Chapter Seventeen

Galileo and the Evidence from the Telescope

Another central player in the transition from an Earth-centered view to a sun-centered view was Galileo (1564–1642). Galileo contributed in important ways to astronomy, physics, and mathematics, but it is his work affecting astronomy that most concerns us here. The main goals of this chapter will be to understand the new data available from the telescope, to see how that data impacts the debate between advocates of the various astronomical systems, and to explore the reception of Galileo's discoveries.

As we will see, Galileo's work with the telescope provided, for the first time, new empirical data relevant to the Earth-centered versus sun-centered debate. However, we will also see that the new evidence did not, by itself, settle the issue. Galileo thought the new evidence supported the sun-centered view, but others, equally familiar with the evidence, did not. As usual, we will begin with some background material.

Background Information

Galileo and the Catholic church

The telescope was invented just before 1600, and Galileo began using it for astronomical observations in 1609. Galileo was one of the first to use the telescope for astronomical observations, and in doing so he discovered interesting new data that very much influenced the debate between advocates of the Earth-centered and sun-centered systems. He published his first set of findings in 1610, and published additional findings over the next several years.

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The new data would eventually involve Galileo in a well-known dispute with the Catholic church. Given this, a few words on the religious situation during Galileo's time are in order.

Although we have not discussed this at any length, it will come as no surprise that the church preferred the Earth-centered view. One of the reasons for this (but not the only reason) concerns various passages in the Christian scriptures that suggest the Earth is stationary and that the sun moves around the Earth. Thus, the dispute between Galileo and the church would necessarily involve scriptural interpretation.

Also worth noting is that the Catholic church, by and large, had a history of being tolerant of new scientific views. For example, for the most part the church was not opposed to the Copernican system. Of course, up until the new evidence from the telescope, the Copernican system was generally taken with an instrumentalist attitude, and as such was not contrary to scripture. But the point is that the church did not generally oppose new scientific views, and was generally willing to reinterpret scripture when required by new discoveries.

This was, however, a rather touchy time for the Catholic church. The Protestant Reformation had begun the previous century, and the church was actively engaged in trying to suppress the spread of what it considered heretical views. So Galileo's work with the telescope came at a time in which the church was not as tolerant as it might have otherwise been.

It is worth mentioning that Galileo himself was a devout Catholic. He certainly had no desire to undermine the church, nor would he take lightly the eventual concerns that some of his views might be heretical. As we will see below, Galileo had genuine differences of opinion involving the interpretation of scripture, and these differences would play a role in his dealings with the church.

A note on the nature of the evidence from the telescope

With respect to the debate between advocates of the Earth-centered and sun-centered systems, it is important to keep in mind that there is no data available from naked-eye observations that can settle the debate. In fact, as emphasized all along, naked-eye observations support an Earth-centered view.

Notably, even with the telescope there is no way to tell directly whether an Earth-centered or sun-centered view is correct. I want to take a moment to discuss this, because I think it is a point that is often misunderstood, and because appreciating this point will help one get a better sense of the nature of the evidence provided by the telescope.

Suppose we leave Galileo for a moment, and jump ahead 400 years to the present time. Even today, with all the technological advances of the past 400 years, we have no technology that directly shows whether the Earth moves around the sun, or whether the sun moves around the Earth. Our most direct evidence that the Earth moves about the sun is the stellar parallax that was finally documented

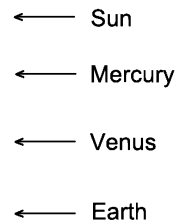

Figure 17.1 "Photo" of sun and planets

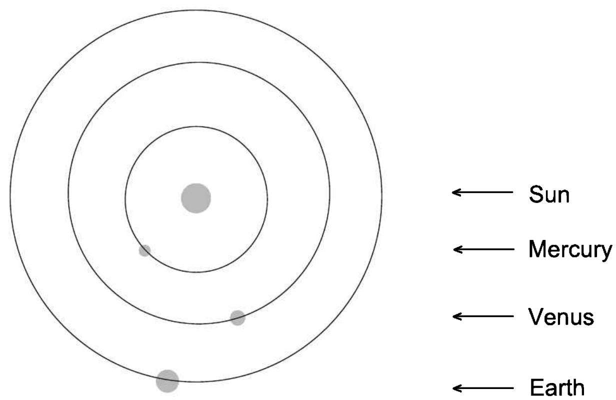

Figure 17.2 Sun-centered interpretation of "photo"

for the first time in the 1800s. But the evidence from stellar parallax is not direct observational evidence, in the sense we discussed in Chapter 3.

