Chapter 6
Geocentrism and heliocentrism

Aristotle and Ptolemy's theories of how the universe works do a good job of explaining what we see in the heavens -- about that there can be no doubt. These *geocentric* (that is, "Earth-centered") theories worked. However, there were aspects of geocentrism that troubled some thinkers.

For one, the motion of the heavens in Aristotle and Ptolemy's geocentric theories was *incredibly* fast. To understand just how fast the heavens moved, first consider the size of the Earth. The ancient Greeks not only knew that the world is round, they had a good idea of just how big it is. The fact that the stars change when you travel north or south as discussed in Chapter 4 can be used to determine the size of the Earth.

For example, suppose we get on southbound I-65 in Louisville, Kentucky, and drive it as far as it goes, to Mobile, Alabama. That is a drive of 600 miles, almost due south. If we observe the star Sirius in Louisville, and then again in Mobile, we will see that in Mobile, Sirius appears to ride about 8 degrees higher in the sky than in Louisville. This tells us that we have traveled about 8 degrees around the Earth. There are 360 degrees in a full circle, and the Earth is a full circle, so the ratio of 8 to 360 is the same as the ratio of 600 miles to the full distance around the Earth. Do the math[1], and you get that the full distance around the Earth, known as the Earth's *circumference*, is 27,000 miles. We got that value with only the most coarse measurement, but actually 27,000 miles is not a bad estimate of the Earth's circumference. Take a little more care (measure the change in Sirius a little more precisely, measure the mileage a little more precisely, make sure your distance is measured truly due south and not just "almost" due south) and you will find that the Earth's circumference is closer to 25,000 miles.

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1 $\frac{8}{360} = \frac{600}{\text{EARTH CIRCUMFERENCE}}$ so

$$\text{EARTH CIRCUMFERENCE} = \frac{600}{8/360} = \frac{600}{1/45} = 600 \ x \ 45 = 27{,}000$$

Ancient people could travel, and they could do the math. They could figure out the size of the Earth. It is on record that Eratosthenes, a librarian at Alexandria, Egypt, did this sort of calculation of the Earth's circumference (using the sun rather than Sirius) several centuries before Ptolemy. No doubt others did it as well.

If the circumference of the Earth is 25,000 miles, then anything revolving around the Earth has to be tracing out a circle larger than 25,000 miles. Compared to Earth, the circle the moon traces out is big, and that which the sun traces is bigger still. The vast sphere that all the fixed stars lie on must be absolutely immense compared to Earth. And yet in geocentric theories this incomprehensibly vast sphere of stars is rotating around the Earth once every day. No one knew how far away the fixed stars were, but suppose the sphere of the fixed stars was 200 times larger than Earth. Then the stars are tracing out a circle whose circumference is 200 times 25,000 miles -- 5,000,000 miles! This would mean stars are moving at more than 200,000 miles per hour![2] This is very fast even by the standards of the 21st century.[3] By the standards of people living over 2000 years ago it must have been an insane speed.

A second aspect of geocentric theories that was troublesome was the point at which the wandering stars underwent retrograde motion. The middle of retrograde motion -- and the point of maximum brightness in the case of Mars, Jupiter, and Saturn -- always occurred when the wandering star, the Earth, and the sun fell in a line. In Ptolemy's epicycle theory there was no particular reason that retrograde motion should have anything to do with the position of the sun -- no reason why an epicycle could not just as easily hit the point for retrograde motion when the sun was *not* in line with Earth and the wanderer. The alignment was just something that happened, and there was no good reason for it.

A third troublesome aspect to geocentric theories concerned the size of the sun. It is actually possible to determine the size of the sun using nothing more than the human eye and some tools for measuring angles, and Aristarchus of Samos, who was a couple of

