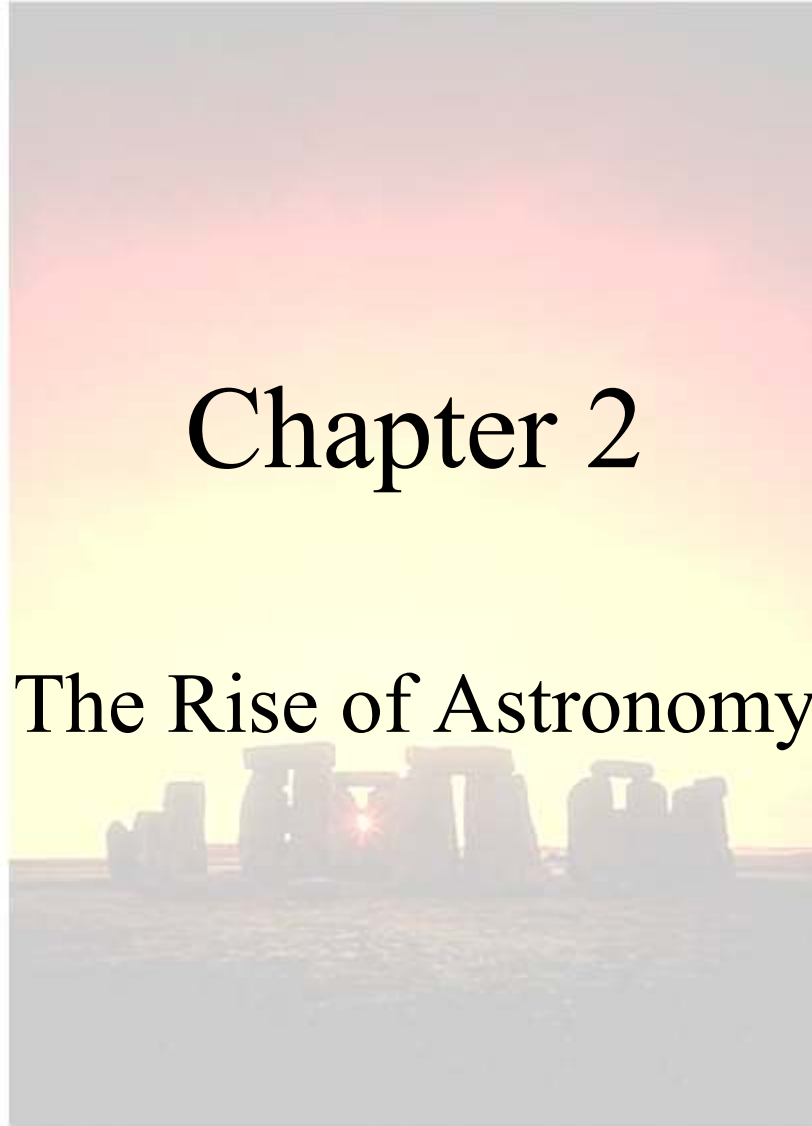


Chapter 2

The Rise of Astronomy

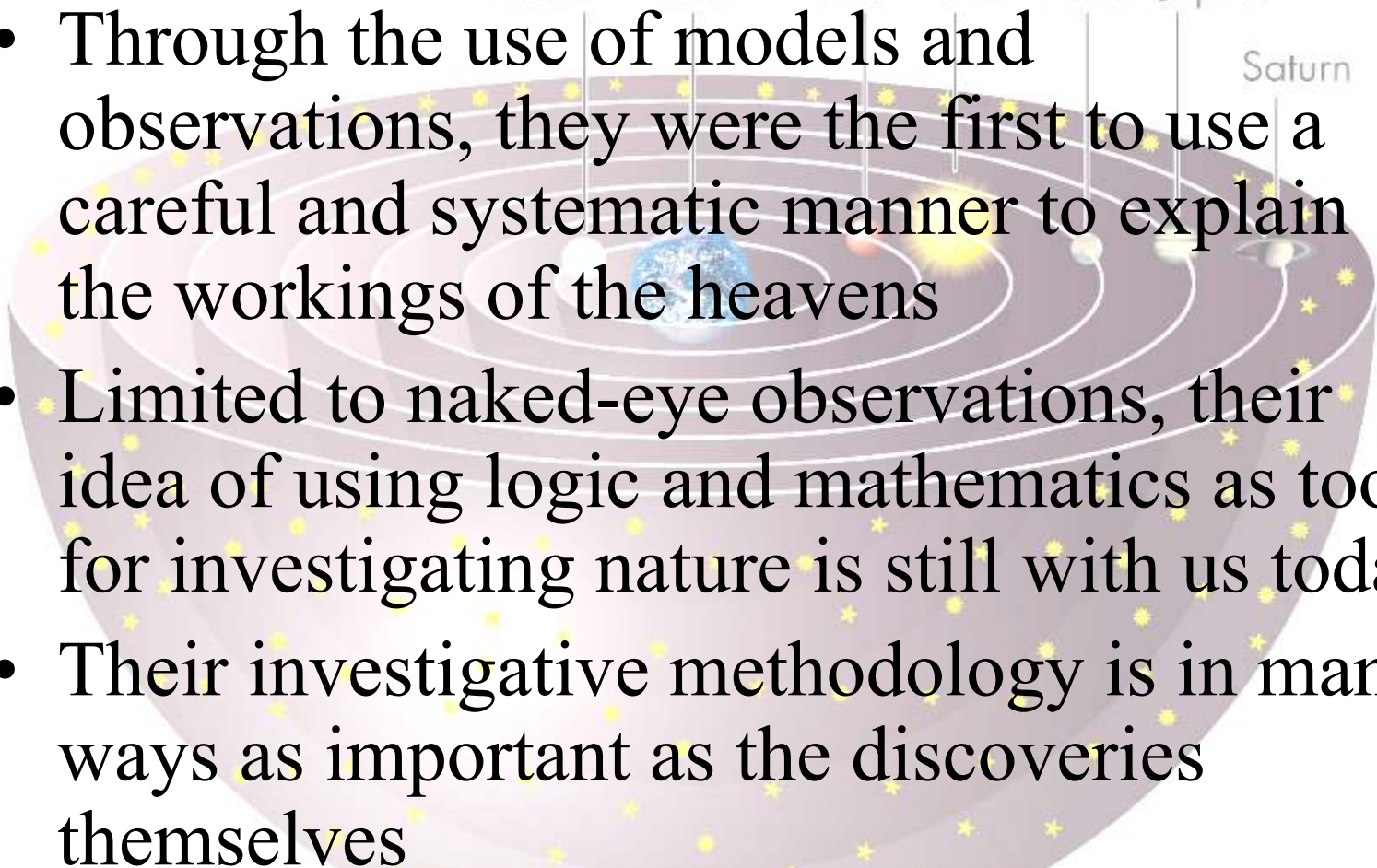


Periods of Western Astronomy

- Western astronomy divides into 4 periods
 - Prehistoric (before 500 B.C.)
 - Cyclical motions of Sun, Moon and stars observed
 - Keeping time and determining directions develops
 - Classical (500 B.C. to A.D. 1400)
 - Measurements of the heavens
 - Geometry and models to explain motions
 - Renaissance (1400 to 1650)
 - Accumulation of data led to better models
 - Technology (the telescope) enters picture
 - Modern (1650 to present)
 - Physical laws and mathematical techniques
 - Technological advances accelerate

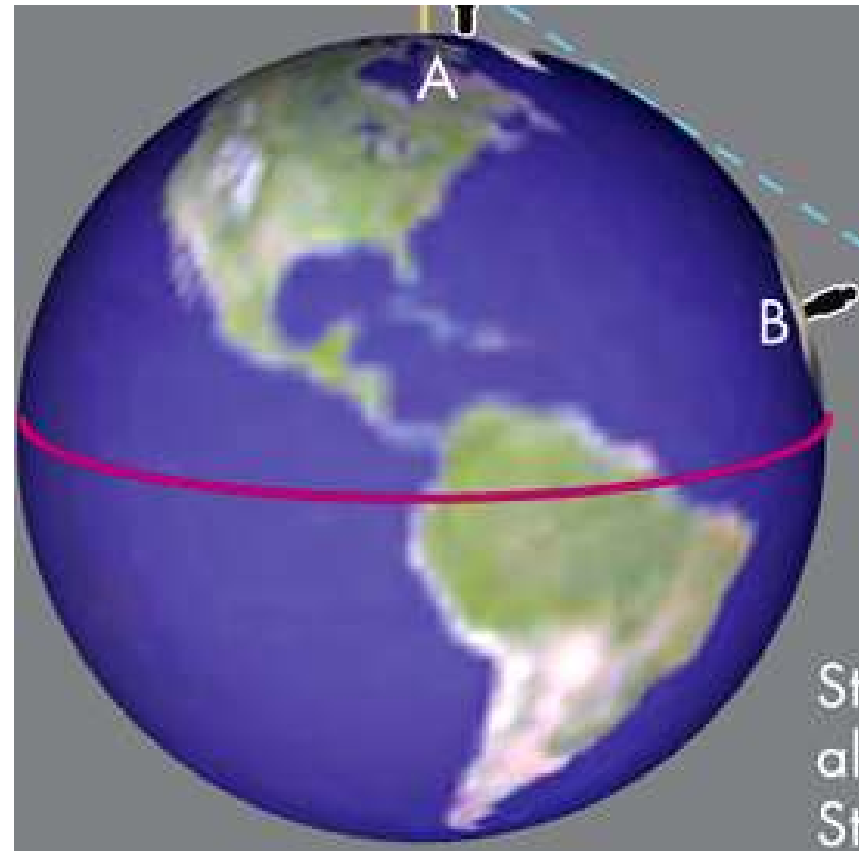
Ancient Greek Astronomers

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- 
- Through the use of models and observations, they were the first to use a careful and systematic manner to explain the workings of the heavens
 - Limited to naked-eye observations, their idea of using logic and mathematics as tools for investigating nature is still with us today
 - Their investigative methodology is in many ways as important as the discoveries themselves

Early Ideas: Pythagoras

- Pythagoras taught as early as 500 B.C. that the Earth was round, based on the belief that the sphere is the perfect shape used by the gods



Early Ideas: Aristotle

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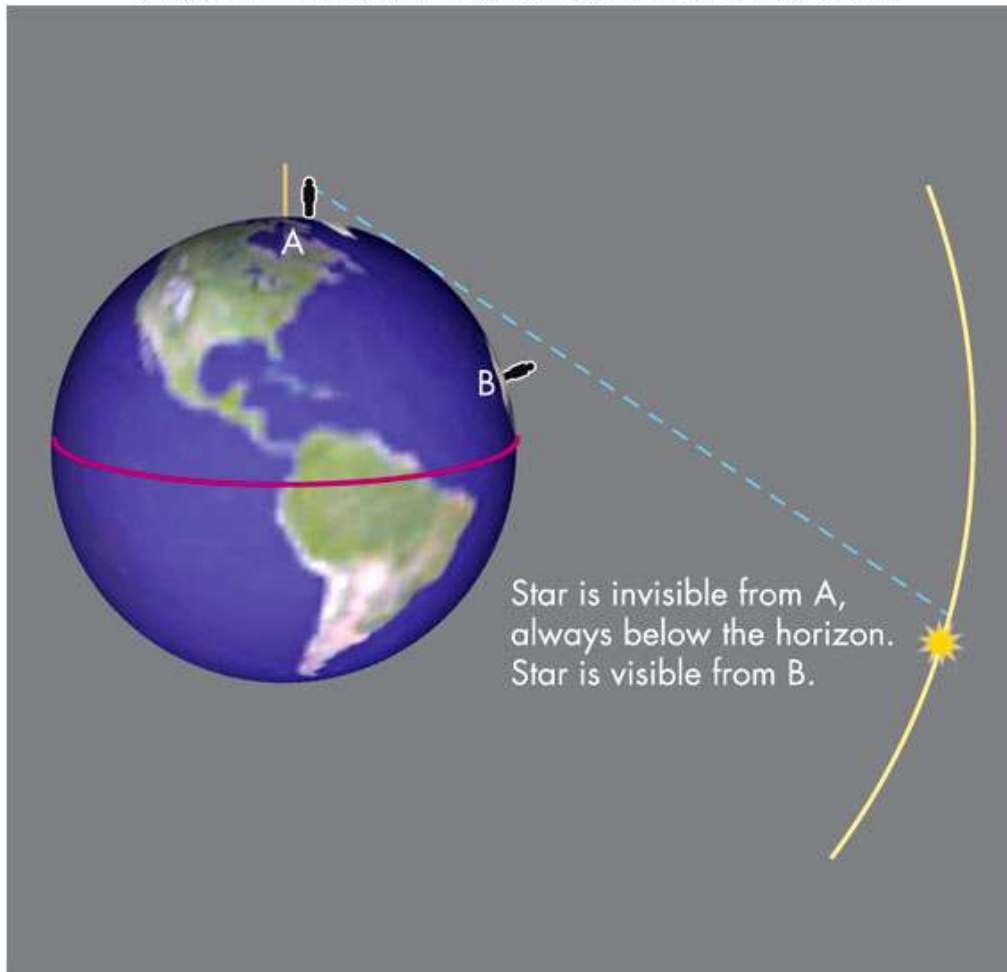


