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Excerpt
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Chapter 1

The history of solar observation: from sun worship to the space age

1.1 Early ideas about the sun

The sun must have been a source of wonder for the earliest people who watched its constant rising and setting and passage across the sky, and very likely it was worshipped as a god by most ancient communities. Many prehistoric monuments show evidence from their alignments that the sun was an important object of study. One of the most famous is Stonehenge, in Wiltshire, England, built between 2800 and 1500 BC. From the centre of the henge a large stone known as the Heelstone, its top level with the horizon, marks the point of sunrise at the summer solstice (21 June).

Sun worship was widespread among ancient eastern and Mediterranean peoples. Thus, the sun for the ancient Egyptians was the god Re, a fiery disc conveyed in a boat across the sky during the day and along a great river surrounding the earth during the night to reach the east by next morning, contending on the way with obstacles; during the day, a serpent would sometimes attack the sun for a time, causing a solar eclipse. For the ancient Babylonians, the sun was a living being which moved against the solid vault of the sky, emerging each morning through a door in the east and disappearing in the west in the evening. Figure 1.1 shows a stone tablet (*ca.* 900 BC) depicting the sun-god Shamash in his temple with a solar disc in front of him, with the Babylonian king being led into his presence. The author of the first chapter of Genesis tells how the sun was made by God, who placed it in the vault of heaven 'to separate light from darkness'. The ancient Israelites are warned that, on entering Canaan, they should not be tempted to worship the gods of the Canaanite peoples, including the sun and other heavenly bodies. This seems to account for the surprisingly small number of astronomical references in the Old Testament. In the religion of the ancient Hindus, the sun-god was one of the principal triad of deities, called by them Surya in their

Vedas or Books of Divine Knowledge. Early Greek lore, as expressed for example by Homer (*ca.* 700 BC), was similar to the Egyptians', with the sun-god Helios rising each morning from the lake of the sun, a gulf in the huge river Oceanos surrounding the earth (Fig. 1.2). From about the fifth century BC, the Greeks associated the sun with their god Phoebus Apollo.

The earliest significant attempts to understand the sun and indeed the universe, including the earth, were made by the Greeks from the sixth century BC onwards. Despite the prevalence of religious beliefs concerning the sun among the ancient Greeks, several philosophers began to speculate freely about its physical nature. Among the earliest ideas was that of Anaximenes (sixth century BC), who thought the sun a flat body supported in the sky by air. Xenophanes (sixth century BC) considered the sun and stars to be fiery clouds, lit up by their own motion in the cosmos; the sun was supposed to be renewed each morning, the stars each evening. The fall of a meteorite in daylight led the Athenian Anaxagoras in the mid-fifth century BC to conclude that the sun was composed of a mass of red-hot iron with a size no larger than the Peloponnessus, roughly 160 km.

Anaxagoras' value for the sun's diameter implied a comparatively small distance to the sun: about 30 000 km, compared with the modern value of

Fig. 1.1 Stone tablet, *ca.* 520 BC, showing the Babylonian sun-god Shamash in a shrine with a solar disc in front of him. From Sippar, Iraq. (Reproduced by courtesy of the Trustees of the British Museum)

Fig. 1.2 Athenian wine bowl, *ca.* 430 BC, depicting a dawn scene with the sun-god in a chariot pulled by winged horses out of the ocean, with stars shown as boys diving and disappearing into the water. (Reproduced by courtesy of the Trustees of the British Museum)

149 600 000 km. An attempt to make an actual measurement of the solar distance, or at least to find the ratio of the moon's distance to that of the sun's, was made by the astronomer Aristarchus of Samos (*ca.* first half of third century BC). The method consisted of measuring the angle between the moon, an observer on earth and the sun at the time when the moon appeared precisely half-illuminated – an angle that is almost indistinguishable from a right angle. Although his method was in principle perfectly valid, the uncertainty of timing the instant of the moon's being half-illuminated led to a considerable underestimation of the sun's distance, just 19 times the lunar distance (the modern value is about 400 times the lunar distance). Unfortunately for the progress of astronomy, a solar distance similar to Aristarchus' was adopted by Claudius Ptolemy of Alexandria in his astronomical compendium known as the *Almagest* (AD 140), and was accepted for the next 1500 years!

