ESS2222H

Tectonics and Planetary Dynamics
Lecture 1 – Big Bang Theory

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Outline of the Course

- **Big Bang Theory**
- **Plate Tectonics**
- **Stress, Strain, Equations of Equilibrium**
- **The Structure of The Earth (PREM & New Models)**
- **Tectonic Evolution of the Terrestrial Planets**
- **Isostasy – Gravity Anomalies**
- **Navier-Stokes Equations**
- **Thermal Convection**
- **Iron Spin Transition in the Lower Mantle**

Big Bang Theory

Once Upon a Time
was No Space, No Time

Big Bang

Nature Timeline

❑ **The Very Early Universe**	**The first $\sim 10^{-12}$ seconds of cosmic time**
❑ **The Early Universe**	**~10^{-12} seconds - 370 Kyr**
❑ **Large-Scale Structure Emergence**	**~370 ka to 150-1 Ga**
❑ **The Universe as it Appears Today**	**~ 1 Ga ~ 13.8 Ga**
❑ **The Universe in Future**	**From now to >100 Ga**

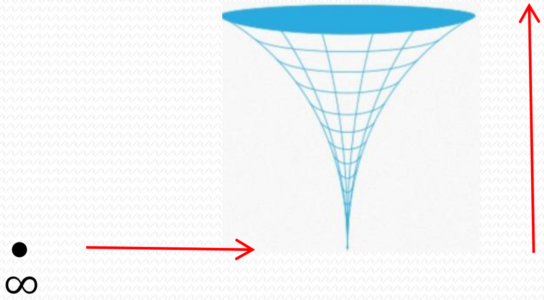
The Very Early Universe

- **Planck epoch**
- **Grand unification epoch**
- **Electroweak epoch**
- **Inflationary epoch**
- **Electroweak epoch and early thermalization**
- **End of electroweak epoch**

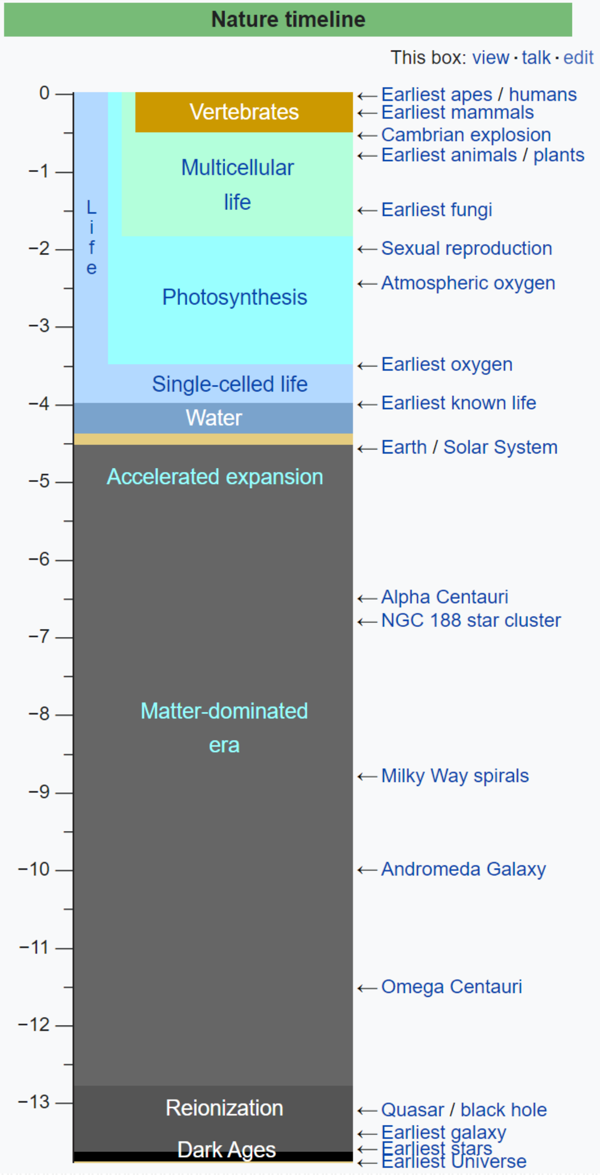
Big Bang
The Very Early Universe

The very early universe – The first $\sim 10^{-12}$ seconds of cosmic time. The universe expansion was extremely large, by a factor of 10^{26} in each dimension ($> 10^{78}$ in volume), like the expansion of one nanometer object (10^{-9}m) to 10.6 light year (10^{14}km). The period ends at 10^{-12}seconds after the Big Bang.

Planck epoch - Times $< 10^{-43}$seconds (Planck time). The current laws of physics may not be applied. The quantum effects of are dominated gravity (strong). Radiation temperature $> 10^{32}\ K$.



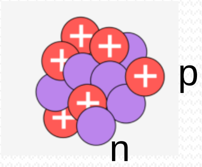
Concentration of infinite energy



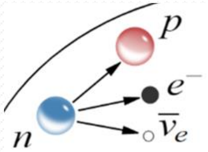
Big Bang
The Very Early Universe

Grand unification epoch - Between 10^{-43} seconds and 10^{-36} seconds after the Big Bang. Standard Model comprising the electromagnetic, weak, and strong forces merged into a single force (no gravity) is governed. Radiation temperature $> 10^{29}\ K$.

Strong force ($\boldsymbol{F_S}$) keeps the protons and neutrons together (range: ~10^{-15} m).



Weak force ($\boldsymbol{F_W}$) is responsible for particle decay (range: ~10^{-17} m).



Electromagnetic force ($\boldsymbol{F_{EL}}$) explains how moving and stationary charged particles interact (range: ∞).

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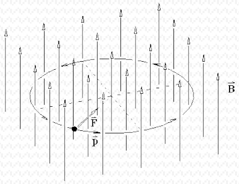
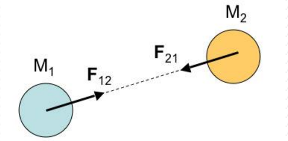


Gravity force ($\boldsymbol{F_G}$) is the force that pulls all the masses in the universe together (range: ∞).



$\boldsymbol{F_S \sim 137 F_{EL}}$ $\qquad$ $\boldsymbol{F_S} \sim 10^6 \boldsymbol{F_W}$ $\qquad$ $\boldsymbol{F_S \sim 10^{38}\ F_G}$

Big Bang
The Very Early Universe

Electroweak epoch - Between 10^{-36} seconds and 10^{-32} seconds (the end of inflation) after the Big Bang. Radiation temperature $10^{28} - 10^{22}K$. The strong interaction becomes distinct from the electroweak interaction. The temperature of the universe falls enough that the strong force separated from the electroweak interaction, but was high enough for electromagnetism and the weak interaction to remain **merged** into a single electroweak interaction.

Inflationary epoch - The rapid expansion of space by a factor of 10^{26} during$10^{-36} - 10^{-32}$ seconds after the Big Bang (vacuum with high energy density causes repulsive forces and expansion).

Electroweak epoch and early thermalization - Between $10^{-22}$and 10^{-15}seconds after the Big Bang, until 10^{-12} seconds after the Big Bang. Mutual interactions lead to thermal equilibrium (thermalization) at a temperature of around 10^{15} K, 10^{-15} seconds after the Big Bang.

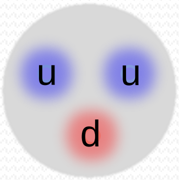
End of electroweak epoch – At 10^{-12} seconds after the Big Bang. Radiation temperature drops to $10^{15}K$.

The Early Universe

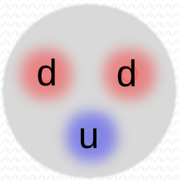
- ❑ **Quark epoch**
- ❑ **Hadron epoch**
- ❑ **Neutrino decoupling**
- ❑ **Leptons epoch**
- ❑ **Nucleosynthesis epoch**
- ❑ **Photon epoch**
- ❑ **Recombination**

Big Bang
The Early Universe

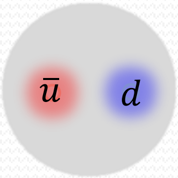
The early universe – Starting from $\sim 10^{-12}$ seconds after the Big Bang, this period lasted around 370 Kyr. During this period of time subatomic particles like proton, neutron, or meson (with composite structure), and electron, photon, or muon (elementary particles) were created. By 20 minutes, the universe is no longer hot enough for nuclear fusion, the universe is opaque plasma (ionized atoms and free electrons).



