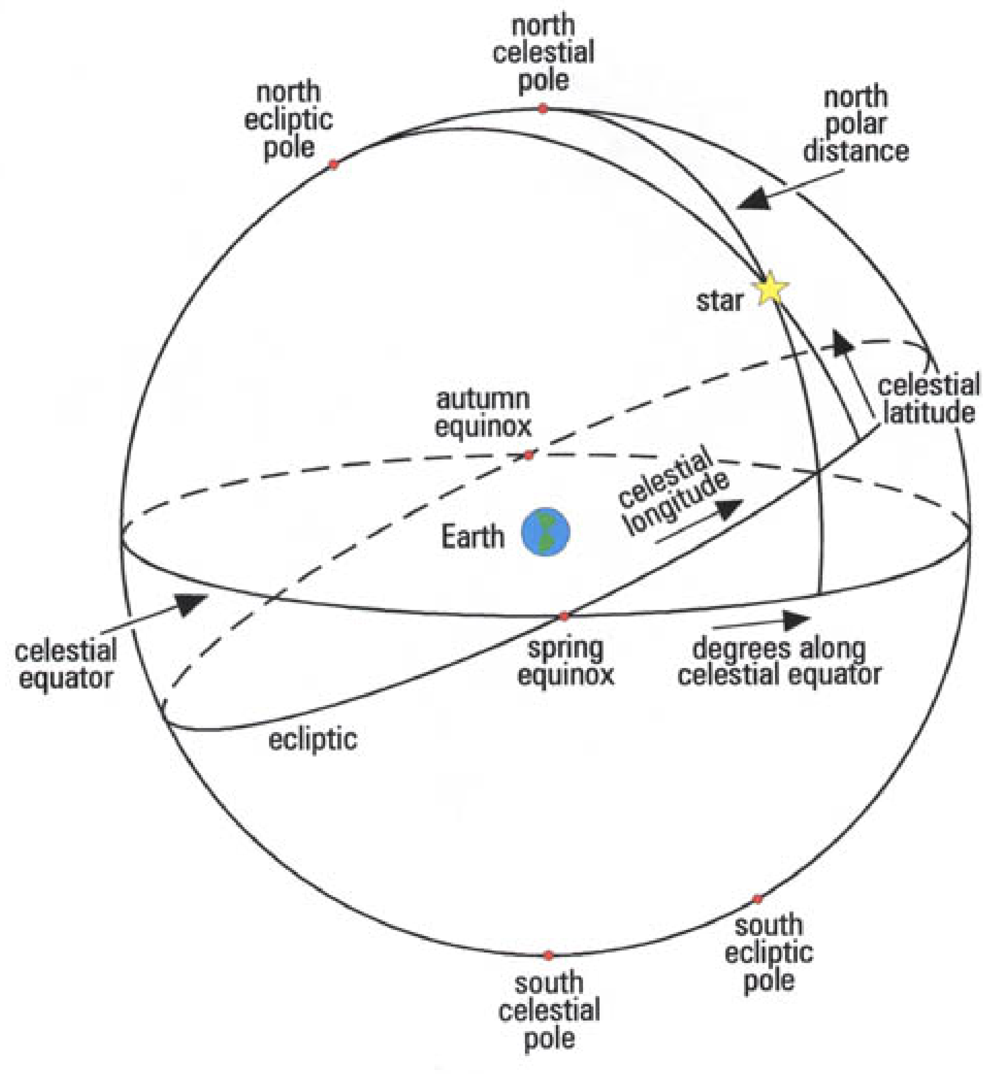
- Homework #2 is due at 11:50am this Friday!
- Thursday is last Planetarium observing.
- Solar Observing is happening now! Check out webpage to see if it is canceled due to weather.
- Nighttime observing starts next week.

Homework

Question 8:

Over the duration of a gi will be observed to pass side to the other of):

1. the zodiac.
2. the celestial equator.
3. the zenith.
4. the vernal equinox.



http://www.hps.cam.ac.uk/starry/mathtechniquesmed.jpg

Outline

- Newton explains Kepler– context
- Newton's Universal Law of Gravity
- Orbits
- Weight depends on mass of planet and distance from the center.
- Planets are actually all falling constantly.
- "Weightlessness" is the feel of falling, elevator, sky diving, space.

A Feather and a Hammer-- New

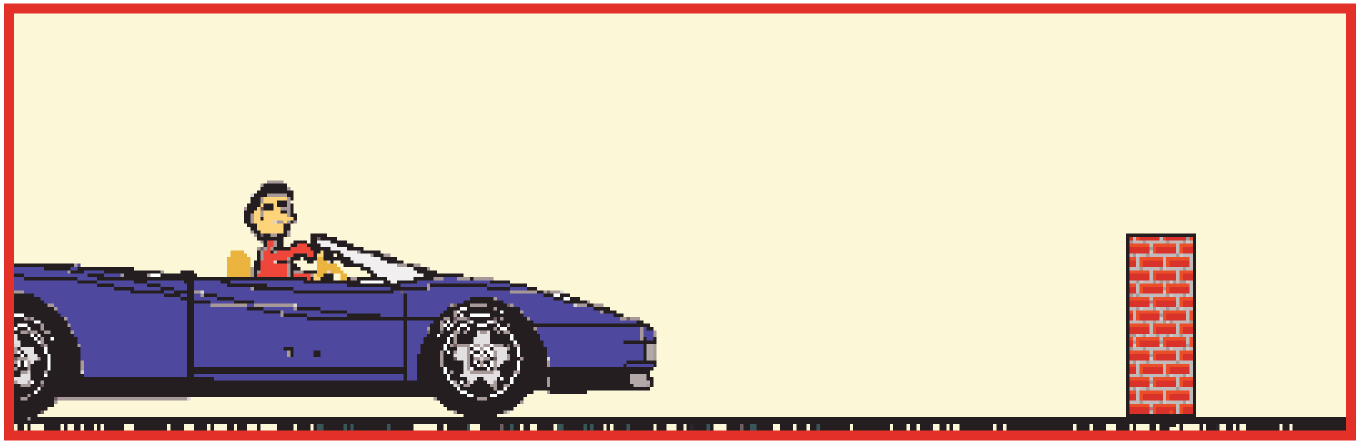
http://www.hq.nasa.gov/office/pao/History/alsj/a15/a15v_1672206.mpg

Isaac Newton– Explaining Kepler

Gave us a reason why Kepler's Laws– which were empirically found – can be derived from universal principles and a way to probe the structure of the Universe!

Newton's 1st Law of Motion

An object in motion will stay in motion and an object at rest will stay at rest unless acted on by a net outside force



http://www.glenbrook.k12.il.us/gbssci/phys/mmedia/newtlaws/cci.html

Planet Motion

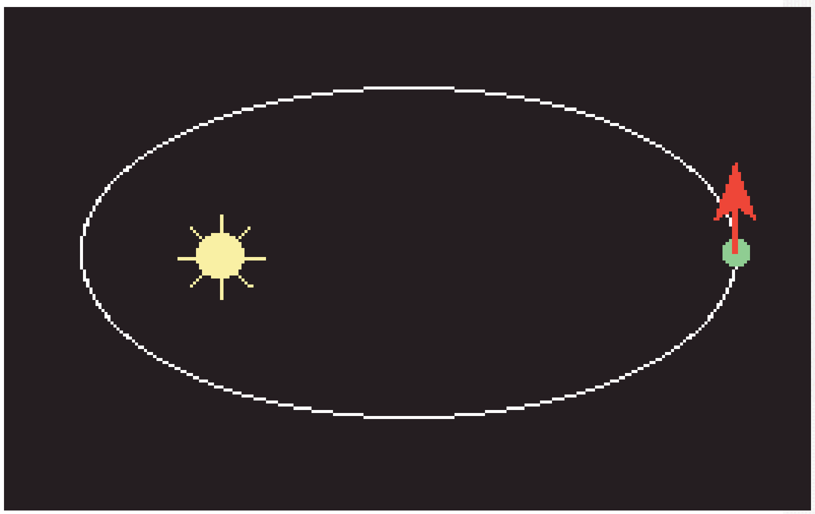
Newton’s first law shows:

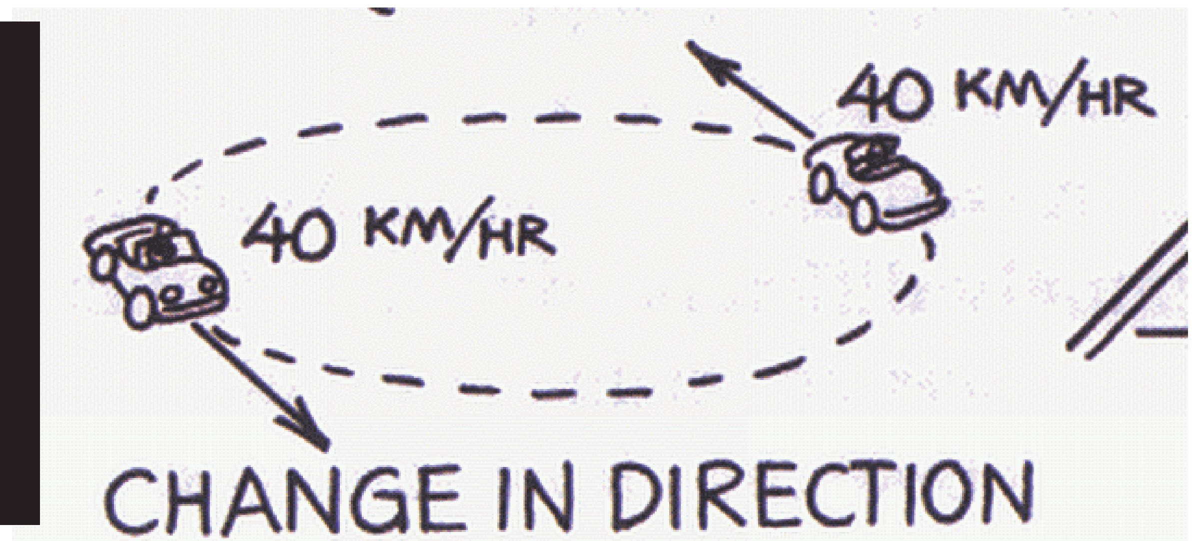
The ball when released just keeps going in a straight line. Hmmm.. That means that there is a <u>net outside force</u> being applied at all times–equivalent to the string.

http://explorezone.space.com/space/orbit.htm

Planet Motion

A constant change of velocity (particularly direction), which means there must be acceleration.





From *Conceptual Physics*

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

Newton's 2nd Law of Motion

The Acceleration of an object is equal to the Force applied, divided by its Mass

$a = F / m$ or $F = m \times a$

http://library.thinkquest.org/CR0215468/newtons_second_law.htm

From *Conceptual Physics*

Nature of Gravity

- As planets are not moving on a straight line, they must be accelerating.

- In our Heliocentric solar system, the Sun MUST be applying a constant centripetal force. <u>Ah gravity</u>!
- By looking at the motions of the planets, Newton realized that the force is inversely related to the square of the distance.

http://explorezone.space.com/space/orbit.htm

The Universal Force

Kepler's 3rd Law and Newton's 3rd Law imply that the force must be proportional to the product of the masses for the planet and the Sun.

Newton's 3rd Law

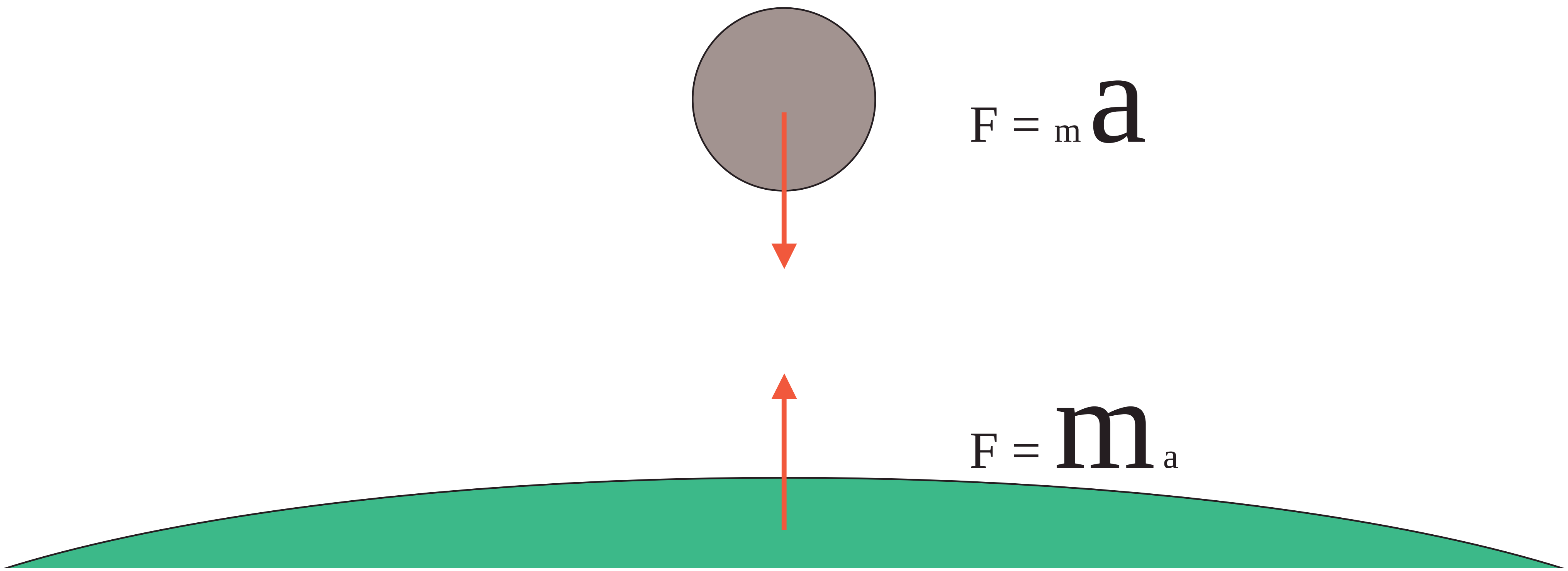
Every action has an equal and opposite reaction! There is an action-reaction pair.

http://www.glenbrook.k12.il.us/gbssci/phys/Class/newtlaws/u2l4a.html

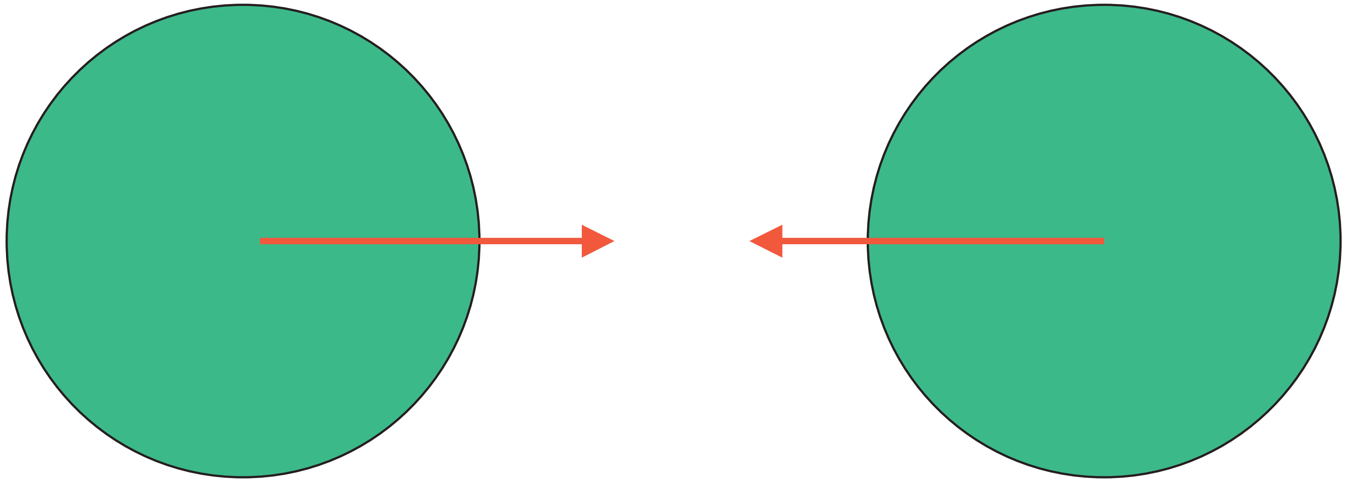
Newton's Universal Law of Gravity

Two bodies attract each other with a force that is directly proportional to the product of the their masses and inversely proportional to the square of the distance between them.

