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Setting the stage

It has taken us a long time to discover where we are. Primitive tribes living in remote jungle valleys have often been astonished to discover that the Earth extends far beyond their limited horizon and that they are not its sole inhabitants. Before Copernicus, similar views were held in the civilised world. It was generally believed that the Earth was the centre of the universe. However, it was gradually realised that we live in a bigger arena. When you look up at the sky on a dark night in the country, the most striking feature, when the Moon is down, is the glowing band of stars, referred to as the Milky Way, a term first used in English literature by Geoffrey Chaucer (1342–1400) in 1384. This splendid band of stars spreading across the heavens is an edge-on view of our galaxy from the inside.

Although there is a place for the Milky Way in most mythologies, before recent times only Kant seems to have realised what we were looking at. From a nearby galaxy, a few hundred thousand light years away, the magnificent spiral structure that is obscured by our edge-on view would be revealed in all its splendour. But even this enormous spiral system is only a tiny portion of the universe. Each new telescope reveals a larger universe than our imagination had conceived. Like travellers lost in an immense wasteland, we desperately seek for signs that we are not alone. Now we have begun to discover 'planets' circling other nearby stars. Then there is the remote chance that life existed at an early stage on Mars. Both have added new hope to the possibility that we are not alone, lost among the incomprehensible spaces that are extended with each new discovery.

Meanwhile, from the past three decades of space exploration, we have developed a new understanding of the solar system, and of the place of the Earth in it. We understand much about the planets, how they were formed and how they evolved. This enables us to take

another look at the idea of 'one world or many?'. How easy or difficult would it be to make a duplicate of our solar system, or of the Earth, complete with its interesting cargo of inhabitants. Are habitable planets, complete with 'little green men (or women)' readily available and common elsewhere? This problem is addressed by looking at what we have discovered about our own system of planets.

I begin by examining what the ancients made of the world in which they found themselves, as civilisation slowly arose following the melting of the great ice sheets. Most of our present ideas were formulated in the great flowering of civilisation in Greece and Rome. Following the collapse of the Roman Empire, there followed a thousand years of intellectual stagnation in the West. Astronomy survived through the work of Arab observers; many of our brightest stars such as Aldebaran still bear their Arabic names. The revival of learning in Europe led to the Copernican revolution in the sixteenth century. This created a new world view that the human ego is still trying to come to grips with.

The place of the solar system in the universe

The view before Copernicus

The comfortable and apparently obvious idea that the Earth is the centre of the universe no longer attracts much attention. This is not only because such notions have been replaced by those of the Copernican Revolution, but because in such models, the origin of the Earth, Sun and planets was tied to the origin of the universe. After all, the Earth could hardly be younger than the rest if it occupied the central position. Now, however, we are aware that the age of the solar system is only about one third of the age of the observable universe. This makes it no longer necessary, as was the case with the authors of the Book of Genesis, to seek a common origin for Earth, Moon, Sun and stars. Most of this progress has been made by the discovery of new facts, not by theories. Galileo's observations, like those of Darwin, have done more to give us a correct view of the world than most of the thinking about it over the centuries.

The Babylonian and Greek astronomers observed the strange motion of the planets against the fixed positions of the stars. In this manner, they became aware that there were two classes of heavenly objects in addition to the Sun and the Moon. The term 'planet' is derived from the Greek word meaning 'wanderer'. It is curious that although the ancient astronomers devoted much study to the movements of the planets, they did not spend much time considering the origin of the solar system. The planets were mostly not clearly distinguished from the other heavenly bodies. The whole question of origins seems to have been the province not of the astronomers, but of the philosophers. There was no shortage of these, nor of their ideas.

Some astronomers, however, took up the challenge. Among them was Anaxagoras (*c.* 500–428 BC), who considered that the Moon was a stone. He thought that the Sun was a red-hot mass of iron bigger than the Peloponnesus, the southern region of Greece that is about the size of Sicily. This idea that the Sun might be made of iron was based on a reasonable interpretation of the available evidence. An iron meteorite had fallen about 467 BC in ancient Thrace and Anaxagoras concluded that the visitor had come from the Sun. He was banished from Athens because his views about the composition of the Sun and the Moon were considered to be heretical. Little of his work has survived, but apparently he pictured the Earth at the centre of a sort of large cosmic whirlpool. In this he anticipated the notions of Descartes in the sixteenth century, demonstrating the truism that few ideas are truly original.