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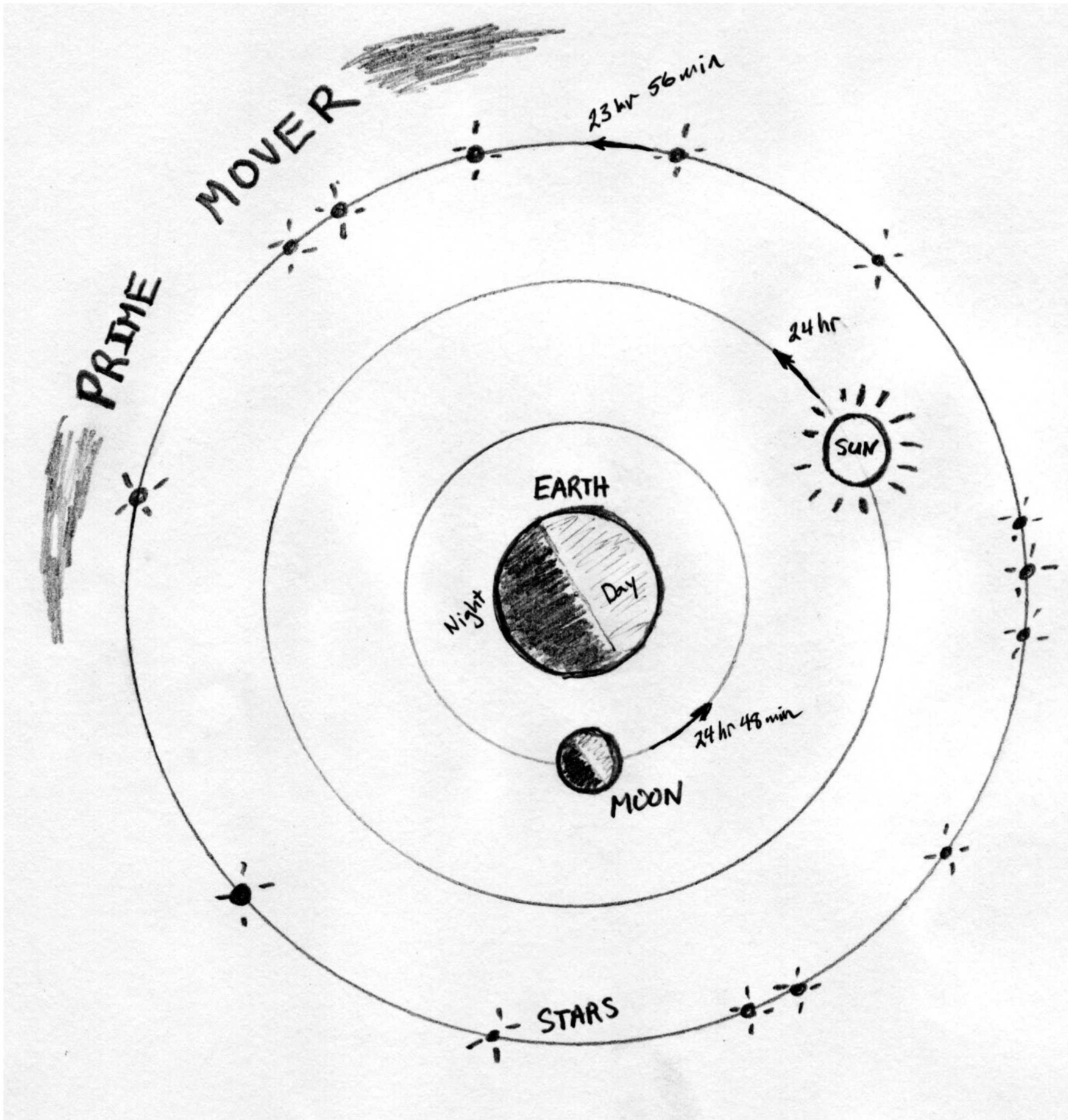
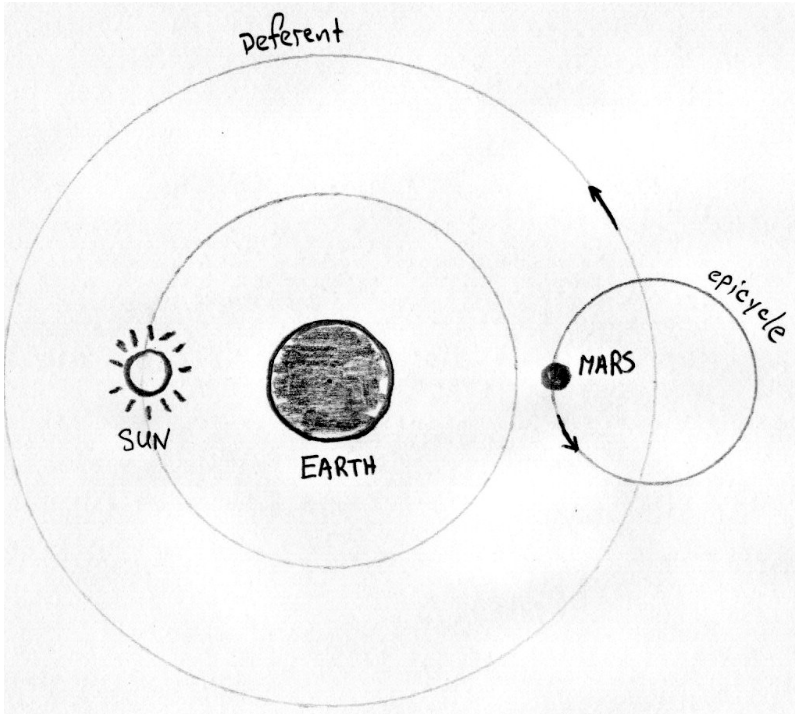
2 Speed = distance/time. The stars go around the Earth once every 23 hours, 56 minutes, or 23+(56/60) hours, or 23.933 hours. Speed = (5,000,000 miles)/(23.933 hours) = 208,914 miles/hour. This answer would apply to the stars above the Earth's equator. Stars above Earth's poles hardly move at all.

