456

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NEUTRINOS, HELIUM FLASH, AND WHITE DWARFS

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In this note we discuss the effect of neutrino processes in delaying or stopping helium burning (and carbon burning) in certain red giants. In a previous paper (Chiu 1963) we have calculated the neutrino energy flux from the core of a red giant model such as was studied by Schwarzschild and Selberg (Schwarzschild and Selberg 1962) (the neutrino process considered is the plasma neutrino process (Adams et al 1963)). The result is:

$$
\begin{aligned}
L_\nu &= \text{neutrino energy flux in the core} \\
&= 2.8\ L_\odot \\
L_g &= \text{gravitational energy flux from the core} \\
&= 13.6\ L_\odot
\end{aligned}
\qquad (1)
$$

A red giant has a highly degenerate helium core of mass around 0.53 $M_\odot$, surrounded by a hydrogen burning shell and an extended convective envelope. The structure of the core is insensitive to its temperature (since the pressure of a degenerate electron gas depends only on the density). The temperature gradient in the core is given by the familiar expression:

$$
-\frac{ac}{3}\frac{dT^4}{dr} = \frac{L_r}{4\pi r^2}\,\kappa\rho \qquad (2)
$$

All symbols have their usual meaning. The difference between the temperature at the center of the core T_c and that at the burning edge T_e is

$$T_c^4 - T_e^4 = \int \frac{3}{ac} \varkappa\rho \frac{L_r}{4\pi r^2} dr \tag{3}$$

The integral may be approximated by assuming that it is proportional to the value of L_r at the boundary of the core (denoted by L_γ). L_γ refers to the radiative part of the gravitational energy flux. Thus

$$L_\gamma = L_g - L_\nu \tag{4}$$

Because of L_ν, the actual temperature at the center will be less than that without the neutrino process. Let the difference be ΔT_c, then it is easy to see

$$\frac{\Delta T_c}{T_c} = \frac{1}{4}\frac{\Delta L}{L_g} = \frac{1}{4}\frac{L_\nu}{L_g} \tag{5}$$

where $\Delta L = L_\nu$.

For the core of a red giant L_g is proportional to $\frac{dM_{core}}{dt}$, the rate at which the burning shell adds mass to the core. $\frac{dM_{core}}{dt}$ is proportional to the overall luminosity L which is proportional to a certain power K of M_{core}:

$$L_g \propto \frac{dM_{core}}{dt} \propto L \propto M_{core}{}^K \tag{6}$$

From Schwarzschild's result we find K = 5.8. In order to compensate for neutrino loss, L_g must be increased by a corresponding amount L_ν; this corresponds to an increase of the core mass ΔM_{core} given by

$$\frac{\Delta L}{L_g} \approx K \frac{\Delta M_{core}}{M_{core}} \tag{7}$$

From Eqs. (1), (5), (7), we find

$$\frac{\Delta L}{L_g} \approx 0.2 \tag{8}$$

$$\Delta M_{core} = \frac{0.2}{K} M_{core}$$

Since in the plasma neutrino process the energy loss rate increases as the density increases (and a fortiori, as the core mass increases), Eq. (8) gives the lower limit (bur rather close to the actual value in our example) for the increase in the core mass necessary to raise its temperature to the helium burning point. For a core mass of around 0.6 $M_{\odot}$ this gives a value of 0.02 $M_{\odot}$. The delay in time is around 3.5×10^5 years (in the model studied by Schwarzschild and Selberg). Since the value of mass of the degenerate core at the helium burning point is not sensitive to the total stellar mass for red giants of masses from 0.7 $M_{\odot}$ to 1.3 $M_{\odot}$ (Hayashi, private communication), Eq. (8) is valid for red giants of these mass ranges. Hayashi (Hayashi 1962) has computed the evolution of small red giants into white dwarfs and he has found that stars of mass around 0.6 $M_{\odot}$ will not go through helium burning stage. On the basis of our computation the neutrino process will not change his result by much. It may be remembered that the value 0.6 $M_{\odot}$ agrees well with the accepted value for the average mass for white dwarfs.

The same analysis may not be applied to a star just prior to carbon burning stage. Because there the neutrino flux is very large ($\sim 10^5\ L_\odot$), its perturbing effect on stellar structure is not negligible.

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