A measurement of the solar and of the lunar distance separately, involving solar and lunar eclipses, was attempted by Hipparchus (*ca.* 140 BC). He gave a surprisingly accurate result for the distance to the moon: 59.1 times the mean radius of the earth (the modern value is 60.3), but the solar distance was too great for him to determine. He used Aristarchus' value that the sun was 19 times more distant than the moon to deduce that the sun's diameter was seven times that of the earth.

Though much ancient Greek astronomy was purely speculative, there began in time to be an accurate understanding of some aspects of the cosmos, for example the shape of the earth, and of some astronomical phenomena such as eclipses. The idea of a spherical earth, replacing the earlier one of a flat earth, had been put forward by Parmenides and the school of Pythagoras as early as *ca.* 500 BC, and generally held by the time of Plato and Aristotle in the fourth century BC. Empedocles (*ca.* 450 BC) knew that a solar eclipse was caused by the moon passing over the sun, and Anaxagoras correctly explained solar and lunar eclipses and the phases of the moon. Helicon, a follower of the more well-known astronomer Eudoxus, even predicted a solar eclipse in 361 BC, illustrating that he knew about the complex nature of the moon's path in the sky. Herakleides of Pontus (*ca.* fourth century BC) put forward the advanced notion that, despite the appearance of the heavens rotating about the earth, it was in fact the spherical earth that rotated on its axis.

For most Greek astronomers, as indeed for astronomers in the west and east right up to the sixteenth century, the earth, rotating or not, was at the centre of the universe, with the sun, moon, planets (five were visible to the unaided eye: Mercury, Venus, Mars, Jupiter and Saturn) and stars all revolving about the earth. Opinions differed somewhat as to the relative disposition of the planets – whether Venus and Mercury, for example, were closer to or farther from the earth than the sun – but it was generally taken that the moon was the closest body, followed by the sun (or Venus and Mercury); the slower-moving planets Jupiter and Saturn were more distant, and the stars most distant of all the visible heavenly bodies. The irregularities of planetary motions which had been noted were sufficiently explained by the complex system of epicycles, expounded by Ptolemy in the *Almagest*. In this, each planet moved round the earth not simply in a circular orbit but rather performing a yearly motion in a small circle – the epicycle – the centre of which moved round the earth.

There were some dissenters among the Greeks who did not hold the prevailing opinion of the geocentric universe, among whom was Aristarchus. He appears to have suggested, some 1700 years before the idea was again seriously raised, that it was the earth that revolved about the sun, not the sun about the earth. The Pythagorean school (*ca.* 500 BC) also had a scheme in which the earth and other planets, including the sun, revolved about a 'central fire'; this was invisible to inhabitants of the Mediterranean area as their part of the earth was supposed to be always directed away from it. Despite these unorthodox ideas, the world of astronomy, both in the west and the near-east (where a considerable interest had been kindled by the Arabs in the seventh century AD), was content right up to the Middle Ages to place the earth at the centre of the universe and the heavens revolving round it. A good illustration of this is to be found in the early fourteenth-century *Divine Comedy* of Dante, particularly the third book (*Paradise*), in which the cosmography of Ptolemy's *Almagest* is faithfully adhered to.

The Ptolemaic system was finally challenged by Nicolaus Copernicus, the Polish astronomer, who in his book *De Revolutionibus Orbium Coelestius* (1543) proposed the sun as the centre of the planetary system. The earth with its companion the moon was held to be in an orbit about the sun between the orbits of Venus and Mars, with Mercury closest to the sun, Jupiter and Saturn the most distant. This is the picture of the solar system we are familiar with today, though Uranus, Neptune and Pluto have since been discovered as part of the sun's family, together with the asteroids and comets. Copernicus envisaged a 'sphere of stars' that was much more distant from the sun than the earth since they showed no motion as the earth went round the sun. He retained circular orbits for the planets with the Ptolemaic epicycles in his new scheme to explain residual irregularities in planetary movements.

The precise nature of the planetary orbits was discovered by Johann Kepler, using the extensive and accurate observations of Mars made by the Danish astronomer Tycho Brahe with whom he had worked. Kepler summarized his findings in his three laws of planetary motion (1609). One of these describes the form of a planetary orbit as a conic section known as an ellipse, produced when a cone is intersected by a plane making a smaller angle to the base than the cone sides. Thus the Ptolemaic epicycles were ultimately buried.

