Cambridge University Press
978-1-107-17624-9 — Dance to the Tune of Life
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# The Universe and the Principle of Relativity

*'Let there be light, and there was light'*

יְהִי אוֹר וַיְהִי אוֹר

(Genesis 1:3) (Figure 1.1)

## The Sky at Night

Now that most of humanity lives in cities, it has become rare for us to experience the full extent of the wonder that our predecessors must have felt as they saw the night sky from open country or from their unlit dwelling places. On every clear moonless night they would have experienced what we can do only by going to remote parts of the countryside far away from the city lights. They would have noticed that as dusk gives way to night, more and more stars appear. And as their eyes slowly adapted to the dark, even more would appear until they became uncountable. On a really clear, cold night they would also experience the feeling that the universe is somehow alive with activity as the faintest stars seem to appear and disappear depending on whether one looks directly at them or at a slight angle. There is a depth also to the sheer blackness of space between the stars that contrasts so markedly with its light blue during the day. The sky at night viewed in this way, when there is little or no moonlight, is a miracle, with a giant belt (the Milky Way) running across it, with countless stars appearing, more the longer we look, and with the occasional larger movement as a meteor appears. To crown the spectacle, it moves slowly and majestically throughout the night.

**Figure 1.1** A view of the Milky Way towards the Constellation Sagittarius (including the Galactic Centre) as seen from a non-light polluted area (the Black Rock Desert, Nevada) (courtesy of Steve Jurvetson). For a colour version of this figure, please see the plate section.

Faced with such glory and spectacular beauty, we are forced to ask a question. Why?

The question pushes its way before us. And the human response to this question has always been the same: to propose an answer. We find it difficult to live without answers. That is what drives our metaphysical instincts, which in turn create our systems of religious and scientific thought. They are not so far apart as many might think. The quest for meaning can be seen as the religious instinct. The quest for explanation in terms of cause can be seen as the scientific instinct. But the two connect through the fact that we cannot even begin to develop an explanation without making some meaningful assumptions about the framework within which we can interpret what we see, feel and hear. We need a metaphysics within which we can develop our physics. That is as true today as it was in the earliest scientific discoveries, as we will see as the story in this book develops. Science also contributes to understanding meaning through identifying what we call function. It is too simplistic to say that science deals only with 'how?', while religion deals only with 'why?'. The two questions intertwine.

So, what did our ancestors do to make sense of what they saw in the darkest of nights in the deep countryside? They saw groups of stars, what we today call constellations. They also imagined that these groups had meaning and so they gave them names. There is one particular constellation, the one we now call the Big Dipper or The Plough, which received names in all the main historical traditions we know about. Many saw a bear, which is why its Latin name is *Ursa Major*, the great bear. It appears in Babylonian and Egyptian astronomy, leading to the Greek system, and in the Jewish system which leads to its reference in the Bible.[1] It appears in ancient Chinese[2] and Indian[3] astronomy, and in every other traditional system. In fact, this constellation is only one of two (the other is *Orion*) that appear as such in both the Western and Eastern astronomical traditions. The Chinese divided the sky up in a different way, based on the pole star, Polaris, whereas the Greeks thought in terms of the relationship of the constellations to the way the sun appears to move amongst them during the year, which is what gave us the signs of the zodiac.

Dividing up the sky into constellations was very practical. Relating them to the pole star was particularly helpful to travellers and mariners. *Ursa Major* points towards the pole star and could therefore be used to find north. It was also possible to use the sky as a timekeeper since it rotates smoothly throughout the night. If one knows the constellations well and how their movements change during the year, one can work out what time of night it is. All of this was important to people navigating through open seas and deserts. The sky was their signpost and clock. Those highly practical results arose from the smooth circular movement of the heaven above us as it rotates around the Earth.

Or does it? Today, we know that assumption is wrong. But it is instructive to understand the steps by which we came to that conclusion. Therein lies the origin of the principle of relativity.[4] Most people think that the principle applies only to physics. One of the purposes of this book is to show that, in its widest sense, it must apply also to biology. First we must understand its use in physics, which is the purpose of this chapter. We will then be able to explore its impact on biology.

