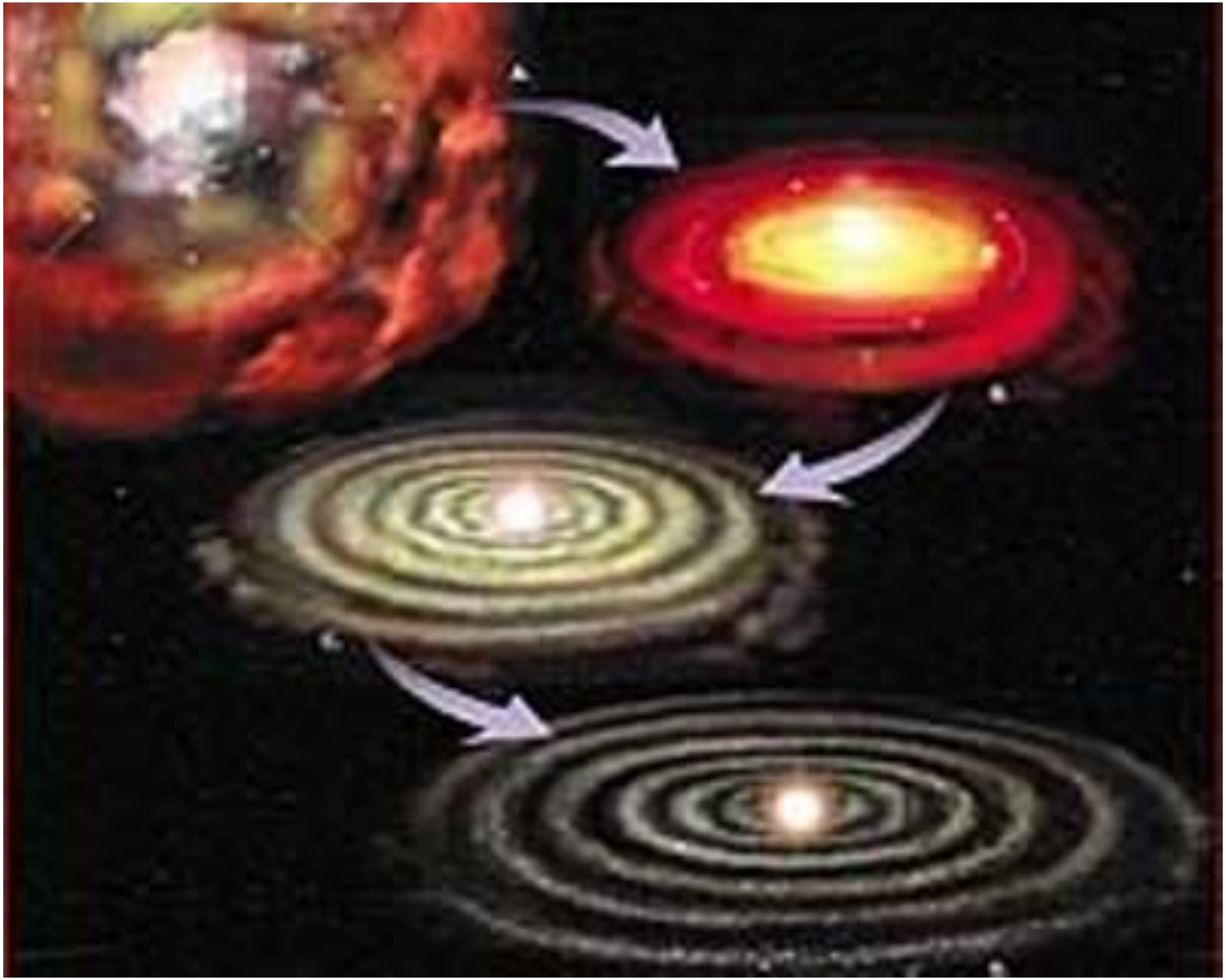
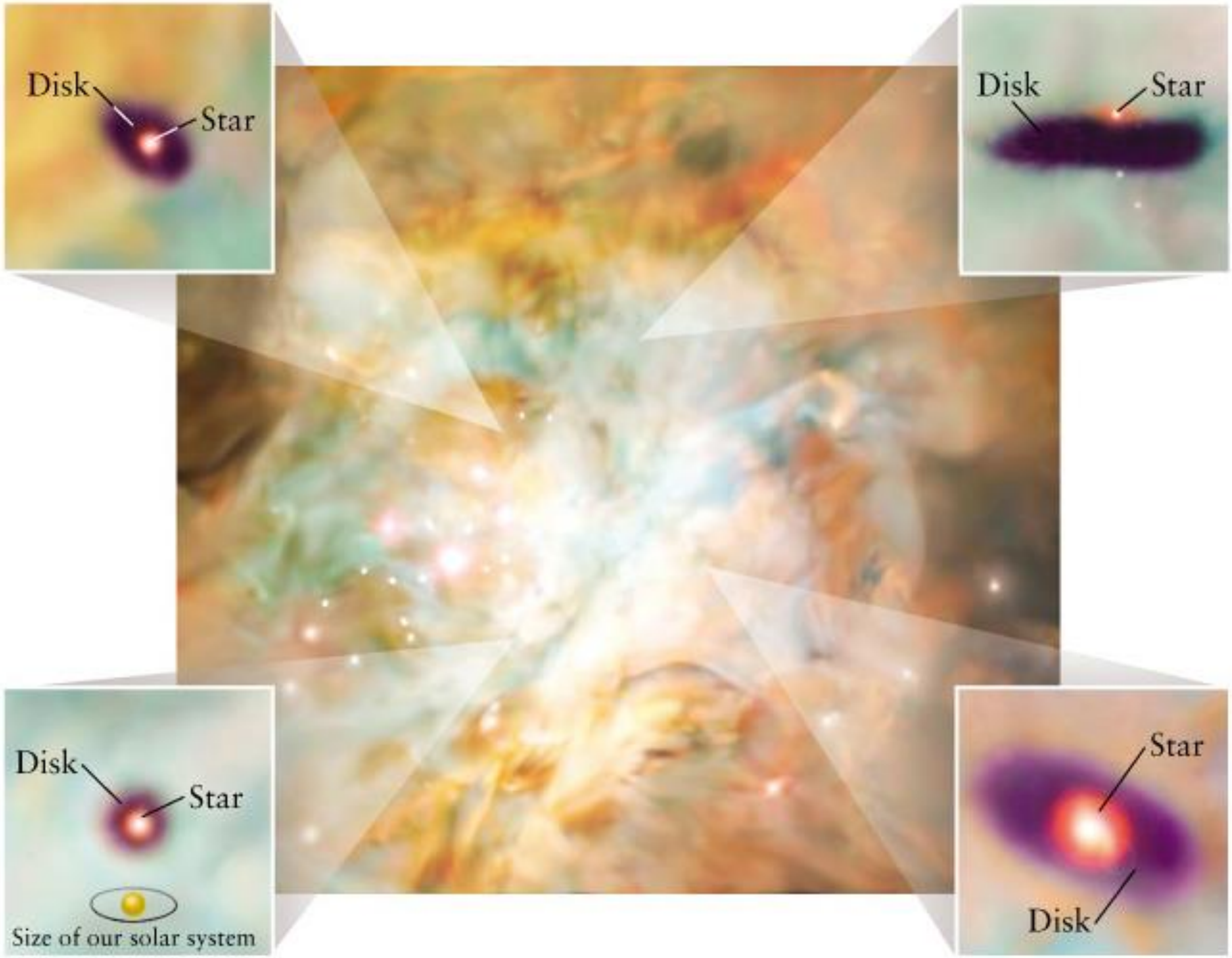
Star Formation → Planet Formation

