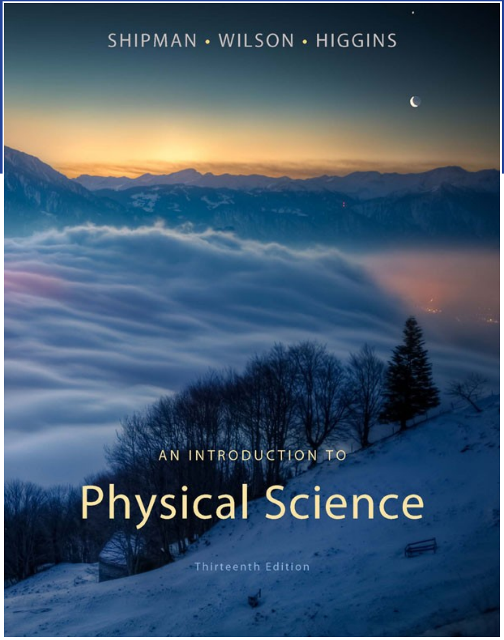


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# Chapter 16
# *The Solar System*

Read sections 16.1 to 16.3, 16.7, and 16.8.

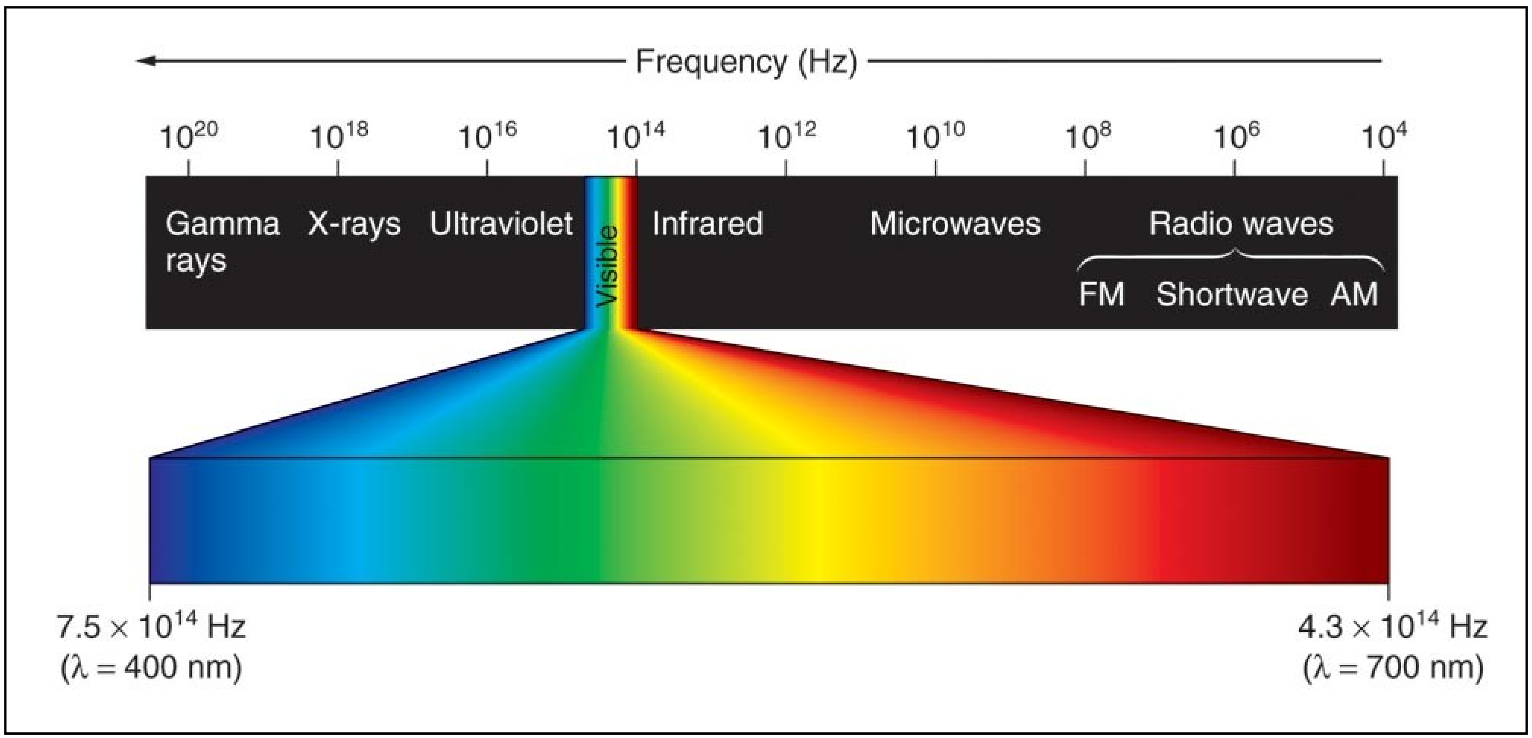
# Introduction

- Astronomy – the scientific study of the universe beyond Earth's atmosphere
- Universe – everything, all energy, matter, and space
- The Milky Way– one of 50 billion galaxies scattered throughout the universe
- Solar System – contains our Sun and 9 planets
- Sun – supplies the energy for nearly all life on the planet earth

