Chapter 5
The wandering stars

So far we have left something out of our observations of the heavens. Something else is up there besides the sun, moon, and stars -- five somethings visible to the person who knows where to look. These are the five "wandering stars".

The wandering stars vary considerably in brightness from one to another. The brightest wandering star, Venus[1], is the most brilliant star in the sky -- only the sun and moon are brighter. On the other hand, the wandering stars Mercury and Saturn are both unremarkable in their brightness, and probably would not be noticed by the average person who looks up at the heavens. What the wandering stars have in common is that they "wander".

What do we mean by "wander"? Recall from Chapter 3 that the stars -- which we should now refer to as the "fixed" stars[2] -- do not change. The dipper or the scorpion look the same as they have always looked since time immemorial. For example, on the next page is a sketch of part of the constellation of Leo, the lion. Like the dipper and the scorpion, the lion has looked basically the same since time immemorial.

However, suppose you happened to look up at the lion on the night of May 23, 2007. Had you done so you would have noticed something different -- an extra star in the lion. The extra star was comparable in brightness to Leo's brightest star, Regulus (Regulus is a noticeable star, but insofar as brightness goes, definitely not in the league of a Sirius or

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1 "Hey wait!" you say, "Venus is a planet." Yes, dear Reader, it is. But for now we are going to avoid the use of the word "planet" (a word which comes from the Greek word for "wanderer"). Thanks to both science fiction like *Star Wars,* and to real science like NASA probes, when we think of "planet" we think of a world as seen in the depictions of Luke Skywalker's Tatooine or in the images from the Mars rovers. However, planets were first known only as lights in the sky -- stars that didn't stay in one place. It is almost impossible for us to use the word "planet" without thinking of our modern concept of a planet, so for now we won't use it at all. In this way we can think more like an ancient Greek for a little while.

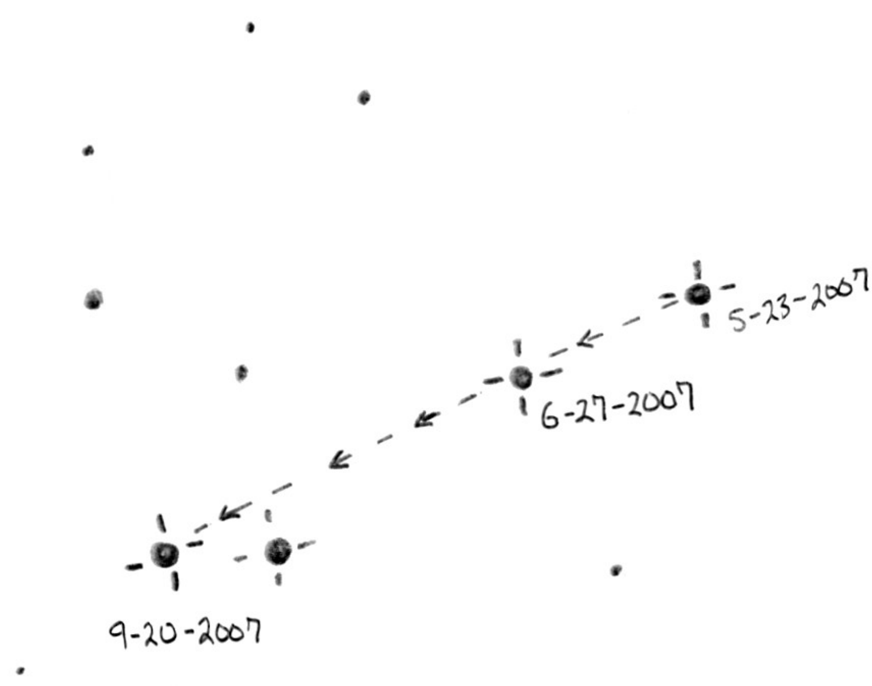
2 Fixed as in "fixed in place", not fixed as in "it was broken but now it is fixed"!

The stars of the head of Leo, the lion. The brightest star shown is called Regulus.

Canopus). Had you continued to look at Leo over the next few nights you would have continued to see the extra star there. But if you looked at Leo a month later, you would notice that, while the extra star was still there, it had now moved. And if you checked back on Leo as best you could into the fall of 2007, you would have seen that the extra star had wandered past Regulus. This wandering star that drifted through Leo in 2007 is called Saturn.