3 A passenger jetliner travels at about 550 mph.



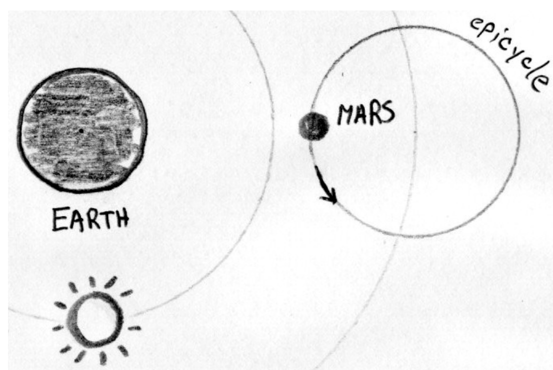
Aristotle's universe (wandering stars not shown – sizes of objects and distances between objects are not to proper scale in this picture). If the Earth measures 25,000 miles in circumference, then the circles that the moon, sun, and stars move in must be substantially larger. The Earth was thought to be much smaller in comparison to the sphere of the fixed stars than is shown in this picture.



A

Retrograde motion of a wandering star (such as Mars) always occurs when the sun, the Earth, and the wanderer fall in a line, as shown in A.

However, there is nothing about the epicycle theory that prevents the sun from being somewhere else, such as is shown in B or C, when retrograde motion occurs. The epicycle theory could provide no good explanation for why only A occurs, and never B or C.



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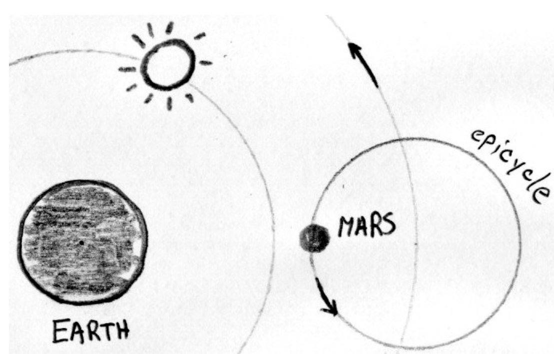
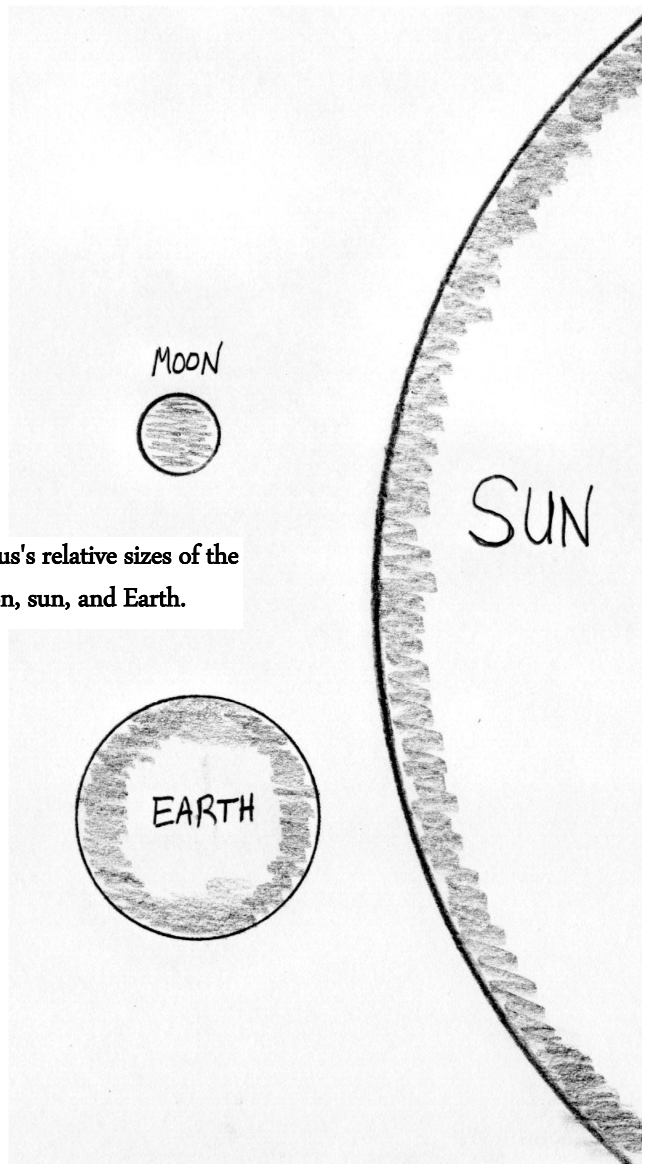


