



Today

- Announcements:
 - HW#2 and 3 is due Wednesday Sept. 20th by 8:00 am
 - Extra Credit project #1 in on the LONCAPA website; due Sept 16. See the lecture on Sept. 1 for an explanation. Length should be about 1 paragraph. An excellent description will get 4 points.
- 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 is a vector, it has a magnitude and a direction.
- A better definition is given by Newton's Three Laws of Force (my versions)
 - 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: $F = ma$.
 - For every force, there is an equal and opposite force.
- Improved definition: Force is the rate of change of momentum.

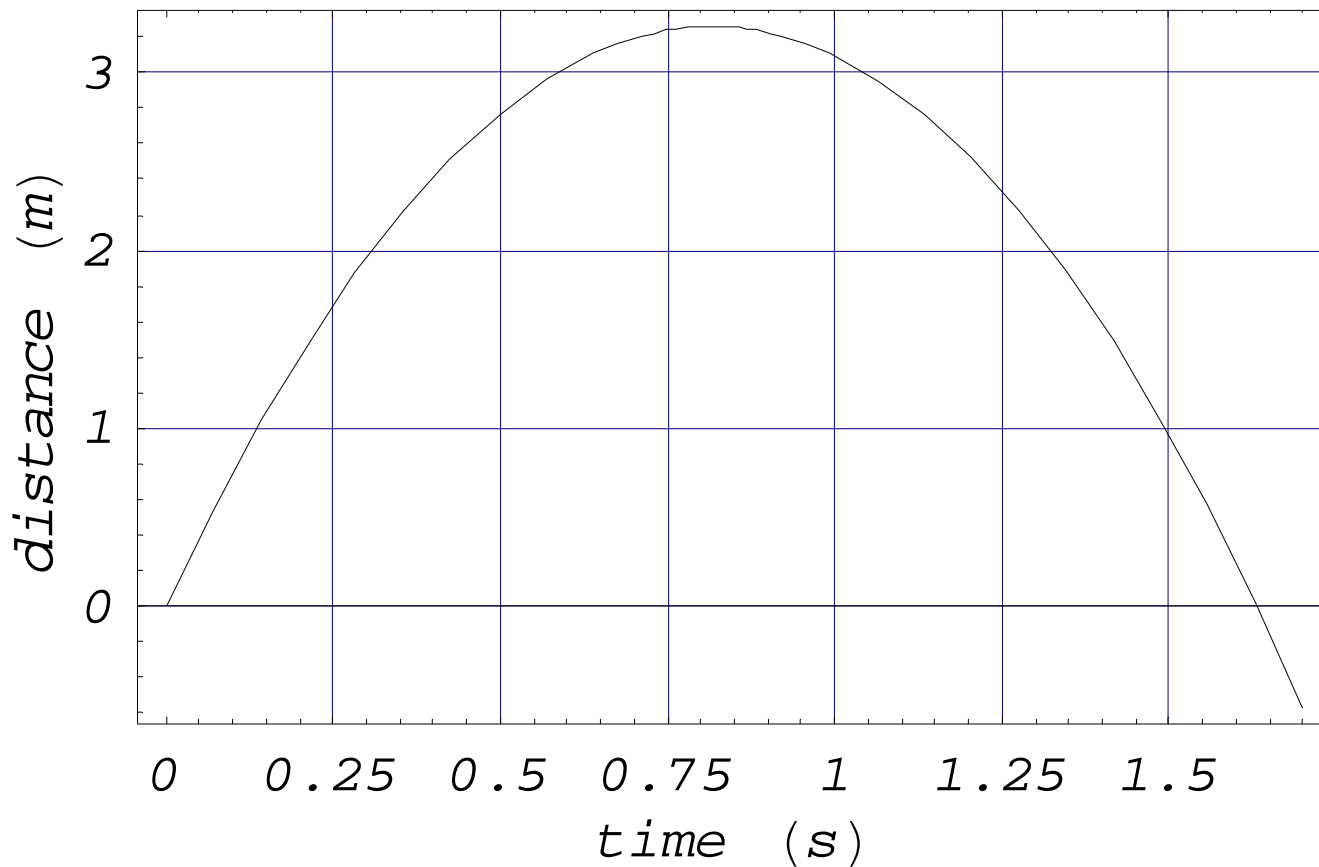


What is a force (continued)?

- These laws let us recognize a force, but what causes a force?
 - The modern view is related to field theory.
 - Forces are the result of an exchange of particles.
- To understand field theory, we have to start with energy (maybe more this lecture).



