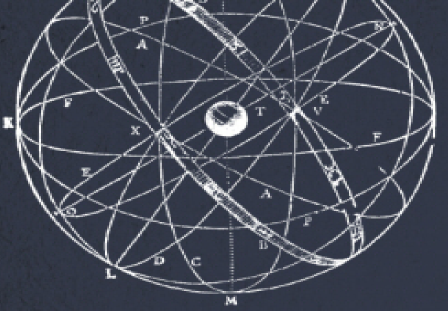
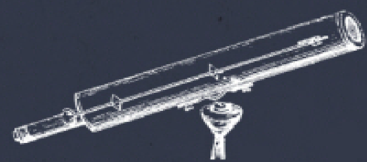
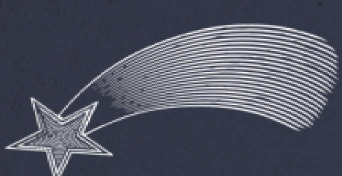




The Sky at Night

HOW TO READ THE SOLAR SYSTEM



FOREWORD
BY
BRIAN MAY

CHRIS NORTH AND PAUL ABEL

BBC BOOKS

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About the Book

We all learned the basics of our Solar System at school – but how much can you remember– In *How to Read the Solar System*, co-presenters of *The Sky at Night* Chris North and Paul Abel take us on a fascinating tour of the stars and planets to reveal their wonders, and show how anyone can view and interpret them.

It’s an epic story, with a colourful cast of characters, from blazing gas giants and wandering stars to distant dwarf planets and icy moons. The authors examine both the mythology that once influenced astronomy and the latest scientific discoveries that help us to understand the night sky better.

With a foreword by fellow astronomer and regular *Sky at Night* guest Brian May, this is an indispensable guide to our Solar System and the Universe beyond.

About the Authors

Dr Chris North is an astronomer at Cardiff University's School of Physics and Astronomy. He has worked on the Planck Satellite and Herschel Space Observatory, which studied how stars, galaxy and the Universe evolved over cosmic time.

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Dr Brian May, founding member of Queen, completed his PhD in Astronomy in 2006 after a 30-year break from his studies. Brian is the co-author of *Bang! The Complete History of the Universe* and *The Cosmic Tourist*, both of which he wrote with Sir Patrick Moore and Dr Chris Lintott.

The Sky at Night

HOW TO READ THE SOLAR SYSTEM

CHRIS NORTH AND PAUL ABEL

BBC BOOKS

for Patrick

Foreword

How To Read the Solar System is a book that would have warmed Sir Patrick Moore's heart – for many reasons. It has a simple aim – to provide, for those just beginning in astronomy, a guide to the awesome motley collection of objects that make up the family of our own star – the yellow ball of incandescence which we call the Sun.

To call this assortment of rocks a 'family' is not quite as far-fetched as it may seem, for although they come in an array of vastly differing shapes and sizes, these lumps of matter all share a common history – the history of the solar system, and many of their births are related. The more we discover about these planets, moons, comets and meteors, the more surprises they reveal. Yet, on a cosmic scale, we are looking here at the tiniest portion of the known Universe – an almost infinitesimally small fraction of the vast expanse of space that we see looking up on a clear night, if we are lucky enough to be able to escape the all-pervasive light pollution of the modern world.

What we see in the heavens, even with the naked eye, is a myriad of stars – each one a Sun in its own right, and recent research indicates that most of them probably have families of planets of their own. This appears to be the norm, rather than the exception, so there are probably even more planets than there are stars out there.

With binoculars or a small telescope, more wonders are revealed. We are able to glimpse, from within, the structure of our own Milky Way galaxy, a kind of greater family into which all the stars in our skies fit. We can look at the brightest parts of the Milky Way and see the massive dense centre of our galaxy, and look in the opposite direction out into the outer reaches of its spiral arms. And looking further out from our galaxy we are even able to see other galaxies of similar size, each containing billions of stars of their own. The most powerful telescopes now available have peered into unimaginably distant space, and, because of the finite speed of their light coming towards us, seen billions of years back in time. What they have shown us is billions upon billions of galaxies stretching out to the limits of the observable Universe.

