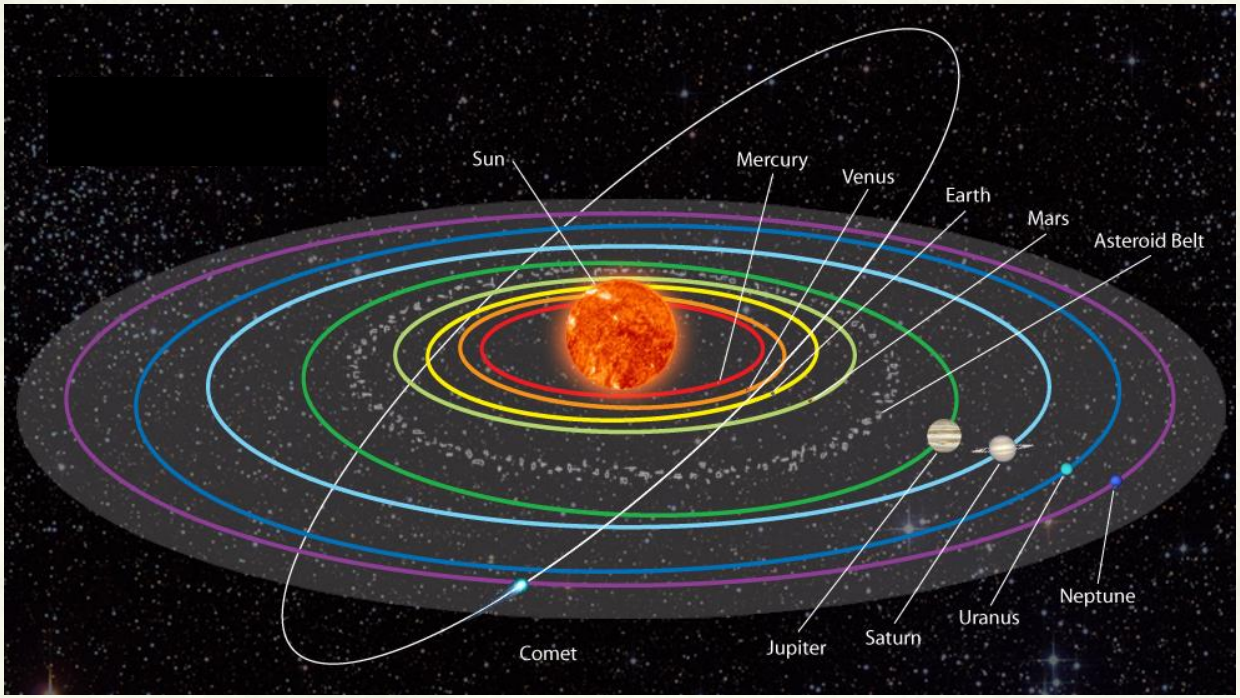
The Solar system

ASTR 101

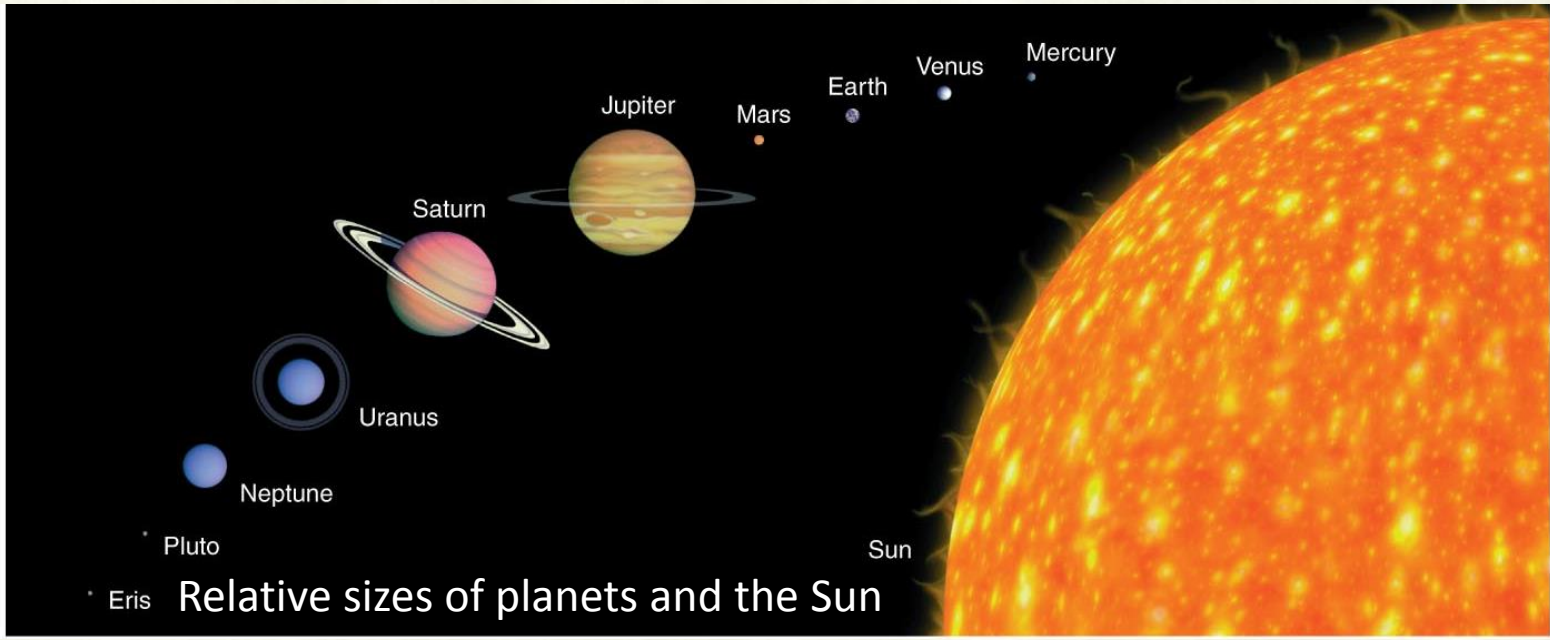
11/7/2017

The Solar System



- The solar system:
  - the Sun (99% of the mass in the solar system)
  - 8 major planets and their satellites,
  - asteroids, comets, and trans-Neptunian objects.
- Most of the planets have slightly elliptical (nearly circular) orbits.
- All planets orbit the Sun in almost the same plane and in the same direction.

