di Galileo Galilei, *vol.* 3, *part* 2, *p.* 427.

not it was reliable for the heavens was another question. Since there was no theory of how the instrument worked, this was a serious problem. And since others were not able to verify Galileo's observations of Jupiter's moons, the discovery was greeted with skepticism. It was not until later in 1610 that other observers were able to confirm the existence of these bodies. The issue was settled when the Jesuit scientists in Rome had verified and certified Galileo's discoveries. In the spring of 1611 Galileo was feted in Rome by these men who may be considered the voice of Catholic orthodoxy in astronomical matters. It was at this time, at another feast, that the name *telescope* was unveiled.

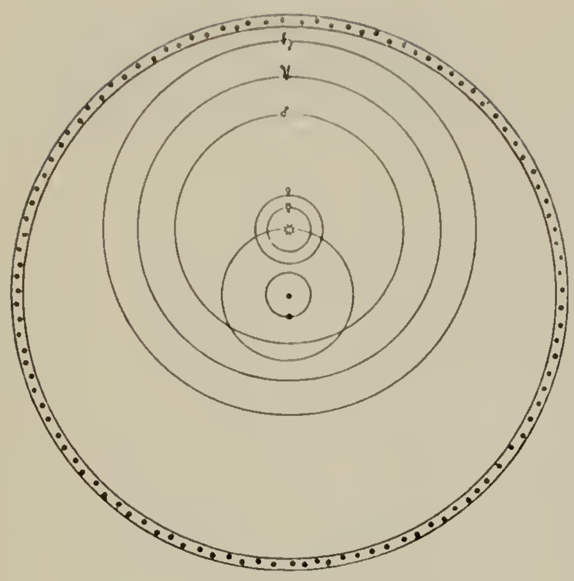
The second problem raised by Galileo's discoveries was one of interpretation. If Galileo said that the telescope resolved nebulae into individual stars, did that mean that *all* nebulae and the entire Milky Way consisted of small stars too small to see individually with the naked eye, as Galileo claimed? If the telescope showed changing shadow patterns on the Moon, did that mean that the lunar surface was indeed rough, as Galileo claimed, or was it perhaps the case that these roughnessses were internal and that they were covered with a transparent (and therefore invisible) envelope whose outer surface was perfectly smooth and spherical? If one accepted that the Moon's surface looked very much like the Earth's, one undermined the Aristotelian dichotomy between the earthly realms of corruption and change and the heavenly realm of perfection and immutability. The Earth became a heavenly body, a planet, and the Moon became an earthly body. These conclusions dovetailed nicely with the heliocentric cosmology put forward by Copernicus in his *De revolutionibus orbium coelestium* of 1543.



SIDEREVS
NVNCIVS
MAGNA, LONGEQVE ADMIRABILIA
Spectacula pandens, ſuſpiciendaque proponens
vnicuique, præſertim verò
PHILOSOPHIS, atq; ASTRONOMIS, quæ à
GALILEO GALILEO
PATRITIO FLORENTINO
Patauini Gymnaſij Publico Mathematico
PERSPICILLI
Nuper à ſe reperti beneficio ſunt obſeruata in LVNÆ FACIE, FIXIS
INNVMERIS, LACTEO CIRCVLO, STELLIS NEBVLOSIS,
Apprime verò in
QVATVOR PLANETIS
Circa IOVIS Stellam diſparibus interuallis, atque periodis, celeritate
mirabili circumuolutis; quos, nemini in hanc vſque
diem cognitos, nouiſſimè Author
depræhendit primus; atque
MEDICEA SIDERA
NVNCVPANDOS DECREVIT.

VENETIIS, Apud Thomam Baglionum. M D C X.
Superiorum Permiſſu, & Priuilegio.

3. *Title page of* Sidereus Nuncius (*Venice*, 1610).



4. *The world system of Tycho Brahe;* J. L. E. *Dryer,* The history of planetary systems from Thales to Kepler (*Cambridge,* 1906), *p.* 364.

One thing was certain. Toward the end of 1610 Galileo had discovered that Venus, as seen through the telescope, goes through phases just as the Moon does. The discovery had been verified by the Jesuit scientists in Rome, and its implication was important. In the traditional geocentric cosmological scheme, Venus was always "below" the Sun, but in the scheme of Copernicus it was sometimes nearer and at other times farther than the Sun. The phases confirmed the latter scheme and falsified the former. Venus therefore moved around the Sun, and for this reason most conservative astronomers who had to reject the traditional cosmological scheme but could not accept the Copernican system now adopted the scheme of Tycho Brahe (the great reformer of naked-eye precision observations), in which the Sun and Moon moved about the Earth but all the planets moved about the Sun (fig. 4). Clearly, within a year or so of its invention, the telescope had caused a major change in cosmology.

