# Theories

## Lesson Procedures

**Part 1: Show** students Video 2: Astronomy Theories [Time – 4:58]. Afterward, note that scientists know that gamma-ray bursts (GRBs) occur randomly on the sky. From the Earth, we could see about one per day if we were able to watch the entire sky all of the time. Note that the study of gammy-ray bursts could yield important discoveries because astrophysicists aren't even sure exactly what gamma-rays bursts (GRBs) are.

Scientists have classified the GRBs into two classes based on how long they last. Those that last less than 2 seconds are put in one class, and those that last longer than 2 seconds are put into another class. Scientists think that the long bursts release about $10^{44}$ J of energy. Our Sun emits about $10^{26}$ J each second. It would take our Sun about 8.8 billion years to put out the same energy as a seconds-long GRB!

When the Swift satellite was launched in 2004, there were a couple of current theories about the origin of GRBs. One theory was that GRBs occur from neutron star mergers. A neutron star is a possible end point of a star. It is very dense and has a mass of about 1.4 times our Sun. The other theory was that GRBs are caused by the collapse of very massive stars—stars whose mass is greater than 40 of our sun's. The resulting explosion is called a hypernova. It's possible that both theories have some truth; the long bursts may be from hypernovae while the short bursts might be from neutron star mergers. In 2008, after three years of Swift data collections, it appears that the data supports both theories. The theory of the neutron star mergers supports the data for the short bursts, while the hypernova data supports the theory for the longer GRBs.

Often, theories compete over a long period of time. The exercise that follows will look at the movement of Mars from the perspective of the astronomer Ptolemy, who lived in the second century A.D. Ptolemy's theory—and the reasons for its demise—are often misunderstood.

Tell your students that they are going to look at the type of data that Ptolemy used to craft a geocentric—earth-centered—model of the universe. From our present-day perspective, we know that his model was incorrect. So why then was it believed to be true for another 1400 years?

Aristotle (350 A.D.) was an ancient astronomer, geographer, and mathematician who proposed the geocentric theory of the solar system. He gave various arguments to prove that, in its position at the center of the universe, the Earth must be immovable. He argued that if the Earth moved, as some earlier philosophers had suggested, then certain phenomena should be observed. In particular, he argued that all bodies fall to the center of the universe, and the Earth must be fixed there at the center; otherwise falling objects would not drop straight down. Also, if the Earth rotated once every 24 hours, a body thrown vertically upward would not fall back to the same place, as it was seen to do. Aristotle accepted the following order for celestial objects in the solar system: Earth (center), Moon, Mercury, Venus, Sun, Mars, Jupiter, and Saturn. But it was Ptolemy who later assembled the mountains of data to test Aristotle's notions. Among other accomplishments, Ptolemy catalogued more than 1000 stars, and made systematic observations over extended periods of time.

**Part 2: Show** your students the QuickTime clip, *Alexandria_Mars.mov*. Explain that this is an animation of the movement of Mars over a four month period, as it would have appeared in 156 A.D. in Alexandria, Egypt where Ptolemy lived. Each frame of the clip is a snapshot of the sky on successive nights, at exactly the same time. By carefully observing the altitude (height in the sky) and azimuth (compass orientation) of Mars and several planets, Ptolemy could visualize what we see in this clip.

Questions to ask your students:

1. What happens during the clip to the position of Mars? The stars? The moon? (Students should note that Mars and the stars appear to move from left to right; that is, in a westward arc. The moon appears to be the only celestial body moving differently, in an eastward arc.)
2. Ask the students if they see anything about the movement of Mars that makes it different than the stars. After viewing the clip a couple of times, you may wish to suggest that they focus on the planet's position in relation to a single nearby star. (Students may note that Mars appears to jump position late in the clip, but what jumps is the label "Mars." The planet itself shows a smooth movement throughout).

Tell your students that Mars is doing something unusual in this clip, but it's difficult to see, even with this visualization. Most of the time, Mars acts just like a star, and appears to be traveling straight forward around the Earth. But occasionally it does something strange. If we understand it and Ptolemy's explanation, it may be easier to understand why the geocentric model persisted for so long.

Divide the class into groups and direct each group to map Mars' position using the data from **one** of the tables in the The Voyage of Mars in the Ancient Night Sky (see Student Handout, pg.10). It probably makes sense for you to assign tables to groups. Briefly explain the terms "Azimuth" and "Altitude." Figure 1 (pg. 7) may make this easier.

Tell the students that the data in the tables will allow them to graph the planet's position while holding the star field still. The picture that results will show Mars's travel within the backdrop of stars. (Later, they'll watch an animation that should help them understand the dynamics of the system.) The students will graph this information on Alexandria, Egypt night sky (see Student Handout, pg. 11).

When the groups have finished their plots, have them compare their results with plots of data from the other table. Table 1 shows the most common planetary motion, which is a simple arc across the sky. Table 2, on the other hand, shows the relatively infrequent retrograde motion where Mars appears to circle back before resuming its original path. Discuss the students' findings and how they think they could account for them, using Ptolemy's earth-centered model.

