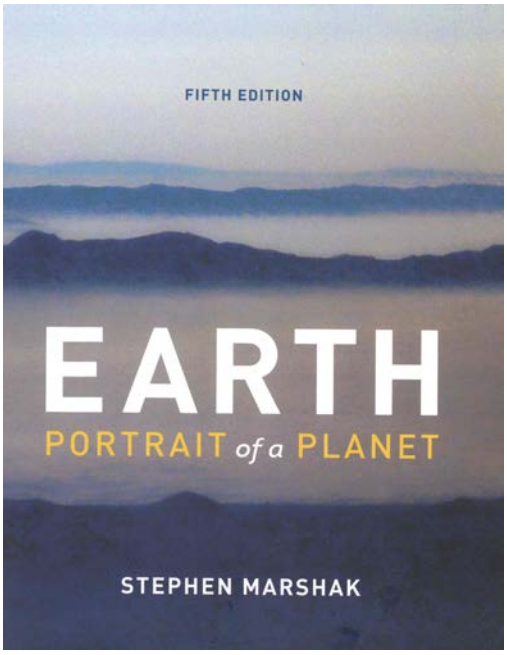
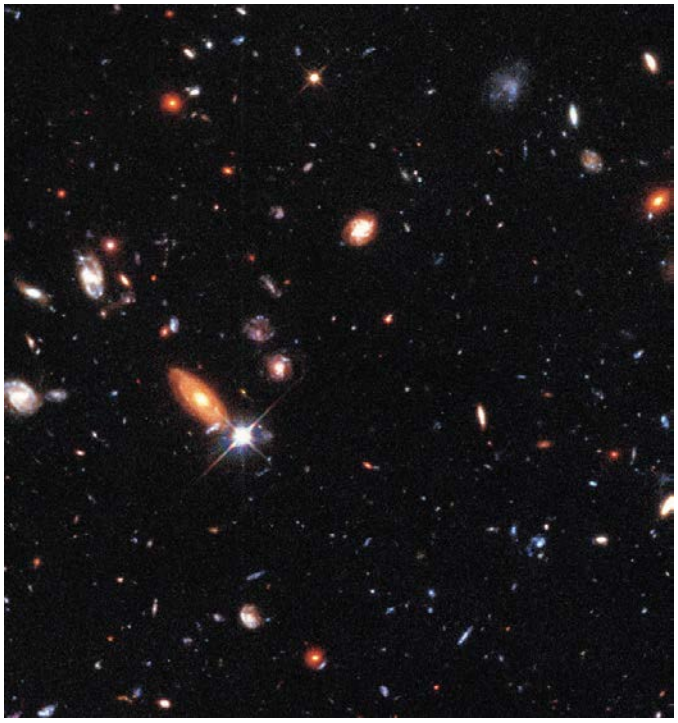
CEEES/SC 10110/20110 Planet Earth



Earth

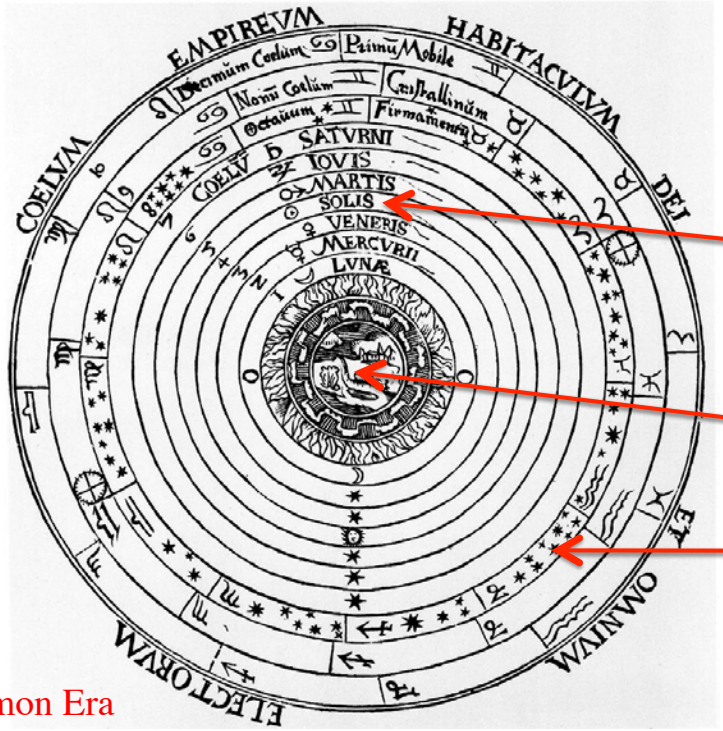
Portrait of a Planet
Fifth Edition

Our Place in the Universe



Cosmology: study of the overall structure of the universe

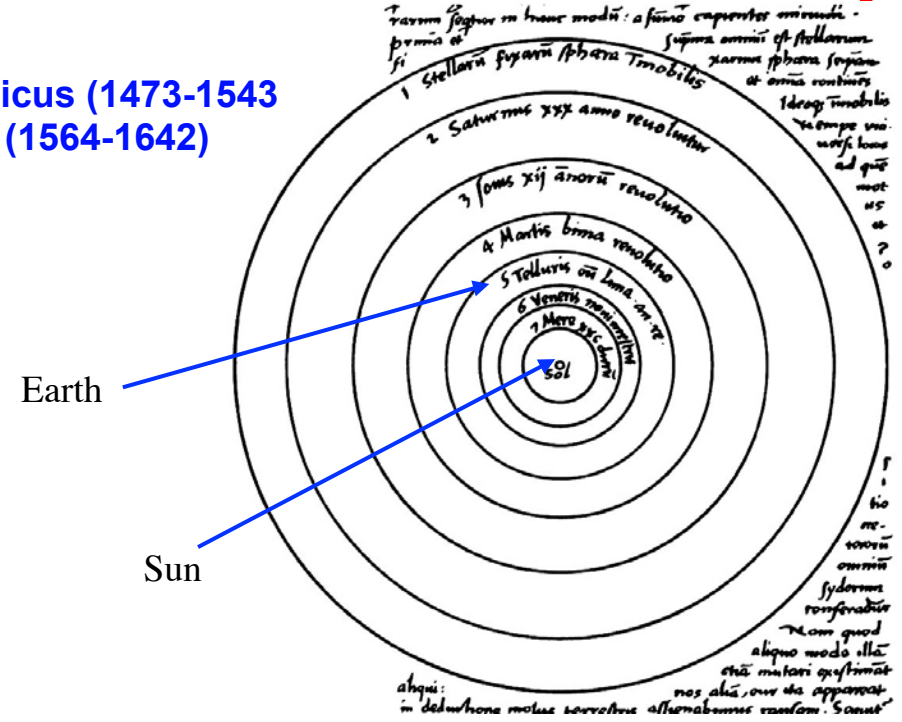
Geocentric Universe Concept: 600 B.C.E.

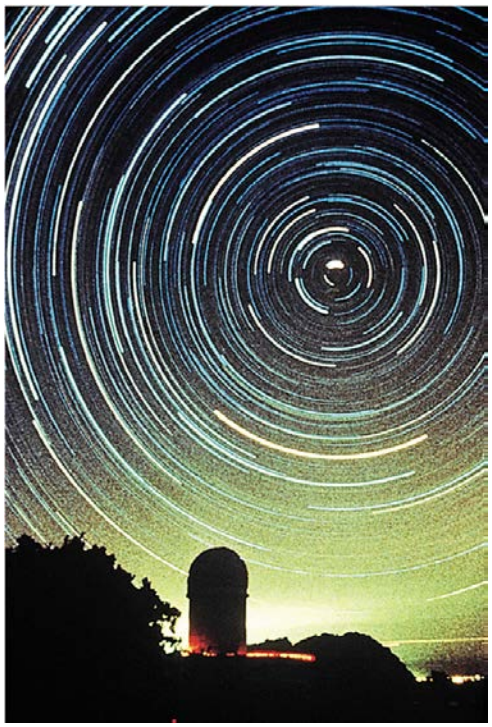


B.C.E. =
Before Common Era

Heliocentric Universe: 250 B.C.E. = heresy!

Copernicus (1473-1543
Galileo (1564-1642)





Axis of Rotation

North (Pole) Star

Shape of the Earth

Eratsothenes (276-194 B.C.E.)
Measurement of the Sun's angle between Syene and Alexandria (800 km or 5,000 *stadia* apart) in Egypt.

