THE PHASE DIAGRAM OF HIGH DENSITY BINARY MIXTURES AND THE LUMINOSITY FUNCTION OF SINGLE WHITE DWARFS

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For the last two decades, plasma physics developments have led to a better understanding of physical conditions in white dwarfs interiors. Following the pioneering work of Mestel (1952), the problem of white dwarf cooling has been a subject of continuous interest until the present time. In the early sixties, Kirzhnits (1960), Abrikosov (1960), and Salpeter (1961) recognized the importance of Coulomb interactions in the dense plasma which forms the white dwarf interior. A first-order transition from liquid to solid phase was predicted and the resultant release of latent heat was shown to somewhat affect the cooling rate (Mestel and Ruderman, 1967). Subsequently, improved theoretical luminosity functions (number of white dwarfs per pc^3 and per magnitude interval as a function of luminosity) taking into account not only Coulomb interactions but also neutrino losses, and using detailed atmosphere models (Van Horn, 1968; Koester, 1972; Lamb and Van Horn, 1975; Shaviv and Kovetz, 1976; Sweeney, 1976). Recently, Iben and Tutukov (1984) have discussed the evolution of a 0.6 $M_\odot$ carbon-oxygen white dwarf from its nuclear burning stages to complete crystallization. Their luminosity function agrees reasonably well with observations in the range $-4 \lesssim \log(L/L_\odot) \lesssim 4$ but it predicts an excess of white dwarfs at low luminosities. Indeed, the luminosity function derived from observations grows monotonically until $\log(L/L_\odot) \simeq -4.5$ ($M_V \simeq 16$) and then makes an abrupt shortfall (Liebert, Dahn and Monet, 1988). The agreement between theory and observations is so good in the aforementioned range luminosity that we can wonder as to whether it is possible not only to test the theory of white dwarf cooling but also to obtain information on the galactic structure and evolution. One example of that is the use of the cutoff in the white distribution to determine the age of the galactic disk (Schmidt, 1959). Using this method, Winget et al. (1987) have found that the galactic disk age could be of the order of 9 Gyr old, in agreement with some predictions from nucleocosmochronology (Fowler et al. 1987).

Nevertheless before using the white dwarf luminosity function as a diagnostic tool of galactic evolution, it is necessary to ensure that we understand the properties of white dwarfs. Three are the main sources of uncertainty: 1) The difficulty of discovering very faint white dwarfs, i.e. is the luminosity function complete? (Liebert, Dahn and Monet, 1988). 2) The equation of state and opacity of the outer layers which control the characteristic cooling time during the late epochs (Iben and Tutukov, 1984). 3) The existence of additional sources of energy due to a chemical differetitation of white dwarf induced by the crystallization process (Mochkovitch, 1983; Garcia-Berro et al., 1988a, b), and the distribution of the chemical elements and its influence on the thermal contents of the star (Mazzitelli and D'Antona, 1986)

The confirmation of either carbon miscibility of inmiscibility in solid phase requires the knowledge of the free energy of the completly ionized carbon-oxygen plasma in both liquid and solid phases. The free energy of the liquid can be well approximated by assuming ion-sphere charge averaging and ideal entropy of mixing (Hansen et al., 1977). To determine the free energy of the solid phase is a more complicated task, as it has been illustrated by the pioneering work of Stevenson (1980). This author obtained either miscibility if the Madelung energy of the alloy was computed assuming ion-sphere averaging or inmisicibility, with a pronounced eutectic in the fluid-solid coexistence diagram, if the adopted electrostatic energy was that of a random alloy. Very recently, Barrat et al. (1988), using a density functional approach, have shown that the phase diagram for a completely ionized carbon-oxygen mixture is of the "spindle" form, with a change of concentration upon freezing but carbon and oxygen remaining completely miscible in the solid phase. This phase diagram is the most physically self consistent calculation up to date. It is necessary, however, that the simplifications that have been introduced, that are valid for a one component plasma, are also valid for a binary or more complicated mixture. So, in view of the uncertainties, it seems useful to compute and compare the effects of the different phase diagrams on the luminosity function of white dwarfs.

