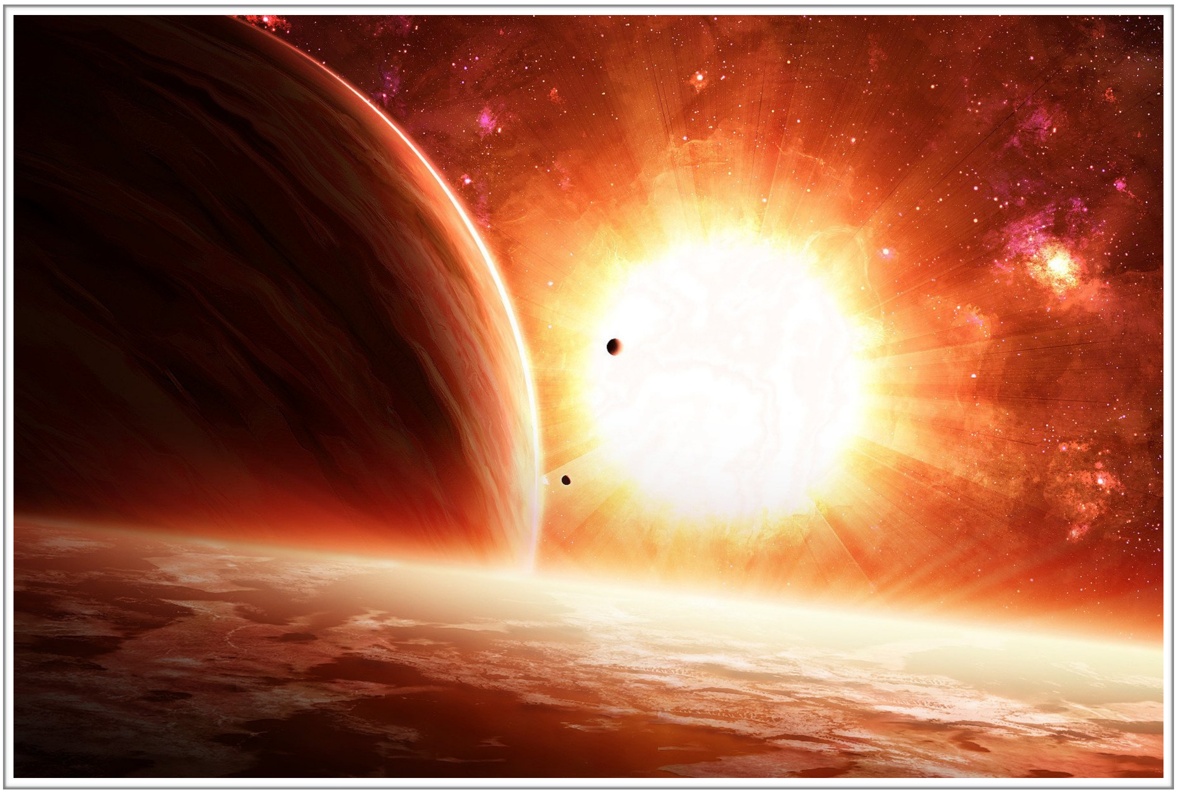
Physics of a Star



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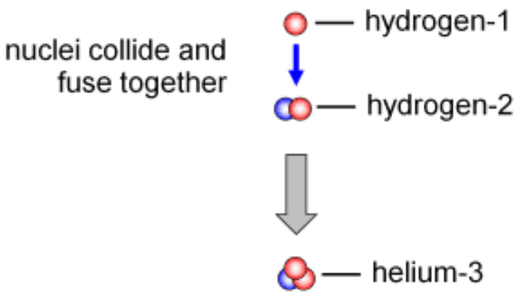
Introduction

Stars have been fascinating to the human civilisation. From the constellations (groups) which they form to the ancient civilisations placing great value in them. They also have a very scientific significance and that is to support life in our case. The Sun is the star that provides the energy to Earth which without there would be no life! The Sun was used in navigation in the olden days as one could comprehend North, West, East and South by knowing the position of the Sun. Many ideas/inventions have been based on the Sun like the sun dial. The position of the Sun is of great meaning as it helps us calculate the position of other planets and celestial bodies and helps deeper research into astrology. So now it would be obvious to study these magnificent works in detail! [1]

Leo constellation [6]

What are Stars?

