# 2 · Celestial Mapping

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The beginning of Islamic celestial mapping can be seen in the central Islamic lands of greater Syria and Iraq, where indigenous Bedouin ideas played a role. Celestial mapping, like many other aspects of Islamic secular culture, drew in its early days upon the techniques and concepts current (though often in a languishing state) in the Roman, Byzantine, and Persian provinces that were its immediate neighbors and over which the emerging Islamic state soon gained dominion. From both written documents and surviving artifacts we can trace, at least partially, a transmigration of ideas and techniques both west and east within the rapidly expanding Islamic empire.

The ideas and techniques associated with celestial mapping were nurtured by Muslims and non-Muslims alike. Though stimulated by the practical needs of religious ritual, their development tended to be unaffected by belief or dogma, except where celestial mapping intruded upon cosmological visualization of the universe. Political and economic changes within an area, as well as aesthetic fashion, had substantial effects on celestial mapping, as on most other aspects of society, since the training and patronage of artisans reflected shifting circumstances. Islam itself provided a particularly encouraging environment for those interested in mapping the heavens. A number of verses in the Qurʾān advocate the use of stars, sun, and moon for reckoning and navigation, as in Qurʾān 6:97: "It is He who has appointed for you the stars, that you might be guided by them in the darkness of the land and sea." The employment of a lunar calendar and the need to convert neighboring calendrical systems into their own lunar one, which began with the Hijrah of Muḥammad in A.D. 622, required knowledge of basic celestial phenomena. Even more conducive to promoting an understanding of the skies was the need to calculate prayer times, for these were based on unequal or seasonal hours, in which the time between sunrise and sunset was divided into twelve equal parts that changed every day.

Beginning in the seventeenth century we can observe a few instances when early modern European ideas on celestial mapping are introduced into the Islamic world. Yet in spite of these points of contact, the concepts and techniques of Islamic celestial mapping remained essentially medieval well into the nineteenth century, particularly in Turkey, Persia, and Mughal India. The reason has not been adequately explored by social historians.

## EARLY SYRIAN ORIGINS

An eighth-century palace in the Syrian Desert provides the earliest evidence of celestial mapping in Islamic culture. Built possibly between 92 and 97 (711–15), this provincial palace, known as Quṣayr ʿAmrah, was constructed in a remote area about fifty kilometers east of the north end of the Dead Sea, probably by the Umayyad caliph al-Walīd I, who ruled from 86–96/705–15.[1]

The Syriac-speaking community in the region appears to have had considerable interest in stereographic projection of the skies, as witnessed by the activities of Severus Sebokht (d. A.D. 666–67). Severus Sebokht was the bishop of Qinnasrīn, an ancient town that held an important position in the defense system of Syrian fortresses from Antioch to the Euphrates River and was about a day's journey from Aleppo. He not only wrote in Syriac a treatise on constellations, but he composed, also in Syriac, a treatise on the astrolabe compiled from Greek sources.[2]

1. Later dates for the building of the palace, ranging from A.D. 723 to A.D. 742, have also been suggested, primarily based on an inscription referring to an emir or a prince rather than a caliph. It was possibly built by the rather libertine al-Walīd II, who lived in the area of Quṣayr ʿAmrah before his brief rule in A.D. 743–44; see Richard Ettinghausen, *Arab Painting* ([Geneva]: Editions d'Art Albert Skira, 1962; New York: Rizzoli, 1977), 33, and Richard Ettinghausen and Oleg Grabar, *The Art and Architecture of Islam: 650–1250* (Harmondsworth: Penguin Books, 1987), 63.

2. F. Nau, "Le traité sur les 'constellations' écrit, en 661, par Sévère Sébokt évêque de Qennesrin," *Revue de l'Orient Chrétien* 27 (1929/30): 327–38; this treatise displays a familiarity with both Ptolemy and Aratus. Both the Syriac text and a French translation of the astrolabe treatise are given by F. Nau, "Le traité sur l'astrolabe plan de Sévère Sabokt, écrit au VIIᵉ siècle d'après des sources grecques, et publié pour la première fois d'après un ms. de Berlin," *Journal Asiatique*, 9th ser., 13 (1899): 56–101 and 238–303. The French translation was rendered into English, with the introduction of some errors, and printed in Robert T. Gunther, *The Astrolabes of the World*, vol. 1, *The Eastern Astrolabes* (Oxford: Oxford University Press, 1932), 82–103. A new critical edition with German translation is being prepared by E. Reich of Munich.

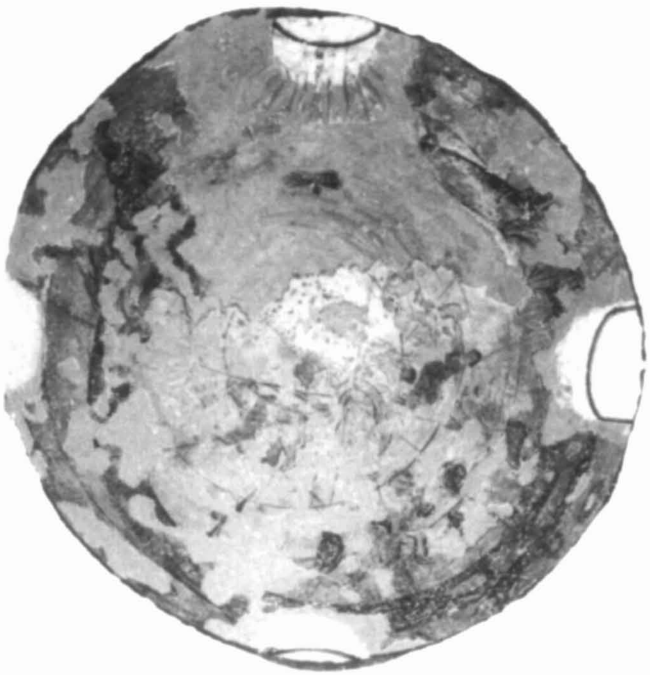

FIG. 2.1. THE REMAINS OF THE VAULT OF THE HEAVENS. Painted on a domed ceiling in the provincial palace of Quṣayr ʿAmrah built in the early eighth century A.D., the design is that which would be seen looking down on a globe.
Size of the original: not known. Photograph courtesy of Oleg Grabar.

The palace of Quṣayr ʿAmrah contains rooms covered with closely packed paintings, frescoes, and mosaics in such a chaotic mixture of themes that an observer of the recently cleaned and restored palace can only conclude that it was built as a private and personal art gallery.[3] Among the rooms is a bath consisting of three rooms: one tunnel vaulted, one cross vaulted, and the third covered by a dome. The dome of this *calidarium* was decorated to resemble the vault of the heavens, reflecting a well-established tradition of decorating cupolas with heavenly images—a custom that can be traced back to the early days of the Roman Empire. This domed ceiling at Quṣayr ʿAmrah is the oldest preserved astronomical dome of heaven (fig. 2.1).[4]

The view of the skies as represented by the painter of this fresco is not as it would appear to an observer on earth, for it displays a larger portion of the sky than could be seen at any one time from one location. The northern and zodiacal constellations recognized in antiquity are represented, along with a number of the southern ones, while the northern celestial pole is indicated directly overhead. The sequence and positioning of the constellations are painted as you would see them when looking down on a celestial globe rather than up into the sky.

It is evident from the general design that the fresco painter was copying onto the domed ceiling a type of planispheric map of the heavens that can be found in a number of Latin and Byzantine manuscripts.[5] Unfortunately, all copies of these planispheric maps preserved today were drawn after the palace of Quṣayr ʿAmrah was constructed. They are, however, clearly copies of much earlier Western planispheric maps.

One such map from a fifteenth-century Greek manuscript is illustrated in figure 2.2, while figure 2.3 demonstrates the method of polar stereographic projection used in producing the map. The map displays the heavens from the north equatorial pole to about 35° south of the equator. The innermost circle represents an ever-visible circle, marking out the area of the sky that was never seen to set for a latitude of about 36° north, roughly that of Rhodes. Proceeding outward, the next three concentric circles represent the Tropic of Cancer, the celestial equator, and the Tropic of Capricorn, with the outside circle delimiting an area approximately 10° south of the Tropic of Capricorn. The equinoctial and solstitial colures are indicated by straight lines at right angles to one another. In an eccentric broad band, the zodiacal constellations are placed in a counterclockwise sequence, in keeping with this diagram's being a polar stereographic projection of a celestial globe rather than a projection of the skies as seen from earth.

Comparing this Byzantine planispheric map with the Quṣayr ʿAmrah dome in figure 2.1 will immediately establish the similarity. Though the fresco in the Syrian dome has been damaged over the years, it is evident that it too represents a stereographic projection from the south ecliptic pole of a celestial globe, showing the skies to about 35° south declination. The iconography of most of the constellations is classical or early medieval (West-

3. See Ettinghausen and Grabar, *Art and Architecture*, 59–65 (note 1).

4. Fritz Saxl, "The Zodiac of Quṣayr ʿAmra," trans. Ruth Wind, in *Early Muslim Architecture*, vol. 1, *Umayyads, A.D. 622–750*, by K. A. C. Creswell, 2d ed. (Oxford: Clarendon Press, 1969), pt. 2, 424–31 and pls. 75a–d and 76a–b; Martin Almagro et al., *Qusayr ʿAmra: Residencia y baños omeyas en el desierto de Jordania* (Madrid: Instituto Hispano-Arabe de Cultura, 1975), esp. pl. XLVIII. For the tradition of decorating cupolas with heavenly and astronomical images, see Karl Lehmann, "The Dome of Heaven," *Art Bulletin* 27 (1945): 1–27.

5. Arthur Beer, in his astronomical interpretation of the fresco, overlooks its relation to the early medieval planispheric maps; Arthur Beer, "The Astronomical Significance of the Zodiac of Quṣayr ʿAmra," in *Early Muslim Architecture*, vol. 1, *Umayyads, A.D. 622–750*, by K. A. C. Creswell, 2d ed. (Oxford: Clarendon Press, 1969), pt. 2, 432–40. That the model the painter used was a planispheric map of the heavens produced by stereographic projection was first suggested by Francis R. Maddison, *Hugo Helt and the Rojas Astrolabe Projection*, Agrupamento de Estudos de Cartografia Antiga, Secção de Coimbra, vol. 12 (Coimbra: Junta de Investigações do Ultramar, 1966), 8 n. 9. Comparing the dome with maps made by the projection of a globe rather than of the skies resolves most of the problems arising in the interpretation of the fresco. See also Emilie Savage-Smith, *Islamicate Celestial Globes: Their History, Construction, and Use* (Washington, D.C.: Smithsonian Institution Press, 1985), 16–17, 300 n. 82.

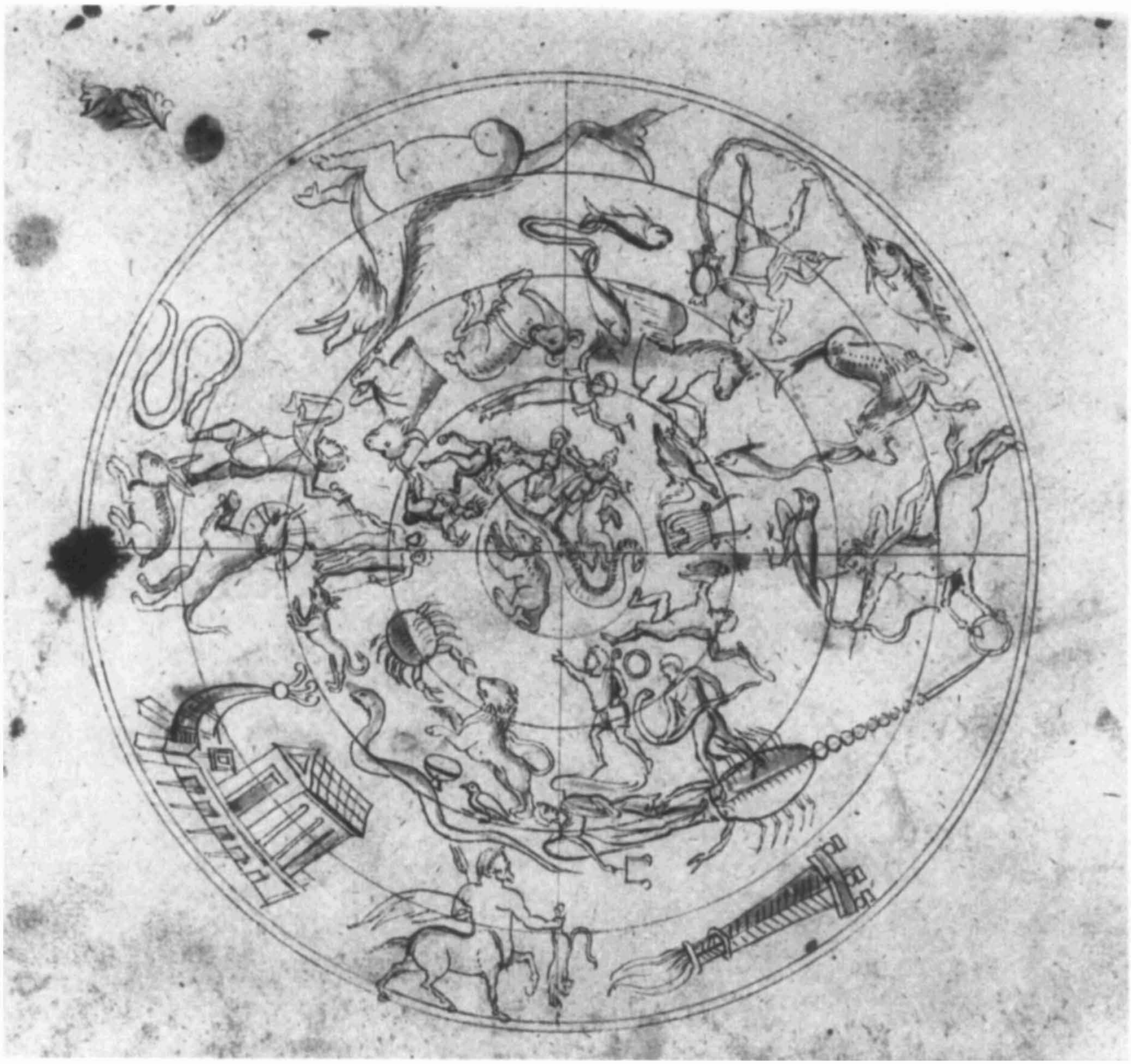

FIG. 2.2. PLANISPHERIC MAP OF THE HEAVENS FROM A FIFTEENTH-CENTURY BYZANTINE MANUSCRIPT. The solstitial colure runs horizontally through the center of the map.

Size of the original: not known. By permission of the Biblioteca Apostolica Vaticana, Rome (Vat. Gr. 1087, fol. 310v).

ern) rather than Islamic and is remarkably similar to that of the Byzantine manuscript. The counterclockwise orientation is the same, and in neither the Byzantine planispheric map nor the Syrian dome are the stars themselves shown.

The Islamic fresco has some features, however, not found on the Byzantine planispheric map. Six great circles, one of which is the solstitial colure, pass through the ecliptic poles and divide the ecliptic into twelve parts, though little more than the northern semicircles of each great circle is actually shown on the dome. These are called ecliptic latitude-measuring circles in this chapter, a term used here to designate certain circles employed in medieval Islamic celestial mapping for which there is no generally accepted modern European term.[6]

6. The phrase means circles drawn at right angles to the ecliptic, along which the celestial latitude may be measured. They are not to be found on any of the few Greco-Roman artifacts or maps, but they are ubiquitous features of later Islamic celestial globes (see, for example, several of the globes illustrated below). Though equator-based and horizon-based systems of coordinates were known in medieval Islam, the ecliptic-based system of coordinates dominated celestial carto-

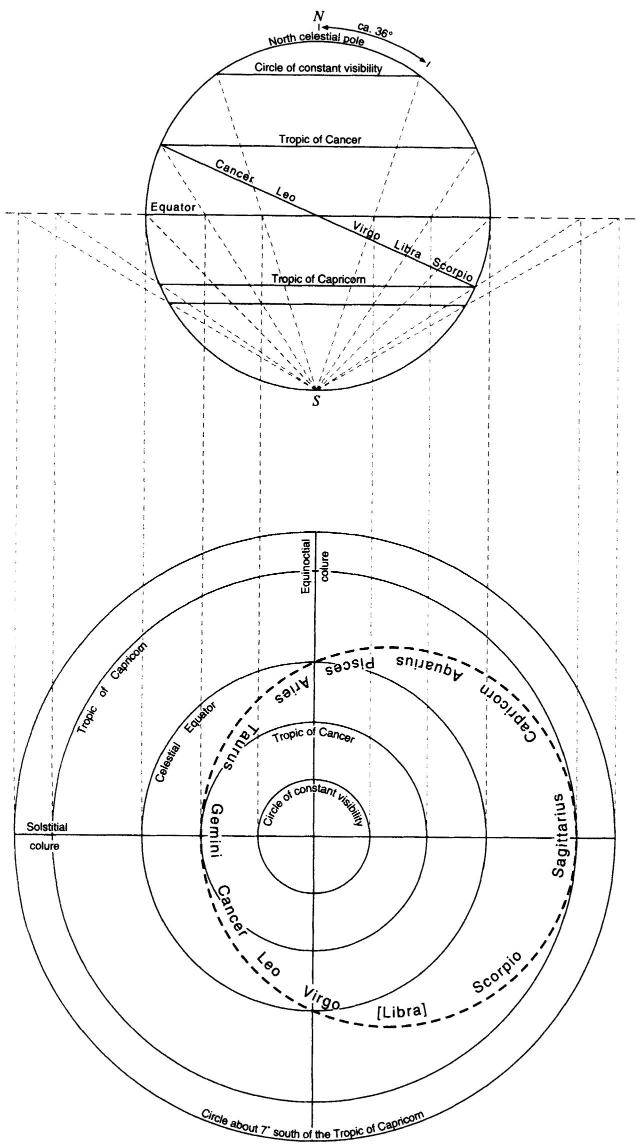


FIG. 2.3. THE BYZANTINE PLANISPHERIC MAP ANALYZED AS A STEREOGRAPHIC PROJECTION FROM THE SOUTH POLE OF A CELESTIAL GLOBE.

At the palace of Quṣayr ʿAmrah, of the six prominent concentric circles painted in dark brown on the ceiling with the equatorial pole as the center, the smallest is the polar circle passing through the ecliptic pole (where the ecliptic latitude-measuring circles intersect) about 23½° distant. This polar circle is a common feature of extant Islamic celestial globes, although it is not found in Hellenistic, Roman, or Byzantine sources. The other dark circles represent the northern tropic, the equator, and the southern tropic, with one circle spaced midway between the southern tropic and the equator and one positioned at one-third the distance between the polar circle and the northern tropic. Three additional concentric circles—one inside the northern tropic and two between the northern tropic and the equator—are very pale and appear to have been preliminary attempts at spacing that were later painted over. In rendering such a planispheric map onto the ceiling of a dome, the painter crowded some of the areas too tightly and failed to have the band of the ecliptic pass through the northern solstitial point. The artist was no doubt constrained by the four windows in the dome and furthermore may not have fully understood the model.

In painting this early Syrian domed ceiling, the unknown artist, as we have seen, was continuing a well-established pre-Islamic tradition of celestial mapping. The Byzantine planispheric map illustrated in figure 2.2 occurs in a Greek commentary on an astronomical and meteorological poem written by the Greek poet Aratus of Soli (ca. 315–240 B.C.).[7] Such illustrations accompa-

graphy, no doubt reflecting the ecliptic coordinates used in the first century A.D. in Ptolemy's star catalog, which formed the basis of all subsequent star catalogs. In Arabic such a circle at right angles to the ecliptic was called "the circle of latitude" (*dāʾirat al-ʿarḍ*), but this nomenclature is inappropriate and confusing in this context, since a "circle of latitude" by modern convention means a circle parallel to the equator and having a uniform latitude. If the medieval system were equator based, the modern term "circle of longitude" might be appropriate, for circles of longitude are circles perpendicular to the equator passing through the celestial poles. But because medieval celestial mapping employed the ecliptic as the frame of reference and the basic circles along which the celestial latitude was measured were at right angles to the ecliptic, none of the modern terms, including meridian, are suitable. In this chapter, therefore, this special term "ecliptic latitude-measuring circle" is used for those circles at right angles to the ecliptic, and the term "meridian" is used only to mean circles at right angles to the celestial equator. The representation of the solstitial colure is, of course, at right angles to both the ecliptic and the equator and thus is an ecliptic latitude-measuring circle as well as a meridian. See Savage-Smith, *Islamicate Celestial Globes*, 62–63 and esp. 305 n. 5 (note 5), where the term employed for these circles is "ecliptic latitude circles." Meridian, in the present chapter, is used in a slightly broader sense than the more technical and restrictive definition as a great circle on the celestial sphere passing through the celestial (equatorial) poles and the zenith of the observer.

7. A similar planispheric map, elegantly painted but crudely composed, is to be found in a fifteenth-century Italian manuscript made in Naples for Ferdinand II and his court; Rome, Biblioteca Apostolica Vaticana, MS. Barb. Lat. 76, fol. 3r. A small illustration of the map is given in John E. Murdoch, *Album of Science: Antiquity and the Middle Ages* (New York: Charles Scribner's Sons, 1984), 247, no. 223, and in Johanna Zick-Nissen, "Figuren auf mittelalterlich-orientalischen Keramikschalen und die 'Sphaera Barbarica,' " *Archaeologische Mitteilungen aus Iran*, n. s., 8 (1975): 217–40 and pls. 43–54, esp. pl. 52.1. Similar planispheric maps with counterclockwise rotation are to be found in a tenth-century *Aratea* (Berlin, Staatsbibliothek, Cod. Phillippicus 1830, fols. 11v–12r) reproduced by a drawing in Georg Thiele, *Antike Himmelsbilder mit Forschungen zu Hipparchos, Aratos und seinen Fortsetzern und Beiträgen zur Kunstgeschichte des Sternhimmels* (Berlin: Weidmannsche Buchhandlung, 1898), 164; in a Carolingian copy of an *Aratea*, not particularly well drawn (Basel, Öffentliche Bibliothek der Universität, Cod. Basilensi A.N. 18, p. 1), reproduced in Zick-Nissen, "Figuren auf mittelalterlich-orientalischen Keramikschalen," pl. 52.3; and in a twelfth-century Spanish manuscript in Osma cathedral reproduced in color by Gérard de Champeaux and Dom Sébastien Sterckx,

nying copies of the *Aratea* (the name given to all the translations and adaptations of the poem by Aratus) usually consisted of forty-one classical constellations and the Pleiades and frequently included either a diagram illustrating the configurations of the planets for a specific date or a planispheric map of the heavens.[8] The earliest completely preserved planispheric map of the heavens produced by stereographic projection is a diagram in a Carolingian copy of such an Aratean manuscript, one copied in A.D. 818 (fig. 2.4). In this vividly colored version the orientation of the constellations is as it would be seen in the sky, which is to say that the zodiacal constellations are drawn in a clockwise sequence, rather than counterclockwise as is found on the previously mentioned planispheric maps and on the dome roof at Quṣayr ʿAmrah. Moreover, the Milky Way is indicated by a second eccentric circle, and neither of the colures is shown.[9]

Although the fresco at Quṣayr ʿAmrah predates the Carolingian map by a century, it seems certain at this point that the extant Western manuscripts of planispheric celestial maps produced by stereographic projections represent a much older, continuous tradition of mapping that reached Syria by the early eighth century along a route at present unknown.

There are many accounts of the importing of Byzantine artisans into the capital, Damascus, by al-Walīd I for the construction of the great Umayyad mosque in the early eighth century,[10] and the ceiling at Quṣayr ʿAmrah tends to confirm such reports. An established pre-Islamic model was clearly being employed by the painter of this astronomical fresco. The dome's dependence on a planispheric map similar to that illustrated in figure 2.2 extends even to its repeating the identical, but incorrect, placement of Hercules after the serpent charmer Ophiuchus rather than face to face in front of him. The classical Greco-Roman iconography found in Aratean manuscripts is evident in most of the constellations at Quṣayr ʿAmrah. An example is the nude form of Serpentarius (Ophiuchus), who is turned partially away from the observer, with both feet firmly planted on Scorpio below and holding a thin snake whose head is toward Ophiuchus.[11] Orion maintains the shepherd's crook and animal skin over his left shoulder that later Islamic artists were to transform into a club and a long sleeve. The figures' headgear and clothing display no identifiable Islamic features. Libra is not represented on the dome, just as it was omitted on the planispheric maps and the individual constellation figures found in Aratean manuscripts. Libra was not distinguished by an iconography distinct from that of Scorpio until after the time of Ptolemy.[12] Consequently, work that reflects a pre-Ptolemaic conception of the skies, such as the Aratean treatises and the dome at Quṣayr ʿAmrah, which apparently is derived from them, would also omit Libra. A few features on the ceiling foreshadow later Islamic mapping, such as the polar circle and the ecliptic latitude-measuring circles, as well as the drawing of the constellation Cepheus as a kneeling or walking man with hands uplifted rather than the classical standing form with outstretched arms.

*Introduction au monde des symboles* (Saint-Léger-Vauban: Zodiaque, 1966), 66. A later version illustrating an astronomical treatise by Giovanni Cinico was drawn in Naples in 1469 (New York, Pierpont Morgan Library manuscript) and is reproduced in color by George Sergeant Snyder, *Maps of the Heavens* (New York: Abbeville Press, 1984), pl. 5.

8. See Ranee Katzenstein and Emilie Savage-Smith, *The Leiden Aratea: Ancient Constellations in a Medieval Manuscript* (Malibu, Calif.: J. Paul Getty Museum, 1988); Bruce Stansfield Eastwood, "Origins and Contents of the Leiden Planetary Configuration (MS. Voss. Q. 79, fol. 93v), an Artistic Astronomical Schema of the Early Middle Ages," *Viator: Medieval and Renaissance Studies* 14 (1983): 1–40 and 9 pls.; C. L. Verkerk, "*Aratea*: A Review of the Literature concerning MS. Vossianus Lat. Q. 79 in Leiden University Library," *Journal of Medieval History* 6 (1980): 245–87; and Anton von Euw, *Aratea: Himmelsbilder von der Antike bis zur Neuzeit*, exhibition catalog (Zurich: Galerie "le Point," Schweizerische Kreditanstalt [SKA], 1988).

9. For an analysis of this map from the standpoint of stereographic projection, see John D. North, "Monasticism and the First Mechanical Clocks," in *The Study of Time II*, Proceedings of the Second Conference of the International Society for the Study of Time, Lake Yamanaka—Japan, ed. J. T. Fraser and N. Lawrence (New York: Springer-Verlag, 1975), 381–98, esp. 386–87 and fig. 1; reprinted in John D. North, *Stars, Minds and Fate: Essays in Ancient and Medieval Cosmology* (London: Hambledon Press, 1989), 171–86, esp. 179–80 and fig. 6. Other very similar planispheric maps, with a clockwise sequence and with the Milky Way shown, occur in a ninth-century copy of Cicero's version of the *Aratea* (London, British Library, MS. Harley 647, fol. 21v) and in two tenth-century *Aratea* manuscripts (Boulogne-sur-Mer, Bibliothèque Municipale, MS. 188, fol. 26v, and Bern, Burgerbibliothek, MS. 88, vol. 11v). The last is illustrated by Zick-Nissen, "Figuren auf mittelalterlich-orientalischen Keramikschalen," pl. 52.2 (note 7), and also by Verkerk, "*Aratea*: A Review of the Literature," fig. 9(b) (note 8). The first two are illustrated in the *Encyclopedia of World Art*, 16 vols., ed. Massimo Pallottino (New York: McGraw-Hill, 1957–83), vol. 2, pl. 21.

10. Ettinghausen and Grabar, *Art and Architecture*, 42 (note 1).

11. Compare these with the separate drawings of Ophiuchus (Serpentarius) in the *Aratea* manuscripts illustrated in Katzenstein and Savage-Smith, *Leiden Aratea*, 20–21 (note 8), and in Verkerk, "*Aratea*: A Review of the Literature," 271 (note 8). For a color plate showing in detail the constellation Ophiuchus on the ceiling of Quṣayr ʿAmrah after the recent cleaning and restoration, see Almagro et al., *Qusayr ʿAmra*, pl. XLVIII (note 4). For further comparisons, see Saxl, "Zodiac of Quṣayr ʿAmra" (note 4), and Zick-Nissen, "Figuren auf mittelalterlich-orientalischen Keramikschalen" (note 7).

12. The assertion made by Willy Hartner that Aries and Taurus are combined into one constellation like Libra-Scorpio is unfounded. There is adequate space for both Aries and Taurus, though the ceiling is badly damaged in this area and only a trace of Taurus is visible today. Moreover, neither Mars nor any other planet is represented on this ceiling. See Willy Hartner, "Qusayr ʿAmra, Farnesina, Luther, Hesiod: Some Supplementary Notes to A. Beer's Contribution," in *Vistas in Astronomy*, vol. 9, *New Aspects in the History and Philosophy of Astronomy*, ed. Arthur Beer (Oxford: Pergamon Press, 1967), 225–28; reprinted in Willy Hartner, *Oriens-Occidens: Ausgewählte Schriften zur Wissenschafts- und Kulturgeschichte*, 2 vols. (Hildesheim: Georg Olms, 1968 and 1984), 2:288–91.

FIG. 2.4. A PLANISPHERIC MAP OF THE HEAVENS IN A LATIN COPY OF THE *ARATEA* DATED A.D. 818. Size of the original: 31.2 × 24 cm. By permission of the Bayerische Staatsbibliothek, Munich (Clm. 210, fol. 113v).

The influence that illustrations associated with copies of the *Aratea* had on the delineation of constellations in the Islamic world has received little consideration by historians. The original Greek poem by Aratus was translated into Arabic early in the ninth century A.D. and was used in a universal history titled *Kitāb al-ʿunwān* (The book of models) written in 330/941–42 by Agapius (or Maḥbūb), who lived in Manbij, a Syrian town northeast of Aleppo.[13] It is not known whether the copy of Aratus's poem that was translated into Arabic was illustrated, and consequently it is difficult to determine its impact on Islamic constellation iconography. The texts of the Latin and vernacular adaptations apparently remained unknown in the Near East. The dome at Quṣayr ʿAmrah, however, is evidence that at least one of the illustrations

13. Ernst Honigmann, "The Arabic Translation of Aratus' Phaenomena," *Isis* 41 (1950): 30–31.

that came to be part of later copies of the *Aratea* was known in Syria in the early eighth century. This astronomical ceiling, painted in the early days of Islamic dominion over Syria, may have been the work of an itinerant Byzantine fresco painter who slavishly copied manuscript illustrations. The dome may also be testimony to the survival of techniques of stereographic projection in the provinces of the Roman and Byzantine empires before the earliest extant astrolabes and before the translation of Greek astronomical texts into Arabic. The omission of the circle of constant visibility and the addition of the polar circle and the ecliptic latitude-measuring circles (characteristics of later Islamic celestial globes) encourage this hypothesis.

## Planispheric Astrolabes as Celestial Maps

Despite the large number of medieval Islamic manuscripts preserved today, it is notable that none of them contain planispheric maps of the sky. It is only through instrument design and production that we find any further evidence for planispheric celestial mapping in the Islamic world before the nineteenth century.

The conventional astrolabe consists of a pierced planispheric star map placed over a projection of the celestial coordinate system as it relates to the observer's locality. The result is a representation of the positions of the fixed stars with respect to the local horizon. In other words, a planispheric astrolabe is a two-dimensional model of the heavens. The word astrolabe comes from the Arabic *aṣṭurlāb* or *asṭurlāb*, which was a transliteration of the Greek ἀστρολάβος or ἀστρολάβον ὄργανον, a term applied to a variety of astronomical instruments.[14] When the Arabic word was used without an adjective, it referred to the planispheric astrolabe, though in Arabic writings the planispheric astrolabe could be additionally specified by the adjective *saṭḥī* or *musaṭṭaḥ*, meaning "flat."

The method of producing this planispheric celestial map employs the same principle as that used in the Latin and Byzantine maps of the heavens mentioned earlier—that is, stereographic projection from a pole of a celestial globe onto the plane of the equator. The result is a mirror-image map of the skies, with east to the left and west to the right. Since a large portion of the southern skies was unmapped and the primary use was in the northern latitudes, the South Pole was commonly taken as the center of projection. In theory the North Pole could be used as well, but in practice it was very rarely employed in the Islamic world.

The top plate of an astrolabe, which is an openwork star map, was in Arabic called *ʿankabūt*, meaning "spider," for which reason it was later in Latin termed *aranea*, also meaning "spider." In Latin, however, it was also called *rete*, "net," and it is this term that is commonly used today. An astrolabe from the late ninth century is illustrated in figure 2.5, and a more elaborate example from a seventeenth-century workshop in northwestern India is illustrated in figure 2.6, with its constituent parts. In figure 2.7 the stereographic projection producing the basic features of the rete is illustrated. Note that the sequence of the zodiacal houses is counterclockwise, since it is a projection of the celestial sphere or globe. The rete represents the stereographic projection of an area of the celestial sphere extending from the north celestial pole to the Tropic of Capricorn, with a number of delicate pointers indicating certain designated stars. Although the positioning of the circles on the rete is relatively simple, the determination of the boundary points between the zodiacal houses is more complicated. For example, to find the zodiacal boundary points, the maker needed to determine the point of intersection of the equator with a great circle on the sphere passing through the celestial poles and the zodiacal boundary point. Once the corresponding point on the projection of the equator was located, a line could be drawn connecting it to the polar center of the projection. Where this radius crossed the projected ecliptic determined the zodiacal boundary line, as illustrated in figure 2.7. On the rete illustrated in figure 2.6*a* and diagrammatically interpreted in figure 2.8, the ecliptic has been divided by this manner (see also table 2.1). On less well-made astrolabes, the zodiacal boundary lines are sometimes approximated by using rays intersecting the ecliptic that emanate from the polar center of projection at thirty-degree intervals.[15] The unequal spacing of the zodiacal boundary lines between the northern and southern halves of the ecliptic motivated some makers to design retes of a totally different shape that would render the two halves of the ecliptic symmetrical, and several treatises consider such designs.[16]

On every rete a select number of stars are named and indicated by the tips of brass pointers. The number and selection of stars varied among makers, though the stars of greatest magnitude visible at northern latitudes were

14. King provides a detailed discussion of medieval explanations of the term astrolabe in David A. King, "The Origin of the Astrolabe according to the Medieval Islamic Sources," *Journal for the History of Arabic Science* 5 (1981): 43–83; reprinted as item III in David A. King, *Islamic Astronomical Instruments* (London: Variorum Reprints, 1987).

15. Sharon Gibbs with George Saliba, *Planispheric Astrolabes from the National Museum of American History* (Washington, D.C.: Smithsonian Institution Press, 1984), 220–22. Emmanuel Poulle, "La fabrication des astrolabes au Moyen Age," *Techniques et Civilisations* 4 (1955): 117–28, describes five alternative ways of determining the zodiacal boundaries.

16. See David A. King, "Astronomical Instrumentation in the Medieval Near East," in David A. King, *Islamic Astronomical Instruments* (London: Variorum Reprints, 1987), item I, 1–21, esp. 5 and pls. 3 and 4.

generally included. There are fifty-three stars on the astrolabe illustrated in figure 2.6*a*, which was made in 1060/1650 in Lahore (in modern Pakistan) by a prolific astrolabe maker belonging to a four-generation family of

FIG. 2.5. PLANISPHERIC ASTROLABE MADE IN THE LATE NINTH CENTURY A.D. BY KHAFĪF, THE APPRENTICE OF ʿALĪ IBN ʿĪSĀ. An inscription on the front states that it was made for Aḥmad al-munajjim al-Sinjārī (Aḥmad the astronomer of Sinjār). It is known that ʿAlī ibn ʿĪsā, the master astrolabe maker, at the orders of the caliph al-Maʾmūn, took part in an expedition to the plain of Sinjār, which lies between the Tigris and Euphrates rivers, in order to measure a degree of latitude (see pp. 178–81).
Diameter of the original: 11.3 cm. Museum of the History of Science, Billmeir Collection, Oxford (inv. no. 57-84/155). By permission of the Bettman Archive, New York.