The Solar System



Relative sizes of planets and the Sun

planet	Distance to the Sun(AU)	Diameter (Earth =1)	mass (Earth=1)	density (kg/m^3)	Orbital period	rotation period	number of moons
Mercury	0.387	0.38	0.055	5430	87.9 d	58.6 d	0
Venus	0.723	0.95	0.82	5243	225 d	243 d	0
Earth	1.00	1	1.00	5515	1.00 y	23.93 h	1
Mars	1.52	0.53	0.11	3934	687 d	24.6 h	2
Jupiter	5.20	11.2	318	1326	11.9 y	9.93 h	67
Saturn	9.54	9.44	95.2	687	29.5 y	10.6 h	62
Uranus	19.2	4.01	14.5	1318	83.8 y	17.2 h	27
Neptune	30.1	3.88	17.1	1638	165 y	16.1 h	13

Terrestrial planets: relatively small, rocky, dense, close to the Sun

Jovian planets: large, gaseous, less dense, farther from the Sun

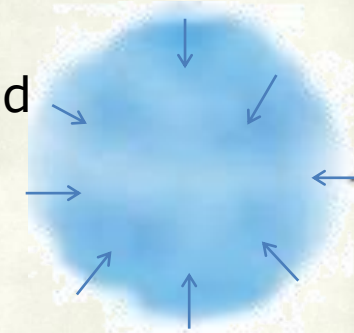
Planetary Moons of the Solar system

	Moon	Io	Europa	Ganymede	Callisto	Titan	Triton
Parent planet	Earth	Jupiter	Jupiter	Jupiter	Jupiter	Saturn	Neptune
Diameter (km)	3476	3642	3130	5268	4806	5150	2706
Mass (kg)	7.35×10^{22}	8.93×10^{22}	4.80×10^{22}	1.48×10^{23}	1.08×10^{23}	1.34×10^{23}	2.15×10^{22}
Average density (kg/m^3)	3340	3530	2970	1940	1850	1880	2050
Substantial atmosphere?	No	No	No	No	No	Yes	No

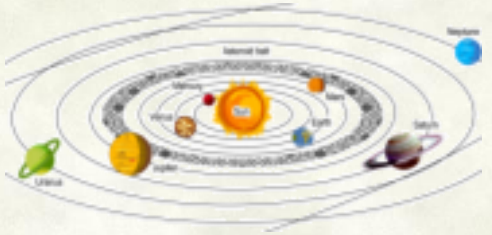
- Seven large planetary satellites are comparable in size to the planet Mercury.
  - Most of them are with Jovian planets.
- The remaining satellites of the solar system are much smaller (less than 250 km).

Origin of the Solar system

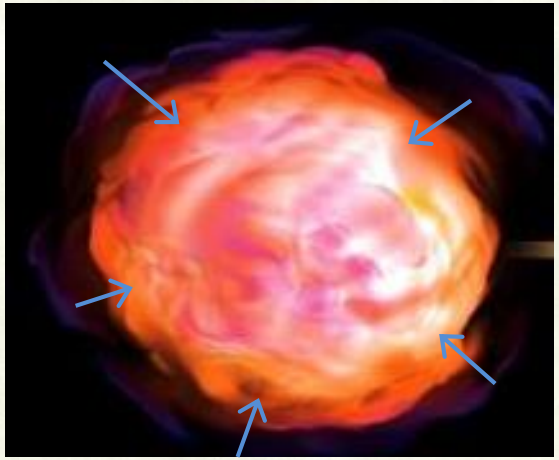
- **The nebular hypothesis :**
  - States that the solar system formed from the gravitational collapse of large interstellar cloud of gas and dust—*the solar nebula.*
  - Originally proposed by the philosopher Immanuel Kant and later by the mathematician Pierre Laplace in mid 18th century.



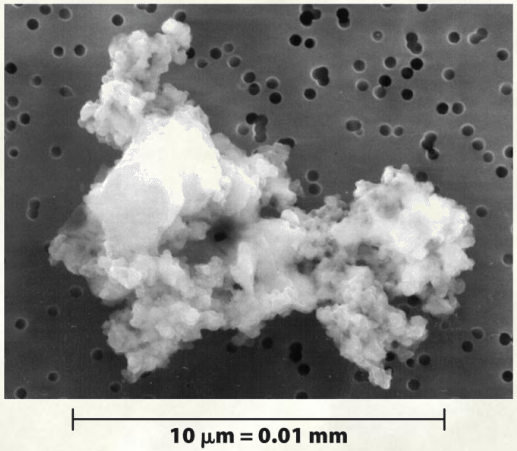
- A large amount of evidence supports this idea and explains major features of the solar system well :
  - Existence of two types of planets:
    - Terrestrial and Jovian: their sizes and the composition.
  - Patterns of motion of the planets and large objects:
    - Orbit in same direction and plane, most rotating in the same direction
  - Existence of smaller objects:
    - Asteroids and comets.



- About 4.6 billion years ago, a cloud of interstellar gas and dust, few light years in size started contracting under its own gravity.
  - Contained mostly (98%) Primordial matter (hydrogen and helium)
  - and 2% of other elements in the form of ice and dust
    - These were formed in older stars and thrown into the interstellar space when they ended their lives in supernova explosions.
      - 0.2% Metals: iron, nickel, aluminum
      - 0.4% Rocks: silicon-based minerals
      - 1.4% Ices: hydrogen compounds like methane (CH_4), ammonia (NH_3), water (H_2O)

