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Prologue

This book attempts to provide glimpses into the currently exciting areas in astronomy and astrophysics.

The seven 'wonders' described here are not individual objects; they represent a range of mysterious phenomena, a class of spectacular events or a population of remarkable cosmic objects. The attempt to understand them has posed great challenges to human curiosity and ingenuity.

Although a connected theme runs through the seven wonders, each can be read independently.

I hope that, through these wonders, the reader will share the excitement of investigating the cosmos with the professional astronomers who observe and theorize about it.

WONDER

Leaving terra firma 1

THE DAY I SAW THE SUN RISE IN THE WEST

It was a wintry day in 1963, December 14 to be exact, when I saw the Sun rise in the west.

No, I am not trying to pull a fast one! The event actually happened just as I have stated above. But, to restore credibility to the above statement I should elaborate the circumstances. So here is the full story . . ..

It happened while I was on a British Airways flight out of Heathrow, bound for Chicago. I was in a window seat of the Boeing 707, and next to me was the astronomer David Dewhirst of the observatories of Cambridge University. We were both heading for Dallas, Texas for an international symposium on gravitational collapse and relativistic astrophysics.

The sky was clear, of course, at above thirty thousand feet and I had been looking out of the window at the crimson hues towards the southwestern horizon and had seen the Sun go down. A post-lunch stupor was setting in and I was about to doze off for a nap, when David Dewhirst suddenly spoke out. 'Look, there is the Sun coming up again: I am sure I saw it go down below the horizon a few minutes ago.' Even his normally matter of fact way of speaking betrayed suppressed excitement.

I looked out of the window. Sure enough the Sun had indeed come up on the southwestern horizon. And as we both watched over the next few minutes it even rose perceptibly. But this unique spectacle did not last long: the Sun halted in its tracks and finally went down as the plane changed direction southward. It was quite dark when we began our descent into the O'Hare Airport area.

This was the spectacle David Dewhirst and I witnessed that evening. It was an experience I shall never forget.

Why did the Sun rise in the west?

The answer to the question does not call for miracles or for optical illusions. The sight we witnessed was of a real and perfectly natural event that has a perfectly reasonable explanation. And this example demonstrates how different our experiences can be once we leave Mother Earth.

First, let us try to understand why, every day, we see the Sun rise in the east and set in the west. Or, for that matter, why we see the stars move across the night sky from east to west. Today a primary school pupil knows the reason: the Earth spins about its north–south axis and viewed from this moving platform the starry heavens appear to rotate in the reverse direction. This is just like the way a rider on a merry-go-round perceives the surrounding trees and houses go round, in the reverse direction. In order that we see the Sun and the stars go east to west, the Earth itself must be a gigantic merry-go-round spinning from west to east.

Simple! With the help of a globe anyone can understand this hypothesis; but it took mankind millennia to accept it as the true explanation. Let us digress a little and take a peep into recorded history.

'Eppur si muove'

More than two thousand years ago the Greeks, who then had the most sophisticated civilization in Europe, believed that the Earth is immovable and it is the cosmos that revolves round it. Imagine the sky to be a sphere with the stars stuck on it, with the Earth at the centre of the sphere. The Sun and the planets also were supposed to revolve around the Earth though at distances closer than the stars.

Based on a superficial examination of our own experience this belief seems entirely reasonable. Figure 1.1 shows the circular trajectories of stars photographed by a camera that was kept exposed throughout the night. Notice that if a typical star is viewed at any given time it appears like a point source of light. Its position changes slowly, and this is hardly perceptible if we stand and watch it only for a few minutes. However, if we look after a couple of hours, it, along with other stars, will have shifted. The camera in Figure 1.1 has captured the continuous change in the position of each star so that we see a circular track instead of a point source. Compare this figure with, for example, Figure 1.2, which captures the headlights of moving cars in a busy city. In daytime