C

generations after Aristotle[4], but still centuries before Ptolemy, did just that. By using some basic observations of the moon and sun, he determined the following:

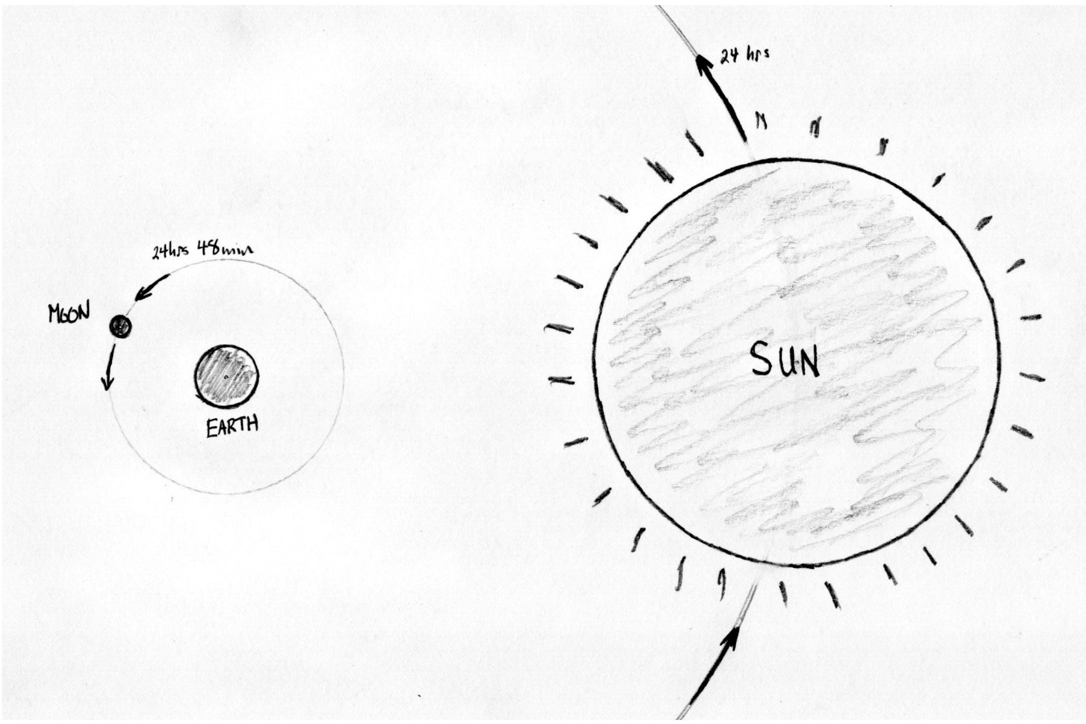
- ✔ the distance between the sun and the Earth is 19 times greater than the distance between the moon and the Earth
- ✔ the sun is 19 times larger than the moon, measured by diameter
- ✔ the Earth is 2.9 times larger than the moon, measured by diameter
- ✔ the sun is 6.7 times larger than the Earth, measured by diameter



Aristarchus's relative sizes of the moon, sun, and Earth.

4 Aristarchus lived from 310 B.C. to 230 B.C.

Have you noticed that the pictures I have been drawing of Aristotle's and Ptolemy's geocentric models of the universe have all been “not to proper scale”? Well, let's show the geocentric model with the Earth, sun, and moon to proper scale, at least in terms of their size as determined by Aristarchus:



Here it is -- the sun and the moon are circling the Earth (the fixed and wandering stars are not shown). Now you see the problem with the size of the sun! It seems a little silly to have the big sun revolving about the much smaller Earth. Note that in this picture only *sizes* are to proper scale (as calculated by Aristarchus[5]). The picture above shows the sun and moon as being the size Aristarchus calculated, but it shows the sun as being much

