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MASS LOSS IN GALACTIC GLOBULARS: RED GIANT STRAGGLERS AND HELIUM WHITE DWARFS

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RESUMEN

En este trabajo se estudia la evolución de las gigantes rojas de población II con pérdida de masa, esquematizada a través de la formula de Reimers. Se presentan cálculos evolutivos para modelos caracterizados por $M = 0.8 M_{\odot}$, $Y = 0.23$ y $Z = 0.0002$, y un amplio conjunto de valores del parámetro η que determina la tasa de pérdida de masa.

Se encuentra que, para valores de η mayores que 0.70 aproximadamente, la disminución de la masa en la envolvente obliga a la estrella a dejar la rama de las gigantes, antes de que pueda ocurrir el *flash* del helio. Sin embargo, la evolución del núcleo no se afecta por las condiciones de la superficie durante mucho tiempo después de la fase de gigante roja, de manera que modelos con η menor que 0.80 logran encender el helio en la parte azul del diagrama H-R.

Se discute también la variación de este escenario con la metalicidad.

Finalmente, se analiza la producción y el enfriamiento de enanas blancas de helio producidas por el mecanismo de pérdida de masa. En la última sección se discuten los vínculos teóricos sobre la posible existencia de enanas de helio, y se muestra cómo una fracción de "RG stragglers", tan pequeña como el 10%, puede dar una contribución detectable a las secuencias de enfriamiento de enanas blancas observadas en los cúmulos.

ABSTRACT

The evolution of Population II Red Giants has been studied by adopting Reimers' formalism for the efficiency of mass loss. Evolutionary computations for models of $0.8 M_{\odot}$, $Y = 0.23$ and $Z = 0.0002$ are presented for a wide range of values of the parameter η governing the mass loss rate.

We find that for values of η greater than about 0.70 the decrease in the envelope mass forces the star to leave the RGB before undergoing the He flash. However, the core evolution is not affected by the surface conditions until long after the RG phase, and models with η less than 0.80 eventually succeed in igniting the helium on the blue side of the H-R diagram.

The variation of such a scenario with metallicity is also discussed.

Finally, we analyze the production and cooling of He white dwarfs produced by the mass loss mechanism. Theoretical constraints concerning the possible occurrence of He dwarfs are discussed, showing that even a 10% of RG stragglers can give a significant contribution to the white dwarfs' cooling sequence observed in clusters.

Key words: **GLOBULAR CLUSTERS: GENERAL — STARS: EVOLUTION — STARS: WHITE DWARFS — STARS : MASS LOSS — STARS: POPULATION II**

1. INTRODUCTION

Standard evolutionary models indicate that a low mass star, after undergoing the He-flash, settles down on its zero-age horizontal branch (ZAHB) position, which depends on the structural parameters developed during the red giant (RG) phase. As a general rule, one finds that the luminosity of the horizontal branch (HB) is a function of the core mass, while its effective temperature depends on the envelope mass.

However, while comparing observational H-R diagrams (HRDs) with theoretical prescriptions, one often finds striking differences. The starting point for this work is a HB anomaly observed in some globular clusters (GCs). One observes in practice that the temperature distribution of HB stars is markedly bimodal, with the redder stars separated by a wide gap from a conspicuous group of very blue ones. Keeping in mind the HB topology mentioned before, one can suppose that this morphological anomaly is originated by a mass loss process, acting with different rates on different stars, and hence determining a spread in the values of the envelope mass of coeval stars.

Searching clues for this problem, this work is devoted to investigate the effect of mass loss on Pop. II stars in a much more systematic way than has been done until now in literature. In the first section we will present the models and discuss the conditions allowing a RG structure and the onset of the He flash. In the subsequent section the cooling laws of the He white dwarfs (WDs) and the resulting theoretical constraints concerning the WDs' luminosity function (LF) will be analyzed.