Each wandering star has different characteristics. Saturn is relatively dim -- only as bright as the second-rate fixed stars. Its brightness varies, but not wildly. Of all the wandering stars, it drifts the most slowly through the constellations. It is slow, it is steady, and it doesn't stand out. Saturn is named for the father of the Greek and Roman gods. Jupiter, by contrast, is very bright -- always beating even Sirius in brightness. Jupiter always is a commanding presence any time it is visible in the sky. It wanders more quickly than Saturn, but still not too rapidly. "Jupiter" is the name of the king of the gods. Mars wanders rapidly and erratically. Its brightness varies wildly -- it can be as dim as Saturn at

The stars of the head of Leo, the lion, as seen on May 23, 2007. Note the extra star.



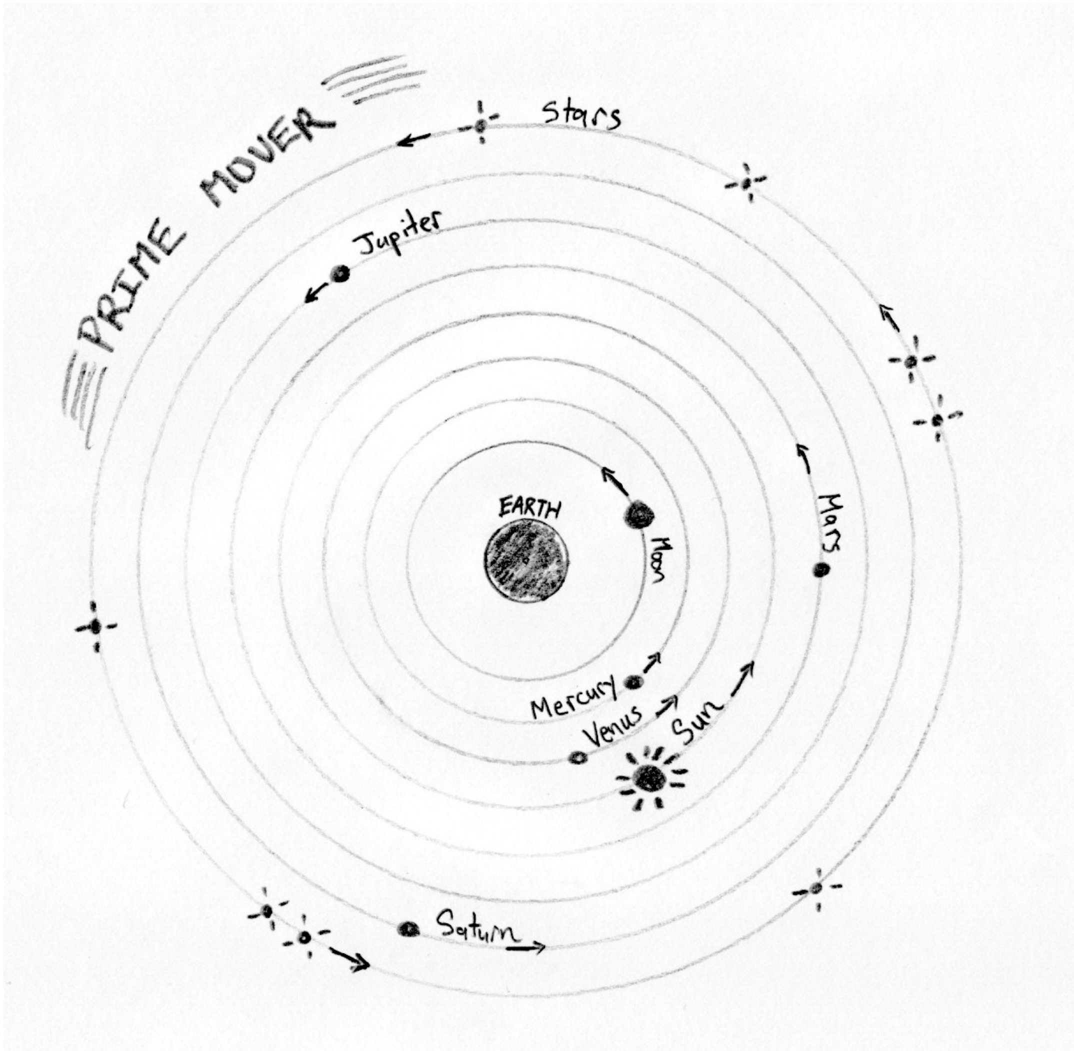
Locations of the extra star on May 23, June 27, and September 20 of 2007,
as the wandering star moves through Leo.