Audio Link

# Electromagnetic Spectrum

Astronomers are interested in studying the full range of electromagnetic spectrum coming from space



# Astronomy

- Much of the incoming solar radiation does not make it to the Earth's surface – due to atmospheric absorption
- Electromagnetic radiation that will pass through the Earth's atmosphere can be studied using ground-based detectors
- Other regions of the electromagnetic spectrum must be detected by space-based instruments
  - The Hubble Space Telescope is a good example of an instrument outside Earth's atmosphere

# The Solar System

- The solar system - complex system of moving masses held together by gravitational forces
- Sun is center
- Sun is the dominant mass
- Revolving around the sun – 8 major planets with over 170 moons, 4 dwarf planets, and 1000’s of other objects (asteroids, comets, meteoroids, etc.)

# The Solar System

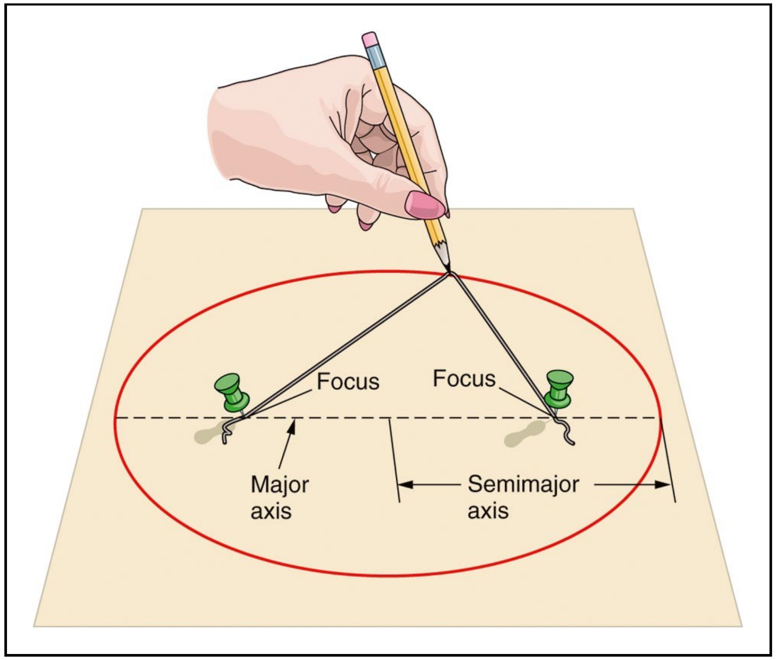
- Geocentric Model – early belief that the Earth was motionless and everything revolved around it
  - Claudius Ptolemy (**A.D.** 140)
- Heliocentric Model – a Sun-centered model
  - Nicolaus Copernicus (1473-1543)

# Johannes Kepler (1571-1630)

- German mathematician and astronomer
- Kepler's 1st Law – Law of Elliptical Orbits – All planets move in elliptical orbits around the Sun with the Sun as one focus of the ellipse
- An ellipse is a figure that is symmetric about two unequal axes

# Drawing an Ellipse

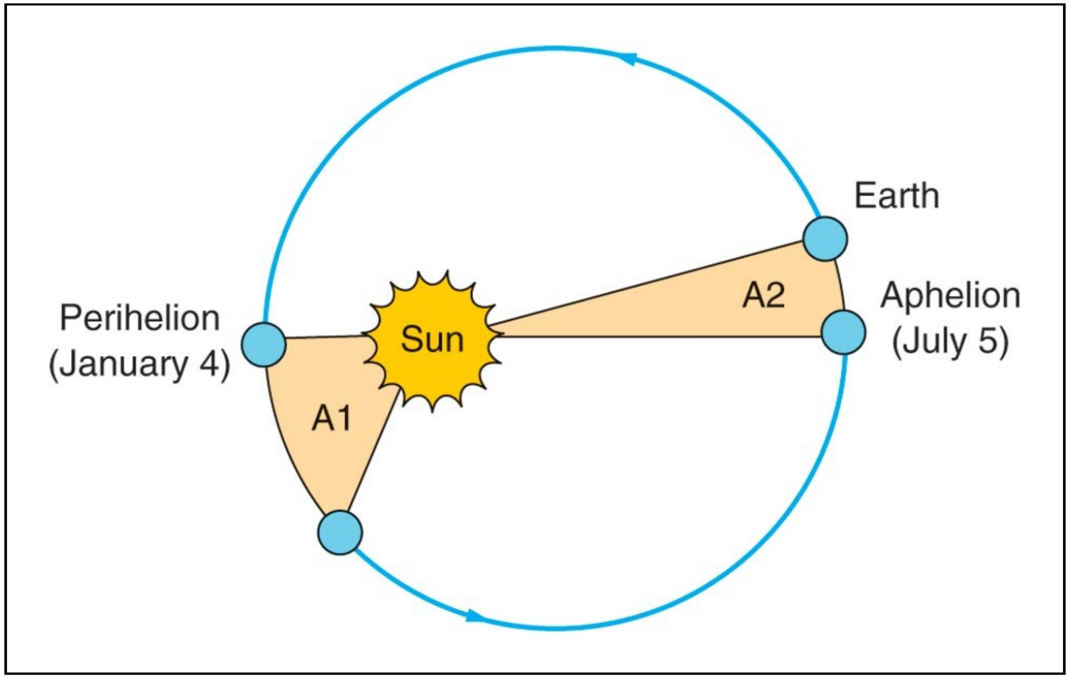
- An ellipse has two foci, a major axis, and a semimajor axis