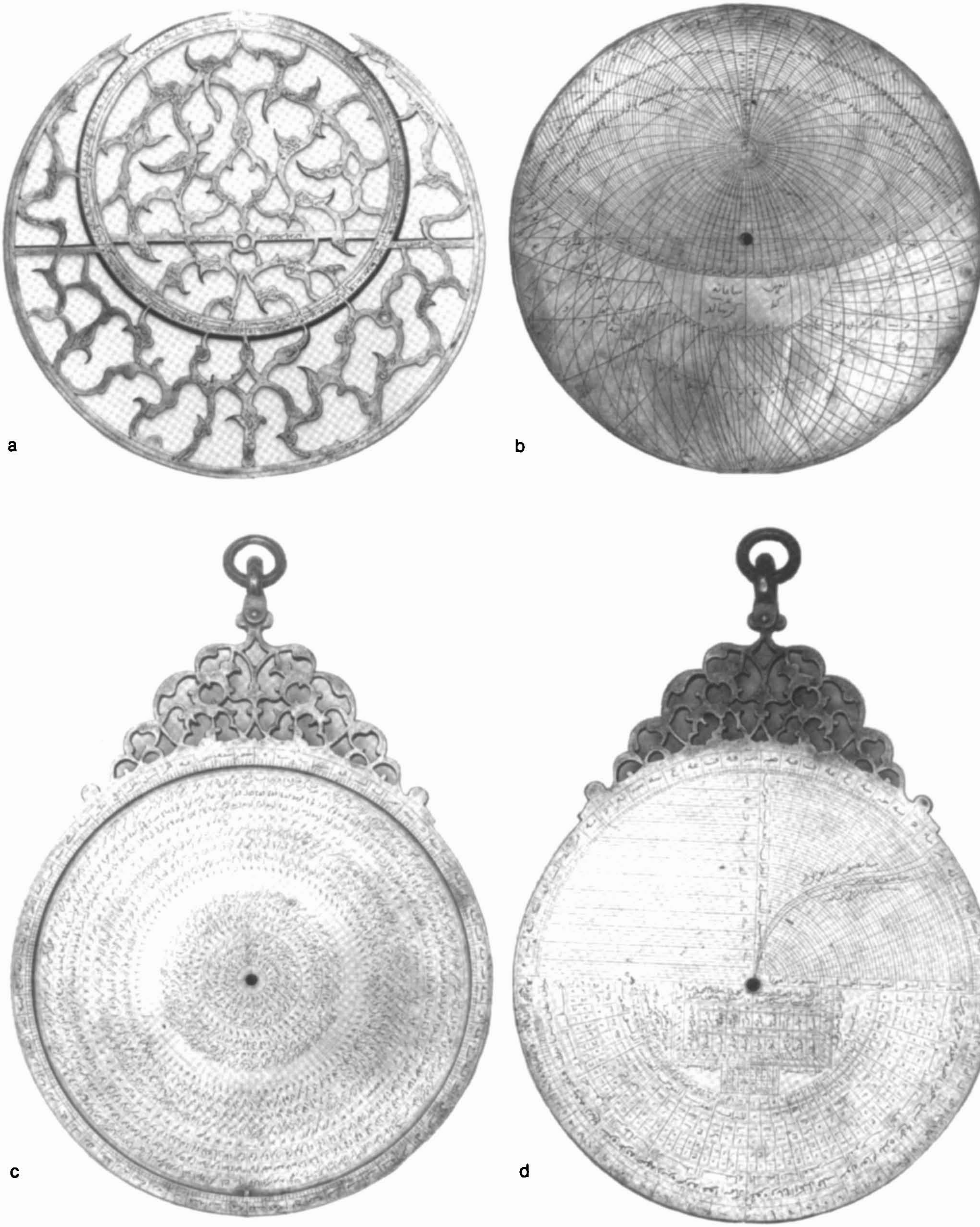

FIG. 2.6. AN ASTROLABE MADE IN 1060/1650 BY ḌIYĀ' AL-DĪN MUḤAMMAD. Made in Lahore, in modern Pakistan, the parts of this astrolabe are: (*a*) rete; (*b*) plate for latitude 29°N; (*c*) mater or base; (*d*) back of the astrolabe. Diameter of the original: 31.4 cm. By permission of the Brooklyn Museum, Department of Asian Art, New York (acc. no. X638.2).

instrument makers.[17] The astrolabe illustrated in figure 2.5, probably made in Baghdad in the ninth century A.D., displays much simpler tracery supporting only seventeen star pointers. Because the rete of an astrolabe also has the equator shown on it, it will become outdated owing to the precession of the equinoxes. The usable life of such an instrument was the better part of a century.

This open star map in the form of a metal rete was then placed over a plate designed for a specific geographic latitude (see fig. 2.6*b*). Each plate—*ṣafīḥah* in Arabic or *tympanum* in Latin—was also produced by polar stereographic projection, thus having the north celestial pole at the center with the Tropic of Cancer and equator as concentric circles and the outside edge marking the Tropic of Capricorn. Over these circles there were then drawn three different sets of circles, or parts of circles. The basic design of a plate is shown in figure 2.9. There are almucantars,[18] which are stereographic projections of circles of equal altitude above and parallel to the horizon. There are also stereographic projections of lines of equal azimuth, which are arcs of circles running from the zenith to the horizon. Usually only the portions above the horizon are shown, but on later products, as in figure 2.6*b*, some arcs extend below the horizon. Finally, there are the stereographic projections of lines of unequal hours, which, for clarity, are usually shown on the plate only below the horizon.[19] Timekeeping and the calls to prayers were determined by unequal or seasonal hours, in which the period of daylight and the period of darkness were each divided into twelve hours. As a result, only at the equinoxes would the length of a daylight hour be equal to an hour at night.

The plate with the rete on top (and usually plates underneath for other latitudes not being used at the moment) was then placed in the recessed front of the body of the astrolabe. The recessed area in the base (see fig. 2.6*c*) was called in Arabic *umm*, "mother," and in Latin *mater*, the name still commonly used for it. It was often engraved with a gazetteer, giving different localities and their geographic longitudes and latitudes, along with the length of the longest day or the distance to Mecca

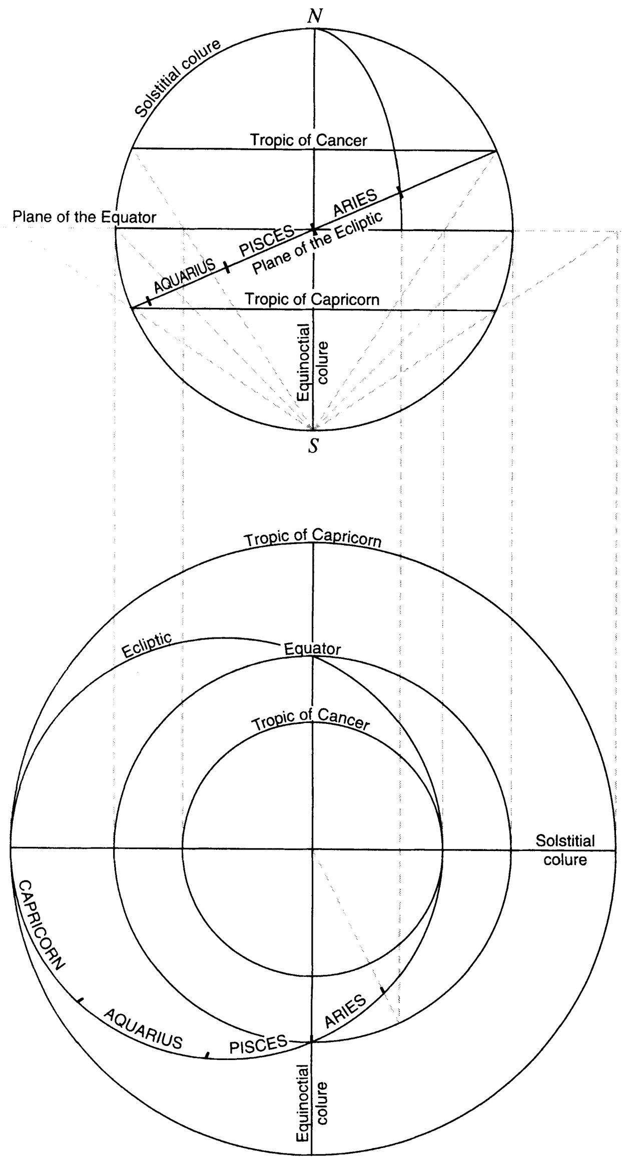


FIG. 2.7. POLAR STEREOGRAPHIC PROJECTION OF THE BASIC FEATURES OF AN ASTROLABE RETE.

17. The rete on an astrolabe made by the same maker in 1073/1662–63 is analyzed by Owen Gingerich, "Astronomical Scrapbook: An Astrolabe from Lahore," *Sky and Telescope* 63 (1982): 358–60; see also Gunther, *Astrolabes of the World*, 1:191–200 and 1:208–10 (note 2), and Gibbs with Saliba, *Planispheric Astrolabes*, 132–34 (note 15). For further information on this workshop of instrument makers, see Savage-Smith, *Islamicate Celestial Globes*, 34–43 (note 5). For astrolabe stars in general, see Paul Kunitzsch, "The Astrolabe Stars of al-Ṣūfī," in *Astrolabica*, no. 5, *Etudes 1987–1989*, ed. Anthony John Turner (Paris: Institut du Monde Arabe/Société Internationale de l'Astrolabe, 1989), 7–14.

18. From the Arabic *al-muqanṭarah*. For Arabic nomenclature, see Paul Kunitzsch, "Remarks regarding the Terminology of the Astrolabe," *Zeitschrift für Geschichte der Arabisch-Islamischen Wissenschaften* 1 (1984): 55–60; idem, "Observations on the Arabic Reception of the Astrolabe," *Archives Internationales d'Histoire des Sciences* 31 (1981): 243–52; and Willy Hartner, "Asṭurlāb," in *The Encyclopaedia of Islam*, new ed. (Leiden: E. J. Brill, 1960–), 1:722–28; reprinted in Willy Hartner, *Oriens-Occidens: Ausgewählte Schriften zur Wissenschafts- und Kulturgeschichte*, 2 vols. (Hildesheim: Georg Olms, 1968 and 1984), 1:312–18.

19. For illustrations of the stereographic projection of almucantars, lines of equal azimuth, and lines of unequal hours, see John D. North, "The Astrolabe," *Scientific American* 230, no. 1 (1974): 96–106; reprinted in his *Stars, Minds and Fate: Essays in Ancient and Medieval Cosmology* (London: Hambleton Press, 1989), 211–20. Other useful discussions of the design and construction of astrolabes are Henri Michel, *Traité de l'astrolabe* (Paris: Gauthier-Villars, 1947); *The Planispheric Astrolabe* (Greenwich: National Maritime Museum, 1976; amended 1979); and Anthony John Turner, *Astrolabes, Astrolabe Related Instruments*, Time Museum, vol. 1 (Time Measuring Instruments), pt. 1 (Rockford, Ill.: Time Museum, 1985), 1–9.

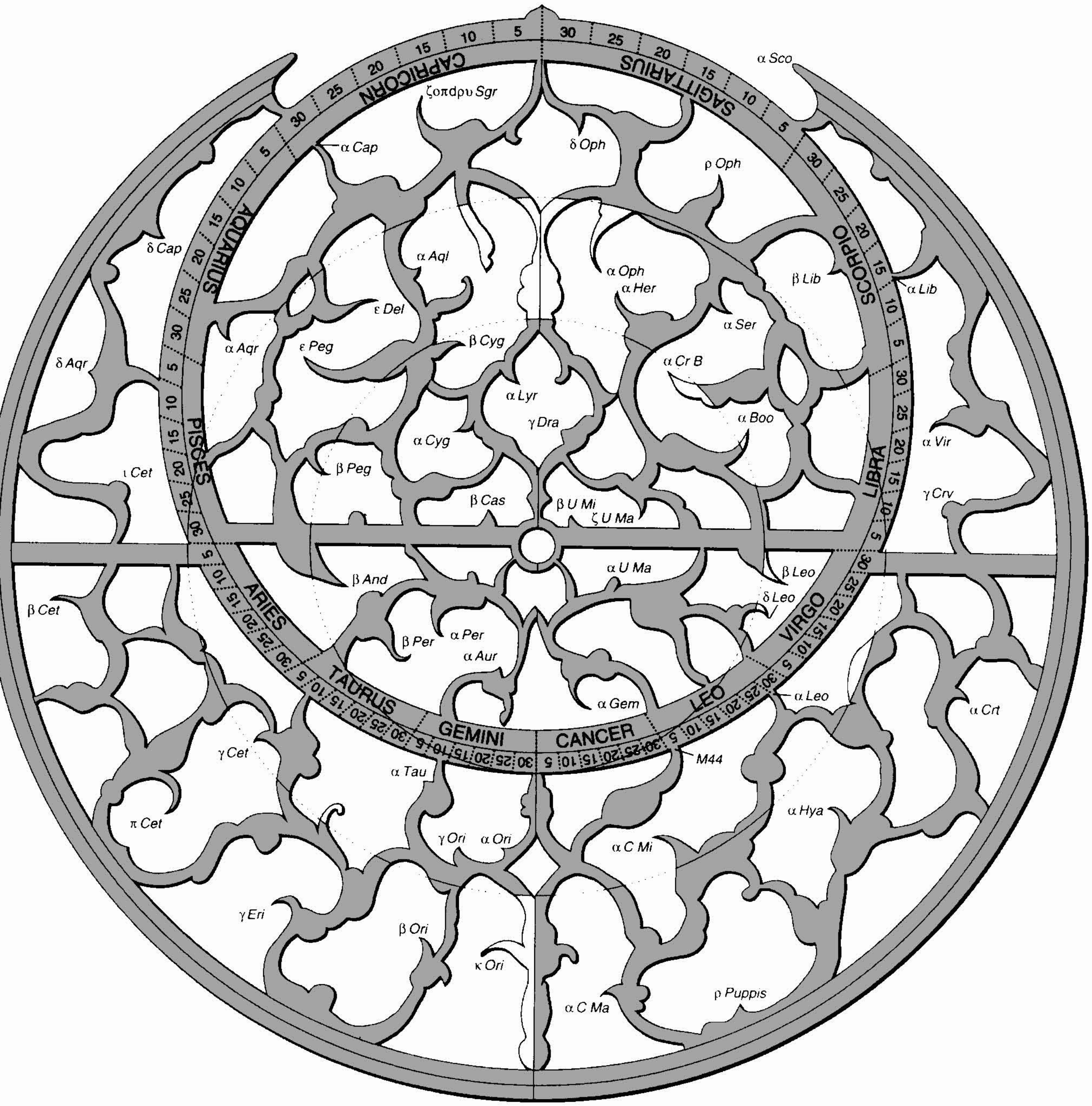


FIG. 2.8. THE STARS ON THE ASTROLABE RETE MADE IN LAHORE BY ḌIYĀʾ AL-DĪN MUḤAMMAD IN THE YEAR 1060/1650. A diagram of the rete with each pointer given modern star identifications. See figure 2.6*a* and table 2.1.

TABLE 2.1 Stars on the Astrolabe Made by Ḍiyāʾ al-Dīn Muḥammad

| Modern Identification | Arabic Name | English Translation |
|---|---|---|
| β Ceti (Deneb Kaitos) | Dhanab al-qīṭus al-janūbī | The southern tail of the sea monster Cetus |
| β Andromedae (Mirach) | Baṭn al-ḥūt | The belly of the fish |
| γ Ceti | Fam al-qīṭus | The mouth of the sea monster Cetus |
| π Ceti | Ṣadr al-qīṭus | The breast of the sea monster Cetus |
| β Persei (Algol) | Raʾs al-ghūl | The head of the ghoul |
| α Persei (Algenib) | Mirfaq al-thurayyā | The elbow of *al-thurayyā* |
| γ Eridani | Masāfat al-nahr | The length of the river |
| α Tauri (Aldebaran) | ʿAyn al-thawr | The eye of the bull |
| α Aurigae (Capella) | ʿAyyūq | (Untranslatable) |
| β Orionis (Rigel) | Rijl al-jawzāʾ al-yusrà | The left foot of *al-jawzāʾ* |
| γ Orionis (Belletrix) | Yad al-jawzāʾ al-yusrà | The left hand of *al-jawzāʾ* |
| α Orionis (Betelgeuse) | Yad al-jawzāʾ al-yumnà | The right hand of *al-jawzāʾ* |
| κ Orionis (Saiph) | Rijl al-jawzāʾ al-yumnà | The right foot of *al-jawzāʾ* |
| α Canis Majoris (Sirius) | Shiʿrà yamānīyah | [The] southern *shiʿrà* |
| α Geminorum (Castor) | Raʾs al-tawʾam al-muqaddam | The head of the foremost twin |
| α Canis Minoris (Procyon) | Shiʿrà shāmīyah | The northern *shiʿrà* |
| ρ Puppis | Ṭarfat al-safīnah | The extremity of the ship |
| M44 in Cancer (Praesepe) | Maʿlaf | Manger |
| α Hydrae (Alphard) | Fard al-shujāʿ | The isolated one of the serpent |
| α Leonis (Regulus) | Qalb al-asad | The heart of the lion |
| α Ursae Majoris (Dubhe) | Ẓahr al-dubb al-akhbar | The brighter of the two calves |
| α Crateris | Qāʿidat al-bāṭīyah | The base of the bowl |
| δ Leonis (Zosma) | Ẓahr al-asad | The back of the lion |
| β Leonis (Denebola) | Ṣarfah | Change of weather |
| β Ursae Minoris (Kochab) | Anwār al-farqadayn | The brighter of the two calves |
| ζ Ursae Majoris (Mizar) | ʿAnāq | The goat |
| γ Corvi (Gienah) | Janāḥ al-ghurāb | The wing of the raven |
| α Virginis (Spica) | Simāk aʿzal | [The] unarmed *simāk* |
| α Bootis (Arcturus) | [Al-] simāk al-rāmiḥ | The armed *simāk* |
| $\alpha^{1,2}$ Librae (Zubenelgenubi) | Kiffah janūbī | [The] southern plate [of the balance] |
| β Librae | Kiffah shamālī | [The] northern plate [of the balance] |
| α Coronae Borealis (Alphecca) | Nayyir al-fakkah | The luminous one of *al-fakkah* |
| α Serpentis (Unuk) | ʿUnq al-ḥayyah | The neck of the serpent |
| α Scorpii (Antares) | Qalb al-ʿaqrab | The heart of the scorpion |
| ρ Ophiuchi | Rijl al-ḥawwā al-yamīnī al-muqaddam | The forward, right foot of the serpent charmer |
| α Herculis (Rasalgethi) | Raʾs al-jāthī | The head of the kneeling one |
| α Ophiuchi (Rasalhague) | Raʾs al-ḥawwà | The head of the serpent charmer |
| γ Draconis | ʿAyn al-tinnīn | The eye of the dragon |
| δ Ophiuchi | Yad al-ḥawwà al-yumnà al-muqaddam | The forward, right hand of the serpent charmer |
| α Lyrae (Vega) | Nasr wāqiʿ | A falling eagle |
| $\xi^2$οπdρυ Sagittarii | ʿIṣābat al-rāmī | The headband of the archer |
| β Cygni (Albireo) | Minqār al-dajājah | The bird's beak |
| α Aquilae (Altair) | [Al-]nasr al-ṭāʾir | The flying eagle |
| α Capricorni | Qarn al-jadī al-thānī | The second horn of the goat |
| ε Delphini | Dhanab al-dulfīn | The dolphin's tail |
| α Cygni (Deneb) | Dhanab al-dajājah | The tail of the bird |
| ε Pegasi (Enif) | Fam al-faras | The mouth of the horse |
| δ Capricorni (Deneb Algedi) | Dhanab al-jadī | The tail of the goat |
| α Aquarii | Mankib sākib al-māʾ | The shoulder of the water pourer |
| δ Aquarii | Sāq sākib al-māʾ al-janūbī | The southern leg of the water pourer |
| ι Ceti | Dhanab al-qīṭus shamālī | The northern tail of the sea monster Cetus |
| β Pegasi (Scheat) | Mankib al-faras | The shoulder of the horse |
| β Cassiopeiae (Caph) | [Al-]kaff al-khaḍīb | The dyed hand |

*Note:* This astrolabe was made in Lahore in 1060/1650. The stars are listed in order of increasing celestial longitude beginning at the first house of the zodiac.

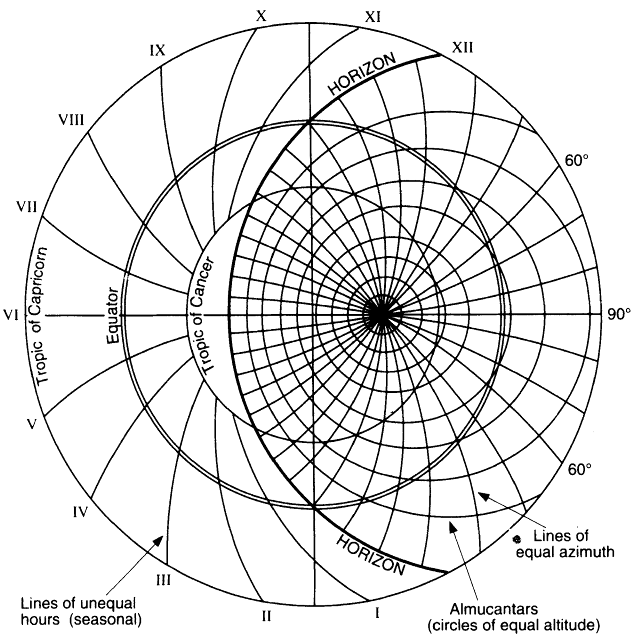


FIG. 2.9. BASIC DESIGN OF AN ASTROLABE PLATE. Since the projected curves depend on the latitude of the observer, separate plates are required for different geographic latitudes.

and angular measurements necessary for orientation toward Mecca.[20]

A pin passed through the rete and plate(s) and the body of the astrolabe and also, on the back of the device, through a rotating flat ruler with sighting holes. The pin itself was secured on top of the rete by a wedge inserted through a hole near the end of the pin, as can be seen in figures 2.5 and 2.14. The rotation of the fretted star map over the plate on the front of the astrolabe assembly represented the daily rotation of the celestial sphere relative to an observer at that particular geographic latitude and during an interval of about fifty to seventy-five years after the construction of the instrument.

On the back of the astrolabe assembly there were any number of scales and charts providing a variety of information (see fig. 2.6*d*). There could be shadow squares, calendar scales, and astrological charts, but there nearly always was a scale of degrees around the edge for use in angular measurement of altitudes. The rotating sighting device, called an alidade, from the Arabic *al-ʿiḍādah*, "rule," could be used, when the assembly was properly suspended, to find the position of the sun within the zodiac by adjusting the alidade so that a ray of light passed through the two smaller holes in its sights. The altitude of celestial bodies could be ascertained by sighting the star or planet through the two large holes. When used in conjunction with the rotating celestial map (rete) on the front of the device, the alidade could be used to tell time, day or night, as long as the sun or some star marked on the rete was visible. Similarly, the astrolabe could be used to calculate the geographic latitude, to determine information needed in casting horoscopes, and to undertake a host of other useful calculations.[21]

Over the centuries and in different regions, considerable variation occurred in the patterning of the retes, the design of the suspensory device, and the nature of the charts and grids placed on the back. This variation is evident both in the treatises written on astrolabe construction and in the legions of astrolabes preserved today. The basic nature, however, remained the same throughout the many centuries of their production—an instrument used to make simple observations and an analog computing device used to solve a variety of problems concerning the movement of the sun and stars.

## EARLY HISTORY OF THE ASTROLABE

The precise origins of the astrolabe are obscure. What appears certain is that it was a Greek invention. Theon of Alexandria in the fourth century A.D. wrote on the astrolabe, for his treatise was subsequently used in the sixth century A.D. by Johannes Philoponus, also of Alexandria, who composed in Greek the earliest extant treatise we have on the subject.[22]

The method of stereographic projection used in constructing planispheric astrolabes was described in the second century A.D. by Ptolemy in a treatise now lost in the original Greek but preserved in a Latin translation titled *Planisphaerium*, made by Hermann of Carinthia in Tou-

20. Some of the gazetteers on astrolabes have been studied by Gibbs with Saliba, *Planispheric Astrolabes*, 190–206 (note 15), and by Gunther, *Astrolabes of the World*, vol. 1, passim (note 2), and a few astrolabes were surveyed by Edward S. Kennedy and Mary Helen Kennedy, *Geographical Coordinates of Localities from Islamic Sources* (Frankfurt: Institut für Geschichte der Arabisch-Islamischen Wissenschaften, 1987). See also the discussion of geographical tables in chapter 4, on the early development of terrestrial cartography in Islam, and for a fuller discussion of the methods of orientation toward Mecca, see chapter 9 on qibla charts, qibla maps, and related instruments.

21. For its numerous applications, see Edward S. Kennedy and Marcel Destombes, "Introduction to *Kitāb al-ʿamal biʾl-asṭurlāb*," English introduction to the Arabic text of ʿAbd al-Raḥmān ibn ʿUmar al-Ṣūfī's astrolabe treatise (Hyderabad: Osmania Oriental Publications, 1966); reprinted in Kennedy's *Studies in the Islamic Exact Sciences*, ed. David A. King and Mary Helen Kennedy (Beirut: American University of Beirut, 1983), 405–47, and Ibn al-Samḥ, *El "Kitāb al-ʿamal bi-l-asṭurlāb" (Libre de l'us de l'astrolabi) d'Ibn Samḥ*, ed. Mereè Viladrich i Grau, Institut d'Estudis Catalans, Memòries de la Secciá Històrica-Arqueològica 36 (Barcelona: Institut d'Estudis Catalans, 1986).

22. The English translation by H. W. Greene printed in Gunther, *Astrolabes of the World*, 1:61–81 (note 2), is a poor rendering of the Greek text inadequately edited by H. H. Hase in *Rheinisches Museum für Philologie*, 2d ser., 6 (1839): 127–71. A more reliable guide to the text is Johannes Philoponus, *Traité de l'astrolabe*, trans. A. P. Segonds (Paris, 1981). Theon's treatise is also partially preserved in that of Sebokht (see note 2 above).

louse in A.D. 1143 from the Arabic version.[23] In the fourteenth chapter of the *Planisphaerium*, Ptolemy does refer enigmatically to a "spider" (*aranea*) in a "horoscopic instrument" (*horoscopium instrumentum*), but the instrument lacks attributes clearly recognizable as those of a planispheric astrolabe.[24] In Ptolemy's major astrological tract, the *Tetrabiblos*, there is a passage in which the expression δι' ἀστρολάβων ὡροσκοπίων, "by means of astrolabic horoscope instruments," is the recommended method of determining time of birth.[25] The theory among historians today, however, is that here Ptolemy is referring to the observational armillary sphere, just as he was when using the term "astrolabe" in the *Almagest* and in the *Geography*.

Beyond this, little can be said with any certainty. Vitruvius in the first century B.C. knew about stereographic projection, a necessary requisite to the astrolabe, but there is no convincing evidence that Ptolemy or any of his predecessors knew about the planispheric astrolabe; nor are there substantial grounds for considering that Hipparchus, to whom Ptolemy was much indebted, necessarily knew about stereographic projection and applied it to instrument design.[26] There is, however, evidence for interest in Ptolemy's day in its application to instruments, for there is a small portable sundial, probably made in the second century A.D. and now in the Kunsthistorisches Museum, Vienna, that has engraved inside the lid the stereographic projection of the two tropics, as well as the equator and the unequal-hour lines. This sundial, only thirty-nine millimeters in diameter, has other features reminiscent of astrolabes, for it consists of a box containing four circular plates slipped over a vertical pin attached to the bottom of the box. The four plates are engraved on both sides with sundial scales, each for use at a different geographic latitude.[27]

Certainly the early Arabic-speaking historians thought Ptolemy knew of the astrolabe, for the bibliographer Ibn al-Nadīm, writing in the tenth century A.D., said: "In ancient times the astrolabes were plane. The first person to make them was Ptolemy. It is said that they were made before his time, but this has not been verified."[28]

Early medieval compilers of biographies and histories often, however, interlaced their accounts with charming but misleading anecdotes. A particularly delightful example is the anecdotal account of the origin of the astrolabe given by the thirteenth-century A.D. Syrian bibliographer Ibn Khallikān. He related that "it is said" Ptolemy invented the astrolabe by accident while out riding and carrying a celestial globe in his hand. When Ptolemy dropped the globe, his mount stepped on it and squashed it. The result was the astrolabe.[29]

Returning from the fanciful to the more concrete, Ibn al-Nadīm stated that the earliest treatise in Arabic on the astrolabe was the *Kitāb ṣanʿat al-asṭurlābāt wa-al-ʿamal bi-hā* (The construction and use of astrolabes) by Māshā'allāh, whose dates are uncertain but who was still alive in 193/809. Māshā'allāh was a Jewish astrologer working and writing in Basra southeast of Baghdad.[30] A Latin treatise on the astrolabe under the name of Messahalla, the Romanized form of his name, had the greatest

23. Contrary to what is usually stated in the literature, the Arabic translation had probably not been made by Maslamah ibn Aḥmad al-Majrīṭī (d. 398/1007), an astronomer and mathematician of Córdoba; 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 (1981): 42–62, esp. 50 n. 38.

24. Claudius Ptolemy, *Opera quae exstant omnia*, 3 vols., ed. J. L. Heiberg (Leipzig: B. G. Teubner, 1898–1907), vol. 2, *Opera astronomica minora* (1907), 225–59, esp. 249; German translation by J. Drecker, "Das Planisphaerium des Claudius Ptolemaeus," *Isis* 9 (1927): 255–78, esp. 271. Neugebauer interprets the "horoscopic instrument" mentioned in the *Planisphaerium* as an anaphoric clock with the stars and ecliptic forming a movable overlay, employing a design later developed in the Islamic world rather than the design that became dominant in Vitruvian or European anaphoric clocks, in which the stars and ecliptic were stationary; Otto Neugebauer, *A History of Ancient Mathematical Astronomy*, 3 pts. (New York: Springer-Verlag, 1975), 2:865–66 and 871.

25. The passage is *Tetrabiblos* 3.2; see Ptolemy, *Tetrabiblos*, ed. and trans. F. E. Robbins, Loeb Classical Library (Cambridge: Harvard University Press, 1940; reprinted 1980), 228–31. Note that ὡροσκοπίων is a noun here, and not an adjective.

26. In this interpretation of the Ptolemaic and pre-Ptolemaic antecedents of the astrolabe, Neugebauer, in *Ancient Mathematical Astronomy*, 3:858, 868–69 and 871 (note 24), severely modified and even reversed many points he had made in a study nearly thirty years earlier: Otto Neugebauer, "The Early History of the Astrolabe: Studies in Ancient Astronomy IX," *Isis* 40 (1949): 240–56; reprinted in Otto Neugebauer, *Astronomy and History: Selected Essays* (New York: Springer-Verlag, 1983), 278–94. For arguments that Ptolemy knew the astrolabe and that Hipparchus could well have developed the planispheric astrolabe, see Neugebauer, "Early History of the Astrolabe," 241–42 and 246–51, and Germaine Aujac and editors, "Greek Cartography in the Early Roman World," in *The History of Cartography*, ed. J. B. Harley and David Woodward (Chicago: University of Chicago Press, 1987–), 1:161–76, esp. 167 n. 35. An important source in these arguments is Synesius of Cyrene, who died shortly before A.D. 415 and was a pupil of Hypatia, the daughter of Theon of Alexandria; Joseph Vogt and Matthias Schramm, "Synesios vor dem Planisphaerium," in *Das Altertum und jedes neue Gute: Für Wolfgang Schadewaldt zum 15. März 1970* (Stuttgart: W. Kohlhammer, 1970), 265–311, esp. 279–311.

27. Vienna, Kunsthistorisches Museum, inv. no. VI 4098. For an illustration and discussion, see Turner, *Astrolabes*, 10–11 (note 19).

28. Muḥammad ibn Isḥāq ibn al-Nadīm, *al-Fihrist*; see *Kitâb al-Fihrist*, 2 vols., ed. Gustav Flügel (Leipzig: F. C. W. Vogel, 1871–72), 1:284, or *The Fihrist of al-Nadīm: A Tenth-Century Survey of Muslim Culture*, 2 vols., ed. and trans. Bayard Dodge (New York: Columbia University Press, 1970), 2:670.

29. The passage from Aḥmad ibn Muḥammad ibn Khallikān (608–81/1211–82) is discussed in detail by King, "Origin of the Astrolabe," 45, 55, 60–61, with Arabic text on 71 (note 14). The instrument that Ptolemy was said to be carrying was called a *kurah falakīyah*, a common designation of a celestial globe meaning literally "celestial sphere."

30. Not in Egypt, as many have asserted; Julio Samsó, "Māshā' Allāh," in *Encyclopaedia of Islam*, new ed., 6:710–12; Ibn al-Nadīm, *Fihrist*; Flügel's edition, 1:273, Dodge's edition, 2:650–51 (note 28).

influence in the Latin West of all astrolabe writings and eventually became the basis of Geoffrey Chaucer's treatise on the astrolabe written in A.D. 1392 for his son Lewis. Recent scholarship, however, has shown that this immensely popular Latin version is not in fact a translation of a writing by Māshā'allāh of the late eighth century A.D., but rather a Western compilation based on the translations of works by Ibn Ṣaffār (d. 426/1035), a mathematician and astronomer of Córdoba.[31]

From Ibn al-Nadīm we have the names of other early treatises on the subject, though few are extant today. The earliest Arabic treatise on the planispheric astrolabe still preserved today in the original is that written by the instrument maker and astronomer ʿAlī ibn ʿĪsā, who in 214/829–30 and again in 217/832–33 participated in observations at Baghdad and Damascus.[32] An astrolabe made by one of his apprentices is among the earliest to have survived and is illustrated in figure 2.5. Thereafter, numerous treatises on the construction and use of the astrolabe were composed both in Arabic and, slightly later, in Persian as well.

Ibn al-Nadīm also supplies the names of many early artisans manufacturing astrolabes. The earliest—presumably in the Islamic Near East—was Abywn (or Abiyūn; Apion the patriarch) al-Baṭrīq, who he said lived a little before or a little after the advent of Islam.[33] Elsewhere in his history, however, Ibn al-Nadīm said that al-Fazārī, a well-known astronomer in Baghdad during the reign of the caliph al-Manṣūr (r. 136–58/754–75), was the first person in Islam to make an astrolabe.[34] The identity of Abywn al-Baṭrīq is uncertain, though a later writer, the eleventh-century scholar al-Bīrūnī, who himself wrote on astrolabes, stated that Abywn al-Baṭrīq wrote a treatise on the astrolabe that was translated, presumably from Coptic or Syriac, by Abū al-Ḥasan Thābit ibn Qurrah al-Ḥarrānī at the end of the ninth century A.D. in Baghdad.[35]

Clearly from Ibn al-Nadīm's account, and other sources as well, the earliest center for astrolabe production—as well as other astronomical instruments—was within the domain of Syria, in the city of Harran, lying between the northern reaches of the Euphrates and Tigris rivers, southeast of Edessa. Though today it lies in ruins in modern Turkey, it was an ancient and important town, known to the Romans as Carrhae and to the church fathers as Hellenopolis, at the intersection of major caravan routes to Syria, Mesopotamia, and Asia Minor. In the ninth and tenth centuries A.D. it had a prominent Sabian community, whose pagan religious interest in the stars and sun perhaps was particularly conducive to the study of astronomy.[36] In any case, many of the early Islamic astronomers and instrument makers were members of the Sabian sect, whose center was in Harran. Ibn al-Nadīm also mentioned the patronage of one of the tenth-century Hamdanid rulers of Syria, Sayf al-Dawlah, whose center of power was in Aleppo during his rule from 333/944 to 356/967. Among the astrolabe makers supported by this ruler was a woman named al-ʿIjlīyah, who had been apprenticed under the same master with whom her father, al-ʿIjlī, had trained.[37]

It is clear that Syria in the eighth, ninth, and tenth centuries A.D. was a region where much information circulated and was exchanged regarding the mapping as well as metalworking techniques necessary for producing planispheric astrolabes. The earliest surviving planispheric astrolabes are Islamic products of the second half of the ninth century A.D. Knowledge and production of astrolabes rapidly spread throughout Islamic lands from southern Spain to western India. Their styles varied in different workshops and regions, from the clean simple lines of the earlier western Islamic products, as seen in figure 2.5, to the rather ornate and delicate work of the eastern Islamic areas of Persia and western India, as illustrated in figure 2.6.[38] Knowledge of the astrolabe reached southern Europe about the middle of the tenth century, as evinced by a collection of scientific treatises compiled in a scriptorium at the Benedictine monastery of Santa

31. Kunitzsch, "Astrolabe Ascribed to Messahalla" (note 23).

32. ʿAlī ibn ʿĪsā al-Asṭurlābī, *Kitāb al-ʿamal bi-l-asṭurlāb*, ed. by P. Louis Cheikho: "Kitāb al-ʿamal bi-l-asṭurlāb li-ʿAlī ibn ʿĪsā," *al-Mashriq* 16 (1913): 29–46; German translation by Carl Schoy, "ʿAlî ibn ʿÎsâ, Das Astrolab und sein Gebrauch," *Isis* 9 (1927): 239–54.

