6 Ptolemy's Astronomy and the Rationality of the Greek / Medieval World View

In this Chapter we have to do something slightly technical. You do not need to master its content in its technical detail. But, we will need to learn something about Greek astronomy, because it is only by learning what it was about that we can understand what was really going on in the Copernican Revolution, in the 'astronomical revolution' so called. So this Chapter try to help you to deal with the bits that are important. That will help guide you through other secondary reading that inevitably will be more technical and at times perhaps written from a more Whiggish standpoint.

We have seen the Aristotelian two-sphere cosmos, looking at it in some detail as part of an analysis of Aristotle's Natural Philosophy. You will remember that we tried to see that Aristotle was merely one of the Greek Natural Philosophers, although his version of Natural Philosophy became dominant in the West, during the middle ages and Renaissance, and that he, like other Natural Philosophers was interested in the 'big physical picture':what is matter, how is it organised, what causes natural phenomena and how do we know?

Now when we talked about Aristotle's cosmology, I mentioned very briefly how the sun the moon and the planets were fitted into this model (fig. 1). Briefly, you remember we said they occupy the space between the sphere of the fixed stars and the earth, and in very general terms each of these objects has a slow west to east circular motion, a slow west to east cycle against the background of the fixed stars. Each one also has a certain period of rotation. In figure 2 we have certain data well known to ancient astronomers and philosophers about that slow west to east motion of these objects. For example, it takes the moon about 27 days to go around the earth from west to east and it takes the sun about 365 days to do the same.

If the behaviour of the planets were as simple as that, there would have been no reason for the Greeks to ever have gone beyond the teachings of this basic two sphere cosmology. The planets' motions would have been simple and would have been fitted right in. Unfortunately for you, because you are going to have to learn something about it, but very fortunately for the history of Western science, the planets do not behave in quite so simple a fashion. In many ways the problem of explaining exactly what the planets are doing invited the creation by the Greeks of a technical, mathematical, theoretical discipline or subject, which they and we call astronomy. It was dedicated in the first instance to explaining the rather bizarre behaviour of the planets. If the planets did not behave oddly, there would have been no mathematical astronomy--just this big picture--and so, no Greek astronomy, therefore no later Copernican astronomy; or, following from that, no Newtonian physics and celestial mechanics, and probably, therefore, no mathematisation of other physico-chemical sciences later in the 19th century. In other words no Western mathematical physical science, although there probably would have been Western Natural Philosophy. This is because the problem of the motion of the planets was the first technical question that attracted sophisticated, mathematical, technical attention, in the form of this early science or discipline of astronomy, developing under the umbrella or inspiration of Natural Philosophy, in particular the under the two-sphere cosmos picture common to the Natural Philosophies of Plato and Aristotle.

What is the problem of the planets? (fig. 3) Here we have the background of the fixed stars as you might see it from earth, with a planet tracking along west to east against the background. The problem is that planets do not always move west to east. Each planet has its own characteristically timed additional weird behaviour, which consists in periodically slowing down, stopping and turning back to move in the opposite direction, east to west, for a time, until slowing, stopping and then resuming the usual west to east motion. Seen from earth this motion traces out a looping motion over time. Each planet performs such loops against the background of the fixed stars; each planet has its own characteristic period when it does this. For example, Venus does this every 116 days; Mars every 780 days etc. These loopings we shall call "retrogressions"

These retrogressions obviously undermine any simple cosmology and make it impossible to stay with the simple version of the two-sphere cosmos. We need to add more to the model beyond a constant slow west to east motion. The working out of mathematical models to produce the retrogressions within the usual west to east motion, models which predict observed planetary positions 'reasonably' accurately, **that** is the key original problem of Western theoretical astronomy.

The retrogressions of the planets and many other curious astronomical phenomena had been observed and recorded by astronomers prior to the Greeks, particularly by Babylonian astronomers -- not in the really old Babylonian empire about 2000 BC., but in the New Babylonian empire about 1000 to about 700 BC. They wrote in cuneiform on clay tablets, and they developed a very nice little astronomy, although it was not a theoretical astronomy, but more what I would call a "time-table" astronomy or a 'craftsman's astronomy' (rather than a Natural Philosopher's astronomy). What they did was make observations, generation after generation, of astronomical phenomena, including retrogressions and many other things. They would record their observations and make guesses about the periodic cycles governing the phenomena they were studying. Then they would do more observations, and refine their time-tables of the cyclical recurrence of key phenomena. By a series of approximations, they were able to build up cuneiform tablets that were essentially time-tables for key astronomical phenomena.