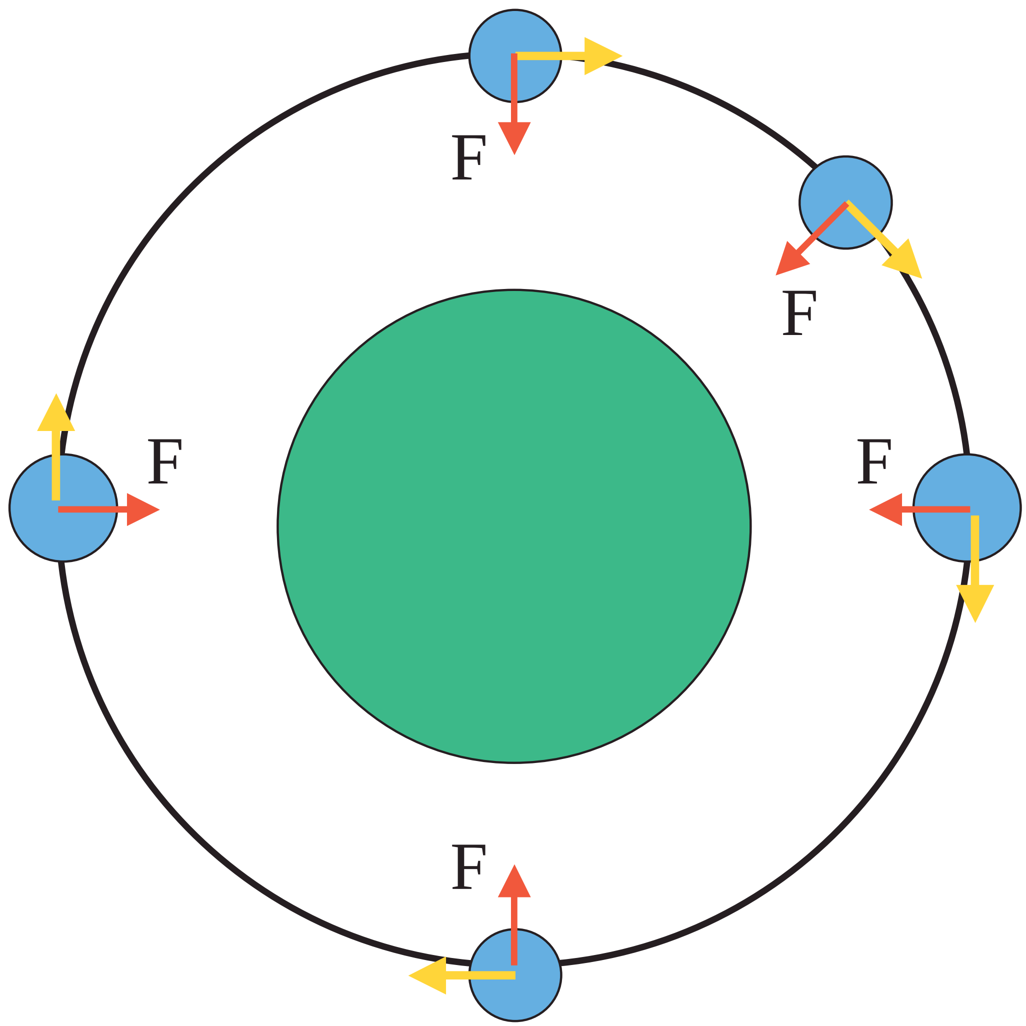
The Earth pulls you and you pull it. But Earth wins.



F = m a
F = m a



$F = m\,a$ $\qquad$ $F = m\,a$


F
F
F
F
F

Universal Gravity

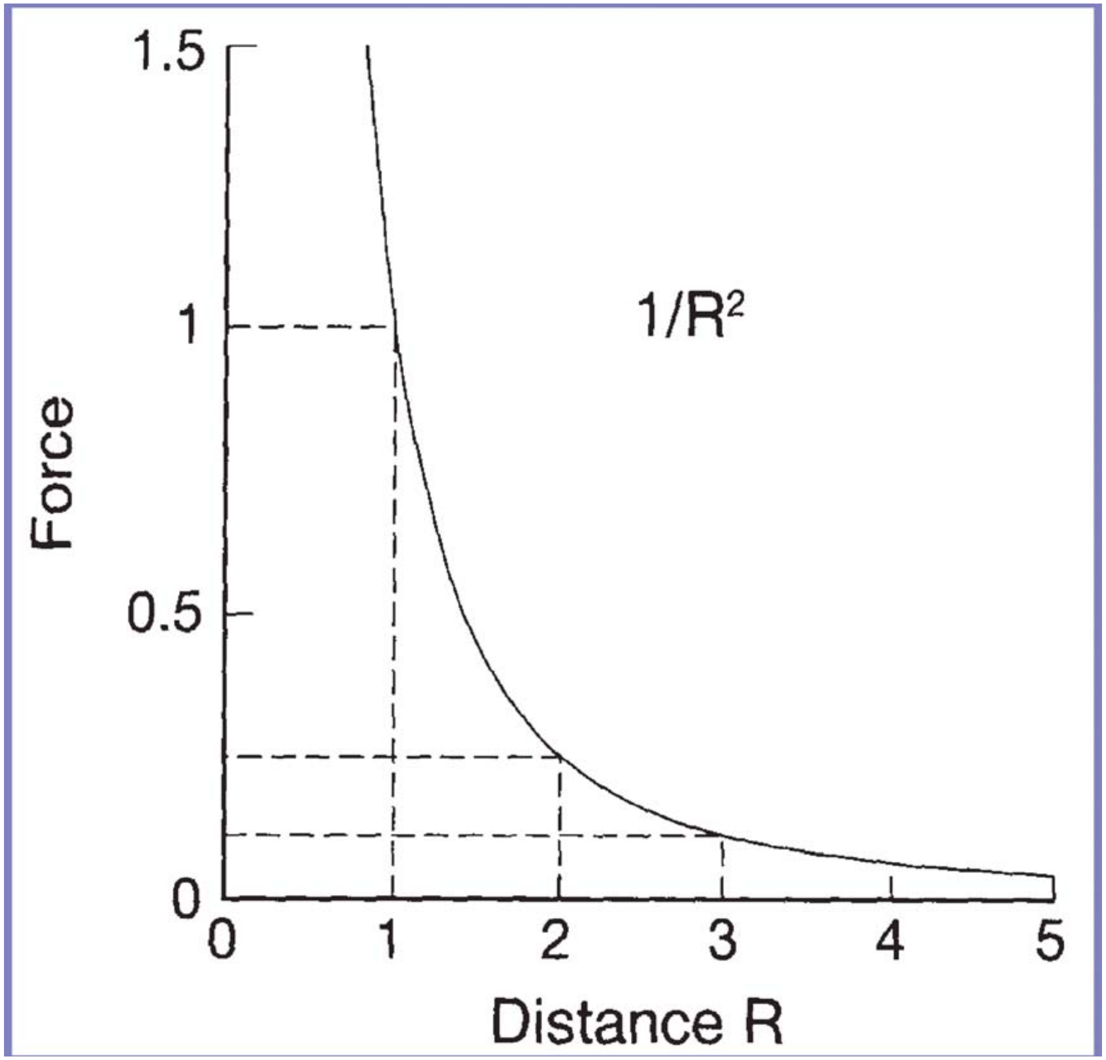
- Any two masses have a gravitational force between them:

$$F = \frac{GM_1M_2}{R^2}$$

- M_1 and M_2 are the masses
- R is the distance between the 2 masses
- G is the gravitational constant

(G = 6.67 x 10^{-11} when kg and meters are used)

Inverse Square Law



Strong function of separating distance!

Doubling the distance quarters the force!

