Astronomy Through the Ages

The story of the human attempt to understand the Universe

Robert Wilson

Taylor & Francis
Publishers since 1798

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Not from the stars do I my judgement pluck,
And yet methinks I have Astronomy
Shakespeare

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Dedicated to the memory of a Durham miner

Full many a gem of purest ray serene
The dark unfathom'd caves of ocean bear:
Full many a flower is born to blush unseen,
And waste its sweetness on the desert air.

Gray

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Preface

This book grew out of an undergraduate course that the writer gave at University College London on the foundations of modern astronomy, but with a difference. It was aimed at the non-scientific faculties and therefore had to be non-mathematical; as such it was unique in the UK. The reason behind the course was to broaden the education of students in the humanities, but the book has a much wider purpose and has been written with that in mind.

In 1959, C.P.Snow, an accomplished scientist and distinguished novelist, wrote about what he called the "two cultures", by which he meant those individuals whose training and activities were scientifically and technologically based on the one hand, and those whose training was in the area of the humanities—classics, history, literature, and so on—on the other. His point was that each culture knew little about the other, that communication between the two was difficult (and sometimes impossible) and that this situation was bad for society as a whole. The writer agrees with this view by Snow, which was based on his experience in the 1950s, and believes that the separation is even more marked in the 1990s and even more damaging. There is a very clear absence of scientifically trained personnel in the influential areas of society—in politics, in the civil service, in the media, in business and industry. This observation is not made as a prelude to an argument in favour of more scientists in influential positions (I have met many who would not be up to running a coffee stall), but it is an argument in favour of those in such influential positions knowing *something* about science, because it touches on so many important issues of the day. However, in the writer's experience (confined mainly to the UK), many influential people not only know nothing about science or technology, they are almost proud of it and can hardly wait to proclaim the fact. Such individuals far outnumber those scientists who disdainfully reject an interest or knowledge in the fine arts, who would regard the *Davids* of Michelangelo and Donatello as chunks of white and black marble, Rembrandt's *Night Watch* as a splash of paint, and Goya's *Maja* as a tawdry attempt at pornography. It is to their counterparts in the humanities that this book is addressed in an attempt to communicate a knowledge of science, in the form of astronomy, and to illustrate the fascination and beauty of the subject.

Of necessity, the presentation is non-mathematical (even graphs are excluded), but the subject matter is not simplified in any way. The deep concepts of space and time, of relativity and quantum mechanics (the two classic examples of the incomprehensible to the general public), and of the nature and origin of the universe, are described and discussed without resort to the meaningless analogies that so often mark works in popular science. The aim of this book is not to impress but to inform and at the same time, hopefully, to interest and to entertain. Sadly, this aim seems to be the inverse of that of much of the media in presenting scientific matters; this is particularly evidenced, at the very moment this Preface is being written, by the levels of hysteria that were reached in reporting findings of some components of a meteorite from

Antarctica, but presumed to have come from Mars, as representing definite evidence that life had existed on that planet.

This is an appropriate moment to mention the scientific method, which the writer hopes will be better understood after the reading of this book. It was first practised by Kepler, then defined and elucidated by Galileo, and finally brilliantly demonstrated by Newton. It has been the basis for the great scientific advances of the past four centuries and is not really a method but a discipline, or a set of rules by which science should be pursued. It states, very simply, that all claims, all propositions, all hypotheses and all theories should be subject to the test of explaining *all* available information, and then be subject to a further test of predicting some new effect which can be investigated and measured. The scientific method is therefore completely opposed to dogma and requires that all claims and statements should be verified by an appeal to the available facts. Some readers may feel that this is so obvious that it does not need saying, but, unfortunately, dogma has played a major role in history, and still does today in many important areas of human activity.

As mentioned earlier, this book developed from an undergraduate course for non-science students. Those students taught the writer a great deal, in particular, that they more easily absorbed science if it was placed in a human context. This determined the structure and theme of the book as being the story of the human endeavour to understand the universe.

