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Stellar Evolution: Life Cycle of Stars

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Abstract: *The origin of our universe is one of the biggest mysteries to date. There are numerous theories that point towards the 'Big Bang' to being the origin. But still, no experiments proved the Big Bang theory. But what we can do to study the origin of the universe is by going backward in time and questioning 'How did the universe begin to evolve?', 'What processes gave rise to the present universe?', etc. And one of such questions is 'How are the stars formed?'. By knowing how stars are born, and their processes, we can say what were the initial conditions of the universe and draw conclusions on its origin. In our present paper, we have studied the chronology of our universe according to inflationary cosmology, then how the interstellar gas clouds aggregated to form protostars. The study of stellar birth requires nuclear physics to understand fusion, conditions for stellar birth, properties of a star like pressure, mass profile, temperature, luminosity, magnitude system, etc. We have also done analysis of the HR diagram, Main sequence stars, the life cycle of different mass categories of stars, and finally, Supernova remnants like Neutron stars and Black holes (Sagar J. C., 2021).*

Keywords: *Stellar Nebula. Red Super Giant, Black hole, Red Giant, Interstellar medium, Planetary Nebula, White Dwarf, Protostars, Massive star, Supernova, Neutron star, Main sequence.*

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Introduction:

Today we realize that stars are an important source of raw materials in the universe, recycling and annoying the elemental constructing blocks of the entirety. We observe new star nebula of gas and dust, planets, and even humans. All life on the earth contains the element carbon and all carbon was originally formed in the core of the star. Stars have populated the universe with elements through their "life cycles" and the ongoing process of formation, burning fuel, and dispersal of material when all the fuel is used up. Different stars take different paths, however, depending on how much matter they contain and their mass. A star depends on how much hydrogen gas is brought together by gravity during its formation. We measure the mass of stars by how they compare to the "parent star" of our system, the sun. Stars are considered high mass when they are five times more massive than the sun. When high-mass stars have no more fuel to generate outward energy, their iron cores start to collapse until the pressure overcomes the inward push of gravity and they explode in a spectacular supernova, dispersing elements into space to recombine as future stars, planets, steroids, or even eventually life like us. After a supernova, massive stars can go one of two ways. If the remnant of the explosions is about 1.4 to 3 times the mass of our sun, it will collapse into a very small, very dense core of neutrons called a neutron star. If the remnant is more than three times as massive as the sun, gravity overwhelms the neutrons and the star collapses completely into a black hole- It is so-called because the matter within is so compressed and the pull of gravity is so intense that when light is drawn in and it is not reflected, so that area is "black" and arable.

Stars: Stars are huge celestial bodies that are made up of hydrogen and helium mostly. These are able to produce light and heat from the churning nuclear forces within their cores. Besides our sun as a star, the dots of light we can see in the sky. They are all star's light-years away from the Earth. These are the building blocks of galaxies. Many of which are billions in number in the universe. It is actually impossible to know how many stars exist.

But astronomers estimate that in our Milky Way galaxy alone, there are approximately 300 billion. The life cycle of any star spreads over billions of years. As a general rule, the more massive the star, the shorter its life span. The structure of any star can often be thought of as a series of thin nested shells, similar to the onion (Branley, Franklyn,1986).

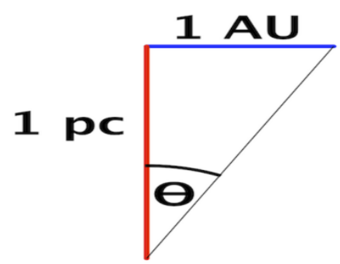
Our universe is thought to have originated from a process called the 'Big Bang' and time should have started only after the Big bang. So, at Big bang, time, t = 0s and as time increased, many events happened as the temperature decreased. In the below table, we can see the summary of the different events.

How Many Types of Stars are There?

It is difficult to organize stars by using only one way to classify them, so scientists have come up with systems to help make sense of the information. There are many different types of stars, and they can be classified by three major category systems: Spectral classification, size, and life cycle. Each category has its unique way of describing stars. Spectral classification uses a system that organizes stars by temperature, color, and luminosity. The classes range from the O-cla**ss**, the hottest, blue, and brightest stars to the M**-**Cla**ss** which are the coolest, red, and less bright stars. Organized by size, the largest stars are the super giants, and the smallest are the brown dwarfs. The life cycle of a star ranges from the protostar stage to the brown dwarf stage but can sometimes end as a neutron star instead of a brown dwarf. Our Sun is a medium-sized main-sequence star that is about halfway through its life cycle. It will take billions of years to reach the final stage of its life.

