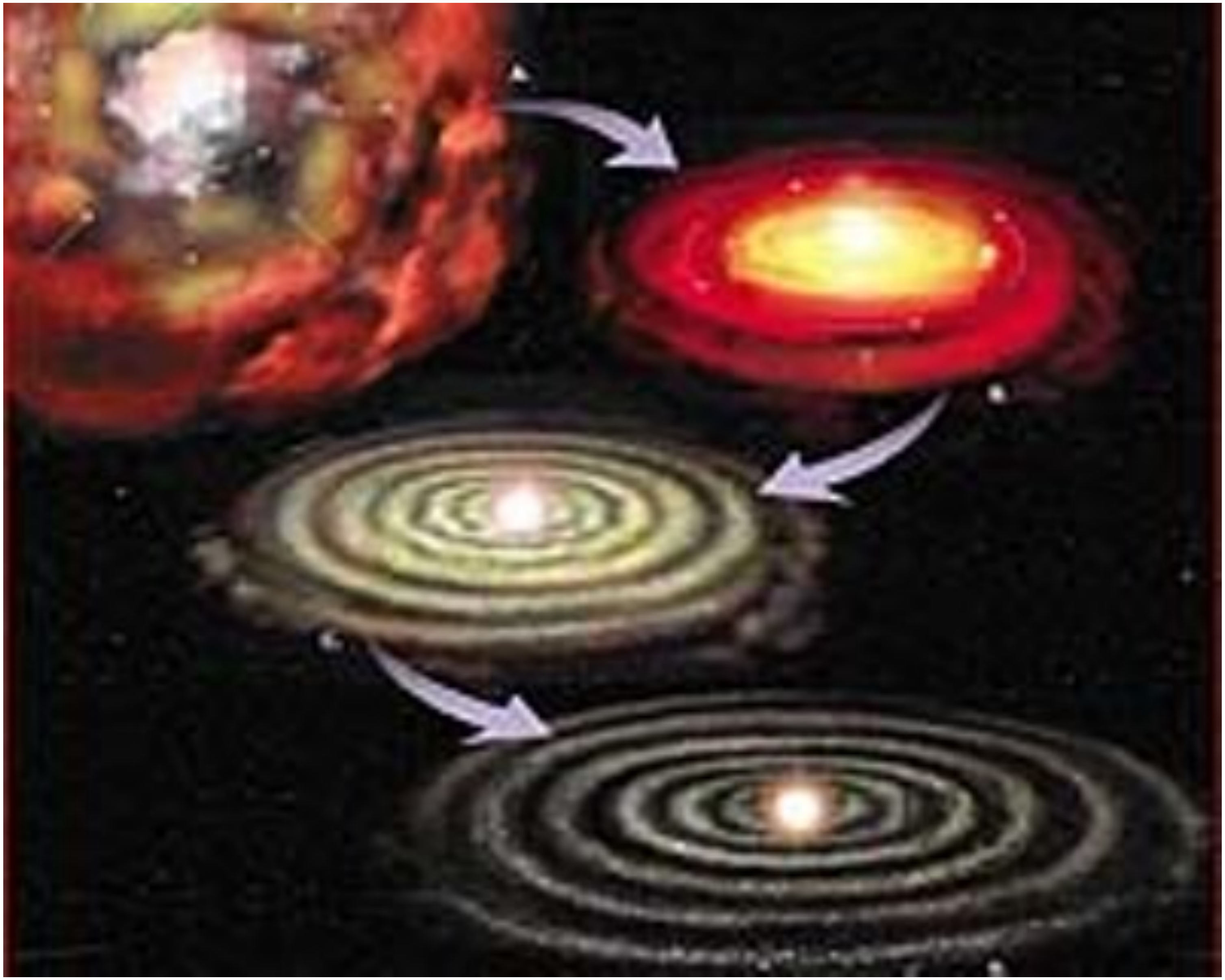
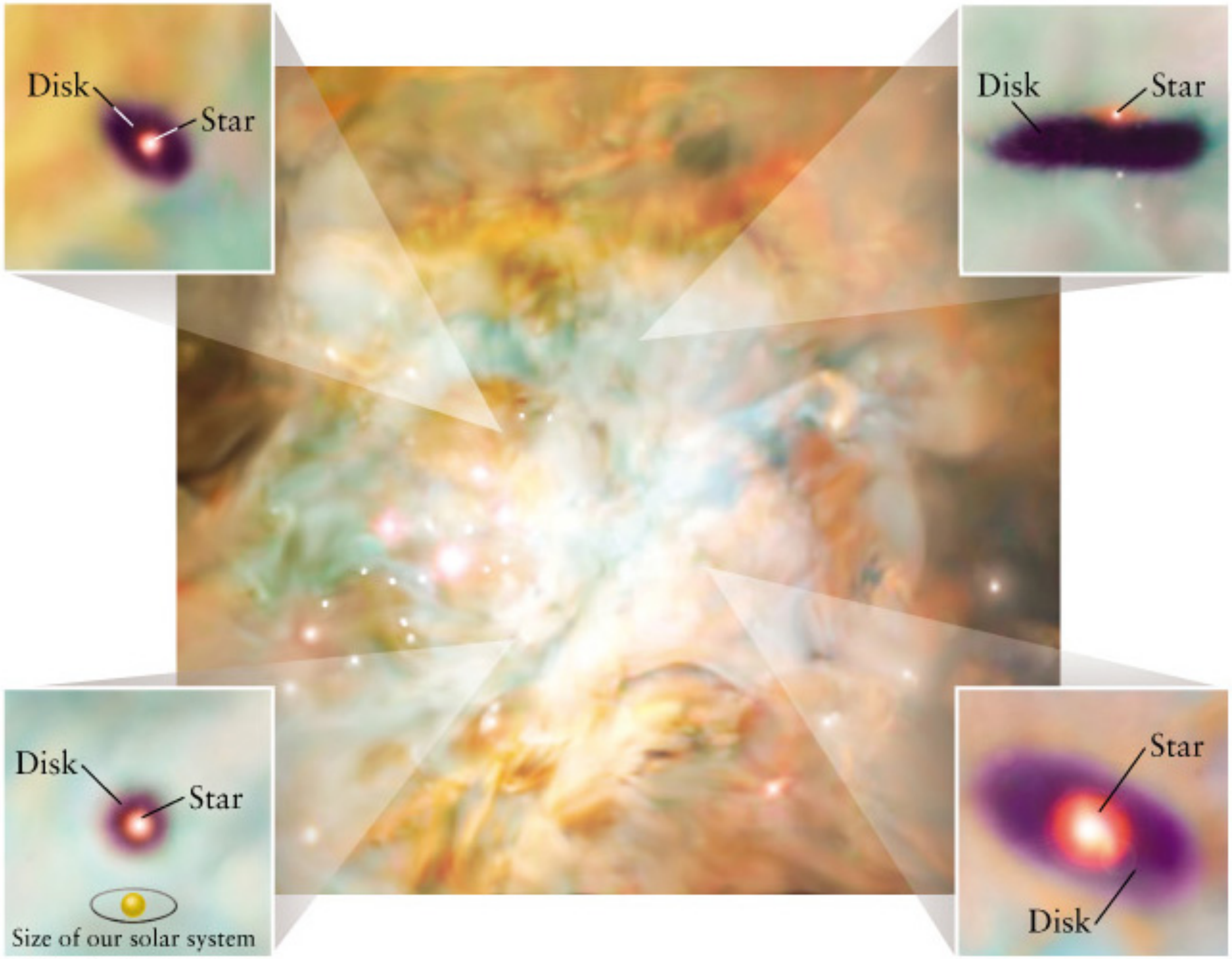
Planet Formation

- Stars formed by gas/dust cloud contracting due to gravity
- Results in swirling disk of material (mostly H, He, C, O, plus some heavier elements, some molecules, some "dust") that can form planets **if conditions are right**
- New born star will heat up material, blow it out of the solar nebula → planets need to form before material is blown away