There was no cosmology, no picture or blueprint of the structure of the universe behind Babylonian time-table construction. There was no theory of the cosmological architecture upon which that construction was based, and which was supported by the empirical work on time-tables. It was just time tables. This could be a time table say, of Mars' retrogressions. It would have a series of dates, positions in the sky, and if you were out by a few degrees or a few days, you would go back and refine or interpolate something into your existing guess about the cyclical, period pattern and churn out a replacement time-table. If you do this for hundreds of years, you can get pretty good timetables.

How did Greek Natural Philosophy respond to alla this? The earliest Greek Natural Philosophers, about 600 BC. were not knowledgeable or skilled enough to be interested in this wonderful, accurate Babylonian time-table astronomy. By the time you get to the more ripe period of Greek Natural Philosophy, in classical Athens, in say the 5th century BC., with the school of Plato and his student Aristotle, you get a new realisation amongst Natural Philosophers. If you want the two-sphere cosmos--and that is the Platonic (and later Aristotelian cosmology)--and, if you have heard about the problem of retrogressions, and if you've got some Babylonian and other data, then you are going to ask whether there is anything we can do to accommodate all these now documented details into the basic model... The question becomes, 'Is there any more technical, detailed theoretical model that we can build, and place within the basic cosmology to explain the details, like retrogressions?'

Plato saw this, and encouraged his more mathematically adept students to develop a detailed mathematical theory of the motion of the planets that could broadly be fitted within the basic two sphere cosmos. The Babylonians had not done that. We saw all they had were time-tables. Their basic picture of reality was still given by myths; they did not have a discourse or a tradition of Natural Philosophy within which to pose the further theoretical question of a model of planetary motions. You might say that their time-tables were time-tables of the behaviours of Gods and Goddesses. They did not need a concrete picture or model of the cosmos, only a table of comings and goings of planets -- of supernatural entities as it were.

So you might say that Natural Philosophy, plus Babylonian time tables, yields in Plato's Academy the possibility of the problem of theoretical astronomy. (fig. 4) That problem is, again, to explain the motions of the planets in a mathematical way, in a manner arguably consistent with the basic and very plausible two-sphere cosmos. This is why I would want to say that the Greeks invented the science of astronomy (under the umbrella of Natural Philosophy), and that the Babylonians were doing something very interesting and fruitful -- but it was not quite what we should mean by a 'science' of astronomy, rather more a mythologically 'embedded' craft of astronomical prognostication.

Let's note here how Whiggish it would be to criticise the Greeks for their 'stupid' or narrow minded earth-centred astronomy. In their terms, and in our terms if we are fair and historically minded, they were being exceedingly smart. They were trying to polish up and articulate a plausible cosmology by taking on board the problem of finding a mathematical theory of the time tables of planetary motion. They should be applauded for their cleverness and daring -- not castigated for not believing what we have believed since the 17th century. Especially since our astronomy and modern world view developed only out of the maturation and subsequent collapse of their world-view and astronomy, and not as a totally new growth with no historical sources and continuities.

Plato said to his students, in effect, "Gentlemen, we have a spherical universe, with lots of circular motions going on. I therefore want you to try to explain the detailed, weird motions of the planets using some combination of uniform circular motions, and making the best use of the available observational data, including the Babylonian stuff" Obviously, one circular motion--west to east--was not going to be sufficient, so Plato set down this challenge, or condition, on the content and structure of the new astronomy-to-be: whatever the result his 'experts' came up with, it would arguably be consistent with and 'fit in with' the broad thrust of the existing two-sphere cosmos model.

One of his students, Eudoxus, came up with an astronomy, which in effect had each planet moving around the earth on several circles at the same time. We can ignore the details of this, because as the first 'astronomy' it was not as successful or fruitful as some of the versions of astronomical theory developed later in the Greek tradition. We need only study one version of Greek astronomy, that of Ptolemy who was a great, and rather late practitioner in the tradition, who codified and systematised much that had gone before.

Ptolemy worked about 500 years after Eudoxus, so you can see this work had matured and developed over quite some period of time. Ptolemy's version of astronomical theory provided the exemplar and basis for astronomy in the West right up through the 16th century. So to put the history in a nutshell: In the West, after the development of Universities in the high middle ages, that is from the 13th century down through the period we are studying, the dominant Natural Philosophy was that of Aristotle and the version of astronomy that was fitted into it was that of Ptolemy. That does not mean that the fit was perfect, or even seen to be terribly good in some respects as I shall discuss below; but that combination of Aristotle andPtolemy defined more or less the field of Natural Philosophy and accompanying technical astronomy. It was this package that came under attack in the Scientitic Revolution.

So now we must talk about Ptolemy's astronomy and here things are going to get a little mathematical. You to understand the theory in the sense of being able to work with it and apply it. I simply want to show the kinds of things he did and some of the strengths and weaknesses of what he did, not to get inside the technicalities of what he did. After all, it was done after all with highly esoteric solid geometry and trigonometry -- no calculus and no computers, and it took years for even talented people to master the techniques.

