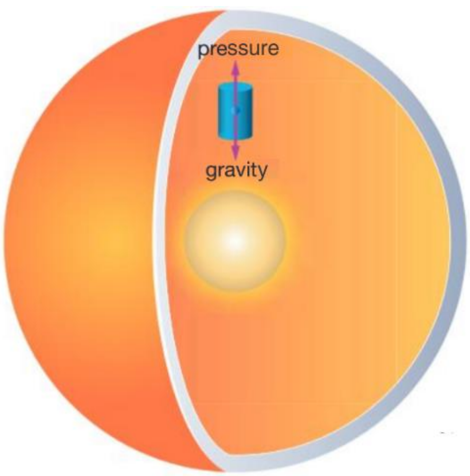
Stars

A star is a giant sphere of gas formed through the contraction of matter within vast nebulae.



Credit: J. Paul/J.-L. Robert

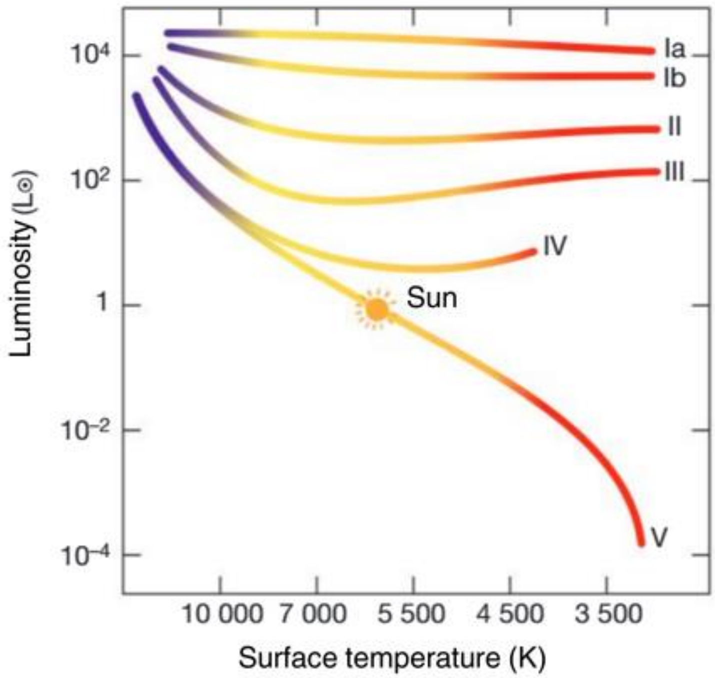
Initially, there is a nebula primarily consisting of hydrogen, a little helium, and a pinch of all the other elements. Suddenly, perhaps due to the explosion of a nearby supernova, a small fragment of the nebula collapses on itself. As the fragment contracts, the pressure and temperature at its core rise dramatically until nuclear fusion of hydrogen into helium begins. This process releases an enormous amount of energy that counteracts the collapse: a star has just started to develop! This equilibrium stage continues until all the hydrogen in the stellar core is exhausted. Our Sun, which is over 5 billion years old, is currently in the middle of this stage.

Equilibrium in a star

A small fraction of a star, isolated by thought (blue cylinder), is in equilibrium under the action of two antagonistic phenomena: gravity, which pulls it inward, and the pressure of radiation from the core, which pushes it outward.

The star then undergoes a considerable evolution: its core contracts and its temperature increases. Concurrently, the outer layers expand, causing the stellar radius to grow significantly. Once the core's temperature becomes high enough, everything stabilises again as helium fusion into carbon begins. The star transitions into the red giant phase, expanding to hundred times the size of the Sun.

If the star is massive enough, further nuclear reactions can occur. They involve carbon, nitrogen and oxygen nuclei capturing helium nuclei. But when the energy produced is no longer sufficient to counteract radiation losses, the core contracts again, and the envelope expands further. During this 'supergiant' stage, the core reaches temperatures of 10^9 K, allowing carbon and oxygen nuclei to fuse into nuclei of silicon, sulphur, phophorus, etc. Meanwhile, nuclear fusions involving carbon, nitrogen and oxygen also release numerous neutrons that interact with other nuclei to form increasingly heavy elements.



Credit: Astrophysique sur mesure/Paris Observatory/O.F.E.

The final fate of a star depends on its mass. For stars with masses less than a few solar masses ($M_\odot$), the outer layers swell until they spread out to form a planetary nebula, while their core shrinks into a white dwarf. Stars with masses up to 8–10 solar masses undergo a much more dramatic end, exploding in a supernova.

By classifying stars according to their luminosity and temperature, astronomers produce a plot, known as the Hertzsprung-Russell diagramme, which represents stellar evolution. The points representing the majority of stars – including the Sun – that are stabilised by hydrogen nuclear fusion form the main sequence, a diagonal strip across the entire diagramme. At the end of this long stable phase, the points representing stars move to the upper right of the diagramme to form the strips of giants and supergiants, stars that are much less abundant but significantly more luminous.

Hertzsprung-Russell diagramme

Stars are classified based on their luminosity, measured in solar luminosity ($L_\odot$), and their surface temperature. The Hertzsprung-Russel diagramme employs a logarithmic scale on both axes. Stars are plotted along distinct sequences. From bottom to top: the main sequence (V), representing stars that are stabilised by hydrogen nuclear fusion; subgiants (IV); giants (III); bright giants (II); and supergiants, types Ib and Ia. The point representing the Sun, which is currently a main sequence (V) star, will move to the giant sequence (III) at the end of its evolution.

Translated from 'Les étoiles', **Passeport pour les deux infinis,** ***IN2P3/Dunod,*** **https://pass2i.ijclab.in2p3.fr/** ***(French); updated with ICHEP2024 conference (https://ichep2024.org) for IPPOG***