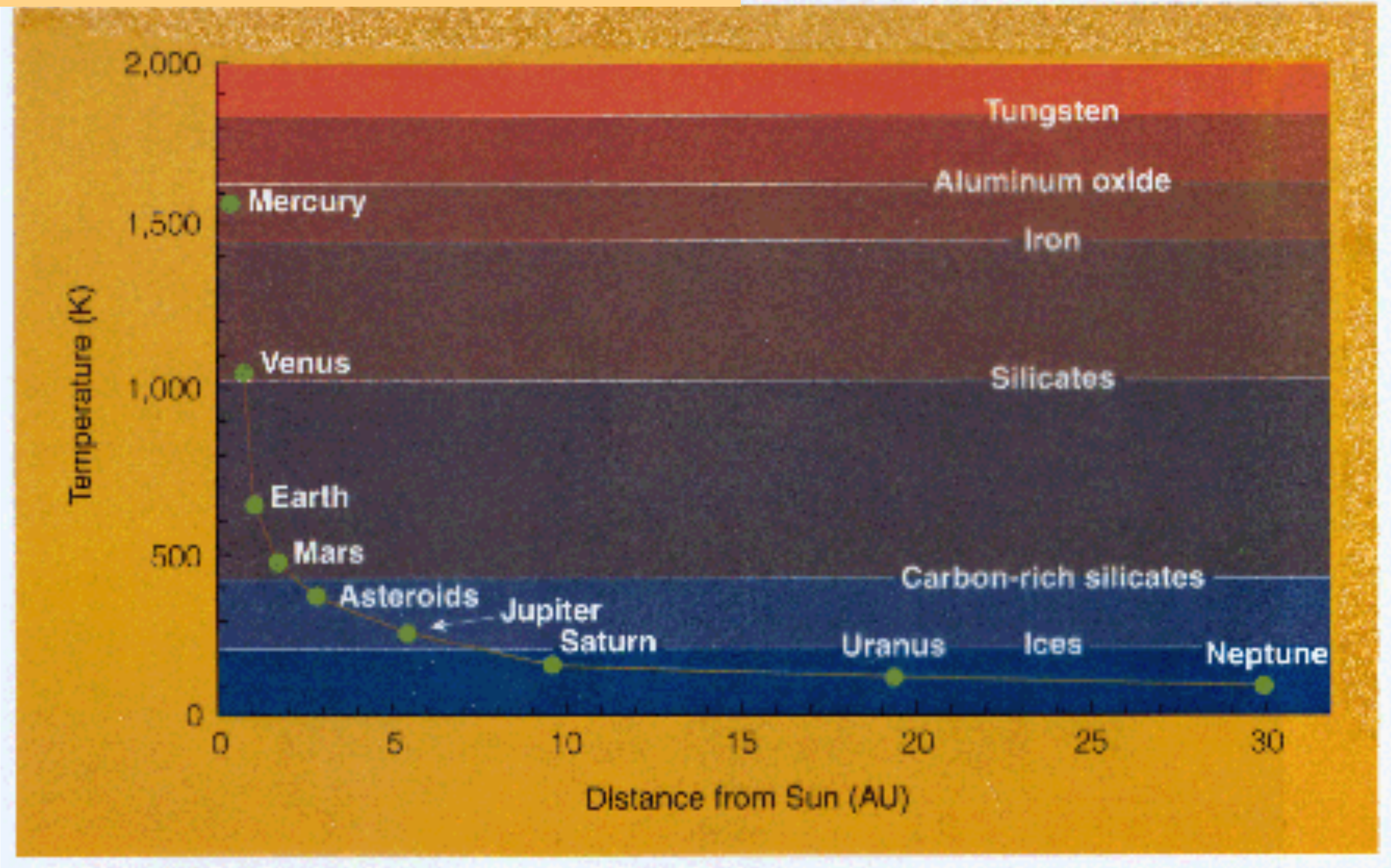
see disks around new stars in Orion nebula

Planet Formation II

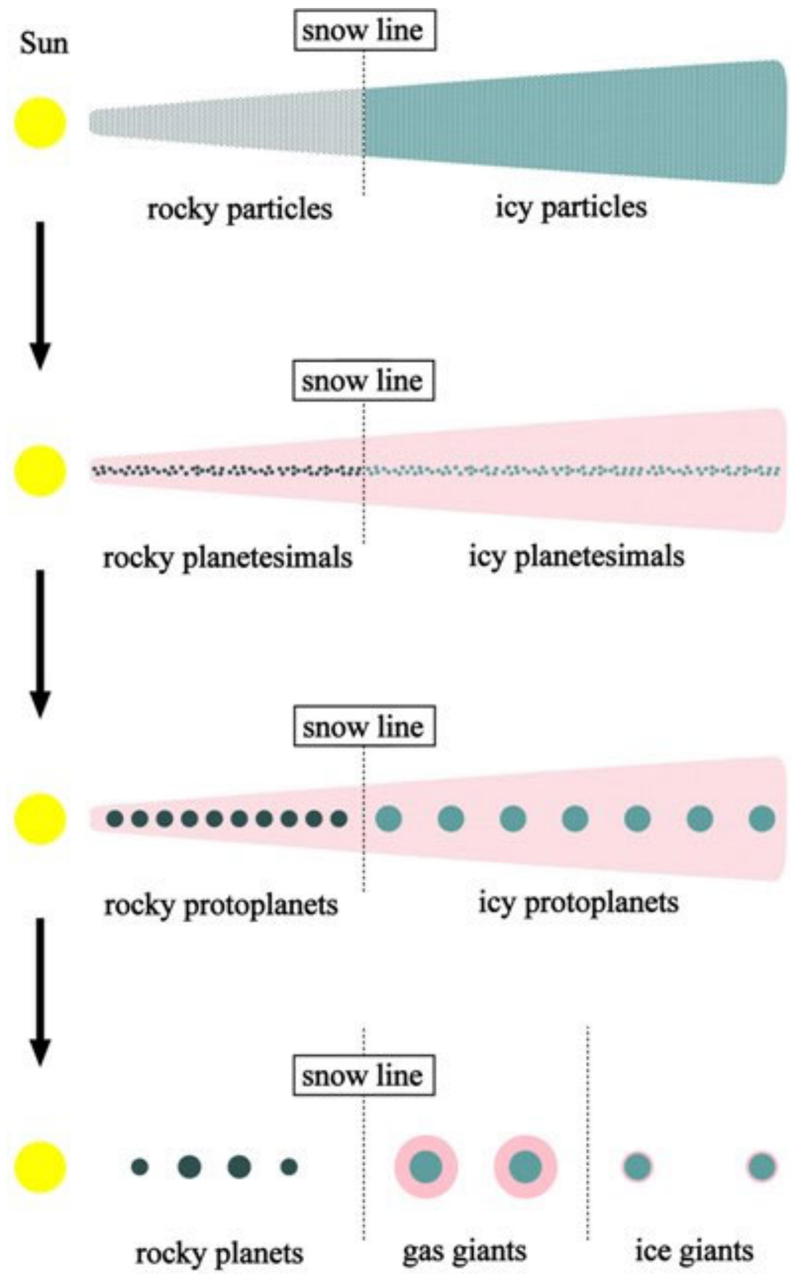
- Material can condensate if cool enough (gas → liquid/solid)
- Heavier elements (metals, silicates) condense first, at higher temperatures, then molecules like water. H and He remain gases
- Density and temperature falls with distance from star. Planet formation occurs when not too far and not too close
- There is a "snow line" which separates the type of planets being formed

Temperature in early Solar Nebula

Condensation of different chemicals



The “snow line” in early Solar Nebula



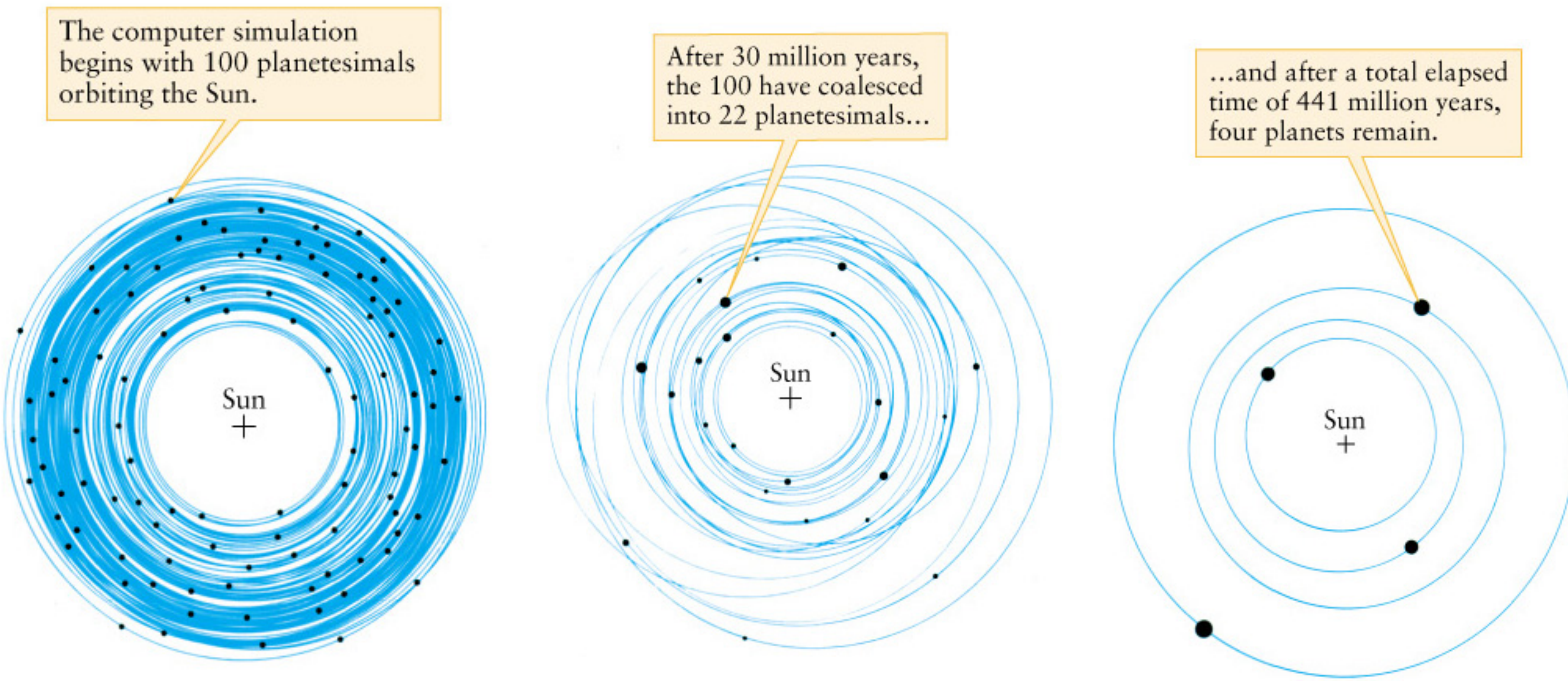
Planet Formation III

- Once condensation starts, protoplanets can grow in size

  -objects collide and stick together

  -gravity pulling together

- Over millions of years most smaller objects swept out as they will end up colliding with larger objects → existing planets
- only ~circular orbits won't collide any further (asteroid belt between Mars and Jupiter)
- Possible motion of planets to and from stars



