Astrophysics

Stellar Evolution

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1 Introduction

Experimentally, seeing the luminosity and the effective temperature of different stars with same mass (in this case It is discuted for stars with one solar mass), It is possible to draw a graphic, where the stellar evolution is clearly visible, and easy to follow and explain the stages of the star, since the beggining, being a protostar, until the end, to a white dwarf.

In this work It is explained the different stages for a star with one solar mass.

2 Methods

We will follow the Jupyter notebook given in PRADO, just running the different cells to see the graphics. For this, it's been used the help of MESA, which data is in history.data.

3 Results

In the next graphic we are going to represent the Hertzsprung-Russell diagram for a star with one solar mass:

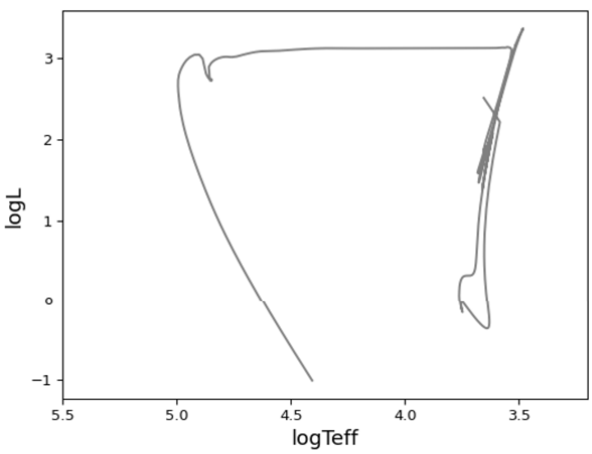

Figure 1: Hertzsprung-Russell diagram of a star with one solar mass.

And, in the following graphic, the same but with colors to see the time evolution:

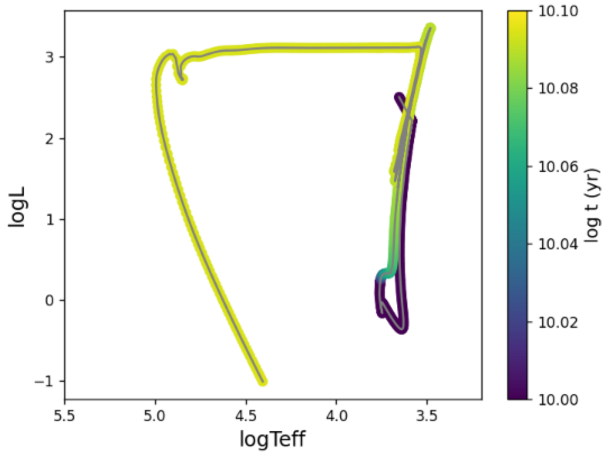

Figure 2: Hertzsprung-Russell diagram of a star with one solar mass, where we can see also the time.

Seeing Figures 1 and 2, It's deduced that the gas started to collapse gravitationally, doing it really fast, until we had explosions in the core gas, becoming into a star, that will be a long time in the main sequence. After that, the star gain mass until it exploded as a nova in a short period of time. Then, the core remains (white dwarf), and will have it luminosity and temperature lower and lower, where it will transform to a white dwarf.

4 Discussion

4.1 Pre-main sequence

In first case, we have:

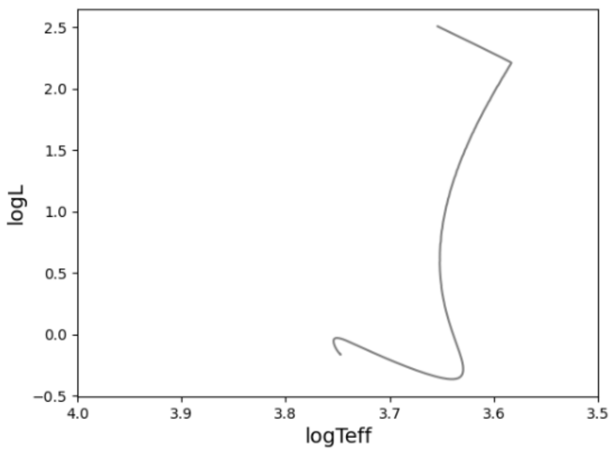

Figure 3: Hertzsprung-Russell diagram of a star with one solar mass, where we only represent the part corresponding to the pre-main sequence.

The formation of protostars is the first step to a star, that are pre-nuclear objects from interstellar molecular clouds. Due to the virial theorem, if the internal kinetic energy is too low, the molecular cloud will collapse. The temperature remains nearly constant while the gravitational potential energy is released.

This whole process take around 40 Myr for a star with one solar mass.

4.2 Zero-age main-sequence

See the zero-age main-sequence (ZAMS), at Figure 4, where a star as the Sun converts hydrogen into helium thanks to pp chain, so the mean molecular weight of the core increases. The density of the core increases while the gravitational potential energy is released, and following the virial theorem, half of the energy is radiated away and half of the energy goes into increasing the thermal energy and hence the temperature of the gas. In this process also happen the reaction that turn C_6^{12} to N_7^{14}, until the carbon is finally exhausted, where pp chain becomes important, so there is a establishment of a stable energy source, and the gravitational energy term becomes insignificant.