Saturn's dimmest; it can be as bright as Jupiter at Jupiter's brightest. Mars has a distinct reddish hue, whereas the other wandering stars all appear sort of yellow-white. Probably because it is so wild, Mars was tagged with the name of the god of war. Venus wanders but stays close to the sun -- it is only seen in the morning or evening sky, and is often referred to as the "Morning Star" or the "Evening Star". Venus is brilliant and beautiful -- far more brilliant even than Jupiter. Venus is appropriately named for the Greek and Roman goddess of love and beauty. Mercury hangs even closer to the sun than Venus, and so is hard to see. It is a very fast wanderer. Mercury bears the name of the swift messenger of the gods.

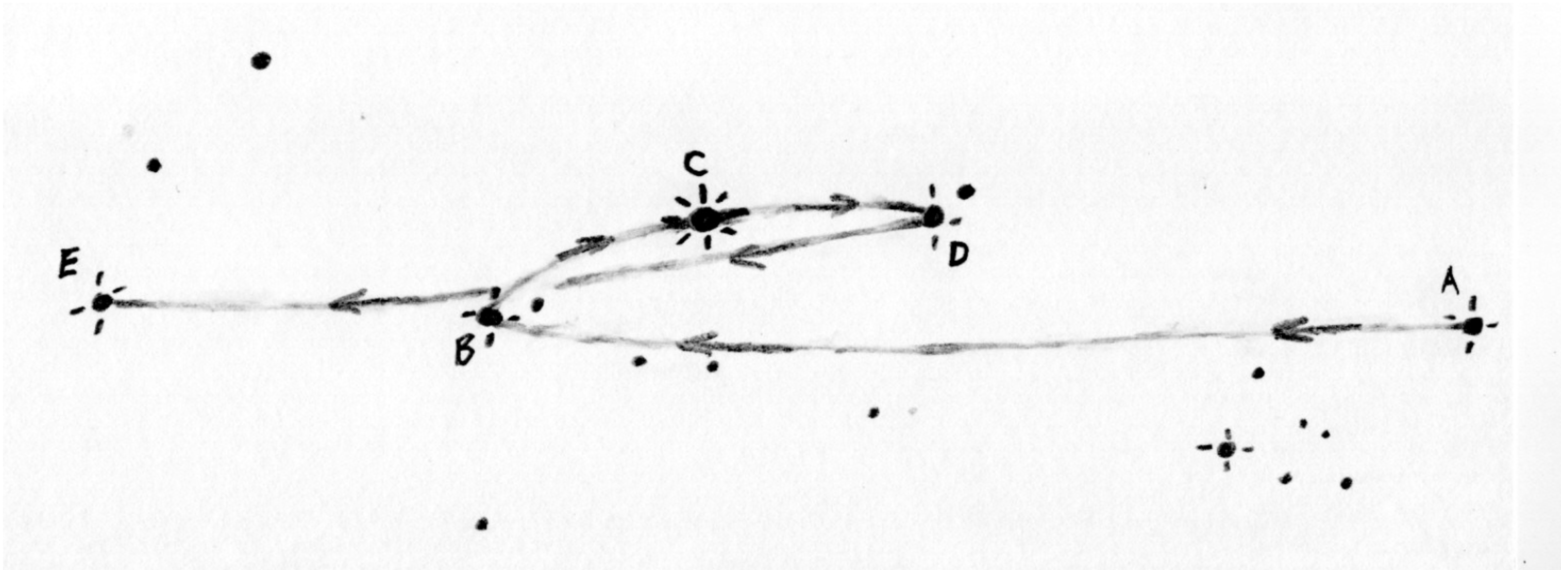
Explaining how the wandering stars fit into the overall picture of the universe was tough for Aristotle. Loosely speaking, the wandering stars drift through the fixed stars in the same general manner as the moon (recall from Chapter 2 how the moon moved through the fixed stars) -- they just drift more gradually. This motion is known as the *prograde* or *direct* motion of the wandering stars. Saturn drifts the most slowly, followed by Jupiter, etc. Aristotle could explain this prograde motion by simply having the wandering stars move around the Earth the way the sun and moon do (see the figure on the next page). Thus Aristotle could explain, for example, how Saturn, which was in Leo in 2007, gradually drifts through the constellations, to return to Leo in 2036, a 29-year cycle -- while Jupiter cycles through the stars in 12 years, and the moon does it in under a month.

However, the motions of the wandering stars are more complex than the motion of the moon. While most of the time the wandering stars move in a manner similar to the moon (the prograde motion), every wandering star will periodically reverse its motion for a while. This reverse motion is called *retrograde* motion. Associated with the retrograde motion of the wandering stars are changes in brightness. Mars, Jupiter, and Saturn all appear brightest when in retrograde motion. Mercury and Venus undergo retrograde motion, but they pass close by the sun during retrograde and cannot be seen much of the time.

