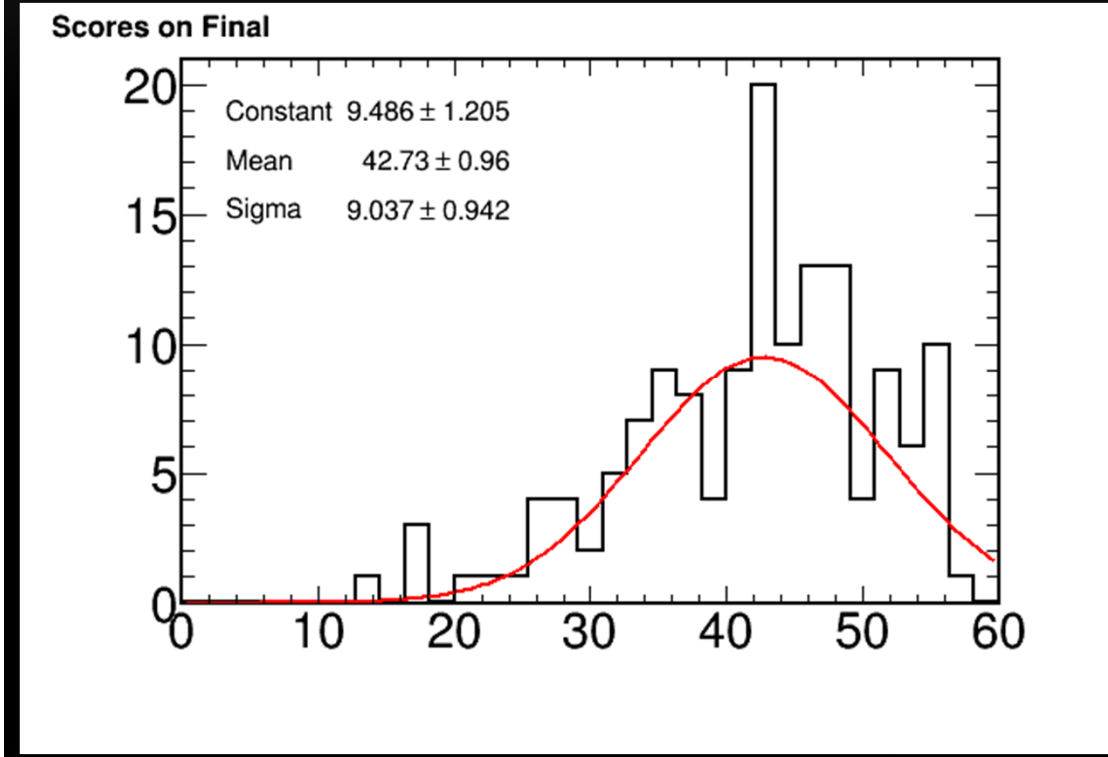
TEST AND GRADES



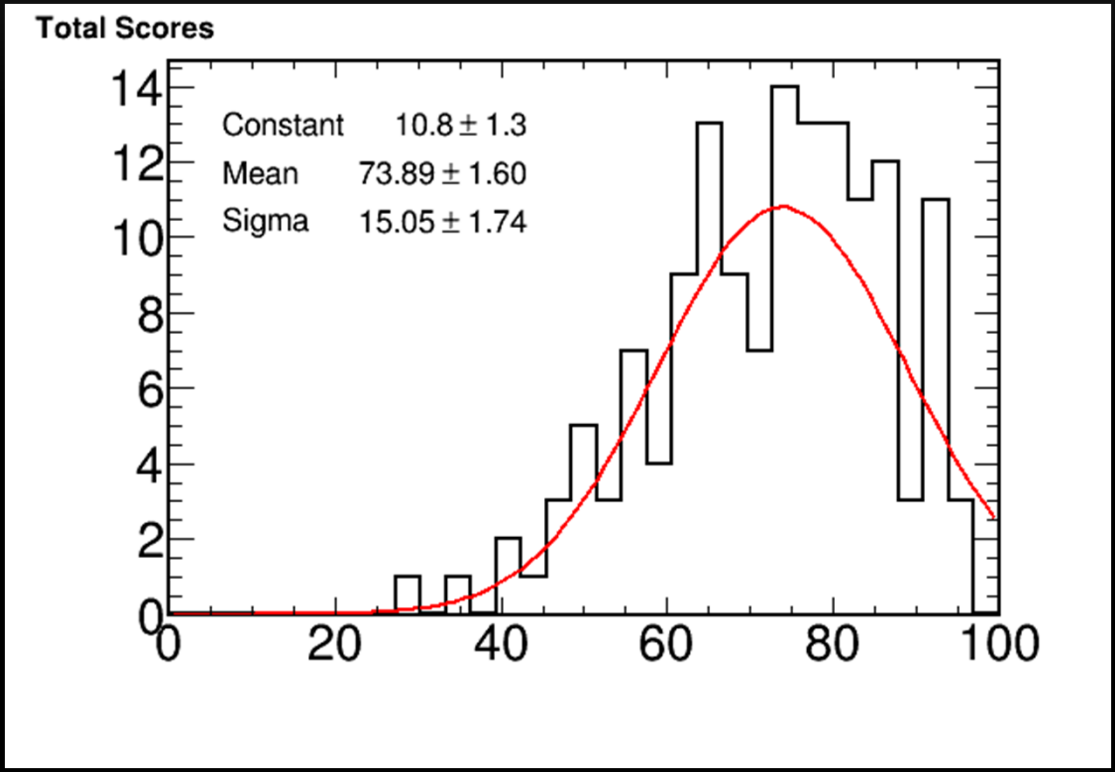
Raw test scores (out of 60)

Note these graphs are posted online along with the test solutions

This is why you wrote your answers on your test paper and kept it:

- so you can learn from any mistakes

TEST AND GRADES



- Total scores (including HW, clickers)
  - Lowest scores dropped for HW, RQ, clickers

eGradebook has a guess as to what your letter grade would be if the semester ended today

- Check your email or the class website for a link

FORMATION OF SOLAR SYSTEM

Ch.6

WHAT'S IN THE SOLAR SYSTEM?

- … and what is it doing?

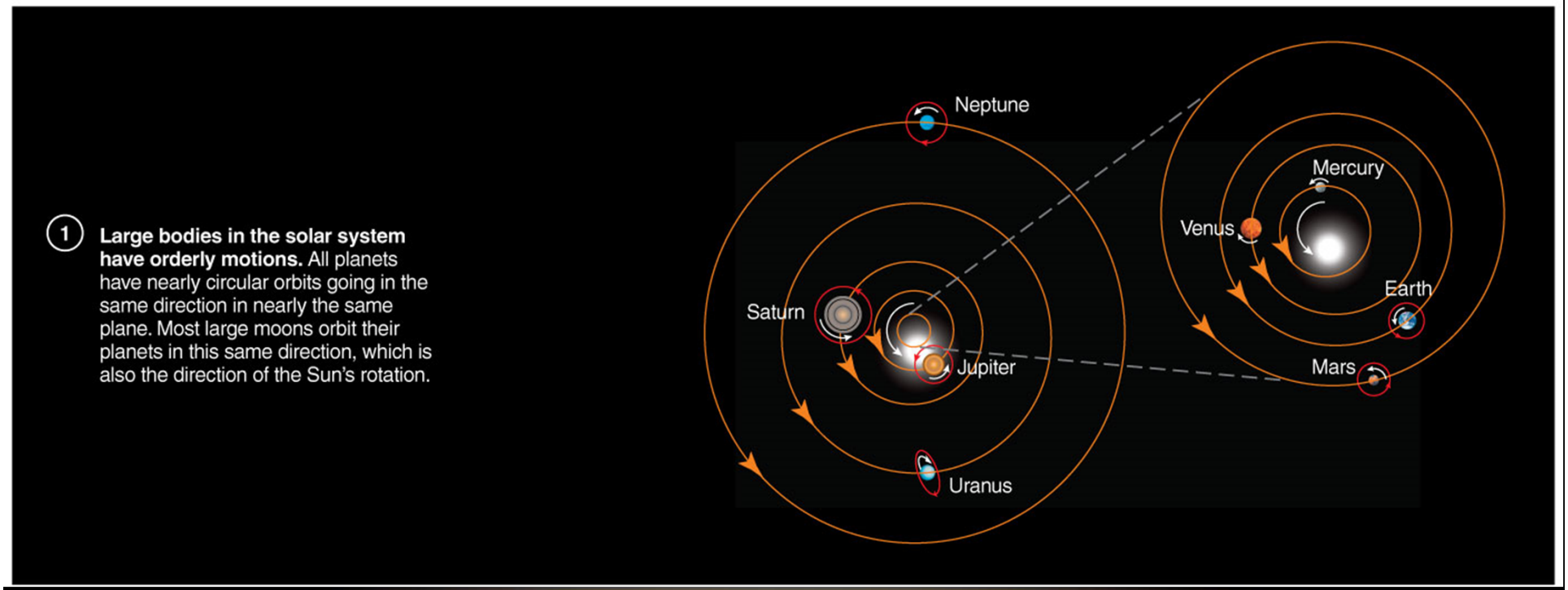


Fig.6.1.1

PLAY

TWO MAIN SORTS OF PLANETS

2 **Planets fall into two major categories:** Small, rocky terrestrial planets and large, hydrogen-rich jovian planets.

terrestrial planet

jovian planet

Fig.6.1.2

PLUS ASSORTED DEBRIS

- Asteroid Belt, Kuiper Belt, Oort Cloud

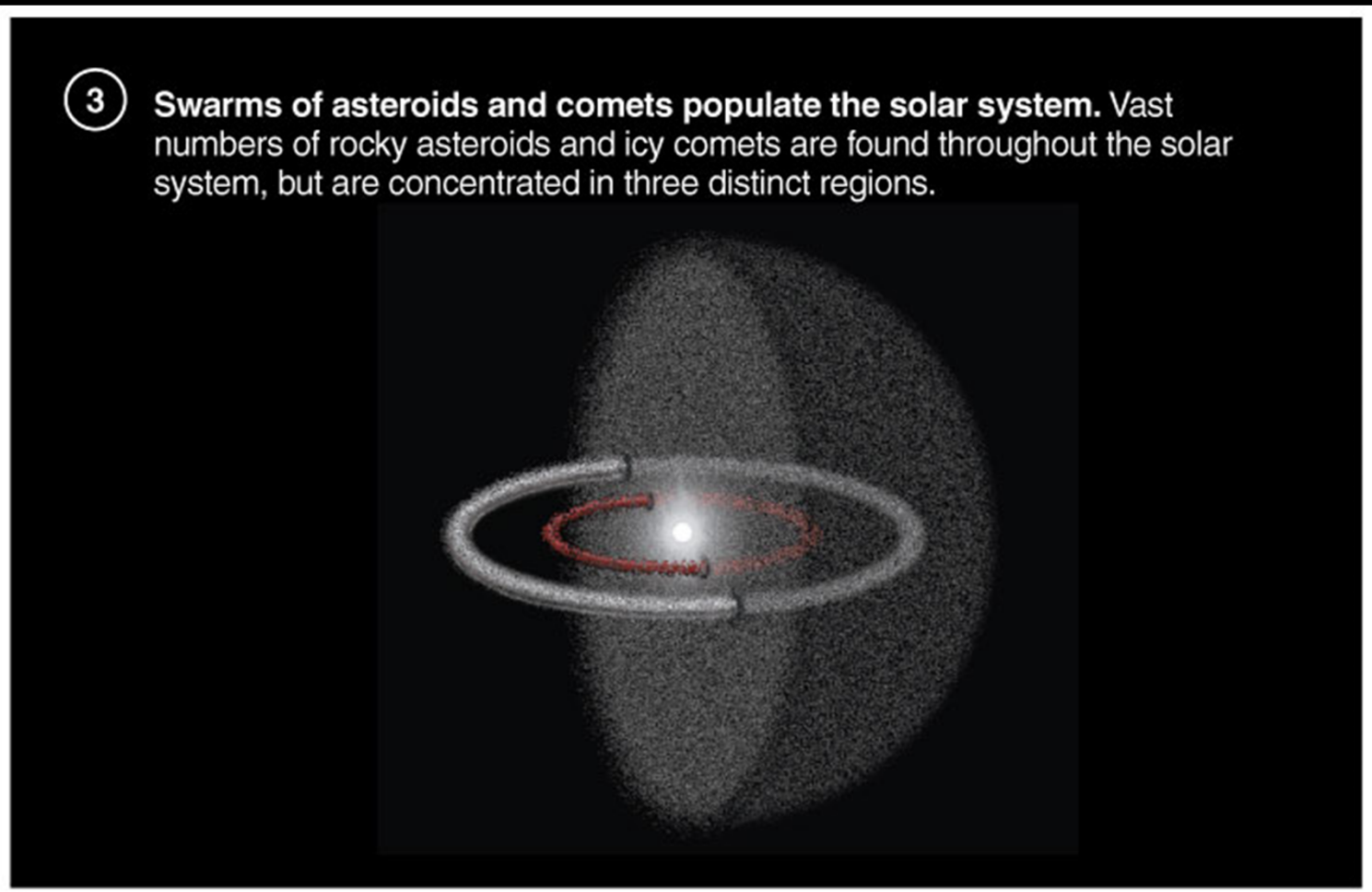


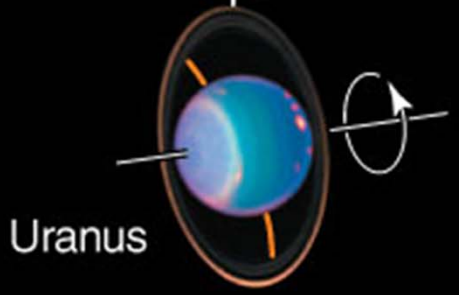
Fig.6.1.3

ODDBALL BITS

4

Several notable exceptions to these trends stand out.
Some planets have unusual axis tilts, unusually large moons, or moons with unusual orbits.

