THEORY OF RED GIANT VARIABLE STARS

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Abstract

The development and structure of red giant variables is reviewed qualitatively.

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Observational astronomy has its counterpart in theory, which seeks to discover how certain processes take place, as well as giving reasons for them. With regard to long period variable stars, we can ask what causes the particular variations of brightness that we observe. I would like to examine the processes that occur over the lifetime of a variable star, and show how these can account for the observed changes. We will also see how a long period variable can undergo 'rebirth' a number of times.

Long period variable stars are, for the most part, of spectral type M, and have a temperature of about 2000-3000° K. Their spectra show strong bands of titanium oxide, and since this absorbs heavily near the blue end of the spectrum, they appear red.

The characteristic that distinguishes between long period variables and Mira stars is primarily the amplitudes of light variation. Long period variables all have visual amplitudes smaller than 2.5 magnitudes, whereas the amplitudes of Mira stars are greater.

A variable star having a visual amplitude of 9 magnitudes will be approximately 4000 times brighter at its maximum light than at its minimum. The overall variation in radiated energy is, however, much smaller because the greater part of the radiation is in the infrared region where the amplitude is only about 1 magnitude. Additionally, only 75% of the difference between the amplitudes of the radiometric and visual light curves is due to Planck's law for black-body radiation (According to this law, a temperature decrease from 2300°K to 1800°K produces a change in intensity of 3.42 magnitudes in the visual portion of the spectrum). The remaining 25% of the difference is accounted for by the obscuring effect of molecular bands,which becomes stronger at the lower temperatures.

Having now dealt with the outward appearance of long term variables, we can look for an explanation of this appearance in terms of its stellar evolutionary stages. A star ends its lifetime on the main sequence when its hydrogen becomes depleted. Helium, which is the end product of the hydrogen fusion that takes place in stars, builds up in the center of the star, with hydrogen burning only in the outer part. Gravity acts to compress the helium core, causing an increase in temperature and a subsequent increase in the nuclear reaction rate of the burning hydrogen. The star doesn't immediately increase in luminosity, however; the hydrogen in the outer layers absorbs the upward-moving radiation from the core,and the hydrogen is lifted up and outward. Trillions of tons of it are lifted over distances of hundreds of thousands of miles. As the size increases, the amount of energy radiated per square centimeter drops, and so does the surface temperature - to between 3000°K and 4000° K. This makes the star red in color. Eventually, the core becomes so hot and radiates so much energy that the radiation cannot all be absorbed by the hydrogen expansion process just described. At this point the luminosity increases so much that we call the star a red giant. (See diagram at end.)

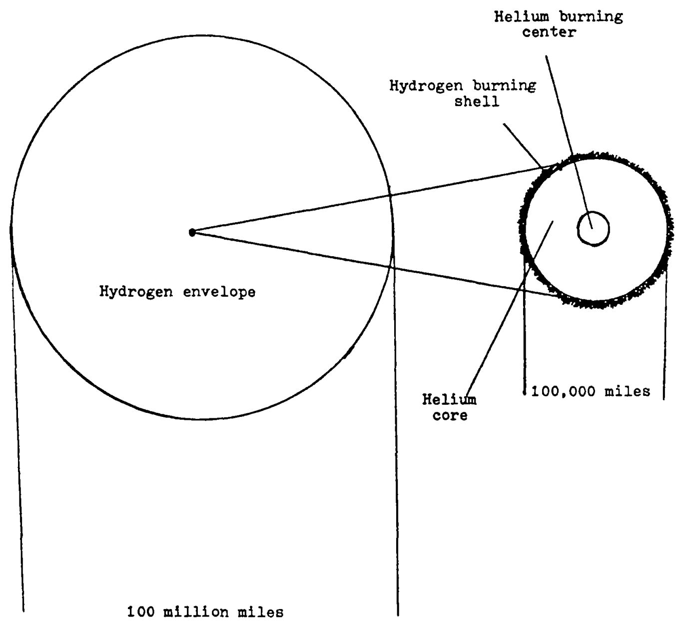
The only energy release taking place in the core of the star is gravitational energy; the luminosity in that region is consequently quite low. Because of this low central luminosity, only a very slight temperature gradient is required to carry energy outwards, and the consequences of this are important. The star can radiate energy back and forth between its core and outer layers quite easily, and the stage is set for the changes in magnitude we observe during the star's lifetime as a variable. The star expands and contracts periodically, and we observe these pulsations as variations in brightness.

The remainder of the hydrogen in the outside shell continues to burn very quickly, and this heats the helium core resulting in a violent instability when the temperature reaches 200,000,000^{o} K. Although the helium nuclei begin to fuse, the core acts like a solid, and the reaction becomes so unstable that it runs away with itself, and the core explodes. This is known as the helium flash; but it does not add to the star's luminosity, because most of the energy is taken up in the expansion of the core, and very little reaches the surface.

In fact, the luminosity declines, due to the decrease in hydrogen fusion brought about by the expansion and cooling of the helium core. The star moves vertically down on the Hertzsprung-Russell diagram, back toward the main sequence.

During this transition, the star contracts, since no nuclear fusion is forcing it outward, and gravity again takes over. The helium is again compressed, and the core is heated. The temperature eventually becomes high enough for helium to fuse, although this time, no explosion takes place, since the core is far less dense, and the electrons do not have the solid-like incompressibility they did previously. In this manner, a star can again enter the red giant region, and become a long period variable time after time. This is the 'rebirth' I mentioned previously.

During the entire time, the end-product of helium fusion, carbon, continues to build up in the core. The path a star takes from this point onward depends on its mass. If it is a small star, it will become a planetary nebula, and, subsequently, a white dwarf; if it is large, it will become a supernova, and finish its life as either a neutron star or a black hole.



STRUCTURE OF A RED GIANT