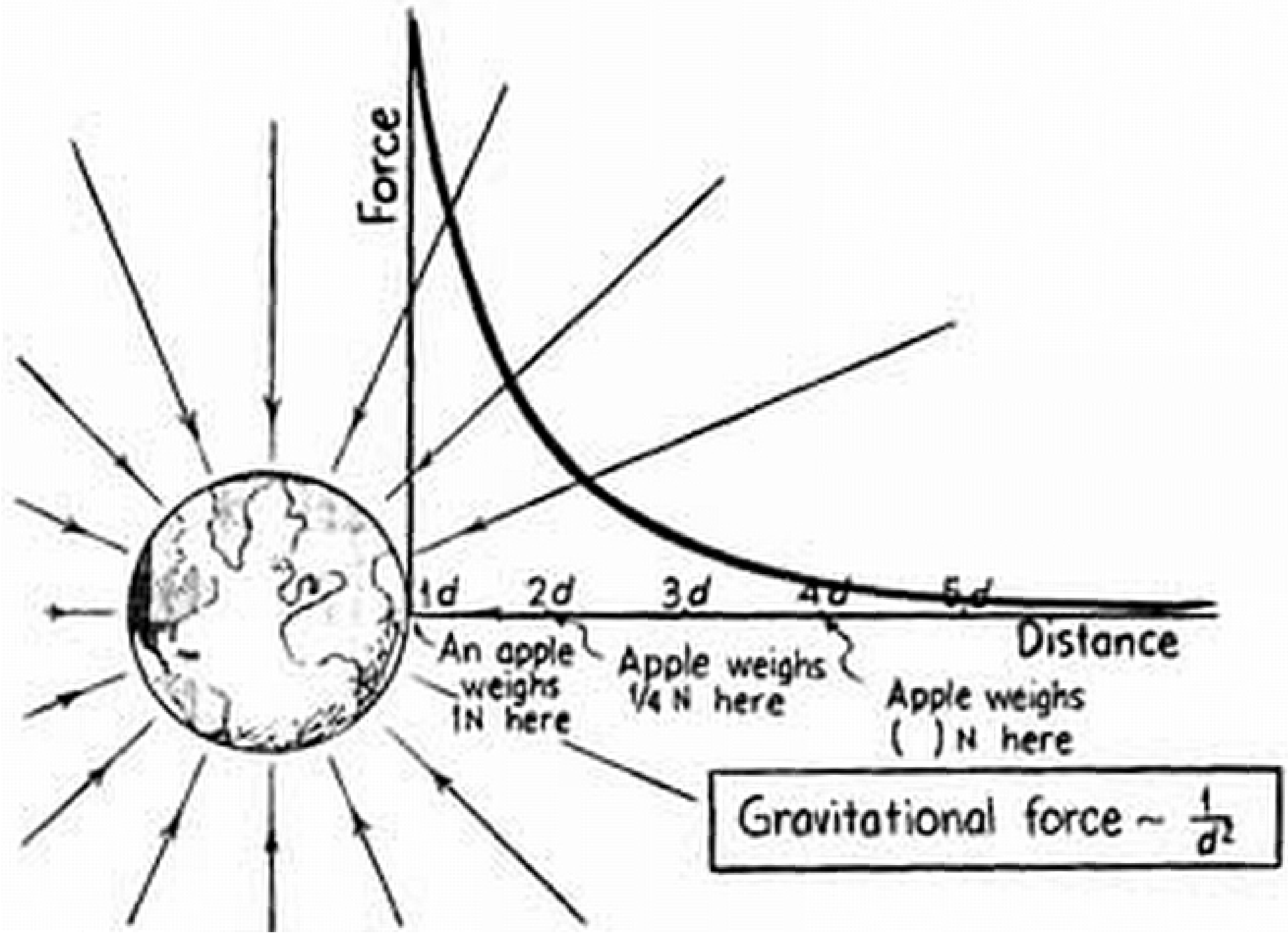
What is weight?

- What we feel as weight is actually the force we feel from Newton's Law of Gravity.

$$Weight = \frac{GM_{Earth}M_{you}}{R_{Earth}^{2}}$$

- It is confusing since social convention has made weight and mass the same at the earth's surface, but what happens to your weight elsewhere?

Inverse Square Law



http://www.west.net/~ger/inversesquare.html

Weight in an Airplane

Question: When you fly in an airplane, you increase your distance from the center of the Earth. Does your weight:

1. Increase.
2. Decrease.
3. Stay the same.

And your mass?

Weight in an Airplane?

Question: When you fly in an airplane, you increase your distance from the center of the Earth.

If the distance increases, d^2 is larger, so your weight is reduced.

$$Weight \propto \frac{1}{{d_{Earth}}^2}$$

Moon weight

- The Moon is around 3.7 times smaller and 81 times lighter than the Earth

$$Weight = \frac{GM_{Moon}M_{you}}{R_{Moon}^{\ 2}}$$

- Your mass would be exactly the same, but your weight would be around 1/6th of your weight on Earth.

Moon weight

$$Weight = \frac{GM_{Moon}M_{you}}{R_{Moon}^{\;2}} = \frac{G\left(\frac{M_{Earth}}{81}\right)M_{you}}{\left(\frac{R_{Earth}}{3.7}\right)^2}$$

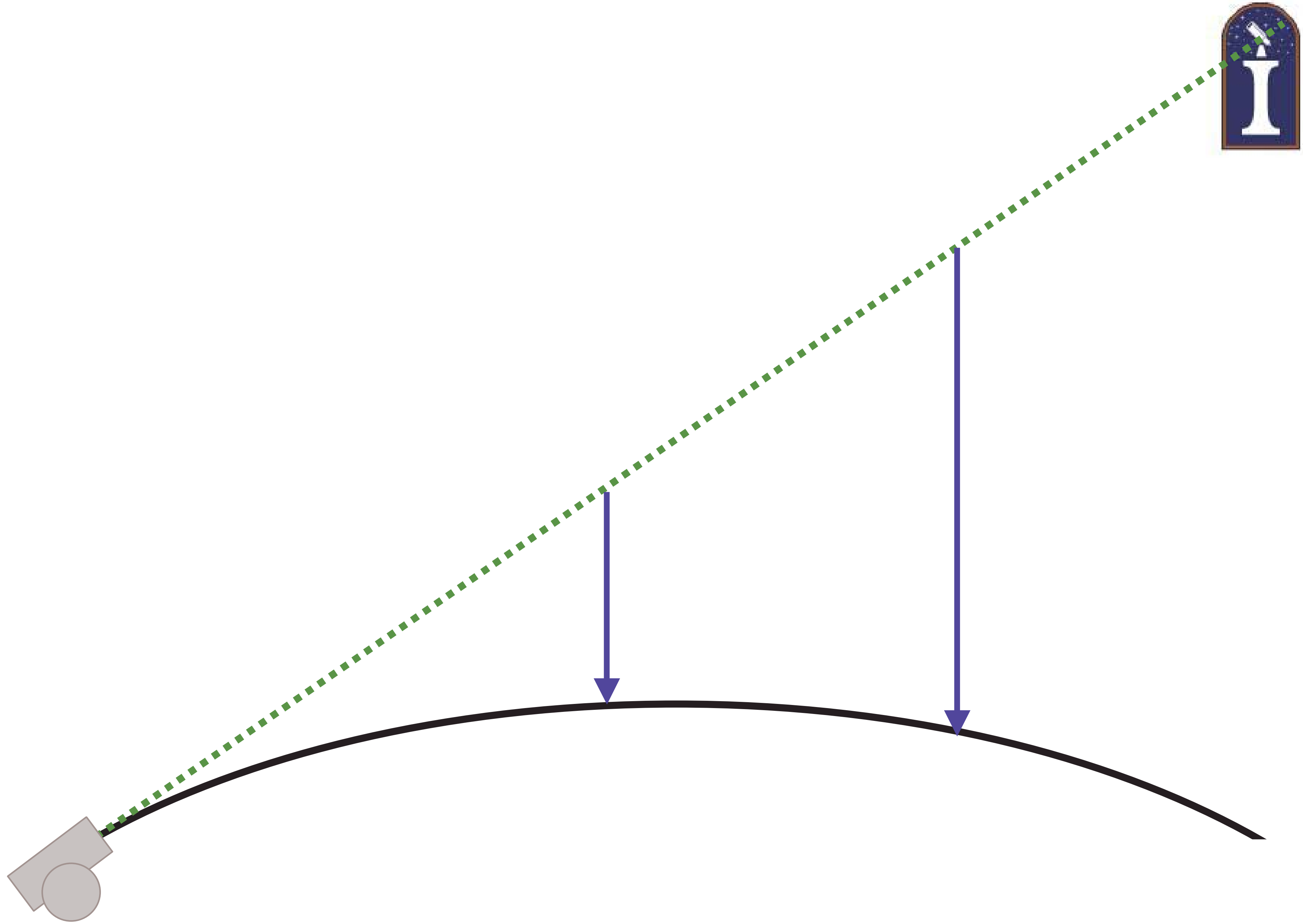
$$or \ldots = \frac{1}{81}(3.7)^2\frac{GM_{Earth}M_{you}}{R_{Earth}^{\;2}} \approx \frac{1}{6}Weight_{Earth}$$

Gravity on the Moon

Is there gravity on the moon?