Uranus's odd tilt

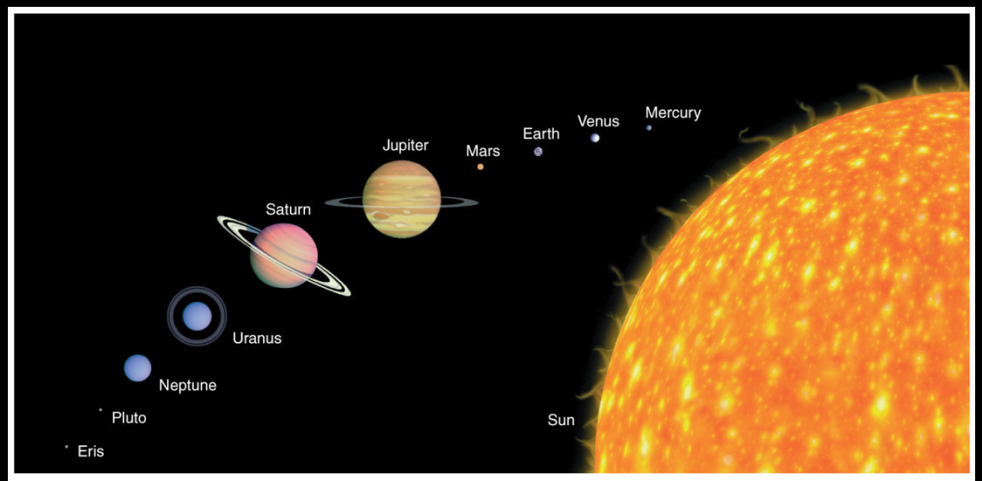


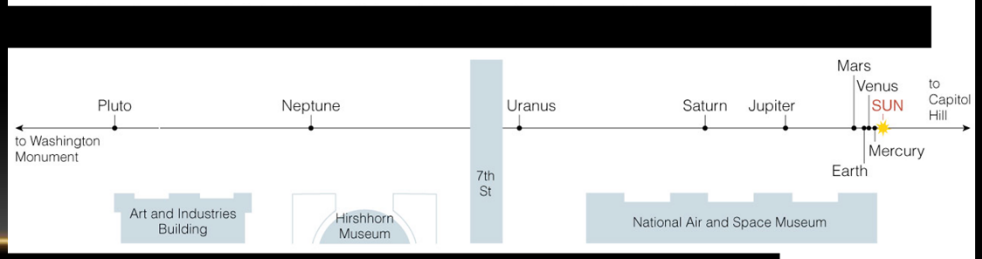
Earth's relatively large moon

Fig.6.1.4

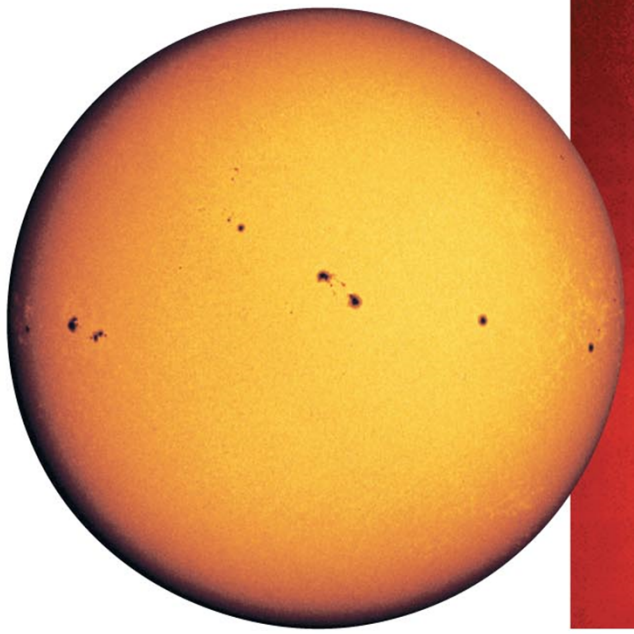
STILL A PRETTY EMPTY PLACE!

- Planets are really far apart compared to their sizes
  - Book uses the scale model on the National Mall as an ongoing example

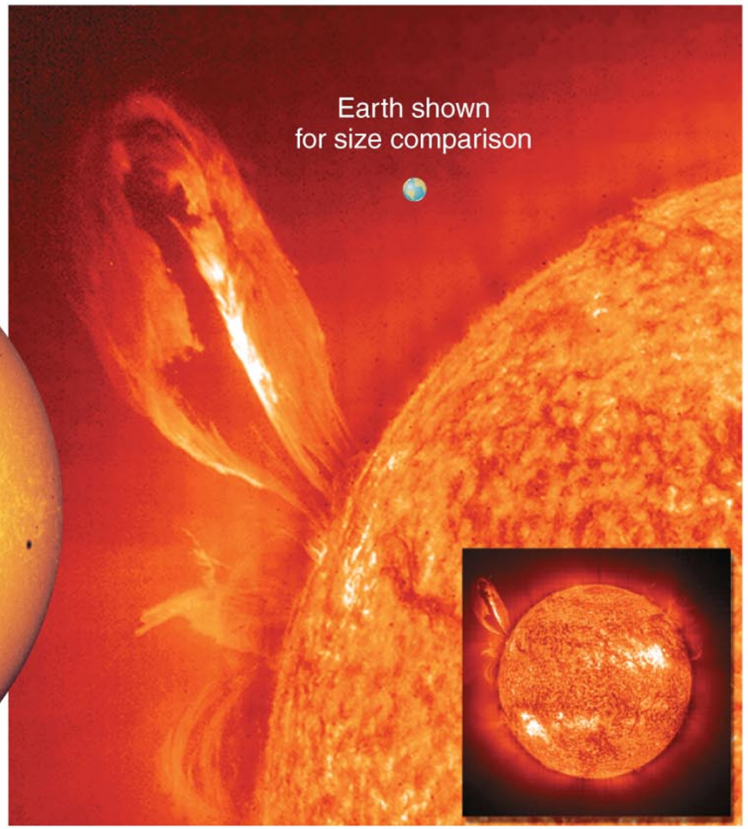




SUN



a A visible-light photograph of the Sun's surface. The dark splotches are sunspots—each large enough to swallow several Earths.



b This ultraviolet photograph, from the *SOHO* spacecraft, shows a huge streamer of hot gas on the Sun. The image of Earth was added for size comparison.

- Over 99.8% of solar system's mass
- Made mostly of H/He gas (plasma)
- Converts 4 million tons of mass into energy each second

Fig.6.2

MERCURY

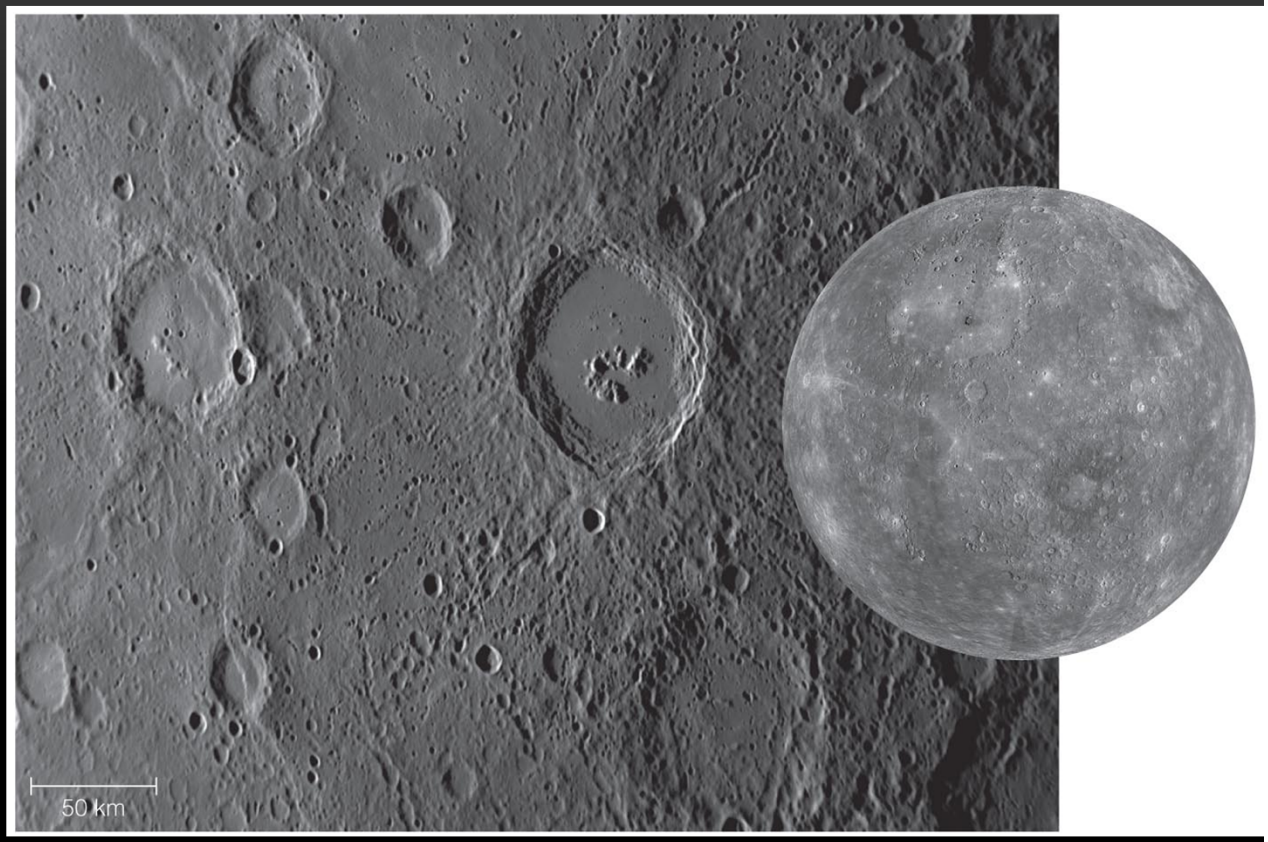
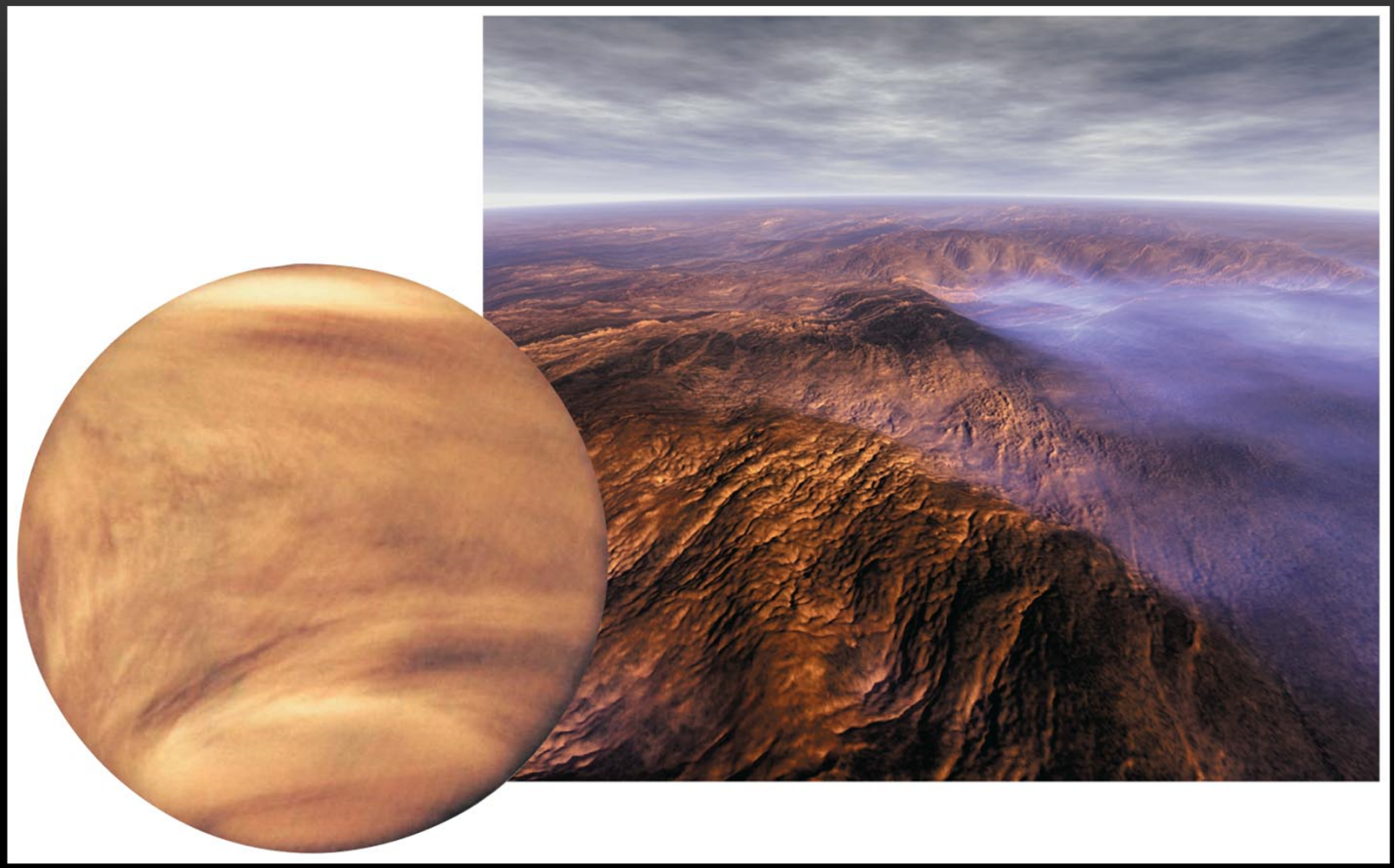