According to Kepler, the planets were impelled to move round the sun by a force which was tangential to the planet's orbit rather than directed at the sun, and which had its origin in the rotation of the sun on its axis. In addition, there was supposed to be alternately an attraction and repulsion from the sun as the planet's north and south magnetic poles were directed towards the sun: hence arose the deviation of a planet's orbit from a circle to an ellipse, with the planet sometimes nearer to, sometimes farther from, the sun. Kepler's rather complicated explanation for how the sun kept its attendant planets in their orbits was superseded half a century later by the work of Sir Isaac Newton, who found that Kepler's laws had the consequence that the force controlling each planet's motion round the sun was directed towards the sun, falling off as the inverse square of the distance to the sun. This force of gravitation was universal in character, since it was the same as that which causes objects near the surface of the earth to fall. The mechanics of the solar system could thus be understood in terms of something with an everyday familiarity.

The gross underestimates that Aristarchus and Hipparchus had made of the sun's distance and diameter were still used by astronomers up till the time of Kepler. Though the absolute scale of the solar system was poorly known, the relative distances of all the planets could be determined with great accuracy: Kepler's third law stated how the orbital period of a planet (which was easily measured) was related to its mean distance from the sun, so that the distances of planets from the sun could be given in terms of the earth's distance. A means of determining the earth's distance was provided by the very rare occasions when the planet Venus passed over the sun's disc – a 'transit' of Venus. A young Lancashire curate and amateur astronomer, Jeremiah Horrocks, was the first to see such an event, in 1639, which he had predicted. The next transits of Venus were due to occur in 1761 and 1769. In 1716, Edmund Halley, famous for the comet that bears his name, suggested that Venus would be sufficiently close to the earth during transit that observers at different locations would see Venus take different tracks across the sun's disc. Comparison of the observations would give the distance of Venus to the earth and, since the relative distances of the two planets from the sun were known, the distance of the earth to the sun could be found. The 1761 and 1769 transits occurred after Halley's death, but his suggestion was put into effect, especially for the 1769 occasion for which Captain James Cook was commissioned to make his first voyage. From his observations in New Zealand and those made in Europe, a value was eventually (1824) obtained for the earth's distance to the sun – 153 000 000 km, or about 2% more than the present estimate.

1.2 Sunspot observations

Aristotle had maintained that the sun was perfect and blemish-free, but solar observers long before the invention of the telescope around 1608 had discerned small dark features within the face of the sun. Many of their records give what are now considered accurate accounts of genuine 'naked-eye' sunspots on the solar disc, some fancifully described as objects familiar to the culture of the time, though some may be merely the sighting of, for example, birds or small terrestrial clouds. The earliest reasonably certain reference to a sunspot seems to have been due to Aristotle's own pupil Theophrastus of Athens in the mid-fourth century BC, to whom is also credited a sighting of the aurora.

There has been much interest in large numbers of oriental records of what appear to be naked-eye sunspots. A 1988 catalogue (by K. K. C. Yau and F. R. Stephenson) lists 157 such records before the invention of the telescope. They are mostly from China but also from Korea, Vietnam and Japan, and occur in dynastic histories, chronicles and local gazettes. Some are from very early on, but the earliest definite sunspot sighting is Chinese, dated 165 BC. The descriptions in these accounts suggest that the sun when observed was dimmed by fog or dust in the atmosphere. There are long periods when there were no sunspot records, but it is uncertain whether these were when sunspots were really scarce or were simply times when there was a lack of scientific interest due, for example, to political unrest.

There are records from other areas of the world also – for example, some Russian chronicles record sunspot sightings when the sun was dimmed by a forest fire in 1371 – but those of western Europe up to the seventeenth century are generally lacking, owing apparently to the prevailing Aristotelian view, vigorously upheld by the Church, of the immaculate sun. One exception was the observation of a spot by Kepler in 1607, which he attributed at the time to Mercury crossing the solar disc though later he realized it must have been a sunspot.

The invention of the telescope offered a completely new means of exploring the sky. Galileo is the most celebrated of the early astronomers to use the telescope. He was already well known for his experiments on the pendulum and his theory of motion, in which he disproved Aristotle's assertion that different weights fall at different speeds. When a professor at the University of Padua, he made his own telescope with which he observed the moon, planets, stars and the sun. He found that the solar surface was marked by dark spots which appeared and disappeared, with lifetimes that were variable but on average a few days (Fig. 1.3). The more persistent were seen to cross the sun's disc from east to west in about two weeks, which he explained by the rotation of the sun on an axis. Although he first saw sunspots in 1610, Galileo evidently did not feel confident enough to announce his discovery for another two years; he then wrote a discourse on their nature to his former pupil the Grand Duke of Florence in which he says: 'Having made repeated observations I am at last convinced that the spots are objects close to the surface of the solar globe, where they are continually being produced and then dissolved, some quickly and some slowly; also that they are carried round the sun by its rotation, which is completed in a period of about one lunar month.'

