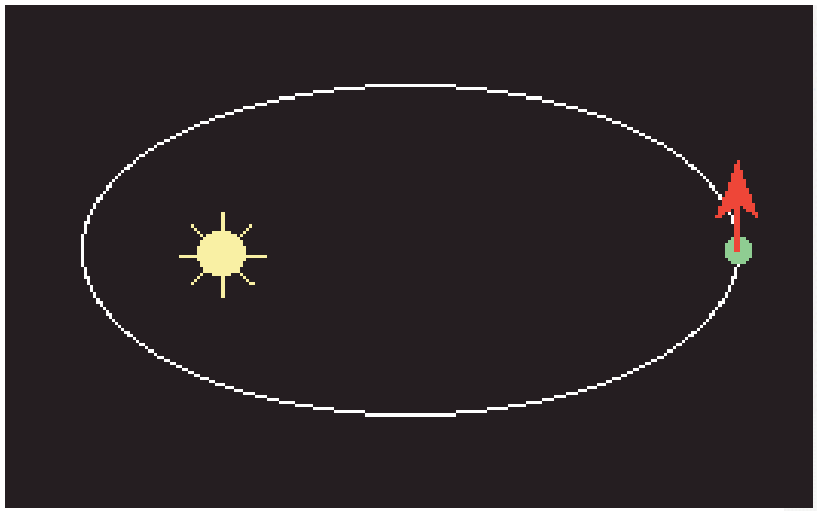
- Homework #2 is due at 11:50am this Friday!
- Thursday is last Planetarium observing.
- Solar Observing is happening now! Remember to check webpage. Last day is Thursday.
- Nighttime observing starts next week.

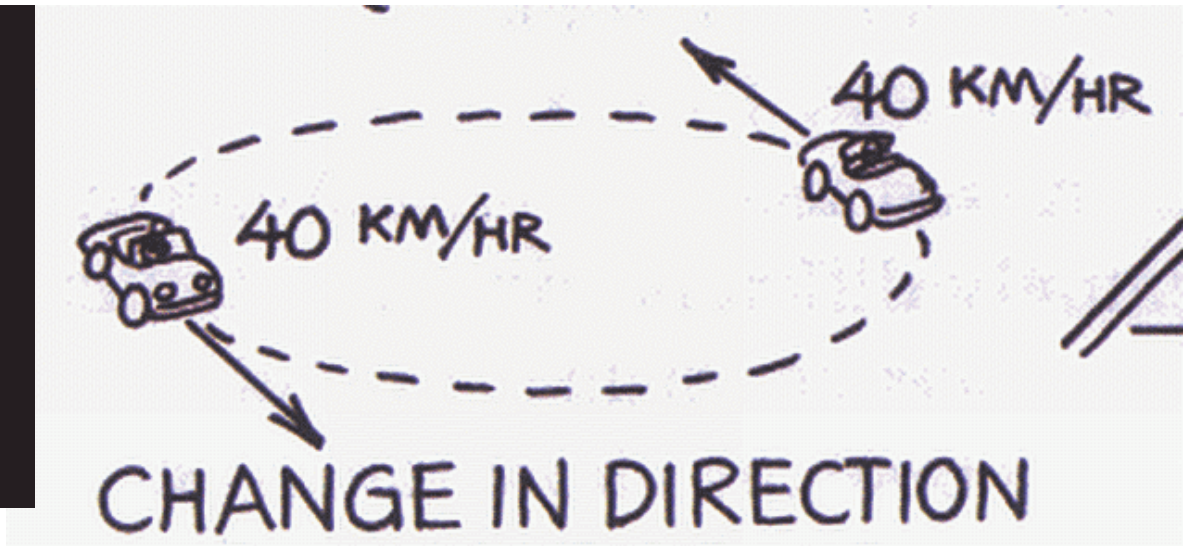
Outline

- Newton's Universal Law of Gravity
- Switch Gears– Solar System Introduction
- What is Density?

Planet Motion

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





By looking at the motions of the planets, Newton realized that the force is inversely related to the square of the distance.

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

From *Conceptual Physics*

Universal Gravity

- Any two masses have a gravitational force between them:

$$F = \frac{GM_1M_2}{R^2} \propto \frac{M_1M_2}{R^2}$$

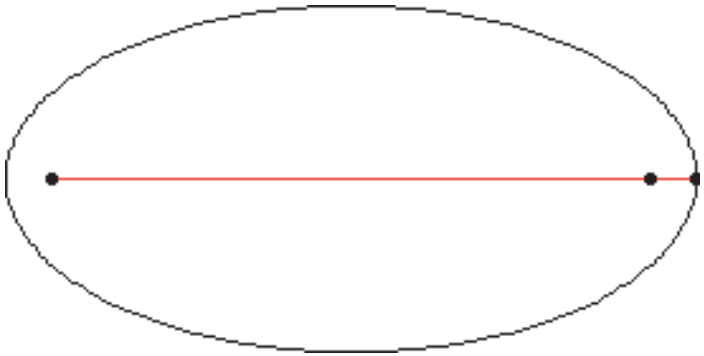
- M_1 and M_2 are the masses
- R is the distance between the 2 masses
- G is the gravitational constant

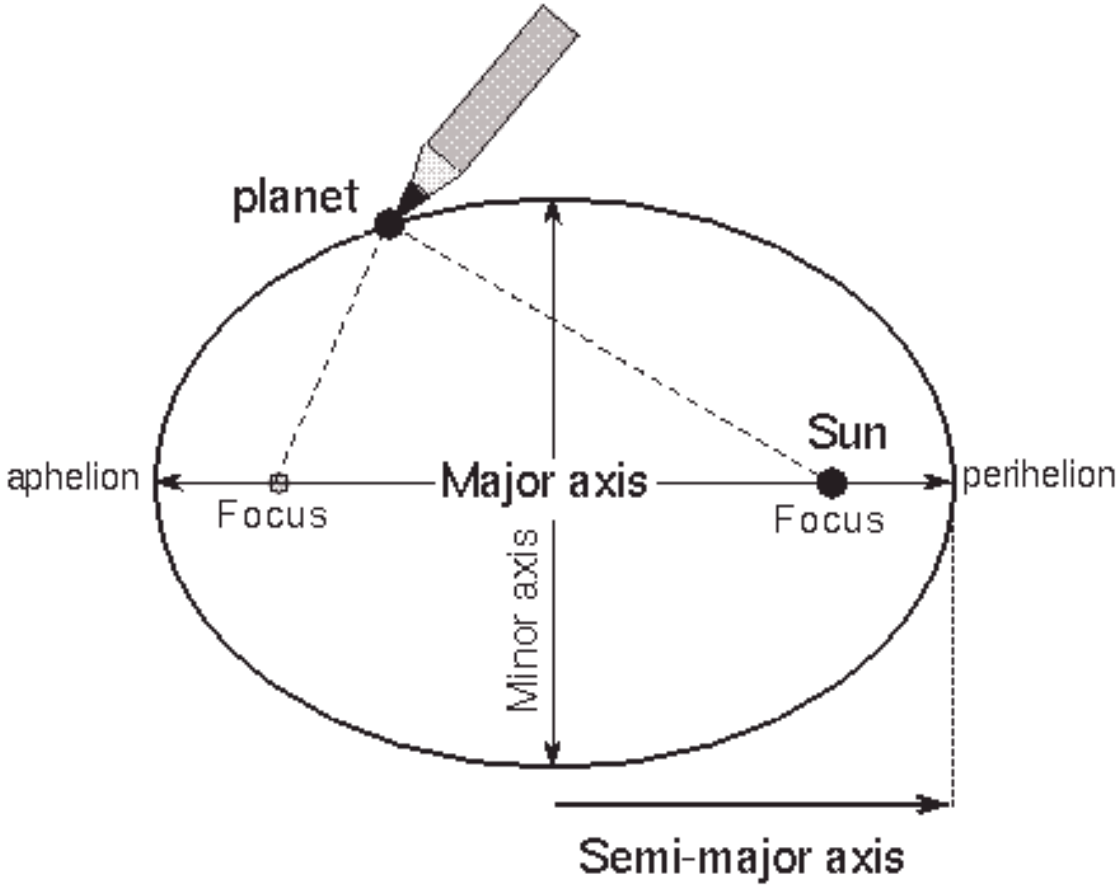
(G = 6.67 x 10^{-11} when kg and meters are used)

Cannon Shots

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

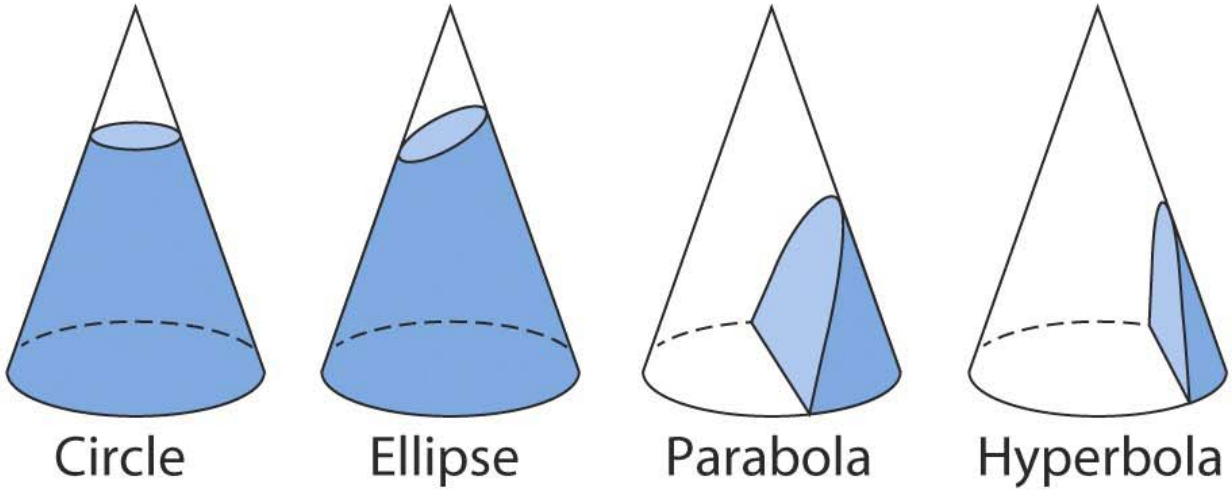
Kepler's 1st Law: Orbits of planets are ellipses with the Sun at one focus

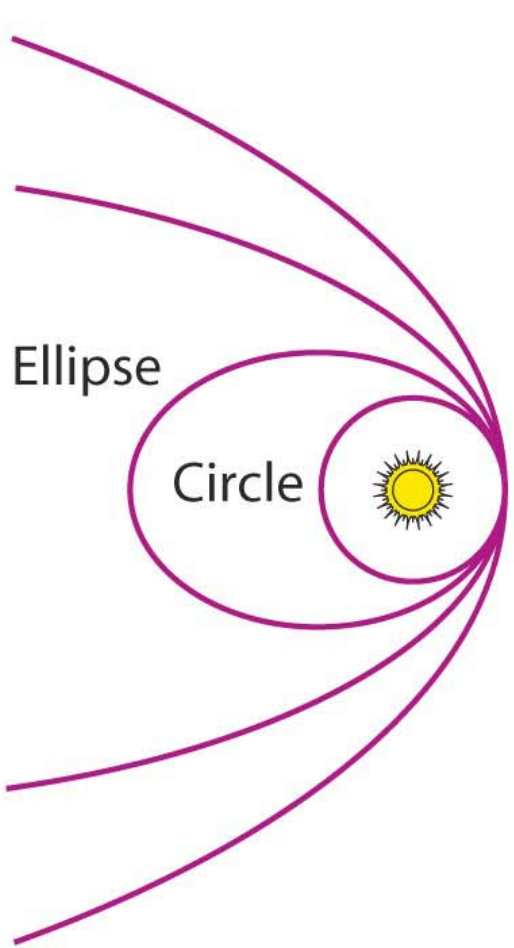




Newton's Ellipses

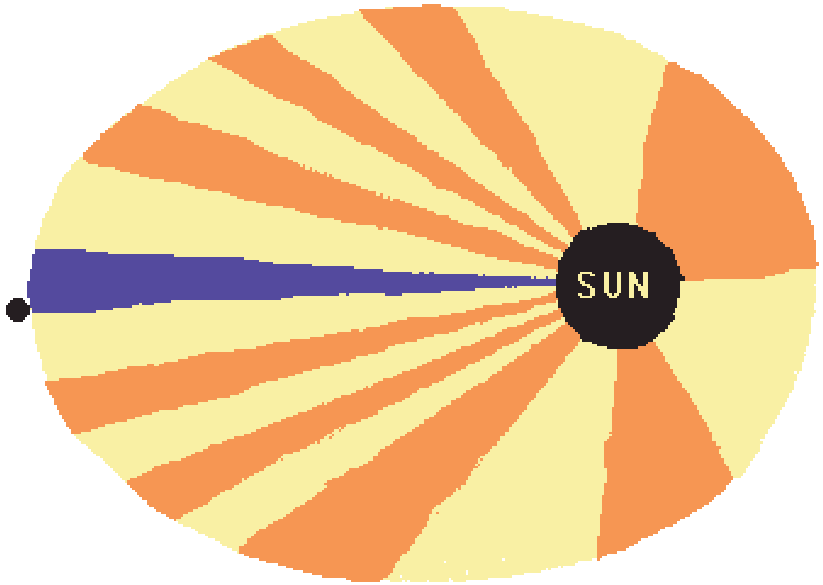
Actually Newton also found more options that satisfied his universal law of gravity.