The book is written for the intelligent lay-person and is therefore directed at a very wide audience. The one person the book is not intended for is the professional astronomer and, just in case one should read it, I should explain that I am not following the strict scientific practice of referencing all the contributions of individual astronomers, but only when such reference aids the story for the non-scientist. Hence, particularly in the final chapters, several hundred astronomers who have contributed to the developments outlined are not mentioned and the writer makes this broad acknowledgement now.

Although the book is strictly non-mathematical, there may be technical terms used with which the lay-reader is unfamiliar. I have tried to explain these in the text as they arise but, as a backup, I have also compiled a glossary at the end of the book and the reader should consult this whenever necessary.

Finally, I would like to say that I hope this book will project a knowledge and feeling for the fascination of astronomy to a wide audience. Writing it has been a very personal activity, but one that has been shared by one other person who processed the manuscript, commented on its content, suggested many of the quotations used, and was a pillar of support throughout—my wife Fiona. It is our book.

Robert Wilson August 1996

PART I

THE EARLY DEVELOPMENTS IN ASTRONOMY

This part of the book covers the period when observations of the Universe relied entirely on the unaided human eye with its consequent limits and constraints. It starts in ancient times when the earliest civilizations showed a fascination for astronomy, albeit with astrological overtones, and it ends with the Renaissance when the subject was put on to a firm scientific footing and when a new age was heralded by the invention of the telescope.

PART I

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CHAPTER ONE
The Beginning

Before the beginning of years
There came to the making of man
Time, with a gift of tears;

Swinburne

About five thousand million years ago, a new star was born in our Milky Way galaxy. It was an average star, neither over-bright nor over-faint, and was formed like all other stars by condensation of the interstellar gas under the all-pervading force of gravity. In all such contractions some degree of rotation exists and this causes the material to form into a circulating disk within which condensations occur to form a number of gravitationally bound objects. Whether these objects become a star or a planet depends entirely on the amount of material condensing in the gravitational contraction. If this is large enough, the interior will heat up to the ultra-high temperature needed to ignite a nuclear furnace which generates enormous energy by fusing the most abundant element, hydrogen, into helium. In our Solar System, only the Sun reached this critical mass and the other condensations resulted in the formation of the planets. In more than half of other star formations, more than one body exceeded the critical mass to become a star. This is demonstrated by the fact that more than half of the stars in the sky are multiple, with two or even three stars in orbit about themselves, possibly with some planets.

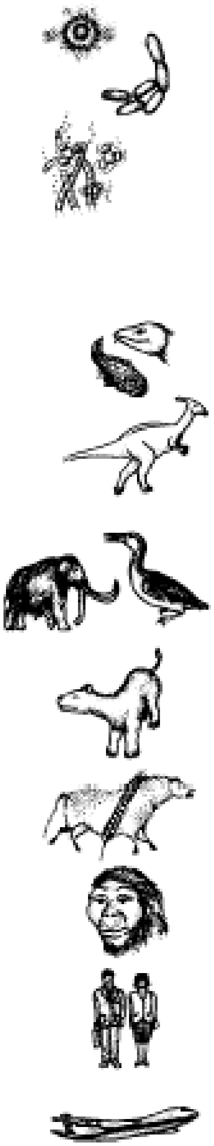
The interstellar gas from which the Solar System was formed was composed mainly of hydrogen (74 per cent by mass) with 24 per cent helium and all the other heavier elements from carbon to uranium contributing only 2 per cent by mass. These elemental abundances are reflected in the composition of the Sun and the giant planets, Jupiter, Saturn, Uranus and Neptune, but the Earth and the other terrestrial planets, Mercury, Venus and Mars, are rocky in nature, indicating a chemically selective process in their formation which favoured the heavier elements and allowed most of the hydrogen and helium to escape. Yet the heavier elements did not exist at the start of the Universe when the primeval matter produced in the Big Bang was composed entirely of hydrogen and helium, with minute traces of lithium, beryllium and boron; but there was no carbon, nitrogen, oxygen or any of the other 87 elements found on Earth. Hence, the very first stars that were formed in the rapid star-burst era that marked the beginning of our galaxy contained no heavy elements, and any planets formed at that time could not have been even remotely like the Earth. But many of those early stars were more massive than the Sun and, consequently, evolved more rapidly to the extent that they had gone through their whole life-cycles by the time the Solar System was formed. As will be related later in this book, they had successively fused hydrogen into helium, helium into carbon, nitrogen, oxygen, silicon and all the other elements in the periodic table up to iron; then, in an immensely explosive event called a supernova, all the elements heavier than iron, from cobalt to uranium, were formed, and these, together with the lighter elements, were hurled into space in a high-velocity expanding shell. Far from being a contamination of the primeval interstellar gas, this was, as far as we are concerned, a crucial enrichment of it, because it provided those elements essential to life. Indeed, apart from the hydrogen present in the water of our bodies, all the other elements that constitute more than 90 per cent of what we are made of are the result of nuclear processing in the interiors of massive stars and the cataclysmic explosion that heralds the end of their life. We are children of the stars.