Sir Patrick Alfred Caldwell Moore (1923-2012).

This is a very big picture, and the study of it, on this enormous scale, is called cosmology. Yet, this book has no truck with cosmology. It’s impossible to see any of this vastness at close quarters, but many of us, including Sir Patrick Moore, have found great thrills in examining what is on our own doorstep, relatively speaking. Looking up at the skies of our own Solar System, we soon become aware of those ‘wanderers’ which move their position on the starry vault every night – the planets which have been known to our ancestors since before recorded history:

Mercury, Venus, Mars, Jupiter, Saturn. And we may be lucky enough to see a visiting comet or a minute piece of rock flash its burning path through our atmosphere as it burns up – the ‘shooting stars’ which also fascinated our forbears.

It is this close-up drama that is the subject of this book. It is a modest aim, to survey only material within a couple of light years of our Sun, but in this study, we will see in miniature the whole of the Universe, since it seems that no matter where we go in the Universe things look very much the same. So a careful study of our immediate surroundings can tell us so much about the wider cosmos. Indeed, Sir Patrick Moore, though well versed in every aspect of current knowledge in astronomy and astrophysics, devoted a large fraction of his entire life to detailed observations of the planets, and in particular, our own Moon, a mere quarter of a million miles from Earth. His meticulous lunar mapping was so extraordinarily accurate that is was used by the first US astronauts, to plan their conquest of the Moon.

Sir Patrick was not the only astronomer to become absorbed in the uncovering the secrets of our Solar System, but our knowledge of this subject has exploded in the last 20 years, as a succession of unmanned probes have been launched on missions to rendezvous with the planets, their moons, and even with cometary nuclei and asteroids. The photographs and data these probes have sent back to Earth have brought us shockingly clear information about all these objects, and it is fair to say that the truth about the composition of all these objects was a surprise in every case.

Does that ‘uniformity’ we see in the Universe include life? Are those other planets inhabited too, with the wonderful array of creatures which Man has done such a good job of bringing to the brink of extinction? We may never know. But looking at those rocks and stones, and the very dust that surrounds us on our tiny blue planet is a very good place to start. Certainly for this Sir Patrick, to whom this admirable book is dedicated, and who is the reason so many of us have discovered the thrills of astronomy, would be smiling.