Let's also note that Ptolemy was one of the last great mathematically oriented Natural Philosophers of antiquity -- he practiced not only astronomy, but optics, music theory, geometry, as well as astrology, which was one of the mathematical sciences. If not a brilliant innovator, he was a brilliant synthesiser of material in the ancient tradition on the eve of the decline of ancient science. Hence his importance for the later tradition in the west.

Consider figure 5: we have sphere of the fixed stars; the central earth and a planet circling the earth simple west to east. That, we have seen, will not do, for where are the retrogressions? We have to have a way of representing the loops, or of explaining the loops. Ptolemy did not invent the way of doing this, but he certainly put it to work. To get the planet looping, Ptolemy makes use of an epicycle, a circle on a circle (fig. 6A). We take the planet off point B, and put it on a circle, an epicycle, centred on point B as point B rotates around E. The epicycle rotates as well, in the same direction as the larger circle. So the epicycle carries the planet around as it itself, or its centre B is carried around about E in the larger circle, called the deferent . If we adjust the sizes and speeds of these circles correctly to the available data, we can get any shape orbit of P we like and any shape and placement of loops (fig 6). So, obviously we can model the particular looping frequency and period of a particular planet.

We should also note that the loops, which are the retrogressions, always occur when the planet is closest to the earth, when the planet swings around on the "inside" part of its epicyclic path about B. This is interesting, because it had been observed always that when planets retrogress, they are brighter than at other times. Ptolemy's model explains this, by saying retrogressions occur when the planet is closest to the earth and therefore brightest! So this detailed model is looking pretty good! It makes extra predictions that accord with known data that in turn suppoort the prediction and the general plausiblity of the model.

What Ptolemy does is he takes Babylonian, and additional Greek data (which let us note is theory-loaded, by for example considerations of the atmosphere refracting light, and the theoretical limits of human naked eye perception etc), and he tries to build a picture on paper like figure 6. When you manipulate it, the model will predict your data or make predictions you can later try to check with further observations. And if your model is 'not sufficiently accurate' (a judgment) you will fiddle a few parameters here or there and try to ‘close the gap’ between predictions made by the model, and available data.

In sum, epicyclic models are rather good. But unfortunately things are still not that simple. In order to increase accuracy of prediction in respect of the available data, two further geometrical ‘devices’ had to be added to the models by Ptolemy. In figure 7 we add the first of these -- by moving the earth out of the centre of the deferent, moving it off-centre, what is called an ‘eccentric’. Now this is not strictly in accord with cosmology, because in cosmology, in Natural Philosophy, the earth is strictly in the centre of the universe. It turns out in Ptolemy's system, that for purposes of accurate prediction, all the models of the planets have to embody an eccentric, off-centre earth! An example of the use of the eccentric is to explain the seasons, as in figure 8 to get the measured lengths of the northern hemisphere seasons.

Finally, we come to a device that really puts off many modern students. Copernicus, too, hated this device, but not because he didn’t understand it, but rather because, as we shall see in Chapter 8, it offended him, offended him philosophically or aesthetically, so much in fact, that he may have been driven to the sun centred system by the desire to get rid of this ‘unacceptable’ device. But Copernicus was the first in the Ptolemaic tradition (and he was a skilled worker in that tradition) to object to this device, so let’s see what it was.

In figure 9 we have deferent, epicycle, eccentric and the third device, the ‘equant’. Now what is an equant or, as we say, an equant point? We can see what it does by looking at what happens when there is no equant. In that case the centre of the epicycle B is carried around the deferent circle at a uniform speed with respect to the centre C of the deferent circle. That is in one-quarter of the deferent period the point B travels 90 degrees around C, in one-half of the deferent period 180- degrees and so on.

Now an equant is that point <u>not in the centre of the deferent circle</u> about which the point B is carried with a uniform angular speed. So in figure 10 with the notion of B referred to equant point Eq, imagine B is on a track, the deferent , and from Eq, the equant point, a pointer or rod extends, like a clock hand, rotating around Eq with a uniform speed, pushing B along the deferent track. Say it takes 100 days for the clock hand to rotate once around Eq. Then B will be at point X after 25 days, at point Y after 50 days and at point Z after 75 days, returning to the top point W after 100 days. You can now see what this means: the motion of B, seen from C (rather than Eq) will be slow in the first 25 days, rather faster in the next 50 days, and rather slow again in the last 25 of the 100 days. (The motion seen from Eq will be uniform) This then, is the point; the equant allows us to produce the effect of acceleration and deceleration of motion as seen from some other point inside the deferent--point C say, in the centre, or point E where the ‘eccentric’ earth resides in this model.