Fig.6.3

- Made of metal and rock; large iron core
- Desolate, cratered; long, tall, steep cliffs
- Very hot and very cold: 425°C (day), –170°C (night)

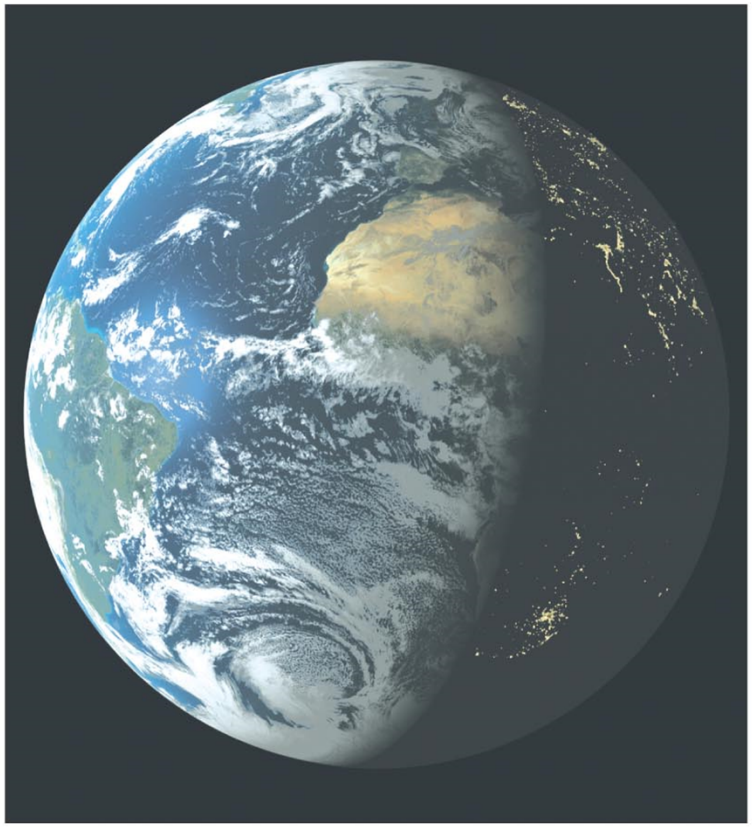
VENUS



- Nearly identical in size to Earth; surface hidden by clouds
- Hellish conditions due to an extreme **greenhouse effect**
- Even hotter than Mercury: 470°C, day and night

Fig.6.4

EARTH



a This image (left), computer generated from satellite data, shows the striking contrast between the day and night hemispheres of Earth. The day side reveals little evidence of human presence, but at night our presence is revealed by the lights of human activity. (From the Voyage scale model solar system, developed by the Challenger Center for Space Science Education, the Smithsonian Institution, and NASA. Image created by ARC Science Simulations © 2001.)

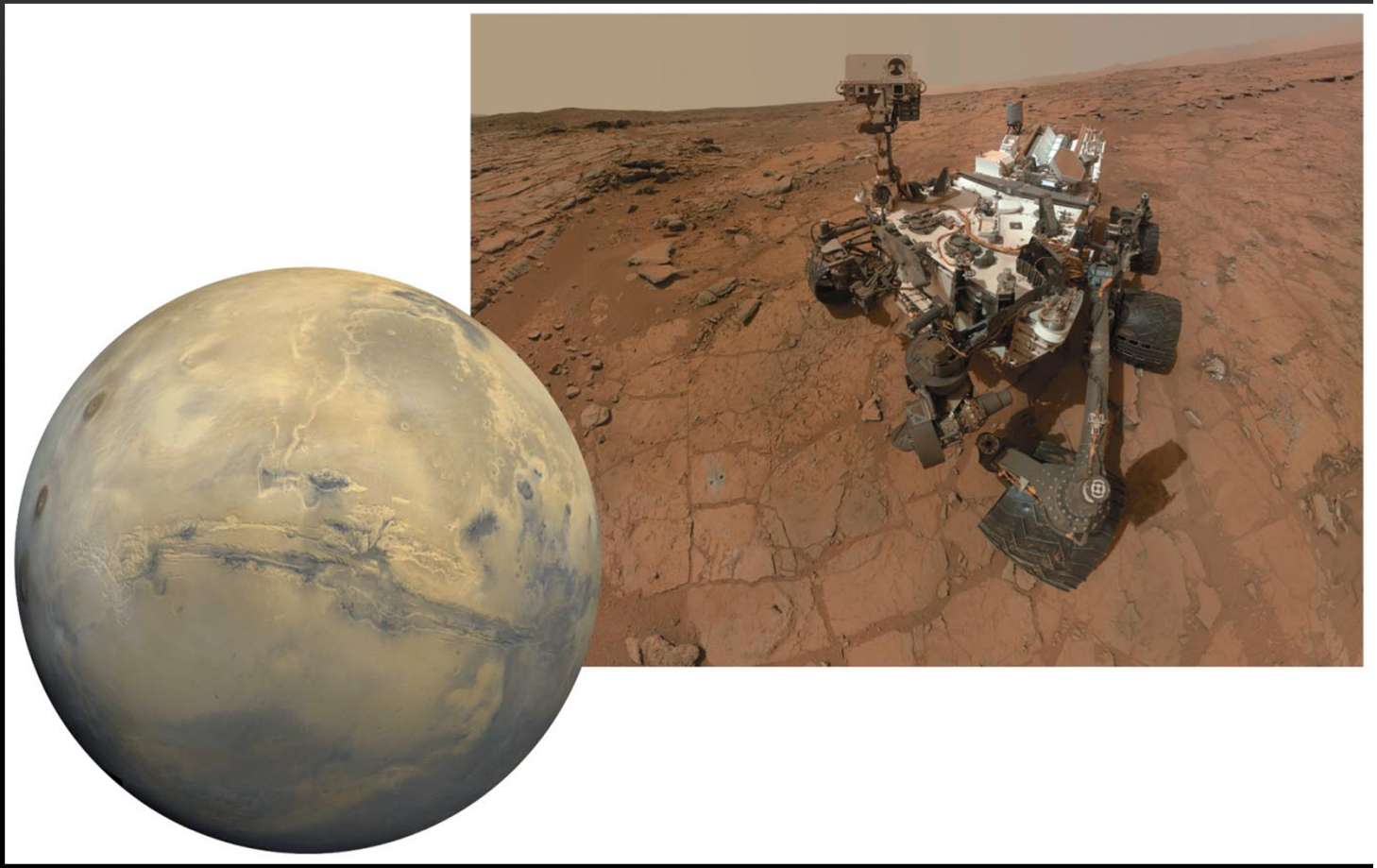
Earth and Moon to scale

b Earth and the Moon, shown to scale. The Moon is about 1/4 as large as Earth in diameter, while its mass is about 1/80 of Earth's mass. To show the distance between Earth and Moon on the same scale, you'd need to hold these two photographs about 1 meter (3 feet) apart.

Fig.6.5

- An oasis of life
- The only surface liquid water in the solar system
- A surprisingly large moon

MARS

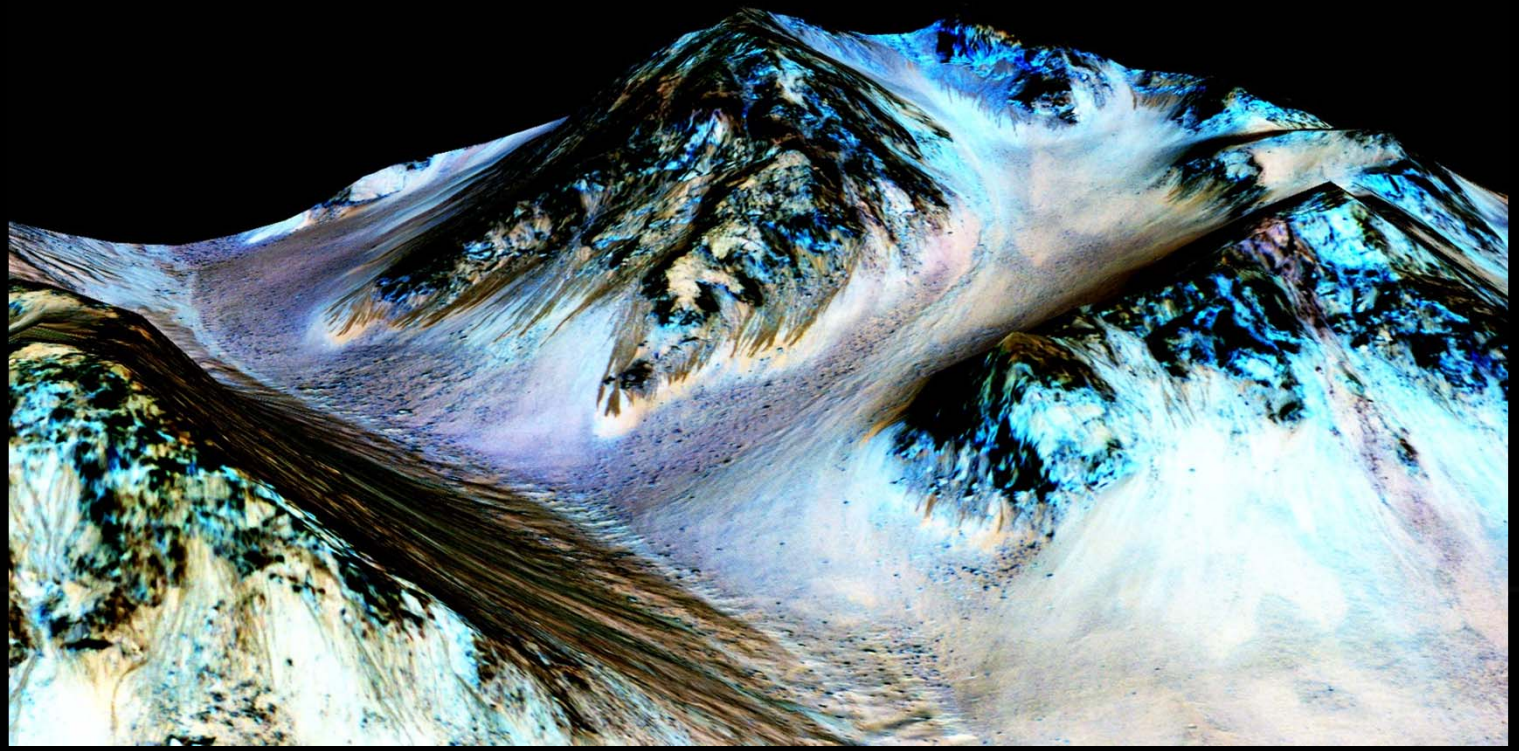


- Looks almost Earth-like, but don't go without a spacesuit!
- Giant volcanoes, a huge canyon, polar caps, and more
- Water clearly flowed in the distant past; could there have been life?