What prevented Church astronomers from accepting the Copernican theory, which—although it seemed at first glance to fly in the face of common sense—was a very elegant astronomy compared to the cumbersome eccentrics and epicycles of the astronomy of Ptolemy? Note that there had been very little objection to the Copernican hypothesis in the sixteenth century. Many astronomers had used Copernicus's astronomy without accepting his cosmology. Predictive astronomy was a subject full of mathematical hypotheses: one did not, after all, have to believe that epicycles really existed; they were convenient hypothetical constructs that led to reasonably accurate predictions of positions. We can count perhaps a dozen astronomers in the sixteenth century who believed that the universe was really constituted as Copernicus had proposed. It was only with the generation of Galileo and Johannes Kepler, early in the seventeenth century, that a wider discussion of Copernicus's cosmological assumption began. An open clash with religious authorities followed.

The centrality and stability of the Earth was a fundamental tenet in the Aristotelian natural philosophy that had been merged with Christian theology in the thirteenth century. But whereas Christian philosophers had enjoyed a fair degree of license when it came to interpreting biblical passages, the Reformation resulted in limits on this freedom. In Protestant theology, biblical interpretation became the right of the individual, but this did not mean that Protestant astronomers were, for the time being, any more likely to accept a heliocentric cosmology than Catholic astronomers. After all, there were a number of biblical passages that asserted the stability of the Earth, and early Protestant interpretation tended toward the literal. The Catholic Counter-Reformation began with the Council of Trent, which lasted, off and on, from 1545 to 1563. In that council Catholic theologians addressed the issue of biblical interpretation and decreed that in matters of faith and morals (a category later expanded to include astronomical issues), the Church was the judge of "true sense and interpretation." Further, if the Church Fathers (influential early Christian theologians) had agreed on the meaning of a biblical passage, then no individual was allowed to interpret it in a contrary way. The Church Fathers all agreed that the Earth was the center of the universe. Therefore, any Catholic could agree with this and argue *against* Copernicus on biblical grounds, but when it came to arguing *for* Copernicus, a Catholic was walking on thin ice.

Galileo had preferred the Copernican theory at least since 1597, but he had not taken a public stand on the issue. As a "mathematician" he was perfectly free to use it as a hypothesis. The telescope strengthened him in his Copernican convictions, and he thought that with the new evidence, he could convince the Church to allow open discussion of the biblical issue. In this he was mistaken. Because of his increasingly open Copernican stance and the furor this created among certain of the clergy, the Church decided in 1616 to examine the issue, and its theologians officially condemned the Copernican cosmology. Galileo was told henceforth not to "hold or defend" it. But he was not forbidden to discuss it as a mathematical hypothesis. It was at this time that Copernicus's *De revolutionibus* was put on the Index of Forbidden Books, established by the Council of Trent.

