

# THE BIRTH, LIFE AND DEATH OF OUR STAR

Newbury Beginners

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## The Birth of our STAR the Sun

Before considering where our Sun came from

We must consider where the 'building blocks' came from

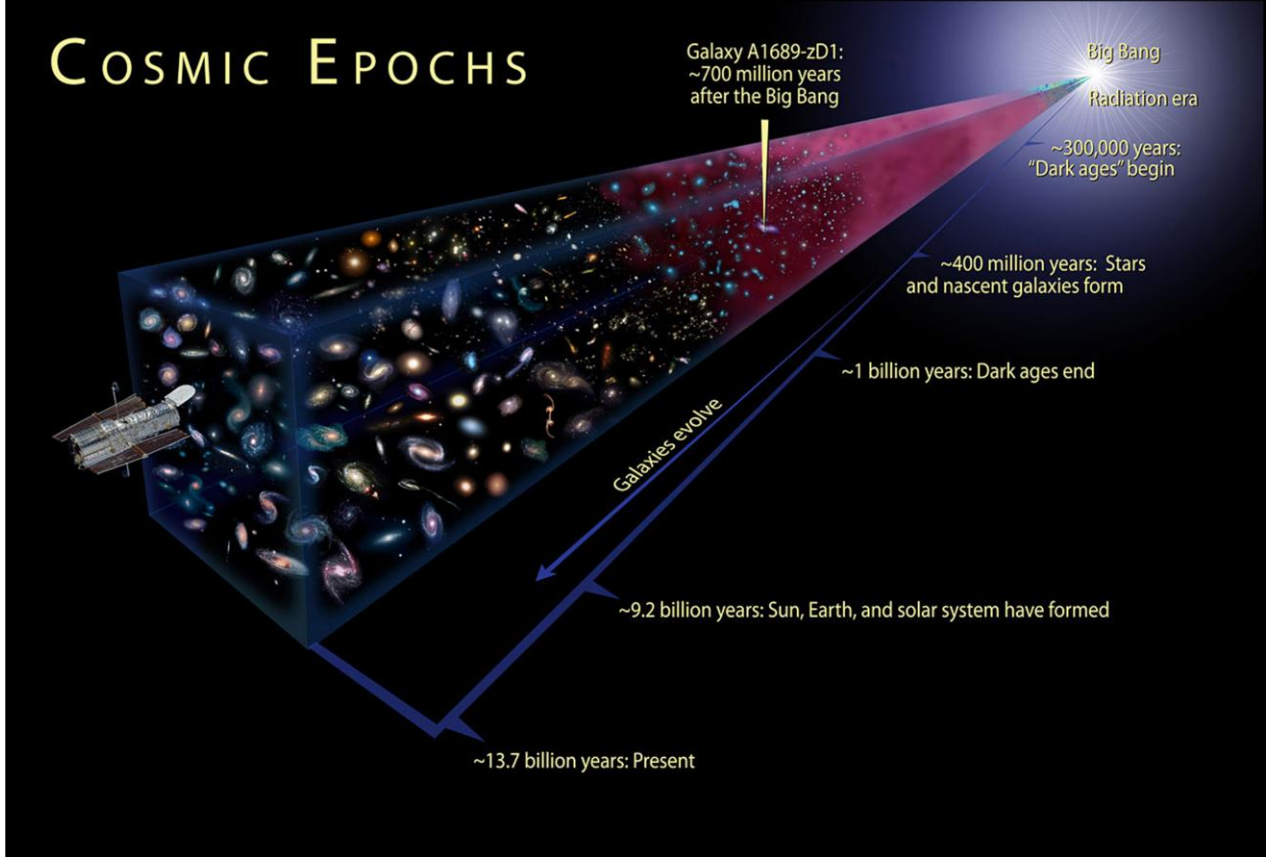
To do this we must start at the very beginning

THE BIG BANG is where our Universe began

So let us go back to the very beginning

# The James Webb Space Telescope looking back

## COSMIC EPOCHS



The diagram above shows a slice of the Universe.

The Hubble space telescope is shown looking back towards the big Bang.

We refer to the moment of creation of the Universe as the 'Big Bang'.

The event that we call the 'Big Bang' occurred about 13.8 billion 'Earth' years ago.

This is when time began for us and everything in our Universe was created.

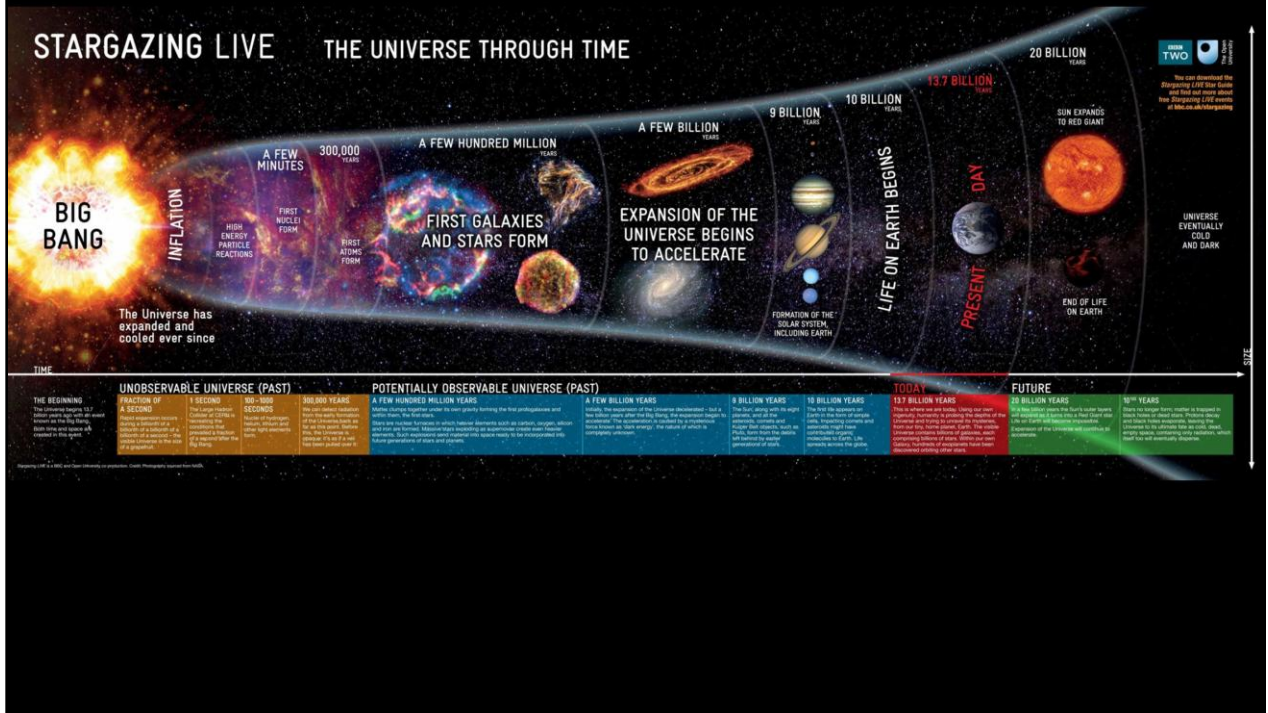
For us anything that happened or was there before the Big Bang has no meaning to us because we can never see out beyond our Universe.

It is now too big and it is too far for us to see to outer the edges.

We have already mentioned how the Universe began with the 'Big Bang' 13.8 billion years ago.

Now we can consider how the unbelievably small, dense and hot fireball expanded and cooled into the complex Universe we can observe today.

# The JWST will be able to see back to the first stars



The diagram above shows how the Universe developed over the 13.8 billion years. Things began to develop very fast immediately after the Big Bang. If we look at the horizontal scales at the bottom of the diagram above the time scale begins on the left using very small decimal fractions of a second.

In the first sub-second phase on the diagram the pure energy from the Big Bang expanded and cooled enabling sub-atomic particles (proto-matter) to form.

