

The following notes roughly correspond to Section 2.4 and Chapter 3 of the text by Bennett. This note focuses on the details of the transition for a geocentric model for understanding the universe to a heliocentric understanding

Babylonian Astronomy

Cultures of Mesopotamia apparently had a strong tradition of recording and preserving careful observations of astronomical occurrences

Babylonians used the long record of observations to uncover patterns in the motion of the moon and planets (occurrence of notable configurations of planets, e.g., opposition).

The Babylonians were not interested in explaining the motion of the moon and planets but were satisfied with using the patterns they uncovered for predicting the occurrences of astronomical events for practical purposes.

Can we understand something with out fully explaining it?

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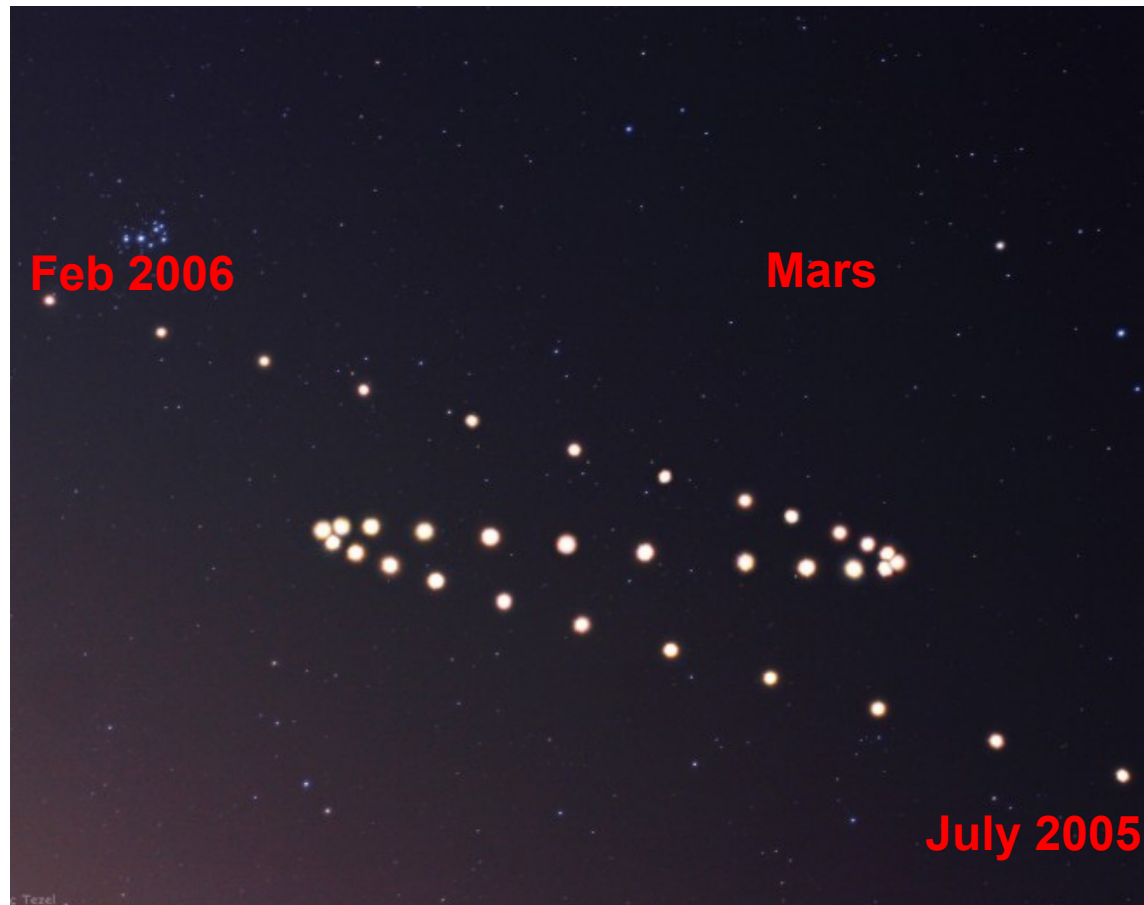
Can we understand something with out fully explaining it?

Greek Astronomy

While Greek Astronomers continue the tradition of observing and recording celestial observations, in my view, they advance the science in a couple general ways.

- In addition to uncover the *patterns* in the motion of the celestial objects they begin to try to explain the nature of this motion.**
- They make extraordinary progress in fundamental geometry (Pythagoras) and the application of geometry to the understanding of nature.**

Explaining Retrograde Motion of the Planets



Retrograde Motion occurs when for a brief period of time a planet appears to move backwards (westward) against the background of stars when observed from earth.

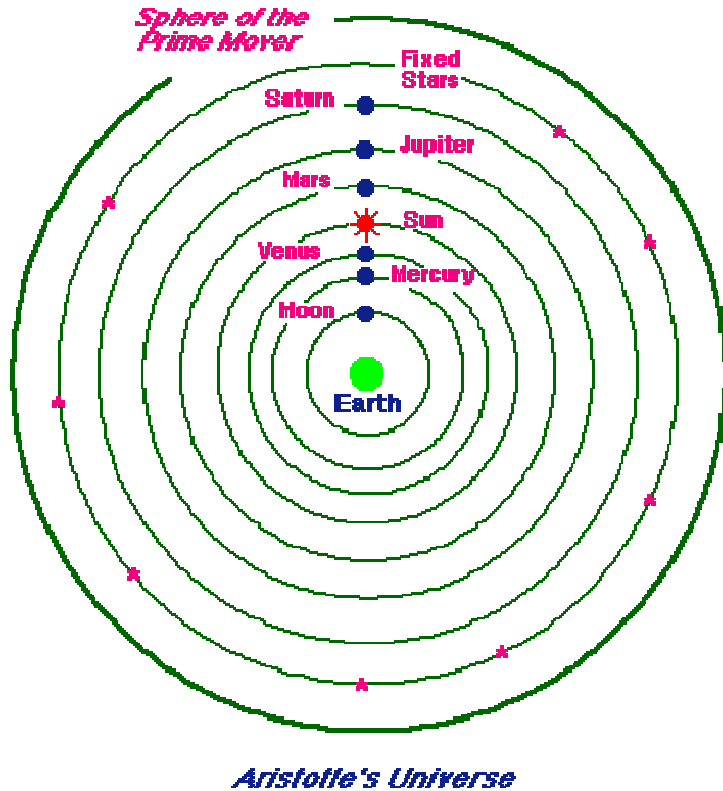
The planet appears brightest during retrograde motion.

Explaining Retrograde Motion of the Planets



In addition to uncovering the *patterns* in the motion of the planets, Greek Astronomers, consistent with the developing Greek tradition, begin to try to explain the nature of this motion.

Geocentric Model



- Aristotle and other Greek thinkers were proponents of a Geocentric (Earth Centered) Model of the Solar System.
- While the Geocentric Model shown here explains the motion of the planets and sun most of the time, it will not explain retrograde motion without modification.

Support of Geocentric Model

Earth too large to move.