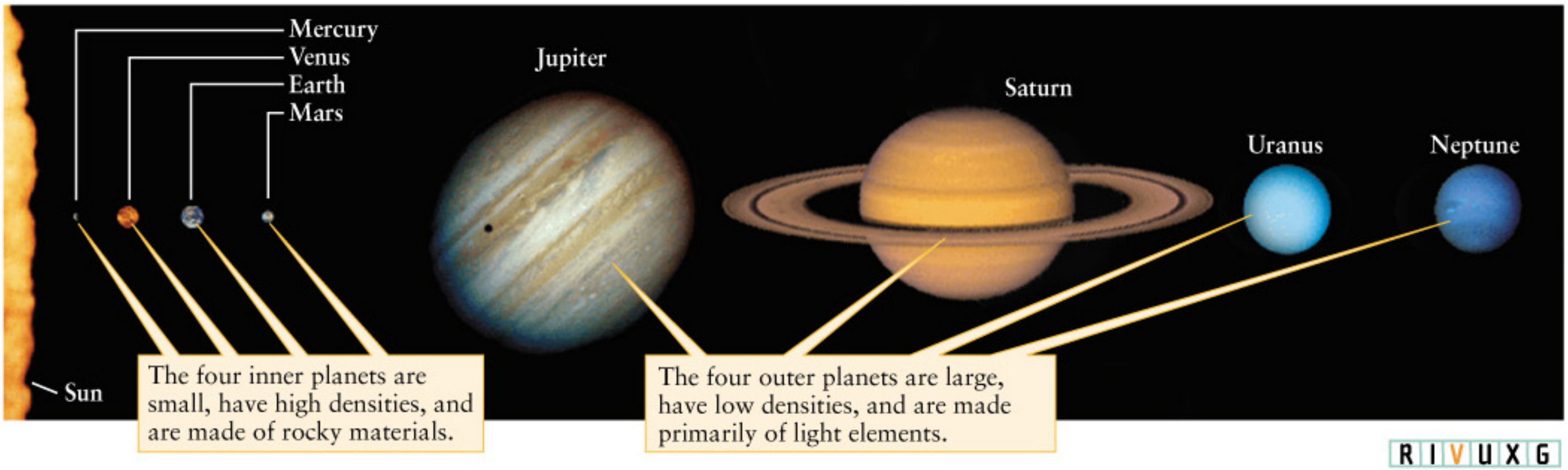
planetisimals (little dust grains) → protoplanets by accretion, collisions and gravity causing smaller objects to stick together

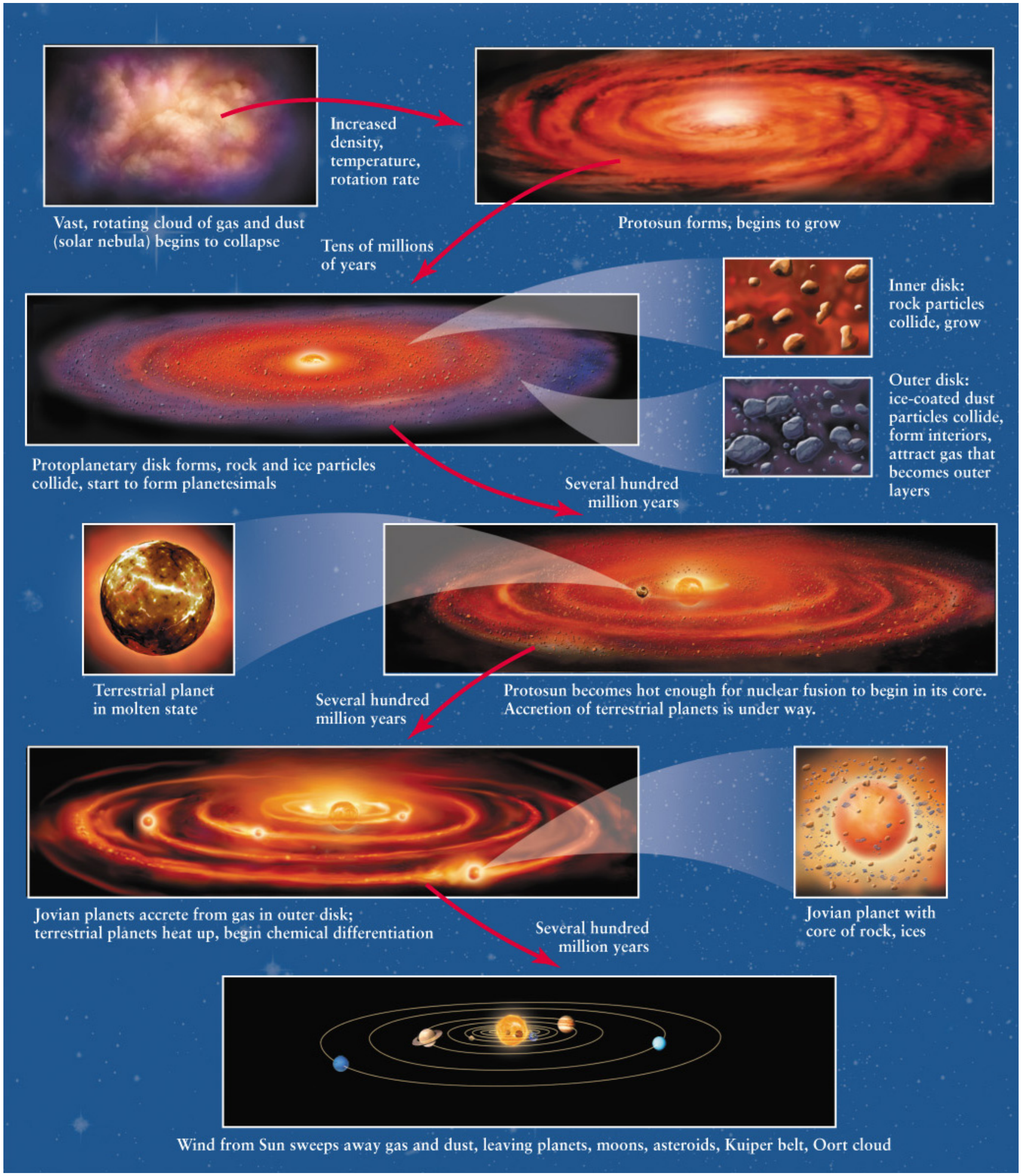
Planet Formation IV

- Close to star (inside snow line) have planets made from heavy elements (iron,nickel,silicon)

  -water may be trapped from the beginning in dust grains or may have come later from comets hitting surface after the planet had cooled ???

- Further away from star are Gas Giants as ices (water H_2O, methane CH_4) froze out early creating larger protoplanets allowing more material to accrete
- Studying comets, meteors, asteroids can give clues as they have composition of early solar system

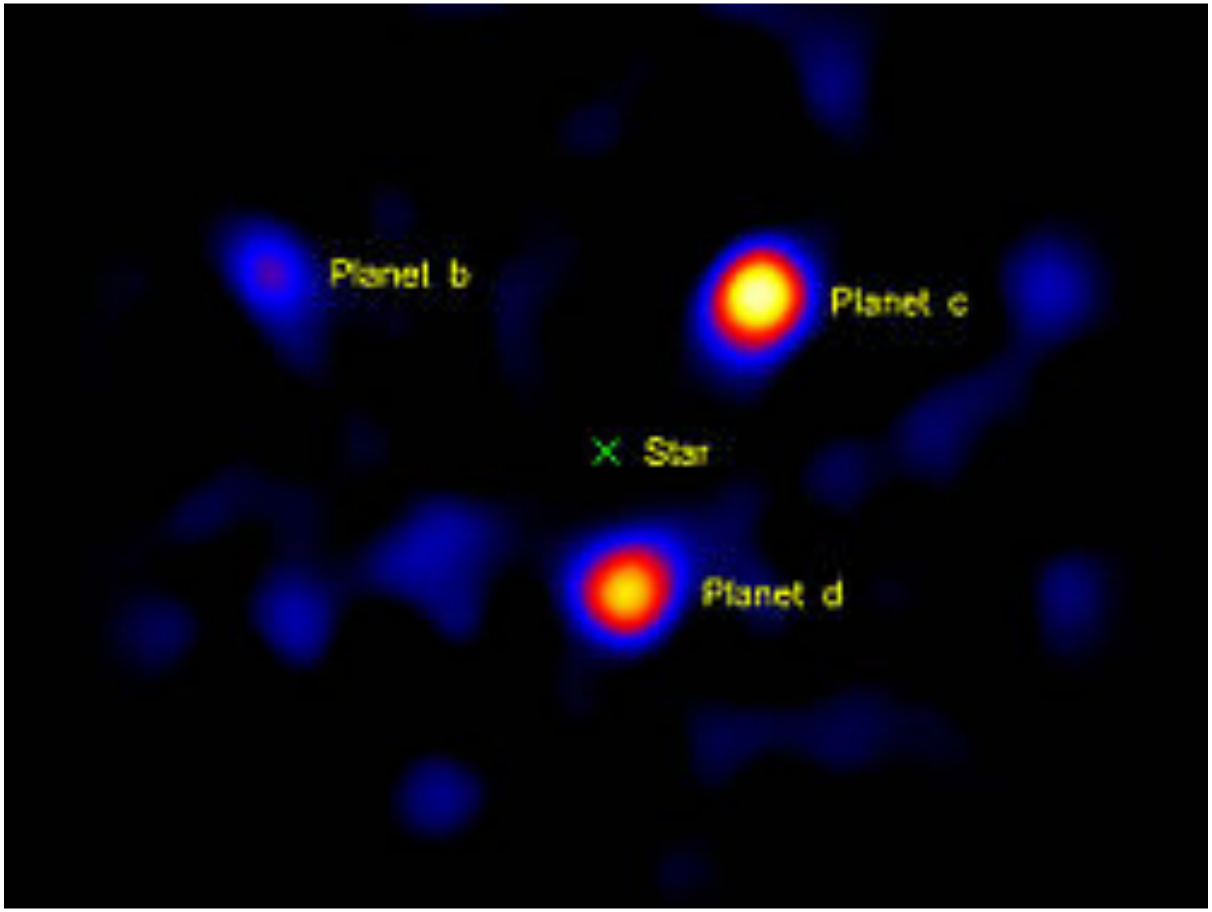

Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptune
Sun
The four inner planets are small, have high densities, and are made of rocky materials.
The four outer planets are large, have low densities, and are made primarily of light elements.
R I V U X G