Dr Brian May

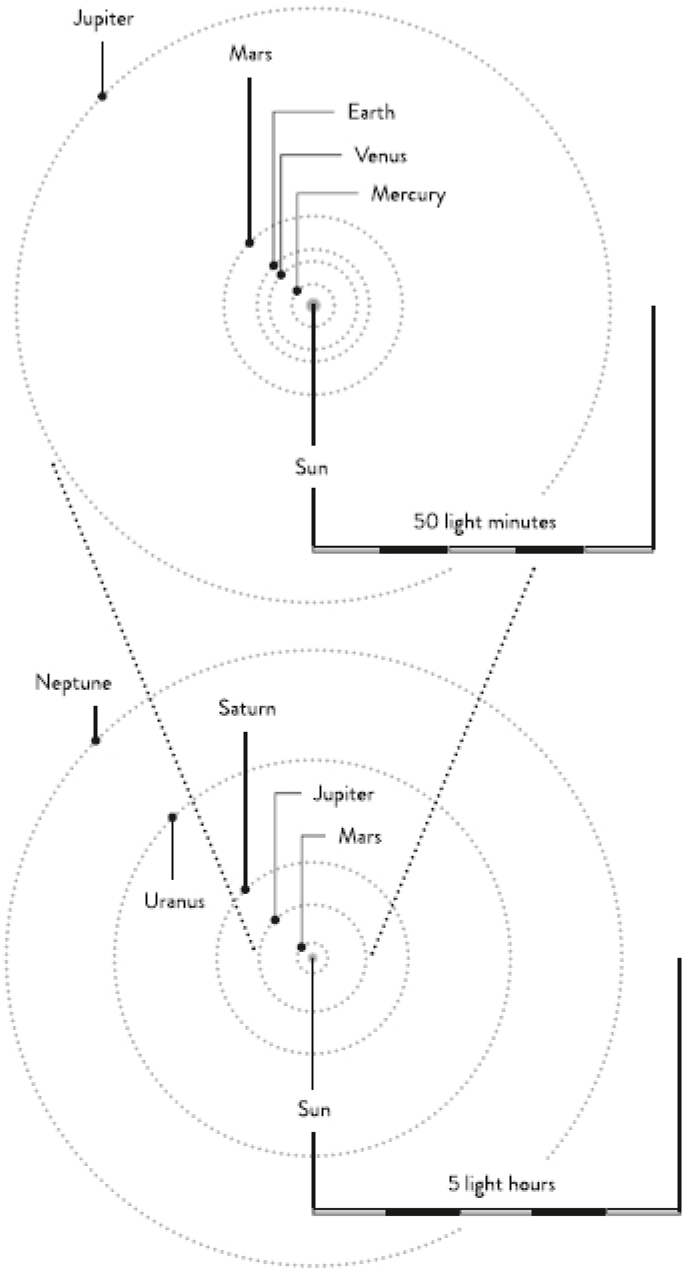
1

What is the Solar System?

We should probably start this book by stating what is meant by the Solar System, and what better place to look than the dictionary. The word ‘solar’ comes from the Latin *solaris*, which means ‘of the Sun’, and so we define the Solar System to be the collection of objects that ‘belong to’ the Sun – that is to say, everything that orbits it.

The Sun is the powerhouse of the whole Solar System, and presents a perfectly good place to start our introduction to the Solar System. Although it may be incredibly important to our brief lives here on Earth – and was portrayed by our ancestors as an all-seeing deity – the Sun is in fact more or less an ordinary star. But in astronomy, the word ‘ordinary’ is often overused. The Sun is over a million kilometres across, and weighs in at a whopping two thousand million million million million tonnes. Its surface is pretty hot by human standards, at around 5,500°C, but its centre is at a temperature of tens of millions of degrees – so hot and dense that nuclear fusion is converting four million tonnes of matter into pure energy *every single second*.

This incredible star, while not significantly different from the others in our Galaxy, is host to a magnificent array of planets, moons, asteroids and comets – including one very special planet that we call home. There are, of course, the eight major planets, which in order of increasing distance from the Sun are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune. We often groups these into two main sections, the inner planets (Mercury through to Mars) and outer planets (Jupiter to Neptune), and there are useful distinctions to be made at this level.



The orbits of the planets in our Solar System, with distance scales shown in light travel time.

THE INNER PLANETS

The inner planets are, on the face of it, not too unlike the Earth – hence their other common name of ‘terrestrial planets’, with the word terrestrial originating from the Latin *terrestris*, or ‘earthly’. They are largely made of rocky material, and are thought to have formed from the collision of lots of smaller pieces of space rocks around four and a half billion years ago. They are all – aside from the odd mountain range and deep canyon – almost completely spherical, with diameters ranging from 5,000 km (3,000 miles) for the tiny Mercury up to 13,000 km (6,000 miles) for the Earth.

Beyond that, however, these four worlds are all very different, and each has its own unique characteristics. Let’s start with something we’re all familiar with – Earth. While we inhabitants of the planet are aware of temperature variations that seem huge to us, these variations are tiny in the context of other planets and stars. In those terms, at an average of 150 million km (93 million miles) from the Sun, the Earth’s surface temperature never moves too far from 0°C, allowing it to host rivers, lakes and oceans of liquid water. Its atmosphere is primarily a mixture of nitrogen and oxygen – a combination that supports a diverse ecosphere. Beneath the surface it has a molten mantle and a dense iron core, with geological features such as volcanoes dotted over its surface.

The least unlike the Earth of the other terrestrial planets is probably Mars, although it is only half the diameter. It is also further from the Sun than the Earth, at a distance of 225 million km (140 million miles) and its maximum surface temperature is just 35°C. Its atmosphere is much thinner, and composed primarily of carbon dioxide, and so is far less conducive to life. With such a thin atmosphere, and temperatures that can drop as low as -110°C at the poles, there is no standing liquid water on Mars – though there is lots of water ice both on and beneath the surface, and evidence that small amounts can flow on the surface for brief periods. It is not inconceivable that people could survive on Mars, although a spacesuit would certainly be required. There is also evidence of ancient volcanoes – Mars is host to the largest volcano in the Solar System – though they are long extinct. Its small size means that the interior of Mars cooled long ago and stopped all geological activity.

