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Astrolabes: A Cross-Cultural and Social Perspective

Sara Schechner Genuth

"Little Lewis," Chaucer told his ten-year-old son as he packed him off to Oxford, "I have perceived well...thy ability to learn sciences touching numbers and proportions; and I [have] also consider[ed] thy earnest prayer specially to learn the Treatise of the Astrolabe." Here is "an astrolabe for our horizon," he continued, and a "little treatise...to teach thee a certain number of conclusions appertaining to the same instrument."[1] Chaucer's instrument — a planispheric astrolabe — was a portable model of the heavens, simulating the apparent rotation of the stars around the North Celestial Pole. It was also an analogue computer, which could be used to solve astrological and astronomical problems.[2]

Although Chaucer subtitled his treatise "Bread and Milk for Children," the astrolabe had been in the hands of scholars since antiquity. Indeed, an astronomer was seldom depicted without an astrolabe, the instrument becoming a badge of the profession.[3] (Figures 1-3) By the Renaissance, the astrolabe had also earned the respect of those whose work was not strictly astronomical. In the words of Jacob Köbel, this "marvelously delightful" instrument was "not only very practical and even necessary for astrologers, doctors, geographers, and others cultivating the arts and sciences, but also truly advantageous for mechanics [and] certain artisans."[4]

ORIGIN AND DIFFUSION

The origin of the astrolabe is somewhat obscure. The stereographic projection, which lies at the heart of its construction, was likely known by Hipparchus (*c.* 150 B.C.) and familiar to readers of *De architectura,* for in that work, Vitruvius (d. post-A.D. 27) described an anaphoric clock that used the projection on its dials. Ptolemy treated the projection in a theoretical way in his *Planisphaerium* (*c.* A.D. 160) and referred to a horoscopic instrument resembling an astrolabe at the end of this work. Even though Ptolemy's instrument consisted of a starry rete that turned on top of a plate marked with altazimuth coordinates, it likely lacked an

1. Geoffrey Chaucer, *Treatise on the Astrolabe* (1391); revised/modernized text based on the Rawlinson MS printed in Robert T. Gunther, *Chaucer and Messahalla on the Astrolabe*, Early Science in Oxford, vol. 5 (Oxford, 1929a), 1; *cf.* Geoffrey Chaucer, *A Treatise on the Astrolabe addressed to his son Lowys, A.D. 1391*, ed. Walter W. Skeat (London, 1872); and *idem*, *The Riverside Chaucer*, ed. Larry D. Benson, 3rd ed. (Boston, 1987), 661-83. Chaucer's treatise was based on an enormously popular Latin text, which survives in nearly 200 manuscripts and which was long ascribed to Māshā'allāh, but is now known to be a 13th-century, Latin compilation. See Paul Kunitzsch, "On the Authenticity of the Treatise on the Composition and Use of the Astrolabe Ascribed to Messahalla," *Archives internationales d'histoire des sciences* 31 (1981b): 42-62. For more on Chaucer's interest in astronomy, see John D. North, "Kalenderes Enlumyned Ben They: Some Astronomical Themes in Chaucer," *The Review of English Studies*, n.s., 20 (1969): 129-54, 257-83, 418-44; and *idem*, *Chaucer's Universe* (Oxford, 1988).

2. General works on the astrolabe include Robert T. Gunther, *The Astrolabes of the World*, 2 vols. (Oxford, 1932); Willy Hartner, "The Principle and Use of the Astrolabe," in *A Survey of Persian Art*, ed. Arthur Upham Pope, 3: 2530-54 (London/New York, 1939); *idem*, "Asṭurlāb," in *Encyclopedia of Islam*, new ed., 1: 722-28 (1960); both reprinted in *idem*, *Oriens-Occidens*, 2 vols. (Hildesheim, 1968/1984), 1: 287-318; Henri Michel, *Traité de l'astrolabe* (Paris, 1947); Leo Ary Mayer, *Islamic Astrolabists and Their Works* (Geneva, 1956); John D. North, "The Astrolabe," *Scientific American* 230 (1974): 96-106; reprinted in *idem*, *Stars, Minds and Fate: Essays in Ancient and Medieval Cosmology* (London, 1989), 211-20; National Maritime Museum, *The Planispheric Astrolabe* (Greenwich, 1976); Sharon Gibbs with George Saliba, *Planispheric Astrolabes from the National Museum of American History* (Washington, D.C., 1984); Roderick S. Webster, *The Astrolabe: Some Notes on Its History, Construction and Use*, 2nd ed. (Lake Bluff, Ill., 1984); A. J. Turner, *Astrolabes, Astrolabe Related Instruments*, The Time Museum: Catalogue of the Collection, ed. Bruce Chandler, vol. 1: Time Measuring Instruments, part 1 (Rockford, Ill., 1985); Owen Gingerich, "Zoomorphic Astrolabes and the Introduction of Arabic Star Names into

alidade. Ptolemy's planisphere performed the functions of a star-finder, but it appears not to have been used for directly measuring the altitudes of stars. The instrument we have come to know as the astrolabe — complete with rete, tympans, and alidade — was invented sometime before the late fourth century, when Theon of Alexandria wrote a tract on it. Treatises by John Philoponus (A.D. 530), Severus Sebokht (pre-660), al-Fazārī (late 8th century), and others followed in Greek, Syriac, Arabic, and lastly Latin, as knowledge of the instrument was diffused. Early manufacture was centered on Ḥarrān, a city between the Tigris and Euphrates rivers, which was also a hub for the translation of Greek and Syriac works into Arabic.[5]

Prior to the tenth century, knowledge spread eastward from the Syro-Egyptian region through Ḥarrān to Iraq and Persia.[6] In the *Mashriq* (the East), the astrolabe-making craft was highly esteemed during the reigns of the first 'Abbāsid Caliphs, and that of al-Ma'mūn (787-827) in particular. The profession often passed down from father to son through several generations.[7] From Persia, interest passed to Mughal India in the mid-sixteenth century in the wake of new rulers, who regulated their affairs according to the principles of astrology and valued astrolabes for this purpose. Lahore (in what is now Pakistan) became a center for the production of Indo-Persian astrolabes.[8] South of Lahore, Hindus had been introduced to the astrolabe perhaps as early as the eleventh century by traveling scholars, such as al-Bīrūnī.[9] The first Sanskrit treatise on the astrolabe was composed around 1370. Few Indian astrolabes, however, predate the seventeenth century, and most surviving examples date from the eighteenth century onward,

FIGURE 1 *Astronomia with an astrolabe. Detail from Joannes de Sacrobosco,* Textus de sphera *(Paris, 1500). Courtesy of the Adler Planetarium, Chicago.*

Europe," in *From Deferent to Equant: A Volume of Studies in the History of Science in the Ancient and Medieval Near East in Honor of E. S. Kennedy*, ed. David A. King and George Saliba, 89-104, Annals of the New York Academy of Sciences, vol. 500 (New York, 1987); David A. King, *Islamic Astronomical Instruments* (London, 1987a); and *idem*, "Die Astrolabiensammlung des Germanischen Nationalmuseums," trans. Kurt Maier, in Germanisches National Museum, *Focus Behaim Globus*, exhibition catalogue edited by Gerhard Bott, 2 vols., 1: 101-14, 2: 568-602, 640-43 (Nuremberg, 1992).

3. On astronomers and their obligatory astrolabes, see, for example, an illuminated Hebrew manuscript from Spain, *c.* 1350-1399 (Copenhagen, Det Kongelige Bibliotek, Cod. Hebr. 37, fol. 114^{r}); another Hebrew-Spanish manuscript, 1472 (Oxford, Bodleian Library, MS Kennicott 1, fol. 90^{r}); and a Hebrew manuscript from Germany, *c.* 1400-1450 (London, British Library, MS Or. 10878, fol. 17^{r}); all are discussed in Thérèse Metzger and Mendel Metzger, *Jewish Life in the Middle Ages: Illuminated Hebrew Manuscripts of the Thirteenth to the Sixteenth Centuries* (New York, 1982), 157, 166. The Spanish manuscript in Oxford depicts Balaam, who was identified as an astronomer in Jewish tradition and was shown holding an astrolabe in some Biblical miniatures. For examples from the Christian tradition, see a Czech manuscript of *Mandeville's Travels* (London, British Library, Add. MS 24189, fol. 15^{r}); reproduced in Josef Krása, ed., *The Travels of Sir John Mandeville: A Manuscript in the British Library*, trans. Peter Kussi (New York, 1983), plate 19; Hartmann Schedel, *Büch der Cronicken* (Nuremberg, 1493), fol. CCLV^{r}, which shows Regiomontanus with an astrolabe; and Johannes Kepler, *Tabulae Rudolphinae* (Ulm, 1627), frontispiece. Astronomia with an astrolabe appears in a woodcut in Joannes de Sacrobosco, *Textus de sphera* (Paris, 1500). An astronomer was often depicted with an astrolabe, just as a physician was typically shown with a flask of urine; see Schedel (1493), *passim*.

4. Jacob Köbel, *Astrolabii declaratio, eiusdemque usus mire jucundus, non modo astrologis, medicis, geographis, caeterisque literarum cultoribus multum utilis ac necessarius; verum etiam mechanicis quibusdam opificib. non parum commodus* (Mainz, 1535).

5. Otto Neugebauer, "The Early History of the Astrolabe," *Isis* 40 (1949): 240-56; *idem*, *A History of Ancient Mathematical Astronomy*, 3 vols. (New York, 1975), 2: 868-79; Paul Kunitzsch, "Observations on the Arabic Reception of the Astrolabe," *Archives internationales d'histoire des sciences* 31 (1981a): 243-52; David A. King, "The Origin of the Astrolabe According to Medieval Islamic Sources," *Journal for the History of Arabic Science* 5 (1981): 43-83; reprinted in *idem* (1987a); Hartner (1968/1984), 1: 288-90; Turner, A. J. (1985), 10-14. *Cf.* the introduction of A. P. Segonds, in Jean Philopon, *Traité de l'astrolabe*, ed. and trans. A. P. Segonds, *Astrolabica* 2 (Paris, 1981).

6. Turner, A. J. (1985), 14, 21-22.

7. Hartner (1968/1984), 1: 289-90.

8. Sayyid Sulayman Nadvi, "Indian Astrolabe Makers," *Islamic Culture* 11 (1937): 537-39; Turner, A. J. (1985), 25-26.

9. Turner, A. J. (1985), 26.

FIGURE 2 *Regiomontanus with an astrolabe. From Hartmann Schedel,* Büch der Cronicken *(Nuremberg, 1493). Private collection.*

suggesting that interest in Sanskrit circles was awakened by the observatory-building program of the Maharajah Jai Singh II (1686-1743).[10]

Traveling to the northeast, the astrolabe reached China by 1267, when Jamāl al-Dīn, a Persian astronomer, brought Kublai Khān models of some astronomical instruments that equipped the Marāghah observatory newly erected by his brother, Hūlāgū Khān.[11] Within ten to twenty years, Marco Polo claimed to have observed the widespread use of a kind of astrolabe among astrologers in Beijing, and *The Travels of Sir John Mandeville,* written around 1357, described the instrument's importance to the philosophers at Kublai Khān's table.[12] There are reasons, however, to question the accuracy of these two European reports. First, no astrolabes (or texts describing them) are known to be preserved in China.[13] Second, it seems implausible for the astrolabe to have achieved the popularity Polo claimed for it within twenty years of Jamāl al-Dīn's visit, for the Chinese had no prior knowledge of stereographic projections, spherical trigonometry, and the twelve-partite zodiac, which underlay the design of the astrolabe.[14] Polo may have been mistaken in identifying the instruments he saw, or he may

10. David Pingree, "Islamic Astronomy in Sanskrit," *Journal for the History of Arabic Science* 2 (1978b): 315-30; *idem*, "History of Mathematical Astronomy in India," in *Dictionary of Scientific Biography*, 15: 533-633, esp. 626-28 (New York, 1978a); Virendra Nath Sharma, "The Great Astrolabe of Jaipur and Its Sister Unit," *Archaeoastronomy* no. 7, *Supplement to the Journal for the History of Astronomy* 15 (1984): S126-28; Turner, A. J. (1985), 26-28.

11. Willy Hartner, "The Astronomical Instruments of Cha-ma-lu-ting, Their Identification, and Their Relations to the Instruments of the Observatory of Marāgha," *Isis* 41 (1950): 184-94; Joseph Needham, *Science and Civilisation in China*, 6 vols. (Cambridge, England, 1954-88), 3: 372-74.

