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David Leverington
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Introduction

Astronomy is like no other science, being partially associated, as it was in ancient times, with religion and superstition. It was studied by priests, philosophers, soothsayers and mystics, as well as the forerunners of today's men and women of science. In those early days, astronomy was seen as the most fundamental and important of the sciences, as it dealt with the motion of the sun, moon and planets across the sky, and their alignments, eclipses, and so on, to which the ancients attached great significance.

Today all that has changed in our cynical, materialistic world, where religion is struggling to survive, and where science is judged by most people on whether it is useful or not. On that basis, computer technology and genetic engineering are considered more important than trying to understand how the universe started, or whether there is life on other planets of the solar system or elsewhere in the universe. And yet, we are now beginning to understand how fragile and delicate the balance of nature is on earth, and to realise that a study of the other planets of our solar system could help us in this. Hopefully, such studies will help us to decide how to correct our harmful developments on earth before it is too late, and life, as we know it, becomes seriously compromised.

In 1600 Giordano Bruno suggested that there was a limitless number of planets around other stars supporting intelligent life. This was a challenge to the religious doctrine of the period, but, even today, the discovery of such intelligent life would have profound effects in some religious circles. Although it may be unlikely that we will discover such evidence in our lifetimes, we may find elementary lifeforms of some sort on Mars, Titan or Europa in the next few years or decades. Such a discovery would be yet one more twist to the tale featured in this book, which explores the vast increase in our knowledge of the solar system over recorded time, and which ends with the discovery of other planetary systems around other stars. In fact, by the time that you read this book, life may well have been discovered elsewhere in the universe. Who knows? That is the thrill of astronomy.

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Chapter 1 | THE ANCIENTS

1.1 Early astronomy

It is easy to ignore the skies these days when many of us live in light-polluted cities, rushing around without time to think, but things were very different for our distant ancestors. In those days, before the rise of the great civilisations of Babylon and Greece, for example, primitive peoples needed to know when to plant and harvest their crops, when to move their animals to winter pasture, and so on. They regulated their working and sleeping patterns according to the times of the rising and setting of the sun, and understood the regular cycle of the moon, but working out the seasons was more difficult. In the absence of any other information, they used their own experience, but this could sometimes prove unreliable, so a more structured guide to the seasons would be useful.

It was easy to measure a day or a lunar month, its so-called synodic period from one new moon to another, but how could a year and its seasons be determined? Some civilisations used midsummer's day as a baseline, when they knew that the noon-day sun was at its maximum altitude,[1] and worked out the seasons from that. Others used standing stones or stone circles, like Stonehenge, to measure the position of the rising or setting sun against the horizon on midsummer and midwinter's day. Yet others determined the seasons from the rising or setting of certain stars. The Egyptians, for example, knew when they were developing their calendar in about 3000 BC that the annual Nile floods occurred when Sirius, the brightest star in the sky,

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[1] This is not so in equatorial regions, of course, where the seasons alternate between dry and rainy periods, rather than between the winter, spring, summer or autumn of higher latitudes.

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became visible for the first time in the morning twilight just before dawn. On the other hand the Australian aborigines linked the start of spring to the visibility of the Pleiades star cluster in the evening sky. So the ancient civilisations became familiar with the movements of the sun, moon and stars in the heavens.

As time passed, more advanced civilisations started to use the sun and stars for navigation, which required a knowledge of their position in the sky with some accuracy. Other people began to ask not just where the sun, moon and stars were at a particular time of day or night, but what caused their movements through the heavens. The planets that were known to the ancients, that is Mercury, Venus, Mars, Jupiter and Saturn, were seen to move in the sky in a peculiar way which seemed to have a meaning. Total solar eclipses and comets were also observed from time to time, spreading alarm and despondency through many populations. So early astronomy became inextricably linked with religion and superstition.

Religion placed a different requirement on astronomy compared with agriculture, however. The start of the various seasons did not need to be known exactly for agricultural purposes, but religious observances demanded a precise calendar so that their rituals could be planned in advance. The problem is that there is not an integral number of days in a lunar month, nor is there an integral number of lunar months in a year, which complicated matters greatly.

One lunar (synodic) month, from new moon to new moon, is now known to be, on average, 29.53059 days, and one solar or tropical year,[2] as it is known, is 365.24220 days. So, one solar year is 12.3683 lunar months, or about 11 days longer than 12 lunar months. In fact, over 19 years there are almost exactly 235 lunar months, which is 7 months more than if there had been just 12 months in each of the 19 years. So, provided 7 extra, so-called 'intercalary' months are added over 19 years, the lunar phase on the first day of the year is almost exactly the same as it was 19 years previously. Such a discovery of this so-called 'Metonic cycle'[3] was made only gradually, by the empirical approach of adding an extra month, as required, to a year of 12 lunar months to correct for the observed agricultural seasons. Eventually the

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[2] A year based on the seasons.