- In discussing the Earth's elliptical orbit, the semimajor axis is the average distance between the Earth and the Sun = Astronomical Unit (AU) = $1.5 \times 10^8$ km

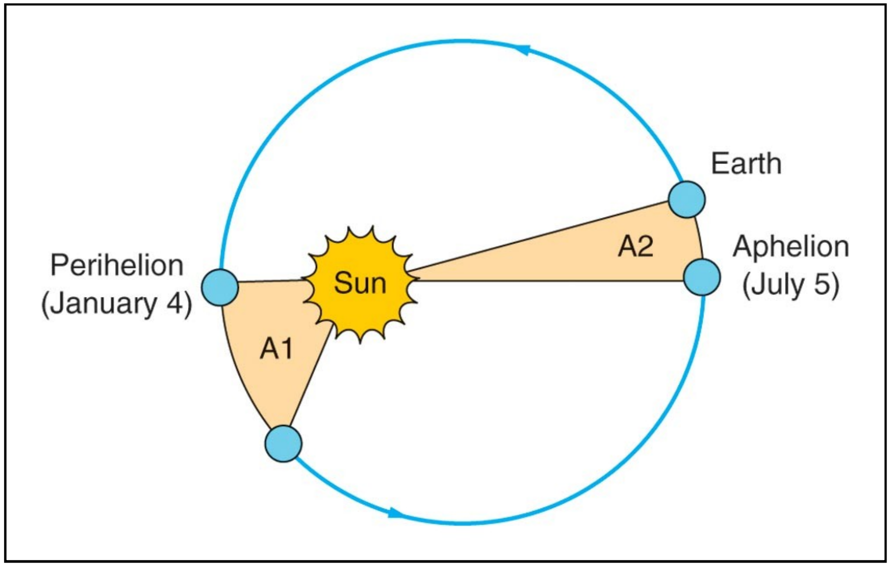
# Kepler's Second Law

- Law of Equal Areas – An imaginary line (radial vector) joining a planet to the Sun sweeps out equal areas in equal periods of time



# The speed of a revolving planet varies

- Perihelion – the closest point in a planet's orbit around the Sun, speed is the fastest
  - Perihelion occurs for Earth about January 4
- Aphelion – the farthest point in a planet's orbit around the Sun, speed is the slowest
  - Aphelion occurs for Earth about July 5



# Kepler's Third Law

- Harmonic Law – the square of the sidereal period of a planet is proportional to the cube of its semimajor axis
- $T^2 = k R^3$
- $T$ = period (time of one revolution)
- $R$ = length of semimajor axis
- $k$ = constant (same for all planets) = $1 y^2/AU^3$

# Calculating the Period of a Planet - *Example*

- *Calculate the period of a planet whose orbit has a semimajor axis of 1.52 AU*
- $T^2 = k\,R^3$
- $T^2 = \dfrac{1\text{y}^2}{\cancel{\text{AU}^3}} \times (1.52\ \cancel{\text{AU}})^3$
- $T^2 = 3.51\text{y}^2$
- $T = 1.87$ y
- *This is for Mars*