2. THE MODELS

Castellani & Castellani (1993) presented a series of evolutionary calculations for a model of $M = 0.80M_{\odot}$, $Y = 0.23$ and $Z = 0.0002$. The mass loss mechanism was represented by a Reimers' type formalism, with the parameter η ranging from 0.0 to 2.0. The grid has now been extended to further values of η. We also varied the chemical composition, allowing for metallicity values ranging from 0.0002 to 0.01, but still focusing on the lower metallicity case.

In Figure 1 we report a selected sample of evolutionary tracks, which summarizes our main results. One can immediately notice how the RG location becomes progressively redder with increasing the mass loss rate, in agreement with the canonical prescription for which the Hayashi track becomes cooler when the total mass decreases. In a similar way, other features referring to the envelope evolution - such as the red giant branch (RGB) clump location - show that the models are readjusting their outer structure to the "instantaneous" value of the total mass. We find that models with low mass loss rate ($\eta \leq 0.60$) undergo the He-flash while still on the RGB. However, their tracks appear progressively bending towards high effective temperatures, so that one finds that increasing the value of η, the flash location becomes more and more anomalous. Models with high mass loss rates ($\eta > 0.80$) are left with too small an envelope to further support a red giant structure, so they are forced to leave the RGB, crossing the H-RD at a nearly constant luminosity and finally settling down on a WD cooling sequence.

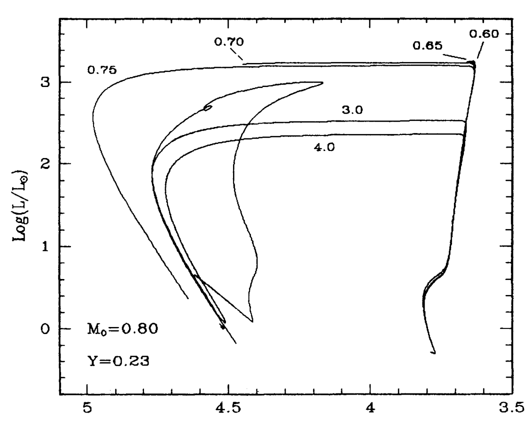

Fig. 1. Selected evolutionary tracks for the Z = 0.0002 case and the labeled values of η.

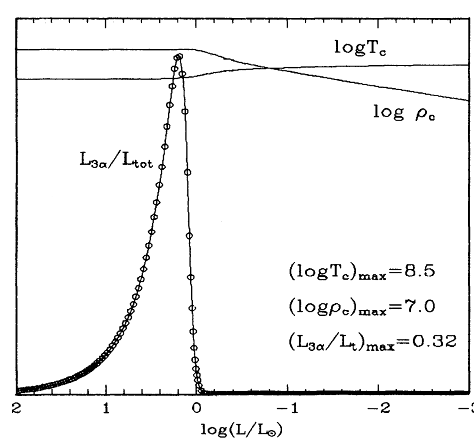

Fig. 2. Internal evolution of the $\eta = 1.0$ model. The variables are normalized to the values indicated.

For the intermediate range of η values which remains, we found that, even if the models leave the RGB, hey finally succeed in igniting the helium with the flash occurring either in the upper part of the track or on he cooling sequence; these stars are left with an envelope mass of the order of $10^{-3}M_{\odot}$, so we expect them to ;ive very blue HB stars.

As a general rule we found that the core evolution appears to be decoupled from the envelope evolution. n particular, one finds that the models which succeed in igniting the helium reach the flash with the same ore mass as the $\eta = 0$ model: while, if it were following the actual total mass, this value should be greater, lue to the enhanced degeneration effects in lower mass stars. This decouplement between internal and external volution occurs even in those models which do not ignite the helium, in the sense that the core keeps ignoring he surface conditions and evolving as a RG core long after the star has left the RGB.

As an example of this behaviour, in Figure 2 selected He-core structural parameters relative to the $\eta = 1.0$ nodel along the cooling sequence, from $\log L/L_{\odot} = 2.0$ down to $\log L/L_{\odot} = -3.0$ are shown. One can see that in he upper part of the track the 3α luminosity keeps increasing until it reaches a maximum near $\log L/L_{\odot} \simeq 0.0$, nd then it falls abruptly. Correspondingly, the central temperature, after a slow but monotonous increase, alls, while the central density starts increasing as is due for a star contracting towards its WD stage.

