The Sun

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The Sun

A User's Manual

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For Penelope

Preface

Few of us have any idea of how the Sun works and how it affects our lives beyond the obvious business of night and day and summer and winter. Yet we cannot make sensible decisions about dark glasses or long-distance air travel or solar panels, or fully understand global warming or the aurora borealis or racial characteristics, without some grasp of the workings of our neighbouring star. And quite apart from questions such as these, many of us may just be curious. The 19th century American poet Walt Whitman became *tired and sick* in a lecture by *a learn'd astronomer* and wandered out, *in the mystical night air, to look up in perfect silence at the stars*. If he'd concentrated a bit harder in class he would have started noticing all sorts of new marvels in the sky.

The Sun is intended for the curious reader. Some of the material is hard but no more so than you find in a decent biography or a gardening manual. In any case the sticky bits can be skipped on first reading (or forever), although I suspect anyone who is really interested in the world outside the window will relish getting his or her mind around neutrinos, cosmic rays, and even a dash of relativity, and will not want to be patronized.

The book is designed to portray some of the myriad ways in which the Sun impinges on our lives. I had been working on a period of silting that affected the rivers of southern Europe and north Africa during the Middle Ages and that tends to be blamed on humans and their goats, and I found that it could be explained better and more simply by shifts in climatic belts caused by a flickering Sun. That led me to investigate how far the Sun's output does change over time and whether we can plan ahead to prepare for the next serious blip; and that in turn led to the early history of the Sun, its workings, and the many ways in which it interacts with humanity.

This brings me to my favourite moment on an Italian beach, when a fashion-conscious mother with one of those bandsaw Milanese voices called out to her little daughter 'Marisa, don't go in the water. You'll get your bathing suit wet.' What she should have said was 'if you stay in the August sun between 11 and 2 pm and get burnt three times you will increase the odds of getting skin cancer as an adult by 60% and even if you don't your face will look like a prune.' But no such simple formula for mothers is yet available, nor do I advocate that, like radiologists and nuclear power engineers, children should wear radiation badges. All I do is try to explain *how* we toast so that the reader can choose his or her sun lotion rationally.

But there is much more to the Sun than sunbathing, and I try to follow the same approach in discussing human evolution, climate change, solar energy, the Sun's effect on radio broadcasts, and the internal workings of the Sun itself. I do go on a bit about hydrogen and helium but my excuse is that they make up the bulk of the visible matter in the Universe. Similarly wavelengths, which, like frequency, can be used to describe the behaviour of different kinds of solar energy from X-rays to radio waves. You do not have to be a geek to appreciate such matters, witness a useful mnemonic for the relationship between wavelength and frequency to be found in one of the tales of diplomatic life by Lawrence Durrell:

> "If there is anything worse than a soprano," said Antrobus judicially, as we walked down the Mall towards his club, "it is a mezzo-soprano. One shriek lower in the scale, perhaps, but with higher candle-power."

Just bear in mind that he got it the wrong way round.

There are many paradoxes in my account. The Sun drives the weather and keeps the Earth's temperature at tolerable levels, it is the basis of photosynthesis and thus the life of plants and the creatures they sustain, and its magnetic field shelters us from dangerous cosmic rays; yet at the same time the ultraviolet (UV) part of the solar spectrum may damage DNA and human tissue, solar flares can destroy spacecraft, power systems and computers, and there is every indication that the Sun precipitated a mini Ice Age less than two centuries ago. Sunshine allows us to generate vitamin D but too much of it can lead to skin cancer and cataracts. Etcetera etcetera.

As is by now obvious, and the end notes confirm, my sources range from astronomy to archaeology and from geology to genetics. The references are numerous, but it seems unjust not to give credit to the boffin who has slaved for years to bring you a vital piece of nature's mosaic, and you are free to ignore the tiny superscript numbers that lead to the fountainhead. There are many excellent books on each of the topics I discuss but so far as I know none that tries to cover all the topics at introductory level. Unfamiliar terms and abbreviations are defined when first used. Although astronomers normally employ the Kelvin temperature scale I have stuck to degrees Celsius (°C) as the book deals with everyday temperatures on Earth as well as those within the Sun's interior where -273.16°C (zero on the Kelvin scale) hardly makes a difference to 15,000,000 K. I use the power notation (10^{10}, for example, for 10,000,000,000) or Myr (for a million years) when a row of noughts, as you can see, is no more informative.