[3] This cycle was named after Meton, a Greek astronomer, who lived about 460–400 BC, and who was originally thought to have discovered it. The discovery was made more gradually, however, as mentioned above, but Meton was the first person to propose that it be adopted as the basis for a calendar.

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Egyptian,[4] Babylonian and Jewish calendars were structured to have 12 years of 12 months and 7 years of 13 months in each 19 year period.

1.2 The Babylonians

The Babylonians of about 2000 BC, who lived in southern Mesopotamia,[5] had had to observe the western horizon to detect the new moon, and hence to officially start a new month. In the process they not only deduced its 29.5 day cycle, but also clearly observed Venus (called Nindaranna), which is often very bright in the west after sunset and in the east before sunrise. Venus' periods of visibility near the western and eastern horizons, and its periods when it could not be seen (because it is too close to the sun), have been clearly recorded in a text from Ashurbanipal's library of the seventh century BC, which was based on a text of about 1600 BC.[6]

The Assyrians, who came from northern Mesopotamia, became the most powerful force in Mesopotamia in about 800 BC, conquering Babylon and adopting a large part of their culture.[7] They studied the sky as a source of omens, however, rather than to improve their calendar, linking the planets to their gods like talismans. Mercury was linked to Nabu, Venus to Ishtar, Mars to Nergal, Jupiter to Marduk and Saturn to Ninib. Nabu was the god of wisdom, Ishtar the goddess of love, Nergal the god of war and the underworld, Marduk the god of Babylon and the chief god, and Ninib a solar deity responsible for the seasons.

Now that the positions of the planets in the sky were linked to omens, their movements were more closely studied by the Assyrians, as was that of the moon, in order to predict lunar eclipses which were considered to be of special significance. A record of previous omens, used by the priests to interpret new celestial alignments and positions, was contained in a collection of seventy tablets called the 'Enuma Anu Enlil', which dated back to the pre-conquest era of about 1400 BC.

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[4] The Egyptians ran two calendars in parallel. The one described above was the astronomical calendar, but there was also an administrative calendar with a year of exactly 365 days, which was $^1/_4$ day shorter than in the astronomical calendar!

[5] Mesopotamia was the region of the Middle East which was based on the Tigris and Euphrates rivers. It is approximately equivalent to modern Iraq.

[6] These observations relate to the reign of King Ammisaduqa of Babylon who is variously thought to have reigned about 1702–1682 BC, 1646–1626 BC, or 1582–1562 BC, depending on whose chronology is used.

[7] The Assyrians first captured Babylon in 1234 BC but the occupation did not last long.

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In 612 BC the Assyrian empire finally collapsed, and Babylon became the centre of a new empire under Nebuchadnezzar, but in 539 BC it became part of the Persian empire under Cyrus the Great. As time progressed the Babylonians became less and less interested in interpreting messages from the gods, as seen by planetary alignments and lunar eclipses, and became more interested in trying to see patterns in planetary and lunar movements to enable astronomical predictions to be made. Water clocks were used to measure time, and in a text of 523 BC the relative timings of sunrise and sunset, and moonrise and moonset, are recorded to an accuracy of about a minute. The Babylonians measured the positions of the planets in the sky relative to the stars, and deduced their synodic periods. So in the case of Jupiter, for example, they observed that the turning point in its movement amongst the stars was reached every 1.09 years, that is its synodic period, resulting in there being almost exactly 65 of Jupiter's synodic periods in 71 years. The Babylonians also recorded both partial and total lunar eclipses, and observed that the cycle of eclipses repeated itself almost exactly every 223 synodic months, a period now called a 'saros'. We now know that the reason for this is that eclipses can only take place when the sun–earth–moon line lies approximately along the line of nodes, which is where the inclined orbit of the moon intercepts the orbit of the earth around the sun. This line of nodes is not fixed in space, however, as it regresses (i.e. precesses backwards), allowing an alignment of the sun–earth–moon line every 223 synodic months.

Babylon was part of the Persian empire for about two hundred years, but in 331 BC it became part of the empire of Alexander the Great. Alexander's conquest resulted in the arrival of the Greek influence in the so-called Seleucid period which lasted until 247 BC. The Parthians then took control of the area, and successfully withstood invasion attempts by Rome, in particular, over the next three centuries. Fortunately, during all these changes the priests continued with their astronomical observations and analysis.

