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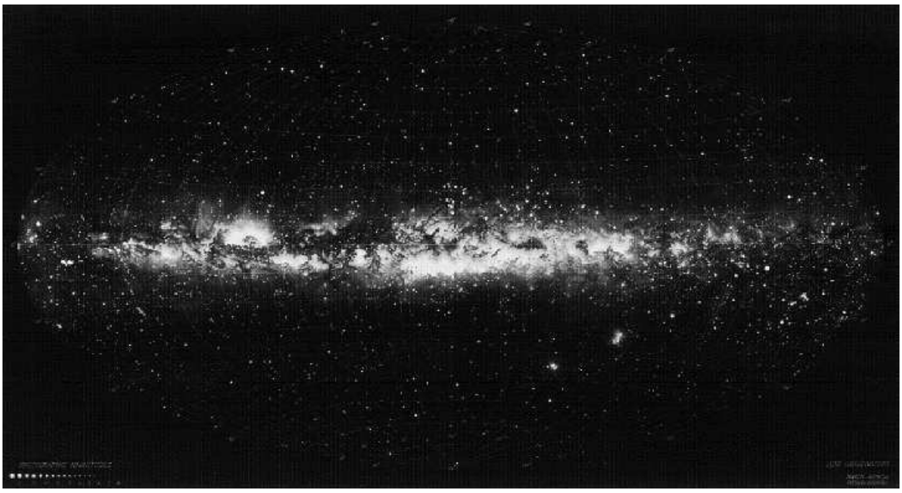
Excerpt
More Information

The Sky Viewed from Earth

1 How many stars are visible to the naked eye?

The total number of stars visible to the naked eye from Earth is estimated to be approximately 8000, half of which are visible from the northern hemisphere and half from the southern. But at any one time, in either hemisphere, only about 2000 stars can be seen because the other 2000 are then in the daytime sky. To see even the night-sky 2000 requires a very dark site, however, well away from any city, and the eye must be fully dark adapted, which means a wait of 20 to 30 minutes in complete darkness.

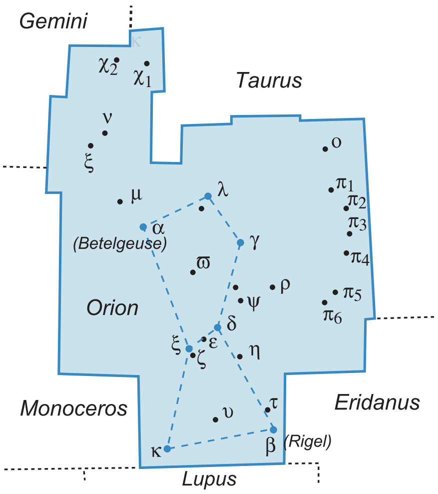
Observing visually with a small amateur telescope or binoculars will show many more stars, especially in the Milky Way; but stars will remain points of light and do not become more detailed. The most interesting aspect in observing through amateur telescopes is that we can observe the planets and some beautiful nebulae that cannot be seen easily with the naked eye (Q. 197).



A panorama of the sky showing most of the stars visible to the naked eye. This is actually a drawing in which 7000 individual stars are shown as white dots, with size indicating brightness. The Large and Small Magellanic Clouds are the two fuzzy patches in the lower right quadrant. Credit: Lund Observatory/Knut Lundmark.