Not even photographs from space directly settle the issue of whether the Earth moves around the sun. To see this, suppose we had a photograph, such as Figure 17.1 showing the sun, Mercury, Venus, and the Earth. Incidentally, we have no such photograph. Such a photograph would have to be taken from a vantage point above or below the axis of the Earth, but as a matter of fact, we do not send spacecraft in that direction. The interesting features of our solar system – the planets, asteroids, and so on – tend to lie more or less on a plane that cuts roughly through the equator of the Earth. So our spacecraft are generally sent out along that plane, and not in the direction of the axis of the Earth. But the point is that, even if we did have such a photograph, it would not show whether the Earth or sun is the center of our solar system.

To see this, notice that the "photograph" in Figure 17.1 is equally compatible with either an Earth-centered or a sun-centered system. That is, the photograph is compatible with the sun-centered view illustrated in Figure 17.2. But the photograph is equally compatible with the Earth-centered view illustrated by Figure 17.3.

In short, even if we could take such photographs of our solar system, they would not show whether the Earth or sun was the center. Even if we took, say, long-running videotapes, so as to plot the position of the sun and planets over the course of time, such videotapes would show only the relative motions of the

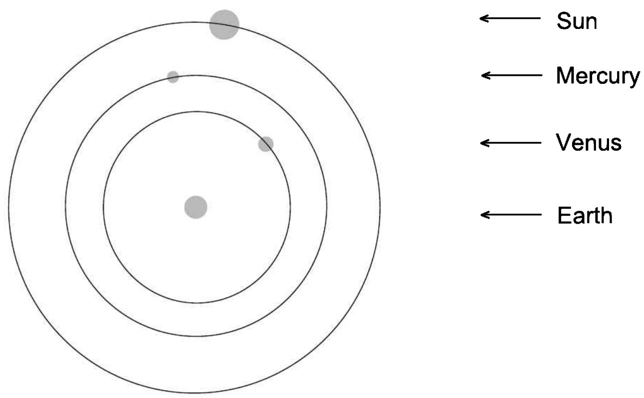

Figure 17.3 Earth-centered interpretation of "photo"

sun and planets. That is, such videotapes would show only the way in which the sun and planets move relative to one another. But the relative motions of the sun and planets on an Earth-centered Tychonic system are the same as the relative motions of the sun and planets on a sun-centered system. In other words, even if we had such videotapes, they would turn out to be compatible with an Earth-centered Tychonic system. (I should note that such a videotape would not be compatible with the original Tychonic system, with its epicycles, perfect circles, and uniform motion, but rather with a modified and "modernized" Tychonic system. Such a modified Tychonic system is similar to what is shown in Figure 15.1, but incorporates elliptical orbits with planets moving at varying speeds. It is this modified Tychonic system that is preferred by the modern-day advocates of an Earth-centered system mentioned at the end of Chapter 15.)

I am going on at some length on this issue, but it illustrates a general, and important, point: the evidence we gain from our technology is rarely as direct as it is often assumed to be. This is an important point to keep in mind as we consider Galileo's evidence from the telescope.

So Galileo's evidence from the telescope, although fascinating and important, does not directly settle the debate between advocates of the sun-centered and Earth-centered systems. But the evidence does provide a range of indirect evidence that certainly impacts the debate. Let's now move on to consider Galileo's evidence.

Galileo's Evidence from the Telescope

Galileo reported a variety of new observations gathered from his use of the telescope. Some of this data raised only relatively minor issues for Earth-centered views, whereas other data raised more substantial issues. In each case, we will discuss not only what Galileo reported seeing, but also how the new data influences the issue of a sun-centered versus an Earth-centered view.

Mountains on the moon

Galileo was one of the first to use the telescope to observe some of the features of the moon's surface, including mountains, plains, and what we now know to be craters. To some extent these can be seen with the naked eye, and others before Galileo had even speculated that there were mountains on the moon, but only with the telescope can one make out these features in any detail.

The fact that the moon has features such as mountains does not in any way directly show that the Earth moves around the sun. Rather, this fact figures into the debate because it undermines the general Aristotelian picture of the universe. Recall that on the Aristotelian worldview, the objects in the heavens were composed only of ether, and this fact figured into the general Aristotelian explanation of the movements of the heavenly bodies. So the fact that the moon appears to be a large rocky body, similar in appearance in many ways to the Earth, shows pretty clearly that this Aristotelian belief cannot be correct.

It is worth noting that this evidence, by itself, would never have been sufficient to seriously undermine the Aristotelian worldview. While it is true that the Aristotelian worldview included the belief that heavenly bodies were composed of ether, that particular belief – that part of the jigsaw puzzle – could have been modified without seriously changing the overall set of beliefs. For example, the moon is on the border of the sublunar and superlunar regions, so it would not be unreasonable to envision the moon containing both sublunar and superlunar elements. To put it another way, the Aristotelian beliefs about the moon are not core beliefs. But without question, the existence of features such as mountains on the moon shows that the Aristotelian worldview could not remain unchanged in the face of the new evidence from the telescope.

