Chapter Fourteen

The Copernican System

In the previous chapter we looked at the Ptolemaic system. As we saw, Ptolemy's system was quite successful in terms of predicting and explaining the relevant data. Although the theory was modified in the centuries following Ptolemy's death, the modifications were relatively minor, and the dominant astronomical theory for the next 1,400 years was essentially that of Ptolemy.

In the 1500s, Nicolas Copernicus (1473–1543) developed an alternative theory of the universe. Copernicus developed his system in the early 1500s, and published it the year he died. One of our main goals in this chapter will be to see how the Copernican system works. In addition, we will look at a brief comparison of the Copernican and Ptolemaic systems, including a discussion of which system provides the more plausible model of the universe. Finally, we will explore the question of what motivated Copernicus, with particular emphasis on ways in which certain philosophical/conceptual beliefs influenced his work.

Background Information

The Copernican system is a sun-centered system. Today we view the sun as the center of our solar system, but, notably, Copernicus' system did not merely have the sun at the center of the revolution of the planets; rather, he placed the sun at the center of the entire universe.

In many ways the Copernican system is like the Ptolemaic system, but with the position of the Earth and sun swapped. For example, like Ptolemy, Copernicus viewed the stars as all being equidistant from the center of the universe, embedded in the so-called sphere of the fixed stars. As it did for Ptolemy, this sphere defined the outermost boundary of the universe. Copernicus' universe was larger than

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Ptolemy's, that is, the sphere of the fixed stars was larger and further than generally believed by advocates of the Ptolemaic system, but the Copernican universe, like Ptolemy's, was relatively small compared to our conception of the size of the universe. And also as with the Ptolemaic system, the Copernican system used epicycles, deferents, and eccentrics, though notably it did not require equant points. Again, generally speaking, the Copernican system had a great many similarities to the Ptolemaic system, with the most obvious difference being the position of the sun and Earth.

It is also worth noting that Copernicus was dealing with essentially the same empirical facts as Ptolemy (again, the main such facts are covered in Chapter 11). The data was not exactly the same – in the 1,400 years separating Ptolemy and Copernicus, some new astronomical observations had been made, some existing observational mistakes had been corrected, and quite a few new observational mistakes had been introduced (either by mistaken observations or by mistakes in copying records). But, generally speaking, the empirical data available during Copernicus' time was still based on naked-eye observation, and this data was similar to the data with which Ptolemy worked.

In addition, Copernicus was firmly committed to the same key philosophical/conceptual facts as Ptolemy. That is, Copernicus firmly believed (as did almost all his contemporaries) that an acceptable model of the universe must respect the perfect circle and uniform motion facts.

It is often claimed that the Copernican system is vastly simpler than the Ptolemaic system, and that the Copernican system is superior at prediction and explanation. But as we will see shortly, this is simply a mistake. The Copernican system is easily as complicated as the Ptolemaic system, and no better (or worse) at prediction and explanation than the Ptolemaic system. When authors claim the Copernican system is simpler than Ptolemy's, and superior at prediction and explanation, they most likely are thinking of Kepler's system, which was not developed until 70 years after Copernicus' death, and which is the subject of a later chapter.

With this background material in mind, let's look at an overview of the Copernican system.

Overview of the Copernican System

As we did with the Ptolemaic system, we will simplify matters by focusing on the motion of a single planet. We will again use Mars as an example, and again begin with a picture. It should be noted that, in Figure 14.1, the circles are not drawn to scale, but rather drawn so as to be more easily distinguishable. On the Copernican system, Mars moves in a circle around point A (again, a small circle such as this is called an *epicycle*). Point A moves in a circle around point B (again, such circles are known as *deferents* or, if off-center, *eccentrics*). Point B also moves,