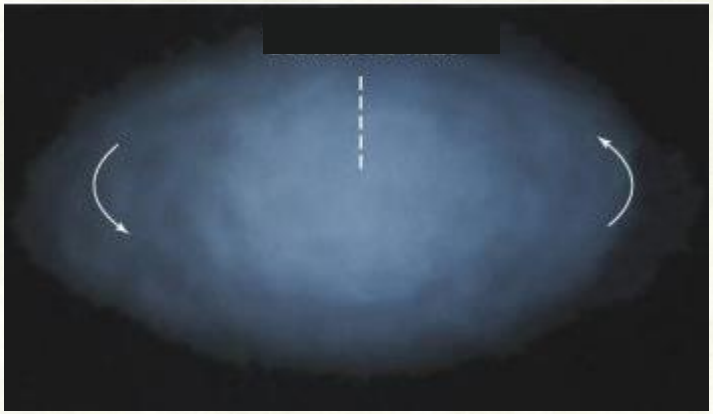


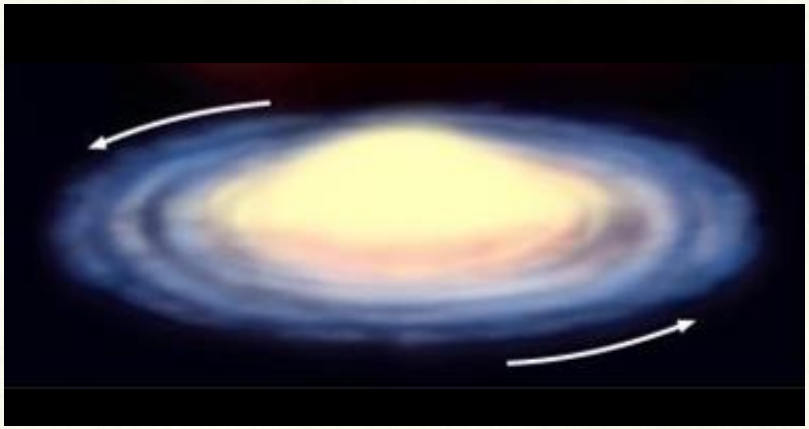
Simeis 147: A Supernova Remnant, Stellar debris cloud from a supernova occurred about 100,000 years ago. (now spans 150 light years).



A grain of cosmic dust (collected by a high flying air craft)

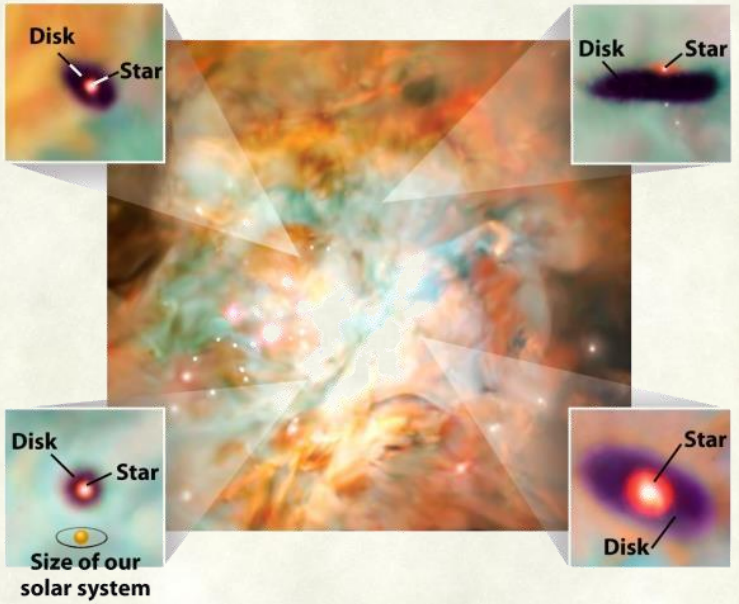
Forming the planetary disk





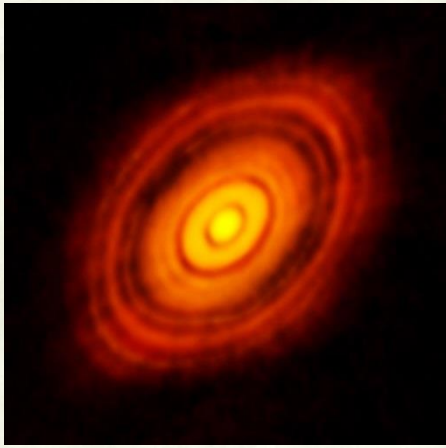
- Most of the gas collapsed to the center forming the proto-Sun.
- As the gas cloud contracts, its rotational speed increased due to the conservation of angular momentum

Forming the planetary disk



Proto stars in the Orion nebula

- The rotation of the disk prevented further collapse of the disk stabilizing at a diameter of about 200 AU(0.003 ly)
- The rotating ball collapsed into a thin disk with most of the mass concentrated near the center forming a protostar (protosun)
- The disk (proto planetary disk) evolved into the planetary system.