Increased
density,
temperature,
rotation rate
Vast, rotating cloud of gas and dust
(solar nebula) begins to collapse
Protosun forms, begins to grow
Tens of millions
of years
Inner disk:
rock particles
collide, grow
Outer disk:
ice-coated dust
particles collide,
form interiors,
attract gas that
becomes outer
layers
Protoplanetary disk forms, rock and ice particles
collide, start to form planetesimals
Several hundred
million years
Terrestrial planet
in molten state
Several hundred
million years
Protosun becomes hot enough for nuclear fusion to begin in its core.
Accretion of terrestrial planets is under way.
Jovian planets accrete from gas in outer disk;
terrestrial planets heat up, begin chemical differentiation
Several hundred
million years
Jovian planet with
core of rock, ices
Wind from Sun sweeps away gas and dust, leaving planets, moons, asteroids, Kuiper belt, Oort cloud

Planets in other Star Systems

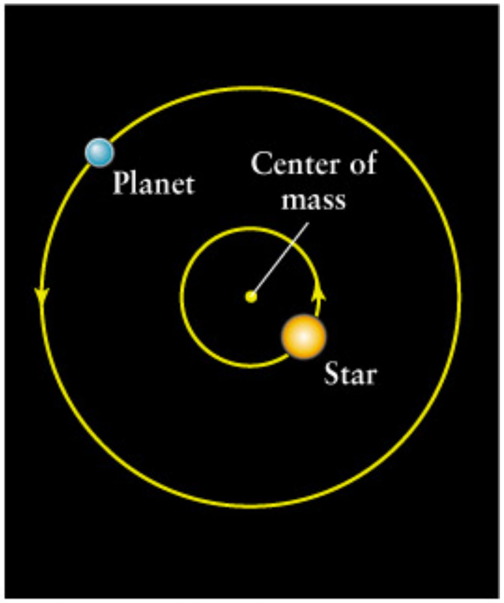
- Test out how planets are formed with more examples
- First extrasolar planet observed in 1995. In Jan 2000, 28 observed and now > 3500 (1/9/2012). Many systems with 2 or more observed planets
- Difficult to observe directly (gravitational lensing helps)
- Now mostly look for impact on Star: wobbles due to gravity of planets or reduction of light due to “eclipse”
- Planet orbits obey Kepler’s laws. If multiple planets, will have to add effects of planets (our solar system, have Jupiter with 12 year orbit, Earth with 1 year, etc)

Observe Directly

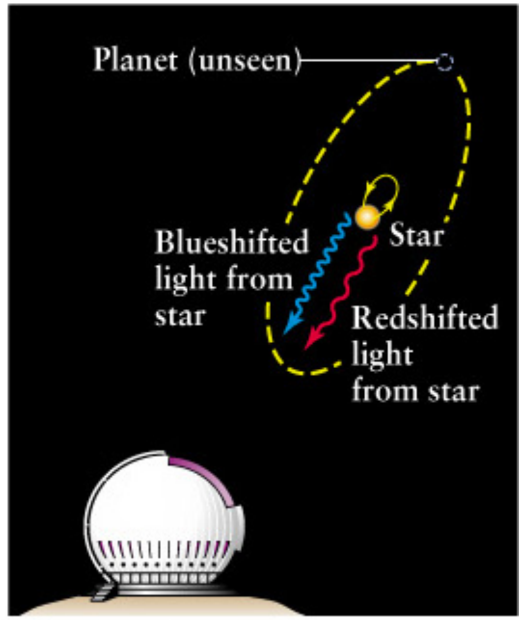


block out star
in telescope
optics

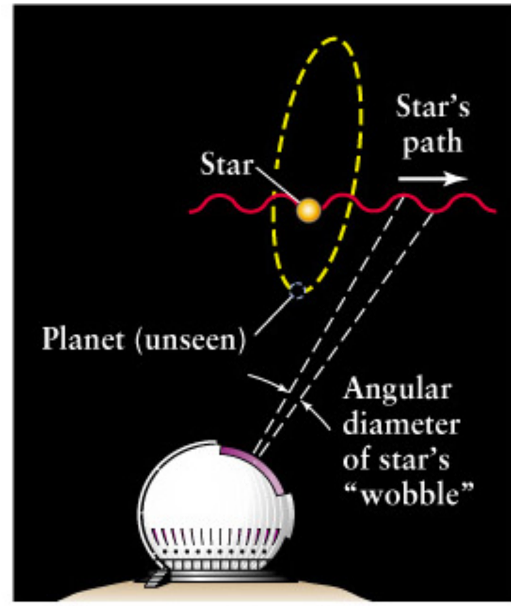
Observe by Star’s Wobble: Doppler Shift or Proper Motion



a. A star and its planet



b. The radial velocity method



c. The astrometric method

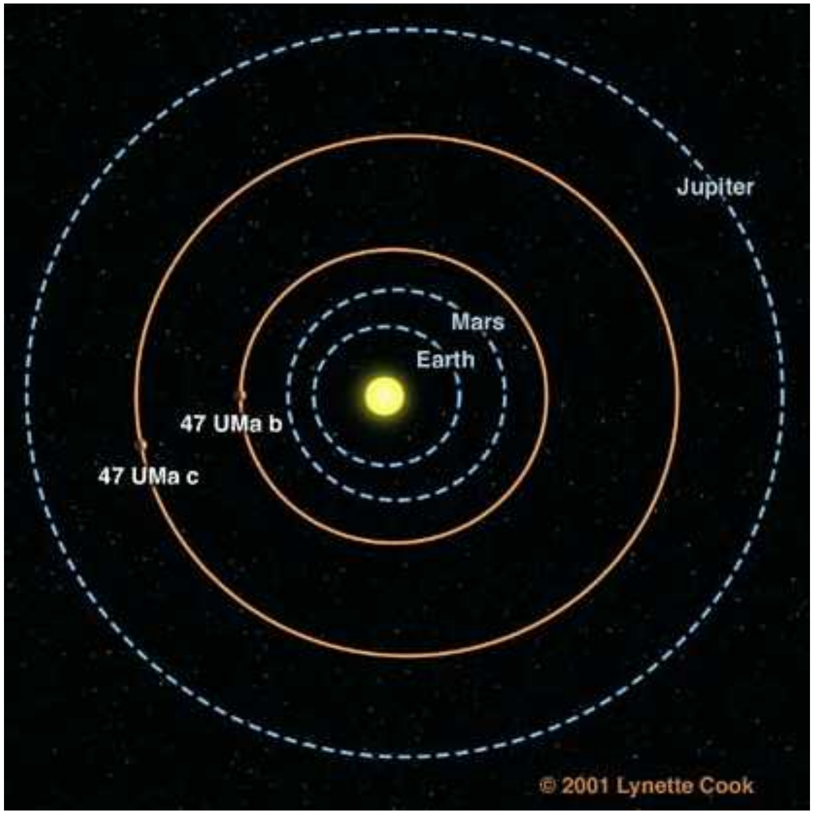
The larger the planet the larger the gravitational pull

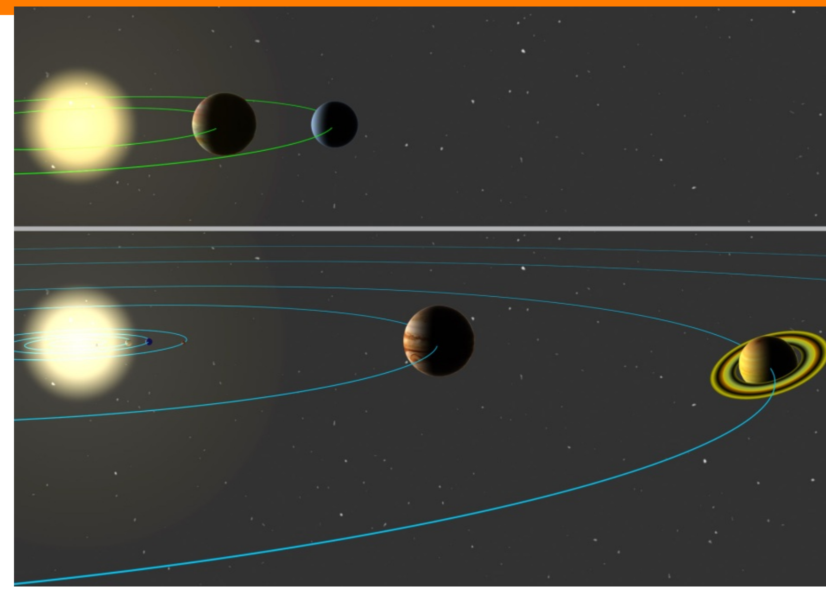
The smaller the orbit the larger the gravitational pull