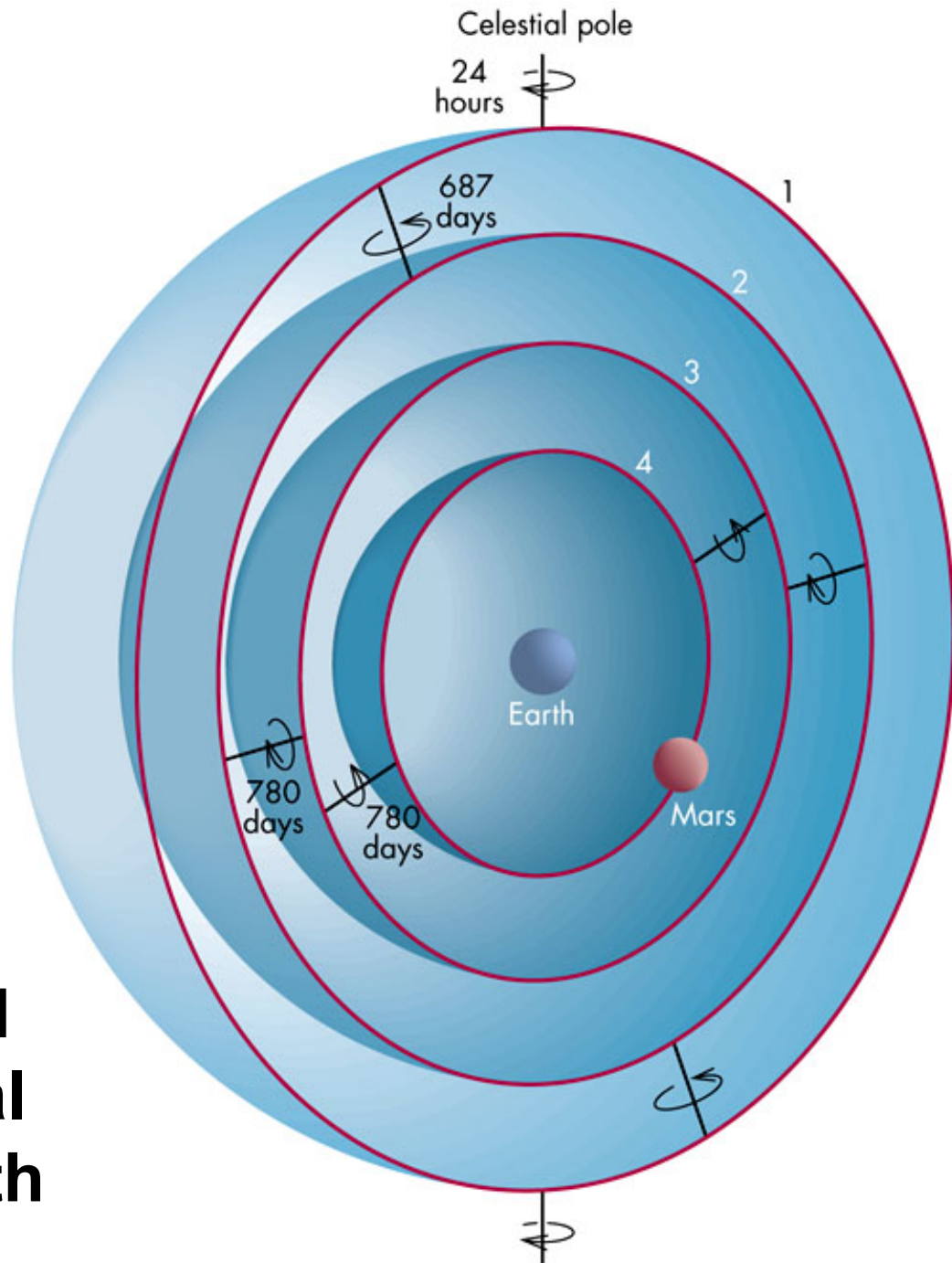
No obvious effects of moving at very high speeds.

No measurable stellar parallax.

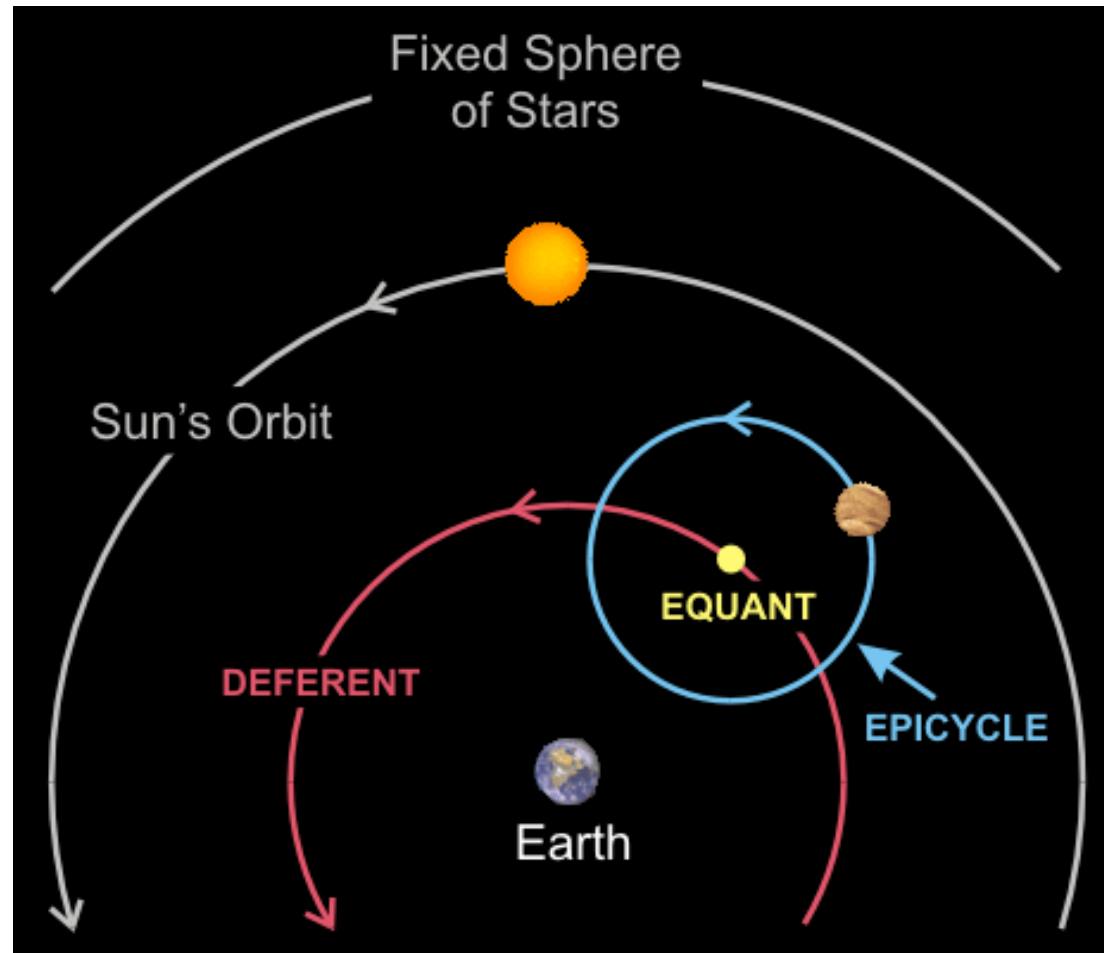
As we will see, Geocentric Models (e.g., Ptolemy's model) do an excellent job predicting the location and brightness of the planets and sun.