Our nearer neighbour, Venus, is about the same size as the Earth – but that is where the similarities cease. Like the porridge in *Goldilocks*, while the Earth is just the right temperature to support life and Mars is too cold, Venus is far, far too hot. Although it is closer to the Sun, at 108 million km (68 million miles), the main reason for its high temperature is its thick atmosphere. At some point in its past Venus experienced a runaway greenhouse effect, and its thick, sulphurous atmosphere bakes its surface to a staggering 450°C. Not only would anyone exploring Venus be boiled alive, and their craft gradually melted by the rain of sulphuric acid, they would also be crushed, as the thick atmosphere creates a surface pressure almost 100 times higher than Earth's.

Finally, we come to Mercury, the real oddball of the inner planets. It is the smallest of the four, the closest to the Sun – at an average distance of 58 million km (35 million miles) – and also the only one without an atmosphere. This means there is nothing to protect the surface from the Sun's glare, or to retain heat overnight. Mercury's surface drops to a chilly -180°C in the middle of the night at the poles, but reaches a searing 400°C at midday on the equator.

THE OUTER PLANETS

The inner planets may be weird and wonderful, but in comparison the outer planets are truly strange. The two largest, Jupiter and Saturn, are true giants, with Jupiter having more than ten times the diameter of the Earth. But neither is a solid ball of rock – both are composed almost entirely of gas, and may not even have a solid surface at all. They have storms in their atmospheres that could swallow the Earth, most notably Jupiter's Great Red Spot. Saturn is also accompanied by an impressive system of rings, made of billions of small icy particles, giving it perhaps the most iconic appearance of all the planets. As interesting as the planets themselves are their families of satellites, which number in the dozens. Some of these icy moons are planet-sized – Jupiter's largest moon, Ganymede, is larger than Mercury – and many of them have their own fascinating stories.

Beyond Jupiter and Saturn we have the ice giants, Uranus and Neptune. Although smaller than Jupiter and Saturn, they are still around four times the diameter of Earth. Beneath their thick atmospheres they are thought to have solid, icy cores. At distances of more than two billion km from the Sun, these planets are the ones we know least about, though what we do know tells us that they have their own intriguing characteristics and histories.

There is far more to say about these eight major planets and their moons, but there are also a whole host of smaller bodies is orbit around the Sun. First there are the minor planets: lumps of space rubble ranging in size from the size of pebbles up to dwarf planets hundreds of kilometres across. Most of these reside in the asteroid belt, between the orbits of Mars and Jupiter, and the Kuiper Belt, out beyond Neptune. Then there are comets, dirty balls of ice which lose matter as they come close to the Sun, forming beautiful tails of material. Though beautiful, the tails of comets are incredibly tenuous and only visible because the material they're made of reflects light so well. Throughout this book we will come to each of these objects in turn, though we will not be able to discuss each asteroid and comet individually as they number in the hundreds of thousands.

HOW DO WE KNOW ALL THIS?

There is much more to be said about all of these objects, but the next question that is commonly asked about our understanding of the Solar System is: how do we know all this? We haven't sent people to all these places, as the distances are simply too vast. The furthest a human being has been from the Earth is just over 400,000 km (250,000 miles), a feat achieved by the Apollo 13 astronauts on their ill-fated and near-disastrous trip to the Moon in 1970. Today, astronauts venture only as far as low Earth orbit, just a few hundred miles above the surface. Compare those distances with a minimum of 75 *million* kilometres to Mars, or more than a *billion* kilometres to Saturn, and the scale of the problem of human exploration becomes apparent.