Fig.6.6

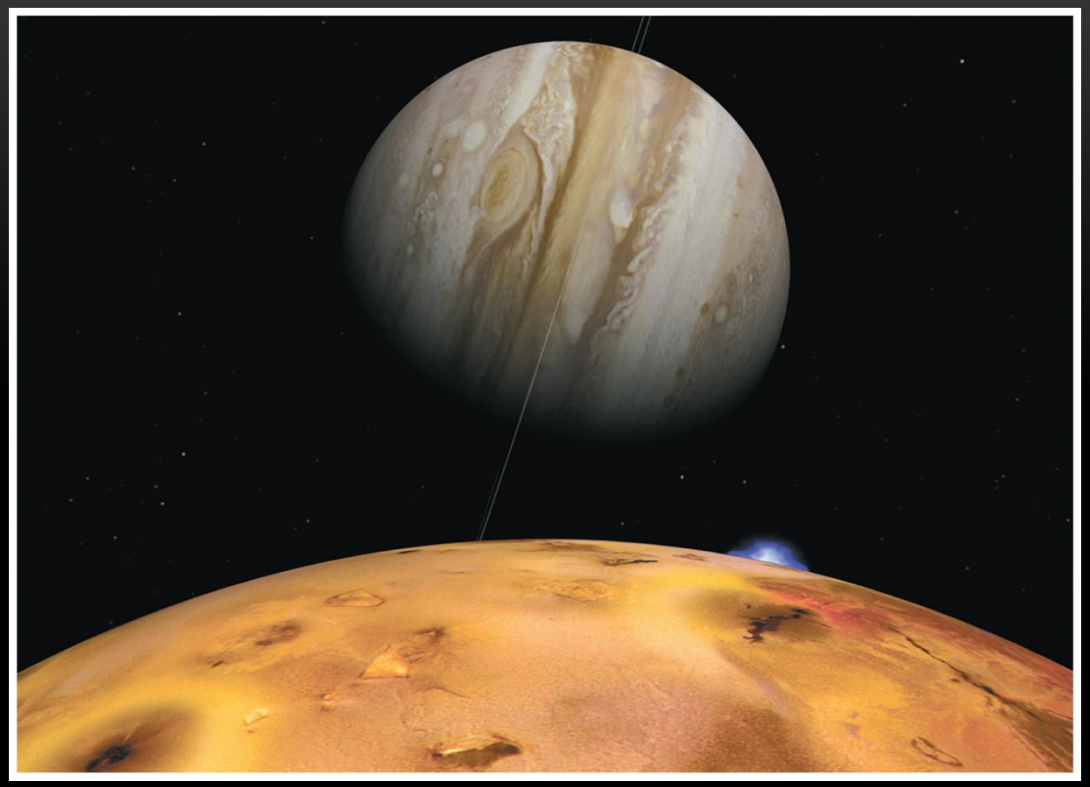
MARS NEWS

- Just in last couple of years:
- Evidence of water flowing on surface now:



JUPITER

- Much farther from Sun than inner planets
- Mostly H/He; no solid surface
- 300 times more massive than Earth
  - By far the largest planet
- Many moons, rings



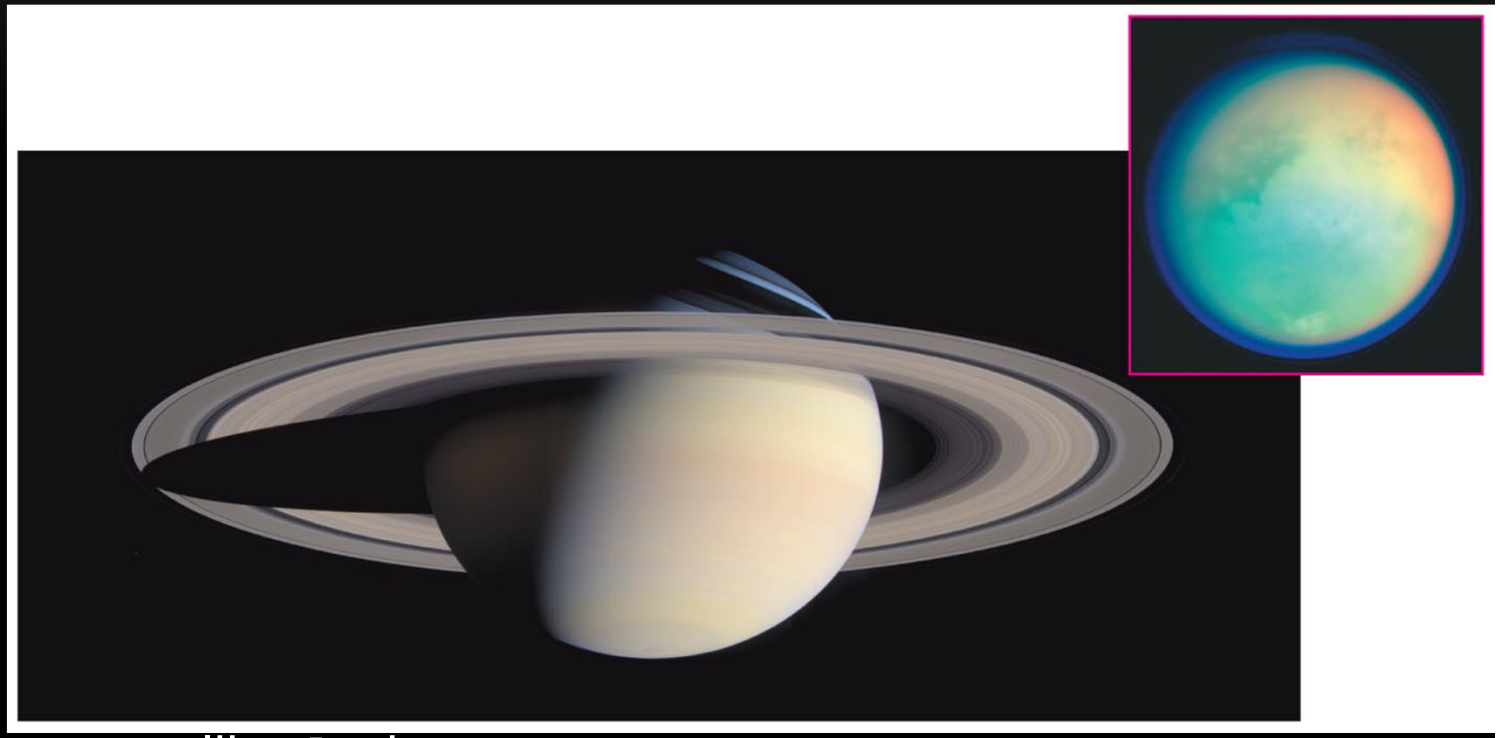
Jupiter's moons can be as interesting as planets themselves, especially Jupiter's four *Galilean moons.*

- Io (shown here): Active volcanoes all over
- Europa: Possible subsurface ocean
- Ganymede: Largest moon in solar system
- Callisto: A large, cratered "ice ball"

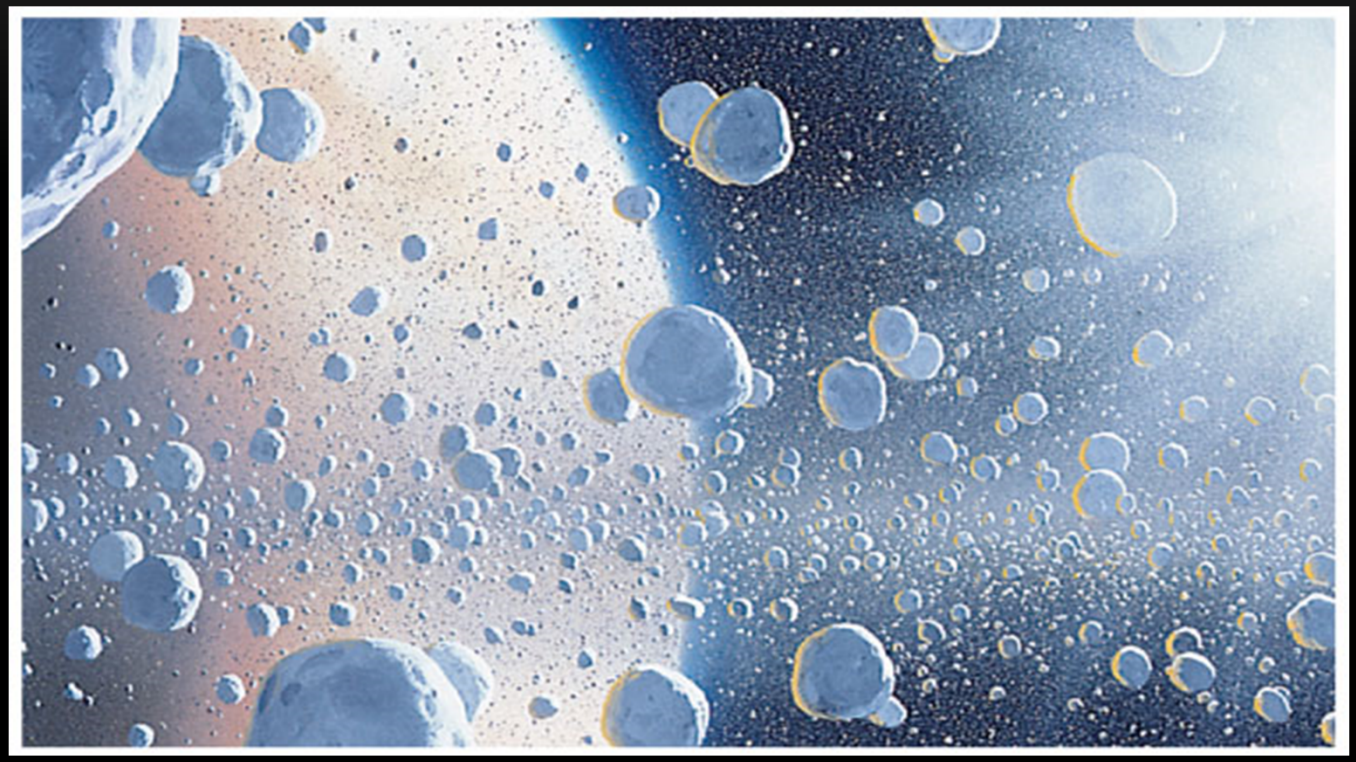
Fig.6.7

SATURN

Fig.6.8



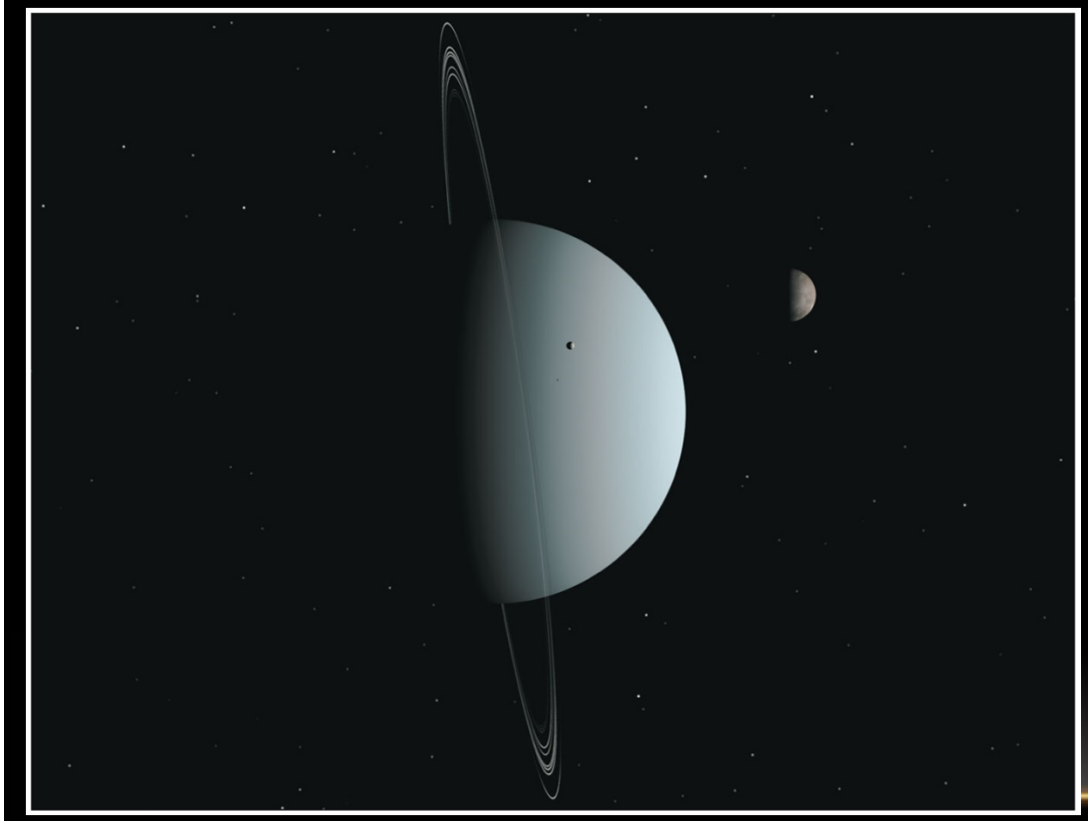
- Giant and gaseous like Jupiter
- Spectacular rings
- Many moons, including cloudy Titan



Artist's conception of Saturn's rings

Rings are NOT solid; they are made of countless small chunks of ice and rock, each orbiting like a tiny moon.