- contracting cloud → forms stars AND planets
- → swirling disk of material around forming star (H, He, C, O, heavier elements, molecules, "dust") → form planets
- New born star heats up material, blows away solar nebula → planets (or least protoplanets = size of asteroids) need to form before material dissipates
- We will do a simple model of planet formation around a single star (not binary system) and then go over state of exoplanet discoveries



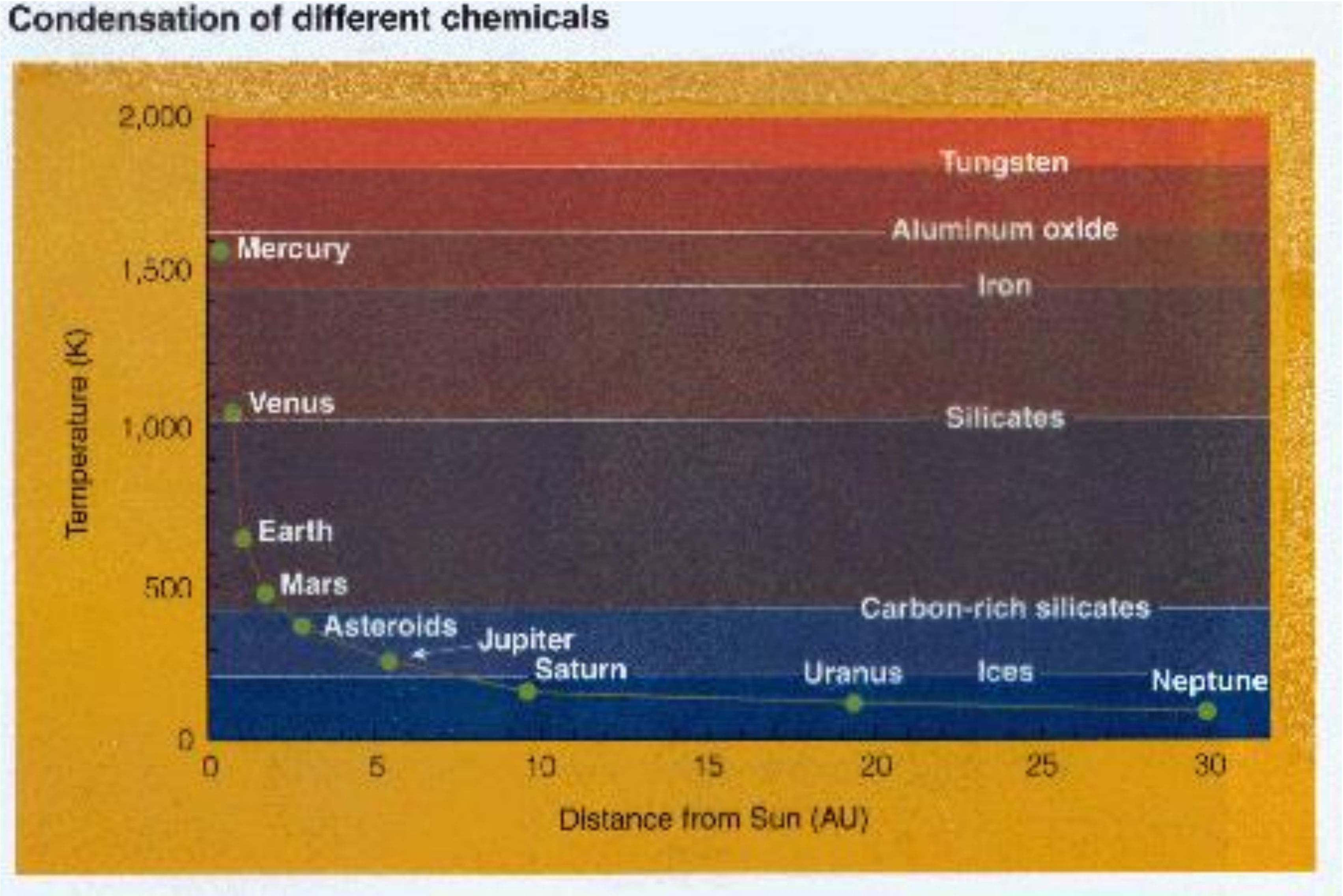


see disks of material around new stars in Orion nebula where planets are probably being formed

Planet Formation II

- material condensates if cool enough (gas→liquid/solid)
- heavier elements (metals, silicates=silicon+oxygen+carbon) condense first, at higher temperatures, then at lower temperatures molecules like water and methane. H and He remain gases
- Reminder from previous lecture, after H and He, the most common elements in our universe are carbon and oxygen
- density and temperature falls with distance from star. Planet formation occurs when not too far and not too close from newborn star
- "snow line" → separates type of planets being formed