Yes! But as the Moon has less mass, the pull of gravity is less than on Earth. Result is that your weight is 1/6th of your Earth weight.

http://btc.montana.edu/ceres/html/weight1.htm

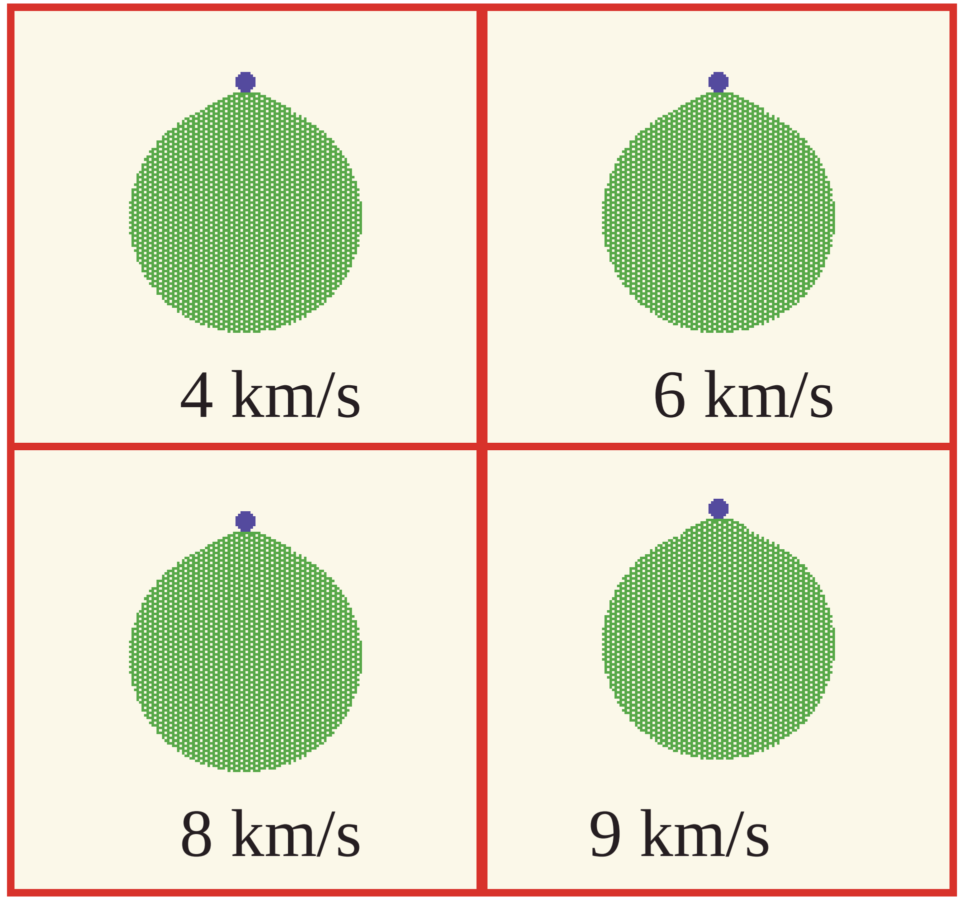


Cannon Shots

http://spaceplace.jpl.nasa.gov/orbits1.htm

A Cannonball Shot from a Mountain

Orbital bodies are actually falling bodies– at 8 km/s the cannonball is falling at a rate such that the Earth curves below it

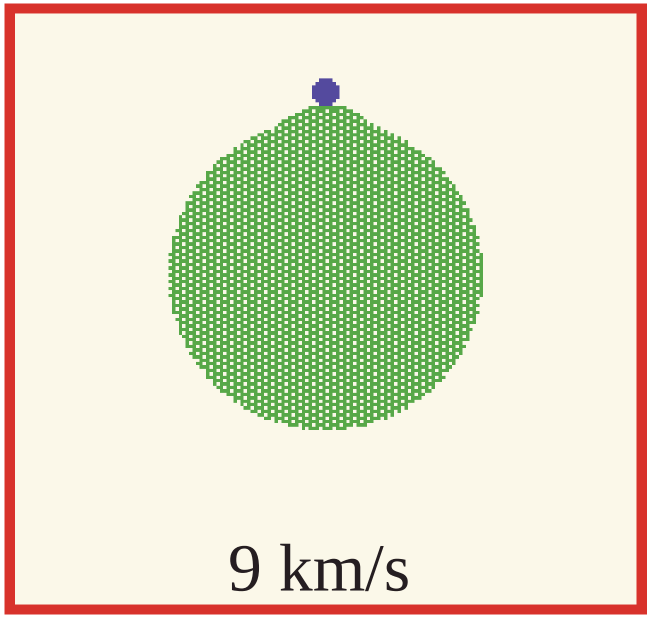


An ellipse

http://www.physicsclassroom.com/mmedia/vectors/sat.html

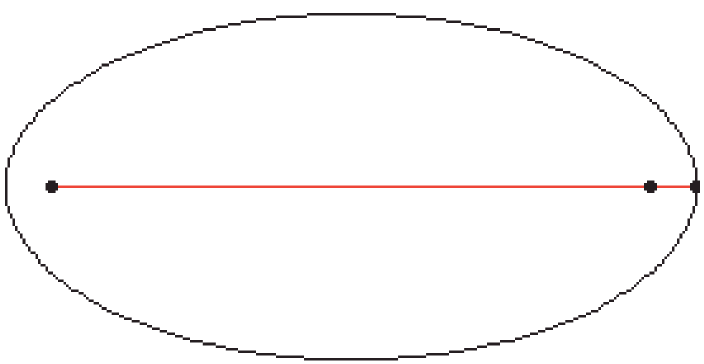
Ellipses

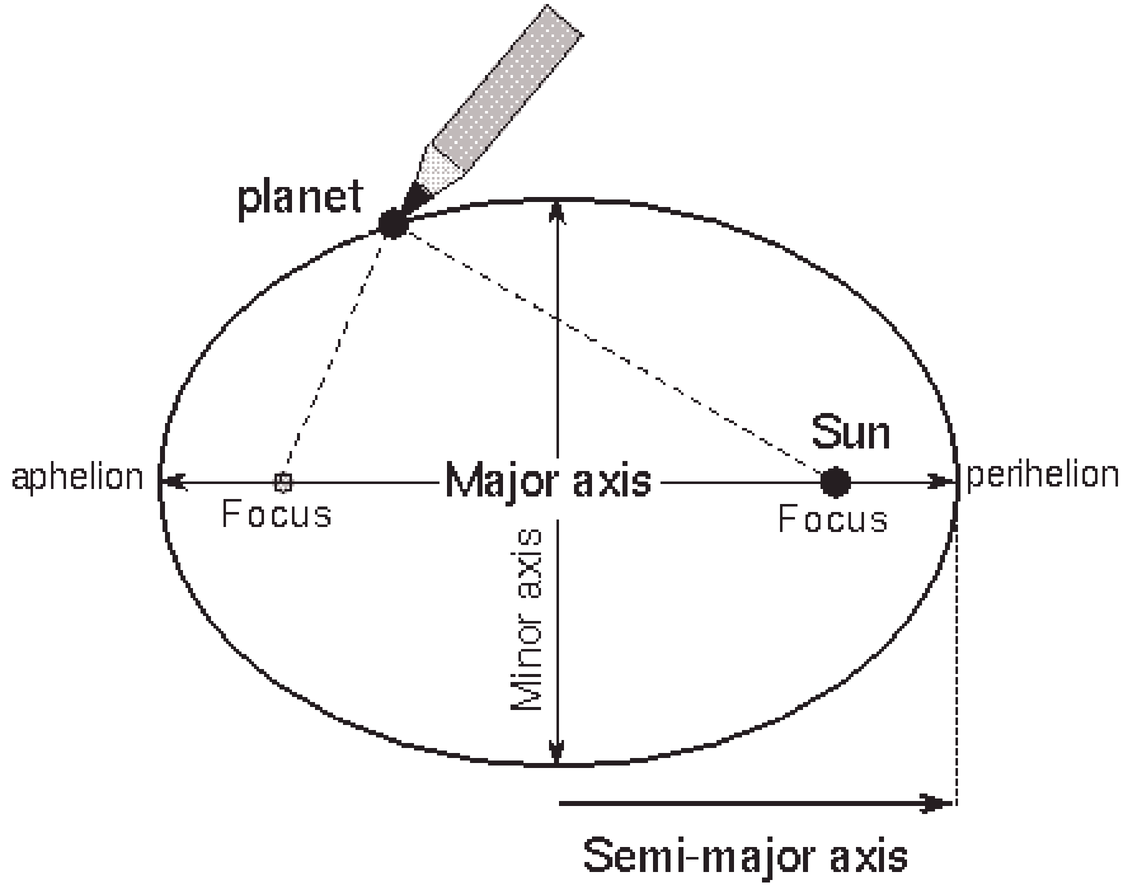
- So, following Newton's description of gravity, we find that he predicts that orbits are ellipses
- Reproduced Kepler's first Law.



