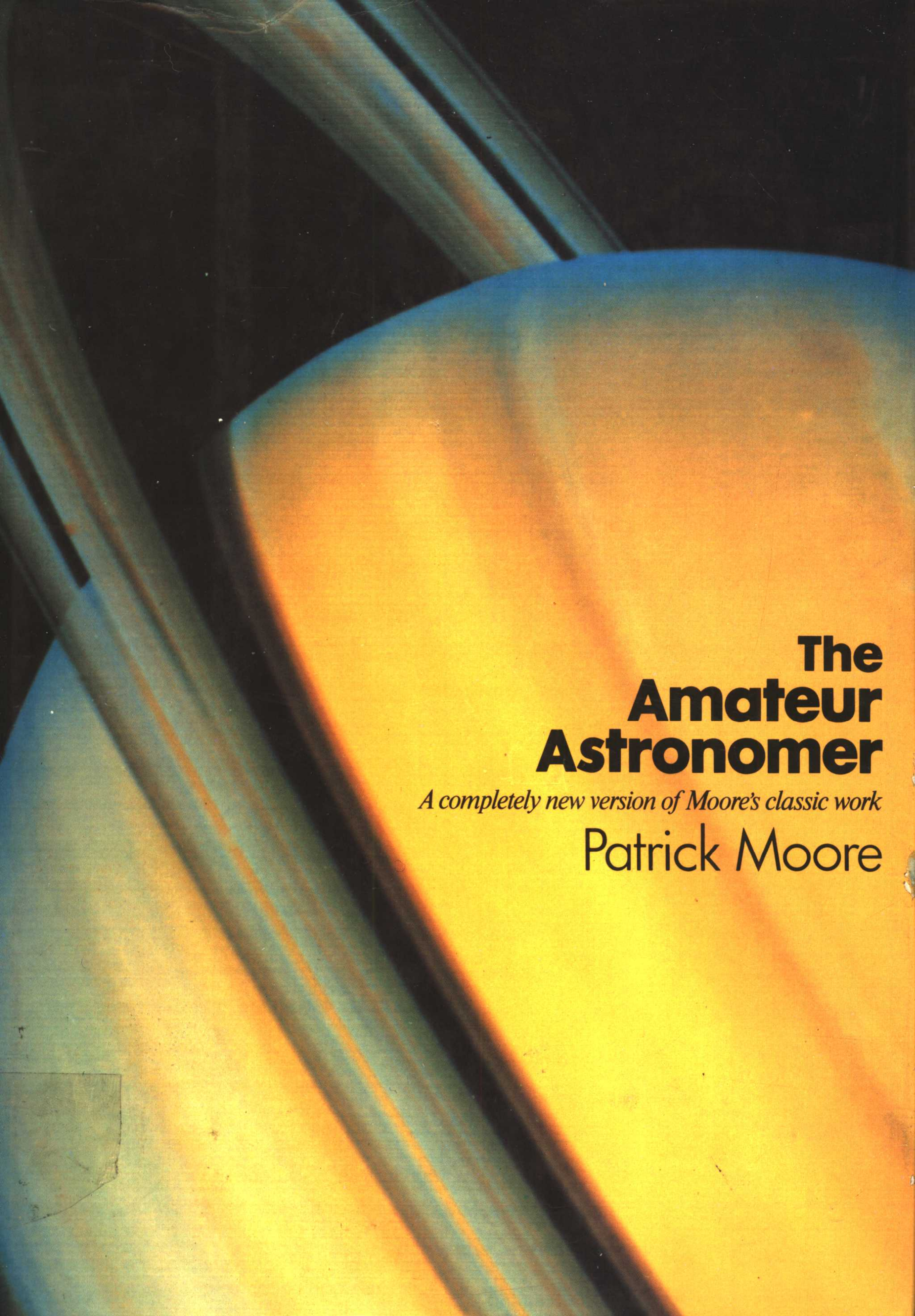

The Amateur Astronomer

A completely new version of Moore's classic work

Patrick Moore

The Amateur Astronomer

PATRICK MOORE

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INTRODUCTION

When I wrote the first edition of this book, in 1957, the Space Age had not begun. Even artificial satellites lay in the future, and anyone who talked about sending men to the Moon was dismissed as an amiable eccentric. Yet there was a general interest in astronomy – after all, the sky is something which can hardly be overlooked – and my aim was to help the newcomer in making a start.