All of this retrograde motion business is difficult to explain using Aristotle's methods. If all the heavens are moving in circles around the Earth, why do the wandering stars get brighter and dimmer? If everything in the heavens moves in unending circles, how do we explain a wandering star reversing its motion, and then reversing again?



Aristotle's universe showing the wandering stars along with the sun, moon, and stars (which we should now refer to as "fixed" stars to distinguish them from the "wandering" stars). The fixed stars circle the Earth once every 23 hours, 56 minutes. Everything else circles more slowly – the sun once every 24 hours, the moon once every 24 hours, 48 minutes. The wandering stars range from Saturn, which is just a little slower than the fixed stars, down to Mercury. The differing rates of movement cause the sun, moon, and wandering stars to move among the fixed stars. Mercury and Venus stay close to the sun – unlike the moon, Mars, Jupiter, and Saturn. The placement of Mercury and Venus was somewhat uncertain in Aristotle's universe – they could be inside the sun's orbit or outside. This picture shows the order that was adopted over time – Mercury and Venus inside the sun's orbit.



Motion of the wandering star Mars through the fixed stars of the constellations Taurus and Gemini in 2007 and 2008. Mars is at point A in early August 2007 and very dim. It reaches B in late November of that year. The motion from A to B is prograde, and Mars is brightening the whole time. Then Mars reverses direction at B, continually increasing in brightness until it reaches maximum brightness at the mid-point of its retrograde motion, C, in late December 2007. It continues in retrograde from C to D, but now its brightness begins to fall off. Mars halts its retrograde motion at D at the end of January 2008, and resumes prograde motion. It is at E, and back to being quite dim, by the end of April 2008. Mars then stays in prograde motion until December of 2009 when the next round of retrograde motion begins.

Aristotle did not really make a serious effort at explaining the retrograde motion of the wandering stars. Perhaps he thought that having a system that explained the sun, moon, and fixed stars quite nicely, and that explained the prograde motion of the wandering stars, too, was pretty good. Perhaps he thought he would get around to figuring out the retrograde motion some other time, and just never did.

The fact that Aristotle developed a good theory did not prevent others from trying to improve on it, or supplant it, by coming up with a satisfactory explanation of the motions of the wandering stars. Such an explanation took a long time to develop. It did not reach maturity until five centuries after Aristotle. This first satisfactory explanation of the motions of the wandering stars was the *epicycle theory* of Claudius Ptolemy, who lived and worked in Alexandria, Egypt during the time of the Roman Empire.[3] Just like many different thinkers contributed to the ideas of Aristotle, different thinkers contributed to the epicycle theory. And just as we talk about Aristotle, and not the others who influenced Aristotle, we will talk about Ptolemy, and not those who influenced Ptolemy.

The epicycle theory was basically a modification of Aristotle's ideas. Here's how it worked: Following Aristotle's ideas, the Earth was at the center of the universe with the heavens revolving about it. In fact, the sun, moon, and fixed stars worked the same way in both Aristotle's and Ptolemy's theories. The difference came with the wandering stars. In Ptolemy's epicycle theory, a wandering star moved about the Earth on a large circle, similar to how Aristotle envisioned them moving. This large circle was called the *deferent*. But Ptolemy added a second circle to the wandering star's motion. This second circle was called the *epicycle*. The wandering star rode on the epicycle, which in turn rode on the deferent. While the wandering star was carried around the Earth on the deferent, the rotation of the epicycle brought the wanderer closer to Earth and then carried it further from Earth. When the wanderer was further from Earth, the movement caused by the epicycle and the movement caused by the deferent worked together, and the wanderer moved in one direction against the stars. However, when the wanderer was close to Earth, the movement caused by the epicycle and the movement caused by the deferent were contrary to each other, and the wanderer would slow, stop, and move opposite the direction of the deferent for a little while. This reversal always occurred when the