Distance to star:

Angular distance between stars is measured in angles such that 1°=60', 1'=60"



The unit for distance measurement is Light year, defined as the distance travelled by light in a year. Unit: Light year(ly)-9.461×10^{15}m Astronomical unit (AU)1.496x10"m.

Parsec: (pc) distance at which 1 Au subtends angle of 1".1 pc = 3.086 $\times10^{16}$m.

Distance to stars: very important parameters (luminosity)many methods: parallax, moving clusters,variable stars etc.

Parallax: Apparent motion of stars due to Earth's motion around sun.

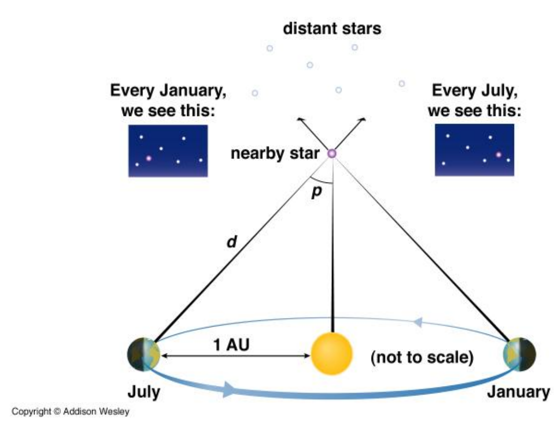


Fig.1. Parallax method to measure distance between stars

Small angle approximation (radian) tan p≈p

Distance to star D=1 Au/p

If p=1"=1/206265 radians

D= 3.086 X1016m. = 1 pc.

D(PC)=1/PN

Parallax of Proxima Centauri ~768.5 mas. = 1·30pc = 4.24 ly

Space mission to measure distances:

Hipparcos- High Precision Parallax Collecting Satellite (ESA 1989-1993)

Measured positions & parallaxes of 118200 stars.

Star & Stellar-evolution- 1

A star is defined as a body (i) bound by self gravity spherical spheroidal for stars with significant rotation (example. Achernar, rotation velocity ~ 230km/s) and (ii) Radiates energy from internal sources nuclear fusion for at least a part of it's life (Gravitational P.E contribute in the case of Protostars) Planets, Asteroids, Comets - do not satisfy one or more conditions. Planets such as Jupiter & Saturn generate significant internal energy.

Our Star - Sun

Next nearest star- Proxima Centauri (4.24 light yes)

About 100-400 billion stars in our Galaxy milky way.Composition of star ~ 71%. H, ~27 He, small fraction of heavy elements (ly mass). We consider the Sun as a useful reference point in stellar evolution.

Mass $M_{\odot}$= $1{\cdot}99\times10^{30}$kg

Radius $R_{\odot}$= 6.96×10^{8}m

luminosity $L_{\odot}$=3.83×10^{26}w

Effective surface temperature

$T_{\odot}$=5780K

Age $t_{\odot}$=4.55×10^{9}years

Core density $\rho_{\odot}$=1.48×10^{5}kgm^{-3}

The core temperature is $T_{\odot}$=15.6×10^{6}K

Core pressure $P_{\odot}$=2.29×10^{10}Pa

Atmospheric pressure→10^{5} Pascal

Measuring angles in the sky (Celestial sphere)

Angular size of moon ~0.5°

1°= 60' arc min = 3600" arc sec.

Small angle approximation.

Sin θ≈θ≈ tan θ

If two stars are at a similar distance, D & angular separation is known, then linear separating

S = D θ (radians)

88 official constellations'

We have considered a co-ordinate system on a sphere: Earth as an example shown in Fig. 2

Latitude & Longitude

Similar to spherical coordinates,r fixed.One axis (Rotation) defines latitude (z-axis) measurement from the XY plane (equator)rather than the z axis

Definition of O'longitude (x-axis)-Greenwich

latitude = 90°- θ→ZY plane

Longitude=Φ→ Z axis

Greenwich as the standard.