Centripetal Force

Because the planet-Sun line sweeps out equal areas in equal times (Kepler's 2nd Law), it is possible to confirm 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

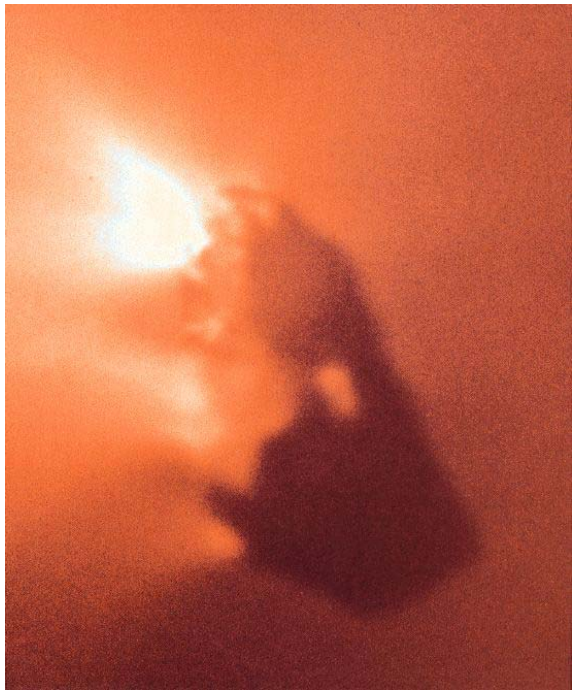
- Constant is actually $4\pi^2/G$
- Kepler's 3rd law only works because the mass of the Sun is much larger than the mass of any of the planets

Result

- Now we know that the orbiting planets are just perpetually 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.

Testing: Halley's Comet

Edmund Halley realized that Newton's formulism allowed Kepler's Laws to be applied to Comets too. Realized that one comet was in the sky every 76 years and predicted its return in 1758.



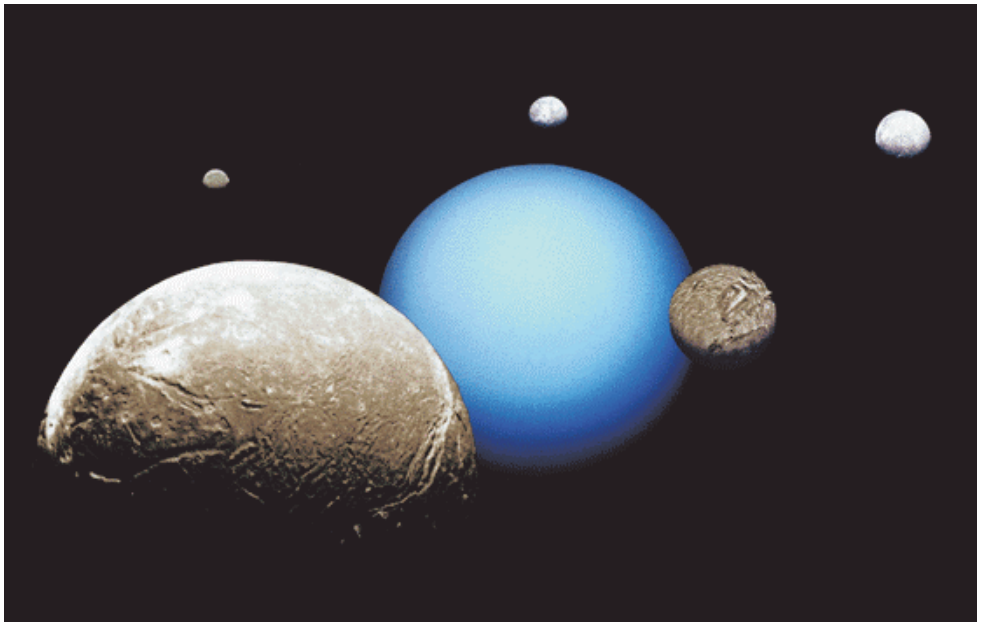
http://seds.lpl.arizona.edu/nineplanets/nineplanets/halley.html

Bayeux Tapestry – Battle of Hastings 1066

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

Testing: Uranus and Neptune

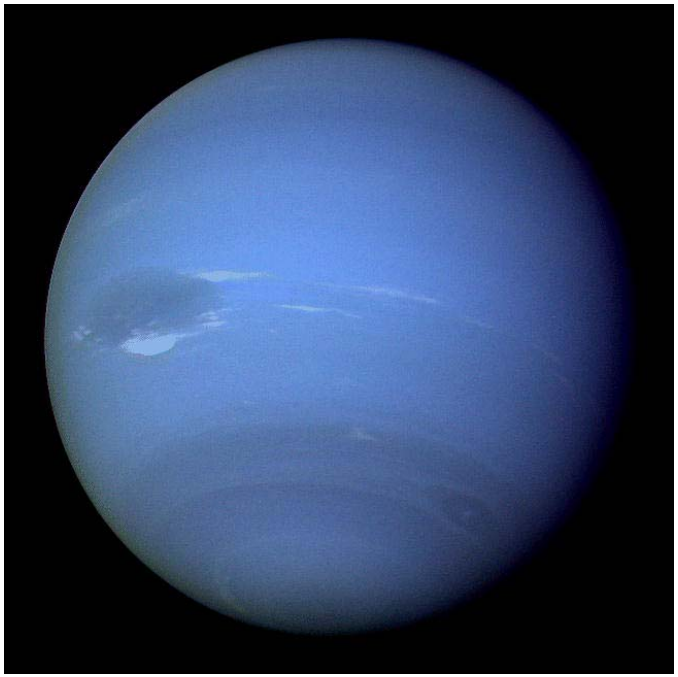
- Uranus was discovered as the 8th planet in 1781 by accident.
- The FIRST planet discovered since ancient times!
- Galileo almost discovered it in 1613.



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

Testing: Uranus Orbit

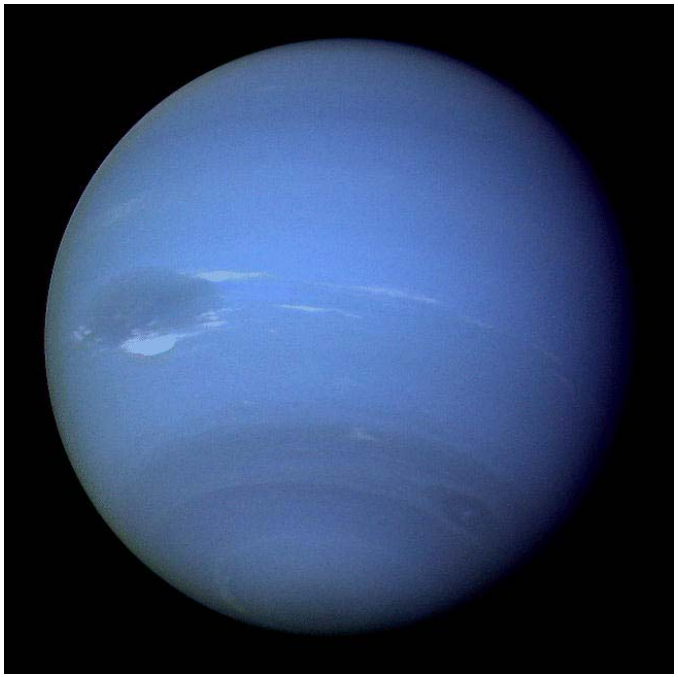
- Observations showed that it was not orbiting the way Newton predicted– off in position by 1 to 2 arcminutes.
- Either Newton's formulism was wrong, or there was something else out there.
- Using Newton's Laws, 2 scientists derived that there must be another undiscovered planet that was causing the 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

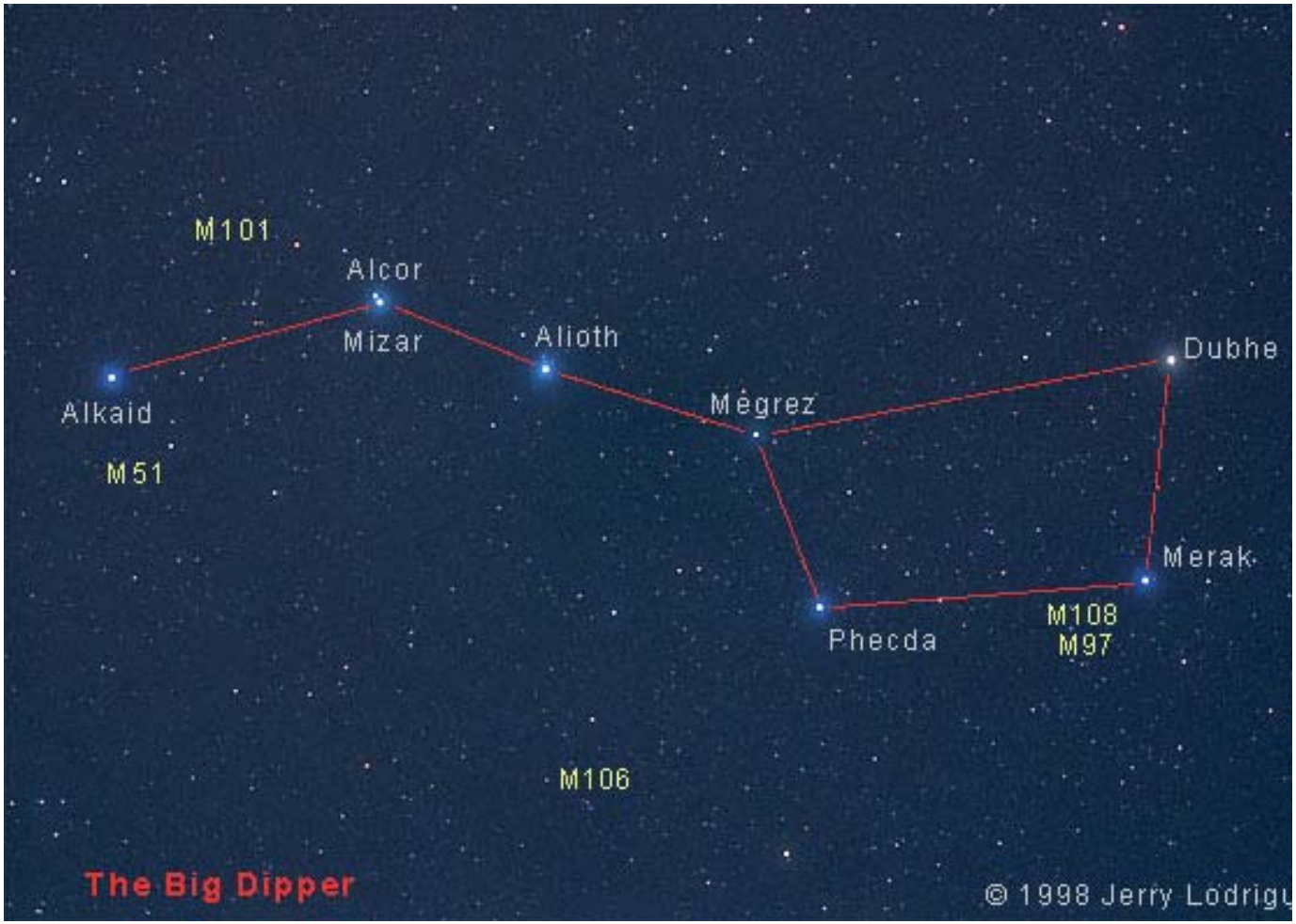
- The first object that was really discovered with pencil and paper and not direct observation.
- Newton's theory can predict observations!!!
- Science can move from empirical concepts.
- Now, we can make concrete predictions.



