



Today

- Announcements:
 - HW#2 is due Wednesday 8:00 am. HW#3 will be due Wednesday Jan 30 at 8:00am
 - Extra Credit project #1 is on the LONCAPA website; due Jan 23.
- Review
- Gravity, Planetary Orbits - Important lesson in how science works and how ultimately there are simple explanations for complex observations. All observations are unified under Newton's Universal Law of Gravity.



Review

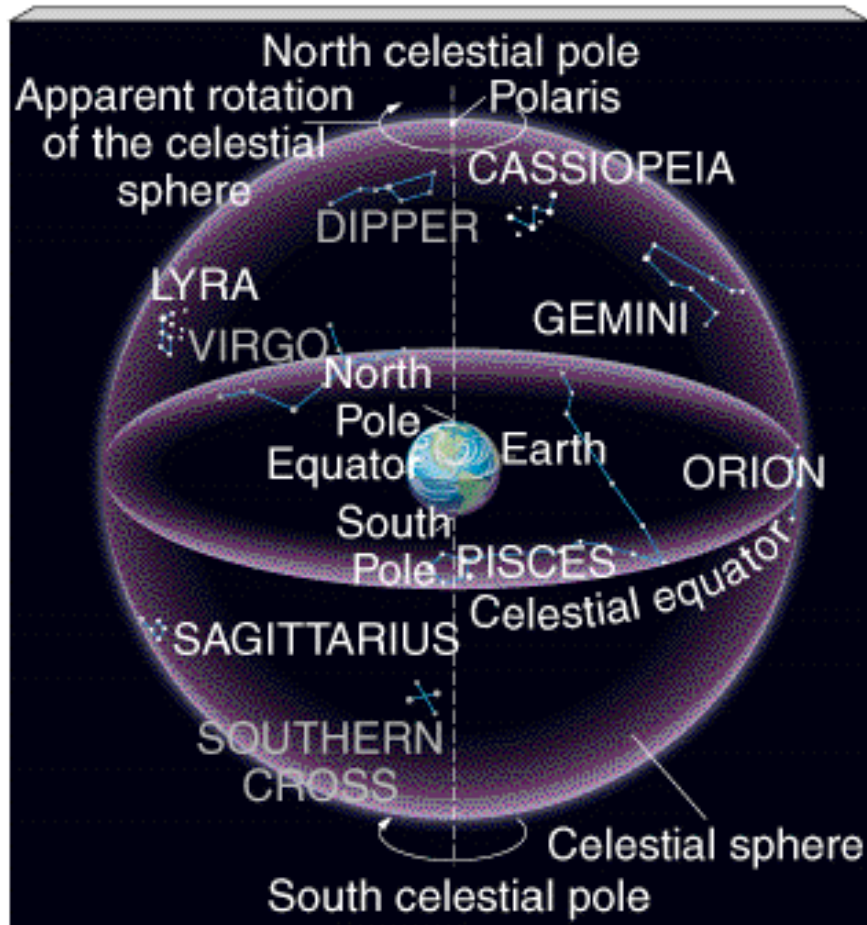
- Motion (position, velocity, acceleration) – what causes acceleration? Force
- Force is a vector, it has a magnitude and a direction.
- A definition is given by Newton's Three Laws of Force
 - If the net force on an object is zero the object will not accelerate.
 - The amount of acceleration depends on the mass of the object and the amount of the applied force: $\mathbf{F} = m\mathbf{a}$.
 - For every force, there is an equal and opposite force.

Motions of the Stars and Planets

- Motions of the heavens
- See the example in class from the program CyberSky (can be downloaded from the web).



