The Solar System and the apparent motion of planets

Earlier, we mentioned that the Earth orbits around the Sun. However, the Earth is not the only one which orbits around the Sun. There are other astronomical objects called “planets” which also orbit around the Sun. Some are closer to the Sun than the Earth is, and some are farther away from the Sun than the Earth is. See Fig. 1. All the ellipses (An ellipse is a squeezed circle. See “Conic Sections” to learn what it is.) are the orbits of planets, and the little dot in the center is the Sun. Actually, the Sun should be smaller if I drew in scale, but then you can’t see it. The closest ellipse (the blue one) is the orbit of “Mercury.” You see that the ellipse is quite eccentric (i.e., elliptical or far from being circular) compared to the other orbits. The second one (orange one) is the orbit of Venus. The third one (green one) is the orbit of the Earth. The fourth one (the red one) is the orbit of Mars.[1]

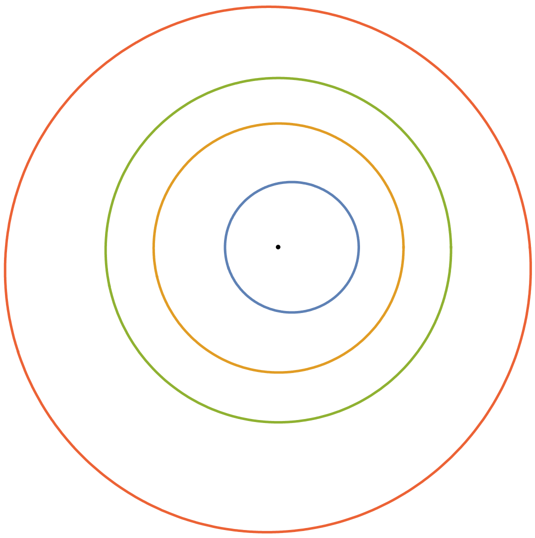

Fig. 1

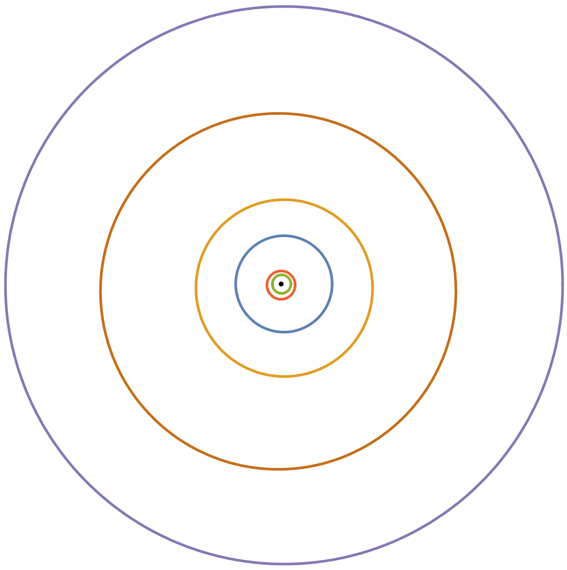

Fig.2

There are other planets, but their orbits are so big that they don’t fit in Fig. 1. So, I drew Fig. 2. The small dot at the center is the Sun. The two small ellipses around the Sun are the orbits of the Earth and Mars. The next smallest orbit (the blue one) is the orbit of Jupiter. The other three ellipses are the orbits of Saturn, Uranus, and Neptune, in the order of the smallest to the biggest. Mercury and Venus are called “inner planets” as they are closer to the Sun than the Earth is, and Mars, Jupiter, Saturn, Uranus, and Neptune are called “outer planets” as they are farther from the Sun than the Earth is.

[1] I did some internet research, and tried to draw the shape of the orbits (which are ellipses) as accurate as possible. However, I couldn’t find which directions they were squeezed, so I arbitrarily set them.