Then the sub-atomic particles combined to create atoms.

The first atoms were Hydrogen (89%), Helium (10%) and a tiny amount of Lithium.

The next slide shows the first part (left side) of the diagram above expanded.





In the next 1000 years the sub-atomic particles were forced together by the pressure and heat and started to create Protons (the positive (+) nucleus of an atom) and Electrons (the negative (-) particles orbiting a Proton).

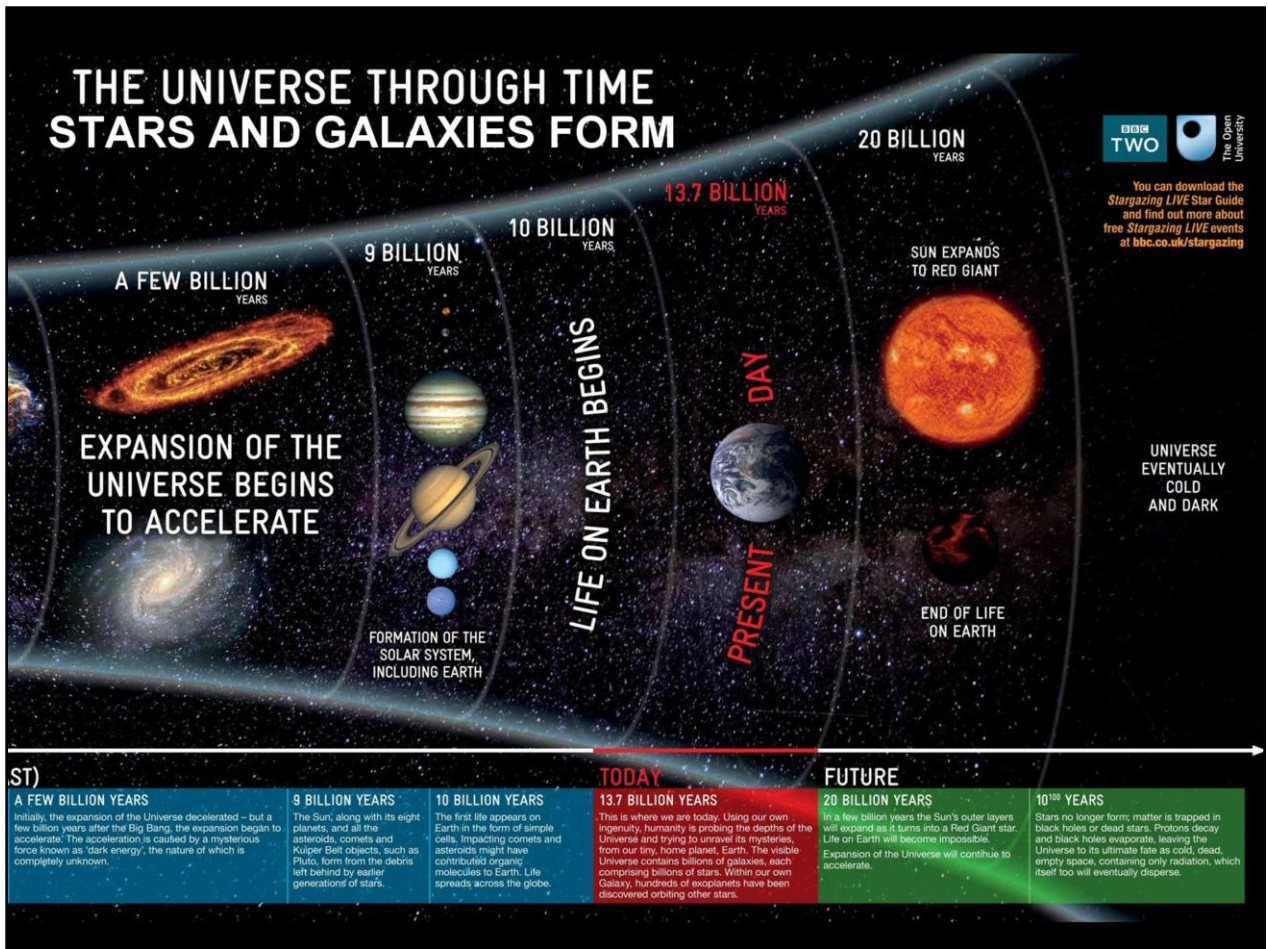
As a Proton and Electron fuse together they create an atom of Hydrogen gas.

There were some fusion events that joined two Protons and two Electrons together to create an atom of Helium gas.

Some sub atomic particles called Neutrons (similar to Protons but with no electrical charge (neither + or -) but were able to be combined into the forming atoms to create stable isotopes of these atoms.

The Nuclear Fusion process also produced sub-atomic energy packets called photons that are the carrier of what will become light. However these photons could not leave the expanding fireball because it was too dense and opaque.

After about 300,000 years most of the subatomic particles had been converted into atoms and the universe became transparent. The photons could then be released as electromagnetic waves (light).



After 300,000 to 400,000 years the first stars began to form as atoms were drawn together by gravity.

On a largest scale, the clouds of gas (Nebulae [single Nebula]) formed and were pulled into denser areas that formed into vast filaments (like a gigantic spider web). As the gas was pulled into filaments huge voids developed where there were virtually no atoms left.

At the largest scale, within these filaments galaxies began to form.

At the smallest scale, within these developing galaxies, stars formed.

This star and galaxy formation began within the first 500 million years.

At this early stage all the matter (mainly Hydrogen atoms with 10% Helium) was still close together but expanding.

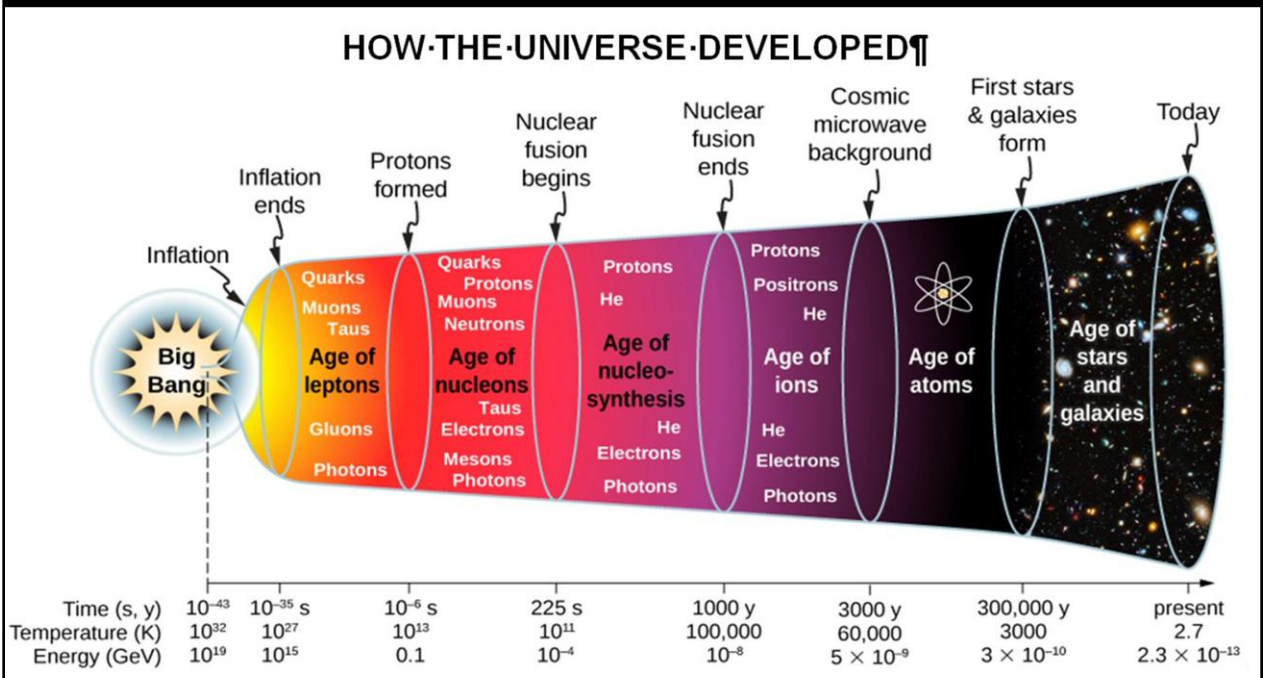
As there was so much matter packed into a relatively small volume, the very first stars were able to grow very large, very powerful but lived very short ‘lives’.