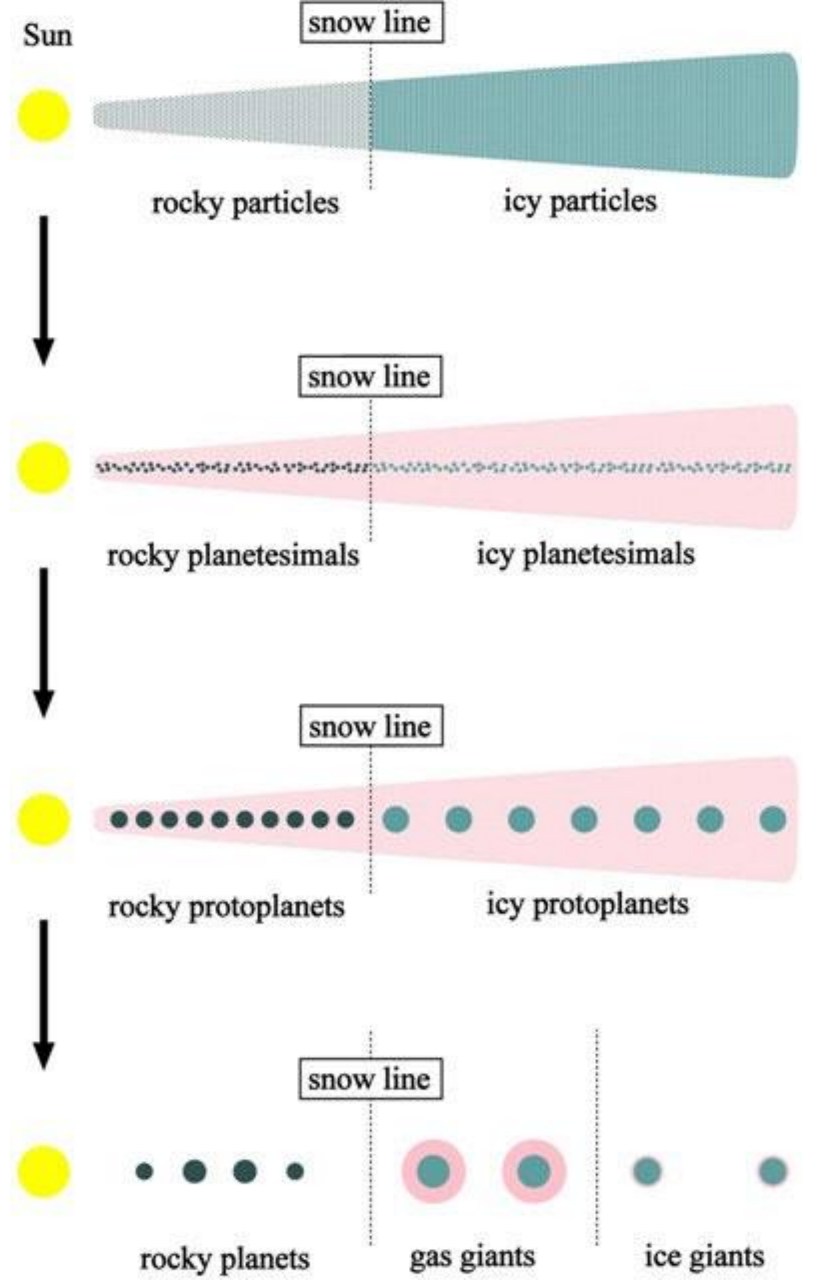
Temperature in early Solar Nebula



“snow line” in early Solar Nebula

Very, very simplistic. Rocky planets form closer to the Sun where temperature is higher.

Further away cold enough for ice to form. There is more water and methane (H_2O and CH_4) in nebula than silicon oxides and so much more ice giving larger planets further away

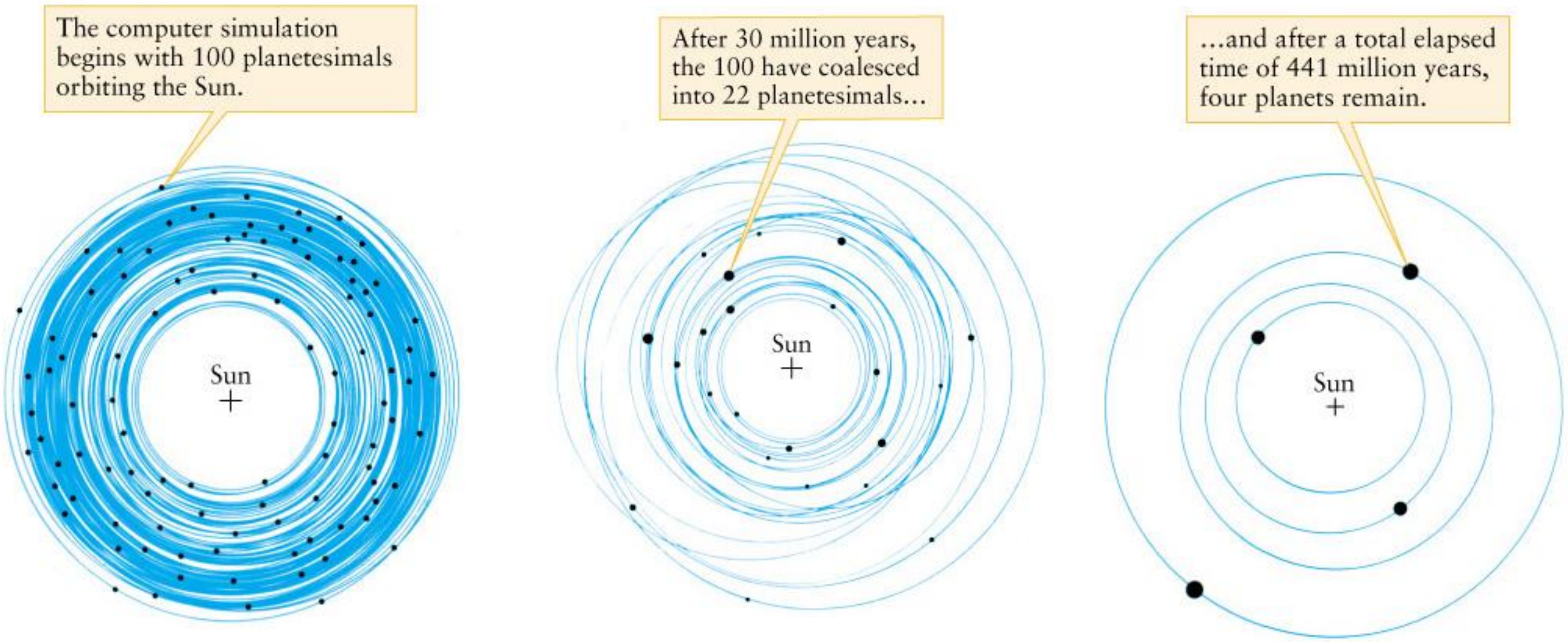


Planet Formation III

- condensation starts, protoplanets grow in size

  -objects collide; stick together. See "fossils" of these collisions as craters on the Moon