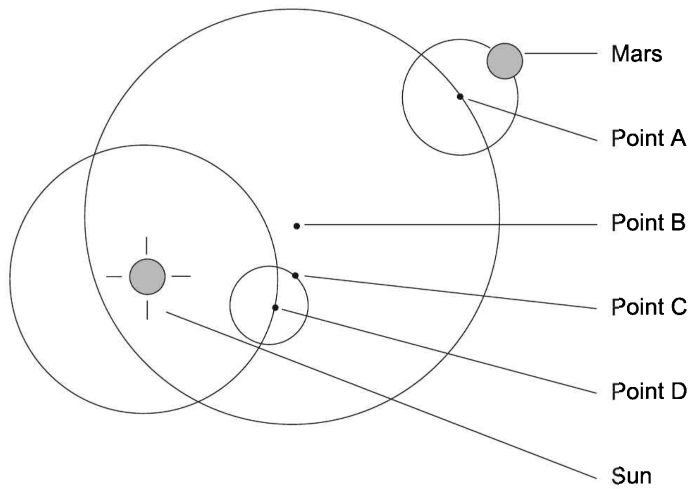

Figure 14.1 The treatment of Mars on the Copernican system

but as it moves it remains in a fixed position relative to point C. Point C is the center of the eccentric on which the Earth moves (to simplify the picture, the Earth is not shown in this diagram, but if the Earth were in the picture, point C would be the center of its eccentric). Point C moves in a circle around point D, and finally, point D moves in a circle around the sun. Not for nothing did I say the Copernican system was as complicated as the Ptolemaic.

Again, much like the Ptolemaic system, the Copernican system employs epicycles, deferents, and eccentrics, in a complicated system of circles on circles. Notice, however, that there is no equant point in the diagram, and in fact the Copernican system does not use equant points. Also, although the Copernican system does require epicycles, the epicycles are used for the flexibility they provide, but they are not needed to account for retrograde motion, as is the case with the Ptolemaic system.

If we ask the question "Why did Copernicus need this complex apparatus?" the answer, in a nutshell, is that without it the predictions and explanations do not work out. In other words, as with the Ptolemaic system, by using these complicated devices, Copernicus was able to work out a system that does a quite good job at explanation and prediction (as good as, though not better than, the Ptolemaic system). And without such devices, Copernicus was unable to get the model to match the known data. In short, just like the Ptolemaic system, the Copernican system is complicated, but when all is said and done, it works – that is, it explains and predicts the relevant data to a remarkable degree of accuracy.

So far, we have discussed only the motion of Mars. On the Copernican system, the apparatus needed to account for the other outer planets, that is, Jupiter and Saturn, is similar to that shown in the diagram above. The apparatus needed for the Earth is somewhat less complicated, as is that for the moon. Finally, the devices used for the movement of the inner planets, Mercury and Venus, are more complicated than those for Mars. In short, it should be clear that the Copernican system is easily as complicated as the Ptolemaic system.

Comparison of the Ptolemaic and Copernican Systems

Respecting the facts

As discussed in earlier chapters, whatever else we wish from scientific theories, they must be able to predict and explain the relevant data. In this regard – that is, in terms of accuracy with respect to accounting for the empirical data – the Ptolemaic and Copernican systems are essentially the same. Neither is perfect, but both are quite good. For example, if we use each of these systems to predict where Mars will appear in the night sky exactly a year from now, or to predict exactly when the summer solstice will occur for the next 10 years, or to predict any of a vast range of astronomical events, both systems will provide predictions that closely match the facts.

With respect to the philosophical/conceptual facts of perfectly circular and uniform motion, the Copernican system is slightly better. Both systems respected the perfect circle fact, that is, both systems modeled the motion of the planets and stars using only perfect circles. But, as discussed in the previous chapter, the Ptolemaic system respects the uniform motion fact only by using the rather strained device of equant points. In contrast, Copernicus was able to eliminate this hedge, and was able straightforwardly to respect the uniform motion fact. Again, even though these "facts" sound quite alien to our ears, most of Ptolemy's and Copernicus' contemporaries were committed to them, and so respecting them is a matter of some importance. In this respect, it is worth noting that Copernicus himself considered the elimination of equant points to be one of the most important reasons for preferring his theory.

In short, there is little difference between the Ptolemaic and Copernican systems in terms of predicting and explaining the empirical facts. With respect to the relevant philosophical/conceptual facts, the Copernican system respects the uniform motion fact in a somewhat more straightforward way.

Complexity

There is little difference between the two systems in terms of complexity. For example, if we look at the types of devices required (such as epicycles, deferents, eccentrics, and the like), as well as the number of such devices employed, the Copernican and Ptolemaic system are about equally complicated. Even though the complexity of systems such as this cannot be precisely quantified, and so it is not possible to compare exactly the complexity of the two systems, I think we can all agree on this point: both systems are very complex, and with respect to complexity, there is little to distinguish them.