All of this is a bit weird, if the idea, the rule according to Plato, is to use uniform circular motions, because it would seem that that idea refers to the centre of the circle, not to some esoterically selected point outside the centre of the circle. To Copernicus this looked a bit disreputable, a move not really in accord with Plato’s stated rule of using combinations of uniform circular motions. But, again, I stress, Copernicus was the first astronomer (1400 years later) to be so offended by this device.

Well, things have gotten quite complex. A planetary model has to use a lot of geometrical machinery to produce adequate predictions. A typical Ptolemaic planetary model, in order to be sufficiently accurate, had to look something like figure 11. Here we have a deferent, and eccentric earth and an equant, and not just one epicycle carrying the planet, but the planet is on an epicycle which itself is carried on a larger epicycle which rides on the deferent! Ptolemy had to work out one of these models for each of the planets, as well as the moon and sun. It tooks years to do each of them. And this was done, of course in the interest of accuracy, of 'reasonable agreement' with the data.

In fact in the interest of accuracy Ptolemy had to calculate a different model for each different phenomenon being predicted. In other words, if, for example, we are talking about the moon, and we want to explain the anglular position of the moon relative to the earth we draw something like say figure 11. But if the question is one of explaining the varying brightness of the moon, we need a different model -- one with a much smaller main epicycle because the brightness variation is nothing like the earth-moon distance variation that our first model would give (fig. 12).

Well, which model is the real one? Clearly in some sense, neither is: we have different models, different versions of a planet's deferent, epicycles, eccentric and equant, depending upon which aspect of its behaviour we are trying to model. Astronomy is starting to look rather hypothetical or fictitious -- as though the models are not meant to be representations of reality but only little mills or calculating devices to churn out predictions to be matched to data!

We have to be careful here, because a very important and misunderstood issue comes in at this point. Some people have concluded from this situation that Ptolemy and other astronomers, as well as Natural Philosophers, therefore believed that astronomical models had **no** relation to the issue of physical truth. That is, as in figure 13a, the truth (in Natural Philosophy and cosmology which amount essentially to the content of Aristotle's Natural Philosophy) was one thing, and the bizarre predictive machinery in astronomy was another thing: just useful as a set of 'computers' for making numerical predictions, but not *physically* true.

The basis for this view is, for example, the contrast between the commonsense and Aristotelian conviction that physically speaking, the earth is in the centre of the universe, compared to the astronomical outcome that each model has the earth outside the centre and in a somewhat different non-central point each time. Well, really! Those can't be physically true.

Similarly, do you really think there are two three or even four epicycles up there for each celestial body? That is not physically plausible. Maybe one epicycle could be there per object, but not several, and not different ones for different phenomena, and so on.

So we have the idea that astronomy is irrelevant to the issue of physical truth, which is solely contained in a separate realm of Natural Philosophy.

Clearly we would like astronomy to map entirely and completely onto Natural Philosophy. We would like, that is, an astronomy that is physically true, entirely consistent with Aristotle that is, and that retains all its mathematical predictive power and score. Unfortunately, it looks like we cannot have both at the same time.

However, this overstates the case and the problem. There was not a total disjunction between physical truth (defined by Aristotle) and astronomical models, rather there was some overlap as in figure 13b. **It surely was the case that certain aspects of astronomical model building were constrained by or consistent with Aristotelian**

criteria of physical truth. For example the finite, spherical cosmos is given in Natural Philosophy, as the general picture of motionless earth surrounded by celestial bodies moving 'in circles' around it. That too is given as physical truth in Aristotle and is preserved in Ptolemaic astronomy. You could even, like certain Arabic theorists later, build some models of how at least one epicycle per planet might be real and consistent with the basic Aristotelian picture.

So in general, the situation was not one of total disjunction, but only partial overlap, an overlap important in shaping astronomy, but not extensive enough to hold out the promise of a completely physically true, and *simultaneously* accurate astronomy. Out in the non-overlap area are all the 'unreal' devices of the models--eccentrics, equants, numerous epicycles, multiple models per object etc. They are useful for accuracy and scope but they are not real. What helps to make astronomy accurate, tends also to make it unreal, or fictional, or hypothetical compared to reality defined by the 'truth' of Aristotle's Natural Philosophy and cosmology.

This then was the situation. Ptolemy knew all this; the Moslem astronomers knew it; the Medieval and Renaissance European astronomers knew it. Their view was not one of total disjunction, although some older historians of science have thought that. Rather, they knew that this was the bind, the limitation, the 'condition' of astronomy. This is as good as things get, they thought: we have Aristotle for physical truth, and we want accuracy in astronomy, and they relateto each other as in figure 13b. In Copernicus' day, in the 16th century, any intelligent, educated person would thus conclude that this is the situation: we've been doing Natural Philosophy and astronomy for 2000 years, and this is as good as the human mind can produce.

