The life of a star
Autonomous project : English

PAULINE DUBUC, SUZON THENAUX, AYMERIC BOUZIGUES
Mines Nancy
December 20, 2017

Abstract

To write.

Star cluster captured by the Hubble Telescope

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.

The theory principles behind a star and its creation

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*.

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].

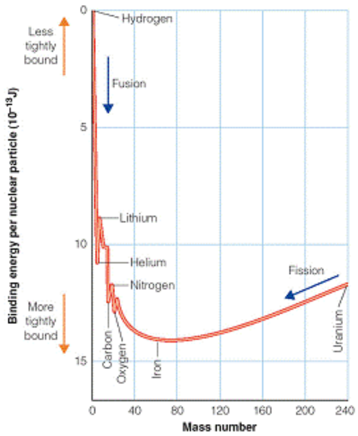

Figure 2: Energy contained in atoms

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 :

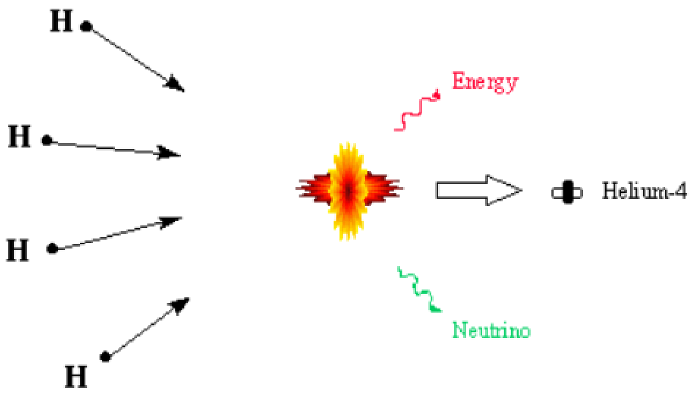

Figure 3: Hydrogen fusion

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.

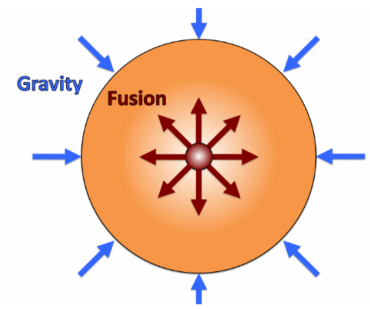

Figure 4: Balance between fusion and gravity

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.

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

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**

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. 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.

[5]For example, if a mobile phone was as dense as a White Dwarf it would weigh approximately 10 ton