33. Ibn al-Nadīm, *Fihrist*; Flügel's edition, 1:284, Dodge's edition, 2:670 (note 28).

34. Ibn al-Nadīm, *Fihrist*; Flügel's edition, 1:273, Dodge's edition, 2:649 (note 28). For Muḥammad ibn Ibrāhīm al-Fazārī, see David Pingree, "al-Fazārī," in *Dictionary of Scientific Biography*, 16 vols., ed. Charles Coulston Gillispie (New York: Charles Scribner's Sons, 1970–80), 4:555–56.

35. King, "Origin of the Astrolabe," 49 (note 14). See also Fuat Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, *Astronomie bis ca. 430 H.* (Leiden: E. J. Brill, 1978), 103.

36. Ibn al-Nadīm, *Fihrist*, Dodge's edition, 2:670–71 and 745–72 (note 28); G. Fehérvári, "Ḥarrān," in *Encyclopaedia of Islam*, new ed., 3:227–30; Bernard Carra de Vaux, "al-Ṣābiʾa," in *The Encyclopaedia of Islam*, 1st ed., 4 vols. and suppl. (Leiden: E. J. Brill, 1913–38), 4:21–22; Savage-Smith, *Islamicate Celestial Globes*, 18 and 23 (note 5). For further discussion of Harran as a center of instrumentation, see the historical introduction to Alain Brieux and Francis R. Maddison, *Répertoire des facteurs d'astrolabes et de leurs oeuvres: Première partie, Islam* (Paris: Centre National des Recherches Scientifiques, in press).

37. Ibn al-Nadīm, *Fihrist*; Flügel's edition, 1:285, Dodge's edition, 2:671 (note 28).

38. Numerous planispheric astrolabes are extant today, more than any other Islamic scientific instrument. For various makers and their products, see Gunther, *Astrolabes of the World* (note 2); Gibbs with Saliba, *Planispheric Astrolabes* (note 15); Sharon Gibbs, Janice A. Henderson, and Derek de Solla Price, *A Computerized Checklist of Astrolabes*, photocopy of typescript (New Haven: Yale University Department of the History of Science and Medicine, 1973); and Turner, *Astrolabes* (note 19). A comprehensive history and examination of all signed or dated astrolabes, as well as other Islamic astronomical instruments, will be found in the forthcoming Brieux and Maddison, *Répertoire* (note 36).

Maria de Ripoll at the foot of the Pyrenees.[39] During the eleventh century, knowledge of it spread to northern Europe, so that by A.D. 1092 an astrolabe was being employed in England during an eclipse of the moon.[40] The earliest European artifact preserved today dates from about A.D. 1200. After reaching great popularity in Europe in the fifteenth and sixteenth centuries, the astrolabe fell into disuse after the end of the seventeenth century,[41] but in the Islamic world its production continued, particularly in the East, through the nineteenth century.

The astrolabe was a convenient and portable multifunction instrument, combining the attributes of a two-dimensional model of the heavens, a computing device for calculating astronomical information, and an instrument for making simple observations. It should be noted, however, that its use as an observational instrument was primarily for timekeeping, determining ascendants for horoscopes, and geographical orientation. Serious observation by astronomers of planetary and stellar coordinates would have been done with other instruments, such as a parallactic ruler, the dioptra, large quadrants, and observational armillary spheres.[42] Though it was sometimes used to measure the heights of objects on earth, such as buildings or mountains, the astrolabe was not accurate enough for tasks requiring much precision. It was prized as a teaching device as well as a necessary aid to any enterprising astrologer casting a horoscope as preparation for predicting the course of an illness, the prospects of a child from the moment of birth, or the advisability of travel, marriage, war, and similar matters. In Islamic countries the astrolabe was a necessity to any *muwaqqit* of a mosque in determining the hours of prayer, which depended on calculating the sunrise and sunset at that particular location, and it was frequently used to determine the direction toward which a Muslim must face when performing the obligatory daily prayers (see chapter 9 on qibla orientation). In both Islamic Near Eastern and Christian European societies the instrument became the symbol of the professional astrologer or astronomer, as indicated by its frequent depiction in miniatures.

A remarkable full-page painting from a manuscript preserved today in Istanbul (fig. 2.10) depicts the astronomers and staff of a sixteenth-century Ottoman observatory employing a range of small instruments.[43] The short-lived observatory was built in the European section of Istanbul in 1577 under the direction of the chief astronomer in the Ottoman capital, Taqī al-Dīn Muḥammad al-Rashīd ibn Maʿrūf. In an illustrated verse chronicle of the reign of Sultan Murād III (982–1003/1574–95), who had been responsible for the building of the observatory as well as its demolition several years later, a poem described the functioning of the observatory. In figure 2.10, six lines of three couplets written in the upper section of the miniature read as follows:

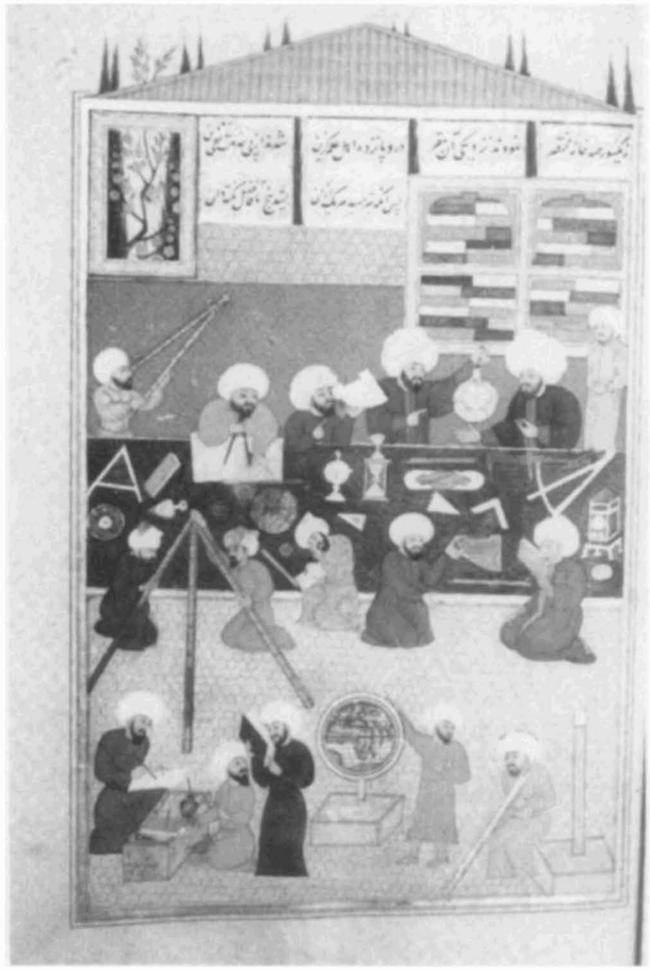

FIG. 2.10. ASTRONOMERS AT WORK. Astronomers are shown at work in this miniature of the "small" observatory, part of the observatory built in Istanbul in A.D. 1577. It is illustrated in the *Şāhanşāhnāme* (Book of the king of kings), a verse chronicle of the reign of Sultan Murād III, who was responsible for building the observatory.
Size of the original: not known. By permission of the Istanbul Üniversitesi Kütüphanesi (FY. 1404, fol. 57a).

And they also built a small-scale observatory
In the vicinity of the main building.
In it fifteen distinguished men of science
Were in readiness in the service of Taqî al Dîn.
In the observations made with each instrument
Five wise and learned men cooperated.

39. Barcelona, Archives of the Crown of Aragon, MS. Ripoll 225.

40. For the transmission to Europe of theoretical knowledge about the astrolabe as well as artifacts, see Turner, *Astrolabes*, 16–20 (note 19).

41. For reasons why it fell into disuse in Europe, see Turner, *Astrolabes*, 56–57 (note 19).

42. See King, "Astronomical Instrumentation," 1–3 (note 16), and Turner, *Astrolabes*, 29 n. 91 (note 19).

43. Istanbul Üniversitesi Kütüphanesi, MS. F. 1404 (Yıldız 2650/260), fol. 57a.

The poem goes on to say of the five men:

> There were two or three observers,
> and the fourth was a clerk,
> And there was also a fifth person
> who performed miscellaneous work.[44]

The painting itself illustrates the smaller, portable instruments that were kept in a small-scale adjunct observatory where minor observations were done, as well as recording, calculating, drawing, and studying. In front of the bookshelves drawn in figure 2.10, two astronomers discuss an astrolabe while a small figure, a student perhaps, looks on. Next to them an astronomer is using a quadrant, and far to the left another employs a dioptra. At the large table, which in the miniature forms a dark band across the middle of the painting, another astronomer constructs a diagram using a compass or dividers. In front of him on the table is what appears to be a celestial globe without rings or stand. Other instruments on the table (right to left) are a clock, an adjustable protractor, a pair of scissors, calipers, a straightedge, a pen box, a set square, triangles of various sizes, two sandglasses, a small globe without meridian ring, several plumb bobs, a book, and some type of plate. In front of the table one person reads while another demonstrates a quadrant; another writes while two work with a tripod for supporting a plumb line. In the foreground are figures variously engaged in reading and writing, while one appears to be discussing a large terrestrial globe on which Africa, Asia, and Europe are delineated in some detail.

Through this miniature we gain a glimpse of one aspect of the medieval Islamic observatory. Although the sixteenth-century Istanbul observatory was short-lived, its medieval predecessors, such as those at Maragheh in the thirteenth century or Samarkand in the fifteenth century, were active and important centers of study and research. Such illustrations also make it clear that astrolabes and related instruments as well as terrestrial globes were considered a necessary part of a working center for astronomical study. Many of the instruments preserved today, however, were clearly intended for wealthy and influential patrons who considered them an essential accoutrement for the library of any learned or cultured person.

### VARIANTS OF PLANISPHERIC ASTROLABES

The conventional type of planispheric astrolabe required that a different plate be inserted under the rete for every geographic latitude where it was to be used. In Toledo in the eleventh century A.D., an important development in the design occurred, owing to the efforts of two individuals. The result was a universal astrolabe that could be used at any location without special plates. The basic principle involved substituting the plane of the solstitial colure for the plane of the equator in the stereographic projection.

ʿAlī ibn Khalaf, perhaps also known as al-Shakkāz and possibly an apothecary or herbalist, designed a plate on which he inscribed the stereographic projection of the ecliptic coordinates onto the plane of the solstitial colure. Over this plate he placed a special "rete," one half of which represented the equatorial coordinates of meridians and parallels (derived through equatorial stereographic projection onto the plane of the solstitial colure) while the other half was similar to an ordinary rete displaying the fixed stars, but with the northern and southern halves superimposed.

The result was one plate and a "rete" that could solve problems of spherical astronomy for any geographic latitude, though in somewhat more complicated fashion than with the standard astrolabe.[45] The universal astrolabe of ʿAlī ibn Khalaf was not known outside southern Spain, and no examples are known to be preserved today. His treatise on the subject, dedicated to Yaḥyā al-Maʾmūn, the local ruler of Toledo from 435/1043–44 to 467/1074–75, is known through a thirteenth-century Castilian translation prepared as part of the *Libros del saber de astronomía* compiled largely from Arabic sources for Alfonso el Sabio (the Wise), who in A.D. 1251 was crowned Alfonso X of Castile.[46]

A contemporary of ʿAlī ibn Khalaf in Andalusia, the astronomer al-Zarqēllo (d. 493/1100), known in the West as Azarquiel, also designed a universal astrolabe and wrote three treatises on it, one of them dedicated to the same Toledan ruler who had patronized ʿAlī ibn Khalaf.[47]

44. Translation is that of Aydın Sayılı, *The Observatory in Islam and Its Place in the General History of the Observatory* (Ankara: Türk Tarih Kurumu, 1960; reprinted New York: Arno Press, 1981), 294; see also 289–305 of Sayılı's study for further discussion of this poem and a general account of the observatory in Istanbul. Sayılı attributes the poem to ʿAlā al-Dīn al-Manṣūr; the authorship of the *Şāhanşāhnāme* (History of the king of kings) in which the poem appears is disputed, see appendix 12.1, footnote o.

45. King, "Astronomical Instrumentation," 7 (note 16); David A. King, "On the Early History of the Universal Astrolabe in Islamic Astronomy, and the Origin of the Term 'Shakkāzīya' in Medieval Scientific Arabic," *Journal for the History of Arabic Science* 3 (1979): 244–57; reprinted in David A. King, *Islamic Astronomical Instruments* (London: Variorum Reprints, 1987), item VII. See also Turner, *Astrolabes*, 151–55 (note 19).

46. *Libros del saber de astronomia del rey D. Alfonso X de Castilla*, comp. Manuel Rico y Sinobas, 5 vols. (Madrid: Tipografía de Don Eusebio Aguado, 1863–67), 3:1–132. For a discussion of the *Libros del saber de astronomía*, see E. S. Procter, "The Scientific Works of the Court of Alfonso X of Castille: The King and His Collaborators," *Modern Language Review* 40 (1945): 12–29; and *De astronomia Alphonsi Regis*, ed. Mercè Comes, Roser Puig [Aguilar], and Julio Samsó, Proceedings of the Symposium on Alfonsine Astronomy held at Berkeley (August 1985), together with other papers on the same subject (Barcelona: Universidad de Barcelona, 1987).

47. For the spelling of his name as al-Zarqēllo, see Lutz Richter-

Al-Zarqēllo's solution was to inscribe a plate with the ecliptic coordinates projected stereographically onto the solstitial colure. The ecliptic latitude-measuring circles and longitude-measuring circles for every five degrees were indicated, and the projection taken with the vernal equinox as the center of projection was superimposed over the projection taken with the autumnal equinox as center of projection. Over this ecliptic grid he then superimposed, at an angle equal to the obliquity of the ecliptic, a similar projection of the equatorial coordinates, with the parallels and meridians indicated for every fifth degree. Stars were then placed directly on the plate. See figure 2.11 for a reconstruction of the basic method employed by al-Zarqēllo and figure 2.12 for an illustration of one of the few astrolabes of this design preserved today, made in the late fourteenth or early fifteenth century by an otherwise unknown maker named ʿAlī (or ʿAlā) al-Wadāʿī.[48]

With this design there was no need for a rete, but only a movable rod (called *ufq māʾil*, "oblique horizon") that could rotate at the center of the plate. When set at an appropriate angle, the rod could represent the horizon. The back of this plate would have an alidade and scales similar to those on conventional planispheric astrolabes.

This particular style of universal astrolabe was later called *al-ṣafīḥah al-Zarqāllīyah*, "the al-Zarqēllo plate," in Arabic after its inventor, and in Europe *azafea* (or *saphaea*) *Azarchelis*. Al-Zarqēllo himself called it *ṣafīḥah Maʾmūnīyah*, "a Maʾmūn plate," in the version of his treatise dedicated to the Toledan ruler Yaḥyā al-Maʾmūn before al-Zarqēllo moved to Córdoba. In the other two drafts of the treatise he called it *ṣafīḥah ʿAbbādīyah*, "an ʿAbbādid plate," in honor of Muḥammad II al-Muʿtamid, a ruler of the ʿAbbādid dynasty based in Seville and a rival of the Toledan ruler Yaḥyā al-Maʾmūn. The longer of the versions dedicated to al-Muʿtamid was translated into Castilian for Alfonso el Sabio,[49] while a shorter version for the same patron was transmitted to the West through translations of Jacob ben Machir ibn Tibbon of Marseilles and William the Englishman.[50] These translations subsequently influenced Gemma Frisius in the sixteenth century.[51]

Another type of universal astrolabe employing stereographic projection onto the plane of the solstitial colure was called *ṣafīḥah shakkāzīyah*, "a *shakkāzī* plate." Scholars have differed as to the origin of the design and of the name.[52] A number of treatises are extant on the instrument, including one by an important mathematician in Marrakesh, Ibn al-Bannāʾ (d. 721/1321),[53] and there are a few artifacts remaining today. The *shakkāzīyah* variant of the universal astrolabe resembled that of al-Zarqēllo except that the ecliptic system was simplified to show only the ecliptic latitude-measuring circles that are between the zodiacal houses (in other words, one every thirty degrees), and no parallels to the ecliptic were indicated at all. Stars were still placed on the plate, so that no rete was needed, and a ruler rotating over the plate served as both oblique horizon and ruler-protractor. The reverse of the plate was identical to that of a conventional astrolabe with an alidade having two sights. See figure 2.13 for an illustration of a *shakkāzīyah* astrolabe probably made in the thirteenth century.

ʿAlī ibn Khalaf and al-Zarqēllo may not have been the first to conceive the basic ideas of these universal plates. There is the intimation that the ninth-century Baghdad astronomer Aḥmad ibn ʿAbdallāh Ḥabash al-Ḥāsib al-Marwazī, who was possibly still alive in 300/912, may have written about a plate of horizons closely related to the *shakkāzīyah* plate.[54] Furthermore, a recently discovered manuscript by an astronomer of Shiraz in Persia, Abū Saʿīd al-Sijzī (d. ca. 415/1024–25), appears to be on the same topic.[55] Whatever their theories may prove to

Bernburg, "Ṣāʿid, the *Toledan Tables*, and Andalusī Science," 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, Annals of the New York Academy of Sciences, vol. 500 (New York: New York Academy of Sciences, 1987), 373–401, esp. 391 n. 5. For al-Zarqēllo's life and writings, see Juan Vernet Ginés, "al-Zarqālī (or Azarquiel)," in *Dictionary of Scientific Biography*, 16 vols., ed. Charles Coulston Gillispie (New York: Charles Scribner's Sons, 1970–80), 14:592–95. For a recent study and translation of one version of his treatise on the universal astrolabe, see Roser Puig Aguilar, *Los tratados de construcción y uso de la azafea de Azarquiel*, Cuadernos de Ciencias 1 (Madrid: Instituto Hispano-Arabe de Cultura, 1987).

48. Rockford, Illinois, Time Museum, inv. no. 3529. A full catalog description is given by Turner, *Astrolabes*, 168–73 (note 19).

49. *Libros del saber de astronomía*, 3:133–237 (note 46).

50. Vernet Ginés, "al-Zarqālī," 594 (note 47); José María Millás y Vallicrosa, ed. and trans., *Tractat de l'assafea d'Azarquiel* (Barcelona: Arts Gràfiques, 1933), critical edition of the thirteenth-century Hebraic and Latin texts by Jacob ben Machir ibn Tibbon; Turner, *Astrolabes*, 155–56 (note 19).

51. Maddison, *Hugo Helt*, 9–12 (note 5), and Turner, *Astrolabes*, 157–60 (note 19).

52. King, "Universal Astrolabe" (note 45); Hartner, "Asṭurlāb," 727, reprint 317 (note 18).

53. *Risālat al-ṣafīḥah al-mushtarikah ʿalā al-shakkāzīyah* (Rabat, Royal Library MS. 6667), recently studied by Roser Puig [Aguilar], "Concerning the Ṣafīḥa Shakkāziyya," *Zeitschrift für Geschichte der Arabisch-Islamischen Wissenschaften* 2 (1985): 123–39, and Emilia Calvo, "La *Risālat al-ṣafīḥa al-muštaraka ʿalà al-šakkāziyya* de Ibn al-Bannāʾ de Marrākuš," *al-Qanṭara* 10 (1989): 21–50. For a detailed explanation of the operations of a universal astrolabe, see Roser Puig [Aguilar], ed. and trans., *Al-Šakkāziyya: Ibn al-Naqqāš al-Zarqālluh* (Barcelona: Universidad de Barcelona, 1986). Turner refers to the design termed *shakkāzīyah* by Puig Aguilar as *Saphea Azarchelis*; Turner, *Astrolabes*, 174–79 (note 19).

54. This information is based on a remark by a later astronomer; see King, "Universal Astrolabe," 255 n. 22 (note 45), and idem, "Astronomical Instrumentation," 7 (note 16). On Ḥabash al-Ḥāsib, see Sezgin, *Geschichte des arabischen Schrifttums*, 6:173–75 (note 35). The only treatises by him preserved today are on the celestial globe, the spherical astrolabe, and the armillary sphere.

55. Damascus, Dār al-Kutub al-Ẓāhirīyah, MS. 9255; King, "Universal

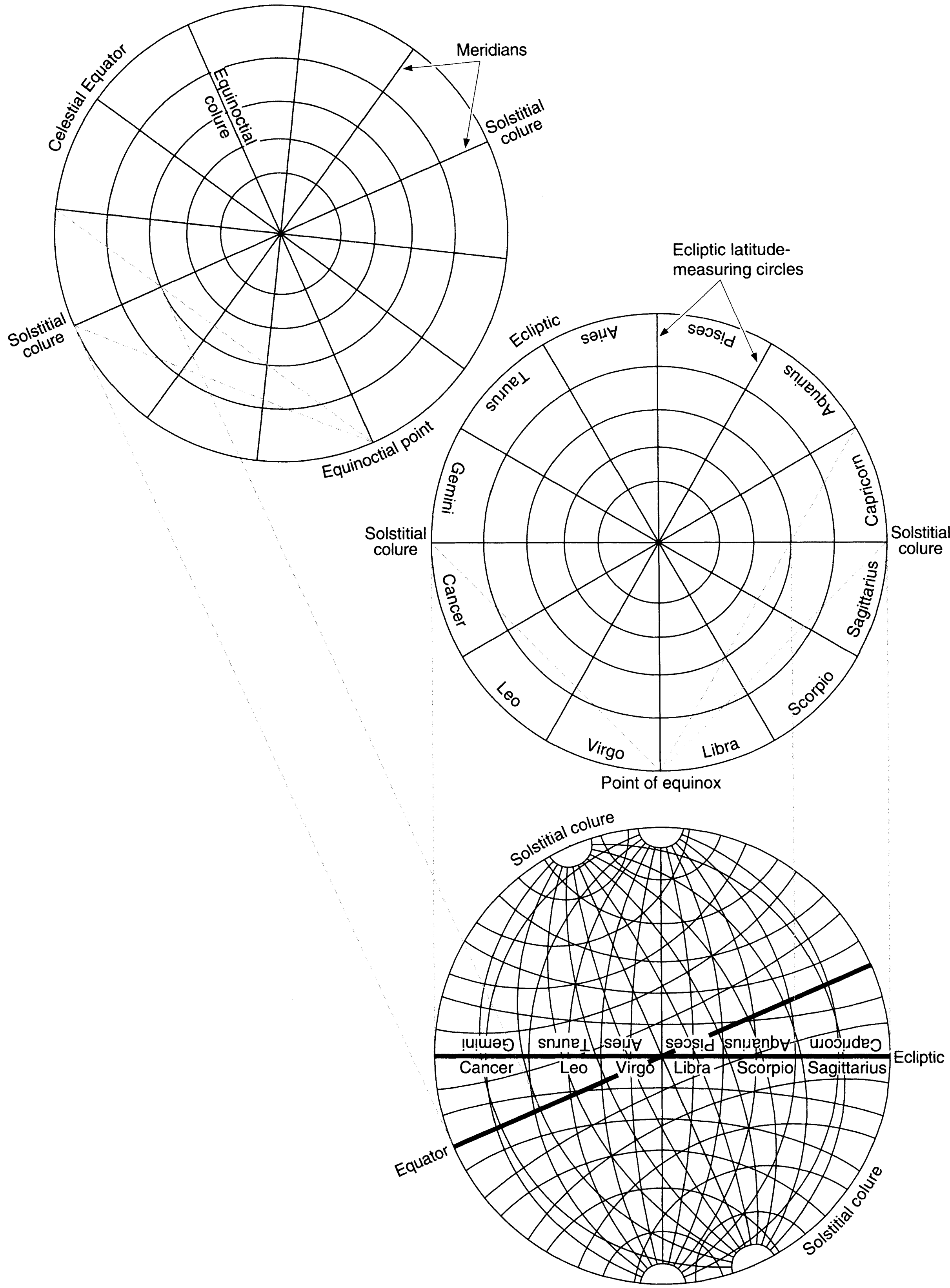


FIG. 2.11. SCHEMATIC INTERPRETATION OF ALZARQĒLLO'S DESIGN FOR A UNIVERSAL ASTROLABE TO BE USED AT ANY GEOGRAPHIC LATITUDE. The basic principle involved substituting the plane of the solstitial colure for the plane of the equator in the stereographic projection and superimposing a projection of the ecliptic coordinates over those of the equatorial coordinates.

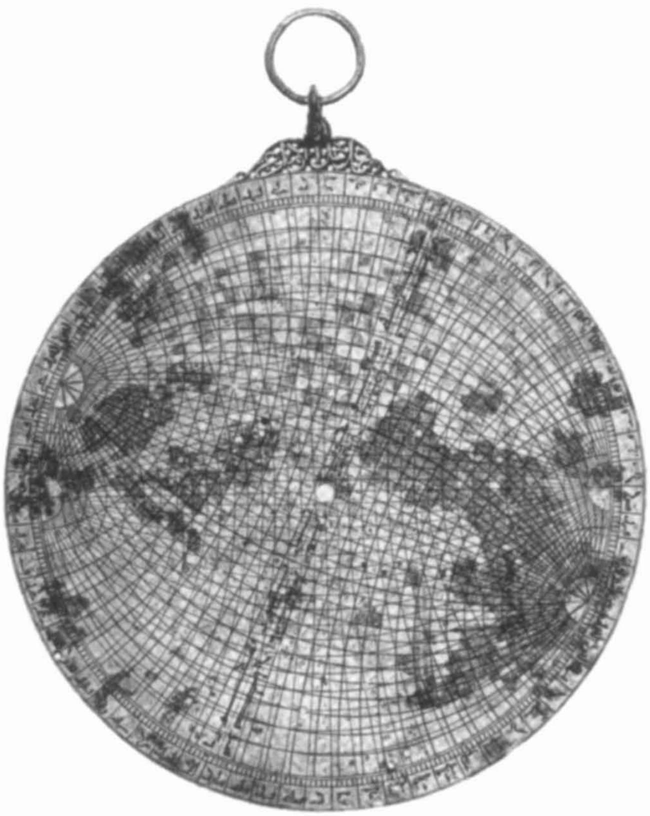

FIG. 2.12. A UNIVERSAL ASTROLABE OF THE TYPE DESIGNED BY AL-ZARQĒLLO. Undated (fourteenth or fifteenth century) astrolabe made by ʿAlī (or ʿAlā) al-Wadāʿī. This type of astrolabe is very rare.
Diameter of the original: 17 cm. By permission of the Time Museum, Rockford, Illinois (inv. no. 3529).

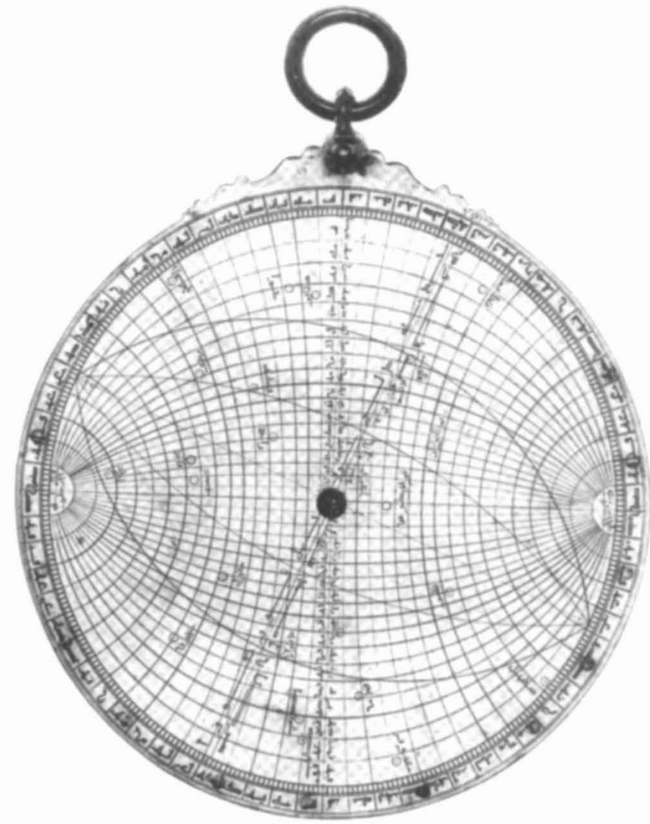

FIG. 2.13. A TYPE OF UNIVERSAL ASTROLABE CALLED *SHAKKĀZĪYAH*. Unsigned and undated (probably thirteenth century).
Diameter of the original: 22.7 cm. Museum of the History of Science, Barnett Collection, Oxford (IC-139). By permission of the Bettman Archive, New York.

have been, however, ʿAlī ibn Khalaf and al-Zarqēllo concretely applied the principle of stereographic projection onto the solstitial plane to the design and production of an astrolabe. A version of a universal astrolabe was reinvented in Syria in the early fourteenth century by the Aleppo astronomer Ibn al-Sarrāj. The only example of Ibn al-Sarrāj's instrument known to be preserved today is one he made himself (fig. 2.14). It is considerably more complicated and sophisticated than the form originally developed in southern Spain. A recent historian of Islamic instrumentation has declared that this universal astrolabe by Ibn al-Sarrāj is the most sophisticated astronomical instrument from the entire medieval and Renaissance periods.[56]

### EXTENDED USE OF ASTROLABIC MAPPING

Another attempt to simplify the conventional planispheric astrolabe was devised by Sharaf al-Dīn al-Muẓaffar al-Ṭūsī, a Persian mathematician who died in the early thirteenth century. His idea was a linear astrolabe that was sometimes called "the staff of al-Ṭūsī" (*ʿaṣāt al-Ṭūsī*) after its inventor. Although stereographic projection was still employed in its design, the key elements of the mapping were reduced to the sides of one rod, which had a sight at each end and a plumb line in the middle. There was also a fixed thread at one end and a movable thread. Such an instrument had many limitations and seems to have been of little practical use. No examples are known to have survived.[57]

The astrolabic quadrant also developed from the planispheric astrolabe. In this distinctly Islamic development, a portion of an astrolabe plate was inscribed on a quadrant. A cord attached to the center of the quadrant takes

Astrolabe," 255 n. 23 (note 45). For further information on al-Sijzī, see Yvonne Dold-Samplonius, "al-Sijzī," in *Dictionary of Scientific Biography*, 16 vols., ed. Charles Coulston Gillispie (New York: Charles Scribner's Sons, 1970–80), 12:431–32.

56. King, "Astronomical Instrumentation," 7 (note 16); David A. King, "The Astronomy of the Mamluks," *Isis* 74 (1983): 531–55, esp. 544. See also the forthcoming study by David A. King, *The Astronomical Instruments of Ibn al-Sarrāj* (Athens: Benaki Museum).

57. For a diagram illustrating the principle, see Turner, *Astrolabes*, 184 (note 19). See also Bernard Carra de Vaux, "L'astrolabe linéaire ou bâton d'et-Tousi," *Journal Asiatique*, 9th ser., 5 (1895): 464–516. For a diagram in a copy of al-Ṭūsī's treatise extant in Istanbul, see King, "Astronomical Instrumentation," pl. 5 (note 16).

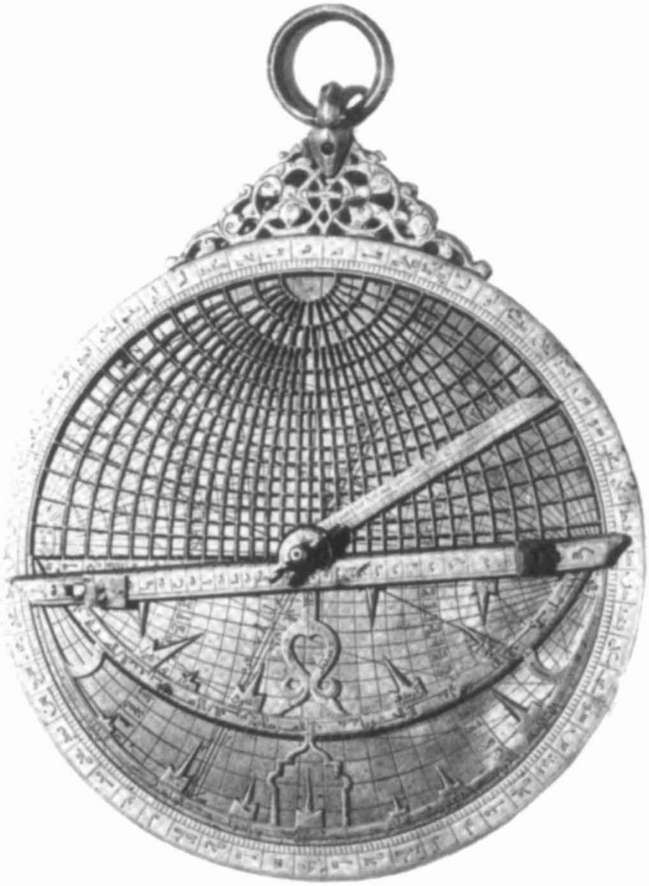

FIG. 2.14. THE UNIVERSAL ASTROLABE DESIGNED BY IBN AL-SARRĀJ IN THE EARLY FOURTEENTH CENTURY.
Diameter of the original: 15.8 cm. By permission of the Benaki Museum, Athens (inv. no. 13178).

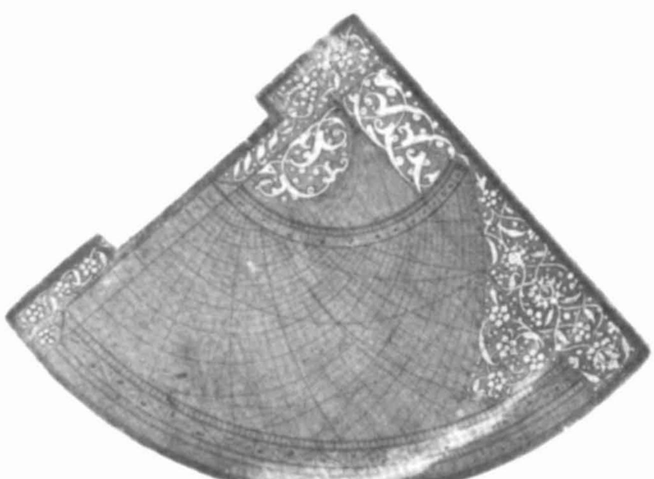

FIG. 2.15. A WOODEN ASTROLABIC QUADRANT FOR LATITUDE 41°. This quadrant was made in Istanbul in 1094/1682–83 by Aḥmad al-Ayyūbī.
Size of the original: 10.4 cm. Museum of the History of Science, Oxford (inv. no. 60-70). By permission of the Bettman Archive, New York.

the place of the rete of the astrolabe; a bead on the cord can be adjusted to represent the position of the sun or a star, whose positions were read from markings for the ecliptic and star positions that are included on the quadrant. Thus an astrolabic quadrant also represents the position of the sun or fixed star with respect to the local horizon.[58]

A recently discovered twelfth-century Egyptian treatise indicates that the astrolabic quadrant was already known at that time. Its precise origins are unknown. Except in Persia and India, the astrolabic quadrant had to a large extent replaced the astrolabe in popularity by the end of the sixteenth century. Most of the astrolabic—also called almucantar—quadrants preserved today are Ottoman Turkish products (fig. 2.15).

There are also quadrants employing *shakkāzīyah* curves of the type developed for universal astrolabes. Several treatises were written on the subject, an especially interesting one by the late fourteenth-century astronomer Jamāl al-Dīn al-Māridīnī, who worked in Damascus and Cairo.[59] This type of quadrant was clearly related in design to the universal astrolabes of the eleventh-century Toledan astronomers, as were also the class of quadrants called meteoroscopes by later European astronomers.[60]

In Islam, anaphoric clock dials, made to simulate the motion of the heavens, resembled astrolabes in appearance. They were open star maps over a projection of the celestial coordinate system as it relates to the observer's locality. Such an astrolabic clock dial was seen, for example, by a fourteenth-century Arab historian in 743/1342–43 in the Damascus home of the astronomer Ibn al-Shāṭir.[61] Similarly, a clock in Fez, Morocco, was outfitted during a restoration in A.D. 1346–48 with an astrolabic rete still to be seen today.[62] This design is in contrast to the typical European astronomical clock dials on which the stars and constellations had an overlay of wires representing the local celestial coordinates and horizon.