The late Babylonian period

Our knowledge of astronomy in the late Babylonian period, covering the last three centuries BC, is contained in about 300 cuneiform tablets excavated from Babylon at the end of the nineteenth century, and from Uruk in southern Mesopotamia in the early twentieth century.

The Babylonian astronomers produced numerous extensive tables containing intricate calculations of the movements of the sun, moon and

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planets through the heavens. By now their positions were measured in ecliptical longitude and latitude coordinates.[8] The longitudes were recorded in one of twelve zodiacal signs, each of which covered 30° longitude, with their subdivisions being recorded in the sexagesimal notation based on units of sixty. So $28^\circ\ 10'\ 39\frac{2}{3}''$ or 28°.177685 in our decimal system, based on powers of ten, becomes 28°,10,39,40 in the Babylonian system, based on powers of sixty.

Two systems were used in these cuneiform tablets to predict the movements of the sun and moon. So the first visibility of the crescent moon could be predicted every month, thus enabling the new month to be officially started.

The first analysis system was given in the earliest cuneiform fragments, dated about 170 BC. In these it was assumed that the sun moved along the ecliptic at 30° per synodic month for 194° of the ecliptic, and at $\frac{15}{16} \times 30^\circ$ per month for the remaining 166°. This implied that there are 12.36889 or $12\frac{83}{225}$ synodic months in a sidereal year (of 360°), or that there are 2783 synodic months in 225 sidereal years. Assuming a mean synodic month deduced by the Babylonians of 29.530594 days (29d 12h 44m $3\frac{1}{3}$s, see later), gave a sidereal year of 365.260637 days or 365d 6h 15m 19s, which is only just over six minutes too long compared with the value known today.

The second analysis system was found in cuneiform tablets dating from about 130 BC. It assumed that the sun's velocity per synodic month varied linearly, in a zig-zag fashion, from $30^\circ\ 1'\ 59''$ to $28^\circ\ 10'\ 39\frac{2}{3}''$ and back again, changing at the rate of $0^\circ\ 18'$ per synodic month. This gave an average velocity of $29^\circ\ 6'\ 19\frac{1}{3}''$ per synodic month, compared with the currently accepted value of $29^\circ\ 6'\ 20\frac{1}{5}''$, which is remarkably close. Given the average solar velocity of $29^\circ\ 6'\ 19\frac{1}{3}''$ per synodic month, it would take 12.368851 synodic months to complete a full 360° sidereal year.

At the rate of $0^\circ\ 18'$ per synodic month, however, it would take 12.369136 synodic months for the sun's velocity to go from maximum to minimum and back again, which is higher than the number of synodic months needed to traverse the 360° of a sidereal year. The time for the sun to go from maximum velocity to maximum velocity is now called the anomalistic year. The above estimate is 12;22,08,53,20 synodic months in Babylonian notation,[9] or $12\frac{299}{810}$ synodic months using fractions, implying that there are 10,019 synodic months in 810 anomalistic years. At an average velocity of $29^\circ\ 6'\ 19\frac{1}{3}''$ per synodic month, the sun would move $360^\circ\ 0'\ 29''.8$ along the ecliptic in

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[8] The ecliptic is the plane of the earth's orbit around the sun.

[9] The semicolon separates the full number from numbers less than unity.

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an anomalistic year. So the Babylonians appear to have realised that the sun moves slightly more than 360° in going from maximum velocity to maximum velocity, the excess being $29''.8$, compared with the presently known value of $11''.6$.

The Babylonians, who were fascinated by numbers, saw the heavens in two dimensions, rather than the three dimensions envisaged by the Greeks. They were content to analyse the movements in the sky by arithmetic means, whereas the Greeks tried to explain the movements by recourse to geometrical figures. Although the Babylonians observed that the sun's motion along the ecliptic was not uniform, they did not seem to ask themselves why this was. We now know that this is because the earth's orbit around the sun is elliptical, with the earth moving faster when it is nearer to the sun at perihelion, and slower when it is furthest away at aphelion. As a result, the apparent solar velocity varies sinusoidally between these two extremes, rather than in the zig-zag fashion assumed by the Babylonians. We also now know that the orbit of the earth is not fixed in space, but it is moving such that the perihelion is precessing, thus explaining why the anomalistic year is not the same as the sidereal year.