So the existence of mountains on the moon largely factored into the debate by showing there were some cracks in the Aristotelian worldview. But there was another way this data helped make the sun-centered view more plausible. Recall the argument for a stationary Earth (discussed in Chapter 10) that was based on the idea that nothing could keep the Earth in motion. Again, the Earth is a large, rocky body, and, much like the large boulder in my front yard, it will remain stationary unless something continually moves it. The argument seems compelling enough. But with the telescope we can now see that the moon appears to be a large rocky body, and it clearly is in continual motion. So if the large rocky moon can be in continual motion about the Earth, perhaps the large rocky Earth could be in continual motion about the sun.

Sunspots

Galileo was also one of the first to use the telescope to observe sunspots, that is, dark regions that can be seen when looking at the sun. One cannot observe the sun directly through a telescope, as this would make short work of one's retina, but the telescopic image of the sun can be observed by projecting it on a piece of paper.

Galileo used this method to observe sunspots. Using his observations, Galileo was able to argue convincingly that such spots must be regions on the sun itself, rather than, for example, being the images of small planets moving in front of the sun.

As with the mountains on the moon, this data also does not provide direct evidence for a sun-centered view. But the sun is clearly in the superlunar region (not merely bordering the region, as with the moon). So if sunspots are on the sun, as Galileo convincingly argued, then the superlunar region must not be the region of unchanging perfection it was believed to be on the Aristotelian worldview. So as with the mountains on the moon, this data proves to be another crack in the Aristotelian worldview.

The rings, or "ears," of Saturn

Galileo's evidence concerning Saturn had a similar consequence to that of the evidence concerning the moon and sun. Galileo was the first to observe that, at times, Saturn has bulges on the side, appearing to be something like handles or ears. We now know that Galileo was observing the rings of Saturn, although the resolving power of his telescope was not sufficient to see the rings as anything but bulges on the sides of Saturn. (It would be about another half-century before the bulges were correctly hypothesized to be a ring structure around Saturn.)

Once again, this data provides another small crack in the Aristotelian worldview. Recall that the heavenly bodies were composed of ether, which naturally has a perfectly spherical shape. The planets, then, since they are composed of ether, must be perfectly spherical. Galileo's observations showed that Saturn, along with the moon and sun, did not fit the expectations of the Aristotelian worldview.

The moons of Jupiter

Of all the phenomena capable of being viewed with Galileo's telescope, the moons of Jupiter were probably the most enjoyable to observe. Through a telescope, Galileo was able to observe four small points of light, which vary their position around Jupiter over time, and which Galileo correctly reasoned were moons orbiting Jupiter. Even today, the moons of Jupiter are perhaps the most pleasant sight available through a small telescope (as enjoyable to observe as the rings of Saturn).

In a wise career move, Galileo named the moons of Jupiter the "Medicean Stars," in honor of the Medici family (one of the most powerful families of Italy). Galileo hoped to become a member of the Medicean court, and he would soon be successful, shortly afterwards being named the chief mathematician and philosopher ("philosopher" more in the sense of what we would call a scientist) of the Medicean court.

Galileo spent a great deal of time carefully observing and plotting the position of the moons, and was able to establish that they were indeed bodies moving about Jupiter. This too was evidence that did not fit easily into the Aristotelian worldview. Recall that, on the Aristotelian worldview, and in particular on the Ptolemaic system, the Earth is the single center of all rotation in the universe. All heavenly bodies – the moon, sun, stars, and planets – move in circles about the center of the universe, that being the center of the Earth. But Galileo's discovery of bodies orbiting Jupiter shows conclusively that, contrary to the Aristotelian belief, there is not only one single center of rotation in the universe.

As a corollary, it is worth mentioning that supporters of the Earth-centered view had argued against the sun-centered view on the grounds that the movement of the Earth's moon was rather awkward. That is, it is somewhat inelegant to have a body moving around the Earth, and then have the Earth moving around the sun. But Galileo's discovery of the moons of Jupiter puts this argument to rest, since even the advocates of the Earth-centered view would have to accept that at least one body – Jupiter – has bodies moving about it while it itself moves.

The phases of Venus

The phases of Venus provide some of the most dramatic evidence relevant to the debate. With the naked eye, one cannot observe the fact that Venus, like our moon, goes through a full range of phases. But with a telescope, the phases of Venus are easily observable, and Galileo was the first to discover them. Moreover, not only does Venus go through a full range of phases, but it differs in size depending on what phase it is in. Figure 17.4 illustrates Venus as it appears in its full, three-quarter, half, quarter, and crescent phases. To understand the importance of this data, we need to understand why Venus appears in different phases at different times. Since the explanation will be essentially the same as the explanation for why the moon goes through phases, let us first discuss the moon, and then turn to Venus.

