GRADIENTS IN SUPERGIANT AND WR STARS ACROSS THE GALACTIC PLANE

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Summary

The conclusion by Maeder et al.(1980) that the strong gradient in N_R/N_{WR} results from the effect of metal content on the rate of mass loss is reconsidered. We suggest that the above gradient simply reflects a similar gradient in the progenitor stars, although effects of metallicity cannot be excluded.

It is well knwon that the galactic distribution of WR stars is strongly concentrated toward the galactic centre, in fact the surface number density of these objects approximately increases by a factor of 10 over a distance of 5 Kpc centered on the sun. In addition to this, Maeder et al. (1980) showed that the surface number densities of WR (N_{WR}), blue (N_B) and red (N_R) supergiant stars obey the following relations:

i) N_R/N_{WR} increases rapidly with galactocentric distance, a factor of 100 over a distance of 6 Kpc.

ii) $(N_R+N_{WR})/N_B$ is nearly constant over the same distance.

Out of these observational relations the suggestion was that the strong gradient in N_R/N_{WR} ratio results from effects of the heavy element abundance gradient on the rate of mass loss. In fact, the relative duration of the red supergiant phase with respect to the WR phase is found to depend on the mean mass-loss rate. The higher is the mass-loss rate, the shorter is the lifetime spent as red supergiant (Maeder, 1981). On the other hand, the constancy of the $(N_R+N_{WR})/N_B$ ratio is thought to simply reflect the constant ratio between core He- (red supergiant and WR phase) and H- (blue supergiant phase) burning lifetime . Although we expect that differences in the abundance of heavy elements may well affect the mean mass-loss rate from stars in different regions of the galactic plane, we suspect that the strong gradients found by Maeder et al.(1980) may be subjected to some criticism. We can single out three critical po

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ints in the procedure followed by Maeder et al.(1980) in deriving the above relations: a) The choice of the lower luminosity boundary (M_b=-6) above which stars of the Humphreys (1978) catalogue are counted. b) The dependence of the surface number densities N_R and N_B on the adopted zoning. c) The incompleteness of the Humphreys catalogue, which does not include all stars brighter than M_b=-6 in the solar vicinity. In the following we discuss points a), b) and c) in some detail.

a) Lower luminosity boundary

In correlating the surface densities of blue and red supergiant stars with the surface density of WR stars, one implicitly assumes that some genetic scheme exists among the three types of star. According to current scenarios of WR formation,these stars are the descendents of O-type stars, through the effect of mass loss (see Chiosi (1982) for an updated review of the subject). More precisely, stars of initial mass in the approximate range 20 $M_\odot$ to 60 $M_\odot$ first become blue and red supergiants and then WR stars. On the contrary, stars initially more massive than about 60 $M_\odot$ miss the red supergiant phase, but directly evolve from O to WR type. As massive stars are known to evolve at nearly constant luminosity, we expect on the base of the available numerical models, WR stars to have the same (or lower) luminosity as the progenitors. Current estimates of WR luminosities locate them on the HR diagram above M_b=-7.5 to -8 (Smith, 1973; Conti, 1976; van der Hucht et al., 1981). Therefore, all stars with luminosity $-6 \gtrsim M_b \gtrsim -7.5$ will unlikely be progenitors of WR stars. At the light of the above considerations, the limit magnitude M_b=-6 adopted by Maeder et al.(1980) seems to be unacceptably low. The effect of different assumptions for the limit magnitude of WR progenitors on N_R/N_{WR} ratios is shown in Table 1. In addition to this, Table 1 contains star densities N_B, N_R, N_{WR} as functions of the limit magnitude and distance R from the galactic centre. At M_b=-6 we obtain the same results as Maeder et al.(1980). Going from 8 to 12 Kpc, the density N_R of red supergiants increases by a factor of two, the ratio N_R/N_{WR} increases by a factor of twelve, while the ratio $(N_R+N_{WR})/N_B$ remains approximately constant. At M_b=-7.5 the density of red supergiants is constant and independent of galactocentric distance, the ratio $(N_R+N_{WR})/N_B$ decreases by a factor of two, so that the increase of the ratio N_R/N_{WR} simply reflects the strong density gradient in WR stars. Further remarks on the densities reported in Table 1 are necessary for the sake of completeness:

i) The association Per OB1, located at a distance of 11.7 Kpc from the galactic centre, counts one third of all the red supergiants brighter than M_b=-6 of Humphreys' catalogue, while its contribution to the number of red supergiants brighter than M_b=-7.5 is negligible. It is not a pure coincidence that our results start differing from those of Maeder et al. (1980) at the same M_b at which the contribution by the the popolous assoc

Table 1 (Star Densities)

M_b	R^+	N_B^{++}	N_R^{++}	N_{WR}^{++}	$(N_R+N_{WR})/N_B$	N_R/N_{WR}
-6	8 - 10	31.7	1.7	3.3	0.16	0.5
	10 - 12	33.8	3.6	0.6	0.13	6.0
-7	8 - 10	25.5	1.4	3.3	0.19	0.4
	10 - 12	25.8	2.7	0.6	0.13	4.5
-7.5	8 - 10	21.9	1.0	3.3	0.20	0.3
	10 - 12	18.6	1.2	0.6	0.10	2.0
-8	8 - 10	16.9	0.9	3.3	0.25	0.3
	10 - 12	12.2	0.4	0.6	0.08	0.6