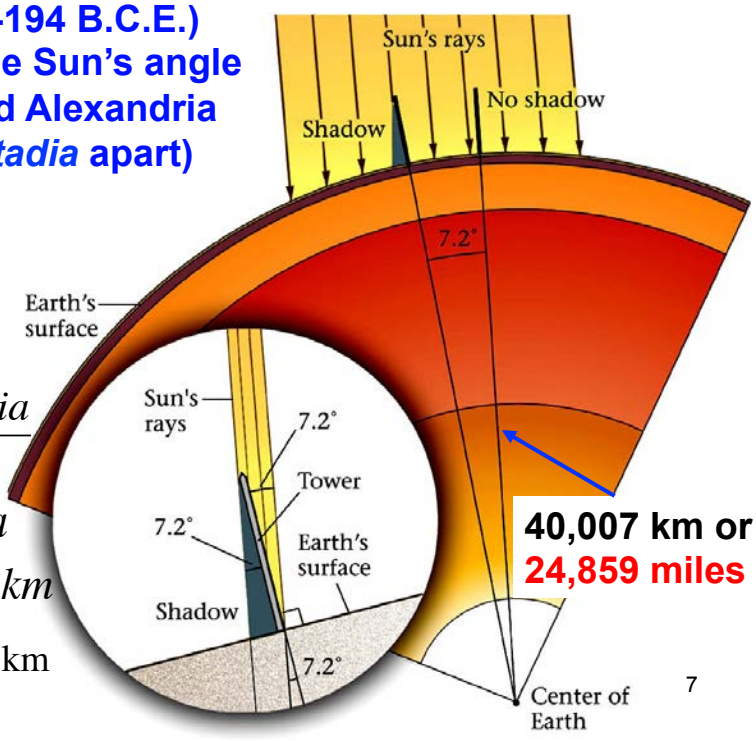
$$\frac{360^\circ}{x} = \frac{7.2^\circ}{5{,}000 \ \ stadia}$$

$$x = \frac{360^\circ \times 5{,}000 \ \ stadia}{7.2^\circ}$$

$$x = 250{,}000 \ \ stadia$$

$$1 \ \ stadia = 0.1572 \ \ km$$

Therefore, x = 39300 km or 24,421 miles.

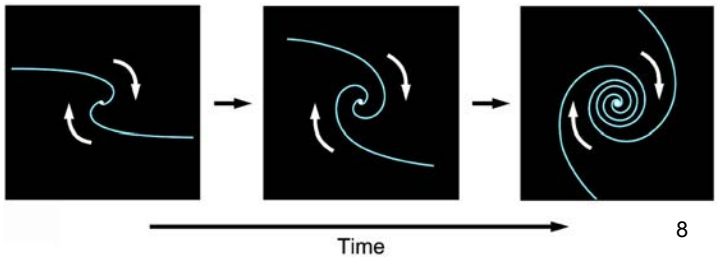


Distance & Subdivisions

Earth-Moon: 381,555 km (average);
Earth-Sun: 149,600,000 km.

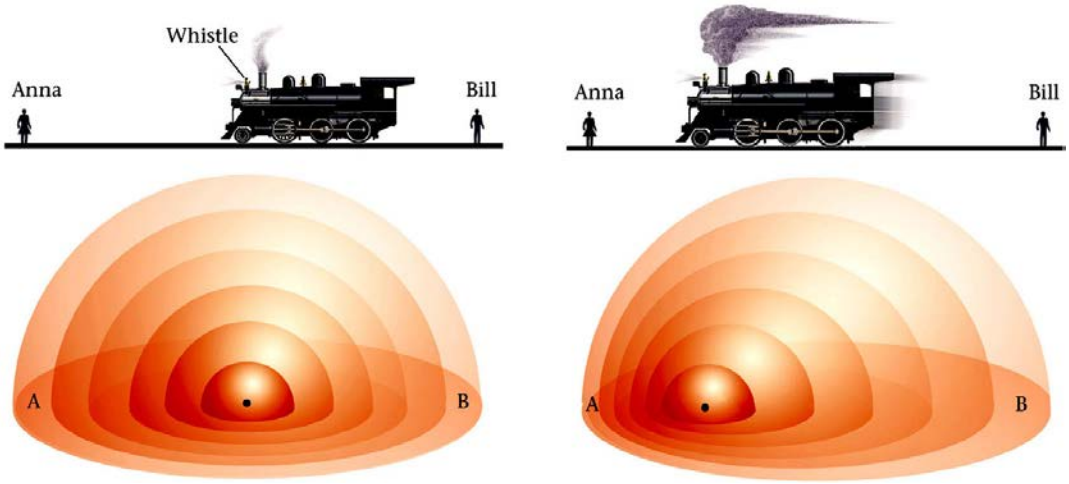
Light Year: distance light travels in one Earth year (~9.5 trillion km).

Solar System: Collection of planets around a star;
Galaxy: Vast collection of solar systems/stars (e.g., Milky Way: 100,000 light years across.



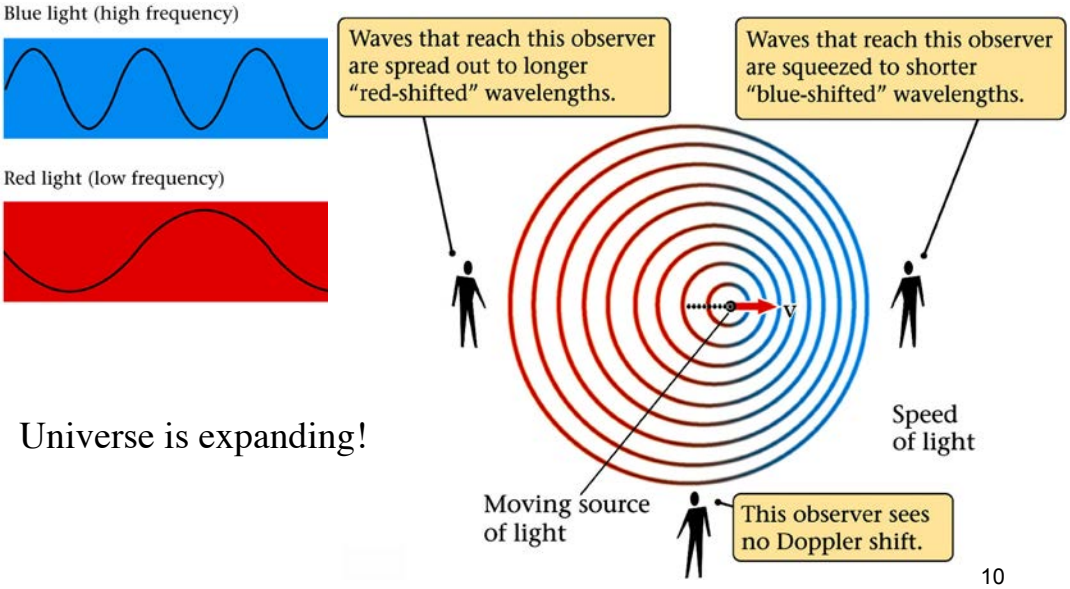
Doppler Effect

Train whistle changes pitch depending on where you here it when the train is moving - wavelength changes.



Doppler Effect

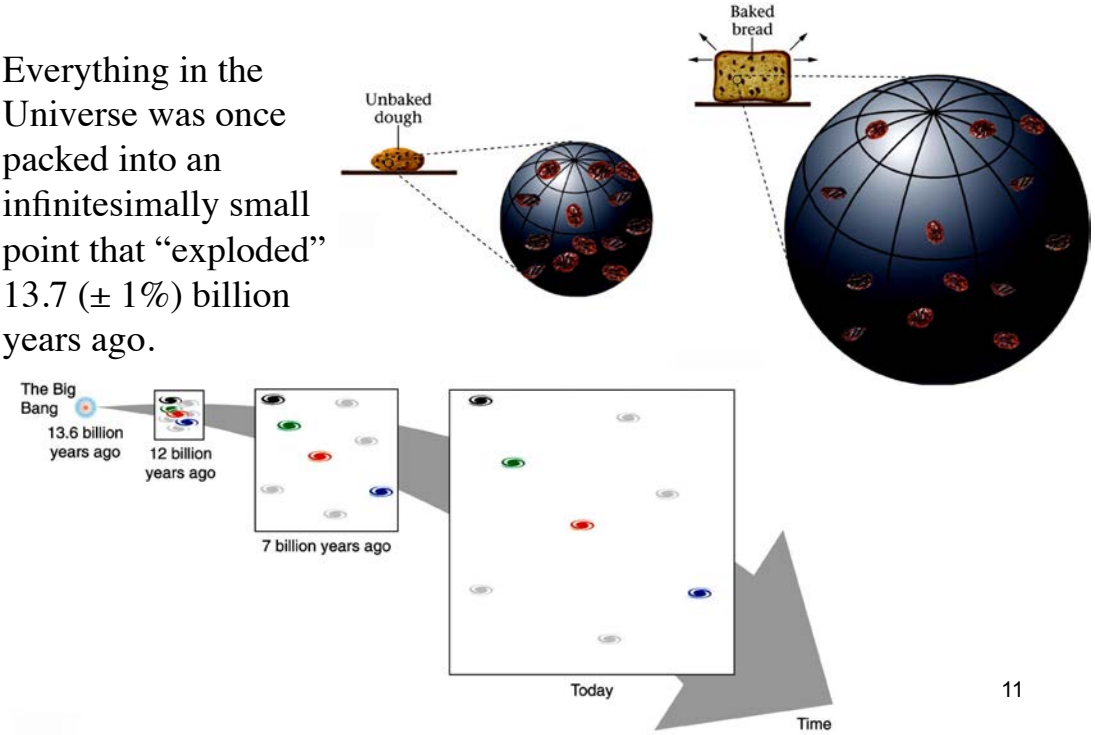
Galaxies further away are “redder” than ones closer.