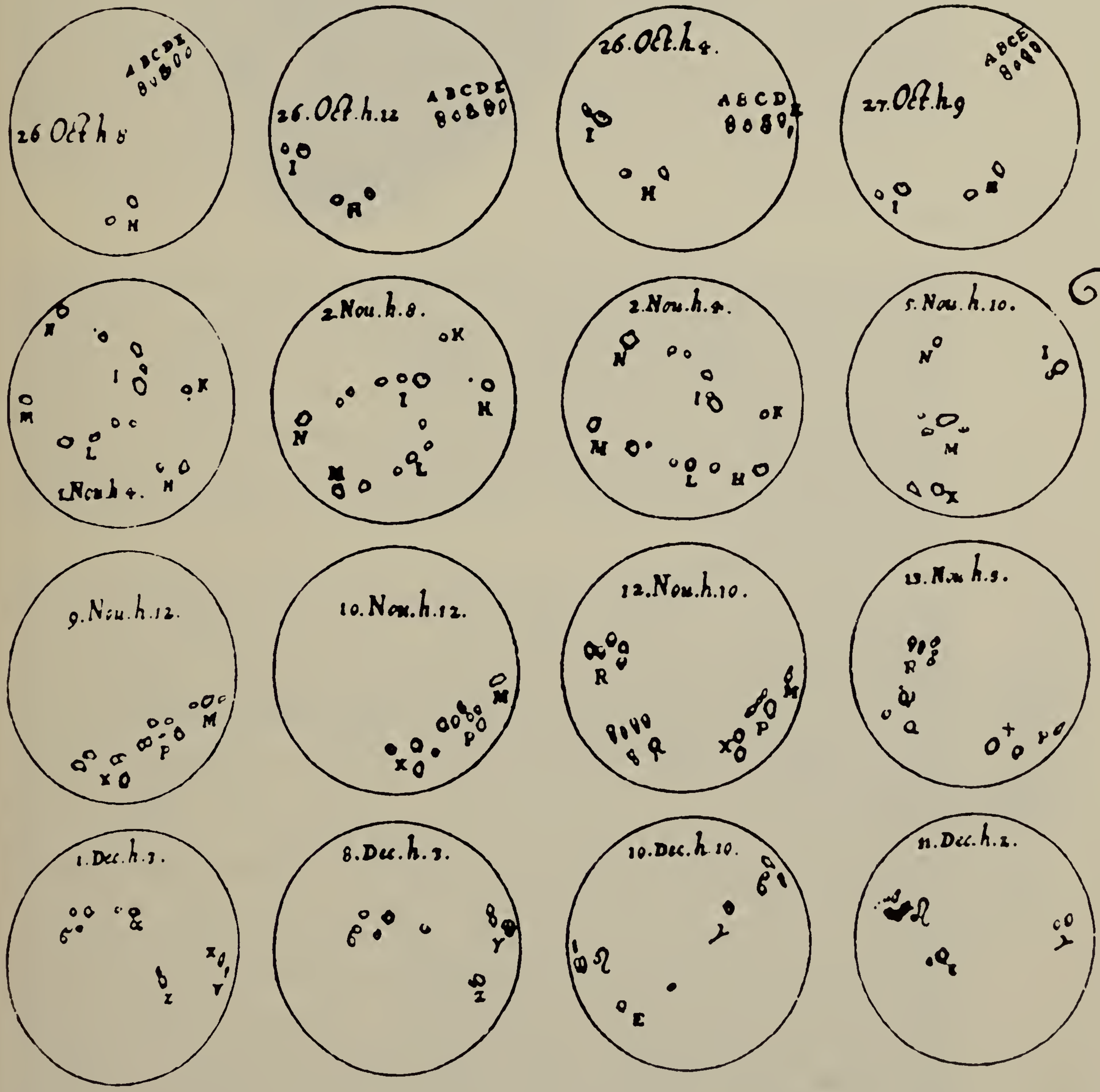
When in 1623 Maffeo Barberini, a patron and admirer of Galileo, became Pope Urban VIII, Galileo took up the issue again, and in 1632 published his *Dialogue on the Two Chief Systems of the World*, in which he discussed the cosmologies of Aristotle and Copernicus. But although he purported to speak hypothetically, he clearly favored the Copernican theory. He went so far as to offer as proof a theory of tides. As a result, his opponents pressed the Church to take action against him. In 1633 Galileo was brought to Rome and tried by the Inquisition. He was forced to abjure his errors and was condemned to house arrest for the rest of his life. His *Dialogue* was put on the Index, where it remained for over a century.

However one wanted to think about the constitution of the universe, it is clear that after 1610 Europeans lived in a different world of observable phenomena. Whereas before all heavenly bodies had been made up of some perfect substance and were perfect and unchanging—they were all "stars"—now they had acquired disturbingly imperfect and changing natures. The moon had mountains and valleys like the Earth. In 1611 Galileo and others discovered that the Sun has dark spots which come and go. Obviously the heavens were no longer perfect and unchanging. There were also many more fixed stars than had ever been thought, and four new planetary bodies that had never been seen before. What was their purpose? Whatever cosmological system one believed in, one had to admit that there was more than one center of motion in the universe. The telescope set the minds of many free to speculate about the universe, and ideas about extraterrestrial life became common in literature.

For astronomers the telescope opened up a new dimension to their practice, and the instrument was slowly incorporated into the usual complement of astronomical instruments. The earliest telescopic research projects involved preparing tables of the motions of Jupiter's satellites, cataloguing sunspots (and thereby determining the rotation period of the Sun), and mapping the Moon. It was quickly apparent that the formation of Jupiter's satellites could serve as a celestial clock which could be seen by widely separated observers, and thus the satellites promised a solution to the pressing problem of longitude. If a captain on the high seas had tables of the motions of the satellites he could check his local time against the time of the location for which the times were given, thus determining his longitude. Efforts to make accurate tables of the satellites were begun by Galileo and several others shortly after their discovery. But the desired accuracy escaped these early investigators. Galileo's early negotiations with the Spanish Crown, which had offered a prize for a satisfactory method of determining longitude at sea, bore no fruit. In the 1630s, when the Dutch offered a similar prize, Galileo tried again, this time advocating the observations of eclipses of the satellites in Jupiter's shadow—instantaneous events—but again the tables were not sufficiently accurate. It was not until the 1660s that accurate tables were published. It proved impossible, however, to make the necessary observations from the deck of a moving ship. On land the situation was different. If two observers witnessed a satellite eclipse they could by letter compare their observations and determine the difference between their local solar times, which translated directly into a longitude difference. This method was central in the tremendous improvements in maps in the seventeenth century. It was found, for instance, that the Mediterranean was too long by 500 miles!