2 How many constellations are there?

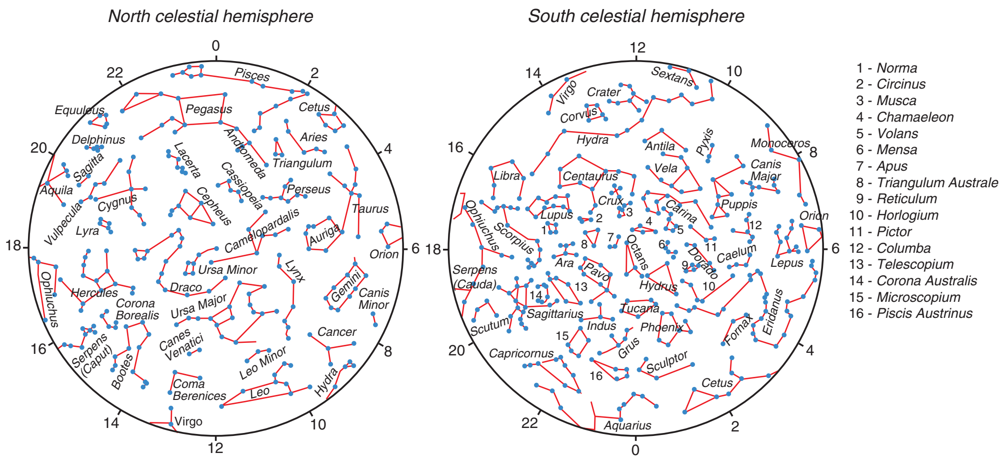
Even though the constellations no longer play the same important role in modern societies as they did in ancient ones, they remain a convenient way to divide the sky



The limits of the constellation Orion (light blue) on the sky. The stars in the figure of Orion himself are represented in blue, with the other main stars in black. As is customary, the brightest stars are identified by a Greek letter (Q. 4).

into different areas. Astronomers of the world have therefore agreed to partition the sky into 88 mutually agreed constellations. These official constellations include most of those in the northern hemisphere known to the ancient Greeks. As a whole, they are an interesting mix: 14 men and women, 9 birds, 2 insects, 19 land animals, 10 marine animals, a centaur, a unicorn, a dragon, a winged horse, a river, and 29 inanimate objects, including a furnace, a compass, and a pump.

In order to cover the whole sky, the constellations have been assigned specific limits of meridians and parallels (right ascension and declination) to surround the symbolic central



The constellations of the north and south celestial hemispheres.

figure, resulting in a patchwork effect, like a set of puzzle pieces fitted together. In scientific parlance, the constellations are referred to by their Latin name. For example, the Big Dipper is referred to as *Ursa Major.*

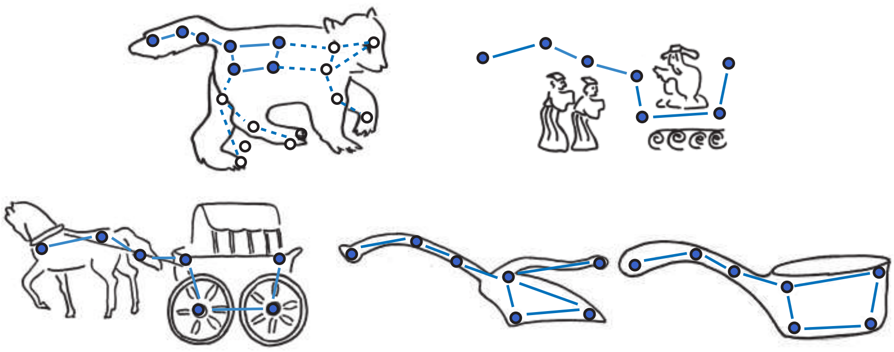
3 Do all civilizations recognize the same constellations?

Today, we have no problem knowing what day and month it is. We have calendars, watches, newspapers, television, computers, and Internet to keep us informed. But what about 4000 years ago? Back then, there was only the sky . . .

Knowing one's way around the sky was very useful in the past; it was an excellent calendar, if one knew how to read it. It could tell the farmer when to plant, the herder when to move his animals to new pastures, the shaman when to repeat his rituals. To distill sense from the myriad bits and bytes of information contained in the starry firmament, nothing was easier for pre-technical peoples than to pick out patterns – persisting, recurring patterns – in the stars. Looking up at the sky on an August night in the northern hemisphere, we can see the summer patterns: Lyra, Cygnus the swan, and Aquila the eagle. In December, those patterns are absent, but we know that they will come back, and that when they do, summer will be back, too.