58. For diagrams illustrating the principle of astrolabic quadrants and the folding of the stereographic projection that is part of their design, see Turner, *Astrolabes*, 202–3 (note 19).

59. King, "Astronomy of the Mamluks," 545 (note 56), and David A. King, "An Analog Computer for Solving Problems of Spherical Astronomy: The *Shakkāzīya* Quadrant of Jamāl al-Dīn al-Māridīnī," *Archives Internationales d'Histoire des Sciences* 24 (1974): 219–42; reprinted in David A. King, *Islamic Astronomical Instruments* (London: Variorum Reprints, 1987), item X.

60. John D. North, "Werner, Apian, Blagrave and the Meteoroscope," *British Journal for the History of Science* 3 (1966–67): 57–65 and pl. II.

61. On ʿAlāʾ al-Dīn Abū al-Ḥasan ʿAlī ibn Ibrāhīm ibn al-Shāṭir, see David A. King, "Ibn al-Shāṭir," in *Dictionary of Scientific Biography*, 16 vols., ed. Charles Coulston Gillispie (New York: Charles Scribner's Sons, 1970–80), 12:357–64, esp. 362.

62. Derek J. de Solla Price, "Mechanical Water Clocks of the 14th Century in Fez, Morocco," in *Proceedings of the Tenth International Congress of the History of Science (Ithaca, 1962)*, 2 vols. (Paris: Hermann, 1964), 1:599–602, esp. 600 and fig. 2.

FIG. 2.16. A UNIQUE ASTROLABE, WHICH IS ALSO A MECHANICAL, GEARED CALENDAR (FRONT). This astrolabe was made in 618/1221–22 in Isfahan by Muḥammad ibn Abī Bakr al-Rashīdī.
Diameter of the original: 18.5 cm. Museum of the History of Science, Lewis Evans Collection, Oxford (inv. no. IC5). By permission of the Bettman Archive, New York.

FIG. 2.17. REVERSE SIDE OF THE ASTROLABE SHOWN IN FIGURE 2.16. The phases of the moon are displayed through the circular window near the top of the instrument. Two circular plates beneath, one with a disk for the sun and the other with a disk for the moon, rotate within a zodiacal calendar.
Diameter of the original: 18.5 cm. Museum of the History of Science, Lewis Evans Collection, Oxford (inv. no. IC5). By permission of the Bettman Archive, New York.

A unique and most remarkable astrolabe was produced by a thirteenth-century Persian metalworker who worked in Isfahan (figs. 2.16 and 2.17). This device, made in 618/1221–22, was both an astrolabe and a mechanical calendar, for it was fitted with a geared mechanism by which it could reproduce the motions of the sun and moon. It is the oldest geared machine in existence in a complete state. Because the motions of the sun and moon are displayed through windows on the back of the astrolabe, the maker, Muḥammad ibn Abī Bakr al-Rashīdī, called also al-Ibarī al-Isfahānī, "the needlemaker of Isfahan," had to place two lugs on the rete to serve as sights instead of the alidade on the back. The geared calendar was moved by turning the wedge and pin at the center of the rete. On the reverse of the instrument, the phases of the moon were displayed through a circular window, with the age of the moon in letter-numerals showing through a small rectangular window. Two circular plates, one with a gold disk for the sun and the other with a (now missing) disk for the moon, rotated within a zodiacal calendar scale, representing their relative positions within the zodiac. A quite similar mechanism was designed in the eleventh century by al-Bīrūnī in his *Kitāb istīʿāb al-wujūh al-mumkinah fī ṣanʿat al-asṭurlāb* (Comprehensive study of all possible ways of making an astrolabe).[63] The precise

63. The section concerned with the mechanical calendar has been edited from three manuscripts and translated by Donald R. Hill, "Al-Bīrūnī's Mechanical Calendar," *Annals of Science* 42 (1985): 139–63. For the extant astrolabe/calendar see Silvio A. Bedini and Francis R. Maddison, "Mechanical Universe: The Astrarium of Giovanni de' Dondi," *Transactions of the American Philosophical Society*, n. s., 56, pt. 5 (1966): 3–69, esp. 8–10; and J. V. Field and M. T. Wright, "Gears from the Byzantines: A Portable Sundial with Calendrical Gearing," *Annals of Science* 42 (1985): 87–138.

relation of such mechanical devices to earlier Byzantine ones as well as to later European examples has not been fully established, though it has attracted the attention of recent scholars.

## Al-Bīrūnī on Celestial Mapping

One of the most versatile and original of Islamic medieval scholars, al-Bīrūnī (d. after 442/1050) is also an important source of information on celestial mapping in the late tenth century. About 390/1000, while a young man in his middle twenties, al-Bīrūnī wrote *Kitāb al-āthār al-bāqīyah min al-qurūn al-khālīyah* (The chronology of ancient nations, literally, The remaining traces of past centuries), in which he compared calendrical systems among different peoples of the world. In this treatise he devoted one chapter to several methods for projecting star maps.[64] A few years later he composed a small monograph on the same subject, entitled *Kitāb fī tasṭīḥ al-ṣuwar wa-tabṭīḥ al-kuwar* (The book of the projection of the constellations and the flattening of the sphere),[65] dedicated to an unspecified Khwārazmshāh, the title given to Central Asian rulers along the lower Oxus River (modern Amu Darya). In this case the Khwārazmshāh was probably Abū al-Ḥasan ʿAlī, who died in 399/1008–9. Though world maps are mentioned, al-Bīrūnī's focus in both these discussions is on celestial mapping.

In the course of these two major discussions, al-Bīrūnī refers to or describes seven methods of projecting a celestial sphere or globe onto a flat surface.[66] For the first four methods he does not claim originality, only better understanding that allows him to criticize them as inadequate. For the other three methods he mentions no previous authorities and offers no criticisms, which encourages the conclusion that they were his own inventions.

The first projection he says he drew from Ptolemy's *Geography*, where it is given on the authority of Marinus.[67] The projection is formed with straight and perpendicular lines of latitude and longitude, resulting in considerable deformation. It produced a rectangular projection similar to what is today called an equidistant cylindrical projection.

The second projection is one that he notes was commonly used in astrolabes—that is, it is the polar case of stereographic projection. He states that it is simply one case of what he calls conical (*makhrūṭī*) projection, which is to say that the center of projection could be moved inside or outside the sphere, as the earlier astronomer al-Ṣaghānī had suggested in the tenth century.[68] In *Kitāb al-durar fī saṭḥ al-ukar* (Book of pearls concerning the projection of the spheres),[69] a treatise on the construction of the astrolabe, al-Bīrūnī expands on the idea of conical projections whose center of projection is at various fixed points along the north-south axis of the sphere. In this latter tract, al-Bīrūnī cites no predecessors.

The third technique he called "cylindrical" (*usṭuwānī*), but from his description it is evident that it corresponded to what today would be called orthographic (fig. 2.18). In *al-Āthār al-bāqīyah*, al-Bīrūnī claimed that no one had mentioned this projection before him, though in his specialized monograph written slightly later he disparagingly

64. Abū al-Rayḥān Muḥammad ibn Aḥmad al-Bīrūnī, *al-Āthār al-bāqīyah*; see *Chronologie orientalischer Völker von Albērūnī*, ed. Eduard Sachau (Leipzig: Gedruckt auf Kosten der Deutschen Morgenländischen Gesellschaft, 1878), 357–63; and *The Chronology of Ancient Nations: An English Version of the Arabic Text of the "Athâr-ul-bâkiya" of Albîrûnî, or "Vestiges of the Past," Collected and Reduced to Writing by the Author in A.H. 390–1, A.D. 1000*, ed. and trans. Eduard Sachau (London: W. H. Allen, 1879; reprinted Frankfurt: Minerva, 1969), 357–64. Al-Bīrūnī's ideas on projection presented in this treatise are discussed briefly by Matteo Fiorini, "Le projezioni cartografiche di Albiruni," *Bollettino della Società Geografica Italiana*, 3d ser., 4 (1891): 287–94. See also chapters 6 and 8 below.

65. The treatise is extant in two manuscripts, Leiden, Universiteitsbibliotheek, MS. Or. 14, 300–314, and Tehran, Dānishgāh, MS. 5469, fols. 7b–13b. English translation and analysis, with reproduction of the Leiden manuscript, by J. L. Berggren, "Al-Bīrūnī on Plane Maps of the Sphere," *Journal for the History of Arabic Science* 6 (1982): 47–112; and an earlier partial German translation by Heinrich Suter, "Über die Projektion der Sternbilder und der Länder von al-Bîrûnî," in *Beiträge zur Geschichte der Mathematik bei den Griechen und Arabern*, ed. Josef Frank, Abhandlungen zur Geschichte der Naturwissenschaften und der Medizin, vol. 4 (Erlangen: Kommissionsverlag von Max Mencke, 1922), 79–93. See also Lutz Richter-Bernburg, "Al-Bīrūnī's *Maqāla fī tasṭīḥ al-ṣuwar wa-tabṭīkh al-kuwar*: A Translation of the Preface with Notes and Commentary," *Journal for the History of Arabic Science* 6 (1982): 113–22.

66. This count does not include his description of al-Ṣūfī's method of copying constellations from a globe, which will be discussed below.

67. This projection is not mentioned in *al-Āthār al-bāqīyah*. Marinus is certainly the correct interpretation of the name Fārabiyūs given in the Leiden manuscript; Berggren, "Al-Bīrūnī on Plane Maps," 50, 62, and 92 line 19 (note 65). It is certainly not to be interpreted as Hipparchus, as Suter did; Suter, "Über die Projektion der Sternbilder," 82 (note 65). For Marinus's projection, see O. A. W. Dilke and editors, "The Culmination of Greek Cartography in Ptolemy," in *The History of Cartography*, ed. J. B. Harley and David Woodward (Chicago: University of Chicago Press, 1987–), 1:177–200, esp. 178–80 and 185, and Neugebauer, *Ancient Mathematical Astronomy*, 2:879–80 (note 24).

68. Abū Ḥāmid al-Ṣaghānī al-Asṭurlābī (d. 379/989–90) was a famous geometer and astronomer in Baghdad and was also, judging by his name, an astrolabe maker; Sezgin, *Geschichte des arabischen Schrifttums*, 6:217–18 (note 35), and Berggren, "Al-Bīrūnī on Plane Maps," 69 (note 65). Although in *al-Āthār al-bāqīyah* al-Bīrūnī cites al-Ṣaghānī as the authority on this topic, he fails to mention him in his later monograph on projections (*Kitāb fī tasṭīḥ*). A treatise by al-Bīrūnī on the ideas of al-Ṣaghānī on the "complete projection" (*Jawāmiʿ maʿānī kitāb Abī Ḥāmid al-Ṣaghānī fī al-tasṭīḥ al-tāmm*) is preserved in Leiden, Universiteitsbibliotheek, MS. Or. 123, fols. 2b–13b, and deserves attention and study by historians.

69. Recently edited, translated, and studied from three manuscripts at Oxford by Ahmad Dallal, "Bīrūnī's *Book of Pearls concerning the Projection of Spheres*," *Zeitschrift für Geschichte der Arabisch-Islamischen Wissenschaften* 4 (1987–88): 81–138. In some cases where the center of projection onto the equatorial plane was not at one of the poles, certain circles on the sphere would map as an ellipse, a parabola, or a hyperbola.

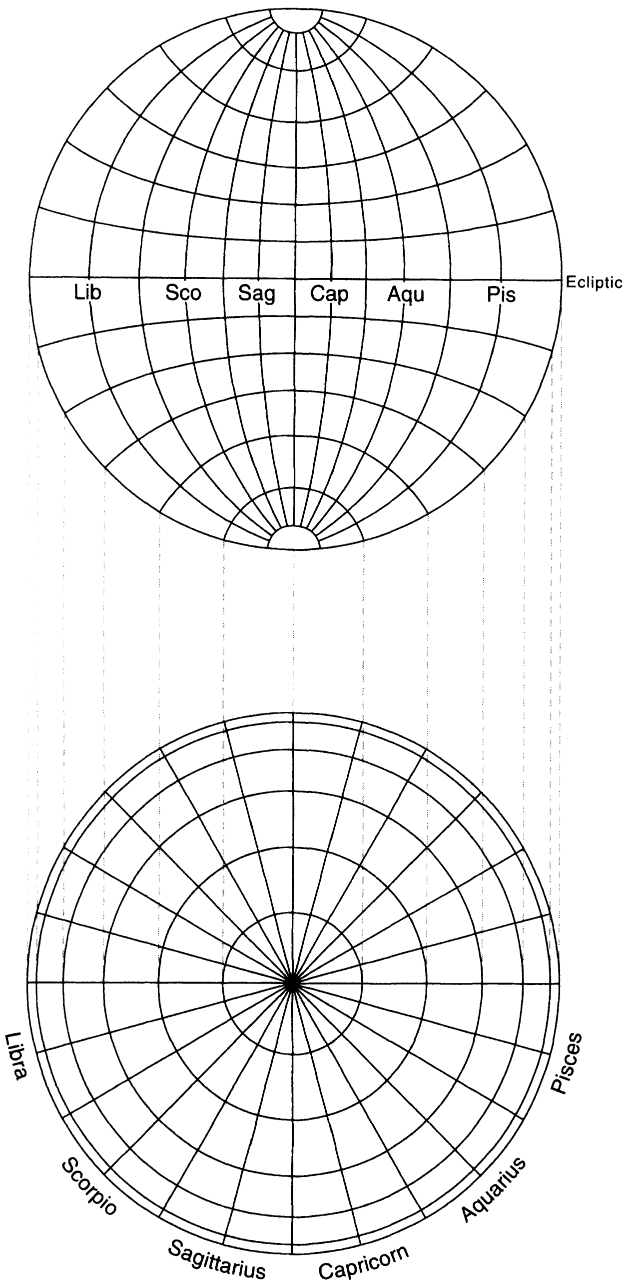


FIG. 2.18. RECONSTRUCTION OF AL-BĪRŪNĪ'S "CYLINDRICAL" PROJECTION. This corresponds to what today is called an orthographic projection.

refers to its description by the ninth-century astronomer al-Farghānī.[70] Al-Bīrūnī also stated in *al-Āthār al-bāqīyah* that he had explained this method in greater detail in his *Istīʿāb*.[71] The disadvantage of this method, al-Bīrūnī noted, is that the stars become increasingly compressed as they near the periphery of the map.[72]

The projection that al-Bīrūnī says was used in a "flattened" (*mubaṭṭaḥ*)[73] astrolabe, he admits to have also drawn from the writings of al-Farghānī. According to al-

70. Abū al-ʿAbbās Aḥmad ibn Muḥammad al-Farghānī is known to have been active between 218/833 and 247/861; Sezgin, *Geschichte des arabischen Schrifttums*, 6:149–51 (note 35). His treatise on the construction of astrolabes, *al-Kāmil fī ṣanʿat al-asṭurlāb al-shimālī wa-al-janūbī*, is extant in several manuscripts and in need of editing and analysis. See also N. D. Sergeyeva and L. M. Karpova, "Al-Farghānī's Proof of the Basic Theorem of Stereographic Projection," trans. Sheila Embleton, in *Jordanus de Nemore and the Mathematics of Astrolabes: De plana spera*, introduction, translation, and commentary by Ron B. Thomson (Toronto: Pontifical Institute of Mediaeval Studies, 1978), 210–17.

71. Extant in numerous manuscript copies. The pertinent section was not included in the partial translation and study, based on one manuscript in Leiden, by Eilhard Wiedemann and Josef Frank, "Allgemeine Betrachtungen von al-Bîrûnî in einem Werk über die Astrolabien," *Sitzungsberichte der Physikalisch-Medizinischen Sozietät in Erlangen* 52–53 (1920–21): 97–121; reprinted in Eilhard Wiedemann, *Aufsätze zur arabischen Wissenschaftsgeschichte*, 2 vols. (Hildesheim: Georg Olms, 1970), 2:516–40. *Kitāb istīʿāb al-wujūh al-mumkinah fī ṣanʿat al-asṭurlāb*, in which al-Bīrūnī also cited al-Farghānī in a different context, was apparently written before 390/1000, if the reference to it in *al-Āthār al-bāqīyah* is not a later interpolation; Richter-Bernburg, "Al-Bīrūnī's *Maqāla fī tasṭīḥ*," 115 n. 3 (note 65).

72. The plane of projection employed by al-Bīrūnī is not the one commonly used today in orthographic projection. Al-Bīrūnī advocated the plane of the ecliptic as the plane of projection, with the result that circles parallel to the ecliptic are mapped as concentric circles and those at right angles are mapped as radii. In modern orthographic projection, the plane of the solstices forms the plane of projection (or in a terrestrial map, a plane perpendicular to the equator) so that the equator and parallels are displaced as straight and parallel lines and the meridians as semiellipses. The latter form of orthographic projection was employed by Hugo Helt and published in the sixteenth century by Juan de Rojas as part of his commentary on the astrolabe. See Maddison, *Hugo Helt* (note 5), and Turner, *Astrolabes*, 161–64 (note 19).

73. Even though both the text of *al-Āthār al-bāqīyah* and the Leiden manuscript of the specialized monograph (*Kitāb fī tasṭīḥ*) clearly have the word *mubaṭṭaḥ* ("flattened"), some have interpreted this word as *mubaṭṭakh*, "melon shaped," a difference of one additional diacritical point; Suter, "Über die Projektion der Sternbilder," 84 n. 20 (note 65); Berggren, "Al-Bīrūnī on Plane Maps," 63 (note 65); Richter-Bernburg, "Al-Bīrūnī's *Maqāla fī tasṭīḥ*," 116 (note 65). There appears to be confusion between this particular type of projection and a special style of planispheric astrolabe in which the almucantars and other circles on the plates are projected as ellipses and hence called "melon shaped." For example, in al-Bīrūnī's *Kitāb al-tafhīm li-awāʾil ṣināʿat al-tanjīm* (Book of instruction on the principles of the art of astrology), he mentions a type of astrolabe called *mubaṭṭakh* (melon shaped) "because the almucantars and the ecliptic are flattened into an elliptical form like a melon" (author's translation); al-Bīrūnī's *al-Tafhīm*; see *The Book of Instruction in the Elements of the Art of Astrology*, ed. and trans. Robert Ramsay Wright (London: Luzac, 1934), 198 (sect. 328); see also Wiedemann and Frank, "Allgemeine Betrachtungen von al-Bîrûnî," 103–13, reprint 522–32 (note 71).

In the monograph on projections (*Kitāb fī tasṭīḥ*), al-Bīrūnī stated that he believed the "flattened" projection was another type of conical projection (*tasṭīḥ makhrūṭī*) like the one commonly used on astrolabes (i.e., polar case of stereographic projection), an idea he said he would discuss further in a later writing. In *Kitāb al-durar fī saṭḥ al-ukar*, which is devoted to astrolabic projections derived from various conical projections, al-Bīrūnī does not mention a melon-shaped one, though some of his projections could produce ellipses; Dallal, "Bīrūnī's *Book of Pearls*" (note 69). In the projection called *mubaṭṭaḥ* (flattened), described in great detail in *al-Āthār al-bāqīyah*, there are no elliptical curves or almucantars or other curves distinctive to astrolabic plates mentioned, only concentric circles and radii.

Bīrūnī, al-Farghānī had in turn attributed it to the ninth-century polymath Abū Yūsuf Yaʿqūb ibn Isḥāq al-Kindī or to Khālid ibn ʿAbd al-Malik al-Marwarrūdhī, astronomer to the caliph al-Maʾmūn in Baghdad in the early ninth century; different manuscript copies available to al-Bīrūnī gave different authorities.[74] Al-Bīrūnī also mentions a treatise on this type of astrolabe by Ḥabash al-Ḥāsib, the Baghdad astronomer and instrument maker of the late ninth century.[75]

From the lengthy discussion of this method given in *al-Āthār al-bāqīyah*, it seems that al-Bīrūnī had in mind a star chart rather than an instrument or astrolabe. In any case, he described what today is called a polar case of the azimuthal equidistant projection. The parallels to the ecliptic are shown as equidistant concentric circles, and the ecliptic latitude-measuring circles by radii at equal angular distances, with the north (or south) ecliptic pole at the center of the projection (fig. 2.19). Al-Bīrūnī directs that ninety concentric, evenly spaced circles be drawn, the center being one of the ecliptic poles. The circumference, which represents the ecliptic, is to be divided into four quadrants of ninety equal spaces each, and then radii are to be drawn from the center to each peripheral graduation. After selecting one point on the periphery as the beginning of the house of Aries, the coordinates taken from any star catalog (and augmented to compensate for the precession of the equinoxes) are to be plotted on the projection, measuring their celestial longitude along the periphery and their celestial latitude along the appropriate radius. All the stars in that given hemisphere are to be indicated in yellow or white paint, in different sizes corresponding to the six classes of magnitude. The circles are then to be painted in blue and the constellation outlines drawn around the stars. Al-Bīrūnī's major objection to this method is that the zodiacal constellations are only partially represented because only one hemisphere at a time can be shown. He explains that if you incorporate within the design an area past the ecliptic, as is done on the conventional astrolabic projections, the distortion becomes too great. Furthermore, he objects that the relative positions of the stars toward the periphery of this projection differ greatly from the relative positions of the stars as seen in the heavens.

The next method, al-Bīrūnī felt, was free of the inconveniences posed by the previous one. It is known today as globular projection, and al-Bīrūnī gave both a graphic description and a geometrical explanation of its construction. Since only one hemisphere at a time could be mapped (a limitation he found objectionable in the previous model but allowable here, since it is mapped pole to pole), for completeness he recommended making four maps, two showing hemispheres equinox to equinox and two with the equinoxes at the center of the map. To make one of the first type, he directed the mapmaker to draw a circle the desired size of the map. The horizontal diameter is designated the ecliptic, and the vertical diameter at right angles is labeled the solstitial colure. By arbitrarily dividing the solstitial colure into 180 equal parts and the periphery into equal parts, 90 to each quadrant, longitude-measuring circles parallel to the ecliptic could be determined by passing arcs of circles through each degree boundary mark of the solstitial colure and the corresponding division marks of the periphery. Similarly, by marking off the ecliptic into 180 equal parts and passing through these divisions arcs of circles that also intersect the two ecliptic poles, the ecliptic latitude-measuring circles are laid out (fig. 2.20).

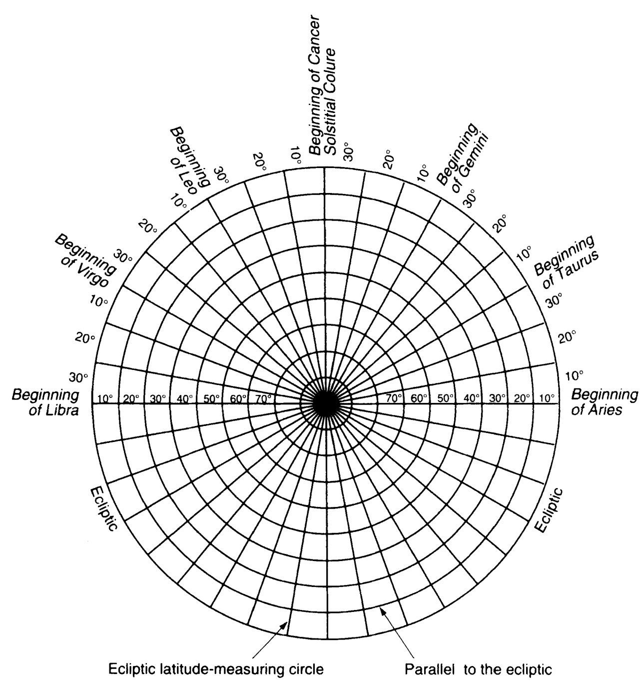


FIG. 2.19. RECONSTRUCTION OF AL-BĪRŪNĪ'S PROJECTION FOR A "FLATTENED" ASTROLABE. According to his specifications there would be ninety equally spaced concentric circles, one for each degree, representing the parallels to the ecliptic and the ecliptic at the periphery of the map. Similarly, there should be equally spaced radii to represent every degree in each quadrant. The result in modern terms is an azimuthal equidistant polar projection.

74. The attribution of this method through al-Farghānī to al-Kindī or to al-Marwarrūdhī is not mentioned in *al-Āthār al-bāqīyah*. In the *Kitāb istīʿāb al-wujūh al-mumkinah fī ṣanʿat al-asṭurlāb* (Comprehensive study of all possible ways of making an astrolabe), al-Bīrūnī gave al-Kindī as the source used by al-Farghānī. Apparently between the composition of *Istīʿāb* and his monograph on projections (*Kitāb fī tasṭīḥ*), al-Bīrūnī saw other copies of al-Farghānī's treatise, some of which gave al-Marwarrūdhī rather than al-Kindī as the originator. These citations are our only source of information that these two astronomers wrote on the subject; Richter-Bernburg, "Al-Bīrūnī's *Maqāla fī tasṭīḥ*," 120 (note 65).

75. Following the reading of Richter-Bernburg, who emends that of Berggren; Richter-Bernburg, "Al-Bīrūnī's *Maqāla fī tasṭīḥ*" (note 65). On Ḥabash al-Ḥāsib, see above, note 54.

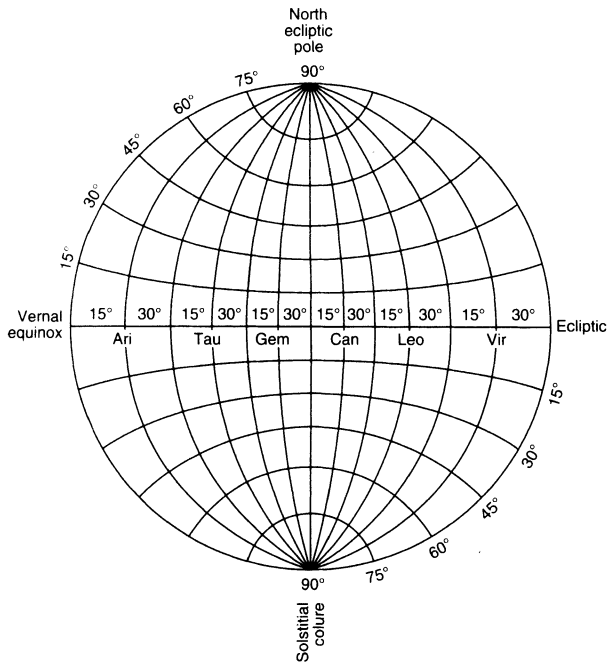


FIG. 2.20. RECONSTRUCTION OF AL-BĪRŪNĪ'S PREFERRED METHOD FOR PRODUCING A STAR MAP. The ecliptic is divided into equal parts (180 according to his specifications) by the ecliptic latitude-measuring circles, which are arcs of circles also passing through both ecliptic poles. The solstitial colure is also to be divided into 180 equal parts by arcs of circles that intersect the periphery and divide it into equal parts. The result in modern terms is a globular projection.

Al-Bīrūnī offers no criticism to the projection by this last method and in fact devotes more time to it than to any other technique, recommending it also for a map of the earth. He presented detailed directions for using it as a grid by which one could transfer the coordinates of each star onto this map by counting the star's longitude along the ecliptic, allotting one space for each degree, and its latitude north or south as the star catalog specified. The magnitudes of the stars are to be indicated by white dots of varying sizes. After all the stars are drawn on it, the background behind is to be painted blue, with the representations of the constellations painted in white over the lapis lazuli ground.

Al-Bīrūnī's sixth method for producing a star map employed dividers, a celestial globe, a graduated straightedge, and a graduated arc for measuring distances between stars on the globe. The distance between any two stars in a constellation is to be measured, then the equivalent number of graduations are to be counted on the graduated straightedge and these two stars placed on the map with that distance between them. The position of a third star was then to be determined by measuring its distance on the globe from each of the first two stars. The equivalent distances were then measured from each of the two stars on the chart, using dividers to find where the two lengths intersect. Another star could then be measured in relation to two of the three already determined, and so on. Though al-Bīrūnī offers no criticism, such mapping would quickly result in enormous angular distortions. It is essentially equivalent to a two-point equidistant projection,[76] which ceases to be useful for more than three stars. No further details are given by al-Bīrūnī, who mentions this method, as well as the final one, only in the specialized monograph on projections.

The final method al-Bīrūnī suggests is to coat each star on a celestial globe with something that will adhere to a surface when touched. The sphere, he says, is then to be rolled on a flat surface with a circular movement in all directions equally, always returning to the same point at which it started. This deceptively simple but thoroughly imprecise method is described only very briefly by al-Bīrūnī.[77]

Because he cites no previous authorities, as was his custom, and offers no critiques, the last three methods are presumably original with al-Bīrūnī. Of these last three, the final two are highly impractical, and in all three instances the descriptions betray no actual experience with practical mapmaking. For example, no one would reasonably put the ground color on after and around the stars, which number over five hundred in each hemisphere. Anyone who had tried that procedure once would thereafter paint the ground first, allowing the grid to show through only slightly. The other two techniques al-Bīrūnī invented are so briefly and vaguely described as to be useless, and it is highly doubtful he ever tried either of them. It is likely that these last three projections were simply ideas of al-Bīrūnī's quite in keeping with his creative and wide-ranging intellect.

Quite certainly the first of his original projections—that now called globular—is carefully delineated mathematically, and it was to have a vigorous and long history in later European cartography, as were the polar case of

76. John P. Snyder, *Map Projections—A Working Manual* (Washington, D.C.: United States Government Printing Office, 1987), 192; see also Berggren, "Al-Bīrūnī on Plane Maps," 67 (note 65).

77. Berggren says that the resulting map is an azimuthal equidistant projection with the pole replaced by an arbitrary point; Berggren, "Al-Bīrūnī on Plane Maps," 67 (note 65). In theory this may be true, but al-Bīrūnī's very brief, nontechnical, nonspecific, nonmathematical description is so vague and impractical that it scarcely merits being equated to a method of projection allowing sufficient precision that a mathematician can calculate a less than 2 percent difference between it and a globular projection with respect to the delineation of the parallels and meridians (not that al-Bīrūnī used meridians). Nor does al-Bīrūnī's description justify the belief that "Bīrūnī was cognizant of this fact when he conceived his . . . mapping"—that is, the fact that the globular map is a good approximation to the equatorial case of azimuthal equidistant projection; Edward S. Kennedy and Marie-Thérèse Debarnot, "Two Mappings Proposed by Bīrūnī," *Zeitschrift für Geschichte der Arabisch-Islamischen Wissenschaften* 1 (1984): 145–47, esp. 147.

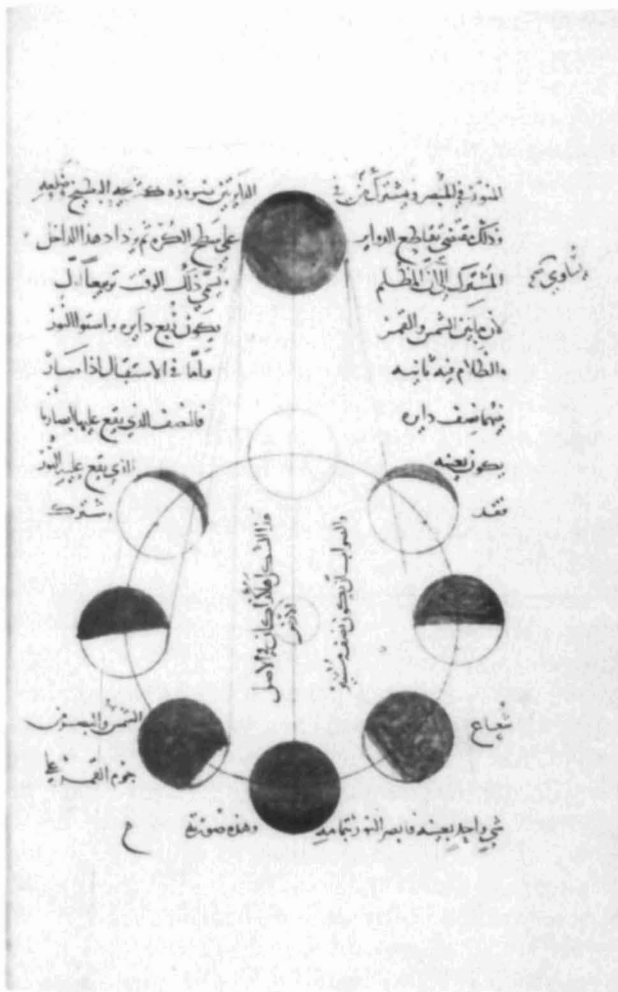

FIG. 2.21. WAXING AND WANING OF THE MOON AS ILLUSTRATED IN THE *KITĀB AL-TAFHĪM LI-AWĀ'IL ṢINĀʿAT AL-TANJĪM* (BOOK OF INSTRUCTION ON THE PRINCIPLES OF THE ART OF ASTROLOGY) BY AL-BĪRŪNĪ. This copy was produced before 839/1435-36.
Size of the folio: ca. 23 × 14.5 cm. By permission of the British Library, London (MS. Or. 8349, fol. 31v).

azimuthal equidistant projection and the orthographic projection, both of which he also carefully described though he did not originate them. How much immediate influence al-Bīrūnī's writings had on projections, however, is difficult to assess.[78] The version of orthographic projection described by al-Bīrūnī employed a plane of projection different from that subsequently used in Europe and produced a map visually quite unlike later orthographic projections. No celestial maps are known to have been produced in the medieval Islamic world by any of the methods described other than stereographic projection, which was continually employed in the construction of astrolabes.[79] These projections that al-Bīrūnī described for celestial maps are good examples of the inventive ideas generated by one of the most creative and profound of medieval savants. Yet his consideration of variant methods of projecting the sphere of stars onto a flat surface had no apparent direct effect upon subsequent celestial or terrestrial mapping in the Islamic world.

## Additional Planar Mapping

Arabic, Persian, and Turkish manuscripts abound with diagrams of the celestial spheres and planetary models. It is not my purpose to survey theories of planetary models, many of which showed considerable originality and mathematical sophistication. Such a survey belongs more to the realm of the history of mathematical astronomy than to the history of celestial mapping. Here I attempt only to introduce briefly the various types of celestial maps and diagrams and their applications.

Astronomical treatises are the most important source for diagrams representing the epicycles, deferents, and eccentrics employed in mathematically modeling the course of the planets. Though no artifacts survive, a number of Islamic treatises describe an equatorium—a mechanical computing device for determining the positions of the sun, moon, and planets by means of a geometrical model rather than through calculation. The earliest Islamic treatises on equatoria were composed by three astronomers in Andalusian Spain between A.D. 1015 and 1115. The most sophisticated was the equatorium described by Ghiyāth al-Dīn Jamshīd Masʿūd al-Kāshī, a famous astronomer and mathematician working in

78. An early fifteenth-century Latin manuscript (Rome, Biblioteca Apostolica Vaticana, MS. Palat. 1368, fols. 63v-64r) contains a planispheric map of the heavens drawn in azimuthal equidistant projection. The design is closely allied with that described by al-Bīrūnī, with the ecliptic forming the boundary of the circular map, ecliptic latitude-measuring circles at five-degree intervals indicated by radii, and the longitude-measuring circles at five-degree intervals. Only a few stars and seven constellations are drawn. For a reproduction of this map, along with a trapezoidal projection from the same manuscript, see Richard Uhden, "An Equidistant and a Trapezoidal Projection of the Early Fifteenth Century," *Imago Mundi* 2 (1937): 8 and one pl.

79. Orthographic projection was employed in the unusual Islamic astrolabe, now preserved in Leningrad, made anonymously in the late seventeenth or early eighteenth century for the Safavid ruler Shāh Ḥusayn. The plane of projection al-Bīrūnī employed is different, however, for al-Bīrūnī used the plane of the ecliptic whereas this astrolabe maker used the plane of the solstices. The similarity of this late Safavid astrolabe to that used by Hugo Helt and associated with the name Juan de Rojas is so striking that it seems certain this unique Islamic example was in fact based directly on a European model; see Maddison, *Hugo Helt*, 21 n. 32 (note 5). See also Roser Puig [Aguilar], "La proyeccion ortografica en el *Libro de la Açafeha* Alfonsi," in *De astronomia Alphonsi Regis*, ed. Mercè Comes, Roser Puig [Aguilar], and Julio Samsó, Proceedings of the Symposium on Alfonsine Astronomy held at Berkeley (August 1985), together with other papers on the same subject (Barcelona: Universidad de Barcelona, 1987), 125-38.