Table 1: Selected evolutionary parameters for models with Z=0.0002.

η	M^{fin}	M_c^{fin}	L^{flash}	T_e^{flash}	$M_e(3.8)$	$L(3.8)$	$M_e(L=1)$	Evolutionary behavior
0.00	0.8000	0.5031	3.285	3.625	-	-	-	He flash
0.50	0.5866	0.5009	3.262	3.625	-	-	-	He flash
0.60	0.5286	0.5007	3.262	3.635	-	-	-	He flash
0.65	0.5091	0.5003	3.255	3.657	-	-	-	He flash
0.70	0.5020	0.4991	3.223	4.448	0.0046	3.241	-	He flash
0.75	0.4930	0.4922	0.368	4.640	0.0048	3.204	0.0009	He flash
0.80	0.4871	0.4870	-	-	0.0050	3.174	0.0009	Cooling
0.85	0.4818	0.4816	-	-	0.0050	3.146	0.0010	Cooling
0.90	0.4800	0.4793	-	-	0.0050	3.133	0.0010	Cooling
1.00	0.4686	0.4677	-	-	0.0055	3.075	0.0010	Cooling
2.00	0.4161	0.4151	-	-	0.0075	2.745	0.0016	Cooling
3.00	0.3885	0.3867	-	-	0.0090	2.523	0.0020	CNO flash
4.00	0.3697	0.3675	-	-	0.0100	2.358	0.0024	CNO flash

In Table 1 selected structural parameters illustrating the models' behaviour for the case with $Z = 0.0002$ re listed. From left to right we report: the assumed value of η, the total mass and the core mass of the final 1odel, either at the He-flash or as a cooling dwarf, the luminosity and effective temperature at the He-flash, he mass of the envelope and the luminosity of the models leaving the RG branch when $\log T_e = 3.80$, and the nvelope mass in the cooling phase at $\log L/L_{\odot} = 1.0$.

3. RG STRAGGLERS AND He WHITE DWARFS

The mass loss mechanism introduced to explain the observed HB peculiarities provides at the same time a atural way to produce WDs from individual stars rather than from binary systems. One can use this fact to ut constraints on the actual occurrence of RG stragglers in clusters.

Cooling He WDs are partially supported by p-p burning in the hydrogen rich envelope down to a luminosity alue of about $\log L/L_{\odot} = 0.0$, so that the evolution is significantly slowed down. Since models with higher 1ass loss rate leave the RGB with a thicker envelope, their cooling rate will be slower.

When the hydrogen contribution disappears all the models converge to a common cooling sequence. In 'igure 3 we compare the cooling laws of a typical He dwarf and of CO dwarfs with two different values of the nvelope mass (from Castellani et al. 1994), while Figure 4 shows the variations of the cooling rates of models 'ith different values of η. The peak which is observed in the $\eta = 4$ case is due to the occurrence of the first of

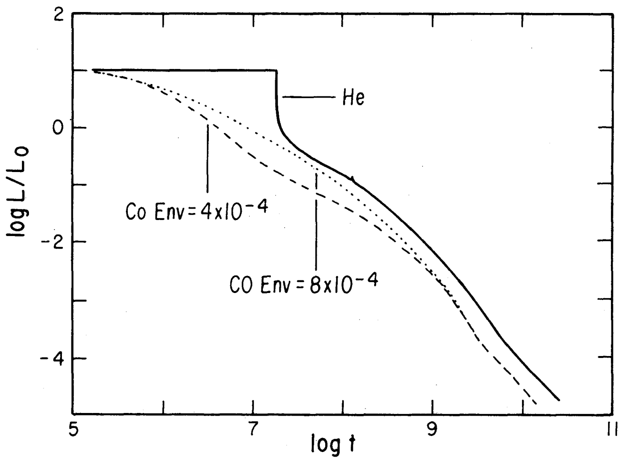

Fig. 3. Cooling rates for He and CO WDs.