12. Henry Yule, trans. and ed., *The Book of Ser Marco Polo The Venetian Concerning the Kingdoms and Marvels of the East*, 3rd ed., rev. Henri Cordier, 2 vols. (London, 1903), 1: 446-47, containing book 2, chap. 33: "Concerning the Astrologers in the City of Cambaluc [Beijing]." Polo wrote that amongst the Christians, Saracens, and Cathaians, there were five thousand astrologers provided with annual maintenance and clothing by the Great Khan. "They have a kind of astrolabe on which are inscribed the planetary signs, the hours and critical points of the whole year." All three sects used their instruments for the practice of natural and judicial astrology and answered horary questions for many people. M. C. Seymour, ed., *Mandeville's Travels* [*c.* 1357] (London, 1968), chap. 25: 179; this reference is discussed below, on pp. 13-14.

13. Needham (1954-88), 3: 376.

14. Hartner (1950), 192; *cf.* Needham (1954-88), 3: 375-77.

FIGURE 3 *Hebrew astronomer holding an astrolabe and consulting astronomical tables. Miniature illustrating the second part of Maimonides'* Guide to the Perplexed, *in a manuscript executed in Barcelona in 1348 by Levi ben Isaac hijo Caro of Salamanca. By permission of Det Kongelige Bibliotek, Copenhagen, Cod. Hebr. 37, fol. 114r.*

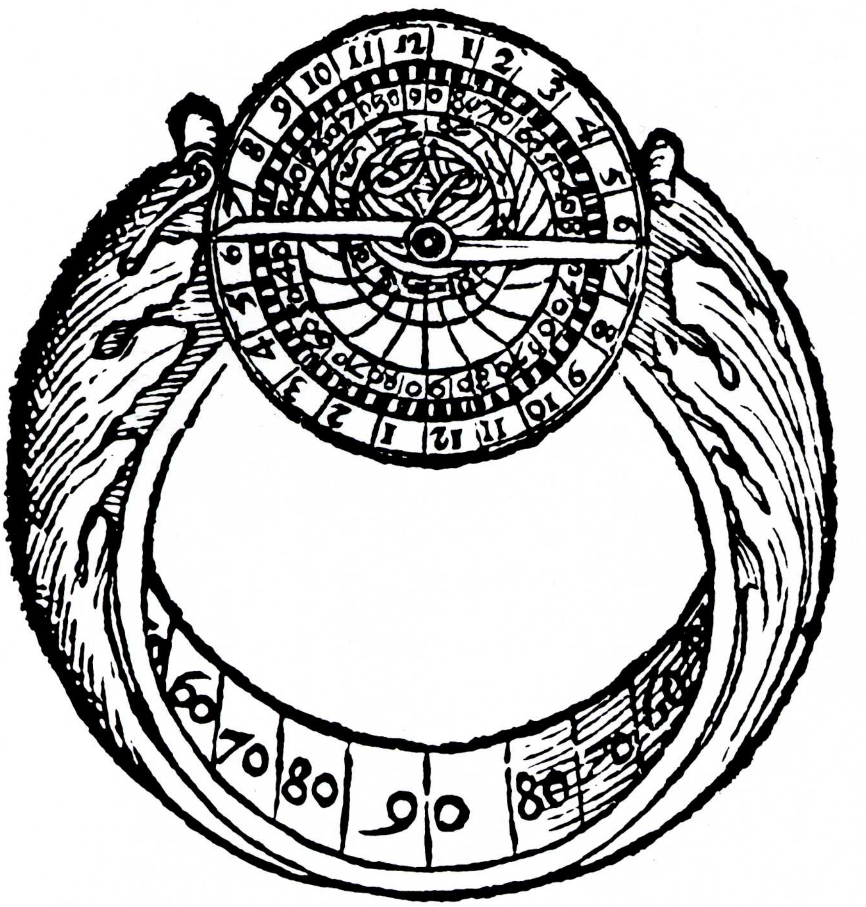

FIGURE 4 *Astrolabe ring of Bonet de Lattes. From* Annuli astronomici *(Paris, 1558). Courtesy of the Adler Planetarium, Chicago.*

have called them astrolabes for want of a better term.[15] In any case, it seems that the astrolabe did not catch on in China. If it found favor at all, it would appear to have been among foreigners. In this regard it is interesting to note that some medieval Persian astrolabes list China on their gazetteers.[16]

Traveling in the other direction, knowledge of the astrolabe spread westward to North Africa (the *Maghrib*) and Muslim Spain (Andalusia) by the tenth century, and from there to Christian Europe. Arabic texts were translated into Latin, and Jewish scholars contributed to the transmission process by translating into Hebrew.[17] Students from northern Europe crossed into Spain and returned with treasures of Greco-Arabic science. Prominent among them was Gerbert of Aurillac (*c.* 945-1003), who became Pope Sylvester II in 999. Gerbert introduced the astrolabe to his pupils at Rheims and elsewhere on his return from Catalonia.[18] Within 50 years, Hermann Contractus of Reichenau (1013-1054) prepared an adaptation of *De utilitatibus astrolabii,* one of the treatises likely imported by Gerbert.[19] And in 1092, Walcher (d. 1135), prior of the Abbey of Malvern in England, observed the time of a lunar eclipse with his instrument.[20] The diffusion process, apparently, was well under way. By the mid-thirteenth century, the astrolabe was known to scholars as a teaching, calculating, and observing instrument. Astrolabes were

15. Another way to reconcile this is to discount his claim that the astrolabe was used by Christians, Saracens, and Cathaians alike and assume that it was principally used by the Christians and Muslims to whom he refers.

16. See astrolabes made by ibn Dawlatshah, 1388 (N-70) and ibn Ja'far, 1433/4 (A-91). See the A. P. catalogue of Eastern astrolabes (forthcoming).

17. J. M. Millàs-Vallicrosa, "Translations of Oriental Scientific Works (to the End of the Thirteenth Century)," in *The Evolution of Science*, ed. Guy S. Metraux and François Crouzet, 128-67 (New York, 1963); David C. Lindberg, "The Transmission of Greek and Arabic Learning to the West," in *Science in the Middle Ages*, ed. David C. Lindberg, 52-90 (Chicago, 1978); *Encyclopaedia Judaica, s.v.* "Astrolabe."

18. See Millàs-Vallicrosa (1963), 139-43, on Gerbert's sojourn in Spain and his contact with the treatises on the astrolabe prepared at the Monastery of Santa Maria de Ripoll.

19. *Ibid.*, 146; Lindberg (1978), 60-61; *cf.* Mary Catherine Welborn, "Lotharingia as a Center of Arabic and Scientific Influence in the Eleventh Century," *Isis* 16 (1931): 188-99.

20. Charles Homer Haskins, *Studies in the History of Medieval Science*, 2nd ed. (Cambridge, Mass., 1927), 114-15; *cf.* Emmanuel Poulle, *Walcher de Malvern et son astrolabe (1092)*, Centro de Estudos de Cartografia Antiga, no. 132 (Coimbra: Junta de Investigações Científicas do Ultramar, 1980b).

21. For lectures on the astrolabe at Bologna, see Lynn Thorndike, *University Records and Life in the Middle Ages* (New York, 1944), 281, 403. Astronomical codices typically contained Sacrobosco's *Tractatus de sphaera*, *Compotus*, and *Algorithmus*, the *Theorica planetarum*, astronomical tables, and treatises on the astrolabe and quadrant; see Edward Grant, ed., *A Source Book in Medieval Science* (Cambridge, Mass., 1974), 451; and Olaf Pedersen, "Astronomy," in *Science in the Middle Ages*, ed. David C. Lindberg, 303-37 (Chicago, 1978). Medieval treatises and astrolabe observations are discussed in Haskins (1927), *passim.* On borrowing astrolabes, see Turner, A. J. (1985), 30 n. 99.

22. Emmanuel Poulle, "L'astrolabe médiévale d'après les manuscrits de la Bibliothèque Nationale," *Bibliothèque de l'École de Chartes* 112 (1954): 81-103, esp. 89. In the Duomo of Pisa, one can still see the figure of a muse wielding an astrolabe, which Giovanni Pisano carved into the Gothic pulpit he created between 1302 and 1311.

23. A. J. Turner (1985), 26, suggests that the presence of few Indo-Persian astrolabists in Lahore might indicate that astrolabes were not in general use throughout the society, but were reserved for members of the Mughal court.

24. Lynn Thorndike, *Michael Scot* (London, 1965), 32.

25. Metzger and Metzger (1982), 157.

26. All in all, Charles V's collection included seven astrolabes of copper, two of brass, two of silver, and one of gold. See Jules Labarte, *Inventaire du mobilier de Charles V, roi de France* (Paris, 1879), line items 1990, 2072, 2216, 2270 (2 astrolabes), 2427 (3 astrolabes), 2714, 2817, 3119, 3121; and Turner, A. J. (1985), 32, 34.

frequently found with treatises on their use in university libraries; they could even be borrowed.[21]

Evidence of cultural diffusion appeared as early as the twelfth century, when Héloise and Abelard named their son "Astrolabe" and images of the instrument began to appear in cathedral sculpture and miniatures.[22] Beyond the ken of universities and cathedrals, astrolabes made their way into court, where court astrologers in the West found them as indispensable as those in the East.[23] When traveling with Frederick II (1194-1250), Michael Scot discussed astronomical matters with the Holy Roman Emperor and took readings from his astrolabe (perhaps to predict the outcome of military campaigns).[24] A Jewish professor of astronomy and astrology at the University of Salamanca, Abraham Zacuto, similarly served John II and Manuel I of Portugal in the fifteenth century.[25] Charles V (1337-1380) of France deemed the astrolabe so essential that he owned at least twelve, including one of gold and two of silver.[26] Elizabeth I (1533-1603) of England had two of gilt brass, one of which was dated 1559, the year of her coronation. Elizabeth had come to power on an astrologically propitious day (selected by John Dee), and the symbolism of her coat-of-arms being surrounded by tables of planetary virtues on the back of one astrolabe was not likely lost on the queen.[27] A similar touch appeared in an astrolabe ring invented by Bonet de Lattes (d. *c.* 1514), a rabbi who became doctor and astrologer to Pope Alexander VI in 1498 and later served Pope Leo X. In wearing this ring, a commanding individual might believe he had the power of the heavens close at hand.[28] (Figure 4)

The apogee of astrolabe production in Europe occurred during the late fifteenth and sixteenth centuries, and many tracts tried to help

FIGURE 5 *Astronomical compendium with astrolabic projections, by Christopher Schissler, Augsburg, 1559. On the left, a de Rojas projection of the celestial sphere. On the right, a north-polar, stereographic projection of the earth. Courtesy of the Adler Planetarium, Chicago (M-365).*

27. George H. Gabb, "The Astrological Astrolabe of Queen Elizabeth," *Archaeologia* 86 (1937): 101-3; R. T. Gunther, "The Astrolabe of Queen Elizabeth," *Archaeologia* 86 (1937b): 65-72.

28. Bonet de Lattes, *Annulus astronomicus* (Rome, 1493); reprinted many times as *Annuli astronomici utilitatum liber*. See, for example, Johann Dryander, *Annulorum trium diversi generis instrumentorum astronomicorum, componendi ratio atq; usus, cum quibusdam aliis lectu iucundissimis* (Marburg, 1537), sigs. Hiij^{r}-Kiij^{r}; or *Annuli astronomici, instrumenti cum certissimi, tùm commodissimi, usus, ex variis authoribus, Petro Beausardo, Gemma Frisio, Ioāne Dryandro, Boneto Hebraeo, Burchardo Mythobio, Orontio Finaeo* (Paris, 1558), fols. 103^{v}-117^{v}. It is interesting to note that the illustration of the ring in Dryander (1537) is surrounded by the words "ANNULUS BONETI / INEVITABILE FATUM" (once repeated), suggesting Bonet's ring revealed one's inescapable fate. At first glance, this seems to contradict my claim that wearing an astrolabe was empowering, but this is not so. To be forewarned was to be forearmed, and astrology was valued because it offered the prospect of control over future effects and repercussions. For more on Bonet de Lattes, see *Encyclopaedia Judaica*, *s.v.* "Lattes, Bonet."

the novice learn his way around the instrument.[29] Notable makers included Jean Fusoris (*c.* 1365-1436) of Paris, whose career came to an end with his arrest on espionage charges; Gualterus Arsenius (fl. 1554-1579) of Louvain, who incorporated many innovations made by his uncle Gemma Frisius (1508-1555); and Georg Hartmann (1489-1564) of Nuremberg.[30] Hartmann's output was considerable, and in his workshop, craftsmen finished several astrolabes simultaneously. The evidence for a division of labor is to be found in the use of assembly marks. In Hartmann's case, these were numbers stamped in unobtrusive places on rough-hewn components that had been assembled. The parts were then separated, finished by different artisans, and reassembled into a complete instrument.[31]

In general, astrolabes were elegant instruments produced for elite patrons. In the East, Persian instruments were kept in small sacks and regarded by the common people as precious gems.[32] In the West, they were prized as "mathematical jewels."[33] They graced the cabinets of nobles and even ornamented the bindings of books, like those in the magnificent library of Jean, Duc de Berry (1340-1416), a son, brother, and uncle of three kings of France.[34] During the Renaissance, astrolabic devices were incorporated in astronomical compendia — the pocket-sized, gilt-and-silvered brass instruments that typically contained at least one sundial, a nocturnal, a magnetic compass, a gazetteer, a lunar volvelle, and sometimes an array of maps, tables, and scales.[35] Astrolabes also adorned fabulous clocks, which marked the rotation of the stars as well as the hours.[36] (Figures 5-7) Both compendia and astrolabe clocks were the sumptuous property only of the very wealthy. Like fine astrolabes, they were purchased by aristocrats not so much for daily use, but as a way to patronize the arts, give evidence of their erudition, and enhance their prestige. That is not to say that no one of wealth ever used an astrolabe for its intended astronomical purpose, but there is no doubt that many astrolabes have survived because they were showpieces preserved in the cabinets of patricians.