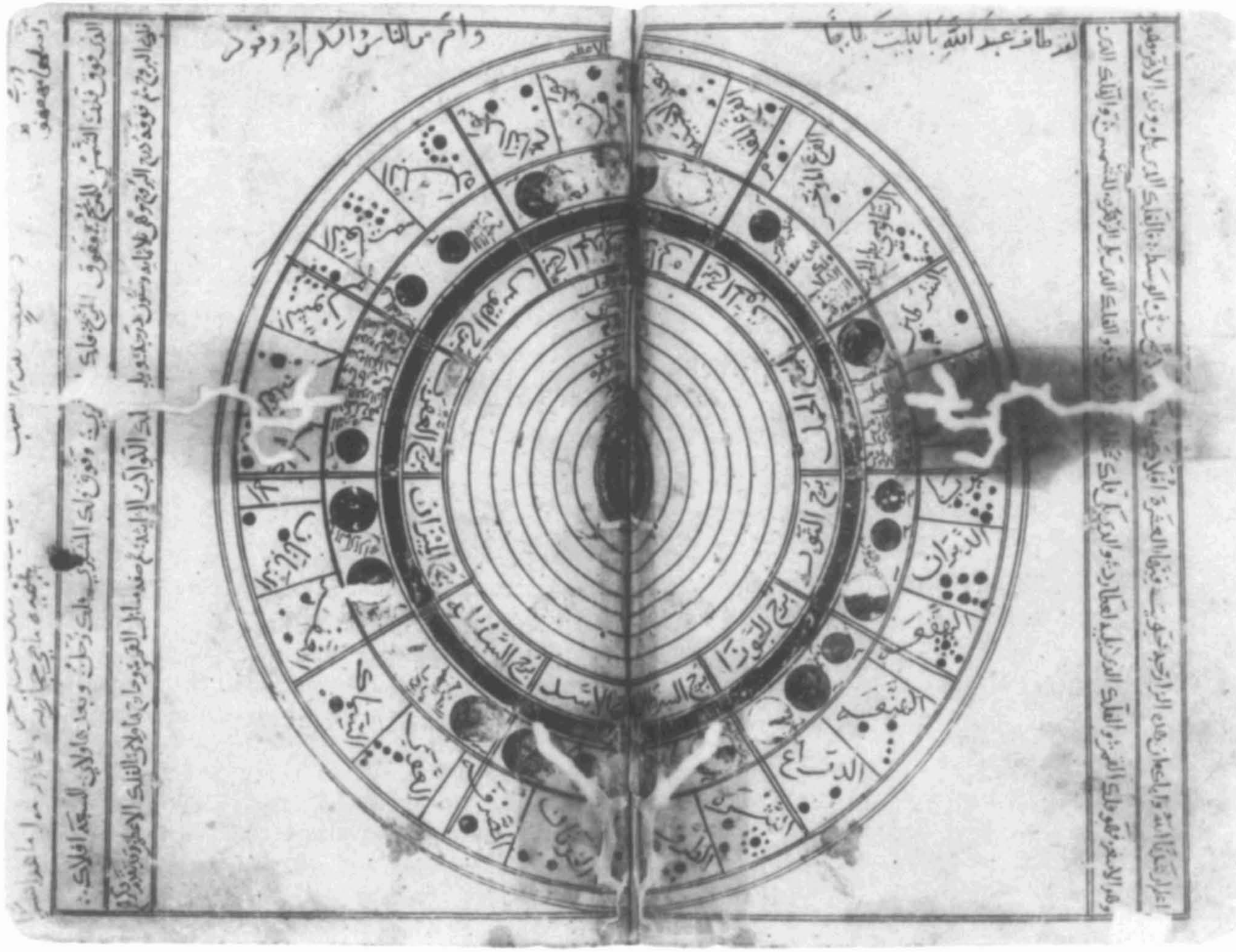

FIG. 2.22. DIAGRAM FROM AN AUTOGRAPH COPY OF *KITĀB AL-DURAR WA-AL-YAWĀQĪT FĪ ʿILM AL-RAṢD WA-AL-MAWĀQĪT* (BOOK OF PEARLS AND SAPPHIRES ON THE SCIENCE OF ASTRONOMY AND TIMEKEEPING) BY ABŪ AL-ʿABBĀS AḤMAD. Twelve concentric spheres are indicated, with the earth in the middle. Then the sphere of the moon, Mercury, Venus, the sun, Mars, Jupiter, Saturn, the names of the zodiacal houses, the degrees of the zodiac, the sphere of the fixed stars with the major stars indicated, and the broadest concentric band with the asterisms of the twenty-eight lunar mansions. The final thin outside band is labeled simply "the largest sphere" (*al-falak al-aʿẓam*).
Size of the image: ca. 23.5 × 31.5 cm. By permission of the Bodleian Library, Department of Oriental Books, Oxford (MS. Bodl. Or. 133, fols. 117b–118a).

Samarkand in the early fifteenth century.[80] One can also find in astronomical/astrological compendiums diagrams of solar and lunar eclipses and phases of the moon. An example from al-Bīrūnī's treatise on astrology is illustrated in figure 2.21.

More extensive and comprehensive diagrams of the entire heavens were, however, included in cosmological as well as astronomical/astrological writings. The example illustrated in figure 2.22 is a particularly elaborate mapping of the entire heavens from an astronomical treatise *Kitāb al-durar wa-al-yawāqīt fī ʿilm al-raṣd wa-al-mawāqīt* (Book of pearls and sapphires on the science of astronomy and timekeeping), written and illustrated in 734/1333–34 by Abū al-ʿAbbās Aḥmad ibn Abī ʿAbdallāh Muḥammad, originally of Egypt. It is unusual in that it attempts to show the major stars of the zodiacal constellations and the asterisms of the lunar mansions (to be discussed further below), in addition to the spheres of the planets, with the earth at the center.

80. Al-Kāshī, *Nuzhat al-ḥadāʾiq*; see *The Planetary Equatorium of Jamshīd Ghiyāth al-Dīn al-Kāshī (d. 1429)*, an edition of the anonymous Persian manuscript 75 [44b] in the Garrett Collection at Princeton University, translated with commentary by Edward S. Kennedy (Princeton: Princeton University Press, 1960); Edward S. Kennedy, "The Equatorium of Abū al-Ṣalt," *Physis* 12 (1970): 73–81.

FIG. 2.23. THE SPHERE OR ORBIT OF THE SUN, LOWER LEFT, AND THE PERSONIFICATION OF THE PLANET VENUS AS A LUTENIST, UPPER RIGHT. From a late fourteenth-century Iraqi copy of *Kitāb ʿajāʾib al-makhlūqāt wa-gharāʾib al-mawjūdāt* (Marvels of things created and miraculous aspects of things existing) by Zakariyāʾ ibn Muḥammad al-Qazwīnī.
Size of the original: 32.7 × 22.4 cm. Courtesy of the Freer Gallery of Art, Smithsonian Institution, Washington, D.C. (acc. no. 54.34v).

A number of illustrations of the orbits of the planets are included in the popular thirteenth-century cosmology *Kitāb ʿajāʾib al-makhlūqāt wa-gharāʾib al-mawjūdāt* (Marvels of things created and miraculous aspects of things existing), by Zakariyāʾ ibn Muḥammad al-Qazwīnī (d. 682/1283). Figure 2.23 is taken from a late fourteenth-century copy written in Iraq, in which the orbit of the sun is shown in the lower left of the page, with the personification of the planet Venus as a lutenist in the upper right. Such planetary personifications will be discussed further below.

Two-dimensional modeling can also be seen in clockface design. In addition to the astrolabic clockfaces with open star maps mentioned earlier, there were also clock designs that called for disks representing the movement of the zodiacal signs and the sun and moon. Ibn al-Razzāz al-Jazārī in his *Kitāb fī maʿrifat al-ḥiyal al-handasīyah*

FIG. 2.24. DESIGN FOR A CLOCKFACE FROM *KITĀB FĪ MAʿRIFAT AL-ḤIYAL AL-HANDASĪYAH* (BOOK OF KNOWLEDGE OF INGENIOUS MECHANICAL DEVICES). The book was written in 603/1206 by al-Jazārī and copied in Ramadan 715/December 1315 in Syria.
Size of the original: 31.5 × 21.9 cm. Courtesy of the Freer Gallery of Art, Smithsonian Institution, Washington, D.C. (acc. no. 30.74v).

(Book of knowledge of ingenious mechanical devices), written in 603/1206, described the face of his first clock as having a copper zodiac disk, only half of which would be visible at any one time. Inside the circular rim containing the zodiacal signs there would be colored disks representing the sun in yellow glass and the moon in white glass. Separate movable plates were required for the sun and moon to allow for their correct positioning for a given day. These plates were to be eccentric to the center point of the zodiac plate in order to show in a general way the relative positions of the sun, moon, and zodiac.[81] A particularly fine illustration of this design is

81. Donald R. Hill, *Arabic Water-Clocks* (Aleppo: University of Aleppo, Institute for the History of Arabic Science, 1981), 92–111 and pls. 1 and 3.

found in a manuscript of al-Jazārī's treatise copied in Syria in 715/1315 (fig. 2.24).

## Three-Dimensional Celestial Mapping
### Spherical Astrolabes

While the conventional astrolabe consisted of a pierced planispheric star map placed over a projection of the celestial coordinate system as it relates to the observer's locality, there was also a three-dimensional version whose construction did not require a knowledge of stereographic projection and allowed for adjustment to different geographic latitudes. It was a spherical astrolabe consisting of a metal sphere on which were inscribed the horizon, circles of equal altitude above and parallel to the horizon (almucantars), circles of equal azimuth (vertical altitude circles), and unequal hour lines. Over this sphere there was a rotating cap of open metalwork representing the ecliptic, the equator, and some fixed stars indicated by pointers. This movable cap, which was the equivalent of the rete of a planispheric astrolabe, also had a graduated vertical quadrant with a sliding gnomon for measuring solar altitudes. Stellar observations were made by using a sighting tube that projected diametrically through the globe and the slot within the graduated vertical quadrant. There is evidence that on some instruments there was a rotating alidade with two sights attached to the ecliptic pole of the "rete" or movable cap. The sphere also had holes bored at various positions to allow the openwork cap to be reset for use at different geographic latitudes.

It seems reasonable that the spherical astrolabe, which is simpler in concept, would have preceded the planispheric astrolabe in development. Historical evidence so far available, however, suggests that the spherical astrolabe may have been an early but distinctly Islamic development with no Greek antecedents.[82] Even so, though it was theoretically appealing in that it generated a number of treatises on its construction and use, it does not seem to have been a viable and practical instrument, since only two are known to exist today. Assuming that the vagaries of time and chance have not unduly skewed the evidence, the spherical astrolabe seems never to have been a very popular form of celestial modeling. The only preserved examples are one by an otherwise unknown maker, Mūsā, made in 885/1480–81 (fig. 2.25),[83] and an unsigned specimen, undated but possibly from the sixteenth century, made for use in Tunis.[84]

FIG. 2.25. SPHERICAL ASTROLABE MADE BY MŪSĀ IN 885/1480–81. On the rotating openwork cap, the broad band represents the ecliptic, with stars indicated by pointers. The smaller circular band concentric with the north celestial pole (indicated by the suspensory device) is parallel to the equator and allows equatorial measurements without the complication of constructing a true equatorial circle. The vertical quadrant, positioned along the solstitial colure, is graduated to permit measurements and has a sliding gnomon in the middle for measuring the altitude of the sun.
Diameter of the original: 8.3 cm. Museum of the History of Science, Oxford (acc. no. 62-25). By permission of the Bettman Archive, New York.

Arabic treatises on the spherical astrolabe (*asṭurlāb kurī*) were apparently written as early as the beginning of the ninth century, for there is extant today a treatise on the subject by Ḥabash al-Ḥāsib, who may still have been living in 300/912.[85] Not long thereafter the mathematician and translator Qusṭā ibn Lūqā (d. ca. 300/912–13), of Baalbek in Syria, may have written one, though the authenticity of this treatise has been questioned, and a treatise is also attributed to Abū al-ʿAbbās al-Nayrīzī,

82. Francis R. Maddison, "A 15th Century Islamic Spherical Astrolabe," *Physis* 4 (1962): 101–9, esp. 102 n. 6; and the introductory historical essay in Brieux and Maddison, *Répertoire* (note 36). For some theories as to the origin of the spherical astrolabe, see Turner, *Astrolabes*, 185–86 (note 19).

83. Oxford, University of Oxford, Museum of the History of Science, acc. no. 62-65; Maddison, "Spherical Astrolabe" (note 82).

84. Collection of Signor Ernesto Canobbio, Como. The rotating pierced cap forming the rete is missing; Ernesto Canobbio, "An Important Fragment of a West Islamic Spherical Astrolabe," *Annali dell'Istituto e Museo di Storia della Scienza di Firenze*, 1, fasc. 1 (1976): 37–41.

85. Three copies of Ḥabash al-Ḥāsib's treatise *al-ʿAmal bi-al-asṭurlāb al-kurī wa-ʿajāʾibuhu* are preserved today, two in Istanbul and one in Tehran; see Sezgin, *Geschichte des arabischen Schrifttums*, 6:175 (note 35).

who died about 310/922–23. Quite certainly al-Bīrūnī wrote on the subject, and one of our most important sources of information on the spherical astrolabe as well as other instruments is the astronomical compendium written about 680/1281–82 by Abū ʿAlī al-Marrākushī in Cairo.[86]

In the thirteenth century a Castilian treatise on the spherical astrolabe was included in the *Libros del saber de astronomía* prepared for Alfonso el Sabio. An Arabic treatise on the subject was apparently not easily available in thirteenth-century Spain, for Isaac ibn Sid (Isḥāq ibn Sīd) was commissioned to write a new treatise for the Alfonsine collection.[87]

There is even less evidence of an interest in the design or production of spherical astrolabes in the eastern parts of the Islamic world than there is for the western regions. It is, however, recorded that a certain Abū Isḥāq al-Ṣābī constructed one for Qābūs ibn Vushmgīr, a ruler in Gurgan in northern Persia from 366/977 to 371/981 and 388/998 to 403/1012–13 and onetime patron of al-Bīrūnī, to whom al-Bīrūnī dedicated his *al-Athār al-bāqīyah*.[88] No examples made in Persia or India are known to be preserved, though the spherical astrolabe by Mūsā (fig. 2.25) is stylistically consistent with instruments produced in the fifteenth century in Persia as well as those made in the Syro-Egyptian region.[89]

Though the spherical astrolabe formed an excellent working model of the heavens and an analog computing device for solving basic timekeeping and astrological problems, it proved not very popular, perhaps because it was less convenient than the easily transportable planispheric astrolabe and because its construction presented more difficult problems to the metalworker.

## CELESTIAL GLOBES

In contrast to the spherical astrolabe, which appears to have been rarely manufactured, the three-dimensional model of the skies that was commonly made in all parts of the Islamic world was the celestial globe. Given the difficulty of producing spherical astrolabes, it is interesting to observe the continuous production of celestial globes in both the eastern and western regions of Islam.

The celestial globe has the longest and most ancient history of any of the forms of celestial mapping. The idea of constructing a physical model to represent the arrangement and movement of the stars appears to have first arisen in Greek antiquity, and if the traditions are reliable it can be traced to the sixth century B.C., when Thales of Miletus first constructed a celestial globe.[90] The stars were commonly perceived—as indeed they still are by the average person looking up at the night sky—as though attached to the inside of a hollow sphere enclosing and rotating about the earth. Consequently, the earliest attempts to represent celestial phenomena in a model were by means of a celestial globe. The earth, which was known from early classical antiquity to be spherical, was imagined at the center of the globe, while the stars were placed on its surface, so that the resulting model presented the stars as seen by an observer outside the sphere of fixed stars. Thus the relative positions of the stars on a celestial globe are the reverse, east to west (or right to left), of their appearance when viewed from the surface of the earth.

The early Greco-Roman celestial globes had circles of constant visibility and constant invisibility on them. These indicated the areas of the sky in which, at a given geographic latitude, certain constellations never passed beneath the horizon or never rose to a position of visibility at that locality. The position of such circles on a globe would differ depending on the geographic latitude for which the globe had been designed. By the time of Ptolemy in the second century A.D. these always visible and always invisible circles were no longer required on celestial globes. Instead, a horizon ring around the globe showed the always visible and always invisible areas of the firmament for any latitude desired. Consequently, on

86. An inadequate summary of the section on instruments in al-Marrākushī's treatise, *Kitāb jāmiʿ al-mabādiʾ wa-al-ghāyāt*, is given by Louis Amélie Sédillot, "Mémoire sur les instruments astronomiques des arabes," *Mémoires Présentés par Divers Savants a l'Académie Royale des Inscriptions et Belles-Lettres*, 1st ser., 1 (1844): 1–229 and pls. 1–36; facsimile reprint Frankfurt: Institut für Geschichte der Arabisch-Islamischen Wissenschaften, 1986. See also David A. King, "al-Marrākushī," in *Encyclopaedia of Islam*, new ed., 6:598.

87. For the Castilian translations of Isaac ibn Sid, see John D. North, "The Alfonsine Books and Some Astrological Techniques," in *De astronomia Alphonsi Regis*, ed. Mercè Comes, Roser Puig [Aguilar], and Julio Samsó, Proceedings of the Symposium on Alfonsine Astronomy held at Berkeley (August 1985), together with other papers on the same subject (Barcelona: Universidad de Barcelona, 1987), 43–50. For the Castilian texts as well as the treatises by al-Nayrīzī, al-Bīrūnī, and Qusṭā ibn Lūqā, see *Libros del saber de astronomía*, 2:113–222 (note 46), and Hugo Seemann and Theodor Mittelberger, *Das kugelförmige Astrolab nach den Mitteilungen von Alfons X. von Kastilien und den vorhandenen arabischen Quellen*, Abhandlungen zur Geschichte der Naturwissenschaften und der Medizin, vol. 8 (Erlangen: Kommissionsverlag von Max Mencke, 1925). A treatise by al-Rūdānī (d. 1094/1683) has been the object of study by Charles Pellat, "L'astrolabe sphérique d'al-Rūdānī," *Bulletin d'Etudes Orientales* 26 (1973): 7–82 and 28 (1975): 83–165, and Louis Janin, "Un texte d'ar-Rudani sur l'astrolabe sphérique," *Annali dell'Istituto e Museo di Storia della Scienza di Firenze*, 3, fasc. 2 (1978): 71–75. For the few European manuscripts on the subject, see Maddison, "Spherical Astrolabe," 103 n. 13 (note 82), and Murdoch, *Album of Science*, 268 (no. 239) (note 7).

88. Sayılı, *Observatory in Islam*, 158 (note 44).

89. Maddison, "Spherical Astrolabe," 106 (note 82).

90. For the history of celestial globes in classical antiquity, see the relevant chapters in *The History of Cartography*, ed. J. B. Harley and David Woodward (Chicago: University of Chicago Press, 1987-), specifically 1:140–47, 167–70, and 181–82, and Savage-Smith, *Islamicate Celestial Globes*, 3–15 (note 5).

all Islamic globes there are no such always visible and always invisible circles. They were replaced by polar circles having the celestial poles as centers and passing through the ecliptic poles (and on some globes ecliptic polar circles passed through the celestial poles). From our fragmentary evidence, it seems that by the second century A.D. most globes would have indicated on their surface the celestial equator, the northern and southern tropic circles, the ecliptic (or wide band for the zodiac), and a selection of stars with constellation outlines. The globe was then attached at the equatorial poles to a meridian ring and set into a horizon ring.

The *Almagest* of Ptolemy is important to the history of Islamic celestial globes for two reasons. First, his star catalog presented in the *Almagest*[91] became in the Arabic-speaking world the basis for all the star catalogs used by instrument makers in designing their instruments. In this catalog each of 1,025 stars was assigned a magnitude of one to six and described in relation to one of the forty-eight constellation outlines, as well as given a specific position in terms of the ecliptic coordinates of longitude and latitude.

Second, also in the *Almagest*, Ptolemy gave explicit instructions for the design of a celestial globe.[92] This globe, however, was not the usual type but was designed so as not to become outdated by the precession of the equinoxes. The customary globe in his day apparently had both the ecliptic and the equator shown directly upon the surface of the sphere along with the stars, which would mean that the passage of time would invalidate the instrument after three-quarters of a century. Ptolemy's design for a celestial globe was unique in that he avoided this problem by placing on the sphere only the stars and the ecliptic, not the equator or its parallel circles. In addition, an arrangement of rings could be adjusted to any time period as well as any geographic latitude. Ptolemy's design is not, however, known to have been followed in the Islamic world, even though the *Almagest* circulated widely and was for many centuries the fundamental astronomical treatise in Islam, as it was in the West.

Though the channels of information regarding celestial globes that extended to the Near East are unknown (other than Ptolemy's *Almagest*, which in this respect was not followed), there clearly were several sources available, probably including some Byzantine globes. It is evident from both written documents and preserved artifacts that by the ninth century celestial globes were being made in the Arabic-speaking world. They were mounted in two graduated rings, a meridian ring and horizon ring, which made them adjustable to different geographic latitudes. On these globes, along with the stars, both the ecliptic and the equator were shown on the sphere itself, nearly always by graduated bands. On all extant Islamic globes that have the constellation outlines on them, the human figures face outward toward the person using the globe rather than in toward the globe with their backs to the observer, as was apparently, from our very fragmentary evidence, common in the Greco-Roman and Byzantine worlds. The same basic orientation of the stars was maintained, however, so that if an Islamic globe is viewed from above the north pole, the sequence of the zodiacal constellations will be counterclockwise.[93]

On every Islamic globe preserved today there is a set of six great circles at right angles to the ecliptic, that is, six ecliptic latitude-measuring circles. When and where this convention first became customary is unknown. The circles no doubt reflect the common use of ecliptic-based coordinates for measuring star positions that had been inherited with Ptolemaic astronomy. The solstitial colure was always shown (since it is also one of the six ecliptic latitude-measuring circles) and sometimes the equinoctial colure, but a full set of six meridians (at right angles to the equator) was not usually present on Islamic celestial globes, the exceptions being nineteenth-century Indian products, just as apparently they were not on Greco-Roman globes. On Islamic globes the Tropic of Cancer and the Tropic of Capricorn were frequently shown as well as the north and south equatorial polar circles. Finally, particularly on some later globes, the ecliptic equivalents of the tropic and polar circles were indicated, apparently in an attempt to complete the symmetry. See figure 2.26 for the basic design of an Islamic globe, to which is attached a rotatable meridian ring.[94] To function, this globe and meridian ring would then be placed in a horizon ring, such as that shown in figure 2.28.

91. *Almagest*, 7.5 to 8.2; Ptolemy, *Opera quae exstant omnia*, 3 vols., ed. J. L. Heiberg (Leipzig: B. G. Teubner, 1898–1907), vol. 1, *Syntaxis mathematica* (1903), pt. 2, 38–169; *Ptolemy's "Almagest,"* trans. and annotated G. J. Toomer (London: Duckworth, 1984), 14–17, 339–99; Gerd Grasshoff, *The History of Ptolemy's Star Catalogue* (New York: Springer-Verlag, 1990); M. Shevchenko, "An Analysis of Errors in the Star Catalogues of Ptolemy and Ulugh Beg," *Journal for the History of Astronomy* 21 (1990): 187–201; Savage-Smith, *Islamicate Celestial Globes*, 8 and 114–15 (note 5). For a revisionist interpretation of the star catalog of Ptolemy, see Robert R. Newton, *The Crime of Claudius Ptolemy* (Baltimore: Johns Hopkins University Press, 1977), 211–56.

92. For an interpretation of Ptolemy's celestial globe different from that given in Dilke and editors, "Culmination of Greek Cartography," 181–82 (note 67), see Savage-Smith, *Islamicate Celestial Globes*, 8–10 (note 5).

93. Among the preserved Islamic globes, three are known to have a clockwise sequence. One is cataloged and illustrated in Savage-Smith, *Islamicate Celestial Globes*, 242 (no. 46) and 51 (fig. 23) (note 5); the other two are as yet unpublished. In all three cases there are other odd features about the globes that encourage the conclusion that they are recent forgeries. The clockwise sequence is occasionally found on modern European celestial globes.

94. For further information on the design of globes and rings, see Savage-Smith, *Islamicate Celestial Globes*, 61–95 (note 5).

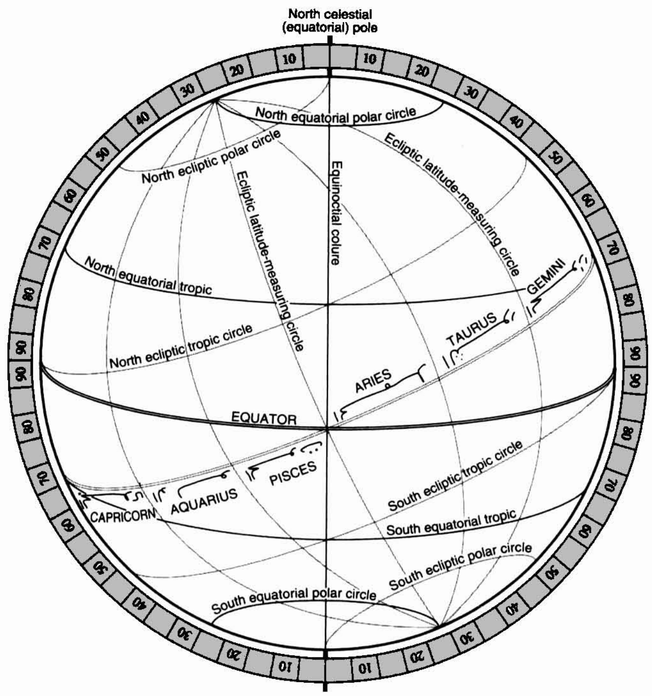


FIG. 2.26. BASIC DESIGN OF EXTANT ISLAMIC CELESTIAL GLOBES, WITH ATTACHED ROTATABLE MERIDIAN RING.

A celestial globe lacks the observational capacity of an astrolabe, for it possesses no sighting device. If, however, a carefully constructed celestial globe with stars is supplemented by a quadrant and a gnomon, as well as calendrical tables of the sort inscribed on the backs of astrolabes, then all the astronomical and astrological data accessible with an astrolabe can also be obtained by means of a celestial globe. Like the astrolabe, the celestial globe is not a direct reading instrument, for the astronomer, after making the initial observation, must manipulate and calculate the desired information. The celestial globe has the advantage of simplicity of design and the ability to function at any geographic location. The planispheric astrolabe, however, is far more portable and requires fewer supplementary instruments. It is clear from the historical evidence that celestial globes were an important part of the equipment of an astronomical observatory and were considered of practical value by astronomers. The maker of one globe informs us that his well-constructed celestial globe with a full set of constellation figures was made "in a manner useful for the knowledge of all the requirements of astrolabemakers, as an *aide-mémoire* to their craft."[95] It is questionable, however, how many of the extant globes were of more than didactic or artistic value to their owners.

Early in the ninth century the Baghdad astrolabe maker and astronomer ʿAlī ibn ʿĪsā al-Asṭurlābī is said to have made a large celestial globe.[96] As with astrolabes, however, the most important Islamic center of globe making was the city of Harran. In the latter part of the ninth century the influential astronomer of Harran, Abū ʿAbdallāh Muḥammad ibn Jābir al-Battānī al-Ṣābiʾ, known in the Latin world as Albategni or Albatenius, wrote a comprehensive astronomical treatise in which he described a celestial globe that was suspended in five rings.[97] This ingenious globe had stars carefully placed by coordinates on the sphere, with the ecliptic, equator, and ecliptic latitude-measuring circles as well. The sphere was attached at the equatorial poles to a graduated meridian ring, which was in turn nested within a second meridian ring, so that the inner ring could be moved while the outer remained stationary. There were also a horizon ring, a zenith ring, and an outside graduated ring that carried a movable gnomon for measuring solar altitudes. The entire assembly was suspended rather than set on a base. No globes exactly of this nature are known to be preserved, although some of the features are to be found on one made between A.D. 1278 and 1310 by Muḥammad ibn Muʾayyad al-ʿUrḍī, the son of the famous astronomer Muʾayyad al-Dīn al-ʿUrḍī al-Dimishqī, who made instruments for the observatory at Maragheh, about fifty miles south of Tabriz in northwestern Persia.[98]

From the ninth century at least two treatises on the celestial globe have been preserved. The Baghdad astronomer Ḥabash al-Ḥāsib wrote a treatise *Kitāb fī maʿrifat al-kurah* (Book of the knowledge of the globe) which is extant in three manuscripts.[99] Toward the end of the ninth century Qusṭā ibn Lūqā, also working in Baghdad, composed *Kitāb fī al-ʿamal bi-al-kurah al-falakīyah* (Book on the use of the celestial globe), which has also survived in several manuscripts.[100] This latter treatise was

95. Part of the signature inscription of a globe made by ʿAlī Kashmīrī ibn Lūqmān in 998/1589–90; London, private collection; see Savage-Smith, *Islamicate Celestial Globes*, 223–24 (no. 10) and 74–79 (note 5), for further information on the use of globes.

96. Abū al-Ḥusayn ʿAbd al-Raḥmān ibn ʿUmar al-Ṣūfī, *Kitāb ṣuwar al-kawākib al-thābitah* (Book of the constellations of the fixed stars); see *Ṣuwaru'l-kawākib or (Uranometry) (Description of the 48 Constellations): Arabic Text, with the ʾUrjūza of Ibn u'ṣ-Ṣūfī Edited from the Oldest Extant Mss. and Based on the Ulugh Beg Royal Codex (Bibliothèque Nationale, Paris, Arabe 5036)* (Hyderabad: Dāiratu'l-maʿārif-il-ʿOsmania [Osmania Oriental Publications Bureau], 1954), Arabic text, p. 5. The name al-Ḥarrānī has been added to ʿAlī ibn ʿĪsā by the editors; he in fact worked in Baghdad and Damascus and does not seem to have been originally from Harran.

97. See Savage-Smith, *Islamicate Celestial Globes*, 18–21 and 88–89 (note 5), for a reconstruction of al-Battānī's globe.

98. Dresden, Staatlicher Mathematisch-Physikalischer Salon; Savage-Smith, *Islamicate Celestial Globes*, 220 (no. 5) (note 5).

99. Recently edited and translated by Richard P. Lorch and Paul Kunitzsch, "Ḥabash al-Ḥāsib's Book on the Sphere and Its Use," *Zeitschrift für Geschichte der Arabisch-Islamischen Wissenschaften* 2 (1985): 68–98.

100. There is a partial translation from one manuscript by W. H. Worrell, "Qusta ibn Luqa on the Use of the Celestial Globe," Isis 35 (1944): 285–93. Lorch and Kunitzsch, "Ḥabash al-Ḥāsib's Book" (note 99), have studied two of the preserved manuscripts.

FIG. 2.27. THE EARLIEST PRESERVED ISLAMIC CELESTIAL GLOBE. Made in Spain, in Valencia, in 473/1080 by Ibrāhīm ibn Saʿīd al-Sahlī al-Wazzān in collaboration with his son Muḥammad.
Diameter of the original: 20.9 cm. By permission of the Istituto e Museo di Storia della Scienza, Florence (inv. no. 2712).

translated into Latin by Stephanus Arnaldus as *De sphaera solida*, into Hebrew by Prophatius Judaeus in the thirteenth century, and into Italian in 1341 by "Maestro Bernardo Arabico ouero Saracino."[101] A Castilian translation was completed in A.D. 1259 under the collaboration of Jehuda ben Moses Cohen and Maestre Johan Daspa and forms part of the *Libros del saber de astronomía* compiled for Alfonso el Sabio.[102]

Thereafter a number of treatises on the celestial globe were composed, including one in the tenth century by Abū al-Ḥusayn ʿAbd al-Raḥmān ibn ʿUmar al-Ṣūfī (d. 372/983),[103] whose treatise on constellations was to prove fundamental to constellation iconography in the Islamic world. From the early twelfth century we have a particularly interesting treatise composed by ʿAbd al-Raḥmān al-Khāzinī, who later dedicated some other astronomical writings to the Seljuk ruler of eastern Persia. This treatise describes a celestial globe that, instead of being placed in the usual set of rings, is half sunk in a box and propelled so as to rotate once a day by a mechanism of pulleys driven by a weight resting on top of a reservoir of sinking sand.[104]

There are known to be preserved today 175 Islamic celestial globes, none predating the eleventh century.[105] The earliest bears a date equivalent to A.D. 1080 and was made in Spain, in Valencia (fig. 2.27).[106] It was made by a leading astrolabe maker Ibrāhīm ibn Saʿīd al-Sahlī al-Wazzān with the collaboration of his son Muḥammad. The most recent dated globe was made in Ottoman Turkey in 1882,[107] and a number of nineteenth-century workshops were active in northwestern India and in Iran.

The language in which a globe is inscribed is not as distinguishing a feature of Islamic celestial globes as might at first be thought, for there are Islamic globes extant today that are labeled and signed in Arabic, Persian, Turkish, Sanskrit, and even entirely in English. Yet even the globe labeled entirely in English is completely within the tradition of Islamic celestial globes. It was made for an English patron, probably in the Indian workshop of Lālah Balhūmal Lāhūrī, who made globes and astrolabes in Lahore in the 1840s.[108] It has the classical

101. Savage-Smith, *Islamicate Celestial Globes*, 21–22 (note 5).

102. *Libros del saber de astronomía*, 1:163–208 (note 46); Julio Samsó, "El tratado Alfonsí sobre la esfera," *Dynamis: Acta Hispanica ad Medicinae Scientiarumque Historiam Illustrandam* 2 (1982): 57–73, interprets the construction differently than does Savage-Smith, *Islamicate Celestial Globes*, 22, 74, and 81–82 (note 5).

103. Recently summarized and discussed by Edward S. Kennedy, "Al-Ṣūfī on the Celestial Globe," *Zeitschrift für Geschichte der Arabisch-Islamischen Wissenschaften* 5 (1989): 48–93.

104. Recently edited and translated by Richard P. Lorch, "Al-Khāzinī's 'Sphere That Rotates by Itself,'" *Journal for the History of Arabic Science* 4 (1980): 287–329.

105. This total includes forty-three that were not known to exist when the history and catalog was prepared by Savage-Smith, *Islamicate Celestial Globes* (note 5). For some recently discovered globes, see Emilie Savage-Smith, "The Classification of Islamic Celestial Globes in the Light of Recent Evidence," *Der Globusfreund* 38/39 (1990): 23–35 and pls. 2–6, and the forthcoming catalog of Islamic scientific instruments in the Nasser D. Khalili Collection of Islamic Art by Francis R. Maddison and Emilie Savage-Smith.

106. Florence, Istituto e Museo di Storia della Scienza, inv. no. 2712. The date has been read as 1 Ṣafar 473/22 July 1080 and 1 Ṣafar 478/28 May 1085; see Savage-Smith, *Islamicate Celestial Globes*, 24 and 217 (no. 1) (note 5).

107. Istanbul, private collection; Savage-Smith, *Islamicate Celestial Globes*, 255–56 (no. 75) (note 5).

108. Nasser D. Khalili Collection of Islamic Art, inv. no. SCI 44. This unsigned and undated globe can with certainty be attributed to the workshop of Balhūmal, who is known to have made an astrolabe for Sir Henry Elliott, K.C.B., chief secretary to his lordship the governor-general in Kapurthala, one of the states of the Punjab. For an illustration of this globe, see Savage-Smith, "Classification of Islamic Celestial Globes," pl. 3 (note 105). For other celestial globes by Balhūmal, see Savage-Smith, *Islamicate Celestial Globes*, 52–55, 235–36 (no. 33), 275–76 (no. 127), and 304 n. 180 (note 5).

FIG. 2.28. ISLAMIC CELESTIAL GLOBE MADE IN 834/1430–31 BY MUḤAMMAD IBN JAʿFAR.
Diameter of the original: 10.5 cm. By permission of the Trustees of the British Museum, Department of Oriental Antiquities, London (inv. no. 26.3.23).

forty-eight constellations, drawn to reflect Mughal artistic conventions found on globes made two hundred years earlier in northwestern India. The star positions are adjusted for the first half of the nineteenth century, and six meridian circles have been added to the globe along with the ubiquitous ecliptic latitude-measuring circles. It can be seen from all the extant Islamic celestial globes that, except for some minor points of design and some considerable progress in construction techniques, the tradition of instrument design inherited from the Hellenistic and Byzantine world remained essentially unchanged through the end of the nineteenth century.