An ellipse

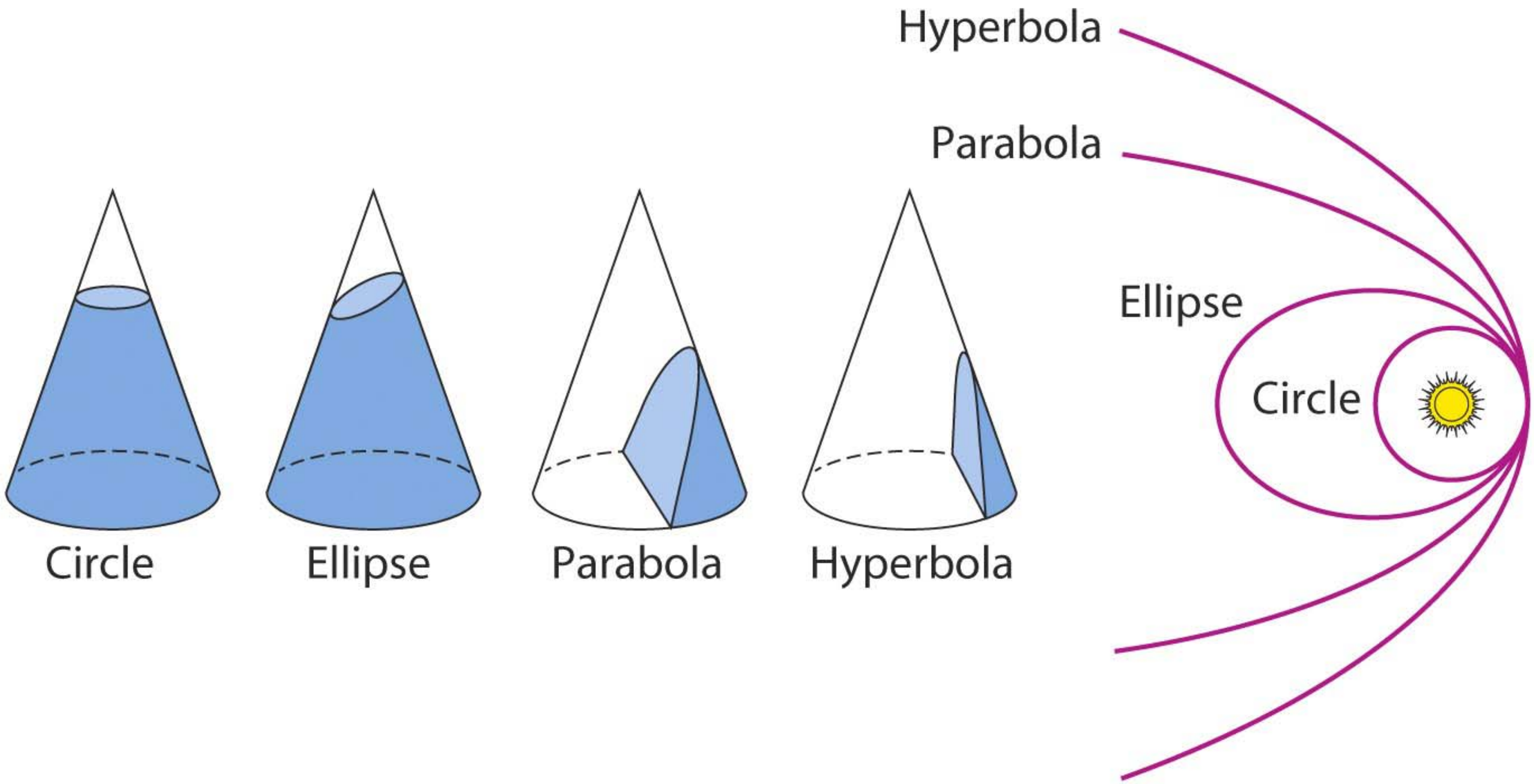
Kepler's 1st Law: Orbits of planets are ellipses with the Sun at one focus





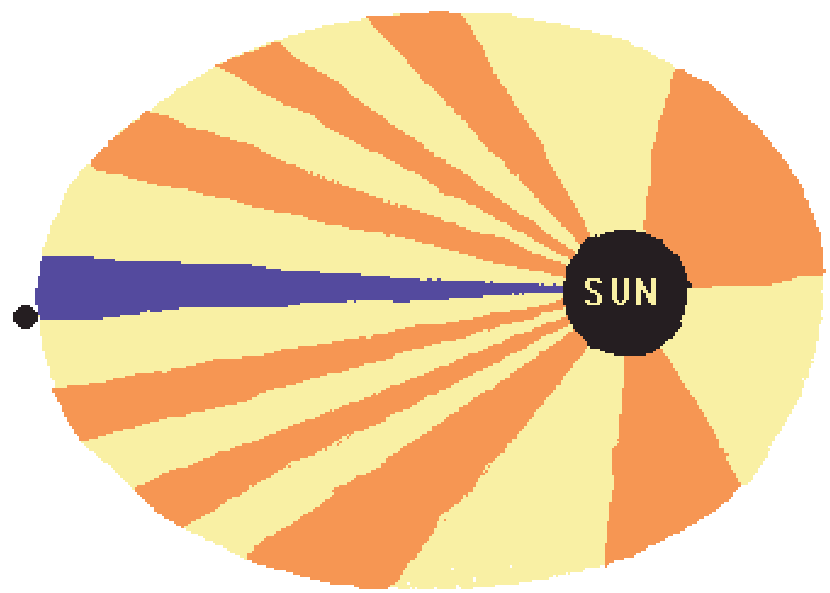
Newton’s Ellipses

Actually Newton also found more options that satisfied his universal law of gravity.



Centripetal Force

Because the planet-Sun line sweeps out equal areas in equal times (Kepler's 2nd Law), it is possible to show that the force must be directed toward the Sun from the planet.



Kepler's 3rd Law:

The squares of the orbital sidereal periods of the planets about the Sun are proportional to the cubes of the orbital semimajor axes

Planet	P (yr)	a (AU)	P^2	a^3
Mercury	0.24	0.39	0.06	0.06
Venus	0.61	0.72	0.37	0.37
Earth	1.00	1.00	1.00	1.00
Mars	1.88	1.52	3.5	3.5
Jupiter	11.86	5.20	141	141
Saturn	29.46	9.54	868	868

$$P^2 = a^3$$

$$P \times P = a \times a \times a$$

Where P is in years and a is in AU.

Newton's Generalization

- Can use the gravitational equation to find that

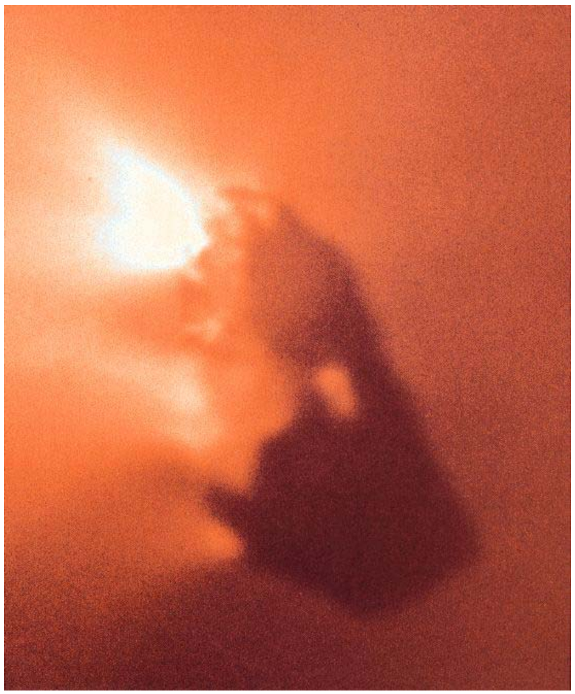
$$P^2 = \text{constant}\,\frac{a^3}{M_1 + M_2}$$

Works for any two objects

- Constant is actually $4\pi^2/G$
- Kepler's 3rd law only works because the mass of the Sun is much larger than the mass of any of the planets