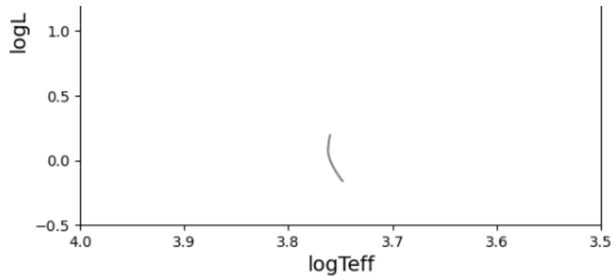

Figure 4: Hertzsprung-Russell diagram of a star with one solar mass, where we only represent the part corresponding to the main sequence.

At this point, as the star's evolution on the main sequence, eventually the hydrogen at its center will be completely depleted.

It takes around 9,3 Gyr.

4.3 SGB

As the shell continues to consume the hydrogen that is available at the base of the star's envelop, the helium core steadily increases in mass and becomes nearly isothermal. Then, with the mass necessary, the core begins to contract rapidly, causing the evolution to proceed on, and the gravitational energy released by the rapidly contracting core again causes the envelope of the star to expand and the effective temperature cools (see Figure 5).

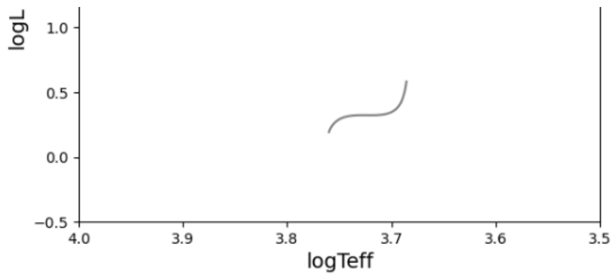

Figure 5: Hertzsprung-Russell diagram of a star with one solar mass, where we only represent the part corresponding to SGB.

It takes around 2,5 Gyr.

4.4 RGB

With the expansion of the stellar envelope and the decrease in effective temperature, the photospheric opacity increases due to the additional contribution of the H^- ion. The result is that a convection zone develops near the surface. As the evolution continues, the base of the convection zone extends deep into the interior of the star. With the nearly adiabatic temperature gradient associated with convection throughput much of the stellar interior, and the efficiency with which the energy is transported to the surface, the star begins to rise rapidly upward (see Figure 6).

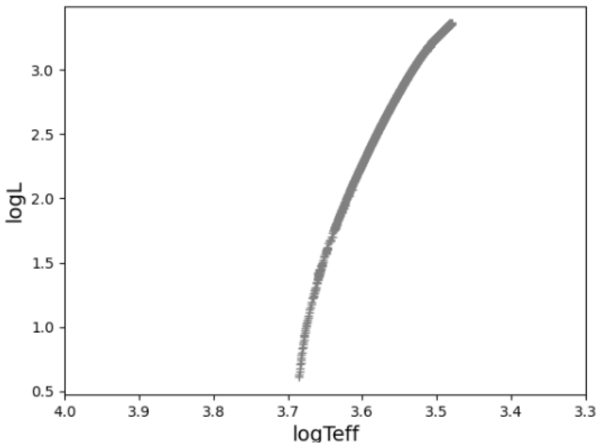

Figure 6: Hertzsprung-Russell diagram of a star with one solar mass, where we only represent the part corresponding to RGB.

It takes around 0,4 Gyr.

4.5 TRGB

At the top of the Figure 6, the central temperature and density have finally become high, so the triple alpha process to begin, doing that the core expands.

4.6 Helium Core Flash

As the helium core continues to collapse during evolution up to the tip of the red giant branch, the core becomes strongly electron-degenerate, and there is a significant neutrino losses. When the temperature and density become high enough to initiate the triple alpha process, the ensuing energy release is almost explosive. The ignition of helium burning occurs initially in a shell around the center of the star, but the entire core quickly becomes involved and the temperature inversion is lifted for only a few seconds (see the right part of Figure 7).

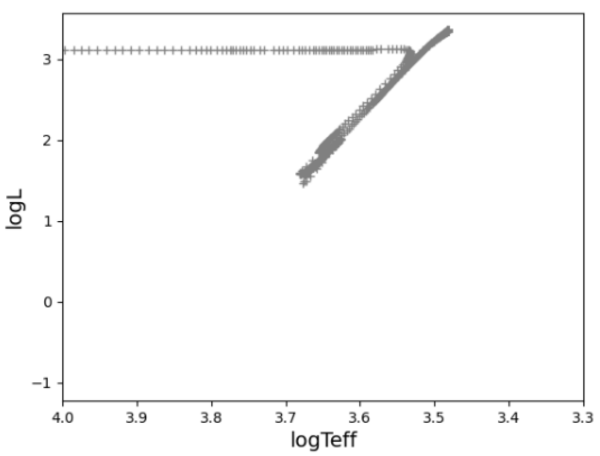

Figure 7: Hertzsprung-Russell diagram of a star with one solar mass, where we only represent the part corresponding to the helium core flash and the horizontal branch.

4.7 Horizontal Branch

The star will begin to rise again because of the increasing compression of the hydrogen-burning shell. The appearance of a convective core is due to the high temperature sensitivity of the triple alpha process (see the left side of Figure 7).

5 Conclusion

We have seen the stellar evolution for a star with one solar mass in Figures 1 and 2, from the dust collapsing, to a single core without internal reactions, a white dwarf.

Then, the principal stages have been explained, from pre-main sequence to the horizontal branch, the last stage of the main sequence.

We can concluded that the evolution of a star is a really complex mechanism, where the reactions are the principal reason that star exists.