Retrograde motion and other more "natural" explanations

Recall the Ptolemaic explanation of retrograde motion, that is, the occasional "backward" motion of the planets. In the Ptolemaic system, each planet required a major epicycle, the primary purpose of which was to account for the retrograde motion of the planet.

In contrast, retrograde motion receives a quite different explanation on the Copernican system. Again we will use Mars as an example, but similar accounts apply for the retrograde motion of the other planets as well.

On the Copernican system, the Earth is the third planet from the sun, and Mars is the fourth planet. Moreover, the Earth completes about two revolutions about the sun for every one revolution Mars completes. As a result, about every two years the Earth catches up to and then passes Mars. During the period in which the Earth is passing Mars, Mars appears, from the Earth, to move backward against the backdrop of the stars. Figure 14.2 may help illustrate this point. The lines are again the lines of sight drawn from the Earth, through Mars, out to the stars, and will show where Mars will appear against the backdrop of the stars. Note that the lines usually move in one direction, representing the usual eastward drift of Mars relative to the fixed stars. For example, in 1 to 3, Mars is shown in this usual eastward motion, then in 4 to 6, Mars is drifting westward, and then in 7 and 8 Mars has resumed its usual eastward drifting.

On the topic of retrograde motion, recall the seemingly minor empirical fact discussed at the end of Chapter 11, that Mars, Jupiter, and Saturn all appear brightest around the same time as they exhibit retrograde motion. Looking again at Figure 14.2, we can see why this would be expected. On the Copernican system, Mars will undergo retrograde motion only when the Earth catches up and passes Mars. Note that this will be the time at which Earth and Mars are the closest together, and so one would expect Mars to appear brighter at these times. The same story goes for Jupiter and Saturn as well – that is, they too will undergo retrograde motion only around those times when they are the closest to the Earth. So the correlation between the retrograde motions of Mars, Jupiter, and Saturn, and the times at which those planets appear brightest, has a quite natural explanation on the Copernican system.

Speaking of more natural explanations, recall also the other seemingly minor piece of empirical evidence discussed at the end of Chapter 11, that Venus and Mercury never appear far from the sun. On the Copernican system, Venus and Mercury are inner planets (that is, they are between the Earth and the sun). So no matter where Venus and Mercury are in their motions around the sun, when viewed from the Earth they must appear to be in the same region of the sky as the sun.