More Practice: Picture of the flight of a ball

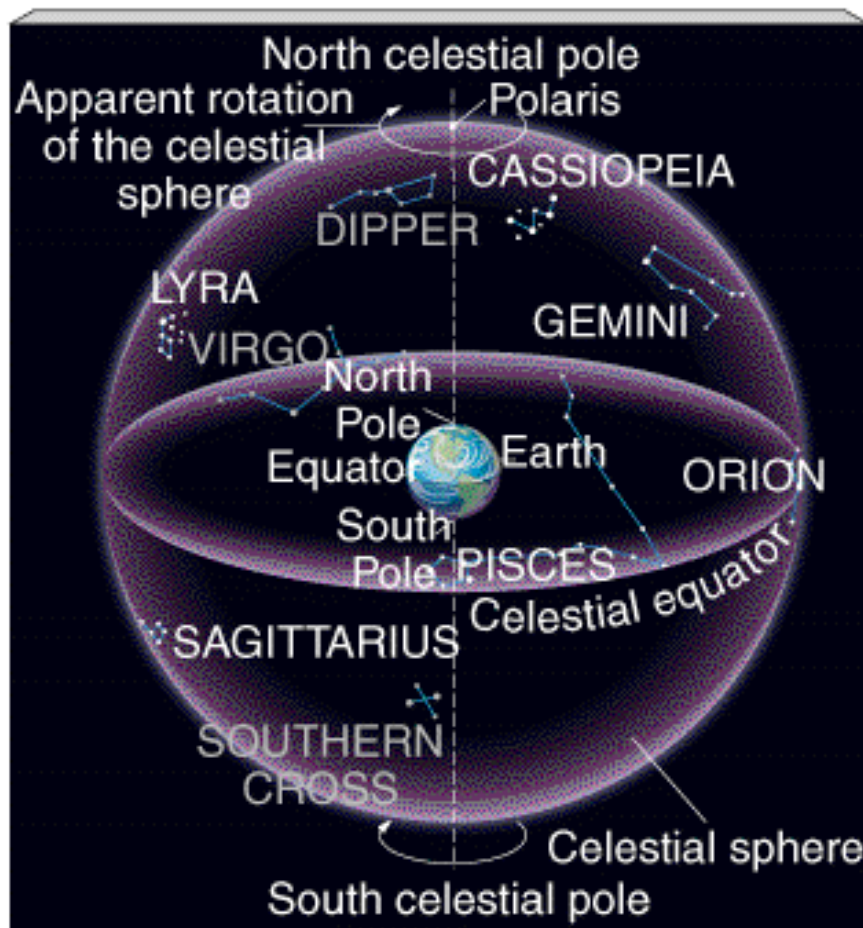


Motions of the Stars and Planets

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



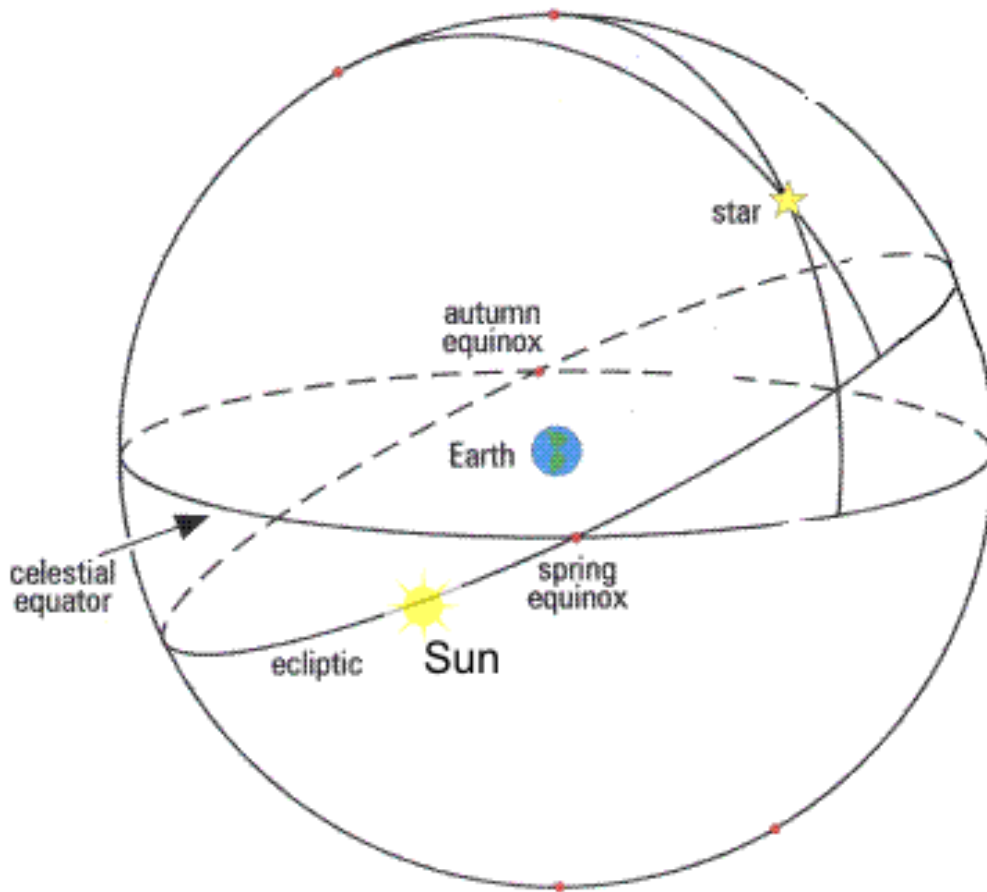
The Celestial Sphere