# Calculating the Period of a Planet – *Confidence Exercise*

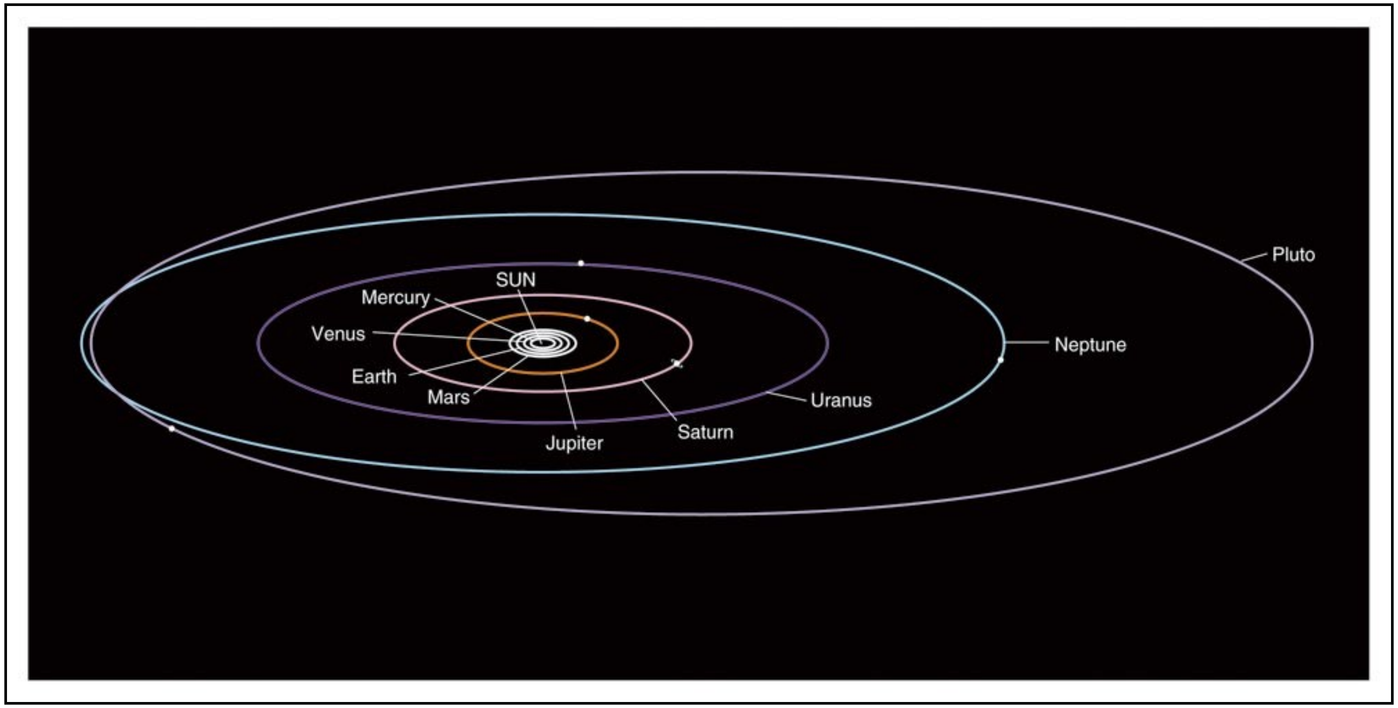
- *Calculate the period of a planet whose orbit has a semimajor axis of 30 AU*
- $T^2 = k\,R^3$
- $T^2 = \dfrac{1\text{y}^2}{\cancel{\text{AU}^3}} \times (30\ \cancel{\text{AU}})^3$
- **$T^2$ = 27,000 y$^2$**
- **$T$ = 164.32 years**

# Major Planet Classification and Orbits in Our Solar System

- Sun – 99.87% of the mass of solar system
- Of the remaining 0.13%, Jupiter is > 50%
- Planets with orbits smaller than Earth are classified as "inferior"
- Planets with orbits larger than Earth are classified as "superior"

# Revolution/Rotation

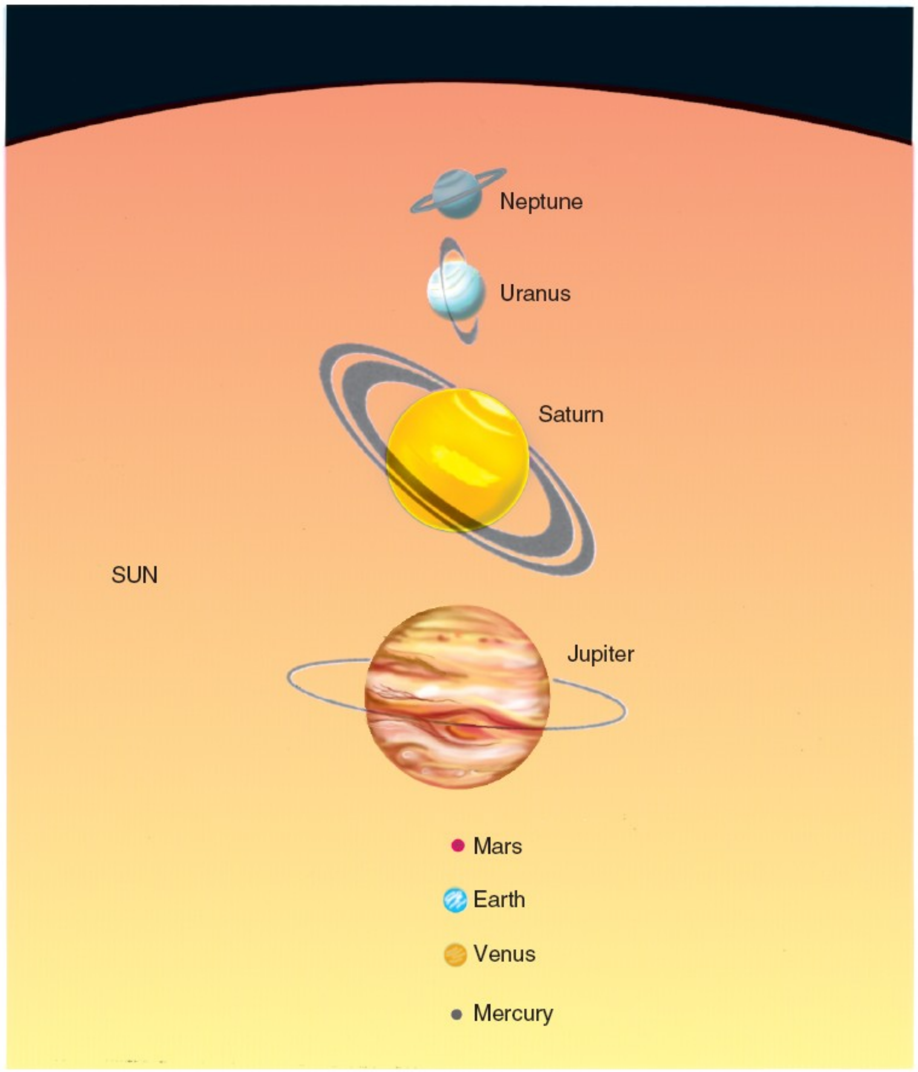
- All planets revolve (orbit) counterclockwise (prograde motion) around the Sun as observed from the north pole. Each planet also rotates counterclockwise on its axis except Venus and Uranus (retrograde motion).