We have computed the cooling process of a 0.6 $M_\odot$ white dwarf (see details in Garcia-Berro et al., 1988) made of an homogeneous mixture composed by half carbon and half oxygen by mass. Probably this is not a very realistic case, as it has been shown by Mazzitelli and D'Antona

(1986), but the actual distribution and abundances of both elements are very uncertain as they depend on the adopted treatement of convection and on the rate of the ^{12}C (α , γ) ^{16}O reaction the later being still poorly determined (Filipone, 1988). Table I shows the time at which the white dwarf reaches different values of the luminosity for the cases of: a) Total miscibility in the solid phase without any change at the phase transition. b) Total miscibility in the solid phase but with the chemical separation introduced by the diagram of Barrat, Hansen and Mochkovitch (1988). c) Partial separation of carbon and oxygen due to an eutectic diagram, and d) Total separation (see Garcia-Berro et al. 1988a for a discussion of the last two cases).

Table 1: Ages of the models (Gyr)

$-\log(L/L_\odot)$	Model a	Model b	Model c	Model d
2.00	0.11	0.11	0.11	0.11
2.50	0.31	0.31	0.31	0.31
3.00	0.76	0.76	0.76	0.76
3.50	1.73	1.76	1.73	1.73
3.75	2.96	3.21	2.58	2.58
4.00	4.43	5.03	4.41	4.41
4.25	6.11	6.98	7.58	9.81
4.50	8.06	9.06	10.33	22.71

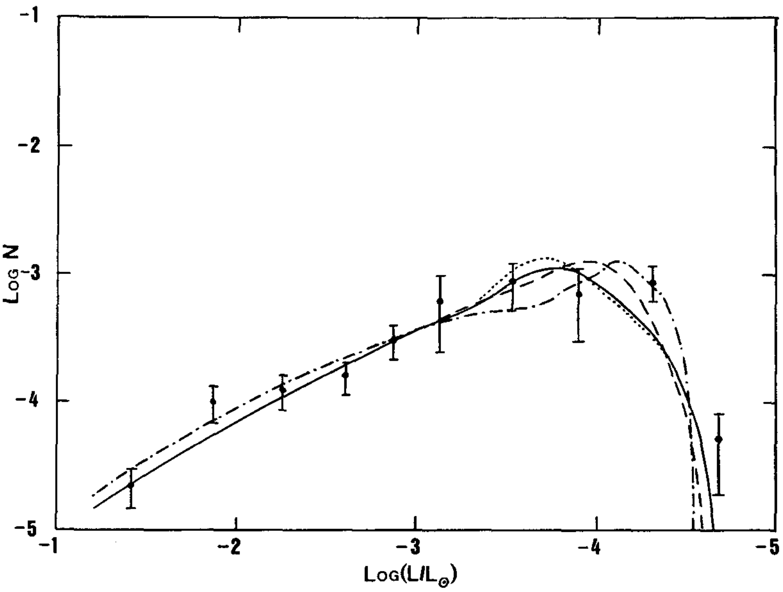

Figure 1. White dwarf luminosity functions in cases a) solid line, b) dotted line, c) dashed line, and d) dashed-dotted line, asuming Salpeter's IMF and a constant SFR. They have been normalized to give the observed value at $\log(L/L_\odot) = -3$. Observational data are from Liebert. et al. (1988).

The release of gravitational energy not only slows down the cooling process, but also produces a bump in the luminosity function. These bumps can be reduced assuming that white dwarfs have a scale height similar to that of Mira variables. Figure 1 shows that the luminosity functions constructed in this way roughly fit the observations if the age of the galactic disk is chosen to be: 8, 9, 9.5 and 15 Gyr for cases a, b, c and d respectively.

We conclude that if the phase diagram of Barrat et al. (1988) is correct, the age of the galactic disk should be of the order of 9 Gyr in agreement with Winget et al. (1987). Furthermore, as the shape of the luminosity function strongly depends on the adopted dilution factor, improved observational luminosity functions together with a better understanding of the cooling process could provide useful constraints to the studies of galactic evolution.

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