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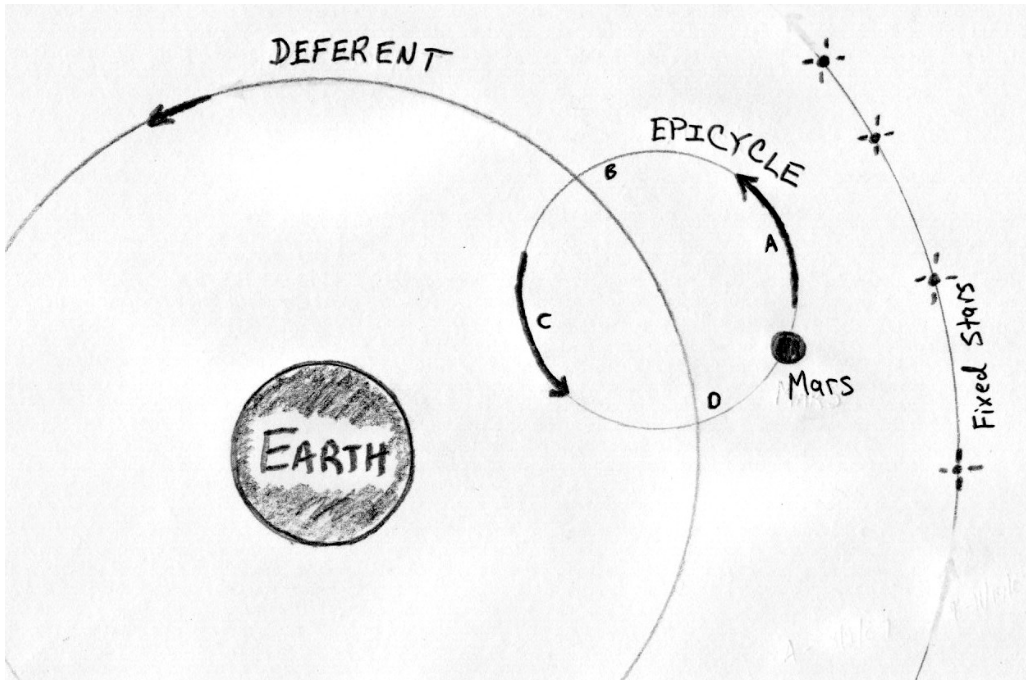
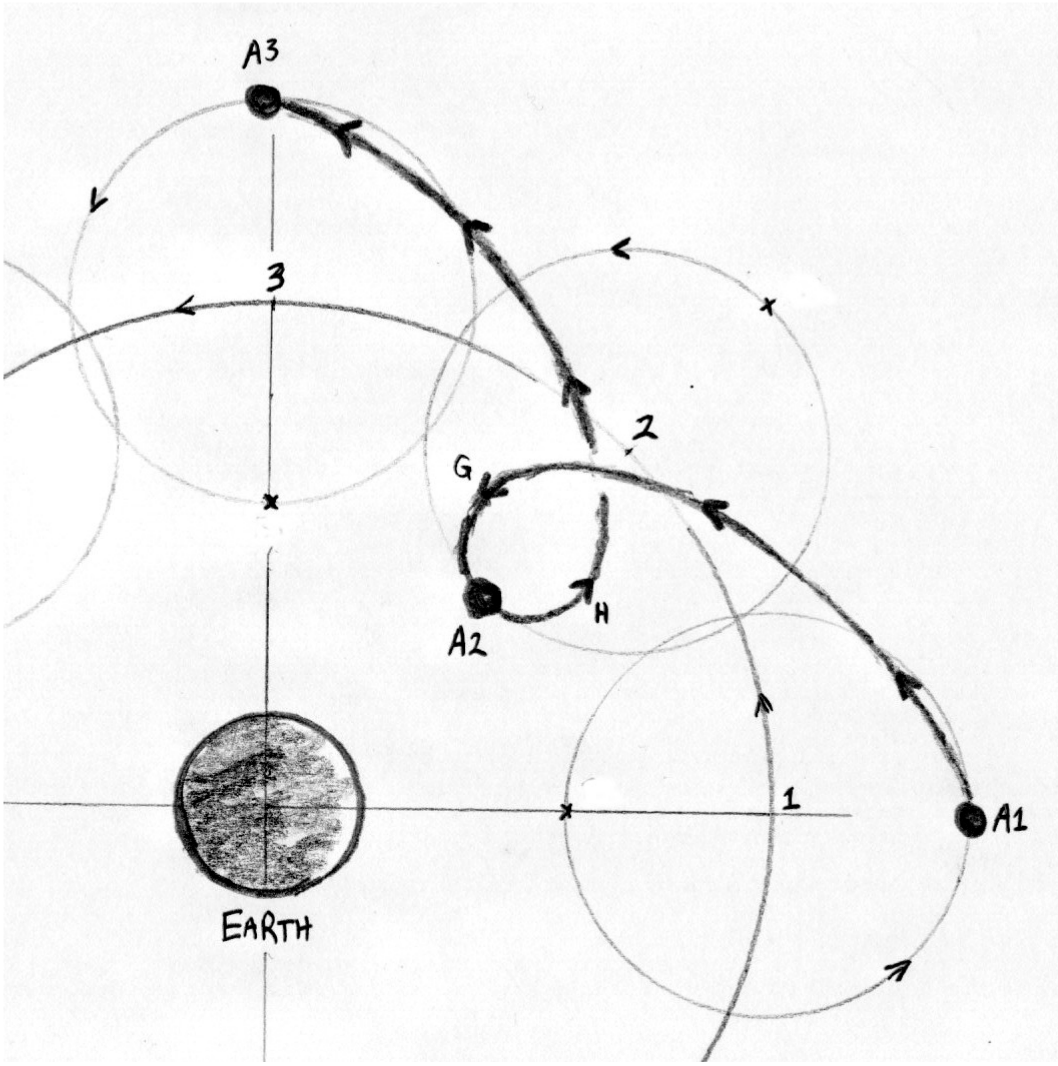
3 Ptolemy was born some time after the year 83 and died in 181.