- over millions of years sweep out most smaller objects as collide with larger objects → existing planets
- only ~circular orbits won't collide any further (asteroid belt between Mars and Jupiter)
- Possible motion of planets to/from star → may be critical. We will skip

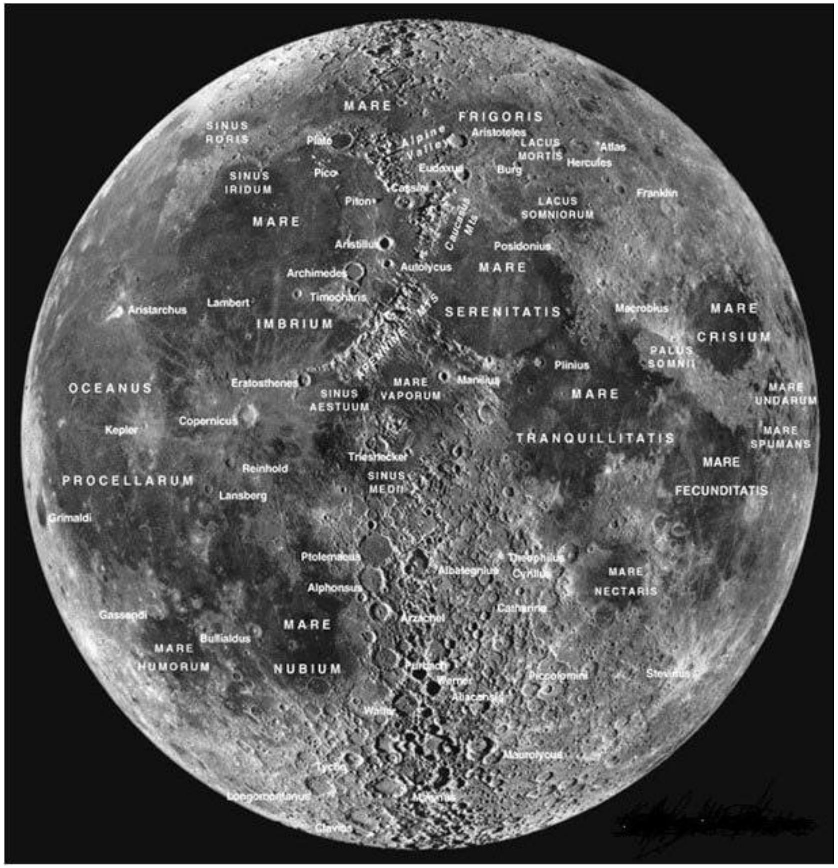


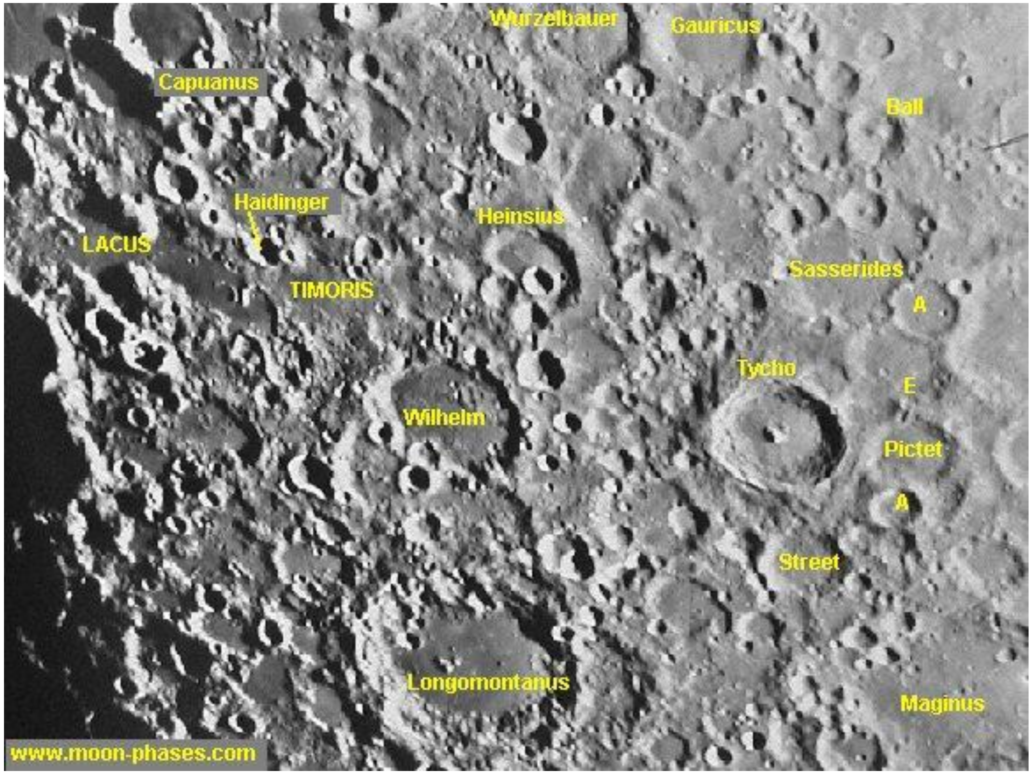
planetisimals (dust grains) → protoplanets by accretion, collisions, gravity → smaller objects stick together. Took 400 million years or so to clear out most smaller objects and form planets as we know them