Before I outline the steps by which the fundamental principle of relativity developed, I would like to ask the reader to adopt the attitude of an inquiring explorer. It is easy for us to laugh at what we see as the misunderstandings of the past. A flat earth? Absurd! A heavenly globe containing the stars? Ridiculous! With that attitude, it is also easy to forget that we will be seen as ancestors in the future. How do we know that we, and we alone amongst the tens of thousands of years of human thought, have at last got the answers right? Many thoughtful scientists today are convinced that there are more revolutions to come and are not at all happy with our current models of nature.

Those models are brilliantly successful at prediction, much more so than ever before. But as a basis for understanding, for feeling certain that we have 'got it', they leave much to be desired. We find it difficult, for example, to unify the physics of the smallest scales, where quantum mechanics is relevant, and the physics of large scales, where general relativity dominates. Nor do we know how to explain the apparently arbitrary nature of the constants of the universe,[5] although we know that they need to be within narrow limits for our universe to exist and for living systems to be possible. In biology, there are many more puzzles calling out for answers: what is life? How did we as a species get to be the way we are? What is a gene? And many more. In the search for those answers, we followed a largely blind alley during the twentieth century. The blind alley is the idea that the genome is the 'book of life', a blueprint from which you and me, and all other living creatures, were made.

We have more to learn from the history of thought about the universe than we might think. If we take each step seriously and understand why it was taken, we will then understand better what steps we can take in the future to distance ourselves from our own misunderstandings. This book is also an appeal for humility in scientific thought. It occupies an intellectual space billions of miles from the naive certainties that many popular science writers portray. We advance in understanding by first coming to know what we don't understand. That kind of knowledge requires hard work. We have to undo some of our cherished basic beliefs.

So, join me on a thoughtful and provocative journey through the questions that we can't help asking. We begin in this chapter by asking how to interpret the sky at night, how that question led to the principle of relativity, and to the Special Relativity and General Relativity forms of the theory proposed by Einstein.[6]

## Early Cosmologies

The oldest Hebrew sources represented the Earth as a flat disc floating in a huge sea. Since no one could consider the possibility of going completely round the Earth, the idea that the habitable Earth must have an edge, beyond which was a sea, was a reasonable assumption. The heavens were then represented as a hollow sphere with the stars set in the surface of the sphere as points of light in what could be viewed as a massive celestial candelabrum. Clearly the sphere must move, which creates the difficult question of where it goes when it moves below the horizon. And there must be several such spheres since the sun moves separately, and so do the 'stars' that we now know are planets.

One way to think about such a universe is that, since it consists of concentric spheres, perhaps its centre is also a sphere. That makes it easier to answer the question of where the spheres go when they disappear below the horizon. They just go round the central sphere, which must be the Earth. We don't know when exactly the idea that the Earth too was a sphere first arose, but we do know that it was a central idea for the astronomer Claudius Ptolemy, who lived around CE 90 to about CE 168. As his given name, Claudius, suggests, he was a Roman citizen, although he lived in Egypt when it was ruled from Rome, and his family name, Ptolemy, is Greek. He wrote in classical Greek.

He is said to have used Babylonian astronomical data to construct an elaborate set of tables and mathematical calculations brought together in the first surviving textbook of astronomy, called the *Almagest*. It includes ingenious geometrical calculations from a Greek mathematician, Hipparchus, which allowed estimations of the distances from the Earth to the sun and the moon. These calculations enabled the celestial spheres to be given dimensions and distances. In addition to the sphere carrying the sun, additional spheres carried the planets, and of course the outermost sphere carried the stars. In addition to the Earth, there were eight spheres carrying the sun, the moon, five known planets (Mercury, Venus, Mars, Jupiter, Saturn) and the fixed stars.

This shift in perception about the Earth and the universe can be represented as the first stage in developing the principle of relativity. As I will use this principle in this book it consists of distancing ourselves from privileged viewpoints for which there is insufficient justification. There are no absolutes – rather, even in science things can only be understood in a relative sense: relative to the question we ask; relative to the scale at which we ask the question; relative to our present knowledge of a universe of which we will always have questions remaining. In this sense, a privileged position is akin to an absolute.