Some stars had Planets form in orbit around them and our Earth formed.

But we must ask, where did the stuff to make planets come from?



# The creation of atoms and photons



Quarks, Muons, Taus, Mesons, Gluons and Photons began to form  
 Then Protons, Neutrons, Electrons Positrons and Ions were created  
 Finally atoms of Hydrogen, Helium and some Lithium were created

In the first sub-second phase on the diagram above the pure energy expanded and cooled enabling sub-atomic particles (proto-matter) to form.

It seems very strange that matter can be created from energy but Albert Einstein's famous equation  $E = mc^2$  shows us it is possible.

If we mathematically transpose ( $E = mc^2$ ) into ( $m = E \div c^2$ ) then we have Mass (matter) was created from Energy (E) divided by the speed of light squared ( $c \times c$ ).

The sub-atomic particles are listed on the diagram above (these became the building blocks of atoms).

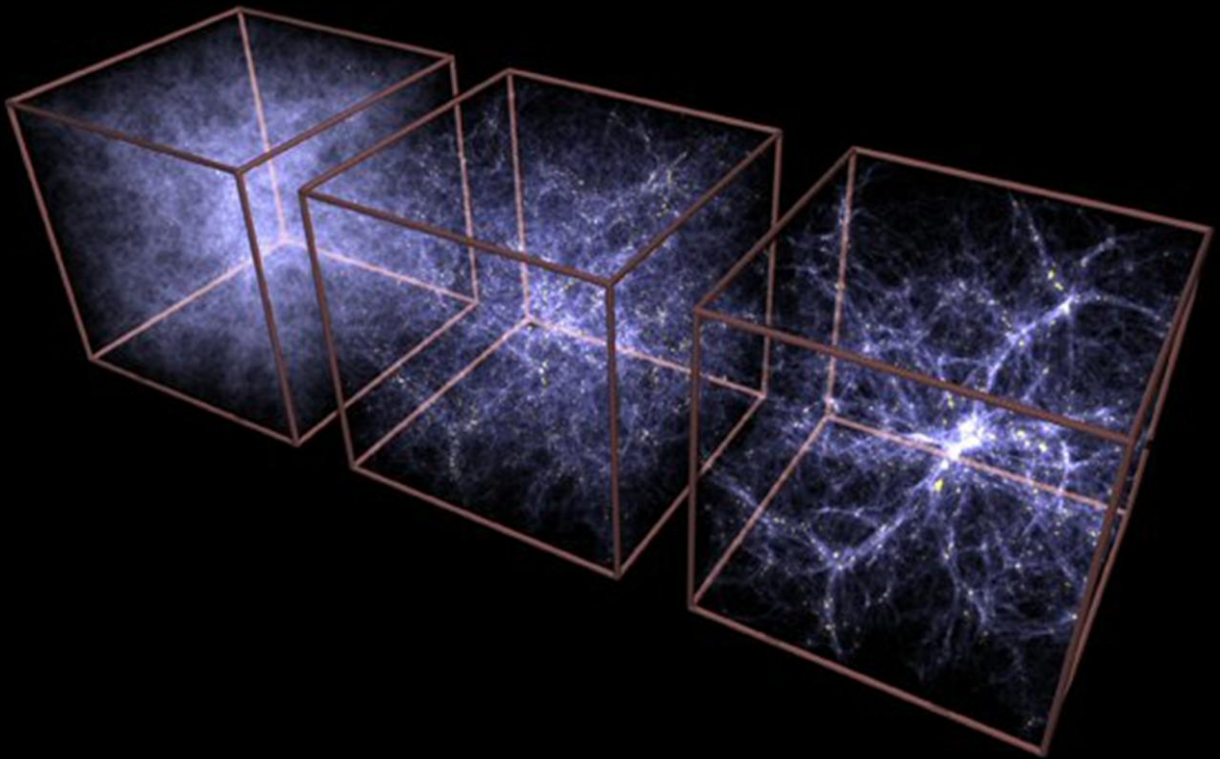
First to be created are: Quarks, Muons, Taus, Gluons and Photons.

These went on to create: Protons, Neutrons, Electrons then Positrons and Ions.

In the time from 3000 to 300,000 years after the Big Bang atoms began to form and when the sub-atomic particles were used up the universe became transparent.

Photons could then travel through space as electromagnetic waves (light).

## Matter was drawn into Filaments and left Voids



A computer generated process showing the development of the Universe

After about 300,000 years the Universe became transparent so the flash could travel through space.

Gravity started to exert its effect on the matter that had been created.

Atoms that were already moving due to the Big Bang were drawn together by their mutual gravity.

As more atoms were drawn together their mutual gravity increased and pulled even more atoms together.

At the largest scales the atoms of Hydrogen and about 11% Helium were drawn into vast filaments stretching across the expanding Universe.

As gas was pulled into the filaments by gravity vast Voids of empty space were left behind.

At a smaller scale the atoms, by virtue of their velocity (movement through space), began to form into great swirling clouds and eventually created spinning Spiral Galaxies.



## Matter was drawn into Filaments and Voids

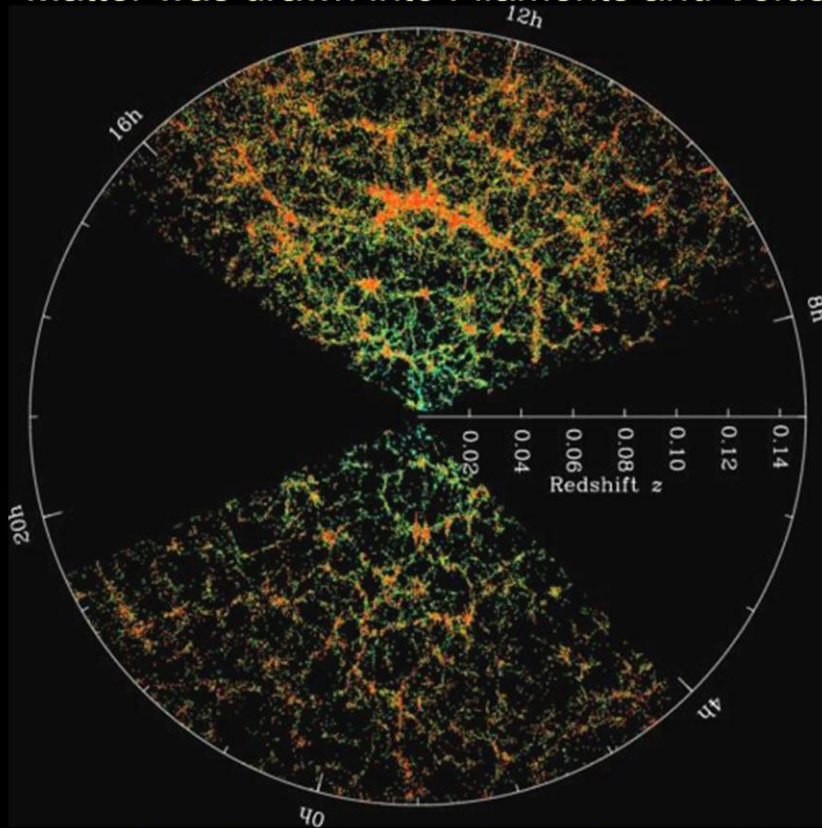


Image from the Sloan Deep Space Survey Telescope

The Sloan Digital Sky Survey has created the most detailed three-dimensional maps of the Universe ever made.