Universe is expanding!

The Big Bang Theory

Everything in the Universe was once packed into an infinitesimally small point that "exploded" 13.7 (± 1%) billion years ago.

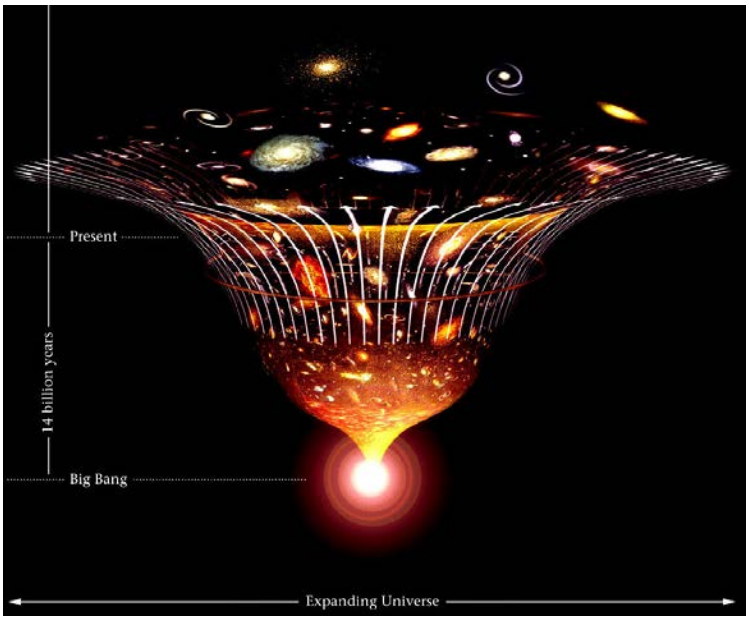


Big Bang Nucleosynthesis

Initial material = protons, neutrons, electrons.

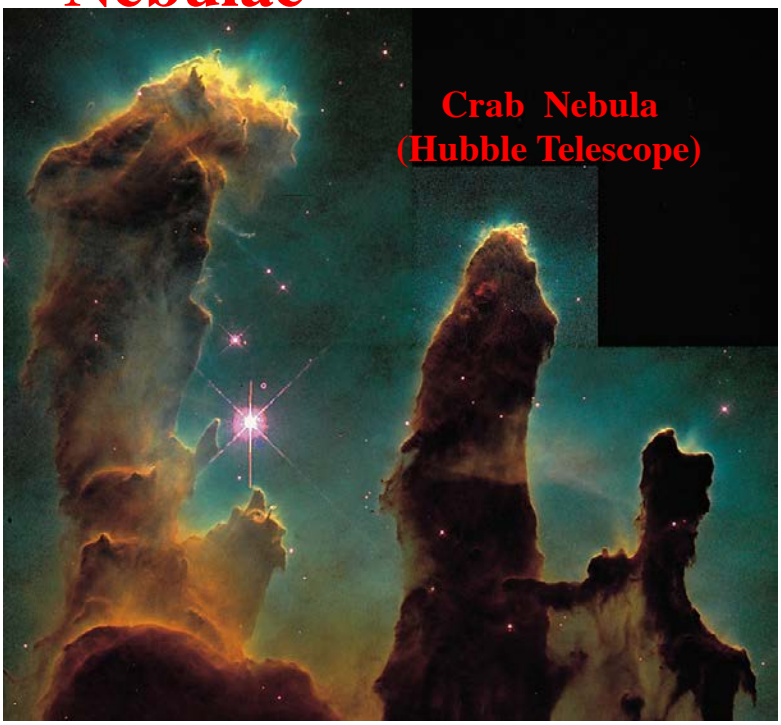
Elements formed before stars: He, Li, Be, B.

Formed in the first 5 minutes - after this, material was too far apart for fusion to occur.



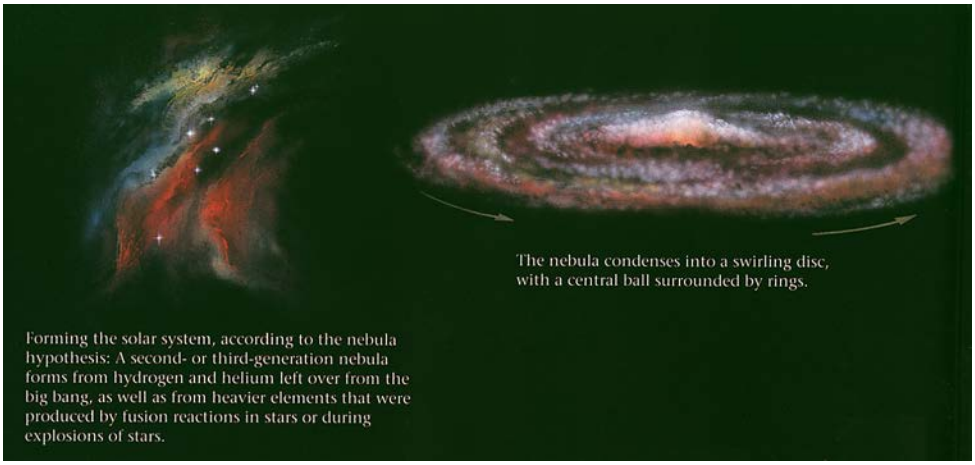
Nebulae

As the universe expanded and cooled, molecules slowed down and accumulated into ***nebulae***.



Forming Stars – Nebular Theory

All matter exerts gravitational pull.
Material accumulated into nebulae and more material gets sucked in causing it to spin.
Material flattens into a spinning **accretion or protoplanetary disk**.
Gravitational pull eventually causes wholesale inward collapse of the surrounding nebula.

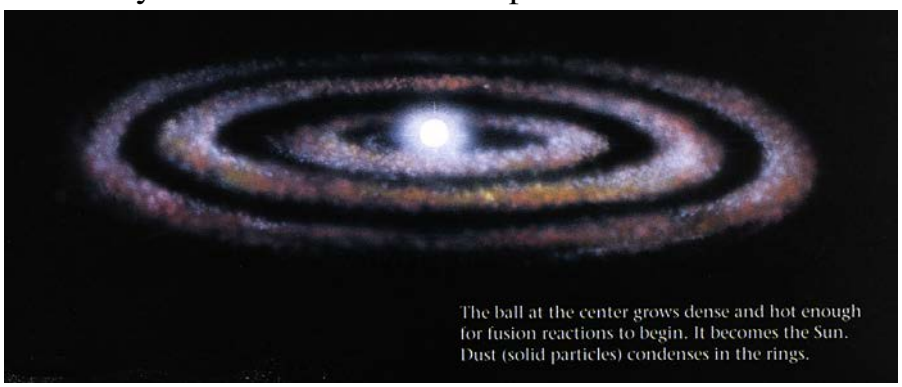


Forming Stars

With the additional mass, gravity pulls the inner portion of the accretion disk into a "ball".

Centrifugal force focuses pressure at the center until this area is hot enough to glow, forming a **protostar**.

More material added to the core of the disk increases temperature and density to the point that nuclear fusion occurs = **star** – blows ***volatile*** elements away from the star leaving ***refractory*** elements. Material away from the central star separates into stable orbits.



Nucleosynthesis

Stars = element factories through two processes:

1. Nuclear Fusion:

Way of building elements from hydrogen.

Releases subatomic particles & requires large amounts of energy.

2. Neutron Capture & Decay:

(a) Neutron sticks to a nucleus - atomic mass increases by 1;

(b) Neutron is transformed into a proton by decay (release of an electron).