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.

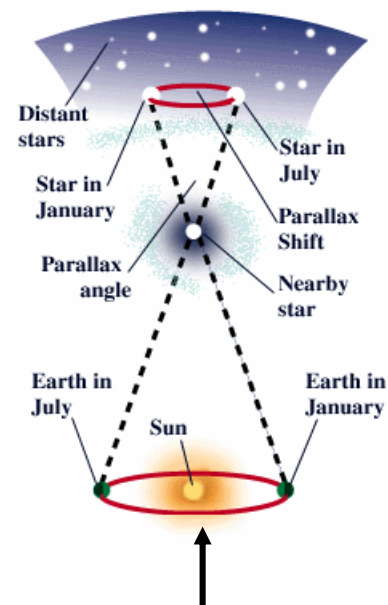
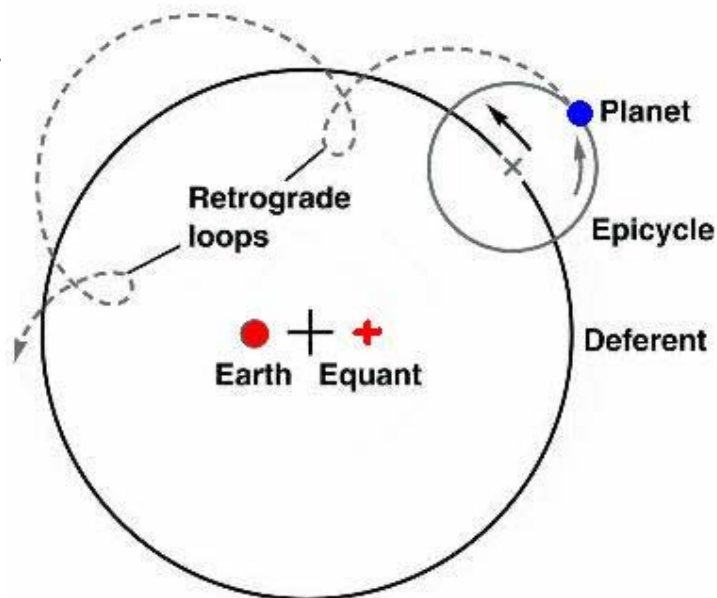


History of Observation of the Stars

- 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.