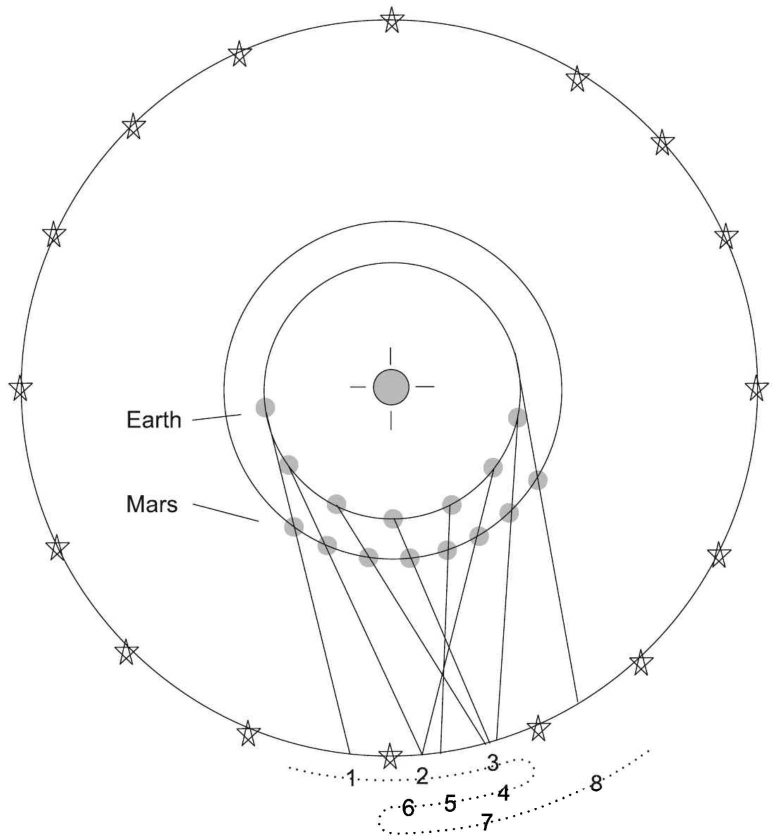

Figure 14.2 Explanation of retrograde motion on the Copernican system

In short, the Copernican system has a more natural explanation for retrograde motion, for the correlation between retrograde motion and the apparent brightness of Mars, Jupiter, and Saturn, and for the fact that Venus and Mercury always appear to be close to the sun. And these are all advantages of the Copernican system.

From a realist standpoint, which system is the more plausible model of the universe?

Recall our earlier discussion on instrumentalism on the one hand, and realism on the other. Again, instrumentalism is an attitude toward a theory in which one is primarily concerned with how well the theory predicts and explains the relevant data. Realism, on the other hand, is an attitude in which a theory is expected not only to predict and explain, but also to model or picture the way things really are.

Almost everyone took the various devices of these systems, such as epicycles, with an instrumentalist attitude. That is, these were generally viewed not as physically real, but rather as mathematical devices necessary to make accurate predictions and explanations. So the issue of realism generally does not arise for devices such as epicycles.

But the realist issue is very much relevant for the Earth-centered versus sun-centered parts of these two theories. So a legitimate question is, from a realist perspective, which model of the universe – Ptolemy's Earth-centered approach, or Copernicus' sun-centered approach – is the more plausible model of the universe?

With respect to this question, the data available at the time strongly supports the Ptolemaic system. Recall the arguments from Chapter 10, supporting the conclusion that the Earth was stationary and at the center of the universe. These are all strong arguments (though they eventually turned out to be mistaken, albeit for subtle reasons), and so with respect to the question of which system was better matched to the best science of the day, the answer is clear: the Ptolemaic system is far better than the Copernican.

In summary, the Ptolemaic and Copernican systems are comparable in terms of prediction, explanation, and complexity. In eliminating equant points, the Copernican system more straightforwardly respects the uniform motion fact, and it more straightforwardly accounts for retrograde motion, for the correlation between the differences in brightness of the planets and their times of retrograde motion, and for the fact that Venus and Mercury always appear near the sun. These seem to be relatively small advantages, however, compared to the evidence available at the time that pointed to a stationary Earth, which was more consistent with the Ptolemaic system.

What Motivated Copernicus?

As noted in the discussion above, the Copernican system was much like the Ptolemaic system. For example, both systems make extensive use of epicycles, deferents, and eccentrics. In most respects (except for the elimination of equant points and the explanation of retrograde motion) the Copernican system was no better than the Ptolemaic system, and in some important respects (for example, the issue of whether it is more reasonable to believe the Earth is stationary or in motion), the Copernican system is much worse off than the Ptolemaic system.

So if the Copernican system had only a handful of minor advantages, and had the substantial disadvantage of being incompatible with the current best physics, then what in the world would have motivated Copernicus to develop his system? Life is short, yet Copernicus devoted much of his life to working out his system. If there were good reasons to think that the Earth could not be in motion, then why would Copernicus spend so much of his life developing a system in which the sun was the center of the universe, with the Earth in motion around it?

This question is a good one to ponder, and one worth re-emphasizing: Copernicus spent an enormous amount of time, over the course of decades, working out his system. Yet his system is clearly at odds with all the evidence pointing toward a stationary Earth. Nor was there any new empirical evidence available to Copernicus that would have supported his view of a moving Earth. So what in the world would have motivated Copernicus to devote his life to develop a theory that seems like it could not possibly be correct?

I do not intend, in this section, to attempt a full answer to this question. I do wish, though, to suggest how philosophical and conceptual issues might motivate the work of a scientist. For some time now various scholars have argued that Copernicus' leanings toward Neoplatonism, and his commitment to the philosophical/conceptual beliefs about perfectly circular, uniform motion, were key motivating factors in the development of his sun-centered system. What follows is an outline of these views.