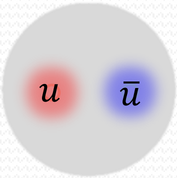
Proton



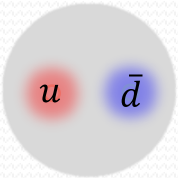
Neutron



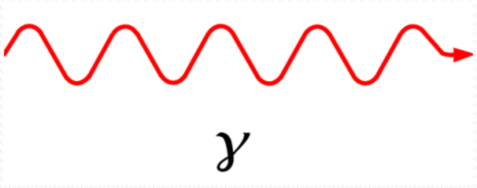
π^-

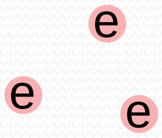


π^0

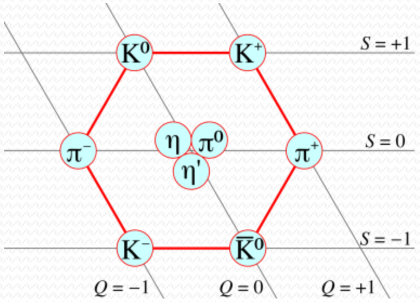


π^+





Electrons



Mesons

Big Bang
The Early Universe

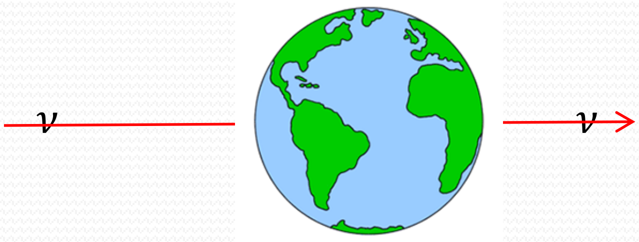
Quark epoch – The forces of the Standard Model have reorganized into the low-temperature form during $10^{-12} - 10^{-5}$ seconds after the Big Bang. Radiation temperature $10^{15} - 10^{12}K$. Energies are too high for quarks to coalesce into hadrons, instead forming a quark–gluon plasma.

Hadron epoch – Quarks become bound as hadrons (e.g., proton, neeutron) during $10^{-5} - 1$ seconds after the Big Bang. Anti-baryons (e.g., antimatter of protons and neutrons) annihilation occurs at this period of time. Up until 0.1 s, muons (μ) (with no sub-structure) and pions (π^-, π^0, π^+) are in thermal equilibrium, 10 times larger in population compared to the baryons. The neutron-proton ratio ~1 starts to decrease. Radiation temperature $10^{12} - 10^{10}K$.

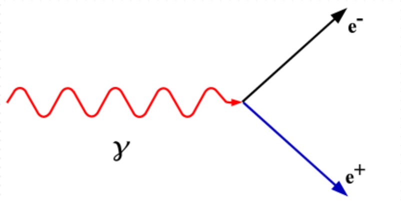
Big Bang
The Early Universe

Neutrino decoupling – At ~1 second after the Big Bang. The density and temperatures drops and neutrinos cease interacting with baryonic matter and form **cosmic neutrino background (CNB)**. Radiation temperature $\sim 10^{10} K$.

Neutrinos (neutral, spin ½ particles with very small mass) rarely interact with matter (unless the density of matter is very high). The **CNB** is a **relic** of the Big Bang (~1 second after the Big Bang); while the **cosmic microwave background radiation (CMB**) dates from when the universe was 379,000 years old. It is estimated today CNB has a temperature of ~1.95 K.



Leptons epoch – 1-10 seconds after the Big Bang. Leptons (like electron, muon, neutrino) and antileptons in thermal equilibrium – the energy of photons still high enough to produce electron-positron pairs. Radiation temperature $10^{10} - 10^{9} K$.

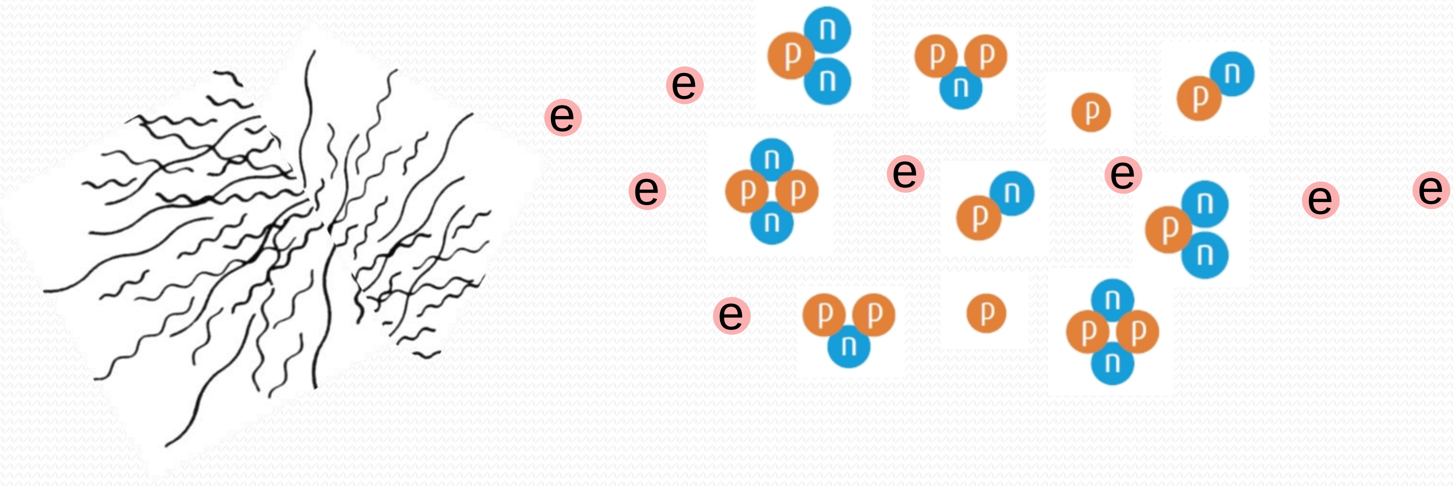


Big Bang
The Early Universe

Nucleosynthesis epoch – 1-1000 seconds after the Big Bang. **Atomic nuclei** formed: hydrogen (${}_{1}^{1}H$), and helium-4 (${}_{2}^{4}He$), trace amounts of deuterium (${}_{1}^{2}H$), helium-3 (${}_{2}^{3}He$), and lithium-7 (${}_{3}^{7}Li$). Most energy at this time is in electromagnetic radiation. Radiation temperature $10^9 - 10^7 K$.

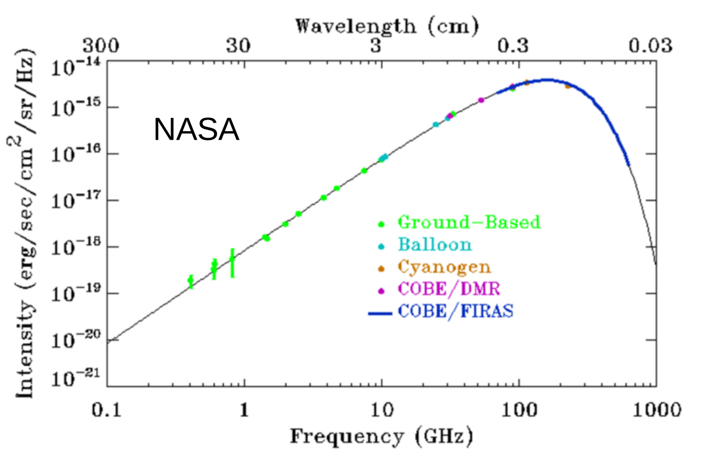
${}^{1}H$ ${}^{2}H$ ${}^{3}H$ ${}^{3}He$ ${}^{4}He$

Photon epoch – 10 s ~ 370 ka after the Big Bang. The universe consists of a **plasma** of nuclei (no bound electrons), electrons, and photons. Radiation temperature $10^9 - 4000K$.

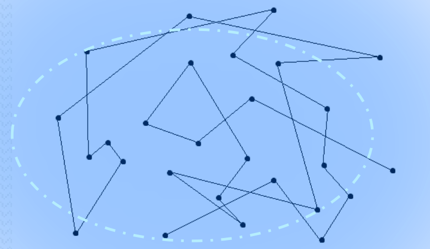


Big Bang
The Early Universe

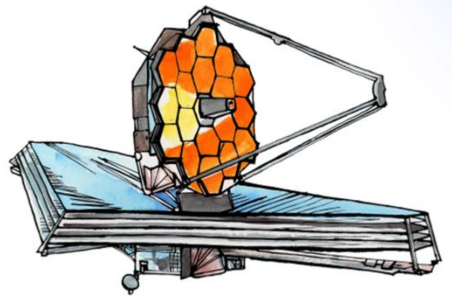
Recombination – By the end of ~ 370 ka **electrons and nuclei become bound** to form neutral atoms (decoupling occurs: separation of light and matter). **Photons are no longer in thermal equilibrium with matter** and the universe first becomes **transparent**. The photons of the **cosmic microwave background (CMB) radiation** originate at this time.