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

Example– Binary Stars

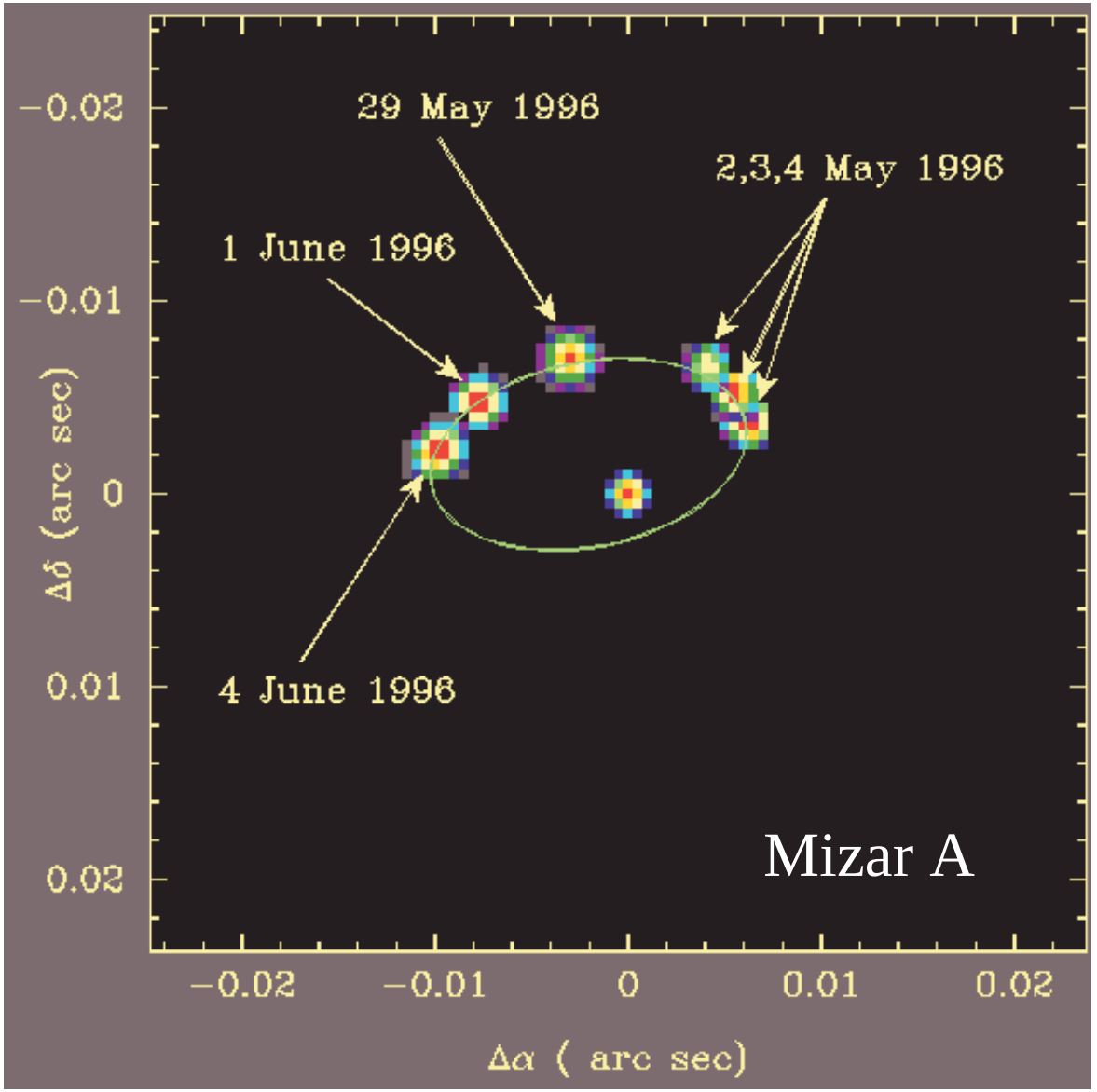
The most famous visual binary star pair is Mizar-Alcor in the Big Dipper. It is a good test of eyesight if you can see the two stars– separation of 12 arcminutes. But they are not really related.



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 2nd brightest cluster in our sky. 20000 light years distance. Newton's laws still hold, but we not sure why the dynamics in the center produces 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.

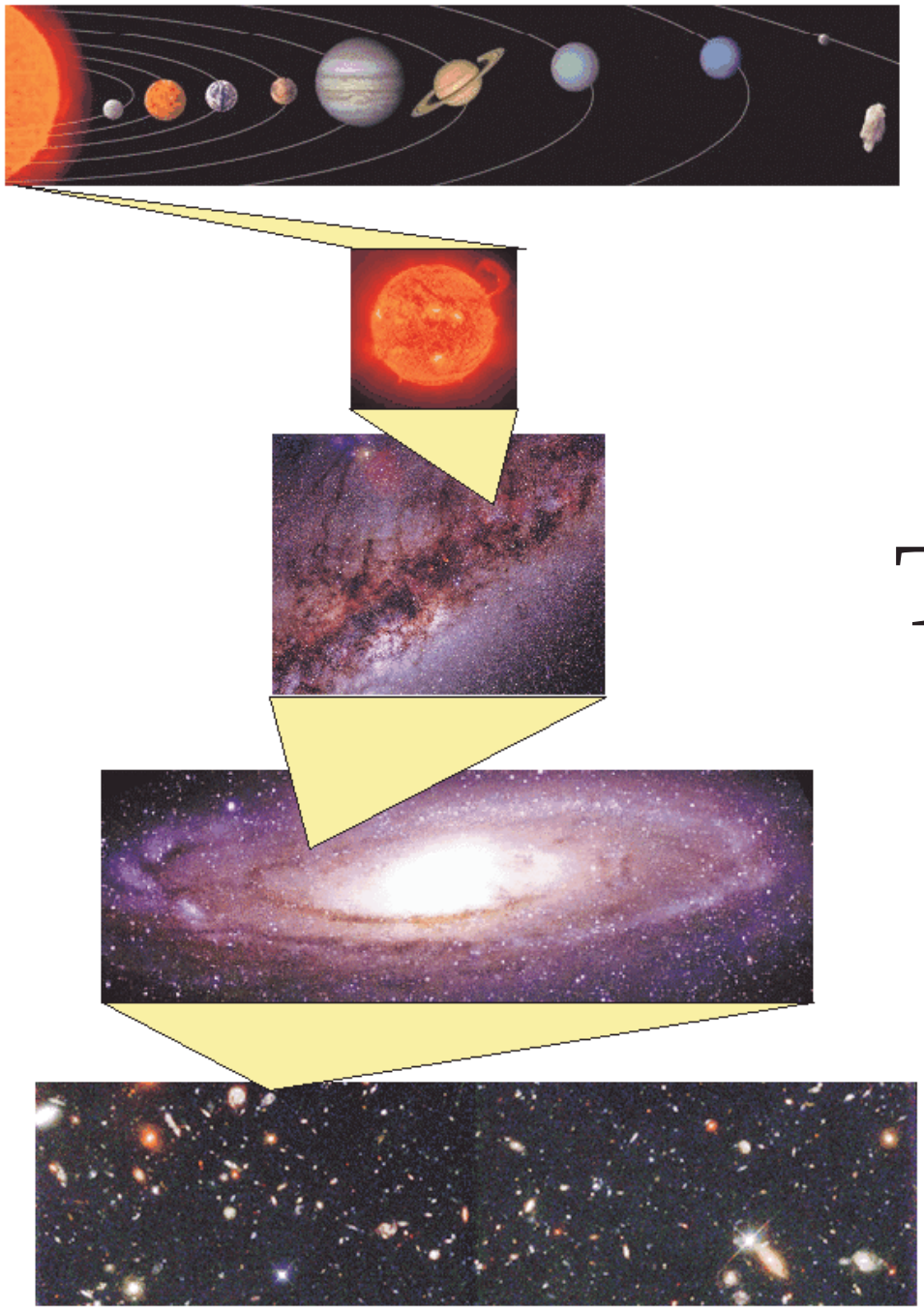
Jules Verne: Moon Ship

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

Next Step

We have learned about the general night sky and the generalization of gravity and the orbits of the planets, shuttles, satellites, moons, etc. We can take the next step in the big picture, moving slightly out to the Solar System, as we understand it today.

We'll be coming back to Ch 3,4. Don't panic.



Astronomy: The Big Picture

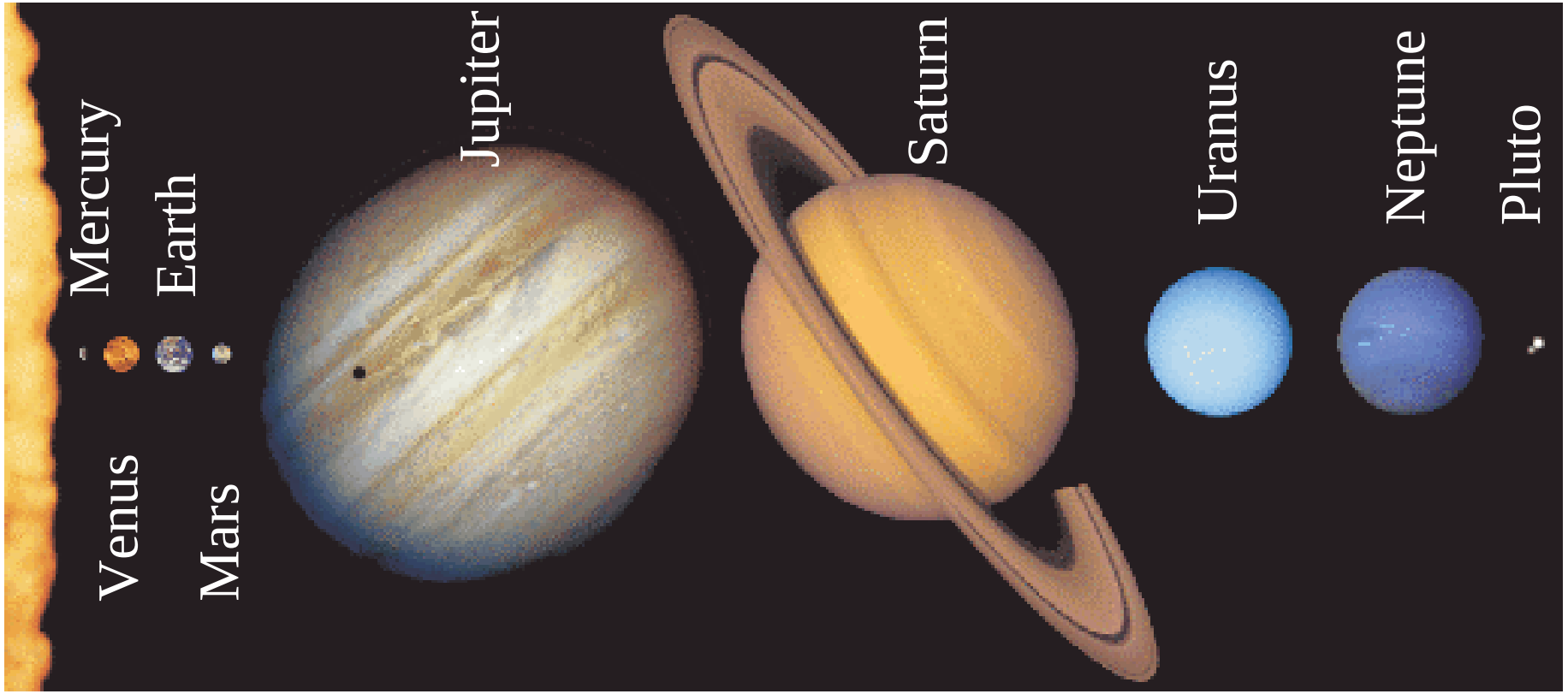
The Solar System

- What do we want to learn about the Solar System? What questions are there?

- Did the Solar System form all at once?
- Is our Solar System special?
- What clues do today's observations tell us about the formation?
- How has it changed since it was formed?