Neoplatonism

In a nutshell, Neoplatonism is sort of a "Christianized" version of Plato's philosophy. Plato lived about 400 BC, and, roughly speaking, he believed there is a wide variety of objectively existing, nonphysical, eternal "forms." These forms are the objects of knowledge, that is, when we acquire a piece of knowledge, as opposed to having a mere belief or opinion, our knowledge is knowledge of one or more of these objectively existing, nonphysical, eternal forms. For example, when we come to know the Pythagorean theorem, or other truths of mathematics, we have acquired knowledge not of objects here on earth (for example, a drawing of a right triangle), but rather we have acquired knowledge of an objectively existing, nonphysical, eternal form.

According to Plato, the forms involve not only truths of mathematics, but "higher" forms as well, such as forms of truth and beauty (such forms are "higher" not just in the sense that they are more difficult to grasp, but more important as well). The highest form of all is the form of the Good. Plato says little directly about the form of the Good. But he does make clear that this form is the highest, most important form.

Instead of trying to describe directly the form of the Good, Plato speaks metaphorically about this form. In particular, Plato always uses the sun as his metaphor for the Good. For example, Plato says that, just as the sun is the source of all life, so too the form of the Good is the source of all truth and knowledge. Likewise, in his allegory of the cave, Plato describes a prisoner who has escaped the cave and is finally able to gaze upon the sun. In this allegory, the prisoner represents the lover of wisdom who has completed his or her intellectual journey, escaping ignorance (represented by the cave), and eventually coming to understand the highest truth of all, the form of the Good (represented by the sun). In short, in the allegory of the cave, as always, the sun is Plato's metaphor for the Good.

Several hundred years after the death of Plato, the movement called Neoplatonism incorporated Plato's philosophy into Christianity. I will ignore most of the details of Neoplatonism, and just emphasize that, for a Neoplatonist, Plato's form of the Good becomes identified with the Christian God. And the sun – Plato's metaphor for the Good – now comes to represent God.

As a philosophy, Neoplatonism has come and gone at various times in western history. During the time of Copernicus, it was a not uncommon philosophy; however, the evidence linking Copernicus to Neoplatonism is not as clear as one would like. It is very likely that Copernicus would have been exposed to Neoplatonic ideas during his student years, and some of what Copernicus writes sounds as if it is coming from someone with Neoplatonic leanings. Some scholars have been fairly convinced that Copernicus was heavily influenced by Neoplatonism; others are less convinced. The usual account linking Neoplatonism to the development of Copernicus' sun-centered view is straightforward: if Copernicus was a Neoplatonist, and viewed the sun as the physical representation of God in the universe, then the appropriate place for the representation of God would be the center of the universe. On this account, a main reason why Copernicus pursued a sun-centered view of the universe stemmed from philosophical beliefs that were substantially influenced by Neoplatonism.

Copernicus' commitment to uniform, circular movement

I have discussed, at numerous points, how deeply committed most astronomers were to the belief that the motion of the stars and planets had to be perfectly circular, and uniform in the sense of never speeding up or slowing down. In hindsight, this commitment was primarily a philosophical/conceptual commitment. Although there is a small amount of empirical evidence supporting the belief (for example, the stars do appear to move in a circular fashion), the degree of commitment to this belief far outstripped the empirical evidence for it.

As described in the previous chapter, Ptolemy was able to respect the uniform motion fact only by using the rather strained device of the equant point. By way of quick review, the epicycle of a planet such as Mars moves with uniform speed relative to an imaginary point, called the equant point. A line drawn from the equant point to the center of Mars' epicycle will sweep out equal angles in equal time, and in this sense, Mars' epicycle moves with uniform speed relative to the equant point. But Mars' epicycle most decidedly does not move with uniform speed relative to the Earth, or relative to the center of the circle around which that epicycle moves.

Given the fact that the Ptolemaic system was able to account quite well for the empirical data, and as such was a very useful and valuable model, almost all astronomers were willing to accept the fudge factor of the equant point. Copernicus, however, was not. He was simply too committed to the uniform motion view to accept a device such as the equant, and this commitment also helped motivate him to develop a system that did not require equant points.