The following have done their generous best to weed out errors of fact on my part in the sections that do not deal with river mud: John Adams, Paul Bahn, Benedetta Brazzini, Charles Cockell, Eric Force, Ian Maddison, Ken Phillips and Ray Wolstencroft. I am also indebted to the late Rhodes Fairbridge for introducing me to Springer, to Petra van Steenbergen, Hermine Vloeman, Padmaja Sudhakher and Maury Solomon there for much support, to Don Braben, Annette Bradshaw, Ann Engel and Penelope Vita-Finzi for astringent comments on an early draft chapter, to Tony Allan, Geoff Bailey, Roger Bilham, Stephen Lintner and Ian Maddison for references, to Leo Vita-Finzi for matchless advice, to John Burgh and Rick Battarbee for musical solace, to Simon Tapper for help with the figures, to the many who generously supplied figures (and are acknowledged in the captions), and to the engineers and scientists responsible for the SOHO (Solar and Heliospheric Observatory) satellite, which was launched jointly by the European Space Agency and NASA in 1995 with a 'nominal' life of 2 years and is still busily at work as I write.

London, January 2008

Who … would not wish to know what degree of permanency we ought to ascribe to the lustre of our sun? Not only the stability of our climates, but the very existence of the whole animal and vegetable creation itself, is involved in the question.

John Herschel, *Treatise on Astronomy*, 1833

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Chapter 1
Looking at the Sun

If curiosity, as Isaac Asimov has eloquently argued, is one of the noblest properties of the human mind, then prediction is its richest reward. And its survival value is obvious. Is the tide about to turn? Do we need more firewood? When will the herds come back?

Some of the best evidence for effective forecasting in prehistory comes from success in the hunt. In the Dordogne region of France, several of the late Pleistocene sites renowned for their rock art and flint work show great economic dependence on reindeer. At the Abri Pataud, for instance, reindeer make up between 85% and 99% of the bones left by its prehistoric occupants.[1] The caves and shelters open onto valleys bordered by steep cliffs which would have created natural corrals in which to confine reindeer transiting between their summer and winter grazing areas. To judge from the bones the cave occupants timed their seasonal visits shrewdly, even if the reindeer they caught did not. Although the first few seasons must have been a matter of trial and error it seems likely that hunting proficiency in the Palaeolithic came to depend a good deal on observing seasonal clues of one kind or another: the first thaw, for example, or the flowering of some dependable shrub, or the departure or return of a migrant bird.

Most prehistoric hunters and gatherers moved periodically to exploit food that was seasonally abundant. In Alaska they did so for berries, shellfish, deer, fish and sea mammals. To be sure, as in much of the panorama of natural selection, we rarely come across the failures: the luckless family which spent the winter forlornly looking for whelks did not leave massive shell middens behind. But there are countless heaps of food remains which reflect seasonal shrewdness and which imply at least a measure of planning.

Sun as clock

Success in such enterprises was more assured once a link was found with the stars, the Moon and the Sun, initially signalled, perhaps, by a change in the length of a distinctive shadow or the illumination of the blank canvas of a smooth rock face. At high northern latitudes the noonday Sun is at its highest in the sky in summer, retreats south to its furthest position in winter, and then gradually returns. Even in

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the monotonous tropics plant life responds to what has been called the drumbeat of the solar year.[2]

Some of the most ancient human structures commemorate the solar year. At the Newgrange passage tomb in the Boyne valley of Ireland, dating from about 3000 BC, the sun at the midwinter solstice shines for a few minutes though the roof box and illuminates the back wall. The axis of the passage corresponds within about 5' to midwinter sunrise at the time the tomb was built.[3] What is perhaps the oldest solar observatory in the Americas, dating from the 4th century BC, was recently excavated at Chankillo in Peru. A series of 13 towers aligned north-south along a low ridge form a "toothed" horizon which, viewed from observation points to the east and west, allow the rising and setting positions of the Sun to be observed at intervals between the winter and summer solstices.[4]

The vast effort required to erect these monuments, where a few sticks would have done the job equally well if timekeeping is all that was required, shows that some kind of ritual accompanied, as it still does, the practical inauguration of a fresh set of seasons. To be sure, there is a strong temptation to read too much wisdom in such alignments. Take, for example, Stonehenge, the mighty complex of earthworks and standing stones built in at least seven stages between 3100 BC and 1900 BC on Salisbury Plain in southern England. The consensus is that Stonehenge was designed to mark the position of sunrise at the summer solstice. The question is whether, besides any religious and social ceremonial associated with that annual event, the stones and banks had any other astronomical function.