Planet Formation IV

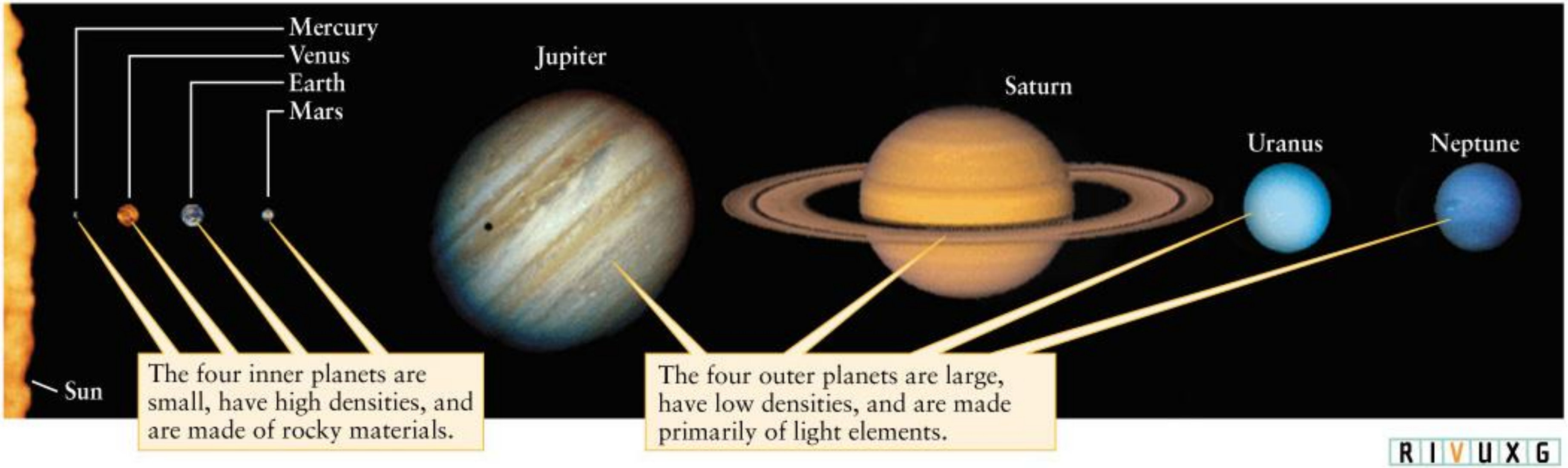
- close to star: planets = heavy elements (iron,silicon)

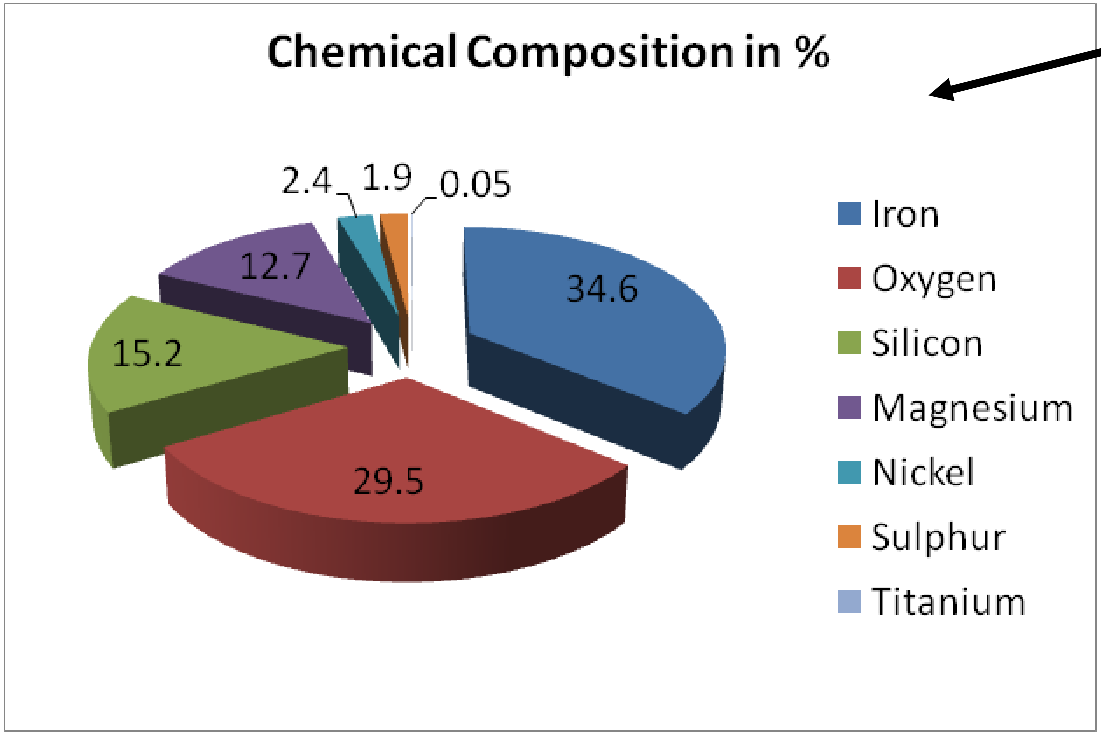
  -water may be trapped at beginning in dust grains and rocks or come later from comets hitting surface or both???
- further from star: Gas Giants ices (water H_2O, methane CH_4) froze out early → larger protoplanets → more material to accrete
- studying comets, meteors, asteroids can give clues as they have composition of early solar system





Craters on Moon (and some of the moons on other planets) are fossil remnants of collisions in solar system at earlier times though not going back to very beginning





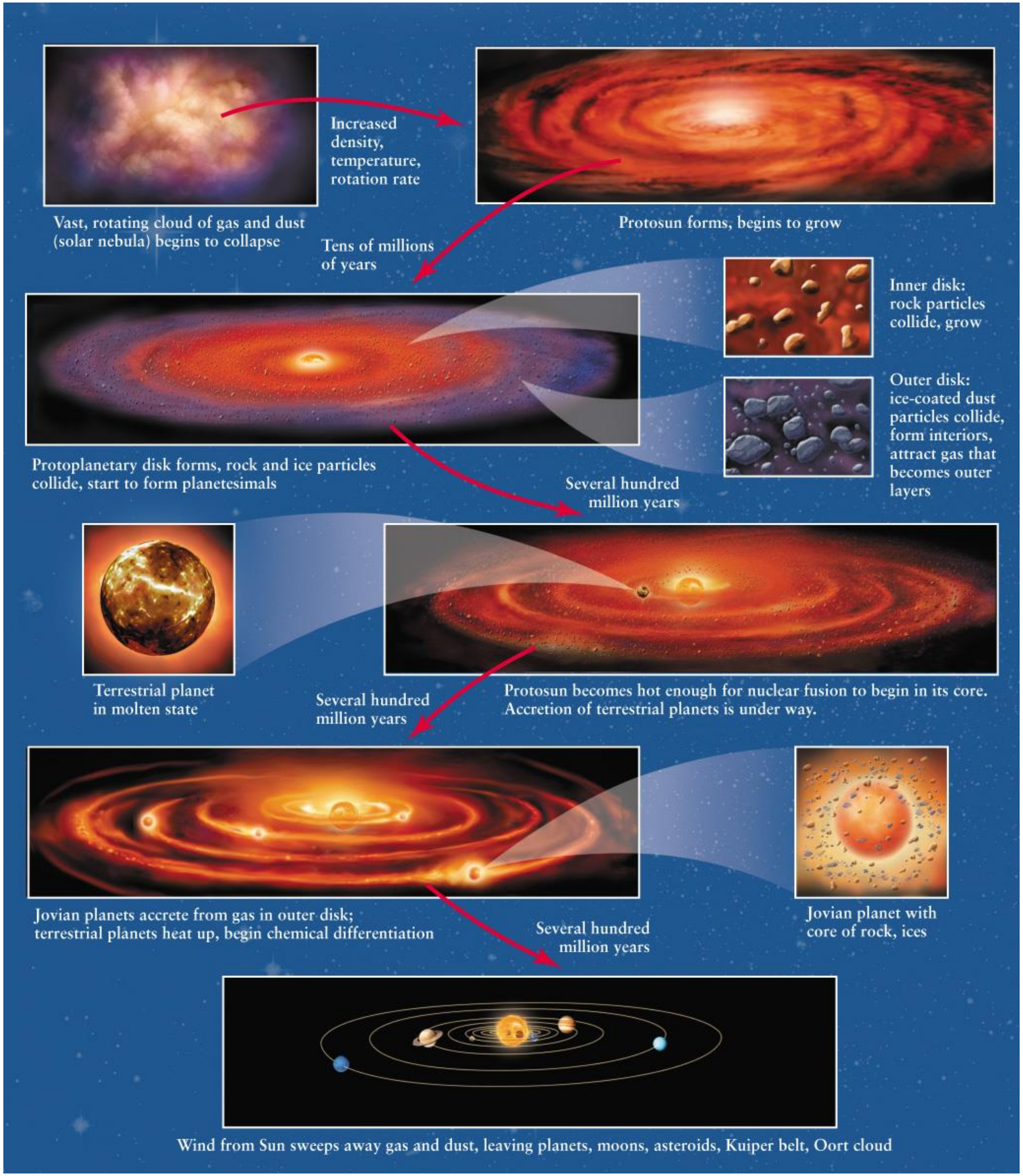
Earth's composition. Mercury has more metals (70%) and less silicates (30%)