FIGURE 6 *Astrolabe clock, by Johann Christoff Lang, Augsburg,* c. *1580. Courtesy of the Adler Planetarium, Chicago (M-383).*

At the other end of the social scale, we find the do-it-yourself astrolabes. Astrolabes were sometimes produced as manuscripts, painstakingly inked on vellum or paper, and glued to wood or pasteboard.[37] These were labors of love. But for those with less patience and skill, Georg Hartmann pioneered the cheap, printed astrolabe, whose paper parts could be cut out and pasted to wood. Four of these instruments, dating from 1531 to 1540, survive. Also connected to the paper-astrolabe trade were Johannes Krabbe, Egnatio Danti, Willem Janszoon Blaeu, Philippe Danfrie, Jean Moreau, Henry Sutton, John Prujean, and Nicolas Bion.[38]

29. Some of the more important works include *Astrolabii quo primi mobilis motus deprehenduntur canones* (Venice, 1512); Johann Stöffler, *Elucidatio fabricae ususque astrolabii* (Oppenheim, 1513); Johann Copp, *Erklaerung unnd Gründtliche underweysung, alles nutzes, so in dem Edlen Instrument, Astrolabiū genañt* (Augsburg, 1525); Joannis Martini Poblacion [pseud. of Juan Martínez Siliceo], *De usu astrolabii compendium* ([Paris], 1527); Oronce Fine, *Quadrans astrolabicus* (Paris, 1534); Jacob Köbel, *Astrolabii declaratio* (Mainz, 1535); Jacques Focard, *Paraphrase de l'astrolabe* (Lyons, 1546); Juan de Rojas, *Commentariorum in astrolabium quod planisphærium vocant, libri sex* (Paris, 1550); Gemma Frisius, *De astrolabo catholico liber* (Antwerp, 1556); Dominique Jacquinot, *L'usage de l'astrolabe....plus est adjousté une amplification de l'usage de l'astrolabe, par Jacques Bassentin Escossois*, 2nd ed. (Paris, 1559); Egnatio Danti, *Trattato dell'uso e della fabbrica dell'astrolabio* (Florence, 1569); John Blagrave, *The Mathematical Jewel* (London, 1585); Robert Tanner, *The Traveller's joy and felicitie, or a Mirror for Mathematics* (London, 1587); and Christoph Clavius, *Astrolabium* (Rome, 1593). Many texts were reprinted, revised, or translated. See, for example, Jacques Focard, *Paraphrase de l'astrolabe*, rev. Jacques Bassentin (Lyons, 1555); Johann Stöffler, *Traité de la composition et fabrique de l'astrolabe, & de son usage....Le tout traduit du Latin de Iean Stofler de Iustingence.... Avecques annotations...faites par Iean Pierre de Mesmes* (Paris, 1560); and Gemma Frisius, *De astrolabo catholico liber* (Antwerp, 1583), reissued as part of Petrus Apianus, *Cosmographia* (Antwerp, 1584), 354-479.

30. The A. P. has instruments by each of these makers. For those by Fusoris, see M-27 (cat. no. 2) and W-264 (cat. no. 3); by Arsenius, M-23 (cat. no. 8) and M-24 (cat. no. 9); by Hartmann, M-22 (cat. no. 6) and W-272 (cat. no. 5). For brief portraits of these makers, see Emmanuel Poulle, *Un constructeur d'instruments astronomiques au XV^e siècle: Jean Fusoris* (Paris, 1963); and Turner, A. J. (1985), 37-47.

31. One Hartmann astrolabe (M-22, cat. no. 6) in the A. P. Collection has the assembly number "2" stamped on its mater. On the production process in Persia, see John Chardin, *Voyages du Chevalier Chardin, en Perse, et autres lieux de l'Orient*, new ed., 4 vols. (Amsterdam, 1735), 3: 168-74.

32. *Ibid.*, 3: 168. The Persian astrolabe (A-40) of al-ʿAbd Amīn of Mashad, dated 1669/70 or 1688/9, has such a leather pouch. See the A. P. catalogue of Eastern astrolabes (forthcoming).

33. In his epistle dedicatory to Catherine de Medici, Jacquinot (1559), sig. āij, alluded to the astrolabe and the mathematical sciences on which it was based as jewels fit for a queen. This tone had been set in France at least 150 years before Jacquinot, when astrolabes were literally treated as jewels by Jean, Duc de Berry (1340-1416), a passionate collector of rare gems and exquisite manuscripts. His library contained books not only fastened in gold and silver and studded with precious stones, but also encrusted with gilt astrolabes. On the Duc de Berry, see Jules Guiffrey, *Inventaires de Jean, duc de Berry (1401-1416)*, 2 vols. (Paris, 1894-96); and Jean Longnon and Raymond Cazelles, *The Très Riches Heures of Jean, Duke of Berry* (New York, 1969). In England, Blagrave (1585) called his new universal astrolabe a "mathematical jewel."

FIGURE 7 *Flemish astrolabe amidst other artifacts of art, science, and commerce. Detail from* Cognoscenti in a Room Hung with Pictures, *Flemish School, early seventeenth century. Courtesy of the National Gallery, London.*

Paper instruments may have helped to popularize the astrolabe — and there is evidence of their use by schoolboys — but they could not compensate for the deficiencies (by seventeenth-century standards) of the brass models.[39] On these small and portable instruments, the scales could not be finely divided, whereas larger and heavier astrolabes, which offered the prospect of being more precise, were inconvenient to hold. Astrolabes, moreover, were mathematically complex, and therefore difficult to construct and expensive to buy.[40] Finally, only those with a good grasp of geometry and trigonometry could learn to use them effectively.

By the seventeenth century, the astrolabe — the queen of medieval instruments — was dethroned in the West. For time-finding, the average person had simpler sundials and nocturnals at his or her disposal. For land measure, the surveyor turned to the new theodolite, graphometer, and circumferentor. For star-finding, the astronomer and astrologer consulted star charts and planispheres. And for demonstrating astronomical relationships and solving basic problems of positional astronomy, the tutor employed armillary spheres and globes. Many specialized instruments — some derived from the astrolabe — took the place of this very compact, multipurpose instrument.

Consequently, the production of astrolabes and companion textbooks in Europe slackened during the seventeenth century and was dead by the eighteenth. The instrument, nonetheless, continued to be a staple of Islamic workshops well into the nineteenth century. The

34. The Duc de Berry was the son of Jean II, le Bon (r. 1350–1364); the brother of Charles V (r. 1364–1380); and the uncle of Charles VI (r. 1380–1422); see note 33 above. On the contents of noble cabinets, see A. J. Turner, *Early Scientific Instruments: Europe, 1400–1800* (London, 1987), 57; and Oliver Impey and Arthur MacGregor, eds., *The Origins of Museums: The Cabinet of Curiosities in Sixteenth- and Seventeenth-Century Europe* (Oxford, 1985).

35. Astronomical compendia will be treated in the time-finding section of the comprehensive catalogue of the Adler collection. Noteworthy among the compendia are those dating from the 1550s, made by Christopher Schissler of Augsburg or his workshop (M-364, M-365, W-77, T-5); these contain stereographic or de Rojas projections.

36. Astrolabe clocks will be treated in the time-keeping section of the comprehensive catalogue of the Adler collection. Noteworthy among them are the Orpheus Clock (M-377), made in Germany, *c.* 1580, and a clock produced by Johann Christoff Lang, Augsburg, *c.* 1600 (M-383). On astrolabe clocks, see Catherine Cardinal, "Horloges de table astrolabiques françaises du XVI[e] siècle," *Astrolabica* 4 (1986): 3–20; and Klaus Maurice and Otto Mayr, eds., *The Clockwork Universe: German Clocks and Automata, 1550–1650* (New York, 1980).

37. See the Laurentius Schreckenfuchs astrolabe, dated 1567 (W-109, cat. no. 12), in this volume.

reason for its continued esteem had much to do with the different social role it played in the East.

USES OF THE ASTROLABE

As might be guessed of an instrument so widely dispersed and used over so many centuries, regional and cultural differences arose with respect to the instrument's design and use. Let us begin with the common features before turning to the variations.

The astrolabe's principal uses were astronomical, astrological, and topographical. For astronomical purposes, the astrolabe was described both as the "most perfect, certain, and necessary" and the "most pleasant, agreeable, and easy" instrument available to locate stars in the sky and discover the times of their risings and settings.[41] If the praise was a bit hyperbolic, it nonetheless conveyed the pride scholars had in owning so handsome and handy an instrument. With an astrolabe, an astronomer could find the altitude and azimuth, the ecliptic latitude and longitude, and the declination and ascension of any planet, comet, or star. He could find the parallax of the moon, the distance between stars, or the length of a comet's tail. He could also determine when a solar or lunar eclipse would occur, how long it would last, and how much of the celestial body would be darkened.[42] What's more, some of these calculations could be done without ever going outside, because the astrolabe was, in effect, an analogue computer. The instrument simulated the apparent rotation of the stars around the North Celestial Pole. Indeed, as John Blagrave remarked, an astrolabe could be used "to know the height of any starre above the horizon [when] sitting close within dores, and thereby to learne to know the starres in the skie."[43] Both Blagrave and Gemma Frisius extolled this pedagogical function.[44] The instrument could also be used indoors to calculate the length of day or night and to determine the beginning, end, and duration of twilight. Back outside, day or night, it could be employed to find the time.[45] Trigonometric scales for determining the sine or cosine of an angle were frequently inscribed on *mashriqi* astrolabes as well, making each example a mathematical tool as much as a star-finder or time-finder.

It has been claimed that the development of Latin astronomy in the eleventh and twelfth centuries owed much to the introduction of the astrolabe.[46] Although the arguments in support of this claim are rather tenuous, it appears that the counterclaim — that the astrolabe was little if ever used for observation and was employed solely as a calculating device or pedagogical model — also needs modification.[47] There is evidence that the astrolabe was occasionally used for astronomical research. In 1092, as we have seen, Walcher used his astrolabe to determine the time of a lunar eclipse, and in 1274, an unknown Danish astronomer at Roskilde measured the altitude of the sun each day in order to determine the length of daylight and compile a table for the calendar of the cathedral chapter.[48] In the early fourteenth century, moreover, Levi ben Gerson (1288-1344) took pains to establish astrolabic observations on a sure footing in his treatise on astronomy.[49] The astrolabe can also be seen in depictions of early observatories, such as that of Taqī al-Dīn in Istanbul, around 1577 (Figure 8); and Tycho Brahe

38. See, for example, the Danfrie astrolabe, 1584, reissued by Moreau in 1622 (w-98, cat. no. 19), in this volume. On makers of paper astrolabes or examples of their work, see Gunther (1932), 358-59, 401-2, 438-40, 448-50, 519; National Maritime Museum (1976), 37, 41; Turner, A. J. (1985), 43-44, 50; A. J. Turner, "Paper, Print, and Mathematics: Philippe Danfrie and the Making of Mathematical Instruments in Late 16th Century Paris," in *Studies in the History of Scientific Instruments*, ed. Christine Blondel, *et al.*, 22-42 (London/Paris, 1989); and King (1992), 2: 602-3. On paper instruments in general, see A. J. Turner, *Paper and Brass: Scientific Instruments and the Art of Printing. A Catalogue of an Exhibition held June...1974* (London, 1974); and Emmanuel Poulle, *Les instruments de la théorie des planètes selon Ptolémée: Équatoires et horlogerie planétaire du XIII^e au XVI^e siècle*, 2 vols. (Geneva, 1980a), *passim.*

39. Oxford, Bodleian Library, MS Aubrey 10, fol. 109; quoted in A. J. Turner, "Mathematical Instruments and the Education of Gentlemen," *Annals of Science* 30 (1973): 51-88 (quotation on 65). For John Aubrey's comments (that every schoolboy should have a paper astrolabe), see below, p. 13.