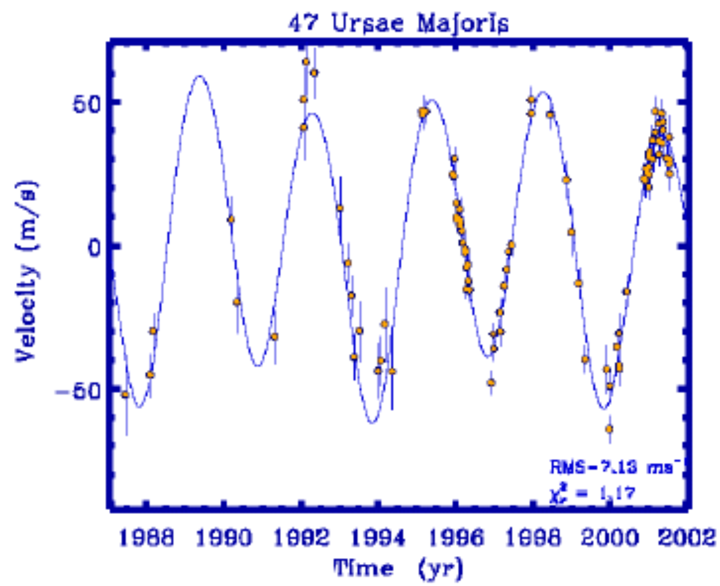
The smaller the orbit the more rapid is the wobble

→ easiest to see large planets which are close to their stars

47 Ursae Majoris (one of first discovered)

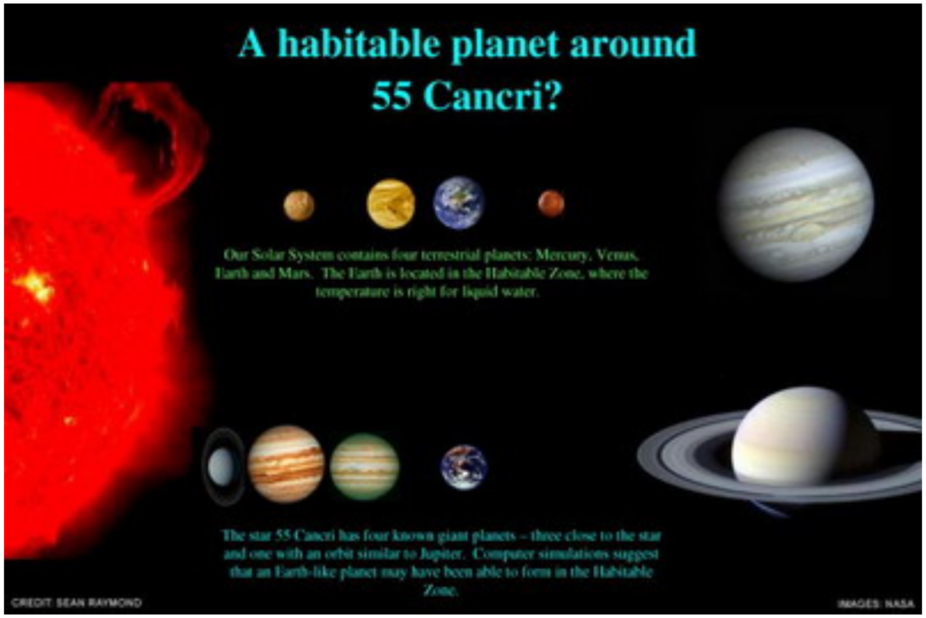


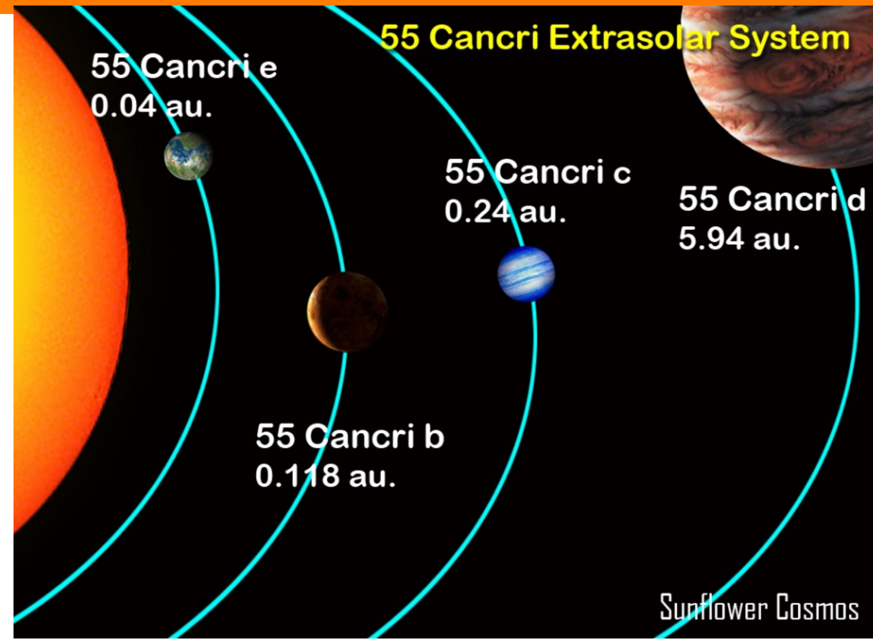




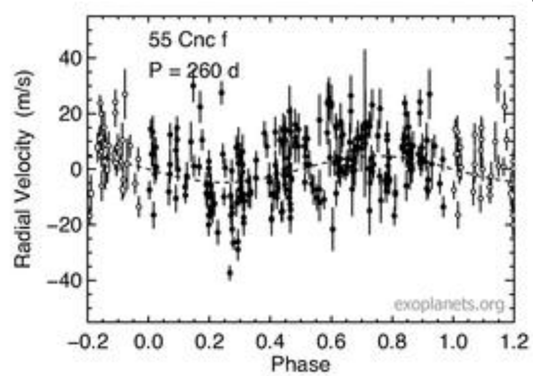
Doppler shift shows at least 2 very large planets

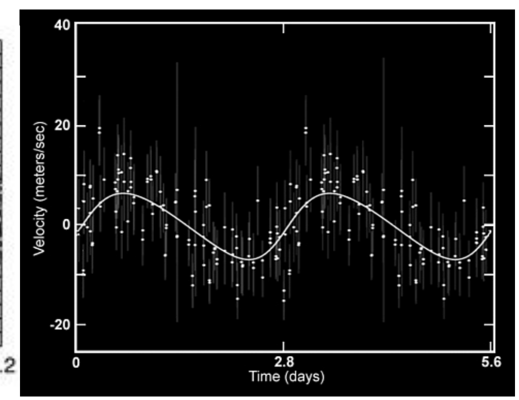
55 Cancri (one of first discovered)