+) in units of Kpc; ++) in units of number of stars/ Kpc^2

iation Per OB1 becomes negligible. We argue that Maeder's et al.(1980) results are biased by the high number of red supergiants of Per OB1 falling within the range of luminosity $-6 \geq M_b \geq -7.5$.

ii) Humphreys'(1978) catalogue turns out not to be complete up to M_b=-6 even for individual clusters and associations, as star counts show that the number of stars per unit range of magnitude starts decreasing at M_b=-7 to -8.

b) Dependence on zoning

In order to test the dependence of Maeder's et al.(1980) results on the type of zoning they have adopted, we have considerd a circular area of 2 Kpc radius centered on the sun. Star densities have been computed for the internal and external part of this area for several values of M_b (-6, -7 and -8). It turns out from this analysis that going from internal to external regions, the surface density N_R of red supergiants decreases, the ratio $(N_R+N_{WR})/N_B$ decreases by a factor of two to three, and the ratio N_R/N_{WR} grows. The increase of the latter has to be totally attributed to the strong gradient in surface density of WR stars. These results greatly differ from those of Maeder et al.(1980), clearly pointing out that the use of different zonings may yield different surface density gradients, and lead to different conclusions.

c) Incompleteness of Humphreys' catalogue

It is worth examining the completeness of the Humphreys (1978) catalogue up to M_b=-8, referring to our selected circular area. The number of O-type stars in the Humphreys catalogue falling within this area and with $M_b < -8$ is about 90, whereas this same number amounts to 161 if Garmany's (1981) catalogue of O-type stars is used. We infer from this that Humphreys' catalogue underestimates the true surface density of bright stars by a factor of two at least. As a consequence of this, the comparison of densities of bright stars, as derived from Humphreys' catalogue, which suffers of incompleteness, with the surface density of WR stars, as esti mated from van der Hucht's et al.(1981) catalogue, which on the contrary is complete within the same area, may lead to questionable results. Furthermore, the incompleteness of the Humphreys (1981) catalogue at M_b=-8 affects the initial mass function of Lequeux (1979) in this range of luminosities (broadly speaking corresponding to stars more massive than 20 $M_\odot$ on the zero age main sequence), which is also underestimated by the same factor.

At the light of the above considerations, we venture to suggest that the gradient in WR stars cannot be entirely attributed to the similar gradient in metallicity, but other explanations have to be invoked.

We argue that the gradient in WR stars mostly depends on a similar gradient in the number of progenitors, even though effects of metallicity gradients on the mechanism of WR formation cannot be excluded.

In order to test the validity of our suggestion, we perform the following analysis. Let N_i be the number of stars brigther than a given M_b with galactocentric distance $R < 10$ Kpc, and N_e the analogous number of stars with galactocentric distance $R > 10$ Kpc. Fig. 1 shows the ratio N_i/N_e as a function of the limit magnitude M_b. Star counts are based on the Humphreys (1978) catalogue (continuous line in Fig. 1). It is evident from Fig. 1 that very bright stars are more numerous in the internal than in the external region of the galactic plane. As the limit luminosity M_b decreses, the ratio N_i/N_e tends to unity. In order to test wheter the above trend may depend on selection effects caused by different area coverage by Humphreys' catalogue in internal and external regions, we repeat our star counts for the standard circular area considerd above. The same trend comes out also in this case (broken line in Fig. 1), and furthermore a steeper gradient results for the most luminous stars. This finding strongly supports the idea that the galactic distribution of WR stars is simply showing the distribution of their most likely progenitors, namely bright stars. With the aid of the ratio N_i/N_e as a function of the limit magnitude M_b and the corresponding ratio $(N_i/N_e)_{WR}$ for WR stars we may infer the limit magnitude (limit mass) of the progenitors. Considering all WR stars of the van der Hucht et al. (1981) catalogue , we derive the ratio $(N_i/N_e)_{WR}$= 2.5. The limit magnitude of the progenitor stars are:

i) M_b=-8, if only stars within the circular area are considered.

ii) M_b=-9, if all stars of Humphreys' catalogue are used.

The above limit magnitudes roughly correspond to stars of 20 $M_\odot$ or 30 $M_\odot$

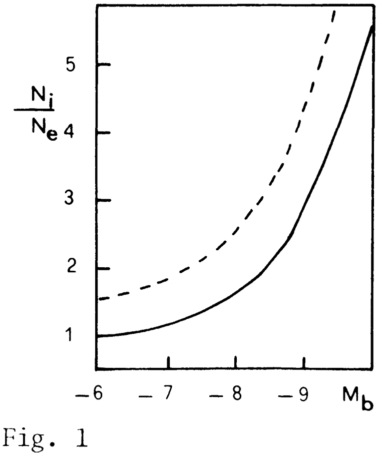

Fig. 1

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on the zero age main sequence, in fair agreement with current scenarios of WR formation and evolution. No better results can be obtained with this kind of analysis because in order to have full consistency we should have a good estimate of the $(N_i/N_e)_{WR}$ ratio for the selected circular area. Unfortunately, this value turns out to be very uncertain owing to to the very poor statistics of WR stars in the external part of the circular area.

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