MASS LOSS FROM METAL-POOR STARS

C. Chiosi, G. Bertelli, E. Nasi, L. Greggio
Institute of Astronomy, University of Padova, Italy

1. Introduction

It is essential to consider the effect of mass loss to understand the distribution of supergiant stars in the HR diagram. This research concerns the evolution of massive stars with X=0.700 and Z=0.001 during the phases up to central He-exhaustion with the inclusion of mass loss. Such low value of Z has been chosen in order to allow a comparison with the supergiant stars of SMC. The rate of mass loss is formulated as in Chiosi, Nasi and Sreenivasan (1978). More specifically, in the range of high effective temperatures, we adopt the mass-loss rate relationship for radiation pressure driven wind of Castor, Abbott and Klein (1975), whereas in the range of low effective temperatures we assume the mass loss rate to be driven by the acoustic flux mechanism of Fusi Pecci and Renzini (1975).

The following sets of tracks have been computed:

i) without mass loss,

20 40 60 80 100 $M_\odot$

ii) with mass loss,

Set A	20, 60, 100 $M_\odot$	α=0.83	K=0.01
Set B	20, 60, 100 $M_\odot$	α=0.90	K=0.01
Set C	20, 60, 100 $M_\odot$	α=0.90	$K \propto Z^{1-\alpha} v_{th}^{\alpha}$

In the computation of set C, the effect of a lower metallicity was taken into account using explicitly the dependence of the parameter K on the metal content according to the mass loss rate formulation of Castor et al. (1975).

2. Evolutionary tracks up to central He exhaustion

From the computed tracks one generally derives that during the core He-burning the lifetime spent in the different regions of the HR diagram is driven by the competition among three different time scales: the time scale τ_{Mc} of increase of the He core mass, the time scale $\tau_{\rho c}$ of variation of density at the edge of He core, and the time scale τ_M of decrea

C. Chiosi and R. Stalio (eds.), Effects of Mass Loss on Stellar Evolution, 297–300.

se of the stellar mass. This partially agrees with Falk's (1979) theoretical analysis. In the light of the previous results the following conclusion can be obtained:

i) 20 $M_{\odot}$ tracks; the zones on the HR diagram where the stationary He burning takes place depend only on the mass lost during the MS phase. In other words, the evolution of stars burning He in the core is fixed by the model structure at the end of MS phase. The mass loss rate during central He burning play a secondary rôle.

ii) 60 $M_{\odot}$ tracks; a correlation exists between the extension of the blue loop and the mass-loss rate by radiation pressure during the core He burning phase. This conclusion and other results, which have been obtained by changing parametrically the mass-loss rate, allow us to point out that rates of mass loss like those used in our computations for blue and red phases are both essential in order to determine the location of stationary He burning in the HR diagram. The same general remarks developed for the 60 $M_{\odot}$ star apply also to 100 $M_{\odot}$ star, with the exception of set B. In this case the envelope is so thin that also the increase of the core mass contributes to the bluewards evolution in the HR diagram.

3. Comparison with observations and conclusions

The theoretical results have been compared with the observational data for SMC supergiants by Azzopardi and Vigneau (1975) and by Humphreys (1979). The dashed areas in Fig. 1, shows the zones populated by supergiants in the Small Magellanic Cloud.

The main observational features which have to be explained by theoretical models can be summarized in the following.

1) Red supergiants more luminous than M_{bol}=-9.30 are absent. This fact implies that stars originally more massive than a limiting value M^{*} cannot become red supergiants. In any case the value of M^{*} derived by our models is approximately 40 $M_{\odot}$.
2) The small number of intermediate spectral type (from F5 to K5 MO) supergiants sets a strong constraint on the lifetime spent in the corresponding regions of the HR diagram, which must be very short.
3) The distribution of stars in the HR diagram defines an upper envelope similar to that we can obtain from analogous diagrams for the Large Magellanic Cloud and our own galaxy. This upper boundary, which can be approximated by a straight line (dashed-dotted line in the Fig. 1) for a given luminosity represents the red edge of the stationary core He-burning.