Eudoxus's Model for the Motion of Mars

Many different models were created to explain the retrograde motion of Mars and maintain the central position of the Earth

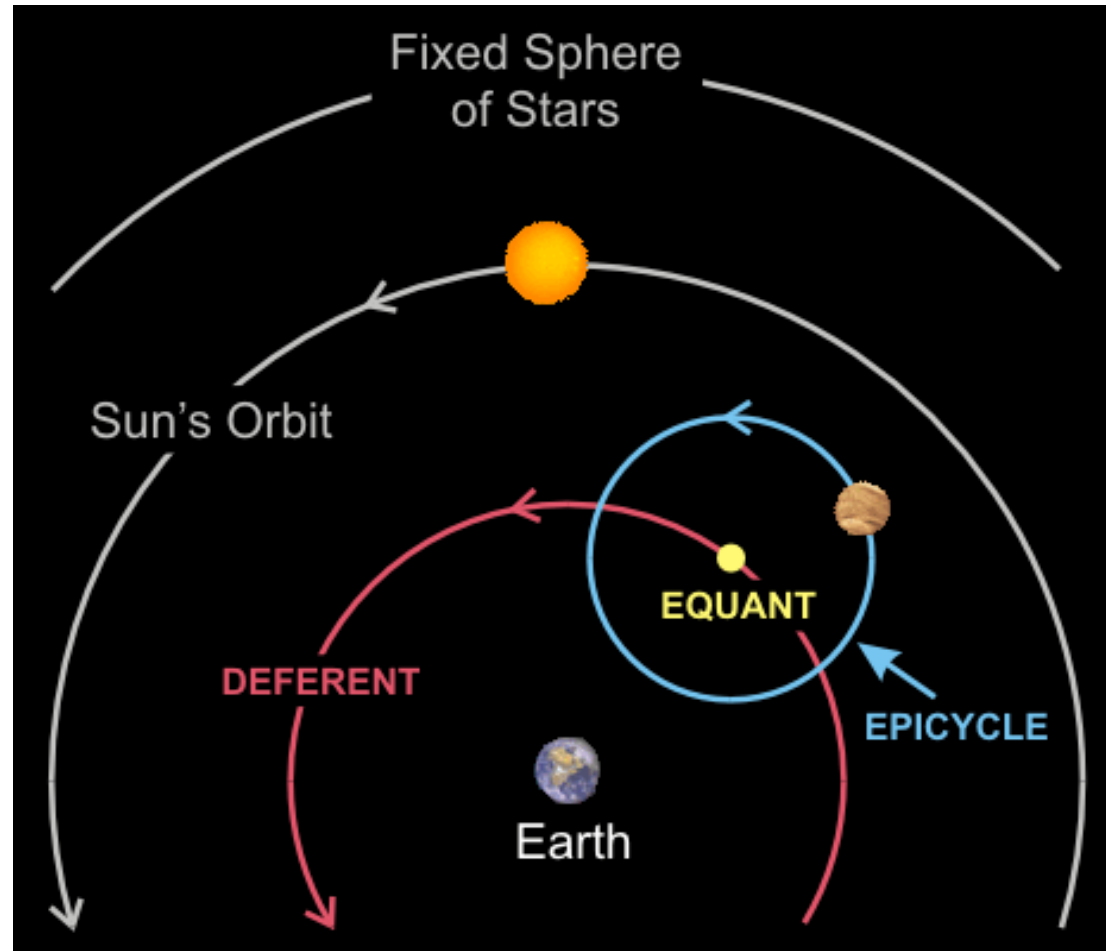


Ptolemy Basic Retrograde Motion Model



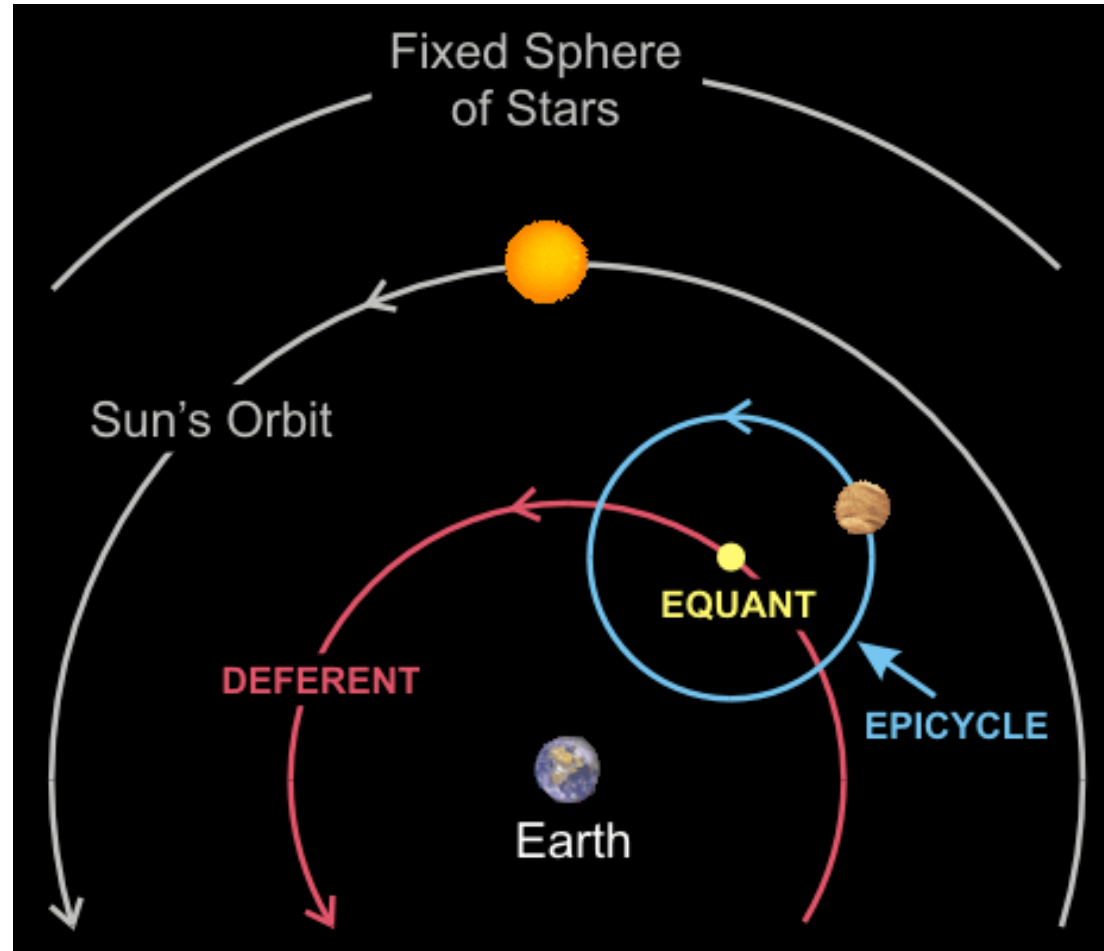
Planet revolves around a small circle called the **epicycle**.