ZY plane - horizon x axis-Normal to this plane (hive joining zenith & nadir)

Z Axis - North direction horizon.

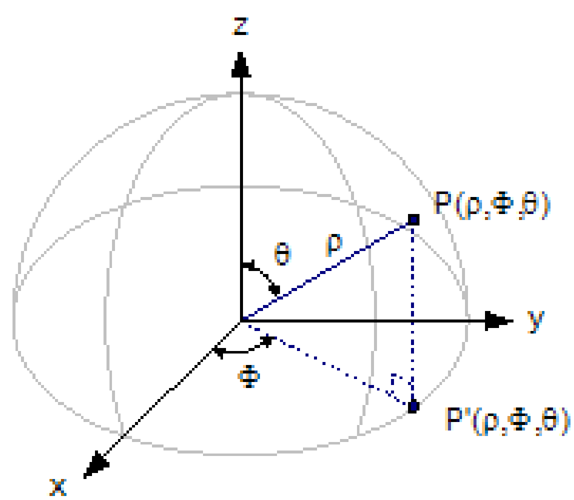


Fig. 2. Spherical coordinates:Φ,θ,ρ

Altitude- Angle measured toward Zenith from the horizon.

The Azimuth-Angle measured horizon from North toward East. These are shown in Fig. 3.

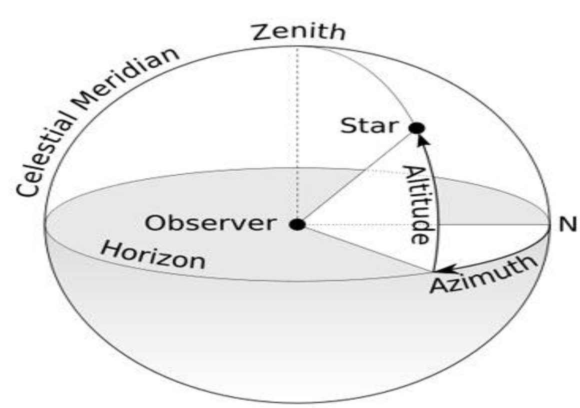


Fig.3. Altitude-Azimuth equatorial coordinate systems

Horizontal co-ordinates of a star are local to every location on earth. The Fig..4 below shows equatorial coordinate systems.

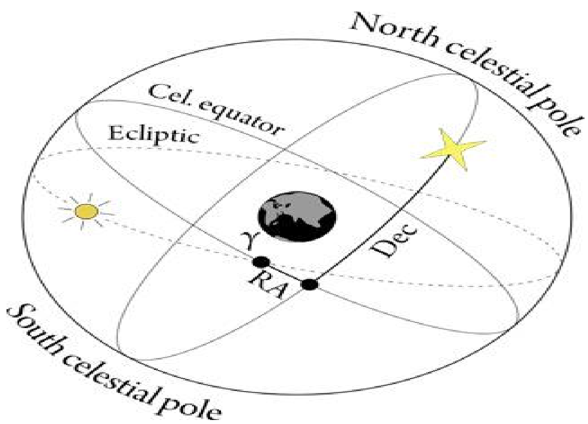


Fig. 4. Equatorial coordinate systems

Horizontal coordinates change with time due to Earth's rotation

Altitude -analogous to latitude on earth.

Horizontal co-ordinate of a star- local to every location on Earth

Horizontal Coordinate change with time due to Earth's rotation

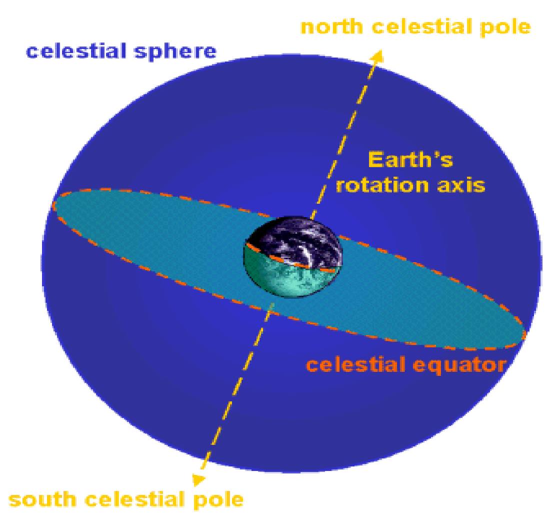


Fig. 5. An illustration of the Celestial Sphere

Equatorial system

XY plane→ Celestial equator.

