THE WHITE DWARF LUMINOSITY FUNCTION AND THE PHASE DIAGRAM OF THE CARBON–OXYGEN DENSE PLASMA

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Abstract. We show that the theoretical white dwarf luminosity function depends very much on the assumed phase diagram for the carbon–oxygen dense plasma. Since it is still very uncertain, we compare the two possible extreme cases of complete miscibility and complete separation of carbon and oxygen in solid phase. In the latter case we find that the paucity of low luminosity — $\log(L/L_{\odot}) \leq -4.5$ — white dwarfs can be explained by the formation of an oxygen core, which releases a large amount of gravitational energy and slows down the cooling rate.

1. Introduction.

The paucity of low luminosity white dwarfs [1], if not a selection effect, can have different origins : (i) uncertainties in the envelope opacity [2], (ii) the presence of some "delay" mechanism which can decrease the cooling rate or simply (iii) an age of the Galactic disk which does not exceed 10^{10} years [3]. In this contribution, we consider case (ii), the "delay" mechanism being the separation of carbon and oxygen during crystallization of the white dwarf interior. We use the phase diagram of the carbon–oxygen plasma proposed by Stevenson [4] where either pure carbon or pure oxygen freezes out, depending on the composition of the liquid mixture compared to an entectic having a carbon mass fraction X_c=0.6.

2. Method.

The energy budget of a cooling white dwarf can be written as follows :

$$L + L_{\nu} = -\int_0^{M_{wd}} C_v \frac{dT}{dt} + \ell \frac{dM_{sol}}{dt} + L_{grav}, \quad (1)$$

where L is the luminosity and L_{ν} are the neutrino losses ; C_v, ℓ, M_{wd} and M_{sol} are respectively the specific heat capacity at constant volume, the latent heat, the total mass of the white dwarf and the mass in solid phase.

The gravitational contribution to the luminosity, L_{grav}, is negligible if carbon and oxygen are miscible in solid phase. When they separate, denser solid oxygen accumulates at the star center and an oxygen core is progressively formed. The white dwarf slightly contracts and then

$$L_{grav} = e_{grav} \frac{dM_{ox}}{dt}, \quad (2)$$

where M_{ox} is the mass of the oxygen core and e_{grav}=10^{14} erg.g^{-1} for a 0.6 $M_{\odot}$ white dwarf with equal mass fractions of carbon and oxygen [5]. This value of e_{grav} represents about ten times the latent heat so that L_{grav} now strongly affects the cooling rate.

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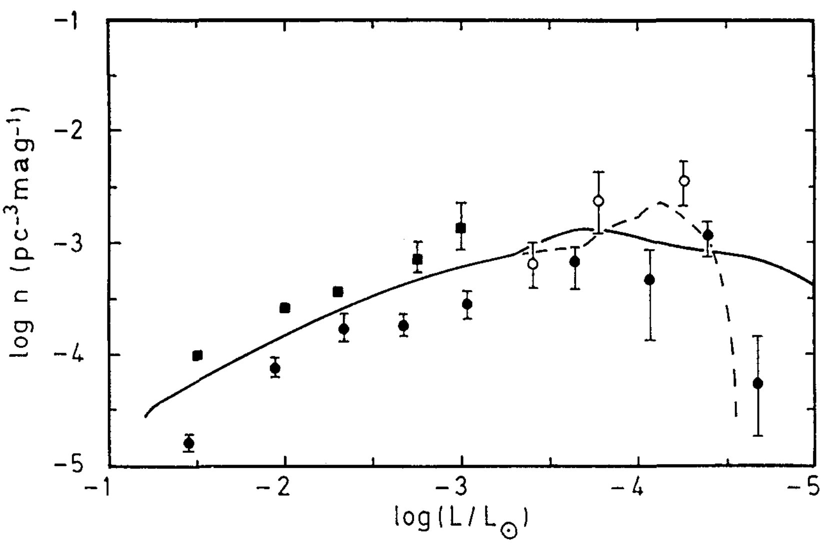
3. Results and discussion.

In Figure 1, we present the luminosity functions obtained with the assumptions of total miscibility (full line) and total separation (dashed line) for an age of the Galactic disk of 15 10^9 years. These luminosity functions take into account the increase of the vertical scale height over the plane of the disk with the age of the objects. This geometrical effect [2] nearly suppress the bump at $L \approx 10^{-4}\ L_\odot$ which would have been produced by the strong decrease of the cooling rate in the case of total separation [3].
It can be seen that the low luminosity cut-off of the luminosity function can be reproduced, even for a large age of the Galactic disk, if carbon and oxygen separate.
The total separation we have considered may be however an extreme case and the time delay introduced by a partial separation would naturally be smaller. The uncertainty on the carbon–oxygen phase diagram then appears to be a main difficulty for a reliable determination of the age of the Galactic disk using the white dwarf luminosity function.

Figure 1



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