Ptolemy Basic Retrograde Motion Model



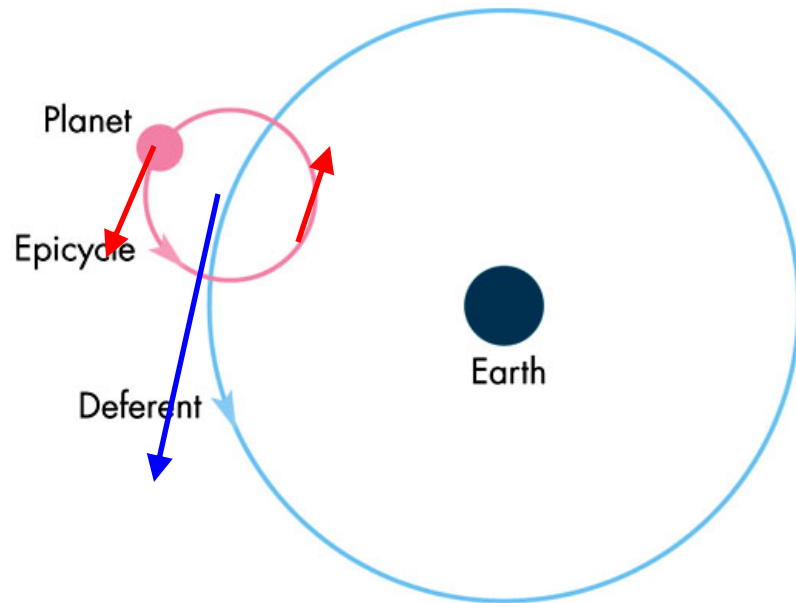
In the basic model, the planet moves around the center of the epicycle at a constant angular speed. Thus we will refer to the center of the epicycle as the **equant**.

Ptolemy Basic Retrograde Motion Model

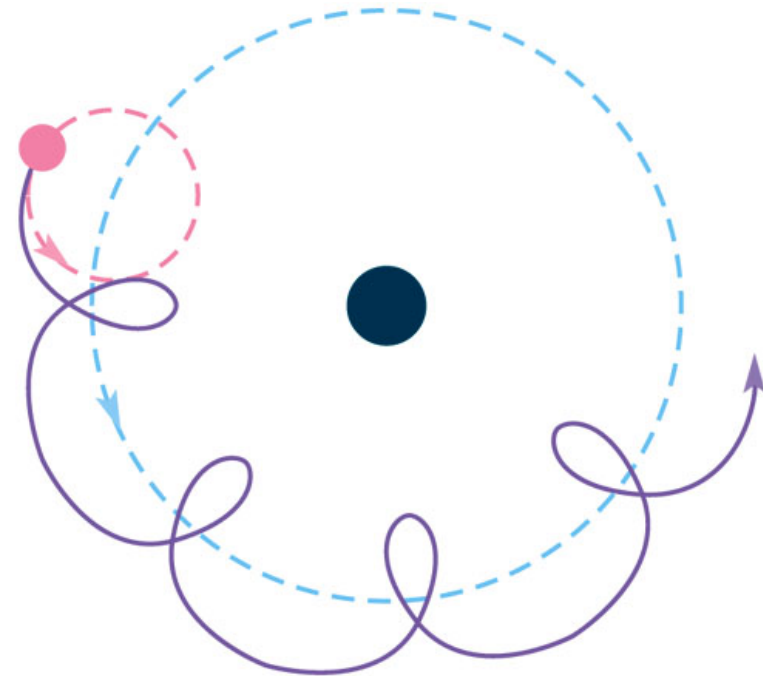


The center of the epicycle revolves around the Earth on a larger circle called the **deferent**.

Ptolemy's Model of Motion of a Planet



A



B

The overall eastward motion of the planet is enhanced when the motion of the planet on the epicycle (red arrow) is in the same direction as the motion along the deferent (blue arrow) and slowed when the motion along the epicycle opposes that along the deferent.

Ptolemy: Basic Model of Planetary Motion

Using the basic model Ptolemy could reproduce a huge variety of paths by adjusting:

- The size of the epicycle**
- The size of the deferent**
- The speed of the planet on the epicycle**
- The speed of the center of the epicycle along the deferent**
- The tilt of the epicycle**

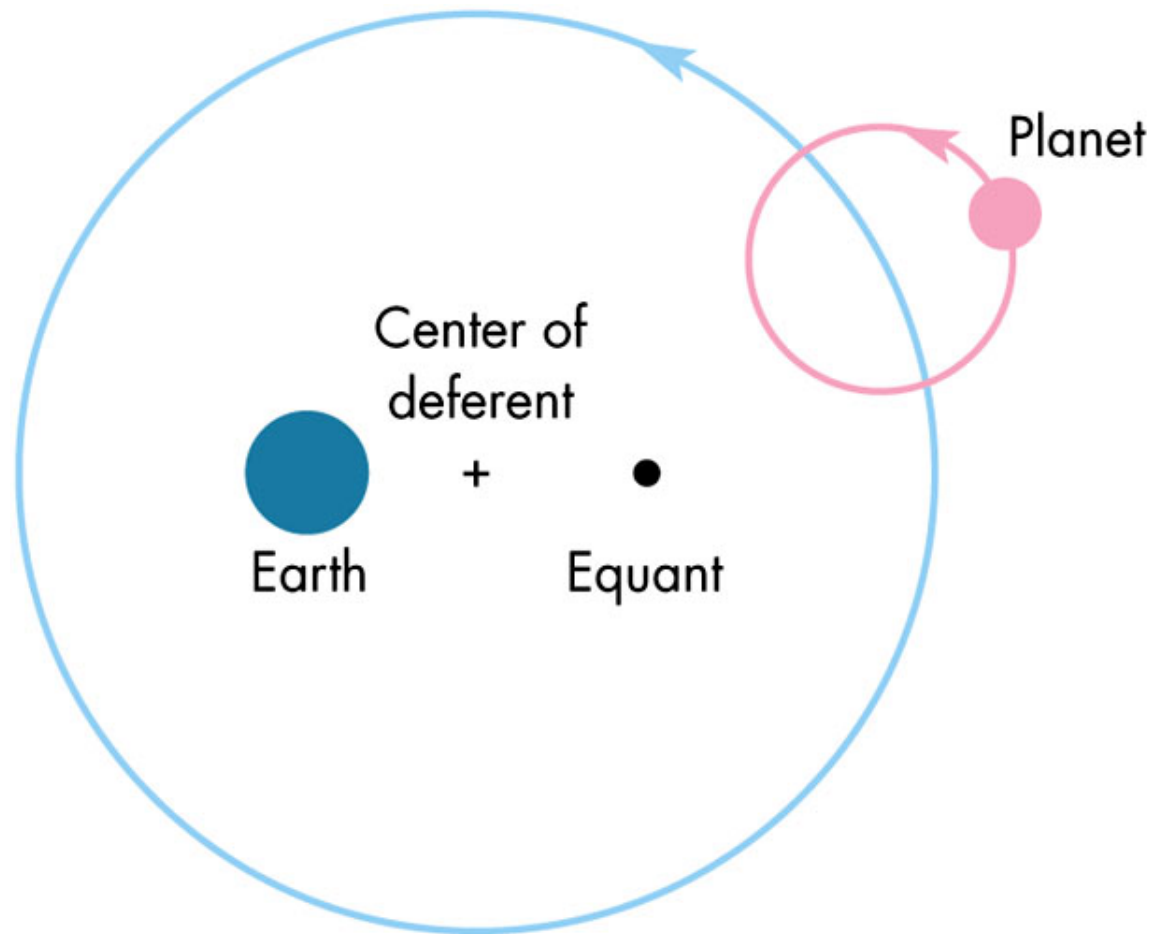
Ptolemy: Basic Model of Planetary Motion

The simulation below shows the wide variety of motions that can be produced using the Ptolemy's model. Thus Ptolemy was able to reproduce the location of the planets with very good accuracy.