**Show** the second QuickTime clip, *Alexandria_Mars_Path.mov*. This clip is identical to the first clip, but with a line plotted to connect observations from successive nights. This dynamic view should help students understand what their own maps show. Although the starfield moves from left to right, Mars moves in a different way: hence the apparent loop.

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Can your students think of a way to account for retrograde motion in Ptolemy's geocentric system?

Explain to the students that the ancient Greeks observed retrograde motion and explained it very cleverly. They assumed that the Earth was stationary and that the planets and the sun went around the Earth. Ptolemy adapted and improved their model.

**Show** the third QuickTime clip, *Geocentric_1.mov*. This is how Mars appeared to behave most of the time: traveling around the Earth smoothly. Note that the clip accounts (correctly!) for the actual positions that ancient astronomers observed the planets to travel, despite the fact that it is not correct. Note also that a small unlabeled body (Mercury) appears to orbit the sun, as we now know our moon orbits the Earth. From the Greeks' perspective, both the sun and Mercury orbited Earth, but Mercury's apparent movement was not as simple as the sun's.

**Show** the fourth QuickTime clip, *Geocentric_2.mov*. This clip tracks Mars during one of its infrequent retrograde periods. Although from our contemporary perspective, Mars' loop seems implausible—What is it looping around, anyway?—Ptolemy's geocentric model was so sophisticated that it could actually predict these periods.

Figure 2 (pg. 8) illustrates Ptolemy's explanation. As you see in the illustration, they thought that Mars (and other planets) went around the earth in roughly circular orbits called Deferents. But this could not explain retrograde motion. Thus they created an **Epicycle** for Mars. An **Epicycle** is a small circle that Mars follows while it goes around the **Deferent**. As observed in the Figure 2, adding the epicycle made it easy to explain retrograde motion.

For example if you are located at point X and observe Mars at various times in the year, it would appear to be at points A B and C at different times of the year. It would move from point A (Dec 6, 156 AD) to point B (Jan 11, 157 AD) and then on March 24, 157 AD it would appear at point C, thus appearing to move backwards.
At this time, point out to the students that the geocentric theory was well received and lasted for more than a century.

**Part 3:** Now ask the students if they know how Mars exhibits retrograde motion in the corrected model (heliocentric model). Ask them why they see retrograde motion at all. Using the Figure 3 (pg. 9), try explaining to the students how the heliocentric model (sun at the center) explains retrograde motion.

According to the heliocentric model the sun is at the center and planets revolve around it. This is the model we currently use to explain the solar system. This model suggests that the Earth has a shorter orbit than Mars. Thus at some point the Earth passes Mars and that's when for a brief time period Mars appears to move in the opposite direction. The black dots at the end of each of the lines passing through Earth and Mars are the points where Mars is observed from the Earth in the sky before retrograde motion happens. The white dots at the end of the line represent the point of observation after retrograde motion occurs.

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Point out to the students that both the models accurately explained a major phenomenon occurring in the sky. Discuss with them that the geocentric theory lasted for many centuries and thus cannot be construed as bad science. Given the available resources, the theory presented a good model of the solar system.

### Assessment Strategies

In evaluating student's understandings, bear in mind that the primary purpose of this lesson was not to teach the correctness of the heliocentric model: after all, your students probably already knew that. What they probably did not know, however, is that the geocentric model that preceded it was a rational one.

Questions you may wish to ask:

1. What is retrograde motion? Can you observe it in a single night's observation?
2. Why did the geocentric model persist as long as it did?
3. Describe how both models accounted for Mars's apparent backward motion across the sky.

### Vocabulary

**Altitude** – a measure of how high an object appears to be above the horizon
**Azimuth** – the angular orientation (N, S, E, W) an object has on the horizon
**Deferent** – the smaller circular orbit of the epicycle
**Epicycle** – the orbit of a planet in a circular motion that also orbits around a larger circle at the same time
**Geocentric** – "earth-centered", Aristotle and Ptolemy's thought of how planets and stars in the universe revolved
**Heliocentric** – "sun-centered", the current accepted version of our solar system's orbital patterns as discovered by Copernicus and Galileo
**Joule** – a measure of energy in the SI unit system. 1 Joule = $1\text{kg-m}^2/\text{s}^2$
**Mass** – the measure of the amount of matter in an object, or roughly the amount of energy required to lift a brick from the floor to your waist in one second.*
**Retrograde Motion** – an orbit that appears to slightly backtrack, then move forward again

*** Special note:** For middle school students, "mass" and "weight" are conceptually interchangeable. Astronomers typically refer to "mass" because in outer space, "weight" has little meaning.

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**Figure 1:** Azimuth (compass orientation) and altitude (height in the sky)

**Altitude** is a measure of how high an object appears to be above the horizon.
**Azimuth** of an object is its angular orientation (or compass bearing) on the horizon

Object

Altitude

Horizon

Azimuth=0°

N