Coming to view the Earth as yet another sphere was precisely such a use of relativity. The Earth was no longer viewed as a uniquely flat object.[7] Like the rest of the universe, it became a sphere. You will learn how this very general principle of distancing ourselves from supposedly unique or privileged viewpoints leads to the more familiar theories of relativity later in this chapter, and then to the theory of Biological Relativity in Chapter 6.

Distancing ourselves from viewing the Earth as a flat object may not have been easy. Many nineteenth-century writers thought that the idea of a flat Earth was originally so convincing that when Christopher Columbus set off in 1492 to sail west in order to arrive at the east, uneducated people still feared that he might reach the edge of the Earth, and perhaps never be seen again. This is a modern myth.[8] Medieval scholars were quite clear that the Earth was round. The mistake Columbus made was to calculate that East Asia was much closer. Finding the Caribbean islands saved him and his crew, and he still believed he had found the East.

## The Copernican Revolution

Distancing ourselves from the geocentric view takes us to another great astronomer, Nicolaus Copernicus. Copernicus was born in 1473 in the Kingdom of Poland, and studied first at the Jagiellonian University in the then capital, Krakow. Later he moved to Italy and the famous universities of Bologna, Padua and Ferrara. Along with the anatomist Vesalius, he became one of the great polymaths of the Renaissance and a trigger of the Scientific Revolution. His book on the universe, *De revolutionibus orbium coelestium* (on the revolutions of the heavenly spheres) was published just before his death in 1543.[9]

The idea that the sun might be the centre of the universe was not entirely new. Similar ideas had been proposed in the third century BC by Aristarchus. We know this because Archimedes describes how Aristarchus thought that the fixed stars and the sun are unmoved, while the Earth revolves around the sun. Aristarchus also correctly thought that the fixed stars were very far away.

Copernicus, though, deserves the credit for providing the mathematical basis to show that the idea was predictive, and that it explained the strange fact that on the geocentric view the planets seem sometimes to move backwards. The Ptolemaic system had been made more complex in order to deal with this problem by postulating the existence of further epicycles.[10] This illustrates a pattern that is often repeated in science. Well-loved theories do not usually die suddenly. People try to find ways of retaining the central ideas of the theory while adding complexity to the explanations to accommodate observations that do not seem to fit the theory. Sometimes, the adoption of a new theory depends more on the overall weight of evidence, rather than on a single knock-down observation. We will have the opportunity to observe this process in science in later chapters of this book.

The clarity with which Copernicus stated the heliocentric view was impressive. He expressed his ideas as seven assumptions. First, that there is not one centre. This was to allow him to retain one aspect of geocentrism, which is that the moon orbits the Earth. This was explicitly stated in his second assumption, together with the statement that the Earth is not the centre of the universe. Instead, in assumption three he stated that the sun is or is near the centre of the universe. He then made a remarkable deduction. From observations of distances, he concluded that the distance to the stars is much greater than the distance of the Earth from the sun. His fifth assumption is also remarkable. This is that the motion of the stars represents simply the spinning motion of the Earth. The fixed stars are just that: fixed, immoveable. Assumption six gives the Earth an additional motion, that of orbiting the sun. Finally, he explained the Ptolemaic apparently 'backwards' movements of the planets as due to the Earth's motion.

This was the second application of the general principle of relativity. Arguably, it may have been the most important one since abandoning the privileged position of the Earth as the centre of the universe was a first step. That idea leads inevitably to the more familiar theories of relativity since, once we abandon the idea that our home, the Earth, is in any way special, why should we be convinced that anything else is the centre of the universe?

But it did not do so immediately. In fact, the ideas of Copernicus did not initially create any great waves of controversy. Significantly, there was no dramatic argument with religious thinkers. This fact is very important in the story of this book. Religious thinkers treated Copernicus as they treated themselves: as metaphysical theorists struggling to make sense of the world and the universe. This is hardly surprising since he was also a canon of the Catholic Church. Moreover, other church leaders had also proposed ideas similar to those of Copernicus. Two centuries earlier the French bishop Nicole Oresme had considered the proposition that the Earth rotates. In fact, his *Livre du ciel et du monde* contains the spirit of relativity, since he showed that to assume that the Earth is rotating rather than the heavens would not change any of the astronomical calculations. He appreciated the fact that different metaphysical standpoints can lead to the same conclusions concerning relative movements. His work did not, however, lead to a revolution of thought in the way that Copernicus' work did. In fact, he concluded that there was no proof that the Earth rotates – and no disproof either!