It takes a longer time to orbit around the Sun once if the orbit is bigger. For example, Mars, of which the mean distance to the Sun is about 1.53 times the one of the Earth takes 1.88 times longer to orbit around the Sun once than the Earth does. In other words, it takes 1.88 years. We say the "orbiting period" of Mars is 1.88 years. Similarly, Venus, of which the mean distance to the Sun is about 0.72 times the one of the Earth takes 0.62 years to orbit around the Sun (i.e., the orbiting period of Venus is 0.62 years); it takes shorter time because the orbit is smaller. However, you might have noticed that the size of the orbit is not proportional to the orbiting period, even though the bigger the former, the longer the latter. For example, the size of the orbit of Mars is 1.53 times the one of the Earth, but the orbiting period is not 1.53 years but 1.88 years. As we will see in later articles, finding and understanding the exact relation between the size of the orbit and the orbiting period brought about the real beginning of physics.

In an earlier article, we have also mentioned that the ecliptic is the plane which the motion of the Sun lies when seen on the Earth. From the point of view of the Sun, the ecliptic is the orbital plane of the Earth. In other words, the Earth's orbit always lies in the ecliptic. The orbital planes of other planets also closely lie with the ecliptic, but not perfectly. They don't overlap perfectly, just like the orbital plane of the Moon and the ecliptic didn't. Nevertheless, all the orbital planes of planets are inclined within only 5 degrees of the one of the Earth (i.e., the ecliptic) except for Mercury, with 7 degrees. Thus, if you see planets on the Earth, they are always found near the ecliptic.

The biggest difference between the planets and the fixed stars is that the motions of the planets are easily observable on the Earth while the motions of the fixed stars are not. Earlier, we mentioned that the fixed stars are so far away that their motions don't change their apparent position in the sky when seen on the Earth. However, the planets are much closer than the fixed stars, so their motion is easily noticeable. The closed fixed star is 4.3 light years away from us. It's about 270,000 times the distance between the Sun and the Earth, and 9,000 times the distance to the farthest planet, Neptune.

So, how does the motion of a planet look like on the Earth? First, I want to mention that all planets, including the Earth, orbit eastwards. (If you are on the Northern hemisphere, it corresponds to the counter-clockwise orbiting around the Sun.) Therefore, normally, both the outer planets and the inner planets seem to move eastwards with respect to the fixed stars background. However, remember that the Earth moves faster than the outer planets. Thus, it sometimes overtakes the outer planets, and they seem to move backward (i.e., westwards) with respect to the fixed stars background. This is known as "retrograde motion" See Fig. 3. T1, T2, T3, T4, T5 denote the time sequence of the motion of the Earth and P1, P2, P3, P4, P5 denote the time sequence of the motion of an outer planet. (As just mentioned, they are both orbiting counter-clockwise.) With respect to the fixed stars background, which is denoted as a blue belt on the right, the outer planet moves from A1 to A2, which is eastwards, then moves retrograde (i.e., westwards) from A2 to A4 through A3, then moves normally eastwards again from A4 to A5. Notice also that the retrograde happens when the planet is near the opposition (i.e., on the right opposite direction of the Sun); when seen at T3, P3 is at the right opposite side of the Sun.