It created deep multi-colour images of one third of the sky, and spectra for more than three million astronomical objects.

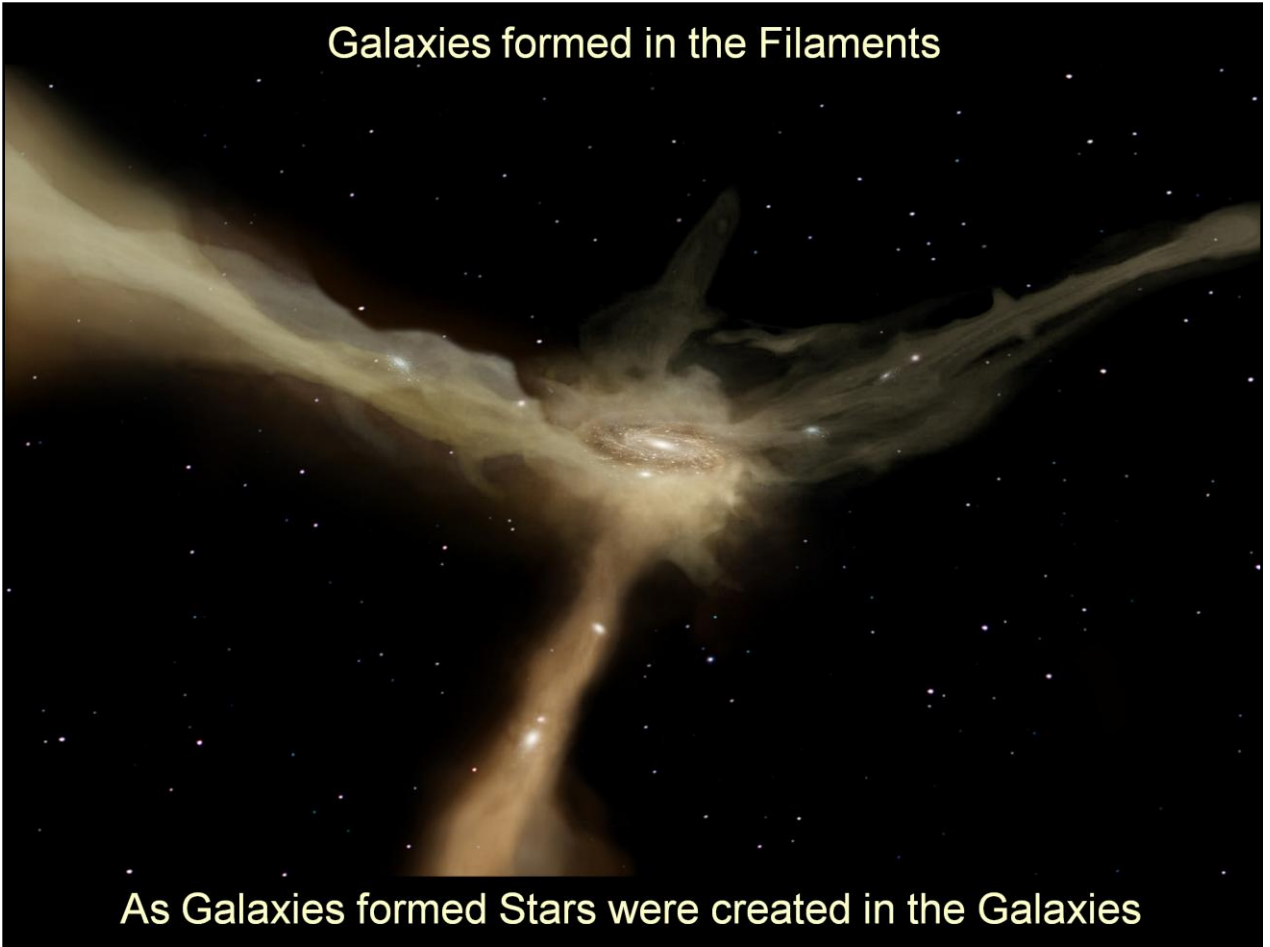
The Sloan Digital Sky Survey (SDSS) is one of the most ambitious and influential surveys in the history of astronomy.

Over eight years of operations it obtained deep, multi-colour images covering more than a quarter of the sky.

It created 3-dimensional maps containing more than 930,000 galaxies and more than 120,000 quasars.

With its upgrades it was also able to determine how galaxies were moving in relation to us and how fast they are moving.

## Galaxies formed in the Filaments



## As Galaxies formed Stars were created in the Galaxies

The original gas Hydrogen (89%) and Helium (10%) was drawn into denser filaments by gravity.

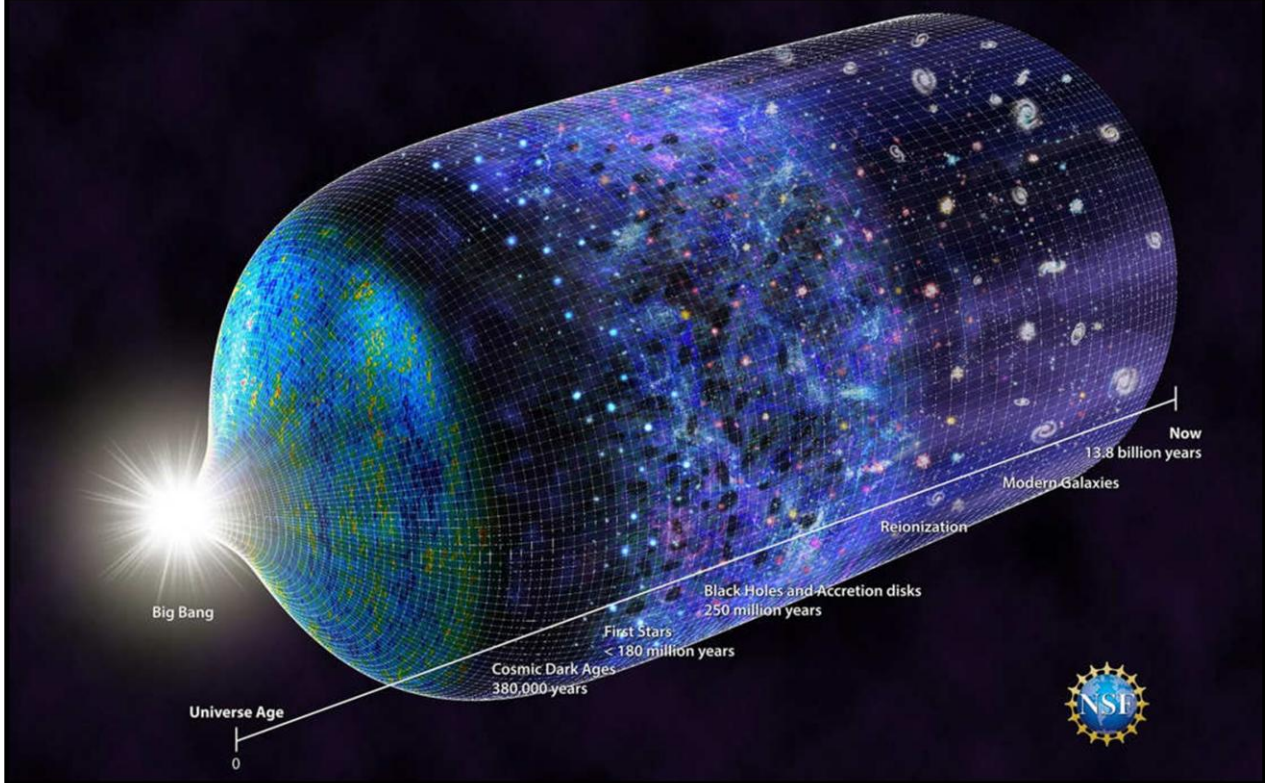
As gas was pulled into the filaments by gravity vast Voids of empty space were left behind.

As the gas was drawn into the filaments, its motion caused huge eddies and swirls to form.

These swirls developed into spinning discs that created Spiral Galaxies.