But Copernicus himself has a very odd, weird viewpoint on all this. He makes a claim that must have struck his contemporaries as bizarre, even megalomaniacal. It's not so much that the earth goes around the sun. It's a deeper claim than that: it is that he has an astronomy in which *physical truth and astronomical accuracy are the same thing* -- they map onto each other! To which his opponents say -- "you do not have that, that is not possible, you have not done that, you are kidding yourself". You are out of step, out of mind and out of order.

Copernicus' opponents did not do what Whig historians would want them to have done; that is, bow down to Copernicus and say, "Oh, right, we missed that, of course you are right, how good of you to have seen things the way they really are" In the professional terms of 16th century astronomy and Natural Philosophy, Copernicus has advanced a more or less ridiculous claim. So, in the next Chapter we must look at Copernicus in his own terms, and in terms of his contemporaries, in order to see what he did and did not accomplish in terms of 16th century techniques, theories and standards. Here again wewill want to avoid Whig history, a simple awarding of points or demerits for being like us or not being like us today.

Figure 1 Two Sphere Cosmos

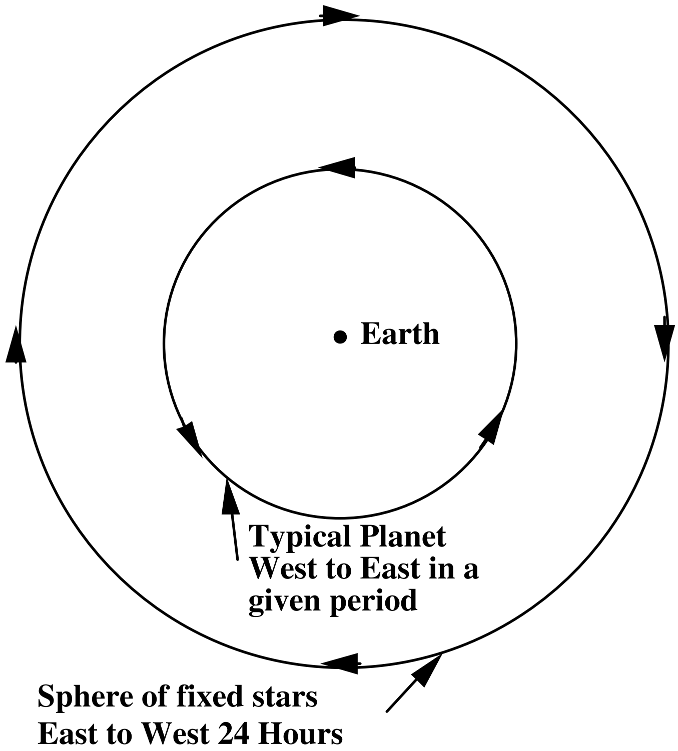
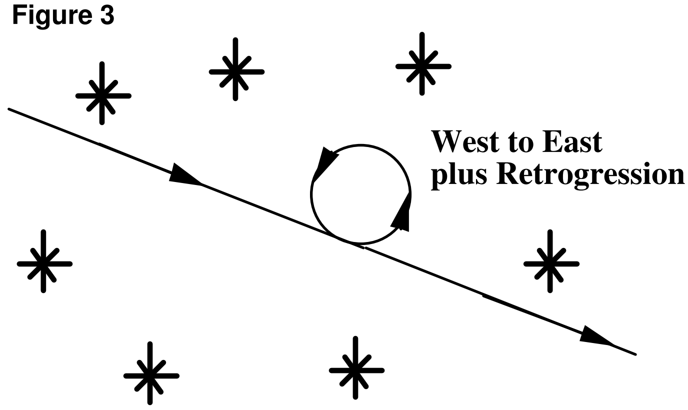


Figure 2

Object	West/East Period	Retrogression Period
Moon	27 days	---
Venus	365 days	116 days
Mercury	365 days	584 days
Sun	365 days	---
Mars	687 days	780 days
Jupiter	12 years	399 days
Saturn	29 years	378 days