The great trio of Greek philosophers, Socrates, Plato and Aristotle, whose ideas have formed the basis for western culture, were mostly concerned with questions of purpose. They distinguished carefully between the Earth, with its obvious imperfections, and the heavens, which they held to be unchanging. Four elements, earth, air, fire and water, sufficed to make up the Earth. The heavenly bodies in contrast were composed of shining crystal, a perfect fifth element, or quintessence. The Moon was also made of this. The dark patches that one could easily see on the face of the Moon were thought to be the reflections in this perfect mirror from the mountains and oceans on the Earth.

The doctrine of Socrates (*c.* 470–399 BC) held that the heavens

were perfect, in obvious contrast to the Earth. This left no room for any changes or evolution and so did little to encourage scientific investigation. Plato (*c.* 428–347 BC) concerned himself with the motions of the planets rather than their origin. He did suppose, however, that the Earth was moving. In his scheme, the heavenly bodies were supposed to move in perfect circles and the apparently chaotic wandering of the planets among the fixed stars was a major problem. The problem of perfectly circular orbits continued to haunt astronomers as late as Copernicus, over 1000 years later, until Kepler finally broke the spell. Aristotle (384–322 BC), the third member of the trio, also thought that the heavens were permanent and thus not subject to the earthly laws of physics as he perceived them. His views, wedded to the concept of a providential Old Testament God who designed all for our well-being, were to dominate Western culture for 2000 years.

A refreshing contrast to these views was proposed by Aristarchus of Samos, who lived around 250 BC. He placed the Sun at the centre of the solar system, and included the Earth with the rest of the planets. He realised that the Earth was small in relation to the Sun. Many people today have not made that intellectual leap. Aristarchus appears to be the first person who suggested that the Earth both rotates and revolves around the Sun. This idea was not forgotten, but lay around until revived by Copernicus over a millennium later. It is fitting that a prominent crater on the Moon is named for Aristarchus.

Epicurus (341–270 BC), who was a strong critic of the views of Aristotle, did not give the heavens any special or separate status. He supposed that the heavenly bodies formed by random collisions of atoms, whose existence had been proposed by Democritus (about 470–400 BC) 150 years earlier. We would now call Epicurus a materialist. The Epicurean School rejected divine explanations, and believed in physical causes. Unfortunately, it did not encourage investigations into natural phenomena, so that no scientific advances resulted. Epicurean philosophy was mostly concerned with freedom and happiness and was very popular. It survived until the fourth century AD before the Christians managed to defeat it. Our best surviving statement of the physical theory of Epicurus comes from the Roman poet and philosopher Lucretius (96?–55 BC). In his long poem *De rerum natura* (*On the Nature of Things*) he adopted many of the ideas of

Epicurus. He encouraged a materialistic outlook and discouraged superstition. It is refreshing that he paid little attention to astrology, which was popular then as now. What path would the history of the world have taken if the ideas of Epicurus and Lucretius had taken root rather than those of Aristotle?

Among others deserving a special mention, Eratosthenes (276–195? BC) correctly calculated the radius of the Earth. His answer to this classical problem was within about one per cent of the modern value, a technical feat that was not rivalled for the next 1500 years.

Ptolemy is famous for his theory of the solar system. He compiled a summary of Greek astronomical thought and data in his book the *Almagest*. It was a triumph of the use of geometry in understanding the solar system. This work was the definitive work on astronomy until the end of the Middle Ages and so remained the acceptable explanation for over a millennium. Like Lucretius, very little is known of his life, except that he lived in the second century AD. The works of Ptolemy were much studied by the later Arab astronomers. His birth and death dates are unknown, although the Arab sources recorded that he lived for 78 years. Nevertheless, in spite of his great reputation, Ptolemy remains an obscure figure. It is not clear how reliable his measurements were, particularly since he worked for the state religion, which was heavily concerned with astrology. He seems to have been endowed with bad judgment, since he rejected both the Sun-centred solar system of Aristarchus and the essentially correct value for the size of the Earth that Eratosthenes had worked out. Both decisions put the progress of scientific knowledge back for the next 1500 years. Perhaps Ptolemy's major achievement was to salvage the star catalogue of Hipparchus. Hipparchus was the greatest of the ancient observational astronomers and had worked in the second century BC. His catalogue listed 850 stars arranged in six orders of apparent brightness, more or less in line with modern concepts.

Like his Greek predecessors, Ptolemy felt that the imperfect Earth could not be given a place among the heavenly bodies, which were composed of shining crystal in their cosmologies. Echoes of this philosophical approach still appear in the very common tendency to consider unknown or distant regions as uniform in composition. Examples include the deep interior of the Earth, the solar nebula and the universe, all of which were thought until quite modern times

to be uniform; more recent information is rapidly dispelling these myths.