SILICATES=Rocks:

	Planet	Mass (kg)	Radius (km)	Density (g/cm^3)	Rotation Period (days)
1.	Sun	1.991×10^{30}	695,950	1.410	24.66
2.	Mercury	3.181×10^{23}	2,433	5.431	58.82
3.	Venus	4.883×10^{24}	6,053	5.256	244.59
4.	Earth	5.979×10^{24}	6,371	5.519	1.00
5.	Moon	7.354×10^{22}	1,738	3.342	27.40
6.	Mars	6.418×10^{23}	3,380	3.907	1.03
7.	Jupiter	1.901×10^{27}	69,758	1.337	0.41
8.	Saturn	5.684×10^{26}	58,219	0.688	0.43
9	Uranus	8.682×10^{25}	23,470	1.603	0.45
10.	Neptune	1.027×10^{26}	22,716	2.272	0.66
11.	Pluto	1.08×10^{24}	5,700	1.65	6.41

“rocky” planets have higher densities. Sun and Jupiter have similar compositions (H+He) and densities due to very high pressure. Neptune and Uranus are more water

Extra Slide
Good poster



Planetary Atmospheres

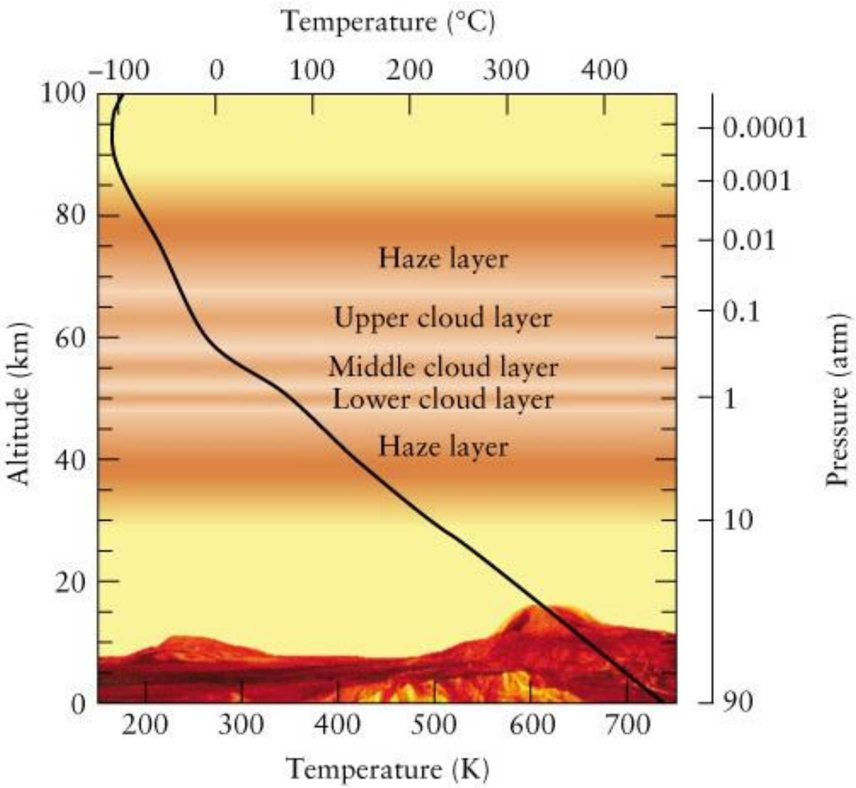
- composition of a planet's atmosphere depends on
  - Surface Gravity
  - Temperature
- light atoms/molecules move faster than heavy molecules
- if velocity greater than escape velocity gas leaves planet
- Mercury, Moon: all gases escape
- Earth: lightest gases (H,He) escape. Why Helium is rare on Earth
- Jupiter: none escape