These astronomical processes, the nuclear synthesis of the heavier elements in stellar interiors, their ejection into the interstellar medium, and the selective condensation of those elements in the formation of the four terrestrial planets in our Solar System, set the scene for the great miracle—the development of life on one of them, Earth, whose size and distance from the Sun were just right. But the development of life and its evolution was slow…very, very slow.

The Earth was formed four and a half thousand million years ago but almost a full thousand million years were to pass before the first micro-organisms appeared and a further thousand million years before marine algae and primitive plants started to generate pure oxygen, not tied up in carbon dioxide, into the atmosphere until, when the Earth was three thousand million years old, it reached a critically important stage for life and the environment when it had an oxygen-bearing atmosphere similar to that of today (except for artificial pollutants). At this point, evolution accelerated greatly and, over the next thousand million years, fish, insects, toothed birds, large reptiles and primitive mammals appeared. Then, 65 million years ago, a catastrophic event, whose cause has just recently been established as a giant meteor or asteroid, led to the extinction of the dinosaurs. It was then that the mammals proliferated and, some 3–4 million years ago, the first human types emerged. But evolution of our own species, *Homo sapiens,* did not occur until a hundred thousand years ago and the earliest civilizations did not develop until after the most recent ice age had ended about 12000 years ago.

To give some idea of the timescale of the development of life on Earth, the important milestones are listed in the table which also scales real times to one year, that is, as if the Earth were formed on 1 January and its present age is midnight on New Year's eve. This demonstrates vividly the very slow initial development, and then the very rapid later evolution of life, together with the relatively brief presence of *Homo sapiens*. Since this story relates the attempts of the human race to study and understand the Universe it lives in, it is confined, in human terms, to the very brief period of civilization which, on scaling to one year, covers only the last two minutes; but in astronomical terms, it goes back to the very beginning when, most astronomers now believe, the Universe started in a single, immense, explosive event—the Big Bang.

The timescale of the development of life on Earth; in the final column the times are scaled to one year as if the Earth was formed at the start of the year, and now is midnight at the year's end.



Event	Years ago	As if
Earth formed	4500 million	1 January
First micro-organisms	3500 million	23 March
Marine algae, primitive plants	2500 million	12 June
Multicellular plants introduce free oxygen into atmosphere		
Atmosphere like today	1500 million	1 September
Evolution greatly accelerated		
Fish, primitive reptiles, insects	300 million	7 December
Large reptiles, toothed birds, primitive mammals		
Dinosaurs disappear	65 million	7 December
Mammals proliferate		
Human types appear	3–4 million	5 p.m. 31 December
Homo sapiens	100000	12 minutes to midnight, 31 December
Civilization	14000	2 minutes to midnight, 31 December
Modern industrial society	200	1.5 seconds to midnight, 31 December

CHAPTER TWO
Ancient Astronomy

Awake! for Morning in the Bowl of Night
Has flung the Stone that puts the Stars to flight:

Rubaiyat

About 10000 years ago, the most recent ice age was over, the ice had fully retreated and the resulting warm period led to a spread of forests, vegetation, fish and mammals. The human race, which had hitherto spent its energy and ingenuity on survival—the acquisition of food and provision of warmth—responded to the greatly increased food supply by accelerating the development of tools and the techniques of hunting and gathering of plants. The increased productivity allowed the human race to exploit its greatest gift, a powerful brain, more fully. It embarked on the development of civilization and found that the setting up of organized societies, in the form of tribes or whatever, resulted in greater prosperity and more effective defence. It found that farming the land to produce the crops that it wanted, and the husbandry of animals to produce the meat that it needed, were far more bountiful than gathering vegetation and hunting game which happened to be present naturally.

With the development of agriculture and the human control of the environment, the land area needed to support a community decreased by a factor of about a hundred compared to that for hunting and gathering. This great increase in productivity caused an increased growth in population; new societies grew and developed with their own structures and customs to become more unified but also more separate; trade between them developed but, not infrequently, disputes occurred which often resulted in warfare. The victor usually took everything and subjected the conquered to slavery, a practice that became extensive in all ancient civilizations. One powerful form of society that developed was the city-state, which often dominated its surroundings as an empire; Babylon was to be the first and Rome the greatest.

By *circa* 5000 BC, food production had reached a level that freed significant time and effort for pursuits beyond those needed for survival alone. The consequent release of human ingenuity caused an acceleration in human progress, with the further development of new tools and techniques, allowing more effective farming (and warfare), the building of cities, the development of language, from spoken to written, the strengthening of social organization and authority, and the creation of wealth. Out of this evolved the first true civilizations: societies with the means and the wish to pursue intellectual, artistic and other creative activities in addition to the most basic needed for survival. The great early civilizations were located in many parts of the globe, usually in the most fertile regions, often watered by great rivers. The first of these was the Sumerian civilization, which was fully established in Mesopotamia by *circa* 3500 BC, so named because it is the land between two rivers (the Tigris and the Euphrates), and is largely embraced by modern-day Iraq. Others were well established in Egypt by *circa* 3000 BC, in India (the Indus valley) by *circa* 2500 BC, in Crete (Minoan) by *circa* 2000 BC, in China by 1500 BC, and in Central America (the forerunners of the Incas and the Aztecs) by 1000 BC.

Many of the intellectual activities pursued in the early civilizations grew from the innate curiosity of the human race in the natural world in which it existed. This was particularly true of astronomy, where the motion of the Sun, Moon, planets and stars caused excitement and puzzlement. You should realize that life in a modern industrial society is a great impediment to viewing the heavens because of artificial lighting and smog. One of the really beautiful sights in nature is of the clear night sky in the absence of city lights, say on a remote mountain, where the sky has great depth and the Milky Way is a bright lane of light. But this sight was available to everyone in the distant past and its beauty led to the pursuit of astronomical studies in all the early civilizations.

But the early developments in astronomy were fired more by practical and mystical rather than scientific considerations. The development of agriculture required that crops be planted in spring and harvested in autumn; hence the times of the seasons needed to be known. In other words, a calendar was required, and several attempts to establish one were made in the period between 5000 and 1000 BC. Natural time-periods were available in the day, determined by the rising, setting and rising again of the Sun; the month, determined by the time it took the Moon to pass through all its phases; and the year, determined by the seasons, over which the Sun reached its maximum noon altitude in mid-summer (for the Northern Hemisphere), its lowest in mid-winter and back again in mid-summer. The first and simplest astronomical instrument, the gnomon, was able to give some indication of the time of day and the season of the year; it consisted of a straight vertical rod and is based on the same principle as the modern sundial. In the early morning, its shadow would be long and point roughly westwards; as the day progressed, it would shorten and rotate until, at noon, it would be at its shortest and would point exactly due north; it would then lengthen and rotate until, in the late afternoon, it was pointing roughly eastwards. If the length of the shadow is measured at noon, it is found to be shortest in mid-summer and longest in mid-winter, thereby allowing the seasons to be estimated. Another way to tell the time of year was afforded by the night sky. The stars were fixed and unchanging relative to each other, but appeared to rotate completely over one year, so that there were winter and summer constellations.