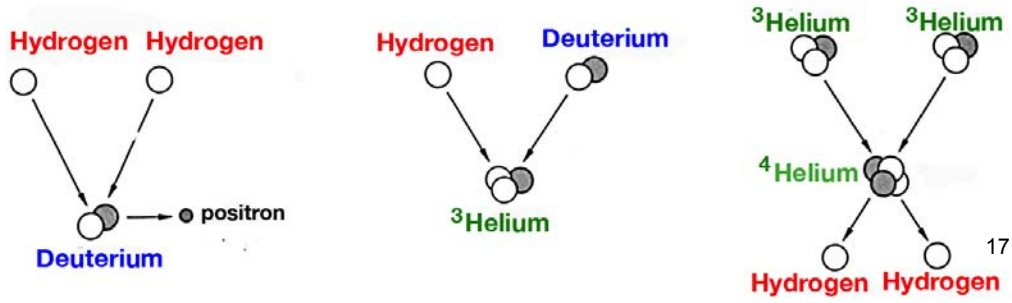
Nucleosynthesis

Hydrogen Burning (T ~10 million K):

$$ {}_1^1H + {}_1^1H \rightarrow {}_1^2D + \ positron $$

$$ {}_1^2D + {}_1^1H \rightarrow {}_2^3He + \gamma - ray $$

$$ {}_2^3He + {}_2^3He \rightarrow {}_2^4He + 2{}_1^1H $$



Nucleosynthesis

As the star becomes hotter, additional reactions can occur.

Helium Burning:

$$ 3\,{}_2^4He \rightarrow {}_6^{12}C $$

$$ {}_6^{12}C + {}_2^4He \rightarrow {}_8^{16}O $$

Nucleosynthesis

Carbon Burning:

O, Ne, Na, Mg

Neon Burning:

O, Mg

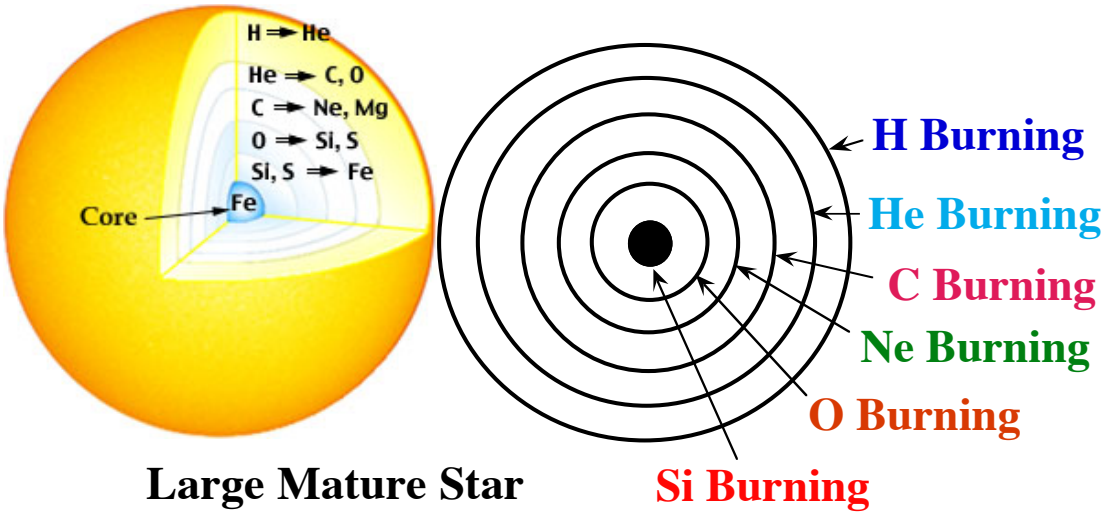
Oxygen Burning:

Mg, Al, Si, P, S

Silicon Burning:

P, S, Cl, Ar, K, Ca, Sc, Ti, V, Cr, Mn, Fe

Nucleosynthesis



Large Mature Star

Stream of atoms emitted from a star = **stellar wind**.
From our Sun = **solar wind**.

Nucleosynthesis

Star runs out of H, it contracts to form a "**white dwarf**".

If a star is 1.4x bigger than the Sun, the density of the matter at the center is high enough for:

Electrons + Protons = Neutrons

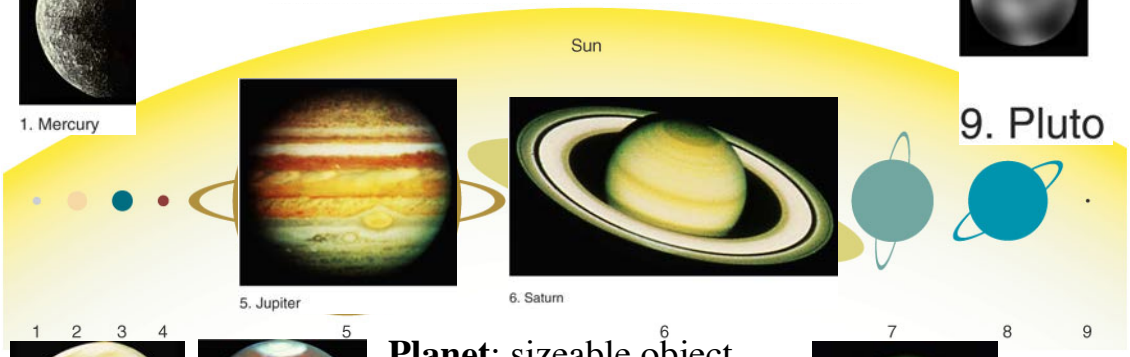
Removes e^- and p^+ from reactions and pressure drops and star suddenly collapses in on itself (Supernova). Intense pressure = ionization – massive repulsion.

Nucleosynthesis

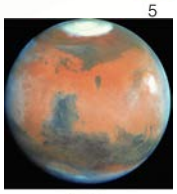
Supernova to create elements > Fe and forms a "nebula".

E.g., Crab Nebula: 7,000 light years away – "Supernova Taurus", July 1054.

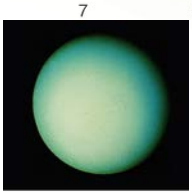
Our Solar System




2. Venus

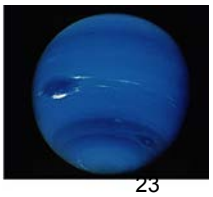

4. Mars

Planet: sizeable object that orbits a star;
Moon = sizeable object that orbits a planet.


7. Uranus

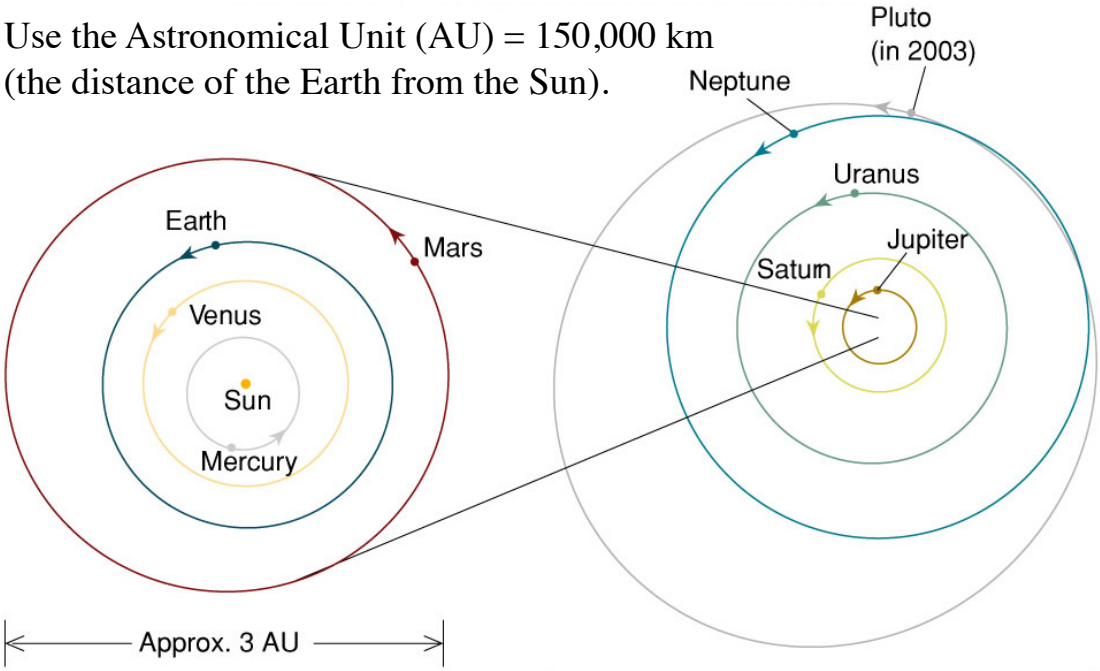

3. Earth

Earth = 3rd rock from the Sun!
One of 8 (or 9!) planets.
The 8/9 planets + their moons + asteroids + comets = Solar System


8. Neptune

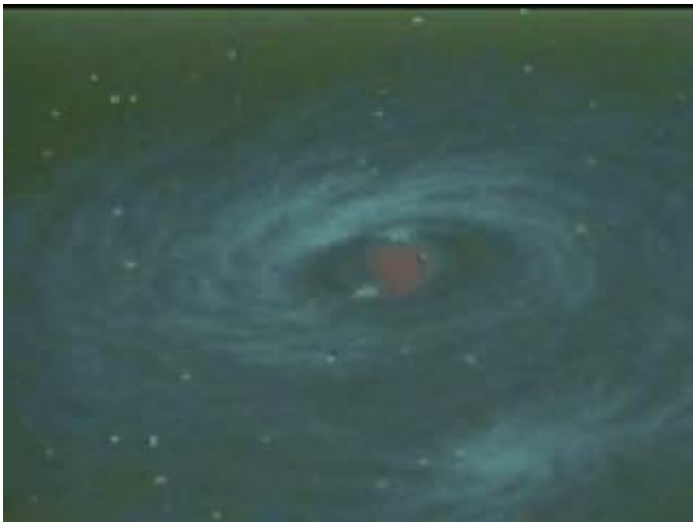
Regular spacing between the planets.

