The life of a star
Autonomous project : English

PAULINE DUBUC, SUZON THENAUX, AYMERIC BOUZIGUES
Mines Nancy
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Abstract

To write.

Star cluster captured by the Hubble Telescope

Contents

Introduction

Stars are everywhere in the universe. They are far from being only the little dots we can see at night when the sky is clear. They are the power plants of the universe and its most common inhabitant. They also are the forge of new matter, as every atom in your body that isn't hydrogen was once created in the heart of a star and expelled in the universe when the star exploded, to later coalesce in matter cluster, forming planets and maybe later, you. These huge spheres of burning gas are essential the universe, and is essential for us, as the sun is our biggest energy source and our only light source.

1 The theory principles behind a star

1.1 The creation process

Stars are created every day, by a random process. They don't arise ex-nihilo, but are formed in **nebulae** that can be as much as 300 light-years[1] wide. In a nebula, there are huge clouds of gas in movement. One slight event can provoke the creation of a star, while nothing can happen in millions of years, making the creation process very random.

In the stars, gas clouds and the universe in general, everything a question of balance. The clouds within the nebula must maintain balance between their inner pressure and their temperature. These are explained by the **equation of state of an ideal gas** :

$$P \cdot V = n \cdot R \cdot T \qquad (1)$$

- P : the pressure
- V : the volume
- n and R : constants of the gas cloud.
- T : the temperature

The temperature within the nebula tends to increase, due to light rays from nearby stars providing a slow heat source, just like the sun with earth. As we can see in this equation, an increase in temperature will trigger an increase in volume and pressure. As the pressure steadily increases along with the temperature, the particles within the gas speed up, as seen in the **equation of particle speed in function of temperature** :

[1] 1 light year is over 9.5 Billion kilometers, in comparison, earth-sun is 0.15 Billion kilometers.

$$v = C \cdot \sqrt{T} \quad (2)$$

- v : the particle speed
- T : the temperature
- C : constant of the gas cloud.

As the particle speeds up, more and more collision occur within the cloud and just like a lighter, the cloud start to ignite and the star is born. The *ignite* is actually the fusion[2] process beginning which is the essence of what a star is and why it *lives*.

1.2 The fusion process

The fusion process is the essence of the star, it makes it shine, and allows it not to collapse into a **black hole**[3]. Atoms, and matter in general contain energy, energy and mass are essentially the same thing[4].

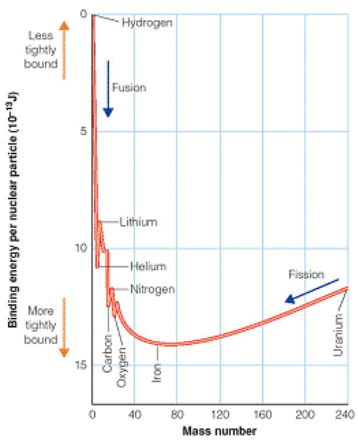


Figure 2: Energy contained in atoms

As said earlier, stars are mainly composed of hydrogen, and they use it to gather energy, the energy they need to shine. As shocks occur, the **Hydrogen in the star becomes Helium**. As we can see in Figure 2, Helium contains less energy than hydrogen, which means that the energy difference when the transformation occurs is released in light and heat.

[2]Explained in next section

[3]A black hole is a object with huge density, when gravity collapses atoms on themselves, they are explain in section REF

[4]Einstein exposed a link between them : $E = mc^2$ chich translates that you can actually convert energy and mass easily.

The fusion process follows this pattern :

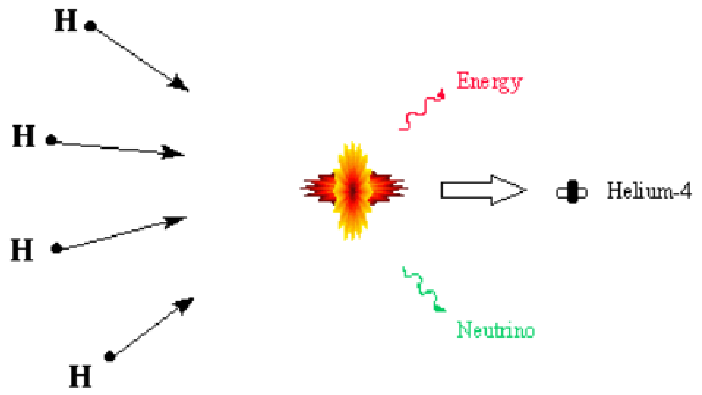


Figure 3: Hydrogen fusion

The interesting fact to notice is that fusion auto-fuels itself : it needs heat and the process generates heat.