At around the time of this discourse, Galileo became more interested in other astronomical studies and made no further systematic solar observations. A more extensive series of sunspot observations was made by his contemporary Christoph Scheiner, a Jesuit priest from Swabia in south Germany. His observations cover the period 1611–27, and were published in an impressively long volume entitled *Rosa Ursina sive Sol* in 1630. This was dedicated to the Duke of Orsini in Rome, whose badge was the rose and the bear mentioned in the Latin title of the book. The illustrations in this book show Scheiner and his assistant recording sunspots from an image projected by a telescope on to a screen (Figs. 1.4, 1.5). This is still a common way to observe the sun with a small telescope and a safe one, unlike direct viewing which Galileo had apparently tried at great risk to his eyesight.

Scheiner and Galileo had both noted that the paths of spots as the sun rotated were in general not straight lines, but rather somewhat curved, which

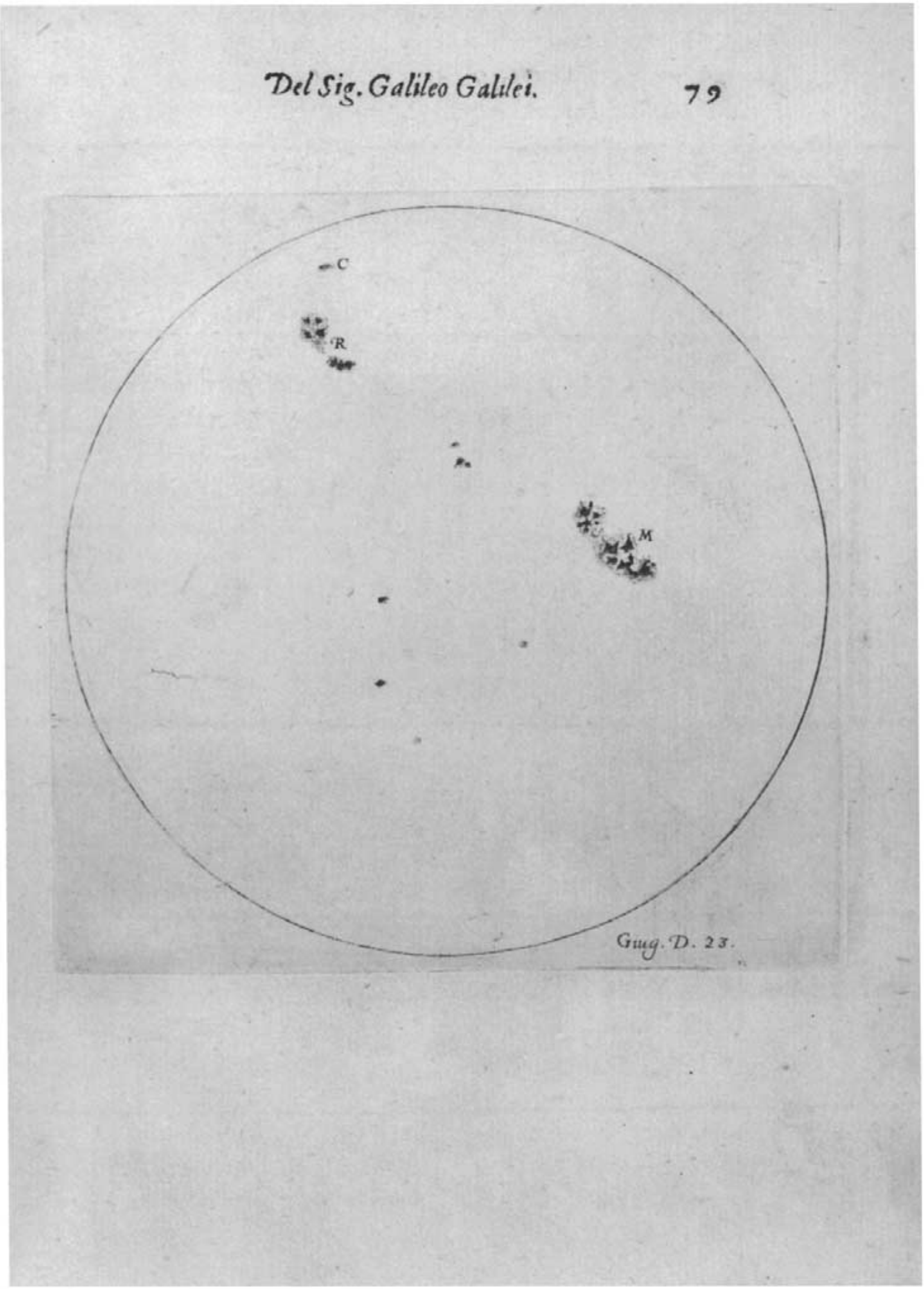
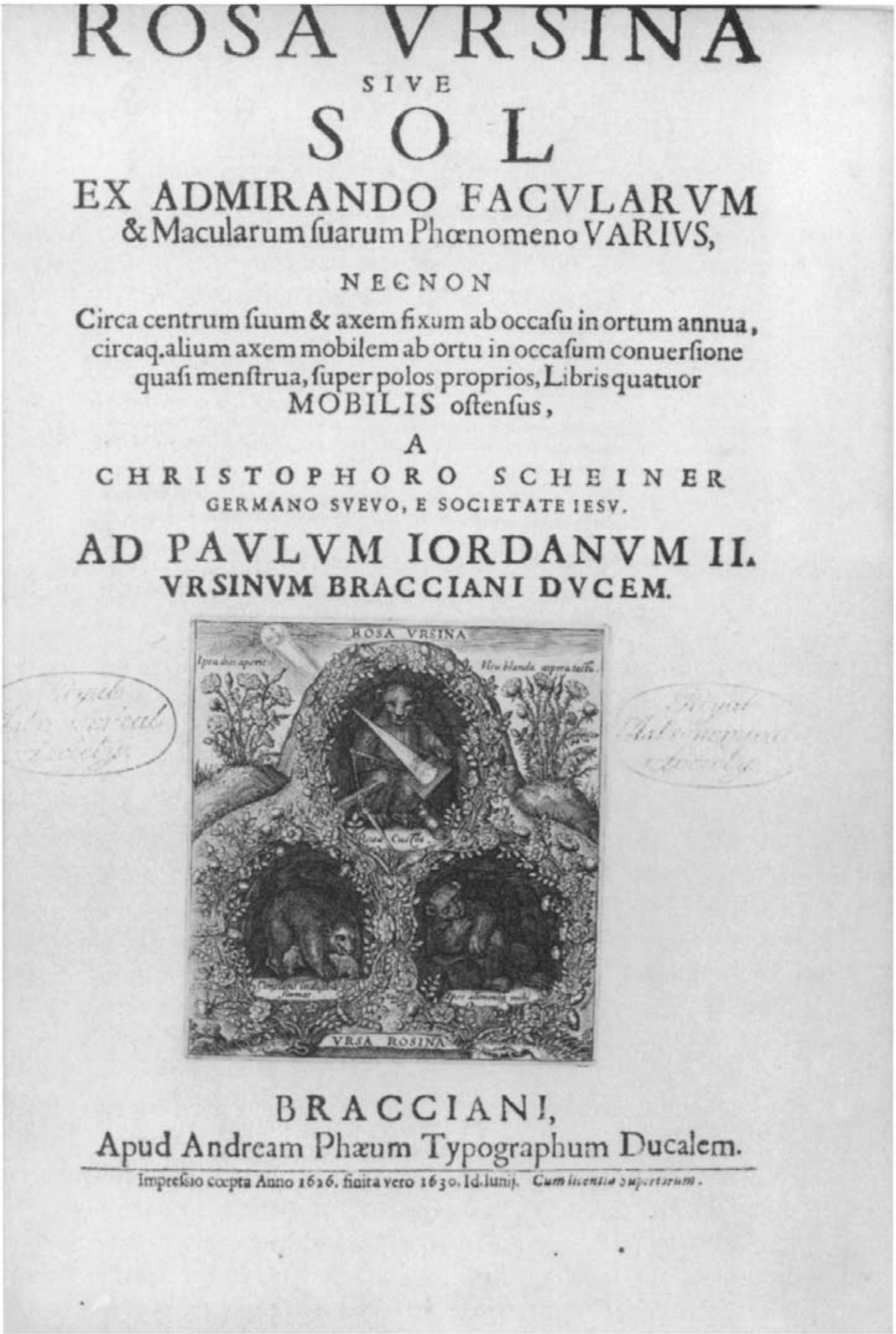