We call these starry patterns "constellations," from the Latin *cum*, meaning with on together, and *stella*, star. The ancient Sumerians gave us the constellations Taurus (in Latin, the bull), Leo (the lion), and Scorpius (the scorpion), animals that were important in their culture. The Greeks linked stellar patterns with their myths: Orion, the hunter with his dogs, and the Pleiades, the "Seven Sisters." When European navigators discovered the sky of the southern hemisphere, they saw "the Telescope," "the Microscope," "the Clock." And if it was up to us to baptize a new pattern in the sky today, we might "see" a car, a plane, or . . . Bowie.

Not all peoples saw the same patterns in the stars. Amerindians, Mayas, African tribes, the ancient Greeks, the Chinese, all imagined different images using different groupings of heavenly bodies. The Big Dipper is an exception. The pattern it makes in the sky of the



The Big Dipper is a configuration of stars that is quite obvious. This pattern has been used by a number of civilizations, but with different interpretations.

northern hemisphere is so distinctive that many different peoples have recognized it – not that they saw the same object in it. For the Greeks and certain Amerindians, the pattern evoked a bear. For the ancient Chinese, it was the carriage of the emperor of the celestial world. In medieval Europe, it was a horse-drawn cart. For Americans today, it is a dipper, and for the British, a plough.

Of course, the stars in a given constellation are not physically linked and are distributed in three-dimensional space, so if there are any other civilizations in the general neighborhood of our galaxy, and if they should search for shapes in their sky, they would see different patterns even if they looked at the same stars as we do. And they would be unlikely to use the same stars for their constellations, but would certainly pick out different ones that would be brighter for them. In matters like this, perspective is everything.

4 How are stars named?

In the western world, the brightest stars had all been given names by ancient Greek times. After the fall of the Roman Empire, however, astronomy was practiced as a science only by the Arabs. They rescued the body of Greek astronomical science, summarized in Ptolemy's *Almagest* (Q. 9),[†] from potential oblivion, and adopted the Greek constellations, but they assigned their own names to many of the brightest stars. When texts were later translated from Arabic into Latin in the later Middle Ages, some of those names became garbled or were changed. Other cultures had their own names for stars, of course, but for European society the Arabic names were retained when Europeans resumed their pursuit of the astronomical sciences during the Renaissance. The most brilliant stars thus have Arabic names, and many of those have poetic meanings. The following table gives the common name and translation of some Arabic names for stars, together with their scientific names.

Name	Arabic name	Meaning	Bayer designation
Aldebaran	Ad-Dabaran	Follower (of the Pleiades)	α Taurus
Altair	At-Ta'ir	The Eagle	α Aquila
Betelgeuse	Yad al-Jauza'	The hand of Orion	α Orionis
Deneb	Dhanab ad-Dajajah	The tail of the Swan	α Cygnus
Eltanin	At-Tinnin	The Dragon	γ Draconus
Rigel	Ar-Rijl	The foot of Orion	β Orionis

It would be an exercise in futility, of course, to try to give a colloquial name to every star in the sky; professional astronomers had to invent coding systems to designate stellar

[†] The Arabs were so impressed by Ptolemy's work that they called his book *Al Magister*, the Grand, which later became *Almagest*.

objects. In the 1600s, Johann Bayer, a German lawyer from Bavaria, invented a system in which stars in the different constellations were labeled in order of descending brightness, but using the Greek symbols and letter order in the alphabet. For example, the star Alpha (the Greek letter α) Centauri, our closest stellar neighbor, is the brightest star in the constellation Centaurus (Q. 129).

For fainter stars, it is difficult to determine by eye which are brighter than others. By 1725, John Flamsteed, Astronomer Royal of England, had decided to establish his catalog of more than 3000 stars by simply assigning a number to each star in a constellation, for example, 61 Cygni or 47 Ursae Majoris. This system has been widely adopted, but the brightest stars are still referred to using the Bayer system or even by their Arabic names. So a bright star may have several names, in addition to catalog numbers.