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- By 300 B.C., Aristotle presented naked-eye observations for the Earth's spherical shape:
 - Shape of Earth's shadow on the Moon during an eclipse

Early Ideas: Aristotle

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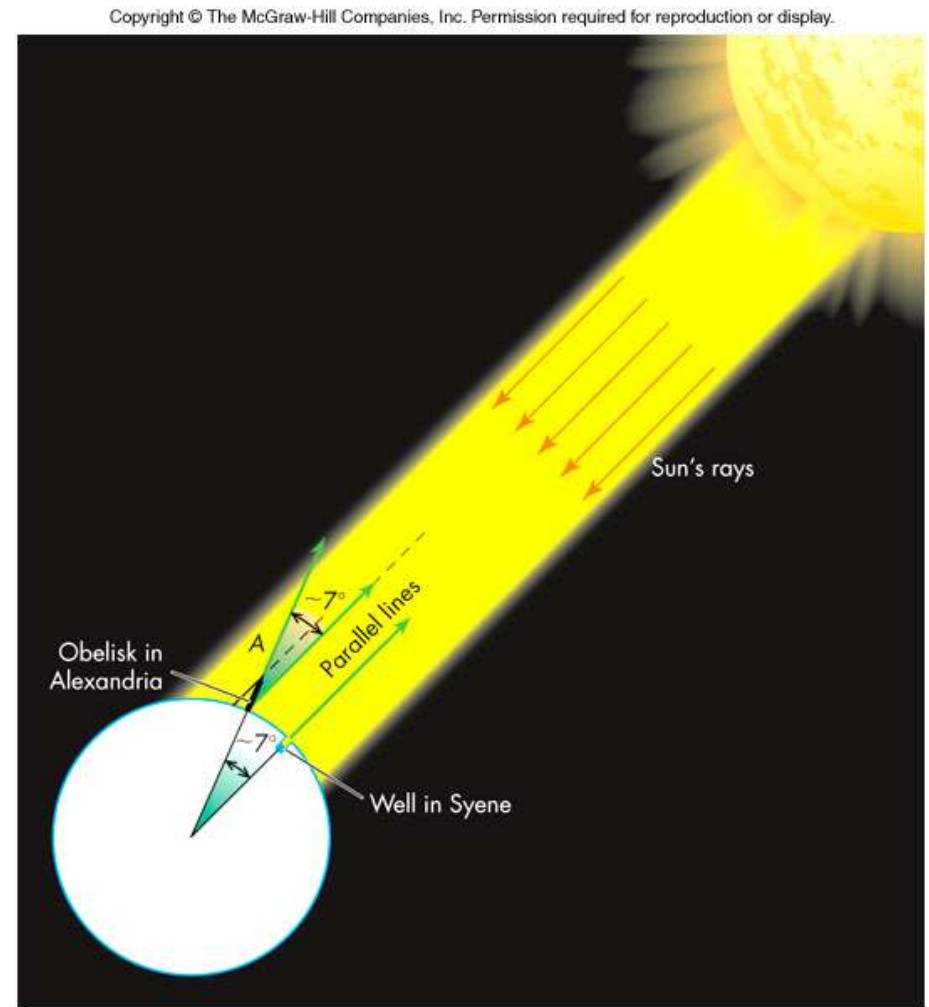


B

- He also noted that a traveler moving south will see stars previously hidden by the southern horizon

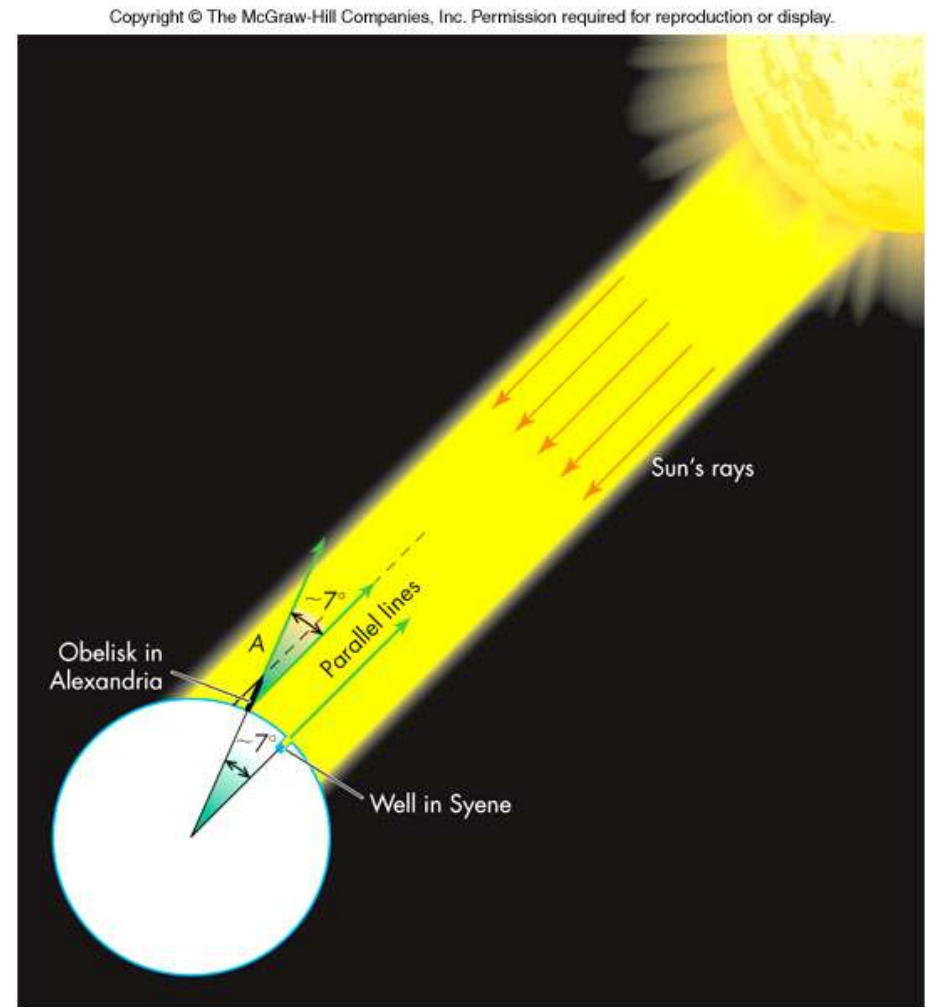
Early Ideas: The Size of the Earth

- Eratosthenes (276-195 B.C.) made the first measurement of the Earth's size
- He obtained a value of 25,000 miles for the circumference, a value very close to today's value



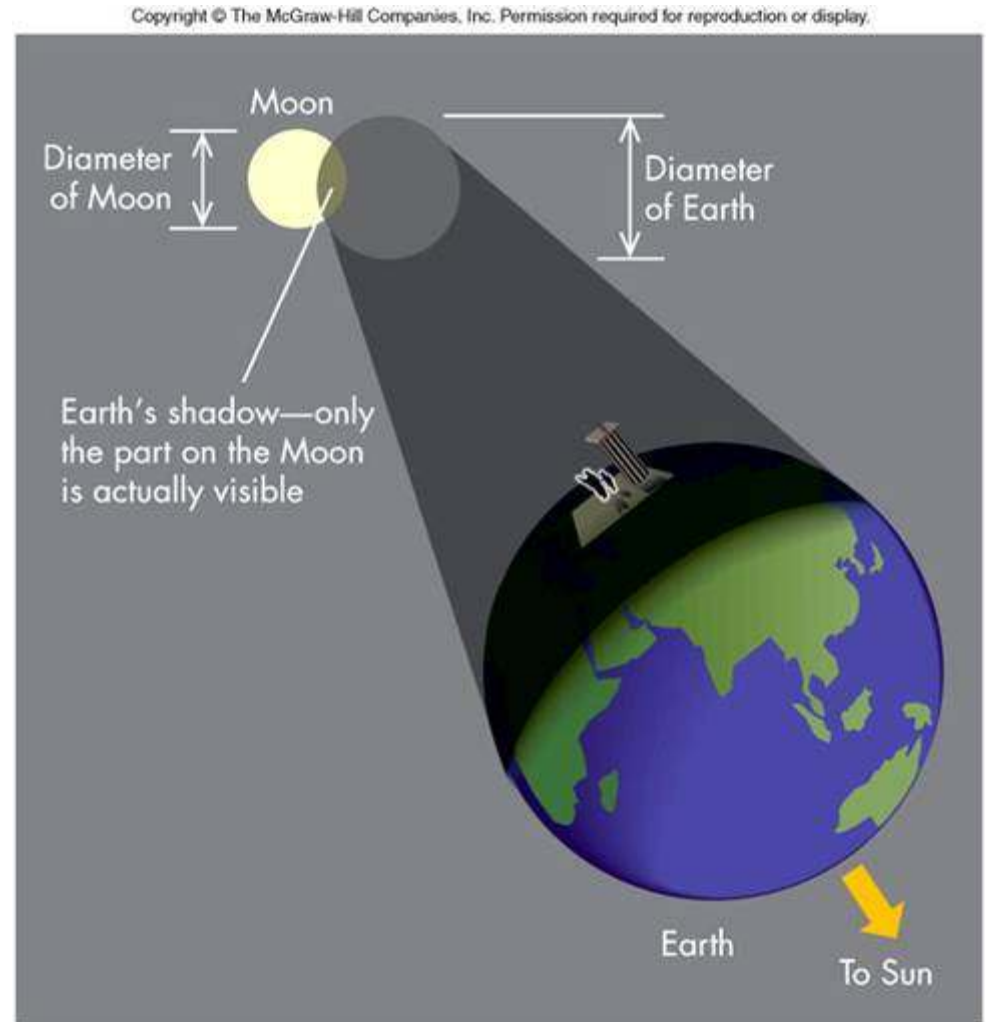
Early Ideas: The Size of the Earth

- He measured the shadow length of a stick set vertically in the ground in the town of Alexandria on the summer solstice at noon, converting the shadow length to an angle of solar light incidence, and using the distance to Syene, a town where no shadow is cast at noon on the summer solstice