# Planet Classification

- Terrestrial planets – Mercury, Venus, Earth, Mars
  - High percent of more massive (non-gaseous) elements
- Jovian planets - Jupiter, Saturn, Uranus, and Neptune
  - High percent of less massive gaseous elements

# The Solar System -- drawn to scale with the eight major planets



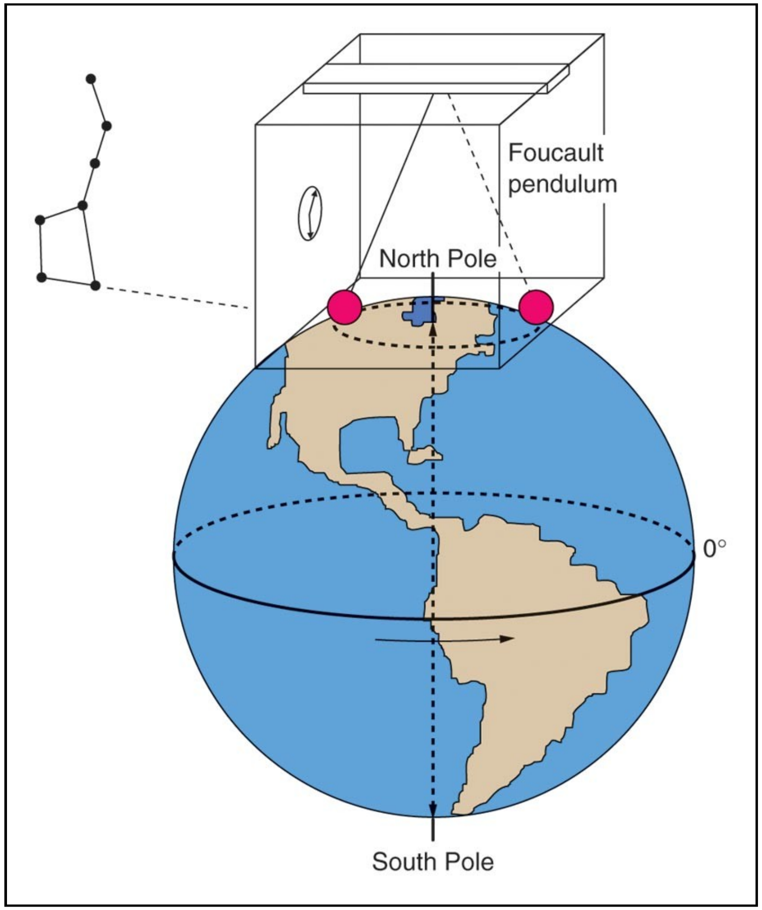
# Earth Motions

- Daily Rotation on its axis (daily cycle)
  - <u>Rotation</u> – spin on an internal axis
- Annual revolution around the sun (annual cycle)
  - <u>Revolution</u> – movement of one mass around another
- Precession – the slow change of the earth’s rotational axis (now at $23.5^{0}$) – see chapter 15