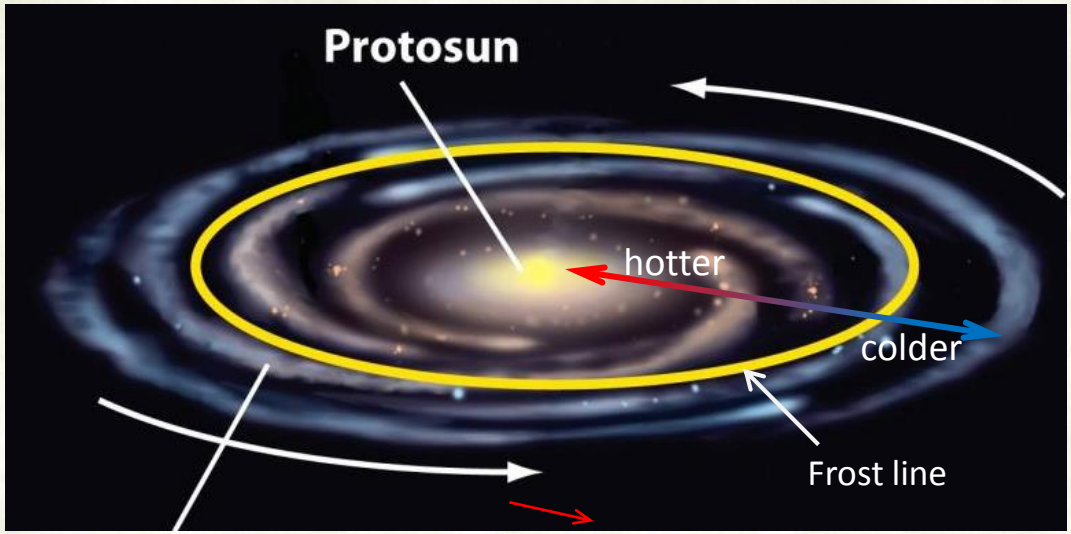


Protostar HL-Tauri

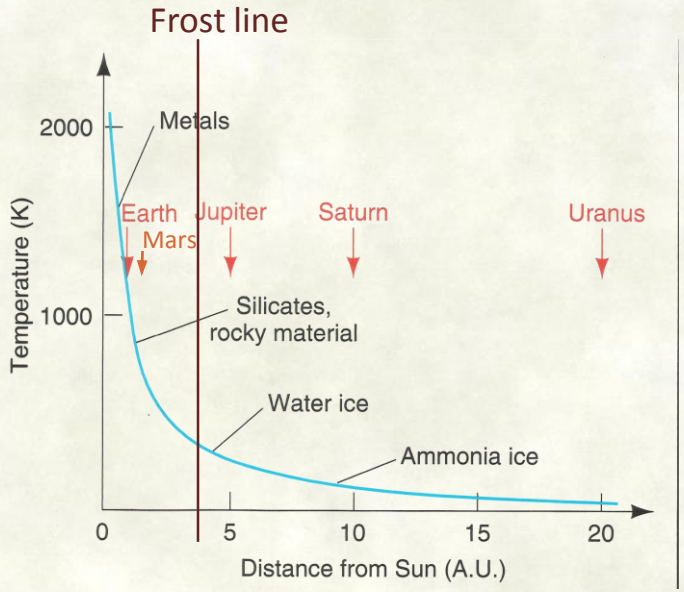
www.eso.org/public/videos/eso1436a

Protostar HL-Tauri www.eso.org/public/videos/eso1436a

Formation of Terrestrial planets



Frost line, beyond with water freezes and ice add to planet forming material



Temperature and distance that various components could have remained as solids in the nebular disk

- The friction between infalling gases heated the nebular disk.
  - Inner parts of the nebular disk got hotter than the outer parts.
- Hottest near the center where the density is highest and the protosun was formed. (no nuclear reactions yet, it is emitting energy from gravitational collapse)

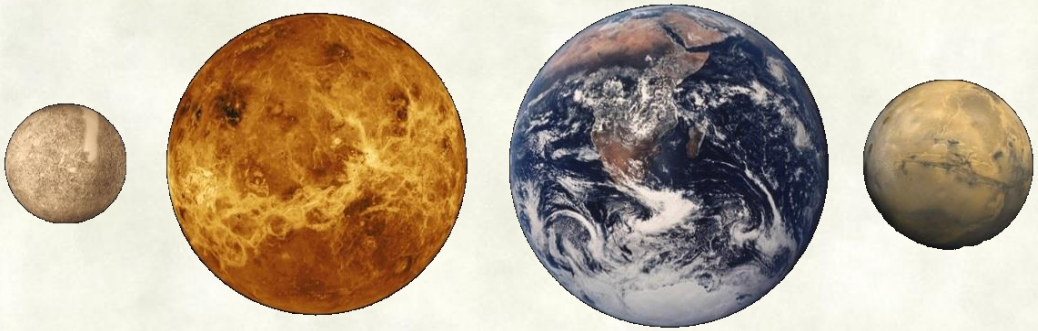
- Higher temperature of the inner region melted and evaporated ice particles.
  - only dust particles made up of rocky material and metals remained solid.

Formation of Terrestrial planets

Small particles in the solar nebula coalesce to form larger particles

- As those dust particles collided and stuck together, larger bodies of rock and metal formed
  - Like a snowball thrown through a blizzard getting larger as it hits other snowflakes
  - They are called Planetesimals (small planets- ~1km in size)
- Further coalescing of those planetesimals under gravity eventually formed planets

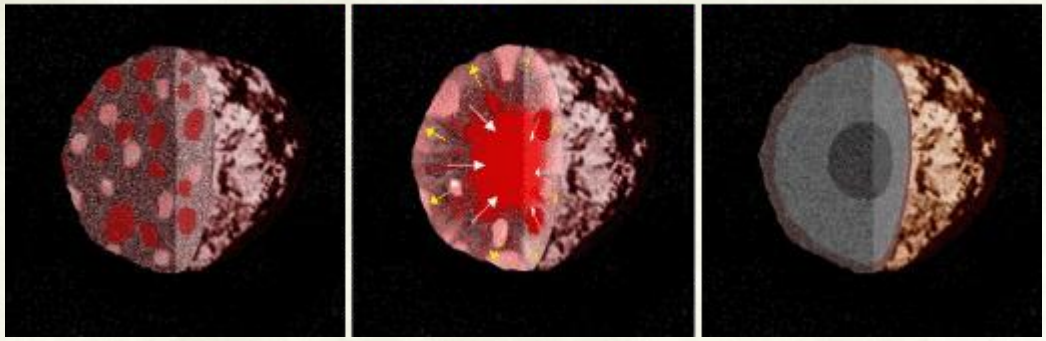
Formation of Terrestrial planets

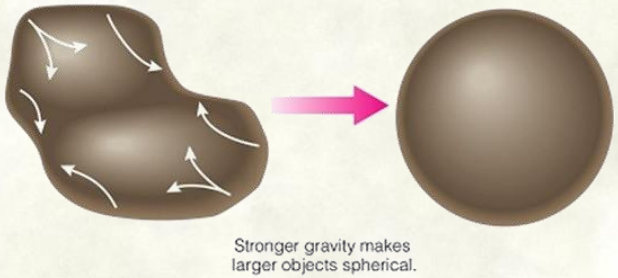


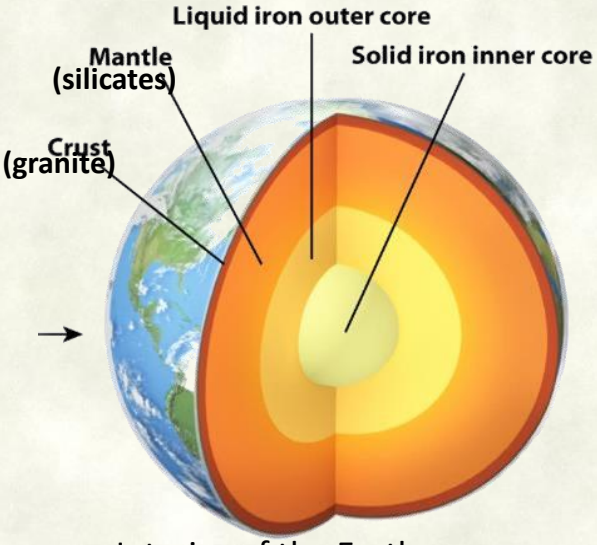
- 0.2% Metals:
- 0.4% Rocks:
- 1.4% Ices:

- Terrestrial planets were formed from Rocky and metallic dust,
  - They made up only 0.6% of the material in the solar nebula, so the amount of material available to form inner planers was small.
  - Therefore terrestrial planets could not grow very large.
- Their smaller size could not exert large enough gravitational pull on hydrogen and helium gas from the surrounding nebula.
  - Whatever gases they initially had, escaped due to higher temperatures.
- Hence, the terrestrial planets (Mercury, Venus, Earth, and Mars) are dense small worlds composed mostly from 0.6% of heavier elements contained in the solar nebula.

Differentiation of a Planetesimal



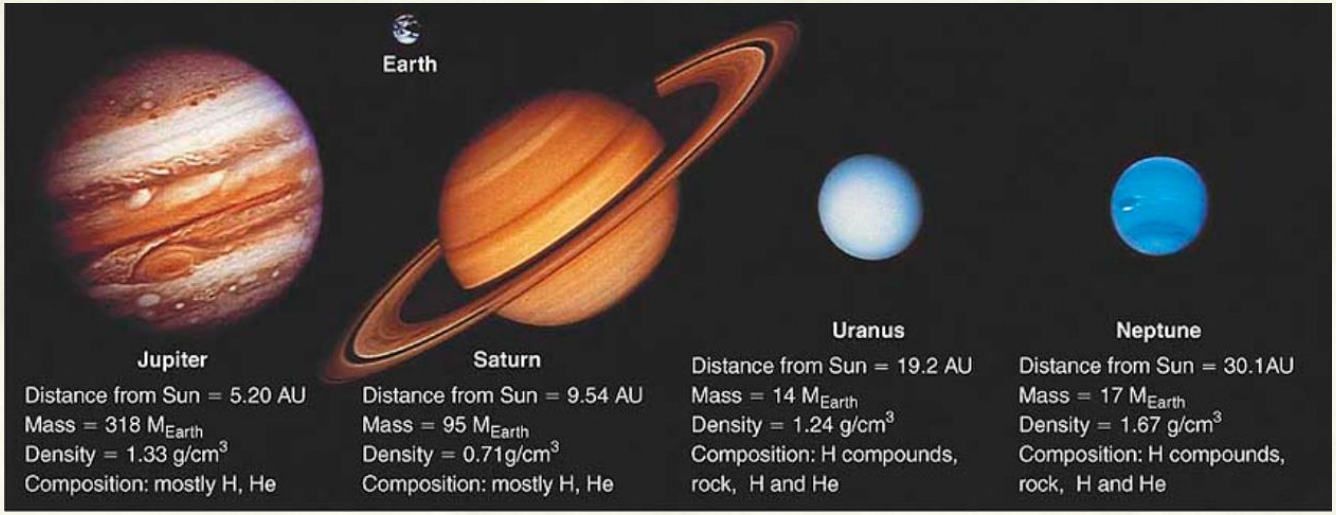




Interior of the Earth

- After protoplanets were formed, energy from the collapse of matter and accumulation of heat from radioactive decays melted them.
  - materials differentiated (separated according to their density, denser to the core, lighter to the surface) and planets took spherical shapes.

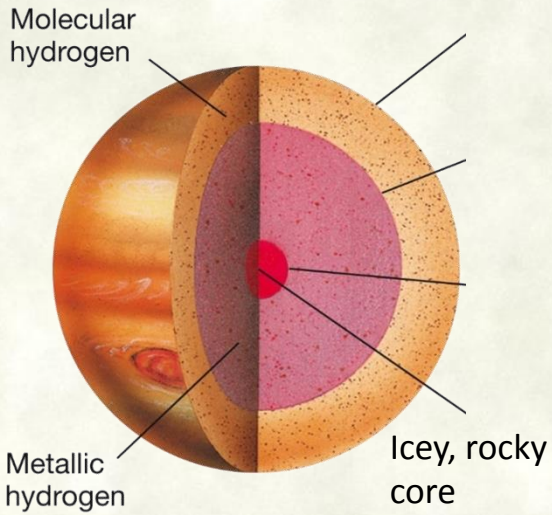
Jovian planets



- Beyond the frost line temperatures were low.
  - Water and other hydrogen compounds (ices) were frozen and in a solid form that could coalesce and form larger objects.

    ⇒ in the outer solar nebula, planetesimals formed from ice flakes in addition to rocky and metal dust.
- Since ices were more abundant (1.4%) the planetesimals grew to much larger sizes, becoming the cores of the four Jovian planets.

Jovian Planets



Interior of Jupiter

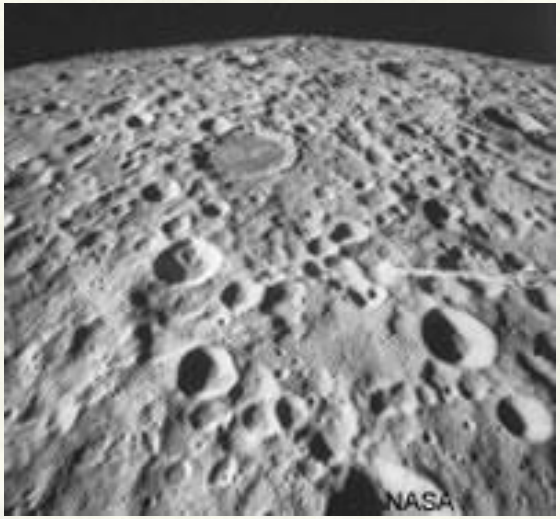
- Large massive cores thus formed had strong enough gravitational pull to capture hydrogen and helium gases from the surroundings nebular disk,
- This added gas made their gravity even stronger allowing them to capture even more gas and grow larger and larger in size.
  - Thus becoming the large, gaseous, low-density worlds rich in hydrogen and helium, with dense solid cores and thick atmospheres.