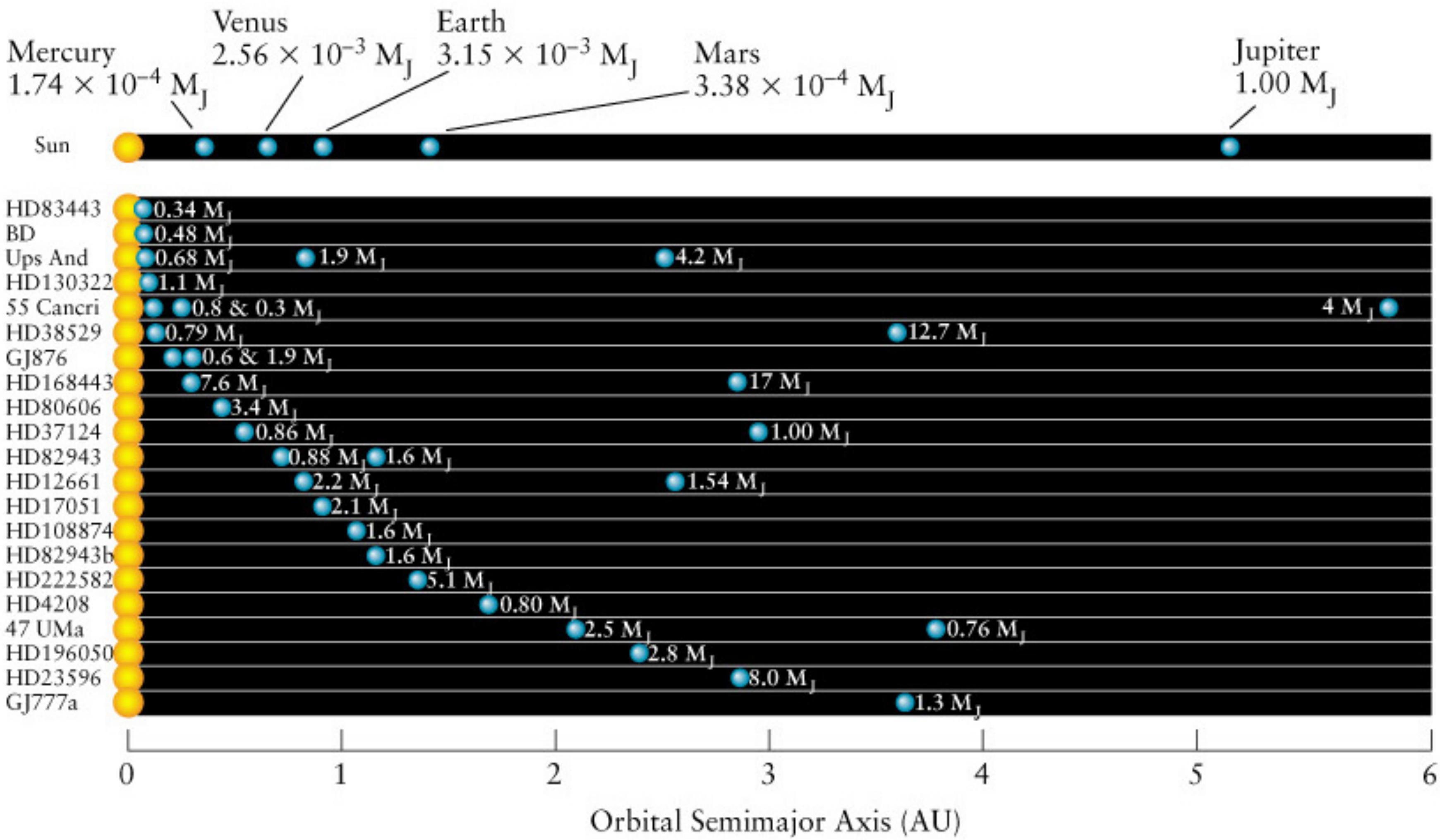


Doppler shift very complicated. One close large planet plus 3-4 more?

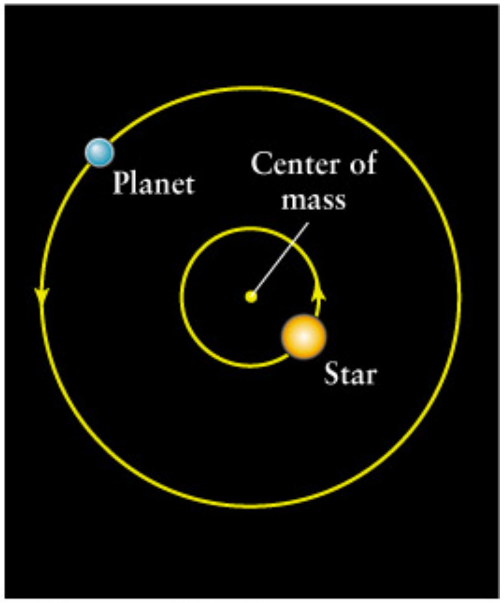




Summary: some of the discovered exoplanets found by Doppler shift -- easiest to find big planets close to a star



Observe by planet eclipsing star



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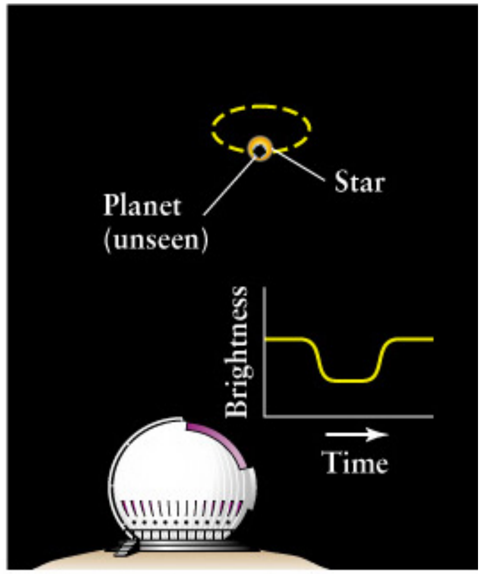
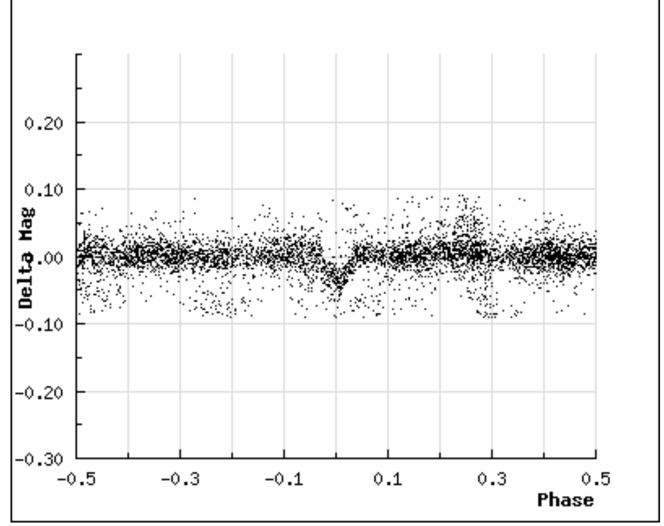


d. The transient method

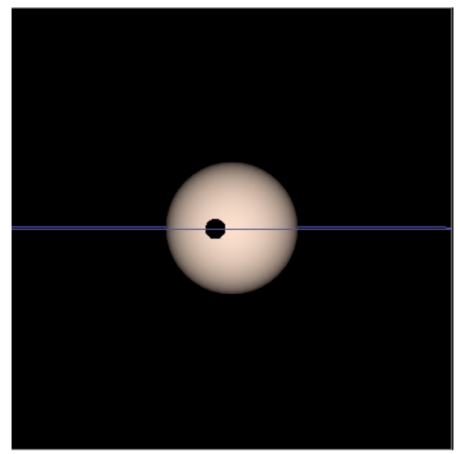
WASP-4 Wide Angle Search for Planets



Jupiter would reduce Sun's light by 1%; Earth reduces by .01%

"easy" (done by 7th grader at NIU Science Fair)

once spotted can also analyze Doppler shift and try and observe atmosphere

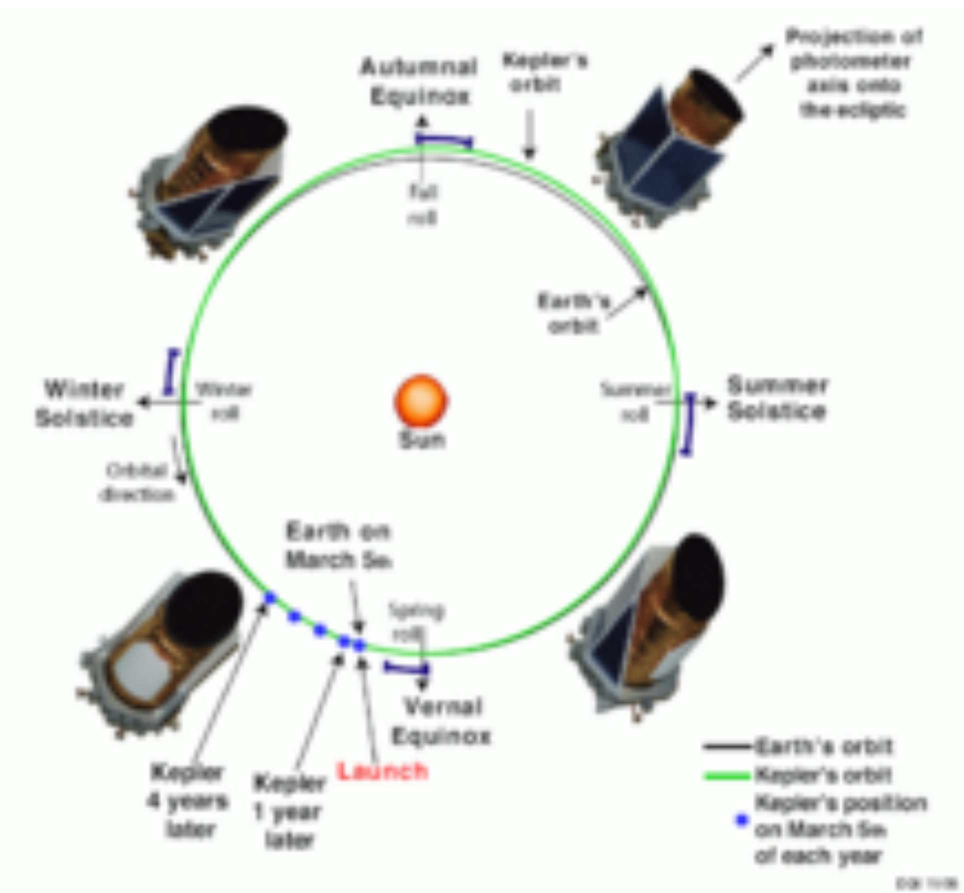


Kepler telescope

- Launched in 2009, designed to detect Earth-sized (or smaller) planets by observing them eclipsing their stars
- In orbit around the Sun….away from the Earth and also points away from the Sun
- Looks at light from about 150,000 main sequence stars and measures their luminosity to about 20 parts per million (0.000002)
- Has discovered over 2000 possible planets (Dec 2011)