The phases of the moon are a consequence of the relative positions of the sun, moon, and Earth. At any given time, one half of the moon will be illuminated by the sun, and the other half will be dark. When the moon and Earth are positioned such that we see the full illuminated side, then we have a full moon. When we see only half the illuminated surface, we have a half-moon, and when

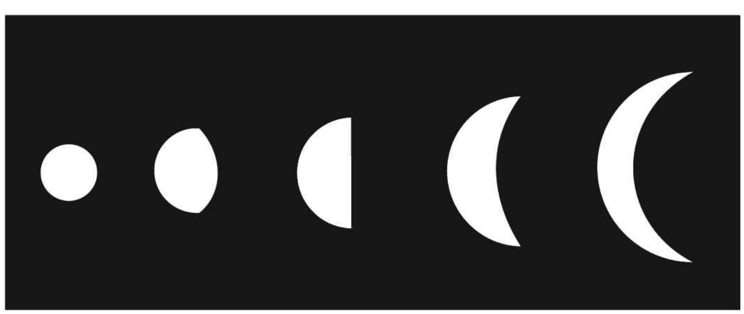

Figure 17.4 Phases of Venus

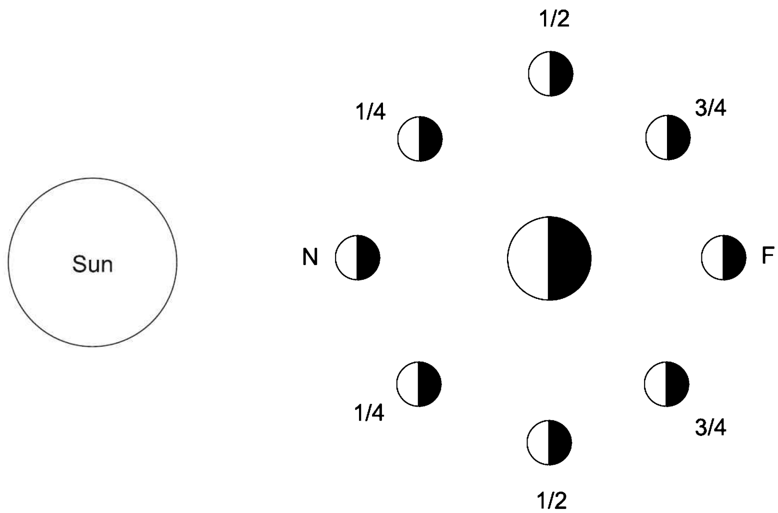

Figure 17.5 Phases of the moon

we see only a small portion of the illuminated half, then we have a crescent moon. Figure 17.5 may help. The various moons labeled ¼, ¾, and so on, represent the various positions, relative to the Earth and sun, that the moon occupies during its approximately 27-day orbit around the Earth. Incidentally, the figure is not at all drawn to scale. For example, from the figure one might get the impression that the moon is often in the Earth's shadow, but that is an artifact of having to condense the figure so it will fit on a page, and of having to put the figure on a two-dimensional sheet of paper. In fact, because the sun is large enough, and the moon and Earth far enough apart, and the orbit of the moon is "tilted," the moon is only occasionally in the shadow of the Earth (and this is why lunar eclipses occur relatively rarely, rather than occurring on every revolution of the moon about the Earth).

When the moon is at the position labeled F, with the illuminated half facing the Earth, we will see a full moon. When the moon is at the point labeled ¾, we see a three-quarter moon, and so on for the half-moon, quarter (or crescent) moon, and for the new moon, where we see no moon in the night sky (the position labeled N).

If Venus goes through a range of phases, as Galileo discovered it does, then like the moon, the phases must be the result of the relative positions of the sun, Earth, and Venus. Importantly, a sun-centered system (either that of Copernicus or of Kepler) leads to a very different prediction concerning the phases of Venus than does the Ptolemaic system. In particular, on a sun-centered view we would expect Venus to go through a full range of phases. In contrast, if the Ptolemaic system is correct, then Venus should at most be seen as a crescent, but never in a half, three-quarter, or full phase.

These differing predictions are best illustrated through diagrams. Let's first consider the Ptolemaic picture of the Earth, sun, and Venus, shown in Figure 17.6.

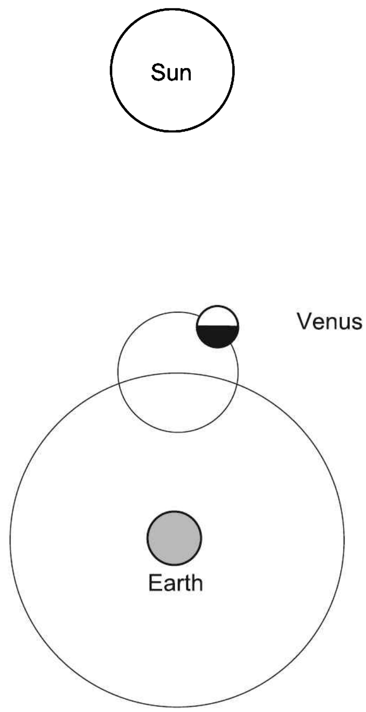

Figure 17.6 Sun, Venus, and Earth on the Ptolemaic system

Here is where a key empirical fact, discussed at the end of Chapter 11, comes into play. Recall that, as a matter of fact, Venus never appears far from the sun. That is, wherever the sun is in the sky, Venus will never be far from it. Again, that is why Venus can be seen only just after sunset (at certain times of the year), or just before sunrise (at other times of the year). The remainder of the day and night Venus cannot be seen, either because (at night) it is below the horizon along with the sun, or else it is in the daytime sky near the sun, and the light from the sun prevents us from seeing it.