Microwave spectrum



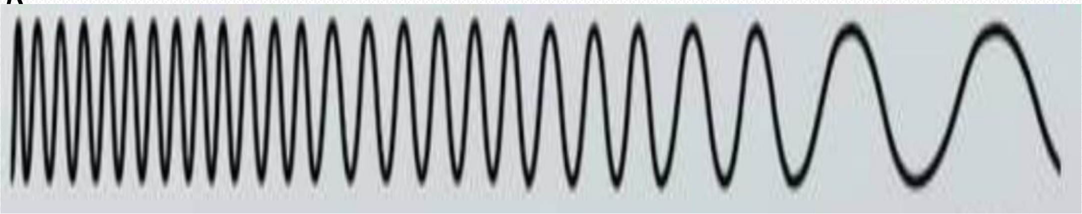
Trapped photons



JWST will look at this radiation

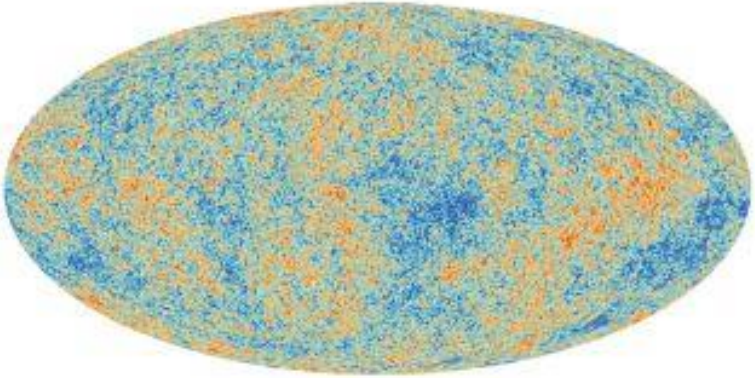
Large-Scale Structure Emergence

Dark ages – 370 ka to 150-1 Ga. The time between recombination and the **formation of the first stars**. Freely propagating CMB photons quickly (in ~3 Myr) red-shifted to infrared, and the universe was **devoid of visible light**. Radiation temperature $4000 - 60\ K$



370 Kyr

13.8 Gyr (present day)



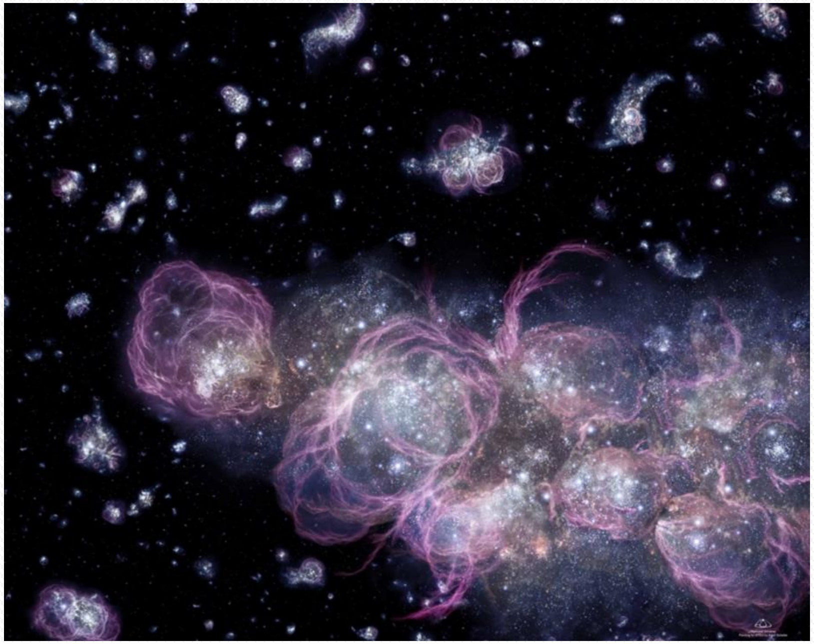
Cosmological redshift: The original wavelength of the light emitted from the galaxies is lengthened as it travels through expanding space (due to the expansion of the universe).

The cosmic microwave background (CMB) radiation, taken by the European Space Agency (ESA)'s Planck satellite (2013), (Image credit: ESA/Planck Collaboration) - (~2.725 K, most evident in 70 -217 Ghz range). Color fluctuation is of order of $10^{-5}K$.

Large-Scale Structure Emergence

The universe after ~370 Kyr years from the big bang was a cold, dark fog of hydrogen and helium atoms. The first stars are thought to have formed within 100 Myr from the big bang when the hydrogen and helium gases collapsed under their gravitational pull. Nuclear fusion started at the center of these early stars, releasing energy in the form of heat and light. Within 400 Myr years infant galaxies appeared.

Until now it is not clear what were the first stars (the building blocks of the first galaxies) like, how and when they were formed. **James Webb space telescope (JWST)** may provide answers to these questions.



Artist's conception of early star formation - CREDIT: Adolf Schaller for STScI

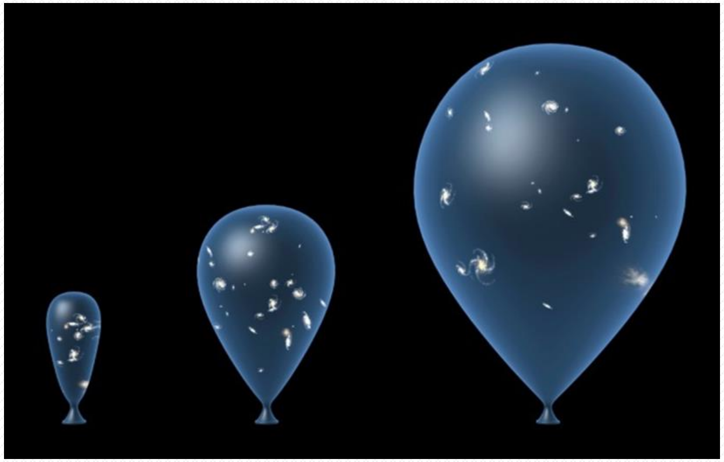
The Universe as it Appears Today

Star and galaxy formation – Earliest galaxies: from about ~300–400 Ma (not well established). **Modern galaxies**: **1 Ga ~ 13.8 Ga.** Radiation temperature decreasing from $60\ K$.




The Universe as it Appears Today

Present time – 13.8 Ga. Farthest observable photons at this moment are **CMB** photons. They arrive from a sphere with the radius of **46 billion light-years** (although the upper limit of speed in the speed of light, however, the universe is expanding) within which is observable universe. Radiation temperature ~ 2.7 K.



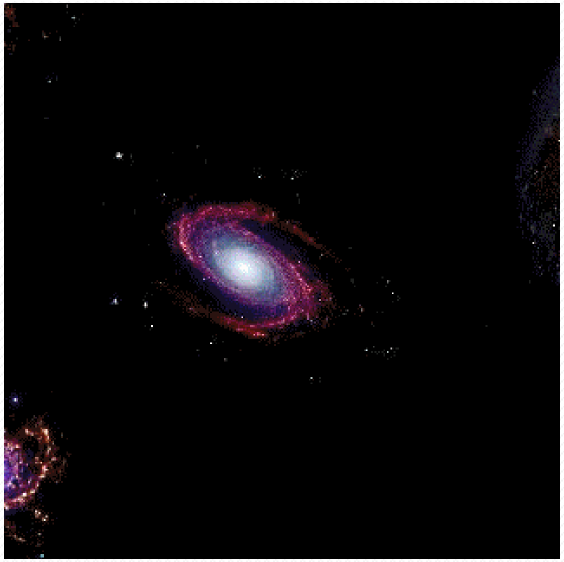
Credit: TAKE 27 LTD/SPL

Artist's logarithmic scale conception of the observable universe.
WIKIPEDIA USER PABLO CARLOS BUDASSI

The Universe in Future

Far future time – >100 Ga. Stars eventually die and fewer are born to replace them, leading to a darkening universe. Matter may eventually evaporate into a Dark Era (heat death). Alternatively the universe may collapse in a **Big Crunch**. Radiation temperature ~ 0.1 K.