Today the overall situation is different. Astronomy and space research have become of everyday as well as academic interest, and it is not often that a year passes without its quota of spectacular discoveries. Great new telescopes have been built, the first space-stations have been put into orbit, and even photography is being rapidly superseded by electronic aids. Astronomy has become a fast-moving science instead of a comparatively static one.

Inevitably, this has affected the amateurs. In 1957 they were concerned mainly with the Solar System, and this was even more true when I started out at the early age of six (which takes me back to 1929). Modern amateurs often use highly sophisticated, computerized equipment and elaborate electronics. I must admit that in this respect I have not moved with the times. My main interest has always been in the Moon and planets, and my observatory is neither computerized nor electronically fitted. I still make my observations at the eye-end of my telescope – and after all, there is no better way to begin.

I have long since lost count of the number of letters I have had asking me, in various ways, how to start making a hobby out of astronomy. My answer is always the same. Do some reading, learn the basic facts, and then take a star-map and go outdoors on the first clear night so that you can begin learning the various stars and constellation patterns. The old cliché that 'an ounce of practice is worth a ton of theory' is true in astronomy, as it is in everything else.

At least I have one qualification: over the past years I suppose I have made almost every mistake that it is possible to make, and I hope, therefore, that I may be able to warn others against falling into the same traps. I have made no attempt to discuss activities which I do not pursue myself. If you want to find out about computer drives, photoelectric photometers, CCDs and the like, you must consult a book written by someone who knows more about them than I do.

It is fair to say that astronomy is still just about the only science in which the amateur can make valuable contributions today, and in which the work is welcomed by professionals. For example, amateurs search for new comets and 'new stars' or novæ, and since they generally know the sky much better than their professional colleagues they have a fine record of success. Routinely, they keep watch on objects such as variable stars, and they monitor the surfaces of the planets in a way that professionals have neither the time nor the inclination to do.

Quite apart from this, astronomy is a hobby which can be enjoyed by everyone. Take it up, and you will meet many people with the same interests; you will make many new friends, and, if you like, you can carry out some useful research. If you decide to follow it through, I can assure you that you will not regret it.

1

The Unfolding Universe

A subject can always be better understood if something is known about its history. Though we no longer worship our 'honourable ancestors', it is a distinct help to look back through time in order to see how knowledge has been built up through the centuries. This is particularly true with astronomy, which is the oldest science in the world – so old, indeed, that we do not know when it began.

Most people of today have at least some knowledge of the universe in which we live. The Earth is a globe nearly 8000 miles in diameter, and is one of nine planets revolving round the Sun. The best way of summing up the difference between a planet and a star is to say that the Earth is a typical planet, while the Sun is a typical star.

Five planets – Mercury, Venus, Mars, Jupiter and Saturn – were known to the ancients, while three more have been discovered in relatively modern times. Jupiter is the largest of them, and its vast globe could swallow up more than a thousand bodies the volume of the Earth, but even Jupiter is tiny compared with the Sun. The stars of the night sky are themselves suns, many of them far larger and more brilliant than our own, and appearing small and faint only because they are so far away. On the other hand, the Moon shines more brilliantly than any other object in the sky apart from the Sun. Appearances are deceptive; the Moon is a very junior member of the Solar System, and it has no light of its own. It has a diameter only about one-quarter that of the Earth, and it is much the closest natural body in the sky.

The whole celestial vault seems to revolve round the Earth once in 24 hours. This apparent motion is due, of course, to the fact that the Earth is spinning on its axis from west to east. Of all the celestial objects, only the Moon genuinely moves round the Earth.

We are used to taking these facts for granted, but in early times it was (rather naturally) believed that the Earth was flat and stationary. The Sun and Moon were worshipped as gods, and the appearance of anything unusual, such as a comet, was taken to be a sign of divine displeasure.

It is usually said that the first astronomers were the Chaldæans, the Egyptians and the Chinese. In a way this is true enough; these ancient civilizations made useful records, but they had no real understanding of the nature of the universe or even of the Earth itself.

The main story begins around 3000 BC, when the 365-day year was first adopted in

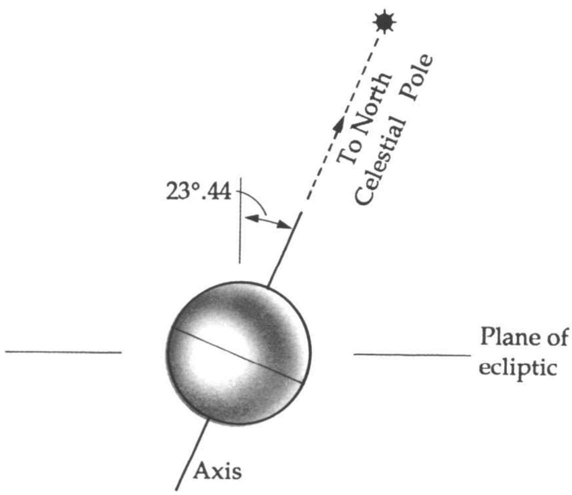

Fig. 1.1. Inclination of the Earth's axis.