Brahe, Kepler, Galileo

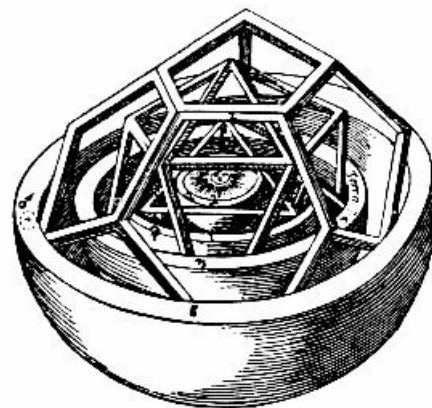
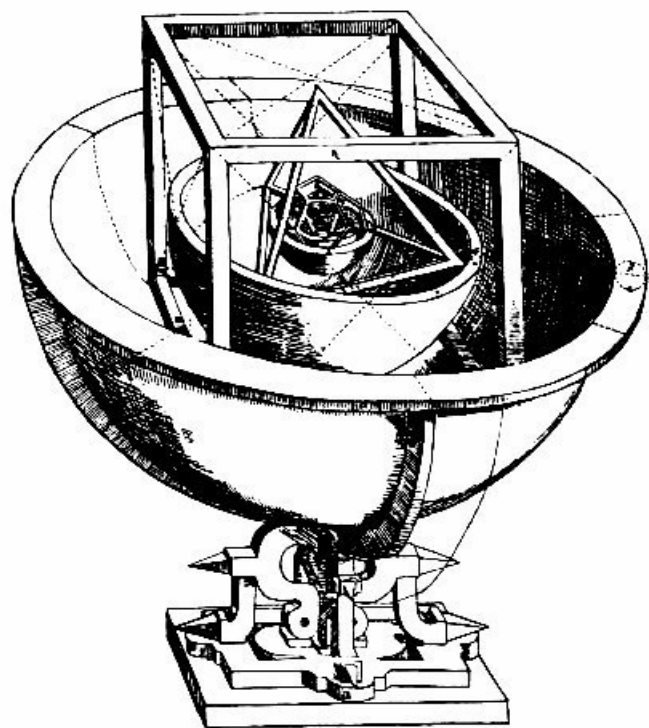
- Tycho Brahe (1546-1601) – set his life's goal to prove the Earth Centered hypothesis (religious motive). His observatory made observations 10 times better than any other. It used 1-1.5% of the Danish national budget.
- Johannes Kepler (1561-1630) – 3 laws
 - Was a brilliant mathematician (and astrologer)
 - Planets move in elliptical orbits
 - As a planet gets closer to a star it moves faster
 - The square of the period is equal to the cube of the semi-major axis of the orbit.
- Galileo
 - First used a telescope to study the heavens
 - Studied motion and devised the concepts of acceleration, etc.



Kepler

- In the course of his work with Brahe's data he discovered that the orbits of the planets fit into the 5 Platonic solids.
- This explains where there are only 6 planets and describes all of Brahe's observations on Mars to within 8 minutes of arc. (The width of the tip of your thumb held at arms length is $60 \text{ arcmin} = 1 \text{ degree}$.)
- Brahe's measurements were good to 1 arcmin (30 times better than previous measurements).

Kepler's Model



A circular orbit for Mars disagreed with Brahe's data to about 8 minutes of arc.



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.

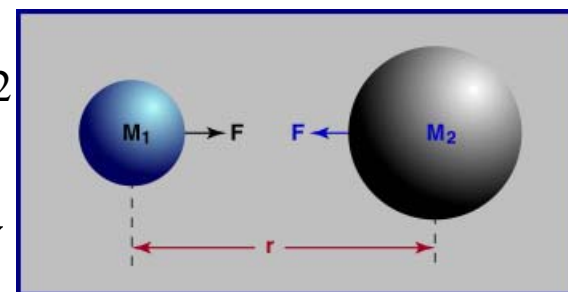
J. Kepler in *New Astronomy: Astronomia nova* (Heidelberg, 1609)

Newton and the Universal Law of Gravity

- Story of the apple tree – may or may not be true
- 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.





Two examples using the Law of Gravity

- What is the force of gravity on a 90 kg professor standing on the surface of the Earth?

$$F = \frac{Gm_e m_p}{r_e^2} = \frac{\left(6.673E-11 \text{ Nm}^2/\text{kg}^2\right) 90\text{kg} \times 5.974E24 \text{ kg}}{\left(6.378E6 \text{ m}\right)^2} = 882 \text{ N}$$

- What is the acceleration caused by this force?

$$F = ma \rightarrow a \equiv g = \frac{F}{m} = \frac{882\text{N}}{90\text{kg}} = 9.795 \text{ m/s}^2$$

- What would happen if the radius of the Earth were doubled, but the mass was the same?

$$F_{2r} = \frac{Gm_e m_p}{(2r_e)^2} = \frac{Gm_e m_p}{4(r_e)^2} = \frac{1}{4} \times F_r$$



Clicker Questions

- What is the force of gravity on a 90 kg astronaut in orbit, 300 km above the Earth?

Choose the best answer:

- A). Nearly 0 N
- B). 880 N
- C). 220 N
- D). 220,000 N



Clicker Questions

- Why is an astronaut in orbit weightless?
 - A). Because they are always in free fall, but constantly miss the Earth.
 - B). Because gravity from the Earth and moon cancels.
 - C). Because gravity from the Earth and Sun cancels.
 - D). Because there is no gravity in space.



Energy – The ability to do work

- Work done on or done by an object:
Work = force x distance (units N*m)
- Work (and energy) are scalars
- There are two kinds of energy
 - Energy of position – potential energy
 - Energy of motion – kinetic energy
- Other types of energy; thermal, chemical, etc. are special cases of kinetic and potential