Astronauts on the International Space Station regularly spend months in space, but the longest trips away from the relative safety of Earth orbit have lasted for less than two weeks. By comparison, a journey to Mars typically takes around 7 months – and that doesn't include any time on the surface or even a return trip. The amount of food, water, air and so on required for such a long trip, which in practice would have to take two years, is immense, and we have not yet managed to prove that we can protect explorers from the hazards of interplanetary travel. Deeper exploration of the Solar System would take longer still, with one-way trips to the outer planets taking several years. Even the fastestlaunched spacecraft, New Horizons, will have been travelling for just shy of a decade by the time it passes Pluto.

All these, so far insurmountable, obstacles mean that we can't send people to the planets, though we can do the next best thing – send robots. Even then, the missions still take years to complete and cost millions of pounds. The results of these missions are fascinating, and well worth the time, effort and money, but it is important to remember that they are building on the successes of observations made right here on planet Earth.

Although modern discoveries about the planets, their moons, and the myriad of other objects in the Solar System tend to be made by expensive telescopes and space probes, many of the key observations about the Solar System can be achieved with much more modest equipment. After all, it must be remembered that much of the celestial mechanics was worked out by astronomers such as Nicolaus Copernicus and Tycho Brahe. They made observations using just their own eyes – combined with a large degree of patience and a very methodical approach to observing. Even after the development of the telescope, the likes of Galileo Galilei, Johannes Kepler and Thomas Harriot used telescopes much less powerful than the smallest astronomical telescopes on sale today.

The discoveries of these great astronomers were largely due to their diligence and dedication to their science, the attention and rigour they paid to the detail of making observations, and in some cases the courage to stand up to the doctrine of their time. But astronomy is far more than catalogues of numbers and observations. The great early astronomers were making observations because they wanted to understand the mechanics of the Universe, and they were driven by a strong sense of curiosity. Astronomy is still doing that, with observations from modern experiments and telescopes continuously updating our view of our place in the Universe. On top of that, our own Solar System can provide some of the most stunning and breathtaking views one is ever likely to see – all it needs is an appreciation of what one is looking at.

2

Ancient Stargazers

A dark night sky is a spectacular sight. Among the best places to view the night sky are the deserts of North America. On a moonless night, the dark velvety backdrop of sky is quite literally powdered with thousands of stars. Indeed it can be hard to make out the constellations when there are a bewildering number of suns present. In summertime, one of the spiral arms of the Milky Way galaxy within which our Sun resides stretches high overhead and looks bright enough to cast shadows. The scene has an almost three-dimensional quality to it, and is as close as a human being can come to touching the face of infinity.

Standing there in the desert, it is not hard to imagine our ancient ancestors hundreds of thousands of years ago, looking up from a similar spot, mesmerised by the silent spectacle above. Only the faint glow of the distant cities on the horizon hints at the technological presence of a species which only recently, by cosmological standards, had cowered in caves under these same stars.

It seems humans are endowed with a compulsion to record not just their own activities, but things that affected their lives. It is no surprise that it wasn't too long ago that mankind started to record the stars. The walls of the well-known Lascaux caves in south-west France are covered in many hundreds of beautiful images laid down by human beings some 17,300 years ago. Among the many images are some of the earliest drawings of the stars. In one particular painting, the eyes of a bull, a bird and a bird-man are believed to represent the three bright stars of the summer triangle, Vega, Deneb and Altair. Another painting shows a figure who seems to be associated with the Pleiades – indisputable proof of how the glory of the heavens captured our imagination at a very early stage in our evolution. It would start humanity on a path of exploration that would begin with mythology and storytelling, but would eventually lead to an understanding of the clockwork precision of the celestial machinery of nature.

A THEATRE IN THE SKY

If you go out on a dark night and look up, even if you live in a town or city, you will still see a number of stars. To our eyes, they form patterns known as constellations. There are 88 constellations in the night sky spread between the northern and southern hemispheres. From our point of view, it takes the stars a long time to move through space, and so as a result a constellation of stars may look the same for many thousands of years.

In the northern hemisphere, these constellations, whose names we use today, were established in Classical times and many of them are associated with various myths of the Ancient Greek period. What is interesting, though, is that not every culture saw the same thing, or used the same stars of a constellation consistently.