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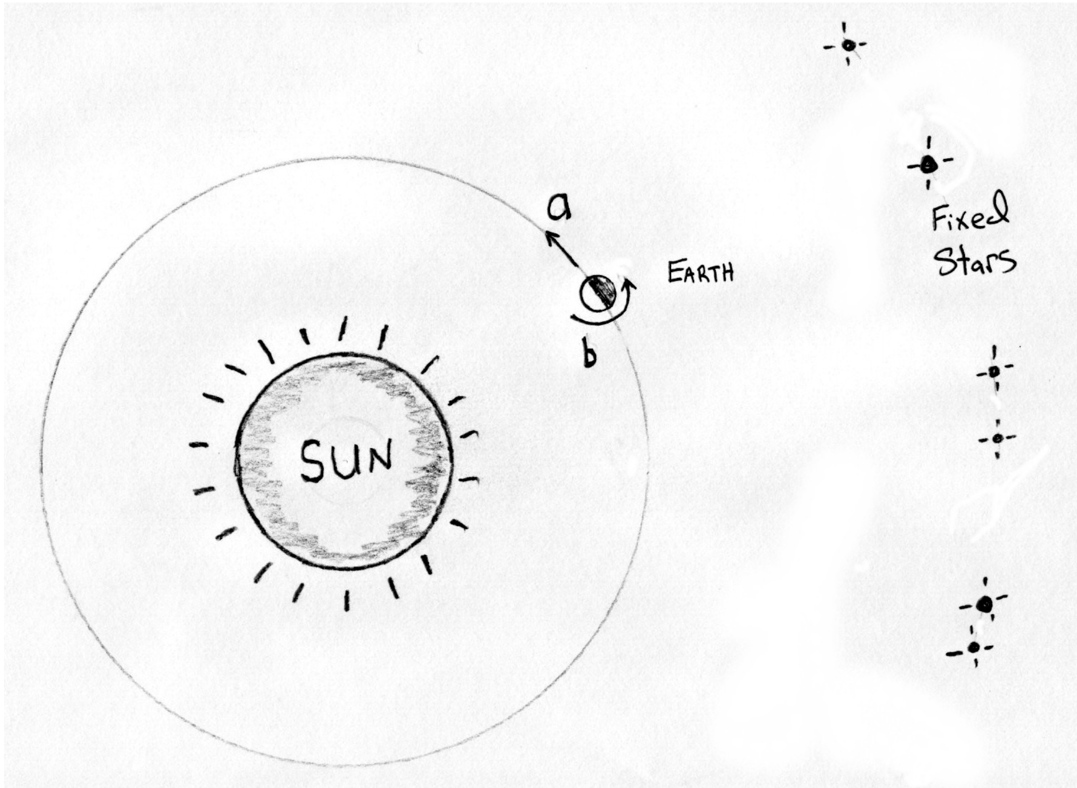
5 We should compare the results of Aristarchus's calculations to modern results. Aristarchus calculated that the Earth is 2.9 times (measured by diameter) larger than the moon -- the modern value is that Earth is 3.7 times larger than the moon. Aristarchus calculated that the sun is 19 times further away and 19 times larger than the moon -- the modern value is 400, not 19. Aristarchus obviously did a much better job with the Earth and moon than with the sun and moon. The source of his error is discussed in Appendix A. Still, he got the picture right in general: first, the sun is vastly larger than the Earth, and the Earth in turn is quite a bit bigger than the moon; second, the sun is much farther from Earth than is the moon.



Aristarchus's heliocentric theory (moon and wandering stars not shown). The sun and fixed stars do not move. The Earth has a double motion – it circles the sun (a) and it also rotates about itself (b). The size of the sun and Earth are to proper scale here, but distances are not – the Earth should be much further from the sun; the stars should lie at a vast distance from the sun.

closer to the Earth than Aristarchus calculated (in Appendix A at the end of this book we see how Aristarchus figured this all out).

Perhaps these troublesome aspects to the geocentric view of the universe led Aristarchus to decide that there had to be a better explanation of how the heavens worked -- to throw out everything and start completely from scratch. Because that is what Aristarchus did. Aristarchus developed a theory for how the universe worked that was completely different from that of Aristotle. In Aristarchus's *heliocentric* ("sun-centered") theory, it was not the Earth that was at the center of everything, but the sun.

Aristarchus's own discussion of his heliocentric theory is lost. What we know about it comes only from what others in his time wrote about it. Therefore what we know is limited. But in Aristarchus's theory, the Earth revolved about the sun, rather than the sun revolving about the Earth. The sun and the fixed stars did not move at all. The rising and setting of the sun occurred because the Earth rotated about itself, like a turning ceiling fan or a child's spinning toy top.

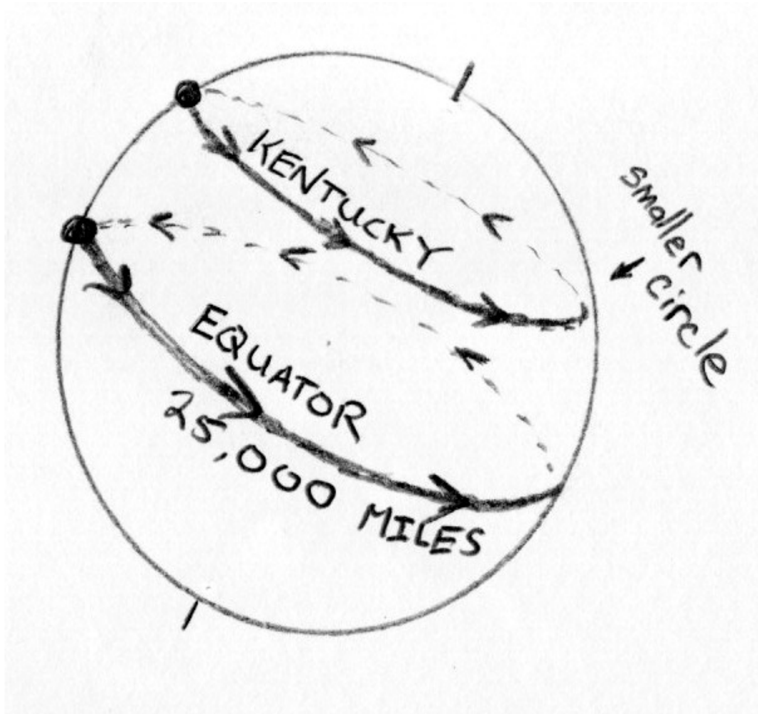
Note how the heliocentric theory immediately takes care of the issue of the heavens moving at high speed -- the sun and fixed stars don't move at all. Also gone is the issue of the large sun revolving about the smaller Earth. However, a heliocentric theory brings problems all its own.