URANUS



- Smaller than Jupiter/Saturn; much larger than Earth
- Made of H/He gas and **hydrogen compounds** (H_2O, NH_3, CH_4)
- Extreme axis tilt
- Moons and rings

Fig.6.9

NEPTUNE

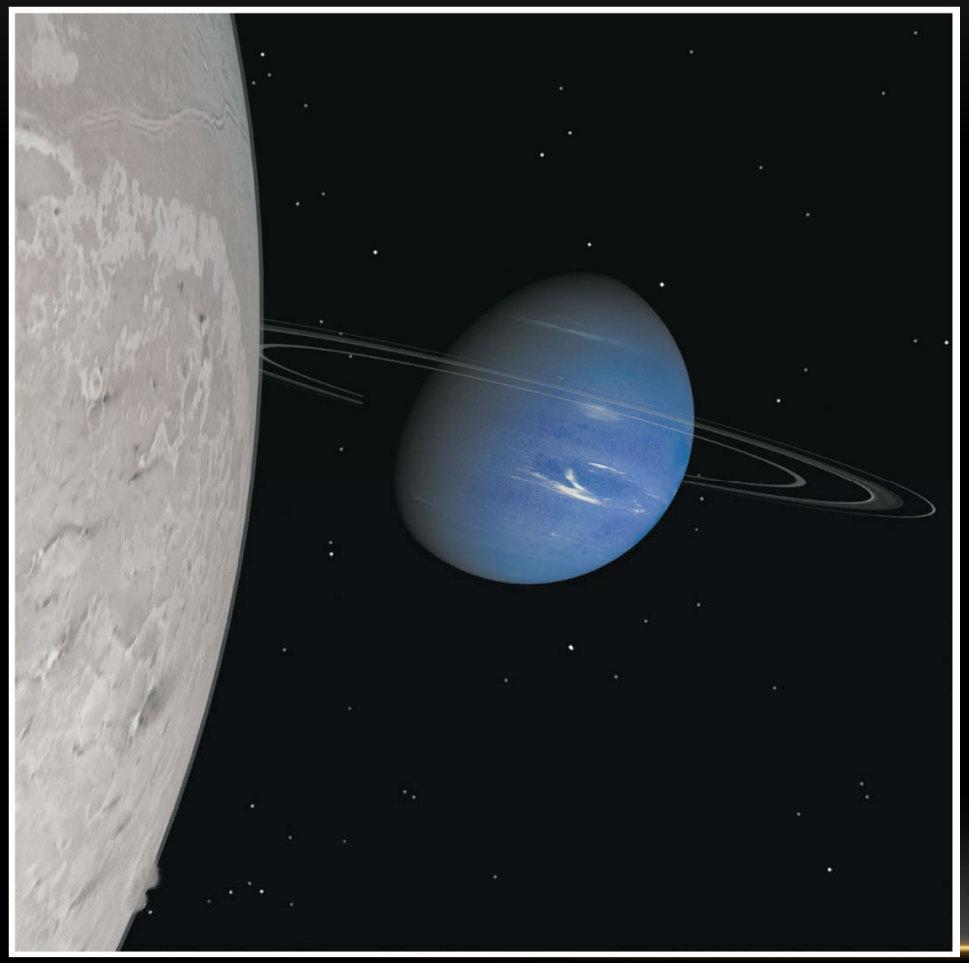
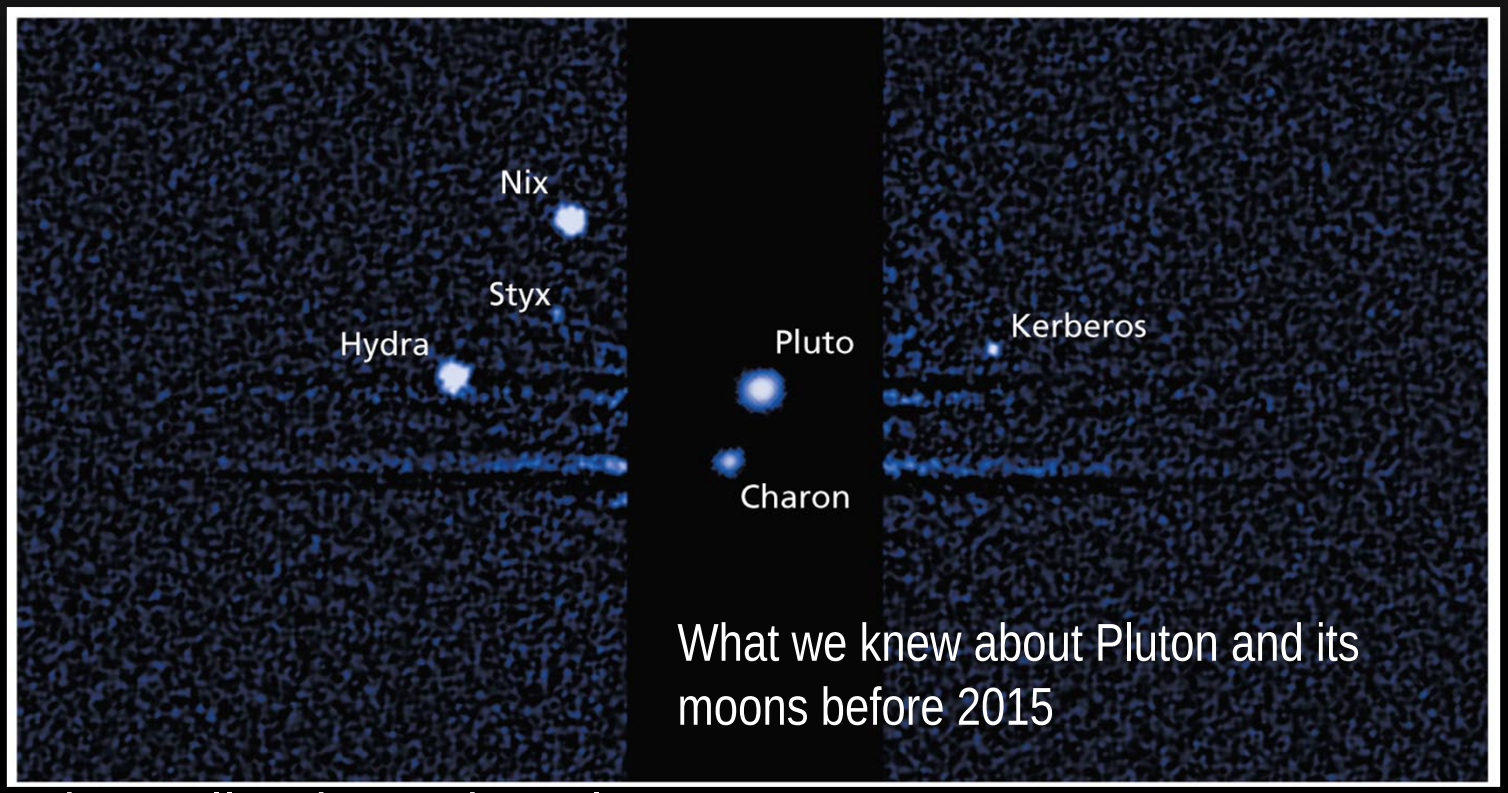


Fig.6.10

- Similar to Uranus (except for axis tilt)
- Many moons (including Triton)

PLUTO AND OTHER DWARF PLANETS



- Much smaller than other planets
- Icy, comet-like composition
- Pluto's moon Charon is similar in size to Pluto

PLUTO AND OTHER DWARF PLANETS

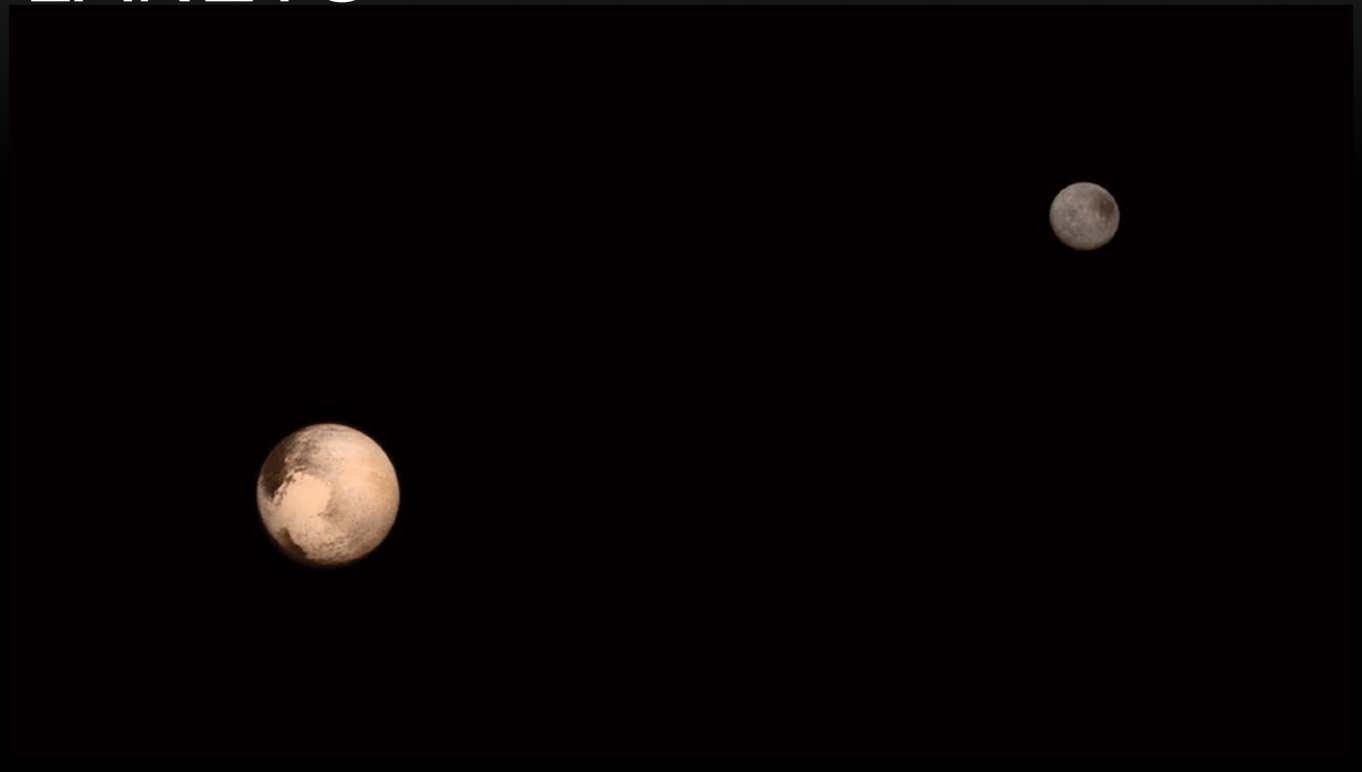
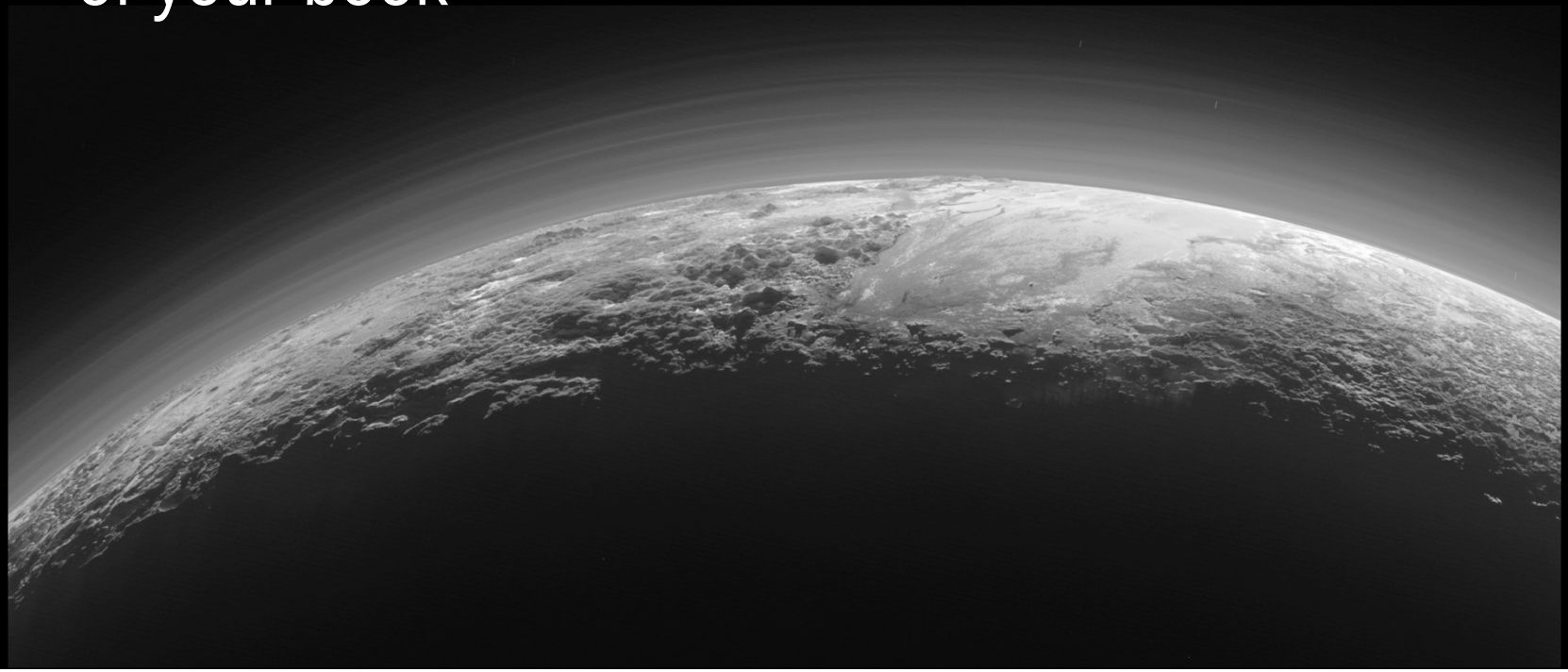


Fig. 6.11
(now that a probe has gone past)

- Much smaller than other planets
- Icy, comet-like composition
- Pluto's moon Charon is similar in size to Pluto

NEW STUFF!