Big Crunch theory – As stars are no longer being born, the universe become to its end and the expansion of the universe eventually reverses and the universe collapses. This can eventually cause another big Bang. But today there are evidences that this theory is **not correct**.



https://commons.wikimedia.org/w/index.php?curid=1297266

The Universe in Future

Big Rip theory – Astronomical observations show that the expansion of the universe is accelerating, rather than being slowed by gravity. The Big Rip is a hypothetical cosmological model in which the matter of the universe and space-time are progressively expanding and will be torn apart by the expansion of the universe at a certain time in the future, until distances between particles will become infinite.


kjpargeter / Freepik

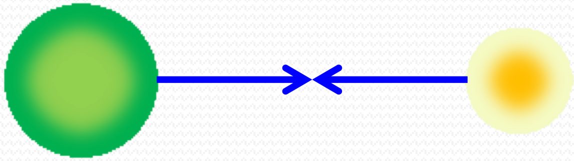
Heat Death (Big Chill or Big Freeze) Hypothesis – Earthy universe was very energetic and matter and energy could easily interchange. As the universe evolved temperature differences increased (e.g., formation of hot stars), which provided more opportunity for work. However, as the universe becomes old, it reaches to its thermodynamically equilibrium and the entropy of the universe increases (i.e., less energy available to do work). Eventually, all temperatures will equalize, and in the absence of temperature gradients, no heat can be changed into the work and the universe will end in heat death.

Primitive Solar Nebula

Solar system formed about 4.6 billion year ago from low-density cloud of interstellar gas and dust (called a **nebula**) by gravitational forces.

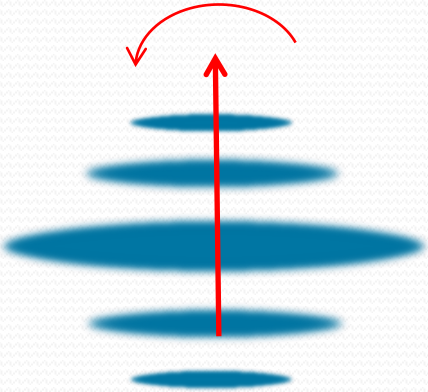
a) Nebula was initially about several light years across

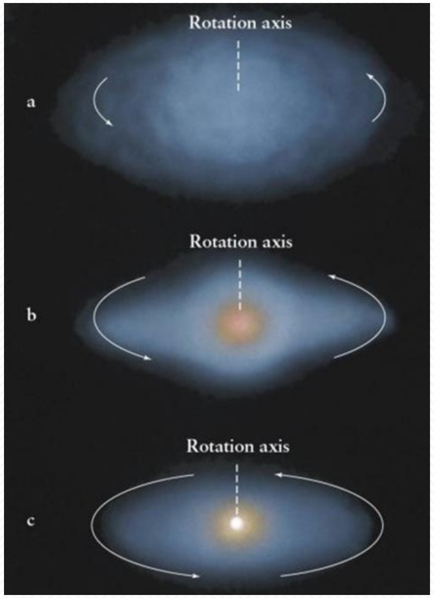
b) Gravitational collapse was more efficient along the spin axis, so the rotating ball collapsed into thin disk with a diameter of 200 AU (0.003 light years) (AU: 149,597,870.7 km).

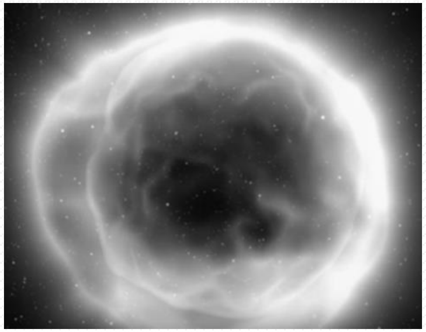


$$F_{Pole} = -G\frac{M\,m}{r^2}$$

$$F_{Equat} = -G\frac{M\,m}{r^2} + \frac{mv^2}{r}$$







Nebula for the formation of new stars

~ 4.571 Ga

https://pages.uoregon.edu/imamura/121/lecture-5/lecture-5.html

Primitive Solar Nebula

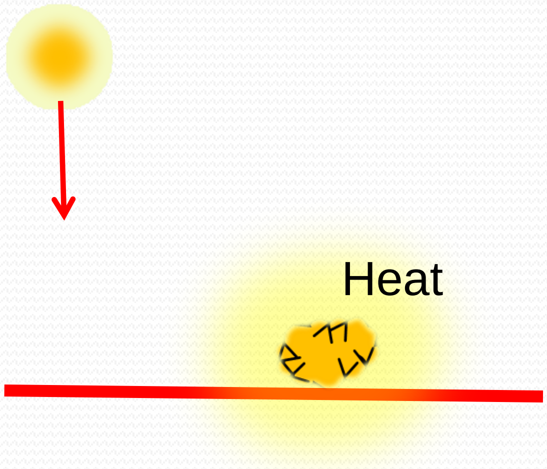
c) Most of the mass was concentrated near the center
d) Gravitational potential energy was converted into kinetic energy
e) The nebula became very hot near the center to form the **protosun** (the cloud of gas that later became Sun)

Heating: The temperature of the solar nebula increases as it collapses.

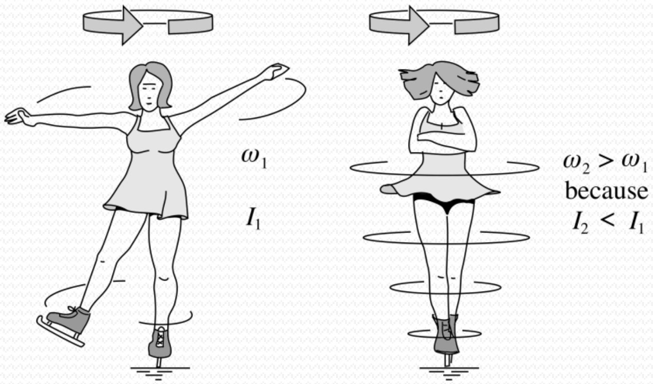
Gravitational potential energy → Kinetic energy

Kinetic energy → Heat

Spinning: Like an ice skater pulling in her arms as she spins, the solar nebula rotates faster and faster as it shrinks in radius.



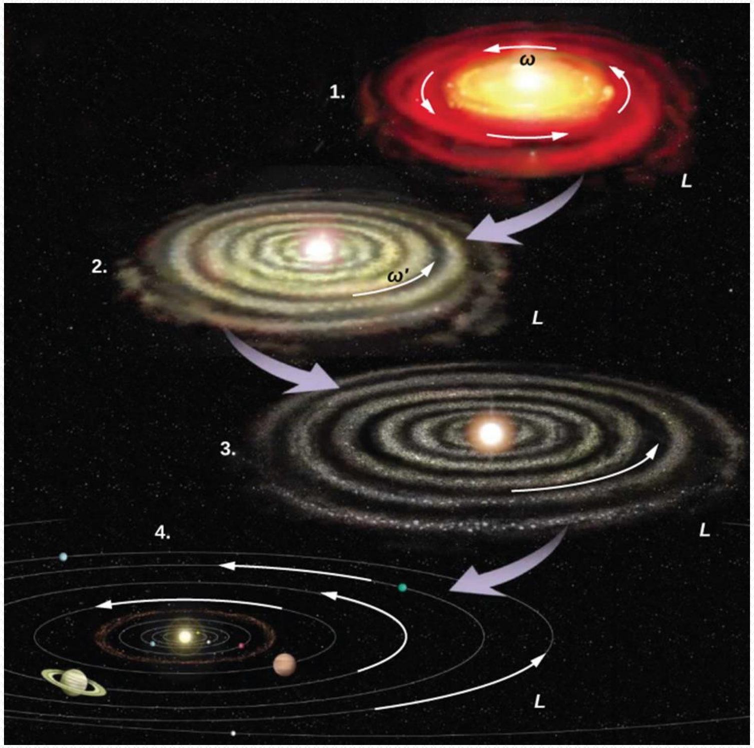
$$L = I\omega$$
$$I = \sum m_i r_i^2$$
$$L_1 = L_2$$



https://www.physics.brocku.ca/PPLATO/h-flap/phys2_8.html

Primitive Solar Nebula

f) The central temperature rose to 10 MK, nuclear reactions began
g) Temperature, density and pressure toward the center increased
h) Hydrostatic equilibrium (balance between the gravitational force and the internal pressure) was reached after 50 million years
i) Sun was born from 99.8% of the nebula mass
j) Around the Sun the remaining mass within the disk formed the planets



https://courses.lumenlearning.com/suny-osuniversityphysics/chapter/11-2-conservation-of-angular-momentum/

Primitive Solar Nebula

Portion of the Carina Nebula, 8,500 light-years from Earth

The elements in the primitive solar nebula by mass

Hydrogen (H) and Helium (He) ~ 99.8% (91% H)
Oxygen, Carbon, Neon, Nitrogen, Silicon, Magnesium, Sulphur, Argon, Iron, Sodium, Chlorine, Aluminum, Calcium, … ~ 0.2%

Number density in the interstellar medium

a) In cool dense regions matter is primarily in molecular form, and reaches number densities of 10^6 molecules / cm^3.

b) In hot diffuse regions matter is primarily ionized, and the density may be as low as 10^{-4} ions / cm^3.