The system devised by Ptolemy placed the Earth at the centre of the universe. The motions of the planets followed extremely complicated paths. Despite its theoretical defects, it was a practical success and remained in use up to the late Middle Ages. However, many of its problems had been long understood by skeptical observers. One of these was Alfonso X (The Wise) King of Castille (1221–1284 AD), who is commemorated by having one of the larger craters on the Moon named in his honour.

Laplace, the French scientist who enters the picture later, tells the following story about him.

> Alfonso was one of the first sovereigns who encouraged the revival of astronomy in Europe. This science can reckon but few such zealous protectors; but he was ill seconded by the astronomers whom he had assembled at a considerable expense and the tables which they published did not answer to the great cost they had occasioned. Endowed with a correct judgment, Alfonso was shocked at the confusion of the circles, in which the celestial bodies were supposed to move; he felt that the expedients employed by nature ought to be more simple. 'If the Deity' said he, 'had asked my advice, these things would have been better arranged'.[1]

Despite such opinions, scientific knowledge in Europe by the fourteenth century was less advanced than in Greece and Alexandria in the second and third century BC. The level of mathematics was about that which the Babylonians had achieved two millennia before.

The Copernican revolution

The Copernican revolution is usually dated at 1543. This was the year of the publication of the great work of Nicolaus Copernicus (1473–1543) *De revolutionibus orbium coelestium, libri VI* (*On the Revolutions of the Celestial Spheres*). He is reputed to have received the book on the day he died. Few modern authors would care to wait so long.

The model of Ptolemy had placed the Earth at the centre of the

universe. This was obvious to everyone and equally agreeable to the ego of *Homo sapiens* (I use throughout the book this scientific term for human beings, thus avoiding the politically incorrect term, mankind, and its ugly politically correct alternative, humankind). After all, it was clear to casual observers that the Earth was flat and that the Sun, Moon, planets and stars all revolved around it. Any child could understand this medieval view of the universe. One is reminded of the current debate over creationism, yet another simplistic view of the world. Furthermore, the Ptolemaic System, for all its complexity, worked well enough for practical matters, including navigation. Columbus used it. Minor problems were accommodated by complicated adjustments until a complex array of epicycles and the like, to which Alfonso had objected, encrusted the whole scheme.

Copernicus however, placed the Sun at the centre. Why did he do this? One can do little more than speculate 400 years later, but he seems to have viewed the Sun-centred system as more intellectually satisfying than the Earth-centred model of Ptolemy. It is curious that Copernicus did not refer to ideas of Aristarchus of Samos, who had proposed a sun-centred system eighteen centuries earlier.

Daniel Boorstin (b. 1914), in *The Discoverers* (1983) records that 'Copernicus possessed an extraordinarily playful mind and a bold imagination'[2] and that his model was driven by aesthetic rather than scientific reasons. But the new idea did not arise in a vacuum, any more than did Darwin's theory of evolution. Along with Alfonso, other thinkers in the Middle Ages, of whom Nicolas of Cusa (1401–1464) and Regiomontanus (1436–1476) were examples, had laid the intellectual framework for dismantling the old system.

The new scheme of Copernicus was not without its problems, and in fact did not work as well as Ptolemy's for practical applications. The planets remained in circular orbits, so Copernicus still had to use even more epicycles than Ptolemy to account for their motions. According to this notion, planets, like a trick cyclist, rotated around in small circles, or epicycles, as they progressed in their circular orbits around the Earth. Epicycles were an obvious solution to the problems of the apparent loops in the motions of the planets as seen from the Earth.

This is seen most easily for Mars, which after moving slowly eastward though the constellations, reverses its normal path and travels

westwards, before resuming its slow eastward course among the fixed stars. We now know that this curious reversal that we observe is due to the Earth, with its orbital period of 365 days, overtaking Mars, which takes 687 days to go around the Sun.

It took a long time after the death of Copernicus for the idea that the Earth goes around the Sun to be commonly accepted. In our age, Darwinian evolution is likewise taking some time to become established as the accepted world view. The next significant step in understanding the solar system was taken by Tycho Brahe (1546–1601), another outstanding figure of Renaissance science. His chief accomplishment was the precise measurement of planetary positions. This was carried out by naked-eye visual observation, as the telescope had not yet been invented. His observatory was on the island of Hven, a short sail from Copenhagen. He was also concerned about the problems with the complicated system of Ptolemy. So he produced a model in which the Sun and the Moon indeed went around the Earth, as everyone could see. However, he had the other planets rotate around the Sun. In this way, he had a foot in both camps. This compromise cosmology was popular, since it appealed to common sense observations and did not conflict with the scriptures. Variations survived until late in the seventeenth century, finally vanishing as the motions of the planets became well understood.