In the second century BC, the Babylonians concluded that the average synodic month was 29d 12h 44m $3\frac{1}{3}$s or 29.530594 days long. It was also found that it could be as long as 29d 17h 57m $48\frac{1}{3}$s or as short as 29d 7h 30m $18\frac{1}{3}$s. The Babylonians analysed the moon's motion using a zig-zag function, with successive synodic periods, on the linear parts, increasing or decreasing by 1h 30m. This meant that it took 13.9444, $13\frac{17}{18}$ or $\frac{251}{18}$ synodic months for the moon to go from the longest synodic month to the shortest and back again. In this time the moon has orbited the earth $\frac{251}{18} + 1$ times, so $251 + 18 = 269$ anomalistic months is equivalent to 251 synodic months. So the average anomalistic month (from maximum to maximum orbital speed of the moon) was found to be 27.554569 days or 27d 13h 18m $34\frac{3}{4}$s, just 2.7 seconds from the value known today. Incidentally as $\frac{269}{251} \approx \frac{239}{223}$, a saros has almost exactly 223 synodic months or 239 anomalistic months.

As mentioned above, the main objective of these Babylonian analyses, which were mainly decoded in the early twentieth century by the Jesuit priest Jos. Schaumberger, was to predict when the crescent moon would first be visible each month. To do this, astronomers used any known lunar eclipse to provide the initial conditions. The angular separation of the sun and moon could then be calculated, knowing their various orbital velocities as determined above. The day of the year gave the inclination of the ecliptic to the horizon, and a knowledge of the moon's latitude

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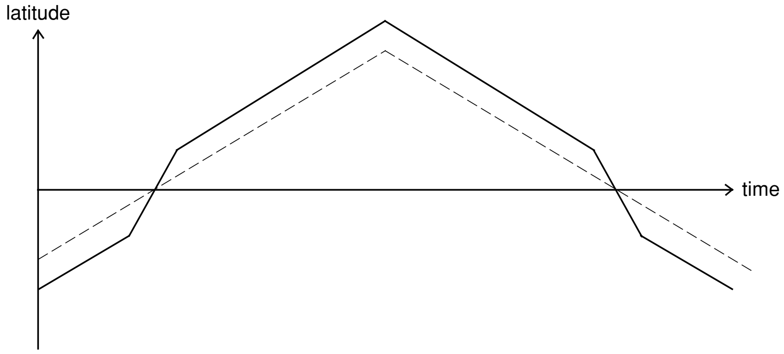

Figure 1.1 Plot of the moon's latitude relative to the ecliptic, versus time, as used by the Babylonians to predict eclipses. The solid line shows the modified zig-zag function used.

relative to the ecliptic then enabled the visibility of the crescent moon to be determined.

The above Babylonian calculations were shown on extensive lunar tables, the most complete of which ran to eighteen columns of numbers, giving values of the various quantities used. These tables were produced not only to predict the visibility of the crescent moon, but also that of lunar eclipses. To do this, astronomers realised that it was vital to get a good estimate of the moon's latitude above or below the ecliptic, which is now known to be due to the moon's orbital plane being inclined at about 5° to the ecliptic. It was recognised by the Babylonians that a straightforward zig-zag function of latitude versus time would not be sufficient, so they used a modified form as shown in Figure 1.1. This enabled them to calculate an index which predicted not only when there would be a full or partial lunar eclipse, but also approximately how long it would last.

A slight diversion is now called for, outlining the movement of the planets as we now know them, before going on to describe the Babylonian observations.

An inferior planet, i.e. Mercury or Venus, that orbits the sun inside the orbit of the earth, has the apparent orbit around the sun as shown schematically in Figure 1.2 relative to a stationary earth. At point A the planet is first seen as a morning 'star', at what is called its heliacal rising. On subsequent days, it appears higher and higher in the sky before dawn until it reaches its greatest western elongation at point B, so-called because it is west of the sun in the sky (although it is seen in the eastern sky). On the following days the planet is seen to be lower and lower in the pre-dawn sky, until it is lost in the bright dawn sky after point C. Some time later at point D the planet

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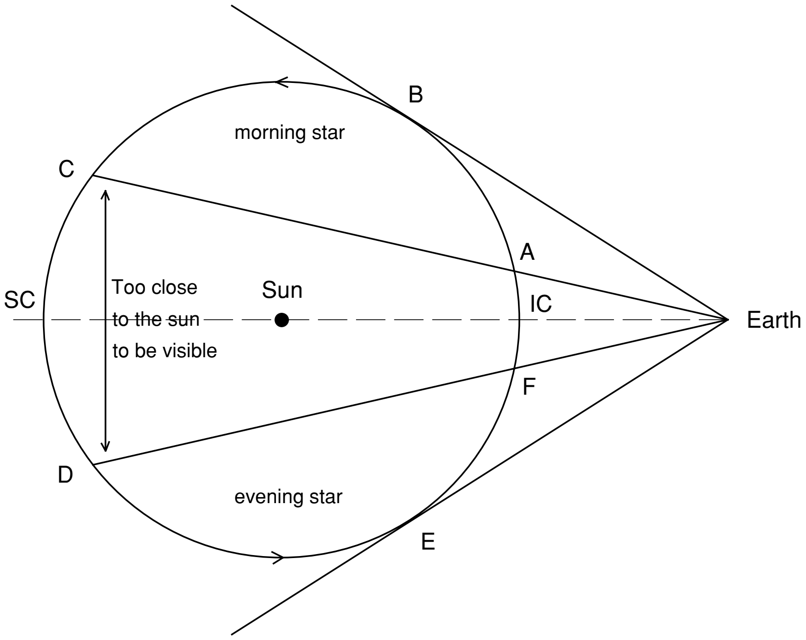