When it came to sunspots, the problem was different. Several observers discovered them independently in 1610 and 1611, and an argument about their nature ensued. Christoph Scheiner, an astronomer at the Jesuit university at Ingolstadt, argued in several tracts early in 1612, that the spots were satellites of the Sun. His smallish and differently oriented illustrations (fig. 5) made his argument seem plausible to those who did not make their own observations. If these spots were satellites, the perfection of the Sun was saved. Galileo argued that the spots were on the Sun or in its atmosphere and that therefore one had to admit change in the heavens. His visual evidence was presented in a better way: his sunspot observations were engraved individually by a well-known Flemish engraver (fig. 6). The Sun's orientation was the same in each case, and since the Tuscan

5. *Scheiner's sunspot illustrations;* Tres epistolae de maculis solaribus (*Augsburg*, 1612).



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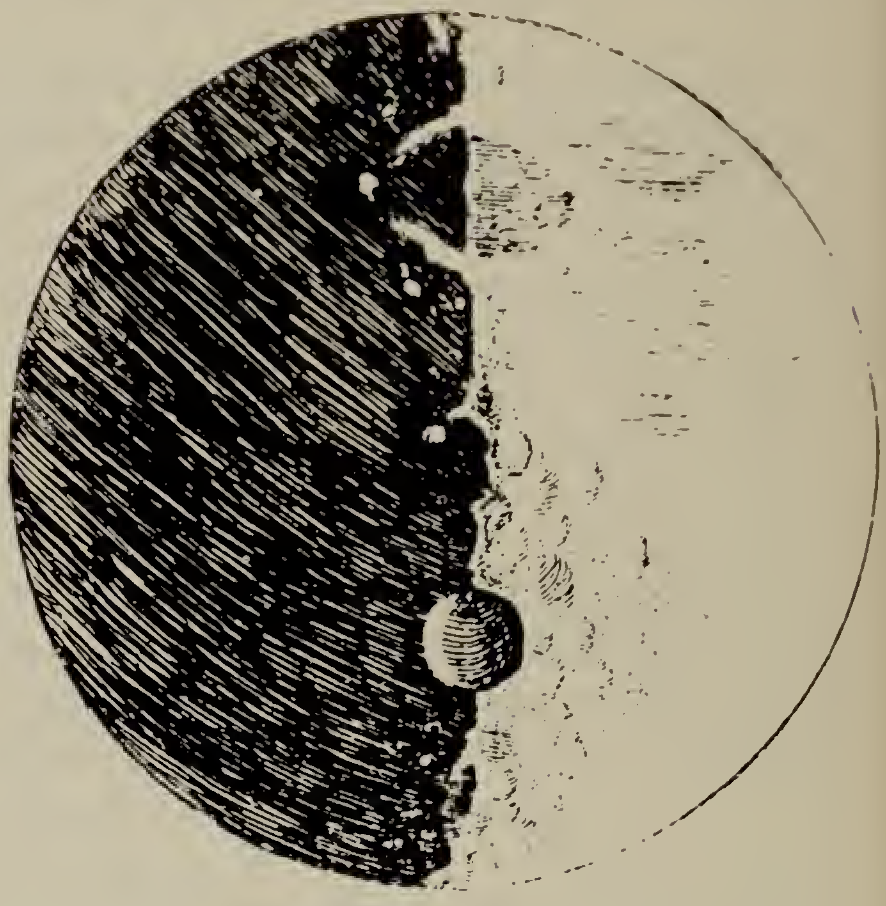
6. Galileo's sunspot observation of 25 June 1612. Reproduced from Historia i dimostrazioni intorno alle macchie solari e loro accidenti (*Rome,* 1613). *Courtsey of Owen Gingerich.*



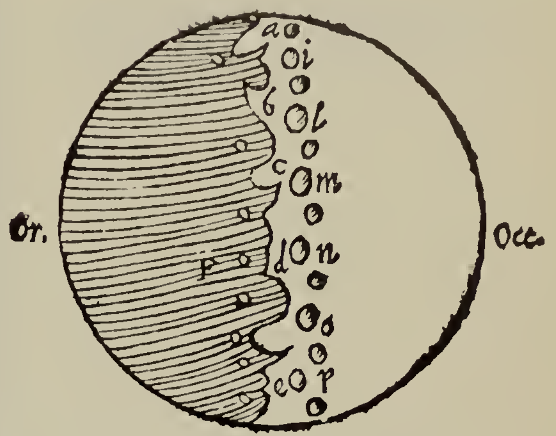
7. Galileo's illustration of the Moon with the exaggerated central "spot", Sidereus Nuncius (*Venice,* 1610)

summer weather allowed an uninterrupted series of observations over a month (something hardly possible in Germany), one could see the spots move across the face of the Sun, change their shape, be born and die. Galileo's visual evidence thus served to destroy Scheiner's verbal argument. Reluctantly convinced by Galileo's argument, Scheiner went on to make a long study of sunspots and in 1630 he published a monograph on the subject that remained definitive for over a century.