Question of Scale

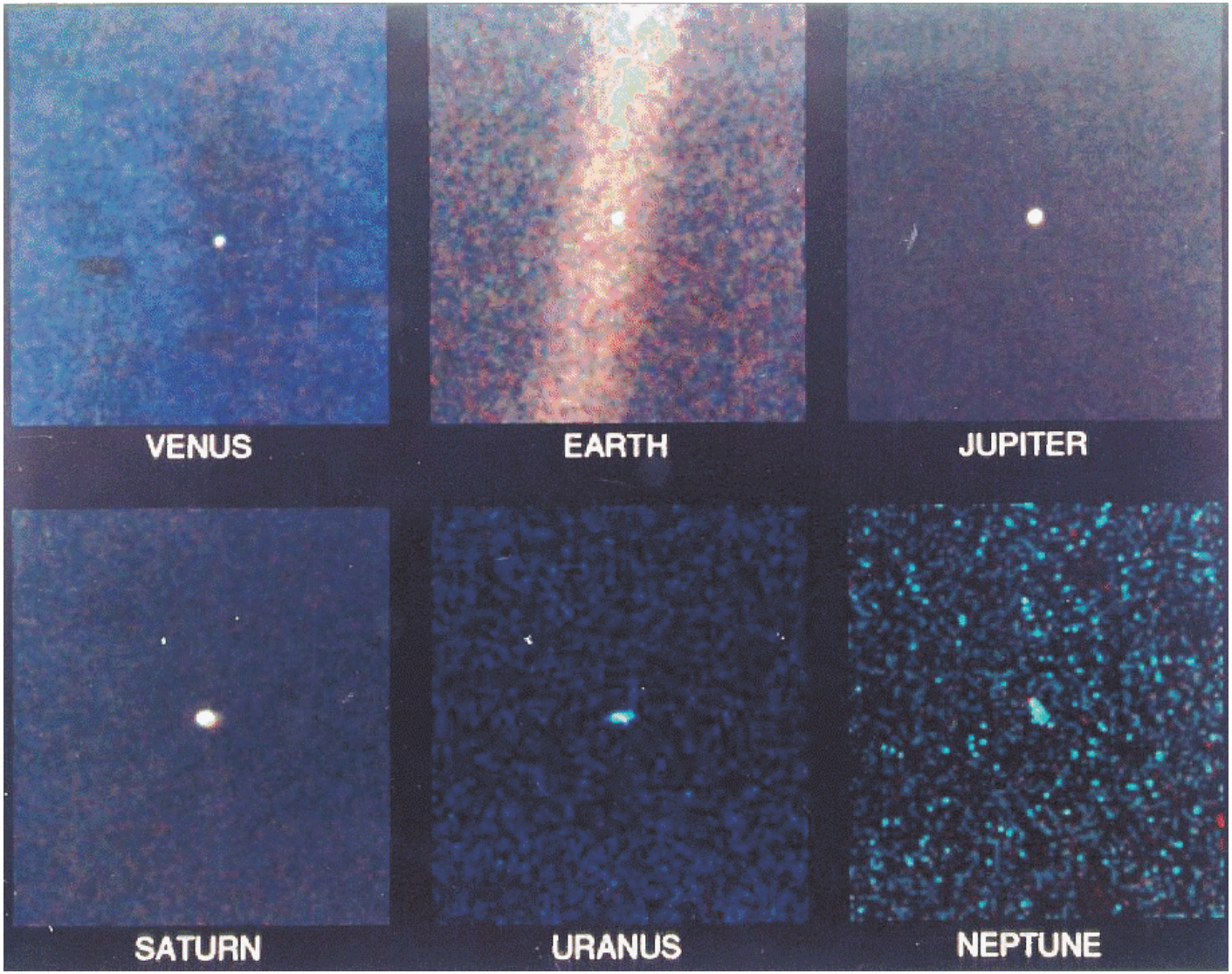
- Images of all planets (from space missions), with the correct scaling.



http://www.jpl.nasa.gov/galileo/sepo/education/nav/ss2.gif

Perspective of Scale

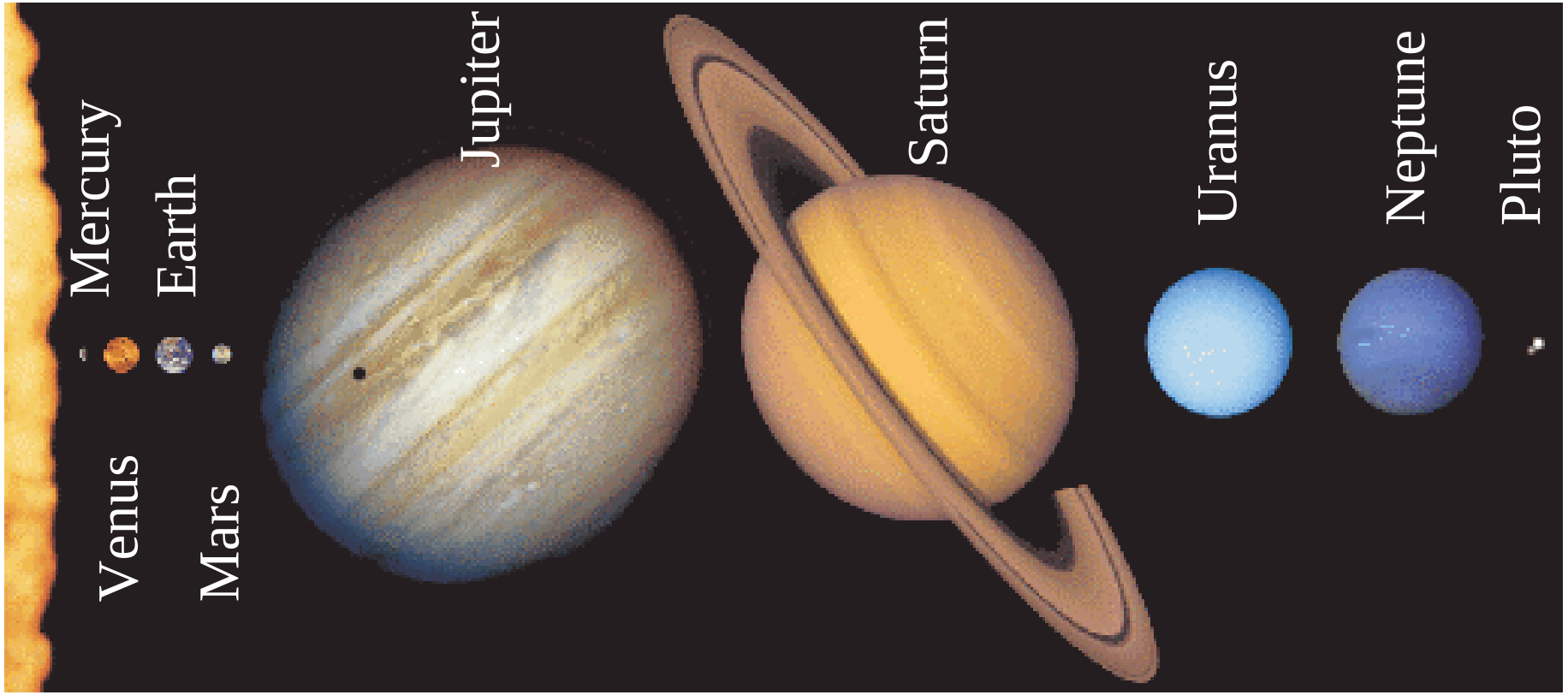
Images from Voyager– 4 billion miles out.



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

Mnemonics

- Mary Vincent Eats Many Jelly Sandwiches Under Neighbor's Porches
- My very easy method, just set up nine planets.



http://www.jpl.nasa.gov/galileo/sepo/education/nav/ss2.gif

Distribution of Mass in Solar System

- Sun has 99.85% of the total mass
- The planets have about 0.135% of the mass
- Jupiter more than twice the mass of *all* of the other planets combined! Or 318 times the Earth.
- Moons of the planets, comets, asteroids, meteoroids, and the interplanetary medium constitute the remaining 0.015%.

Planets Dance

http://janus.astro.umd.edu/javadir/orbits/ssv.html

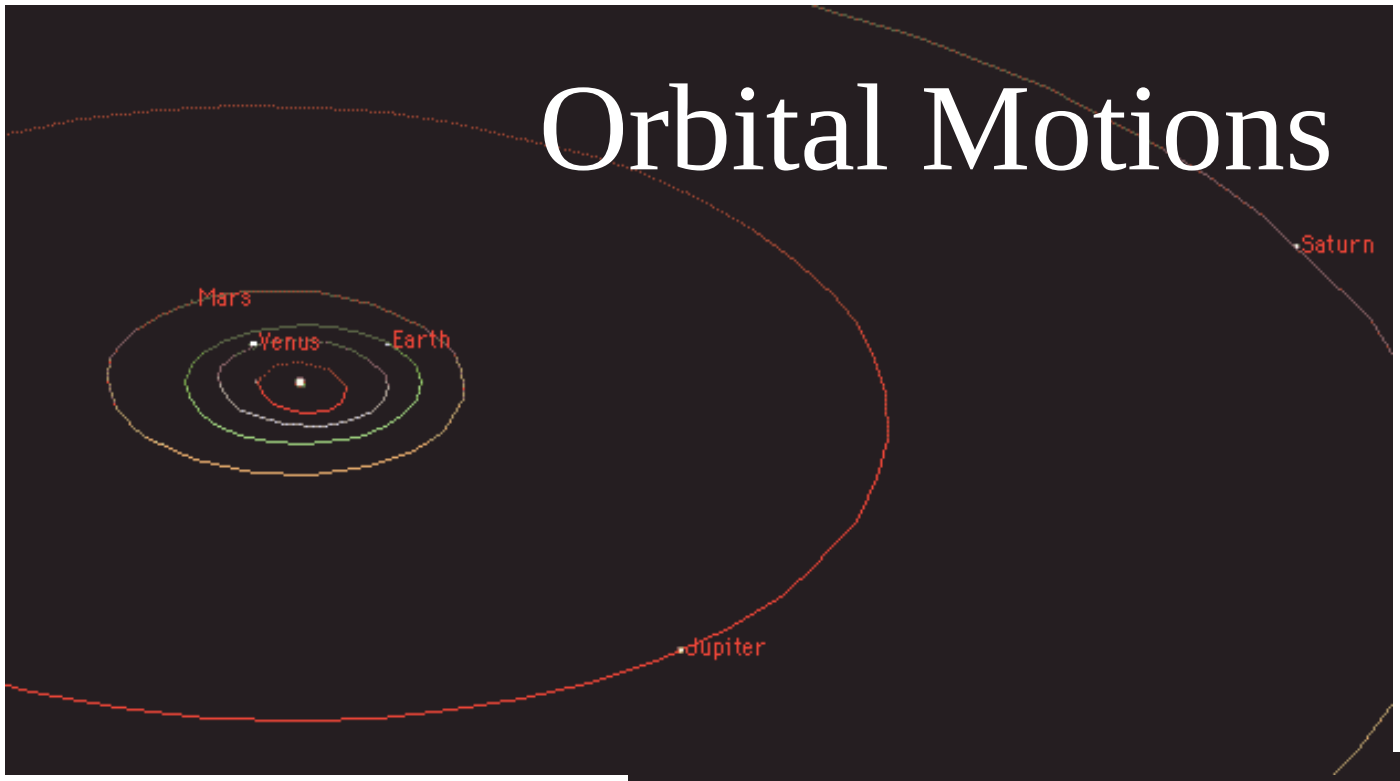
Question

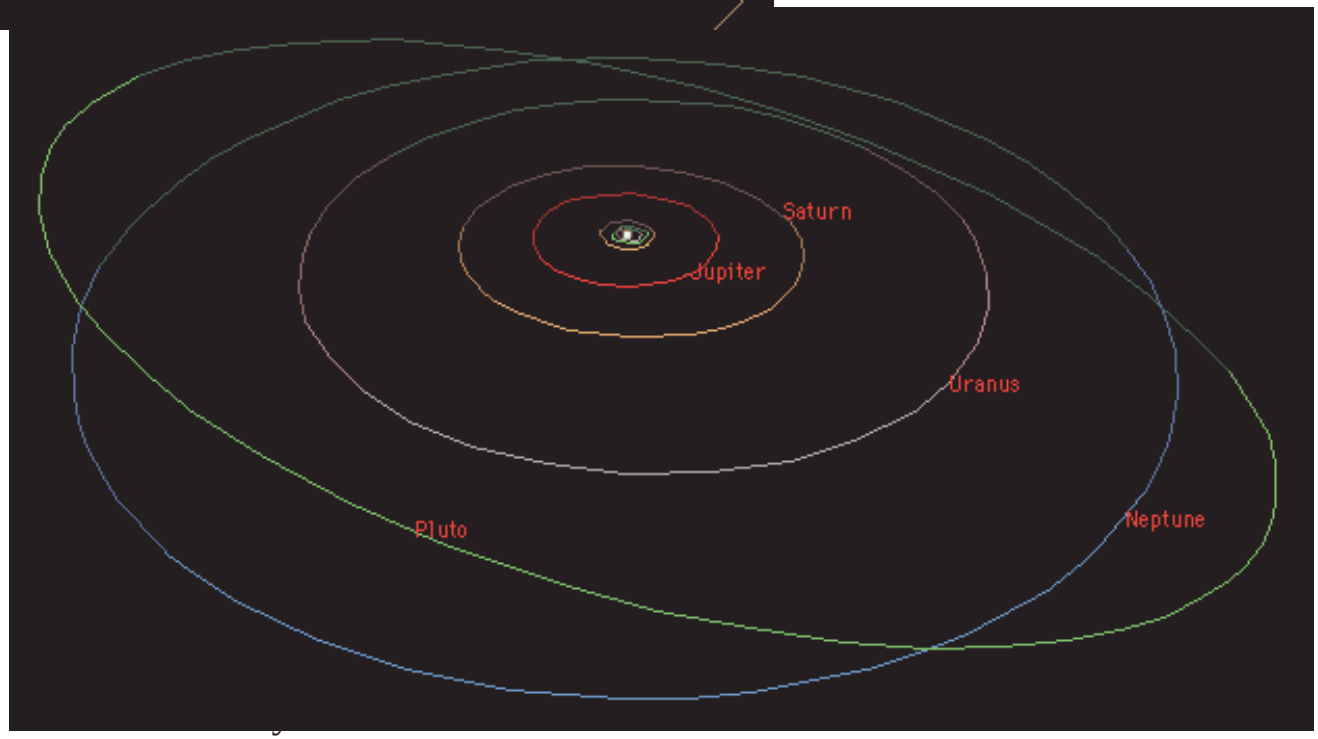
All of the planets, asteroids, and comets, are orbiting counter-clockwise. What is a possible explanation of that data?