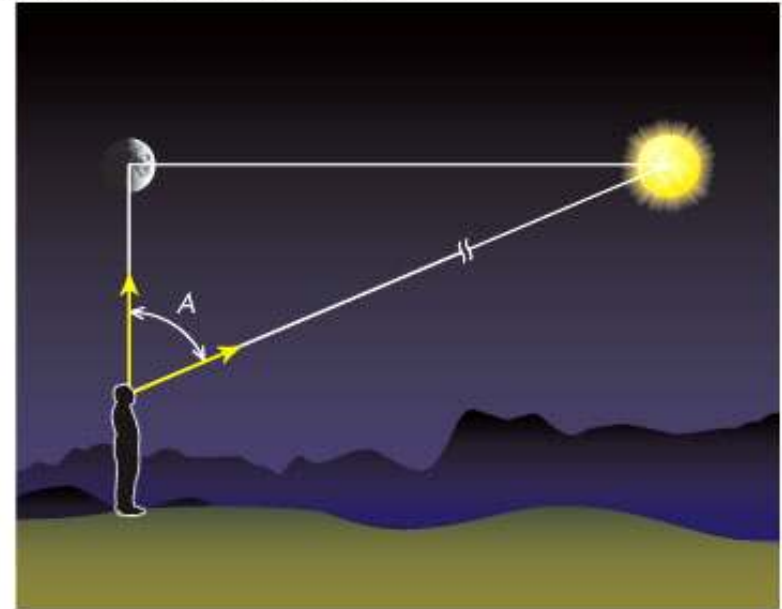
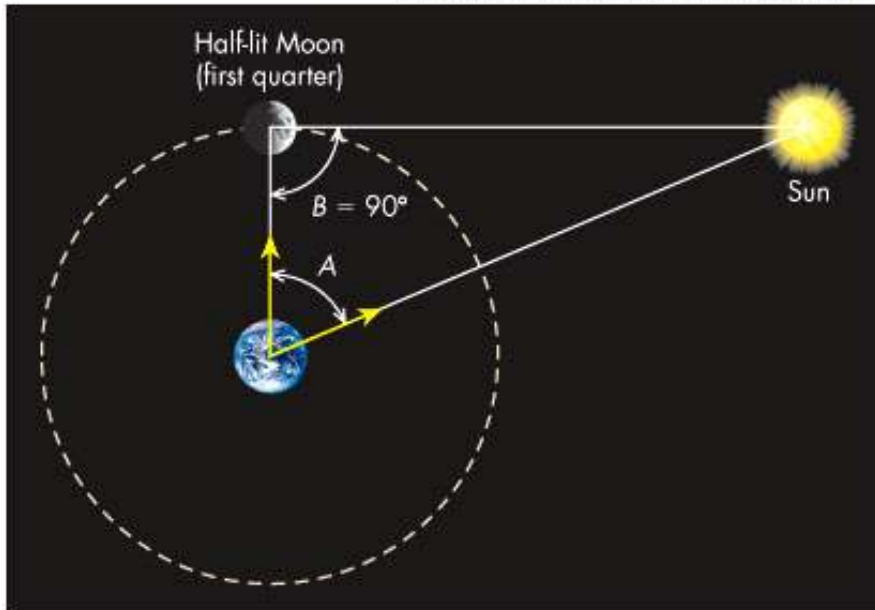
Early Ideas: Distance and Size of the Sun and Moon

- The sizes and distances of the Sun and Moon relative to Earth were determined by Aristarchus about 75 years before Eratosthenes measured the Earth's size
- Once the actual size of the Earth was determined, the absolute sizes and distances of the Sun and Moon could be determined



Early Ideas: Distance and Size of the Sun and Moon

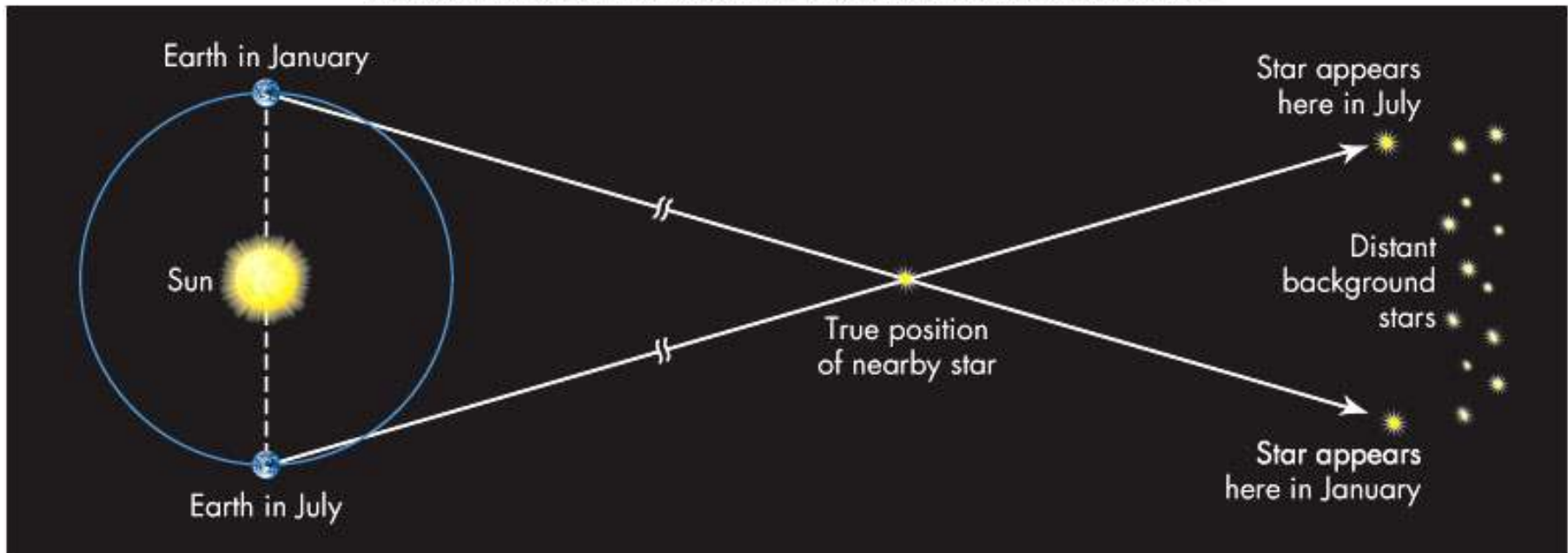
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- These relative sizes were based on the *angular size* of objects and a simple geometry formula relating the object's diameter, its angular size, and its distance

Early Ideas: Distance and Size of the Sun and Moon

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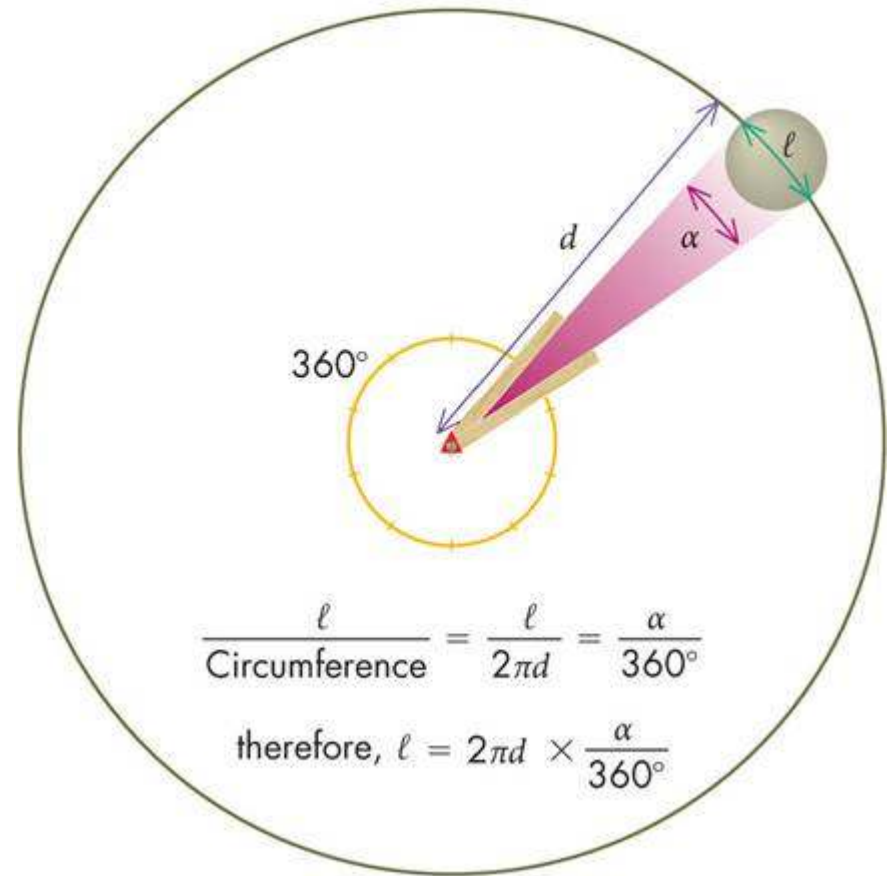
- Aristarchus, realizing the Sun was very large, proposed the Sun as center of the Solar System, but the lack of *parallax* argued against such a model

Measuring the Diameter of Astronomical Objects

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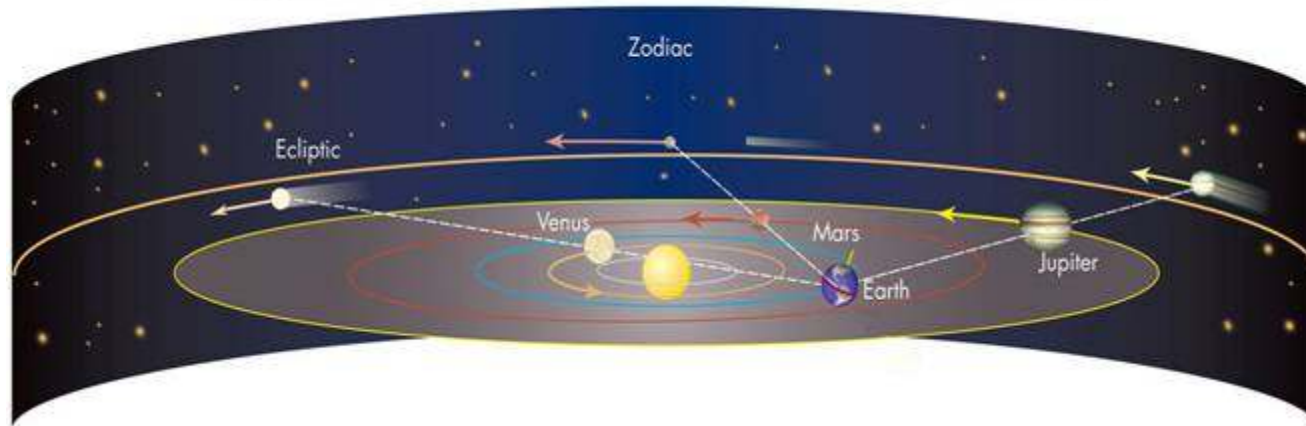
$$l = 2\pi d \times \frac{\alpha}{360^\circ}$$

l – linear size of object
 d – distance to object
 α – angular size of object



Planets and the Zodiac

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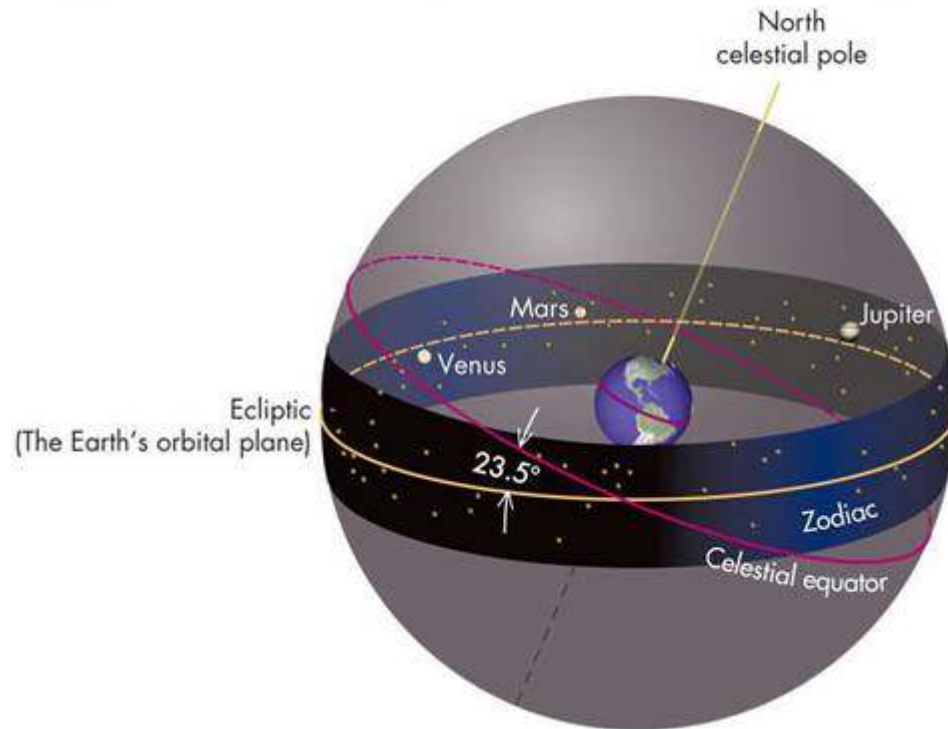


- The planets (Greek for “wanderers”) do not follow the same cyclic behavior of the stars
- The planets move relative to the stars in a very narrow band centered about the ecliptic and called the *zodiac*
- Motion and location of the planets in the sky is a combination of all the planets’ orbits being nearly in the same plane and their relative speeds about the Sun