On the Ptolemaic system, there is one and only one way to explain this fact, and that is to have the sun and Venus complete a revolution about the Earth in the same amount of time (or more precisely, the sun and Venus' epicycle complete a revolution in the same amount of time). In other words, the Earth, sun, and Venus' epicycle must always be arranged in a line, as they are shown in Figure 17.6.

But notice this entails that the illuminated half of Venus is always facing away from the Earth. And so, like the moon when its illuminated half is facing away from the Earth, Venus will appear (at most) as a crescent. In other words, on the Ptolemaic system, we could at most see only a small portion of the illuminated half of Venus. We could never see a full Venus, or a three-quarter Venus, or a half-Venus. All these would require configurations that are impossible on the Ptolemaic system.

Galileo's discovery of the phases of Venus, then, provides straightforward disconfirming evidence for the Ptolemaic system. In contrast, as explained below, on

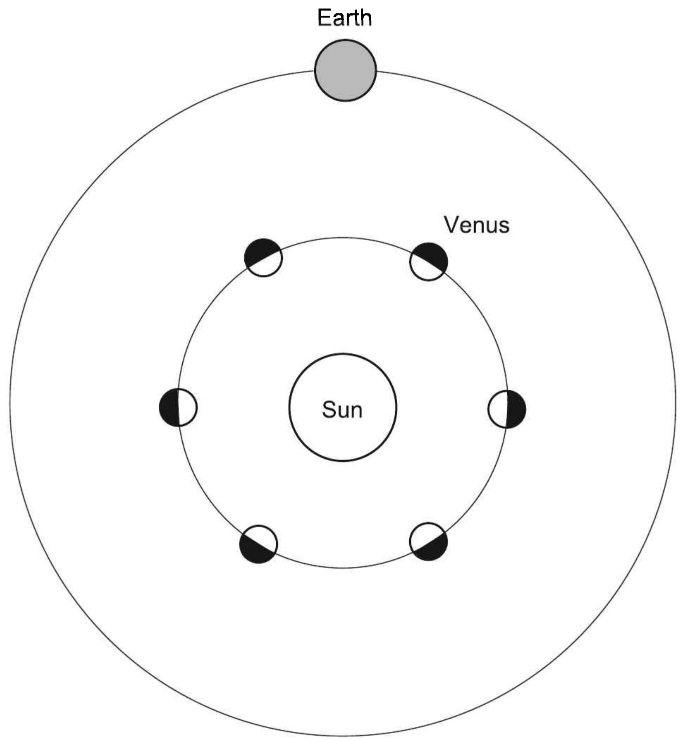

Figure 17.7 Sun, Earth, and Venus on a sun-centered system

a sun-centered view one would expect Venus to go through a full range of phases, and so the phases of Venus provide confirming evidence for the sun-centered view.

Before explaining how a sun-centered view accounts for the phases of Venus, note first that, on a sun-centered view, the empirical fact that Venus always appears in the sky close to the sun is explained by the fact that Venus is an inner planet. That is, Venus is closer to the sun than the Earth is. In Figure 17.7, note that from the Earth, no matter where Venus is in its orbit, it can never appear to be very far away from the sun. Moreover, since on a sun-centered view Venus completes a revolution around the sun in a shorter time than the Earth does (225 days compared to the Earth's 365), Venus will at some times be on the far side of the sun from us, and thus appear as a full Venus, sometimes to the side of the sun and so appear as a half-Venus, sometimes between us and the sun and so appear not at all or as a crescent, and so on. In short, on a sun-centered view we would expect Venus to go through a full range of phases, and so Galileo's discovery provides confirming evidence for the sun-centered view.

Not only does the sun-centered view correctly predict that Venus should go through a full range of phases, but in addition, it quite naturally accounts for the correlation between the phases of Venus and the size Venus appears to be.

Notice in Figure 17.4 that Venus appears smallest when it is in its full phase, and largest when it is in its crescent phase. This is exactly what we would expect from a sun-centered view. Since Venus can be in a full (or nearly full) phase only when it is on the far side of the sun, which will be when Venus is furthest from the Earth, we would expect it to then be at its smallest. Likewise, Venus can be in its crescent phase only when it is between the Earth and sun, at its nearest point to the Earth, and thus it should appear largest during its crescent phase.