The analysis of our theoretical results leads to the conclusion that the satisfaction of all these experimental requirements cannot be accomplished by a single set of tracks. The upper boundary derived from the evolutionary tracks of 100 and 60 $M_{\odot}$ stars for case B roughly reproduces the trend

https://doi.org/10.1017/S0252921100094926 Published online by Cambridge University Press

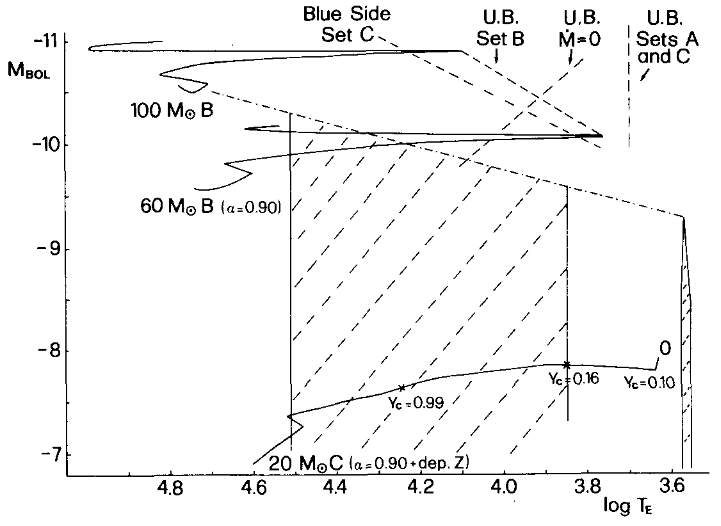

Fig. 1 - The HR diagram for SMC supergiants.

of the observed one; a better agreement could be perhaps ob
tained with a larger mass loss rate, as shown by the general
evolutionary behaviour of our calculations. Fig. 1 also shows
the upper boundaries generated by the other sets: those cor-
responding to sets A and C settle down in the red region and
are almost vertical while that corresponding to the constant
mass evolution shows a slope in opposite direction compared
to the observed one. The left (blue) edge of the stationary
core He-burning obtained from 60 and 100 $M_\odot$ stars of set C
is also plotted. The 20 $M_\odot$ track of Fig. 1 belongs to set C
and partly can reproduce the main characteristics of the ob
served distribution in the mass range $M<M^*$. In any case a
mass loss rate intermediate between cases A and B is requi-
red to explain the presence of red supergiants and the pau-
city of stars in the spectral range F5-K5, M0. Otherwise, we
may, in alternative way, suggest the following picture. We
have pointed out that the position in the HR diagram of the
stationary core He-burning for stars of 20 $M_\odot$ depends only
on the mass loss rate during the core H-burning phase. On
the other hand, for stars of 60 and 100 $M_\odot$ the mass loss ra
te during the core He-burning controls the location of sta-
tionary core He-burning. Therefore, mass loss rates like tho
se of case C in the main sequence phase and assuming higher
values than case B during core He-burning (for example by a
weak dependence on the radius) could satisfy the experimen-
tal requests. In addition to this, the comparison of bright
est supergiants of intermediate spectral type in SMC seems
to indicate that these stars are systematically less lumi-
nous than galactic counterpart. The highest stellar mass of
SMC on the main sequence, given by the interstection of the

extrapolated upper boundary (dashed-dotted line in Fig. 1) with the ZAMS, is 50-70 $M_{\odot}$ less massive than the highest mass of LMC. This fact can be perhaps related to the observed extreme paucity of single WN-late stars in SMC if these objects have progenitors more massive than same critical mass.

References
Azzopardi, M. and Vigneau, J. 1975, Astron. Astrophys. Suppl. 22, 285
Castor, J.I., Abbott, D.C., Klein, R.I. 1975, Astrophys. J. 195, 157
Chiosi, C., Nasi, E., Sreenivasan, S.R. 1978, Astron. Astrophys. 63, 103
Falk, H.T. 1979, thesis
Fusi-Pecci, F., Renzini, A. 1975, Astron. Astrophys. 39, 413
Humphreys, R.M. 1979, Astrophys. J. 231, 384

DISCUSSION

FALK: I would just like to point out that Bertelli's analysis is entirely consistent with my criterion for reversals. His empirically derived terms and my analytic inequality both indicate that when nuclear shell burning dominates, the star evolves to the red and when mass loss dominates, the star evolves back to the blue. He has also confirmed what I suggested (Falk 1979) but did not include in my analysis, that when a third factor, gravitational contraction dominates, the evolution will be back to the red. However, my criterion also shows that the importance of nuclear burning is dependent on the shell position in the star. Once the He core is larger than a certain value ($q_s \simeq .6$ for no mass loss) the star will always evolve to the blue.

https://doi.org/10.1017/S0252921100094926 Published online by Cambridge University Press