To improve the accuracy, Ptolemy created a more complicated model by moving the Earth and the equant of the deferent off the center of the deferent.

<http://astro.unl.edu/naap/ssm/animations/ptolemaic.swf>

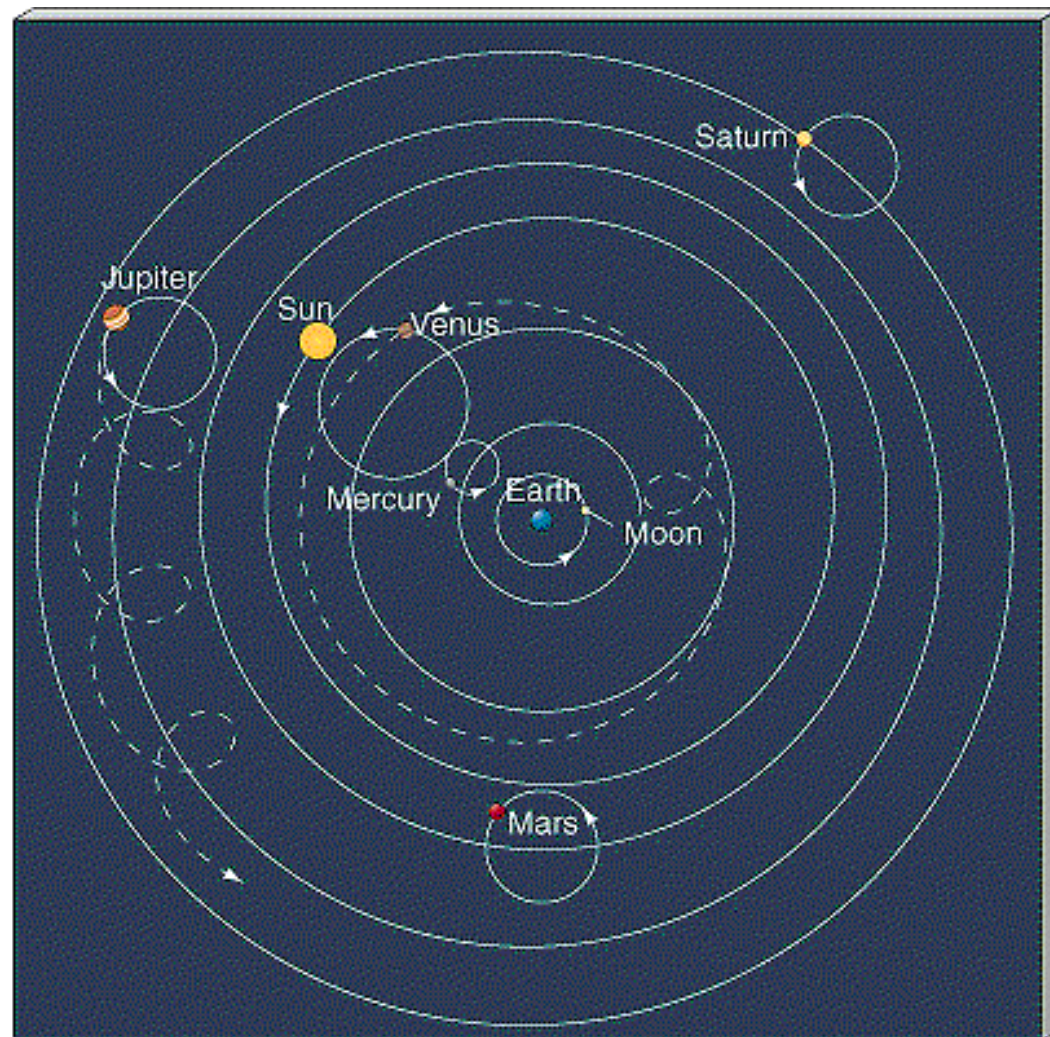
Ptolemy's Advanced Model of Planetary Motion



Retrograde Motion of Jupiter and Saturn

<http://antwrp.gsfc.nasa.gov/apod/ap011220.html>

Ptolemy Retrograde Motion



Support of Geocentric Model

Earth too large to move.

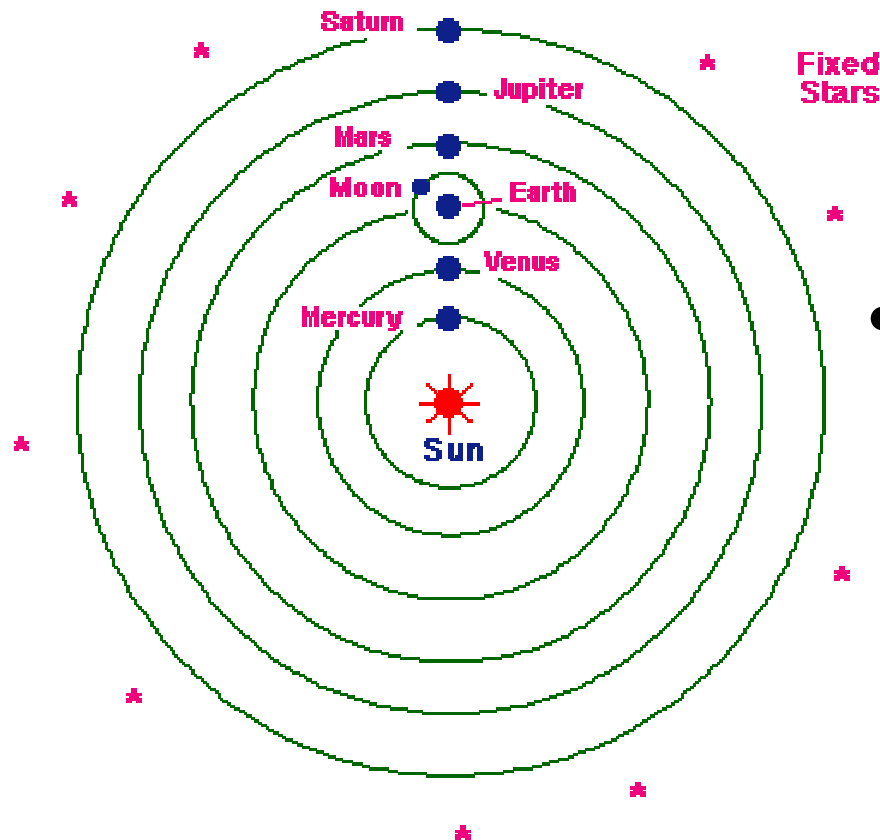
No obvious effects of moving at very high speeds.

No measurable stellar parallax.