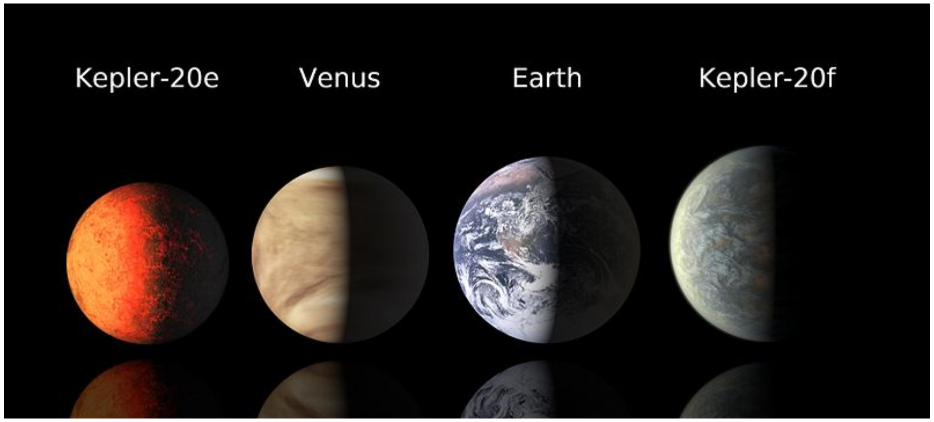
Kepler telescope

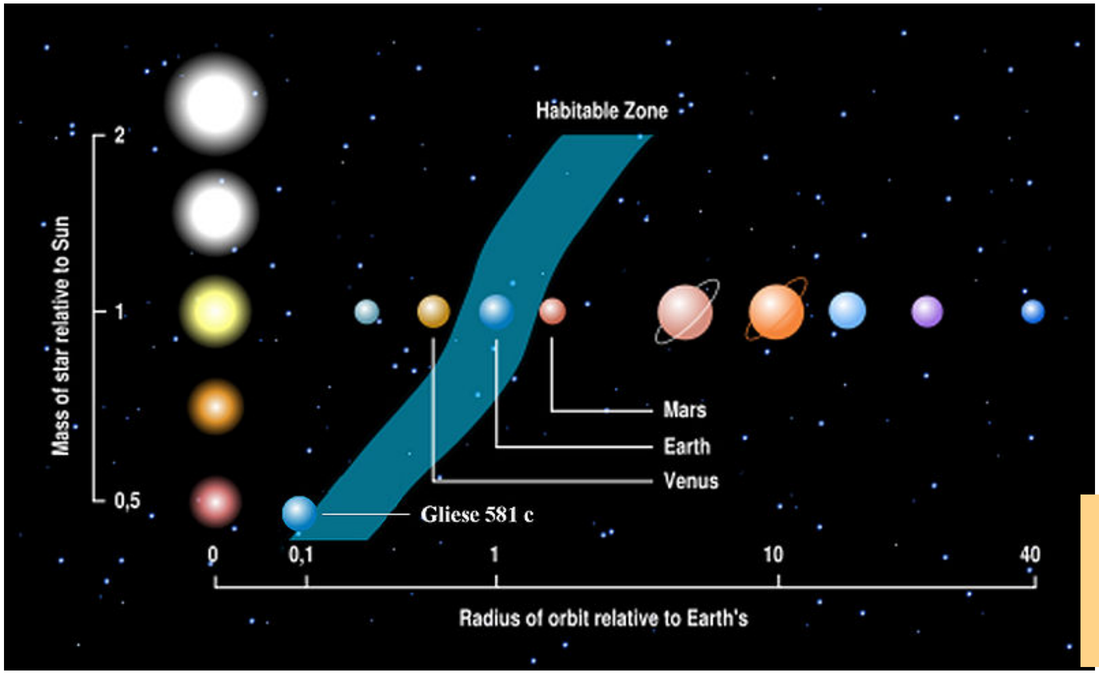
- orbit



field of view (Cygnus + Lyra)

Kepler Results: many Earth-like planets some possibly in habitable zones



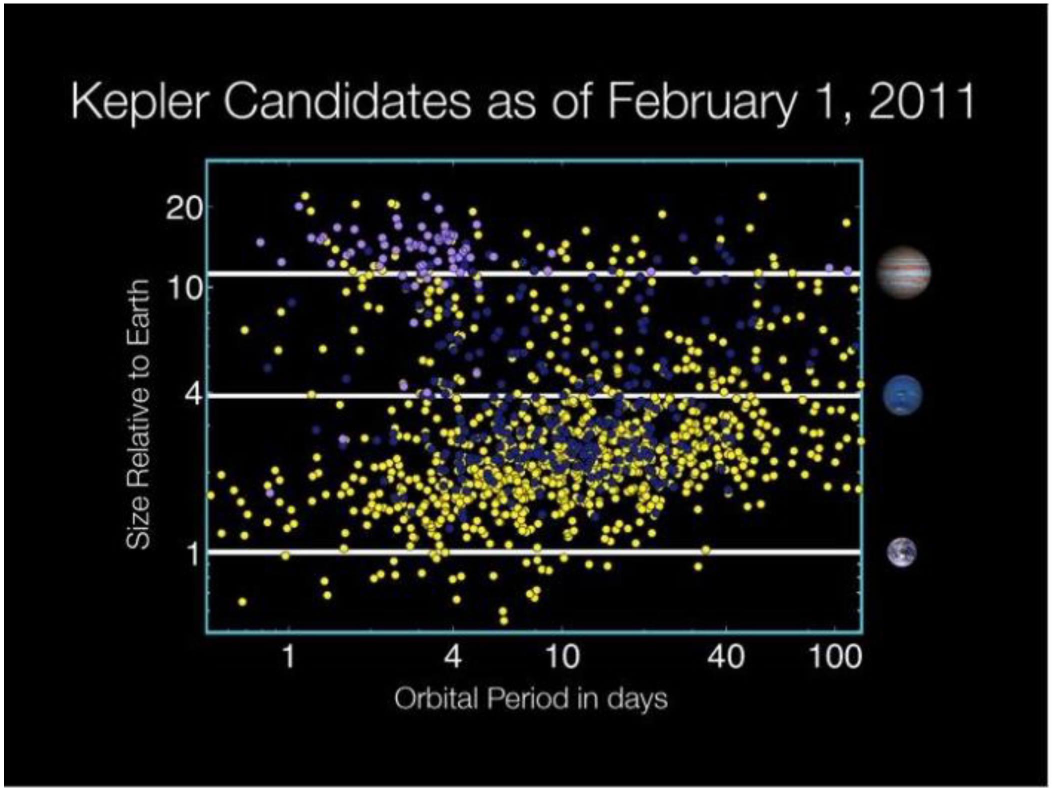


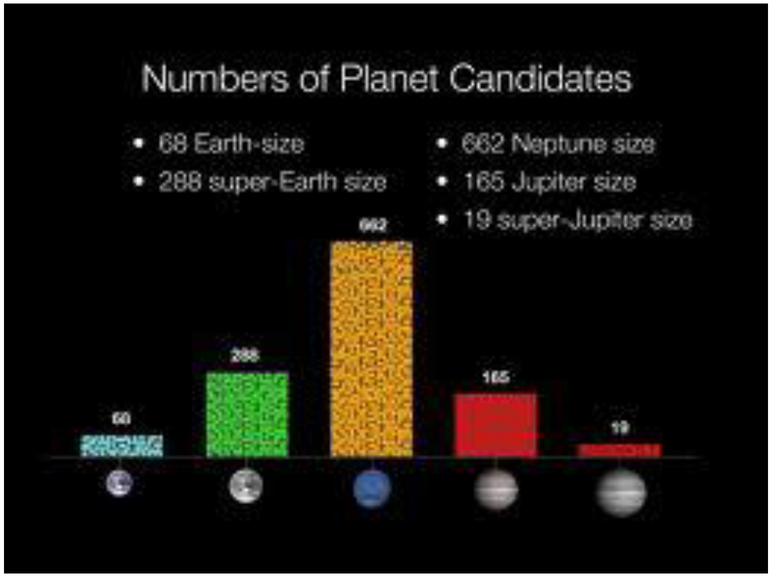
Kepler 35 – binary star

Planet orbiting 4-star (2 close binaries)

Kepler Telescope

- Will collect data from 2009-2013(2014). Runs out of fuel. Not sensitive to long periods like Jupiter's 12 years
- Sees a lot of planets between Earth and Neptune size





