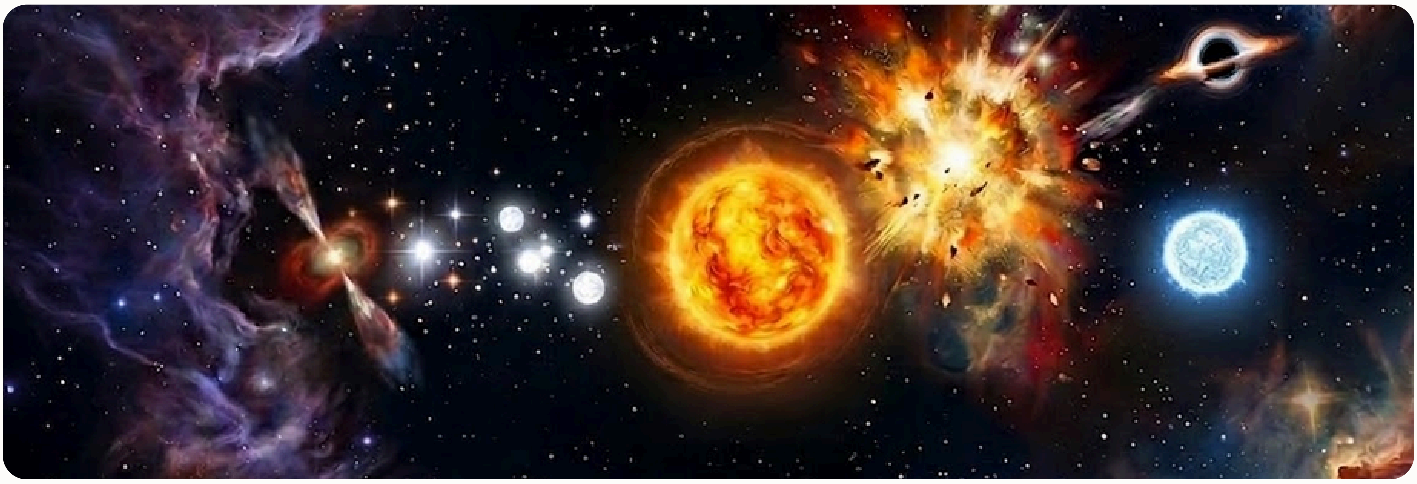
The Life Cycle of a Star



Stars are the heart of the habitable universe, which, like any other living being, are born, evolve with time, and then eventually die. And just like us, all stars are not the same.
According to their respective masses, stars are divided into different categories: low-mass stars, intermediate-mass stars, high-mass stars, and very high-mass stars.

FORMATION OF STARS

Depending on their mass, stars have different life cycles; despite that, the fundamentals of their formation are the same. When a molecular cloud (a type of interstellar cloud) collapses under its own gravity, it increases the cloud's density and temperature. The clouds come closer and closer, spinning rapidly, forming a flattened rotating disk called a "protostellar disk" with a central region called the "protostar."
The protostar is not a star yet. They continue to collapse due to the effect of gravity. As the core gets denser, the gravitational energy converts into heat. The protostar's temperature continues to rise until it reaches 10 million Kelvin. At this temperature, the atoms move very fast, which ignites nuclear fusion. Hydrogen fuses to form helium, releasing an enormous amount of energy in the form of heat, light, and radiation. This is called **stellar ignition,** the birth of the star.
Once the nuclear fusion begins, the energy from fusion resists gravity from further collapsing the star inward. When these forces reach the state of equilibrium, the star becomes stable.

Protostar in Formation

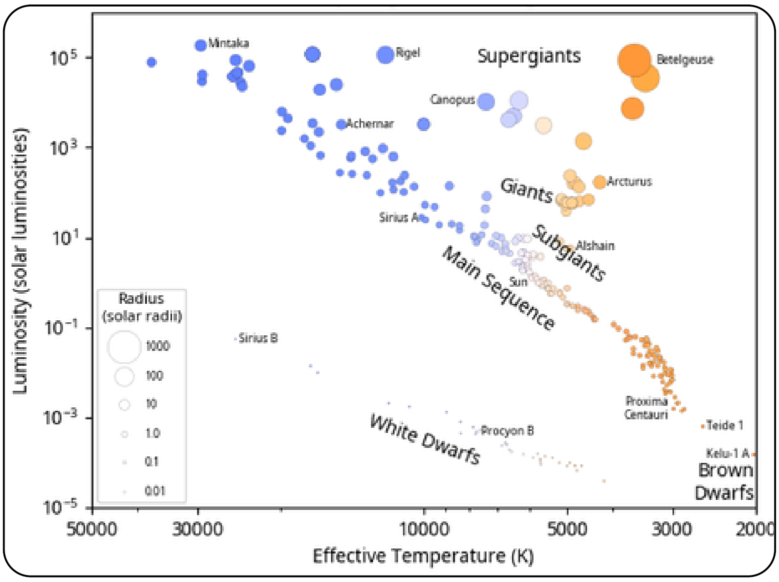
Common intuition might suggest that smaller stars might take a shorter time to form, compared to larger stars, but in reality, this is not true. Due to the action of the gravitational force, which is proportional to mass, larger stars are, in fact, formed faster.