<http://instruct1.cit.cornell.edu/courses/astro101/java/parallax/parallax.html>

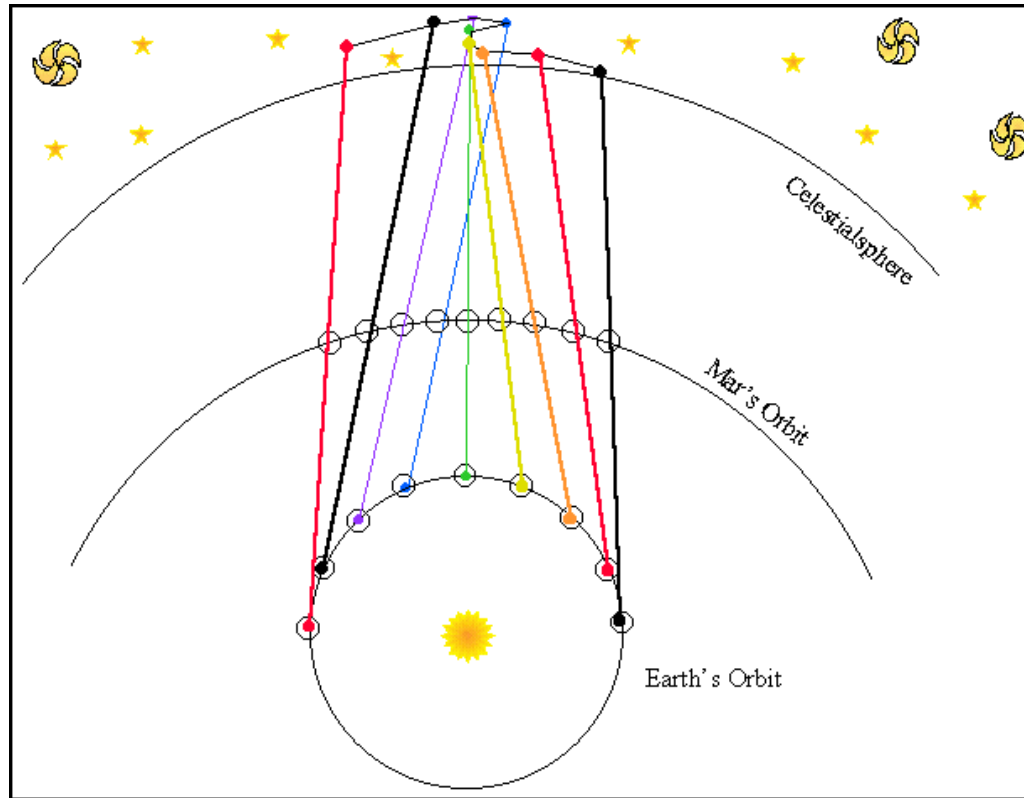
Ptolemy's model did an excellent job predicting the location and brightness of the planets and sun.

Heliocentric Theory of the Solar System



- **Aristarchus of Samos is thought to be the original proponent of the Heliocentric (Sun-Centered) Model**
- **Copernicus (1700 years later) reintroduces the Heliocentric Model to try to provide a simpler more accurate counterpart to Ptolemy's model.**

Retrograde Motion in the Heliocentric Model



In the Heliocentric Model of the Solar System, the Earth and other planets revolve around the sun.

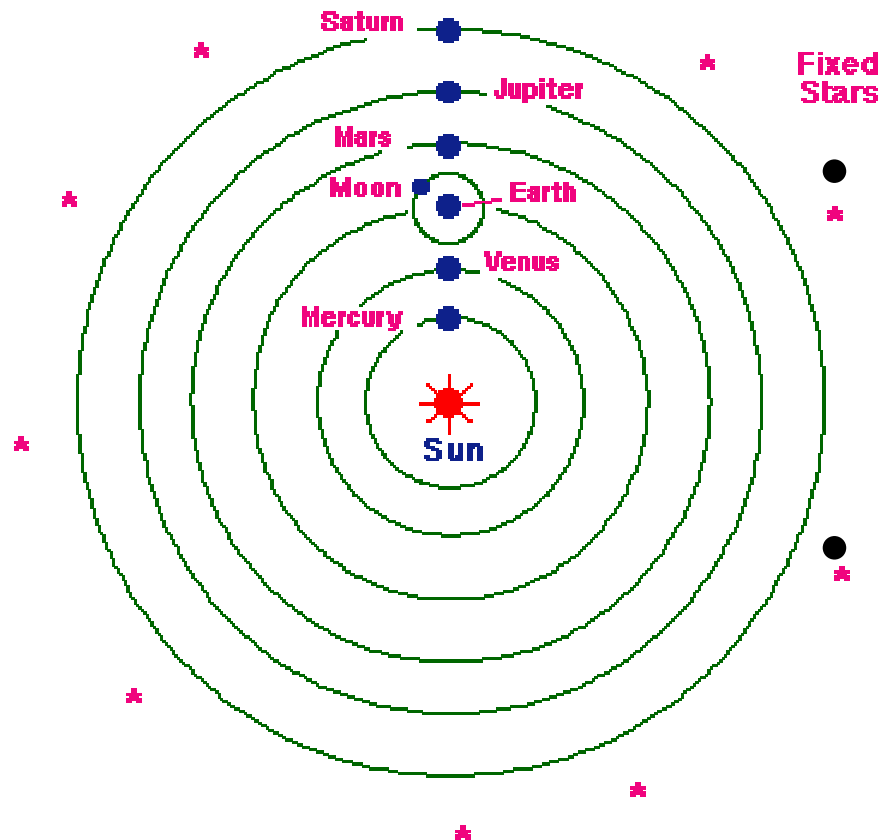
Retrograde motion for outer planets occurs as the Earth passes the planet at opposition. (Like a car you are passing appears to move backwards.)

Retrograde Motion in the Heliocentric Model

[http://alpha.lasalle.edu/~smithsc/Astronomy/
retrograd.html](http://alpha.lasalle.edu/~smithsc/Astronomy/retrograd.html)

Heliocentric Theory of the Solar System

- The Heliocentric Model provides a simple explanation of retrograde motion



- Copernicus Heliocentric Model, like Greek models was heavily dependent on circular motion
- Like Ptolemy's model Copernicus's model was not very accurate (even with complicated perturbations).

Tycho Brahe

- Lived 1546-1601
- Supported by Frederick II of Denmark. Helped him build an observatory on the island of Hven near Copenhagen.
- Built and calibrated larger more stable instrumentation and created a large catalogue of highly accurate astronomical positions.
- Moved to Prague and began work with Johannes Kepler
- Never detected stellar parallax and thus supported a geocentric explanation.



Kepler 1st Laws of Planetary Motion

The planets orbit the sun in ellipses, with the Sun at one focus.

<http://csep10.phys.utk.edu/astr161/lect/history/newtonkepler.html>

Kepler's 2nd Law of Planetary Motion

The line joining the Sun and a planet sweeps through equal areas in equal times.

<http://home.cvc.org/science/kepler.htm>

Kepler's 3rd Law of Planetary Motion

The square of the period of revolution of a planet about the Sun (P, time to go around once) is proportional to the cube of the semi-major axis of the ellipse (a)