An elaborate analysis of Stonehenge and other stone monuments was published in 1909 by Norman Lockyer,[5] who concluded that Stonehenge was a solar temple, as indicated by the alignment of its 'avenue', which marked sunrise on the longest day of the year. This event had, as he put it, not only a religious function: it had also the economic value of marking officially the start of an annual period. But Lockyer did not rule out other 'capabilities' for Stonehenge, such as a connexion with the equinoxes or the winter solstice.

Lockyer used a theodolite, and pen and paper, to make his case. The advent of the computer made even more elaborate analyses possible, and in 1966 the American astronomer Gerald Hawkins presented evidence for Stonehenge as an ancient computer which, among other things, could be used to predict lunar eclipses. The astrophysicist Fred Hoyle went on to suggest in 1977 that Stonehenge was in effect a model of the Solar System and could be made to function as a computer which was even more precise than Hawkins had claimed as it could predict lunar eclipses to the day. There the matter rests, but uneasily, as archaeological excavation continues to reveal more traces of the alleged computer and the order in which it was assembled and repaired.

Much doubtless depended at these ancient observatories – if that is what they were – on shutters and markers of one sort or another which have long turned to dust. The remarkable success ancient Greek astronomers had in tracking and recording heavenly motions likewise appears remarkable partly because we have little trace of the devices with which they made and documented their observations. Consider the phenomenon of precession (strictly speaking the precession of the equinoxes), the cone-shaped path followed by the north Pole and, as we now know, completed in the space of 25,770 years. Hipparchus of Nicea (190–120 BC) had identified the effect in 150 BC or thereabouts by reference to observations made by his predecessors even though the movement amounts to about 1° per 72 years. That achievement argues for good eyesight (as there were no telescopes), stable instruments and dependable archives.

However, the ‘Antikythera instrument’, discovered in 1900 near Crete in a sunken cargo ship full of statues, suggests that we have underestimated the technology that underpinned the Greek achievement. The device was made of bronze, now badly corroded, and housed in a wooden case measuring about 33 × 17 × 9 cm. Its main function, so far as one can tell from its gear wheels and fragmentary engraved inscriptions, and after a century of study combining the skills of computer scientists and historians of astronomy with the results of X-ray tomography, was to predict the position of the Sun and Moon and perhaps also the planets. Apparently the mechanism, which dates from 150–100 BC, even allowed for variations in the Moon’s motion across the sky. It may have been based on heliocentric rather than the geocentric principles then prevailing, and it indicated position in the Saros cycle and a longer eclipse cycle. The Saros cycle, known to the Babylonians, is the period of 18 years and 11^1⁄C days after which the Sun, Earth and Moon return to the same relative position in the heavens.[6]

The solar year

As at Stonehenge, the focus in Greece was on both the Sun and the Moon. The lunar cycle is not straightforwardly related to the solar year. The synodic cycle is the time it takes the Moon to complete a cycle of phases and occupies 29.53 days, so that 12 such cycles total 354.4 days and 13 cycles total 383.9 days. It is impossible to say when an attempt was first made to harmonise the solar and lunar years, but there is some evidence for a tally of lunar phases in Palaeolithic times. The American scholar Alexander Marshack found scratches and cuts on a piece of bone dating from an estimated 30,000 years ago in the Abri Blanchard, near Sergeac in the Dordogne region of France, which he thought represented the phases of the moon over 2¼ lunar months. The Taï bone plaque, dating from about 12,000 years ago, shows sets of 29 notches, which Marshack equated with the synodic month, the average time taken by the Moon to run through a complete cycle of phases.[7]

Whatever the validity of such claims, the lunar month was the basis of the calendar in many societies, including the Sumerians, the Babylonians and the ancient Greeks. Indeed, the lunar calendar has been retained by Muslims and Jews, and by Christians for their movable feasts. But impatience with the mismatch between the lunar calendar and the seasons in the end weakened and then eliminated the Moon’s calendric preeminence in many cultures.