Egypt and in China. This, too, was the approximate date of the building of that remarkable structure which we know as the Great Pyramid of Cheops, still one of the world's main tourist attractions. Astronomically, it is of special interest because its main passage is aligned with what was then the north pole of the sky.

The Earth's axis of rotation is inclined at an angle of $23\frac{1}{2}$ degrees to the perpendicular to its orbit, and points northward to the celestial pole (Fig. 1.1). Today the pole is marked approximately by a bright star known as Polaris, familiar to every navigator because it seems to remain almost stationary while the entire sky revolves round it. In Cheops' time, however, the polar point was in a different position, close to a much fainter star, Thuban in the constellation of the Dragon. The reason for this change is that the Earth is 'wobbling' slightly, in the manner of a gyroscope which is running down, so that the direction of the axis is describing a small circle in the sky. The effect is very slight, but the shift of the pole has become appreciable since the Pyramid was built.

The Egyptians divided up the stars into constellations, though their scheme was different from that which we follow today. They also made good measurements, and they regulated their calendar by the 'heliacal rising' of the star Sirius – that is to say, the date when Sirius could first be seen in the dawn sky. Some of their other ideas were very wide of the mark. They believed the world to be rectangular, with Egypt in the middle, and that the sky was formed by the body of a goddess with the rather appropriate name of Nut.

The Chinese were equally good observers, and made careful records of comets and eclipses. Total eclipses of the Sun are particularly spectacular, and at this point I cannot resist re-telling a famous legend, even though experts assure me that it is certainly untrue! Here, then, is the story of Hsi and Ho.

The Moon revolves round the Earth once a month, while the Earth takes a year to complete one journey round the Sun. The Moon is much smaller than the Sun, but it is also much closer, so that – by pure chance – the two look almost exactly the same size. When the Sun, Moon and Earth move into an exact line, with the Moon in the mid-position, the result is a total solar eclipse. The Moon blots out the bright disk of the Sun, and for a few moments – never as long as eight minutes – we can see the glorious pearly corona and the 'red flames' or prominences; the sky becomes so dark that stars can be seen.

The Chinese knew how to predict eclipses – more or less – but they did not know that the Moon was involved; they thought that the Sun was in danger of being eaten by a hungry dragon, so that the only course was to scare the beast away by shouting, screaming, wailing, and beating gongs and drums. (It always worked!) The legend says that in 2136 BC, during the reign of the Emperor Chung K'ang, the Court Astronomers, Hsi and Ho, failed to give due warning that an eclipse was due, so that no preparations were made – and since Hsi and Ho had imperilled the whole world by their neglect of duty, they were summarily executed. I am sorry that the experts have demolished this tale. Had it been true, Hsi and Ho would have been the first known scientific martyrs in history.

It was the Greeks who turned astronomy into a true science, because they not only made observations but also tried to interpret them. The first of the great philosophers was Thales of Miletus, who was born in 624 BC; the last was Ptolemy of Alexandria, and with his death, in or about 180 AD, the classical period of science came to an end. The whole of the Greek period spread over eight centuries, so that, in time, Ptolemy was as far away from Thales as we are from the Crusades.

Thales himself probably believed the Earth to be flat, but unfortunately all his original writings have been lost, and for definite arguments against the flat-earth theory we must turn to Aristotle, who lived from 384 to 322 BC. Aristotle pointed out that the stars change in altitude above the horizon according to the latitude of the observer. For example, Polaris is fairly high in the sky of Greece, because Greece is well north of the Earth's equator; from Egypt, it is lower; from southern latitutes it can never be seen at all, because it never rises above the horizon. On the other hand Canopus, a brilliant star in the southern hemisphere of the sky, can be seen from Egypt but not from Greece. This is just what would be expected on the theory of a round Earth, but is quite impossible to explain if we assume the world to be flat. Aristotle also noticed that when the Earth's shadow falls across the Moon, the edge of the shadow is curved, indicating that the surface of the Earth must also be curved.