Within the flat rotating discs of these Galaxies stars formed from the gas.

## The first stars to form were very important



## First Stars formed after ~180 million years and were Super Giants

At this phase of the development of Galaxies they were comprised of just Hydrogen and 10% Helium created by the Big Bang.

Everything was much closer together and very hot as the Universe continued to expand it started to cool.

As the atoms cooled they were able to group together due to their gravity.

So the first stars were created from pure Hydrogen and Helium gas.

The conditions in these early galaxies allowed the forming stars to be Super Giants.



The very first stars were Blue Super Giants  
They were ~300 times the mass of our Sun  
and millions of times more powerful



They exploded as Supernovae after ~1 million years

The first stars to be created were Super Giant stars containing up to 300 times the mass of our Sun.

Being too massive their cores had an enormous pressure and very high temperature.

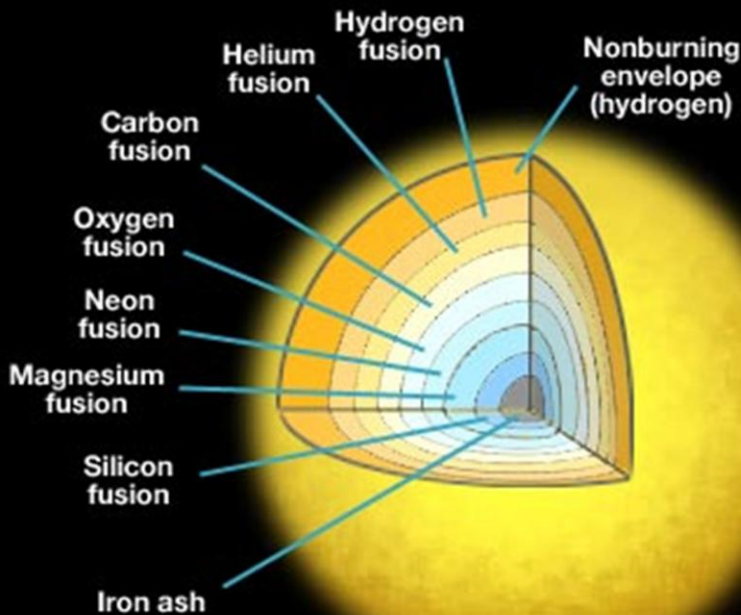
The Hydrogen atoms were compressed together by the enormous gravity and were moving around very fast due to the heat.

Hydrogen atoms were forced together and combined (fused) together to create more Helium atoms.

This Nuclear Fusion process released X-Rays that heated the core to even higher temperatures.

Nuclear Fusion in these giant stars produced huge amounts of energy and consumed enormous amounts of Hydrogen gas.

## Giant stars can fuse heavier and heavier elements



**Giant Stars can fuse Silicon into Iron in the core**  
**There is a problem creating Iron it does not produce energy**

These enormous blue stars were able to continue the Nuclear Fusion process. Helium gas was fused into heavier elements with a bias towards certain elements. First the Helium was fused into Carbon which was in turn fused into Oxygen atoms. The fusion process continued to produce Neon, Magnesium, Silicon and finally Iron. With each stage the heavier atoms sunk to the centre of the core as shown above. All these fusion stages added more energy to the star it became hotter and the increased radiation pushed outwards to increase the diameter of the star. However the final Iron production stage did not produce energy and caused the stars to become unstable.

## Giant stars destroy themselves as Supernovae



The final moments leading up to the death of a Super Giant Star happen very quickly. When Iron begins to form in the core the star it is destined to die within a couple of our days.

Iron rapidly fills the centre of the core until the Iron sphere reaches a mass of 1.4 times the mass of the Sun.

At this point the Iron in the core suffers a catastrophic collapse and briefly exists like an Iron white Dwarf about the diameter of Earth (12,756 km).

Almost immediately the rest of the star collapses at enormous speed on to the super compressed Iron sphere and starts a run away Nuclear Fusion Explosion.

The explosion rips through the star as a Supernova. All the elements already present and new ones created in the Supernova are blow out into space at enormous speed.



## Elements heavier than Helium were created in stars

Periodic Table of the Elements																															
1 IA H Hydrogen 1.008																2 IIA He Helium 4.003															
3 Li Lithium 6.941																4 Be Beryllium 9.012															
11 Na Sodium 22.990																12 Mg Magnesium 24.305															
19 K Potassium 39.098																20 Ca Calcium 40.078															
37 Rb Rubidium 85.468																38 Sr Strontium 87.62															
55 Cs Cesium 132.905																56 Ba Barium 137.328															
87 Fr Francium 223.020																88 Ra Radium 226.025															
13 Al Aluminum 26.982																14 Si Silicon 28.086															
31 Ga Gallium 69.723																32 Ge Germanium 72.631															
49 In Indium 114.818																50 Sn Tin 118.711															
81 Tl Thallium 204.383																82 Pb Lead 207.2															
113 Nh Nihonium [286]																114 Fl Flerovium [289]															
135 At Astatine [210]																136 Lv Livermorium [293]															
153 Fr Francium [223]																154 Ra Radium [226]															
171 Ts Tennessine [294]																172 Og Oganesson [294]															
57 La Lanthanum 138.905																58 Ce Cerium 140.116															
59 Pr Praseodymium 140.908																60 Nd Neodymium 144.242															
61 Pm Promethium 144.913																62 Sm Samarium 150.36															
63 Eu Europium 151.964																64 Gd Gadolinium 157.25															
65 Tb Terbium 158.925																66 Dy Dysprosium 162.500															
67 Ho Holmium 164.930																68 Er Erbium 167.259															
69 Tm Thulium 168.934																70 Yb Ytterbium 173.055															
71 Lu Lutetium 174.967																72 Hf Hafnium 178.49															
73 Ta Tantalum 180.948																74 W Tungsten 183.85															
75 Re Rhenium 186.207																76 Os Osmium 190.23															
77 Ir Iridium 192.22																78 Pt Platinum 195.08															
79 Au Gold 196.967																80 Hg Mercury 200.59															
81 Tl Thallium 204.383																82 Pb Lead 207.2															
83 Bi Bismuth 208.980																84 Po Polonium [209]															
85 At Astatine [210]																86 Rn Radon [222]															
87 Fr Francium [223]																88 Ra Radium [226]															
89-103 Lanthanide Series																104-118 Actinide Series															
89 La Lanthanum 138.905																90 Ce Cerium 140.116															
91 Pr Praseodymium 140.908																92 Nd Neodymium 144.242															
93 Pm Promethium 144.913																94 Sm Samarium 150.36															
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121 Ac Actinium 227.028																122 Th Thorium 232.038															
123 Pa Protactinium 231.036																124 U Uranium 238.029															
125 Np Neptunium 237.040																126 Pu Plutonium 244.064															
127 Am Americium 243.061																128 Cm Curium 247.070															
129 Bk Berkelium 247.070																130 Cf Californium 251.080															
131 Es Einsteinium [254]																132 Fm Fermium [257]															
133 Md Mendelevium [258]																134 No Nobelium [259]															
135 Lr Lawrencium [262]																136 Rf Rutherfordium [261]															
137 Db Dubnium [262]																138 Sg Seaborgium [266]															
139 Bh Bohrium [264]																140 Hs Hassium [269]															
141 Mt Meitnerium [278]																142 Ds Darmstadtium [281]															
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163 Tm Thulium 168.934																164 Yb Ytterbium 173.055</															

During the short life of these Super Giant Stars elements up to Iron (Element 26) are manufactured.

In the short time that the supernova Nuclear Fusion explosion rips through the star all the elements in the table can be forged.


Some elements are short lived and rapidly decay into other elements and add to the energy output.

All these Elements are scattered into the Clouds of Hydrogen around the Supernova.

With millions of these early and short lived Supergiant stars exploding the Nebula becomes contaminated with these heavier elements.

As new stars form in the Nebula they contain more and more of the heavier elements with each subsequent generation.