Another group of objects in the night sky were the five planets or wandering stars. As bright as the brightest stars, they moved in the same plane (the ecliptic) as the Sun and Moon, but in odd and seemingly unpredictable ways. Three of them (Mars, Jupiter and Saturn) would advance across the celestial sphere, reverse their motion and advance again; the other two (Mercury and Venus) also moved but were visible only when they were close to the Sun, just after sunset or just before dawn. The puzzle of the planets was to remain unsolved for several millennia and it posed the greatest problem in early cosmologies—the explanation of the motions of the Sun, Moon, planets and stars.

The mystical aspect of studying the heavens, astrology, developed strongly in the early civilizations and soon became the prime driving force. It was believed that the stars and planets controlled human destiny and therefore their study was encouraged as a means of predicting, or explaining, human triumphs and tragedies. Perhaps this is not surprising: if the heavens could say when crops should be planted or harvested, why not when wars should be embarked upon or preparation made for famine or flood? Religious aspects also crept into the interpretation of the heavens, and astronomical studies were often carried out by priests.

The most ancient civilization, the Sumerian, was based in Mesopotamia, now the southern part of modern-day Iraq. It prospered rapidly and by *circa* 3000 BC had developed a written language which was etched into clay tablets. Unlike the other early civilizations of Egypt and China, it has not retained its name, culture and identity over the centuries, but has changed hands frequently through invasions, migrations and wars. The development of building technology allowed for larger and larger human groupings into city states, and one of these, Ur, became the capital of Sumeria in *circa* 2500 BC. It lay near the junction of the Euphrates and Tigris rivers in the south of Mesopotamia. It is believed to have been the home of Abraham and his Semitic tribe, who developed a belief in a single, unseen, all-powerful God, a belief that forms the ancient roots of today's three great monotheistic religions. Abraham was to take his tribe out of Ur *circa* 2100 BC, when it set off on its wanderings (from which the name Hebrew, or "wanderer", derives), which were to take it to Canaan (Palestine), to Egypt and back to Canaan over a thousand years.

In about 2000 BC Ur was conquered by the Elamites, who came from what is now southwest Iran, and a new powerful city-state emerged, Babylon, which was to establish control of Sumeria and extend its empire over the whole of Mesopotamia. Babylon is on the Euphrates about 80 kilometres south of present-day Baghdad. It became very wealthy and very indulgent in the pursuit of pleasure and consumption, giving it a reputation as a magnificent, worldly, wicked city, which still persists today more than two millennia after its demise. Great buildings were constructed, including the Hanging Gardens, one of the seven wonders of the ancient world. The Sumerian cuneiform script was given a syllabic form, thereby greatly increasing its flexibility. Many written tablets still survive which tell us more about the Babylonian Empire than we know about many European countries during the Dark Ages of AD 500–1000.

Many activities were encouraged, one of which was a study of the heavens, entirely for astrological purposes, since they believed their destiny could be read in the stars, but this had the important result of producing the first major set of astronomical observations ever undertaken. Over centuries, the positions of the bright stars were established and the motions of the Sun, Moon and planets charted against the background of those fixed stars. All these data were recorded in cuneiform script etched into clay tablets, many of which are still available today; they allowed some astronomical analysis, as well as astrological interpretations. By about 1000 BC, lunar eclipses could be predicted with reasonable accuracy and the motions of the outer planets had been established over several centuries.

Studies of the heavens also had religious overtones, and the prime celestial bodies were named after gods, of which the Babylonians had several. But in addition to the religious and astrological applications, there was an astronomical requirement—the prediction of the dates of important events such as festivals and the times of sowing and reaping. This required a calendar and one was constructed which had a year of 12 lunar months, and which started with the vernal equinox in spring, the time for sowing. Each month was defined by the Moon and started at sunset on the evening when the new crescent Moon was visible for the first time. Since a lunar month is not an exact number of days, nor is a solar year an exact number of lunar months, this was a somewhat cumbersome basis for a calendar, as many other civilizations discovered. A lunar month is close to 29.5 days, so, with each month being identified by the first appearance of the new Moon, a month was either 29 or 30 days and a year of 12 lunar months consisted of 354 days. The difference between this and the solar year (365.25 days), which determines the seasons, was accommodated with an extra month about every three years. The Babylonians also introduced the seven-day week in deference to the Sun, Moon and five planets, regarded as representing gods.