The epicycle theory for Mars. (For simplicity's sake we are leaving out the sun, moon, and other wanderers; and, we are looking at the system from the point of view of the fixed stars, so the fixed stars appear to not be moving. The full picture should include the sun, moon, and other wanderers, with the whole thing revolving around the Earth with the fixed stars – once every 23 hours, 56 minutes!)

Mars rides on a circle called an *epicycle*. The epicycle in turn rides on a larger circle, the *deferent*. The motion along the deferent is responsible for Mars' general prograde drift among the fixed stars. The movement caused by the epicycle is faster than that caused by the deferent. The epicycle carries Mars toward and away from the Earth, causing it to change in brightness. If Mars were at A it would be furthest from the Earth. Epicycle and deferent would be working together. Mars would be moving counter-clockwise about the Earth. If Mars were at B the epicycle would be carrying it toward Earth, but the deferent's action would still cause Mars to move counter-clockwise about the Earth. If Mars were at C it would be closest to Earth. The faster movement of the epicycle would more than cancel out the slower movement of the deferent. Mars would be moving clockwise about Earth. In other words, if Mars were at C it would be in full retrograde and very bright because of its closeness to Earth. If Mars were at D the epicycle would be carrying it away from Earth, but the deferent's action would cause it to move counter-clockwise about the Earth.

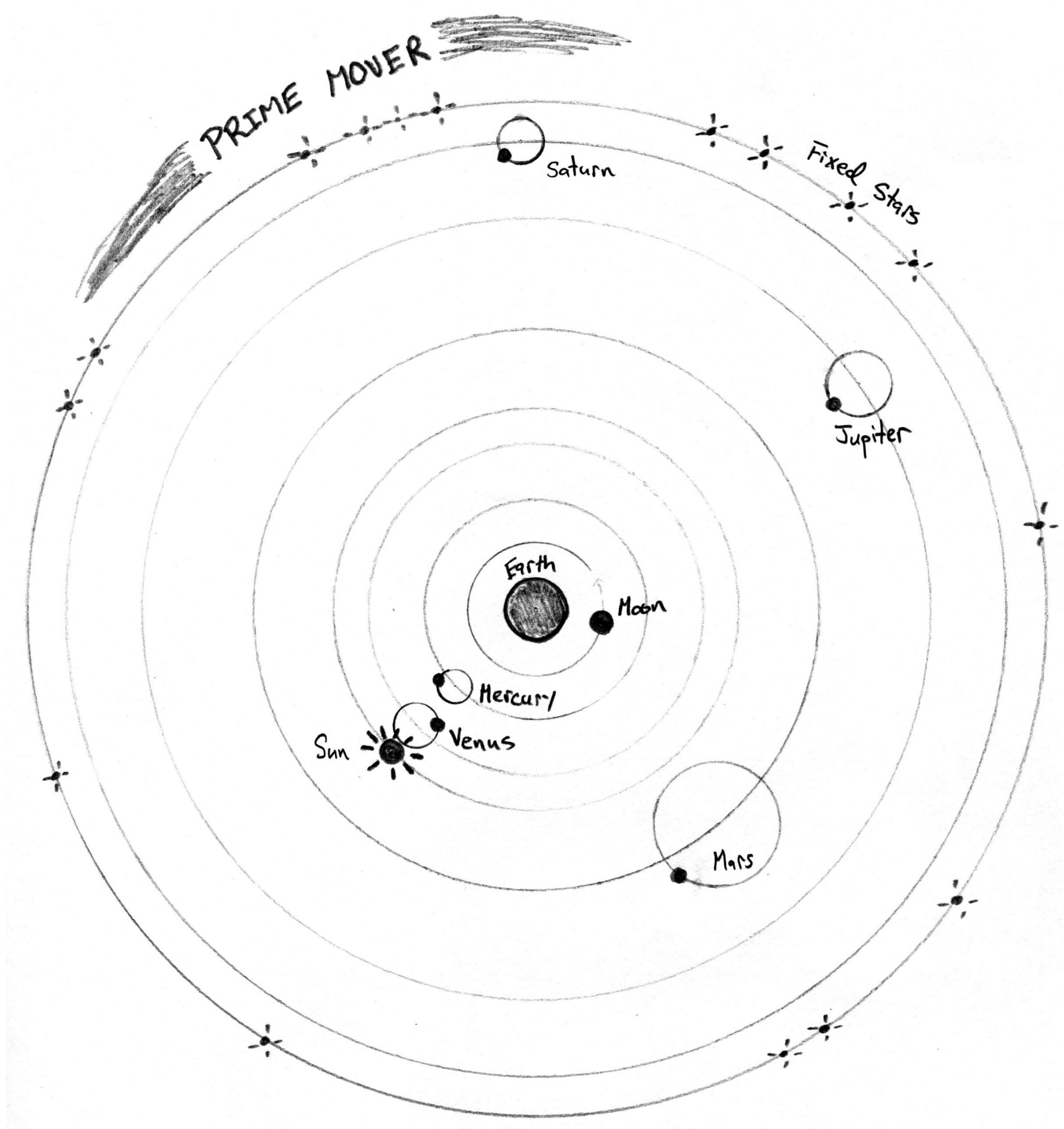
In summary, the combination of the deferent and epicycle causes Mars to generally move counter-clockwise about Earth, with occasional instances of clockwise movement that occur when Mars is closest to Earth. Thus Mars normally moves in one direction against the stars (prograde), but occasionally reverses itself (retrograde). The retrograde motion occurs when Mars is closest to Earth, and therefore when Mars is brightest.