Use the Astronomical Unit (AU) = 150,000 km (the distance of the Earth from the Sun).



Planet orbits as seen from above, looking down on Earth's North Pole

Formation



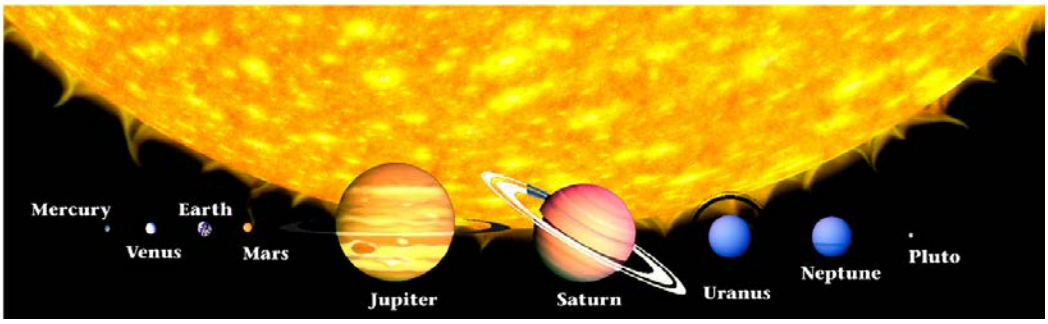
Dust particles grew by accretion, forming **planetesimals** (planet "wannabees"), that in turn accreted to form **protoplanets**

Gases could only condense and become stable far from the Sun (**outer planets**). Uranus and Neptune = ice rather than gas.

ssanim.mov 25

Formation

Outer planets had more material to grow from (e.g., ice stable and abundant; H and its compounds are not "blown away" and can be captured by the larger planets). These are much larger than the **inner planets**.

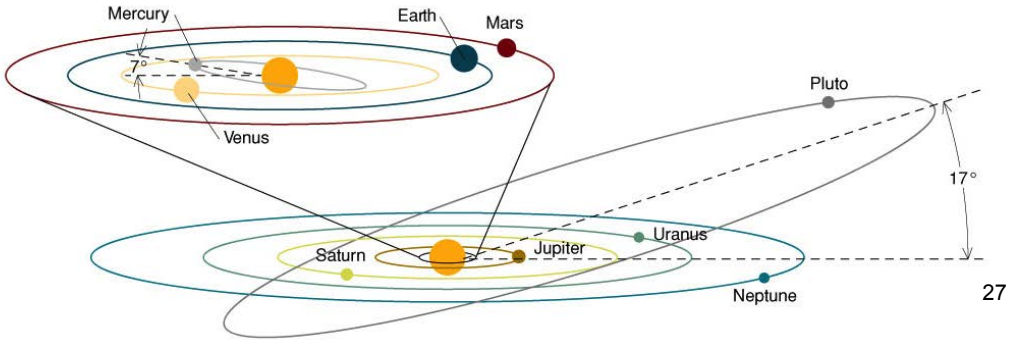


The Solar System

Shows many regularities: All follow ~ circular orbits;

All planets move around the Sun in the same direction;

All have orbits in the same plane, except Pluto (7°) and Mercury (17°) - have inclined orbits relative to Earth's.



Nebular Theory Explains:

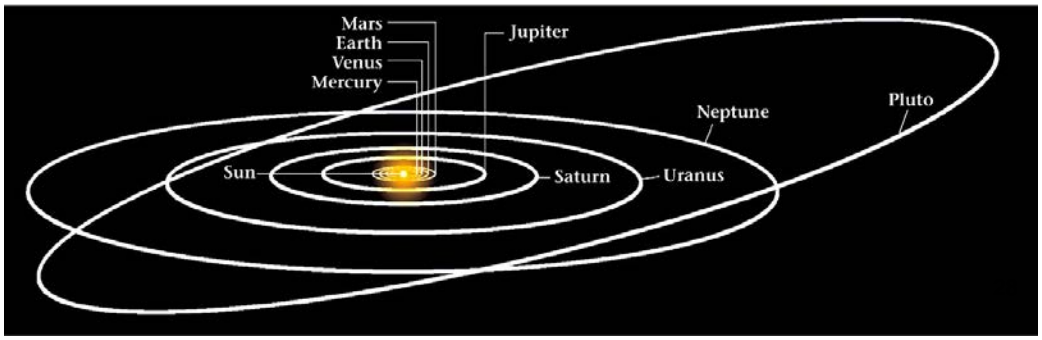
All planets orbit the sun in the same direction and in the same direction that the Sun spins;

Most planets spin the same way that they orbit, and the same way that the Sun spins;

The planets orbit in nearly the same plane;

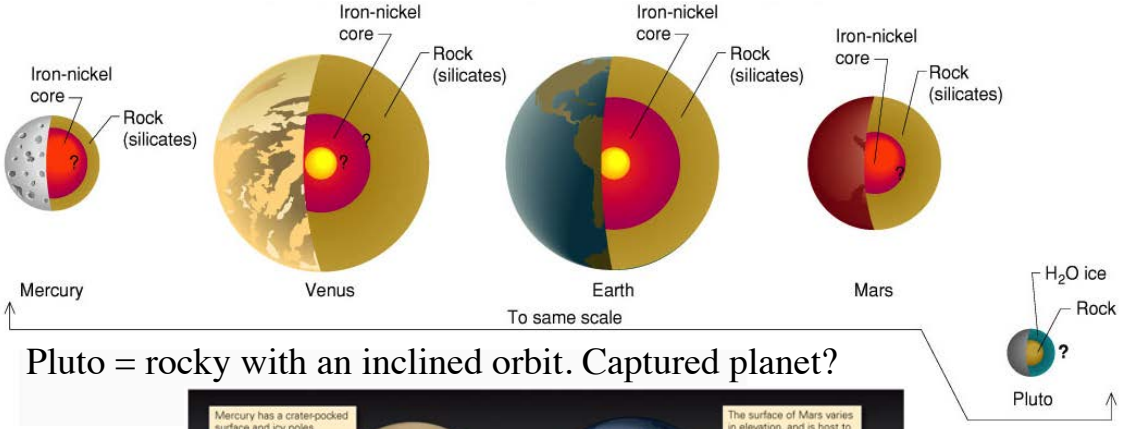
The planets orbits are nearly circular;

Observed distribution of elements.

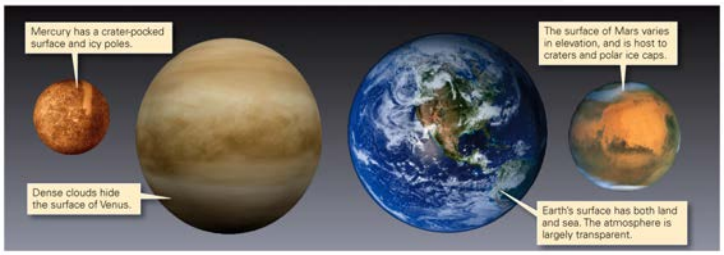


The Solar System

Four planets closest to the Sun = rocky = **Terrestrial (Inner) Planets** (silicates around an Fe core).