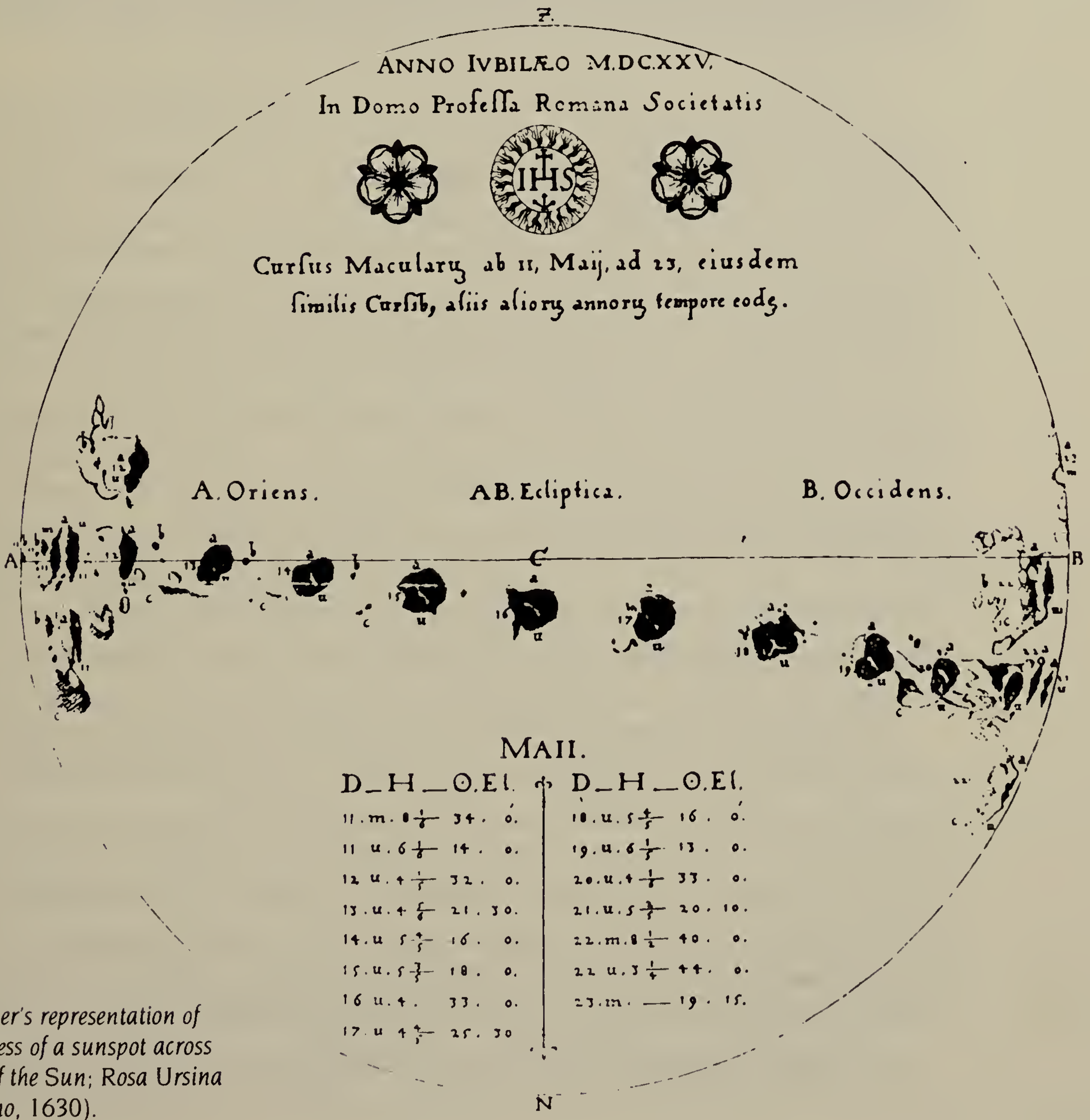
The telescope presented complicated visual evidence to the senses that was not always easily captured by words. Astronomy had been a science that was communicated by words, mathematical symbols, and diagrams. The sunspot controversy was, however, decided by a verbal argument supported by *pictorial* evidence. But just like words, mathematical symbols, and diagrams, pictures also have their conventions. The development of these conventions, which amounted to the formation of a visual language of astronomy, can best be seen in efforts to depict the Moon. In *Sidereus Nuncius* Galileo wanted to draw attention to one prominent "spot" (crater in modern terms). He showed it as in fig. 7. The problem is that this spot occupies about 20% of the visual diameter of the Moon and should therefore be visible with the naked eye. We would have used an inset, but Galileo simply exaggerated the size of the spot in order to make his argument about its size, shape, and its changing pattern of light and shadow. None of his contemporaries commented on the distortion because arranging and rearranging objects to make a point was a common practice in Baroque art and Florentine *disegno*.