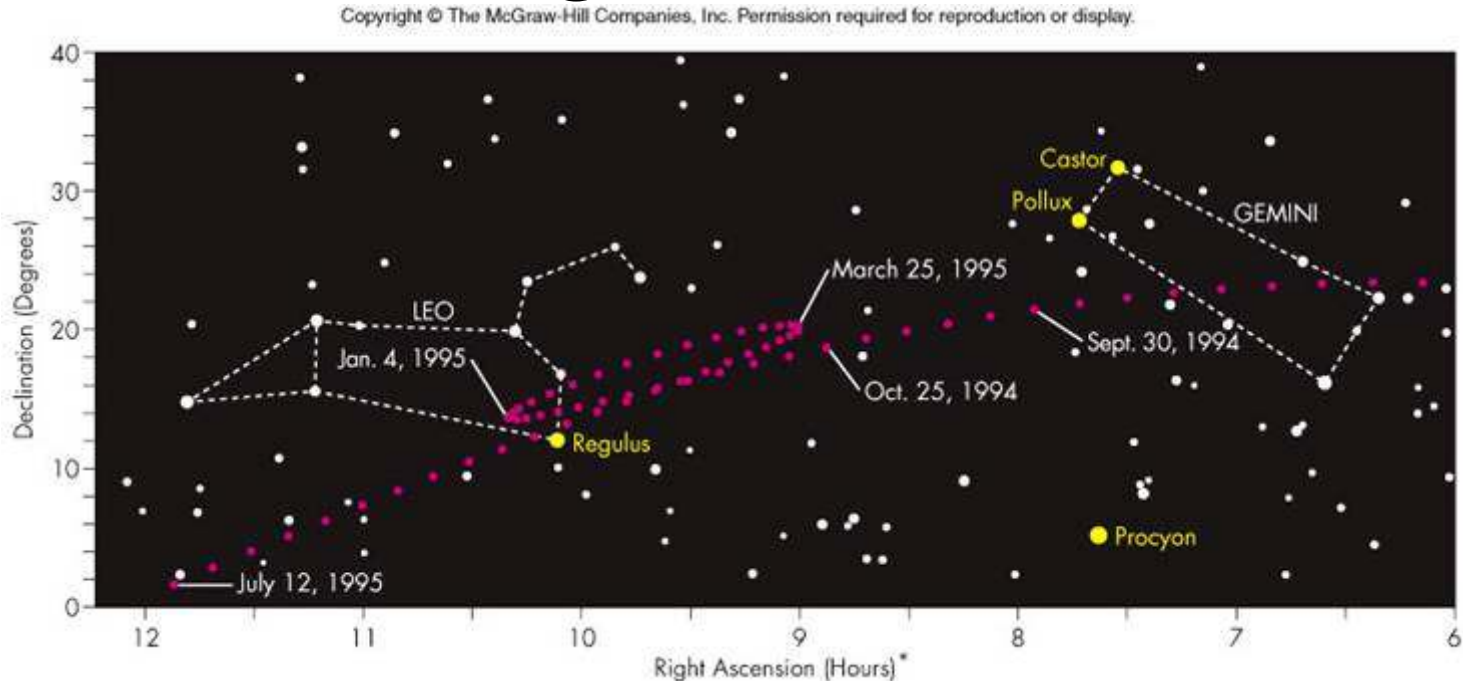
Planets and the Zodiac

- Apparent motion of planets is usually from west to east relative to the stars, although on a daily basis, the planets always rise in the east

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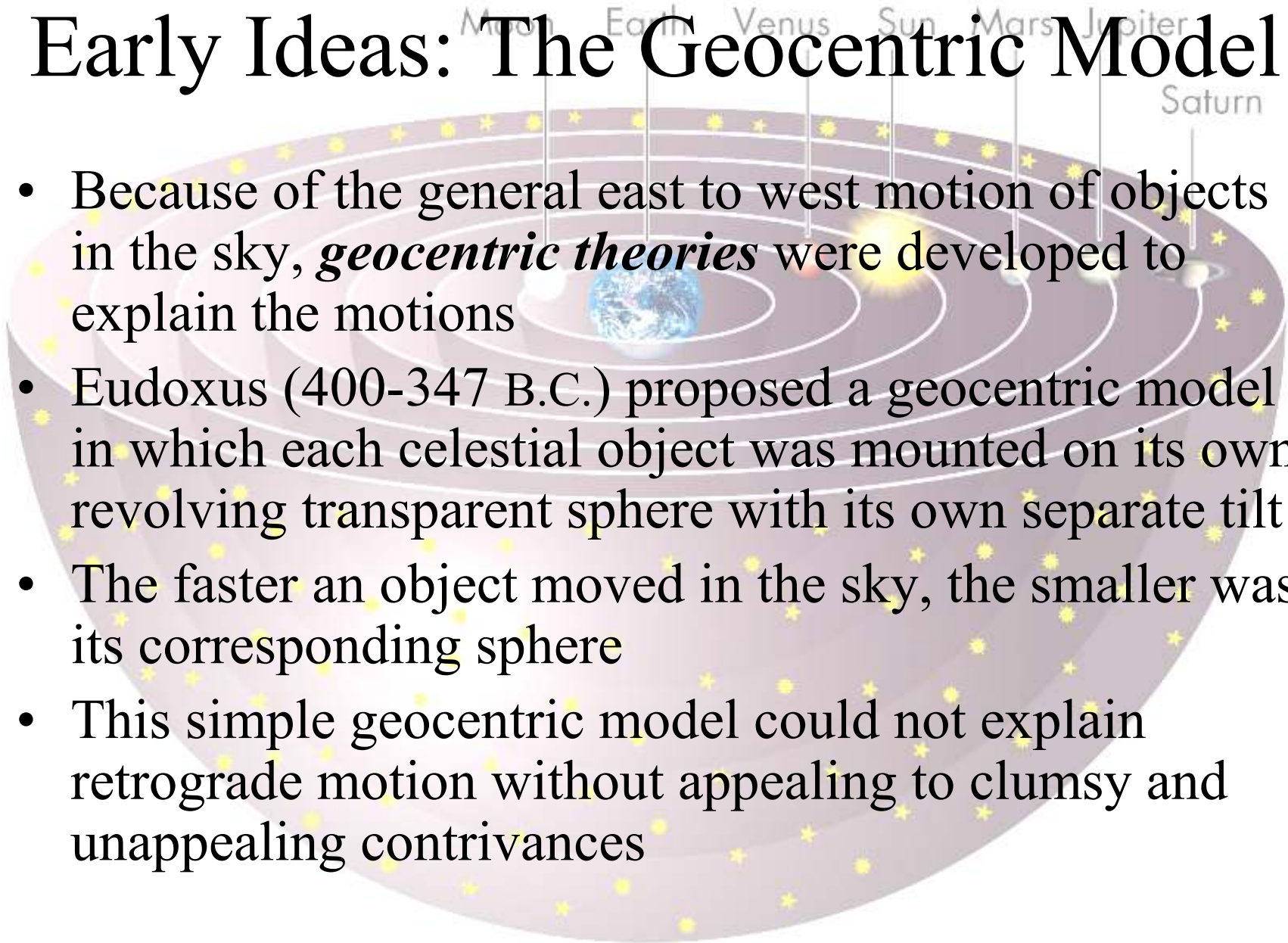
Retrograde Motion



- Occasionally, a planet will move from east to west relative to the stars; this is called *retrograde motion*
- Explaining retrograde motion was one of the main reasons astronomers ultimately rejected the idea of the Earth being located at the center of the solar system

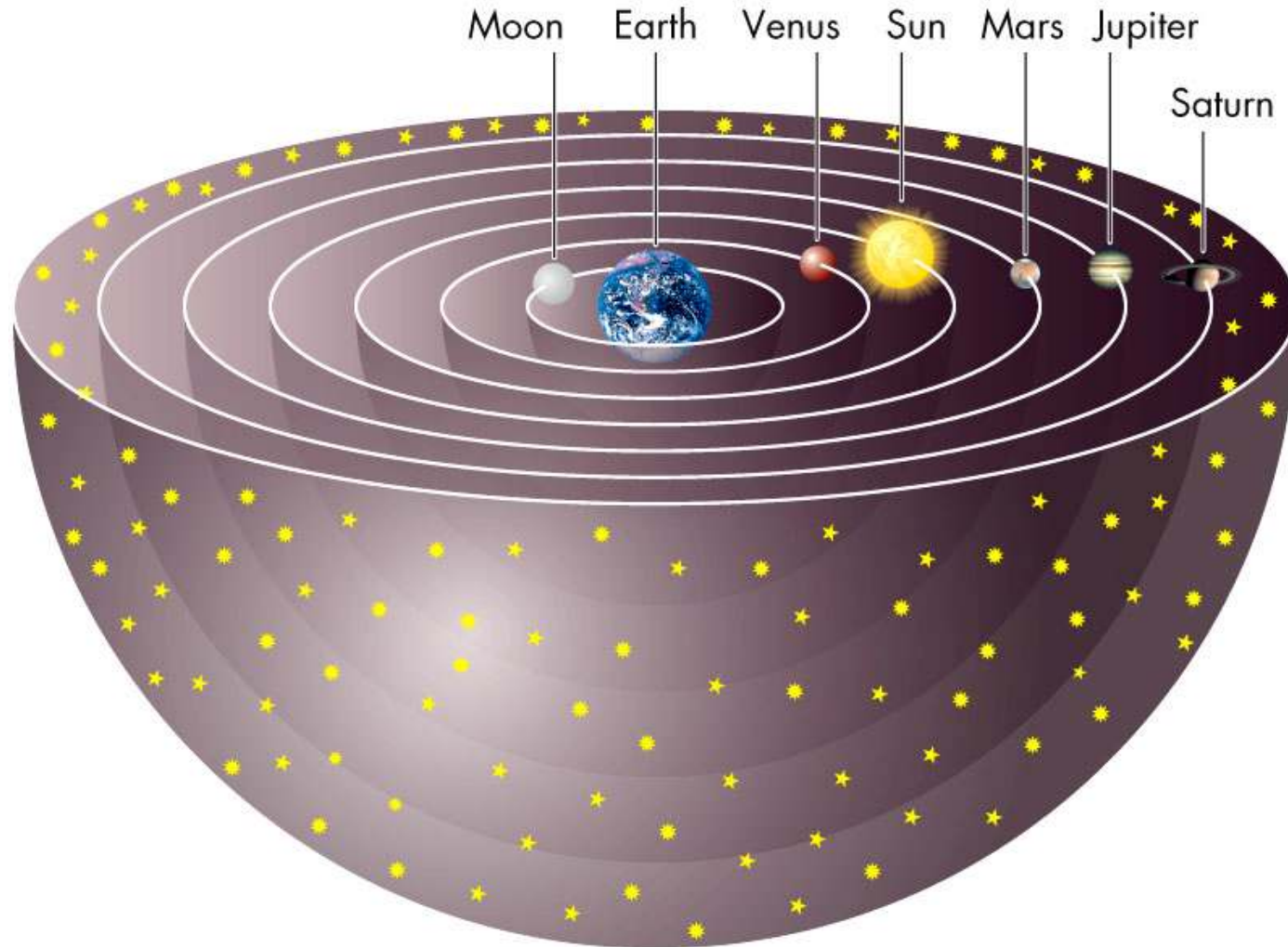
Early Ideas: The Geocentric Model

- Because of the general east to west motion of objects in the sky, *geocentric theories* were developed to explain the motions
- Eudoxus (400-347 B.C.) proposed a geocentric model in which each celestial object was mounted on its own revolving transparent sphere with its own separate tilt
- The faster an object moved in the sky, the smaller was its corresponding sphere
- This simple geocentric model could not explain retrograde motion without appealing to clumsy and unappealing contrivances