In some cases, if the mass of the core is too large, the gravitational pull will s so strong enough for the protostar to collapse completely before the stellar ignition begins. In other situations where the core is too small, even after continuous contraction, the core will never reach the conditions for nuclear fusion. These protostars, which fail to become stars, are referred to as **Brown Dwarfs.**

MAIN SEQUENCE

This is the longest and most stable stage in the life of a star. The main sequence covers approximately 90% of a star's life. It is the stage when nuclear fusion starts in the star, reaching the state of equilibrium. Here, hydrogen fuses to form helium, and the extra mass is released in the form of light. This energy stops the star from collapsing further inwards, and this state is called the hydrostatic equilibrium state.

Hertzsprung-Russell Diagram



Helium gets accumulated in the core of the star, gradually increasing the core density and temperature.
Among all stellar properties, mass plays a crucial role; greater mass usually means higher luminosity. Consequently, more massive stars shine more brightly and have higher surface temperatures compared to smaller, dimmer, and cooler stars.
Likewise, the duration of time a star spends in the main sequence stage also depends on its mass. The less massive a star is, the longer it stays in its main-sequence stage.
The H-R diagram plots stars by their luminosity against their temperature/color, from blue-hot giants to red dwarfs. In the image, it is noticeable that all these stars are not scattered around the graph randomly but form a diagonal band, which is called the main sequence, which extends from the top left to the bottom right.
The off-sequence area shows the evolved stars such as giants, supergiants, and white dwarfs.

Mass plays an important role in the life of a star. On the main sequence, the most massive stars are brighter and hotter, blue or blue-white in color, and are called blue giants or supergiants, while the least massive stars are small, dim, and red in color and are called red dwarfs.
When it comes to the time spent on the main sequence, blue giants or supergiants have the shortest lifetimes, whereas red dwarfs can remain in this stage for trillions of years.

POST MAIN SEQUENCE

After a long period of nuclear fusion, stars run out of fuel, which disrupts the hydrostatic equilibrium. Gravitational force overpowers the equilibrium momentarily, which further contracts the star and heats its core. At this stage, hydrogen begins to burn in a shell around the core, causing the outer layer to expand significantly. A star at this is referred as a red giant or a red supergiant, depending upon its mass.

END OF THE STAR

After the star expands, the final stage depends on its mass. Let's examine these different stars separately.

Low/Medium Mass Stars

During the red giant phase, these stars are extremely bright but have relatively cool surface temperatures, and their cores begin fusing helium. This marks a critical transition in the late stages of stellar evolution, where the outer layers become unstable and start separating from the core.

In the asymptotic giant branch (AGB) stage, thermal pulses drive strong stellar winds that expel the expanded hydrogen and helium as ionized gas. The ejected material gradually forms a surrounding nebula, highlighting the final active phase of the star. The remaining core then contracts into a hot white dwarf, whose ultraviolet radiation ionizes the surrounding shell, causing it to glow.

Over a very long period, this remnant eventually cools and fades, forming a black dwarf.

Large Mass Stars

They turn into red supergiants, where they lose their mass through superwinds, which are stronger than the solar winds of our own sun. This strips off the outer envelope, which forms dusty circumstellar envelopes. The core fuses the helium into carbon, then neon, and it continues till it reaches the formation of an iron core **(helium → carbon → neon → oxygen → silicon → iron)**.

At this stage, the fusion stops, making the gravity crush the core instantly. The core shrinks in milliseconds. At the atomic level, protons and electrons collide, releasing neutrons and neutrinos, which cause an explosion that outshines the galaxies.

After this explosion, either a neutron star or a black hole remains, depending on the mass of the star.

White Dwarf

The Final Explosion

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