Note that air at sea level has a number density of roughly 10^{19} molecules / cm^3. The number density for a laboratory high-vacuum chamber is 10^{10} molecules / cm^3.

Stellar evolution

Stellar evolution is the process by which a star changes over the course of time. All stars are born from:

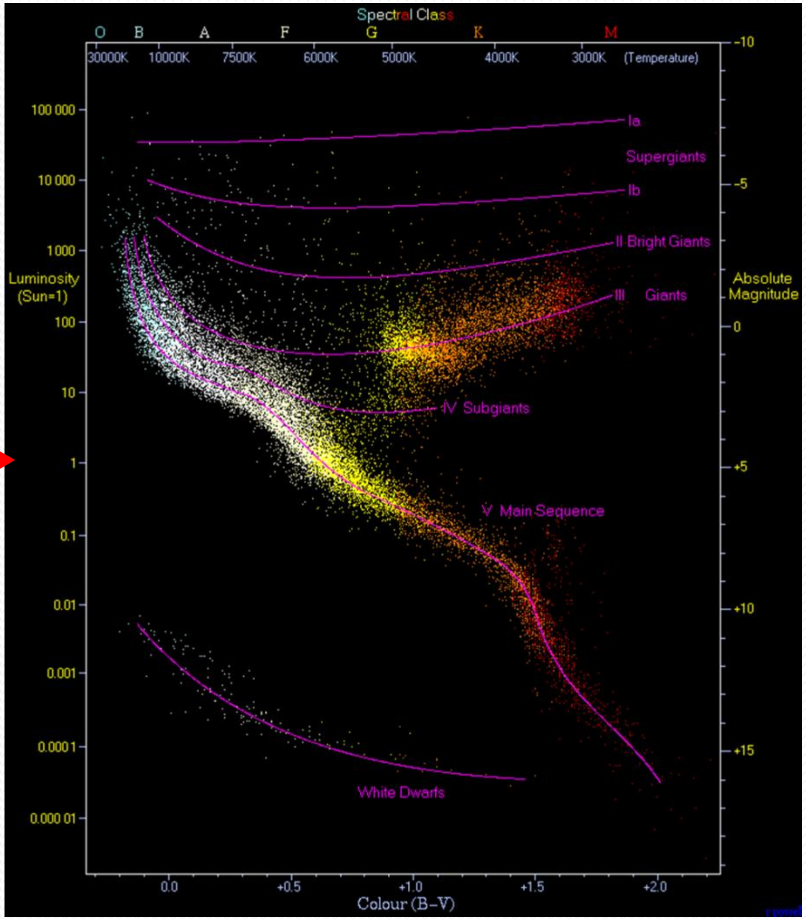
a) Collapsing clouds of gas and dust, often called molecular clouds (nebulae).

b) Over the course of millions of years, these protostars (a very young star gathering mass from its parent cloud) settle down into a state of equilibrium (called main-sequence star).

Most main sequence stars are **dwarf** stars.

Dwarf star: A star of relatively small size and low luminosity

Luminosity
Sun =1

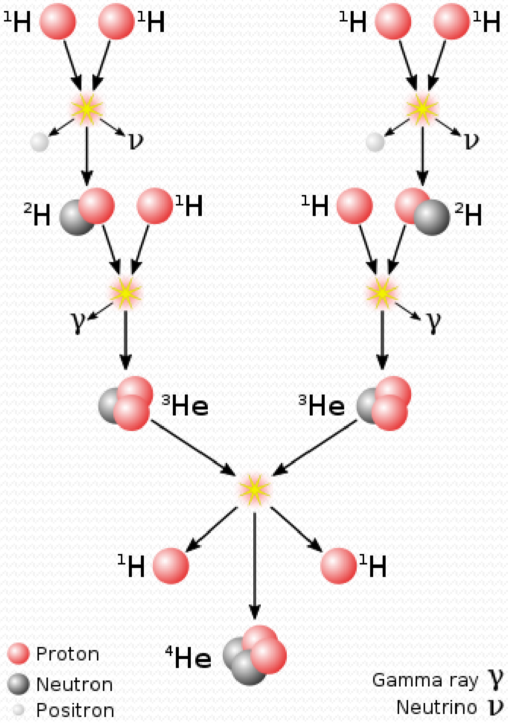


Blue **Red**

Hertzsprung–Russell diagram
https://commons.wikimedia.org/w/index.php?curid=1736396

Stellar evolution

c) Nuclear fusion powers a star for most of its life.
d) Initially the energy is generated by the fusion of hydrogen atoms at the core.
e) Later, as helium increases in the core, stars like the Sun begin to fuse hydrogen along a spherical shell surrounding the core.



https://commons.wikimedia.org/w/index.php?curid=51118538

$$p + p \rightarrow {}_1^2H + e^+ + \nu_e \qquad \longrightarrow$$

$${}_1^2H + e^+ + \nu_e + e^- \rightarrow {}_1^2H + + \nu_e + \gamma(1.442\ Mev)$$

$${}_1^2H + {}_1^1H \rightarrow {}_2^3He + \gamma \qquad (5.493\ Mev)$$

. . . .

. . . .

Fusion of heavy elements (like C,N, O) becomes possible in stars larger than our Sun.

Stellar evolution

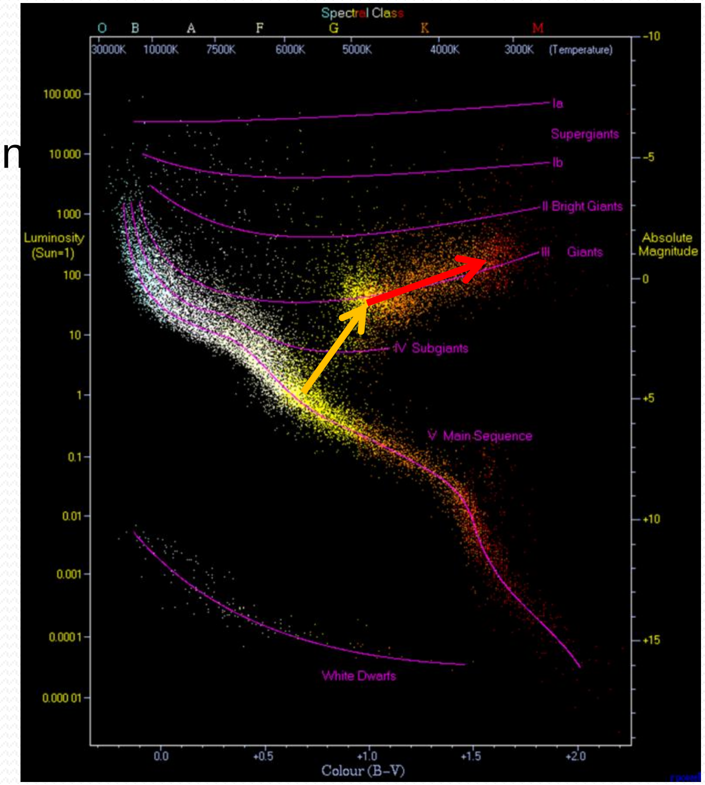
f) The star gradually grows in size, passing through the sub-giant stage until it reaches the red giant phase. At this stage the Sun undergoes the **triple-alpha process** (reactions by which three helium-4 nuclei (alpha particles) are transformed into carbon) with **huge** amount of radiation compared to Sun's current radiation.

Sub-giant star: As star that is brighter than a normal main-sequence star of the same spectral class, but not as bright as giant stars.

Red giant: A red giant is a luminous giant star of low or intermediate mass (~0.3–8 solar masses) in a late phase of stellar evolution.

g) Stars with at least half the mass of the Sun can also begin to generate energy through the fusion of helium at their core.

h) More-massive stars can fuse heavier elements along a series of concentric shells.