When astronomers began to use large telescopes, ever fainter stars could be observed, and catalogs were compiled by various institutions. Since these catalogs overlap, some stars have a great many names! The most common catalogs in use are the *Bonner Durchmusterung* from the Bonn Observatory, published in 1859, the *Henry Draper Catalog*, established in the 1920s, and the *Smithsonian Astrophysical Observatory Catalog*, which was published in 1966. Stars are referred to by their number in the catalog, preceded by the prefixes *BD*, *SAO*, and *HD*, respectively. The *Henry Draper Catalog* is particularly widely used because it contains more than 200 000 stars along with their spectral classifications.

Today, the most precise way to refer to a star is by giving its coordinates in the sky, but since coordinates change with time, owing to the precession of the equinoxes (Q. 14), a reference date for the coordinate system must be added, typically 1950 or 2000. And since stars move on their own as well, the actual year of the observation must also be indicated. Today, the most extensive catalog is *The Second-Generation Guide Star Catalog: Description and Properties*, or GSC2.3, which contains the astrometry, photometry, and classification for 945 592 683 objects.

5 How can planets be spotted in the night sky?

If you are out in the field and are unable to access one of the many sky maps available in magazines, on the Internet, or on your smartphone, the planets can be difficult to pick out from among the many bright stars. The only ones visible to the naked eye are Venus, Mars, Jupiter, and Saturn (Mercury requires exceptional conditions). Here is how to find them.

Since the orbit of Venus is inside that of Earth, this planet never strays far from the Sun (47° at most, i.e. about 3 h of observing time). Look for it in the east before sunrise or in the west after sunset. At maximum brightness it is a spectacular object – the brightest in the night sky after the Moon.

Mars, Jupiter, and Saturn, whose orbits are outside the Earth's, can appear at any time during the night, but only for part of the year. Look for them close to the track followed by the Sun during its daytime apparent trajectory (i.e. the ecliptic). Mars can be identified by its characteristic orange color. Jupiter is as bright as some of the brightest stars, while Saturn is the faintest of the visible planets.

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When in doubt, there is a simple way to confirm that one is really looking at a planet: stars twinkle but planets generally do not (Q. 29), but it is best and easiest to use sky maps to verify the identity of planets and particular stars.

6 Why did ancient astronomers study the sky so intently?

Pharao Akhenaton (circa 1370 BC) making an offering to the Sun.

The Sun dictates our daily activities, and the change of seasons governs our agriculture and livestock management. From earliest times, our ancestors have watched the sky, derived the time of the day by the position of the Sun, and tracked it and other celestial bodies at night to predict the change of seasons and orient themselves on land and sea.

It was evident to all that, without the Sun, life would wither and die. And soon, by extension, similar powers were attributed to the other "moving" bodies in the sky, the moons, planets, and comets. Our ancestors examined them all anxiously, trying to foretell events that could affect their destinies. No wonder then that, between the need for calendars, navigational aids, and heavenly portents, the celestial vault was studied so early and so carefully.

Very early on, burgeoning astronomers in the Middle East, Egypt, and China measured the positions on the horizon where the Sun, Moon, and a few bright stars (Sirius and the Pleiades, in particular) rose and set. The wood or stone instruments at their disposal were rudimentary but precise enough to measure the positions to within

The ceremonial megalithic monument of Stonehenge erected around 3000 BC to 2000 BC north of Salisbury, England. Credit: Diego Delso, Wikimedia Commons, License CC-BY-SA 3.0.

an angle of half a degree (limited mainly by atmospheric refraction near the horizon – Q. 217). Mathematical tools (basic trigonometry and interpolation) were eventually developed to improve their calculations. The ring of standing stones at Stonehenge is likely to have served in ancient astronomy, as the site has alignment with the directions of sunrise at summer solstice and sunset at winter solstice.