By 2000 BC the Sumerians had adopted a year of 12 months of 30 days. Some 1,500 years later the Babylonians squared their lunar calendar with the seasonal or solar cycle by allocating an extra month to 7 years out of every 19. The Greeks retained a lunar calendar but added 90 days to it every 8 years. The Jews added a month every 3 years supplemented from time to time by an additional month. The

Chinese calendar is a combined solar/lunar one for which records inscribed on oracle bones date back to the 14th century BC.[8]

In the Nile valley the solar and lunar calendars were harmonized as early as the fifth millennium by the addition of 5 days to the 360 of the lunar year. Later the start of the year came to be marked by the heliacal rising of the dog star Sirius, that is to say the time when it first became visible above the eastern horizon, but as this was found to occur 6 h later each year, an additional 1/4 day then had to be included as a leap day every four years. The need to safeguard the solar year was once again a key concern.

This was the calendar adopted by Julius Caesar and named Julian after him. At the Council of Nicaea in AD 325 the Emperor Constantine decided that Easter should fall on the first Sunday after the first full moon after the spring equinox according to the Julian calendar. In 1267 the friar Roger Bacon wrote to the Pope to warn him that the official date for the spring equinox was 9 days late. In Bacon's view any layman could tell this was the case by looking at the changing position of the sun's rays on his wall.

The Julian calendar remained in force in the West until the 16th century, by which time it was clear that 365¼ days was an overestimate (by 11 min and 14 s). The discrepancy was put right by Pope Gregory XIII, who decreed that the day following 4 October 1582 would be 15 October, and that 1700 and other end-of-century years would no longer be leap years unless divisible by 400. The Old Style (Julian) calendar was retained in countries not in thrall to the Pope: in England and its dominions, for example, until 1752; it still governs the Greek Orthodox Church. And for some astronomical tasks it is convenient to reckon the passage of time in Julian days, that is to say by the number of days that have elapsed since Greenwich mean noon on Monday 1 January 4713 BC. The Julian date (JD) then is the Julian day number (JDN) followed by the fraction of the day that has elapsed since the preceding noon. Thus the JD for Monday 7 January 2008 at 1800 hrs is 2454473.25.

For normal tasks we cleave to the Sun as yearly measure. Even Napoleon's Revolutionary Calendar began on the autumn equinox of 1792. (The calendar lasted only until 1 January 1806). The solar day changes in length throughout the year both because the Earth's orbit is elliptical, so that its rate of progress must vary, and also because the Earth's axis of rotation is tilted with respect to the Sun's path through the celestial sphere (the ecliptic). In this respect a sundial is superior to any mechanical (or chemical) clock because it faithfully indicates the interval between successive local noons. It can even be made to allow for the equation of time, as the variation in hour length during the year is called, by having curved rather than straight hour lines.

Sundials are doubtless the oldest timepieces. An example from Egypt dates from 1350 BC. The invention of the magnetic compass much benefited the use of portable sundials, which were made in pocket form well into the 19th century. The sundial could of course serve for navigation by being adjusted periodically for local time whereupon the shadow of the gnomon would allow the chosen bearing direction to be followed. A Viking sun compass which worked on this principle and dates from AD 1000 has been found in Greenland. During the Second World War the sun compass came into its own again in North Africa, when long distances had to be covered over featureless terrain under clear skies in vehicles whose moving metal parts reduced the accuracy of magnetic compasses. It proved highly compatible with the bubble sextant, which had been designed for navigation from aircraft to provide an artificial horizon as reference for measuring the elevation of the Sun or a star.[9]

We now use atomic clocks to correct for the unsteady progress of the Earth around the Sun and also to trace changes in the Earth's rotation, which is gradually slowing largely because of the braking effect of the tides. The second was formerly defined as 1/86,400 of a mean solar day and, once the day was found to be inconstant, as 1/86,400 of the mean solar day 1 January 1900. It is now defined as the duration of 9,192,631,770 cycles of radiation corresponding to the transition between two hyperfine levels of the ground state of caesium 133 (^{133}Cs). This new second is the time unit that underpins the management of GPS satellites. It also serves for distance measurement on Earth using signals from quasars far in Space in order to investigate such matters as the relative movements between the continents.[10] Even so a leap second is introduced in some years to keep the difference between international atomic time (TAI) and mean solar time to less than 0.9 s a year: the solar year rules.

