RETROGRADE MOTION OF MARS

OBJECTIVES

1. **To plot the retrograde motion of planet Mars.**
2. **To identify the underlying pattern of retrograde motion.**
3. **To identify the causes of retrograde motion.**

PREPARATION

Earth is so close to the Sun and planets (compared to the immensely far stars) that we observe their position change in the celestial sphere (the back drop of the “fixed” stars) as we all orbit the Sun. The closer a planet is to Earth, the faster we see it move through the constellations. Mars is not only one of the five classical planets visible by the unaided eye, it is also one of the closest and most easily visible object in the night sky. It appears to move faster in front of the stars than any other planet. Mars typically moves eastward about 0.52 degrees per day (0.5 degrees is about the same width as the full moon) against the background of stars. This typical eastward motion is called **prograde** motion**.** When Mars is observed for long periods, it appears to slow down at some point, stop moving eastward, start moving westward a little bit, and then slow down and change direction again back to eastward. This occasional westward motion (backwards compared eastward) is called **retrograde** motion. All planets exhibit retrograde motion, but Mars’ can be observed the best due to its proximity and resulting rapid apparent motion. When you plot Mars’ position in the night sky during one of its retrograde motion periods, Mars’ path through the constellations looks like a loop or zig-zag (going from prograde to retrograde back to prograde).

Keep in mind that we observe the planets go through this zig-zag in front of the backdrop of the constellations because we are observing them from a moving platform. Our planet Earth, revolves around the Sun on its own orbit and with its own speed just like the other planets similar to runners on a nearly circular multi-lane track (see Fig. 2.13 in OpenStax “Astronmoy” or equivalent in your lecture textbook). Imagine being one of the runners and keeping track of another, slightly slower runner on the outside track next to you while running yourself. With the audience playing the role of the “fixed” background stars, you would see how the other runner passes in front of different parts of the audience. And with the track being circular, and the other runner being slightly slower and further out, you will overtake him or her regularly. Think for a moment about how this overtaking affects the way you see the other runner pass in front of the audience. For most of your run around the curved track, the other runner will appear to you to pass in front of the audience in a certain direction. Then, when you come up on him or her from behind, the runner appears to slow down and reverse the direction with respect to the audience. And when you have pulled ahead far enough around the curved track, the other runner appears to slow down with respect to audience and change direction again back to the original direction.

To you, the runner appears to move in a zig-zag with respect to the audience while you're passing him or her. The further the other runner's track is away from yours, the smaller the apparent zig-zag during the overtaking process. This NASA website has a great animation and explanation of retrograde motion: http://mars.jpl.nasa.gov/allaboutmars /nightsky/nightsky04/. The University of Nebraska as another effective animation of the retrograde motion of Mars: http://astro.unl.edu/classaction/animations/renaissance/retrograde.html.

When we are looking at the sky, we have to consider that we are located on a moving object. Historically, it has always been difficult to separate how things appear in the sky and where things actually are in space with respect to each other. To get a different perspective, we will switch to a "top down" view of our solar system which features as parameters the distance of Mars from Earth and the elongation of Mars in the sky. **Elongation** is defined as the angle between the Sun and a celestial object in the sky.

Mars is a *superior* planet. This means that its orbit around the sun is larger than the Earth's orbit. An *inferior* planet has an orbit smaller than Earth's. For a superior planet like Mars, there are specific alignments with the sun that scientists are interested in. These occur at specific elongation angles as shown in Figure 1 below.

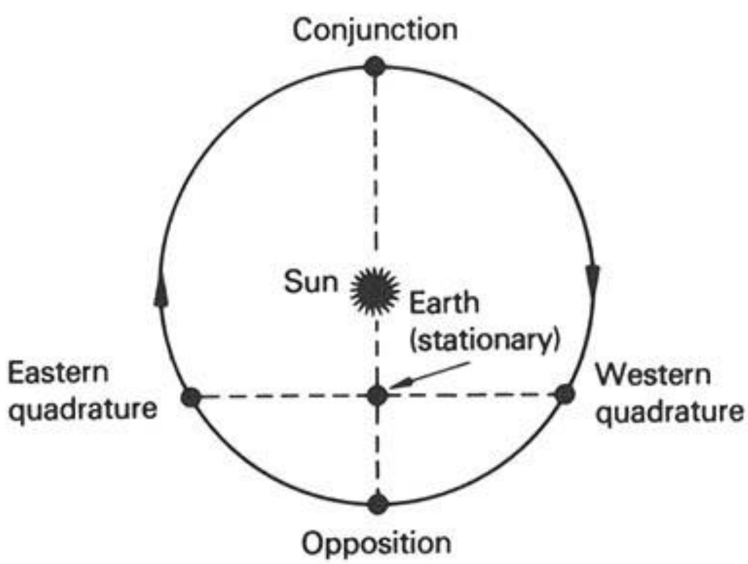

Figure 1: Specific elongation configurations of Mars, by Samuel Glasstone, The Book of Mars, NASA

When the Sun and Mars are in the opposite directions in the sky (as viewed from Earth), then, like the full moon, Mars rises at sunset and sets at sunrise. This is called *opposition*. At opposition, Mars, Earth, and the Sun are all lined up with Earth between the Sun and Mars. At opposition, Mars has an elongation of 180^{o}. Opposition is the best time to observe Mars since it is closest to the Earth and will be at its brightest in our sky. The configuration when Mars lines up behind the Sun is called *conjunction*. Mars, Earth, and Sun are all lined up, but this time the Sun is directly between Earth and Mars. At conjunction, Mars has an elongation of 0^o and will rise and set around the same time as the Sun. This is also when Mars is furthest away from Earth. There are two times when the Sun and Mars are at right angles to each other, as viewed from Earth, these are called quadrature with elongations of 90^o east or west. At *eastern quadrature*, the Sun will rise before Mars, and Mars will be highest in the sky at sunset. At *western quadrature*, Mars will rise before the Sun, and Mars will be highest in the sky at sunrise. The University of Nebraska has an excellent animation of tracking the elongation angle of a superior planet like Mars: http://astro.unl.edu/naap/ssm/modeling2.html.