40. Moreau notes these problems as justification for issuing paper instruments. See Jean Moreau, *L'usage de l'un et l'autre astrolabe particulier et universel* (Paris, 1625); sig. aII; quoted in Turner, A. J. (1989), 33.

41. Jacquinot (1559), sig. ãij^v (my translation); and Denis Henrion, *Briefve explication de l'usage de l'astrolabe* (Paris, 1620), 2 (my translation); separately paginated, but included in Denis Henrion, *Collection, ou recueil de divers traictez mathematiques* (Paris, 1621).

42. See Gemma Frisius (1556), chaps. 47, 65-71, 74-76; and Blagrave (1585), 40-41, 50-61, 73.

43. Blagrave (1585), 38.

44. Gemma Frisius (1556), chap. 38; Blagrave (1585), 38-39.

45. On using the astrolabe to find the time, see North (1989), 218-19; *cf.* John D. North, "Astrolabes and the Hour-Line Ritual," *Journal for the History of Arabic Science* 5 (1981): 113-14.

46. Pedersen (1978), 309-14, reasons as follows: When Walcher used his astrolabe to determine the time of a lunar eclipse in 1092, he recognized that his observation could establish an epoch for a table of lunations, which he prepared in 1108 (the earliest table known to have been created by a Latin astronomer). In 1126, Adelard of Bath (fl. 1116-1142) translated the astronomical tables of al-Khwārizmī, and others drew on the work of al-Zarqālī and al-Battānī. With information on the mean motions of the sun, moon, and planets, these tables allowed astronomers to utilize their astrolabes more fully. The problem was that Western astronomers little understood the astronomical theories on which the tables were based. This impasse led to the translation of Greek and Arabic manuals of astronomy and planetary theory — culminating in the translation of Ptolemy's *Almagest* in the third quarter of the 12th century — and opened the door to new research using precision instruments.

47. Poulle (1980b), 3-4, takes this position.

48. Pedersen (1978), 312, 322.

49. Bernard R. Goldstein, "Levi ben Gerson: On Instrumental Errors and the Transversal Scale," *Journal for the History of Astronomy* 8 (1977): 102-12.

FIGURE 8 *Taqī al-Dīn's observatory, Istanbul,* c. *1577. Miniature from the* History of the King of Kings, *a poem by 'Alā ad-Dīn Mansūr-Shīrazī. Courtesy of Istanbul Üniversitesi Kutüphanesi, MS Yildiz 2652/260, fol. 57*[r]*.*

FIGURE 9 *Oronce Fine discussing the use of the astrolabe and astronomical tables with Urania. Detail of a woodcut in Oronce Fine,* De mundi sphaera *(Paris, 1542). Courtesy of the Adler Planetarium, Chicago.*

had one, "solidly and ingeniously worked in brass," which he bought with his own money.[50]

But as a precision tool, the astrolabe left something to be desired. Levi ben Gerson recognized some of the systematic and random errors involved in using an astrolabe to determine the altitude of a star: (a) the vertical diameter of the instrument might not be aligned with the zenith, thereby throwing off all altitude divisions around the limb; (b) the alidade's line of sight might not correspond with its reading on the scale; and (c) the user might read the scale to minutes even though its smallest subdivisions were degrees. The systematic errors (a and b) were introduced by faulty construction but could be rectified by new procedures for fabrication. The random error (c) was a consequence of method as much as design but could be lessened by the introduction of a transversal scale with finer subdivisions.[51] Few, however, took heed of Levi ben Gerson's recommendations. Although Tycho employed transversals on his mural quadrant and other large instruments, he did not incorporate them into any astrolabe, for he maintained that even the largest astrolabe could not measure the courses and positions of the stars with any sufficient degree of accuracy (or at least with the accuracy that Tycho demanded of his instruments). In comparison to other apparatus, an astrolabe was "neither...very convenient for observations of the stars, nor adequate and reliable." Indeed, the use of an astrolabe presupposed that the paths and positions of stars and planets were already determined by other methods.[52] That was why astronomers with astrolabes typically had ephemerides and other tables at their side.[53] (Figure 9)

If, as a handmaiden to theoretical astronomy, the astrolabe was not sufficiently fastidious, it was, nevertheless, uniquely suited for astrology. In noting this, Tycho took part in a long tradition. With the aid of planetary tables, an astrologer could use the instrument to determine

50. Tycho Brahe, *Astronomiae instauratae mechanica* (Wandesburgi, 1598), "De aliis quibusdam instrumentis nostris"; translated in Hans Ræder, Elis Strömgren, and Bengt Strömgren, eds. and trans., *Tycho Brahe's Description of His Instruments and Scientific Work* (Copenhagen, 1946), 99.

51. Goldstein (1977).

52. Ræder *et al.* (1946), 99-100.

53. See the image of an astronomer with an astrolabe and astronomical tables in a 13th-century manuscript (Paris, Bibliothèque de l'Arsenal, MS 1186, fol. 1^{v}); and that in a manuscript composed between 1350 and 1399 (Copenhagen, Det Kongelige Bibliotek, Cod. Hebr. 37, fol. 114^{r}), reproduced in Figure 3 (above).

the relationship of the planets to key stars and astrological houses.[54] On Latin instruments, the astrological houses were engraved directly on the tympans, while Persian astrolabes used unequal hour lines as the divisions between houses. That is not to say that Persian astrolabists had little interest in astrology, for astrological tables were abundantly inscribed on the backs of *mashriqi* instruments. As al-Bīrūnī observed in a book on the art of astrology (A.D. 1029/30), these included tables of lunar mansions, triplicities, and the relationship of the zodiacal signs to their faces, terms, and lords.[55]

The point of all this astrological furniture was to peep into the future. On one hand, astrologers practiced natural astrology, foretelling the weather, earthquakes, diseases, mortality, wars, discords, and conspiracies from the state of physical conditions, which were thought to be dependent both on the course of the planets through the signs and on the appearance of comets. On the other hand, they practiced judicial astrology, which attempted to divine the outcome of human affairs from the disposition of the heavens at the time of a client's birth or the occasion of an election. Judicial astrologers answered horary questions. In other words, they would be consulted by a person preparing to undertake a great project or go on a business trip. Once the astrologer learned the time of the client's birth, he saw how that person's horoscope corresponded with the aspect of the celestial bodies at the time the inquiry was made. Upon this comparison, he foretold how successful the undertaking would be — typically adding that God may do more or less as he pleased.

The principal appeal of the astrolabe in the late Middle Ages and the Renaissance was its handiness for astrology. In *The Canterbury Tales,* Chaucer gave the Oxford student, Nicholas, an astrolabe with which to practice his prognosticary art.[56] And 300 years later, John Aubrey remarked that every schoolboy should have a paper astrolabe "to teach him to erect a Scheme presently [*i.e.,* cast a horoscope]: wch will much delight & incourage them."[57] Astrolabes were used to determine a newborn's nativity, to find the propitious time to lay cornerstones, and to detect thieves (a common task of astrologers and cunning folk in villages).[58] Astrology was also a major component of medical care, and since the Middle Ages, astrolabes were used to determine the critical days of an illness, the optimum times for bleeding, and occasions for medications.[59]

Stars and human bodies came together in a memorable medieval report of astrolabes amidst the philosophers at Kublai Khān's table. These men were said to be wise in the sciences of astronomy, necromancy, geomancy, pyromancy, hydromancy, and augury:

> And every [one] of them have before them astrolabes of gold, some spheres, some the brainpan of a dead man, some vessels of gold full of gravel or sand, some vessels of gold full of coals burning, some vessels of gold full of water and of wine and of oil, some horloges of gold made full nobly and richly wrought, and many other manner of instruments after their sciences.[60]

54. On the use of the astrolabe to demarcate houses, find horoscopes, or set figures, see Stöffler (1513), part 2, props. 53-56; Köbel (1535), sigs. [C4]^r-D^r; Gemma Frisius (1556), chaps. 50-56; and Blagrave (1585), 42-47, 69-70. Henrion (1621), 62, recommends consulting ephemerides (alongside one's astrolabe) when wishing to determine astrological houses more exactly for the purpose of casting horoscopes.

55. Abū Rayḥān al-Bīrūnī, *Book of Instruction in the Elements of the Art of Astrology*, trans. Robert Ramsay Wright (London, 1934), 195; quoted in Turner, A. J. (1985), 22; Gibbs with Saliba (1984), 16, 32-38.

56. Chaucer (1987), *The Canterbury Tales*, "The Miller's Tale," A3209.

57. Oxford, Bodleian Library, MS Aubrey 10, fol. 109; quoted in Turner, A. J. (1973), 65.

58. Stöffler (1513), part 2, prop. 56; Stöffler (1560), part 2, prop. 56, fols. 175^r-183^r; Blagrave (1585), 47-48; Lynn Thorndike, *A History of Magic and Experimental Science*, 8 vols. (New York, 1923-58), 5: 259, 384. For the social functions of astrology and tasks such as thief detection, see Keith Thomas, *Religion and the Decline of Magic* (New York, 1971), chaps. 10-12.

59. Stöffler (1513), part 2, prop. 55; Franz Ritter, *Astrolabium* (Nuremberg, [1613]), see second part; also note the full title of Köbel (1535): *Astrolabii declaratio, eiusdemque usus mire jucundus, non modo astrologis, medicis, geographis, caeterisque literarum cultoribus multum utilis ac necessarius; verum etiam mechanicis quibusdam opificib. non parum commodus* (which describes the astrolabe as "very practical and even necessary for...doctors"). See also Lynn White, Jr., "Medical Astrologers and Late Medieval Technology," *Viator* 6 (1975): 295-308; reprinted in *idem*, *Medieval Religion and Technology: Collected Essays* (Berkeley, 1978), 297-315; and Nancy G. Siraisi, *Medieval and Early Renaissance Medicine: An Introduction to Knowledge and Practice* (Chicago, 1990).

60. Seymour (1968), 179. On the reliability of reports of the astrolabe in China, see discussion above, on pp. 4-6.

FIGURE 10 *Dr. Faustus conjuring in a chalk circle, with particular and universal astrolabes hanging on the wall. Woodcut from a chapbook in the collection of Samuel Pepys,* First Part of Dr. Faustus, Abreviated and brought into verse *(London, [*c. *1680]). Courtesy of the Master and Fellows, Magdalene College, Cambridge.*

While this passage, taken from *Mandeville's Travels,* may say more about medieval, Western expectations of the Orient than the real activities of the Great Khān's advisors, it should not be discounted as entirely fanciful. The passage may tell us something about the activities of diviners and philosophers in the service of Western potentates, or at least something about popular perceptions of sages among the sovereigns. The presence of astrolabists and astrologers in both Eastern and Western courts is not to be doubted.[61] Western sources, moreover, do confirm that astrolabes were used in the darker, prophetic arts. A medieval manuscript of Czech origin shows astronomers toiling with astrolabes alongside geomancers.[62] And in the *Liber particularis* (written at the turn of the thirteenth century), Michael Scot reported that knowledge of the astrolabe was won by Gerbert from demons whom he had conjured up and forced to teach him! Gerbert reputedly wrote down what he learned and shared his findings with others, later renouncing his contact with demons and becoming Pope.[63] Elsewhere in this text, Scot notes that the astrolabe itself was sometimes used in invoking evil spirits, but added that the Roman Church condemned this practice.[64] As late as the seventeenth century, astrolabes were popularly viewed as Faustian tools. Crude woodcuts in chapbooks (aimed at the lowest levels of the literate) depicted astrolabes alongside Dr. Faustus, seen conjuring in a circle, with the devil beside him.[65] (Figure 10)

61. See discussion above, on pp. 3, 6, and 7.

62. Krása (1983), plate 19.

63. Thorndike (1965), 93-94; *idem* (1923-58), 2: 322.

64. Thorndike (1965), 117. Scot believed that knowledge of astronomy was essential to necromancy, because there were proper times for convening with demons.