Perhaps one of the most recognisable constellations in the northern hemisphere is the Plough, or Great Bear. The main part of this constellation looks like a saucepan; indeed the French called it La Casserole. In Greek mythology, the god Zeus fell in love with a nymph called Callisto. Naturally, his wife was rather enraged at this and, out of jealousy, turned Callisto into a bear. Callisto's son, Arcas, was out hunting one day and was about to kill the bear that was really his mother; in order to avoid tragedy, Zeus put the bear into the night sky whereby it became the constellation of Ursa Major.

The people of Burma had a different name for this constellation. They called it *Pucwan Tārā* (pronounced 'bazun taja'), and to them the stars represented a prawn. From medieval England, people saw yet another pattern. To many of them it represented 'Charles Wain' (a wagon), and later a horse-drawn plough.

Perhaps the most imaginative visualisation of this constellation comes from the Chinese, who had an entirely separate system of constellations. For them, this group of stars represented a celestial bureaucrat who made his eternal rounds of the night sky and was followed by his two loyal petitioners.

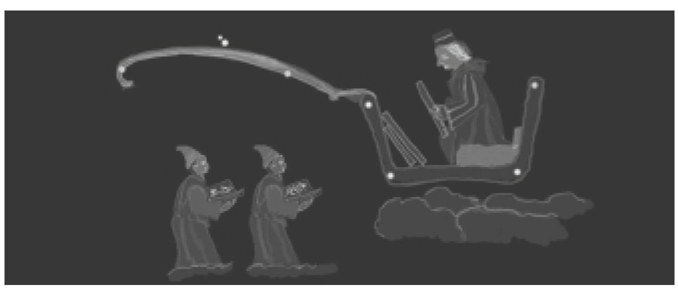
Another striking constellation of the northern hemisphere is the constellation of Orion. In Greek mythology he represents a mighty hunter, but to the Ancient Egyptians the constellation represented the god Osiris, who was killed by his evil brother Set.

The Yognul people of Australia thought the constellation represented a canoe. But as we move into the southern hemisphere, a marked change in the nature of the constellations becomes apparent. The southern constellations were named by explorers of the 16th and 17th centuries. Instead of great heroes and gods, we have the keels of ships, sextants, telescopes and the like, things that mattered most to the people of this era.

What constellations would we put in the night sky today? Indeed, when human beings go out and colonise the stars, what constellations will they put up in their night skies? It would be wonderful to know what constellations the Sun will take part in thousands of years from now.

The Great Bear, or Ursa Major.

The Burmese identify Ursa Major with a prawn or shrimp.



The Celestial Bureaucrat of Chinese mythology, followed by his two faithful attendants.

THE DAWN OF SCIENCE

At first glance, the Universe looks chaotic. The rising and setting of the Sun and Moon, the motion of the planets, all seem somewhat random. However, as we begin to record the times and positions of these objects, we slowly become aware of the underlying clockwork of nature. Having a large number of observations allows us to see the patterns and cycles of nature and, if we can understand them, and find a way to formulate them, we can start to predict them.

Eventually, humans began to do more than just populate the skies with myths and legends – they began to record what they were seeing. The ancients were familiar with a number of events which regularly occurred in the night sky, and noted five bright ‘stars’ which, unlike the other stars in the sky, wandered around the constellations of the zodiac. These were called *planets*. There were also solar and lunar eclipses, which were both spectacular and for some cultures foretold of dire things to come.

Although we would regard the act of recording observations and modelling our results as scientific process, a number of cultures actually did this for superstitious reasons. Many of the great stone circles (like Stonehenge) have an astronomical connection and record the positions of the rising and setting of astronomical bodies at certain times of the year, but they also have religious aspects. Astronomy was presumably being used for the purpose of divining the future. It took a surprisingly long time for science to break free from the chains of superstition.

Perhaps the earliest recorded observations come from Bronze Age China. Dating from between 1400 and 1200 BC, the Shang dynasty oracle has inscriptions which seem to include references to stars and eclipses. These observations were made as it was believed they provided omens which foretold the state of the kingdom. Similarly, although the Ancient Egyptians built monuments to mark the rising and setting of certain stars, this also was for religious reasons connected with the rituals of the Pharaohs.