The star's boring and repetitive life is to maintain an equilibrium between the fusion process and the gravity, the first one expanding the atoms and the star, and the second one collapsing it on itself.

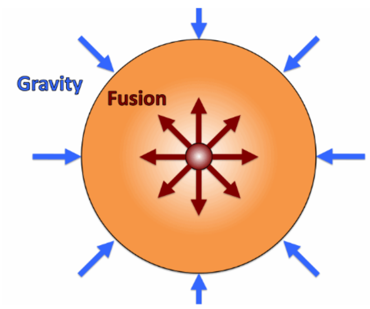


Figure 4: Balance between fusion and gravity

2 The end of the equilibrium and the end of the star

Unfortunately for the star, this balance isn't forever and decays with time. In the beginning, the star fuses Hydrogen, then Helium, then all the way to Iron, which is **the most stable element in the universe**, the star cannot get anymore energy because it has reached the end of the fusion process.

$$H \rightarrow He \rightarrow C\ (Carbon) \rightarrow Ne\ (Neon) \rightarrow O\ (Oxygen) \rightarrow Fe\ (Iron) \tag{3}$$

Then, the fusion process ends, and the only force applying on the star is its own gravity. The star then collapses on itself and begins a long journey to delay a unavoidable end for the star. It can take different path, that vary with the star's mass. The most common, for smaller stars is the **white dwarf**

2.1 White dwarf

A white dwarf is the remains of non-massive star whose fusion has stopped: after merging hydrogen into helium and helium into carbon and oxygen, the gravity is not compensated by the energy of the fusion and the star collapses on itself. But to deceive death and avoid collapsing completely into a black hole, the star still has a trick up her sleeve. Electrons have a very strong repulsive force one towards another. The star then reaches another equilibrium point called a white dwarf.

It is now 1 million times denser than before[5]. Its density reaches 1 ton per cm^2. The White Dwarf usually have the size of planet Earth but their mass is approximately that of the sun.

Since massive stars are very rare, this a the fate of the 96% non massive stars of our galaxy. Nevertheless it keeps shining thanks to the energy stored by the star it once was. Indeed, the reduced surface of the star enables the heat transfer to be also reduced and slow, so that the star can keep the energy longer and delay its certain death.

Then the star starts to decline slowly, its brightness diminishes and its gets colder and colder until the star dies. This process can take a very log time, even from the universe's point of view. The white dwarf are the embers of Red Giant: they are still shining but far less than their parent star but declining slowly. This decline is extremely slow and ultimately, that the **white dwarf** will become a **black dwarf** within around 10 billions years. The universe is too young[6] to know such Black Dwarf.

[5] For example, if a mobile phone was as dense as a white dwarf it would weigh approximately 10 tons.

[6] The universe is approximately 13,7 billion years old.

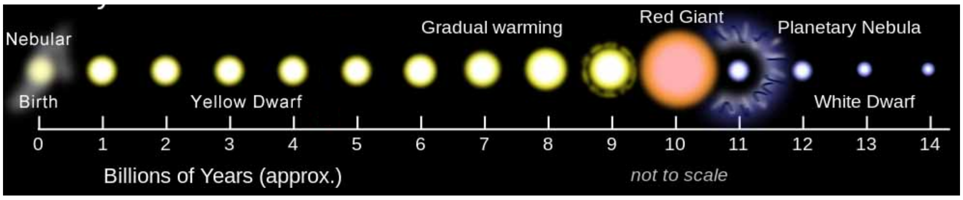


Figure 5: Time scale of a star's life cycle in the universe

If the star is a massive one, meaning at least 10 times the mass of the sun, its destiny is very different. They explode in supernovae. They also are very difficult to find because it is a rare phenomenon: around 2 or 3 supernovae per galaxy per century. To find one, scientist have to scan 1000 galaxies with a telescope that takes pictures every night of these galaxies and compare to the previous pictures too find some supernovae.