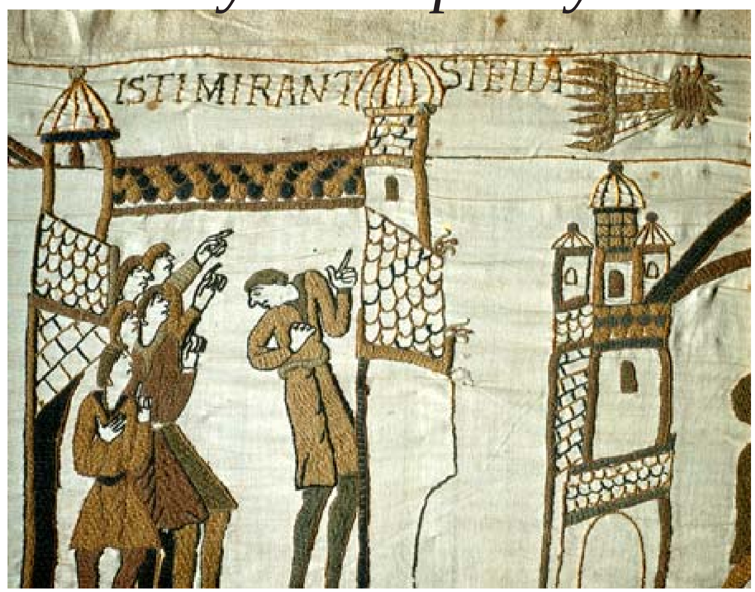
Testing: Halley's Comet

Halley's Comet was known to often reappear. Edmund Halley used Newton's formulism to find next arrival.



http://seds.lpl.arizona.edu/nineplanets/nineplanets/halley.html

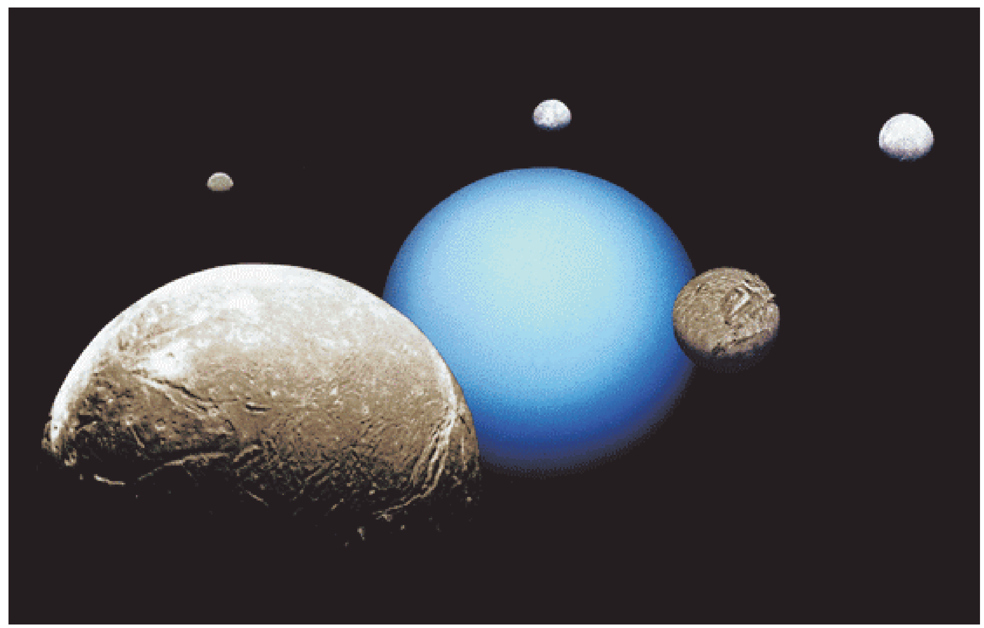
Bayeux Tapestry



http://www.getty.edu/artsednet/resources/Space/Stories/halleys.html

Testing: Uranus and Neptune

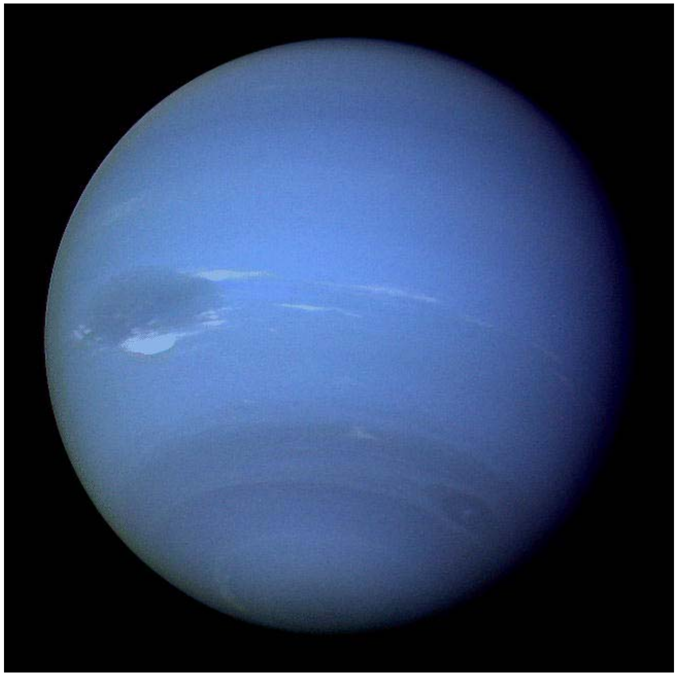
- Uranus was discovered as the 8th planet in 1781 by accident.
- The FIRST planet discovered since ancient times!
- Galileo almost discovered it in 1613.



http://wmatem.eis.uva.es/~marsan/discover/plan-sat/

Testing: Uranus and Neptune

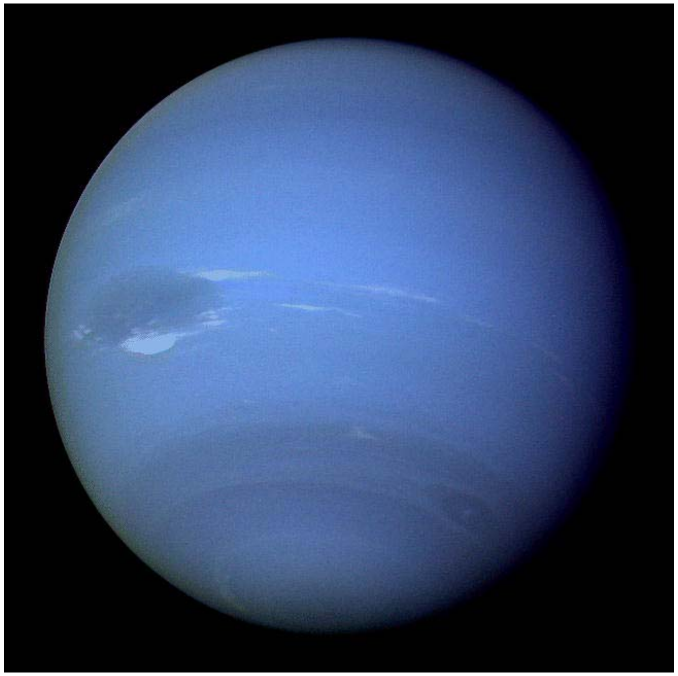
- Observations showed that it was not orbiting the way Newton predicted– off in position by 1 to 2 arcminutes.
- Either Newton's formulism was wrong, or there was something else out there.
- Using Newton's Laws, 2 scientists derived that there must be another undiscovered planet that was causing the perturbation in the orbit of Uranus.
- They predicted a new planet to within 1 degree of where it was found in 1846.



http://seds.lpl.arizona.edu/nineplanets/nineplanets/neptune.html

Testing: Uranus and Neptune

- The first object that was really discovered with pencil and paper and not direct observation.
- Newton’s theory can predict observations!!!
- Science can move from empirical concepts.
- Now, we can make concrete predictions.



