Astronomy and navigation

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For human beings on earth, one of the best views one can have of the celestial vault with its myriad stars is from truly dark places, far from artificial lights and free from any obstacles, such as on the huge surface of the oceans or in vast deserts.

In such locations, the absence of any significant natural landmarks offers an unobstructed view but also makes it necessary to find a specific means of determining one's position and direction. Probably from the dawn of humanity, the stars have been used for this purpose. Astronomy and navigation are therefore linked together, deep in human history.

In European culture, a famous early account of navigation by the stars is provided by the *Odyssey*, the evocative 8th-century BCE poem attributed to Homer, describing the voyage of Odysseus (Ulysses), guided by the goddess Calypso: 'He [Odysseus] sat and guided his raft skilfully with the steering-oar, nor did sleep fall upon his eyelids, as he watched the Pleiades, and late-setting Boötes, and the Bear, which men also call the Wain....For this star, Calypso, the beautiful goddess, had bidden him to keep on the left hand as he sailed over the sea.'

Relatively precise navigation is possible by the observation of the stars without the need for any instruments. Modern expeditions have completed the 4,000-km (2,500-mile) journey from Tahiti to Hawaii in about a month in this manner using a 19-m (60-ft) double-hulled Polynesian canoe equipped with sails, thus illustrating the way the different Pacific islands were colonized from about 3,000 years ago. The technique is called 'sailing down the latitude': that is, in this case, sailing approximately


النقد وكان قد ثم أخذ في مواعدة أهل الخان وإعداد
حلواء الجوزاء فلما مد الليل أطنابه وأغلق كل ذي باب
بابه أذن في الجماعة أن احضروا في هذه الساعة فلم يبق منهم
امرؤ إلا لبى صوته ثم حضر بيته فلما اصطفوا لديه واجتمع الشاهد
والمشهود عليه جعل يرفع الأصطرلاب ويضعه ويلحظ النجوم ويدعي

The Dunhuang star chart

This manuscript is the world's oldest complete preserved star chart (British Library, Or.8210/S.3326). It was discovered in 1900 in a hidden sealed cave among the Buddhist rock-cut temples at Mogao, near the Silk Road town of Dunhuang on the northwest border of China [*see* box on p. 138], but it was almost certainly produced in the Chinese capital, Chang'an [*see* box on p. 286]. Astronomy was strictly controlled by the imperial court as the movements of the stars and planets were believed to be linked to events on earth; so, for example, an eclipse might be interpreted as a result of immoral acts of an emperor and used to justify rebellion.

The well-preserved star chart is on a scroll made of extremely thin paper, with a total length of 210 cm (83 in.) and a width of 25 cm (10 in.). It shows more than 1,300 stars grouped into 257 named Chinese constellations. It displays the full sky visible from China, rigorously organized into twelve equatorial panels, one shown here, complemented by a circular map of the North Polar region. A detailed scientific study has shown that the positions of the brightest stars are surprisingly accurate to within a few degrees, in accordance with a rigorous projection similar to modern ones, such as that of the Flemish cartographer Gerardus Mercator (1512–1594).

The chart has been dated to around 700 CE and, from a mention in the text, its most probable author was Li Chunfeng (602–670), an astronomer of the early Tang dynasty (618–907). It is unknown how it ended up on the borders of China. JMBB

Further reading: Bonnet-Bidaud et al. 2009; Whitfield 1995.

Previous spread — Illustrated edition of al-Hariri's *Maqamat* showing the teaching of the use of the astrolabe.

Right — Illustration from a 15th-century manuscript of Marco Polo's *Travels*, showing a mariner on a *nau* using a magnetic compass. The stars are also depicted.

north until a precise latitude is reached and then steering west keeping the same latitude. The latitude can be estimated quite accurately by the elevation above the horizon of a given star or constellation, such as the distinctive Southern Cross. As any given star always rises or sets on the horizon at the same fixed azimuth, the stars form a natural compass. Arab and Chinese navigators used this 'star compass' to cross the Indian Ocean. Around the equator, the star rising-setting directions only slowly change with latitude and therefore can be used for long-term navigation. This 'astronavigation' has of course to be complemented by solar observations during the day and also by the ability to keep course with respect to waves and currents and to locate land by cloud observations and birdwatching.