2.2 Supernova

Those supernovae are found approximately at 100 billions light year away from our solar system. They were really important for the beginning of earth life because all the heavy elements were formed by the supernovae. Indeed only a star with such power could produce the heavier elements. At the beginning scientist only knew that the first one (until iron) were produced by the red giants in the fusion process but were unable to determine where did the heavier elements (like lead, or uranium or even copper) were created.

But in 1957, in the article B^2FH[7], a team of scientists[8] exposed for the first time the theory that every element on earth was produced by supernovae. In the following years, they managed to find proof of this by analyzing the spectrum of the light at the moment of a supernovae explosion captured by a telescope. They found more than 90 elements within the spectrum ! When the elements burnt they gave off different colors, for example potassium shades the flames in purple, strontium in red, sodium in yellow, copper in green/blue. By diffracting the spectrum it is possible to determine the elements that compose the star's vestigial cloud.

When the star has enough mass, it is layered with different fusion process when you move closer to the core. Of course, all stars are like this but with heavier ones, the separation is more clear.

[7] *Synthesis of elements in stars*

[8] Geoffrey Burbidge, Margaret Burbidge, Fred Hoyle and William Fowler

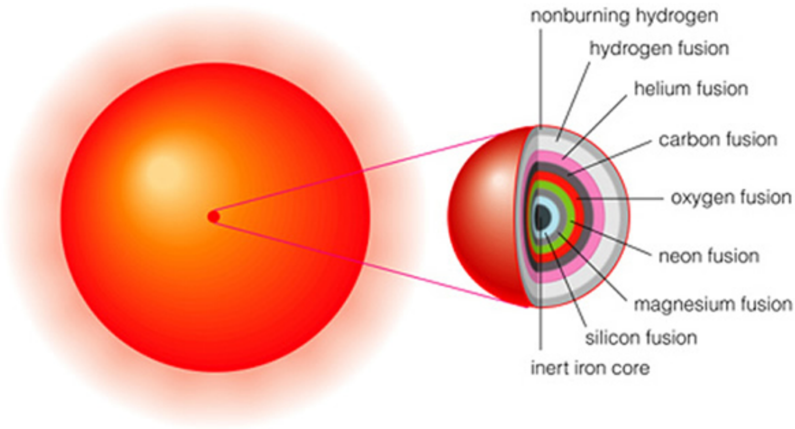


Figure 6: Different layers of a massive star in the end of its life fusion cycle

The red giant[9] at the end of the fusion sequence has an iron core, then a layer of helium, then a layer carbon, oxygen, neon, magnesium, silicon, and finally neon. Each element produced is the fuel for the deeper layer's fusion. This fusion process stops when the most stable element is created : **iron**. The star then has the mass of the earth and no longer has any energy source available to fight against gravitational forces. The core of the star contracts then relaxes and hits its outer layer. By a chain reaction, each layer hit its outer layer and finally the whole star explodes. The speed and the violence of the blast creates enough energy to create by fusion[10] the other elements like zinc, gold, silver, argon, etc... The explosion spreads them in the whole cosmos, and it *is* how all the elements heavier than iron were created on earth.

The supernovae leaves behind it the remains of the star: a neutron star. The scientist predicted the existence of these stars theoretically before observing the first one. They observed in 1967 the first neutron star thanks to radio astronomy. By analyzing the different radio signal emitted in the universe, they discovered a precise periodic signal. The research led to the Crab nebula. A neutron star, also called pulsar is in the core of the residues of a supernovae.