Facts of the Solar System

- Mass of solar system: yes, mostly in the sun, but outer planets more massive than inner
- Orbital motions in solar system are counter clockwise in a flattened system (disk)
- Orbits are actually close to circles, except Mercury and Pluto
- Chemical analysis of meteorites shows condensation sequence– variation of composition with distance from Sun

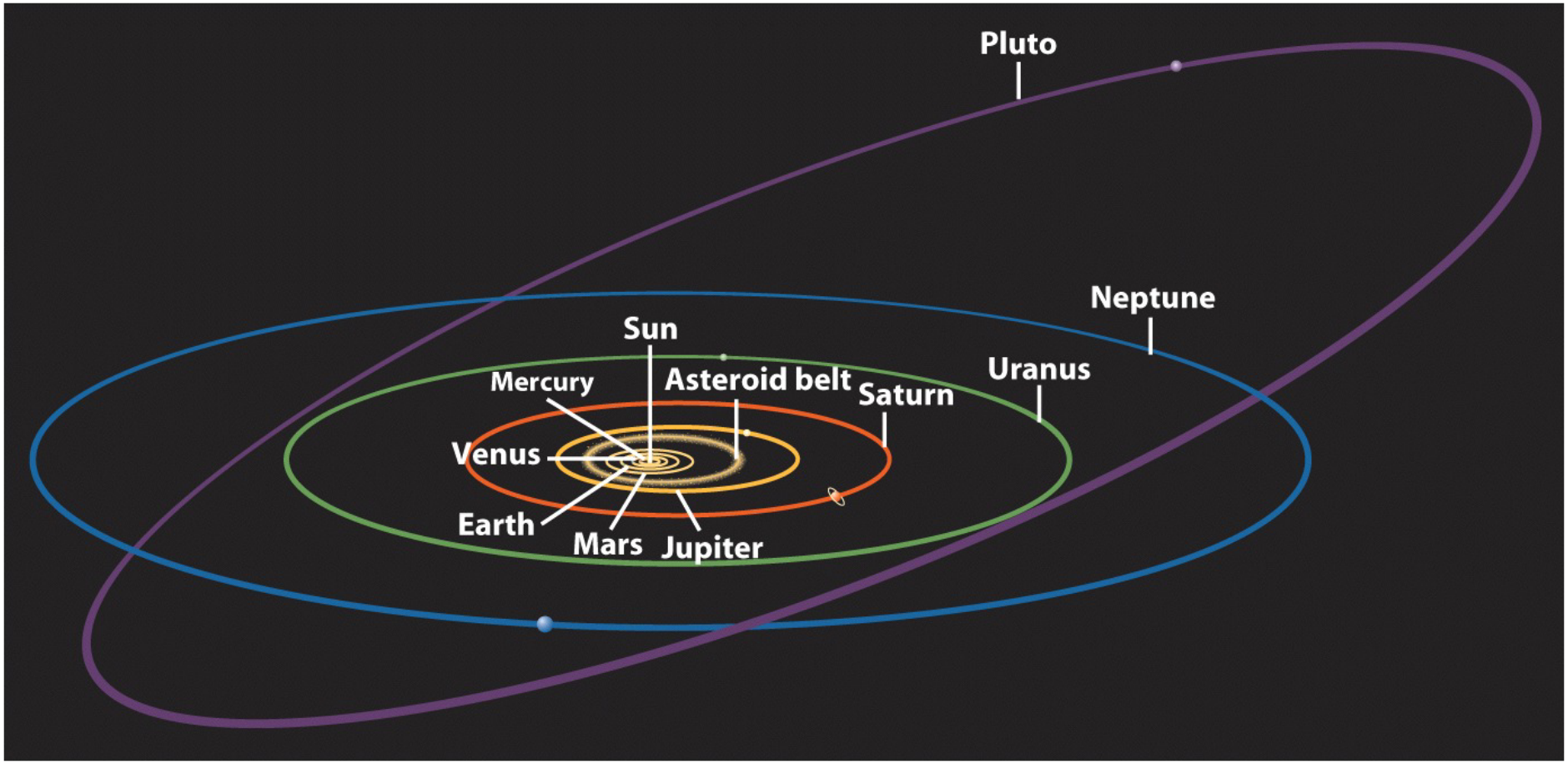
Orbital Motions





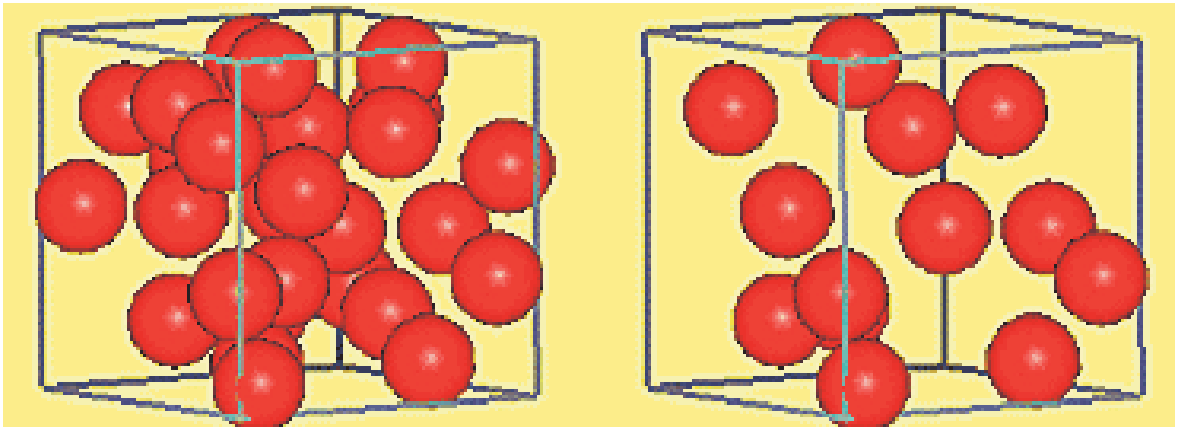
http://seds.lpl.arizona.edu/nineplanets/nineplanets/overview.html

Orbital Motions



What is Density?

$$Density = \frac{Mass}{Volume}$$



- If each ball weighed the same, which box would weigh more?
- Density of Water is 1 g/cm^3, density of steel is 7.85 g/cm^3, density of cork is 0.2 g/cm^3.

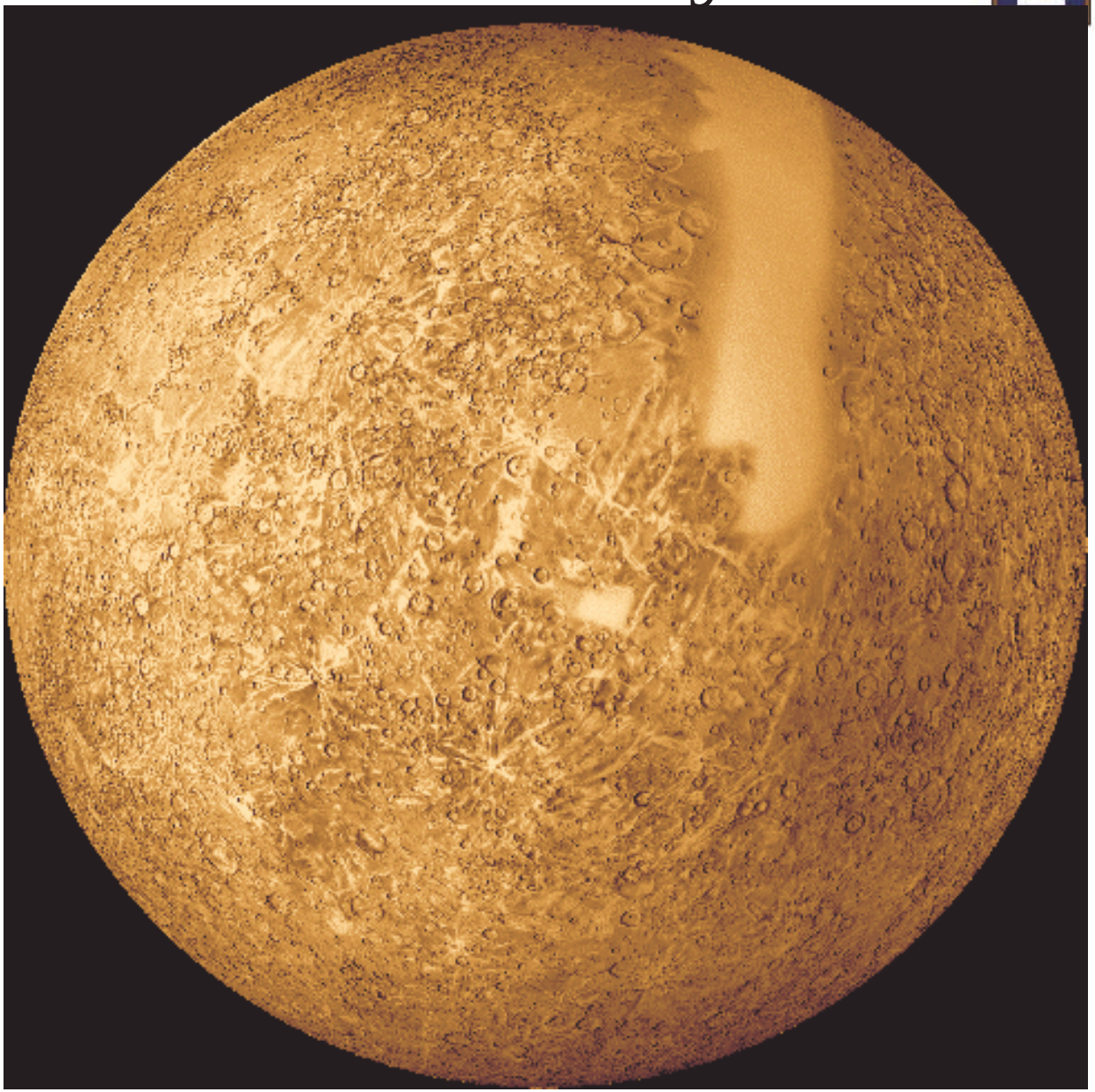
http://www.nyu.edu/pages/mathmol/textbook/density.html

What's this Picture of?

http://www.whfreeman.com/discovering/DTU/EXMOD36/F3609.HTM

Inner Planets: Mercury

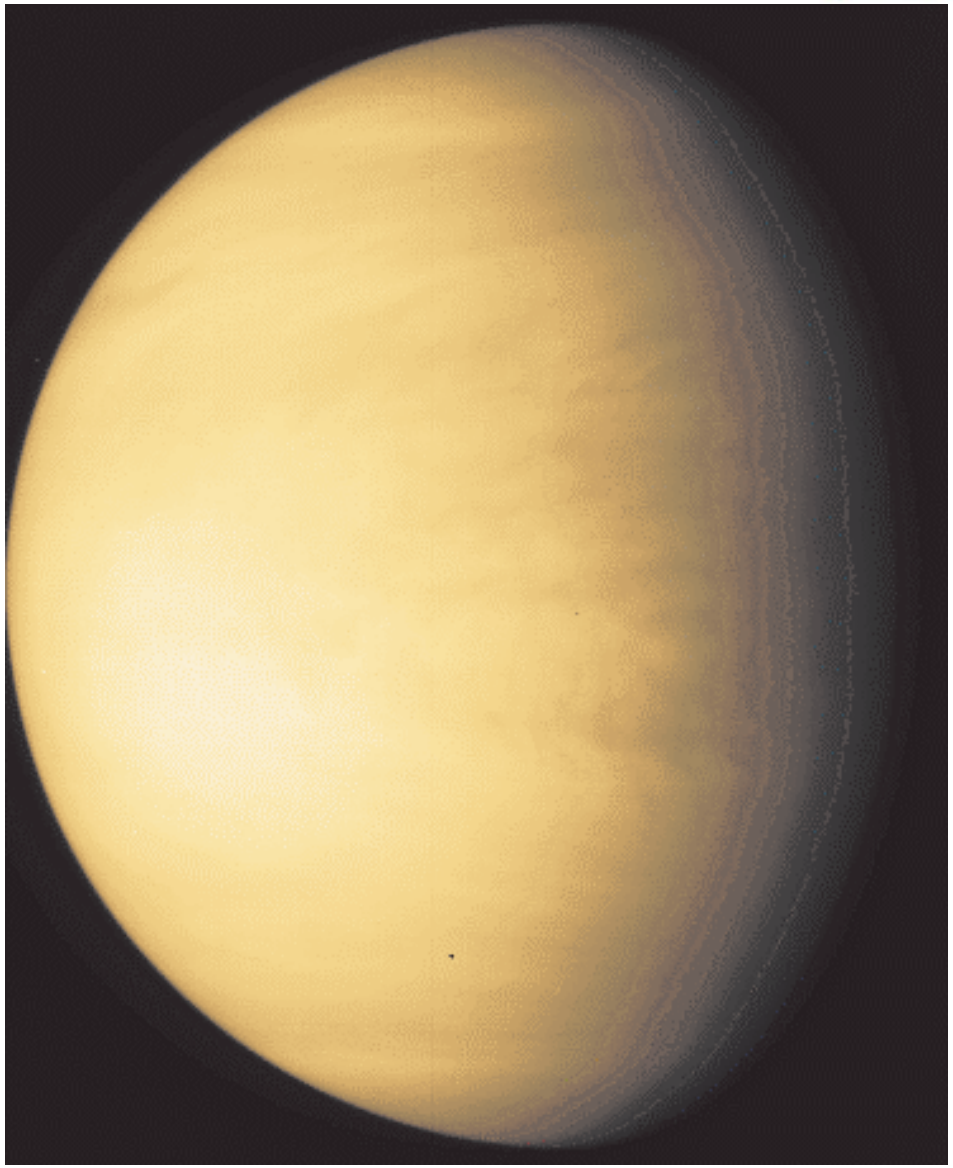
- Closest planet to Sun- 0.38 AU.
- Similar to Moon– smaller than Ganymede or Titan.
- Reaches its greatest angular separation from the Sun on Sept. 27th (rises 1 hr 20 mins before the Sun) easily visible at pre-dawn sky. Look for it below Jupiter.