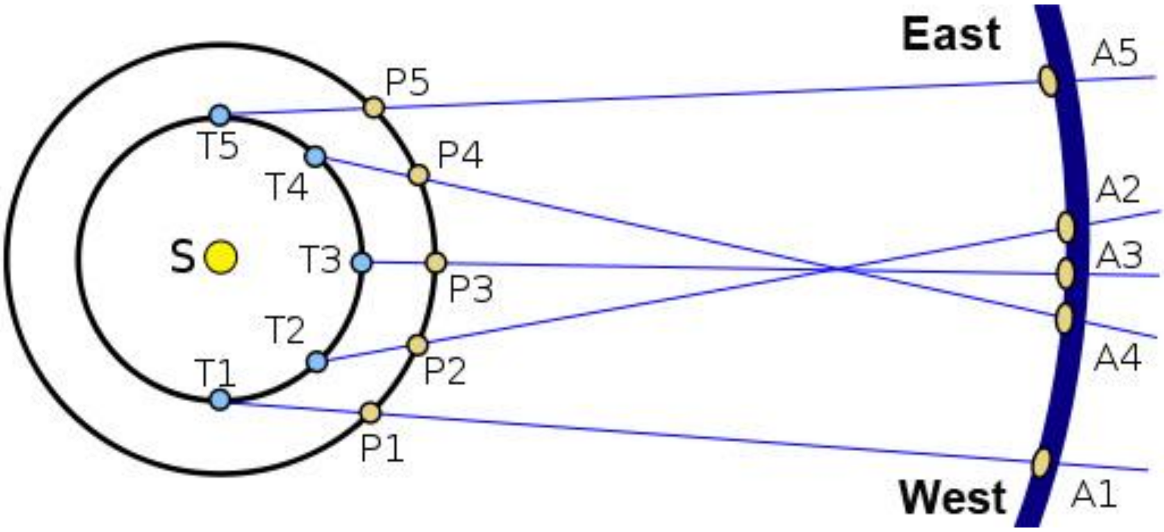

Fig.3

Now, let's think about how long a hypothetical planet that is infinitely far away moves retrograde. See Fig. 4. A hypothetical planet that is infinitely far away barely moves, so let's regard it as not moving. I denoted it as P in Fig. 4. Then, when the Earth moves from T1 to T2 to T3, it moves westwards, which is retrograde. When the Earth moves from T3 to T4 to T1, it moves eastwards, which is a normal motion. So, a hypothetical planet that is infinitely far away moves retrograde for half a year and moves normally for half a year. As all the outer planets are less far away from us as this hypothetical planet is, days in retrogradation are always shorter than half a year, and the closer a planet is to the Sun, the shorter period time it moves retrograde.

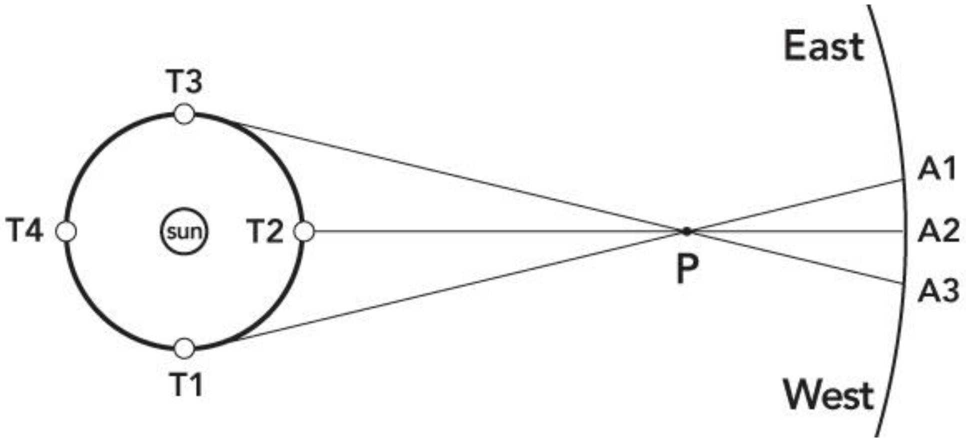

Fig. 4

Before moving on to the retrogradation of inner planets, let's talk about how the inner planets will seem on the Earth. Notice that, when seen on the Earth, Mercury and Venus are always on the side of the Sun, and never on the other side. See Fig. 5. At midnight, you can only see things under the dotted line, and Mercury and Venus are never under the dotted line. So, you can never see Mercury and Venus at midnight; you can only see them in the morning right before the sunrise or in the evening right after the sunset. Of course, they are there on the sky during the day, but the Sun is so bright that no stars are visible during the day.