In terms of design, Islamic celestial globes fall into several distinct categories. The first category includes the largest and the most elaborate artifacts. They average about 168 millimeters in diameter, and they all show the forty-eight constellation outlines and approximately 1,022 stars, those found in the medieval star catalogs.[109] The earliest globe preserved today is of this design (fig. 2.27), and they continued to be made well into the nineteenth century. Other examples are illustrated in figures 2.31 and 2.37 below.[110]

The second style of design[111] is a globe that does not have constellation outlines. Only a selection of the most prominent stars, usually between twenty and sixty, are shown. The same basic great and lesser circles are to be found on these globes as on the more elaborate ones, and when well executed such globes can be fine precision pieces. They tend, in general, to be smaller than the previous category, with an average diameter of slightly over 100 millimeters, though papier-mâché examples are more than double that size. The earliest one dates from the middle of the twelfth century,[112] and this category includes the most recent dated celestial globe. The example illustrated in figure 2.28 was made in 834/1430–31 by an astrolabe and globe maker in Kirman in southeast Persia, Muḥammad ibn Jaʿfar ibn ʿUmar al-Asṭurlābī.[113] His father also made globes of a rather elaborate style with full constellations, done in the precise tradition of a specialist scientific instrument maker. The son produced, as far as is known, only two globes, both of this second type, showing just the major stars. His products tend not to be as accurately inscribed as those made by his father, having slight wobbles in the great circles and

109. This class of globe has been called, for lack of a better term, "Class A Globes" in the study by Savage-Smith, *Islamicate Celestial Globes*, 61–71, 217–47, 275–76, 278–83 (note 5).

110. One of the outstanding examples of this first category was made in 622/1225 for a nephew of the great Saladin in Egypt. This brass globe (Museo Nazionale, Naples) has the classic set of forty-eight constellations engraved and damascened with copper, with approximately 1,025 stars represented by six sizes of inlaid silver points corresponding to the various magnitudes. It also has a scale showing the sizes of silver points used for the first five magnitudes; Savage-Smith, *Islamicate Celestial Globes*, 25–26 and 218–19 (no. 3) (note 5). This globe is the fifth oldest celestial globe known to be extant today.

111. Termed "Class B Globes" in Savage-Smith, *Islamicate Celestial Globes*, 247–63, 276, and 278–83 (note 5).

112. Tehran, Mūzah-i Īrān-i Bāstān; dated 535/1140–41 by Badr ibn ʿAbdallāh Mawlā Badīʿ al-Zamān; Savage-Smith, *Islamicate Celestial Globes*, 247 (no. 59) (note 5).

113. London, British Museum, Department of Oriental Antiquities, inv. no. 26.3.23; Savage-Smith, *Islamicate Celestial Globes*, 32 and 249 (no. 62) (note 5).

some irregularity in the graduation. They are by no means, however, as technically inaccurate and nonfunctional as many of the extant globes whose makers must not have been specialists.

An interesting feature of Muḥammad ibn Jaʿfar's globe is the stationary meridian ring. On most globes the meridian ring is movable, that is, it is attached permanently to the globe and moves with it when the globe is rotated within the horizon ring to adjust for use at different geographic latitudes. In this case, however, the globe is reset within the stationary meridian ring by placing the pin at the end of the chain through the appropriate hole in the meridian ring and the celestial pole of the globe.

The third type of design is one in which the globe has neither constellation outlines nor any stars.[114] In general these globes are the smallest, having an average diameter of 85 millimeters. They have the standard great and lesser circles (equator, tropics, polar circles, ecliptic) and frequently the ecliptic equivalents of the tropic and polar circles, occasionally with additional lesser circles. All the circles are usually labeled, whereas they are seldom labeled on the previous two types. This particular design is not mentioned in any of the written treatises dealing with celestial globes. It appears, at this point at least, to be probably of Persian origin of the late seventeenth or early eighteenth century, though examples of the style were produced later in India as well. The only two dated artifacts are both from the nineteenth century; most examples are unfortunately unsigned and undated products.

The globe shown in figure 2.29 is unusual in two respects. It is more carefully graduated and executed than many examples of this particular design, it is larger than average, and it is made of papier-mâché and plaster over some kind of fiber core.[115] Globes other than metal are relatively rare among the preserved artifacts, primarily, one assumes, because wood and papier-mâché deteriorate easily. Indeed, the one illustrated is in bad condition. In theory, globes of this design, when accurately executed, could be used to determine much of the information (not requiring star positions) that could be found with the other types of globes. In practice, however, most globes of this simplified design were probably used only for didactic purposes, to demonstrate basic principles such as the equality of day and night for any latitude when the sun is at one of the equinoxes or the longest and shortest day for any given terrestrial latitude.

From other types of globes from that region and period, it is clear that globe makers in seventeenth-century Persia were experimenting with designs and products whose function was either decorative or didactic. A globe that defies easy categorization was made in 1012/1603–4 for Shāh ʿAbbās I, during whose reign the Safavid Empire was at its strongest and the artistic achievements of the court artisans and miniature painters were the most conspicuous. Unfortunately, its maker is unknown.[116] The globe has a few poorly positioned stars but no constellation outlines; instead it has the twelve zodiacal signs represented inside medallions. Here the zodiacal signs are not guides to the positions of stars but indicate instead an alternative tradition of displaying the zodiacal signs as emblematic motifs rather than constellation diagrams. The further use of zodiacal signs as emblematic motifs will be discussed below.

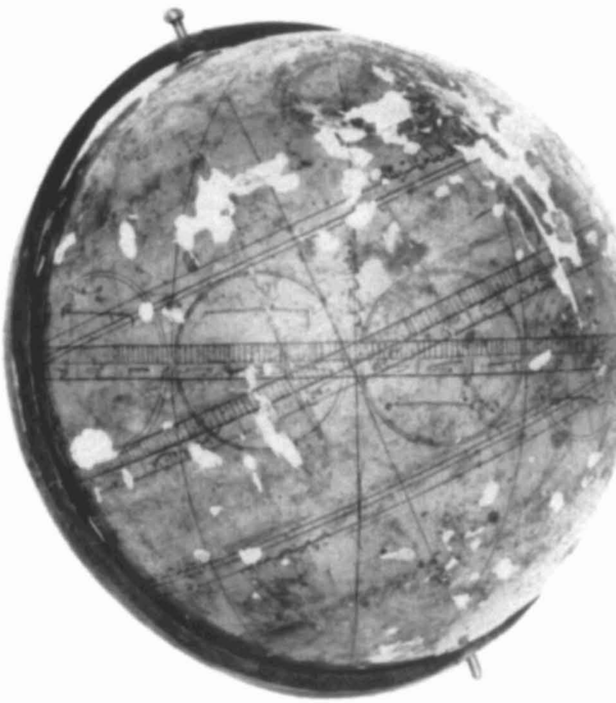

FIG. 2.29. ISLAMIC CELESTIAL GLOBE, UNSIGNED AND UNDATED. This globe, made of papier-mâché and plaster over a fiber core, is probably a seventeenth-century Persian product. Diameter of the original: 17.8 cm. Museum of the History of Science, Oxford (inv. no. 69-186). By permission of the Bettman Archive, New York.

Another globe made about the same time by an unknown artisan working probably in Yazd is illustrated in figure 2.30. In this case the product is a precise instrument for instructing astronomers in the methods of deter-

114. Called "Class C Globes" in Savage-Smith, *Islamicate Celestial Globes*, 56–57, 263–75, and 278–83 (note 5).

115. Oxford, University of Oxford, Museum of the History of Science, inv. no. 69-186, unsigned and undated; Savage-Smith, *Islamicate Celestial Globes*, 264 (no. 93) (note 5).

116. Chicago, Adler Planetarium and Astronomical Museum, inv. no. A 114; Savage-Smith, *Islamicate Celestial Globes*, 45–47 and 249–50 (no. 63) (note 5). There are also two similar unsigned and undated globes; Savage-Smith, *Islamicate Celestial Globes*, 259 (nos. 82 and 83) (note 5).

mining the coordinates of a star.[117] In addition to having a full set of circles parallel to the ecliptic at five-degree intervals, the globe has the unique feature of arcs drawn through a particular star (labeled *ʿayyūq*, which is α Aurigae, Capella in modern terminology), clearly for the didactic purpose of demonstrating the various coordinate systems. The semi-great circle representing the declination circle is marked by a dotted line, while the arc of the ecliptic latitude-measuring circle through the star on which the celestial latitude is measured is an engraved solid line. In addition, there are engraved and labeled on the surface of the globe a circle corresponding to the horizon, another for the meridian ring, and an arc representing the prime vertical (the circle passing through the zenith and intersecting the horizon circle at the east-west points). The arbitrary placing of the horizon and prime vertical on the surface of the sphere thus makes it obvious that this was intended as a demonstrational model of coordinate systems. Furthermore, the coordinate systems shown for the measurement of the star are valid for only one geographic latitude, in this case 32° north, the latitude of Yazd in Persia, where a number of metalworkers and instrument makers are known to have been active.

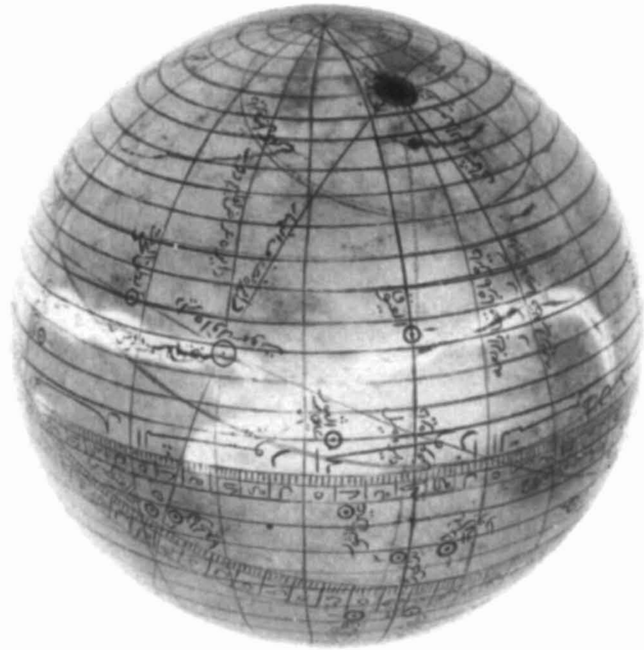

FIG. 2.30. UNSIGNED, UNDATED CELESTIAL GLOBE. Arcs are drawn and labeled through one star (α Aurigae, Capella), indicating different coordinate systems. They are valid for only one geographic latitude, 32° N. This globe is probably a product of a seventeenth-century workshop in or near Yazd. Diameter of the original: 13.1 cm. Museum of the History of Science, Billmeir Collection, Oxford (inv. no. 57-84/182). By permission of the Bettman Archive, New York.

### THE MANUFACTURE OF CELESTIAL GLOBES

Islamic celestial globes can be classified not only by design but also by the method of manufacture. Only a few made of painted wood or painted papier-mâché, such as the one illustrated in figure 2.29, have been preserved. In general it seems that Islamic globes of wood or papier-mâché were hand painted or drawn, in contrast to the use of printed paper gores by Western European globe makers.

The vast majority of extant globes are hollow metal spheres set into metal rings and stands. Such globes were made in two ways: either they comprised two hemispheres of cast or raised metal, or they were cast by the cire perdue (lost wax) process, in one piece and with no seam.[118] Globes made of wood or papier-mâché or with metal hemispheres are of considerable antiquity. Seamless globes, on the basis of evidence so far available, appear to have originated in northwestern India toward the end of the sixteenth century. They became the hallmark of all workshops in the Punjab and Kashmir areas of India through the nineteenth century. Consequently, because of the association of this technique with northwestern India, we can conjecture that unsigned products made at the same time but with a seam (such as most globes having no stars at all) were probably made in Persia rather than India.

The earliest confirmed date for the manufacture of a seamless cast globe is 998/1589–90, when a globe made by ʿAlī Kashmīrī ibn Lūqmān was produced.[119] The workshop that excelled in this technique, however, was a four-generation family of instrument makers working in Lahore.[120] During more than a century, from A.D. 1567 to 1680, this remarkable workshop produced numerous astrolabes and other instruments, including twenty-one signed globes and, no doubt, a considerable number of unsigned ones as well. Examples of the craft of its most prolific member, Ḍiyāʾ al-Dīn Muḥammad ibn Qāʾim Muḥammad Asṭurlābī Humāyūnī Lāhūrī, can be seen in the astrolabe illustrated in figure 2.6 and the rather unusual celestial sphere illustrated in figure 2.33.

117. Oxford, University of Oxford, Museum of the History of Science, Billmeir Collection, inv. no. 57-84/182; Savage-Smith, *Islamicate Celestial Globes*, 49–50, 258–59 (no. 81) (note 5).

118. For details regarding this method of construction, see Savage-Smith, *Islamicate Celestial Globes*, 90–95 (note 5); Savage-Smith, "Classification of Islamic Celestial Globes" (note 105), and the forthcoming catalog of scientific instruments in the Nasser D. Khalili Collection of Islamic Art, by Maddison and Savage-Smith (note 105).

119. London, private collection; Savage-Smith, *Islamicate Celestial Globes*, 35 (fig. 11), 176 (fig. 69), and 223–24 (no. 10) (note 5).

120. For the activities and products of this workshop, see Savage-Smith, *Islamicate Celestial Globes*, 34–43 (note 5), and especially the historical introduction to Brieux and Maddison, *Répertoire* (note 36).

FIG. 2.31. ISLAMIC CELESTIAL GLOBE, UNSIGNED AND UNDATED, ENGRAVED IN SANSKRIT, DEVANAGARI SCRIPT. The sphere is a hollow seamless sphere cast by cire perdue. It is a product of the workshop of Lālah Balhūmal Lāhūrī, who was active in Lahore in the first half of the nineteenth century.

Diameter of the original: 20.5 cm. By permission of the David Eugene Smith Collection, Rare Book and Manuscript Library, Columbia University, New York (inv. no. 27-244).

The technique of making seamless globes continued to be practiced in India after this workshop ceased to make them. A nineteenth-century workshop in Lahore—that of the Hindu metalworker Balhūmal—produced excellent and precise products. He maintained the same basically medieval design with only the forty-eight Ptolemaic constellations, but he did add to all his instruments a full set of meridian circles at right angles to the equator, along with the ever-present ecliptic latitude-measuring circles. Products of his workshop are easily identified and include globes (and astrolabes) labeled entirely in Arabic, in Persian, in English for English patrons, or entirely in Sanskrit. The last type is illustrated in figure 2.31.

Throughout the ten centuries of their production in the Islamic world, celestial globes maintained the medieval tradition of displaying only the Ptolemaic constellations and stars. On none of the Islamic celestial globes known to have survived are there any of the newly recorded stars and constellations of the Southern Hemisphere that resulted from the European explorations of the sixteenth century.

### ARMILLARY SPHERES

A third type of three-dimensional celestial model is the demonstrational armillary sphere—an earth-centered model in which the great and lesser circles of the ecliptic, equator, tropics, and polar circles are represented by rings encompassing a miniature earth and held in place by a graduated meridian ring, all pivoting about the equatorial axis. Moon, planets, and stars were not part of the model. Such a model of the celestial system is not subject to precessional change and consequently will not become outdated.

Armillary spheres are not often mentioned in Islamic astronomical literature. When they are described, except where there was European influence, they are nearly all observational armillary spheres in the Ptolemaic tradition

FIG. 2.32. DEMONSTRATIONAL ARMILLARY SPHERE. The illustration appears at the beginning of a treatise on astronomical tables by the fifteenth-century Cairo astronomer al-Wafāʾī.
Size of the original: not known. By permission of the Biblioteca Apostolica Vaticana, Rome (MS. Borg. Arab. 217, fol. 1a).

rather than demonstrational armillary spheres.[121] The observational armillary sphere had no earth globe at the center and had sighting devices mounted on the rings. As such, it forms a separate class of instruments distinct from demonstrational armillary spheres, celestial globes, or spherical astrolabes.[122] None are extant from the Islamic world, though they were one of the major tools for observing the coordinates of planets and stars.[123] It is the demonstrational armillary sphere, however, rather than the observational, that is most frequently illustrated, usually in relatively recent manuscripts (fig. 2.32).[124]

An unusual and apparently unique variant of a demonstrational armillary sphere is illustrated in figure 2.33. It was made in 1090/1679–80 by Ḍiyāʾ al-Dīn Muḥammad of the Lahore workshop and consists of two raised or hammered hemispheres in which the spaces between the constellations and the great and lesser circles have been cut out, or worked *à jour*.[125] The metal hemispheres have been painted with gilt and varnished, inside and out, while the stars are indicated by holes perforating the sphere, some filled with glass or mica. One might at first think this is simply an ornate version of a celestial globe with the background removed behind the forty-eight constellations. It is clear, however, from the dedicatory inscription that there was at one time a small terrestrial globe inside this gilt celestial sphere. In dedicating this sphere to the Mughal ruler Aurangzīb, whose court was at Delhi, the maker calls the sphere a *kurah-i ikhtirāʿī-i arḍwī* [*sic*] *samāʾī*, "a specially invented terrestrial-celestial sphere."

## Mapping of Individual Constellations and Asterisms

### The Pre-Islamic Astronomic System

The pre-Islamic traditional Arab astronomic system involved a mental mapping of the skies and employed a rich stellar nomenclature quite different from the Islamic system based on Ptolemaic concepts.[126] There was, for

121. Giuseppe Celentano, "L'epistola di al-Kindī sulla sfera armillare," *Istituto Orientale di Napoli, Annali* (suppl. 33), 42, fasc. 4 (1982): 1–61 and 4 pls.; Samuel Miklos Stern, "A Treatise on the Armillary Sphere by Dunas ibn Tamīm," in *Homenaje a Millás-Vallicrosa*, 2 vols. (Barcelona: Consejo Superior de Investigaciones Científicas, 1954–56), 2:373–82. A treatise on the armillary sphere by Ḥabash al-Ḥāsib is extant in two manuscripts in Istanbul; see Sezgin, *Geschichte des arabischen Schrifttums*, 6:175 (note 35).

122. For later versions of observational armillary spheres related to the torquetum of Jābir ibn Aflaḥ of Seville in the early twelfth century, see Richard P. Lorch, "The Astronomy of Jābir ibn Aflaḥ," *Centaurus* 19 (1975): 85–107.

123. For a rather stylized sixteenth-century Ottoman painting of astronomers using an observational armillary sphere in the observatory at Istanbul, see the miniature from Istanbul Üniversitesi Kütüphanesi, MS. F. 1404 (Yıldız 2650/260, fol. 56b), reproduced in Seyyed Hossein Nasr, *Islamic Science: An Illustrated Study* (London: World of Islam Festival, 1976), 125 (pl. 84).

124. For examples, see Stanford University, Lane Medical Library, MS. Z296, inside front cover; Los Angeles, UCLA University Research Library, Near Eastern Coll. 898, MS. 52, fol. 41b; and an eighteenth-century engraving of an Islamic demonstrational armillary sphere from an edition of Kātib Çelebi's *Cihānnümā* (World mirror) printed in Istanbul in 1732 and reproduced in O. Kurz, *European Clocks and Watches in the Near East*, Studies of the Warburg Institute, vol. 34 (London: Warburg Institute, University of London, 1975), 69 and pl. XI (fig. 21).

125. Rockford, Illinois, Time Museum, inv. no. 3406; Savage-Smith, *Islamicate Celestial Globes*, 42–43 and 232–33 (no. 30) (note 5). This unique openwork sphere cannot have been the cap or "rete" of a spherical astrolabe (as suggested by Emmanuel Poulle in a review of *Islamicate Celestial Globes* in *Revue de Synthèse*, 4th ser., 1988, 355–56), for it lacks the requisite circles, shows no signs on the interior of rubbing against a sphere (in fact the gilt surface is better preserved on the inside than on the outside), and specifically refers to a terrestrial globe as being part of the design.

126. Paul Kunitzsch, *Untersuchungen zur Sternnomenklatur der Araber* (Wiesbaden: Otto Harrassowitz, 1961); idem, "Über eine *anwāʾ*-Tradition mit bisher unbekannten Sternnamen," *Bayerische Akademie der Wissenschaften, Philosophisch-Historische Klasse, Sitzungsberichte* (1983), no. 5; Savage-Smith, *Islamicate Celestial Globes*, 117–19 (note 5).

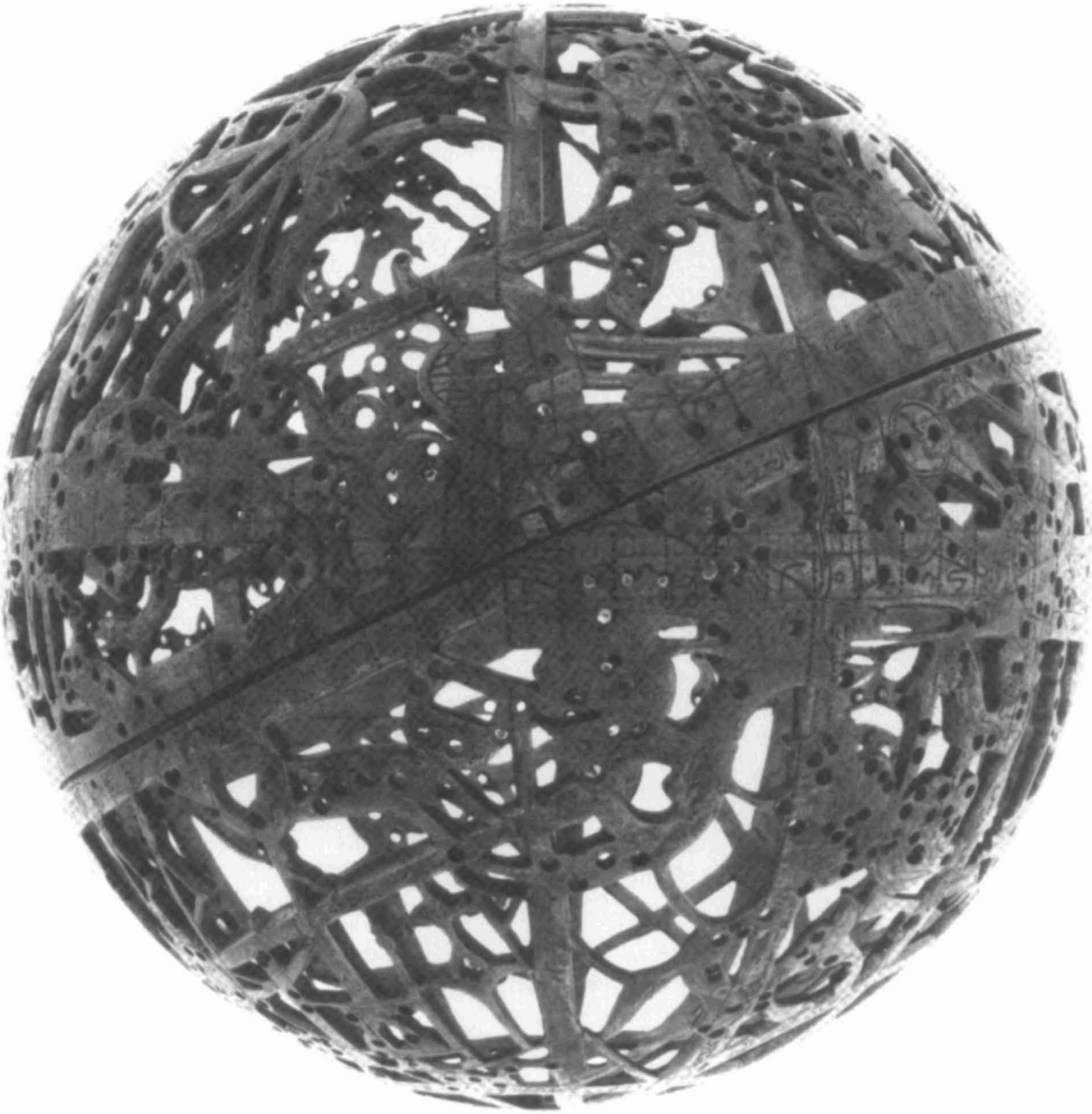

FIG. 2.33. UNIQUE VARIANT OF A DEMONSTRATIONAL ARMILLARY SPHERE/CELESTIAL GLOBE. The instrument was made in 1090/1679–80 by Ḍiyāʾ al-Dīn Muḥammad. Diameter of the original: 16.4 cm. By permission of the Time Museum, Rockford, Illinois (inv. no. 3406).

example, a lion much larger than our Leo, and a bucket covered the areas of Aquarius, Pegasus, and part of Pisces. The region of the constellations Orion and Gemini was seen by Bedouins to contain a huge giant. A bier or corpse-bearing plank with three mourning daughters accompanying it was seen in the area of Ursa Major, with a similar smaller set composing the stars of Ursa Minor. A fish covered the region of both Pisces and Andromeda. In some copies of the major treatise on constellation iconography from the Islamic period, *Kitāb ṣuwar al-kawākib al-thābitah* (Book of the constellations of the fixed stars), written in the tenth century by al-Ṣūfī, there are extra illustrations that show two alternative views of Andromeda with the Bedouin fish.[127]

Many animals, as well as other aspects of pastoral life,

127. For illustrations of these diagrams, see Emmy Wellesz, "Islamic Astronomical Imagery: Classical and Bedouin Tradition," *Oriental Art*, n. s., 10 (1964): 84–91, esp. 88 (figs. 7 and 8); and Emmy Wellesz, "An Early al-Ṣūfī Manuscript in the Bodleian Library in Oxford: A Study in Islamic Constellation Images," *Ars Orientalis* 3 (1959): 1–26 and 27 pls., esp. figs. 11 and 12.

FIG. 2.34. THE CONSTELLATION CASSIOPEIA AS SEEN ON A GLOBE, WITH AN ARAB BEDOUIN ASTERISM OF A CAMEL DRAWN OVER HER. This drawing is taken from a copy, completed in 566/1170–71, of the *Kitāb ṣuwar al-kawākib al-thābitah* (Book of the constellations of the fixed stars) by al-Ṣūfī.
Size of the original: ca. 27.5 × 21.5 cm. By permission of the Bodleian Library, Department of Oriental Books, Oxford (MS. Hunt. 212, fol. 40b).

can be seen in the constellation images described later by al-Ṣūfī as belonging to pre-Islamic Arabia. Gazelles were imagined, and the footprints of their leaps as they ran before the large lion could be seen in the area of Ursa Major. Camels with new foals were seen in the head of Draco. The region of Ursa Minor was also visualized as two calves turning a gristmill, and between the two calves and the camels in the head of Draco were wolves. A herd of goats occupied the area of Auriga, and the stars of Cepheus were viewed as a shepherd with his dog and sheep. A horse was seen above the head of Andromeda, sharing space with our Pegasus.

Some of the stars in Cassiopeia were viewed as a camel, with the brightest star of that group called the camel's hump, but this camel is very rarely illustrated in existing copies of the al-Ṣūfī treatise. One illustration is in a manuscript at Oxford, copied in 566/1170–71 and possibly dedicated, in a now partially illegible dedication, to Sayf al-Dīn Ghāzī II, at that time a ruler in Mosul, north of Baghdad.[128] In the illustration of Cassiopeia as seen on a celestial globe (see fig. 2.34), a camel is drawn over her with its head and forelegs above Cassiopeia's head. The star on her raised elbow is labeled *al-kaff al-khaḍīb wa huwa sanām al-nāqah*, "the dyed hand and it is the hump of the she-camel." The reference here is to two different Bedouin images of the sky: a large camel and an enormous human figure named *al-thurayyā* (a virtually untranslatable name), whose head was in the Pleiades and whose large open hand consisted of five stars including this one. A second illustration in this same manuscript shows the Ptolemaic constellation Andromeda with a fish beneath her, a horse overhead, and a camel to one side (the same camel as encroached on Cassiopeia's territory). All three of these elements (fish, horse, and camel) were drawn from traditional pre-Islamic mappings rather than classical Ptolemaic schemes.[129]

Another aspect of the pre-Islamic Bedouin view of the skies also found graphic expression, but outside the context of constellation diagrams. This involved the zoomorphic interpretation of individual stars. An example is the brightest star in the Ptolemaic constellation of Lyra. In the Bedouin tradition it was called *al-nasr al-wāqiʿ*, "the falling eagle." The star, α Lyrae, is the fifth brightest in the heavens, and its "modern" name Vega derives from a corrupt transliteration of *wāqiʿ* meaning "falling." In all the Arabic or Persian manuscript copies of al-Ṣūfī's treatise on constellations that scholars have examined, the constellation Lyra is always drawn as some sort of musical instrument or merely as a decorative device, with the major star labeled in Arabic. At some point, however, some instrument makers began designing the pointer for this star on the rete for an astrolabe so that it was in the form of a bird with closed wings. This can be seen, for example, in the astrolabe (fig. 2.16) made in Isfahan in 618/1221–22, where Vega is indicated by the bird at the center of the rete. Two other pointers on this astrolabe are shaped like animals, one bird at the upper left facing downward, labeled *al-ṭāʾir* (the flying bird), reflecting an ancient tradition associated with the star whose modern name is Altair (α Aquilae), the eleventh brightest star in the skies. The horsehead to the left on the rete serves as a pointer to a star in Pegasus and in this case is a visualization of a Ptolemaic image. Such pictorial interpretations of star names were quickly introduced into Europe, for a Byzantine astrolabe made in A.D. 1062 has a bird-shaped pointer for the star Vega.[130]

128. Oxford, Bodleian Library, MS. Hunt. 212.

129. Wellesz, "Islamic Astronomical Imagery," 90–91 (note 127), where both illustrations from the Bodleian Library MS. Hunt. 212 are reproduced (figs. 15 and 16).

130. O. M. Dalton, "The Byzantine Astrolabe at Brescia," *Proceedings of the British Academy*, 1926, 133–46 and 3 pls.; Neugebauer, "Early History of the Astrolabe," 249 nn. 57 and 58, reprint 287 nn. 57 and 58 (note 26).

These animal representations of stars appear to have been restricted to instruments and do not seem to have occurred in copies of Islamic treatises illustrating the constellations. It should be noted, however, that no systematic survey and comparison of such material has been undertaken.[131]

### LUNAR MANSIONS

Another facet of traditional Bedouin conceptualization of the skies—the lunar mansions—arose from more complicated and obscure circumstances. Various theories have been advanced about whether the system of lunar mansions was ultimately Babylonian, Indian, or Chinese in origin. It seems evident, however, that the Arabic version was an accretion of the Indian *nakṣatra* system of junction stars upon a Bedouin grouping of fixed stars, applying the traditional Arab star names to the Indian lunar mansion division of the zodiac.[132]

The Bedouins of the Arabian Peninsula in pre-Islamic times had a system by which they estimated the passage of time and predicted meteorological events so as to find winter and spring grazing lands, whose locations varied greatly depending on rainfall. The pre-Islamic system, called *anwāʾ*, was based on a series of prominent stars whose cosmical settings (setting in the west as the sun rises in the east) and heliacal risings (rising in the east with the sun) delineated the solar year by breaking it into about twenty-eight periods. Sometime before the advent of Islam the Bedouins assimilated from India a system in which the zodiac was divided into twenty-seven or twenty-eight "mansions" (*manāzil* in Arabic) of the moon. These mansions corresponded to places in the sky through which the moon passed in twenty-seven or twenty-eight nights in its course from new moon to new moon. Because the brilliance of the moon prevents nearby stars from being observed, the mansions were named for stars in the vicinity of, but not directly along, the ecliptic. Each mansion represented one day's travel of the moon and therefore corresponded to roughly thirteen degrees along the ecliptic beginning at the vernal equinox, with the result that each zodiacal house contained two and a half lunar mansions.

In superimposing the system of *manāzil* upon the Bedouin grouping of fixed stars, the Arabs applied *anwāʾ* star names to the Hindu lunar mansion divisions of the ecliptic. These two systems are not entirely compatible, however, for one is based on the risings and settings of fixed star groups and the other reckoned on regular intervals of the ecliptic taken from the vernal equinox. With the precession of the equinoxes, no fixed star will maintain the same distance from the vernal equinox. Consequently one star group cannot be successfully aligned with one segment of the ecliptic for an extended time.

This attempted compounding of *anwāʾ* asterisms and the lunar mansions (*manāzil*) gave rise to a type of Arabic literature known as *anwāʾ* literature, in which lexicographers, such as the ninth- and tenth-century Iraqi scholars Ibn Qutaybah and Abū Isḥāq al-Zajjāj, attempted to record the Bedouin connection of meteorological phenomena with the *anwāʾ* star groups associated with the twenty-eight lunar mansions.[133] It was this type of writing that al-Ṣūfī employed when comparing the Bedouin and Ptolemaic systems. A second literary genre concerned with the *anwāʾ-manāzil* system was arranged in the form of a calendar and enumerated natural, celestial, and meteorological events of concern to peasants and herdsmen.[134] Astrologers also became seriously interested in the division of the zodiac into lunar mansions and the assigning of good or ill characteristics to each.

There was a tradition in the Islamic world of associating abstract patterns of dots or stars in small geometrical designs with the twenty-eight lunar mansions. Al-Qazwīnī, in his thirteenth-century cosmology, included an extensive section on the lunar mansions illustrated with such configurations of dots.[135] An even longer dis-

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131. For a preliminary study of zoomorphic astrolabes, particularly European ones, see Owen Gingerich, "Zoomorphic Astrolabes and the Introduction of Arabic Star Names into 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, Annals of the New York Academy of Sciences, vol. 500 (New York: New York Academy of Sciences, 1987), 89–104. Curiously, the occurrence of a bird-shaped pointer for Vega is a distinguishing characteristic of late nineteenth-century forgeries of astrolabes made by one particular Persian maker; Owen Gingerich, David A. King, and George Saliba, "The ʿAbd al-Aʾimma Astrolabe Forgeries," *Journal for the History of Astronomy* 3 (1972): 188–98; reprinted in David A. King, *Islamic Astronomical Instruments* (London: Variorum Reprints, 1987), item VI.

132. See Charles Pellat, "Anwāʾ," in *Encyclopaedia of Islam*, new ed., 1:523–24; Daniel Martin Varisco, "The Rain Periods in Pre-Islamic Arabia," *Arabia* 34 (1987): 251–66; and Savage-Smith, *Islamicate Celestial Globes*, 119–32 (note 5), where further references will be found.

133. Paul Kunitzsch, "Ibn Qutayba," in *Dictionary of Scientific Biography*, 16 vols., ed. Charles Coulston Gillispie (New York: Charles Scribner's Sons, 1970–80), 11:246–47, and Daniel Martin Varisco, "The *Anwāʾ* Stars according to Abū Isḥāq al-Zajjāj," *Zeitschrift für Geschichte der Arabisch-Islamischen Wissenschaften* 5 (1989): 145–66.

134. Charles Pellat, "Dictons rimés, *anwāʾ* et mansions lunaires chez les Arabes," *Arabica* 2 (1955): 17–41; ʿArīb ibn Saʿd al-Kātib al-Qurṭubī, *Le calendrier de Cordoue*, ed. Reinhart Dozy, new ed. with annotated French translation by Charles Pellat, Medieval Iberian Peninsula, Texts and Studies, vol. 1 (Leiden: E. J. Brill, 1961).

135. Zakarīyāʾ ibn Muḥammad al-Qazwīnī, *Kitāb ʿajāʾib al-makhlūqāt wa-gharāʾib al-mawjūdāt* (Marvels of things created and miraculous aspects of things existing); see *Zakarija ben Muhammed ben Mahmud el-Cazwini's Kosmographie*, 2 vols., ed. Ferdinand Wüstenfeld (Göttingen: Dieterichschen Buchhandlung, 1848–49; facsimile reprint Wiesbaden: Martin Sändig, 1967), 42–51. Al-Qazwīnī's text on lunar mansions is taken literally from Ibn Qutaybah's *Kitāb al-anwāʾ*; Paul Kunitzsch, "The Astronomer Abu ʾl-Ḥusayn al-Ṣūfī and His Book

cussion with fuller illustrations was included in the thirteenth-century encyclopedia of magic and occult practices written by al-Būnī (d. 622/1225), the acknowledged master of the occult sciences in Islam.[136] In many cases there is little similarity between the graphic representation of a lunar mansion and the actual appearance of the stars in that region of the sky. Even the number of dots used in a diagram may be quite different from the number of stars associated with that mansion. The designs also vary between authors and even among manuscript copies of the same work.

The abstract patterns of lunar mansions are most often associated with writings of an astrological or cosmological nature.[137] There are, however, some astronomical treatises that include diagrams of the lunar mansions. For example, Abū al-ʿAbbās Aḥmad's *Kitāb al-durar wa-al-yawāqīt fī ʿilm al-raṣd wa-al-mawāqīt*[138] has several diagrams of lunar mansions, including the one illustrated earlier in figure 2.22. Similar graphic representations of lunar mansions are not, however, to be found in copies of al-Ṣūfī's influential book on the constellations or in the writings of al-Bīrūnī, who discussed the topic at some length in his *al-Āthār al-bāqīyah*.