As sky configuration and star identifications would otherwise have to be memorized, this probably led to the first star charts. The earliest extant manuscript star map, incorporating the traditional Chinese constellations, was found in Dunhuang [*see* box opposite]. During the Islamic expansion, Persian-Arabic astronomers such as al-Sufi (903–986 CE) designed detailed inventories of constellations such as the *Book of Fixed Stars* [*see* box below].

Navigation by eye is, however, limited in accuracy and, with increased maritime exchanges, navigational instruments were soon introduced. In any location, precise latitude can be estimated by the altitude above the horizon of the celestial North Pole, which lies close to the Polaris star. For this measure, Arab seafarers first used different types of quadrant, basically a graduated quarter-circle with a plumb line attached to the centre. With one edge aligned towards Polaris, the vertical plumb line marked the elevation angle on the graduated scale.

Contrary to what is often stated, the complex astrolabe was not directly used for navigation but was adapted into a simplified version, the sea or mariner's astrolabe. One of the most precious specimens, a finely graduated 17.5-cm (6.9-in.)

The *Book of Fixed Stars*

The *Book of Fixed Stars* (Kitāb al-Kawākib al-Thābita) is the earliest known document providing a complete description of the Arabic stellar constellations. It was composed around 964 CE by the Persian astronomer ʻAbd al-Rahman al-Sufi (903–986 CE).

The Arabic text gives a deeply revised version of the star catalogue included in the *Almagest* (*Mathematika Syntaxis*), an astronomical treatise composed by the Greek-Roman Ptolemy (*c.* 100–170 CE) [*see* pp. 24–25]. It includes fifty-five astronomical tables listing the ecliptic coordinates of 1,022 stars, taking into account precession. Charts corresponding to forty-eight different constellations are also presented in two different forms, one as seen in the sky, the other as a mirror version seen from above as depicted on a celestial globe. The figure of each constellation is drawn bearing Arabic star names.

The original copy of al-Sufi's manuscript is no longer extant. The oldest version is thought to be the manuscript MS. Marsh 144 (Bodleian Library, Oxford). It is dated 1009 CE by its colophon, which states that it was composed by al-Sufi's son, but some parts may have been added up to more than a century later. The manuscript shown here is a late 15th-century copy (Metropolitan Museum of Art, 13.160.10) showing Cepheus (right, and then below from left to right), Cassiopeia, Andromeda B, Sagittarius, Argo Navis and Draco. JMBB

Further reading: Hafez 2010; Schjellerup 1874.