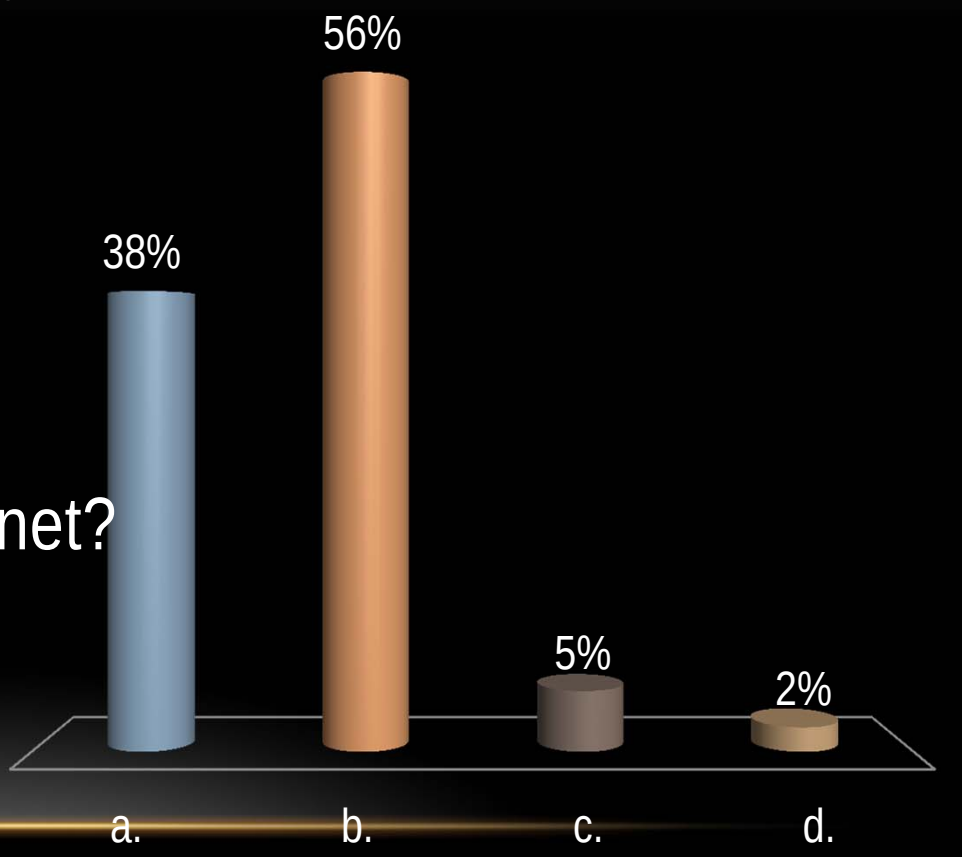
- In 2015 the New Horizons probe flew by Pluto, so we now have a lot of cool (and sometimes baffling) pictures which prompted a new version of your book



PLUTO: PLANET OR NOT

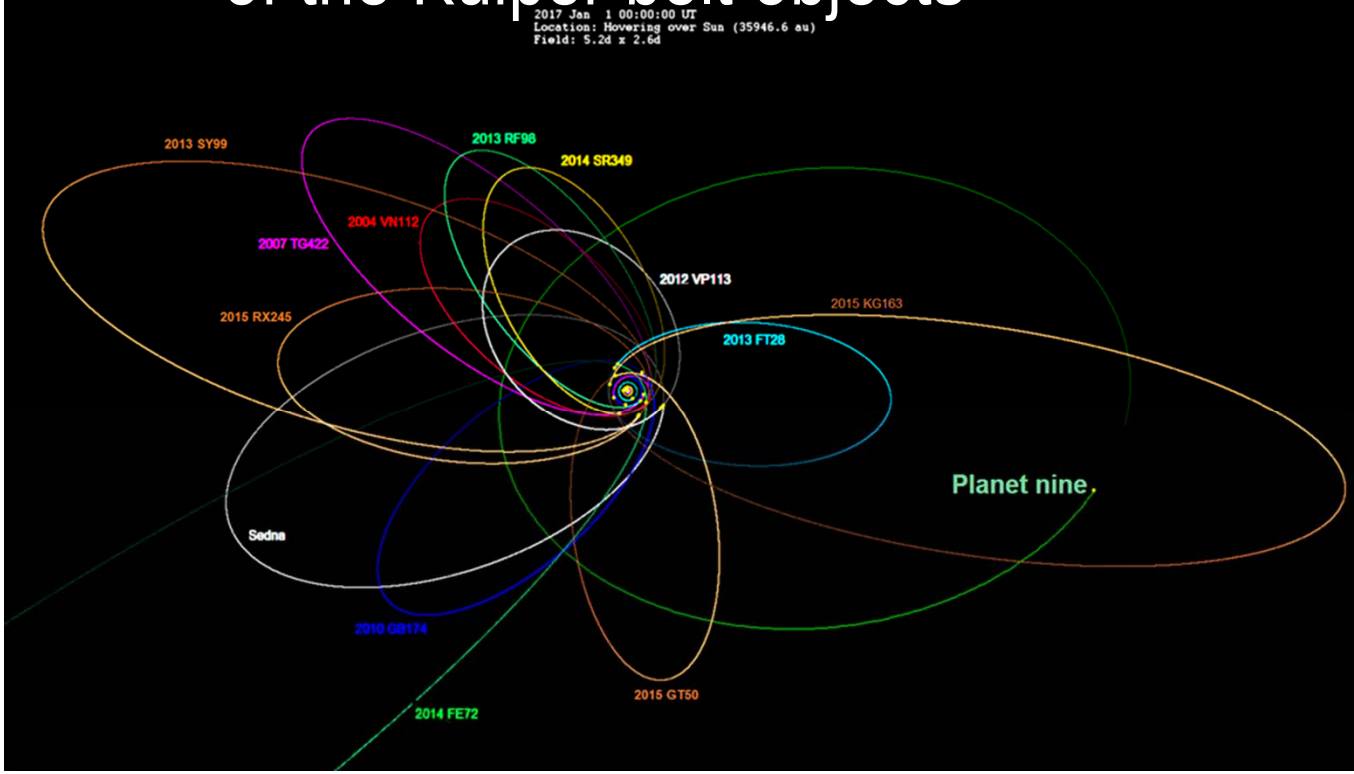
a. I liked Pluto as a planet
b. I'm OK with the new definition as a Dwarf Planet
c. Don't care
d. Huh? Pluto's not a planet?

More on this later when we talk about Pluto in detail



“PLANET NINE”?

- Also in the last few years, a large planet in an odd orbit was proposed to explain the odd orbits of a number of the Kuiper belt objects



Real or not?

We’ll wait and see what more data and a search for actual images might turn up.

Observed orbits could also be a side effect of when it’s easiest for us to see these faint things.

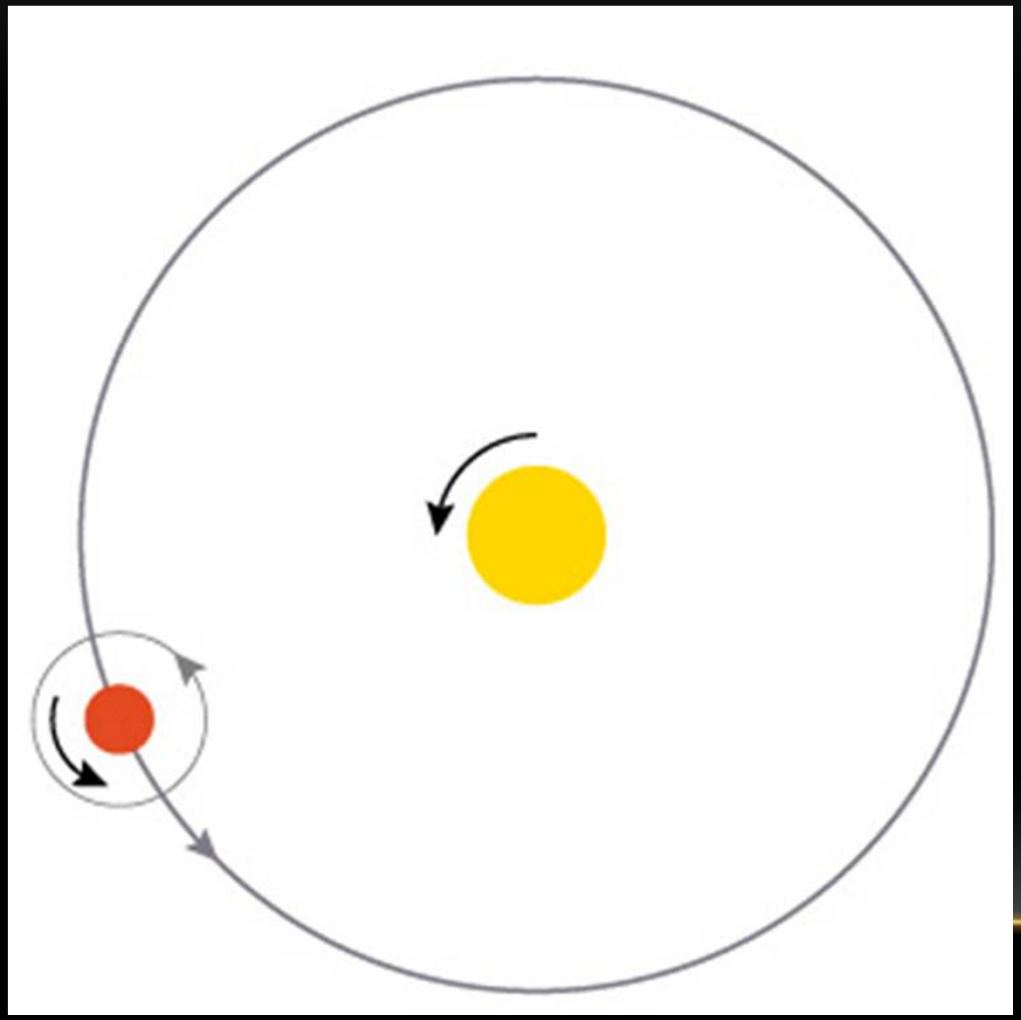
“PLANET X”? “NIBIRU”?

- A made-up disaster clickbait hoax.
- There are no planets out there on a collision course with earth.
- The world did not end last Saturday the 23rd.
- Could there be? No. Given how well we know the orbits of everything within Neptune’s orbit, we’d see any extra gravity from such an object moving stuff around: but we don’t.