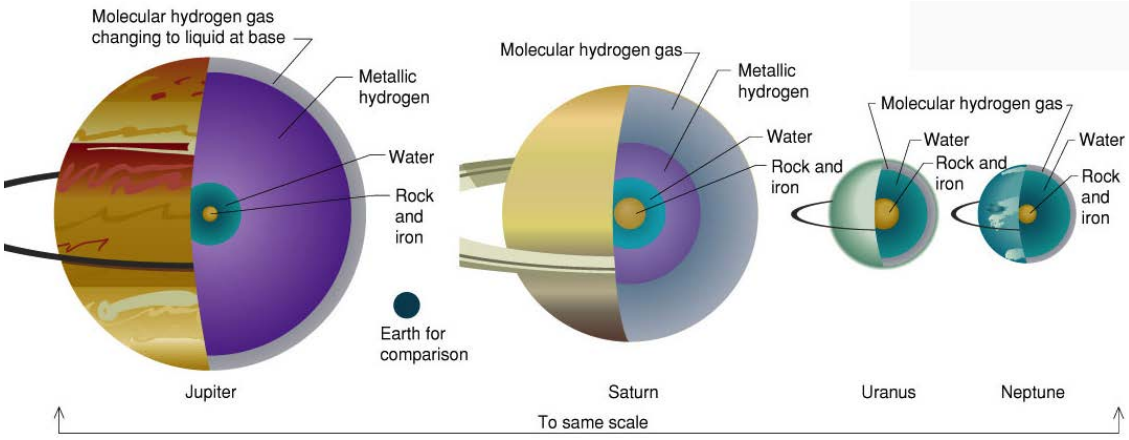


Pluto = rocky with an inclined orbit. Captured planet?



The Solar System

The next four planets are much larger = **Gas Giant (Outer) Planets** (H & its compounds; CH_4, H_2O, NH_4).



The Solar System

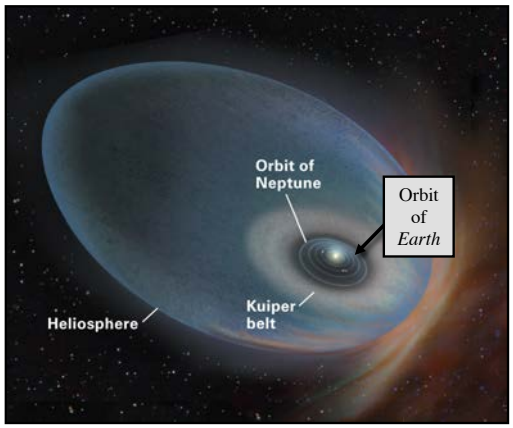
The Asteroid Belt = failed planet (Jupiter's gravity was too strong for a planet to form).
Asteroids = rocky or metallic objects.

Comets = icy objects from two sources:

1) **Kuiper Belt** – extends from a little past Neptune's orbit to a little past Pluto's orbit. Pluto is ~ 4 billion miles from the Sun.

2) **Oort Cloud** – huge spherical region extending thousands of times beyond the Sun than Pluto.

Composition known by looking at the way the sunlight is reflected by them.



Heliosphere: represents the outer reach of solar winds (charged particles from the Sun)

Comets

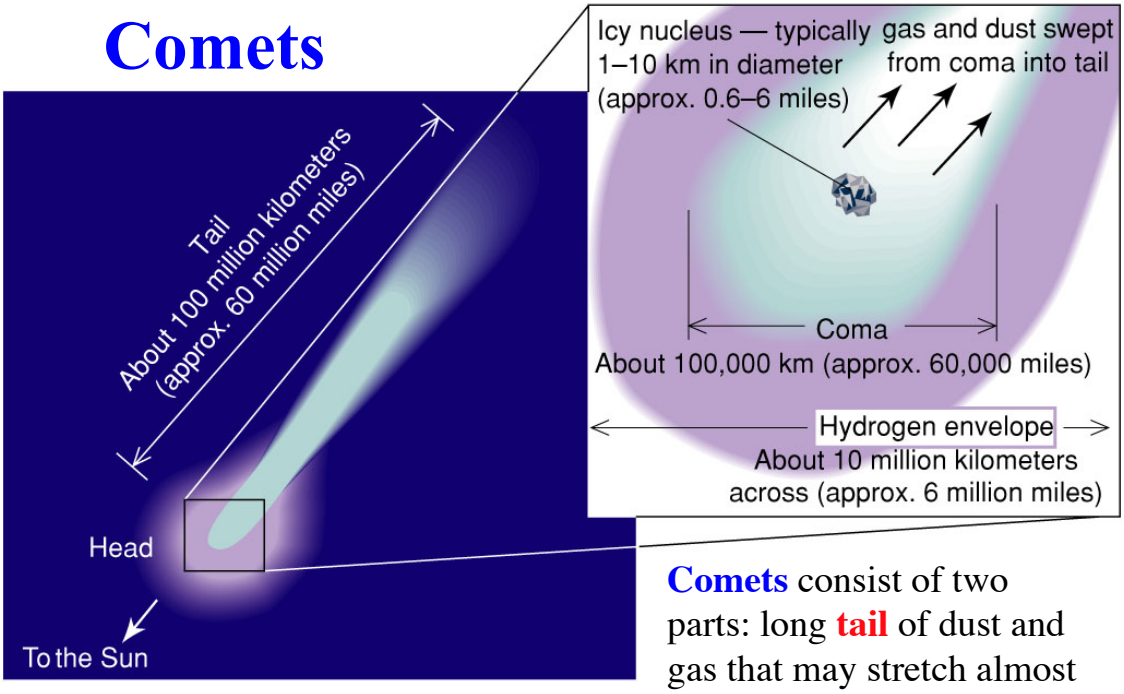
Comets have little mass: Giotto mission (ESA) to **Halley's Comet** showed the nucleus to be fluffy (0.2 g cm^{-3}).

Comet nucleus: block of ice and gases frozen in the cold of space to an irregular block (dirty snowball).

Each **comet** follows it's own orbit – those in the **Oort Cloud** take millions of years to complete an orbit, **Kuiper Belt** = shorter orbits.

Far from the Sun, gases and ices remain deeply frozen. As it gets closer to the Sun, heats up and boils to form the tail.

Comets



Comets consist of two parts: long **tail** of dust and gas that may stretch almost an AU (100 million km).

The **coma** = cloud of gas ~100,000 km around the **nucleus**.

Formation of the Comet Tail

Sunlight imparts slight pressure to dust grains = **radiation pressure**. Dust grains in the **coma** respond to the pressure and are pushed away from the Sun.

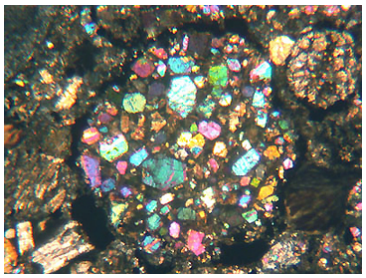
A ***second*** tail may form due to **solar wind** – outflow of gas from the Sun at ~400 km/sec, but is tenuous although strong enough to interact with the comet's **coma**. Tail usually points away from the Sun.

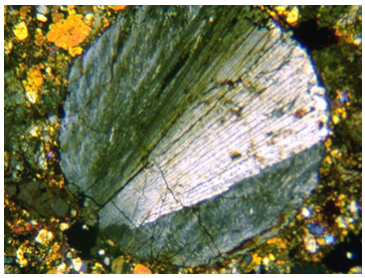
Eventually ice and gas is boiled off and rocky mass may form a meteor shower.

Meteorites

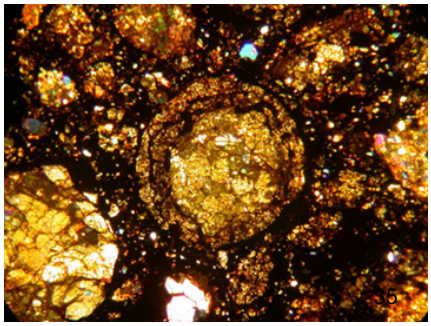
Stony, iron, stony-iron.

Some stony meteorites contain "**chondrules**" = **chondritic meteorites.**



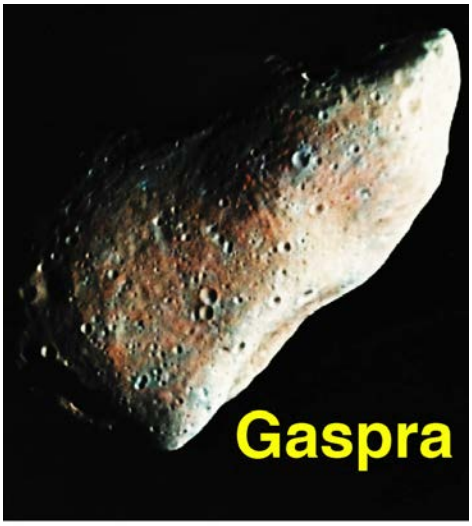


Chondrules = rounded pieces of rock. Appear to have been rapidly melted and cooled. First solid material to condense within the solar nebula and have remained unchanged.