On instruments the representations of the asterisms comprising the lunar mansions are rare. There is an exquisite astrolabe probably made in Egypt for an Ayyubid ruler by ʿAbd al-Karīm al-Miṣrī in 633/1235–36.[139] On the back of the instrument in one of the concentric bands providing a variety of information there are the twenty-eight lunar mansions represented by stars, along with an animal or human form for each mansion. This astrolabe is also notable for having another concentric band with outlines of each of the zodiacal constellations, each depicted twice—as seen on a globe and as viewed in the sky. Only one celestial globe is known to have similar patterns of dots showing the lunar mansions. It bears the date 718 (equivalent to A.D. 1318–19), with the maker given as ʿAbd al-Raḥmān ibn Burhān al-Mawṣilī, that is, of Mosul in northern Iraq.[140] There are, however, problems with the signatures on this globe and with the method of its construction given the date on it. Consequently it is difficult to know with certainty where this product was made or even when, though it is evident the maker employed a different source for his iconography than was usual among globe makers.

### ISLAMIC CONSTELLATION ICONOGRAPHY

The major guide to constellation diagrams in the Islamic world was the Arabic treatise written in the tenth century by al-Ṣūfī, who was a court astronomer in Isfahan to ʿAḍūd al-Dawlah, one of the most expansionist of the Buyid rulers in Persia. In al-Ṣūfī's *Kitāb ṣuwar al-kawākib al-thābitah* (Book of the constellations of the fixed stars), each of the forty-eight classical constellations was discussed in turn.[141] Two drawings were given for each constellation, one showing it as seen in the sky by an observer on earth and the other as seen on a celestial globe, which is to say, reversed right to left (figs. 2.35 and 2.36). In addition to the drawings for each constellation, there was an account of the traditional Bedouin star names and asterisms for that portion of the sky and a catalog of the stars in that constellation, giving celestial latitudes, longitudes, and magnitudes. The star catalog presented by al-Ṣūfī reproduced with only slight revision that given earlier by Ptolemy in the *Almagest*.[142] The stellar coordinates were given in ecliptic coordinates, augmenting the longitudes given by Ptolemy by 12°42′ to correspond to the year A.D. 964. The magnitudes given by al-Ṣūfī are, however, substantial revisions of those of Ptolemy.[143]

on the Constellations," *Zeitschrift für Geschichte der Arabisch-Islamischen Wissenschaften* 3 (1986): 56–81, esp. 60 n. 13.

136. Muḥyī al-Dīn Abū al-ʿAbbās Aḥmad ibn ʿAlī al-Būnī al-Qurashī, *Shams al-maʿārif al-kubrā wa-laṭāʾif al-ʿawārif* (Cairo: Maṭbaʿat Muḥammad ʿAlī Sabīḥ, [1945]), 10–25.

137. For a comparison of some of the patterns representing lunar mansions and their relation to geomancy, see Emilie Savage-Smith and Marion B. Smith, *Islamic Geomancy and a Thirteenth-Century Divinatory Device* (Malibu, Calif.: Undena, 1980), 38–43 (including table 2).

138. An autograph copy of his treatise is the third item in Oxford, Bodleian Library, Department of Oriental Books, MS. Bodl. Or. 133, fols. 94b–130a.

139. London, British Museum, Department of Oriental Antiquities, acc. no. 855.5.9.1; the date on the instrument is not completely legible and has been read as 625, 638, and 648; Leo Ary Mayer, *Islamic Astrolabists and Their Works* (Geneva: Albert Kundig, 1956), 30 and pl. XIIb. A line drawing is given along with some errors in interpretation by Gunther, *Astrolabes of the World*, 1:233–36 (note 2). For a better interpretation, see Willy Hartner, "The Principle and Use of the Astrolabe," in *Survey of Persian Art from Prehistoric Times to the Present*, 6 vols., ed. Arthur Upham Pope (London: Oxford University Press, 1938–39), 3:2530–54 and 6:1397–1404; reprinted in Willy Hartner, *Oriens-Occidens: Ausgewählte Schriften zur Wissenschafts- und Kulturgeschichte*, 2 vols. (Hildesheim: Georg Olms, 1968 and 1984), 1:287–311.

140. Oxford, University of Oxford, Museum of the History of Science, inv. no. 57-84/181; Savage-Smith, *Islamicate Celestial Globes*, 29–31 and 247–48 (no. 60) (note 5).

141. For the printed Arabic text, see the 1954 edition of *Ṣuwar al-kawākib* (note 96). A French translation based on a seventeenth-century copy now in Copenhagen has been published: *Description des étoiles fixes composée au milieu du dixième siècle de notre ère: Par l'astronome persan Abd-al-Rahman al-Sûfi*, trans. Hans Carl Frederik Christian Schjellerup (Saint Petersburg: Commissionnaires de l'Académie Impériale des Sciences, 1874; facsimile reprint Frankfurt: Institut für Geschichte der Arabisch-Islamischen Wissenschaften, 1986), and see Kunitzsch, "Abu ʾl-Ḥusayn al-Ṣūfī" (note 135).

142. For the revisions al-Ṣūfī made in Ptolemy's star catalog, see Savage-Smith, *Islamicate Celestial Globes*, 115 (note 5). The epoch of al-Ṣūfī's catalog is the beginning of the year 1276 of the Alexandrian era, which corresponds to A.D. 1 October 964.

143. Kunitzsch, "Abu ʾl-Ḥusayn al-Ṣūfī," 57 (note 135). The Arabic version of Ptolemy employed by al-Ṣūfī seems to have been that of Isḥāq ibn Ḥunayn.

FIG. 2.35. THE CONSTELLATION AURIGA AS SEEN IN THE SKY. From a manuscript copy of the *Ṣuwar al-kawākib* by al-Ṣūfī, written in the tenth century, made in 400/1009–10 by his son al-Ḥusayn from a holograph of his father's.
Size of the original: 26.3 × 18.2 cm. By permission of the Bodleian Library, Department of Oriental Books, Oxford (MS. Marsh 144, p. 120).

FIG. 2.36. THE CONSTELLATION AURIGA AS SEEN ON A GLOBE. From the same manuscript as figure 2.35.
Size of the original: 23.6 × 18.2 cm. By permission of the Bodleian Library, Department of Oriental Books, Oxford (MS. Marsh 144, p. 119).

According to the eleventh-century scholar al-Bīrūnī, al-Ṣūfī told the Persian geometer and astronomer Abū Saʿīd al-Sijzī that he had laid very thin paper on a celestial globe and fitted it carefully over the surface of the sphere, then traced on the paper the constellation outlines and individual stars as precisely as the transparency of the paper would allow. Al-Bīrūnī adds to this account the comment: "And that is an [adequate] approximation when the figures are small but it is far [from adequate] if they are large."[144]

Maps of individual constellations, when carefully executed, display the relative positions of the component stars and have the advantage of being true for any period, since they do not reflect through a coordinate system a relationship with the sun's movement. Al-Ṣūfī numbered each star in sequence within a constellation so as to correspond to the star catalog. Those within the outlines of the constellation, called the internal or formed stars, were given one set of numbers, while those lying outside the outlines (the external or unformed) were given a different set and frequently were in a different color. In this he followed the convention of numbering established by Ptolemy many centuries earlier. Differentiation in brightness was indicated in al-Sūfī's diagrams by different sizes of dots, corresponding to the six magnitudes of stars recognized by Ptolemy.

Al-Ṣūfī's star catalog was an important direct source for star coordinates used by early makers of astrolabes and celestial globes. For example, Muḥammad ibn Maḥmūd ibn ʿAlī al-Ṭabarī stated on the globe he made in

144. The passage occurs in al-Bīrūnī's *Kitāb fī tasṭīḥ al-ṣuwar wa-tabṭīḥ al-kuwar*; Berggren, "Al-Bīrūnī on Plane Maps," 53 and 89 (note 65); Suter, "Über die Projektion der Sternbilder," 86 (note 65).

FIG. 2.37. GLOBE MADE IN 684/1285–86 BY MUḤAMMAD IBN MAḤMŪD IBN ʿALĪ AL-ṬABARĪ. The maker specified on the globe that the stars were drawn from the *Ṣuwar al-kawākib* by al-Ṣūfī after increasing the longitudes five degrees.
Diameter of the original: 13.4 cm. By permission of the Nasser D. Khalili Collection of Islamic Art (SCI 21).

684/1285–86 that the stars were placed according to the *Ṣuwar al-kawākib* by al-Ṣūfī after increasing their longitudes five degrees (fig. 2.37).[145]

Later instrument makers employed revised star catalogs, especially the one Ulugh Beg prepared at

145. Nasser D. Khalili Collection of Islamic Art, inv. no. SCI 21, the "Khalili Globe." It has recently been demonstrated that this globe is the original thirteenth-century globe of which a copy is now in Paris, Musée du Louvre, Section Islamique, inv. no. 6013. The copy in Paris was described and questionable features were noted by Savage-Smith, *Islamicate Celestial Globes*, 27–29 and 220–21 (no. 6) (note 5). For a

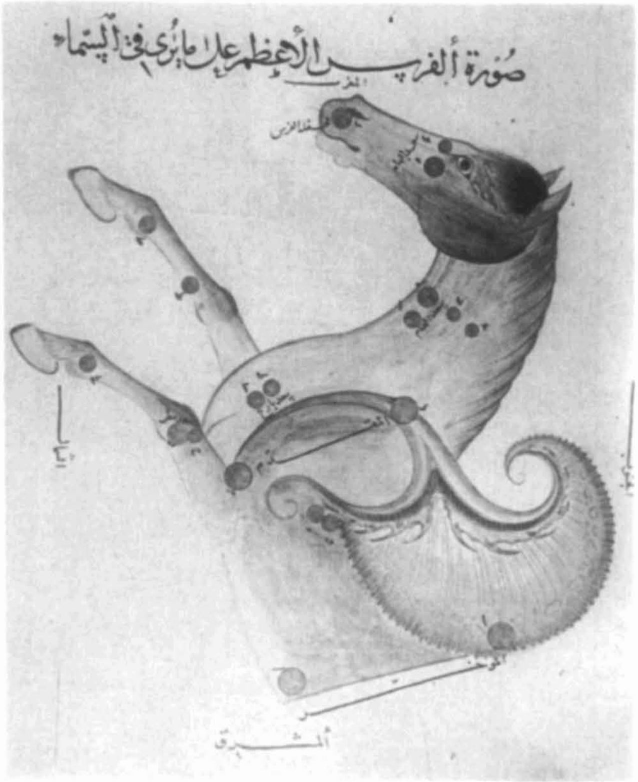

FIG. 2.38. THE CONSTELLATION PEGASUS AS SEEN IN THE SKY. From a copy of the *Ṣuwar al-kawākib* by al-Ṣūfī made ca. 1430–40, probably in Samarkand, in the library of the astronomer Ulugh Beg.
Size of the original: 23.5 × 16.5 cm. By permission of the Bibliothèque Nationale, Paris (MS. Arabe 5036, fol. 93b).

Samarkand[146] for the epoch 841/1437–38. This latter catalog, as Ulugh Beg freely admits, depended heavily on the one in al-Ṣūfī's *Ṣuwar al-kawākib*, which Ulugh Beg knew through a Persian translation made in the thirteenth century by an important scholar and astronomer, Naṣīr al-Dīn Muḥammad ibn Muḥammad al-Ṭūsī. Naṣīr al-Dīn al-Ṭūsī headed the observatory at Maragheh, after entering in A.D. 1257 the service of Hūlāgū Khān, the Ilkhanid ruler who was brother to Kubilay Khān. Two extant manuscripts bear the signature of Ulugh Beg, indicating that they were in his library—one in Arabic and one in Persian. The latter manuscript also claims to be the autograph copy by the translator, Naṣīr al-Dīn al-Ṭūsī. It has been demonstrated recently that Ulugh Beg actually used only the Persian version by al-Ṭūsī.[147] The Arabic copy of al-Ṣūfī's treatise once in Ulugh Beg's library, made about 1430, was probably a presentation copy prepared at Samarkand as a gift to the ruler. Its colorful renderings of the constellation diagrams reflect the current fashion in Timurid art as well as some Chinese-inspired interpretations of the beasts, in keeping with the considerable interest in Chinese art that characterized the Timurid court.[148] See figure 2.38 for an illustration from this manuscript.

A considerable number of illustrated copies of al-Ṣūfī's treatise, in both Arabic and Persian, are preserved today, the earliest being one copied by al-Ṣūfī's son, al-Ḥusayn, in 400/1009–10. The two diagrams of the constellation Auriga from this manuscript are illustrated in figures 2.35 and 2.36. This is the oldest illustrated Arabic manuscript on any topic to be preserved today.[149]

Al-Ṣūfī speaks of having seen a book on constellations by ʿUṭārid ibn Muḥammad al-Ḥāsib, a ninth-century astronomer and mathematician who is said to have also written on the astrolabe and the armillary sphere.[150] Al-Ṣūfī reports seeing a number of celestial globes made by instrument makers in Harran as well as a large one made by ʿAlī ibn ʿĪsā, whose treatise on the astrolabe is the earliest still preserved.[151] None of these earlier globes or books on constellations have survived, as far as is known, so it is impossible to evaluate al-Ṣūfī's work in terms of the sources he employed for constellation mapping. Certainly the Ptolemaic star catalog, which he repeated through its Arabic version, gave explicit verbal directions for locating each star in terms of the constellation form (e.g., on the forward hand, in the tail, etc.) in addition

comparison of the two globes, see Savage-Smith, "Classification of Islamic Celestial Globes," 26 (note 105), as well as the forthcoming catalog of the scientific items in the Nasser D. Khalili Collection being prepared by Maddison and Savage-Smith (note 105).

146. Savage-Smith, *Islamicate Celestial Globes*, 114–16 (note 5); and Kunitzsch, "Abu ʾl-Ḥusayn al-Ṣūfī," 61–64 (note 135).

147. The Arabic manuscript is in Paris, Bibliothèque Nationale, MS. Arabe 5036, and the Persian in Istanbul, Ayasofya MS. 2592. The former was the basis, along with four other manuscripts, for the Arabic printed text (see note 96). The Persian manuscript was printed in facsimile in Tehran in 1969 and employed in the printed edition, *Tarjamat-i ṣuwar al-kawākib ʿAbd al-Raḥmān Ṣūfī bih qalam Khawājat Naṣīr al-Dīn Ṭūsī*, edited with analysis by Muʿiz al-Dīn Muhadawī, Intishārat-i Bunyād-i Farhang-i Īrān 136, ʿIlm dar Īrān 16 (Tehran: Intishārat-i Bunyād-i Farhang-i Īrān, 1972). Paul Kunitzsch argues that only the Persian text was actually used by Ulugh Beg, and that there is some doubt the Istanbul manuscript is in fact the autograph copy of Naṣīr al-Dīn al-Ṭūsī's translation; Kunitzsch, "Abu ʾl-Ḥusayn al-Ṣūfī," 62–64 (note 135).

148. For Timurid art and this manuscript made for Ulugh Beg, see Thomas W. Lentz and Glenn D. Lowry, *Timur and the Princely Vision: Persian Art and Culture in the Fifteenth Century* (Los Angeles: Museum Associates, Los Angeles County Museum of Art, 1989), 152–53, 168–69, 177, and 374.

149. Oxford, Bodleian Library, Department of Oriental Books and Manuscripts, MS. Marsh 144; Wellesz, "Early al-Ṣūfī Manuscript" (note 127); Emmy Wellesz, *An Islamic Book of Constellations*, Bodleian Picture Book, no. 13 (Oxford: Bodleian Library, 1965). For other manuscript copies, see Wellesz, "Islamic Astronomical Imagery" (note 127), and Joseph M. Upton, "A Manuscript of 'The Book of the Fixed Stars' by ʿAbd ar-Raḥmān aṣ-Ṣūfī," *Metropolitan Museum Studies* 4 (1932–33): 179–97.

150. For ʿUṭārid, see Ibn al-Nadīm, *Fihrist*; Flügel's edition, 1:278, Dodge's edition, 2:658 (note 28); and Sezgin, *Geschichte des arabisches Schrifttums*, 6:161 (note 35).

151. See note 32.

FIG. 2.39. THE CONSTELLATION HERCULES AS SEEN IN THE SKY. From a copy of the *Ṣuwar al-kawākib* by al-Ṣūfī made in Morocco in 621/1224–25.
Size of the original: 13.6 × 16.3 cm. By permission of the Biblioteca Apostolica Vaticana, Rome (Rossiano 1033, fol. 19b).

to the precise coordinates of each star, and al-Ṣūfī can be seen to have followed this catalog description faithfully. The clothing and headgear of the constellation figures and the general artistic style of the earliest copy made by his son reflect the fashion current at the Buyid court in Isfahan in the tenth century.

This treatise by al-Ṣūfī was no doubt the most important source for the design of constellation images in the Islamic world. Numerous copies exist in which the iconography has been adapted to local tastes and artistic conventions. Some copies were carefully done for important patrons or as guidebooks to instrument designers, and others were more casually executed for an audience less likely to scrutinize them carefully. See figure 2.39 for the constellation Hercules as seen in the sky, drawn in the thirteenth century in Morocco.

The constellation diagrams were also employed in later astronomical writings. For example, a copy made in 685/1286–87 of a Persian translation of al-Bīrūnī's treatise on astrology, written in A.D. 1029, contains twenty-seven drawings of constellations.[152] Only one view is presented—that as seen in the sky—and the stars are casually placed within the figures. The interpretations of the constellations have many features in common with the al-Ṣūfī diagrams, but there are some differences as well. In figure 2.40, for example, the constellation of Auriga is drawn in the al-Bīrūnī manuscript as a standing figure rather than a kneeling or sitting person as in the al-Ṣūfī iconography illustrated in figures 2.35, 2.36, and 2.37.

It is not known whether al-Bīrūnī intended for this section of his astrology to be illustrated in this manner.

FIG. 2.40. THE CONSTELLATIONS PERSEUS (ABOVE) AND AURIGA (BELOW). From a Persian version of *Kitāb al-tafhīm li-awā'il ṣinā'at al-tanjīm* (Book of instruction on the principles of the art of astrology) written in A.D. 1029 by al-Bīrūnī, copied in 685/1286 by Ibn al-Ghulām al-Qunawī.
Size of the original: Perseus, 9.0 × 11.8 cm; Auriga, 8.8 × 11.8 cm. By permission of the British Library, Oriental Collections, London (MS. Add. 7697, fol. 44a).

There are no specific references to illustrations in the accompanying text discussing constellations, and this Persian manuscript is the only copy known to have constellation diagrams. Al-Bīrūnī, who was born about fifteen years before al-Ṣūfī died, certainly knew of al-Ṣūfī's writings. In this section of the astrological treatise, in fact, al-Bīrūnī makes it clear that he was aware of both al-Ṣūfī's interpretation and that of Aratus, for he says in regard to the constellation Andromeda: "She . . . is also

152. London, British Library, Oriental Collections, MS. Add. 7697, copied by Ibn al-Ghulām al-Qunawī. By the early fourteenth century this manuscript copy was in Turkey, where it was bought in 732/1331–32 in Sivas, according to a note written in Konya. The text on constellations can be found in al-Bīrūnī's *Kitāb al-tafhīm*; see Wright's edition, 69–73 (secs. 159–61) (note 73).

FIG. 2.41. THE ZODIACAL CONSTELLATIONS OF SAGITTARIUS AND CAPRICORN. From a late fourteenth-century Iraqi copy of the cosmology (*ʿAjāʾib al-makhlūqāt*) of al-Qazwīnī.
Size of the original: 32.7 × 22.4 cm. Courtesy of the Freer Gallery of Art, Smithsonian Institution, Washington, D.C. (acc. no. 54.45r).

FIG. 2.42. THE ZODIACAL FIGURE OF TAURUS. From what is probably an eighteenth-century copy of the cosmology (*ʿAjāʾib al-makhlūqāt*) of al-Qazwīnī.
Size of the folio: 30 × 20.5 cm. By permission of the Bayerische Staatsbibliothek, Munich (Cod. Arab. 463, fol. 27b).

called the chained woman, and she is represented as a standing woman; as for Abū al-Ḥusayn al-Ṣūfī, he placed the chains around her feet, while Aratus, in describing this constellation, placed the chain around her hands, as if she were suspended by them."[153]

If this particular copy of al-Bīrūnī's writing was produced at Maragheh, as seems likely,[154] then the artist would have had access to Naṣīr al-Dīn al-Ṭūsī's Persian translation of al-Ṣūfī's treatise. The iconography, however, suggests that there were other influences at work in the artist's rendering of the constellation diagrams.

The iconography of the constellations presented by al-Ṣūfī was also incorporated into constellation diagrams in treatises that were not primarily astronomical. The most conspicuous examples are the numerous constellation diagrams found in manuscript copies of al-Qazwīnī's thirteenth-century cosmology. In this treatise al-Qazwīnī devoted considerable space to celestial phenomena, extracting entire sections on constellations from the book by al-Ṣūfī.[155]

This enormously popular encyclopedic cosmology/cosmography by al-Qazwīnī was translated into Persian, Turkish, and even Urdu, and in nearly all the preserved

153. Al-Bīrūnī, *Kitāb al-tafhīm*; see Wright's edition, 71–72 (sec. 160) (note 73); the translation is my own. For other references to al-Ṣūfī by al-Bīrūnī, see Kunitzsch, "Abu ʾl-Ḥusayn al-Ṣūfī," 59 (note 135).

154. Norah M. Titley, *Persian Miniature Painting and Its Influence on the Art of Turkey and India: The British Library Collections* (London: British Library, 1983), 17–18.

155. Kunitzsch, "Abu ʾl-Ḥusayn al-Ṣūfī," 60–61 (note 135). For al-Qazwīnī, *Kitāb ʿajāʾib al-makhlūqāt wa-gharāʾib al-mawjūdāt*, see Wüstenfeld's edition, esp. 29–41 (note 135); and see also Ludwig Ideler, *Untersuchungen über den Ursprung und die Bedeutung der Sternnamen: Ein Beytrag zur Geschichte des gestirnten Himmels* (Berlin: J. F. Weiss, 1809).

copies there are copious illustrations. The constellation diagrams in the manuscript copies vary widely in style and sophistication; some are drawn with no attempt at all to indicate the stars, showing only the animal or human mythological characters that gave rise to the constellation form (figs. 2.41 and 2.42). No systematic examination of the numerous illustrated copies of al-Qazwīnī has been undertaken.

Al-Qazwīnī made four editions of this treatise. The one that was completed in 675/1276–77 was copied and illustrated in 678/1279–80, about three years before the author's death. Primarily based on this manuscript, now in Munich, it has been concluded that al-Qazwīnī retained many of the features of al-Ṣūfī's iconography, though he used only one drawing for each constellation instead of two.[156]

Al-Ṣūfī's treatise on constellations is notable not only for providing the definitive interpretation of constellation imagery for the Islamic world, but also for discussing the indigenous Bedouin conceptions of the skies. These were presented for each constellation, with the Bedouin stars identified in terms of the Ptolemaic stars. In the star catalog that accompanied the two drawings for each constellation, however, al-Ṣūfī did not include these Bedouin stars, though in a few cases he or subsequent copyists showed them in the drawings.

## Islamic Asterism Mapping and Its Influence in Europe

The influence of the *Ṣuwar al-kawākib* by al-Ṣūfī was not limited to the Islamic world. The first four treatises in the *Libros del saber de astronomía* compiled in Castilian for Alfonso el Sabio are concerned with the fixed stars, and about A.D. 1341 an Italian translation was made in Seville.[157] The general description of the constellations and the tables of coordinates are derived from the treatise by al-Ṣūfī, who is cited by name at one point. There are forty-eight constellation drawings included in the Castilian and Italian versions, though their precise relation to those of the al-Ṣūfī tradition has not been determined.[158] Furthermore, it is not at present clear whether these vernacular versions had any subsequent influence on European constellation mapping.

There was a second point of entry of al-Ṣūfī's ideas into Europe. Nine Latin manuscripts have been identified as making up what has been called the "Ṣūfī Latinus" corpus.[159] There is considerable variation among them, and their origin and subsequent course of transmission and development are unknown. The oldest of the manuscripts was copied about A.D. 1270, possibly in Bologna.[160] It is not, however, the original Latin version but rather was copied from some now unknown earlier Latin manuscript. The manuscript presents a complete Ptolemaic star catalog, with augmented longitudes, and for each constellation it gives one drawing (sixteen as on a globe and thirty-two as in the sky). Latin versions of the discussions of Bedouin star names are missing, but the illustrations retain many distinctive features from al-Ṣūfī's treatise as it is known in the illustrated Arabic/Persian tradition. The other eight manuscripts fall into three groups that show assimilation of European material, to varying degrees, but all eight are derivative from the earliest extant Latin manuscript.[161]

The origin of this series of Latin versions remains a mystery. It represents a mixed tradition whose history is hard to trace. The Latin version of al-Ṣūfī's name employed in these manuscripts, Ebennesophy, seems never to have been used later. The twelfth-century Jewish scholar Abraham ben Meir ibn Ezra of Spain knew some form of al-Ṣūfī's treatise and called him in Latin "Azophi." It was by this name that al-Ṣūfī was subsequently known to European scholars.

By the early fifteenth century it is evident that elements of Islamic constellation mapping were available in Central Europe, although through what routes can only be conjectured. Preserved today is a Latin planispheric map drawn on parchment about 1440, probably made in Vienna. It has been argued that it is a copy of an Italian map made about ten years earlier, which in turn was based on a now lost tradition of Arabic planispheric star maps.[162] In figure 2.43 the northern hemisphere of this two-part map is illustrated. In it the northern and ecliptic Ptolemaic constellations are depicted as they would be seen on a celestial globe, with the constellations in a counterclockwise sequence. The ecliptic latitude-meas-

156. Kunitzsch, "Abu ʾl-Ḥusayn al-Ṣūfī," 60–61 (note 135). The manuscript copied in 678/1279–80 is in Munich, Bayerische Staatsbibliothek, Cod. Ar. 464; it is defective in that it is missing the sections containing Gemini to Orion.

157. *Libros del saber de astronomía*, 1:3–145 (note 46). The Italian version is extant in a unique manuscript (Rome, Biblioteca Apostolica Vaticana, MS. Lat. 8174), of which the section on the fixed stars has been edited by Pierre Knecht, *I libri astronomici di Alfonso X in una versione fiorentina del trecento* (Zaragoza: Libreria General, 1965).

158. Kunitzsch, "Abu ʾl-Ḥusayn al-Ṣūfī," 65–66 and 81 (note 135).

159. The following is based on the study by Paul Kunitzsch, "Ṣūfī Latinus," *Zeitschrift der Deutschen Morgenländischen Gesellschaft* 115 (1965): 65–74, which he updated and emended in "Abu ʾl-Ḥusayn al-Ṣūfī," 66–77 and 80–81 (note 135).

160. Paris, Arsenal, MS. 1036.

161. The illustrations in one of these "Sūfī-Latinus" manuscripts (Gotha, Forschungsbibliothek, M II, 141, dated A.D. 1428) are reproduced by Gotthard Strohmaier, *Die Stërne des Abd ar-Rahman as-Sufi* (Leipzig: Gustav Kiepenheuer, 1984).

162. Vienna, Österreichische Nationalbibliothek, MS. 5415, fol. 168r (Northern Hemisphere) and fol. 168v (Southern Hemisphere). See Zofia Ameisenowa, *The Globe of Martin Bylica of Olkusz and Celestial Maps in the East and in the West*, trans. Andrzej Potocki (Wrocław: Zakład Narodowy Imienia Ossolińskich, 1959), 38–41 and figs. 38 and 39.

FIG. 2.43. THE CONSTELLATIONS OF THE NORTHERN HEMISPHERE. These are as drawn in a Latin parchment manuscript titled *De composicione spere solide*, probably copied about A.D. 1440 in Austria.
Size of the original: 29.1 × 21.5 cm. By permission of the Österreichische Nationalbibliothek, Bild-Archiv und Porträt-Sammlung, Vienna (Cod. 5415, fol. 168r).

uring circles between the zodiacal houses, indicated by four diameters, and the equatorial polar circle are elements found on contemporaneous Islamic globes. A number of star names are Latinized versions of Arabic ones. Although the constellations reflect fifteenth-century Western styles of hair and clothes design and the figures are depicted with their backs to the viewers (apparently a feature common to Western but not Islamic globes), the iconography also retains some Islamic features. For example, the stance of Cepheus and the scimitar of Hercules arose within Islamic iconography.

Of particular interest is the rendering of the constellation Lyra as a bird with closed wings (near the head of the large flying bird Cygnus), which reflects the Bedouin zoomorphic interpretation of the star Vega rather than the Ptolemaic constellation Lyra in which it is situated. It is possible—indeed likely—that this imagery arose from the astrolabe-making tradition, where zoomorphic renderings of individual star names occurred, rather than from the treatise by al-Ṣūfī, where (as far as is known) Lyra is never represented by anything other than a musical instrument or a decorative device.

This Viennese manuscript of 1440 has a striking similarity to a celestial globe made in 1480, probably by Hans Dorn, a Dominican monk in Vienna.[163] The globe was first owned by Martin Bylica, master of Krakow University and one of the best-known astrologers of the fifteenth century. The Bedouin and Islamic features found on this globe and on the manuscript planispheric map are identical, except that here the polar circle is eliminated, the equinoctial colure is added, and Hercules has been further Westernized by restoring the skin of the Nemean lion that disappeared in Islamic iconography after its arrival from the Hellenistic world.

The parchment map of 1440 and the globe of 1480 reflect a prototype that, through a copy now lost, served as a direct source for Albrecht Dürer's woodcut celestial maps executed in 1515.[164] The Latinized Arabic star names are omitted, along with the polar circle and colure, and the star positions are adjusted to correspond to about 1499. In nearly all other respects the dependence on this prototype is evident, though the iconography has been even more Westernized by Dürer and the constellation of Lyra further developed. At Dürer's hand Lyra is rendered as a bird with a musical instrument over its body. The instrument drawn by Dürer is a forerunner of the modern violin, called in his day a *lira de braccio*. Later celestial cartographers, such as Johannes Bayer, represented the image of the bird with an instrument but drew a real lyre rather than a Renaissance *lira*.[165]

Dürer added to the corners of his map portraits of four authorities on celestial matters, each in the act of using a celestial globe. One of them is a turbaned figure labeled Azophi Arabus. By including them he acknowledged the general indebtedness of all astronomers of his day to the tradition of constellation iconography that came from the Islamic world. Yet it is still uncertain to what extent and in what form European astronomers of the fifteenth and early sixteenth centuries would have known the treatise on constellations by al-Ṣūfī.

It has been recently demonstrated that a nearly complete Arabic version of al-Ṣūfī's treatise on the constellations must have reached Germany by the 1530s, for information in it was employed in a limited way by Peter Apian, who from 1527 to 1552 was professor of mathematics at the University of Ingolstadt. Of interest here is a star map printed in Ingolstadt in 1533 as part of Peter

163. Ameisenowa, *Globe of Martin Bylica* (note 162).

164. The woodcut maps of Dürer have been frequently reproduced. See, for example, Deborah J. Warner, *The Sky Explored: Celestial Cartography 1500–1800* (New York: Alan R. Liss; Amsterdam: Theatrum Orbis Terrarum, 1979), 72–73. Compare also the set of maps drawn in Nuremberg in 1503; Ameisenowa, *Globe of Martin Bylica*, 47–55 and figs. 40 and 41 (note 162).

165. Paul Kunitzsch, "Peter Apian and 'Azophi': Arabic Constellations in Renaissance Astronomy," *Journal for the History of Astronomy* 18 (1987): 117–24, esp. 122.

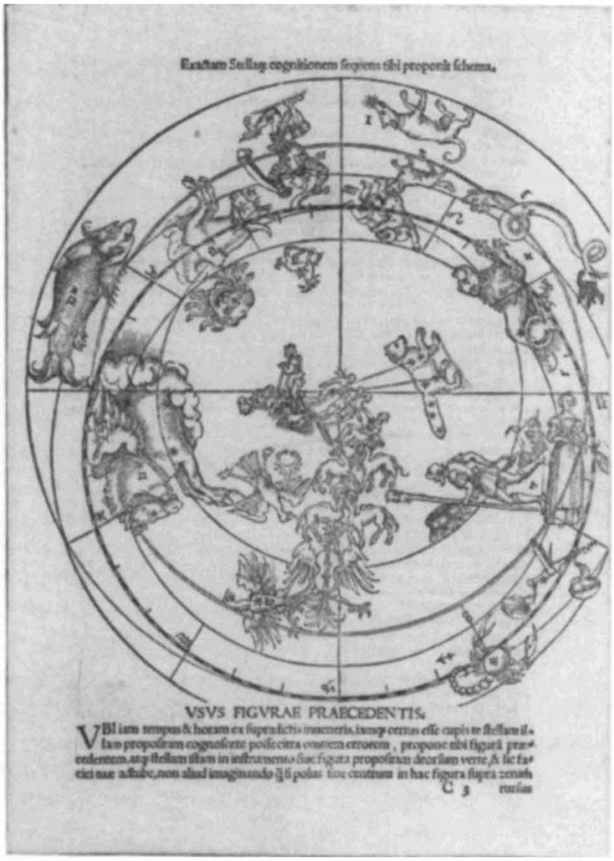


FIG. 2.44. PLANISPHERIC MAP GIVING A SELECTION OF NORTHERN AND ZODIACAL CONSTELLATIONS. Used in identifying sixteen major stars used on instruments. From Peter Apian, *Horoscopion generale* (Ingolstadt, 1533).
Size of the original: not known. Courtesy of the Library of Congress, Washington, D.C. (Rare Book Collection, QB41.A66).

Apian's *Horoscopion generale* (fig. 2.44). Produced by polar stereographic projection, it presents a selection of the northern and zodiacal constellations, oriented as seen in the sky (clockwise in sequence). The map was meant to aid an astrologer/astronomer in identifying sixteen prominent stars near the ecliptic that were used on certain instruments. What is most remarkable is its rendering of a number of Bedouin asterisms rather than Ptolemaic constellations. The stars of Cepheus are here represented as a shepherd with his sheep and dog, and camels with new foals occupy the space of our Draco. The region of Ursa Minor is occupied by three women standing in front of a fourth seated woman, the latter being his misinterpretation of the Arabic word *naʿsh*, usually translated as bier or corpse-bearing plank. These traditional Arab asterisms are not known to have been illustrated in any of the Arabic/Persian copies of al-Ṣūfī's treatise, but they are all verbally described in the text written by al-Ṣūfī to accompany the related Ptolemaic constellations.

It is evident from this star map, as well as from the star names discussed in his *Astronomicum Caesareum* of 1540, that Peter Apian knew in some form the text of al-Ṣūfī's treatise and not just the illustrations. We even know that Apian held a printing privilege issued in 1532 from the emperor Charles V to publish, in Latin presumably, "the book of the ancient astronomer Azophi" (*liber Azophi Astrologi vetustissimi*).[166] A recent historian has argued that for a brief time Apian relied on a translator to inform him of the content of al-Ṣūfī's treatise but then abandoned the project of publishing the treatise after recognizing the inadequacies of his translator.[167]

The drawing of the constellation Lyra in Apian's map of 1533, illustrated in figure 2.44, as a large bird with a violinlike instrument over its body was not Apian's invention but was taken over from Dürer's version of the constellation. It is also worth noting that in his *Astronomicum Caesareum* of 1540 Apian described the meteoroscope, a two-dimensional instrument for measuring stellar elevations that employed a form of universal astrolabe projection also derived from Arabic sources.[168]

The graphic representation of the lunar mansions through a pattern of dots also reached Europe, although not through the al-Ṣūfī constellation tradition. The term lunar mansion is not used, but patterns of dots obviously related to the twenty-eight lunar mansions are found in the Latin *Experimentarius* said to have been translated from Arabic in the twelfth century by Bernard Silvester of Tours.[169]

In the middle of the seventeenth century, a renewed interest in Arabic star names and their use on star maps is evident in a set of engraved gores for a celestial globe printed about 1630 by the Dutch mapmaker Jacob Aertsz. Colom (b. 1599), who worked in Amsterdam. On this rare set of globe gores, the names of the constellations, major stars, lunar mansions, and various circles are given in both Latin and Arabic, along with the Greek names of the Ptolemaic constellations.[170] According to an

166. Kunitzsch, "Peter Apian and 'Azophi,'" 123 (note 165).

167. A detailed account of Apian's maps and his star names, as well as possible sources, has been given by Paul Kunitzsch, "Peter Apian und Azophi: Arabische Sternbilder in Ingolstadt im frühen 16. Jahrhundert," *Bayerische Akademie der Wissenschaften, Philosophisch-Historische Klasse, Sitzungsberichte* (1986), no. 3; and Kunitzsch, "Peter Apian and 'Azophi'" (note 165).