A Babylonian stone tablet.

The Babylonians of ancient Mesopotamia do seem to have recorded their observations out of interest and we find a good deal more textual evidence for systematic observation of the night sky all wonderfully laid down in stone tablets. A number of texts dating from 650–50 BC contain observations of the time of sunrise, the times of the waxing and waning crescent moon, and details of lunar and solar eclipses.

By the 6th century BC, the Neo-Babylonians had begun to notice the patterns and repetitions in their observations. From their simple naked-eye, but faithful, recordings, they were able to calculate the time intervals between moonrise and moonset, the times of sunrise and sunset and the Moon's daily motion through the stars for many months ahead. They were also able to determine the length of daylight which could be expected, and the position of the Sun and Moon at the time of New Moon – an amazing achievement when you realise these people had no telescopes and no clocks. Perhaps for the first time in human history, the foundations of mathematical astronomy had been established.

The Classical Greeks made many of the more important contributions to science in antiquity. They were able to determine a great deal about the Solar System. The most surprising thing about their achievements is that all of their discoveries were made using a combination of simple geometry and naked-eye observations. We often think of the people of antiquity as somewhat primitive creatures. In the 21st century, technology is used as a defining point of civilisation, and it is through this lens of achievement that we often look back to judge the past. In fact, the people of antiquity were every bit as smart as 21st-century humans – biologically speaking, our brains would have been identical, and what they lacked in technology, they certainly made up for with scientific ingenuity.

HIPPARCHUS AND THE PRECESSION OF THE EQUINOXES

Perhaps the greatest Greek observational astronomer of that time was Hipparchus (190–120 BC). Hipparchus was both an astronomer and a superb mathematician. He is recognised as a founder of trigonometry (the study of right-angled triangles and the relationships between their internal angles and the lengths of their sides); he applied his geometry skills to his naked-eye astronomical observations, and in doing so was able to make a number of revolutionary discoveries about the Solar System. In his use of mathematics to explain his astronomical observations, Hipparchus is almost indistinguishable from today's modern astronomers. The problems modern astronomers work on may be more advanced, and the maths certainly is, but the fundamental idea that the workings of the Solar System can be understood by combining observation with mathematics is essentially the same. This concept was intuitively understood by Hipparchus some 2,000 years ago.

Hipparchus was born in the ancient city of Nicaea, which can be found today in the Turkish city of Iznik. In spite of his many great achievements, not much is known about him or how he supported his astronomical endeavours financially, and very little of his published work has survived. However, even though much of his work was lost, it had made enough of an impact to be recorded by other astronomers and philosophers of the period.

Hipparchus also studied the motion of the Sun and Moon. As seen from the Earth, the Moon orbits the Earth roughly once every 27 days. During this time, the Moon passes by many background stars – sometimes it even passes in front of them and this is called an occultation. This leads to an important phenomenon known as a *parallax*. There is a wonderful exercise that Patrick Moore used to demonstrate the phenomenon (you might want to do this at home rather than in public!). First of all, close one eye. Now, hold a finger up towards a distant object like the wall of the room. If you now look through the other eye, you will see that your finger appears to move with respect to the wall, and if you alternate between looking through your left and right eye, you can see your finger appears to move back and forth. This is a parallax, and the amount of motion is called a parallax angle and is measured in degrees.

Now if you were to replace your finger with the Moon and the wall with the background stars, and if instead you look at the Moon from two different places on the Earth's surface (rather than just changing eyes), then the Moon also undergoes a parallax with respect to the background stars, and the lunar parallax angle can be measured. How does this help? Well, by itself the observation doesn't mean much. If, however, we apply some basic trigonometry then we can get an estimate of the distance from the Moon to the Earth.

Perhaps Hipparchus's most outstanding achievement was his discovery of the precession of the equinoxes. We have two equinoxes, one in spring and one in autumn. At these times, if you were to stand on the Earth's equator, the Sun would be directly overhead at the zenith. At this time in spring, the Sun is in the constellation of Pisces; at the corresponding autumn equinox, the Sun is in Virgo. Now, the Earth has an axial tilt, and over the course of many thousands of years the direction the planet's axis points in changes. This is called precession. Currently, the north pole star is Polaris in Ursa Minor, but in 3000 BC it was the star Thuban in Draco. In AD 10,000 it will be the bright star Deneb in Cygnus, and eventually will return once more to Polaris. This slow precession not only changes the pole star, but also means the position of the equinoxes changes over time.