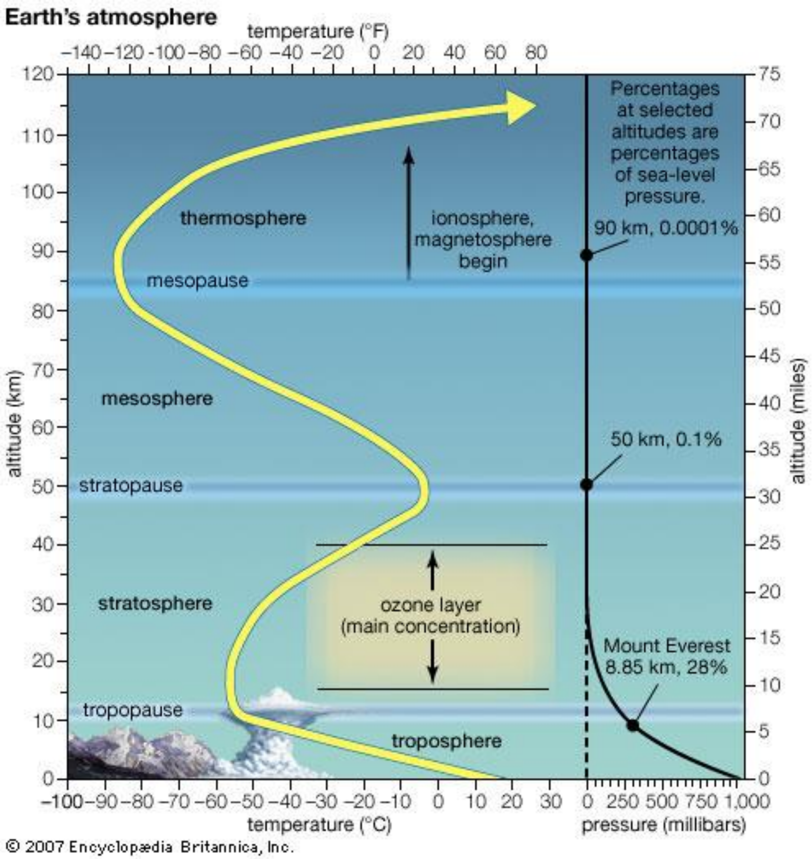
Atmosphere necessary for life-as-we-know-it. Provides steady "warm" temperature, protects from solar radiation