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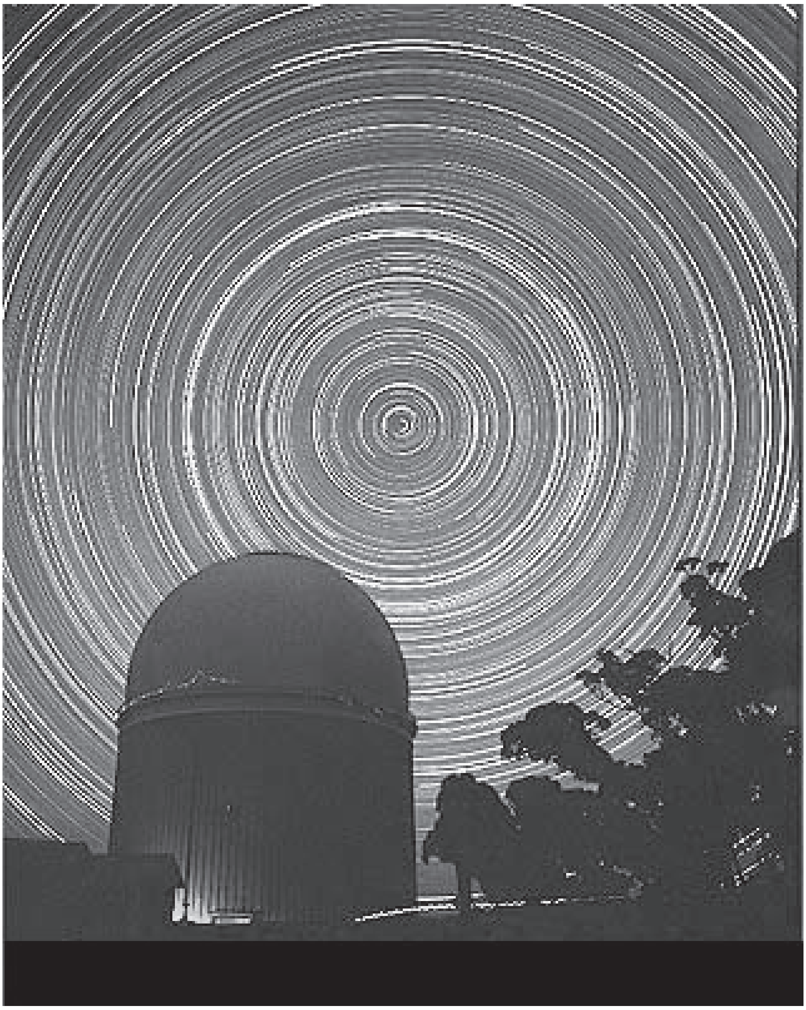

Figure 1.1: Circular paths of stars in the southern hemisphere, photographed against the backdrop of the Anglo-Australian Telescope. Had there been a pole star in the south, it would have appeared as a point at the centre of these stellar arcs (photograph by David Malin; copyright, Anglo-Australian Observatory).

we likewise see the Sun moving along a circular trajectory from east to west, only it is too bright to be caught on a camera! Thus, to an observer on the Earth, it was perfectly natural to assume that the Earth is fixed and the whole cosmos is revolving.

Figure 1.2: Headlights of cars show straight tracks in a busy thoroughfare. (Compare with the stellar tracks in Figure 1.1.)

But there was one thinker who argued differently. The Greek intellectual, Aristarchus of Samos (*ca* 310–230 BC) argued that these observations can be understood more simply by assuming that it is the Earth that spins from west to east and that the cosmos is in fact non-rotating. Aristarchus, whose work was lost with the destruction of the famous Alexandrian Library also believed that it is the Earth that goes round the Sun instead of the other way round (see Figure 1.3). But his ideas found few takers and for good reasons too. Let us see why.

First, take the example of the merry-go-round. A person standing on it experiences an outward force that tends to push him away from the centre. It is the same effect that we feel when riding in a car that rounds a bend at fast speed . . . we are thrown away from the centre of the bend. So, if we are standing on the spinning Earth why are we not thrown out away from the axis of spin? This question could not be answered in Aristarchus's time.