The Babylonians were responsible for some of the earliest mathematics and they set up the sexagesimal system of angular measurement which is based around the number six and is still used today. They defined a full circle as 360°, corresponding approximately to the 360 days in their calendar; hence 1° corresponds approximately to the angular movement of the Earth during one day in its orbit around the Sun, although the

Babylonians did not look at it in that way. They also set up a simple form of algebraic geometry which had many practical uses and formed a basis for surveying.

The Babylonians also initiated the concept of the zodiac, the band in the celestial sphere through which the Sun moves and completes a full revolution in one year. The Moon and planets also move in the same band (but in totally different ways) and we now know that it represents the ecliptic plane in which the planets revolve about the Sun, and the Moon about the Earth. The Babylonians divided it into 12 equal zones of 30° corresponding to the 12 lunar months of their calendar and then assigned each one to the nearest constellation. Constellations were regions of the sky whose stars showed a pattern which could be likened to known people, animals or objects. All the early civilizations identified their own constellations and the 12 signs of the zodiac evolved slowly from ancient roots. The ones that are in use today are those which were recorded by the ancient Greeks; the sequence starts with Aries (the Ram), moves to Taurus (the Bull), then to Gemini (the Twins), to Cancer (the Crab), on to Leo (the Lion), on to Virgo (the Virgin), then to Libra (the Balance or Scales), on to Scorpio (the Scorpion), then to Sagittarius (the Archer), reaching Capricorn (the Goat), then on to Aquarius (the Water Bearer) and to Pisces (the Fishes), which then joins up with Aries to complete the cycle.

During each year, the dates that correspond to each sign of the zodiac are determined entirely by the constellation in which the Sun is located in its migration around the zodiacal plane. The zodiacal year is defined by the time it takes the Sun to complete its full cycle; it is now called the sidereal year, because it is determined by the Sun's movement against the background of fixed stars. In today's terms, it is precisely the time it takes the Earth to complete one full revolution about the Sun. In developing a calendar, the Babylonians knew that a year determined the cycle of seasons, which we now know are caused by the tilt of the Earth's axis of rotation by 23.5° to the plane of its orbit around the Sun. In summer the axis is tilted towards the Sun, causing greater heating because of the longer period of daylight and the greater solar radiation flux per unit area because of the angle of the Earth's surface being less inclined to the direction of the Sun's rays. Mid-summer is defined by the Earth's axis being tilted exactly towards the Sun (the summer solstice), and mid-winter when it is tilted exactly away from the Sun (the winter solstice). (This is the situation for the Northern Hemisphere; the inverse is the case in the Southern Hemisphere.) Spring is defined by the vernal equinox when the Earth's axis is tilted exactly orthogonal to the Earth-Sun line, so that the Earth is equally illuminated from pole to pole and periods of day and night are equal everywhere; similarly, autumn is defined by the autumnal equinox. Hence, a year can also be determined by measuring the direction of the Earth's inclination relative to the Sun, say from vernal equinox to vernal equinox. Such a year, called a solar year, is directly linked to the seasons and is therefore the most important basis for a calendar, the greatest practical value of which is to predict the occurrence of spring, summer, autumn and winter or, more importantly in Egypt, the flooding of the Nile and, in India, the monsoon. Because of this, our modern calendar (whose development I will recount later, starting with the major and leading contribution of the Egyptians) is based on the solar year.