Tycho had other problems. He lost part of his nose in a duel and wore one made of tin for cosmetic reasons. He also disgraced himself in the eyes of his aristocratic family by marrying a peasant's daughter. Finally, he was so unpopular with the other residents of his island that they demolished his observatory when he lost royal favour and he had to move with his data to Prague in 1597.

Here, chance played its role. Just in time, another refugee arrived in Prague in 1600. Johannes Kepler (1571–1630) had been banished from the pleasant town of Graz in Austria, a victim of Catholic persecution. He became Tycho's assistant and succeeded him as Imperial Mathematician when Tycho died suddenly in 1601. Kepler thus inherited or perhaps just took ('usurped' was his word) the boxes that contained Tycho's monumental observations. These data formed the basis for Kepler's basic discoveries of the laws of planetary motion. Kepler's great contribution was to get rid of the notion that had survived since Aristotle that the planetary orbits were circular.

He discovered that the orbits were elliptical and became an advocate of the Copernican System.

However, like many other scientists, he was mainly concerned with other matters so that, as one author has commented, 'the three major gems in Kepler's works on astronomy lay in a vast field of errors, of irrelevant data, of mystical fantasies, and of useless speculations'.[3] It is difficult to imagine the intellectual climate in which he lived. His mother was accused of witchcraft and he spent several years defending her, ultimately successfully, from the appalling fate that accompanied conviction.

Despite such distractions and with a vast amount of labour, Kepler was able to fit the orbits of the planets into spheres based on the five 'perfect' geometrical solids; cube, tetrahedron, octahedron, icosahedron and dodecahedron. These are the only solids bounded by identical faces and were so considered 'perfect'. They have long fascinated philosophers. Plato had used the first four forms as the basic shapes for earth, air, fire and water, while the dodecahedron was the model for the heavens.

Kepler considered that he had answered a fundamental question; why were there only six planets, with five intervals between them (as known at the time)? Kepler's view was that this cosmic limit was imposed because of the small number of 'perfect' solid forms. However, the planetary orbits, on the basis of Kepler's own laws, turned out to be elliptical, not circular. Thus, his elaborate geometrical system fell into ruin.

Clocks had been prominent features in town squares in Europe since the fourteenth century. They became more sophisticated as clockwork became perfected and often included astronomical models as well as religious displays. One of the earliest was constructed by Richard of Wallingford in 1320 at St Albans, in England during the reign of Edward III. Another famous example is the great clock at Strasbourg, dating from 1364. Others were at Mantua, Padua, Prague and Venice, Such mechanical marvels led to the idea that perhaps the universe was some kind of giant clockwork. A clock requires a builder, suggesting that the universe had been created by a master craftsman.

Once the solar system had been constructed by an omnipotent clockmaker and the system was set running, no further attention was needed. It would continue to operate under the laws of physics. Such

ideas went back to Nicolas of Oresme (1330?–1382), a bishop who had conceived of God as the master clockmaker. Kepler was an enthusiastic supporter, suggesting that perhaps magnetism was the driving force, just as falling weights drove earthly clocks.

The clockwork idea was also consistent with the Bible. An Irishman, Archbishop Ussher (1581–1656), calculated that the creation of the world (including the universe) had occurred in 4004 BC on Sunday, October 23 at 9.00 am. This date, although now derided, was carefully derived from the available biblical record. What it represents is essentially that of recorded history. The earliest city, Ur, was founded around that time. It was generally accepted at the time, even now appearing in many editions of the Bible. The significance of this date, if correct, was that the universe had not had much time to evolve and everything must have been created in the beginning, more or less as it appeared now.

The Copernican revolution did not resemble those of more modern times. Fifty years after the publication of his system by Copernicus, little had changed. His ideas had disturbed neither the public nor the church. What was needed was some crucial observation to decide between Copernicus and Ptolemy. This came, as is usual in scientific progress, with a technical advance. The telescope had been invented about 1600 by Hans Lippershey, a Dutch spectacle-maker, apparently by accident. When the news reached Italy, the Senate of Venice asked Galilei Galileo (1564–1642), a skilled maker of instruments, to make some. He was the son of a lute player and composer, but had decided not to follow his father's career. We are still living with the consequences of that decision. It was not of course the intent of the Venetian state to upset the accepted view of the world. Their reasons were more down to earth. Telescopes would obviously be useful for an empire based on sea power. One is reminded that the British Admiralty did not send out HMS *Beagle*, carrying Charles Darwin, because they wished to change our view of nature or overturn the authority of the scriptures. They wanted better charts of the South American coast.

Galileo's observations are famous. The Milky Way was composed of stars, and so maybe the universe was infinite. The Moon was not a smooth mirror after all, but rough like the Earth and so perhaps made of the same material. Venus showed phases like the Moon, including