SOLAR SYSTEM OBSERVED FACTS TO ACCOUNT FOR

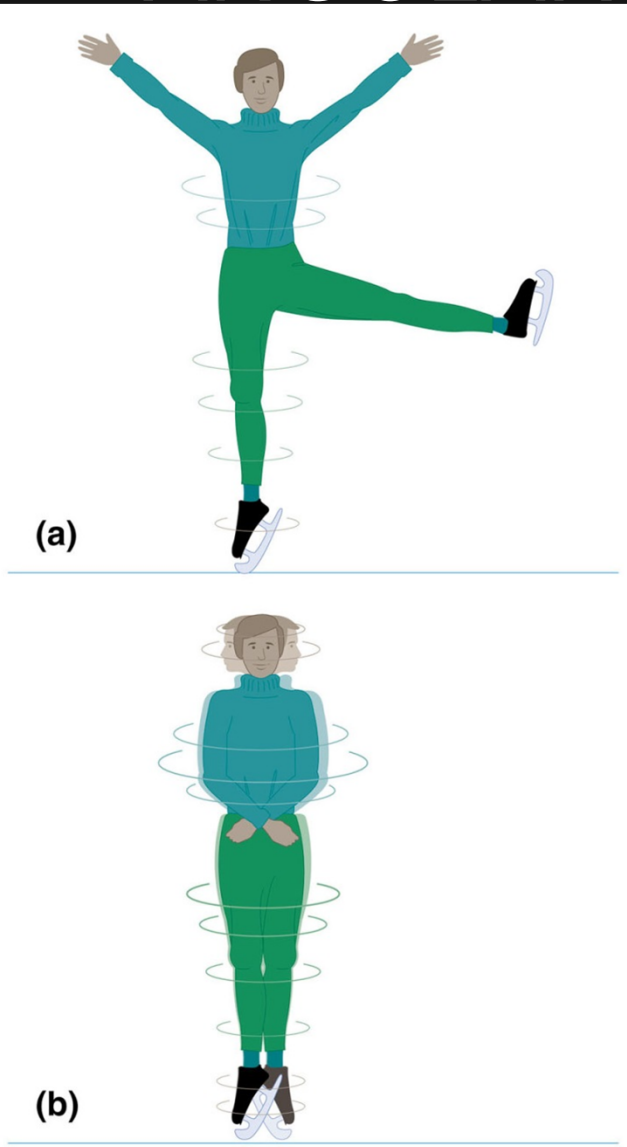
- Everything revolves same way around Sun
  - In about the same plane
  - Most things rotate that same way
  - Most moons revolve that same way
- Composition – less volatile elements close in
- Lots of craters made early on, not so many now
- Angular momentum now
  - Sun has some, planets have most
- Check vs. other stars

ROTATING AND REVOLVING



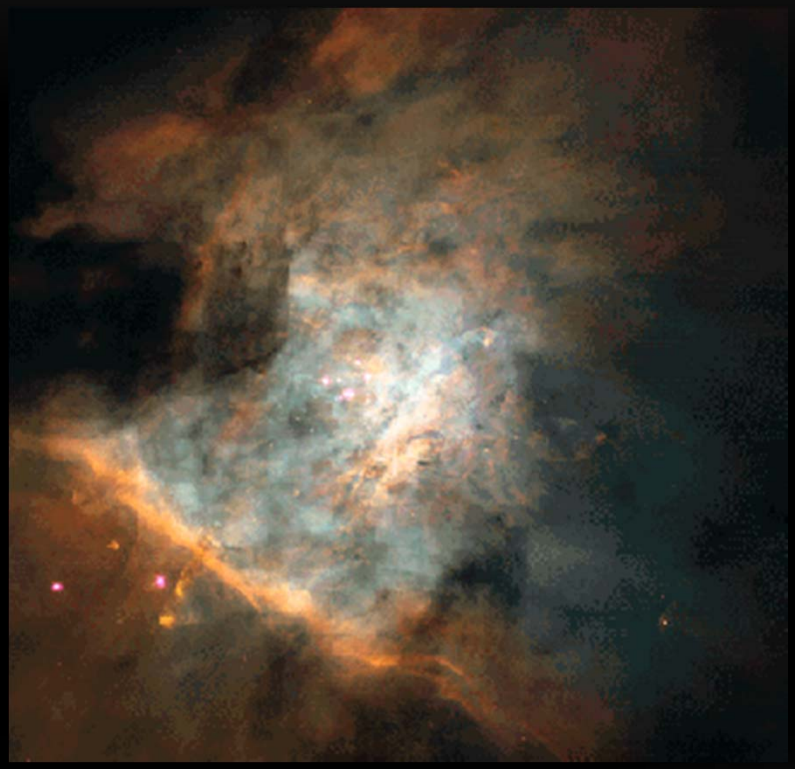
- All large bodies in the solar system orbit in the same direction and in nearly the same plane.
- Most also rotate in that direction.

ANGULAR MOMENTUM?



- L = mvr
  - Mass times velocity times radius
  - L stays the same if smaller r but larger v, like skater
- So as spinning things shrink, they speed up
- Also, things flatten out into disks (like pizza dough)

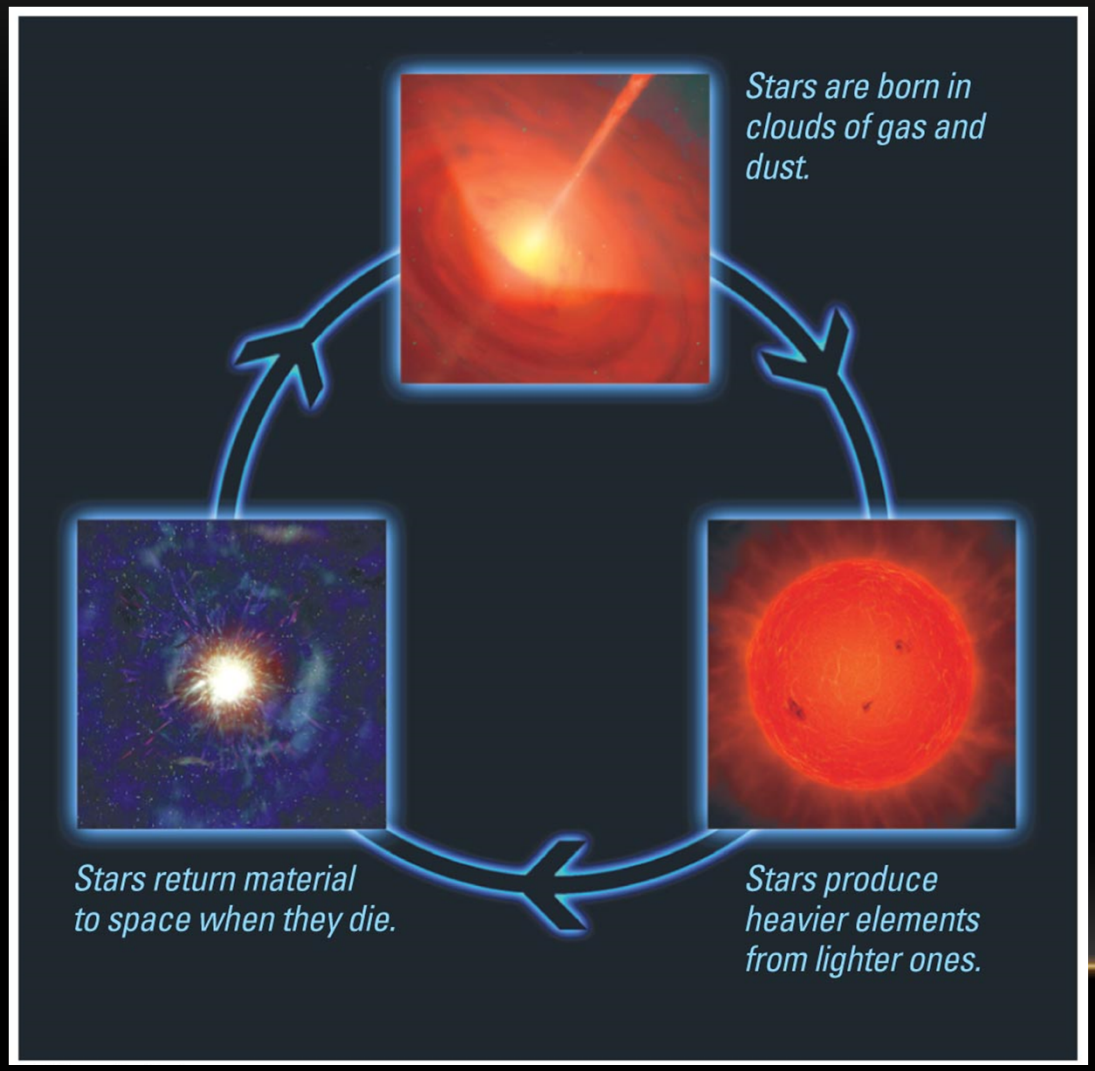
NEBULAR THEORY



- Interstellar cloud of dust and gas collapses due to self gravity
  - Perhaps after getting kicked by a supernova shock wave
- Orion nebula is an example of this happening

("Nebula" means cloud)

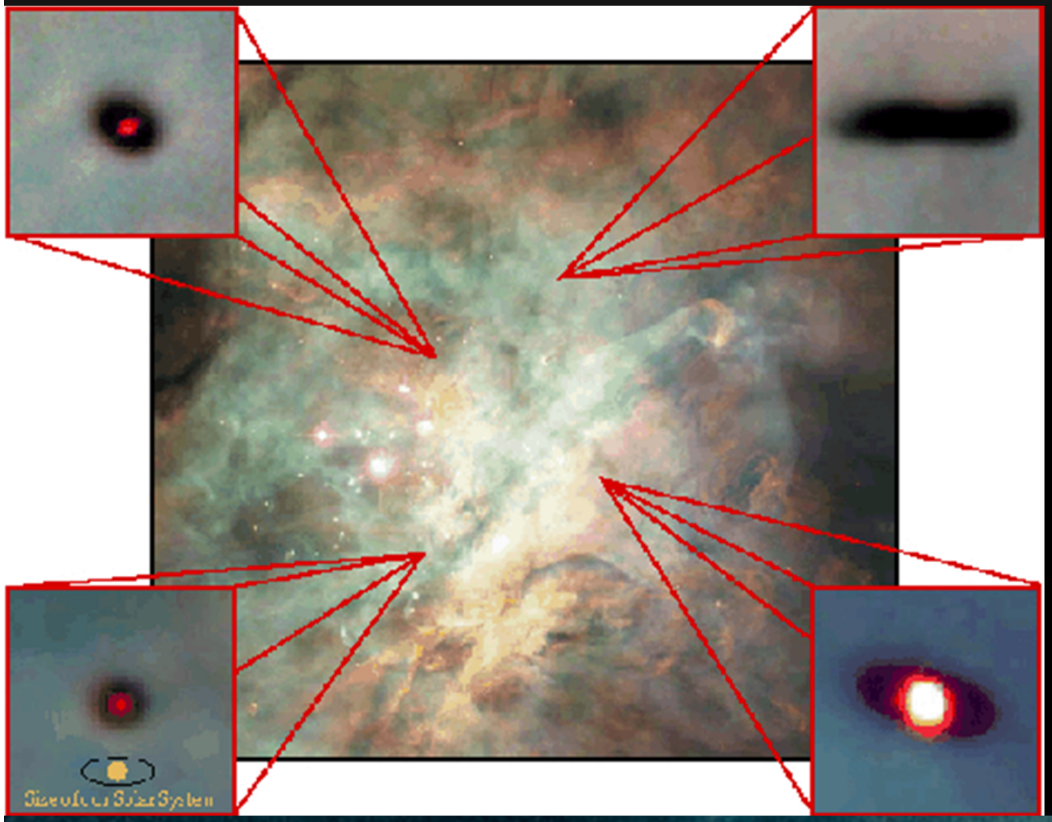
ORIGIN OF THE NEBULA



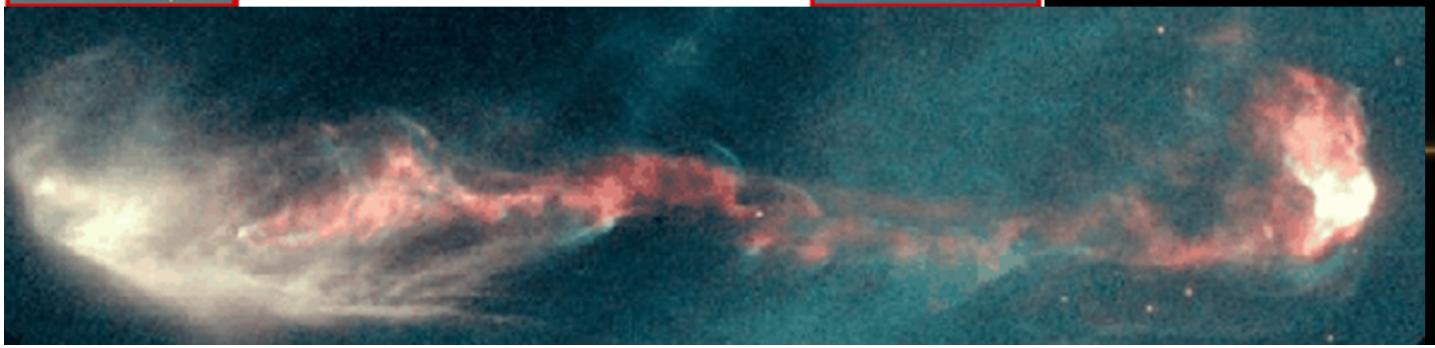
- Elements that formed planets were made in stars and then recycled through interstellar space.
- Still mostly H, He: but more of the other stuff than at the start of the universe