$$\mathbf{P^2/a^3 = constant = 1 \text{ yr}^2 / \text{AU}^3}$$

<http://home.cvc.org/science/kepler.htm>

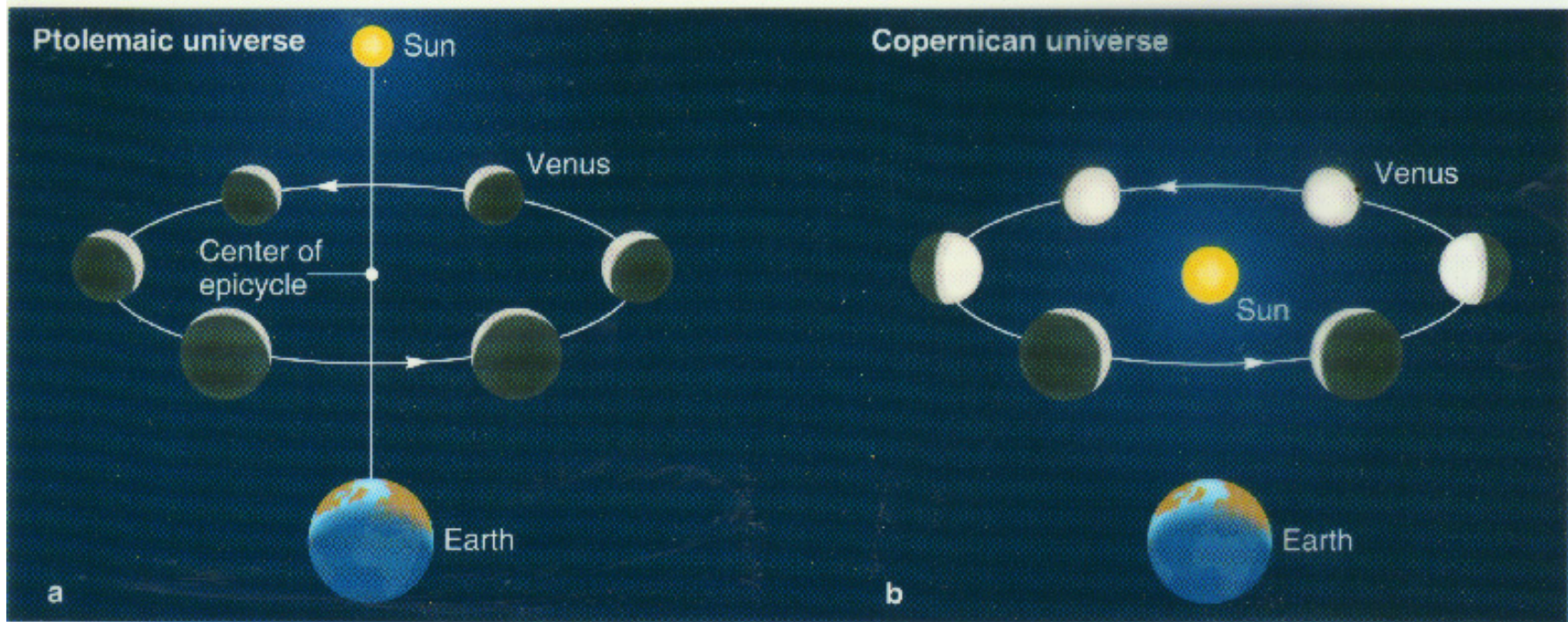
Support Heliocentric Model

Simplicity

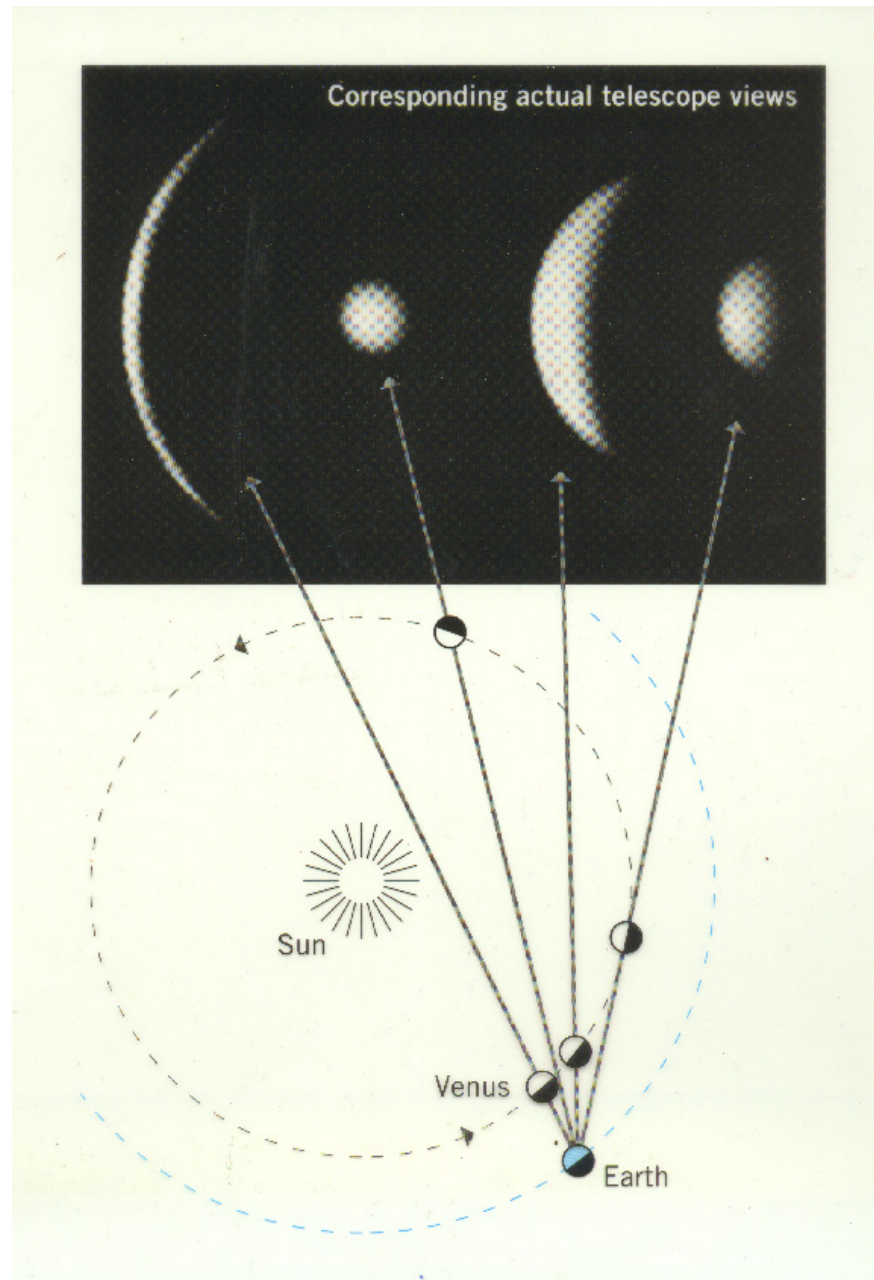
Kepler's Model does a superior job predicting the location (and brightness) of the planets and sun.

Explains the phases of Venus observed by Galileo with an early telescope.

Geocentric Versus Heliocentric: Phases of Venus



Heliocentric: Phases of Venus



Newton and Gravity

In Newton's 2nd Law of Motion we understand that a Force (push or pull) is required to change the velocity (motion, either speed or direction) of the object. [The change in the velocity of an object is also known as acceleration].