At this point, you may think that the two years I have described—the zodiacal, or sidereal year and the solar year—are identical and simply represent two different ways of measuring the same thing, but this is not so; there is a very small difference between them. The difference is so small that it was unknown to the Babylonians and was not detected until nearly 2000 years after they started studies of the zodiac and their calendar. It is so small that it has a negligible effect on everyday life and, even today, it is not well known outside astronomical circles. However, there is one area of modern activity that should be affected by the small difference between solar and sidereal years but which seems to be largely ignorant of it.

As already said, much of early astronomy was driven by astrology, the belief that human destiny can be foretold in the stars. The zodiac became one of its main tools and, since it is still used today, as can be seen from its presence in the columns of many newspapers, it is appropriate that I bring its story up to date. The simple proposition is to assign to each individual person that zodiacal sign that the Sun was located in when he or she was born. Destinies could then be read at any one time from the positions of the Moon or planets as they moved through the different signs of the zodiac. However, the direction of the Earth's axis is not fixed but, because of its rotation, precesses in a way similar to that of a spinning top; it closely maintains a tilt of 23.5° to its orbital plane but rotates very slowly about it at a rate that will see a complete revolution in 25800 years. Because of this the constellations move slowly westwards along the plane of the ecliptic with respect to the calendar. This is because the calendar is based on the solar year, which, because of the precession of the Earth's axis, is about 20 minutes shorter than the sidereal or zodiacal year. Without precession, these two years would be identical and the zodiacal constellations would not drift through the calendar. Precession was discovered in the second century before Christ by Hipparchus, the most brilliant observational astronomer of ancient Greece. Later, I will describe the method he used, together with his many other achievements.

The Babylonians had adopted the vernal equinox, marking spring, as the start of their year and the zodiac. At the time of the ancient Greeks, the vernal equinox lay in Aries, so this constellation was labelled as the first sign of the zodiac and the vernal equinox is still referred to as the first point of Aries. But when the Babylonians first set up their zodiac, the vernal equinox lay in Taurus; this was therefore the first sign of their zodiac and it accounts for the Babylonian description of Taurus as not only "The Bull of Heaven" but also "The Bull in Front". If our present series of zodiacal signs had been adopted from the earlier Babylonian records rather than the later Greek ones, the first sign of the zodiac would have been Taurus, not Aries, and the astrological discrepancy I am describing would have been even greater. Today the vernal equinox, which occurs on 21 March in our calendar, lies in Pisces; hence, most people who are assigned the astrological sign of Aries should, astronomically, have the sign Pisces. This drift will continue and, during the next millennium, the vernal equinox will enter Aquarius, presumably heralding the "dawn of Aquarius" Hence, if anyone wished to know which constellation the Sun was in on any particular date, past or future, the appropriate astronomical tables would be needed or, more simply, a sidereal rather than a solar year used in which the constellations will not drift. A more simple but approximate calculation can be made from the fact that the constellations drift through our calendar by one zodiacal sign every 2150 years and that the vernal equinox lay in Aries during the great Greek period of a few, say four, centuries before Christ. As of today, this places the vernal equinox in the western part of Pisces.

The astronomical developments in Babylon were led from the temple and were interlinked with religion and the several gods of the time. A primitive cosmology developed, influenced by the nature of Mesopotamia, a land subject to much flooding (as southern Iraq, it is still a marshland today). This said that the gods created the world out of a watery waste and made human beings out of mud to be slaves to them, a world picture appropriate to a society where monarchs had full and absolute power.

Babylon was at its zenith between 1900 and 1600 BC, but for the following thousand years Mesopotamia was like a battlefield, with invasions from all sides. In 1595 BC, the Hittites attacked from the north (modernday Turkey) and looted and pillaged Babylon; their monopoly of iron gave them military superiority, as well as a great advantage in agricultural tools. In 1100 BC Babylon was conquered by the Assyrians and finally, in 539 BC, it fell to the Persians who established the greatest empire then known through most of the Middle East.

The other great early civilizations, such as those in Egypt, India and China, also conducted astronomical studies which were driven by practical, astrological and religious motives. In China there is evidence that astronomical observations were well under way as long ago as *circa* 2000 BC. The length of the solar year