Figure 1.2 A schematic showing the apparent orbit of an inferior planet relative to a stationary earth. (The real figure is not a circle, but the diagram illustrates the principle under discussion in the text.)

first starts to be seen low down in the evening sky just after sunset. Point E is its greatest eastern elongation, and point F is its last visible appearance in the evening sky at the planet's so-called heliacal setting. IC is called the planet's inferior conjunction and SC its superior conjunction. Because the orbits of Mercury, Venus and the earth are elliptical, the greatest elongations from the sun vary from about 18° to 28° for Mercury and from 45° to 47° for Venus.

We turn now to the superior planets that were known to the ancients, that is Mars, Jupiter and Saturn. Unlike the inferior planets, the superior planets can be seen at any time of night, depending on their orbital positions. When they reach their highest point in the sky, crossing the meridian at local midnight, they are 180° away from the sun, and are said to be at opposition. Whereas when they are directly in line with the earth and sun, but behind the sun, they are at conjunction.

The orbits of the superior planets, as seen from the earth, are complex, as their orbits are ellipses inclined to the ecliptic. They orbit the sun in the same direction as the earth with lower angular and linear velocities.

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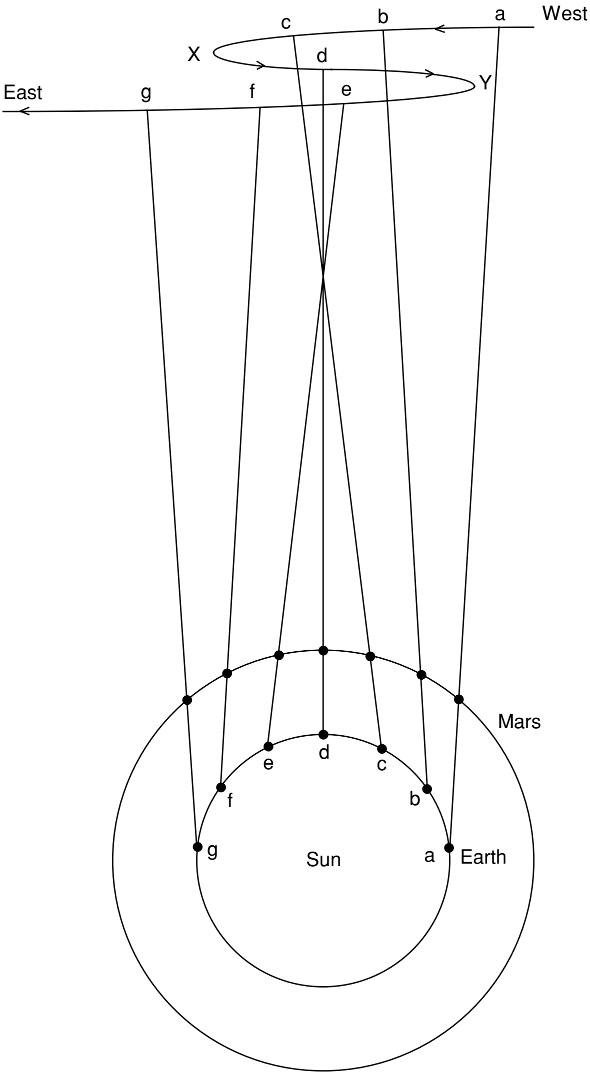

Figure 1.3 Plot to show the apparent movement of Mars against the stars, as seen from a moving Earth. The first and second stationary points are labelled 'X' and 'Y'. Mars is at opposition at point 'd'.

As a result, if the positions of the superior planets are plotted against the stars night after night, they show a general movement to the east (see Figure 1.3).[10] Around opposition, however, they trace out an S-shaped curve, temporarily turning back on themselves at their first stationary

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[10] Although Figure 1.3 is for Mars, the general configuration shown is the same for all the superior planets.

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