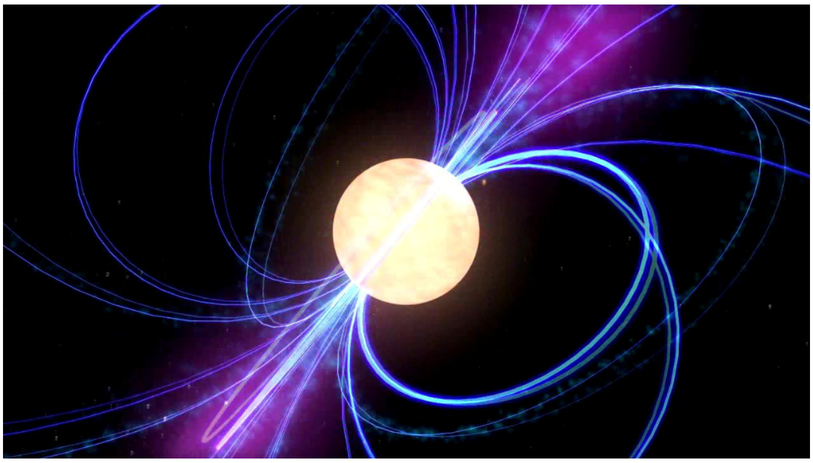


Figure 7: The crab nebula pulsar

2.3 After the supernovae : a pulsar

The pulsar are very dense stars: a handful of matters would weigh as a small planet. They are so dense that the protons and the electrons in the stars merge to form neutrons[11]. The pulsar weights between 1,4 time and 3 times the mass of the sun and is contained in a star whose diameter goes from 10 km to 20 km ! Because of the collapsing of the previous star, the rotation speed and the magnetic field also reaches incredible values ! After the supernovae explosion, the star becomes very small and by the conservation of the kinetic moment the speed is increasing. It's just like a ice skater folding his arms: he turns faster[12]. Moreover because of the conservation of the magnetic flux if the surface is reduced and the magnetic field increases. Pulsars are big magnets turning really fast.

A normal star has a magnetic field of about 1 gauss, a pulsar has a magnetic field of some **thousands gauss**. Ergo, it emits a regular magnetic pulse that can be measured even from earth's outer atmosphere. Their regularity is extremely precise, which make scientist think that they are the best clock, even better than atomic clocks. In the figure 7, the blue lines are the magnetic field and the blue halo is the radiations emitted by the pulsar. On earth, it is this halo that is measured periodically. To spin around

[9] All massive stars, at the end of their fusion stages start growing and gets bigger and bigger, it is called a red giant.

[10] Remember that fusion is actually created by atoms colliding, and the shock is creating new elements.

[11] Remember that the white dwarf doesn't contract more because electrons exerce a repulsive force from one toward another. Neutron are much less repulsive.

[12] Imagine then the difference between a star bigger than the sun shrinking to 10km in diameter, the increase in rotation speed is huge.

faster some pulsar associate with other with another star: for example with a red giant. The matters outflow from a star can reach the spinning matter around the pulsar and hit the pulsar. This gives more and more impulsion to the pulsar: in this case, the pulsar is called a millisecond pulsar. We even discovered a a binary star system of a planet with a pulsar. You can see a 3D modeling of such a system in fugure 8. There is another thing than can affect the speed of a pulsar: the crust of a neutron star is extremely resistant, but the inside of the star is only gas. Just like earth's earthquaques, forces inside the star can make the crust crack, and cause a *starsquake*. When it cracks, the neutron star readjusts and changes its rotation[13]. This phenomenon is called a glitch.

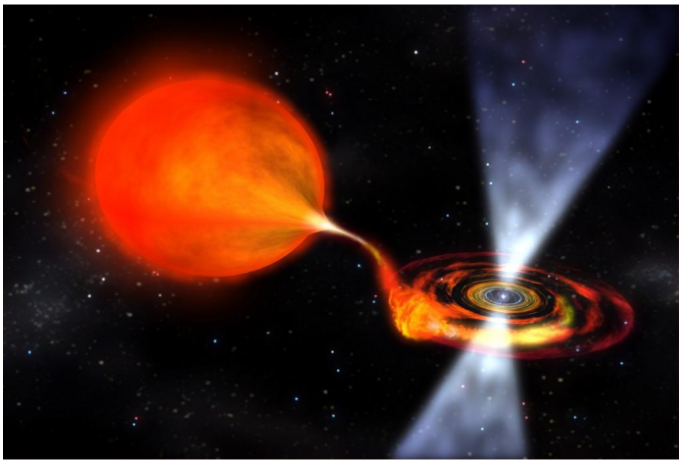


Figure 8: Binary star system with a pulsar and a flow of matter in the center of mass

But even within the pulsars, there are different types. A specific kind of pulsar has been recently discovered and only 15 have been found over 400 billions stars in our galaxy, which makes this type of star extremely rare. They are called **Magnetars**. They are similar to the neutron stars with a magnetic field pushed to the extreme. 1000 millions of millions time higher than the one on Earth. If such a magnetic field was even in a solar system nearby ours, it wouldn't allow life to be, because it tends to align the water molecules as show in the figure 9. The magnetars remain a mystery for the scientists, because it is a very rare phenomenon to observe, and to gather data on.