The Z-axis is→normal for this plane

X-axis→vernal equinox (VB) on Celestial equator

Declination→ Analogous to latitude of earth

Right ascension→ Analogous to Longitude on earth

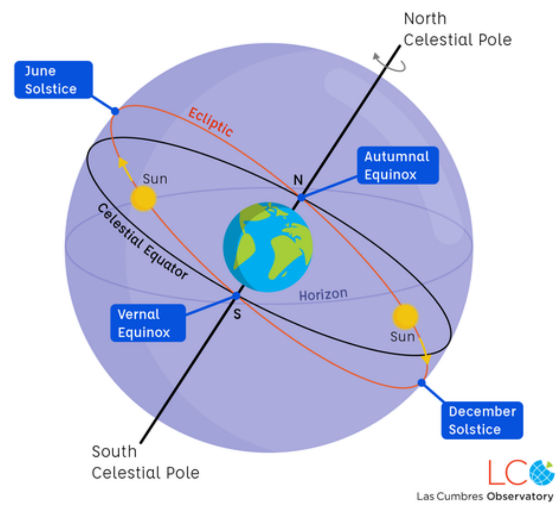


Fig. 6. The Equatorial coordinate system

Right ascension: Angle between great circle passing through VE & star

Declination: Angle between the Celestial equator & star as a great circle passing. through star.

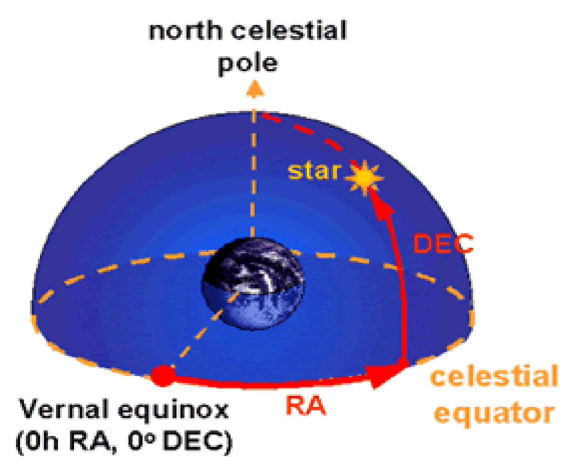


Fig. 7. Celestial hemisphere

Right ascension - Measured in hours, minutes and seconds.

24 hours = 360°

1 hr=15°,1 minute=15',1 second =15"

Declination: Measured in degrees, are-min, arc sec

Precession of equatorial co-ordinate system

Precession of co-ordinates- Time period of ~26000

Precession is due to action of the moon sums on the equilateral of earth.

Changes the position of stars by~1.5" each century.

4. Hertzsprung-Russell diagram:

The Hertzsprung-Russell diagram shows the relationship between a star's temperature and its luminosity. It is also often called the H-R diagram or color-magnitude diagram. The chart was created by Ejnar Hertzsprung and Henry Norris Russell in about 1910. It is a very useful graph because it can be used to chart the life cycleof star.

In the diagram stars' surface temperatures in degrees Kelvin on the x-axis (horizontal axis). The stars' luminosity (or absolute magnitude) showed along the y-axis (vertical axis). It is to be noted that the x-axis of the H-R diagram can use different data. It can show the star's temperature, its spectral class (OBAFGKM), or its color. All these types of data show the same relationship with a star's luminosity.

Most stars, including the Sun, plotted in a band that runs from the top-left to the bottom-right of the chart (Fig. 8). This band contains stars that are in their main sequence stage. We can use the chart to see the temperature of main sequence stars increases with brightness. This is because the star's mass controls both its temperature and brightness.