The first of these problems is that heliocentrism transfers the issue of moving at insane speeds from the stars to the Earth. Yes, in a heliocentric theory you no longer have to deal with the issue of the stars moving at 200,000 mph -- but you have to deal with us Earth-dwellers moving at 1,000 mph. Yes, that's right -- if you explain the rising and setting of the sun by saying the Earth is rotating once per day, then you are saying that people at the equator, who must circle the 25,000 miles around the Earth in just 24 hours, are moving at over 1,000 mph at this very instant. And you are saying that people in Kentucky are hurtling along at over 800 mph even as you read this. The movement of the Earth around the sun would involve even greater speeds still. And to top this all off, all this motion is apparently undetectable -- we have no sense of motion at all.

If the alternative is us moving at 800 mph, then the idea that the heavens are moving at 200,000 mph really doesn't sound so bad. After all, we already know that the heavens are like nothing else we ever see (see Chapter 3). Perhaps the Fifth Element that makes up the heavens is extremely light and strong, and it can move at such speeds. To many people, that would sound more reasonable than the idea that we are all moving at 800 mph but can't tell it.

The second problem with heliocentrism also has to do with the motion of the Earth -- what powers it? In the geocentric theory, the Earth does not move, and the heavens are driven by the Prime Mover. In a heliocentric theory, the fixed stars do not move, and so there would be no Prime Mover out beyond the stars, powering the universe. At the same time, in a heliocentric theory Earth is moving and, as we have just seen, moving very dramatically. What could make the Earth move like that?

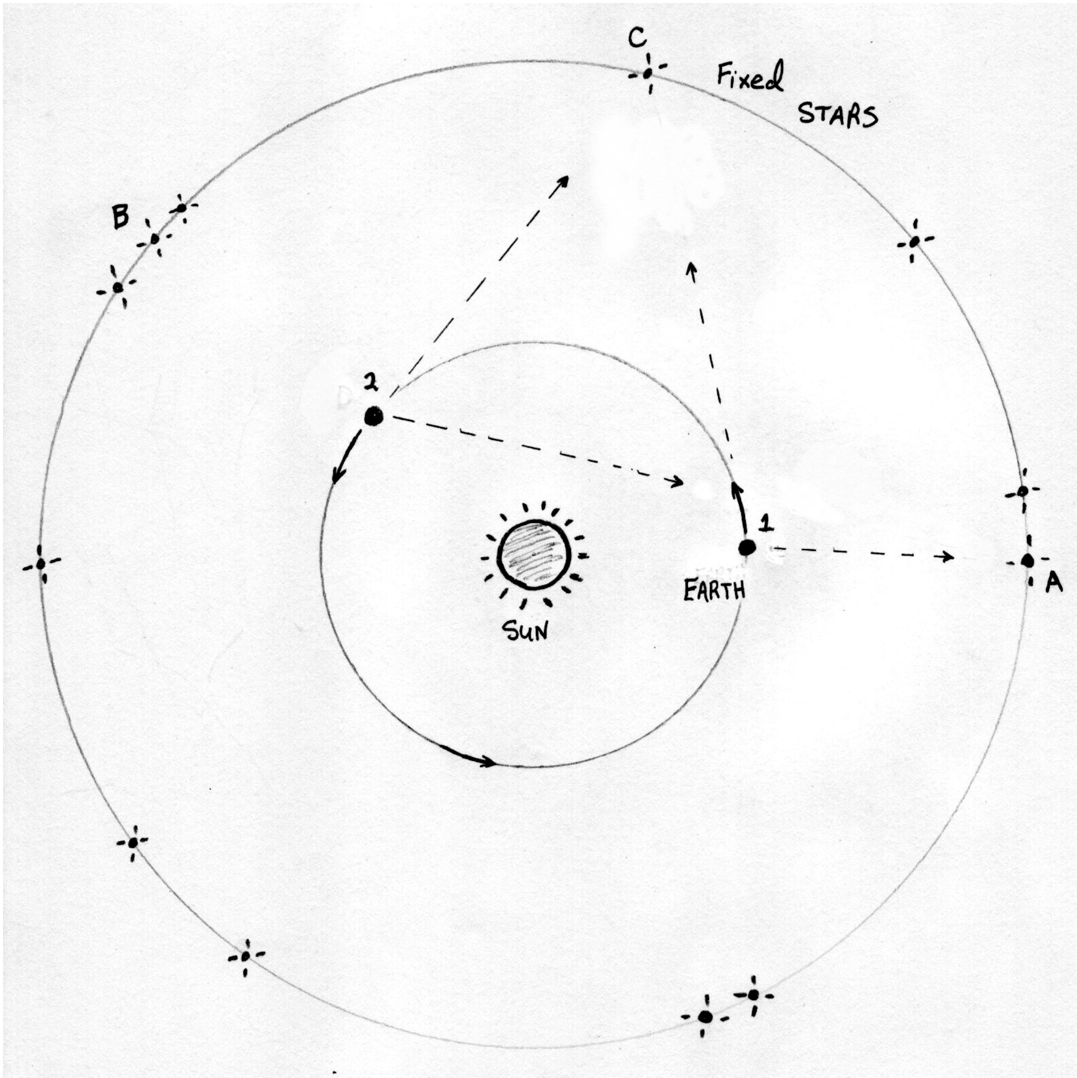
Again, it seems more reasonable to say that the Fifth Element that makes up the heavens is light and strong and can be powered along at extreme speeds by the Prime Mover, rather than to say that some mover is powering the Earth along. We know that the