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 – similar size

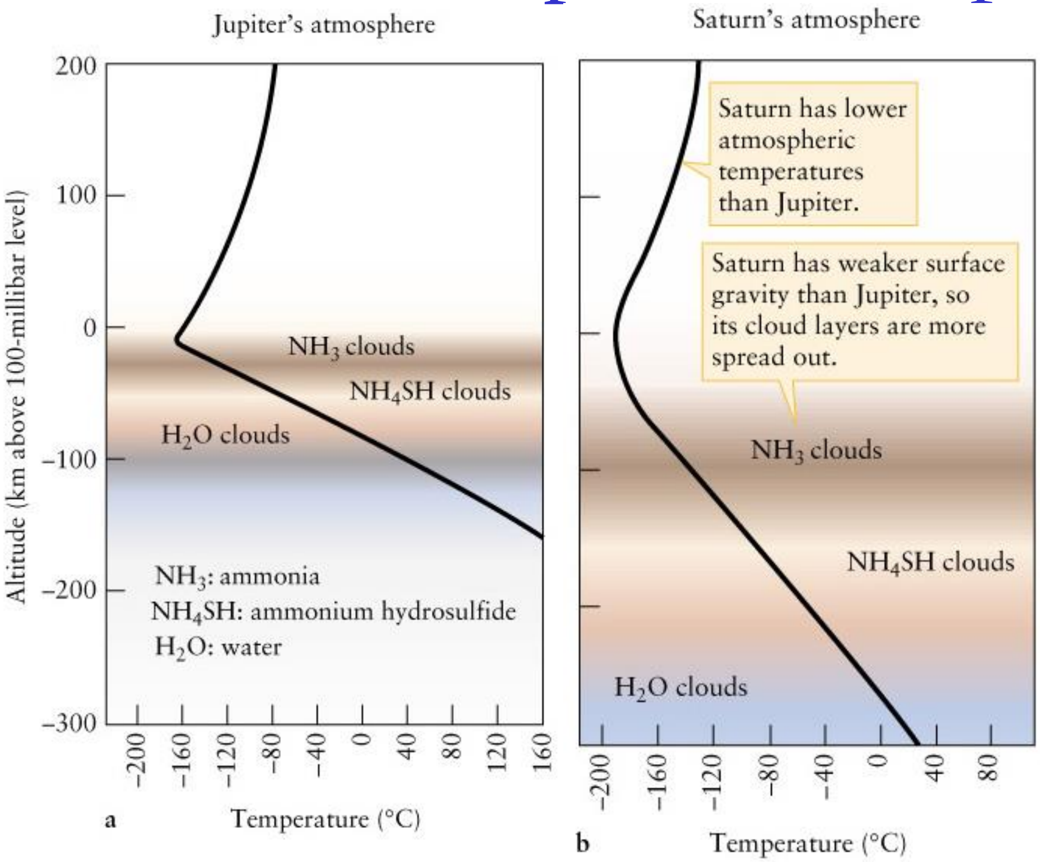


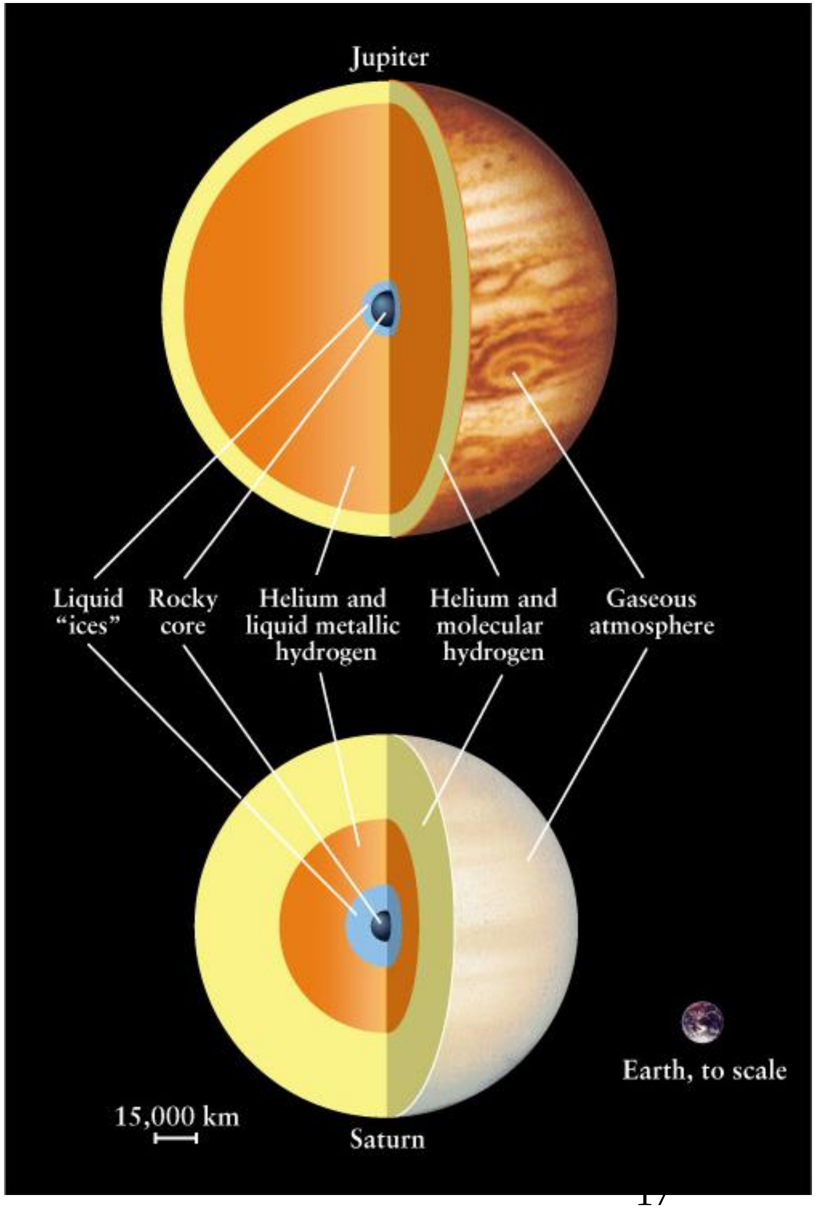


96.5% CO_2, 3% N_2
runaway greenhouse effect due to carbon dioxide and higher pressure. Very hot, hotter than what one would expect compared to Earth due to just Venus being closer to the Sun

78% N_2, 21% O_2, 0.04% CO_2, ~1% H_2O.
most CO_2 absorbed by oceans. Do not want "runaway greenhouse effect" like on Venus to occur

Atmosphere of Jupiter and Saturn

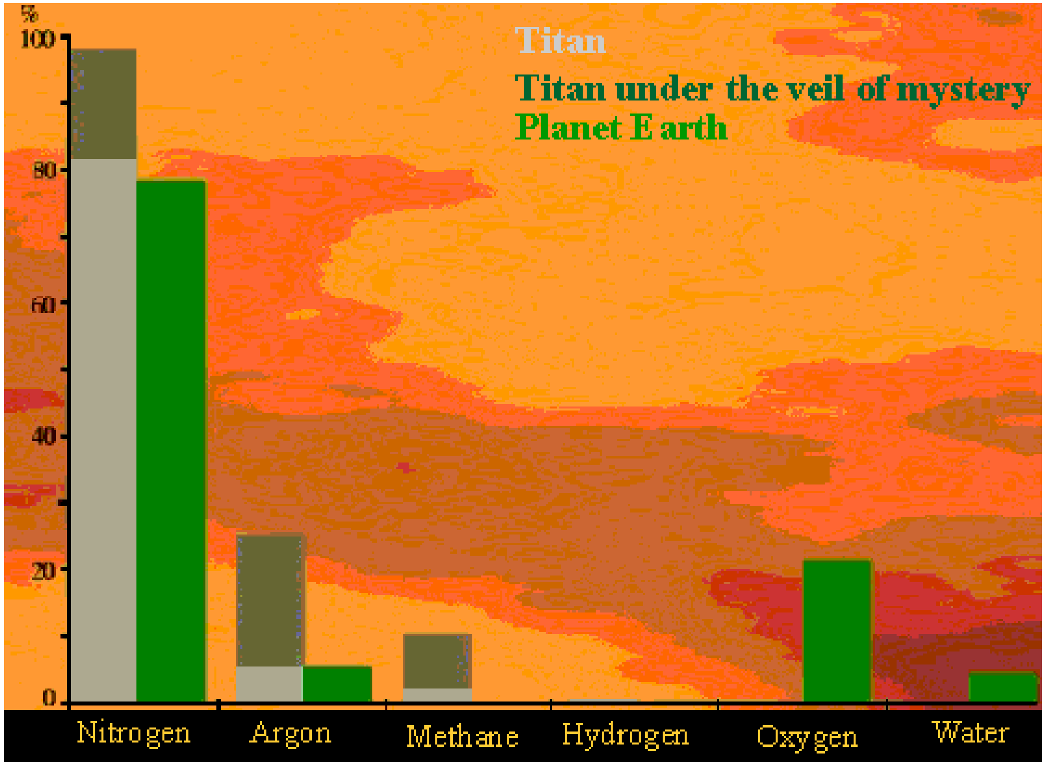


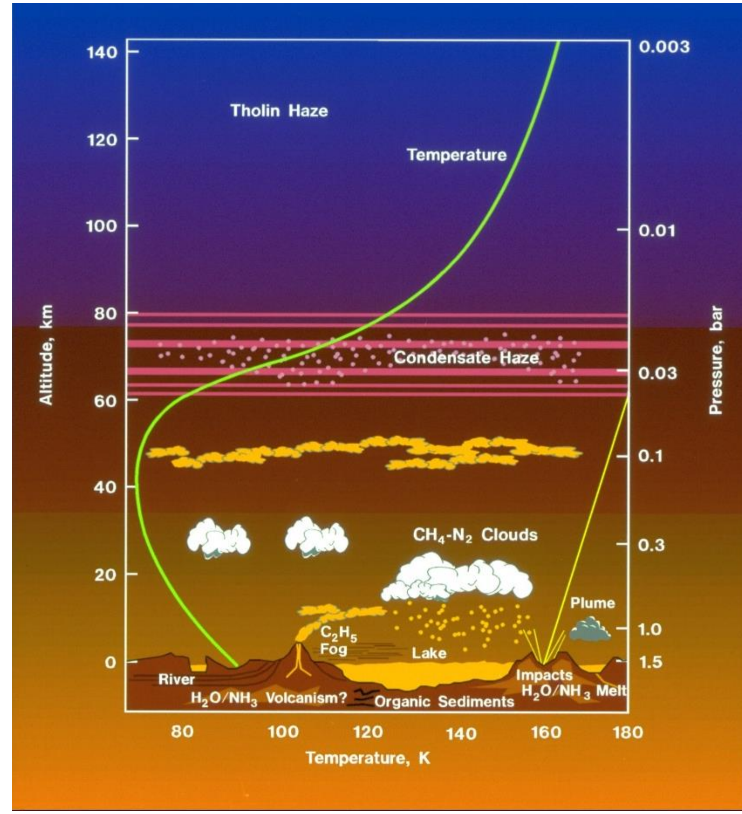


ammonia, sulfuric acid, water

interiors are helium and hydrogen,
core of ice/rock

Atmosphere Titan, moon of Saturn





Titan has ~90% nitrogen rest mostly methane and argon; pressure similar to Earth but lower temperature. Maybe like Earth's early atmosphere