The next major step was taken by Eratosthenes of Cyrene, who succeeded in measuring the length of the Earth's circumference. His method was most ingenious, and proved to be remarkably accurate. Eratosthenes was in charge of a great scientific library at Alexandria, Egypt, and from one of the books available to him he learned that at the time of the summer solstice, the 'longest day' in northern latitutes, the Sun was vertically overhead as seen from the town of Syene (the modern Assouan), some distance up the Nile. At Alexandria, however, the Sun was then seven degrees from the zenith or overhead point (Fig. 1.2). A full circle contains 360 degrees, and seven is about $\frac{1}{50}$ of 360, so that if the Earth is spherical its circumference must be 50 times the distance from Alexandria to Syene. Eratosthenes may have arrived at a final value of

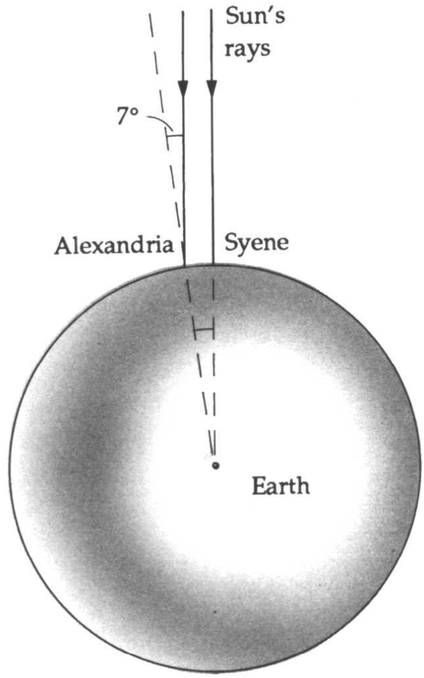

Fig. 1.2. Eratosthenes' method of measuring the circumference of the Earth. When the Sun was overhead at Syene, it was $7\frac{1}{2}$ degrees from the vertical as seen from Alexandria.

24 850 miles, which is only 50 miles too small. Admittedly there is some doubt about this, because we are not sure of the length of the unit he was using, but in any case he was not very wide of the mark. His estimate was much better than the value adopted by Christopher Columbus during his voyage of discovery so many centuries later, which partly explains why Columbus came home without having any real idea of where he had been!

If the Greeks had taken one step more, and put the Sun in the centre of the planetary system rather than the Earth, the subsequent history of astronomy would have been very different. Some of the philosophers, such as Aristarchus of Samos, did believe the Earth to be in orbit round the Sun, but they could give no proof, and the later Greeks went back to the idea of a motionless, all-important Earth.

Much of our knowledge of ancient astronomy is due to one man, Ptolemy of Alexandria (more properly, Claudius Ptolemæus) who flourished between around 120 and 180 AD. We know absolutely nothing about his personality, but he was undoubtedly a brilliant observer as well as an expert theorist, and recent attempts to discredit him have been singularly unsuccessful. His main work has come down to us by way of its Arab translation, the *Almagest*. It is really a summary of ancient science, and it describes the theory of the central Earth which Ptolemy had perfected.

On the Ptolemaic pattern, all the celestial bodies move round the Earth. The Moon is closest; then come Mercury, Venus, the Sun, Mars, Jupiter, Saturn and finally the