[13]this phenomenon is spontaneous, to maintain a balanced state of the pulsar

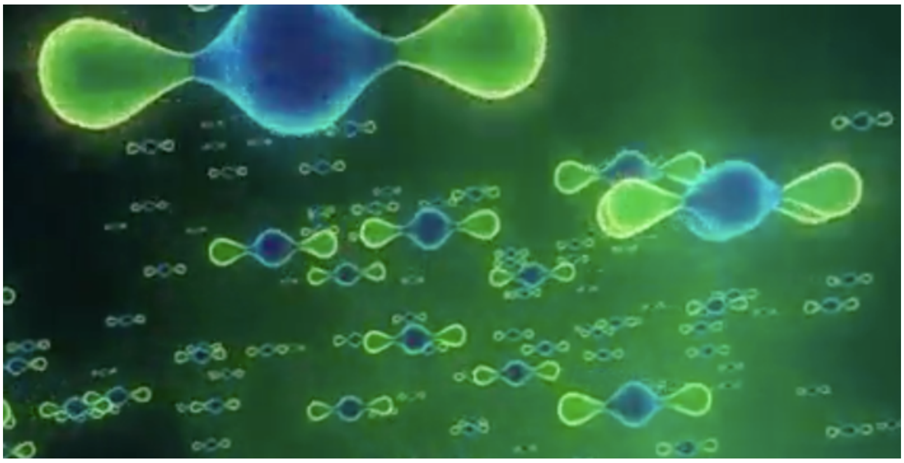


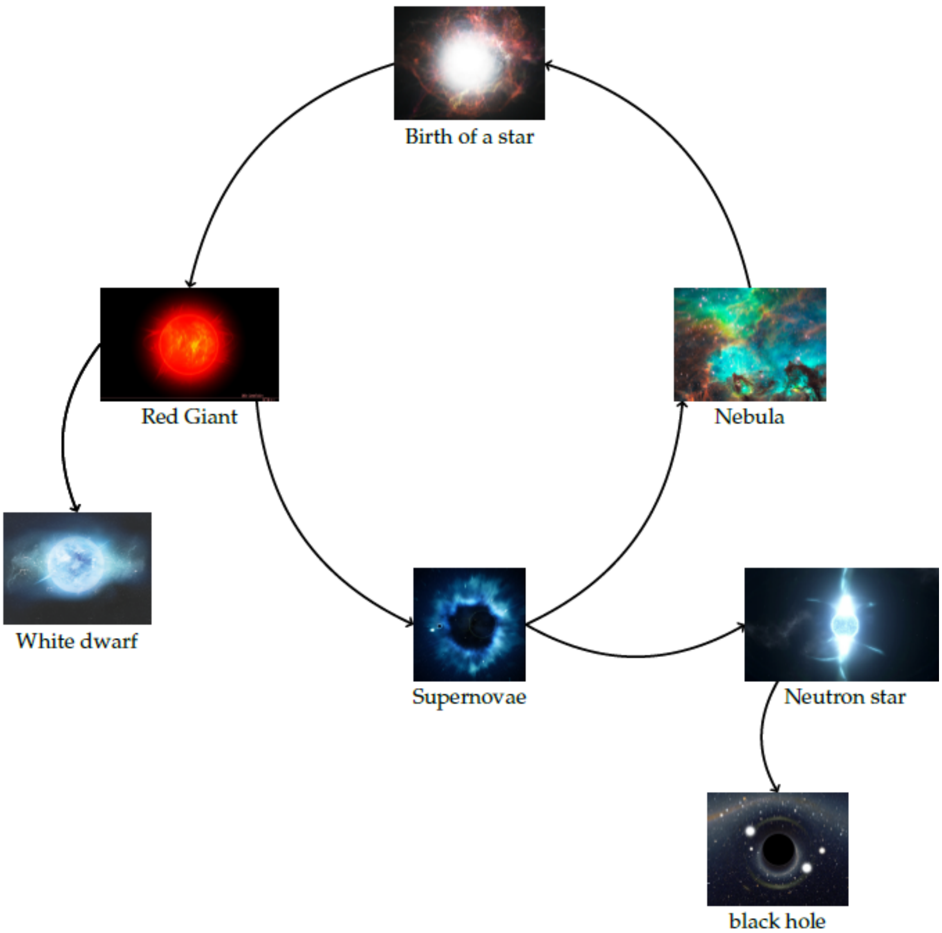
Figure 9: water molecules aligned because of a high magnetic field

If the supernova turn into a neutron planet whose mass is more than 3 times the mass of the sun, they are called Black Holes. These star are so dense that even light cannot escape from the gravitational force.