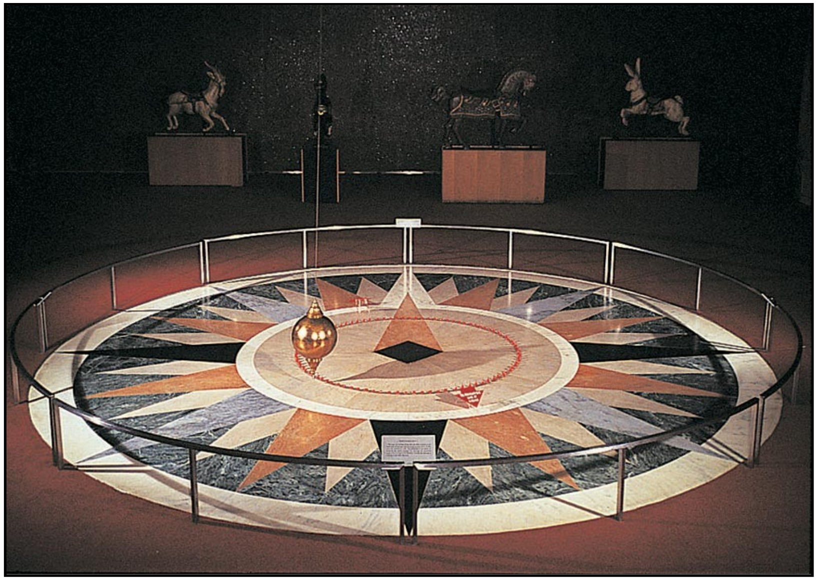
# Earth’s Rotation on its Axis

- Not generally accepted until 19th century
- Very difficult to prove???
- 1851, experiment designed by French engineer, Jean Foucault
- The <u>Foucault Pendulum</u> – very long pendulum with a heavy weight at the end
- Basically, the Foucault pendulum will swing back and forth as the Earth moves under it

# Foucault Pendulum



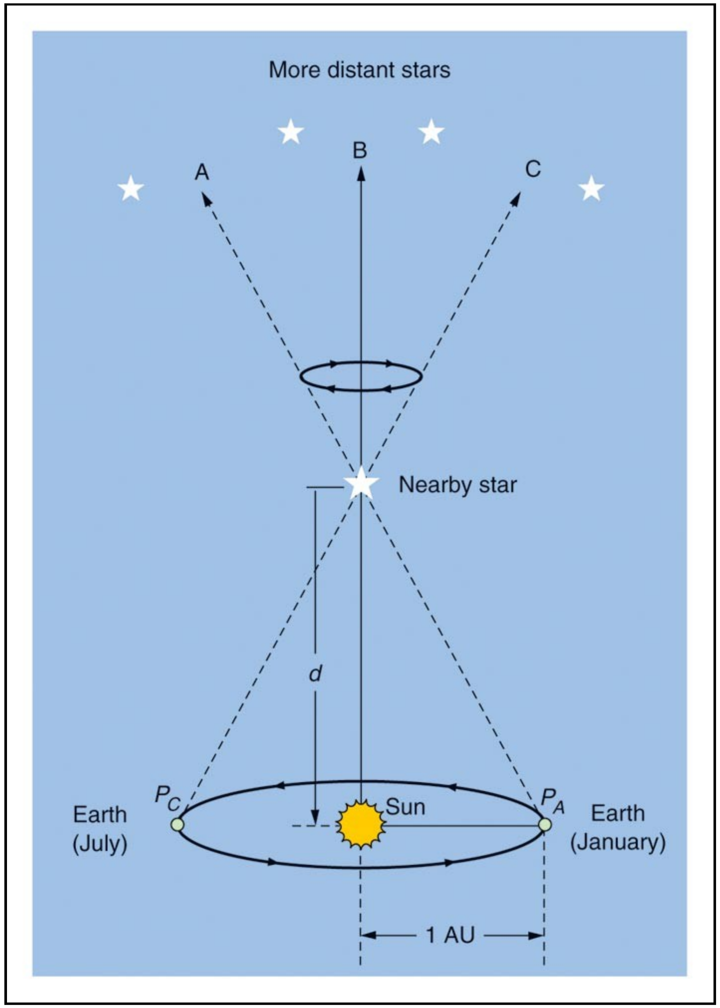

The pendulum does not rotate with reference to the fixed stars.
Experimental proof of the Earth's rotation



# Parallax

- Parallax – the apparent motion, or shift, that occurs between two fixed objects when the observer changes position
- Parallax can be seen with outstretched hand
- The motion of Earth as it revolves around the Sun leads to an apparent shift in the positions of the nearby stars with respect to more distant stars

# Stellar Parallax




- The observation of parallax is indisputable_proof that the Earth revolves around the Sun.
- In addition, the measurement of the parallax angle is the best method we have of determining the distance to nearby stars

# Aberration of Starlight

- A 2nd proof of Earth's orbital motion
- Telescopic observations of a systematic change in the position of all stars annually
  - Due to the motion of the Earth around the Sun
- Angular discrepancy between the apparent position of a star and its true position, arising from the motion of an observer relative to the path of the beam of light observed
  - This is similar to what you see when driving in the rain

# Aberration of Starlight

- This discrepancy is very small and is measured in a -- *parsec*
- Parsec ➔ *par*allax + *sec*ond
- Recall that a circle contains $360^0$.  Each degree is divided into 60 minutes, and each minute into 60 seconds
- Therefore 1 second = 1/3600 degree
- Parsec = the distance to a star when the star exhibits a parallax of 1 second.