Hipparchus made measurements of the longitudes of a number of bright stars including Spica, the bright bluish star in Virgo. To his surprise, when he compared these observations to those made by astronomers over a hundred years previously, he found that Spica had shifted about two degrees with respect to the position of the autumn equinox. He also observed the length of a tropical year – the time it takes the Sun to return to the same point was different in length to a *sidereal* year (the time it takes the Sun to return to the same point in the sky). These observations led him to conclude that the position of the equinoxes changed slowly over time. He estimated one degree per century, astonishing accuracy for a man armed only with eyes and trigonometry – the actual figure is 1 degree 38 minutes.

In later years, Hipparchus made a catalogue of many hundreds of bright stars. This was not simply a list of stars; it also contained an estimate of their brightness. Astronomers use the term *magnitude* to mean how bright an object is in the sky. Hipparchus devised a system where bright stars were given magnitude 1, slightly fainter ones were assigned magnitude 2 and so on, all the way down to stars which were just visible to the naked eye, which were given magnitude 6. Remarkably, Hipparchus's magnitude system still remains in use today, although modern astronomers have updated it. For three centuries, Hipparchus's work would remain the dominant work in astronomy until the arrival of Claudius Ptolemy more than two centuries later.

Moving forward a little in time, there is another Greek philosopher who deserves a mention, Eratosthenes of Cyrene. Like so many people of that era, he was something of a renaissance man. He made many contributions to mathematics, geography and poetry. He was known affectionately as Beta, the second letter of the Greek alphabet, as it was claimed that *he* was the second best at everything.

A NEW SCIENCE

The great Library of Alexandria was constructed some time in the 3rd century BC, and was *the* seat of learning – an enormous centre for academic study in the ancient civilised world. It was a remarkable achievement and had collections of scrolls (called books) from many diverse places. It was the showpiece of Egypt, and Eratosthenes became its third librarian.

Eratosthenes had noticed something interesting. At noon, under the scorching sun on the day of the summer solstice, the Sun appeared to be directly overhead in the ancient city of Syene (now modern-day Aswan). If you were to stand a stick vertically in the ground, it would cast no shadow. However, a few miles away in the city of Alexandria, at precisely the same time, a vertical stick stuck in the ground did cast a small shadow. The only answer that would fit these observations was that the surface of the Earth was curved.

Eratosthenes measured the angle of the Sun's elevation at Alexandria at noon on the solstice and found it to be one-fiftieth of a circle. He knew the distance to the city of Syene was around 5,000 *stadia*, which meant that one degree was equivalent to about 700 *stadia*. Although there were different values of the length of the *stadia*, if we use the Egyptian value then Eratosthenes' simple calculation gives the circumference of the Earth as 39,690 km. Astonishingly this value is only some 2 per cent off the true value. Like the Babylonians before him, Eratosthenes was able to make a significant discovery using little more than some simple solar observations, sticks and numbers.

Eratosthenes and Hipparchus were joined by many other Greek philosophers and scientists who actively tried to understand the physical world around them without a religious framework. The Mediterranean became the birthplace of the scientific process, of using rational arguments and reason to explain what was being observed. What the Greeks wanted to know was how the physical world fitted together in an overall pattern. What they wanted was a new science: the science of cosmology.

As you might expect, there were many early attempts to explain the Universe and our place within it. One early cosmological theory came from the Greek philosopher Anaximander (611–546 BC). Anaximander suggested that the Earth was flat and circular. Above the surface was the air, and clouds. He believed that all of the celestial bodies, the Sun, Moon, stars and planets, were holes in vast moving rings and it was the light from a fiery region behind these rings which shone through the holes.

It was Pythagoras who laid down the real beginnings of cosmology, setting down the basics of a cosmological theory whose underlying elements would last until the