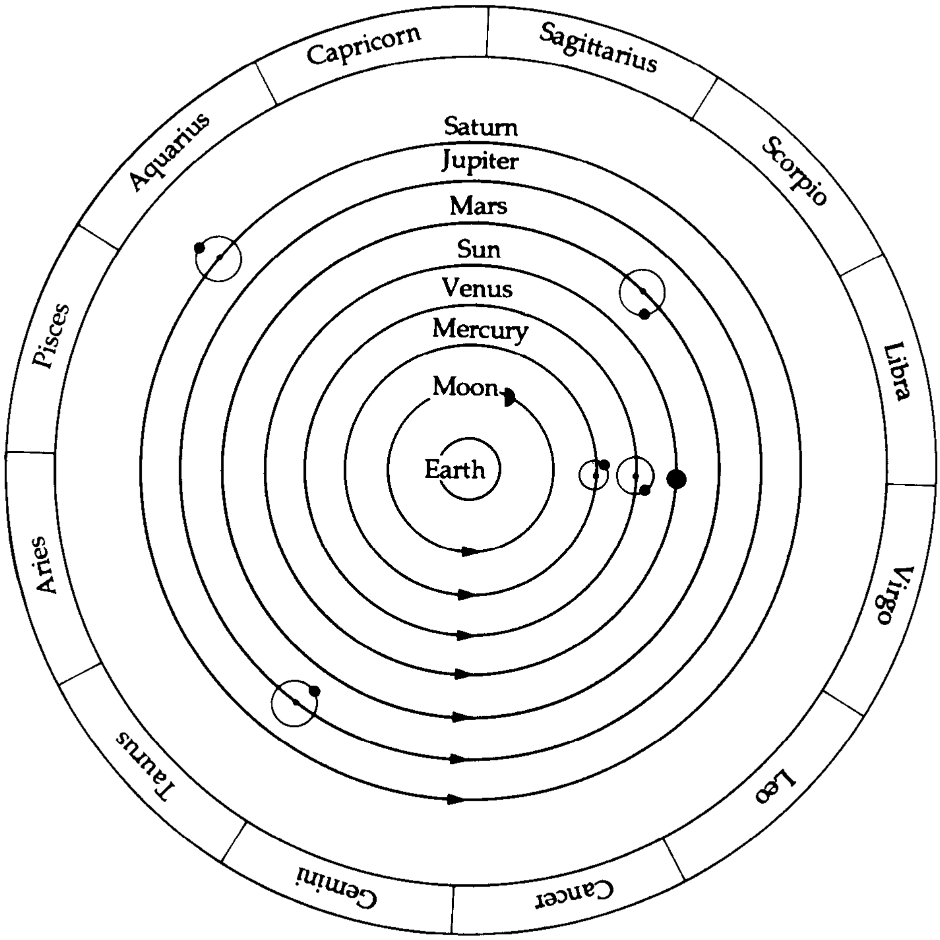

Fig. 1.3. The Ptolemaic system.

stars. Ptolemy maintained that since the circle is the 'perfect' form, and nothing short of perfection can be allowed in the heavens – all bodies must move in strictly circular paths. Unfortunately the planets have their own way of behaving. Ptolemy was an excellent mathematician, and he knew quite well that the planetary motions cannot be explained on the hypothesis of uniform circular motion round a central Earth. His answer was to work out a complex system according to which each planet moves in a small circle or 'epicycle', the centre of which – the 'deferent' – itself moves round the Earth in a perfect circle (Fig. 1.3). As more and more discrepancies came to light, more and more epicycles had to be introduced, until the whole system had become hopelessly artificial and cumbersome. Yet it did fit the observations – and since Ptolemy knew nothing about the nature of gravitation, he could hardly have done any better.

Hipparchus of Nicæa, who had lived two centuries before Ptolemy, had drawn up a detailed and accurate star catalogue. The original has been lost, but Ptolemy reproduced it in the *Almagest*, with additions of his own, so that most of the work has come down to us. We still use the 48 constellation figures which Ptolemy described, even though their boundaries have been modified and new groups added.

When the Greek period came to an end, all scientific progress came to an abrupt halt. The great library at Alexandria was looted and burned in 640 AD, by order of the Arab Caliph Omar, though most of the books may have been scattered earlier; in any case, the loss of the Library was irreparable, and scholars have never ceased to regret it. When interest in the skies did return, it came – ironically enough – by way of astrology.

Even today, there are still some people who do not know the difference between astronomy and astrology. In fact, the two are completely different. Astronomy is an exact science; astrology is a relic of the past, and there is no scientific or rational basis for it, though it still has a considerable following – not only in countries such as India, but in Europe as well.

The best way to define astrology is to say that it is the superstition of the stars. Each celestial object is supposed to have a definite influence upon the character and destiny of each human being, and by casting a horoscope, which is basically a chart of the positions of the planets at the time of the subject's birth, an astrologer claims to be able to look into the future. It takes one back to the Dark Ages, and when an astrologer is asked 'why' he believes that this sort of procedure works, he may well be honest enough to reply that he has no idea. Obviously some astrological predictions are correct – as was once said by an eminent judge, 'it is impossible always to be wrong' (though some modern politicians do their best). My own comment is that astrology does prove one fact, i.e. that 'there's one born every minute'. At least it is fairly harmless so long as it is confined to pier heads, circus tents, and the less serious columns of the Sunday papers.

However, mediæval astrology did at least lead to a revival of true astronomy, because the Arabs, who led the way, needed accurate star catalogues in order to cast their horoscopes. They also needed a knowledge of the movements of the Moon and planets. There were even observatories – very different from the domed buildings of today, but observatories none the less.