The Moon presented Galileo with a problem. His argument about its earth-like nature hinged on the changes in shadow pattern, but since the rise of perspective, pictures had been "snapshots," capturing a scene at a particular instance. The essential argument was therefore carried in the verbal text, and the illustrations of the Moon were visual aids to the words: they could not themselves carry the argument. In the case of sunspots, Galileo wrote three beautifully argued letters, but here the essential part of the argument was carried by the long sequence of pictures.

Curiously, after his sunspot letters of 1613, Galileo did not again have recourse to arguments carried in pictures. In fact, in his great *Dialogue* of 1632 there were no pictures at all, only diagrams. His contemporaries did little better. Illustrations of the Moon were little more than diagrams showing generic moons, not our moon (fig. 8). Only Scheiner, in his *Rosa Ursina* of 1630 dealt seriously with the problem of pictorial evidence. In the same diagram he showed the successive shapes and positions of a single sunspot or group of spots. This was a compromise because he could not show all spots visible at one time: that would have made the diagram too messy. Scheiner therefore showed only the progression of the largest spots (fig. 9).



8. *Giuseppe Biancani's representation of the Moon*; Sphaera Mundi (*Bologna*, 1620).



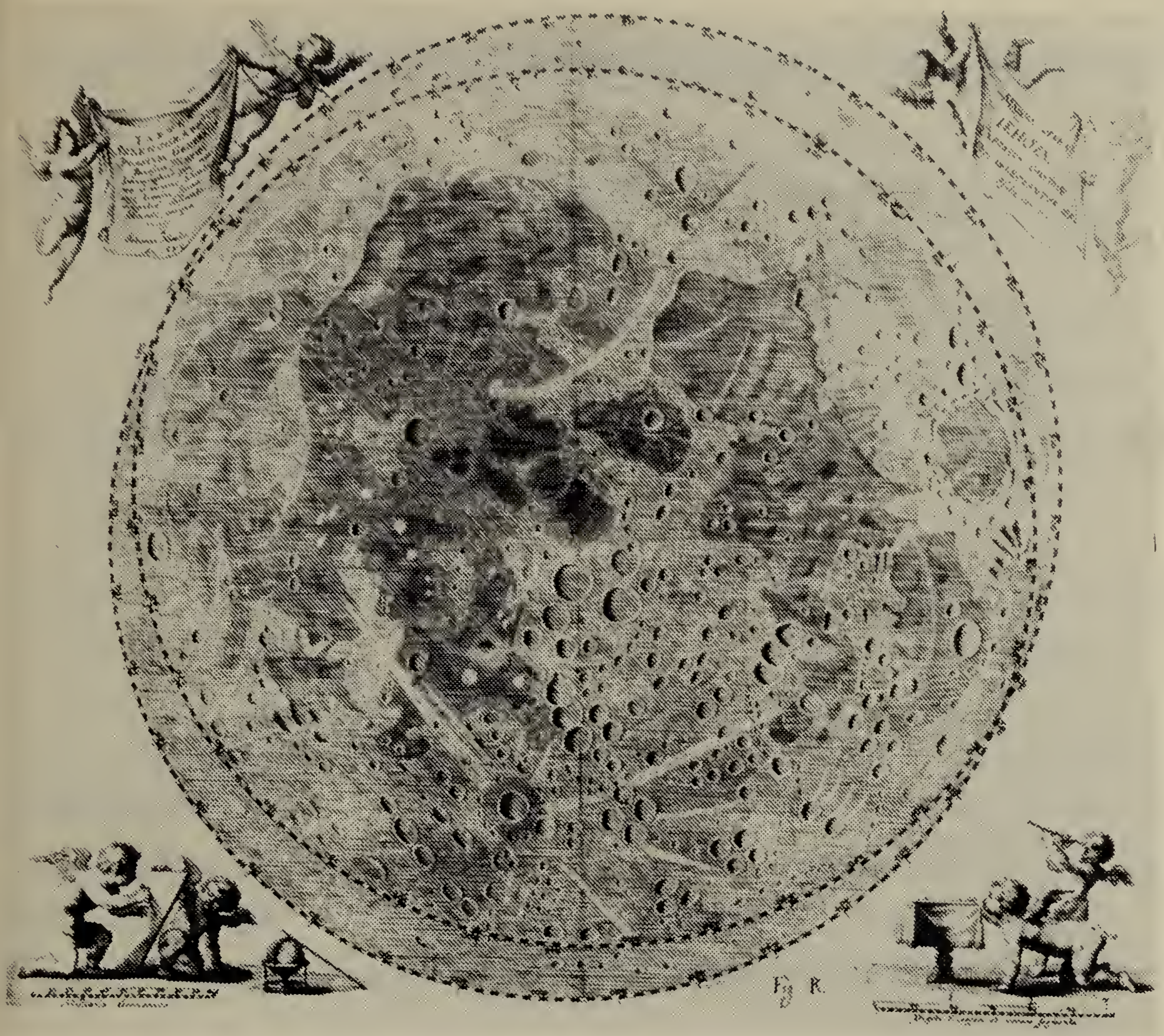
9. *Scheiner's representation of the progress of a sunspot across the face of the Sun; Rosa Ursina* (*Bracciano*, 1630).