Figure 3



Planets's path against background of fixed stars

Figure 4

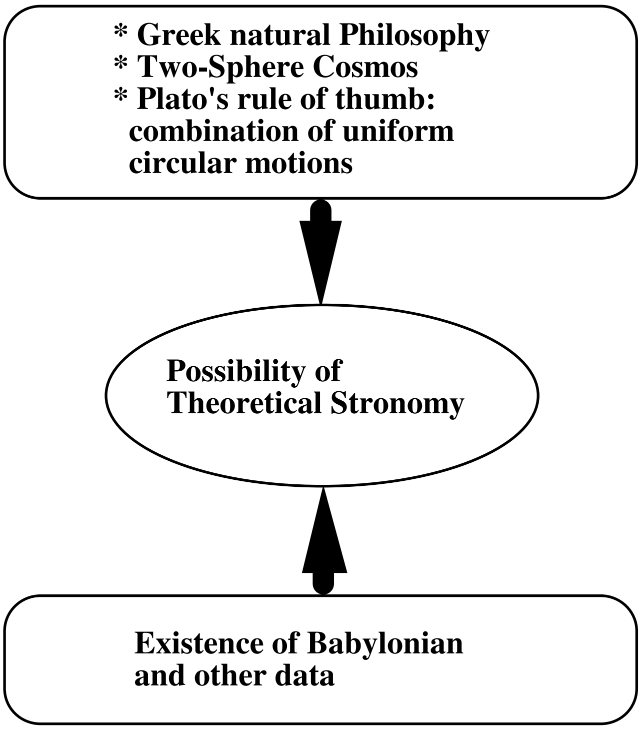


Figure 5 Too Simple: No Retrogressions

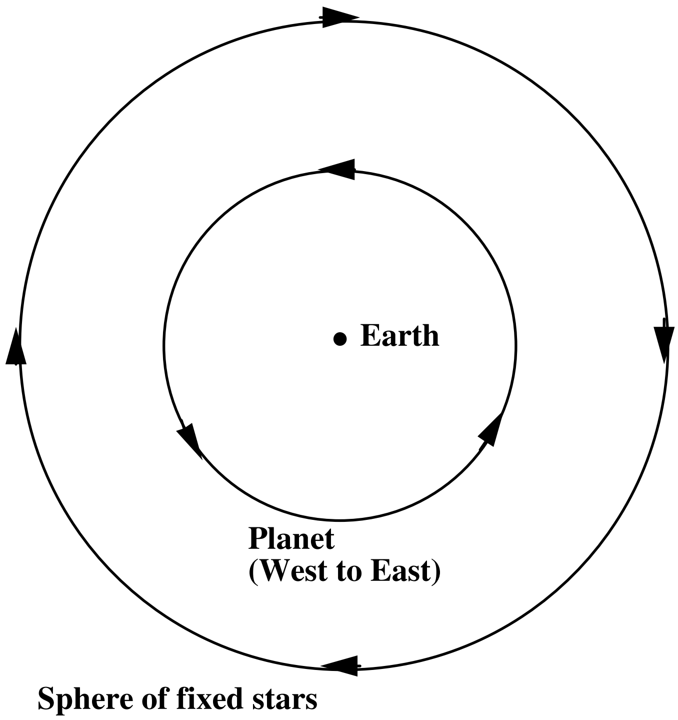


Figure 6a Epicycle

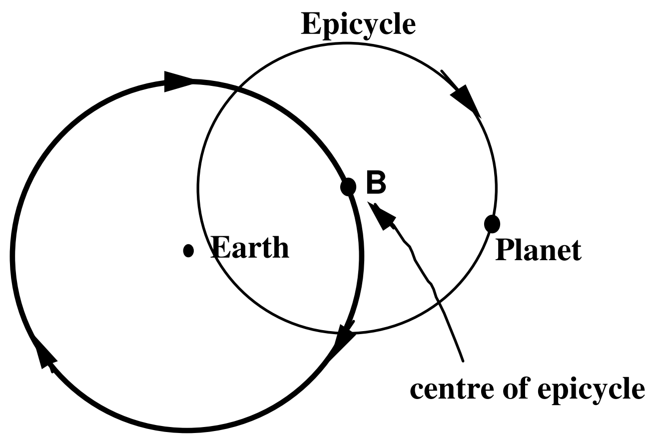


Figure 6b Epicycle and Looping Orbit

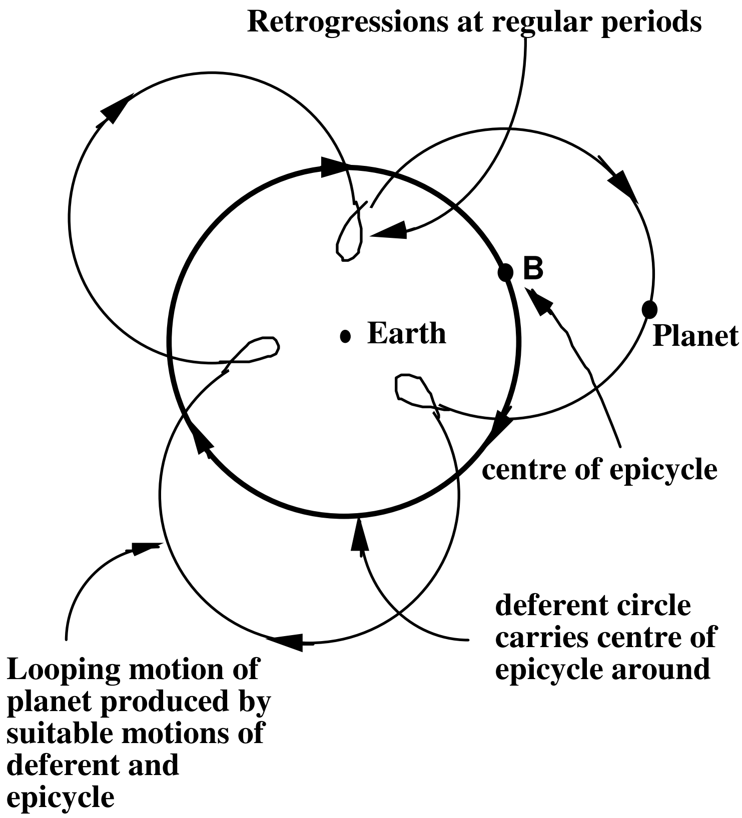


Figure 7 The Eccentric

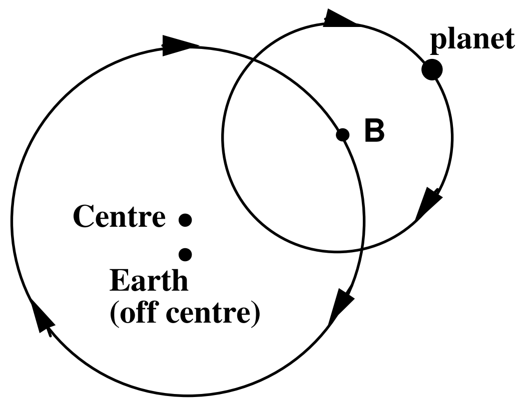


Figure 8 Eccentric Earth & Sun's orbit - length of the seasons (northern hemisphere)