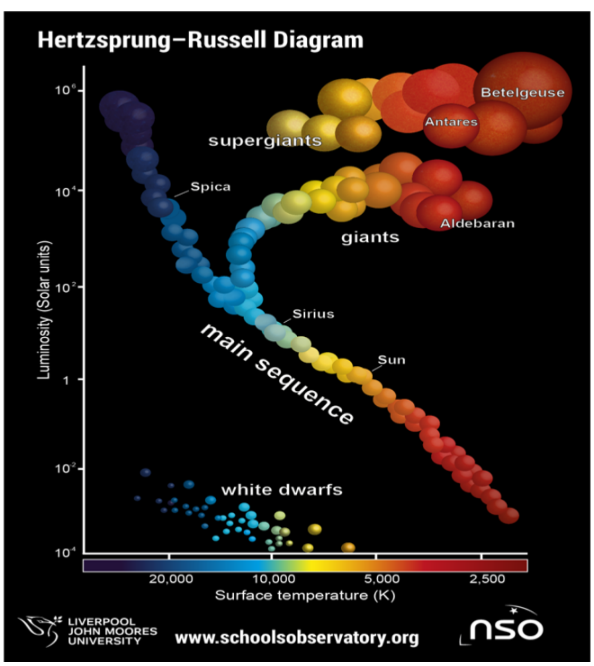


Fig. 8. Hertzsprung-Russell diagram

Giant and super-giant stars are plotted to the top and top-right of the diagram. This tells us they are brighter than main sequence stars but also redder and cooler. This is because they expand and cool as they reach the final stages of their lives. However, because of their large size, they remain very bright.

White dwarf stars can be seen below and to the left of the main sequence. This tells us they are hotter than main sequence stars, but not as bright. This is because they are small in size but contain a lot of mass. Stars tend to spend most of their life (~90 %) on the main sequence stage. After this, they evolve into giant stars for the remaining 10 % of their lives. Finally, they will either explode as a supernova or become a white dwarf (Britannica, 2021).

5. Life Cycle of a Star – Step by Step Explained

Giant Gas Cloud: The life cycle of a star begins as a large gas cloud. Also, the temperature inside the cloud is low enough that a molecule can form in it.

Besides, some molecules such as hydrogen light up and allow astronomers to see them in space. Moreover, the Orion Cloud Complex of the Orion System could be the nearest example of a star in this stage of life (Atkinson N., 2014).

Fig. 9. An Interstellar Cloud, The Rosette Nebula, constellation Monoceros

Protostars: It is a baby star that forms when gas particles in the molecular cloud run into each other and create heat energy. Furthermore, this allows a warm clump of molecules to form in the gas cloud. Besides, this clump is well-known as Protostars.

While Protostars are warmer than other materials in the molecular cloud so they can be seen with infrared vision. In addition, depending on their size, there can be several Protostars in one cloud (Apfel & Necia,1988).

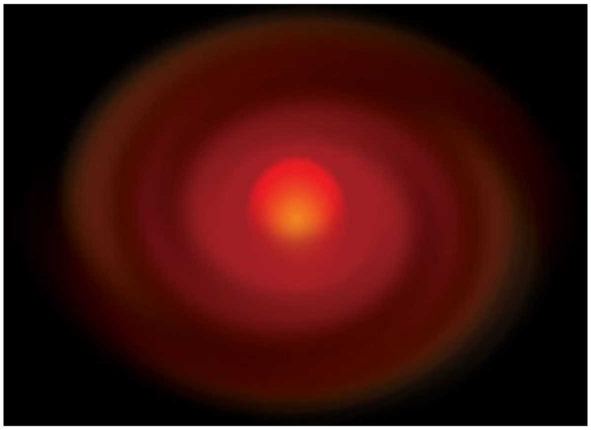


Fig. 10. Illustration of a Protostar

T-Tauri Phase: A young star starts to form in the T-Tauri phase and it begins to produce strong winds that push away the surrounding molecule and gas.

Moreover, it allows the forming star to become visible for the first time. Besides, scientists can spot the star in the T-Tauri phase without the assistance of radio waves and or infrared.

Main sequence star: In this stage, the young star reaches hydro-static balance and its gravity compression is balanced by its outward pressure, giving it a solid shape.

After that, the star becomes a main Sequence star. Also, it spends 90% of its life in this stage fusing with hydrogen molecules and forming helium. Most noteworthy, the sun is currently in this stage.