Second, consider the following simple experiment in a park. View a tree from a distance of say, 50 metres. Now walk about 10 metres side-

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Figure 1.3: Aristarchus of Samos (photograph by courtesy of Spiros Cotsakis, of Samos).

ways from the original direction to the tree and look at it again. Its direction against the background of other trees further back will appear to have changed. So if we look at a star today and then six months later, its direction will appear to have changed relative to the background of other stars farther away *if the Earth has moved during these six months from its earlier location*. Indeed Aristarchus expected this result and, to substantiate his hypothesis, he did try to look for it but could not find it.

So on either count his hypothesis failed. But today we know that he was right after all, despite these objections. The reason why we are not thrown away from the spinning Earth is that the magnitude of this force is very small compared to the pull the Earth exerts on all of us, the pull of gravity. Because of the force of gravity we are attached to the surface of Earth and tend to fall back on it if we attempt to jump up and away from it. This is the force that makes us 'feel our weight'. Compared to gravity, the force arising because the spin of the Earth apparently throws us outwards is negligible, being only about three parts in a thousand at the equator and even less at higher latitudes.

As regards the second effect, Aristarchus had grossly underestimated the distance of the stellar bodies and his estimates of the expected changes in the directions of a star were far above the actual changes. (In our analogy of viewing trees from different locations, we know that the direction of a distant tree hardly changes as we change our viewing location whereas that of a nearby tree changes perceptibly.) Thus the direction of a star does change as we view it after six months, but nowhere near as much as Aristarchus expected. And the actual changes in the stellar directions were much too small to be measurable by the purely visual naked-eye techniques available in his times.

The effect that Aristarchus was expecting to see is known today as *parallax* and, with the help of modern telescopes, it has been measured for the relatively nearby stars. Indeed the first measurements of parallax of stars were carried out by the German astronomer Friedrich Wilhelm Bessel in 1838 for the star 61 Cygni, more than two thousand years after Aristarchus! How tiny was the observed change of direction? If we use the familiar degree as the measure of an angle, then the observed change was through about the *ten thousandth part of a degree*! This was far beyond the capability of measurements of ancient Greeks in the days of Aristarchus. No wonder that the contemporaries of Aristarchus found no change of direction for any star as predicted by him. It is not uncommon in the history of science that a scientist with a correct hypothesis which, however, goes against the prevalent belief has had to face derision or neglect if the hypothesis were ahead of his or her times. The irony is that when these ideas finally do get verified and accepted, the identity of their originator may have been lost in the mists of history.

A similar experience awaited the fifth-century Indian astronomer Aryabhata who sought to explain the observation of westward-moving stellar bodies with the analogy of a boat going down a river. The boatman sees the fixed objects on the banks moving backward in analogy to the fixed stars observed from a spinning Earth. Historical records are rather vague, but it seems that Aryabhata was driven by ridicule out of his native state Bihar in North India and had to migrate to the western state of Gujarat from where he had to go out again, to ultimately settle in the southern state of Kerala. Not only that; even his successors in the following centuries sought to push Aryabhata's remarks under the carpet by either discounting their authenticity or 'reinterpreting' them in more conventional terms.

The cultural barriers that existed in Europe and Asia prevented the acceptance of the modern view until the seventeenth century. In the Middle Ages the concept of a fixed earth had acquired the status of religious dogma. The works of Nicolaus Copernicus and Galileo Galilei finally brought about a revolution in thinking but, again, not during their lifetime. Copernicus (1473–1543) argued that not only does the Earth spin about its axis but it also goes round a fixed Sun. His book *De Revolutionibus Orbium Celestium*, which gave a complete description of how all planets, including the Earth, orbit the fixed Sun had a hostile reception as it was widely believed to be against religious tenets.