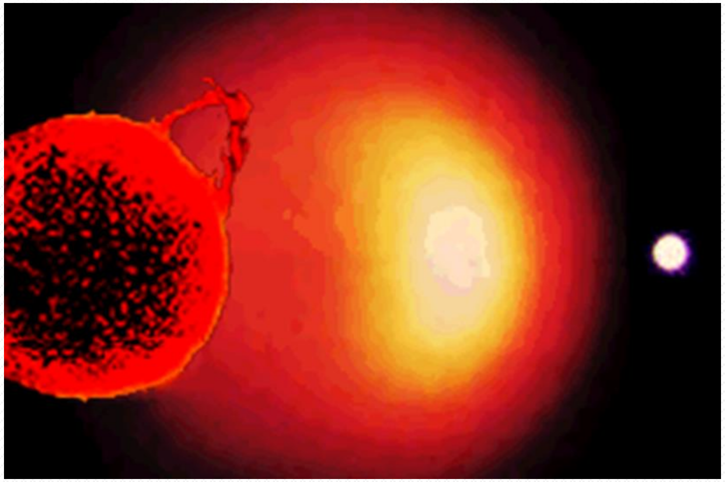


Blue → **Red**

Stellar evolution

i) Once a star like the Sun has **exhausted** its nuclear fuel, its core collapses into a dense white dwarf (hotter and brighter) and the outer layers are expelled as a planetary nebula.

White dwarf: A white dwarf is what stars like the Sun become after they have exhausted their nuclear fuel. Near the end of its nuclear burning stage, this type of star **expels** most of its **outer material**, creating a planetary nebula. Only the hot core of the star remains. This core becomes a very hot white dwarf, with a temperature exceeding 100,000 Kelvin.



An Artist's conception of the evolution of our Sun (left) through the red giant stage (center) and onto a white dwarf (right) – NASA.

j) Stars with around **ten** or more times the mass of the Sun can explode in a supernova (a powerful and luminous stellar explosion) as their inert iron cores collapse into an extremely dense neutron star or **black hole**.

Main-sequence star → collapses into small size (brighter & hot) → sub-giant → red giant → white dwarf

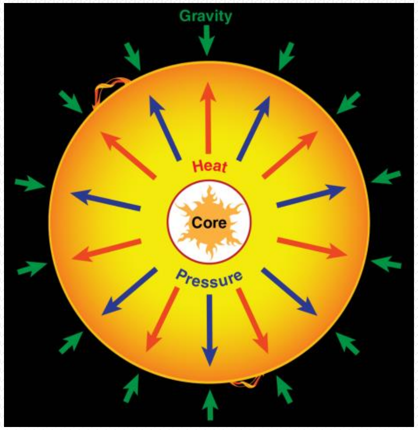
fuel finishes → radiation pressure and gravity imbalance another phase of burning again

Stellar evolution

Two types of supernovae:

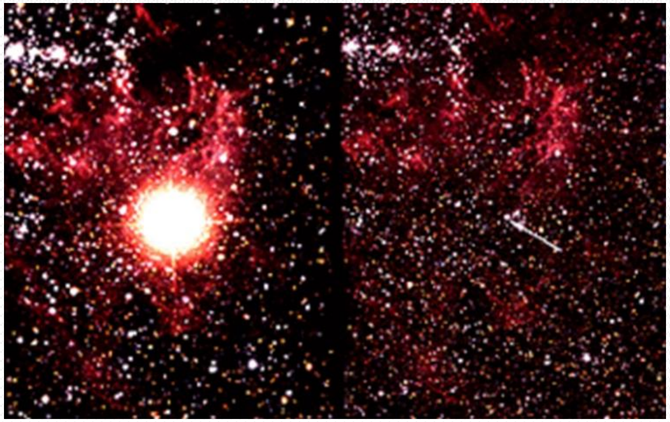
I - The first type happens in **binary star** systems (two stars orbiting the same point. One of the stars, a carbon-oxygen white dwarf, **steals matter** from its companion star. Eventually, the white dwarf accumulates too much matter. Having too much matter causes the star to explode, resulting in a supernova.

II - The second type occurs at the end of a **single star's** lifetime. As the star runs out of nuclear fuel (decease in temperature), some of its mass flows into its core. Eventually, the core is so heavy that it cannot withstand its own gravitational force. The core collapses, which results in the giant explosion of a supernova. The sun is a single star, but it does not have enough mass to become a supernova.

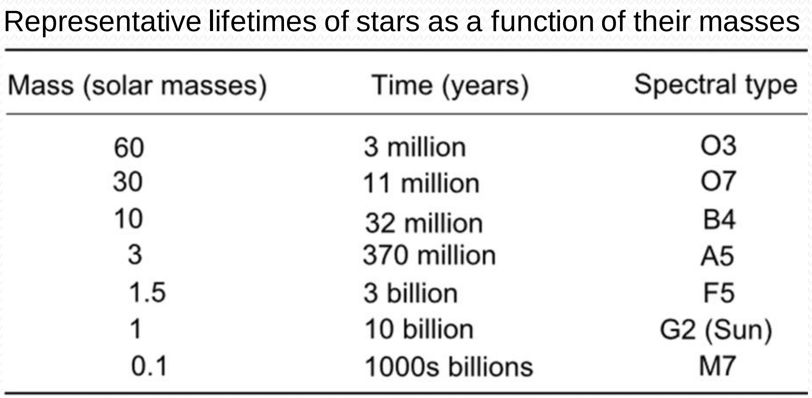


A balance of gravity pushing in on the star and heat and pressure pushing outward from the star's core.
Credits: NASA

On the left is Supernova 1987A after the star has exploded. On the right is the star before it exploded.
Credits: NASA



Stellar evolution



Representative lifetimes of stars as a function of their masses

Mass (solar masses)	Time (years)	Spectral type
60	3 million	O3
30	11 million	O7
10	32 million	B4
3	370 million	A5
1.5	3 billion	F5
1	10 billion	G2 (Sun)
0.1	1000s billions	M7

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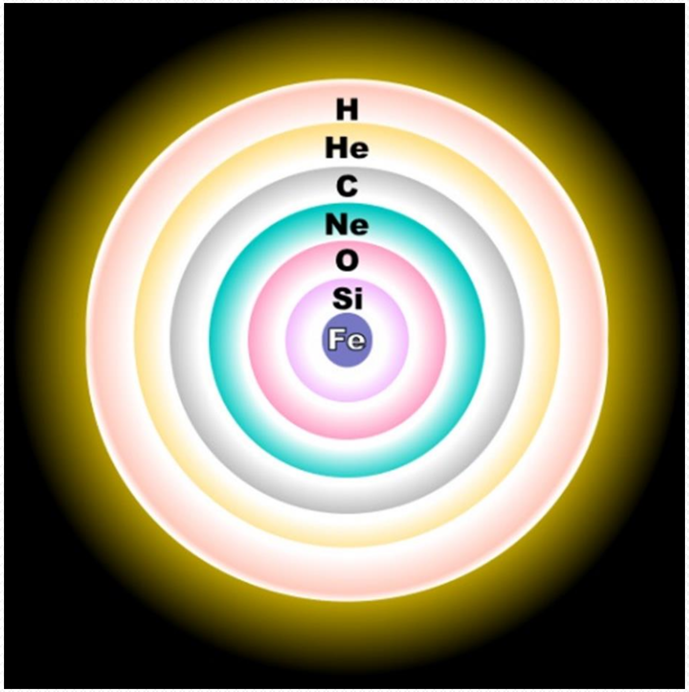