Downgrading of the Star: Stars have been characterized by their mass. A star's mass decides its centre weight and temperature and, in this manner, decides its combination rate. As indicated by this arrangement, stars are low mass or little star, a medium measured star, and a high huge star. At the point when stars run out of their fuel, they don't immediately die and then disappear. Contingent upon their size, they experience a procedure. In this procedure, a normal star and little star become changed into a red giant, planetary cloud and a white midget. Enormous stars wind up like red super Goliath, detonate as a supernova and afterward move toward becoming a neutron star or black hole (Tinsley, 1979).

Downgrading of small Star: Low mass stars burn over billions of years melding hydrogen to helium in their center by means of a proton chain. Over its lifetime, a low-mass star devours its center hydrogen and converts it to helium. As the hydrogen shell consuming produces more helium, the center increases in mass and temperature. The external might of the star, which is still for the most part hydrogen, starts to grow and spark red. The star has now achieved the red giant stage. It is red since it is cooler than it was in the primary succession star stage, and it is a giant on the grounds that the external shell has extended outwards. For allow-mass star, after the helium has combined with carbon, the center crumples again. As the center crumples, the external layers of the star are removed (Sana. et al., 2012). A planetary cloud is framed by the external layers; at that point the center stays as a white smaller person and in the long run cools to wind up a black midget.

Expansion into Red Giant: When all the hydrogen is converted into helium, then the core collapses on itself, which causes the star to expand. On expansion, first it becomes a sub-giant star and after that the Red Giant (Fig. 11).

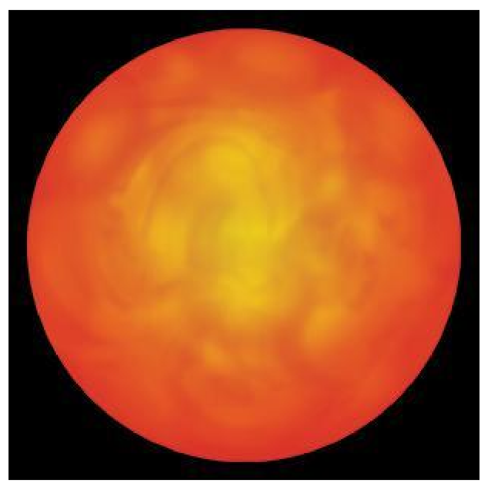


Fig. 11. Red Giant

It is cooler than the main-sequence star and that's why it appears red and it can become large enough to be a super-giant.

The fusion of Heavier Elements: While expanding, the star begins to fuse with helium molecules in its core and this reaction prevents the core from collapsing. After helium fusion ends, the core shrinks, and stars start fusing carbon (Robert W. Conn., 2019).

Moreover, this continues till iron starts appearing in the core. Iron fusion absorbs energy and causes the core to collapse. If the star is massive enough, then the implosion creates a supernova, while small stars like the sun contract into white dwarfs, whereas their outer shells radiate away as planetary nebulae.

Planetary Nebula: A Planetary Nebula is a growing, shining shell of hot gas (plasma), that is pushed off towards the end of a low mass star's life . The word planetary cloud is a misnomer that began in the 1768 S with cosmologist WILLIAM HERSCHEL, in light of the fact that when seen through his telescope, these items look like the adjusted states of planets. A youthful planetary cloud has the most elevated densities, some of the time as high as 106 particles for each cm3. As nebulae age, their development, their thickness diminishes. The mass of planetary cloud mass ranges from 0.1 to 1 sunlight-based masses (Bruzual et al, 1993). Low stars hand over to planetary clouds towards the end of their red mammoth stage. Now the star turns out to be very temperamental and starts to throb. The external layer is shot out by the subsequent solid stellar breezes. As the external layers float away from the star, the remaining center sparkles splendidly and is exceptionally hot (100000°c) and the center is currently changed to a white small star. Planetary clouds are moderately fleeting and last only a couple of a huge number of years. Planetary clouds play a pivotal part in the compound advancement of the smooth route by ousting components to the interstellar medium from stars. The improved material from the planetary cloud is scattered into space and will be utilized for future ages of stars.

