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INITIAL MASS FUNCTIONS OF WOLF–RAYET STARS

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Abstract. On the basis of evolutionary tracks on the HR diagram the lower limit of initial mass functions for Wolf–Rayet stars are estimated. The lower limit to the initial masses of the Wolf–Rayet stars seems to be 20 $M_\odot$ and in this respect there is no significant difference between the WN and WC stars.

1. Introduction

Wolf–Rayet stars are high luminous evolved descendants of massive stars. These stars are highly evolved objects in which core helium burning occurs. In the WN sequence the stellar composition is enhanced in nitrogen byproducts of the CNO cycle appearing at the surface. In the WC sequence there is enhanced carbon due to products of the triple-alpha helium burning reactions coming to the surface. The evolutionary status of these stars are of significant interest, since these stars are suspected to be supernovae precursors. The evolutionary significance of the correct position of these stars on the HR diagram is still not definite and it is not clear whether these objects are pre- or post-Main-Sequence stars (cf. Kitchin, 1982).

If these stars are supernovae precursors then what should be the masses of their progenitors? Do all the O stars necessarily become WR stars during the core He burning phase, or do they preferentially come from a more limited mass range? According to Maeder *et al.* (1980) and Maeder (1981a, b) the massive star progenitors go through both the red supergiant (RSG) and the WR stages with a relative proportion of time they spend on each side of the HR diagram. Stars with higher initial masses would have a higher mass loss rate, and it must be easier from them to release their outer atmospheres to become WR stars. The possibility of red supergiants to become WR stars had been widely studied by Maeder (1983), Humphreys (1983), Humphreys and Davidson (1979), and these authors concluded that there is some upper mass limit above which the stars do not become red supergiants as the brightest red supergiants are not as luminous as the most luminous blue supergiants. Recently, Humphreys *et al.* (1985) have discussed the lower limit of initial masses of the stellar associations and clusters with definite and probable Wolf–Rayet star members and found that the lower limit to the initial masses of the WR stars is 30 $M_\odot$.

In light of the above background in this paper the lower limit of initial masses for the Wolf–Rayet stars has been reinvestigated. Since there are three distinct types of objects as under which exhibit Wolf–Rayet spectra:

(i) the less massive component of a massive binary system,
(ii) single stars, often associated with ring nebulae belonging to Population I, and
(iii) nuclei of some planetary nebulae.

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Therefore, in this paper, we have tried to take into account all the three cases to cover the Wolf–Rayet stars as a category.

2. Observational Data

The observational data have been taken from different sources:

(1) Smith and Willis (1983): For 15 galactic Wolf–Rayet stars the effective temperatures and luminosities have been calculated by these authors. The luminosities have been converted into bolometric magnitudes, so that they can be directly plotted on the HR diagram along with the evolutionary tracks for massive stars borrowed from Maeder (1981a, b, 1983).

(2) Nussbaumer *et al.* (1982): For 9 LMC Wolf–Rayet stars, the effective temperatures and luminosities have been determined by Nussbaumer *et al.* (1982). These luminosities have been converted to bolometric magnitudes.

(3) Singh (1986): For 14 Wolf–Rayet stars the effective temperatures estimated by the author have been taken. For these stars, the bolometric magnitudes were estimated through spectral type-M_{bol} relation (Kaler-Schmidt, 1982).

(4) Van der Hucht *et al.* (1981): For a few Wolf–Rayet stars associated with the ring nebulae, effective temperatures are taken from Van der Hucht *et al.* (1981). The corresponding bolometric magnitudes were estimated through spectral type-M_{bol} relation (Kaler-Schmidt, 1982).

(5) Underhill (1983): For 10 WR stars the values of effective temperatures and luminosities have been taken from Underhill (1983). Their luminosities have been again converted into bolometric magnitudes.

3. The Initial Masses of WR Stars

Here we have followed the method outlined by Lequeux (1979) and Garmany *et al.* (1982) for our calculation of the massive WR star 'IMF' which requires a quantitative M_{bol} versus T_{eff} HR diagram plus an adopted set of evolutionary tracks. The evolutionary tracks used by us are taken from models with mass loss by Maeder (1981a, b, 1983). The M_{bol} and effective temperatures for these WR stars are plotted on the HR diagram with adopted evolutionary tracks as shown in Figure 1.

From Figure 1 we see that the Wolf–Rayet stars are lying on both sides of the HR diagram with the majority of stars lying well above the Main Sequence. However, a few stars are seen to be lying just below the Main Sequence of the HR diagram. Mainly due to errors in effective temperatures and bolometric magnitudes estimations, on an average less than 15% of the WR stars are lying below the Main Sequence of the HR diagram. For these stars the masses have been estimated by moving the stars along the shortest route to the ZAMS (zero-age Main Sequence) in the M_{bol}, log T_{eff} plane assuming them as Main-Sequence stars. The accuracy of masses determined on this basis depends upon the uncertainties in the exact locations M_{bol}, log T_{eff} plane as well as on the reliability of theoretical assumptions used in deriving the theoretical evolution-