65. *First Part of Dr. Faustus, Abreviated and brought into verse* (London, [*c.* 1680]); Roger Thompson, ed., *Samuel Pepys' Penny Merriments* (New York, 1977), 100.

Astronomy and astrology were but two of the practical arts whose practitioners might find cause to consult an astrolabe. Geography, navigation, and surveying — which might be grouped together as topographical arts — were others. Medieval texts made frequent mention of geographical uses.[66] Any astrolabe could be used to find the difference in longitude between two towns if the initial time of a lunar eclipse was noted at each location.[67] Latitude was simply found by observing the altitude of the pole star or of the sun when it crossed the meridian (assuming one made adjustments for seasonal changes in solar declination).[68] Some astrolabes also included a geographical tympan with a map of the world in polar stereographic projection.[69] Features like these made the astrolabe a welcome companion on expeditions. John of Sacrobosco (fl. 1230-1255) pointed out, moreover, that if a person equipped with an astrolabe observed the pole star from two locations that were separated by 1° along a meridian, he could determine the circumference of the earth.[70] And according to *Mandeville's Travels,* itinerant astronomers were able to prove the earth to be round on the basis of such observations.[71]

The ability to find latitude with an astrolabe also made it increasingly attractive to navigators and explorers, who, in the Middle

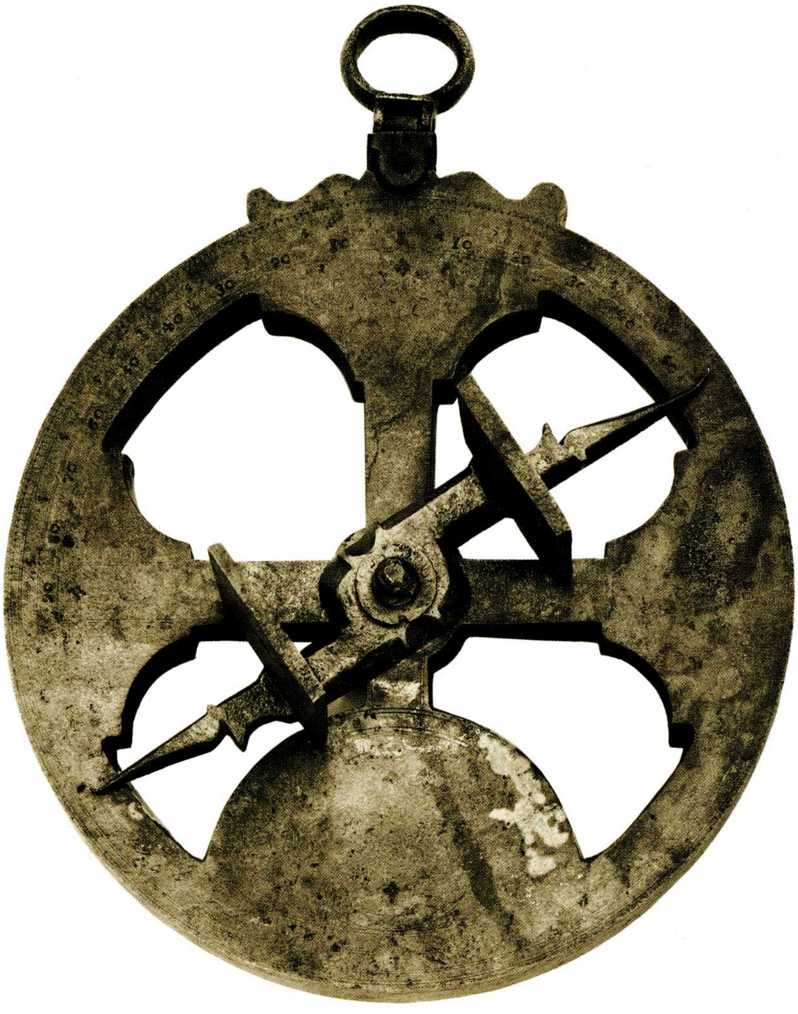

FIGURE 11 *Mariner's astrolabe, dated 1616, recovered from the wreck of the* Atocha *off the Florida Keys. Courtesy of the Adler Planetarium, Chicago (A-275).*

66. Emmanuel Poulle in *Le navire et l'économie maritime du XV^{e} au XVIII^{e} siècle* (Paris, 1967), 113; quoted in Francis Maddison, *Medieval Scientific Instruments and the Development of Navigational Instruments in the XVth and XVIth Centuries*, Agrupamento de Estudos de Cartografia Antiga, no. 30 (Coimbra: Junta de Investigações Científicas do Ultramar-Lisboa, 1969), 12 n. 35.

67. *Astrolabii...canones* (1512), sig. b2^{v}; Stöffler (1513), part 2, prop. 31; Jacquinot (1559), fols. 44^{r}-45^{v}; Danti (1569), 89-90.

68. *Astrolabii...canones* (1512), sig. b2^{r}; Stöffler (1513), part 2, prop. 30; Jacquinot (1559), fol. 43; Danti (1569), 87-88.

69. Gerard L'E. Turner and Elly Dekker, "An Astrolabe Attributed to Gerard Mercator, c. 1570," *Annals of Science* 50 (1993): 403-43, esp. 420. Also see Figure 5 (above) for an astrolabic map plate included in an astronomical compendium by Christopher Schissler.

70. The observations were used to mark the endpoints of an arc of 1°. The length of this arc was multiplied by 360 in order to compute the circumference. Lynn Thorndike, ed., *The Sphere of Sacrobosco and Its Commentators* (Chicago, 1949), 85, 122-23.

71. Seymour (1968), 139-40. Of course, altitude measurements of this sort only show the earth to be round from north to south. The times of lunar occultations or eclipses, observed simultaneously from different longitudes, can be used to show the earth to be round in the east-west direction.

FIGURE 12 *Mariner's astrolabe being used to measure the meridian altitude of the sun. Renaissance woodcut. Private collection.*

72. See, for example, the likely use of an astrolabe made by a priest who returned to Norway in 1364 after a voyage to the "northern islands." R. A. Skelton, Thomas E. Marston, and George D. Painter, *The Vinland Map and the Tartar Relation* (New Haven, 1965), 180; cited in Maddison (1969), 12 n. 35.

73. Alan Stimson, *The Mariner's Astrolabe: A Survey of Known, Surviving Sea Astrolabes* (Utrecht, 1988). Also see a description of a Portuguese mariner's astrolabe (A-275, cat. no. 46), dated 1616, recovered from the wreck of the *Atocha*.

Ages, began to use it occasionally on shore.[72] Early use at sea would have been difficult, given the rocking of the ship and the wind resistance offered by the metal plate. These problems were overcome in the late fifteenth century, when the instrument was stripped of all nonessential parts, leaving only a heavily weighted, graduated limb and an alidade.[73] (Figures 11-12) In this new form, the astrolabe came of age as a nautical tool, and it was readily adopted by Renaissance sailors, who

FIGURE 13 *Planispheric astrolabe being used for navigation. Painting of Noah's Ark,* c. *1590, attributed to Miskin. India, Mughal, Akbar period. Color and gold on paper. 28.1 x 15.6 cm. Courtesy of the Freer Gallery of Art, Smithsonian Institution, Washington, D.C. (48.8).*

were taught to sail by the altitude of the pole star or "run down the latitude."[74]

There is still some question whether the traditional astrolabe ever went to sea.[75] A chart drawn by Diego Ribero in 1525 arguably contains the earliest illustration of a seaman's astrolabe, and it resembles not the mariner's astrolabe in its typical, open form, but the solid back of the traditional planispheric astrolabe.[76] A traditional astrolabe also appears on board ship in an Indian painting from the late sixteenth century.[77] (Figure 13) Texts and instruments further muddle the issue. In a treatise on the planispheric astrolabe first published in 1513 and reprinted many times, Johann Stöffler told explorers how to use the standard instrument to find their location if they went astray in the middle of the sea or in the wilderness; and in another text, John Blagrave taught how to pilot a ship by the stars.[78] Gemma Frisius, moreover, designed a *quadratum nauticum* for mariners, which his nephew, Gualterus Arsenius, included within the mater of many planispheric astrolabes.[79] The *quadratum nauticum* indicated the rhumb — *i.e.*, the course given by a magnetic compass — to be sailed between places of known latitude and longitude.[80] We must ask why Arsenius went to the trouble to put this device on his astrolabes. Perhaps it was sheer fancy for him to think that his magnificent instruments would ever go to sea, or perhaps he thought that the *quadratum* would call attention to the recent evolution of the astrolabe into a nautical instrument. Another possibility may be that the enhanced astrolabe appealed to the armchair traveler!

Whatever the case, the fact that Arsenius also included astrological notations on the star-pointers of his retes reminds us that astrolabists stood at the nexus of astrology, astronomy, and nautical science. No story illustrates this better than that of Abraham Zacuto, the maker of scientific instruments, compiler of astronomical tables, and professor of astronomy and astrology at the University of Salamanca. In 1496, prior to the departure of Vasco da Gama, the king of Portugal asked

74. In sailing by the altitude of the pole star, seamen used the height of Polaris above the horizon as a measure of their vessel's change in the north-south position. Once Europeans ventured south of the equator (in 1471), it became impractical to sight Polaris. For mariners near the equator, Polaris appeared too close to the horizon; for those in southern waters, Polaris was below the horizon. The technique of altitude sailing was then refined into the method of "running down the latitude." According to this method, sailors measured the altitude of either the sun or pole star in order to determine their latitude. Based on this, they sailed north or south until they reached the latitude of their destination and then ran east or west along that parallel until they sighted land. On use of the mariner's astrolabe by Vasco da Gama, see Maddison (1969), 28; and the marginalia of Christopher Columbus in his copy of Pierre d'Ailly, *Ymago mundi* (Louvain, [*c.* 1480-83]); trans. and printed by Grant (1974), 636 n. 42. On navigation, see David W. Waters, *Science and the Techniques of Navigation in the Renaissance*, 2nd ed. (Greenwich, 1980); E. G. R. Taylor, *The Haven-Finding Art* (New York, 1957); and David W. Waters, *The Art of Navigation in England in Elizabethan and Early Stuart Times*, 2nd ed. (Greenwich, 1978).

75. Emmanuel Poulle, for instance, thinks it did not; see Maddison (1969), 12-13.

76. Maddison (1969), 28-29.

77. Painting of Noah's Ark, attributed to Miskin (India, *c.* 1590), accession no. 48.8, Freer Gallery of Art, Smithsonian Institution, Washington, D.C.

78. Stöffler (1513), part 2, prop. 33; Blagrave (1585), 62.

79. Gemma Frisius (1583), chap. 87; Apianus (1584), 55, 459-62. See astrolabes by Arsenius, dated 1558 (M-23, cat. no. 8) and 1564 (M-24, cat. no. 9), and the unsigned Louvain astrolabe, *c.* 1600 (M-25, cat. no. 10), in this volume.