# Periodic Table showing the origin of the Elements

1 H	big bang fusion 																cosmic ray fission 																2 He																																
3 Li	4 Be	merging neutron stars 																exploding massive stars 																5 B	6 C	7 N	8 O	9 F	10 Ne																										
11 Na	12 Mg	dying low mass stars 																exploding white dwarfs 																13 Al	14 Si	15 P	16 S	17 Cl	18 Ar																										
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr																																																
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe																																																
55 Cs	56 Ba						72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn																																												
87 Fr	88 Ra																																																																
																		Iron																Silver																Gold															
																		Uranium																																															
57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu																																																			
89 Ac	90 Th	91 Pa	92 U																																																														

**Uranium is the heaviest naturally occurring element**

The Periodic Table of Elements above has been specially drawn to show the origin of each element.

At the top of the table a colour code shows where the proportions of each element were formed.

Hydrogen, Helium (light blue) was created in the Big Bang with a small amount of Lithium.

Green shows the elements created in Supernovae either prior or during the Supernova.

Orange and yellow elements were created later by Neutron Stars or by dying low mass stars.

Uranium (92) is the heaviest naturally occurring element all the other heavier elements have decayed over millions of years.

Elements like Neptunium (93) and Plutonium (94) and the other heavier elements are created by humans but naturally occurring atoms of these heavier elements have decayed into lower elements over the billions of years.

## Galaxies formed in the Filaments



## As Galaxies formed Stars were created in the Galaxies

The picture above shows what we think our Galaxy 'the Milky Way' looks like.

The red and pink in the spiral arms is areas where stars are forming in Nebulae.

Spiral Arms are created as shock waves from forming and dying stars move around the disc.

Shock waves stir up the nebulae create more star formation that moves through the disc in waves that create the curved spiral arms.

As the shock wave passes through a quiet nebula the atoms are disturbed and begin to be attracted to each other.

Gravity pulls the atoms together and new stars are formed.



## Gravity draws gas and dust together in galaxies



The image above shows a star forming area in one of the arms of our galaxy.

As intense ultraviolet radiation from new stars hits Hydrogen atoms of the surrounding nebula they glow red the natural colour emitted by excited Hydrogen atoms.

In the centre we can see where stars are driving the Nebula to form what looks like pillars of gas and dust.

## A Proto-star and disc



Gas and dust in the nebula begins to create denser areas due to the attraction between atoms.

More mass creates more gravity and the dense regions grow.

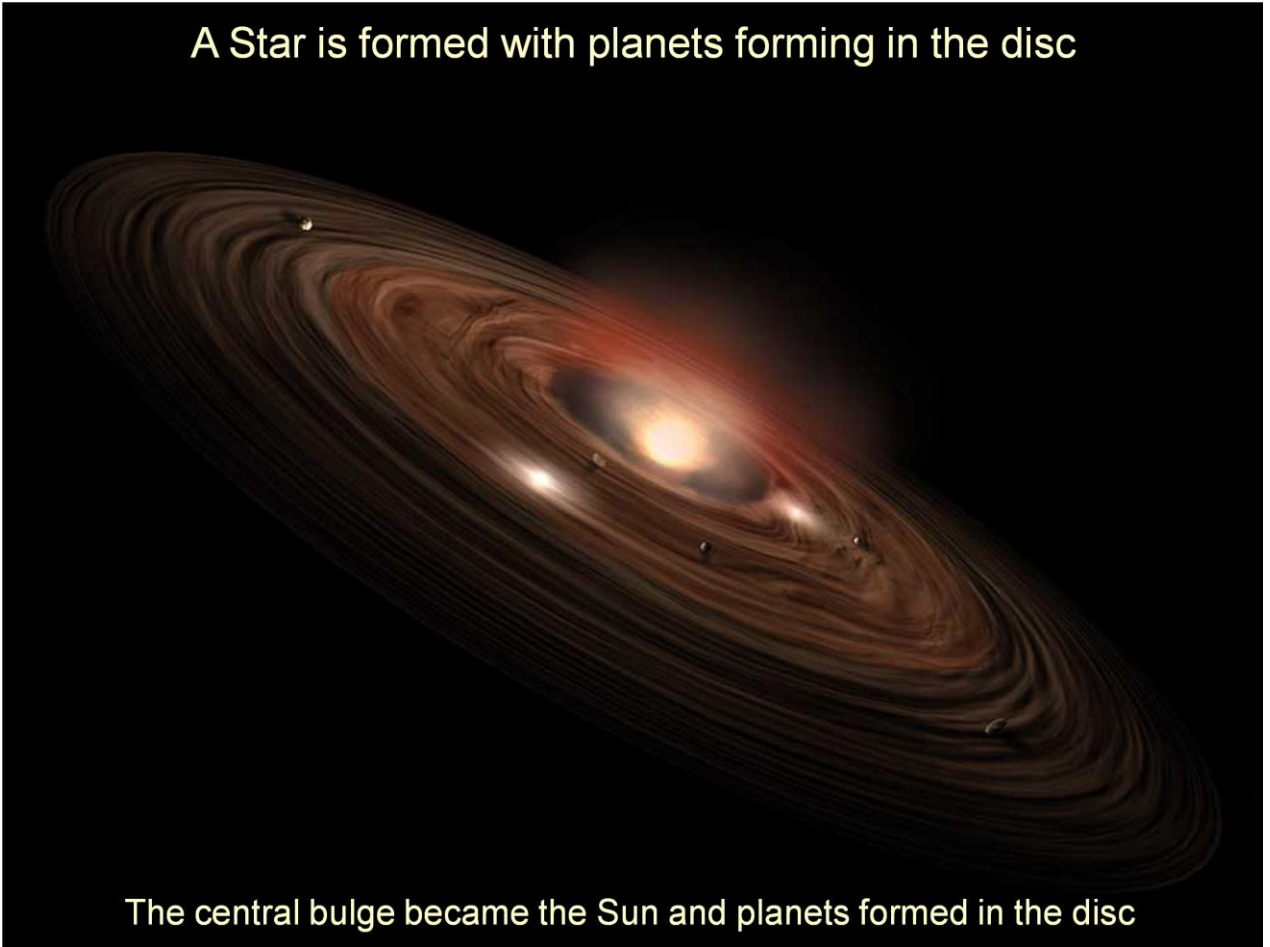
As more material is pulled in, its velocity is added to the area and a rotating disc forms.

Material is drawn to the centre of the disc and a dense sphere of material is created there.

As this central sphere grows the increasing gravity compresses the sphere so the pressure and temperature in the centre increases.

As the pressure rises the temperature rises until Nuclear Fusion can begin and a new star is born.

A Star is formed with planets forming in the disc



The central bulge became the Sun and planets formed in the disc

Our Sun began to form about 4.5 billion years ago in a Nebula in the Galaxy we call the Milky Way.

The original Hydrogen and Helium in our galaxy was contaminated with dust and gas produced by many generations of exploding stars.

As the new proto-star pulled in more and more gas and dust a rotating disc of material formed.