The main handicap was still the universal belief in the Ptolemaic theory. So long as men refused to believe that the Earth could be moving round the Sun, it was almost impossible to make any real advance. Things were not helped by the attitude of the Church, which in those days was all-powerful. Any criticism of Ptolemy was regarded as heresy. Since the usual fate of a heretic was to be burned at the stake, it was clearly unwise to be too candid.

The first serious signs of the approaching struggle came in 1546, with the publication of *De Revolutionibus Orbium Cœlestium* (Concerning the Revolutions of the Celestial Orbs) by a Polish canon, Mikołaj Kopernik, better known to us as Copernicus. Copernicus was a clear thinker as well as being a skilful mathematician, and at a fairly early stage in his career he saw so many weak links in the Ptolemaic system that he felt bound to question it. It seemed unreasonable to believe that the stars could circle the Earth once a day. In his own words, 'Why should we hesitate to grant the Earth a motion natural and corresponding to its spherical form? And why are

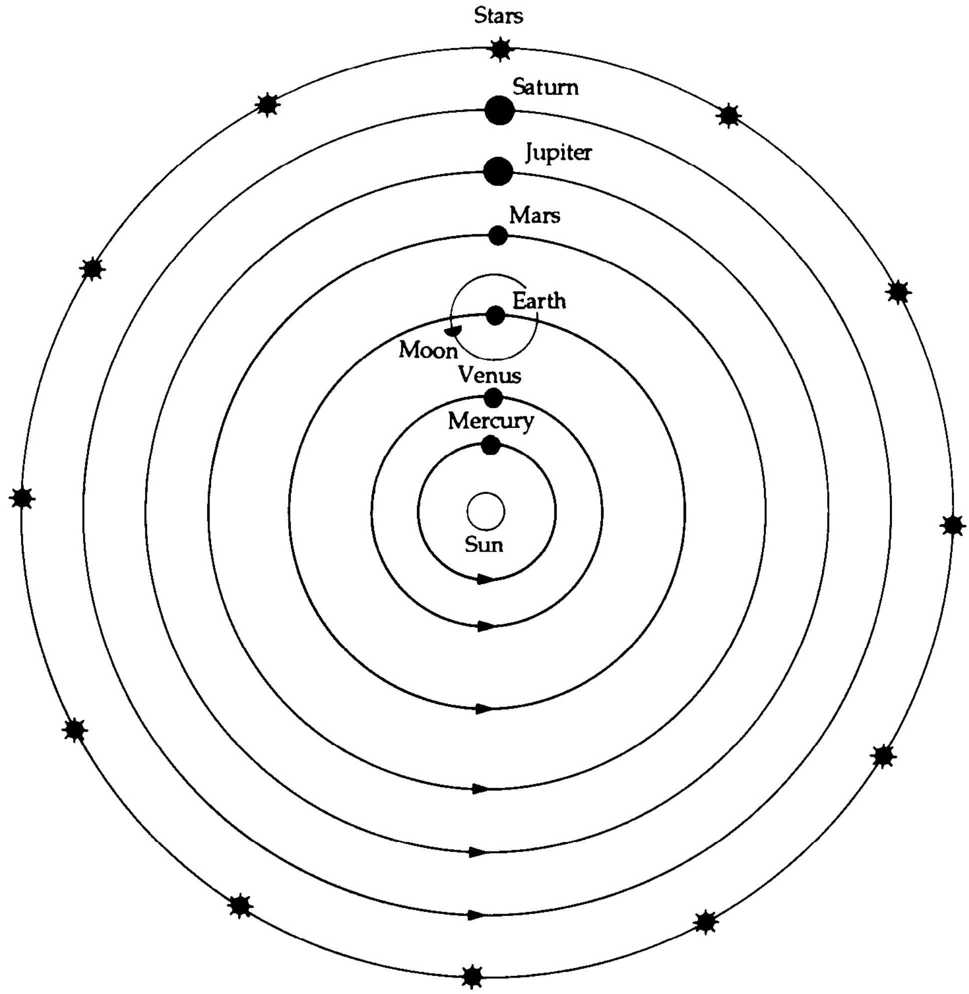

Fig. 1.4. The Copernican system.

we not willing to acknowledge that the *appearance* of a daily rotation belongs to the heavens, its *actuality* to the Earth?' The relation is similar to that of which Virgil's Æneas said, 'We sail out of the harbour, and the countries and cities recede.'

Copernicus' next step was even bolder. He saw that the movements of the Sun, Moon and planets could not be explained by the old system even when Ptolemy's various circles and epicycles had been allowed for, and so he rejected the whole theory. He placed the Sun in the centre of the system (Fig. 1.4), and relegated the Earth to the status of an ordinary planet.