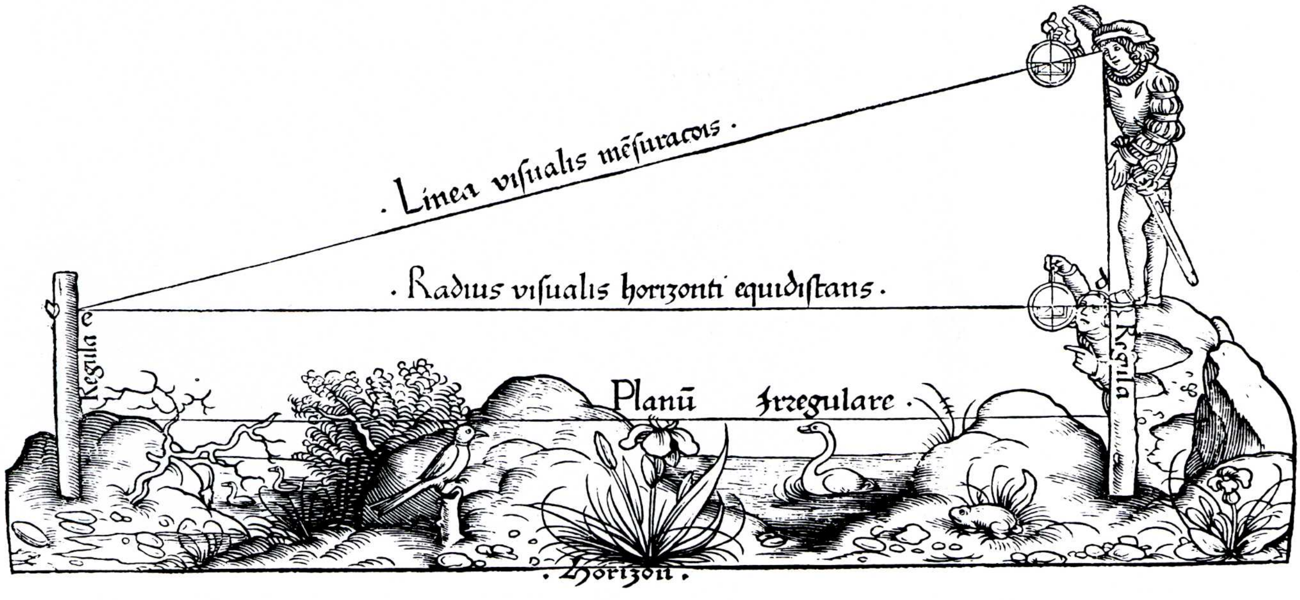

FIGURE 14 *Use of an astrolabe to find the distance between inaccessible places. From Johann Stöffler,* Elucidatio fabricae ususque astrolabii *(Oppenheim, 1524). Courtesy of the Adler Planetarium, Chicago.*

Zacuto not only to train sailors in the use of his astrolabe, astronomical tables, and charts, but also to predict the outcome of the expedition.[81]

While finding one's latitude was an important step in navigation, it was also critical for laying a base line in a geodetic survey. The astrolabe was seldom (if ever) used for this task — its limb being too crudely divided — but it was well-adapted for local surveys of territories filled with landmarks. For this purpose, the surveyor took advantage of a device known as the shadow square found on the back of the mater. The shadow square, which has been attributed to al-Khwārizmī (d. post-A.D. 847/8), was to be found very early on Islamic instruments.[82] In the West, Gerbert was the first to describe its practical use, and medieval treatises on applied geometry, such as that written by Dominicus de Clavasio (fl. 1346), commonly included problems involving the use of the shadow square to determine the distance between places, the height of buildings, or the depth of wells.[83] The same problems were discussed and whimsically illustrated in Renaissance texts that promoted the astrolabe as a tool for the surveyor, architect, and artist.[84] (Figures 14-17)

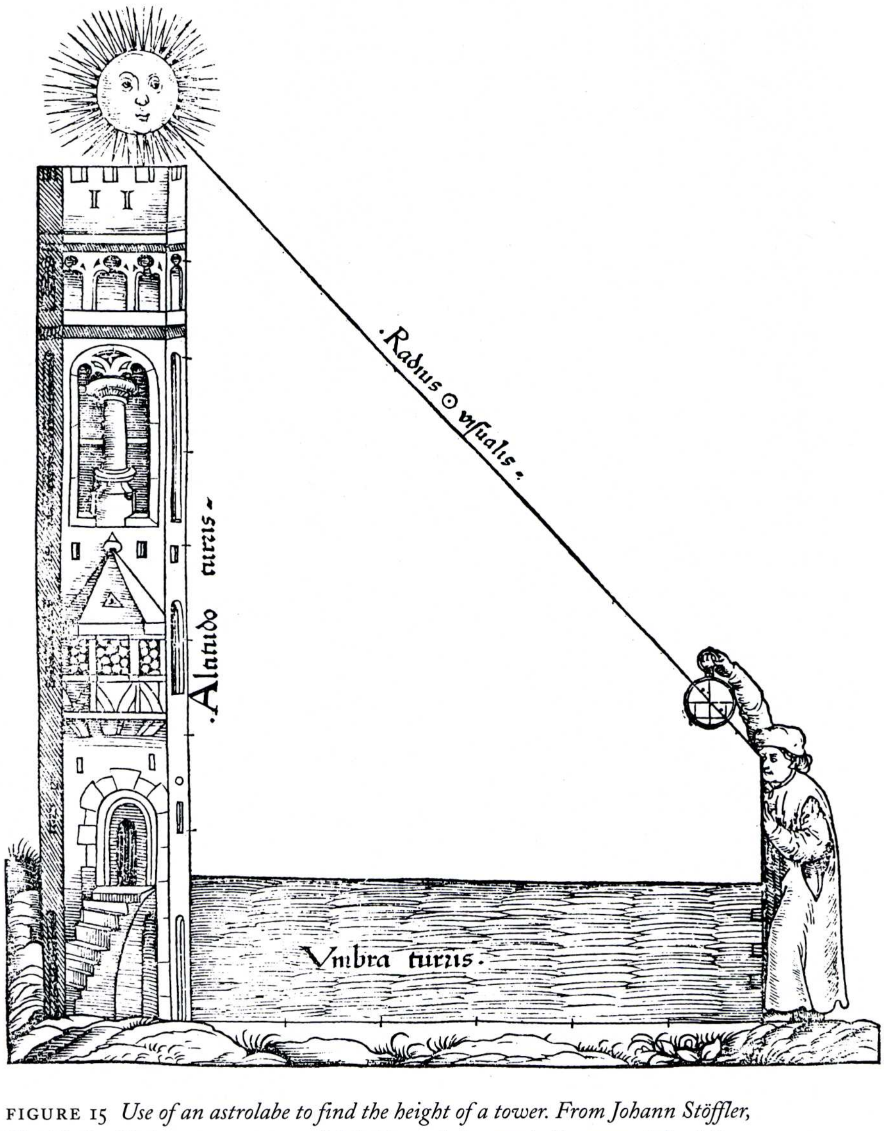

FIGURE 15 *Use of an astrolabe to find the height of a tower. From Johann Stöffler,* Elucidatio fabricae ususque astrolabii *(Oppenheim, 1513). Courtesy of the Adler Planetarium, Chicago.*

80. The *quadratum nauticum* was a windrose within a latitude-longitude grid. It was useful to navigators who wanted to sail between places with known geographic coordinates. The navigator marked the difference in longitude along the horizontal scale and the difference in latitude along the vertical. He then plotted the intersection of these lines within the windrose in order to discover the rhumb to follow. This technique was good only for short distances, as Gemma himself remarked. Michel (1947), 44-45.

81. Metzger and Metzger (1982), 157; *Encyclopaedia Judaica, s.v.* "Zacuto, Abraham ben Samuel."

82. Abū Rayḥān al-Bīrūnī, *The Exhaustive Treatise on Shadows*, trans. E. S. Kennedy, 2 vols. (Aleppo, 1976); quoted in Turner, A. J. (1985), 21. The shadow square is sometimes attributed to al-Battānī (850-929); see Edmond R. Kiely, *Surveying Instruments: Their History* (Columbus, Ohio, 1979), 68.

83. Kiely (1979), 74; Grant (1974), 180-82.

84. *Astrolabii...canones* (1512), sigs. [b8r]-d3r; Stöffler (1513), part 2, props. 58-65; Copp (1525), sigs. fijr-giijv; Köbel (1535), sigs. D2r-[G]r; de Rojas (1550), 165-81, 185-96. For an example of an all-purpose, applied-mathematics book tutoring surveyors, t pographers, architects, and artists on the use of the astrolabe, see Cosimo Bartoli, *Del modo di misurare le distantie, le superficie, i corpi, le piante, le provincie, le prospettive, & tutte le altre cose terrene, che possono occorrere a gli huomini* (Venice, 1564). This astrolabe was so identified with the work of surveyors and architects that one appears in Sir John Harington, *A New Discourse of a Stale Subject, Called the Metamorphosis of Ajax* (London, 1596). In this mock-heroic work, Harington described his invention of a water closet. On one page, we see a "rare Engine[e]r" named "Archimides" using an astrolabe to survey the placement of "a jakes," or privy, of the new form.

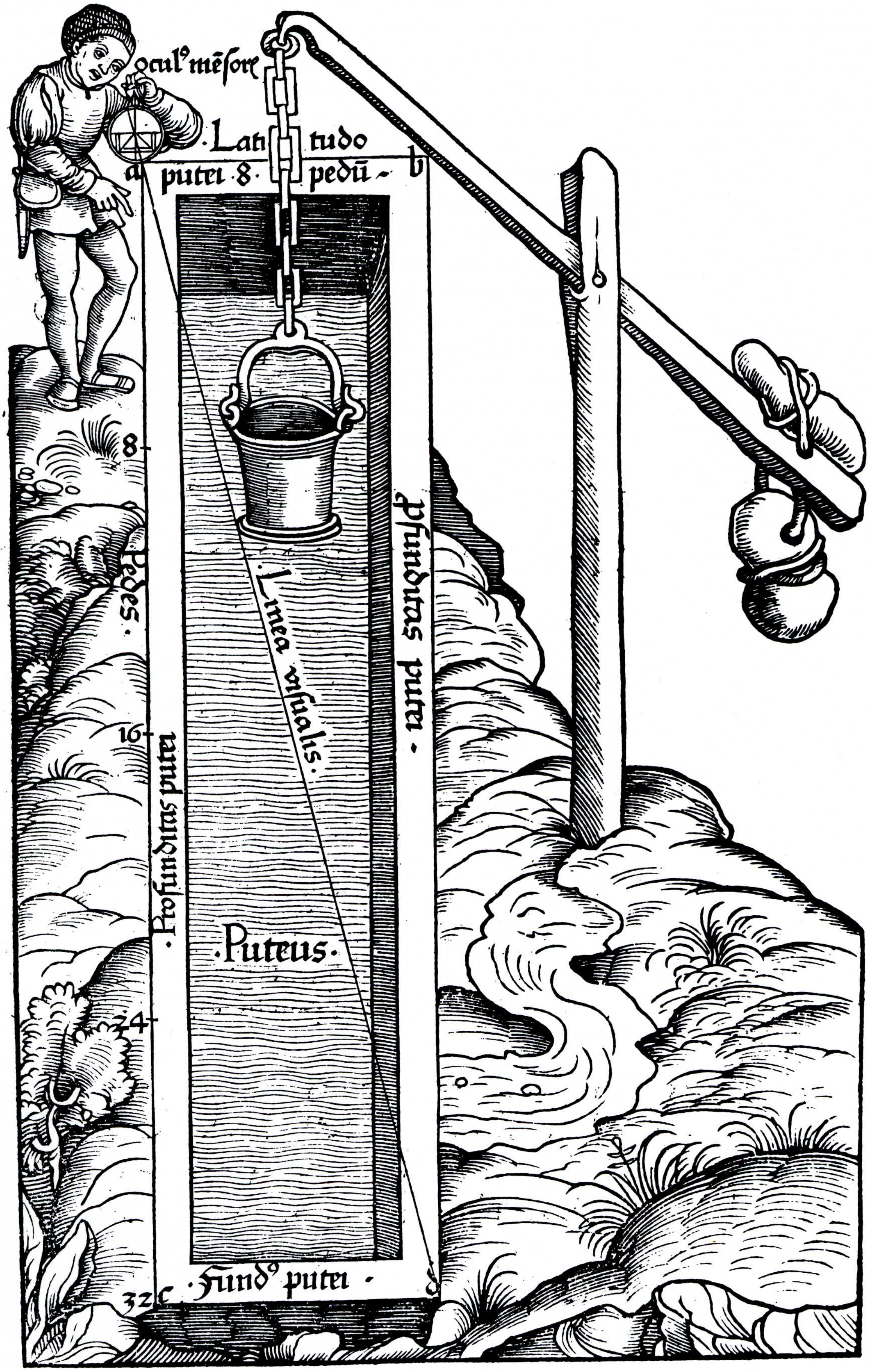

FIGURE 16 *Use of an astrolabe to find the depth of a well. From Johann Stöffler,* Elucidatio fabricae ususque astrolabii *(Oppenheim, 1513). Courtesy of the Adler Planetarium, Chicago.*

Another innovation relevant to surveying occurred in 1486, when Hans Dorn inserted a magnetic compass in the throne of an astrolabe he made for Martin Bylica.[85] This enabled angles of azimuth to be measured along the limb of the astrolabe when the instrument was laid on its side. Gemma Frisius independently endorsed this idea and championed the astrolabe as a tool for land measure and triangulation.[86] (Figure 18) Even without the compass, the astrolabe was helpful in rendering maps and topographical reports.[87] (Figures 19-20) It was further promoted as an agent of geometricized warfare, for it could be suspended from a spear and used to determine whether a distant enemy was advancing or retreating.[88] (Figure 21) The surveyor and military tactician, however, had little need for the stellar rete, tympans, and astrological lines on an astrolabe, and their instruments became stripped of these luxury features.[89] In this way, more specialized apparatus for surveying and navigation evolved from the astrolabe during the Renaissance, and these new tools ultimately superseded it in those fields.