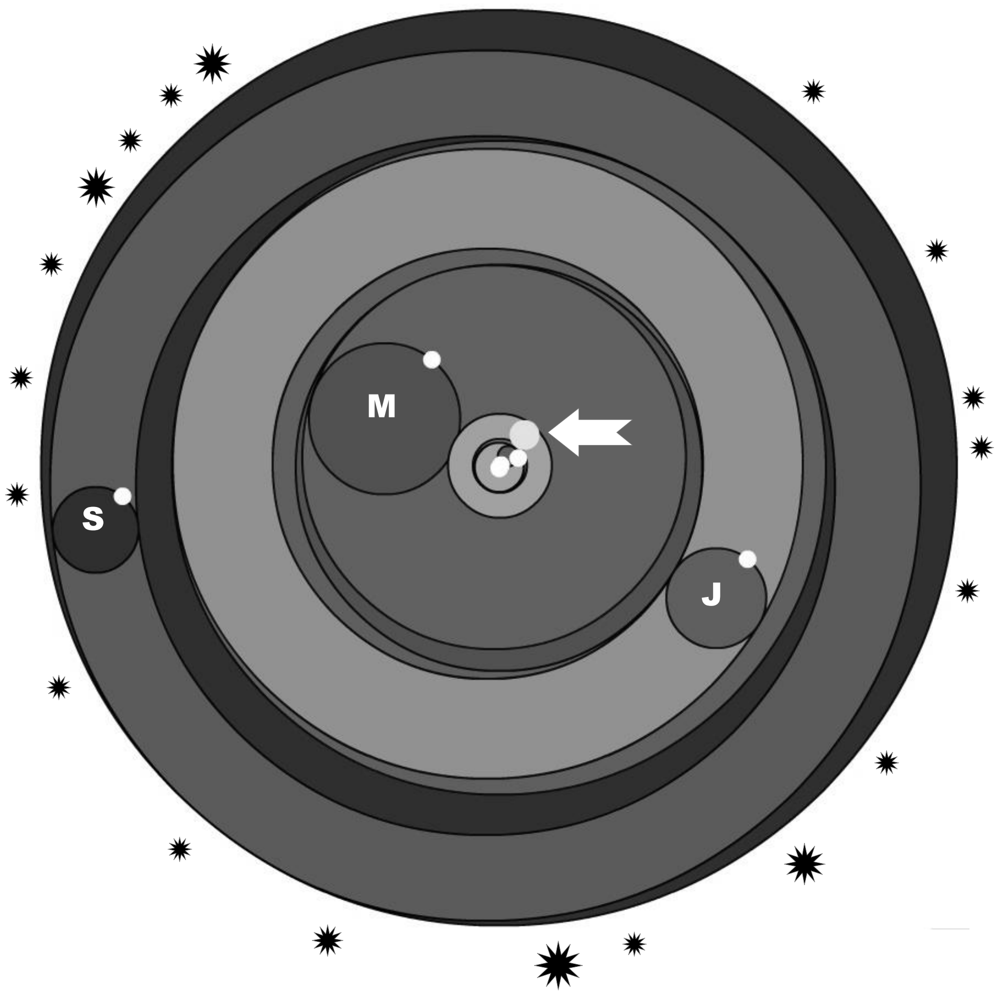
The epicycle in action. The deferent makes a quarter turn in the counter-clockwise direction, carrying the epicycle from point 1 through point 2 to point 3. During that time the epicycle makes one and a quarter turns, also in the counter-clockwise direction.