In short, the phases of Venus provide important disconfirming evidence against the Ptolemaic view. Importantly, however, the phases of Venus do not suffice to settle the sun-centered versus Earth-centered issue. For example, recall the Tychonic system, described in Chapter 15. Again, the Tychonic system is an Earth-centered system, where the moon and sun revolve about the Earth, but in which the planets revolve about the sun. On the Tychonic system, one would also expect Venus to show a full range of phases, and to be smallest when in its full phase and largest when in its crescent phase. Likewise, one could modify the Ptolemaic system, having Venus (and presumably Mercury as well) move about the sun while keeping all other motion around the Earth. Such a modified Ptolemaic system would likewise be compatible with the phases of Venus. In short, to the extent that the evidence from the phases of Venus provides confirming evidence for a sun-centered system, that evidence also provides confirming evidence for an Earth-centered system such as the Tychonic system, or the modified Ptolemaic system just described. So although the phases of Venus provide evidence against the original Ptolemaic system, they do not settle the issue between a sun-centered approach and an Earth-centered approach.

As a brief point, note how this example nicely illustrates the underdetermination of theories discussed in Chapter 5. That is, even new evidence as dramatic as the discovery of the phases of Venus turns out to be perfectly compatible with both a sun-centered approach (including both Copernicus' and Kepler's theories) as well as an Earth-centered approach such as the Tychonic system, or even a modified sort of Ptolemaic system as described above. This is typical in science – new evidence, even dramatic new evidence, is typically compatible with two or more competing theories. In other words, the available evidence usually does not uniquely determine a particular theory as being correct.

Finally, it is worth noting that, although the phases of Venus do not settle the issue, they nonetheless require that substantial changes be made. That is, the Ptolemaic system had been the default system for the past 1,500 years, and now that system had to be replaced. So whether one switches allegiance to a sun-centered view, or to the Tychonic system, or to a modified Ptolemaic system, one is required to make substantial changes in one's beliefs about the structure of the universe.

The stars

One final discovery is worth discussing, even if only briefly. With the telescope, Galileo discovered there were countless more stars than those visible with the naked eye. This at least suggests the possibility that the universe is much larger than previously suspected, and even perhaps that the universe is infinite, with an infinite number of stars. Galileo himself did not advocate this view, but, in the decades to follow, the idea of a huge, perhaps infinite universe took hold, and Galileo's discovery of the vastly greater number of stars would fit into this new view of the universe.

The Reception of Galileo's Discoveries

Galileo's discoveries with the telescope were understandably viewed as exciting new discoveries, and they made Galileo one of the best-known scientists of the time. He published most of his discoveries with the telescope between 1610 and 1613, and in these publications we can see that Galileo is now thinking that the sun-centered view must be the correct model of the universe. Recall that, by this time, the sun-centered Copernican system had been used and taught for about 70 years, but that during this time the Copernican system was generally taken with an instrumentalist attitude. Galileo, now, is suggesting a realist attitude toward the sun-centered view.

The church (that is, the Catholic church, which had strong influence in the Catholic countries of Europe) had no problems with the sun-centered Copernican system, so long as that system was taken with an instrumentalist attitude. But it began to have substantial problems with the idea that the sun-centered view might really be the way the universe is constructed.

Galileo traveled to Rome in late 1615, to try to prevent the sun-centered view from being condemned by the church. By this time Galileo realized the evidence from the telescope alone would probably not be sufficient to convince those on the other side of the debate, and he developed another argument, based on the tides, to support the sun-centered view. This new argument was presented in a work he distributed in 1615. Incidentally, Galileo's account of the tides turned out to be wrong – he was essentially arguing that the oceans sloshed around due to the Earth's movement, much as water on the deck of a boat will slosh around due to the boat's movement.

In spite of Galileo's efforts, in early 1616 the view that the sun was stationary at the center of the universe was judged to be heretical, and the teaching or written defense of such a view was prohibited. Notably, however, the teaching of the sun-centered view was not prohibited outright. Rather, what was prohibited was teaching the reality of the sun-centered view. The sun-centered view could still be written about and taught as a "hypothesis" – that is, it could be treated with what we would term an instrumentalist attitude. Copernicus' own book on the subject, published back in 1543, could still be taught, but only after corrections were made so as to edit out the passages where Copernicus suggests the reality of the sun-centered view.

Given that Galileo was by this point taking a realist attitude toward the sun-centered view, and openly advocating that realist attitude, the church's judgment against the reality of the sun-centered view could have been much worse for Galileo. Neither Galileo himself, nor any of his writings, were mentioned in the church's formal judgment against the sun-centered view. However, Galileo was summoned to a meeting with Cardinal Bellarmine (Bellarmine was one of the leading church figures involved in the decision to judge as heretical the view that the sun was stationary and at the center of the universe). At that meeting, Galileo was instructed clearly and in writing that he was not to hold or to teach the reality of the sun-centered view. But at bottom, although the judgment in 1616 was bad news for Galileo, it could have been much worse.