# Origin of the Solar System

- Any theory that purports to explain the origin and development of the solar system must account for its present form
- According to our best measurements, our solar system has been in its present state for about 4.5 billion years
- A valid theory for solar system formation – must be able to explain a number of major properties of our solar system

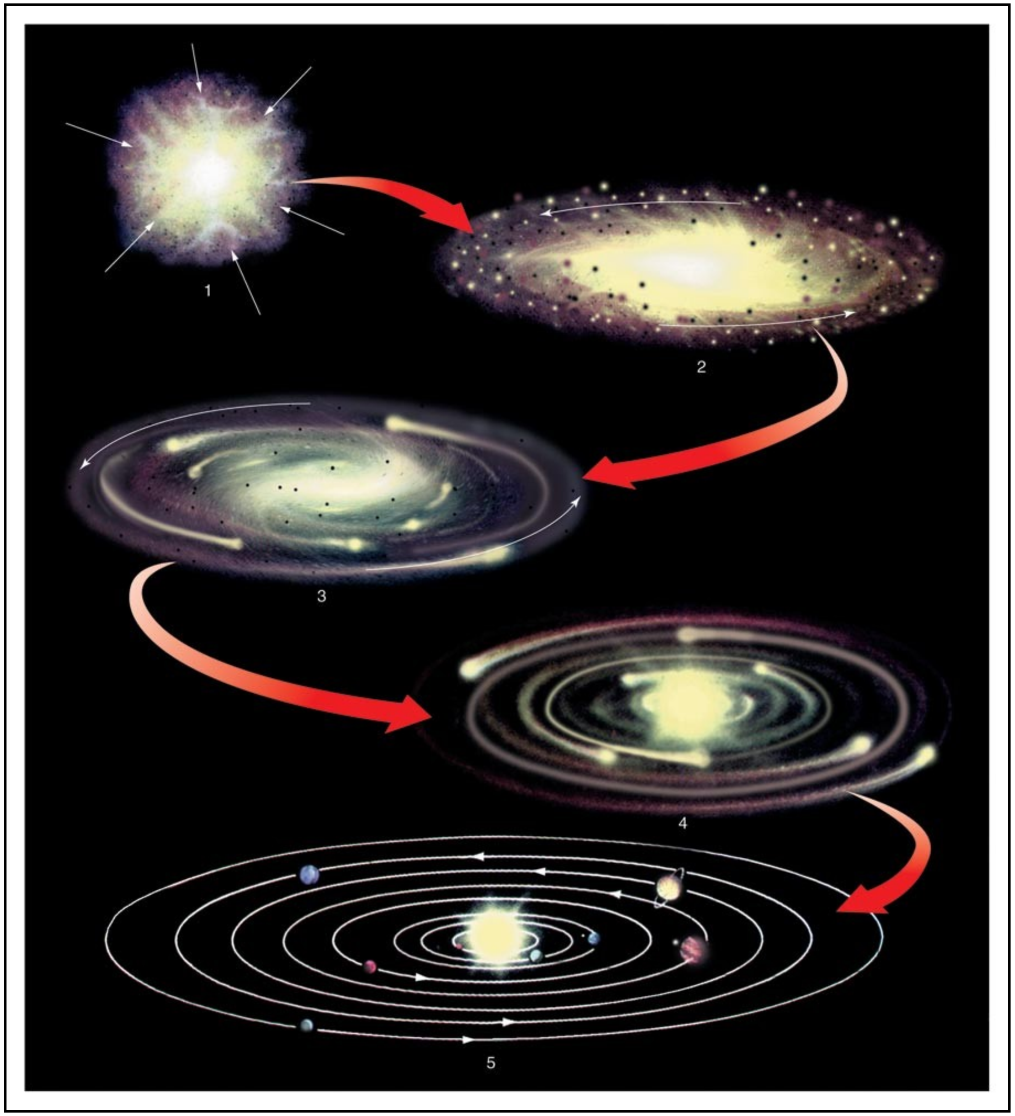
# Major Questions Concerning Solar System

- Origin of material?
- Forces that formed the solar system?
- Isolated planets, circular orbits, in same plane?
- Revolution (orbit) in the same direction?
- Most Rotate in same direction (except two)?
- Terrestrial versus Jovian planets?
- Origin of the asteroids?
- Origin of comets and meteoroids?

# Formation of the Solar System

- Began with a  large, swirling volume of cold gases and dust – a rotating solar nebula
- Contracted under the influence of its own gravity – into a flattened, rotating disk
- Further contraction produced the protosun and eventually accreted the planets
- As particles moved inward, the rotation of the mass had to increase to conserve angular momentum (like an ice skater bringing in her arms)

# The Formation of the Solar System
## Condensation Theory



# Other Planetary Systems

- Are there other planetary systems in the universe?
- If so, we would expect to find some of these systems in different stages of formation
  - In other words, we should be able to find clouds of gas and dust, primordial nebula, and protosuns, etc.
- We should also be able to use gravitational effects to detect small wobbles due to rotational objects in space
- These are called *exoplanets* or *extra-solar planets*