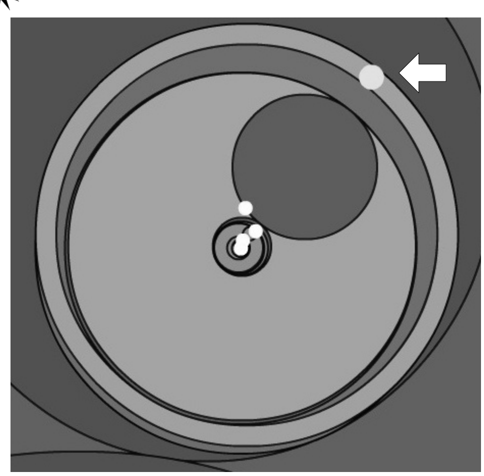
Mars is at position A on the epicycle in all cases. At A1 Mars is furthest from Earth. At A2 Mars is closest to Earth, in the middle of retrograde motion, and at maximum brightness. At A3 Mars is again furthest from Earth. Between points G and H Mars is in retrograde motion. However, the rest of the time Mars is in prograde motion.

Recall that this whole picture is revolving around the Earth once every 23 hours, 56 minutes.



Above is the Aristotelian/Ptolemaic universe, showing the sun, moon, and fixed stars, as well as the wandering stars with their epicycles. This diagram is not to scale. On the opposite page is the Aristotelian/Ptolemaic universe, shown to scale. Earth is at the center. The sun is arrowed. The epicycles of Saturn (S), Jupiter (J), and Mars (M) are large. The epicycles of Mercury and Venus are too small to see in the diagram – the figure at below right on the opposite page shows the inner portion to scale, with the sun (arrowed), the Earth (at center), and the epicycle of Venus. The epicycle of Mercury and the moon's circle are still too small to see. In all these diagrams the whole system revolves around the Earth, along with the fixed stars, once every 23 hours, 56 minutes, powered by the Prime Mover.





In this theory the Earth (anything inside of the moon) is composed of the four elements earth, water, air, and fire. The heavens (the moon and out) are composed of the incorruptible Fifth Element. The motions of the heavens are eternal. The heavens themselves are unchanging. Note that the epicycles of Mercury and Venus lie in a line between the Earth and the sun. While the moon, Mars, Jupiter, and Saturn can be found either near to the sun or far from the sun in the sky, Mercury and Venus are always found near the sun, and so their epicycles have to stay in line with the sun at all times. These diagrams, produced using computer software by Dennis Duke, show some additional details of the Ptolemaic theory that we have not discussed, such as that the deferent circles are not all exactly centered on the Earth.

wandering star was closest to Earth -- neatly explaining both why a wandering star like Mars went into retrograde motion, and why it always brightened while it did so!

So Ptolemy's theory of the universe looks very similar to Aristotle's. As in Aristotle's theory, our Earth lies at the center, or bottom, of the universe and is round. The sun, moon, and fixed stars all circle the Earth just like in Aristotle's theory. The Earth is made of the four elements of earth, water, air, and fire; the heavens are made of the Fifth Element. What is different is that the wandering stars move about the Earth, not just in circles, but with the compound motion of deferents and epicycles that explain both the movements of the wandering stars and their changes in brightness. In Ptolemy's theory a Prime Mover still powers the motion of the heavens.

Ptolemy created a theory that explained everything that Aristotle's theory could explain, and could also explain the motion of the wandering stars. His epicycle theory can be thought of as “Aristotle 2.0” -- the same excellent product, just better with new features and capabilities! The Aristotelian/Ptolemaic view of the universe would dominate scientific thinking for well over a thousand years.