Early Ideas: The Geocentric Model

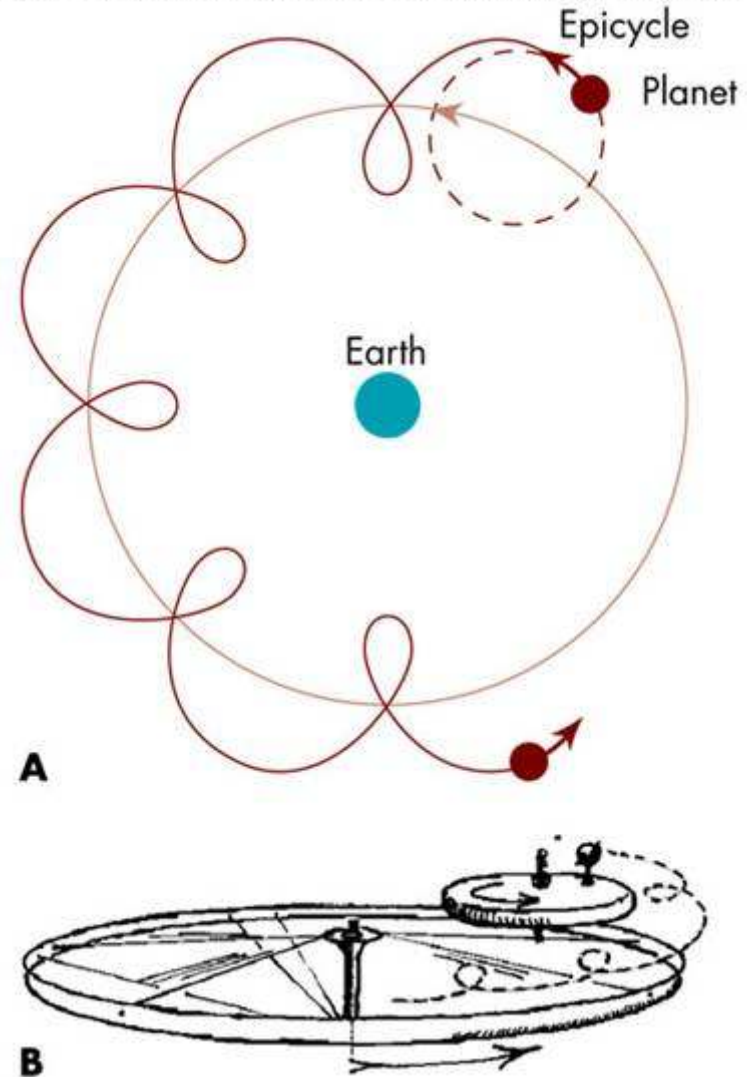
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Ptolemy of Alexandria

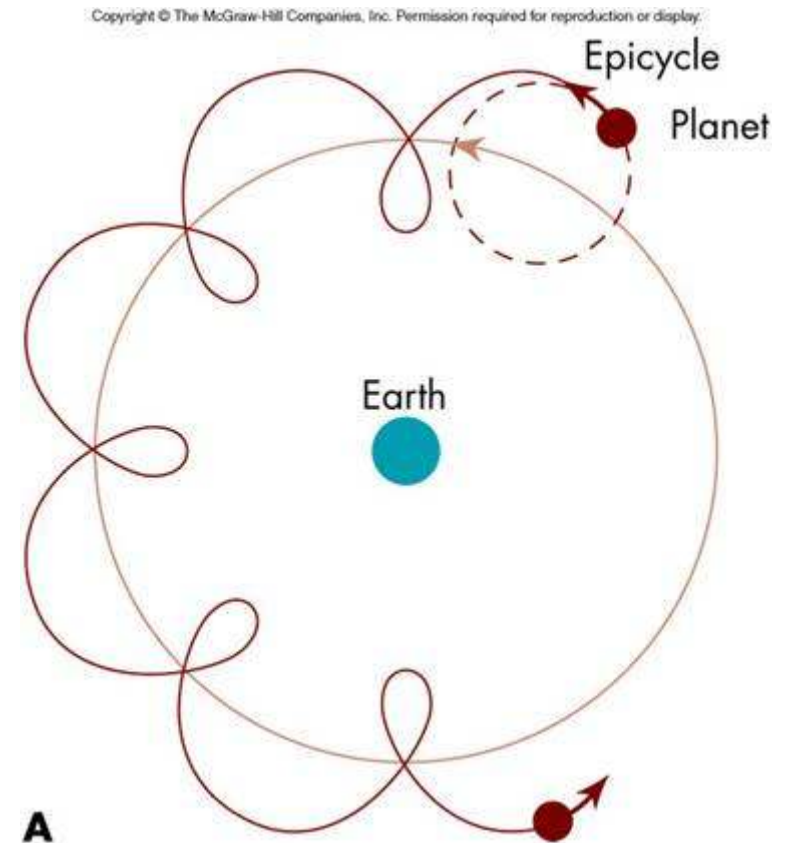
- Ptolemy of Alexandria improved the geocentric model by assuming each planet moved on a small circle, which in turn had its center move on a much larger circle centered on the Earth
- The small circles were called *epicycles* and were incorporated so as to explain retrograde motion

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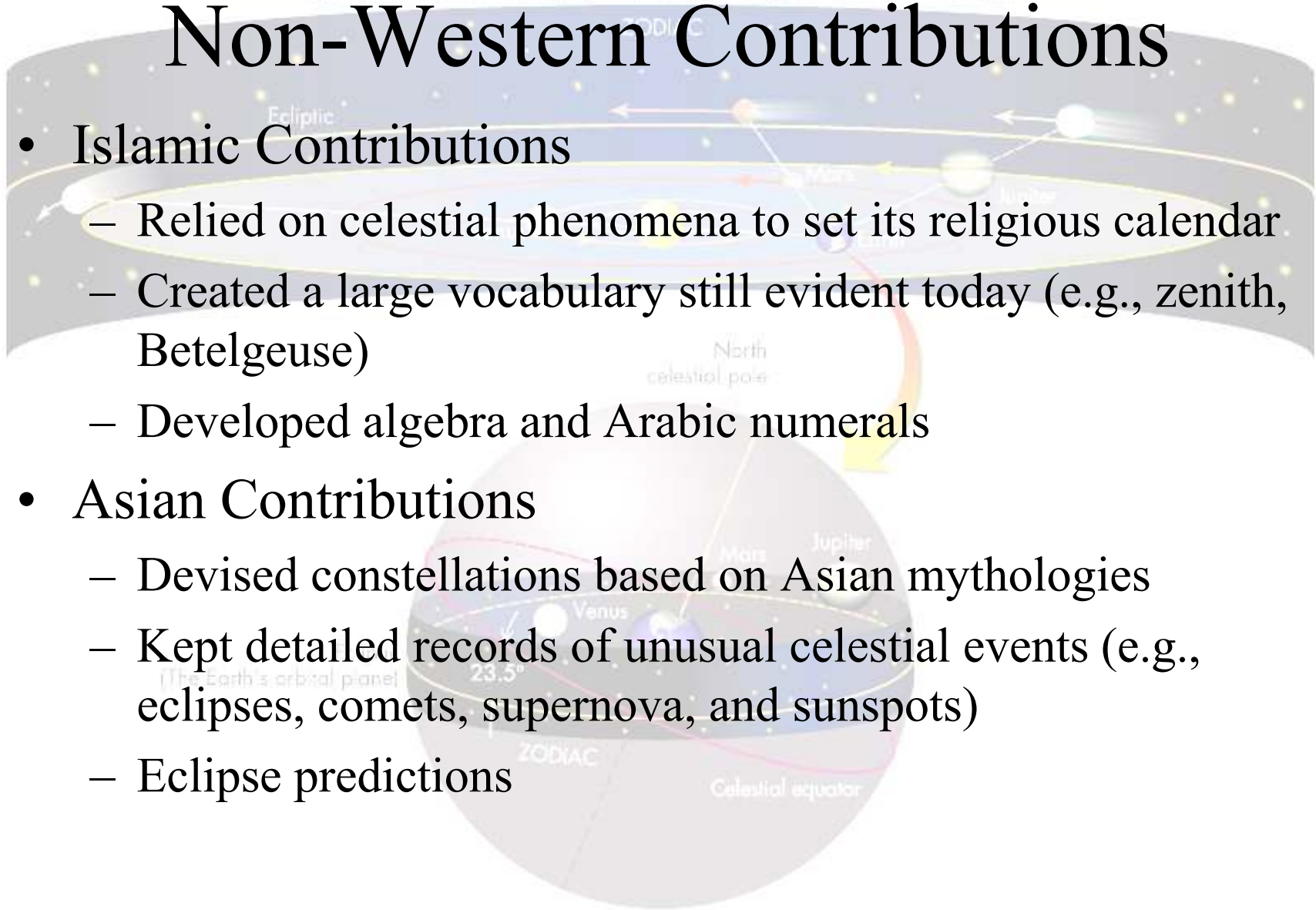
Ptolemy of Alexandria

- Ptolemy's model was able to predict planetary motion with fair precision
- Discrepancies remained and this led to the development of very complex Ptolemaic models up until about the 1500s
- Ultimately, all the geocentric models collapsed under the weight of “Occam's razor” and the *heliocentric models* prevailed



Non-Western Contributions

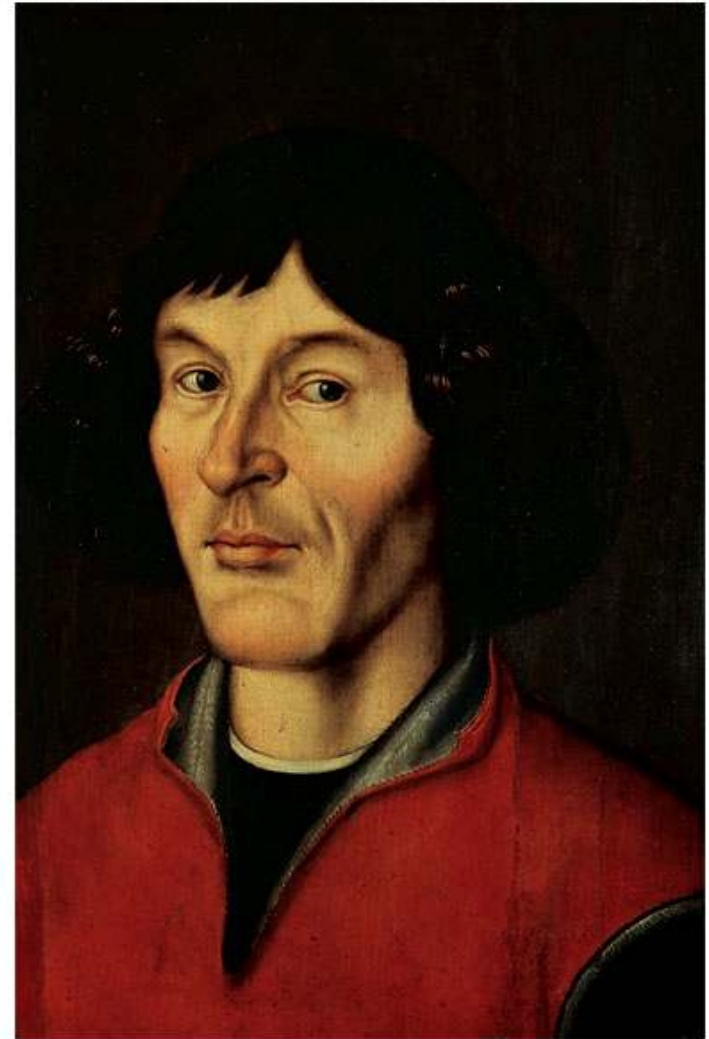
- Islamic Contributions
 - Relied on celestial phenomena to set its religious calendar
 - Created a large vocabulary still evident today (e.g., zenith, Betelgeuse)
 - Developed algebra and Arabic numerals
- Asian Contributions
 - Devised constellations based on Asian mythologies
 - Kept detailed records of unusual celestial events (e.g., eclipses, comets, supernova, and sunspots)
 - Eclipse predictions



Astronomy in the Renaissance

- Nicolaus Copernicus (1473-1543)
 - Could not reconcile centuries of data with Ptolemy's geocentric model
 - Consequently, Copernicus reconsidered Aristarchus's heliocentric model with the Sun at the center of the solar system