7 Why were the Greek and Roman gods associated with the different planets?

The first archaeological evidence for an association between the planets and the gods of antiquity is found in Sumer, circa 2600 BC. The Sumerians were the first to record the irregular movements of the five planets visible to the naked eye: Mercury, Venus, Mars, Jupiter, and Saturn. Having concluded that all "wandering" celestial objects – the Sun, the Moon, and the five planets – were supernatural beings (Q. 6), they revered seven cosmic divinities: Utu, the Sun; Nanna (later Sin), the Moon; Enki, Mercury; Inanna, Venus; Nergal, Mars; Enlil, Jupiter; and Ki, Saturn. At the time of the Babylonians, the names of the gods were changed; the Sun god became Shamash, the Moon, Sin, and Venus, Ishtar. These planet–god associations were eventually retransmitted to the Egyptians, Greeks, and Romans (Q. 81).

Kuduru of Meli-shipak II at the Louvre Museum, a stela with the symbols of Mesopotamian deities: at top, from left to right, as if hanging from the celestial vault, are Sin, the crescent Moon, the goddess Ishtar, Venus, and the radiating shape of Shamash, the Sun god.

8 Can we learn anything from the astronomical phenomena reported in the Bible?

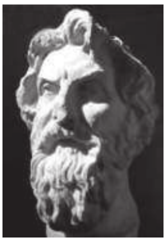
The Bible cannot be considered a historical document any more than most ancient legends, and it is even less a treatise on science or astronomy. The few descriptions of astronomical phenomena in it are rudimentary and so vague that they contain little real information, unlike the documents of Mesopotamia and ancient China, which can be used to reconstruct the history of eclipses, for example.

The cosmogony of the book of Genesis is directly inherited from more ancient texts. The two biblical accounts of the birth of the universe, the Creation week and the Eden narrative, are similar to and most likely based on Sumerian texts written around 2100 BC, more than a thousand years before their biblical rerun.

On the other hand, the Bible does contain some poetic texts that were clearly inspired by celestial objects or phenomena. God's response to Job's speeches is a fine example, in this description of the constellations (Job 38:31):

> Can you fasten the harness of the Pleiades,
> or untie Orion's bands?
> Can you guide the morning star season by season
> and show the Bear and its cubs which way to go?
> Have you grasped the celestial laws?
> Could you make their writ run on the Earth?

9 Who were the most important astronomers of antiquity?


Aristarchus of Samos.


Eratosthenes of Alexandria. Credit: NASA/The Children's Museum of Indianapolis.


Hipparchus of Nicea.

Many of the ancient scholars who contributed to the progress of astronomy are unknown to us. The great majority of them, in particular the Babylonian and Egyptian pioneers, will forever remain in the shadows. The few classical Greek astronomers listed below would never have achieved what they did without the foundations laid by their many anonymous predecessors and contemporaries.

Aristarchus of Samos (circa 320–250 BC), known as the Copernicus of Antiquity, proposed the revolutionary and heretical concept for his time that the Earth and planets revolve around the Sun. He maintained that the stars were other suns, immensely far away, accounting for their faintness and absence of parallax (Q. 113). Using rigorous trigonometric methods, he was the first to calculate the distances to the Moon and the Sun. But measuring the enormous distance to the Sun required better instruments than he had available, and he underestimated it by a large factor. Still, his method was fundamentally correct.

Eratosthenes of Alexandria (circa 276–194 BC), Greek astronomer, mathematician, and geographer, is one of the most famous scientists of all times. He was the first to measure the size of the Earth (Q. 32).

Hipparchus of Nicaea (circa 190–120 BC) is another shining light among the great figures of ancient astronomy. He compiled an extensive star catalog (Q. 4), which was used for almost 2000 years to identify novae and supernovae.

A serendipitous result of his careful measurements was his discovery of the precession of the equinoxes (Q. 14), which he estimated at 1° per century (the modern value is 1.38°). Hipparchus also proposed using lunar eclipses to determine geographic longitude.