What can we say about the church's judgment against the reality of the sun-centered system and, given the relevance of Galileo's evidence from the telescope, what can we say about the church's attitude toward that evidence? Was this a case of refusing even to consider such evidence? Was the church unwilling to accept any evidence against their view, no matter how compelling that evidence was, so that they were treating the Earth-centered view as unfalsifiable?

As is often the case, these questions are more complex than they at first appear. As noted, Bellarmine was one of the leading church figures involved in this decision, so let's focus on his views, and contrast them with Galileo's.

First, there was no issue about accepting Galileo's evidence from the telescope. Bellarmine was a competent astronomer, and he and other church astronomers, including the notable mathematician and astronomer Christopher Clavius, replicated Galileo's observations and certified them as accurate. The church astronomers not only verified Galileo's discoveries, but had high words of praise for them.

The issue was what Galileo's discoveries say about the Earth-centered versus sun-centered issue. As discussed above, Galileo clearly thinks the evidence from the telescope shows the sun-centered system is correct, in spite of what scripture says. Bellarmine, on the other hand, is convinced that what scripture says is correct, and he seems to think that no evidence could possibly run counter to this. So, is Bellarmine treating the Earth-centered view as unfalsifiable?

This is not an easy question. To explore this further, let's look a bit further into Galileo's and Bellarmine's views. As this issue was unfolding, Bellarmine and Galileo had both circulated letters in which they articulated their respective views. Bellarmine's views are best summarized in a relatively short piece of writing from 1615, generally referred to as the *Letter to Foscarini*. Galileo's views are most clearly articulated in portions of a rather longer piece, also circulated in 1615, generally referred to as the *Letter to the Grand Duchess Christina*. (Christina, by the way, was a prominent member of the Medici family, and it was important that he remain in good standing with the family by trying to reassure her and others that his views were not contrary to scripture or Catholic teaching.)

In the *Letter to the Grand Duchess*, Galileo makes it clear that he believes every word of the Bible is correct. But, he says, the Bible was written for everyone, including people who lived in far earlier, less advanced times, and people who have had little or no education. As a result, the Bible was written in such a way that its true meaning is often difficult to determine. So, Galileo argues, if we are dealing with empirical/scientific matters for which we can gather empirical/scientific evidence and proofs, we should never use the Bible to make a final judgment about such matters. First, Galileo says, such matters (for example, whether the sun moves around the earth or vice versa) are not matters relevant to salvation (that is, Galileo thinks that whatever you believe about this matter, your belief will not affect your salvation or lack of salvation). Second, it would be bad for the church to make a final pronouncement on an empirical matter, based on what the Bible says, only to have that pronouncement later be shown by empirical evidence to be definitely wrong. So as a general policy, Galileo is advocating not making any judgments about empirical matters based on scriptural passages.

Bellarmine, in the *Letter to Foscarina*, makes clear his disagreement with Galileo on these points. Bellarmine begins by noting that, with respect to the key question here (whether the sun moves around the earth or vice versa), the relevant biblical passages seem quite clear. Moreover, Bellarmine points out that there is no disagreement about how to interpret the relevant portions of the Bible; for example, Bellarmine notes that all the writers about these biblical passages agree that the Bible says, clearly, that the sun moves about the earth. So contrary to what Galileo suggests, this does not seem to be a situation involving difficult scriptural interpretation.

Bellarmine also clearly rejects Galileo's claim that these are not matters relevant to salvation. Bellarmine grants that, in general, matters involving scientific questions may not be relevant to salvation. But in this case it is relevant to salvation, because the Bible says the sun moves around the earth, and so one cannot reject this belief without rejecting the authority of the Bible, and doing so would be to reject something that God has spoken. So this, on Bellarmine's view, makes the sun-centered versus Earth-centered view relevant to salvation.

Finally, it is worth noting that in the letter, Bellarmine is clear that if it could be demonstrated that the Earth moves around the sun, then we would have to accept that demonstration. But at the same time (presumably for the reasons outlined above), Bellarmine indicates that he thinks such a demonstration would not and could not be forthcoming. Nonetheless, Bellarmine does at least consider the possibility of such a demonstration, and notes that, should such a demonstration be made, church leaders would need to carefully consider how it was they had so badly misunderstood the scriptures on this point.

Note that Galileo and Bellarmine agree on a number of issues. Both accept the data from the telescope, and both accept the authority of scripture. Both agree that scripture suggests the sun moves about the Earth, and both agree that the data from the telescope suggests otherwise.

However, Galileo and Bellarmine differ on how to weigh various pieces of evidence. Galileo's view is that scripture is undeniably correct when it comes to matters involving salvation. But on other matters, those not involving salvation, the scriptures need not be taken as undeniably correct. And since, on Galileo's view, whether the Earth or sun is the center of the universe is not a matter relevant to salvation, this is a situation where the evidence from the telescope can trump the evidence from scripture.