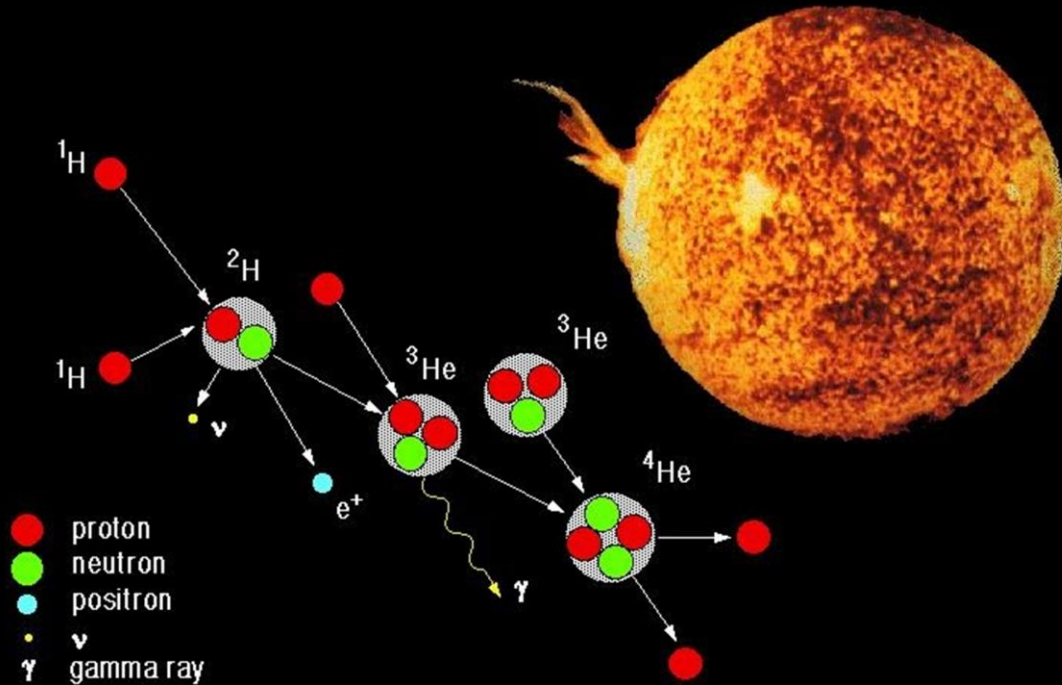
The dense central bulge became highly compressed and Nuclear Fusion began and our star 'the Sun' began to shine.

Material in the rotating disc began to form denser clumps that developed into planets.

Some planets had close encounters and were thrown into the Sun or out into space others planets had collisions.



## Nuclear Fusion creates Helium and Energy



### Solar Nuclear Fusion Reactions via the Proton-Proton Chain

Nuclear Fusion is a natural process that occurs in stars where pressure and heat compresses atoms tightly together.

When the pressure rises to millions of times the pressure of Earth's atmosphere and temperature of millions of degrees the Nuclear Fusion can Begin.

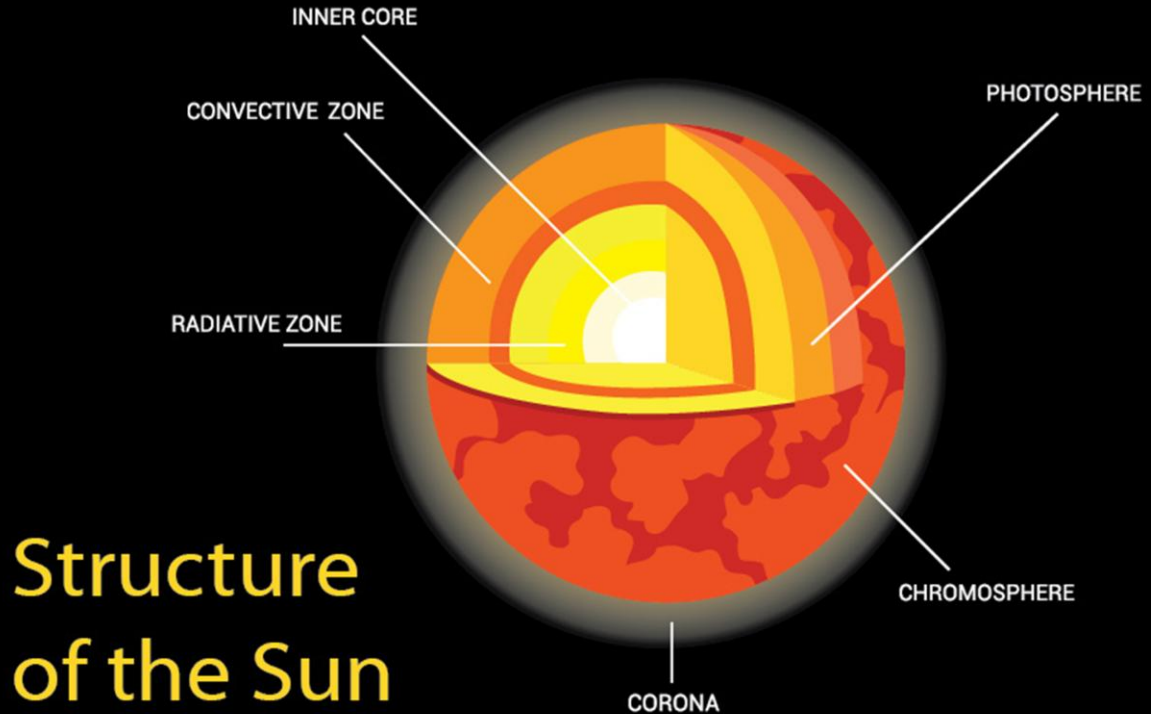
In the diagram above a red Proton and a green Neutron join to become an atom of Hydrogen.

In the high pressure and temperature a second proton can be forced into the Hydrogen atom to create an atom of Helium ( $^3\text{He}$ ).

In this Fusion process a Gamma ray ( $\gamma$ ) is released that provides additional heat to the core.

After this reaction two Helium atoms can also be fused into a single helium ( $^4\text{He}$ ) and two Protons are released to form another ( $^3\text{He}$ ) atom.

## Our Sun has four active layers



## Structure of the Sun

The Fusing of two Hydrogen Atoms into one Helium atom produces a Gamma Ray ( $\gamma$ ) to heat the Sun.

One Helium atom weighs less than the two Hydrogen atoms that created it so where did the mass go?

The mass was converted into energy as seen in Einstein's famous equation  $E = mc^2$  where  $E$  = Energy,  $m$  is Mass and  $c$  is the speed of light.

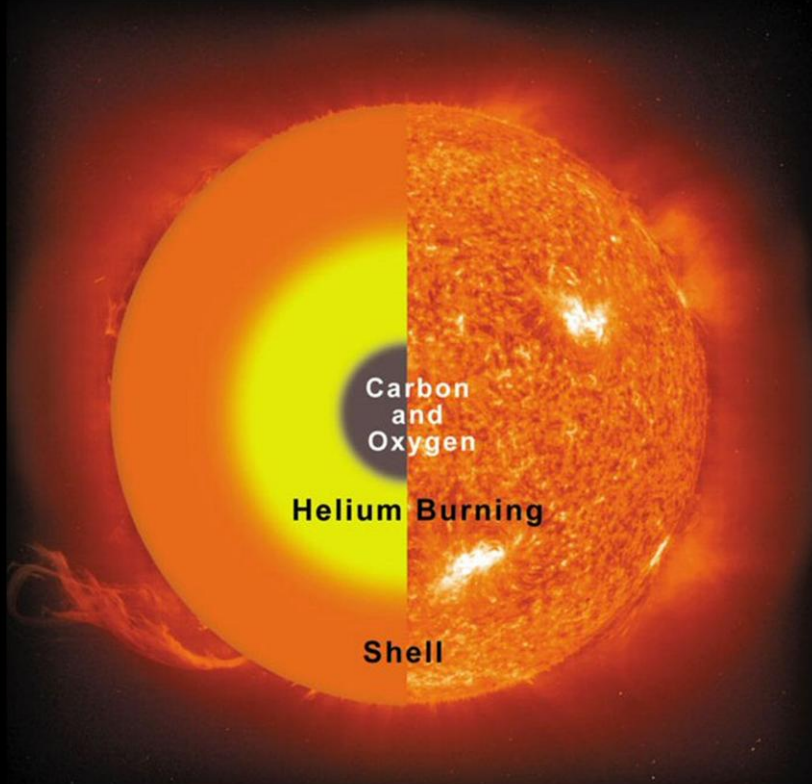
The lost mass has been converted into a Gamma Ray that quickly hits another atom and is absorbed.

To stabilise, the excited atom quickly releases the unwanted Gamma Ray energy as an X-Ray that then continuously hits other atoms and is absorbed and then released again and again.

X-Rays gradually travel away from the core through a 'Radiative Zone' until they reach the 'Convective Zone'.