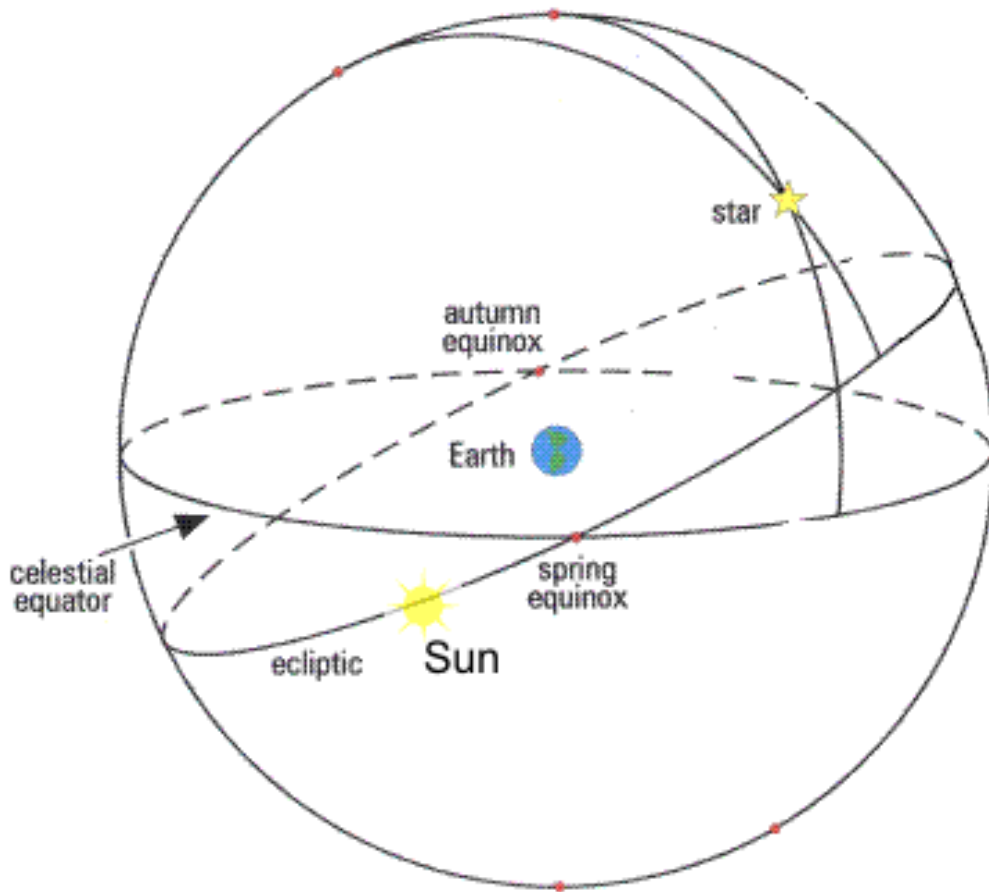
The Celestial Sphere



To us on Earth, it appears that all of the stars, Sun, Moon, and planets move on the underside of a large sphere.

This sphere is called the **Celestial Sphere**.

Landmarks on the Celestial Sphere



- **Celestial equator** – projection of the Earth's equator on the celestial sphere
- **Ecliptic** - apparent path of the Sun through the fixed stars
- **Zodiac** – the 12 (now officially 13) constellations along the ecliptic.