85. The astrolabe is pictured in Turner, A. J. (1987), 36-37; and Turner, A. J. (1985), 48 n. 164. The Italian astrolabe, *c.* 1650 (M-30, cat. no. 24), has a compass in its throne, and the de Rojas-type astrolabe, German?, 17th century (M-42, cat. no. 17), likely did as well.

86. Gemma Frisius's *Libellus de locorum describendorum ratione* (Antwerp, 1533) is printed with an accompanying discussion in de Rojas (1550), 201-25; see also Gemma Frisius (1583), 97-98; and Alexander Pogo, "Gemma Frisius, His Method of Determining Differences of Longitude by Transporting Timepieces (1530), and His Treatise on Triangulation (1533). With...a Facsimile Reproduction (No. XVI) of Gemma's *Libellus de locorum describendorum ratione*, Antwerp, 1533," *Isis* 22 (1934): 469-504.

87. De Rojas (1550), 182-85, 197-98; Bartoli (1564), fols. 43^{v}-46^{v}; Henrion (1620), 2.

88. De Rojas (1550), 199-200; Bartoli (1564), fol. 49.

89. Surveyor's astrolabes will be treated in the surveying section of the comprehensive catalogue of the Adler collection. Examples from the third quarter of the 16th century include M-43, M-44, and M-45 (cat. no. 13).

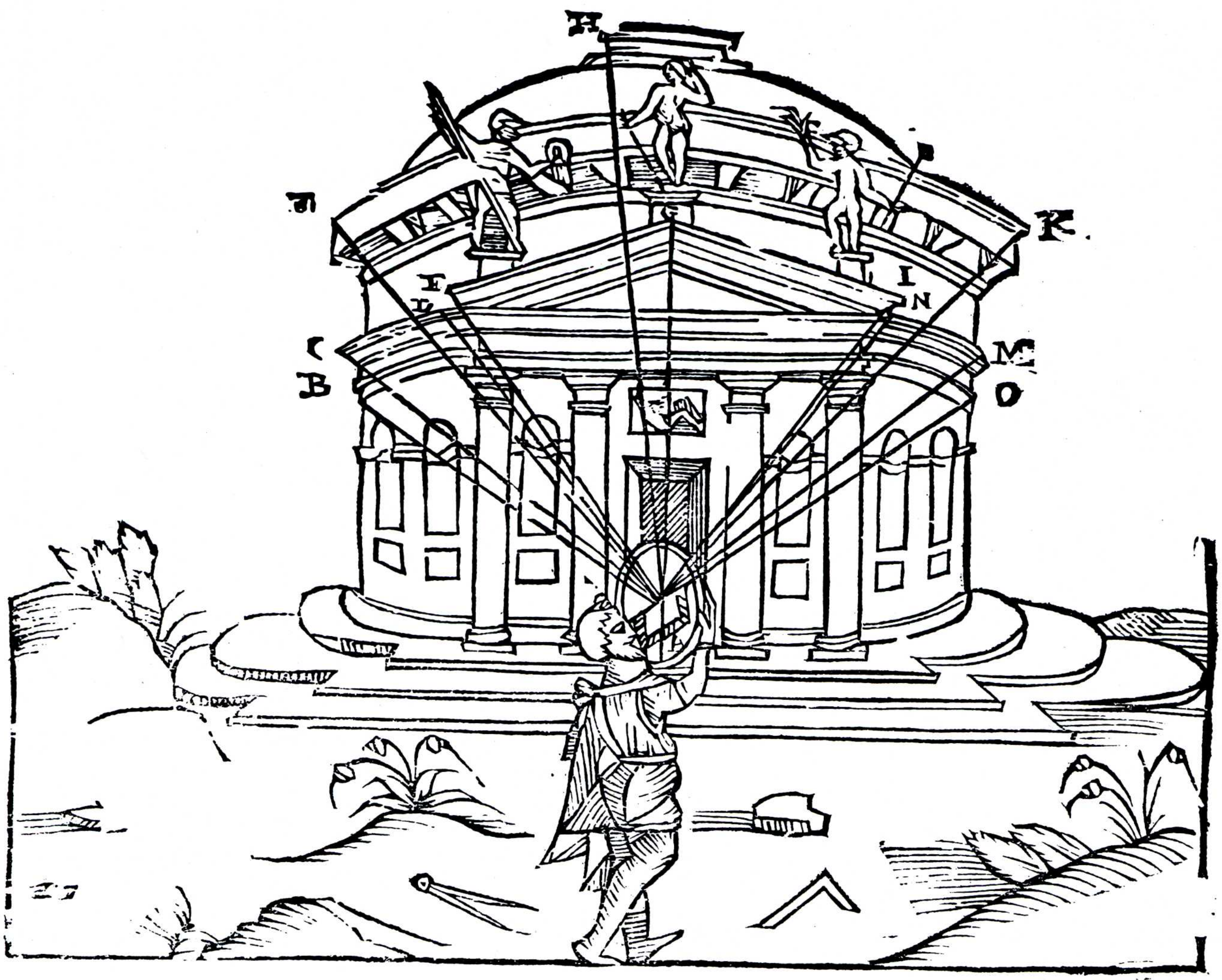

FIGURE 17 *Use of an astrolabe to discover the proportions of a building. From Cosimo Bartoli,* Del modo di misurare *(Venice, 1614). Courtesy of the Adler Planetarium, Chicago.*

As the astrolabe slipped from favor in Christian Europe, it was still prized in Islamic communities because it played a larger social role. It was not simply a tool for astronomy and related land-based sciences (such as navigation and surveying), but an instrument used to bolster faith and ritual.

This had also been true to a modest extant in Judeo-Christian circles. In Biblical exegesis during the twelfth and thirteenth centuries, Jewish scholars argued whether cryptic words, which seemed to indicate

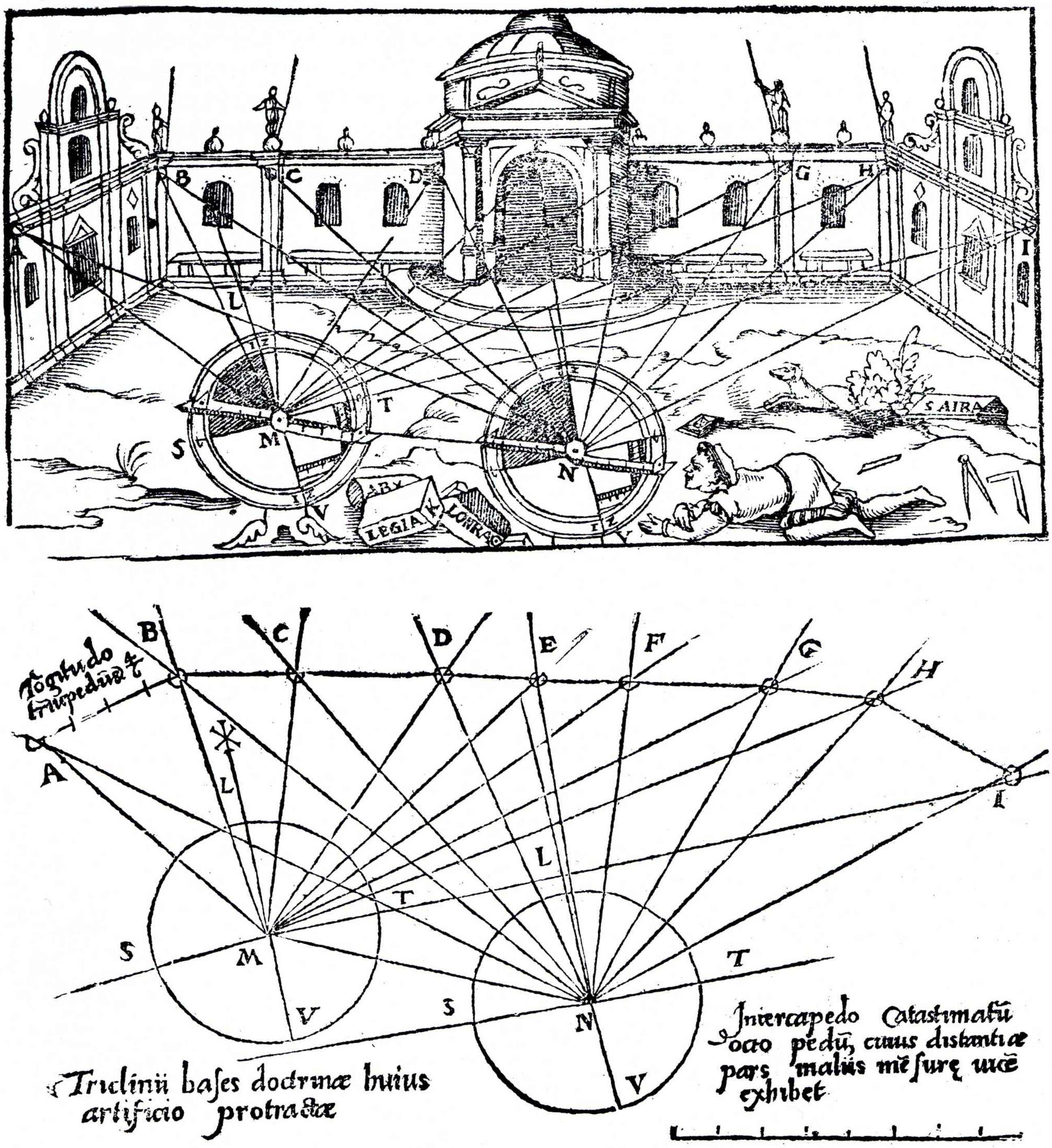

FIGURE 18 *Triangulation with an astrolabe positioned at two stations. From Gemma Frisius,* De astrolabo catholico liber *(Antwerp, 1583). By permission of the Houghton Library, Harvard University.*

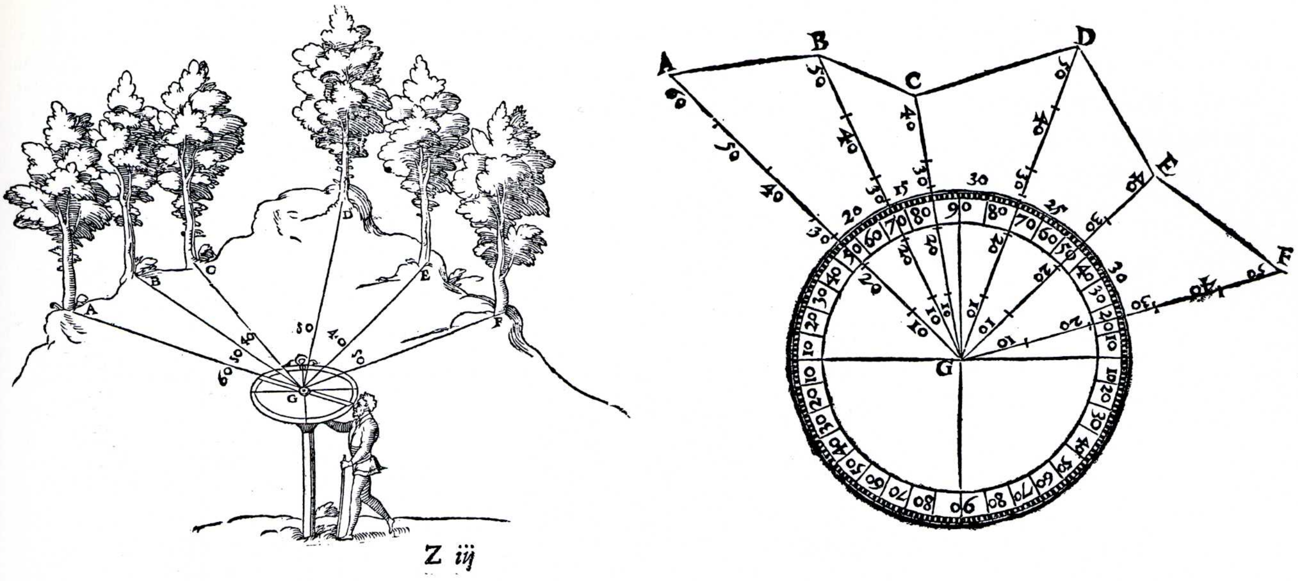

FIGURE 19 *Use of an astrolabe to map the position of some trees: A surveyor observes the angles between the trees and measures the distance between each tree and a reference point. Then, with a protractor and ruler, he reproduces his field measurements to scale on paper, and so constructs a map. From Juan de Rojas,* Commentariorum in astrolabium quod planisphærium vocant, libri sex *(Paris, 1551). Courtesy of the Adler Planetarium, Chicago.*

divinatory devices, might allude to an astrolabe.[90] For instance, Abraham ibn Ezra (*c.* 1090–*c.* 1164), a scholar renowned for his treatises on the astrolabe and works on astronomy as much as for his commentary on the Bible, apparently suggested that the mysterious *urim vethumin* — held in the breastplate of the High Priest and revealing divine will when consulted — referred to an astrolabe.[91] Rabbis also debated whether it was permitted to use an astrolabe on the Sabbath. Solomon ibn Adreth allowed it because it was equal to reading a scientific book; others permitted it because they believed that Rabban Gamliel II (fl. *c.* A.D. 80–116) had used one on the Sabbath.[92]

Christians sometimes made their astrolabes into tools of religion, too. They inscribed tables of Saints' Days, dominical letters, epacts, and the paschal index on the back of the mater so that they could readily determine the date of Easter and other religious festivals.[93] Nevertheless, such tables were added more as an afterthought; they were nice to have, but were not the main reason one owned an astrolabe.