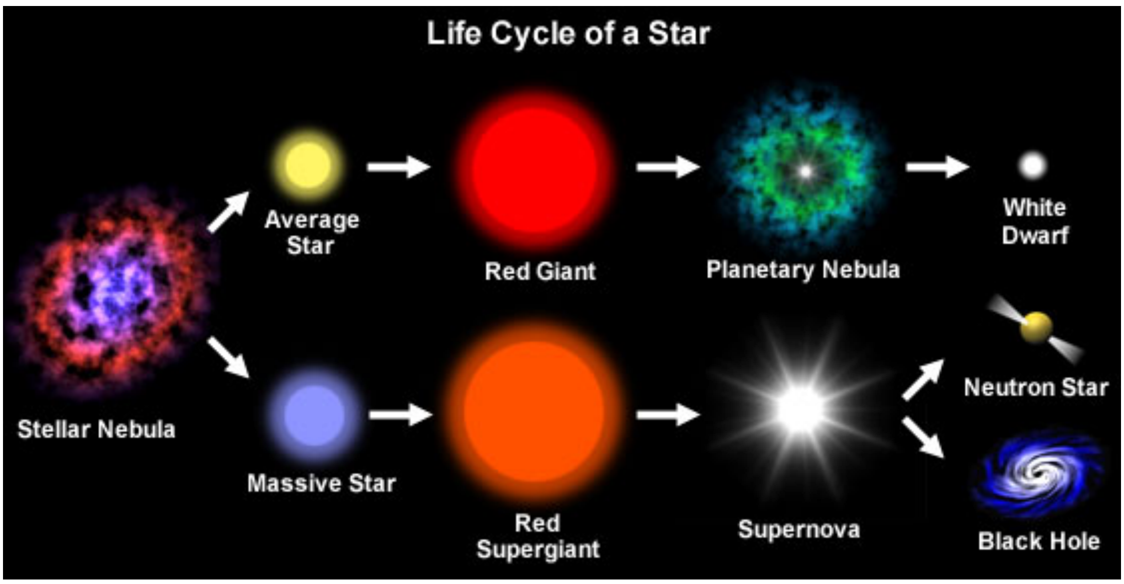
A star can simply be defined as "luminous ball of gas".Hydrogen and Helium make up most of the mass of stars and these gases are held together by the gravity of the star. A critical process that happens in the core of stars is nuclear fusion. Generally, two hydrogen atoms collide to form a helium atom and this process releases a lot of energy in terms of heat and light. This process also balances the inward force of gravity as the internal heat generated from this process has a force that acts outwards from the core of stars. [2]



Nuclear Fusion [4]

Lifecycle of Stars

There are two main lives a star leads and that depends on its size and temperature when it forms. Larger stars only live for a couple hundred thousand years as they burn their fuel quickly, however, smaller stars like our sun can live for billions of years as they burn their fuel slowly. When the fuel(Hydrogen) starts to run out the stars tend to increase in size and cool down in what is known as **red giants.** [3]



Lifecycle of a star [3]

Now the stars can follow two paths depending on their mass. An average star like our Sun will go through the **Planetary Nebula** stage. This stage is when smaller stars pulsate and the outer layers of the star are ejected by the stellar winds. As the outer layers drift away the core is left which releases a lot of ultraviolet radiation and it causes the nearby ejected outer layers to glow resulting into a beautiful spectacle like the one below. [3]

Planetary Nebula[5]

Then when all the ejected layers are no longer nearby then only the core remains and it is known as a **white dwarf**. After cooling down the white dwarf turns into a brown dwarf. One wonders why white dwarfs don't collapse further and quantum mechanics provides that answer and it is that fast moving electrons provide outward pressure preventing a further collapse. This is only true for stars having a mass up to 1.4 times the mass of our Sun. However, a larger star will turn into a red supergiant which will then explode in an explosion known as a **supernova.** The outward pressure isn't enough to prevent this explosion as the mass of the star is greater. [3]

If the core left over has mass between 1.4 - 3 solar masses then the core collapses further until protons and electrons combine to form neutrons. These types of stars are very dense and are known as **neutron stars.** These can be spinning at high speeds and than they are called **pulsars.** If the star was originally huge in size then the supernova might result in a **black hole**! The remaining dust and interstellar gas lead to the formations of new stars. [3][7]