http://www.jb.man.ac.uk/public/nightsky.html

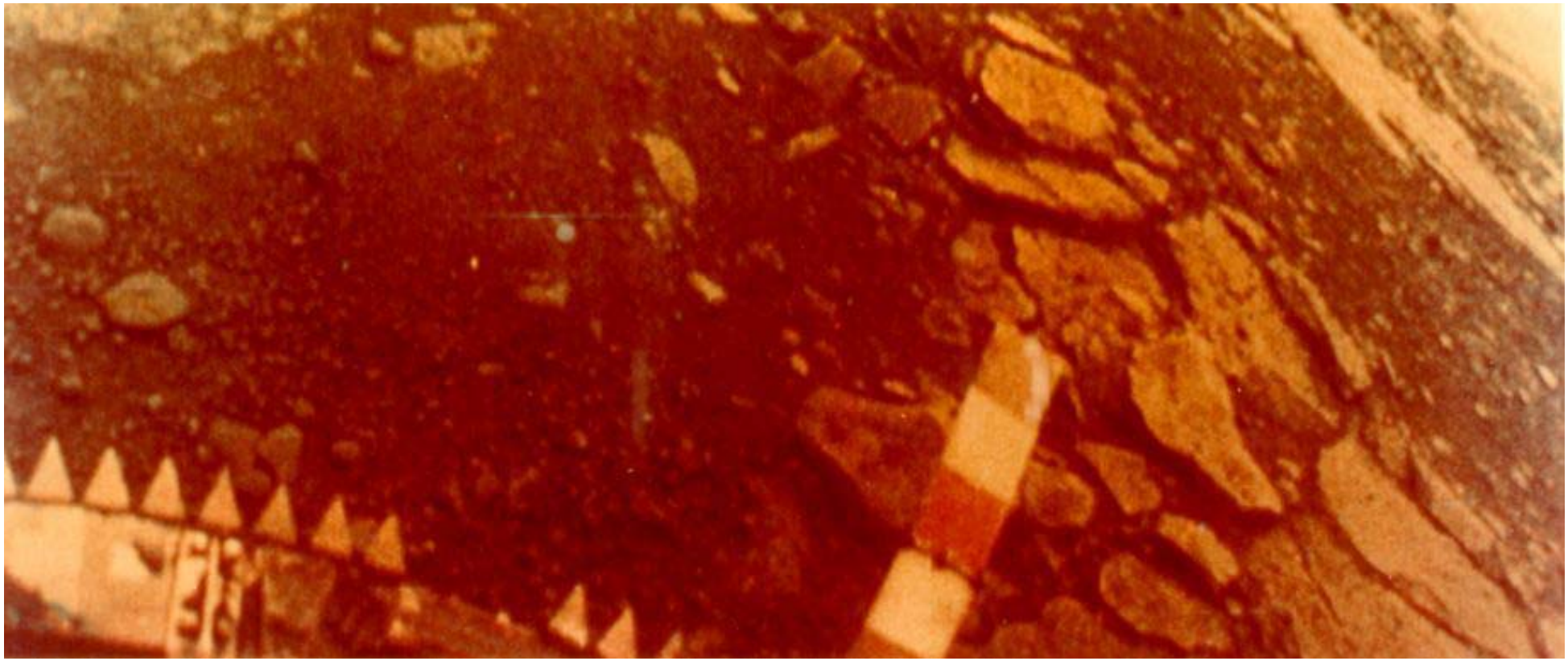
Inner Planets: Venus

- Similar in size and mass to Earth.
- Thick clouds make it the hottest planet.
- Often called the morning star or the evening star. 3rd brightest object in the sky.



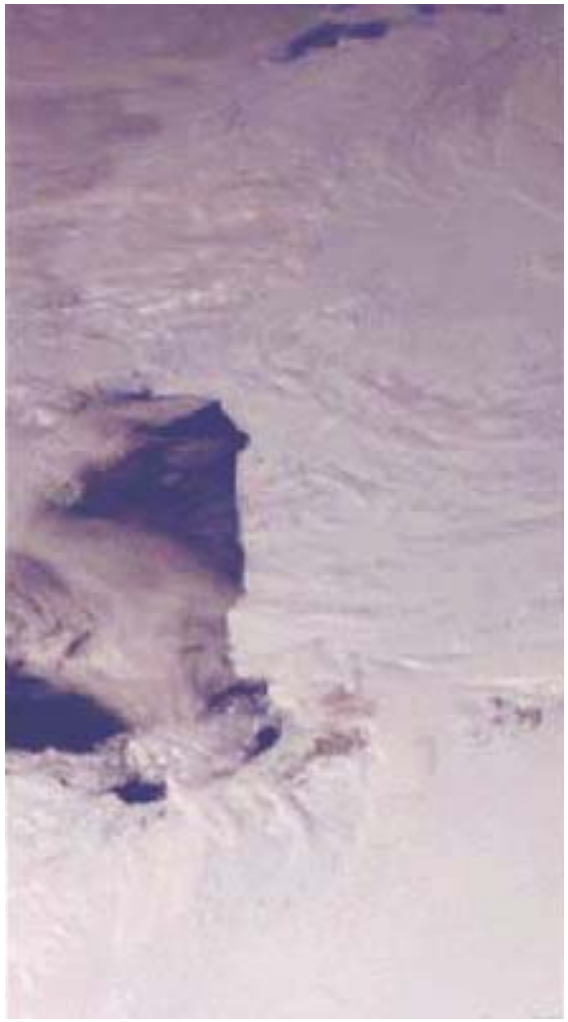
http://antwrp.gsfc.nasa.gov/apod/ap960923.html

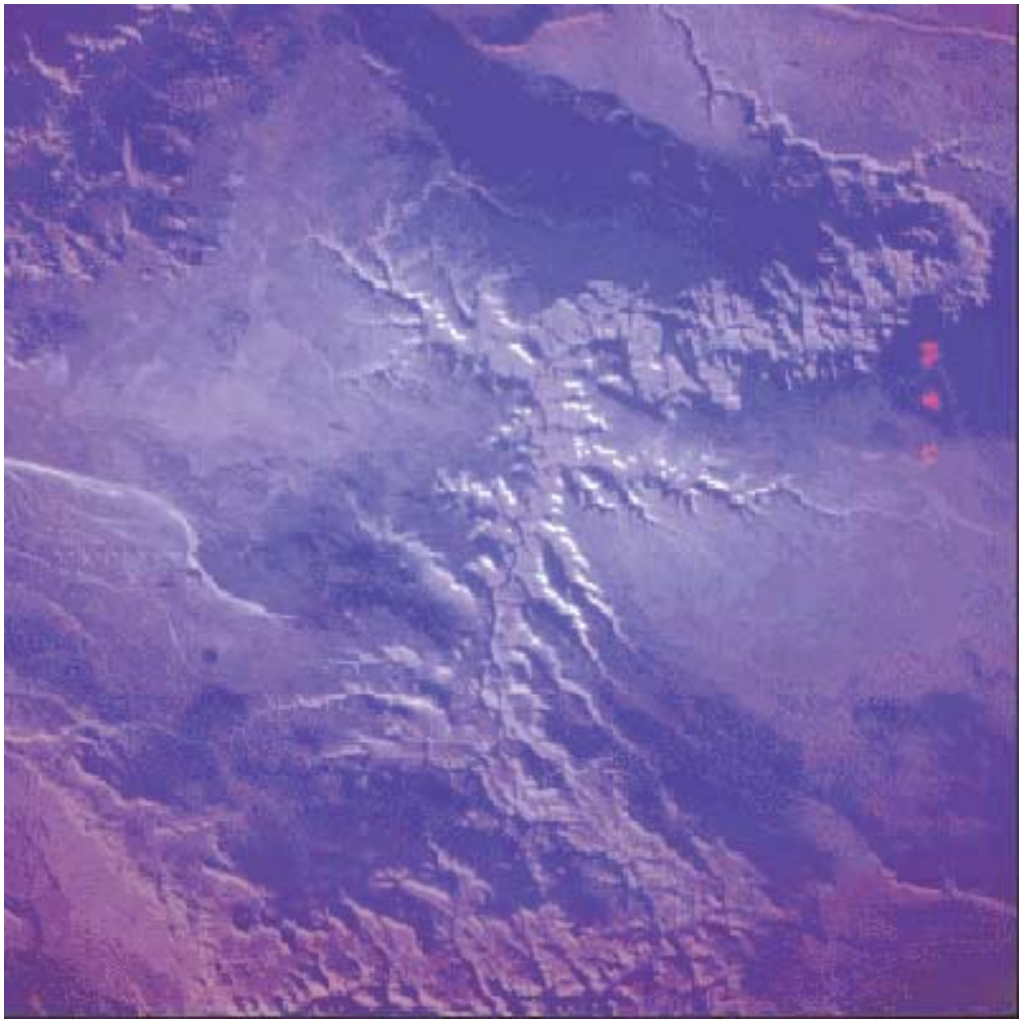
Inner Planets: Surface of Venus



http://nssdc.gsfc.nasa.gov/photo_gallery/photogallery-venus.html

Inner Planets: Earth as a Planet

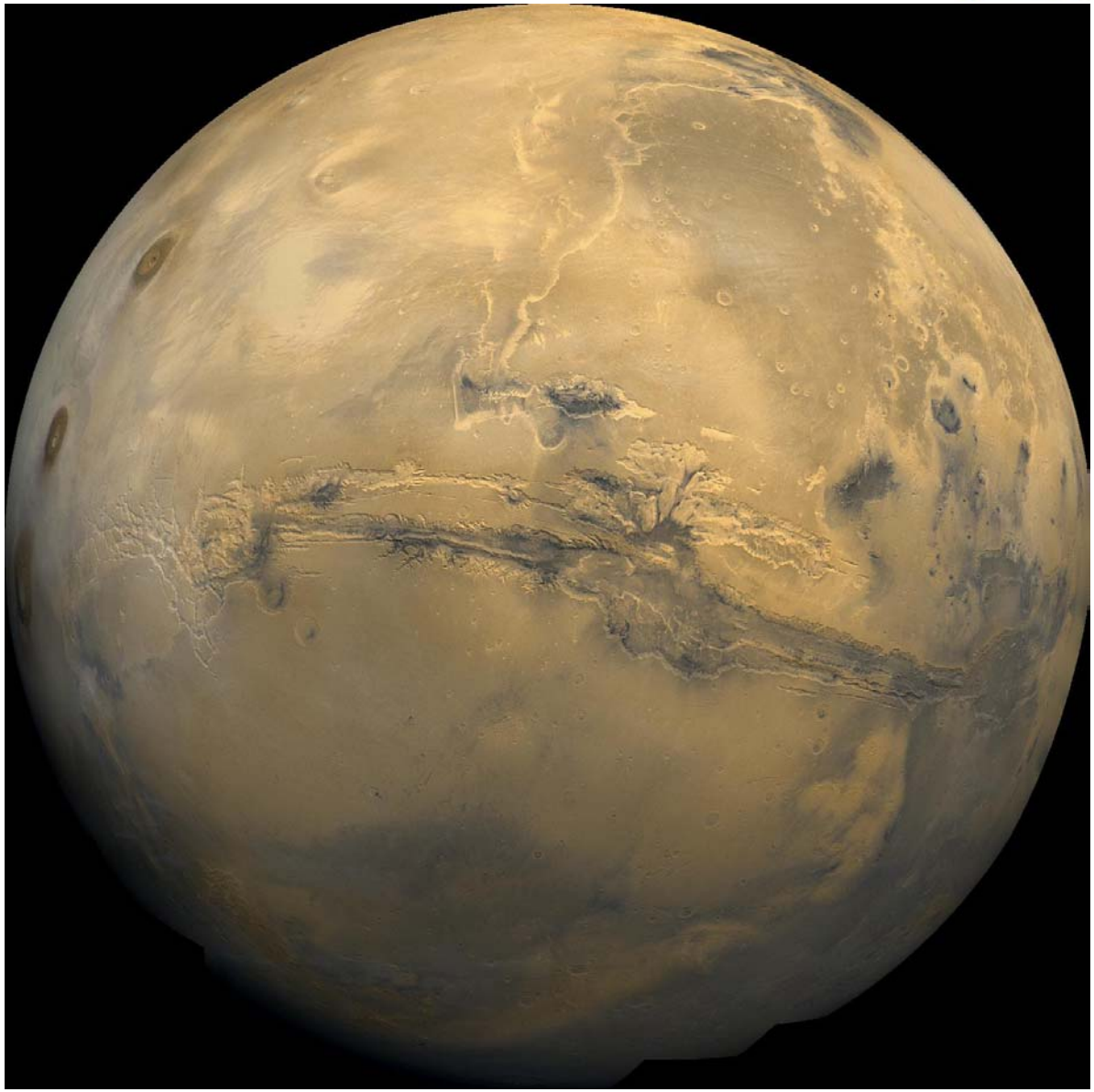




http://pds.jpl.nasa.gov/planets/choices/earth1.htm

Inner Planets: Mars

- Only planet whose surface features can be seen from Earth-based telescopes.
- Some surface features seen from spacecraft indicate that there was once flowing water on Mars.