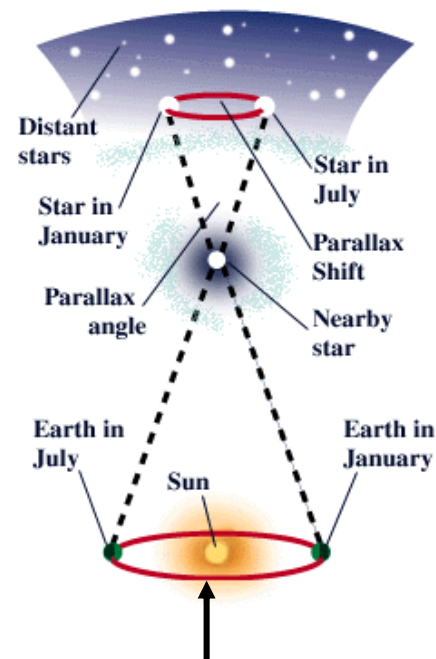
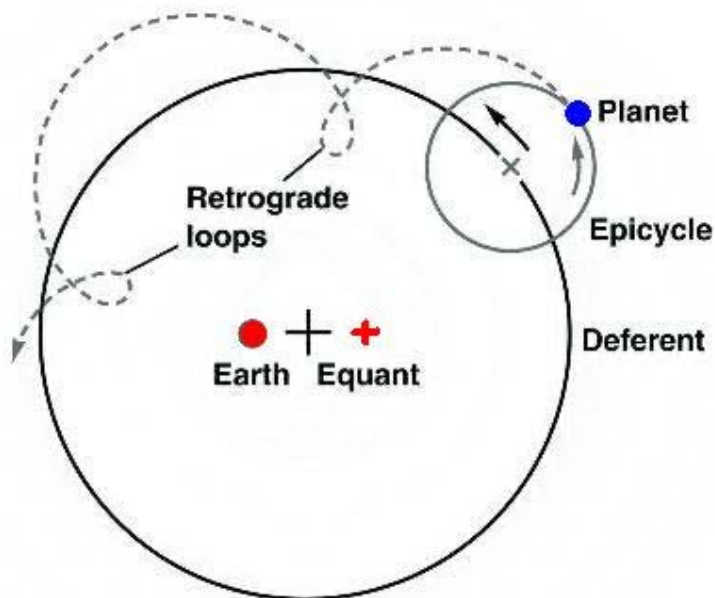


History of Observation of the Stars

- Detailed, recorded observations of the stars go back more than 5000 years. Many star names come from Babylonian and Chaldean times (4000 BC).
- 300 BC Aristarchus proposed a Sun centered solar system. This was rejected because it did not make sense that the Sun would be more important than the Earth.

Ptolemy

- Ptolemy devised an earth centered (geocentric) system.



- It explains retrograde motion, why no stellar parallax was observed, and described all data.
- It became part of Catholic church doctrine. Why?

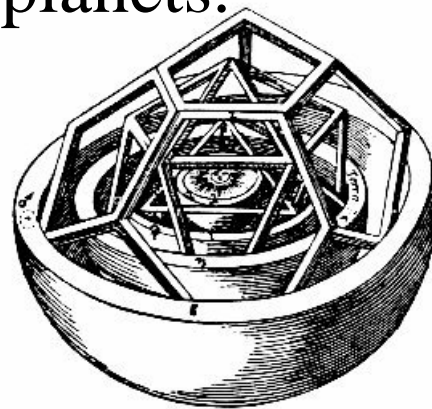
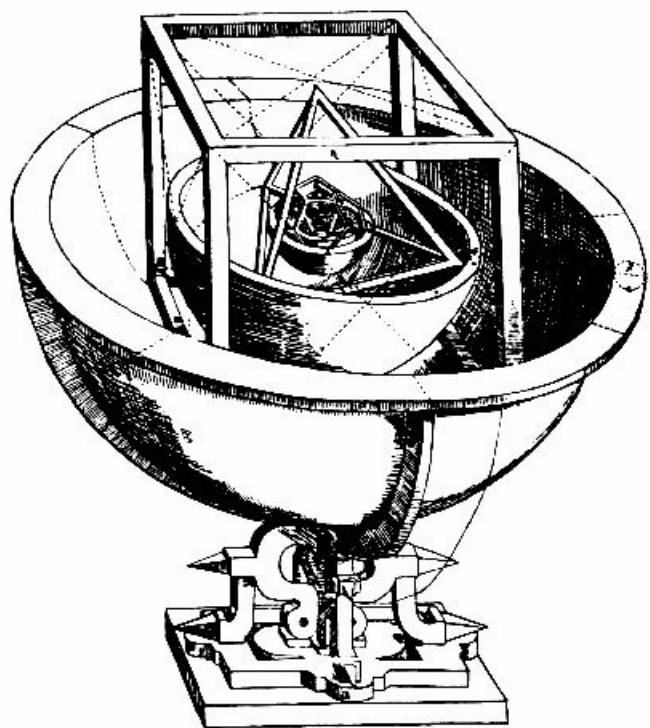