From CH.1:
more in a few weeks

WE SEE OTHER STARS BEING BORN

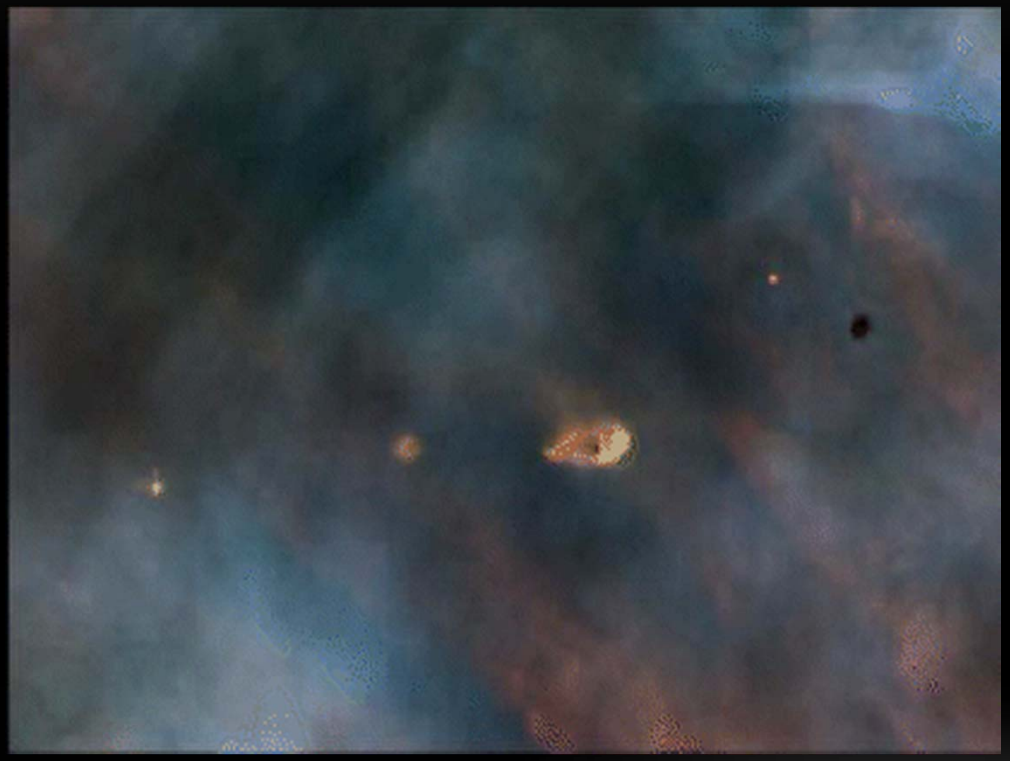


- The densest clumps collapse fastest
  - Most mass goes to center
  - Rest spreads out as disk
- Central mass heats up due to compression, forms a "protosun"
- Hubbel close-ups see these protosuns



With jets!

MEANWHILE, IN THE DISK



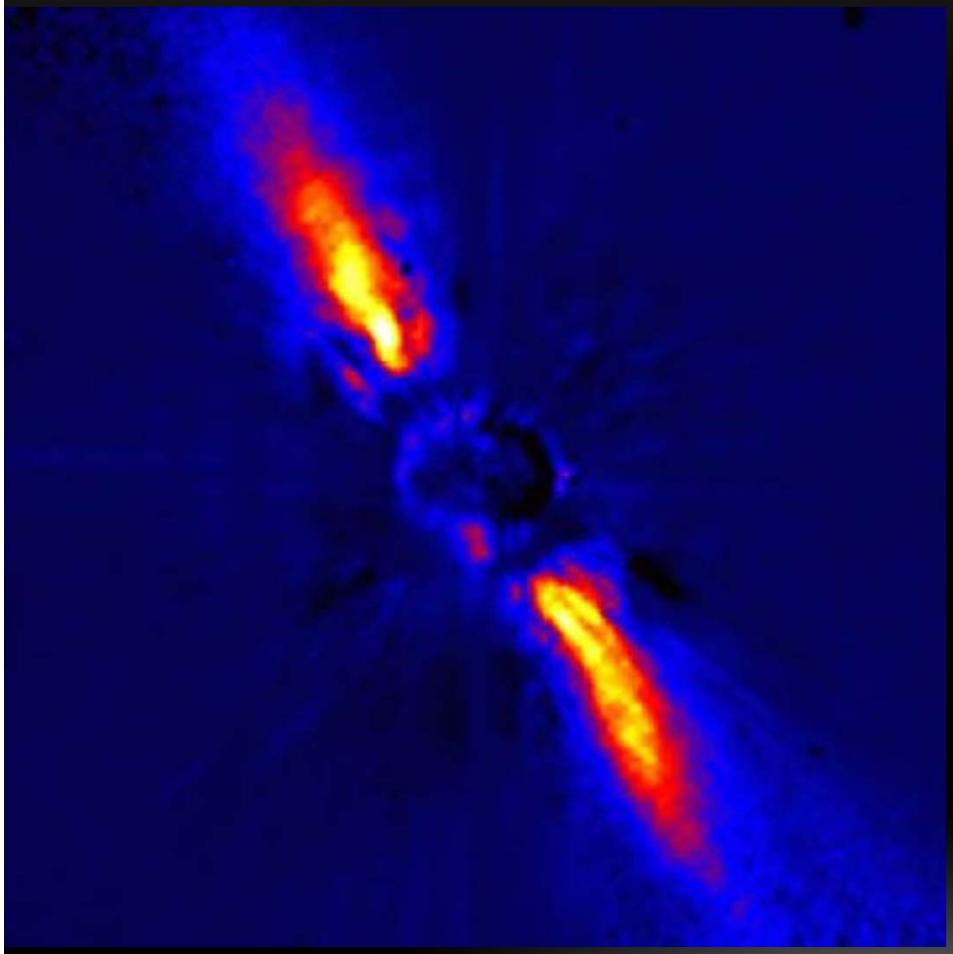
Proplyds (infant solar systems) forming in Orion nebula (HST image)

- Cooler, less dense
- Non-volatile stuff (metals, rocks) condense first – into dust grains
- Dust bumps into each other
  - Gloms together
  - Orbits circularize

PLANETISIMALS

- Eventually larger chunks stick together
  - Called planetisimals
- Larger planetisimals grow faster
  - Central to eddies, which might form into moons
- Stuff heats up as it piles up
  - *Differentiation* happens (iron cores sink etc)
  - Inner smaller planets lose their volatile gases
- Many collisions as planetisimals smack together

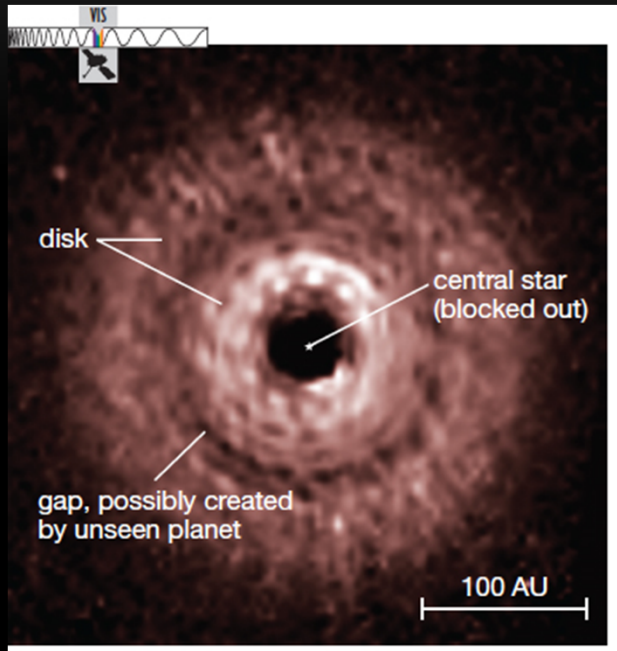
OTHER PLANETARY SYSTEMS?



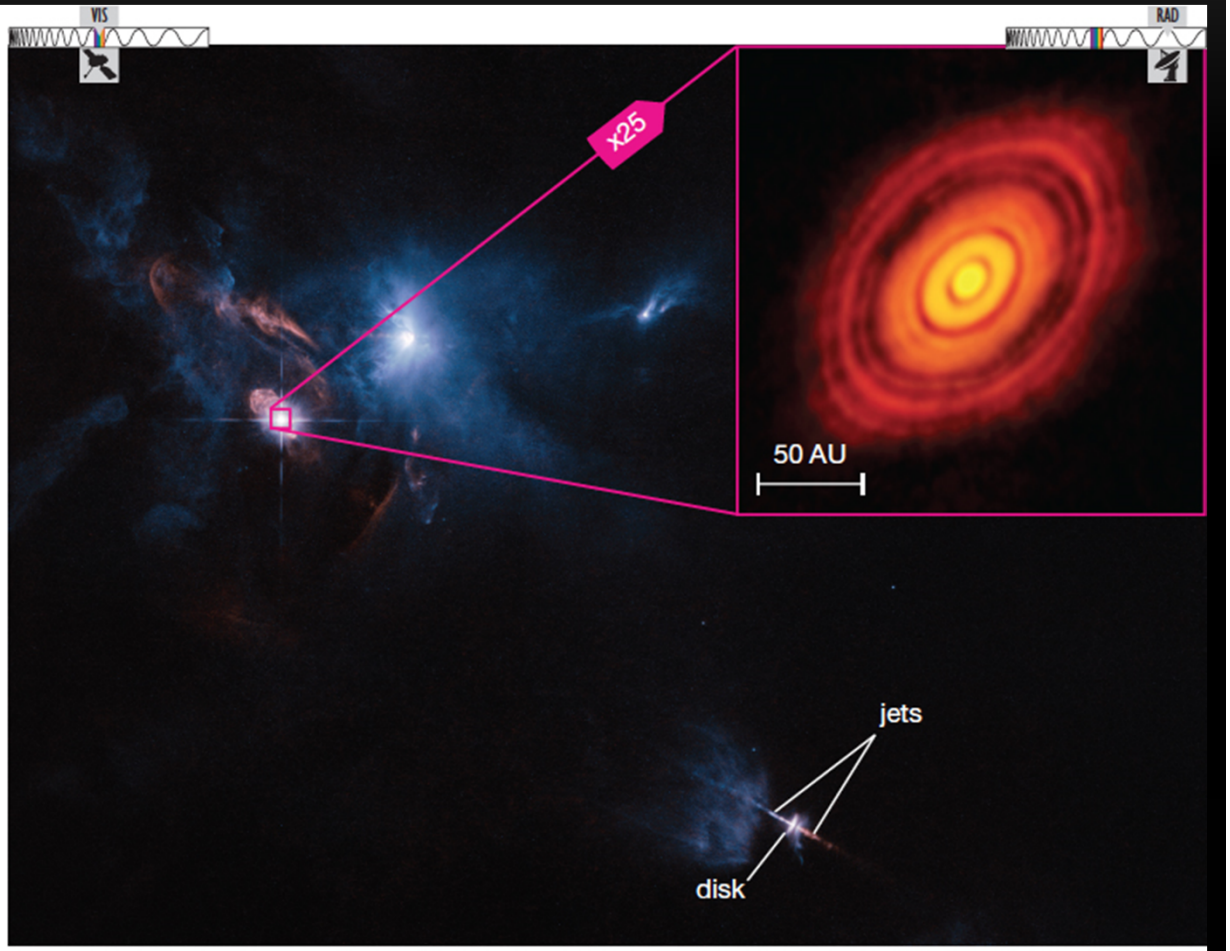
Beta Pictoris and its disk

- Being found all the time
- By their influences on the central star
  - Doppler-shift shows star's wobble
- By infra-red pictures of dust in the ecliptic
- Note clear area, consistent with planet formation
  - Plus twisted disk!

WE SEE THIS HAPPENING AROUND OTHER STARS



a This Hubble Space Telescope image shows a flattened, spinning disk around the star TW Hydrae. This particular disk also shows at least one circular "gap" in which material seems to have been cleared away, probably by a planet forming in the disk, which would have a gravitational attraction that would tend to sweep up material along its path.



b The inset, from the Atacama Large Millimeter/submillimeter Array (ALMA), shows a disk around a star named HL Tauri; the concentric gaps in the disk are almost certainly regions being cleared as planets form. The disk diameter is about three times that of Neptune's orbit around the Sun. The background image, from the Hubble Space Telescope, shows the star-forming region in which this disk is located. Another disk, seen edge-on with jets extending outward, appears at lower right.

Fig.6.17

AFTER STAR FORMATION

- Orion Nebula area will look something like the Pleiades in a few tens of millions of years
- Then the Hyades

"Open Clusters" the Pleiades
And Hyades

DOES THIS EXPLAIN THINGS?

- Motions of large bodies: All in same direction and plane
- Two major planet types: Terrestrial and jovian
- Swarms of small bodies: Asteroids and comets
- Notable exceptions: Rotation of Uranus, Earth's large moon