Later Evolution of the Solar System

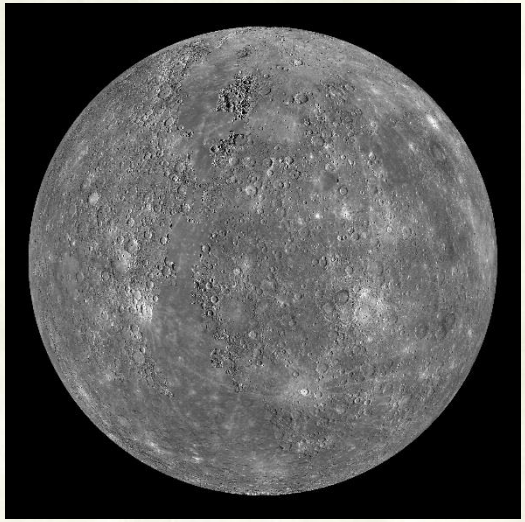
•Planetesimals did not merged into planets left as debris in the early solar system.

- Some of the planetesimals debris collided with planets forming craters on them
- The vast majority of the impacts occurred in the first few hundred million years.

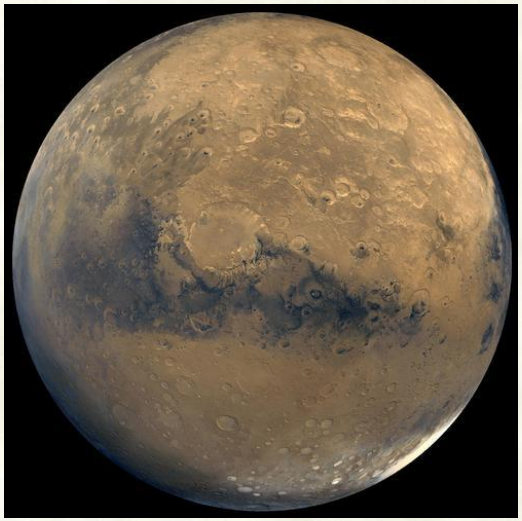
- Such caters can be seen on Moons, and planets which do not have thick atmospheres and much geological activity.
- Erosion and geological processes on Earth have erased most of the craters.



Surface of the Moon without an atmosphere or geologic active craters remain intact



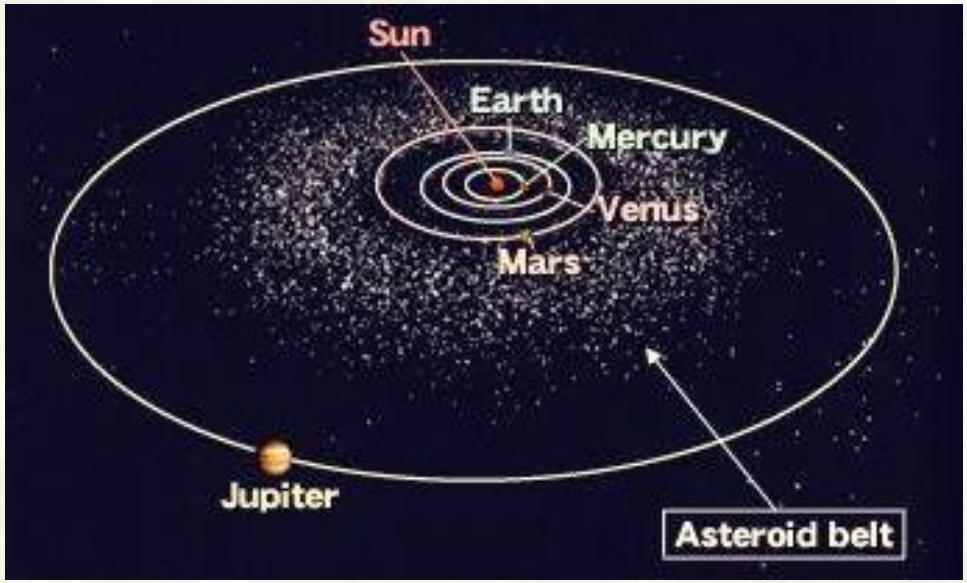
Mercury

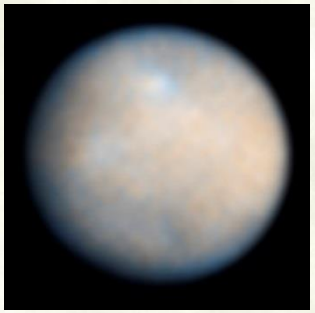


Mars, most of the craters have been erased.

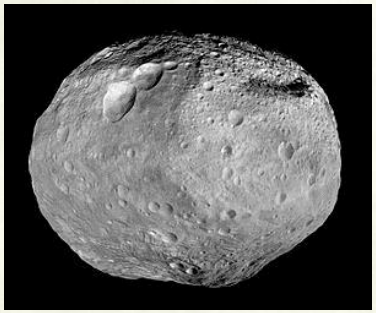
- The protosun continued collapsing under gravity, further heating it up in the process.
- When the core reaches 10 million K, hydrogen nuclei (protons) are moving fast enough to overcome the electrical repulsion between them and combine together.
  - Nuclear fusion of hydrogen begins, converting hydrogen in to helium and releasing energy. $H + H + H + H \rightarrow He$
  - The protosun became a star.
- A combined radiation pressure (photons) and the solar wind (outflowing matter from the Sun) blew away the leftover gases and dust, thus the formation of the solar system came to an end.