Sun as god

How far progress in recording the motions of the Moon and the Sun was matched by improved understanding is not always clear. In many societies astronomy was inseparable from religion, divination and a centralized authority, and it was doubtless politic to retain its symbolic trappings. The Babylonian sun god Shamas, for example, would emerge from a vast door on the horizon every morning, mount his chariot and cross the sky to the western horizon, where he entered another door and travelled through the Earth until he reached his original starting place by the next morning.

But perhaps the error lies in equating vivid imagery with ignorance. Many terms in physics, for example, employ analogies or homely terms which may mislead more than they explain. The spin of atoms, protons or electrons, for instance, though associated with angular momentum and with magnetic moment, is not rotation in the sense of classical mechanics. In particle physics flavour, charm, topness and strangeness are categories proposed by the physicist Murray Gell-Mann which were intentionally whimsical, just as a quark, three of which make up a baryon (baryons include protons and neutrons), alludes to Three quarks for Musther Mark in James Joyce's Finnegan's Wake. This is not to suggest that the Babylonians were a particularly whimsical people but that, as with present-day religions, the celebrants were surely able to juggle imagery with commonsense. Fig. 1.1

The imagery on occasion actually proved a convenient device for correcting the current calendar. Nut, the mother of all Egyptian gods, accounted for the daily solar cycle by swallowing the Sun every evening and giving birth to it every morning in the shape of the scarab beetle, Khepri (Fig. 1.1). The Sun god Ra would then ride west in his sacred boat across the sky until sunset, where he was swallowed again. When it became clear that the length of the solar year needed adjusting the correction was blamed on her gynaecological problems, as she required an extra 5 days to bring several pregnancies to term. Whether borrowed or dreamed up afresh the metaphor of a radiant object crossing the sky in some kind of vehicle recurs in succeeding centuries. In Bronze Age Europe the sun traverses the sky in a chariot.