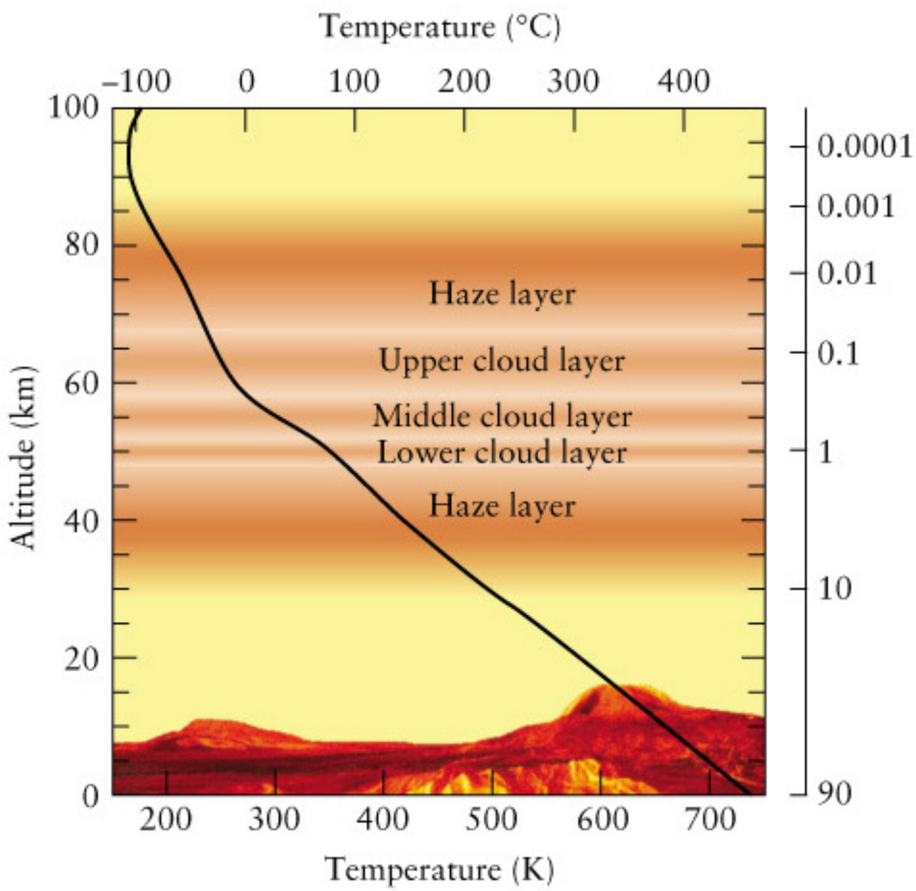
Planetary Atmospheres

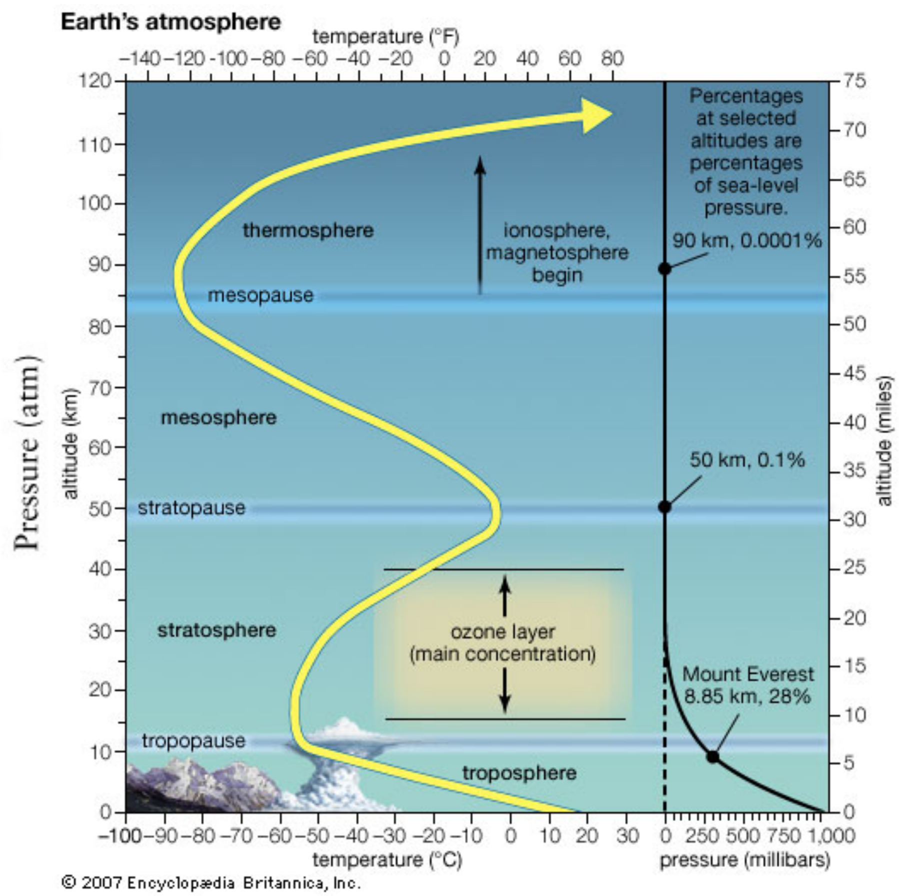
- Composition of a planet's atmosphere depends on
  - Surface Gravity
  - Temperature
- Light atoms/molecules move faster than heavy molecules
- If velocity = escape velocity gas leaves planet
- Mercury, Moon: all escape
- Earth: lightest (H,He) escape
- Jupiter: none escape

Familiar Molecules

molecule	mass
H_2 hydrogen	2
He helium	4
CH4 methane	16
NH3 ammonia	17
H20 water	18
N2 nitrogen	28
O2 oxygen	32
CO carbon monoxide	28
CO2 carbon dioxide	44

Atmosphere of Venus vs Earth



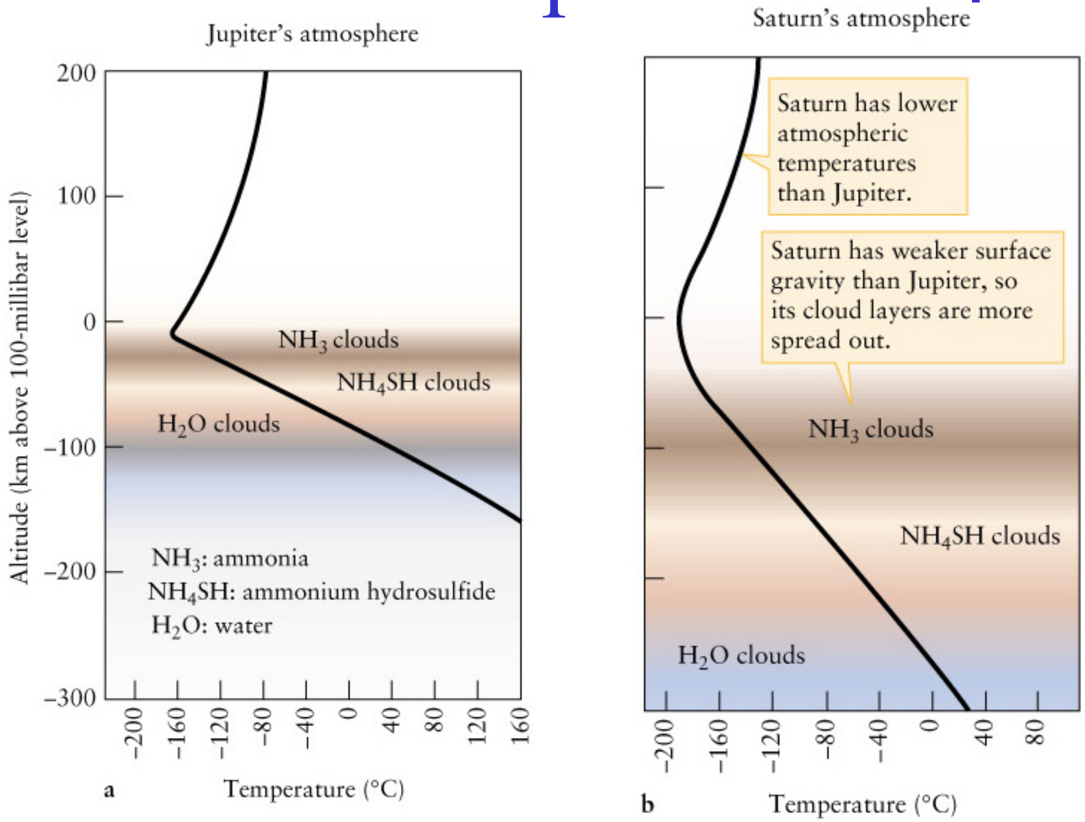


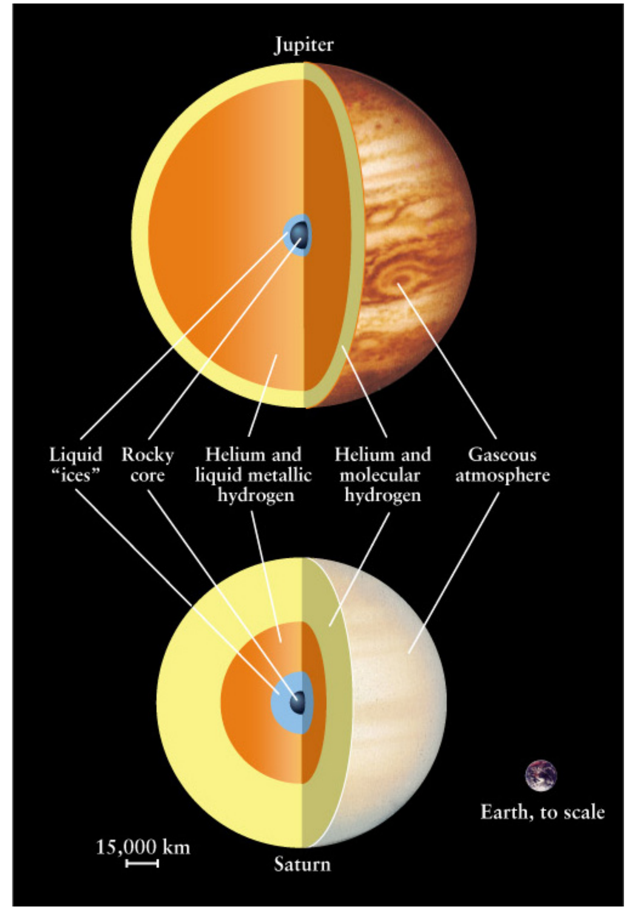
96.5% CO_2, 3% N_2

runaway greenhouse effect

78% N_2, 21% O_2, 0.04% CO_2, ~1% H20. most CO_2 absorbed by oceans

Atmosphere of Jupiter and Saturn





ammonia, sulfuric acid, water

interiors are helium and hydrogen, core of ice/rock

Titan, moon of Saturn, has ~90% nitrogen rest mostly methane and argon; pressure similar to Earth