Brahe, Kepler, Galileo

- Tycho Brahe (1546-1601)
 - Observation: life's goal to prove the Earth Centered hypothesis.
 - His observatory made observations 20 times better than any other. He reduced the errors from 10 minutes of arc to 0.5 arcmin.
 - At its peak his observatory used 1-1.5% of the Danish national budget.
- Johannes Kepler (1561-1630)
 - Was a brilliant mathematician (and astrologer)
 - Based on the data of Brahe, he deduced three laws of planetary motion
- Galileo (1564 – 1642) – Motion, Telescope, Solar System
 - First used a telescope to study the heavens
 - Studied motion and devised the concepts of acceleration, etc.

Kepler's Model

Prior to working with Brahe, Kepler discovered that the orbits of the planets could fit into the 5 Platonic solids. This explained why there were six planets.





Success of this theory

- Kepler was able to construct models to describe Brahe's observations on Mars to within 8 minutes of arc based on Ptolemy's assumption of uniform speed. (The width of the tip of your thumb held at arms length is 60 arcmin = 1 degree).
- Brahe's measurements were good to 0.5 arcmin (20 times better than previous measurements).



Kepler's Giant Leap

And from this such small difference of eight minutes [of arc] it is clear why Ptolemy, since he was working with bisection [of the linear eccentricity], accepted a fixed equant point. ... For Ptolemy set out that he actually did not get below ten minutes [of arc], that is a sixth of a degree, in making observations.

To us, on whom Divine benevolence has bestowed the most diligent of observers, Tycho Brahe, from whose observations this eight-minute error of Ptolemy's in regard to Mars is deduced, it is fitting that we accept with grateful minds this gift from God, and both acknowledge and build upon it. So let us work upon it so as to at last track down the real form of celestial motions (these arguments giving support to our belief that the assumptions are incorrect). This is the path I shall, in my own way, strike out in what follows. **For if I thought the eight minutes in [ecliptic] longitude were unimportant, I could make a sufficient correction (by bisecting the [linear] eccentricity) to the hypothesis found in Chapter 16.** Now, because they could not be disregarded, these eight minutes alone will lead us along a path to the reform of the whole of Astronomy, and they are the matter for a great part of this work.

J. Kepler in *New Astronomy: Astronomia nova* (Heidelberg, 1609)



Kepler's Three Laws of Planetary Motion

- The Sun is at the center of the solar system with planets moving in ellipses around it.
- The planet moves faster when it is closer to the Sun.
- The square of the period is related to the cube of the semi-major axis of the orbit.

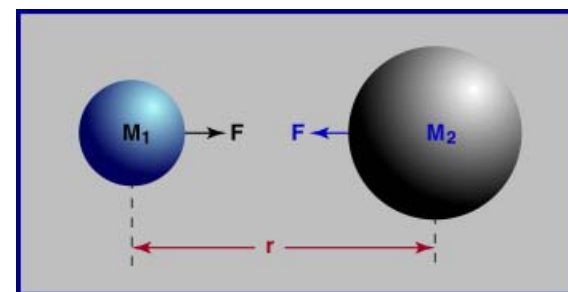
This model works better than Ptolemy's Earth centered one!

Newton and the Universal Law of Gravity

- Story of the apple tree – may or may not be true
- Gravity extends from the Earth to the moon!
- Newton's Universal Law of Gravity:

$$F = \frac{Gm_1m_2}{r^2}; G = 6.673E - 11 Nm^2 / kg^2$$

- Explains all observations of planetary motion, including Kepler's three laws, exactly. One equation unifies three laws!





Newton Explains Kepler's Laws

- Elliptical orbits

$$F = \frac{Gm_1m_2}{r^2}; G = 6.673E - 11 \text{ Nm}^2 / \text{kg}^2$$

- The stronger force means more acceleration when the planet is closer to the star
- A larger distance means less force and a longer time for the orbit