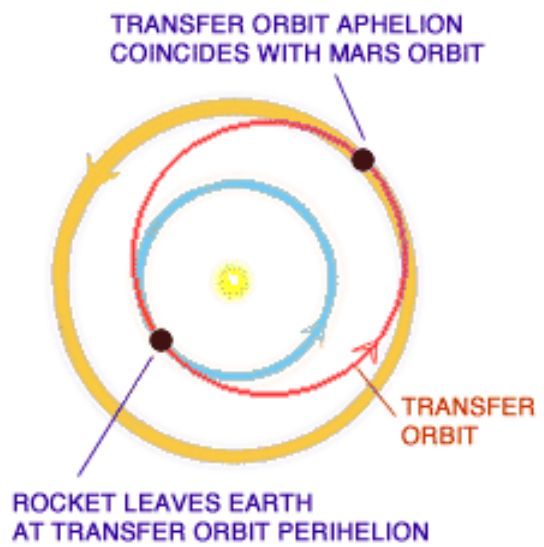
http://www.phys.virginia.edu/classes/109N/more_stuff/Applets/newt/newtmtn.html

Car Headlights separated by .5 meter (L = .5 m)

Car is 1 kilometer away (d = 1 km = 1000 m)

$a = 206,265 (.5 \text{ m}) / (1000 \text{ m}) = 103 \text{ arc seconds}$

- The Ecliptic: Sun's path relative to the stars.
- The Obliquity of the Ecliptic: 23.5°
- Constellations of the Zodiac along the Ecliptic.
- Equinoxes: Sun crosses the Celestial Equator.
- Solstices: Sun at maximum North & South declination.
- Length of the day depends on the location of the Sun along the Ecliptic.



Greek Astronomy: Angles and Distance

Part of their achievement in geometry was to understand and apply the relationship between angle, distance (and/or size)

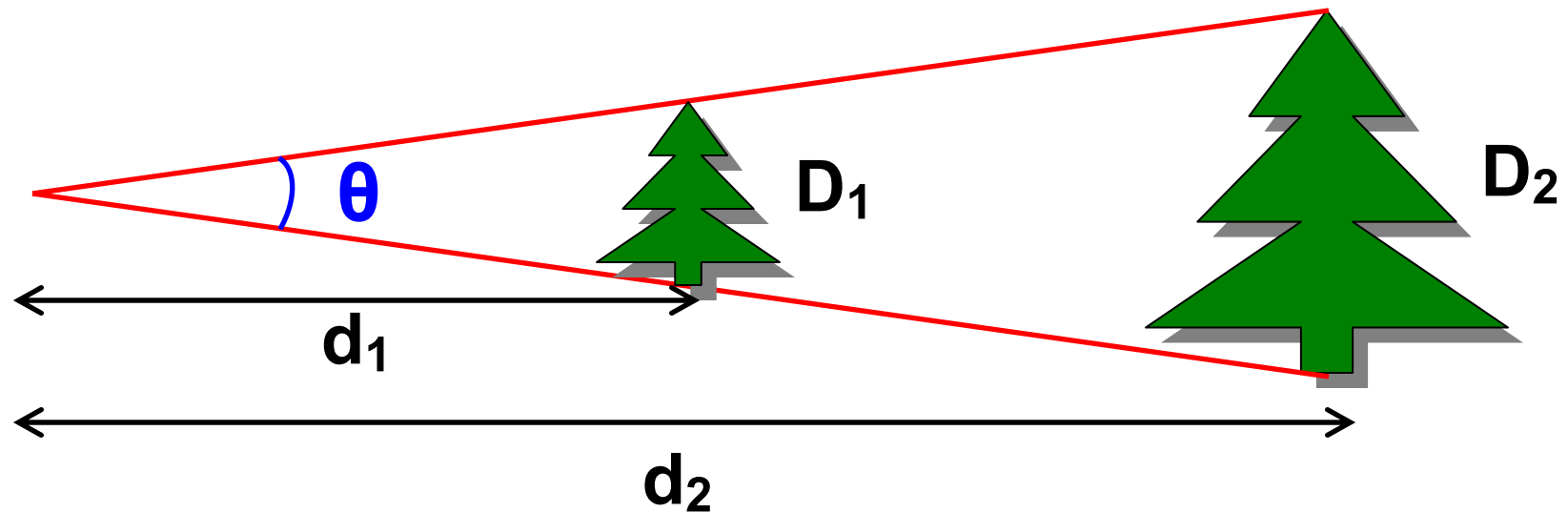
Astronomers use angles to measure how the *size* (angular) of an object. That is the angle the object subtends. However, you can not determine how big an object actually is from the angle unless you know the distance to the object.

Greek Astronomy: Angles and Distance

The understanding of the relationship between the angle subtended by an object, the *size* of the object, and the distance played an integral role in the estimation of the size of the Earth (Eratosthenes), the size and distance of the Moon (Aristarchus and Hipparchus) and the distance of the Sun (Aristarchus)

Their fondness for fundamental geometry also guided their interpretation of the motion of the heavenly bodies in terms of circles, the most fundamental and perfect shape.

Greek Astronomy: Angles and Distance



Note: d is distance to the object, D is the linear size of the object.

While both trees subtend the same angle, they clearly have different sizes because of their distance (however d/D will be constant.

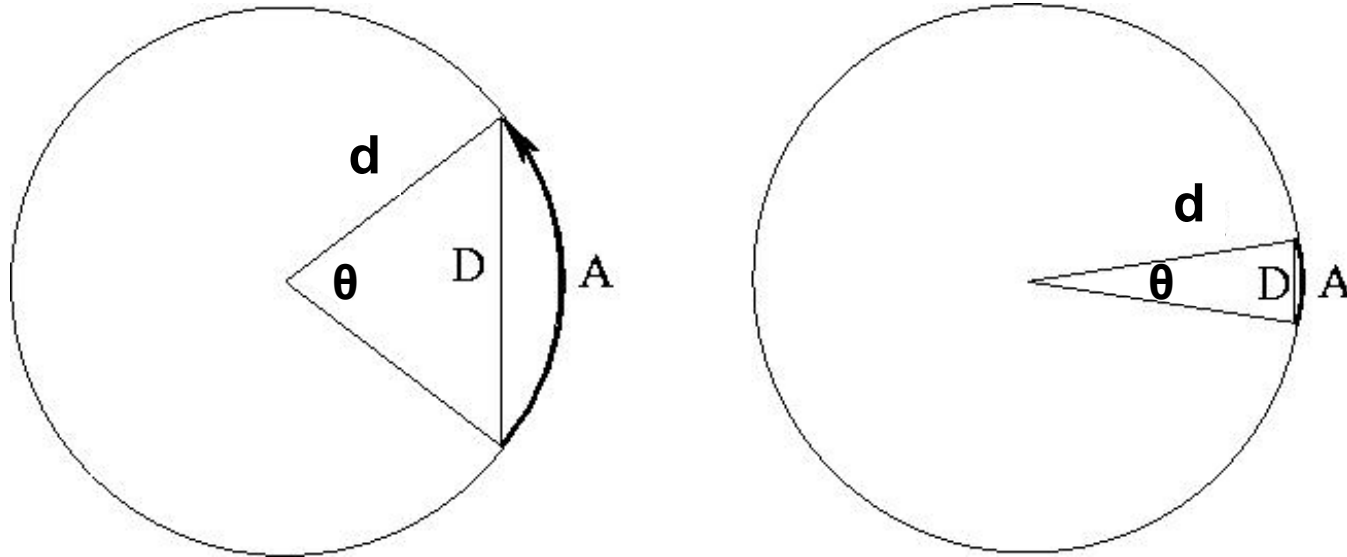
Greek Astronomy: Angles and Distance

The relationship between distance and angle is routed in the formula for the circumference of a circle

$$**c = 2\pi r**$$

$$**Size = Angle (radians) * Distance**$$

Greek Astronomy: Angles and Distance



Like $C = 2\pi r$ for the circumference of the circle, using the variables above, $A = \theta d$ for the arc, A . Note that as the angle gets smaller D becomes the same distance as A . θ is measured in radians (1 radian = 57.3° , $1^\circ = 3600$ seconds of arc)