In the fifteenth century, the German Cardinal Nicholas of Cusa had expressed in a book called *De Docta Ignorantia* (roughly translated as 'On scientific ignorance') a viewpoint that is infused with the central idea of relativity: 'Thus the fabric of the world will have its centre everywhere and circumference nowhere.' This is remarkable since it also anticipates the later stage of questioning whether even the sun (or any other point)

**Figure 1.2** Jupiter and the four Galilean moons observed through a Meade "10" LX200 telescope, i.e. ten times more magnification than was available to Galileo (Jan Sandberg, Wikimedia). For a colour version of this figure, please see the plate section.

could be the centre of the universe. Not surprisingly, he also developed a sophisticated, some would say mystical, concept of god.[11]

These historical facts are important. They show that the widely held view that every major advance in science has provoked reaction from conservative religious thinkers is far too simplistic. The more accurate historical view is that these debates about the nature of the universe occurred as much within the Church as outside it. Arguably, Nicholas of Cusa was the greater revolutionary than Nicolaus Copernicus since he was way ahead in questioning even the idea of giving a privileged position to the sun, *or any other celestial object*.

As to opposition to Copernicus, there were opponents both within and without the Church. Wider scientific acceptance of his ideas had to wait for more experimental proof anyway. This came with the work of Galileo and the first use of the telescope (Figure 1.2).

## Galileo: Father of Modern Science

Galileo Galilei was born in 1564 and studied medicine at the University of Pisa. It was Einstein who called him the 'father of modern science'. He transformed our study of the universe. He did so using his own early telescope of very limited power (magnification about ×20), so with even a modest modern telescope you can easily repeat some of Galileo's key observations, which he made on 7 January 1610.

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The planet Jupiter can often be seen as a bright object. Amongst the planets, only Venus is brighter. Its position in the sky depends of course on its movements, so you need to consult a guide to its position on any given night. It is easily the largest planet, a gas giant 11 times the Earth's diameter. Unless there can be living systems very different from what we know, it could not support life. However, it has many moons and four of these are so large that they could be observed by Galileo. You can also see them. They are arranged on the same plane so you will see them strung out on either side of Jupiter. They orbit Jupiter in a matter of days, so you can also repeat another of Galileo's observations, which is to see that they are in different positions every night. Galileo, of course, saw the point. Here is a miniature solar system with Jupiter acting as the attraction in place of the sun and the moons playing the role of the planets. It is hard to make these observations without realising that the Earth must also go round the sun. And that the planets that do so can have moons just as the Earth has a moon. While Jupiter itself is very unlikely to harbour life, its moons might do so. Europa has a surface of ice and water which might well support life.

Galileo's observations and his defence of the heliocentric idea came about 60 years after Copernicus' publication of his work. This time, the mood within the Church was different. Some, notably amongst the Jesuits, supported him. But it is thought that intrigue at the Vatican led to Urban VIII, who had been a supportive friend, even encouraging him to publish his work, becoming offended by what could be seen to be mockery of him and the geocentric view in Galileo's book *Dialogue Concerning the Two Chief World Systems.*[12] The defender of the geocentric view was a character called Simplicio, which carries the connotation of simpleton. Offending friends by mocking them may not be wise. Perhaps Galileo meant no offence. Simplicio was simply a literary device.

There have been many books and articles written on these events and the subsequent famous 'recantation' of Galileo.[13] It is true that Galileo was found guilty of heresy by the inquisition and put under house arrest, while his books were banned. The ban on his books was not lifted until the eighteenth century. Famously, in 1992 Pope John Paul II expressed regret for the events that led to the Church accusing him of heresy and subjecting him to house arrest.

It is right to condemn the seventeenth-century Vatican inquisitors. They were certain they were right and Galileo was wrong, so wrong that