By contrast, religion was a driving force in the acquisition and use of astrolabes in Islamic communities, where every *muwaqqit* (the astronomer at the local mosque) might use one in determining the times of the five daily prayers — namely, sunset, nightfall, daybreak, midday, and mid-afternoon.[94] In fact, mosque astronomers were sometimes drawn from the ranks of astrolabists, and various devices adapted the astrolabe to their needs.[95] Arcs for determining the hours of prayer from the altitude of the sun were inscribed on the back of *mashriqi* instruments, whereas prayer lines were placed on the tympans of *maghribi* astrolabes. On instruments from both eastern and western Islam, circular cotangent scales could also be used to determine the times of afternoon prayer from the ratio of a gnomon's length to the length of its shadow. Twilight lines occasionally appeared on the tympans, too, dawn and nightfall being times for prayer.[96]

90. Texts of particular interest included Genesis 31:19, Exodus 28:30, and Numbers 22:7; see *The Soncino Chumash: The Five Books of Moses with Haphtaroth*, Hebrew text with English translation and commentary, ed. A. Cohen (London, 1947); and Solomon Gandz, "The Astrolabe in Jewish Literature," *Hebrew Union College Annual* 4 (1927): 469–86, esp. 480–81.

91. Ibn Ezra's commentary on Exodus 28:30; discussed in Gandz (1927), 471–72, 480. On ibn Ezra's scientific work, also see Millàs-Vallicrosa (1963), 151–52.

92. Gandz (1927), 481–82. For discussion of Hebrew astrolabes, see Bernard Goldstein, "The Hebrew Astrolabe in the Adler Planetarium," *Journal of Near Eastern Studies* 35 (1976): 251–60.

93. See the English astrolabe, *c.* 1250 (M-26, cat. no. 1), the Martinot astrolabe, 1598 (M-31, cat. no. 15), and the Danfrie-Moreau astrolabe, 1584–1622 (W-98, cat. no. 19) in this volume.

94. King (1987a), 2: 105. I am speaking here of people working in the tradition of Islamic mathematical astronomy. Folk astronomy was also concerned with the religious aspects of Muslim daily life, but writers on folk astronomy rarely, if ever, recommended astrolabes, quadrants, sundials, or tables, which were the standard instruments of the mosque astronomer. Instead, they advocated crude formulas and simple procedures for regulating the times of prayer or finding the direction of Mecca. For a comparison of mathematical and folk astronomy, see David A. King, *Astronomy for Landlubbers and Navigators: The Case of the Islamic Middle Ages*, Centro de Estudos de História e Cartografia Antiga, no. 164 (Lisbon: Instituto de Investigação Científica Tropical, 1984).

95. Mayer (1956), 40–41, 61.

96. Gibbs with Saliba (1984), 31–33, 38–39, 51, 54; Hartner (1968/1984), 1: 299.

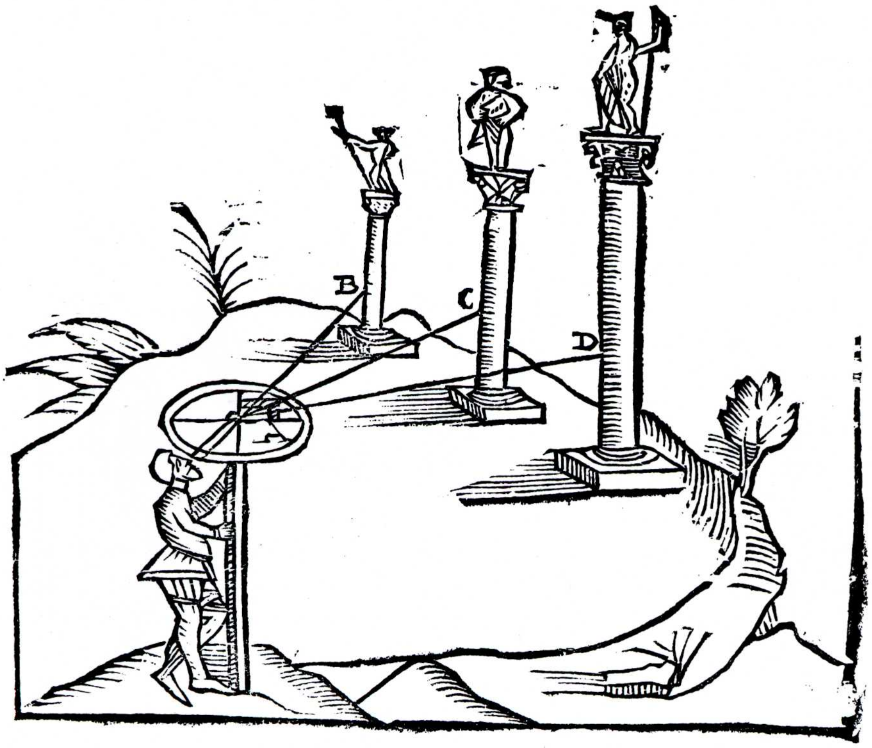

FIGURE 20 *Use of an astrolabe to map the placement of some statues. From Cosimo Bartoli,* Del modo di misurare *(Venice, 1614). Courtesy of the Adler Planetarium, Chicago.*

Devout Muslims, moreover, were not only required to pray at certain times of day, but were expected to face Mecca. Hence, *mashriqi* astrolabes typically had arcs representing the azimuth of the *qibla* for key cities, and these were employed in finding the direction of Mecca from the altitude of the afternoon sun.[97] Persian and Indo-Persian astrolabes also contained gazetteers, which listed cities, their latitudes, longitudes, and other geographic parameters pertaining to their orientation to Mecca. Such parameters included the *inḥirāf* (the azimuth of the *qibla*) or *jihat* (the direction of the azimuth of the *qibla* with respect to the four cardinal points). As might be guessed, Mecca and Medina were often given pride of place in the gazetteer.[98]

By the seventeenth century, the throne of Persian instruments was sometimes inscribed with verses from the Koran containing the word *"kursī,"* which is Arabic for "throne."[99] This was tantamount to a pious dedication, and appropriate for an instrument so imbued with religious purpose.

Prized for its utility, convenience, and beauty, the astrolabe was the most important astronomical instrument of the Middle Ages and early Renaissance, and is justly famous today. It is appropriate that the first two volumes of the catalogue of scientific instruments in the History of Astronomy Collection at the Adler Planetarium be devoted to this sophisticated instrument.

97. *Qibla* is the Arabic term denoting the direction of Mecca, or to be precise, the direction of the *Ka'ba*, the most important sanctuary of Islam, situated near the center of the great mosque in Mecca. Muslims around the world direct their prayers to this sanctuary. See David A. King, "Ḳibla," in *Encyclopedia of Islam*, new ed., 5: 83-88 (1979b).

98. Gibbs with Saliba (1984), 26-33; Hartner (1968/1984), 1: 303.

99. Gibbs with Saliba (1984), 22.

100. Welborn (1931), 191.

Let me conclude with a short story: In 1025, Radulf of Liège wrote to a school friend, Ragimbold of Cologne, inviting him to visit during the festival of St. Lambert, in order to see his astrolabe. "You will not be sorry for it," he added.[100] As you begin to peruse this catalogue of astrolabes, the curatorial staff of the Adler Planetarium joins me in saying, like Radulf, that it will be well worth your while.

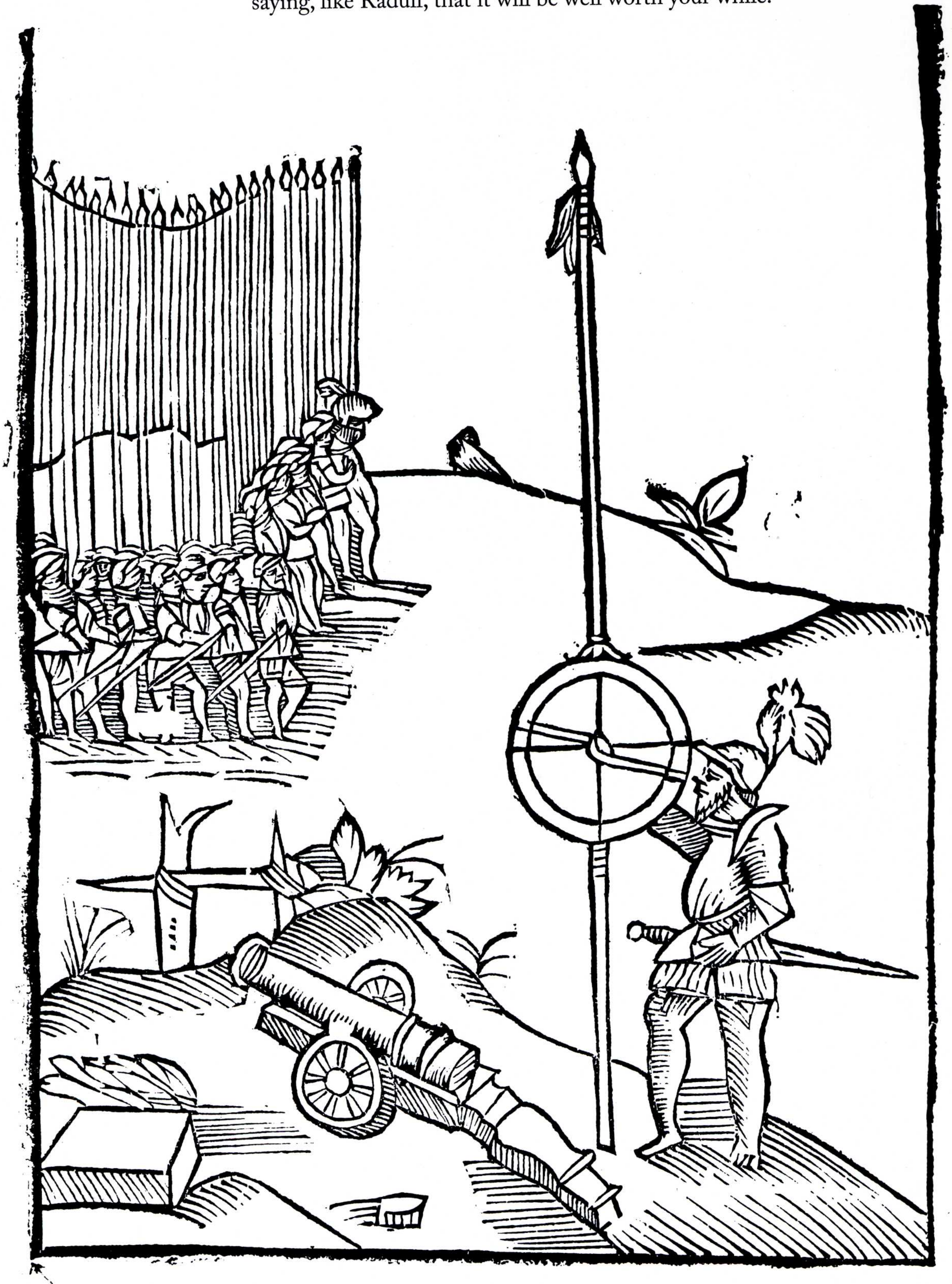

FIGURE 21 *Use of an astrolabe to survey enemy lines. From Cosimo Bartoli,* Del modo di misurare *(Venice, 1614). Courtesy of the Adler Planetarium, Chicago.*