In contrast, Bellarmine's view is that all aspects of scripture are undeniably correct. We can, Bellarmine believes, misunderstand scripture, but in such cases it is our misunderstanding that is at fault, not the scriptures. Since it is unlikely we are misunderstanding the scriptural passages that speak of a stationary Earth and moving sun, in this dispute the scriptural evidence trumps the evidence from the telescope. In short, I think it is fair to say that, if asked, Bellarmine would have agreed that he was willing to give up the Earth-centered view if provided with sufficient evidence. But it is clear that Bellarmine has a different notion than Galileo on which evidence counts the most, and given the evidence Bellarmine favors, he thinks it extremely unlikely, perhaps impossible, that such evidence will ever be forthcoming.

This situation is exactly what we discussed earlier, when we first explored the issue of falsifiability back in Chapter 7. As we saw then, issues involving falsifiability often come down to the issue of what evidence is weighed most heavily. And the issue of what evidence is weighed most heavily is usually a matter of one's overall view. Bellarmine was quite respectful of scientific discoveries, but he was first and foremost a church leader, and for him scriptural evidence trumps scientific evidence. Galileo, on the other hand, was very respectful of religious matters, but he was first and foremost a scientist, and for him evidence gathered from new scientific discoveries trumps religious evidence.

So where does this leave us with respect to the question of whether Bellarmine was treating the Earth-centered view as unfalsifiable? I think that if Bellarmine were advocating these views today, following 400 years of extraordinarily successful and productive science based on respect for empirical evidence, then his attitude would be as unreasonable and unfalsifiable as Steve's views (from Chapter 7) are. But in the context of the early 1600s, there was no good reason to think that the sort of empirically based approach Galileo was advocating would be as successful as it has been. So I think the only fair answer is that there simply is not a clear yes or no response to the question of whether Bellarmine was treating the Earth-centered view as unfalsifiable. As we investigate these sorts of cases, we find they are far more complex than they at first appear. And this complexity is, I think, much of what makes the history and philosophy of science so interesting.

Concluding Remarks

As noted above, Galileo came through the church's 1616 judgment against the reality of the sun-centered view relatively unscathed. Some years later he was less fortunate. In early 1632 Galileo published *Dialogues Concerning the Two Chief World Systems*, which was a substantial book discussing the arguments for and against the Earth- and sun-centered systems. Recall that merely discussing the sun-centered system was not prohibited; only advocating the reality of it was.

This book was not well received by the church, and the view of the church was that it crossed the line between discussion of the sun-centered view, and advocacy of that view. There were a number of issues that complicated this situation. The book is written as a dialogue, and so technically Galileo could claim that it was his characters in the dialogue, rather than he himself, that were advocating various positions. But this really convinced no one. The book is pretty clearly advocating the reality of the sun-centered view. And given the meeting mentioned earlier (including written documentation) in 1615 with Bellarmine, in which he was told he could not teach or hold the reality of the sun-centered view, there is not much question that Galileo did cross the line. However, as another factor to complicate the situation, the book had gone through the church's standard review process, and had been approved for publication. Also relevant is the fact that, over the years, Galileo had managed to offend a number of influential people. In his writing, he could at times be extremely sarcastic and unflattering toward various individuals, and he managed to accumulate a number of enemies, some powerful, who disliked him. Moreover, Galileo seemed at times to be rather politically tone-deaf. Then as now, there are always various political realities that need to be recognized. Today, for example, it would not be politically wise to put forth a grant request to, say, the National Science Foundation, and begin the request by insulting the panel that will judge the request. For Galileo, it would not have been politically wise, say, to publish a book with sections that offended the Pope. Yet his 1632 book did seem to offend the Pope. At the very least, there were those who tried to convince the Pope that he should be offended, and this surely did not help the situation.

The details of Galileo's trial are complex and in some respects controversial, but the eventual outcome was that his book was prohibited by the church, Galileo was judged as suspected of heresy and sentenced to imprisonment, and he was made to formally declare that the sun-centered view was false. He spent the remainder of his life under house arrest, dying in 1642. He did, however, manage to continue working while under house arrest, returning to some of his earlier work on the mechanics of bodies in motion, and producing some important writing on this subject.

Given the issues involving the church, many of Galileo's contemporaries were understandably hesitant to openly advocate the sun-centered view. But eventually the cumulative effect of discoveries – such as Kepler's discovery that a system using elliptical orbits and varying speeds could account for the data much better than any alternative; Kepler's publication in 1627 of astronomical tables far superior to any others, based on his system; and Galileo's evidence from the telescope – would convince most of those who paid attention to such matters that the Earth and planets do indeed revolve about the sun, and do so in elliptical orbits with varying speeds. This would in turn raise a host of problems for the existing world-view. We turn next to these issues.