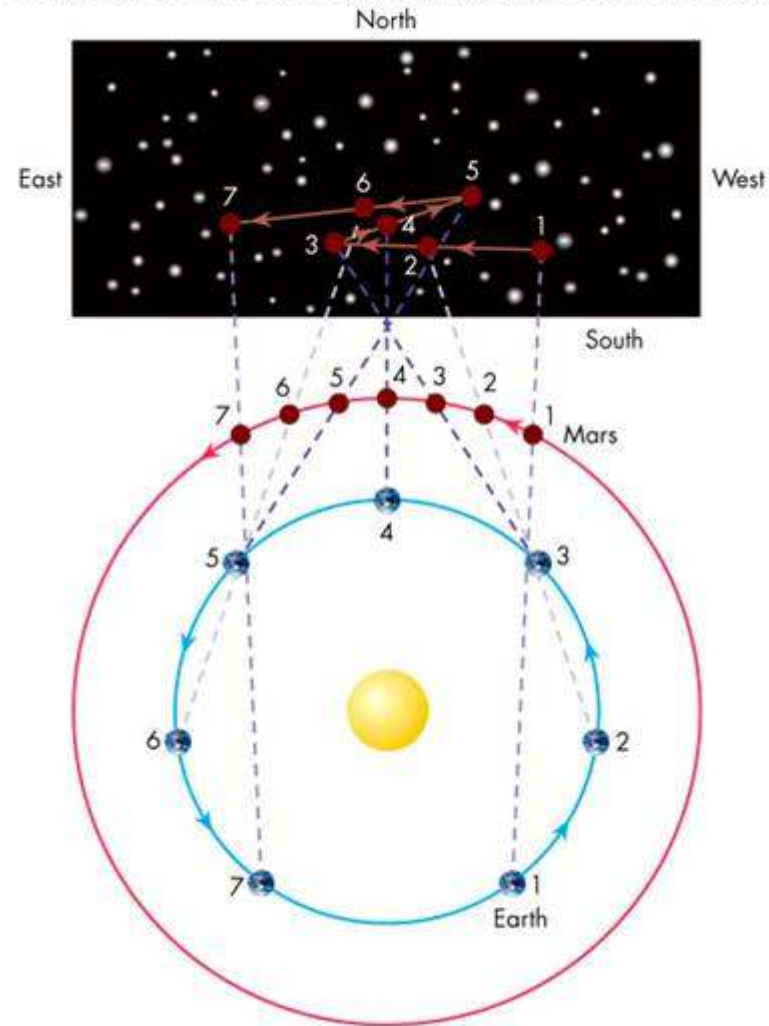
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Astronomy in the Renaissance

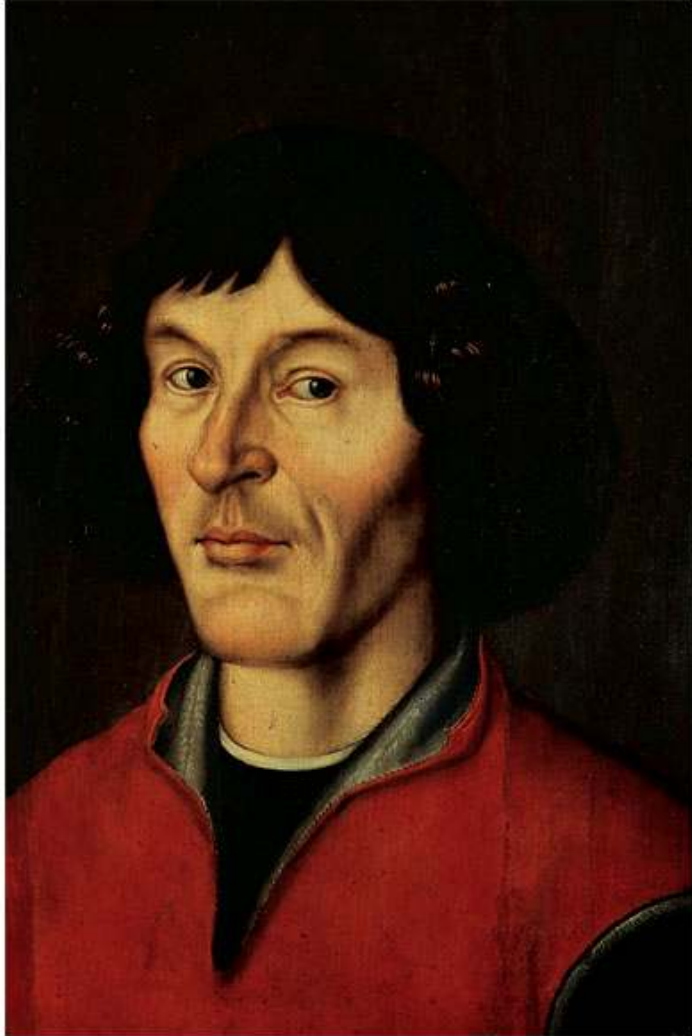
- *Heliocentric models* explain retrograde motion as a natural consequence of two planets (one being the Earth) passing each other
- Copernicus could also derive the relative distances of the planets from the Sun

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Astronomy in the Renaissance

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- However, problems remained:
 - Could not predict planet positions any more accurately than the model of Ptolemy
 - Could not explain lack of parallax motion of stars
 - Conflicted with Aristotelian “common sense”

Astronomy in the Renaissance

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- Tycho Brahe (1546-1601)
 - Designed and built instruments of far greater accuracy than any yet devised
 - Made meticulous measurements of the planets

Astronomy in the Renaissance

- Tycho Brahe (1546-1601)
 - Made observations (supernova and comet) that suggested that the heavens were both changeable and more complex than previously believed
 - Proposed compromise geocentric model, as he observed no parallax motion!

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Astronomy in the Renaissance

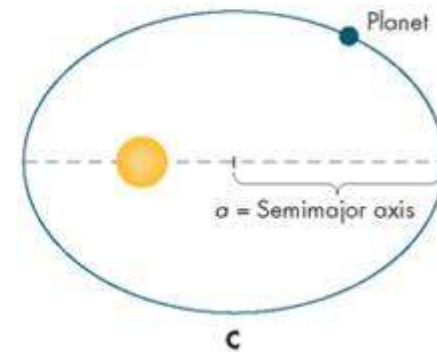
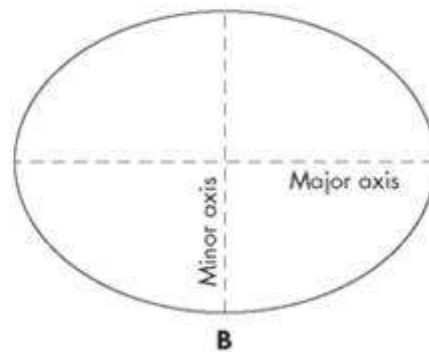
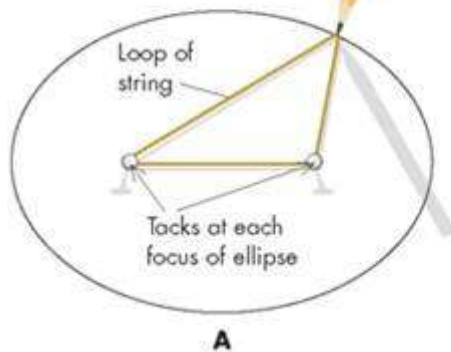
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- Johannes Kepler (1571-1630)
 - Upon Tycho's death, his data passed to Kepler, his young assistant
 - Using the very precise Mars data, Kepler showed the orbit to be an *ellipse*



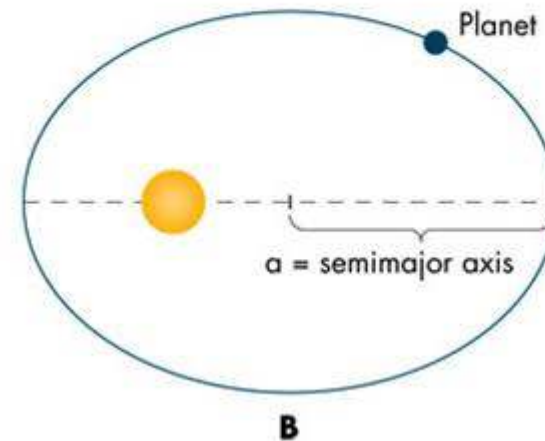
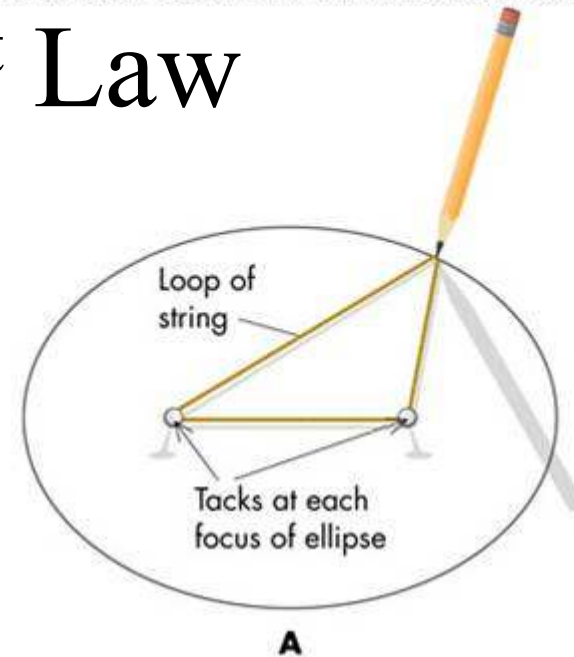
Johannes Kepler (1571-1630)

- Using Tycho Brahe's data, discovered that planets do not move in circles around the Sun, rather, they follow ellipses with the Sun located at one of the two foci!
- Astronomers use the term *eccentricity* to describe how round or “stretched out” an ellipse is – the higher (closer to 1) the eccentricity, the flatter the ellipse.



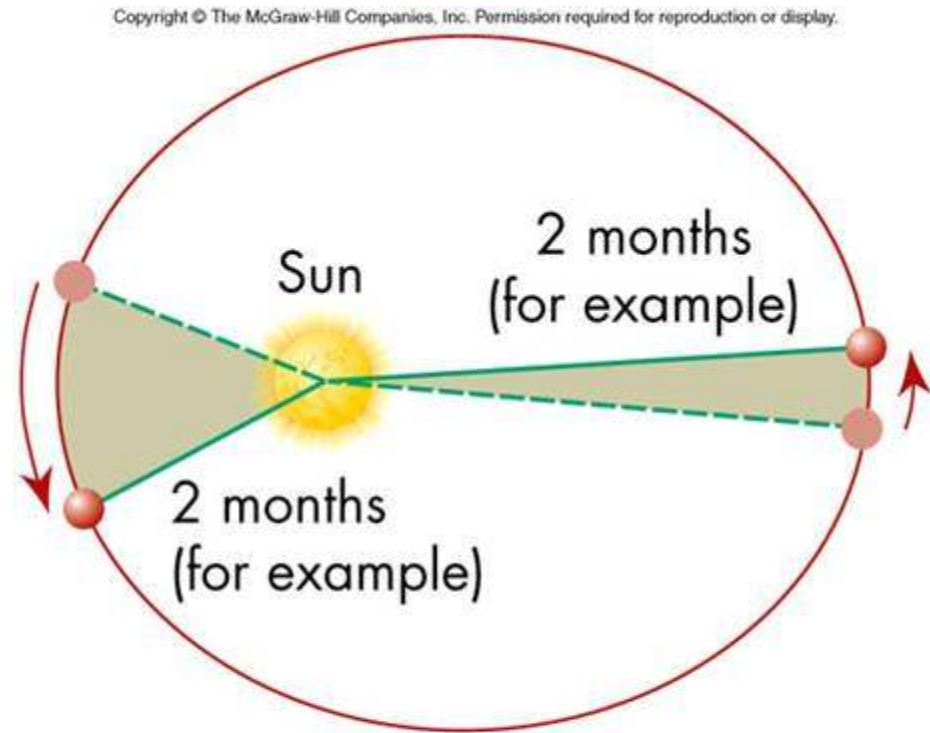
Kepler's 1st Law

- Planets move in elliptical orbits with the Sun at one *focus* of the ellipse



Kepler's 2nd Law

- The orbital speed of a planet varies so that a line joining the Sun and the planet will sweep out equal areas in equal time intervals
- The closer a planet is to the Sun, the faster it moves