Carbonaceous chondrites: contain black, organic matter. Building blocks for life?

Asteroids



Small rocky bodies that orbit the Sun.

Most are in the "**Asteroid Belt**" (between Mars & Jupiter).

Some can reach the size of Texas; have gravity that forms them into a sphere (e.g., Ceres).

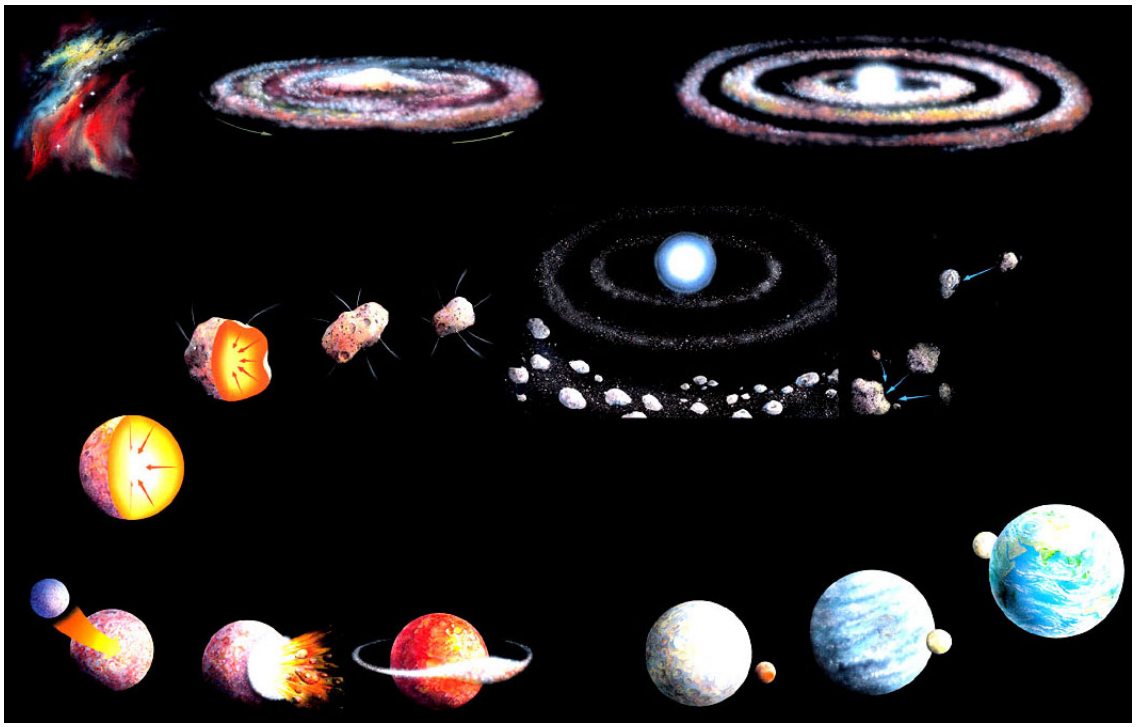
Smaller bodies = irregular. Collisions leave them "lumpy".

Probably fragments of planetesimals. Failed to form a planet because of Jupiter's tremendous gravity.

The **Apollo asteroids**. Orbit takes them across Earth's orbit.

Made up of ~700 bodies (≤ 1 km) – one hits Earth every ~10,000 years. Maybe "dead" comets.

Formation of the Earth-Moon System



Formation of the Earth-Moon System

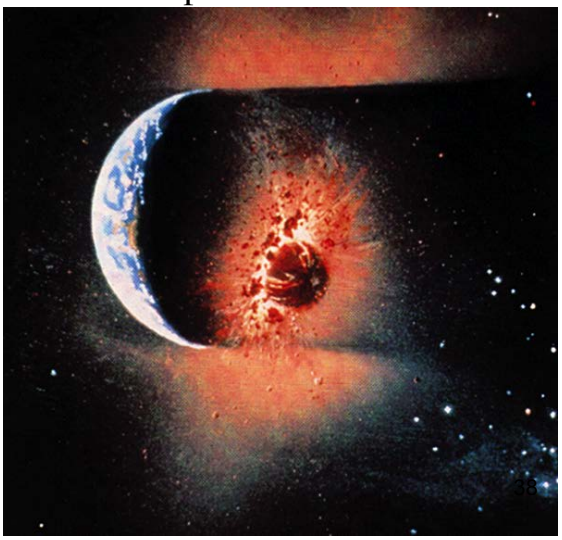
If a planet gets big enough, its gravity attracts more material.

A ring of material forms around the planet and could coalesce into a moon.

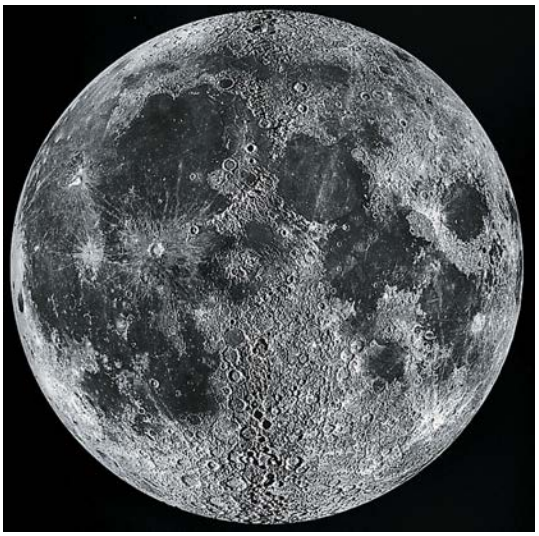
Moons could also be captured asteroids and planetesimals.

The Earth's Moon is special!

Our Moon is likely to have been formed by a Mars-sized planetesimal impacting the Earth.



The Moon



One-fourth the diameter of the Earth. Dry. Gravity = one tenth.

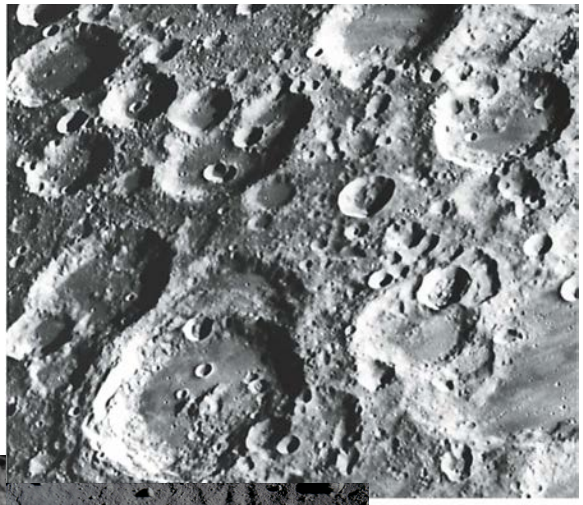
Bright areas = highlands.
Composed of anorthosites.

Maria are younger than the highlands.
Smooth dark areas = Maria or Seas - composed of basalt.

Contains a record of the early solar systems history – lack of "recent" activity - tectonically dead.

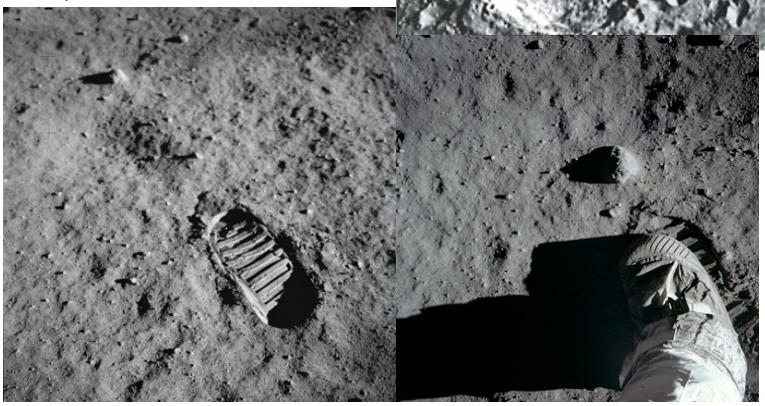
Large impacts occurred shortly after Moon formation and these subsequently filled with lava to form the Maria.