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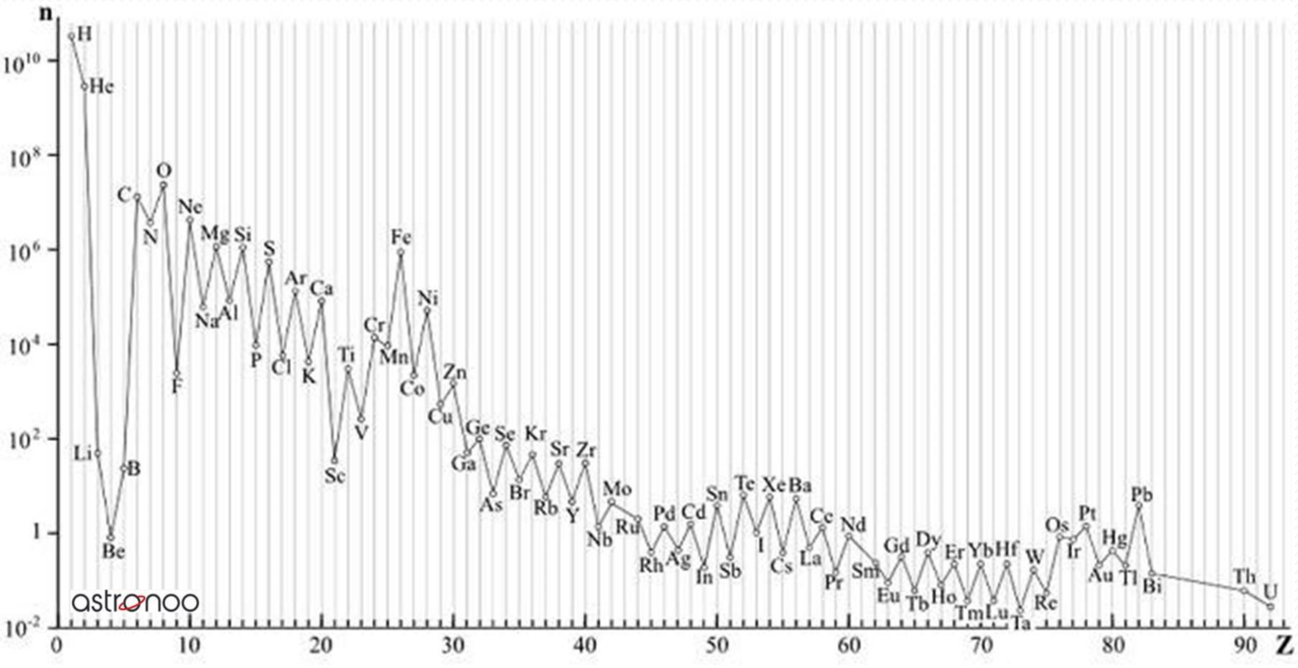
The onion-like layers of a massive, evolved star just before core collapse (not to scale).

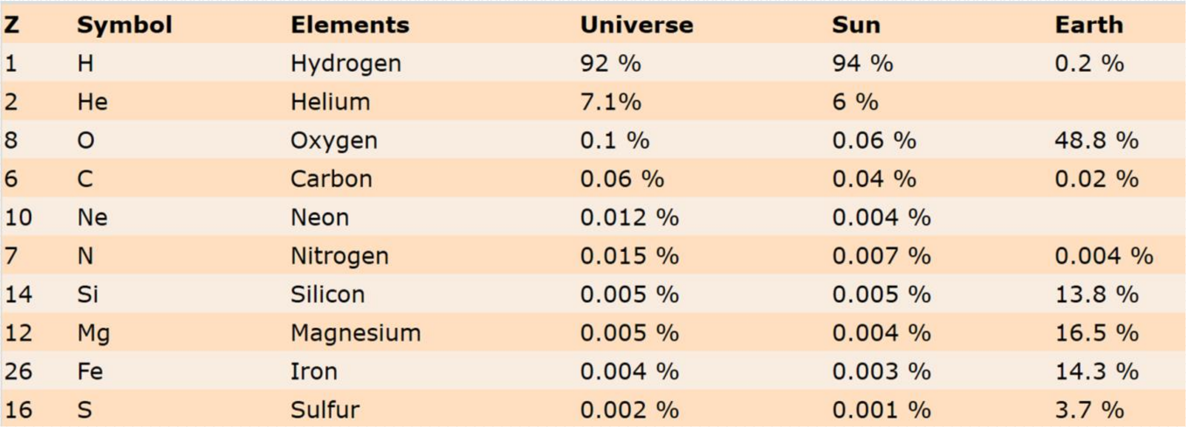
Brown dwarf: Stars with less than 0.08 the Sun's mass. They are not massive enough to sustain nuclear fusion of ordinary hydrogen ${}_{1}^{1}H$, however, they are able to fuse deuterium ${}_{1}^{2}H$.

Red dwarf: Stars half as massive as the Sun (slow nuclear fusion)

Yellow dwarf: Our Sun

Relative Abundance of the Chemical Elements





Z	Symbol	Elements	Universe	Sun	Earth
1	H	Hydrogen	92 %	94 %	0.2 %
2	He	Helium	7.1%	6 %	
8	O	Oxygen	0.1 %	0.06 %	48.8 %
6	C	Carbon	0.06 %	0.04 %	0.02 %
10	Ne	Neon	0.012 %	0.004 %	
7	N	Nitrogen	0.015 %	0.007 %	0.004 %
14	Si	Silicon	0.005 %	0.005 %	13.8 %
12	Mg	Magnesium	0.005 %	0.004 %	16.5 %
26	Fe	Iron	0.004 %	0.003 %	14.3 %
16	S	Sulfur	0.002 %	0.001 %	3.7 %

Relative abundance of chemical elements in the Universe, based on digital data A.G.W. Cameron (1973).

The structure of the disk

a) The rotation of the particles within the disk (having 0.2% of the mass of the solar nebula) around the center of nebula prevented further collapse of the disk

b) The temperature of the disk was several thousands degree near the center due to the gravitational energy release, bringing the matter to vapour state

c) The lighter gas swept far out the Solar System by Solar winds, increasing the temperature of the rocky material to the melting point near the Sun

d) As the disk cooled by infrared radiation, the temperature dropped and the process of condensation began (formation of tiny solid or liquid droplet from the heavy molecules)

e) Molten metals and dust stuck together to form clusters which in turn stuck together to form rocks

f) Near the Sun the heaviest compounds condensed forming heavy solid grains (orbits with high temperature)

g) Far from the center where the temperature was low, that hydrogen-rich molecules condensed into lighter ices, including water ice, frozen methane, and frozen ammonia

Formation of the Planets

h) The initial microscopic particles formed larger particles by sticking together by collision (accretion)

i) Planetesimals (small planets) formed by accretion as seeds for planet formation. They were consolidated into larger objects, forming clumps of up to a few kilometers across in a few million years.

j) Planetesimals grown to this sized then occasionally were fragmented by collisions. Only larger Planetesimals could survive to slowly grow into protoplanets by accretion.

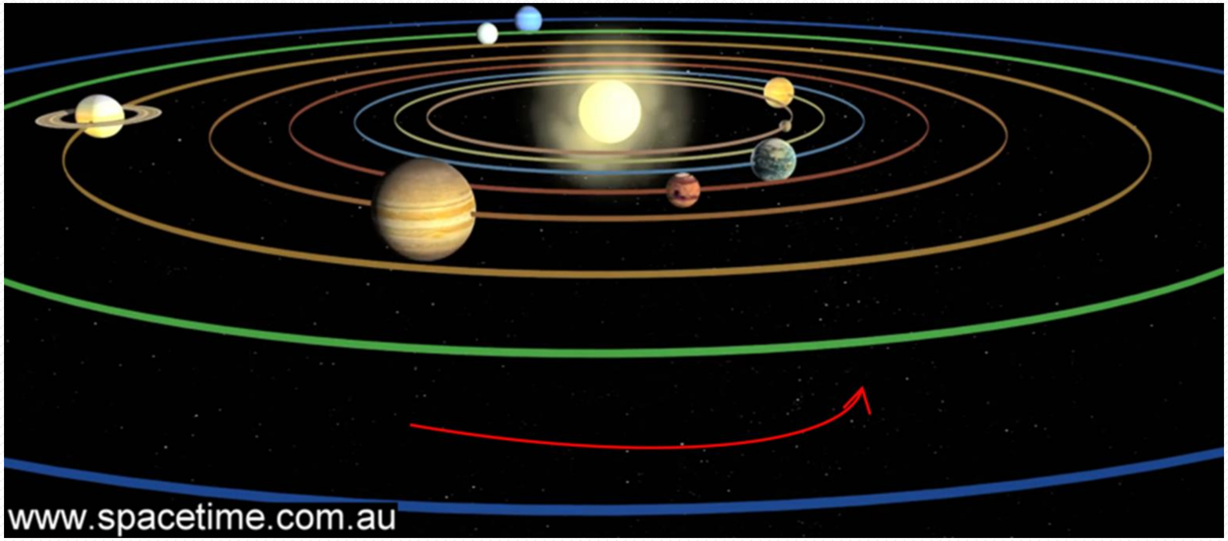
k) Accumulation of heat from radioactive decay of short-lived elements melted planet allowing differentiation of the materials.

Formation of the Planets

1) All the orbits of the planets are prograde (the same dir.)

2) The orbital planes of the planets (except Pluto) are inclined by less than 6 degrees with respect to each other.

3) Jovian planets (Jupiter, Saturn, Uranus and Neptune) are gaseous and large, while terrestrial planets are rocky and small.