From this reason, Venus was known both as the "morning star" and as the "evening star" in the ancient days. Some didn't know then that the morning star and the evening star were the same object, even though the ancient Sumerians and the ancient Babylonians knew it. The ancient Greek didn't also know it initially, but Pythagoras and Parmenides introduced the idea that they were the same object. Also, like the Moon, Venus changes its phases, but this was not discovered until telescopes were invented in the 17th century. We will talk about the historical significance of the discovery in "History of Astronomy up until the 17th century."

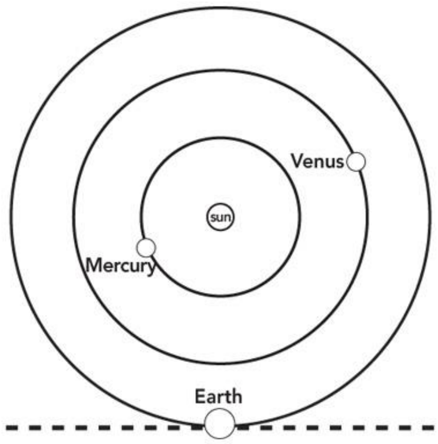

Fig. 5

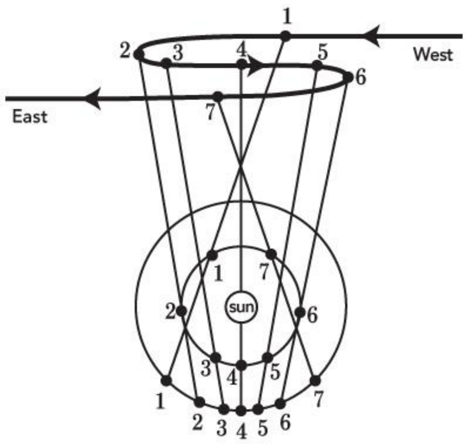

Fig. 6

Inner planets also retrograde. See Fig. 6. From 2 to 6, the inner planet retrogrades.

Problem 1. Is the morning star seen in the western sky or in the eastern sky? How about the evening star? Explain why.

Problem 2. In Fig. 6, is 2 the morning star or the evening star? How about 6?

Some comments. First, this strange retrograde motion of planets confused the ancient people. Nevertheless, we are no longer confused as Copernicus introduced the idea that the planets and the Earth orbit around the Sun in the 16th century. We will talk more about it in "History of Astronomy up until the mid 17th century."

Second, Mercury, Venus, Mars, Jupiter, and Saturn were known in ancient times. On the other hand, Uranus and Neptune were too dark to be discovered through human eyes, even though Uranus is sometimes visible to human eyes on very dark nights. Uranus and Neptune were only discovered in the 18th century and in the 19th century with the aid of telescopes. We will talk more about it in "History of astronomy from the late 17th century until the early 20th century."

Third, planets are not the only astronomical objects that orbit around the Sun. There are also many "asteroids" and many "comets." Asteroids are rocks that are too small to be called planets. Sometimes, they can hit the Earth. Scientists believe that a big one hit the Earth about 66 million years ago, causing a catastrophic change in the weather, which resulted in the extinction of dinosaurs. Comets are astronomical objects of which the orbits have very high eccentricity (i.e., the elliptical orbit is very much squeezed). For example, "Halley's comet," the most well-known comet, comes closer to the Sun than Venus is close to the Sun, when it is closest to the Sun, but it gets farther from the Sun than Neptune is when it is farthest from the Sun. This is in contrast to planets and the Earth, of which the distances to the Sun do not change as much, as you can see in Fig. 1 and Fig. 2. Nevertheless, comets also have fixed orbits.

Summary

- Earth is the only one which orbits around the Sun. "Planets" do as well.
- "Inner planets" are closer to the Sun than the Earth is. Mercury and Venus are inner planets.
- "Outer planets" are farther to the Sun than the Earth is. Mars, Jupiter, Saturn, Uranus, Neptune are outer planets.
- One can see Mercury and Venus only right before the sunrise or right after the sunset.
- Comets also orbit around the Sun. However, their orbits have very high eccentricity.

Fig. 3 is adapted from https://commons.wikimedia.org/wiki/File:Retrogradation.svg