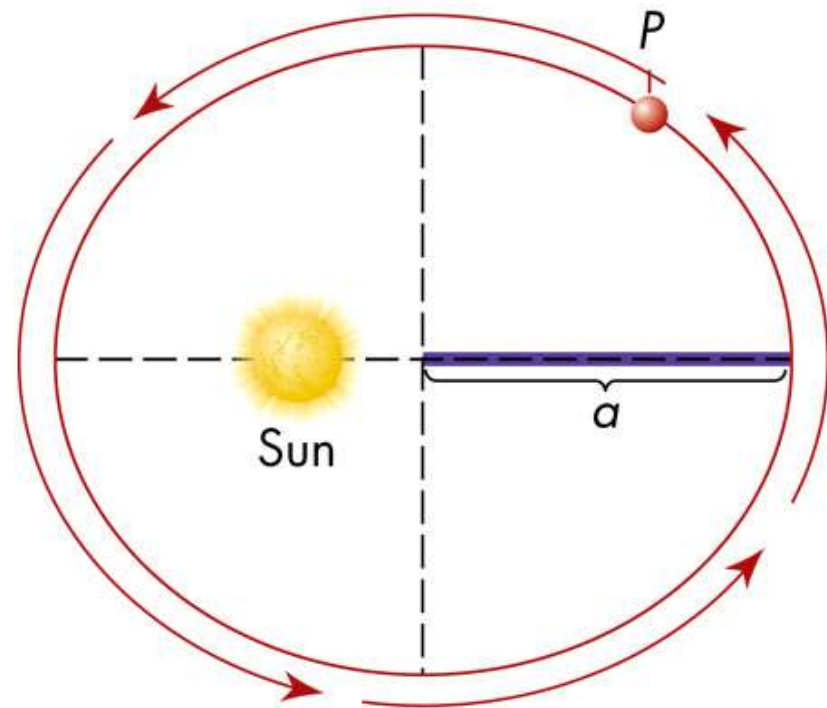


Kepler's 3rd Law

- The amount of time a planet takes to orbit the Sun is related to its orbit's size
- The square of the period, P , is proportional to the cube of the *semimajor axis*, a

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$$P^2 \text{ years} = a^3 \text{ AU}$$



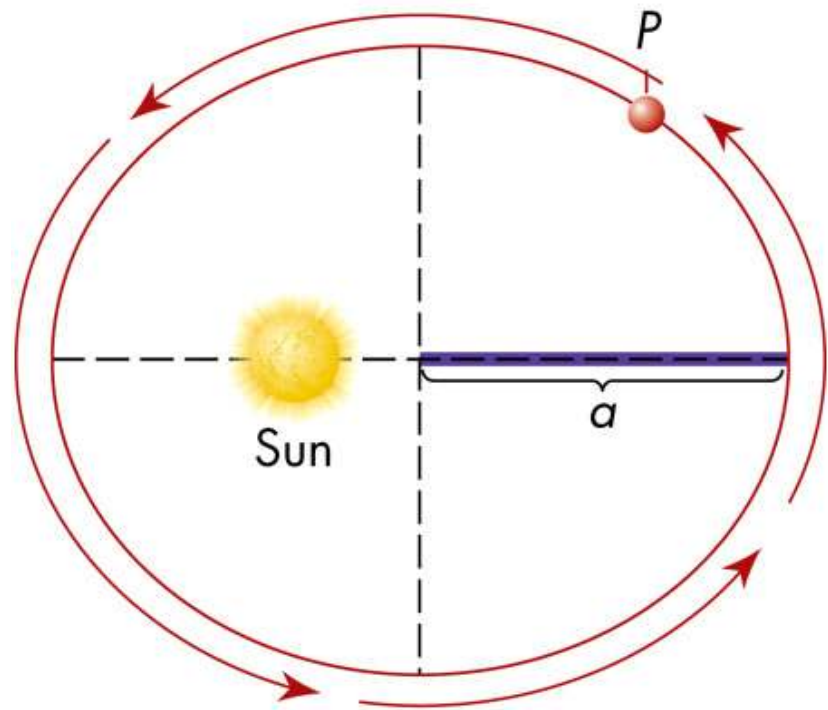
P = time to complete orbit
 a = semimajor axis

Kepler's 3rd Law

- This law implies that a planet with a larger average distance from the Sun, which is the semimajor axis distance, will take longer to circle the Sun
- Third law hints at the nature of the force holding the planets in orbit

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$$P^2 \text{ years} = a^3 \text{ AU}$$



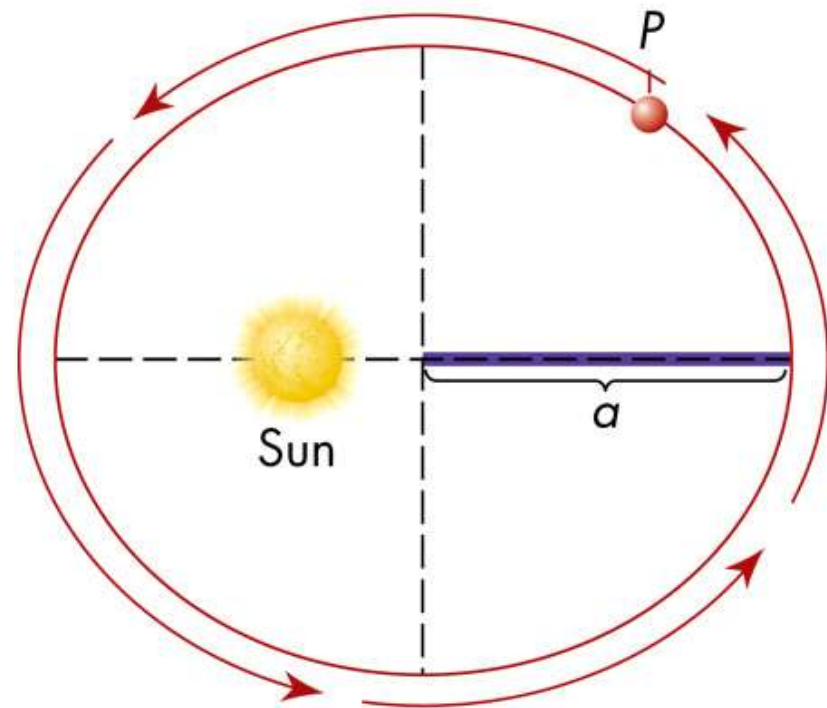
P = time to complete orbit
 a = semimajor axis

Kepler's 3rd Law

- Third law can be used to determine the semimajor axis, a , if the period, P , is known, a measurement that is not difficult to make

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$$P^2 \text{ years} = a^3 \text{ AU}$$



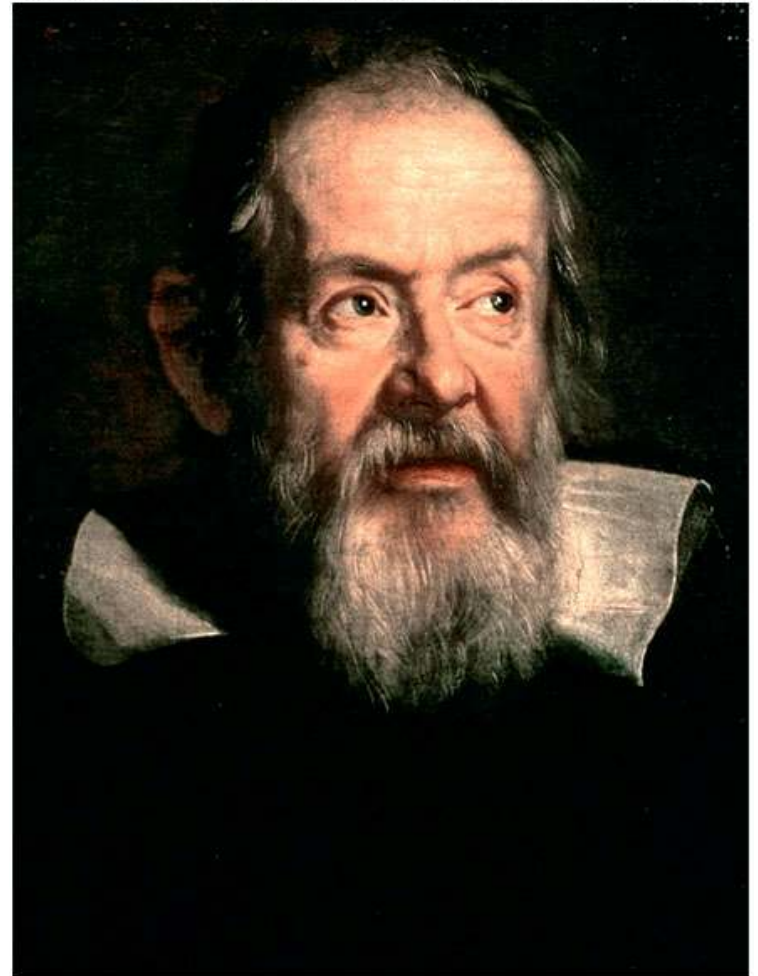
P = time to complete orbit
 a = semimajor axis

C

Astronomy in the Renaissance

- Galileo (1564-1642)
 - Contemporary of Kepler
 - First person to use the telescope to study the heavens and offer interpretations
 - The Moon's surface has features similar to that of the Earth \Rightarrow The Moon is a ball of rock

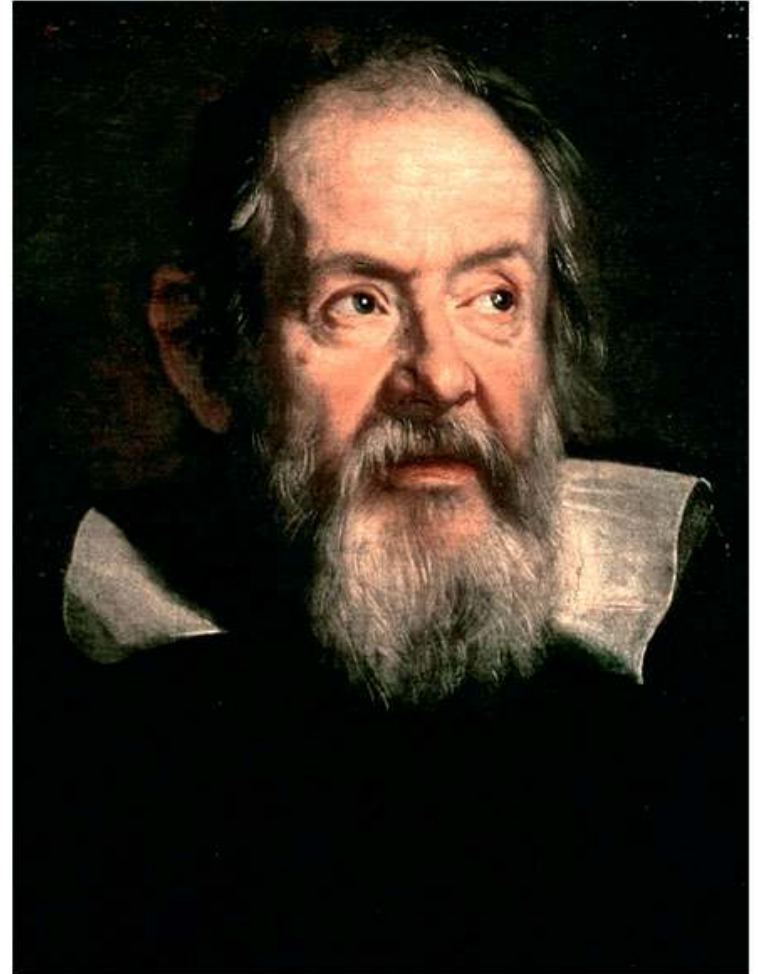
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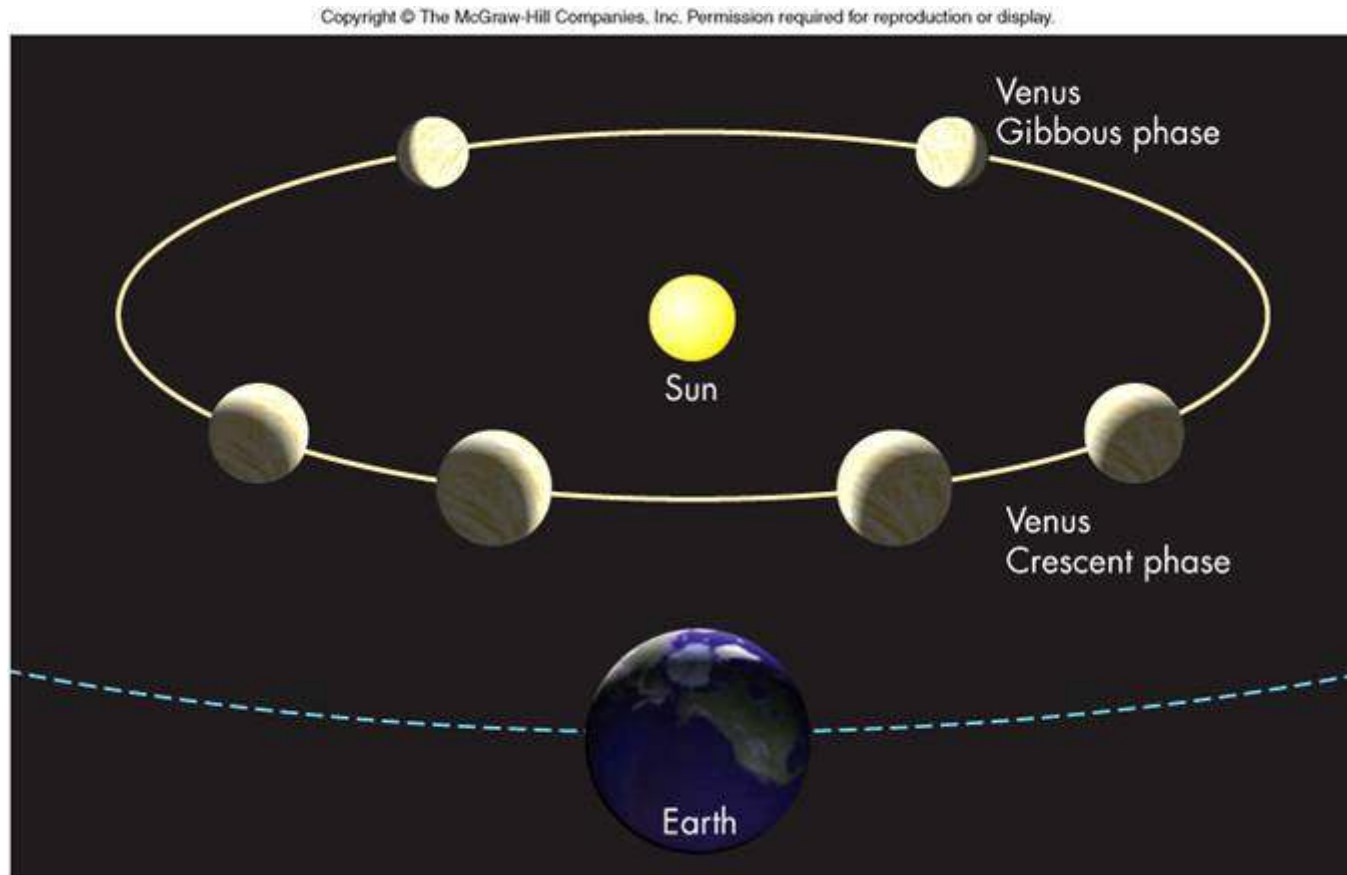
Astronomy in the Renaissance