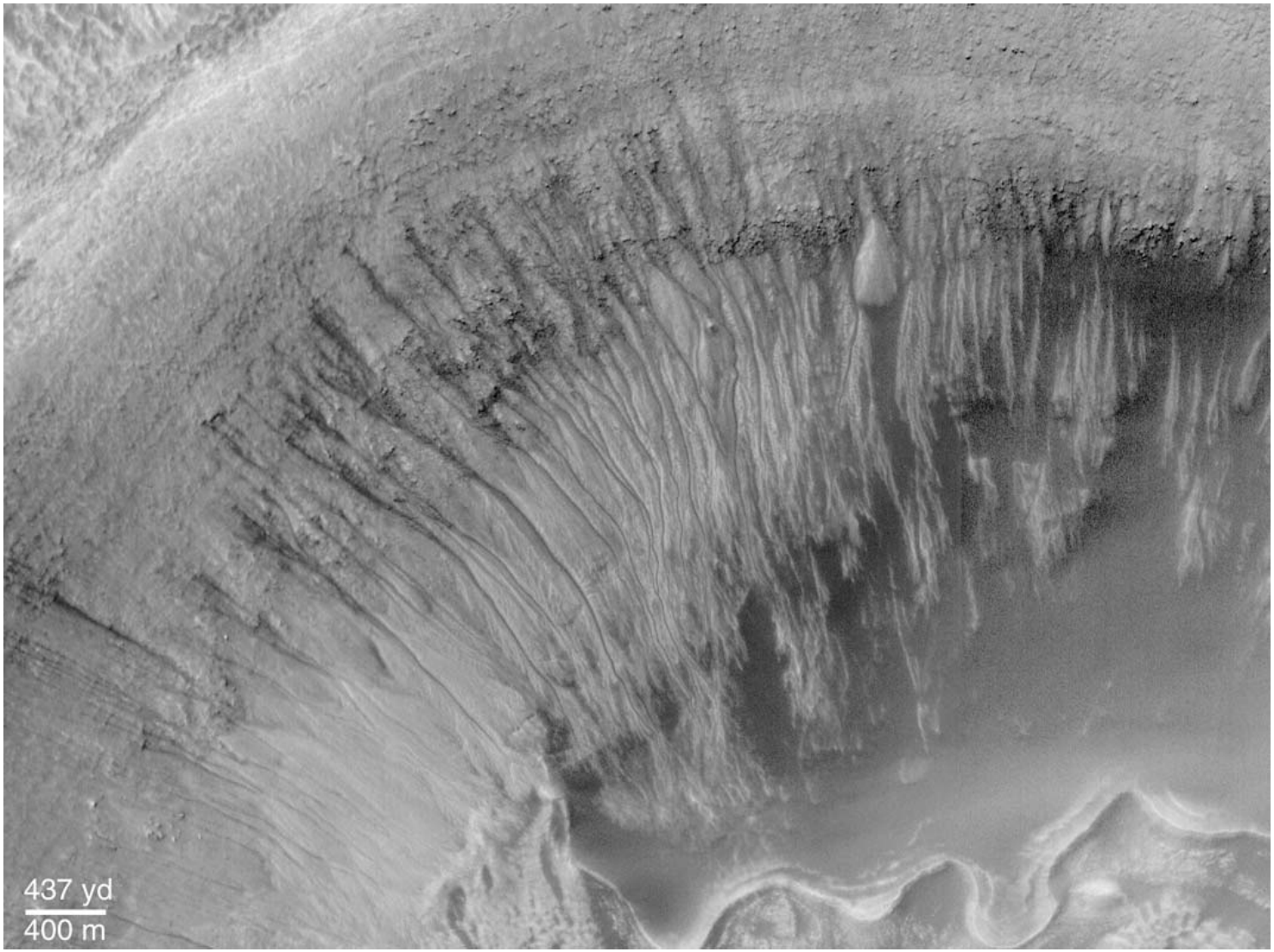


http://www.seds.org/nineplanets/nineplanets/mars.html

Mars: Surface

http://www.grc.nasa.gov/WWW/PAO/html/marspath.htm

Mars: Surface– Evidence for Water



http://antwrp.gsfc.nasa.gov/apod/image/0006/marsnewton_mgs_big.jpg

Mars: Olympus Mons

- The largest mountain in the Solar System rising 24 km (78,000 ft.).

- Its base is more than 500 km in diameter and is rimmed by a cliff 6 km (20,000 ft) high (right).

http://hyperphysics.phy-astr.gsu.edu/hbase/solar/marsoly.html

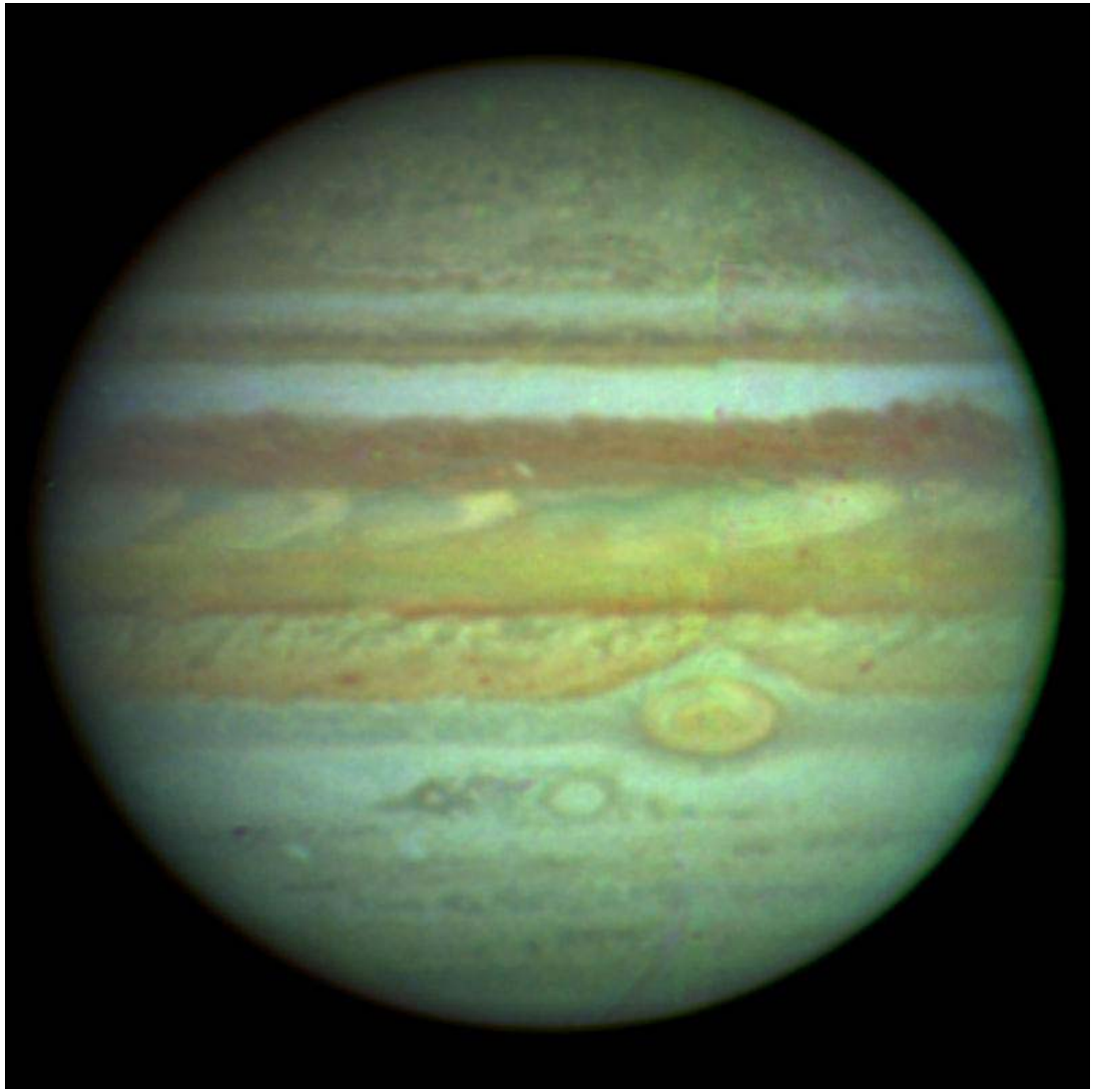
Junk? Asteroids-- Eros

- Between Mars and Jupiter, there are millions of asteroids ranging in size from dust to 900 km in size.
- Eros is actually labeled a near-Earth asteroid, as its orbit brings it close to Earth. 33 x 13 x 13 km in size.
- Semimajor Axis: 1.458 AU

http://near.jhuapl.edu/iod/20000222/index.html

Jupiter– Big Boy

- By far the largest and most massive planet.
- No solid surface. The gas just gets denser as we get deeper.
- 90% Hydrogen and 10% Helium with traces– like the early solar system.
- Has 61 known moons.