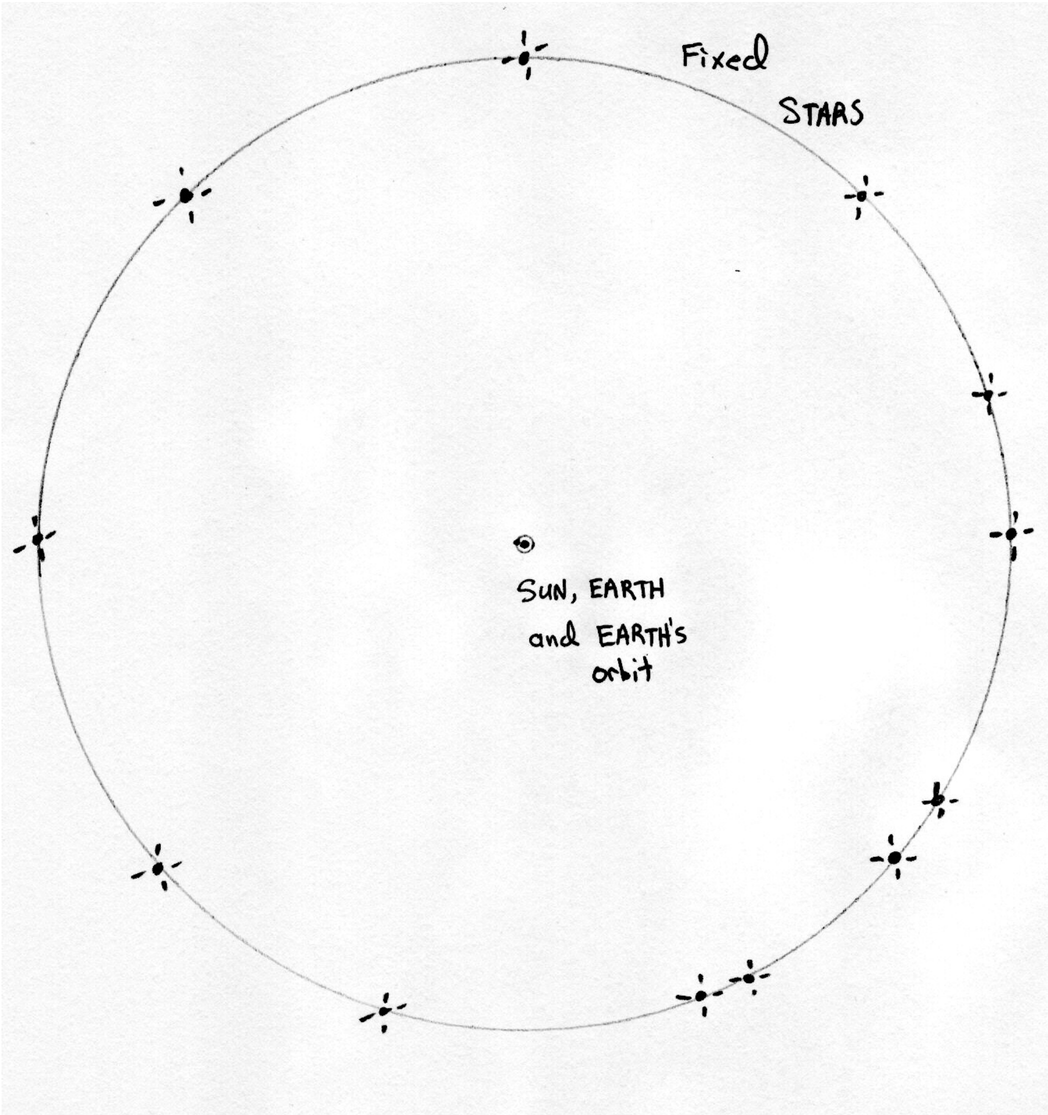
If the Earth rotates once per day, then a person at the Earth's equator will travel in a 25,000 mile circle (all the way around the Earth's circumference) in 24 hours. Speed = distance/time.
Speed = (25,000 miles)/(24 hours) = 1,042 miles/hour. Because Kentucky is a little closer to the North pole, the circle is a little smaller, so the speed is a little less -- about 800 mph. A person standing on the North pole doesn't move at all, but rather just turns in place.