Galileo (1564–1642) argued even more forcefully for the Copernican theory and was hauled before the Inquisition for propagating heretical views. In the interest of his own survival Galileo recanted but privately continued to believe in the Copernican moving-Earth hypothesis. After the recantation he is believed to have muttered to himself 'Eppur si muove', meaning *but it (the Earth) does move*.

The mystery explained

With this digression over, let us return to the sunrise problem. We will follow Copernicus and Galileo and work with the spinning-Earth model. Figure 1.4(*a*) shows the latitude circle of Chicago. This runs west to east all round the globe and passes through the location of Chicago. Draw a tangent to the circle. As the globe revolves, this tangent changes direction in space. In Figure 1.4(*a*) it has the Sun below it, that is, the Sun is below the eastern horizon and therefore not visible. A little later, as shown in Figure 1.4(*b*), the tangent line touches the Sun and so this represents the sunrise, while in Figure 1.4(*c*) the Sun is above the line, that is, above the horizon. Thus, the rising of the Sun over in the East is entirely understood by the spin of the earth from west to east. Similarly we can explain the setting of the Sun as the upward movement of the horizon from below.

Now imagine that the spin is reversed! That is, instead of west to east the Earth spins from east to west. Then, by an exactly similar argument, we can deduce that on an Earth spinning in this new fashion the Sun would rise in the west and set in the east.

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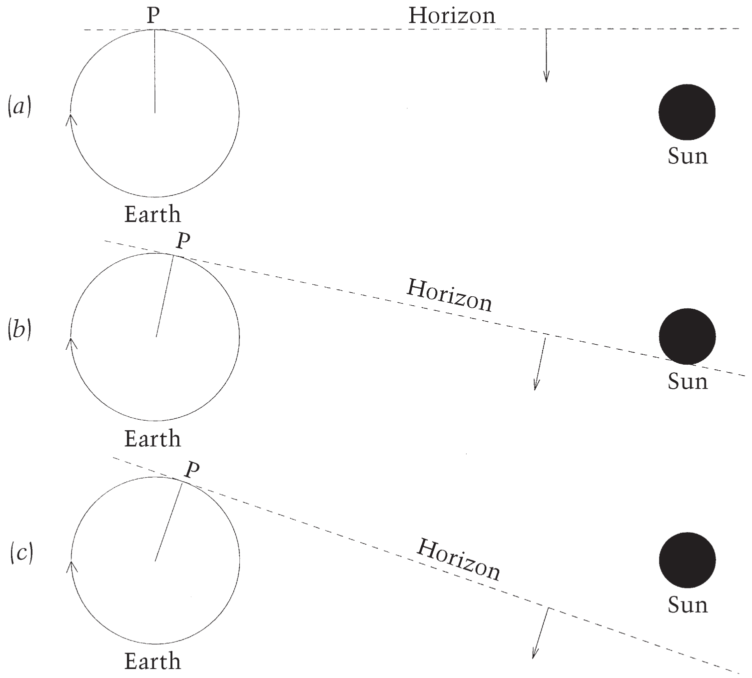

Figure 1.4: Viewed along the south–north axis of the Earth, the latitude circle rotates in a clockwise fashion. In (*a*) we see a tangent drawn eastward which represents the horizon with the Sun below it. In (*b*) the Sun is just above the horizon at the time of sunrise while a little later in (*c*) the horizon has moved further so that the Sun is above it.

But there is a snag in the reasoning developed so far. We cannot in reality reverse the spin of the Earth. So what is the use of this imaginary argument? How can it explain a real experience like the one David Dewhirst and I had? It can, provided we add to it the one clue as yet not used. The clue is: *we were travelling in a jet plane from east to west*. What if our speed in the westerly direction exceeded the Earth's speed in the easterly direction?

An analogy will help. When you stand on a moving belt in an airport you are carried along in the direction of the belt's motion without having to walk on it. If you are in a special hurry you walk on the belt in the same direction and increase your effective speed. But suppose, just to be perverse, you decide to walk in the opposite direction. Then, unless you walk (or run) fast enough you are still moving in the direction of the