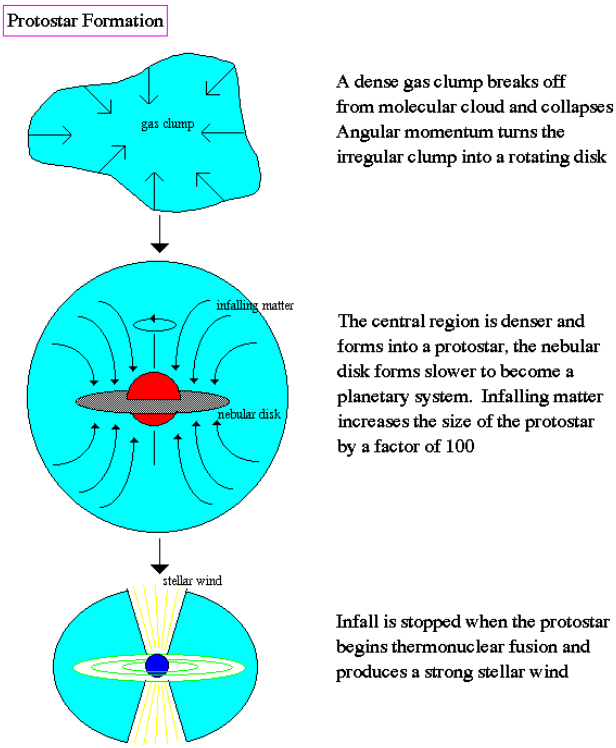
Star Formation

Stars from inside dense regions of interstellar gas known as molecular clouds. These regions are extremely cold at about 10-20K (just above absolute zero). At these temperatures atoms start to bind together and then from molecules and the most common molecules present are H_2 and CO. This binding together keeps on increasing the density and at a point star formation begins. These regions are opaque and they don't shine light so they are known as dark nebulas.[8]

Dark Nebula[9]

Some parts of the molecular cloud then collapse because of their own gravity/weight. The core of the cloud collapses first as they are denser than the outer parts of the cloud. The “core then fragments into clumps” then these turn into protostars. This process itself can take 10 million years.[8]

Once the clump is free of the molecular cloud then it has its own gravity and it is called a protostar. The loose gas around it starts falling into the centre of the protostar. This gas releases kinetic energy in the form of heat and light and the pressure in the centre of the protostar goes up.[8]

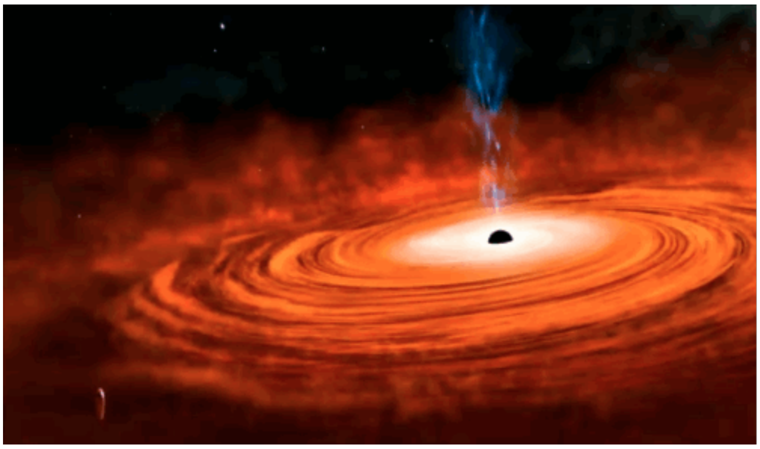


Protostar formation[8]

The angular momentum causes some of the in falling matter to form a disk which afterwards becomes a planetary system. This is also the reason why many stars have planets revolving around them. After a few million years the matter stops falling when the protostar begins thermonuclear fusion as it produces stellar winds. Now it is considered as a young star as its mass is fixed.

<u>T-Tauri phase</u>

Now, these stellar winds from along the axis of rotation and many have a bipolar wind outflow(wind out of the poles of the star). This can be seen by radio telescopes and hence your stars canoe observed. This phase is known as the T-Tauri phase.[8]

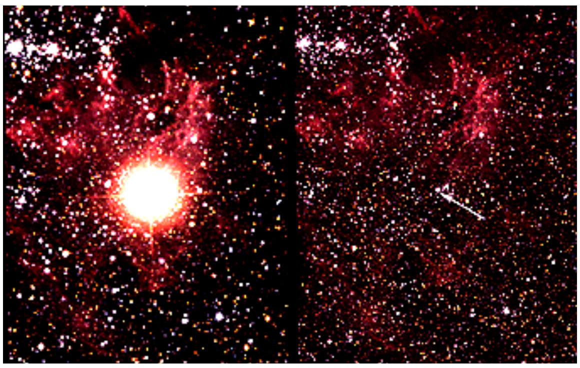


T- Tauri phase[8]

This disk around the star radiates energy at where it becomes a part of the sun and this energy can be picked up by radiation detecting equipment. This disk slowly starts to settle as planets start forming by constant collisions. In this phase, a star has very vigorous reactions on its surface, strong winds and irregular light waves.[8]

Brown dwarfs are stars that have failed to become stars. A star has to have a minimum mass of 75 times that of Jupiter or 8% of our Sun if that is not reached then the gravitational force because of the mass isn't enough to continue the thermonuclear fusion. These brown dwarfs(red in colour) slowly after roughly 15 million years cool down and become black dwarfs.[8]