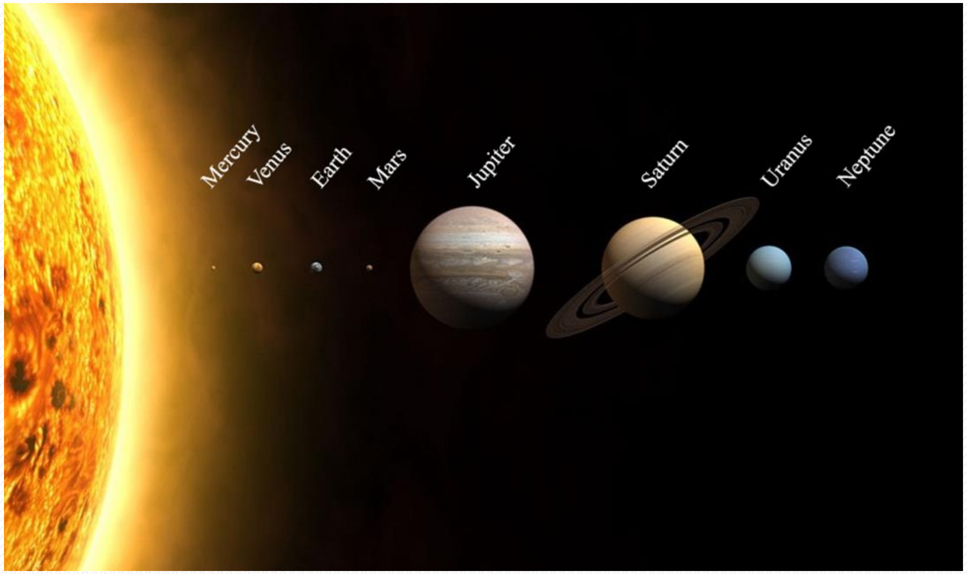


Terrestrial planets

a) In the inner orbits (warmer) planetesimals formed from rock and metal (heavy materials).

b) Near the Sun objects were moving faster and more likely to collide with each other (destructive), so the planets couldn't grow to form large planets. Due to the smaller size they could not keep large amounts of Hydrogen and Helium (though due to the proximity to Sun would cause the light gas elements to escape).

c) The terrestrial planets (Mercury, Venus, Earth, and Mars) formed from mostly heavy elements of nebula.



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Jovian planets

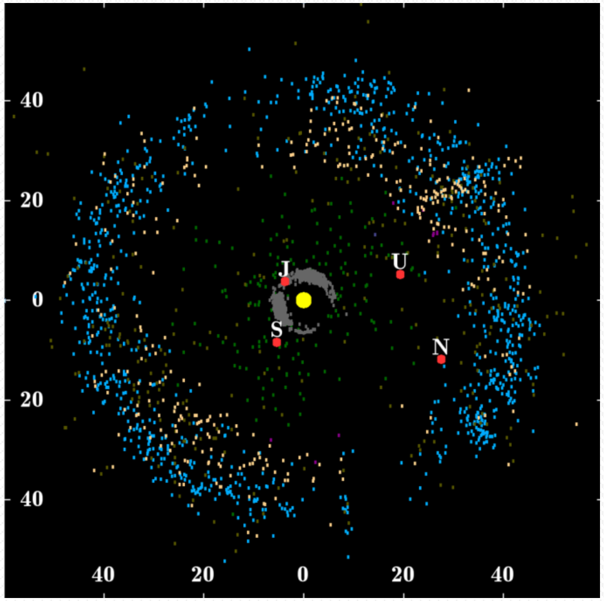
a) In the outer orbits (**colder**), planetesimals formed from ice flakes in addition to rocky and metal flakes.

b) Ices were more abundant and the planetesimals grew to larger sizes (Jupiter, Saturn, Uranus, and Neptune).

c) The planets were sufficiently large that they were able to capture hydrogen and helium, forming a thick atmosphere.

d) These planets are large, gaseous, low density, rich in hydrogen and helium, with dense solid cores.

e) Beyond Neptune (very cold region), icy planetesimals could survive but could grow just to the size of few kilometres due to having lower density and not being to accrete. They constitute the family of **Kuiper** belt comets.



Known objects in the Kuiper belt beyond the orbit of Neptune. (Scale in AU)

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Other Objects

a) Pluto, far away from Sun, is small like terrestrial planets and low density like Jovian planets. It does not fit to neither to terrestrial nor to Jovian planets. Pluto more likely belongs to the family of comets.

b) Asteroid belt are thousands of rocky planetesimals located between Mars and Jupiter of size from 1,000 km to a few meters across. They are likely the debris of the formation of the solar system that couldn't grow to a planet due to Jupiter's gravity.

c) When these objects collide, their small fragments occasionally fall on Earth (meteorites) that provide valuable information about the primordial solar nebula.

Other Objects

Comet: An icy, small Solar System body that, when passing close to the Sun, warms and begins to release gases, a process that is called outgassing.

Asteroid: Small object (not large as a planet) orbiting the Sun.

Meteoroids: Objects in space that range in size from dust grains to small asteroids.

Meteors: When meteoroids enter Earth’s atmosphere at high speed and burn up, the fireballs are called meteors.

Meteorite: When a meteoroid survives a trip through the atmosphere and hits the ground, it’s called a meteorite.

Other Facts

a) Rings around giant planets, such as Saturn's, `captured by the gravity of these planets.

b) Venus, Earth and Mars acquired their atmospheres at later stages in formation of Solar System. Water and atmosphere were brought to Earth from compounds by early bombardment of planetesimals formed in the outskirts of the solar system.

c) Outgassing (from gas blown out of volcanoes) is one of the sources for atmosphere's formation.

d) 65 million years ago, an asteroid or comet impact is thought to have caused the extinction of 90% of the species on Earth.

Appendix

Dark matter - A hypothetical form of matter. Various astrophysical observations — including gravitational effects cannot be explained unless more matter is present in the universe. It is called “dark” because it does not appear to interact with the electromagnetic field (absorb, reflect, emit).
The primary evidence for dark matter comes from calculations showing that many galaxies would fly apart, that they would not have formed, or that they would not move as they do if they did not contain a large amount of unseen matter.

Dark energy- An unknown form of energy that affects the universe on the largest scales. Measurements on supernovae showed that the universe does not expand at a constant rate; rather, the universe's expansion is accelerating. Before these observations, it was thought that the expansion of the universe should slow down by time and collapse due to the gravity. Dark energy is necessary to explain this expansion. It is thought that ~68% of the universe is dark energy (dark matter about 27%, the rest observable universe ~5% of the universe). It’s density is very low ($\sim 7 \times 10^{-30}$gr/cm^3), much less than the density of ordinary matter or dark matter within galaxies.

Appendix

Redshift - In astronomy and cosmology, the three main causes of redshift are:

I - **Relativistic redshift:** The shift in the radiation travelling between objects which are moving apart.

II – **Gravitational redshift:** Einstein's theory of general relativity predicts that the wavelength of electromagnetic radiation will lengthen as it climbs out of a gravitational well. Photons must expend energy to escape.

III - **Cosmological redshift:** The original wavelength of the light emitted from the galaxies is lengthened as it travels through **expanding space**.

Appendix

Planck's constant - Planck's constant (h), relates the energy in one quantum (photon) of electromagnetic radiation to the frequency of that radiation. In the International System of units (SI), the constant is equal to:

$h \approx 6.626176 \times 10^{-34} \frac{kg\, m^2}{s}$ *joule . second*

$E = h\, f$ *quantum energy*

In physics, natural units are physical units of measurement based only on universal **physical constants**.

Fundamental units (Natural Units) in terms of the universal constants (c, G, h, K_B)

$$Planck\ time = \sqrt{\frac{\hbar G}{c^5}} = 5.39116 \times 10^{-44}\ s$$

$$Planck\ length = \sqrt{\frac{\hbar G}{c^3}} = 1.6229 \times 10^{-35}\ m$$

$$Planck\ mass = \sqrt{\frac{\hbar c}{G}} = 2.17647 \times 10^{-8}\ kg$$

$$Planck\ temperature = \sqrt{\frac{\hbar c^5}{G {K_B}^2}} = 1.417 \times 10^{32}\ K$$

where

$G = 6.67430 \times 10^{-11} \frac{m^3}{kg \cdot s^2}$

$c = 299792458 \frac{m}{s}$

$K_B = 1.380649 \times 10^{-23}\ J.K$

Historical unit for length (MKS)

$meter : \frac{1}{40{,}000{,}000}$ Earth's circumference