This is a good illustration of the way in which it was not empirical data, but rather, philosophical/conceptual "data" that helped motivate Copernicus to develop his theory. As it turns out, this is not a particularly unusual event. In the history of science, it is often (though not always) philosophical/conceptual commitments that in part motivate scientists to develop new theories. So in this respect, Copernicus was not an unusual scientist at all.

As a final point in this section, it is worth noting that we all have such philosophical/conceptual beliefs, many of which are so embedded in our way of thinking that they appear to be straightforward empirical facts. When we look back in history, it is relatively easy to identify beliefs, such as the perfect circle and uniform motion facts, that were primarily philosophical/conceptual in nature. It is also relatively easy to see how such facts motivated scientists such as Copernicus. In contrast, it is very difficult to put our fingers on the philosophical/conceptual commitments of ours that are masquerading as empirical beliefs. Later in this book, when we turn to some examples from more recent science, we will attempt to flesh out some of our own philosophical/conceptual commitments.

The Reception of the Copernican Theory

Recall that all the evidence of the time pointed to a stationary Earth, and so it seemed that Copernicus' theory could not possibly be correct. Given this, one might think that his theory would have been immediately dismissed, and would certainly not have been widely read or discussed.

But in fact, in the years following Copernicus' death (the same year his system was published), and continuing through the remainder of the 1500s, his theory was widely read, discussed, taught, and put to practical use. Part of the reason for this was that Copernicus' system was the first thorough, sophisticated astronomical system published in the 1,400 years since Ptolemy. People of his time were justifiably impressed, and Copernicus was widely referred to as a "second Ptolemy."

Another reason involved the production of astronomical tables. Such tables were the primary way that an astronomical system, such as Ptolemy's, was put to practical use. An analogy might help clarify this. Suppose I need to find out about some astronomical event – for example, suppose I am planning a late-afternoon outdoor social, and I need to know what time the sun will set. It would be *possible* for me to compute the time of sunset from our current best astronomical theories, but it would be extremely burdensome to do so. What I would do instead is take the much simpler route – I would probably go to the Internet and search for information on what time the sun sets.

The data on sunset times I would find on the Internet (or in other sources, such as a current almanac) is derived from our current astronomical theories, but the people who put together this data have done all the hard work. Astronomical tables were somewhat similar. They were derived from the current best theory – for most of our history, this would have been the Ptolemaic theory – and then those who needed astronomical data would use the tables as a source.

In the 1500s, a new set of astronomical tables was badly needed (the previous set had been produced in the 1200s, and were out of date). As it turns out, the astronomer who produced these new tables based them on Copernicus' theory. Again, since the Copernican and Ptolemaic systems were essentially equivalent with respect to prediction and explanation, this astronomer could have used either system and arrived at about equally good tables. But he used the Copernican system, and this both publicized it and gave it added prestige.

So in the second half of the 1500s, the Copernican system was widely known, widely read, and widely taught in European universities. Importantly, though, it was taken with an instrumentalist attitude by almost everyone. That is, with few exceptions (there were some Neoplatonists who took it realistically, as well as a few others) the Copernican system was used as a practical device, but not one that people thought reflected the way the universe really was. In short, in the late 1500s the Ptolemaic and Copernican system coexisted peacefully. (At least, this was true among astronomers – there were some attacks by religious leaders who vigorously opposed the Copernican system, but for religious, not empirical, reasons.) Generally speaking, among astronomers the Ptolemaic system was taken with a realist attitude (or at least, the Earth-centered part of the theory was taken realistically), and the Copernican system was taken with an instrumentalist attitude. That is, the Copernican system was taken as a system that was useful, though not one that reflected the way the universe really was.

Concluding Remarks

In this chapter, we have looked at an overview of the Copernican system, compared this system with the Ptolemaic system, discussed Copernicus' motivation for developing his system, and noted that the Copernican system was well received, albeit with an instrumentalist attitude, by astronomers in the late 1500s. This presentation was rather brief, covering a lot of ground in a fairly short space, but it should convey at least a good flavor of the Copernican system and some of the key issues surrounding it.

This relatively peaceful situation would change dramatically in the early 1600s. At this time the telescope was invented, and this produced, for the first time since before recorded history, new astronomical data. In the next two chapters we will look briefly at two more key astronomical systems, and then turn to the new data generated by the telescope.