It is fair to say that this was Copernicus' only major contribution; he made many errors, and in particular he retained the idea of perfectly circular orbits, so that in the end he was even reduced to bringing back epicycles. Still, he had taken the essential step. He was wise enough to be cautious; he knew that he was certain to be accused of heresy, and though his theory was more or less complete by around 1530 he refused to publish it until the year of his death. As he had foreseen, the Church was bitterly hostile; one of his strongest critics was Martin Luther. Later, in 1600, the Italian philosopher Giordano Bruno was actually burned in Rome because he insisted that Copernicus had been right. True, this was not Bruno's only crime in the eyes of the Inquisition, but it was certainly a serious one.

Tycho Brahe, born in Denmark only a few months after Copernicus died, was a man of entirely different type. He was a firm believer in astrology, and an equally firm opponent of the Copernican system, preferring a sort of hybrid pattern according to which the planets moved round the Sun while the Sun itself moved round the Earth. He built an observatory on the island of Hven, in the Baltic, and between 1576 and 1596 he made thousands of amazingly accurate observations of the positions of the stars and planets, finally producing a catalogue which was far better than those of Ptolemy or the Arabs. Of course he had no telescopes, but his measuring instruments were the best of their time, and Tycho himself was a magnificent observer.

The story of his life would need a complete book to itself. Tycho is, indeed, one of the most fascinating characters in the history of astronomy. He was proud, arrogant and grasping, with a wonderful sense of his own importance; he was also landlord of Hven, and the islanders had little cause to love him. His observatory was even equipped with a prison for those who refused to pay their rents; he had a false nose, to replace the original which had been sliced off in a student duel, and his retinue included a pet dwarf. Yet despite all his shortcomings, he must rank with the intellectual giants of his age, and Hven became very much a scientific centre; one man who visited it was the King of Scotland, afterwards James I of England. After Tycho left the island, following a quarrel with the Danish court, his observatory, Uraniborg, fell into ruin, and today nothing remains of it. I visited it a few years ago; the site is covered by grass, though it is overlooked by a huge statue of Tycho himself.

When Tycho died, in 1601, his observations fell into the hands of his last assistant, a young German named Johannes Kepler. After years of careful study, using Tycho's observations of the planets (particularly Mars), Kepler saw that the movements of the planets could be explained neither by circular motion round the Earth nor by circular motion round the Sun, so that there was something badly wrong with Copernicus' system as well as with Ptolemy's. Finally he found the answer. The planets do indeed move round the Sun, but not in perfect circles. Their paths, or orbits, are elliptical.

One way to draw an ellipse is shown in Figure 1.5. Fix two pins in a board, and join them with a thread, leaving a certain amount of slack. Now loop a pencil to the thread, and draw it round the pins, keeping the thread tight. The result will be an ellipse,* and the distance between the two pins or 'foci' will be a measure of the eccentricity of the ellipse. If the foci are close together, the eccentricity will be small, and the ellipse very little different from a circle; if the foci are widely separated, the ellipse will be long and narrow. Obviously, a circle is simply an ellipse with an eccentricity of zero.

The five planets known in Kepler's day proved to have orbits which were almost circular, *but not quite*. The slight departure from perfect circularity made all the

* The method is excellent in theory. In practice, what usually happens is that the pins fall down or the thread breaks. One day, I hope to carry out the whole manœuvre successfully!

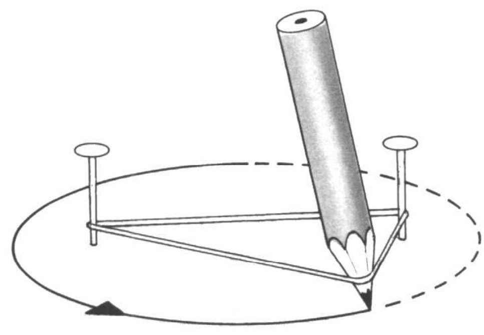

Fig. 1.5. How to draw an ellipse.

difference, and Tycho's observations fell beautifully into place, like the last pieces of a jigsaw puzzle. The age-old problem had been solved, though the Church authorities were not in the least impressed, and kept up their opposition for as long as they could. Kepler's three Laws of Planetary Motion, the last of which was published in 1618, paved the way for the later work of Isaac Newton.

Kepler's work was not the only important development of the early years of the seventeenth century. In 1608 Hans Lippershey, a spectacle-maker of Middleburg in Holland, found that by arranging two lenses in a particular way he could obtain magnified views of distant objects. Spectacles had been in use for some time, but nobody had hit upon the principle of the telescope until Lippershey did so, apparently by accident.