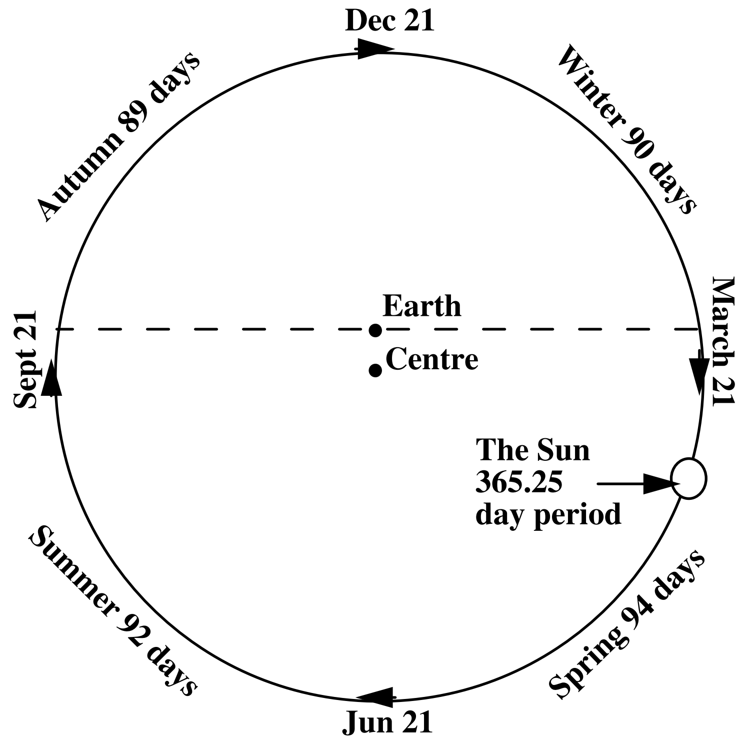


Figure 9 Equant Point added

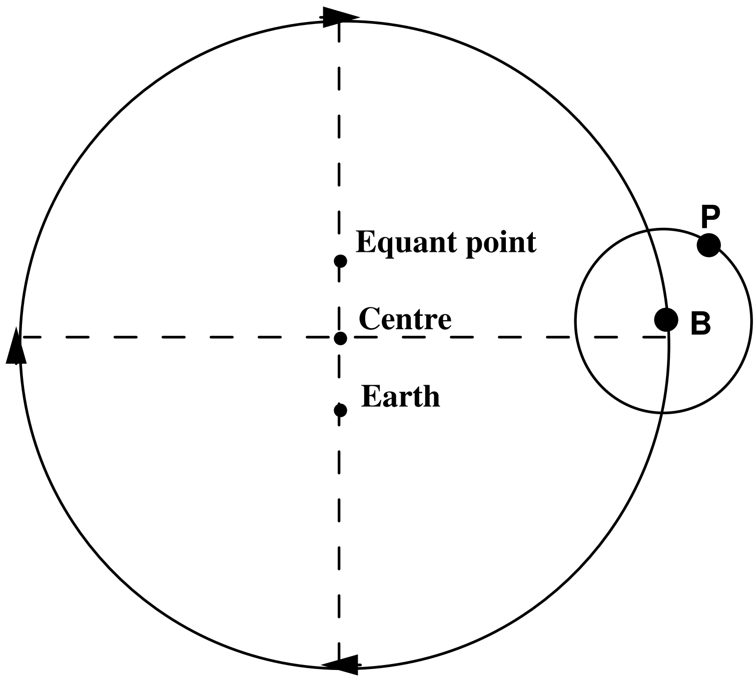


Figure 10 Equant Motion
B moves on deferent at uniform angular speed with respect to the Equant Point

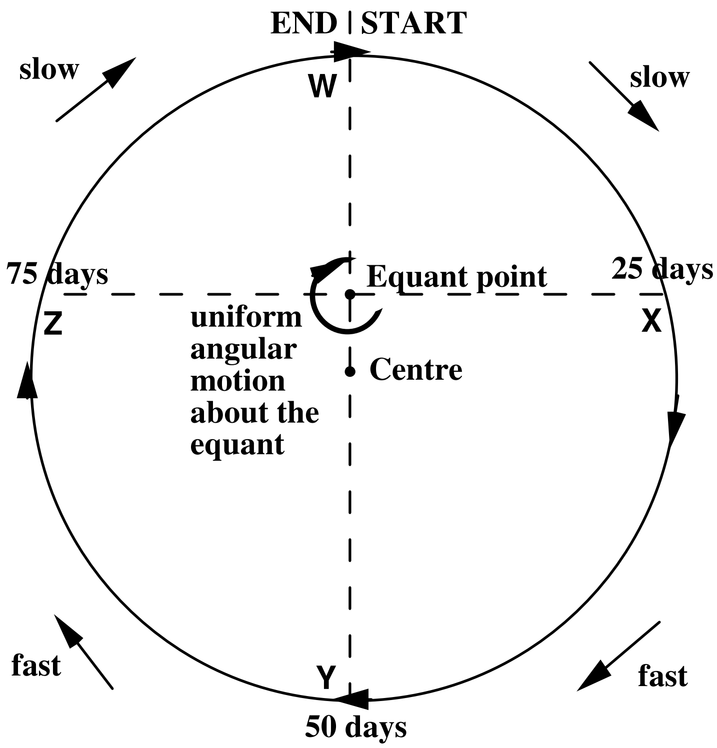