Claudius Ptolemy of Alexandria (AD 100–165) is the author of a comprehensive work summarizing classical Greek astronomy, the *Greatest Compilation*, better known by its Arabic title, the *Almagest*. This monumental work in 13 volumes became the basic reference work for Islamic and medieval scholars. Ptolemy also made original contributions to the science with his precise determination of the distance to the Moon, using Aristarchus's parallax method, which he significantly improved. However, his reputation and influence are mainly due to his famous geocentric model of the Sun and planets (Q. 71). This was a complex model that eventually proved to be wrong, but it did predict the positions and movements of celestial bodies with much greater accuracy than had been achieved previously.

Claudius Ptolemy.

The Greek civilization disappeared, and the western world was plunged into an intellectual night that lasted 1000 years. Only the strong Arabic and Byzantine respect for ancient science kept the astronomical and geographical knowledge of antiquity alive.

10 What were the early contributions of the Chinese, Indian, and Islamic civilizations to astronomy?

In view of the fundamental contributions made by Mesopotamia, Egypt, Greece, and, beginning in the seventeenth century, by Europe and America, one might be tempted to conclude that astronomy is overwhelmingly a mid-eastern and western science. Were the two great civilizations of the East, India and China, left behind? If not, what contributions did they make?

Indian astronomy has ancient roots, going back as early as 2000 BC in the Indus Valley. It was then probably centered on establishing calendars. Scientific astronomy only began to develop in India around the sixth century AD after coming into contact with the Greek and Byzantine traditions. At that time, Indian mathematics was already well advanced, probably more so than anywhere else in the world, and astronomers used that to advantage. Aryabhata (AD 476–550)[†] and Brahmagupta (AD 598–668), the two dominant mathematician–astronomers of this epoch, used new mathematical techniques to establish tables showing the positions and movements of planets, the phases of the Moon, and solar eclipses.

In the eighteenth century, Maharajah Sawau Jai Singh, an astronomy enthusiast, had several observatories built, including the Jaipur Observatory, which is now a tourist attraction.

[†] Aryabhata taught that the Earth rotated while the stars were fixed, and it has been alleged that he actually proposed a heliocentric model, but there is no firm evidence for this.

Jaipur Observatory (1734).

These observatories were equipped with large instruments used for measuring the positions of stars and planets with great accuracy. It was a medieval kind of astronomy, however, contributing no new knowledge, whereas a century earlier Galileo, Copernicus, and Newton had already transformed the science.

Chinese astronomy, also very ancient, had its beginnings as early as 2000 BC and developed quite independently. It was at least as advanced as western astronomy when it came into contact with European civilization in the sixteenth century.

Chinese science generally differs from its western counterpart by its very practical approach. While ancient Greek scholars were fascinated by theoretical questions and felt that practical applications were beneath them, in China it was the reverse. The main purpose of Chinese astronomy was not intellectual investigation but calendars and divination. The Emperor embodied the connection between human beings and nature, and the calendar was a manifestation of this relationship. Astronomers had to create new calendars based on new observations every time a change of dynasty took place.

For the Chinese the sky was also an open book that held the secrets of the future. It was important to learn how to read and interpret it. Whether for the Emperor's needs or common people's daily lives – a businessman's prospects, choice of a spouse, destiny of a newborn – it was important to scrutinize the sky, which could provide useful clues.

These sociopolitical connections may explain why Chinese astronomers kept detailed records of astronomical events from very early on, leaving us lists of a thousand eclipses and great auroral displays, 360 comet passages (31 of which refer to Halley's comet), 700 meteoric falls, many novae and supernovae, including the famous supernova of 1054 in the Crab Nebula, and lists of sunspots from as early as 28 BC.

These catalogs, covering almost 3000 years, have been a gold mine for modern astronomers. Yet, although Chinese astronomers could predict eclipses and realized that planets were different from stars, they did not attempt to *understand* what they were observing. For this reason, in spite of its relative advance, Chinese astronomy did not bring much to western astronomy once it had renewed contact with Europeans in the