10. *Claude Mellan's representation of the Moon*, 1636.

In order to time lunar eclipses accurately, astronomers began, in the 1630s, to time the advance and retreat of the shadow over specific lunar features. This practice called for a realistic likeness of the Moon, and therefore astronomers began mapping the Moon. Fig. 10 shows one of the first, and perhaps the most spectacular, lunar likeness from an artistic point of view. It was made in 1636 by Claude Mellan, one of Europe's foremost engravers. Mellan set out to make, as it were, a portrait of the Moon. He made three views, first quarter, full moon, and last quarter. In the view of the first quarter shown here, the details at the terminator are breathtakingly sharp and realistic. Near the limb, however, the features look washed out. This is how the Moon appears in reality. The light of the Sun, coming from the right, rakes the lunar surface near the terminator but is almost perpendicular near the limb, where accordingly there are few shadows. With the full moon the situation is reversed: the center shows few details, while near the limb the features stand out in sharp relief.

To make a moonmap that shows all the details equally clearly, astronomers had to make a composite. All features needed to be equally prominent, which meant that the resulting map would not look like an instantaneous image of the Moon at any one time. We see the result in the work of Johannes Hevelius, who published his *Selenographia* in 1647. Hevelius prepared several composite maps of the full Moon. He chose morning illumination, showing all features with sunset illumination—an obvious impossibility (fig. 11).

It is interesting to note that Hevelius was scrupulous about his method. He made his own telescopes, did his own observing, draw-



11. *Johannes Hevelius's moonmap;* Selenographia (*Gdansk*, 1647).

ing, and even engraving, and closely supervised the printing process. He thus guaranteed to the reader that what was represented on the page was what he had actually observed, and the reader became as it were a fellow observer, or a virtual witness to Hevelius's observations. When it came to assessing previous lunar depictions, Hevelius offered some severe criticism of Galileo's efforts. He said that Galileo either did not have good telescopes, or did not take enough care with his drawing, or—most likely—was ignorant of the art of drawing. Galileo's instruments were not very much inferior to those of Hevelius; Galileo drew with care and supervised the engravings; and—as we have noted—he was well trained in *disegno*. What Hevelius did not fully realize is that the *conventions* of representing the Moon had changed.

By the middle of the seventeenth century, four decades after Galileo's pioneering observations, astronomy had acquired a visual language of its own. In the best practice, communicating telescopic observations, whether by letter or in printed form, now included pictures. What had occurred in anatomy and botany a century earlier, with the work of Andreas Vesalius and Conrad Gessner, had now also happened in the physical sciences. As the telescope became a routine part of the arsenal with which the astronomer assaulted the heavens, pictorial evidence became a routine part of their communications. And the heavens thus depicted were very different from those of the traditional, Aristotelian, cosmology. It was this new universe, first unveiled by Galileo, that Newton quantified at the end of the seventeenth century.

SIGNIFICANT EVENTS IN THE LIFE AND TIMES OF GALILEO

1543	Nicolaus Copernicus's book, *On the Revolutions of the Heavenly Spheres*, is published.
1545-1563	The Council of Trent meets and the Counter- Reformation begins.
1564	Galileo Galilei is born in Pisa.
1581-1585	Galileo studies mathematics and medicine at Pisa but leaves without a degree.
1592	Galileo becomes a professor of mathematics at Padua.
1609	Johannes Kepler publishes *New Astronomy*.
Fall 1609	Galileo builds telescopes and begins to observe the heavens.
March 1610	*Sidereus Nuncius* (*Starry Messenger*) is published and causes an immediate sensation.
June 1610	Galileo is made Chief Mathematician and Philosopher to the Grand Duke of Tuscany and resigns his professorship.
1613	Galileo's *Sunspot Letters* are published by the prestigious Lincean Society.
1613-1615	Various clerics challenge Galileo's theories and assert they are heretical.
1615	Galileo writes the "Letter to Grand Duchess Christina", in which he argues that Copernican theory does not necessarily clash with the Bible.
1616	The Copernican theory is declared heretical, and Copernicus's *On the Revolutions* is placed on the Index of Forbidden Books. Galileo is told by Cardinal Bellarmine not to "hold or defend" the Copernican theory.
1623	Florentine Cardinal Maffeo Barberini, an admirer and patron of Galileo, is elected Pope Urban VIII.
1630-1632	Galileo seeks Church approval of the manuscript of his *Dialogue* but delays are encountered; the book is finally published in Florence with only conditional approval from the Florentine Censor.
1632	In response to a special papal commission report, the Inquisition summons Galileo to Rome.
1633	Galileo is tried by the Inquisition and is made to abjure and condemn his errors. He is condemned to house arrest for the remainder of his life, and the *Dialogue* is placed on the Index of Forbidden Books.
1638	While under house arrest, Galileo writes his *Discourses and Mathematical Demonstrations on Two New Sciences*, which contains his mature thoughts on motion. The book is published in Leyden in the Netherlands.
1642	Galileo dies at his villa near Florence.