Figure 11 Typical Ptolemaic Model

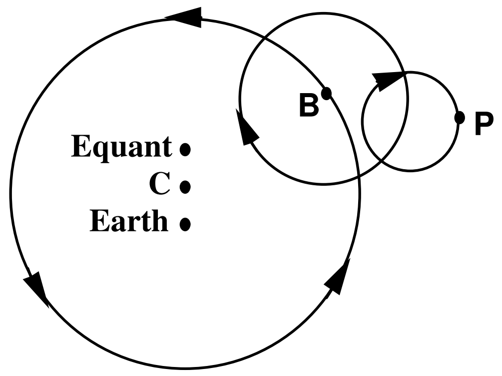


Figure 12 Model for the Moon's variation Much smaller main epicycle than in figure 11.

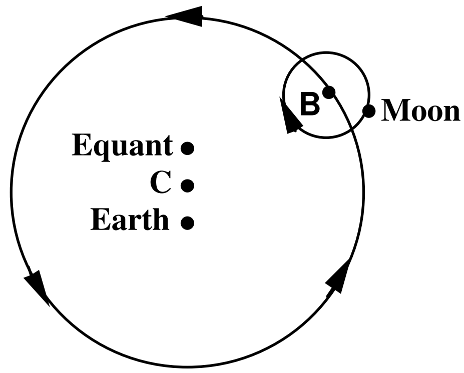


Figure 13a

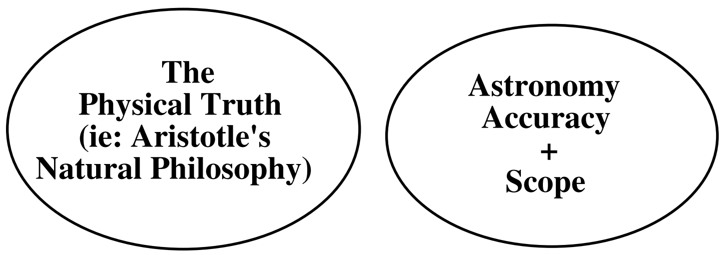


Figure 13b