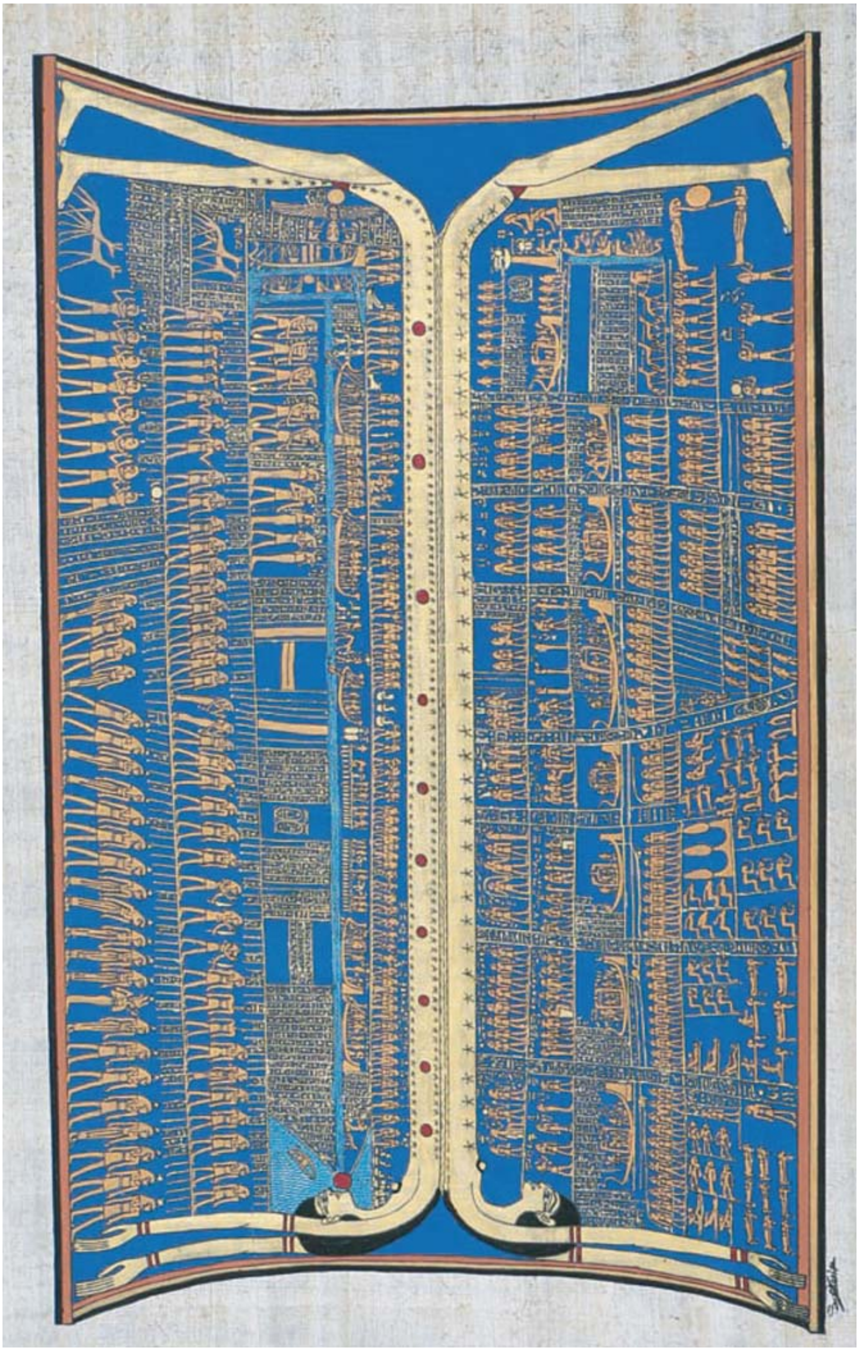

Fig. 1.1 The Goddess Nut swallows the Sun at dusk and gives birth to it at dawn. Painted ceiling of the tomb of Rameses VI (20th Dynasty, 12th century BC). The image of Nut representing the Book of the Day displays 10 solar disks along her body, one in her mouth and one being born bearing the image of the dung-beetle Khepri, symbol of rebirth (Courtesy of Anthony Kosky, Copyright 1991)

In Greek mythology Helios was imagined as a god crowned with the solar halo who drove a chariot across the sky each day and night.

It was a short and tempting step for the human ruler to identify with that shining figure. The archaeologist Jacquetta Hawkes[11] argued that, once the pattern of movement among the Sun, Moon and planets had been to some extent comprehended, the Sun God was accepted as its master, and the earthly ruler in Mesopotamia, Egypt, Mexico or Japan came to be seen as its agent or even its incarnation. Pharaoh Amenhotep III, for example, was 'the dazzling sun'. Atahualpa, killed by Pizarro, was the last of the Inca sun-gods. The Persian kings ruled by divine grace and accordingly received a fiery aureole as a gift from the Sun God. Gold was the chosen substance and a wheel the symbol. The god sometimes demanded a price for defeating darkness. For the Aztecs the Sun's arrival each day could be guaranteed only by the regular sacrifice of pulsating human hearts (Fig. 1.2). The arrangement seemed to work.

Regeneration, recurrence, periodicity and the struggle between light and dark are common themes in solar mythology. The cult of the Unconquered Sun, introduced by the Roman Emperor Aurelian in AD 274 and celebrated on 25 December, is perpetuated in the art and ceremonial of the Christians. In Peru, Garcilaso de la Vega[12] reported in the *Comentarios Reales de los Incas* in 1609

> Of the four festivals which the Inca kings celebrated in the city of Cuzco, which was another Rome, the most solemn was the festival of the Sun in the month of June, which they called Inti Raimi, meaning the solemn resurrection of the Sun. They … celebrated it when the solstice of June happened.

Eclipse as weapon

Not all representations or modes of veneration of the solar deity embodied profound astronomical truths: the wheel could denote movement, or the fiery disk, or neither. But eclipses would surely prove a useful device for cowing the multitudes.