168. North, "Meteoroscope" (note 60).

169. Savage-Smith and Smith, *Islamic Geomancy*, 39 and table 2, pp. 40–41 (note 137).

170. A possibly unique set of gores for this celestial globe (diameter 340 mm) is to be found at the Bodleian Library, Oxford, bound at the back of a treatise on the Chinese language by Jacob Golius. Regarding this celestial globe and the globe making of Colom, see Peter van der Krogt, *Globi Neerlandici: De globeproduktie in de Nederlanden* (Utrecht: HES, 1989), 179–83 (an English edition is forthcoming); see also the "globobibliography" of Peter van der Krogt, which is also forthcoming. I wish to thank Dr. van der Krogt for supplying information before publication.

inscription on the gores, the Arabic terms, which are engraved in Arabic script, were the work of one of Colom's compatriots, the Orientalist Jacob Golius (A.D. 1596–1667),[171] who made several trips to the Middle East to collect Arabic manuscripts for the University of Leiden. The terrestrial globe Colom intended as a companion piece to this celestial globe is dedicated to Golius.[172]

The constellation designs and the star positions on this set of globe gores by Colom are identical in every respect to those on the revised edition of 1603 of the earliest celestial globe designed by the Dutch cartographer Willem Janszoon Blaeu (A.D. 1571–1638).[173] The human figures are dressed for a northern European winter, with Boötes, for example, wearing a large fur hat, and in Cygnus there is clearly indicated and labeled the Nova Stella of 1600, which Blaeu had discovered on 18 August 1600. The same non-Ptolemaic constellations appear both on Blaeu's gores and on those of Colom and Golius. In the Northern Hemisphere, two constellations introduced by Mercator but based on Ptolemaic asterisms are depicted: Coma Berenices and Antinoüs, the latter being the young friend of the Roman emperor Hadrian, represented as a kneeling figure over the head of Capricorn. In the Southern Hemisphere, the new constellations of Columba Noë (Noah's dove) and El Cruzero Hispanis (the Spanish cross) are depicted along with the twelve constellations mapped by the Dutch navigators Pietr Dirksz. Keyser and Frederick de Houtman, which comprised Apous Indica (a bird of paradise), Chamaeleon (a chameleon), Vliegende Vis (a flying fish), Dorado (a goldfish), Phoenix, Grus (a crane), Pica Indica (a toucan), Hydrus (a small serpent), Indus (a native holding a spear), Pavo (a peacock), Triangulum Astrinum (the southern triangle), and Musca (a fly).

Of these non-Ptolemaic constellations, all but Coma Berenices, Antinoüs, and Vliegende Vis were given Arabic names by Golius. It is not known whether Golius himself coined the Arabic names for the newly demarcated constellations of the southern skies, but their inclusion on this set of engraved gores for a celestial globe may be the earliest recorded effort to give Arabic names to the newly outlined asterisms. The set of gores also indicates that Golius was interested in star names even before his edition and Latin translation of an astronomical compendium by the ninth-century astronomer al-Farghānī, published two years after the death of Golius and more than thirty years after the publication of the globe gores.[174] In addition, this set of gores made in Amsterdam by Colom and Golius appears to be the only known example of printed gores for a celestial globe that have Arabic star names written in Arabic script.

## Personifying and Allegorical Interpretations of Celestial Bodies

The use of the twelve zodiacal signs as emblematic motifs rather than as constellation diagrams occurs frequently in Islamic art, particularly on metalwork. No attempt is made to represent stars; rather, each sign is represented by a commonly accepted convention, such as a bull for Taurus, frequently with a hump on its back and a bell round its neck, or a man sitting cross-legged with scales over his shoulders like a yoke for the sign of Libra. I noted above that some Persian celestial globes of the seventeenth century used such designs inside medallions. The globe made for the Safavid ruler Shāh ʿAbbās I is a notable example. His contemporary, the Mughal ruler Jahāngīr, prided himself on designing a series of coins employing these motifs.[175]

The seven classical planets (moon, Mercury, Venus, sun, Mars, Jupiter, and Saturn) were frequently represented by human personifications in Islamic manuscripts as well as in metalwork and other media. The form of these personifications, except those for the sun and moon, is fairly consistent and may have derived from early Babylonian conventions.[176]

A particularly fine display of the artistic interpretation of zodiacal signs and planets is also one of the outstanding examples of manuscript production to come from early fifteenth-century Persia.[177] A double-page painting

171. "Plurimarum quoque nomina Arabica operâ Iacobi Golii partim emendata, partim nunc primum addita: Inter quae xxviii Mansiones Lunae notis Arithmet. juxta seriem suam expressae et distinctae sunt" ("through the efforts of Jacob Golius the Arabic names of most of them have been emended, with some now added for the first time, among which are the twenty-eight lunar mansions represented and distinguished by numerical notations in accordance with their sequence"). It is unclear whether Golius is correcting the Arabic terms on an earlier set of globe gores, now lost, or whether the "emendata" are corrections of the Latinized forms of Arabic names used earlier in Europe. For the life and writings of Golius, see Johann Fück, *Die arabischen Studien in Europa bis in den Anfang des 20. Jahrhunderts* (Leipzig: Otto Harrassowitz, 1955), 79–84.

172. Two of the terrestrial globes are preserved at the National Maritime Museum, Greenwich, inv. nos. G. 170 and G. 171.

173. See van der Krogt, *Globi Neerlandici*, 181–82 (note 170); for Blaeu's globe, see Warner, *Sky Explored*, 28–31 (note 164).

174. For al-Farghānī, see note 70.

175. Savage-Smith, *Islamicate Celestial Globes*, 47 (note 5). For a color photograph of the coins, see Bamber Gascoigne, *The Great Moghuls* (London: Jonathan Cape, 1971), 140.

176. Maurizio Taddei, "Astronomy and Astrology: Islam," in *Encyclopedia of World Art*, 16 vols., ed. Massimo Pallottino (New York: McGraw-Hill, 1957–83), vol. 2, cols. 69–73; Fritz Saxl, "Beiträge zu einer Geschichte der Planetendarstellung im Orient und im Okzident," *Der Islam* 3 (1912): 151–77; Eva Baer, "Representations of 'Planet-Children' in Turkish Manuscripts," *Bulletin of the School of Oriental and African Studies* 31 (1968): 526–33; Ziva Vesel, "Une curiosité de la littérature médiévale: L'iconographie des planètes chez Fakhr al-Din Râzi," *Studia Iranica* 14 (1985): 115–21. The crescent moon had a slightly separate but vigorous history in Islamic art; Richard Ettinghausen, "Hilāl: In Islamic Art," in *Encyclopaedia of Islam*, new ed., 3:381–85.

177. London, Wellcome Institute Library, MS. Persian 474. Fateme Keshavarz, "The Horoscope of Iskandar Sultan," *Journal of the Royal*

(reproduced in plate 1) represents the heavens as they were on 3 Rabīʿ I 786/25 April 1384, the birthdate of Iskandar Sultan, grandson of Tīmūr (Tamerlane) and cousin of Ulugh Beg, who undertook important astronomical observations in 841/1437–38. The large nativity book of which this horoscope is a part was prepared in 813/1410–11 by Maḥmūd ibn Yaḥyā ibn al-Ḥasan al-Kāshī, who may well have been the grandfather of Ulugh Beg's famed astronomer and mathematician Ghiyāth al-Dīn Jamshīd Masʿūd al-Kāshī.

The artist who executed the horoscope was probably not the astrologer/astronomer al-Kāshī who compiled it. In the painting the twelve zodiacal signs are represented as emblematic motifs in roundels running in counterclockwise sequence. At the top is the first house, the house of the ascendant, occupied by Capricorn. The third house, moving counterclockwise, is the house of Pisces, and in it sits the figure of Venus portrayed as a woman playing a lutelike instrument (see fig. 2.23 for a similar portrayal of Venus). In the fifth house, that of Taurus, there squats a figure wearing a gold-speckled red robe and holding a disk over its face—the personification of the sun. The adjacent segment, the sixth house occupied by Gemini, has four planetary figures represented in human form. The seated turbaned man in a blue robe reading from a bookstand is Jupiter. The squatting figure in a dark blue gown with gold dots, holding a disk over its face, represents the moon. A dark-skinned bearded man (Saturn) carries two crowns rather than an ax, which is his usual attribute. The remaining figure must be Mercury, though drawn here in an unusual manner: as a turbaned man using an astrolabe instead of in the act of writing, as he is usually portrayed. In the eleventh house, that of Scorpio, the figure of Mars can be seen, with a sword in one hand and a severed head in the other. Mars wears a helmet, as befits a warrior, but all the other planetary figures are crowned except Jupiter and Mercury, to whom Saturn seems to be bringing crowns. In the corners four angels bearing gifts complete the composition. As exquisite as this painting is, the artist did make some mistakes. According to the details of the horoscope given elsewhere in the manuscript, the sun ought to have been in the fourth rather than the fifth house, and Mercury and Jupiter should have been in the fifth instead of the sixth house.[178]

In addition to these somewhat straightforward anthropomorphic and zoomorphic representations of zodiacal signs and planets, there were astrological and allegorical interpretations of designs that combine zodiacal and planetary symbols. Two basic systems of combining the zodiacal symbols with planets were used. One system, the more favored of the two, associated the "domicile" (Arabic *bayt*) of each planet with one or more zodiacal signs. Thus the moon was most frequently associated with or domiciled in Cancer and the sun in Leo. The remaining five planets were each assigned two zodiacal signs as their domiciles; for example, Venus with Libra and Taurus, Mercury with Gemini and Virgo, and Mars with Scorpio and Aries.[179] Artisans following this system would draw Taurus as a bull ridden by a figure playing the lute (Venus), Cancer with a lunar disk, and Leo surmounted by the radiant disk of the sun. Sometimes only the sun with Leo and the moon with Cancer were illustrated, while the other zodiacal signs would be depicted without planets.

The second system combined the zodiacal signs with the "exaltation" or "dejection" of a planet. The "exaltation" (Arabic *sharaf*) was a specific point in the zodiacal sign at which a planet was at its maximum influence, and conversely the "dejection" (*hubūṭ*) was the point of minimum influence. For example, the sun had its exaltation at 19° Aries and its dejection at 19° Libra; the moon's exaltation was at 3° Taurus and its dejection at 3° Scorpio, Saturn's exaltation at 21° Libra and dejection at 21° Aries, and so forth.

The "pseudoplanet" was also part of this second scheme. This consisted of the lunar nodes, the northern and southern intersections of the moon's orbit with the ecliptic. These two points were referred to as the head (*raʾs*) and tail (*dhanab*) of the dragon (*jawzahr*). Every time a conjunction or opposition of the sun and moon occurs near these lunar nodes, a solar or lunar eclipse occurs. The lunar nodes constantly change their position with respect to the fixed stars. Astrologers came to interpret the "dragon" as another planet, bringing the total number of planets to eight. The pseudoplanet was associated particularly with Sagittarius and Gemini, and this association is reflected in its artistic interpretation.[180] Two illustrations from a Turkish manuscript copied in 990/

*Asiatic Society of Great Britain and Ireland*, 1984, 197–208; Laurence P. Elwell-Sutton, "A Royal Tīmūrid Nativity Book," in *Logos Islamikos: Studia Islamica in Honorem Georgii Michaelis Wickens*, ed. Roger M. Savory and Dionisius A. Agius (Toronto: Pontifical Institute of Mediaeval Studies, 1984), 119–36.

178. See Elwell-Sutton, "Nativity Book," 129 and 135 n. 13 (note 177); I do not agree that the figure in the fifth house must be Jupiter.

179. For an example of a thirteenth-century mirror with zodiacal signs shown with the planets domiciled in each, see Ettinghausen and Grabar, *Art and Architecture*, 364 (note 1). See also Willy Hartner, "The Pseudoplanetary Nodes of the Moon's Orbit in Hindu and Islamic Iconographies," *Ars Islamica* 5 (1938): 112–54, esp. 115–17; reprinted in Willy Hartner, *Oriens-Occidens: Ausgewählte Schriften zur Wissenschafts- und Kulturgeschichte*, 2 vols. (Hildesheim: Georg Olms, 1968 and 1984), 1:349–404.

180. Hartner, "Pseudoplanetary Nodes" (note 179); Willy Hartner, "D̲jawzahar," in *Encyclopaedia of Islam*, new ed., 2:501–2; and idem, "The Vaso Vescovali in the British Museum: A Study on Islamic Astrological Iconography," *Kunst des Orients* 9 (1973–74): 99–130; reprinted in Willy Hartner, *Oriens-Occidens: Ausgewählte Schriften zur Wissenschafts- und Kulturgeschichte*, 2 vols. (Hildesheim: Georg Olms, 1968 and 1984), 2:214–45.

1582–83 show very graphically the exaltation and dejection of Mars, the sun, the moon, and the "dragon."[181]

Some have maintained that whenever the tail of the centaur in the constellation Sagittarius is drawn with a knot and a dragon's head at the tip of the tail, the reference is to the lunar node called the tail of the dragon, whose exaltation was thought to be in Sagittarius.[182] Such a rendering of Sagittarius can be seen in the horoscope prepared for Iskandar Sultan illustrated in plate 1, the drawing of Sagittarius in the al-Qazwīnī manuscript illustrated in figure 2.41, and the constellation as shown on the clockface design for al-Jazarī's water clock shown in figure 2.24.

Anthropomorphic and zoomorphic figures were also associated with the twenty-eight lunar mansions. These can be seen on the astrolabe made by ʿAbd al-Karīm al-Miṣrī in 633/1235–36 as well as in a number of manuscripts.[183] The history of these curious figures has not been traced.[184]

Occasionally on Mesopotamian and Syrian metalwork of the twelfth and thirteenth centuries a ruler assumes the mantle of the sun and in this cosmic setting is surrounded by the other six planets and the zodiacal signs.[185] Celestial symbolism was an obsession of the early Mughal rulers of northwestern India. Humāyūn (d. 963/1556), well known for his interest in astrology, had a tent designed to resemble the twelve zodiacal houses and dressed his attendants in uniforms with symbols of the planets.[186] His son and successor Akbar I took solar symbolism even more seriously and claimed descent from the sun. Consequently it is not surprising to find a number of allegorical paintings of the grandson Jahāngīr assuming the mantle of the sun.

In a painting made about A.D. 1618–22, the Mughal emperor Jahāngīr embraces the Persian emperor Shāh ʿAbbās I, while behind Jahāngīr there is a large and brilliant disk of the sun, with a lunar crescent beneath supported by two putti (see fig. 17.12, below). The illustration portrays a dream of Jahāngīr's, probably reflecting anxieties over tensions between the two great empires of India and Persia.[187] The two rulers stand on two animals of the Golden Age that rest on the globe of the earth. The lion Jahāngīr stands on extends over a considerable part of Persia, which is labeled beneath the lion's paws. The city of Tabriz, the former capital of the Safavid Empire, is labeled just beneath the head of the lamb under the feet of Shāh ʿAbbās I. The encroaching of the lion into the territory of the lamb suggests that the artist was trying to reflect an expansionist dream of Jahāngīr, who as a ruler cloaked by the heavens would dominate the earth beneath.

## The Introduction of Early Modern European Celestial Mapping

It is in the workshop of an instrument maker in seventeenth-century Persia that the earliest interest in early modern European celestial mapping is displayed. Muḥammad Mahdī al-Khādīm ibn Muḥammad Amīn al-Yazdī, a well-known astrolabe maker of Yazd, southeast of Isfahan, is known to have produced over twenty astrolabes between A.D. 1640 and 1670.[188] An astrolabe made by Muḥammad Mahdī in 1065/1654–55 has two plates with engraved star maps of the Northern and Southern Hemispheres (figs. 2.45 and 2.46). The maps are polar stereographic projections with the ecliptic pole at the center and the periphery formed by the ecliptic. Each plate has the ecliptic latitude-measuring circles shown every thirty degrees as well as the equatorial polar circle, the tropic circle, and the appropriate part of the equator. In addition, the astrolabe's northern hemisphere has the equinoctial colure and is graduated by single degrees

181. New York, Pierpont Morgan Library, MS. 788, a Turkish astrology titled *Kitāb maṭāliʿ al-saʿādah wa-manāfiʿ al-siyādah*; this manuscript is closely related to one copied in the same year, now at Paris, Bibliothèque Nationale, MS. Suppl. Turc 242, and also to one at Oxford, Bodleian Library, Department of Oriental Books and Manuscripts, MS. Bodl. Or. 133, item 1.

182. Hartner, "Pseudoplanetary Nodes," 135–38 and corresponding figs., reprint 381–84 (note 179).

183. For the astrolabe, see note 139. For some manuscripts, see New York, Pierpont Morgan Library, MS. 788, fols. 33b–34a, and Paris, Bibliothèque Nationale, MS. Suppl. Turc 242, fols. 34b–35a; Hartner, "Vaso Vescovali," 124–28, reprint 240–43 (note 180).

184. For talismanic use of lunar mansions in both Arabic and Latin traditions, see Kristen Lippincott and David Pingree, "Ibn al-Ḥātim on the Talismans of the Lunar Mansions," *Journal of the Warburg and Courtauld Institutes* 50 (1987): 57–81, and Kristen Lippincott, "More on Ibn al-Ḥātim," *Journal of the Warburg and Courtauld Institutes* 51 (1988): 188–90.

185. Eva Baer, "The Ruler in Cosmic Setting: A Note on Medieval Islamic Iconography," in *Essays in Islamic Art and Architecture: In Honor of Katherina Otto-Dorn*, Islamic Art and Architecture, vol. 1, ed. Abbas Daneshvari (Malibu, Calif.: Undena, 1981), 13–19 and pls. 1–14; James W. Allan, *Islamic Metalwork: The Nuhad es-Said Collection* (London: Sotheby, 1982), esp. 23–25; Ettinghausen and Grabar, *Art and Architecture*, 362–64 (note 1).

186. William A. Blanpied, "The Astronomical Program of Raja Sawai Jai Singh II and Its Historical Context," *Japanese Studies in the History of Science*, no. 13 (1974): 87–126, esp. 112.

187. Washington, D.C., Freer Gallery of Art, Smithsonian Institution, acc. no. 45.9. For a discussion of this and similar paintings, see Robert Skelton, "Imperial Symbolism in Mughal Painting," in *Content and Context of Visual Arts in the Islamic World: Papers from a Colloquium in Memory of Richard Ettinghausen, Institute of Fine Arts, New York University, 2–4 April 1980*, ed. Priscilla P. Soucek (University Park: Published for College Art Association of America by Pennsylvania State University Press, 1988), 177–91 (figs. 1–5).

188. See Gibbs with Saliba, *Planispheric Astrolabes*, 17, 65–68, 79–82, 224 n. 44, and 225 n. 54 (note 15); Mayer, *Islamic Astrolabists*, 70–71 (note 139); Turner, *Astrolabes*, 86–91 (note 19); and Brieux and Maddison, *Répertoire* (note 36).

FIG. 2.45. CONSTELLATIONS OF THE NORTHERN HEMISPHERE ON AN ASTROLABE PLATE MADE IN 1065/1654-55 BY MUḤAMMAD MAHDĪ OF YAZD.
Diameter of the original: 16.2 cm. Present owner unknown. Photograph courtesy of the Ahuan Islamic Art Gallery, London.

FIG. 2.46. CONSTELLATIONS OF THE SOUTHERN HEMISPHERE ON AN ASTROLABE PLATE MADE IN 1065/1654-55 BY MUḤAMMAD MAHDĪ OF YAZD.
Diameter of the original: 16.2 cm. Present owner unknown. Photograph courtesy of the Ahuan Islamic Art Gallery, London.

along half of the solstitial colure. The sequence of constellations is counterclockwise, representing the projection of a globe. The iconography is completely European—human figures either nude or wearing European clothing and drawn with their backs to the user. A leaf-shaped cartouche in the northern hemisphere has the following statement in Persian: "Since there are contradictions in the locations of the fixed stars among previous scholars, and because the most accurate [star maps] are in the observatories of the Franks [western Europe], the locations of the fixed stars are shown here according to authoritative observations made within the past ten years."[189]

The plates of this astrolabe are remarkable within the Islamic world in showing for the first time the new mappings of the southern constellations after the European explorations of the sixteenth century. The non-Ptolemaic constellations of Columba Noë and those mapped by the Dutch navigators Keyser and Houtman can be seen in the southern hemispheric map engraved by Muḥammad Mahdī. Notable as well is the depiction in the Northern Hemisphere of the non-Ptolemaic forms of Coma Berenices and Antinoüs and the rendering of Lyra, which here is a bird combined with a lyrelike instrument. With this astrolabe by Muḥammad Mahdī we have the introduction into the Islamic world of a European rendering of a Bedouin asterism, or more precisely a Bedouin star name, that was not previously illustrated in Islamic constellation drawings.

These planispheric star maps engraved by Muḥammad Mahdī in 1654 are virtually identical to the map printed about 1650 by the Parisian mapmaker Melchior Tavernier,[190] illustrated in figures 2.47 and 2.48. The similarity between Tavernier's map and Muḥammad Mahdī's plates extends even to the unexplained omission of one of Keyser and Houtman's constellations (Musca, the fly). Furthermore, Columba Noë, which was to represent Noah's dove in front of the ship, is drawn on both as an unnamed triangular device. Muḥammad Mahdī has, of course, rendered the Ptolemaic constellation names into Arabic and placed his leaf-shaped cartouche exactly where Tavernier

189. *Islamic Science and Learning, Washington, D.C., July 1989*, exhibition catalog (Saudi Arabia: High Commission for the Development of Arriyadh, 1989), 14. The translation is taken from that given in the exhibition catalog. The present location of this astrolabe is unknown.

190. Warner, *Sky Explored*, 248-49 (note 164). The map by Tavernier is undated. This Melchior Tavernier (the Younger) was born in Paris in 1594 and died there in 1665. He was the son of Gabriel Tavernier, also an engraver and a seller of maps, and is often confused with his uncle Melchior Tavernier, who was born in 1564, the second son of a Huguenot artist who emigrated to France. Both Melchiors were mapmakers, and both were engravers for the king. See *Nouvelle biographie générale depuis les temps les plus reculés jusqu'à nos jours*, 46 vols. (Paris: Firmin Didot Frères, 1852-66), 44:934-35.

FIG. 2.47. CONSTELLATIONS OF THE NORTHERN HEMISPHERE ON A PLANISPHERIC STAR MAP PRINTED IN PARIS ABOUT 1650 BY MELCHIOR TAVERNIER. This star map was probably transported to Persia in 1651 by the traveler Jean-Baptiste Tavernier, brother of the mapmaker Melchior Tavernier, and was clearly the design model employed by Muḥammad Mahdī for his astrolabe plate made in 1654 and illustrated in figure 2.45.
Diameter of the original: 26.5 cm. By permission of the Bibliothèque Nationale, Paris.

FIG. 2.48. CONSTELLATIONS OF THE SOUTHERN HEMISPHERE ON A PLANISPHERIC STAR MAP PRINTED IN PARIS ABOUT 1650 BY MELCHIOR TAVERNIER. See also figure 2.47.
Diameter of the original: 26.5 cm. By permission of the Bibliothèque Nationale, Paris.

earlier gave his name as mapmaker. In contrast with Golius's collaborative effort with the Dutch mapmaker Colom, printed in Holland some years earlier, Muḥammad Mahdī did not attempt to give Arabic names to the non-Ptolemaic constellations, except for the southern triangle and Pavo, the peacock, whose Arabic name, *ṭāwūs*, was a common word for an easily recognized bird.[191]

Another Parisian mapmaker, Antoine de Fer (d. 1673), worked just across the Seine from Melchior Tavernier, and his map, printed in 1650, is remarkably similar to that of Tavernier, but with the names in French instead of Latin. So great is the similarity between these French celestial maps and the astrolabe plates made in Yazd that it seems certain either Tavernier's or de Fer's map was carried to Persia shortly after it was printed and was virtually copied in Yazd by the astrolabe maker Muḥammad Mahdī.

It is likely that the means by which the European map—most likely that engraved by Melchior Tavernier—was transmitted to Persia so soon after its publication was the traveler Jean-Baptiste Tavernier, brother of Melchior. Jean-Baptiste, who was born in Paris in 1605, made six trips to the Near East before his death in 1689.[192] His fourth trip extended from 1651 to 1655, at precisely the appropriate time for him to transport the map of his brother, printed about 1650, to Persia, where it attracted the attention of one of the most proficient Safavid astrolabe makers.

During the seventeenth century, contacts with Europe were numerous and at many different levels. Shāh ʿAbbās I, who ruled from 996/1588 to 1038/1629, established diplomatic relations with Europe, and there was considerable interchange between the Safavid court and the courts of Elizabeth I and James I of England, Philip II of Spain, Ivan the Terrible of Russia, and the Mughal emperors of India. Travelers and merchants frequented the area, although France had little contact with Persia until the end of the 1620s. With such an exchange of

191. There are other differences as well between the Arabic labels on Muḥammad Mahdī's plate and those prepared by Golius for the European gores. In addition to some differences in spelling, Muḥammad Mahdī included considerably more star names than Golius did but omitted the lunar mansions. Muḥammad Mahdī, following Tavernier, also omitted the depiction of the constellation El Cruzero Hispanis.

192. *Encyclopaedia Britannica*, 11th ed., s.v. "Tavernier, Jean Baptiste." The accounts of his travels were published in 1676, with an English version in 1678, though no mention is made in them of astrolabes or star maps; *The Six Voyages of John Baptista Tavernier, a Noble Man of France Now Living, through Turkey into Persia, and the East-Indies, Finished in the Year 1670*, trans. John Phillips (London: Printed for R. L. and M. P., 1678).

peoples, it is not surprising that an early modern European celestial map would be transported to Persia by a traveler from a family of mapmakers and that it would attract the attention of an instrument maker from Yazd who made products for the court.[193]

What is perhaps unexpected is that these astrolabe plates by Muḥammad Mahdī appear to be the whole extent of the interest in the matter. Muḥammad Mahdī is known to have made two other astrolabes with similar plates having planispheric star maps, both produced in 1070/1659–60 and clearly copies of the earlier plate, though not quite as carefully engraved.[194] His plates appear to have had no subsequent influence in instrument design, either in celestial globes or in astrolabes, and as far as is known no other planispheric maps were drawn that represent these newly outlined constellations and stars until the nineteenth century.

In the seventeenth and eighteenth centuries the tastes and fashion at the Ottoman court were also affected by exchanges with western European courts. European influence is evident in the iconography of individual constellations that were painted in 1104/1692–93 to illustrate a Turkish translation of an Arabic encyclopedia written originally in the fifteenth century by Abū Muḥammad Maḥmūd ibn Aḥmad al-ʿAynī (d. 855/1451–52). The first part of this three-volume manuscript has individual constellation figures depicted with a definite European style of hair, dress, and figural delineation, but it appears that only Ptolemaic constellations were included.[195]

These seventeenth-century introductions of early modern celestial mapping were apparently premature. It is not until the nineteenth century that any further interest in the new stars and constellations can be discerned. In 1218/1802–3 Arabic versions of the planispheric celestial maps printed in 1660 by the Dutch cartographer Andreas Cellarius (b. ca. 1630) were published. The two maps—which, like the original Dutch maps, employed polar stereographic projections—were part of a Turkish atlas of the world published in the Üsküdār district of Istanbul by ʿAbd al-Raḥmān Efendī.[196] Yet even with these new maps made available in the Near East, celestial mapping remained through most of the nineteenth century steadfastly Ptolemaic and medieval in concept.

It is fitting to end this survey of Islamic celestial mapping with a magnificent manuscript produced in India in the first half of the nineteenth century.[197] It represents well the ambivalence of Islamic astronomers/astrologers schooled in a tradition with roots that extend to antiquity and yet faced with modern European concepts. The term Islamic, of course, is here used in the general cultural rather than religious sense, for the volume presents a horoscope of the prince Nau Nihāl Singh of Lahore (1821–40), grandson of Ranjit Singh, the important leader who united the Sikhs in their bid for power. It also contains in its 293 folios a great deal of general information on astrology and astronomy and a large number of illustrations and miniatures. The name of the artist is unfortunately not known. The author of the volume was Durgāshaṅkara Pāṭhaka, a famous astronomer of Benares, who wrote the treatise in Sanskrit sometime before 1839.

In this manuscript there are two different sets of planispheric star maps. One set (figs. 2.49 and 2.50) shows the Ptolemaic constellations. Most of the iconography retains elements of Mughal renderings of constellations that can be seen on celestial globes from northwestern India. A few of the constellations, however, have been given more identifiably Indian interpretations. The style of painting is in general consistent with that of a late Mughal provincial workshop.[198]

The projections employed in these Ptolemaic planispheric maps are unusual. They represent a view of a celestial globe with one of the equinoxes at the center of each hemisphere. The southern polar circle is lightly indicated on each, as are the equator and the equinoctial colures formed by two diameters intersecting at right angles. From the south pole there can be seen lightly inscribed arcs and one straight line, which represent the ecliptic latitude-measuring circles at every thirty degrees.

193. Other European influences on instrument design can be observed at this time as well, such as a Rojas universal astrolabe projection engraved on an instrument made for the Safavid ruler Shāh Ḥusayn, who ruled from 1105/1694 to 1135/1722 (see note 79). On European contacts with Persia, see Laurence Lockhart, "European Contacts with Persia, 1350–1736," in *The Cambridge History of Iran*, vol. 6, *The Timurid and Safavid Periods*, ed. Peter Jackson and Laurence Lockhart (Cambridge: Cambridge University Press, 1986), 373–411, though it should be noted that Lockhart incorrectly refers to Tavernier as a jeweler and the son of a jeweler when in fact he was a mapmaker who married the daughter of a jeweler.

194. Greenwich, National Maritime Museum, inv. no. A64/69-6, and the University of Cambridge, Whipple Museum of the History of Science, inv. no. 1001. Both of these astrolabes were made in the same year, 1070/1659–60, for on the rete of both instruments there is the statement in Persian, "It is the mirror of Alexander and the mirror representing the entire universe," forming a chronogram that yields the date 1070 by adding the numerical values of the letters forming the statement. Not very good tracings of the plates now at the Whipple Museum are given in Gunther, *Astrolabes of the World*, 1:49 (note 2).

195. Istanbul Üniversitesi Kütüphanesi, MS. TY. 5953; see Nasr, *Islamic Science*, 101 (pl. 47) (note 123) for an illustration. A number of illustrations from a later copy of this manuscript made in 1160/1747 (Istanbul, Topkapı Sarayı Müzesi Kütüphanesi, MS. B. 274) are reproduced in *The Topkapi Saray Museum: The Albums and Illustrated Manuscripts*, translated, expanded, and edited by J. M. Rogers from the original Turkish by Filiz Çağman and Zeren Tanındı (Boston: Little, Brown, 1986), pls. 177–81.

196. See Warner, *Sky Explored*, 280–81 (note 164). There is a copy at the Royal Geographical Society in London that contains these celestial maps. They are, however, frequently missing from copies of this Ottoman atlas.

197. London, British Library, MS. Or. 5259.

198. J. P. Losty, *Indian Book Painting* (London: British Library, 1986), 78–79.

FIG. 2.49. HEMISPHERIC MAP OF PTOLEMAIC CONSTELLATIONS WITH THE AUTUMNAL EQUINOX AT THE CENTER. From the Sanskrit manuscript *Sarvasiddhāntatattvacūḍāmaṇi* (Jewel of the essence of all sciences), written before 1839 by Durgāshaṅkara Pāṭhaka, an astronomer of Benares.
Size of the original: 21.5 × 17.5 cm. By permission of the British Library, London (MS. Or. 5259, fol. 56v).

FIG. 2.50. HEMISPHERIC MAP OF PTOLEMAIC CONSTELLATIONS WITH THE VERNAL EQUINOX AT THE CENTER. From the same Sanskrit manuscript as fig. 2.49.
Size of the original: 21.5 × 17.5 cm. By permission of the British Library, London (MS. Or. 5259, fol. 57r).

The Milky Way is also shown on the map, a very unusual feature in Islamic cartography.

Near these two medieval Islamic star maps, the author has placed two early modern European planispheric star maps, illustrated in plate 2 and figure 2.51. The maps are polar stereographic projections with the equatorial pole at the center and the equator at the periphery. The sequence of constellations on the northern map is as seen on a globe, that is, counterclockwise, but on the southern map the maker has also drawn the constellations in a counterclockwise sequence, which for the southern hemisphere produces a map of stars as seen in the sky. The polar and tropic circles are indicated concentric to the center of projection. In the northern hemisphere the equinoctial colure is drawn through the equatorial pole; this is omitted in the southern hemisphere. Ecliptic latitude-measuring circles at ten-degree intervals are shown radiating from the ecliptic pole.

Though the faces of some of the human figures, particularly the women, have been painted in the style of late provincial Mughal artists, the maps are clearly close renderings of a European model. The maps of Johannes Hevelius (1611–87), a Danish astronomer, most closely resemble these maps in the selection and iconography of the constellations. The style of projection is similar to that used by the Parisian astronomer Noel André (d. 1808), also known as Father Chrysologue de Gy.[199] Numerous non-Ptolemaic constellations are depicted in this set of maps, including Antinoüs, Coma Berenices, Columba Noë, the twelve of Keyser and Houtman, and the nine devised by Hevelius. These latter include two dogs on a leash held by Boötes (Canes Venatici), the small lion over Leo (Leo Minor), and the lynx in front of Ursa

199. For Johannes Hevelius, see Warner, *Sky Explored*, 112–16 (note 164). The maps of Georg Christoph Eimmart (1638–1705) of Nuremberg, Pieter Schenck (1660–1718/19) of Amsterdam, and Tobias Conrad Lotter (1717–77) of Augsburg are also similar; Warner, *Sky Explored*, 76–77, 222–23, and 164. For Noel André, see Warner, *Sky Explored*, 4–6 (note 164).

FIG. 2.51. PLANISPHERIC MAP SHOWING SOUTHERN CONSTELLATIONS. As in plate 2, this planispheric map is from the *Sarvasiddhāntatattvacūḍāmṇi.*
Size of the original: ca. 21 × 17.5 cm. By permission of the British Library, London (MS. Or. 5259, fol. 60r).

Major. The form of Cameleopardus can be seen over the head of Ursa Major.

The four hemispheric star maps that this nineteenth-century artist working in Benares produced to accompany a horoscope and general astronomical compendium show the later phase of medieval Islamic astronomy giving way, reluctantly and uneasily, to the European approach to celestial mapping. The workshop of Balhūmal, operating in Lahore at the same time, displayed even greater conservatism, for on none of its celestial globes are there any but the Ptolemaic constellations and stars (filtered through Arabic/Persian versions). One of the products of the Balhūmal workshop, a globe engraved in Sanskrit, is illustrated in figure 2.31. The addition of a set of meridian circles at right angles to the equator indicates some exposure to a possibly European model, and certainly the workshop excelled in producing technically precise instruments. By the last quarter of the nineteenth century, however, the Balhūmal workshop had stopped functioning, and the last traces of medieval Islamic celestial mapping disappeared.

It was not until the nineteenth century that early modern European ideas on celestial mapping made a profound impact upon the practices in Islamic lands. At first such approaches were mixed with the older medieval traditions, but by the end of the nineteenth century little trace of medieval Islamic celestial mapping could be detected. The older tradition represented primarily the Ptolemaic conceptualization of the skies, with some elements introduced from pre-Islamic Bedouin customs. Although celestial iconography formed an important part of the corpus of medieval miniatures, the interest in celestial mapping in medieval Islam was expressed primarily through instrument design. Though a substantial number of treatises dealt with the principles of planispheric projection, particularly that of stereographic projection, there are not known to be extant today any medieval Islamic celestial maps other than those in architectural remains or on scientific instruments. Yet from these remaining artifacts it is possible to detect a vigorous interest in the subject from the earliest days of Islam during the Umayyad caliphate in Syria, to the Muslim scientific communities of southern Spain in the eleventh and twelfth centuries, to the Safavid Persian empire with its interest in European ideas, and finally in the ornate products of western India, where the last vestiges of medieval celestial mapping gave way to non-Ptolemaic modern European techniques.