Asteroids

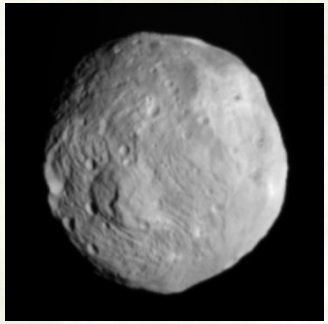


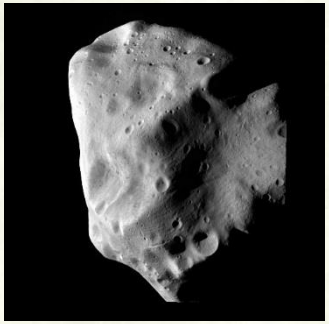


Ceres, 952km



Vesta, 572km

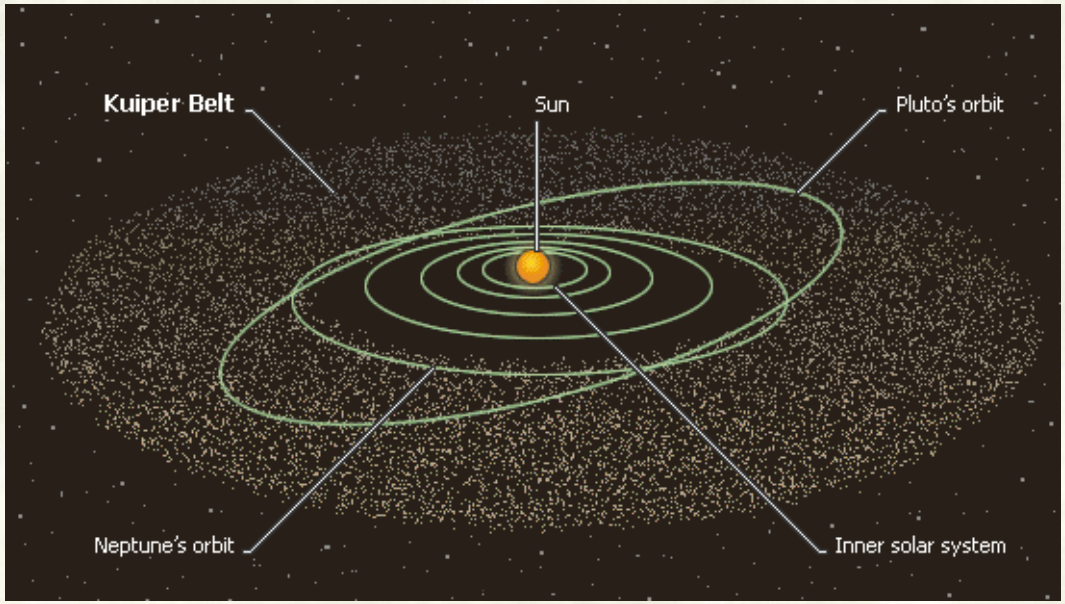




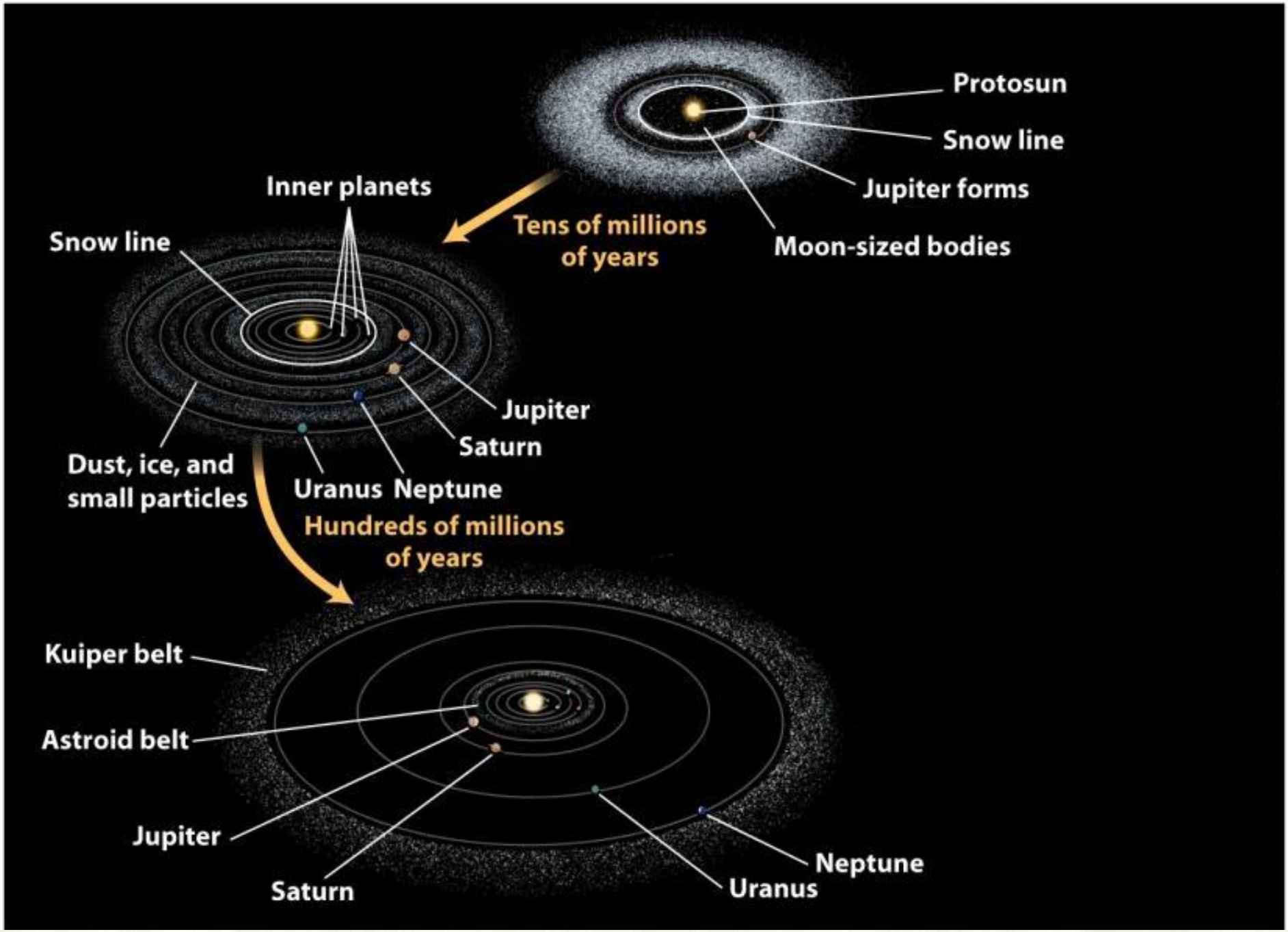
Lutetia, 100km

- Between Mars and Jupiter there are thousands of rocky planetesimals from 1,000 km to a few meters across called Asteroids.
  - Those are thought to be debris of the formation of the solar system that could not merge to form a planets due to influence of Jupiter's gravity.
- About 6 are larger than 300 km, most are smaller (< 10 km) and do not have enough mass to be spherical.
- More than 300,000 *asteroids* have been identified and cataloged, over a million asteroids lager than 1km are estimated to be there and many millions smaller ones.