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Rarely seen outside of Florence, an exhibit of Galileo's instruments is currently on display at the California Academy of Sciences. Presented in conjunction with Humanities West, the exhibit continues until December 2, 1993. Featured are four originals and seven exact copies of Galilean instruments, including the proportional compass designed by Galileo, a copy of the original telescope designed and made by Galileo and a copy of the astrolabe made by Danti. The exhibit has been made possible through the cooperation of the Instituto e Museo di Storia della Scienza in Florence, Italy, with the assistance of the Consul General of Italy in San Francisco.

THE PODIUM FLOWERS

The flower arrangement in front of the podium has been provided by designer Signa Houghteling. Mixed traditional flowers, identified from illustrations of the period, as well as some whimsical additions, suggest the science of the time as well as Galileo's new observations of the starry sky.

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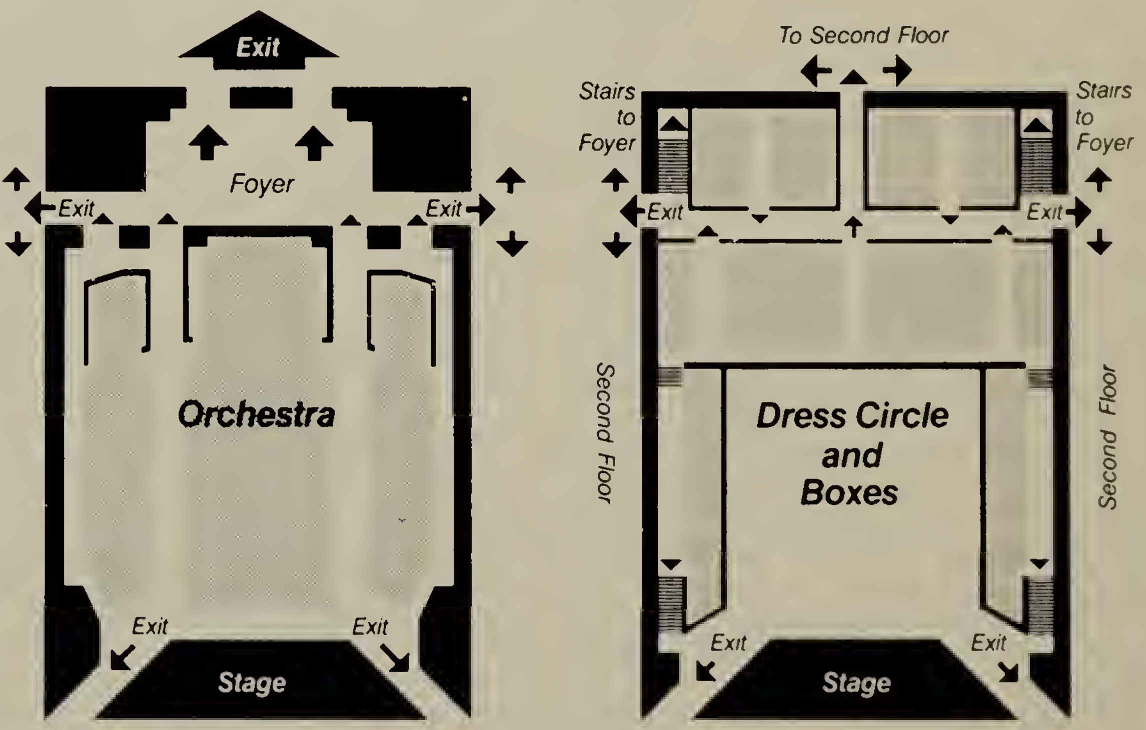

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The exit indicated by the lighted "exit" sign nearest your seat is the shortest route
to the street. In case of fire please do not run — walk through that exit.

A Sennheiser Listening System is installed at Herbst Theatre. Wireless headphones and induction devices (adaptable to hearing aids) are available in the main lobby of the theatre. There is no charge, but an ID deposit is required.