Earth must be *immensely* heavy -- because we know that the rocks and water that make up the Earth are heavy. But if the sun, moon, and stars are made of the Fifth Element, they may actually be very light and easy to move. Perhaps even the sun, despite the fact that it is so much larger than Earth, is actually quite light. Perhaps the sun is like a giant, glowing, Fifth Element "bubble" -- large, yes, but insubstantial, and lacking in weight. Again, to many people that would sound more reasonable than the idea that something is powering the Earth along at dramatic speeds.

The third problem with heliocentrism has to do with the fixed stars. If the Earth is moving, then our distance from, and views of, the fixed stars must change. We would expect that as the Earth circled around the sun the appearance of the fixed stars would



Annual parallax in the heliocentric theory. Earth circles the sun. When Earth is at position 1 it is closest to star A; the angle between stars A and C (dotted lines) is greater than 90 degrees. When Earth is at position 2 it is closest to star B and fairly distant from A. The angle between star A and C, as seen from position 2 (dotted lines), is less than 90 degrees. So as the Earth moves from 1 to 2, star A gets dimmer, star B gets brighter, and the angle between A and C decreases. When Earth continues back to 1, star A returns to being bright, etc. These sorts of changes are *not* seen in the fixed stars – as discussed in Chapter 3, the fixed stars do not change. (Moon and wandering stars not shown.)



Aristarchus theorized that the stars were so far away that the orbit of the Earth was just a tiny point by comparison. If this is true, then the Earth is not moving a significant amount compared to the stars, so there should be no annual parallax. (Moon and wanderers not shown.)

change over the course of a year. Different stars would grow brighter and dimmer as the Earth moved toward and away from them. The relative positions of the stars would change as Earth's position relative to them changed. This effect is called *annual parallax*. Of course the fixed stars don't change -- as we saw in Chapter 3, the stars of the scorpion are not brighter at one time of the year and dimmer at another, nor do their positions change with respect to each other. This lack of annual parallax would indicate that the Earth is, in fact, *not* moving.

Aristarchus actually had an answer for this third problem. The ancient Greek mathematician Archimedes described Aristarchus's answer this way:

> *His [Aristarchus's] hypotheses are that the fixed stars and the sun remain unmoved, that the Earth revolves about the sun in the circumference of a circle, the sun lying in the middle of the orbit, and that the sphere of the fixed stars, situated about the same center as the sun, is so great that the circle in which he supposes the Earth to revolve bears such a proportion to the distance of the fixed stars as the center of the sphere bears to its surface.*[6]

The last three lines of that quote mean that the fixed stars are so distant that by comparison the orbit of the Earth is like a little point at the center of them. If this were true, then there would not be any noticeable annual parallax, because the Earth is not moving any noticeable amount compared to the stars. While, yes, this would explain the lack of annual parallax, to many people a more reasonable explanation for the lack of annual parallax would be simply that the Earth is not moving!

Ultimately Aristarchus's heliocentric ideas did not win out over the geocentric ideas of Aristotle (and later Ptolemy). The serious problems with Aristarchus's heliocentrism were too much. The geocentric Aristotelian theory, followed by the Aristotelian/Ptolemaic geocentric theory (which, as mentioned in Chapter 5, can easily be thought of as “Aristotle 2.0”) came to dominate thinking about the universe for over a thousand years.

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6 Archimedes, *The Sand Reckoner*, 216 B.C. Archimedes didn't write in English (English didn't even exist in 216 B.C.); this English translation is from *The Works of Archimedes* by T. L. Heath (Cambridge University Press, 1897), p. 222. Translations of *The Sand Reckoner* are also available on-line.