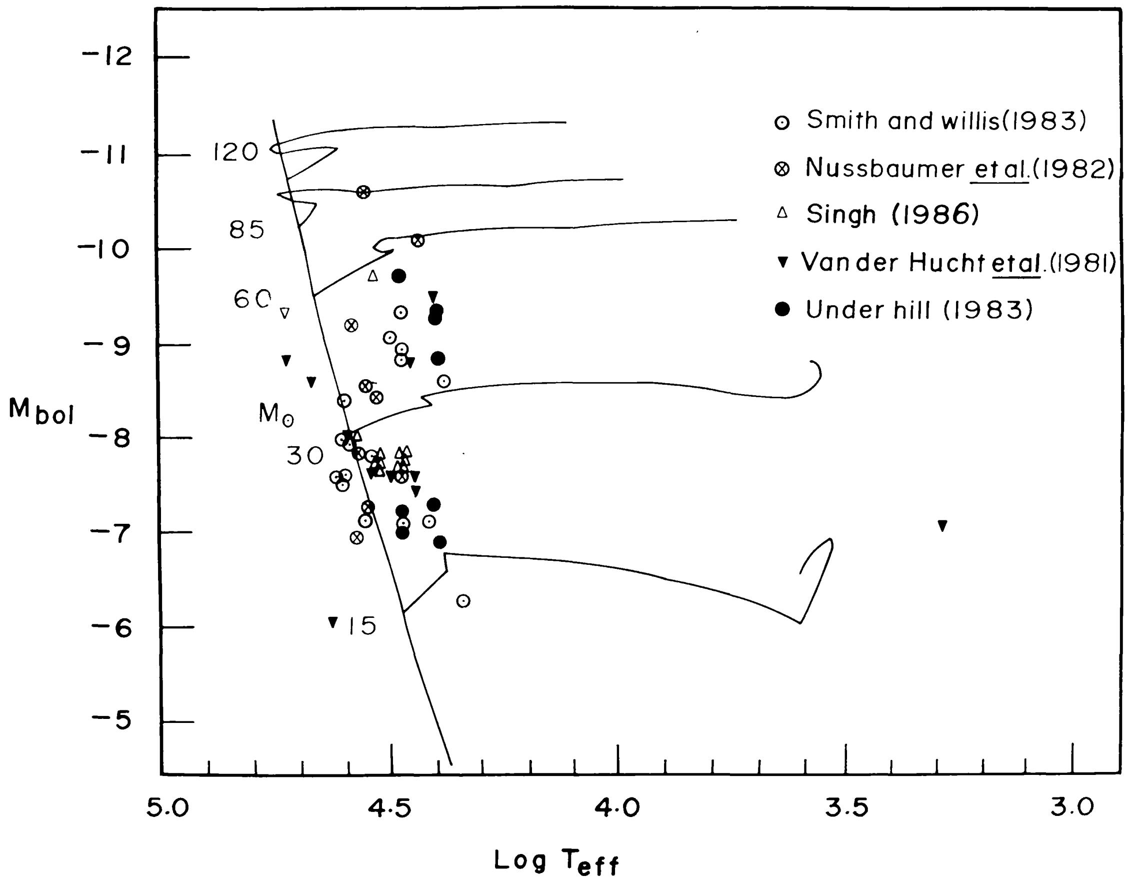

Fig. 1. Positions of the studied Wolf–Rayet stars on the HR diagram with adopted theoretical evolutionary tracks for massive stars by Maeder (1981a, b, 1983).

ary tracks. However, the errors in mass determinations due to inexact positioning of a star on the HR diagram is rather small, e.g., with an increase in mass from 1 $M_\odot$ to 15 $M_\odot$. δM (error in mass determinations) varies from 1 to 7% (Piskunov, 1977). From Figure 1, it is also clear that most of the stars lie well above the 15 $M_\odot$ evolutionary track. The respective numbers of stars in each mass interval as estimated from Figure 1, are shown in Table I. From Table I we see that the maximum number of stars lie in the

TABLE I

The respective numbers of stars in each mass interval as estimated from Figure 1

Mass interval	No. of stars
$M < 15\,M_\odot$	1
$15\,M_\odot < M < 25\,M_\odot$	8
$25\,M_\odot < M < 35\,M_\odot$	28
$35\,M_\odot < M < 60\,M_\odot$	17
$60\,M_\odot < M < 85\,M_\odot$	1

mass interval 25–35 $M_\odot$ and the lower limits to the initial masses must be 20 $M_\odot$ which are in good agreements with those of Chiosi (1981), Maeder (1981b, 1982), and Firmani (1982). We also find that there is no significant difference between WN and WC stars on account of initial mass functions, although WC stars are supposed to be more highly evolved than WN stars.

4. Conclusions

Our investigation shows that the lower limit of the initial mass of the star should be $\geq 20\,M_\odot$ to become a Wolf–Rayet star. This limit seems to be valid for all the Wolf–Rayet stars irrespective of they are whether galactic stars, LMC stars or, Wolf–Rayet stars associated with ring nebulae and also irrespective of their type (WN or WC).

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