- The Sun has spots \Rightarrow The Sun is not perfect, changes its appearance, and rotates
- Jupiter has four objects orbiting it \Rightarrow The objects are moons and they are not circling Earth
- Milky Way is populated by uncountable number of stars \Rightarrow Earth-centered universe is too simple

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Evidence for the Heliocentric Model

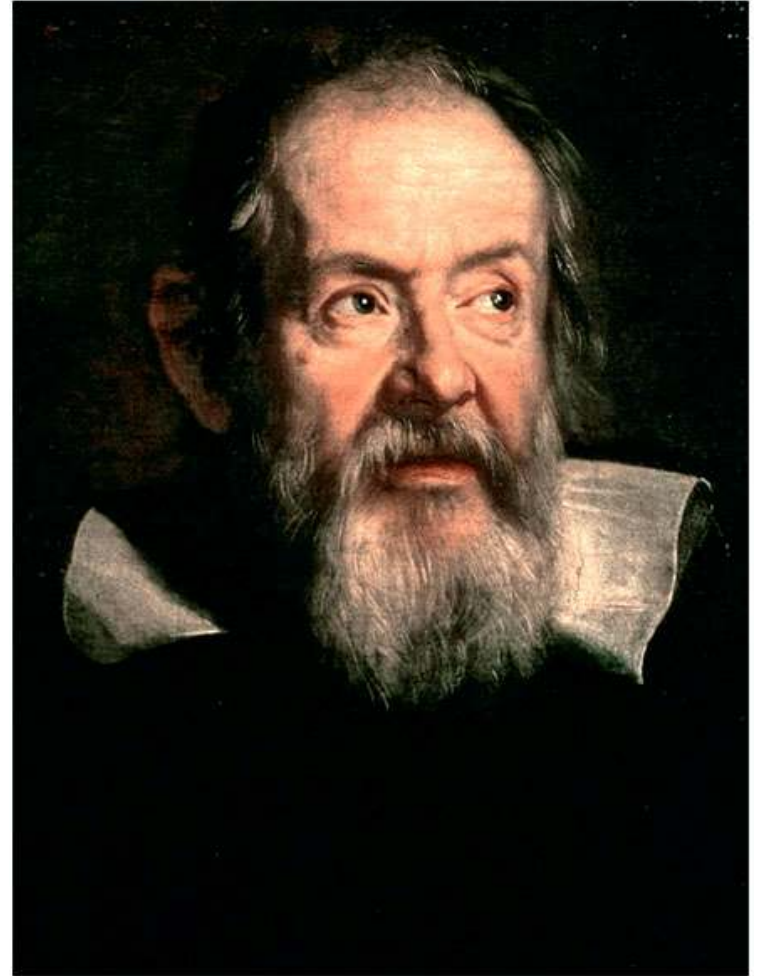


- Venus undergoes full phase cycle \Rightarrow Venus must circle Sun

Astronomy in the Renaissance

- Credited with originating the experimental method for studying scientific problems
- Deduced the first correct “laws of motion”
- Was brought before the Inquisition and put under house arrest for the remainder of his life

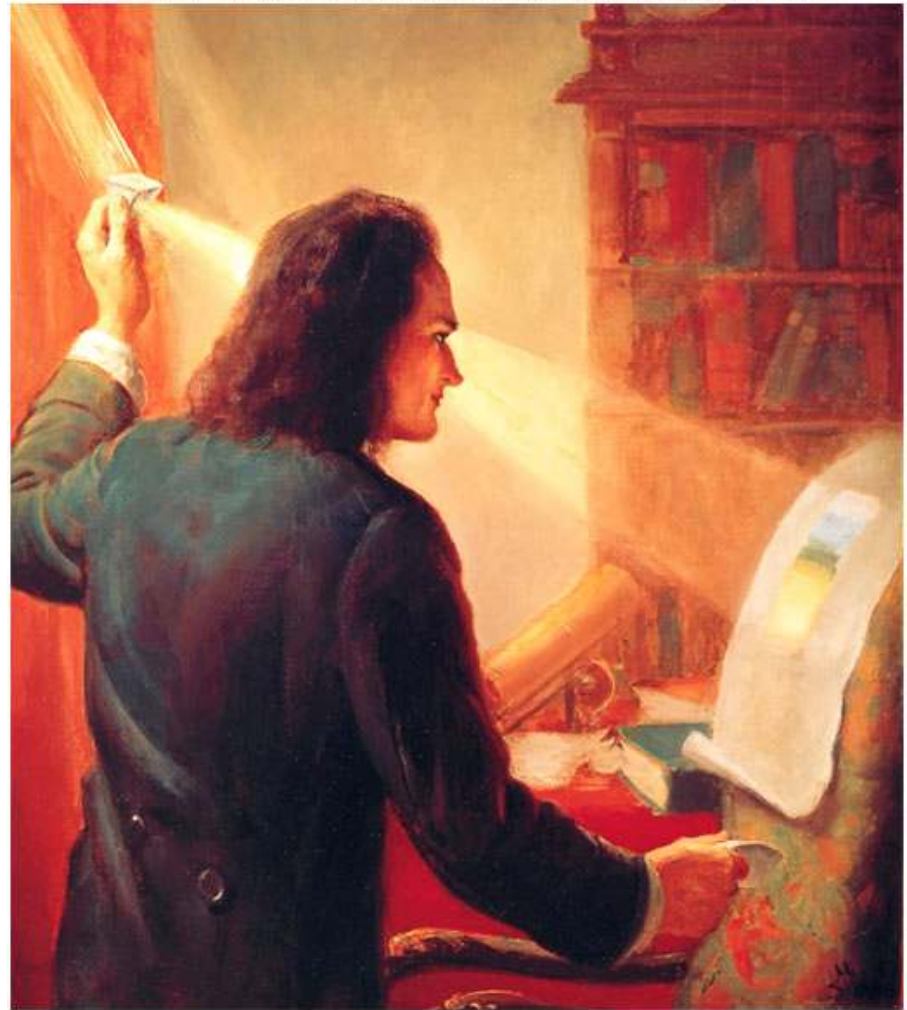
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Isaac Newton

- Isaac Newton (1642-1727) was born the year Galileo died
- He made major advances in mathematics, physics, and astronomy

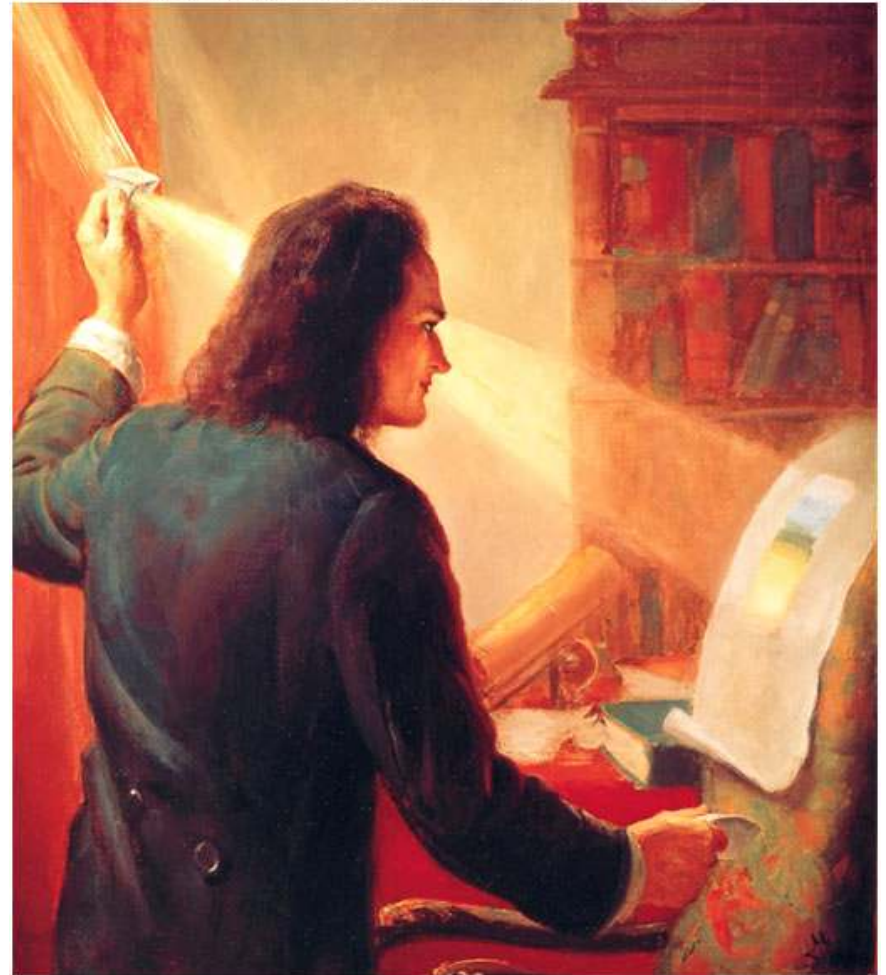
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Isaac Newton

- He pioneered the modern studies of motion, optics, and gravity and discovered the mathematical methods of calculus
- It was not until the 20th century that Newton's laws of motion and gravity were modified by the theories of relativity

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The Growth of Astrophysics

- New Discoveries
 - In 1781, Sir William Herschel discovered Uranus; he also discovered that stars can have companions
 - Irregularities in Uranus's orbit together with law of gravity led to discovery of Neptune
- New Technologies
 - Improved optics led to bigger telescopes and the discovery of nebulae and galaxies
 - Photography allowed the detection of very faint objects