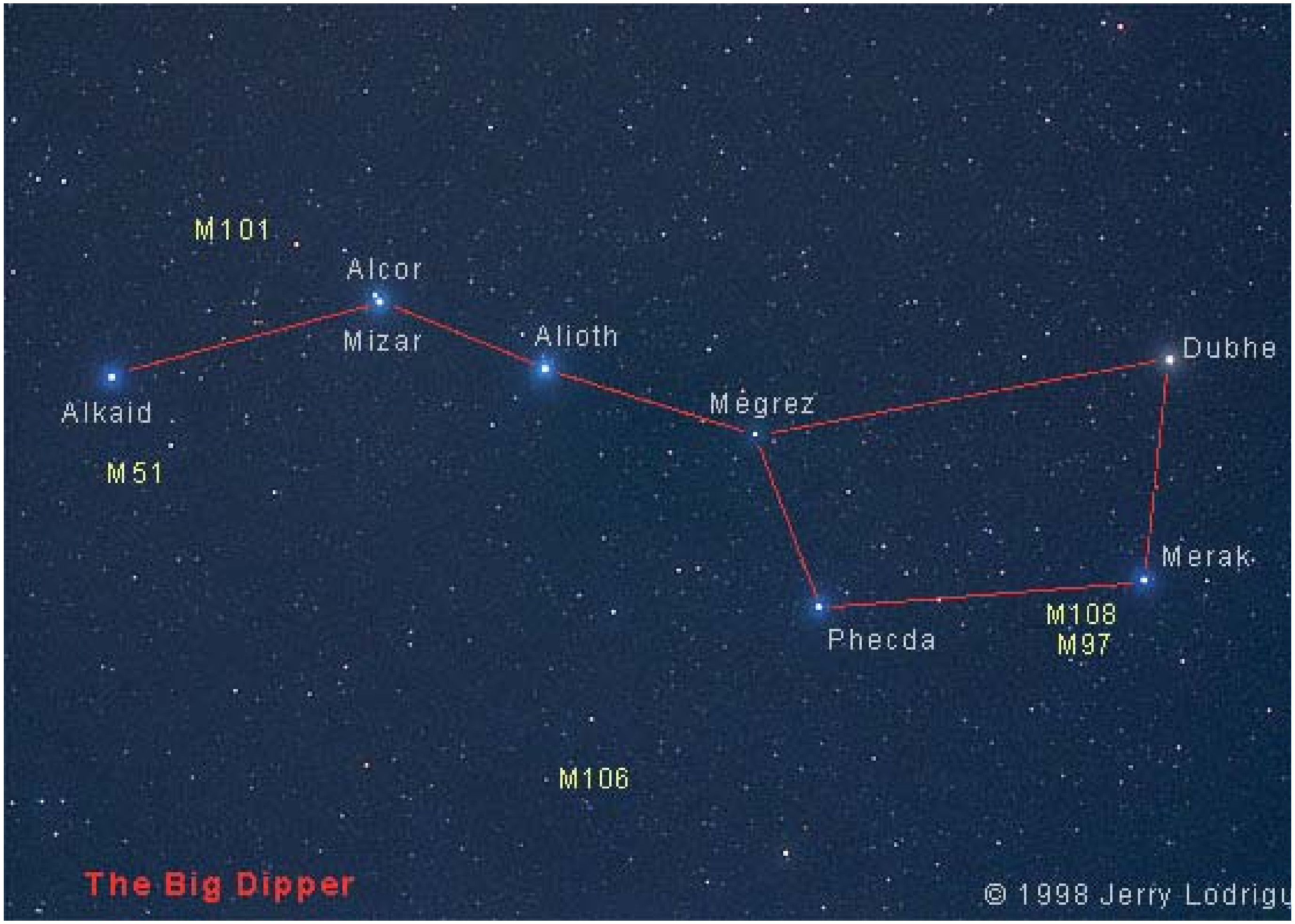
http://seds.lpl.arizona.edu/nineplanets/nineplanets/neptune.html

Result

- Now we know that the planets that orbit the Sun are just always falling bodies. This includes the shuttle, satellites, etc.
- "Weightlessness" is just like falling. There is gravity on the shuttle, but as one is in freefall it is not noticeable.
- Kepler had thought briefly about this, but he decided he needed forces along the direction of the velocity, not perpendicular to it.
- So Newton realized that like an apple falling from a tree or a really big tree, the moon must have a force toward the Earth.
- Newton did not discover gravity, but he realized that it was universal.

Example– Binary Stars

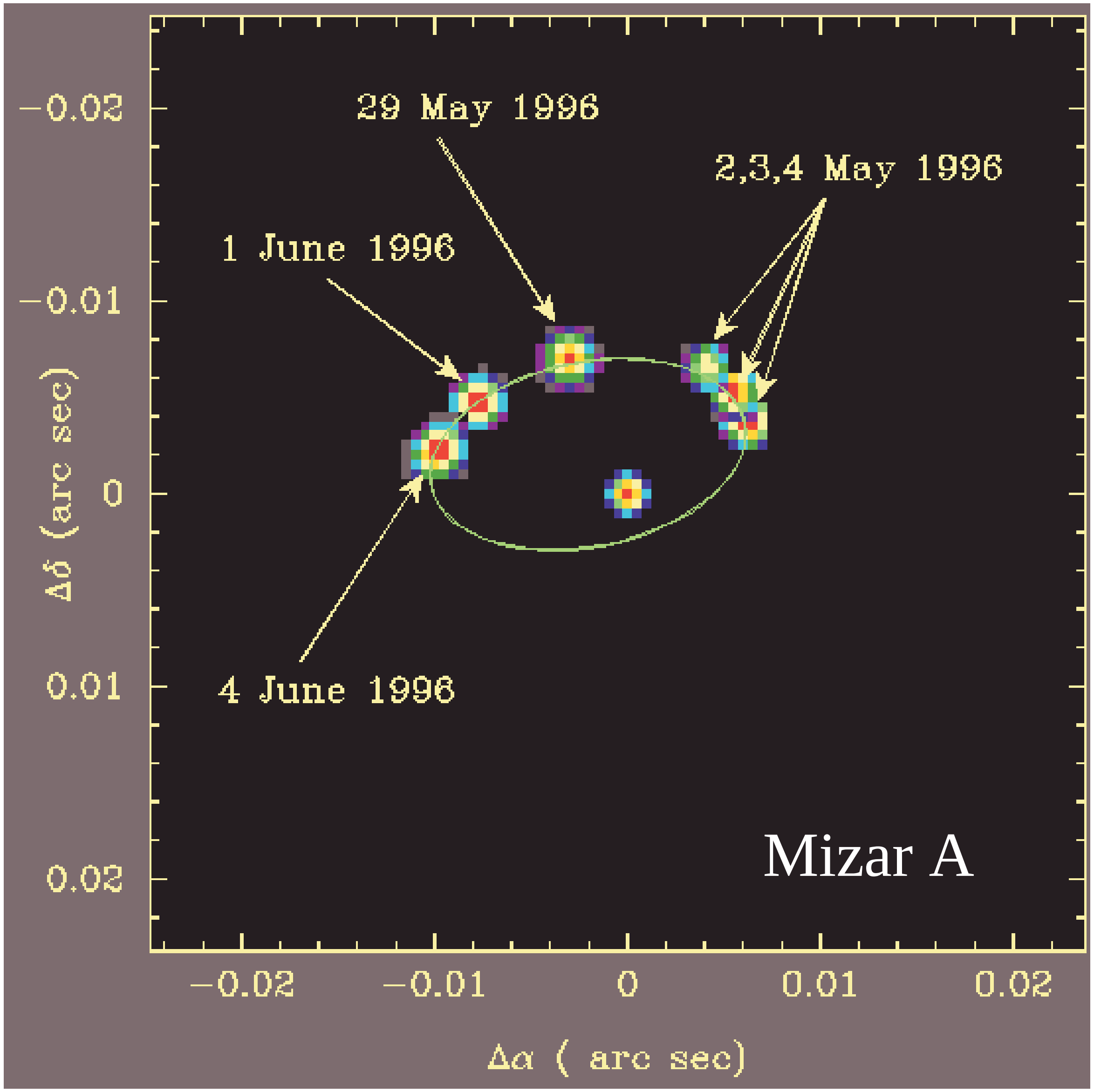
The most famous visual binary star pair is Mizar-Alcor in the Big Dipper. It is a good test of eyesight if you can see the two stars– separation of 12 arcminutes. But they are not really related.



http://www.astropix.com/HTML/C_SPRING/BIGDIP.HTM

Example– Binary Stars

Mizar itself (88 light year distance) has been known to be a true binary star– the first binary star pair to be determined by telescope (340 AU separation). But each of those are also binaries. Mizar A has a separation of 0.2 AU!!!



http://antwrp.gsfc.nasa.gov/apod/ap970219.html

Example: Globular Cluster

47 Tucanae in Southern Skies. The 2^{nd} brightest cluster in our sky. 20000 light years distance. Newton’s laws still hold, but we not sure why the dynamics in the center produce so few binary systems.

Escape Velocity

We talked about the horizontally aimed cannon, but if we fired it vertically, what velocity do we have to fire it so that it doesn't fall back down?

At some velocity the cannonball outruns gravity's pull. That number is 11.2 km/s or 25,000 m/hr.

http://vesuvius.jsc.nasa.gov/er/seh/earlysf.html