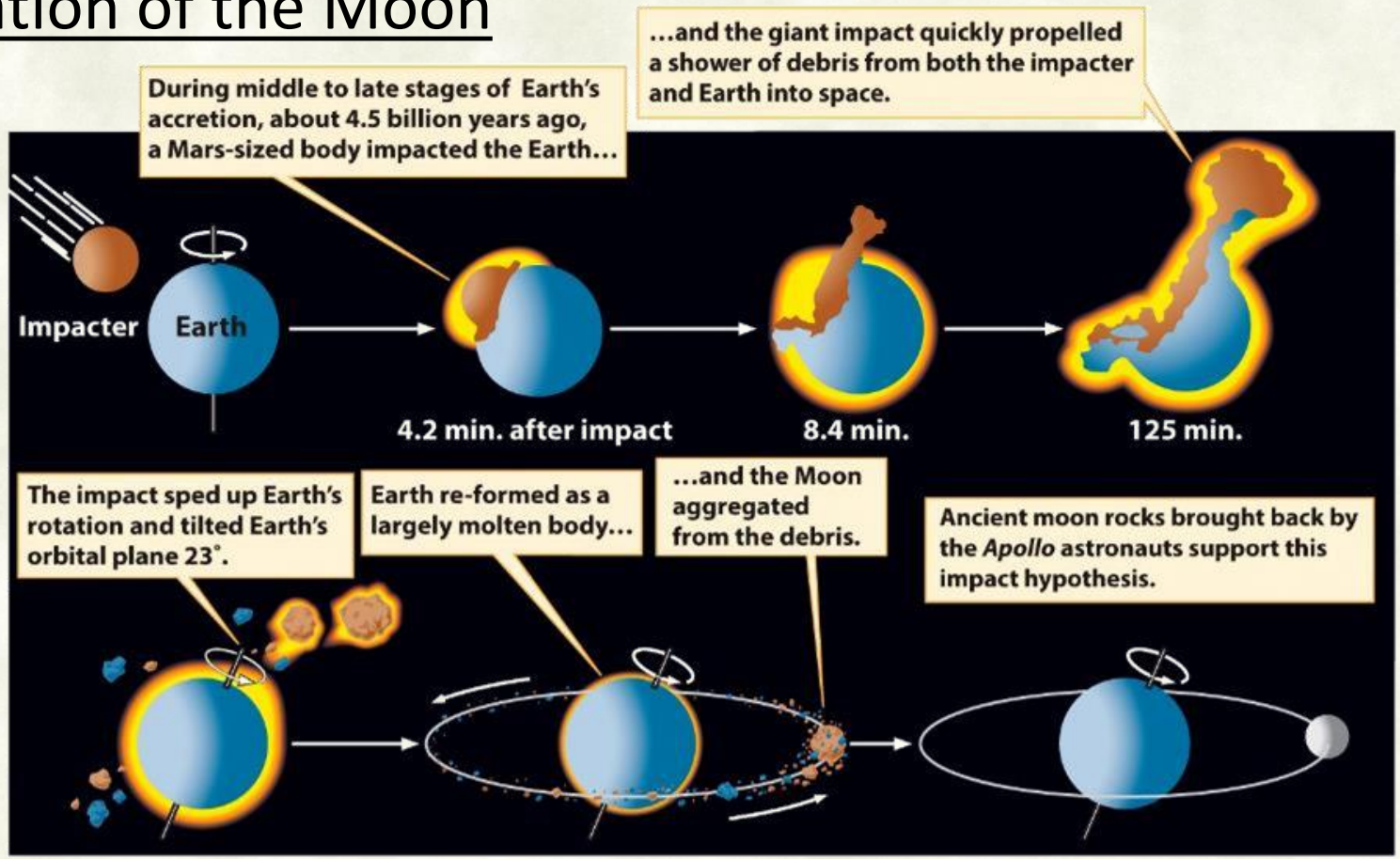
Comets



- Comets are also debris left over from the formation of the solar system.
- They were located beyond the frost line,
  - so unlike for asteroids, in addition to metal and silicate dust, ice particles were also coalesce to form planetesimals
- But away from the Sun, beyond Neptune in coldest regions of the nebula, the density was low that those icy/dusty planetesimals could not grow very large.


Protosun
Snow line
Jupiter forms
Moon-sized bodies
Inner planets
Tens of millions of years
Snow line
Jupiter
Saturn
Dust, ice, and small particles
Uranus
Neptune
Hundreds of millions of years
Kuiper belt
Astroid belt
Jupiter
Saturn
Uranus
Neptune

Formation of the Moon



- The Earth's gravitational field was not strong enough to attract material from the surrounding solar nebula and from an accretion disk that would evolved into the moon.
- The leading moon formation theory is that, some 4.5 billion years ago a planetary body of the size of Mars collided with the young Earth.
- That collision ejected a large amount of planetary material into space, which accreted to create our Moon.
- That collision could also be the reason Earth's axis is tilted by 23.5^0.

Review Questions

- What was the composition of the solar nebula (the nebula that collapsed to form the solar system)?
- How does the nebular hypnosis explain the existence of two types of planets, terrestrial and Jovian?
- How old is the solar system? How old is the Universe.
- Can there be planetary systems as old as the universe?
- What is the role of Supernovas in the formation of the solar system?
- Why are there many impact crates on the Moon, but only a few on the Earth.
- Why do Jovian planets like Jupiter and Saturn have so many moons?
- How did the asteroid belt formed?
- What are the Kuiper belt objects?
- What could be the reason that no large planets had formed beyond Neptune?
- Where are the asteroids located in the solar system?
- What are comets? How do they form?
- What are shooting stars?
- Why do meteors in the meteor shower appear to be radiating from a point in the sky.
- What is the different between comets and asteroids?