# Gravitational Effects

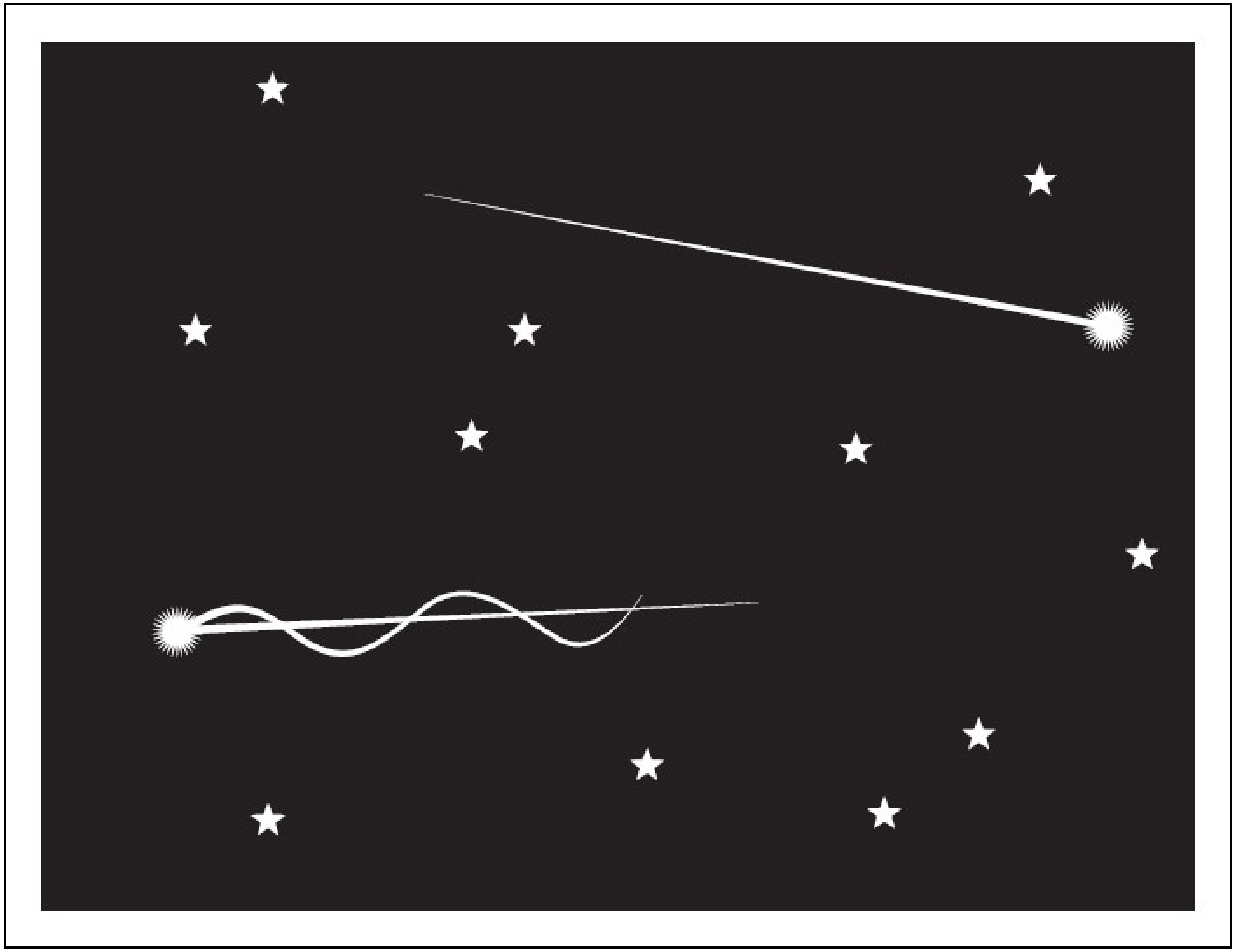
- A star with a large planet orbiting about it will have a small wobble superimposed on its motion as a result of gravitational effects
- This change in motion (the wobble) is likely to be very slight, but in some cases may be detected as a Doppler shift of the star's spectrum
  - As the star approaches the observer, the wavelengths are compressed ('blue shift')
  - As the star move away from the observer, the wavelengths are lengthened ('redshift')

# Gravitational Effects

- The amount of wobble can be used to determine the planet's mass (related to gravitational pull)
- The wobble's cycle time can be used to determine the orbital period
- Once the orbital period is known, Kepler's third law ($T^2 = kR^3$) can be used to determine the planet's average distance from the star

# Star Wobble

## Due to the gravitational pull of an orbiting planet.



The wobbling in this illustration is greatly exaggerated!

# Transit method

- A planet passing in front of its star as seen from Earth
- The star’s light will temporarily dim
- The *Kepler* mission uses the transit method.

# First Planets Discovered Beyond our Solar System

- In 1992, using the Arecibo Observatory in Puerto Rico, astronomers reported the discovery of two objects revolving about a pulsar
  - Pulsars are very dense, rapidly rotating stars
  - Pulsars have a very precise rotation period
  - If the rotation period is disrupted, this would indicate the presence of an object rotating about the pulsar
- These two objects are the first planets detected beyond our solar system

# Planets Beyond our Solar System

- There have now been approximately 500 planets detected around other stars and *Kepler* is finding more and more.
- These findings strongly indicate the existence of many other planetary systems in the universe
- Scientists are also *s*earching for signals from *e*xtra*t*errestrial *i*ntelligence (SETI)
- Equipment today is being used to scan wide frequency ranges over vast areas of the sky