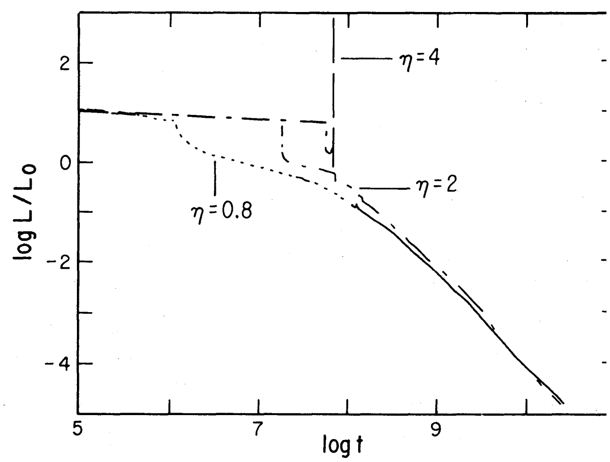

Fig. 4. Cooling rates of HeWDs for different assumptions on η

a series of strong CNO flashes, which characterize the models with high η and thick envelope mass (see alsc Kippenhahn et al. 1967; Giannone et al. 1970; Webbink 1975; Iben & Tutukov 1986).

The features of He WDs' cooling sequences reflect on the resulting WDs' LF. It is possible to mak theoretical predictions on the LF as a function of the percentage of RG stragglers and hence, of the number c He WDs produced with respect to the number of CO dwarfs.

In Figure 5 the results for the LF are shown, obtained assuming the total number of dwarfs to be given b five different mixtures of CO and He dwarfs, parameterized with the number of HB stars n_0. Allowing for eve a small fraction of He dwarfs, a characteristic peak at about $\log L/L_\odot = 0.0$ appears. The peak becomes moı and more pronounced as the fraction of He dwarfs in the mixture increases. Simple statistical evaluations sho that in observing a cluster populated by 100 HB stars, one would be able to detect even a population of onl 10% stragglers (see also Castellani et al. 1994).

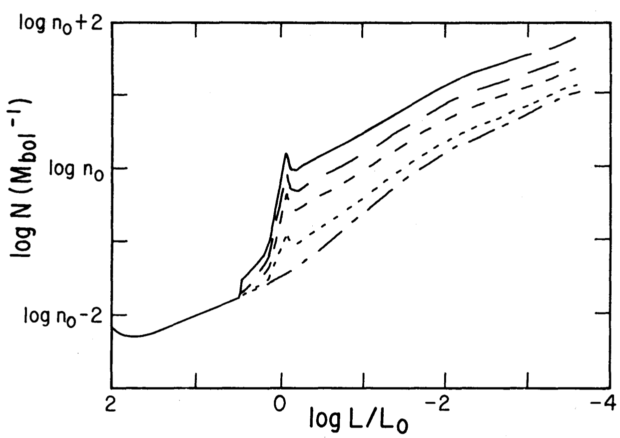

Fig. 5. The expected LF of cluster WDs. Top to bottom: n_{CO}/n_{He} = 2/3, 1/2, 1/3, 1/10 and 0.

4. CONCLUSIONS

The evolutionary scenario concerning the evolution of RG stars with mass loss and the subsequeı production of He WDs has been discussed. We found that a mass loss mechanism can give the clue to problen referring to the HB morphology and, at the same time, provide a way to produce He WDs. We finally ha shown how theoretical constraints on the number of RG stragglers result from the observed WDs' LF.

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DISCUSSION

imbert: Other authors obtain M(core) =0.55 $M_\odot$ for the oldest stars in the Galaxy while you obtain (core) = 0.50 $M_\odot$. Can you comment on this difference?

ridiana: The fact that we obtain a smaller core mass doesn't create any difficulty with the stars' ages, cause in low mass stars decreasing the total mass leads to bigger He-cores, due to the enhanced degeneration ects. Actually a 0.55 $M_\odot$ core corresponds to stars which are less massive than our models and hence are er. We obtain for our models a final age of about 15 Gyr.

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