2.4 Black Holes

Annex 1 : All the stages of a star's life

To recap all being said in this paper, we made a little understanding visual graph of all the possibilities in a star's life-cycle, in function of mass.



Annex 2 : Star classification in function of light

There are several ways to make a star classification, all this document, we have explained that the key factor is mass, but mass cannot be measured from afar : you cannot weight an object from billions of kilometers away. The criteria used ten is the luminosity and color of the star, basically red stars are less massive stars, then yellow stars, then blue stars. All of this ei explained in the following figure :

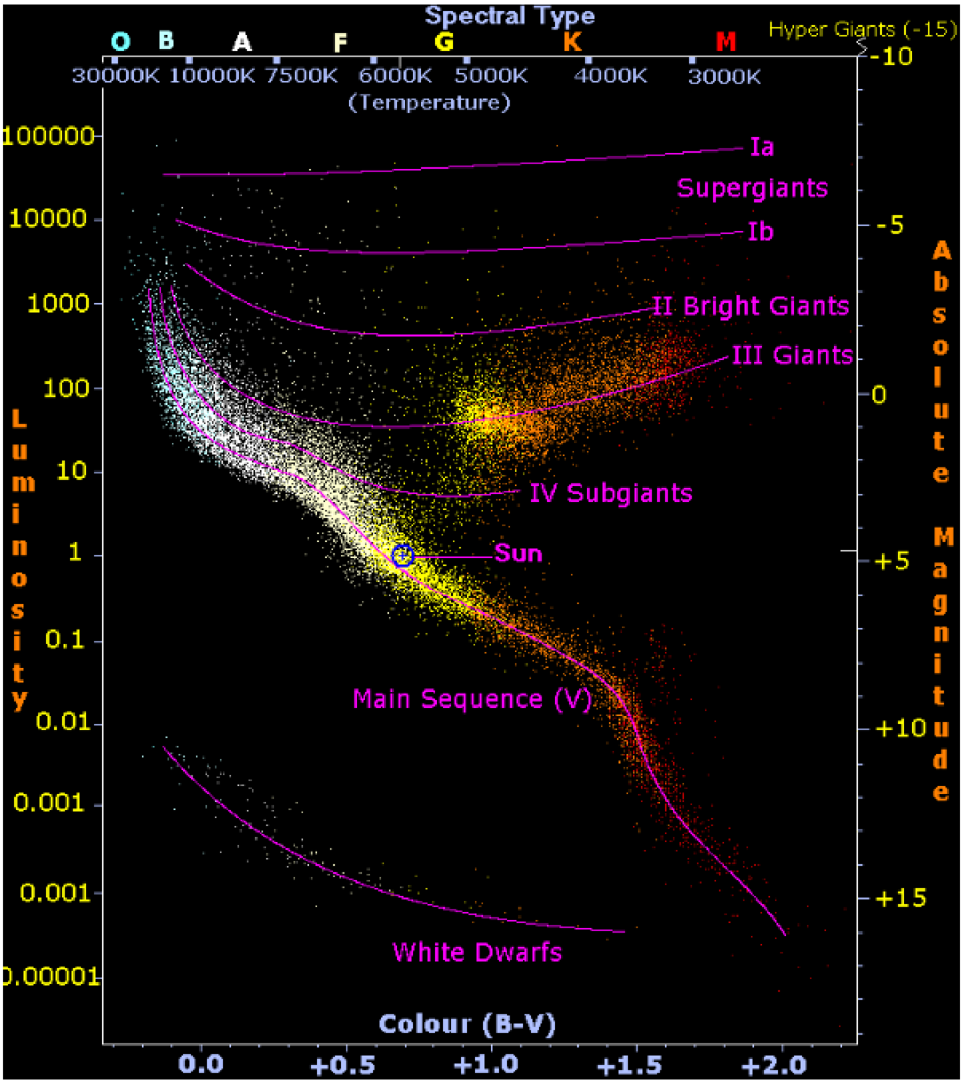


Figure 10: Star classification by light emission

References

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- National France Library - Understanding the star's life
- France National Research Center - Star theory

Videos :

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- Discovery channel - The Universe