http://www.ast.cam.ac.uk/hubblepics/

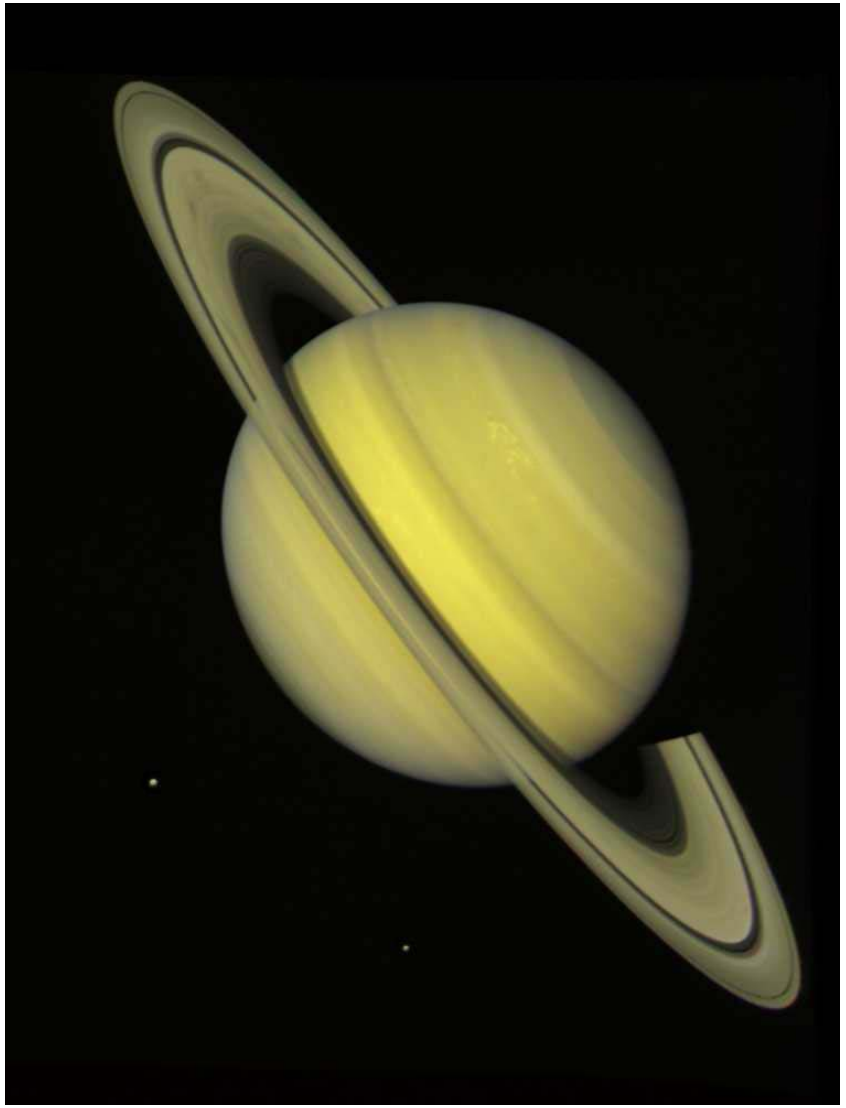
Jupiter

http://www.solarviews.com/raw/jup/vjupitr5.mpg

http://www.solarviews.com/raw/jup/vjupitr2.mov

Outer Planets: Saturn

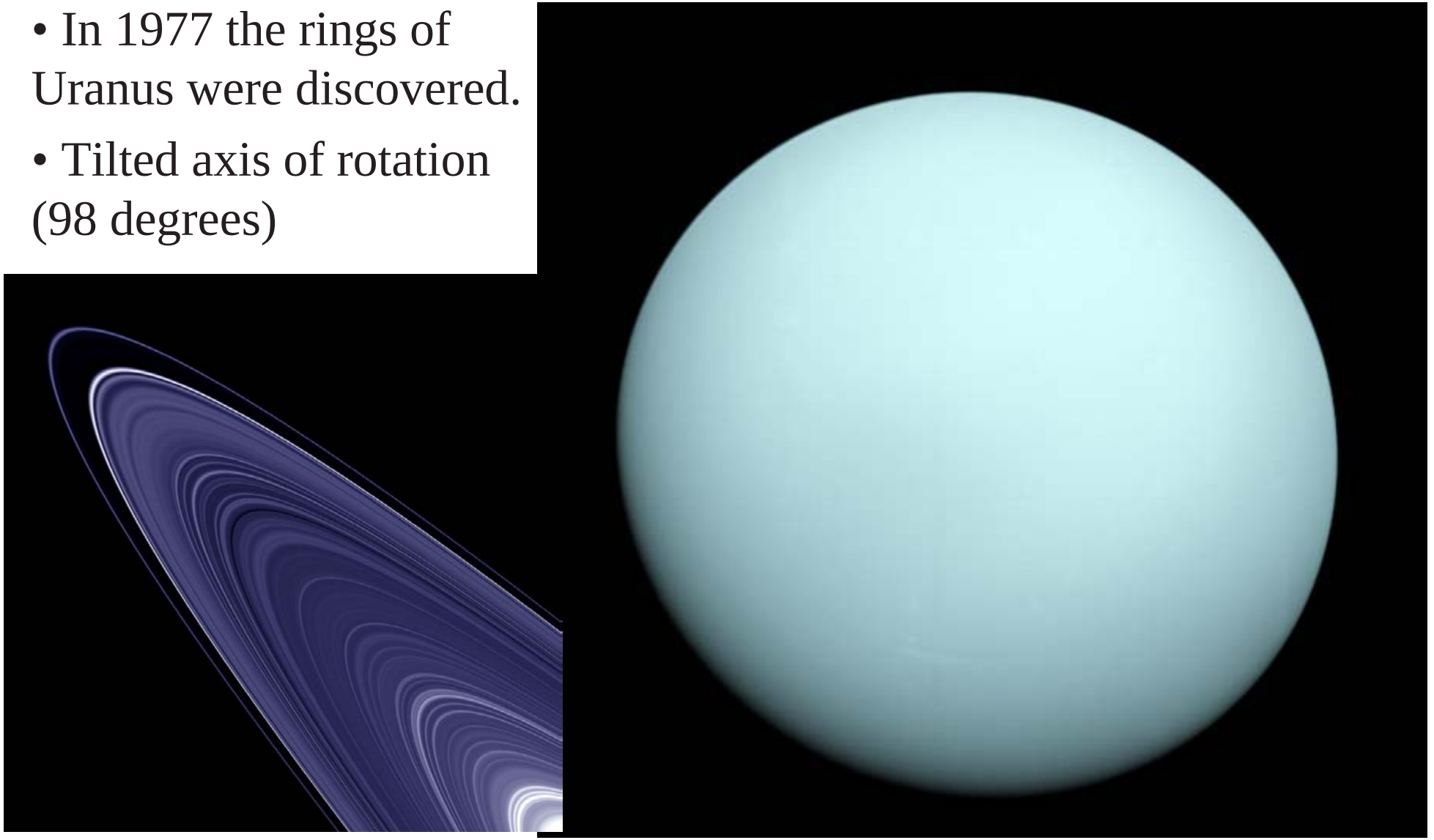
- The Lord of the Ring
- Ring has gaps
- Only planet less dense than water
- Broad atmosphere banding is similar to Jupiter
- http://www.solarviews.com/raw/sat/vsaturn1.mpg
- http://www.solarviews.com/raw/sat/spoke.mov



http://www.solarviews.com/cap/sat/saturn.htm

Outer Planets: Uranus

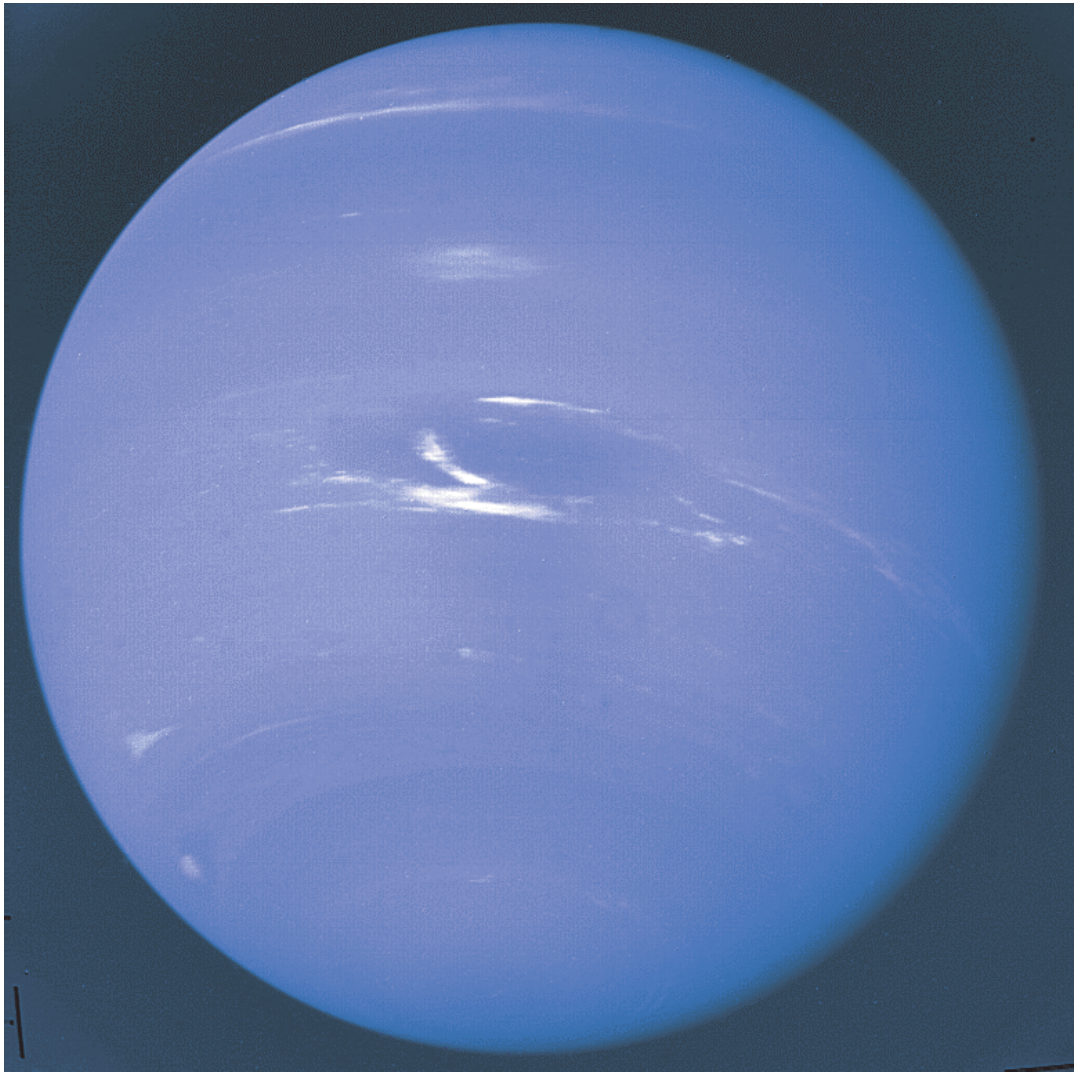
- In 1977 the rings of Uranus were discovered.
- Tilted axis of rotation (98 degrees)



http://www.solarviews.com/eng/uranus.htm

Outer Planets: Neptune

- Outermost Gas Giant
- Methane gives it the blue color
- Has the fastest record wind speed of 2000 km/hr.
- Also has a faint ring system
- Seasons last 40 years!



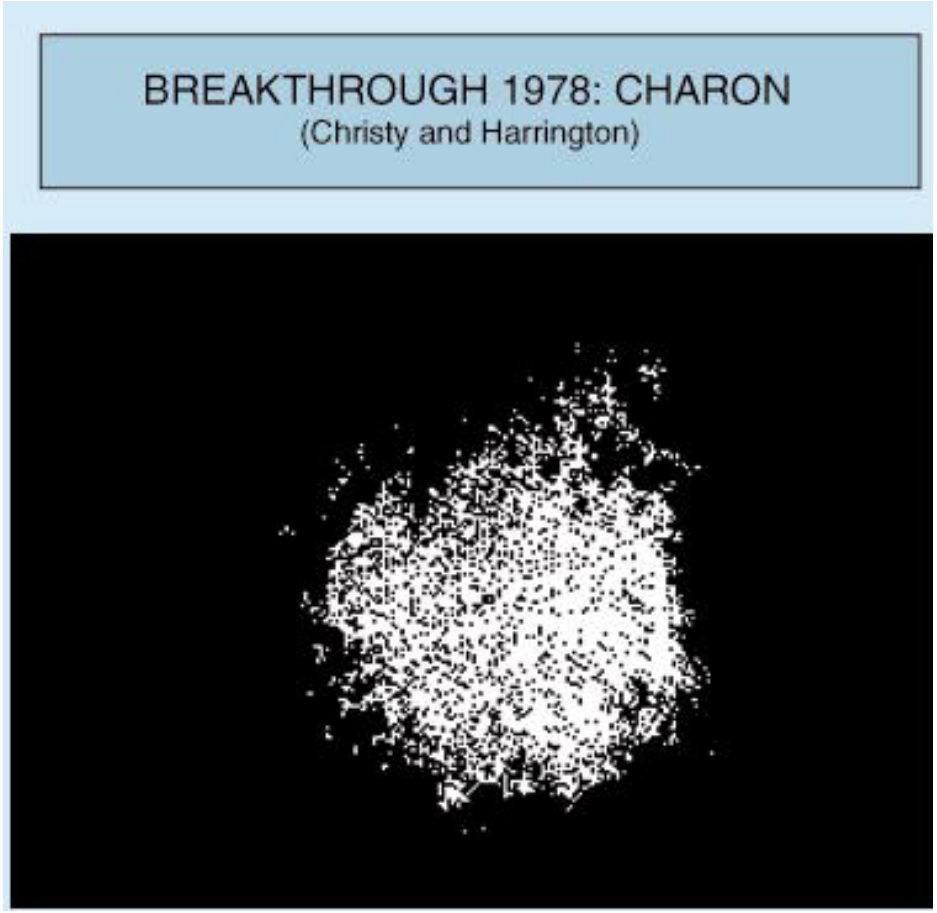
http://www.solarviews.com/cap/nep/neptunes.htm

Outer Planets: Neptune

http://www.solarviews.com/raw/nep/vneptune.mov

Pluto

- Discovered in 1930 by telescope in AZ.
- A blob was noticed in 1978 that circled Pluto every 6 days. It proved that Pluto had a moon named Charon.



http://www.solarviews.com/cap/pluto/hstpluto.htm

Pluto

- The only planet not yet visited by a spacecraft
- Has tilted and very eccentric orbit
- Moon Charon and Pluto always face each other

- Gravity pull is only 8% of Earth's.
- Smallest Planet? Or not?

http://www.solarviews.com/cap/pluto/hstpluto.htm

Pluto

http://www.solarviews.com/raw/pluto/vpluchar.mpg