The less dense Convective Zone absorbs the heat and is convected (boils) up to the surface (Photosphere) where the energy is radiated away from the Sun as white light.

## Our Sun will create Carbon from Helium as it gets older



## Extra energy from Helium and Carbon will inflate the Sun

Our Sun has been processing Hydrogen into Helium for about 4.5 billion years.

It has enough Hydrogen to last about another 4.5 billion years.

Helium builds up in the centre of the core so the Nuclear Fusion zone occurs on the outside of the developing Helium inner core.

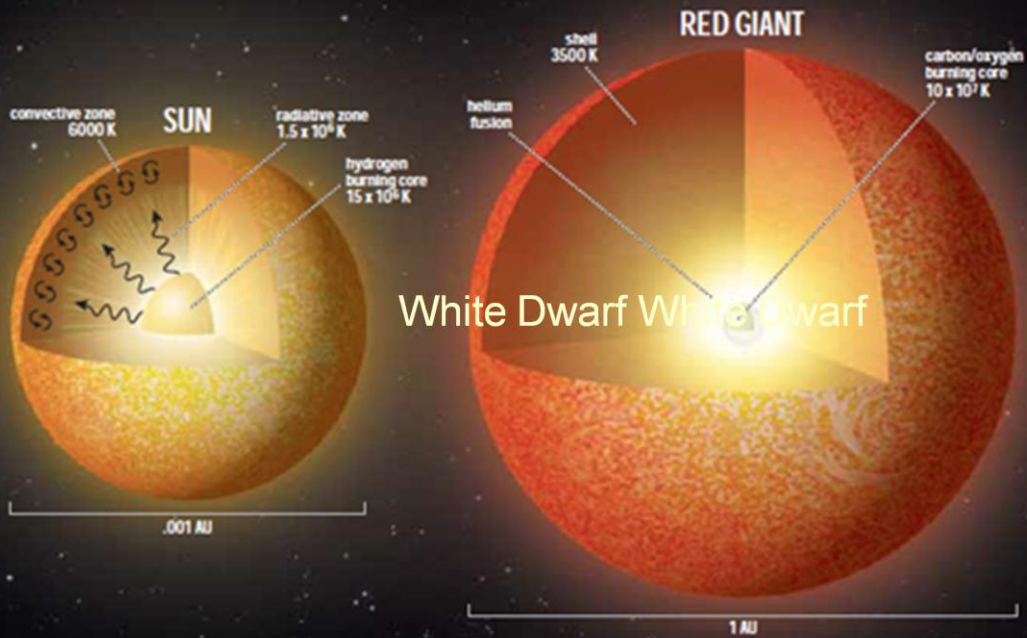
In about 3 to 4 billion years time the Helium Nuclear Fusion will begin to fuse Helium into Carbon.

This Helium / Carbon fusion will produce additional energy and radiation that will push outwards and the Sun will begin to expand.

The diameter of the Sun will increase to beyond the orbit of Earth so Mercury, Venus and Earth will be consumed by the Sun.



## Our Sun will become a Red Giant in 5 billion years



Our Sun today compared to the Red Giant Sun  
It will be 1000 times its present diameter

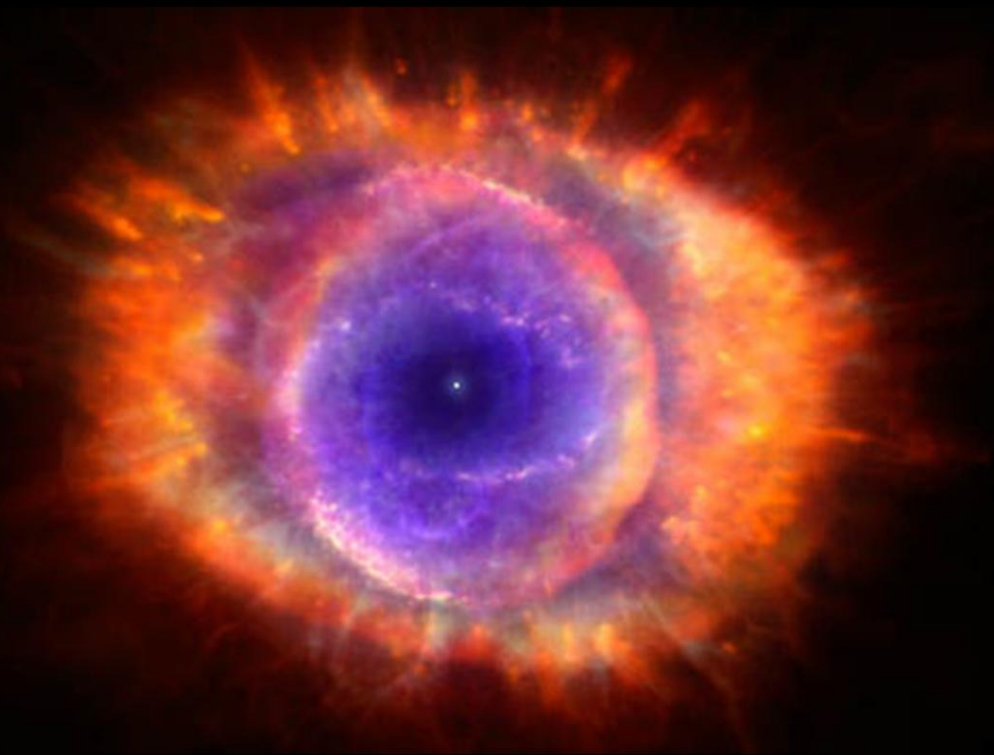
As the Sun expands the heat produced in the core will be distributed over the much larger surface.

Receiving less heat the surface will be cooler so will become yellow then orange and finally red.

Our Sun is currently 1.4 million kilometres in diameter but as develops into a Red Giant it will expand in diameter to between 300 million to 400 million kilometres.

Eventually as the Hydrogen and Helium fuel runs out gravity will start to take over and the Sun will slowly collapse.

## Our Sun will produce a Planetary Nebula



## Our Sun as it collapses into White Dwarf and Planetary Nebula

With the Nuclear Fusion reducing the outward force provided by the radiation starts to lessen.

Gravity begins to pull the gas in towards the core and the Sun will eventually be compressed to about the size of Earth (12,756 kilometres).

The enormous pressure compresses what remains into white hot Carbon sphere known as a White Dwarf Star.

The outer layers of the Red Giant will be left behind to form a halo that will continue to expand and dissipate.

So our Sun may develop into a Planetary Nebula (like the one shown above) with a central White Dwarf that was formerly our Sun.

## Our Sun will become a White Dwarf



## Our Sun compared to the White Dwarf Sun

After the Planetary Nebula Halo has dissipated our Sun will spend billions of years as a White Dwarf.

White Dwarfs slowly cool down from their original temperature of  $\sim 50,000^{\circ}\text{C}$  until they become cold Black Dwarfs.

White Dwarfs can exist up to 1.4 times the mass of our Sun (today).

The larger White Dwarfs can compress to transform their Carbon into Diamond and become a planet sized diamond.

If the created White Dwarf exceeds the 1.4 Sun size its structure will collapse further and form into a Neutron Star.

A Neutron Star is about 25 km in diameter, will weigh more than our Sun and will be rotating very fast.



## What will be the end for our Sun?



White Dwarf



Earth



Black Dwarf

Our Sun will become a White Dwarf then a Black Dwarf

White Dwarfs can be between 0.5 to 1.4 times the mass of our Sun when their star collapses.

A White Dwarf Star typically has a temperature of between 50,000°C and 100,000°C when they form.

So although they are very small they do shine very brightly.

They are incredibly dense with an average density of about 1 billion tonnes per cubic metre.

White Dwarfs are cooling down but they are expected to take trillions of years to cool completely.

When they have completely cooled they will not emit any light and will become a Black Dwarf Star.

Beginner's Website:  
[naasbeginners.co.uk](http://naasbeginners.co.uk)