Fig. 1.3 One of Galileo's sunspot drawings from the early seventeenth century, from his manuscript *Delle Macchie Solari*. (Courtesy Royal Astronomical Society)



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circaq. alium axem mobilem ab ortu in occaſum conuerſione
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A
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GERMANO SVEVO, E SOCIETATE IESV.
AD PAVLVM IORDANVM II.
VRSINVM BRACCIANI DVCEM.

BRACCIANI,
Apud Andream Phæum Typographum Ducalem.
Impreſſio cœpta Anno 1626. finita vero 1630. Id. Iunij. *Cum licentia superiorum.*

Fig. 1.4 Title page of Christoph Scheiner's volume on observing sunspots *Rosa Ursina sive Sol* (1630). (Courtesy Royal Astronomical Society)

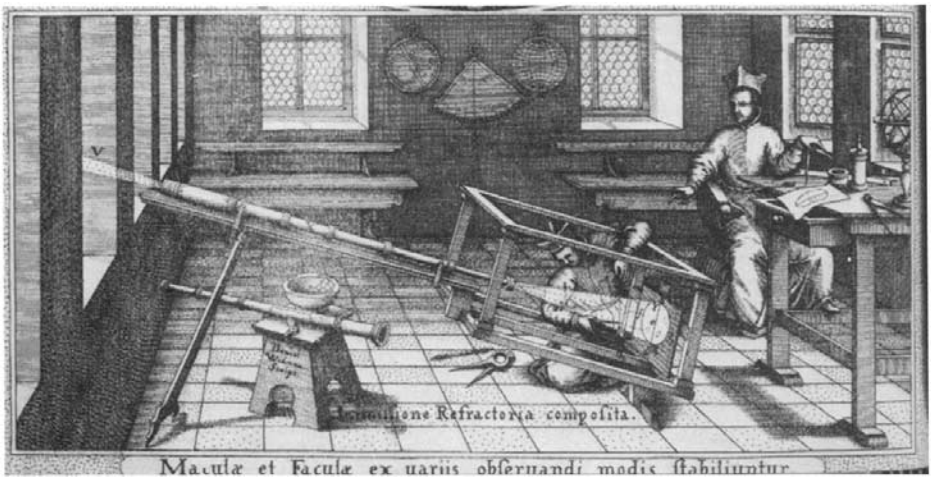

Fig. 1.5 A page from Scheiner's *Rosa Ursina* showing the projection method used by him for recording sunspots. (Courtesy Royal Astronomical Society)

they both correctly explained by the fact that the solar equator is inclined by a small angle to the plane of the earth's orbit round the sun. For one half of the year, the solar north pole is tilted towards the earth, and for the other half the south pole. They also both showed that sunspots were not distributed over all the sun but were confined to a band extending to latitudes roughly 30° north and south. When near the edge (or *limb*) of the sun, the spots were often associated with small bright patches which became known as faculae (Latin for 'little torches'). The two astronomers at first differed in their opinions of the nature of the spots. Scheiner's observations that the sun was not after all spotless was unpalatable to his fellow Jesuits, one of whom refused to believe that there were spots since he had not found mention of them in Aristotle's works. Scheiner himself at first thought that the spots were not strictly solar in origin, but attributable to small planets revolving near the solar surface. This idea was advanced in documents, written under a false name, to a friend of Galileo's. Galileo replied asserting his own view that sunspots were on the solar surface, this being proved by the fact that their shapes changed when near the east or west limbs, becoming elongated or foreshortened. Galileo also stated that sunspots only appeared dark by contrast with the brilliant solar surface, but were in fact as bright as the brightest areas on the moon. His drawings, like Scheiner's, showed that larger sunspots had a darker inner region, the *umbra*, and a lighter outer part, the *penumbra* (this can be seen in Fig. 1.3). The intensity of the umbra is in fact as much as a quarter of that of the unspotted sun. It was in Galileo's reply to Scheiner that he first mentioned his support of the Copernican system of the sun-centred universe in place of the Ptolemaic, an opinion which led to a collison with the authorities