White Dwarf: In the white smaller stars, organized stars have passed over their external layers late in their lives. These stellar leftovers never again create vitality to balance their mass and are bolstered against gravitational crumple by a procedure called electron decadence weight. The surface temperature of a white diminutive star is 8000K-4000K. It is shown in Fig. 12. The spectral type of white smaller star is D. White smaller stars comprise of deteriorated matter with a high thickness because of gravitational impacts. The common period of white midget is 100,000-10 billion years. More than 91%of stars are speculated to begin with the white smaller star. These super hot structures will stay hot for trillions of years before cooling to become black holes

Fig.12. White Dwarf

Downgrading of Massive Star: A star which is bigger than eight sun-based masses amid its normal fundamental grouping lifetime, is viewed as a monstrous star. They ordinarily have a speedy main sequence arrangement stage, a short red super monster stage and a staggering pass through a supernova blast. Enormous stars are born simply like normal stars, out of dust called clouds. On the off chance that the dust storms are vast, it will make a huge star. Huge stars consume their "atomic combination" considerably quicker than low-mass stars. The surface temperature of huge stars is 2000-30000°C, and generally seem blue and radish blue. An enormous star will consume at a very high temperature, it will be flawlessly brilliant, and however, its hydrogen will just last a huge number of years. This may appear like quite a while, yet it is a flicker of the eye in contrast with littler stars that existed for billions of years. Toward the end of their development, they deliver a standout amongst the most tremendous wonders that can be seen in the sky: a supernova blast.

Red Supergiants: Red supergiant stars are stars that have depleted their supply of hydrogen at their centers and therefore their external layers extend massively as they develop (Reimers, 1975) off the primary succession. The spectral type of red super monster is K, M. The temperature of this sort of star is 3500-4500 K. The stars of this composition are the greatest stars. The period of red super monster is 3 million to 100 million years. In uncommon cases, red super Goliath stars have sufficiently gigantic to meld high components, that around the center. The red super monster inevitably crushes them in a supernova, deserting a neutron star or black hole. The case of red super monsters are Betelgeuse and Antares.

Supernovae: The Supernova explosion is the biggest event in the universe. Furthermore, most of the material blows away but the core implodes rapidly into a neutron star, or a singularity known as a black hole.

While small stars don't explode and contract into tiny hot stars called white dwarfs while their outer material drifts away (Fig. 13). Moreover, astronomers suspect some red dwarfs have been in their main sequence since shortly after the big bang (Branley, 1987; Singh, 2005).

Fig. 13. Simulated image of a supernova

Black Holes: Black holes are objects so dense that not even light can escape their gravity and, considering the fact that not anything can travel faster than light, nothing can escape from inside a black hole. It is depicted in a pic by NASA in Fig. 14. Nevertheless, there's now a great deal of observational proof for the existence of two types of black holes: those with masses of a typical star (4-15 times the mass of our Sun), and those with masses of a typical galaxy.

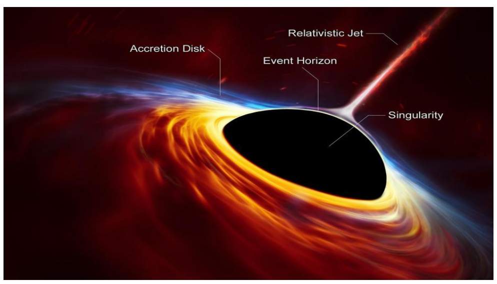


Fig. 14. Computerized image of Black hole

Neutron Stars: Neutron stars are generally approximately ten miles in diameter, have approximately 1.4 times the mass of our Sun, and spin very rapidly (one revolution takes mere seconds!) (Fig. 15). Neutron stars are fascinating because they are the densest objects known. Due to its small size and high density, a neutron star possesses a surface gravitational field approximately 300,000 times that of Earth.

Fig. 15. Neutron star

Conclusion:

This paper provides an informative description of the life cycle of a star. It started with nothing, but modern astronomy has made it possible for mankind to come up with a convincing sequence for the life cycle of a star. The paper has noted that all stars are formed from a nebula cloud.

It has been revealed that the life expectancy of stars can vary from a million to many billions of years depending on their mass. A star begins to die when it runs out of hydrogen and the fusion reaction can no longer occur. The paper has also demonstrated that the death of a star is dependent on its mass. If a star is the size of the Sun, it will die off as a white dwarf, while if it is significantly bigger, it will have an explosive death as a supernova.

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