A refracting telescope consists basically of two lenses. One, the larger, is the object-glass; its function is to collect the rays of light coming from the target object, and bunch them together to form an image at the focus (Fig. 1.6). The image is then enlarged by a smaller lens or eyepiece.

The news of the discovery spread across Europe, and came to the ears of Galileo Galilei, Professor of Mathematics at the University of Padua (also, incidentally, the real founder of the science of experimental mechanics). Galileo was quick to see that the telescope could be put to astronomical use, and 'sparing neither trouble nor expense', as he put it, he built an instrument of his own. It was a tiny thing, much less effective than modern binoculars, but it helped toward a complete revolution in scientific thought.

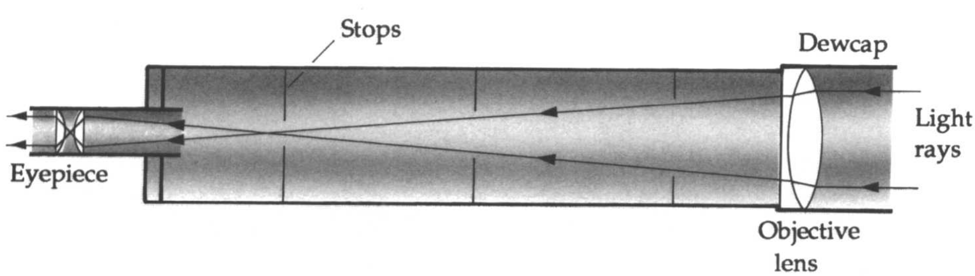

Fig. 1.6. Principle of the refractor.

Galileo first used his telescope in January 1610, and proceeded to make a whole series of spectacular discoveries. The Moon was found to be covered with dark plains, lofty mountains and giant craters; Venus, the Evening Star of the ancients, presented lunar-type phases, so that it was sometimes crescent, sometimes half and sometimes nearly full; Jupiter was attended by four smaller bodies or satellites, while the Milky Way proved to be made up of innumerable stars.

Galileo had always believed in the Copernican theory, and his telescopic work made him even more certain. For example, Venus could never show phases if it moved according to the Ptolemaic system, while the satellites of Jupiter proved that there must be more than one centre of motion in the Solar System. Unlike Copernicus, Galileo was headstrong and impetuous, and he found himself in serious trouble with the Church. He was accused of heresy, brought to trial in Rome, and forced to 'curse, abjure and detest' the false theory that the Earth moves round the Sun. But few people outside the Church were deceived, and before the end of the century the Ptolemaic theory had been abandoned forever. The publication of Newton's *Principia*, in 1687, marked the end of what is often called the Copernican Revolution.

Most people have heard the story of Newton and the apple. It is interesting because unlike most stories of similar type, such as Canute and the waves, it is probably true. Apparently Newton was sitting in his garden one day when he saw an apple fall from its branch to the ground, and realized that the force pulling on the apple was the same force as that which keeps the Moon in its path round the Earth. From this he was led on to the concept of universal gravitation, upon which the whole of later research has been based. It is fair to say that Kepler found out 'how' the planets move; Newton discovered 'why' they do so.

Newton also constructed an entirely new type of telescope. Galileo's instrument was a refractor, using an object-glass to collect its light. Newton believed that refractors could never be completely satisfactory, and he looked for some way out of the difficulty. Finally he decided to do away with object-glasses altogether, and to collect the light by means of a specially-shaped mirror.

When Newton rejected the refractor as unsatisfactory, he was making one of his rare mistakes. However, the Newtonian 'reflector' soon became popular, and has remained so. Mirrors are easier to make than lenses, and today all the world's largest telescopes are of the reflecting type.

Astronomy was growing up. So long as observations had to be made with the naked eye alone, little could be learned about the natures of the planets and stars; their movements could be studied, but that was all. As soon as telescopes made their appearance, true observatories were built. Copenhagen and Leyden took the lead; the Paris Observatory was completed in 1671, and Greenwich in 1675.

Greenwich was founded for a special reason. England has always been a seafaring nation; and before the development of reliable clocks, the only way in which sailors could fix their position when far out in the ocean, out of sight of land, was to observe the position of the Moon against the stars. This involved the use of a good star catalogue, and even the best one available, Tycho's, was not accurate enough. King Charles II, that much-maligned monarch, therefore ordered that the star places must