The Moon

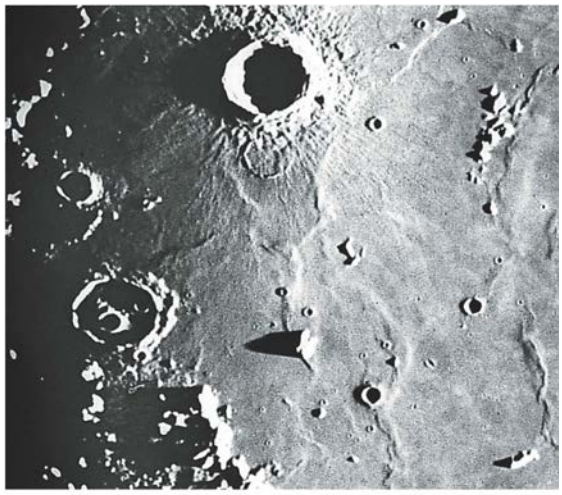


Surface is covered with impact craters – from micro to macro (240 km diameter).

Continual bombardment produces the lunar regolith - broken rock, even down to powder.



Impact Craters



B

C

Some larger craters have a central peak (rebound due to compression of material at impact).

Impact Craters

Also have "crater rays" (e.g., Tycho).

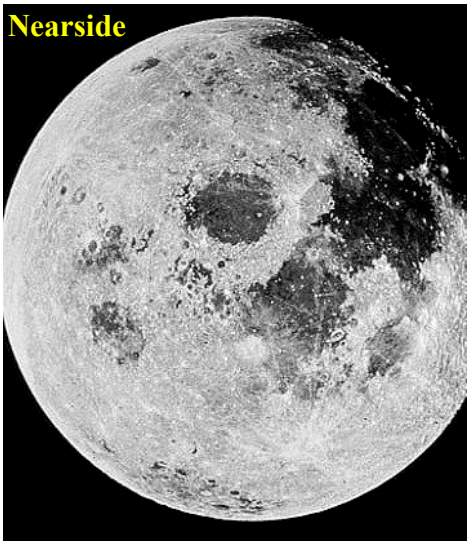
A

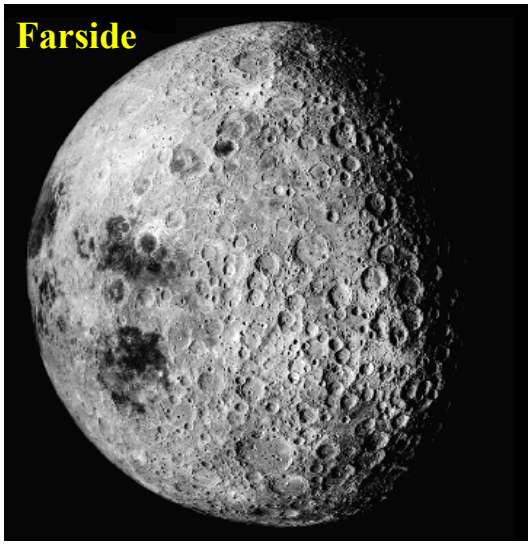
Internal Structure of the Moon

Difficult to understand – no seismic network.

What we do know:

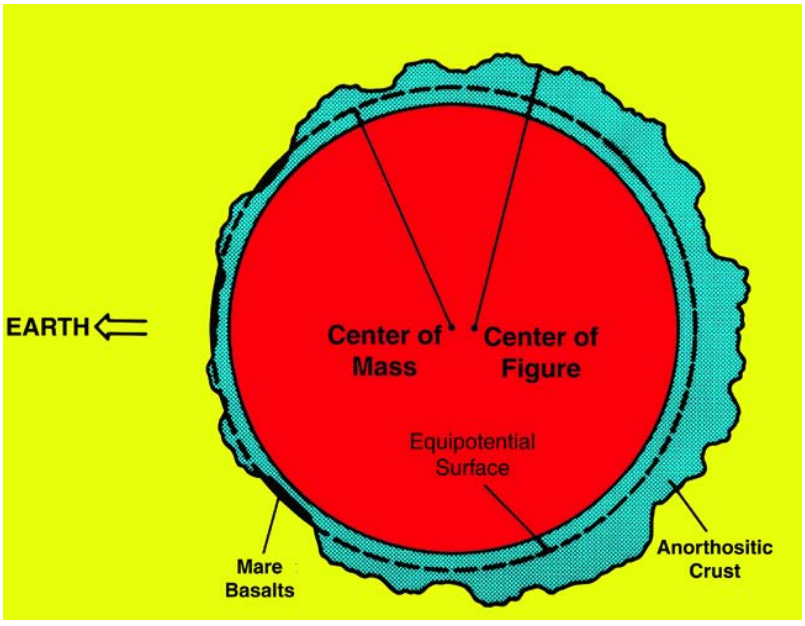
1) Crust is thicker on farside – no Maria there.





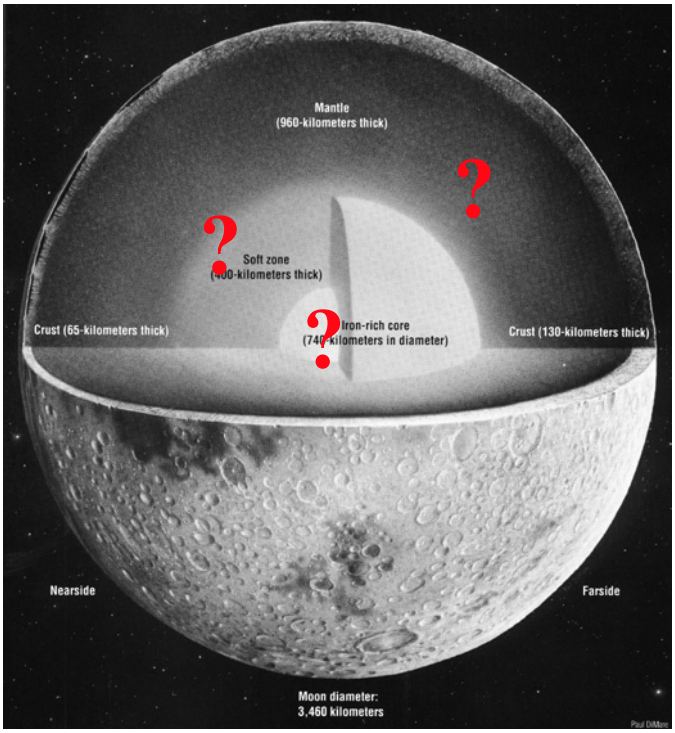
Internal Structure of the Moon

2) Center of mass is offset from the center of figure.



Internal Structure of the Moon

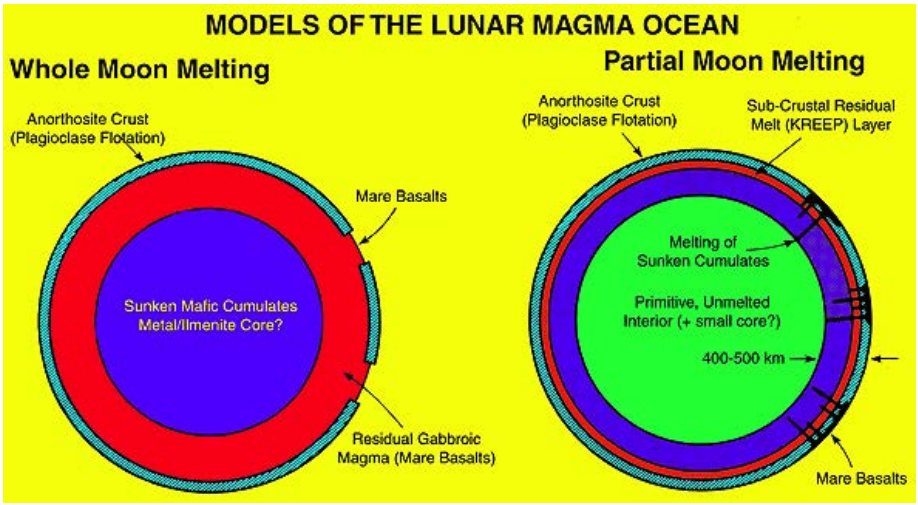
3) MAY have a small core ~250 km. MAY be Fe, but MAY be ilmenite ($FeTiO_3$). Difficult to tell – no magnetic field.



Internal Structure of the Moon

4) Lunar crust = plagioclase-rich (anorthosite) flotation cumulates.

5) Evolved through a magma ocean. The source regions of the lunar or mare basalts = mafic cumulates, but…..



Summary

Cosmology: study of the overall structure of the universe.

Geoccentric vs. **Heliocentric** orbits.

Axis of Rotation (North Star).

Distance and Subdivisions.

Doppler Effect.

Big Bang Theory.

Nebulae.

Star Formation: Accretion Disk, Protostar, Star.

Nucleosynthesis: Nuclear Fusion & Neutron Capture/Decay; H, He, C, Ne, Si Burning; Supernova.

Our Solar System: Regular spacing, inner/outer planets/ similar orbits, Nebular Theory.

Planetary Differentiation.

Comets, Asteroids, Meteorites.

Formation of the Earth-Moon System.