Columbus used a lunar eclipse in 1504 to impress an Amerindian community with his powers when they threatened to cut off his supplies. Lunar eclipses are relatively easy to forecast and can be viewed from anywhere on the night side of the Earth. During a solar eclipse, however, the Moon's shadow on Earth is at most 270 km wide and its path is both narrow and difficult to predict without a very precise knowledge of the Moon's orbit (Fig. 1.3).

There is, moreover, no simple pattern of recurrence. The first known report of an eclipse of the Sun was made in China in 2136 BC although the oldest true record was made in 1375 BC at Ugarit in Mesopotamia. Prediction was apparently delayed until the 1st century BC and even then was based not on a full grasp of the orbital complexities but on the Saros cycle. Cuneiform experts claim that the Babylonian astronomers could predict solar as well as lunar eclipses as early as the 4th century BC. Thus Tablets BM 36761 and 36390 predict a solar eclipse for 6 October 331 BC; the translators remark 'As a matter of fact a solar eclipse did take place … but it could be watched in Greenland and North America, not Babylonia'.[13]

Once solar eclipses could be predicted the scope for playing on gullibility blossomed. In Mark Twain's *A Connecticut Yankee in King Arthur's Court* the hero in

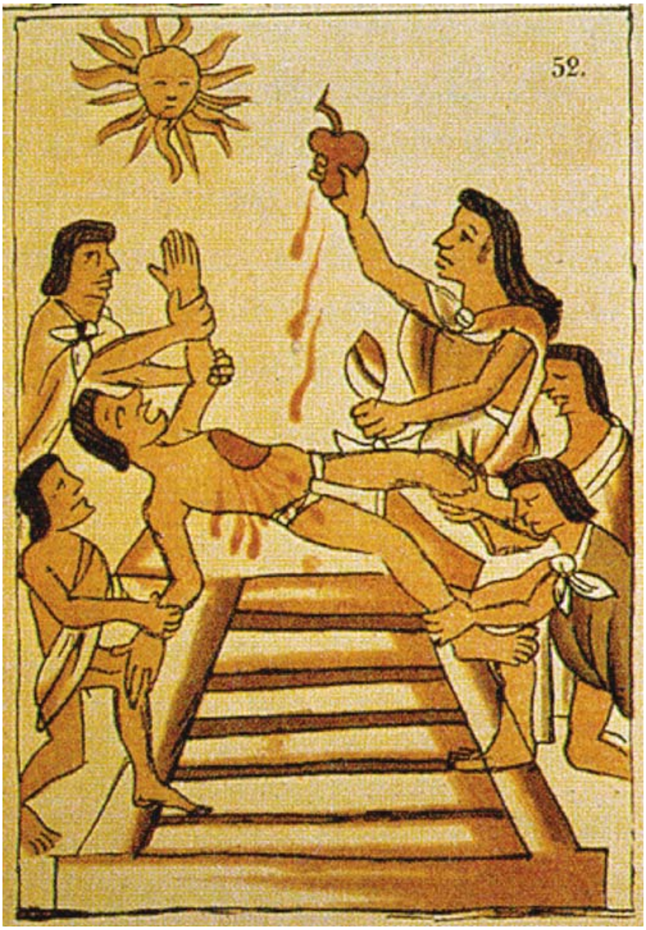

Fig. 1.2 Aztec sacrifice as nourishment for the Sun god Huitzilopochtli to ensure the Sun's daily journey across the sky (Courtesy of Prof. G. Santos)

AD 528 is about to be burnt at the stake but he secures his release by predicting a solar eclipse. So does Hergé's Tintin in *Prisoners of the Sun*, with the Incas unfairly portrayed as astronomically inept.

In Babylon the gods used heavenly signs as warnings, and the astronomers meshed their observation with earthly events, such as the level of the River Euphrates or the price of barley, to construct the Astronomical Diaries (now in the British Museum in London) and thence to devise omens. The cuneiform tablets in question range from the 8th to the 1st century BC. Eclipses warn of imminent danger. A solar eclipse on 29 Nisannu (12 May), for example, meant that the king would die within a year. Alexander was accordingly warned by the Babylonian astronomer Bêl-apla-iddin[14] to avoid Babylon and appease Marduk, the supreme god of Babylonia, by rebuilding his ziggurat. Alexander agreed but then changed his mind, entered Babylon, and on 11 June he died.