Supernova

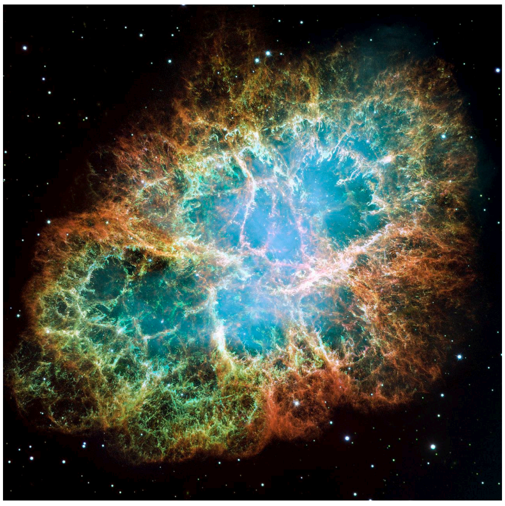


"After" and "Before" pictures of Supernova 1987A[13]

The picture above on the left is after the supernova and the one on the right is the picture before the explosion occurred. One can see the amount of the explosion emitted.

A supernova is the explosion of a star. It is the largest explosion in outer space. The main reason behind a supernova is a change in the core of a star and there are two different ways which result in a supernova. Both will be explained below.[11]

Firstly, in a binary star system(two stars orbiting the same point) "the carbon-oxygen white dwarf steals matter from the companion star" and has too much mass and explodes resulting in a supernova. The second type is at the end of the of a star's lifetime when the mass falls into the core and the can't handle its own gravitational pull leading to an explosion. This only happens to stars with greater mass than our Sun. A supernova is an essential area of research as it has told scientists a lot about the universe. Firstly, it has told scientists that we live in an expanding universe. Also, supernovae are considered important events as they are considered to be the ones that distribute elements across the universe as the stars explode. Many elements on Earth were made in the core of stars. [11]



Supernova[12]

So as we discussed earlier there are two different ways a supernova happens. The way where the white dwarf steals matter from the companion star is known as type 1A and the supernovae that occur at the end of a star's life is type 2. [13]

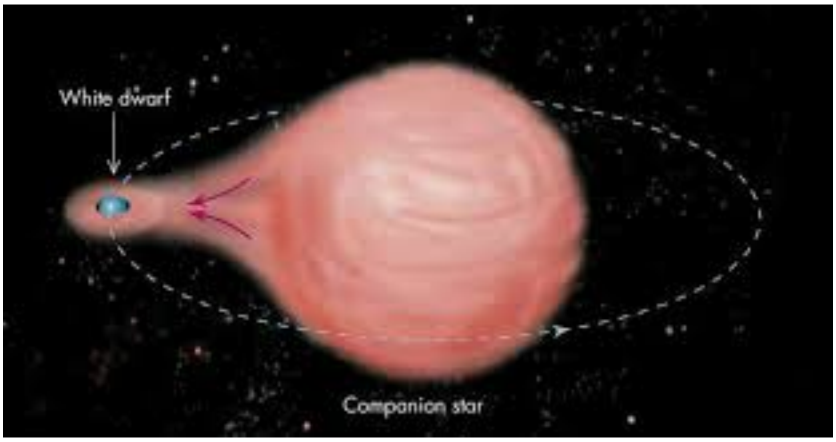
Type 1A Supernova

Type 1A supernovae are really valuable to astronomers as they help them calculate distances. To find the distance in space scientists use a method as "standard candles". An example of this would be "if one were to be standing on a road with evenly lit street lamps then according to the inverse square law the second street lamp will look one-fourth as bright as the first street lamp, and the third street lamp will look one-ninth as bright as the first street lamp, and so on." By looking at how dim the street lamps get one can calculate the distance.

Lampost analogy[14]

Scientists use a Cepheid variable for distances within our group of galaxies. This star pulsates and by observing star pulses the astronomers can then calculate its brightness and hence its distance. For distances further than our local group of galaxies, scientists need something brighter.

Now scientists have to refer to supernova and type 1A in particular. The type 1A has a binary system (two stars orbiting) where one is a white dwarf. The white dwarf is very dense (have immense gravitational pull)second only to neutron stars and black holes that they pull matter off their companion star and increase their mass. When the mass of the white dwarf reacher 1.4 solar masses(40% greater than our Sun) then it explodes under its own gravity. The light from this reaction is 5 billion times brighter than our Sun. Because this reaction happens at the same mass and in the same way the brightness is always the same. "The explosion point is known as the Chandrasekhar limit, after Subrahmanyan Chandrasekhar, the astronomer who discovered it." To measure distances the scientists know how bright the explosion should be and now compare it with how bright it appears and using the inverse square law compute the distance.[14]



Binary system [15]

Conclusion

Now one can see the significance of a star in life. It is not only is a vital part of solar systems much like ours but also a fascinating beast of nature. Stars help astronomers better understand the universe and advance human research. We also now understand the beauty and immense scale of supernovae and their significance in space explorations.

Citations

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