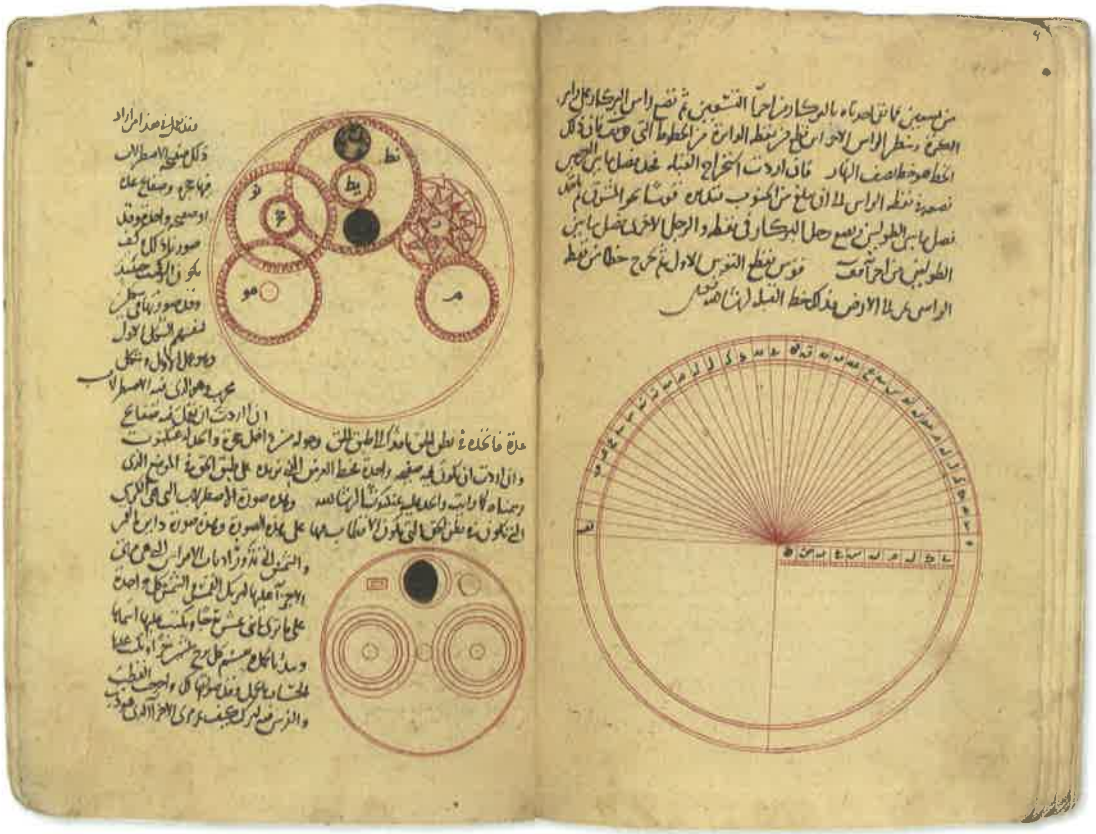
Nasṭūlus astrolabe

The earliest known astrolabe is an Islamic planispheric instrument precisely dated 927/928 CE (315 AH) and preserved in the Kuwait National Museum (LNS 36 M). The 20-cm (8-in.) diameter disc is made of cast brass and the maker's name and date of manufacture are indicated below the suspension ring: 'Made by Nasṭūlus in the year 315', with the date given in the year of the Hijra. Little is known of Nasṭūlus, who can possibly be identified as the astronomer Muḥammad ibn 'Abd Allāh, working in Baghdad [*see* box on p. 336].

The astrolabe is a complex instrument designed primarily to compute date and time from the stars or sun altitudes and vice versa. The front face realized a stereographic projection of the celestial sphere. It is made of a background plate (the mater) graduated in altitude and azimuth on which is superposed a rotating hollowed disk (the rete) bearing pointers representing a number of fixed stars. On the back, a rotating bar with two aligned sights (the alidade) allows star altitudes to be measured when the astrolabe is held vertically, suspended by its ring on the top (the throne).

The astrolabe was intensively used in the Islamic caliphate to schedule Muslim prayers, find the direction of Mecca and for navigation. For this last purpose, however,, a simplified version was developed by the 15th century, if not before; this was the mariner's astrolabe, which had parts of the disc cut away to reduce wind resistance on ships.
JMBB

Further reading: King 1987; Morrison n.d.; Stimson 1988; Whitfield 1995.



Al-Bīrūnī' (973–1050), an astronomer and mathematician working in the Ghaznavid court, wrote a treatise on the astrolabe, including descriptions of those invented by Nasṭūlus [*see* box above]. This is a 13th-century copy of this work, produced in Persia or Anatolia.

diameter bronze disc, was excavated in 2014 in the wreckage of *Esmeralda*, a Portuguese ship from Vasco da Gama's fleet, which sank in 1503 off the Oman coast. The magnetic compass invented in China was used concurrently to provide steering directions when no star was visible, as attested in China from around 1100 CE.

With a one-degree error in latitude translating into a distance of 111 km (69 miles), early astronomical instruments were of limited accuracy. The Europeans improved the technique of astronavigation with the use of the more elaborate sextants, able to measure angular distances down to one hundredth of a degree. Finally, the inception of stable marine chronometers, starting in 1773, solved the long-standing problem of the longitude measure, allowing a precise location also in the east-west direction.

Further reading: de Saussure 1928; Ferrand 1928; King 1987; Kyselka 1987; Mörzer Bruyns & Dunn 2009; Thompson 1980.

Above left — Part of the observatory in Samarkand built in the 1420s by the astronomer Ulugh Beg (1394–1449).

Left — A mariner's astrolabe recovered from the *Esmeralda*, part of Vasco da Gama's fleet that sunk off the coast of Oman in 1503.