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MASS LOSS FROM WOLF–RAYET STARS

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Abstract. Mass loss rates for 9 LMC WR stars are determined using IUE, UV, and visible spectrophotometric observations. A good correlations of mass loss rate with effective temperature and luminosity is indicated by the data, in agreement with the theoretical predictions.

1. Introduction

Discovered over 100 years ago, the Wolf–Rayet stars are some of the most interesting objects in the sky. These stars suffer mass loss through strong stellar winds. Evidence for mass loss processes in WR stars has been known for some time, manifested in P Cygni-type line profiles (Beals, 1929), in IR excess from an extended ionized envelope (Hackwell *et al.*, 1974; Cohen *et al.*, 1975), in IR emission from circumstellar grains presumably condensed out of outflowing matter (Cohen *et al.*, 1975) and, in some cases, in the presence of an associated ring nebula (Johnson and Hogg, 1965). Observations in radio wavelengths are available for only a few stars (Seaquist, 1976; Florkowski and Gottesman, 1977; Dickel *et al.*, 1980; Hogg, 1981; Bieging *et al.*, 1982), mainly because the radio flux density is very weak. To obtain a complete picture of stellar winds it is necessary to observe their low-density outer portions, which is best done in the UV region. A group of 15 galactic WR stars have been observed by Nussbaumer *et al.* (1982) in the UV and visible regions. The numerous strong resonance lines which are accessible in this portions of the spectrum provide information on the velocity, density, and ionization conditions in the outflowing material which, when combined with the visible and IR data, can provide sufficient information to be of use in constraining possible models for the winds.

In this paper we have determined mass loss rates for nine LMC WR stars using IUE, UV, and visible spectrophotometric observations taken from Smith and Willis (1983).

2. Determinations of Mass Loss

For the models of the radial symmetric mass outflow the mass loss rate of a star may be estimated from the formula

$$\dot{M}_{\mathrm{WR}} = 4\pi\rho V R_e^2 .$$

Here ρ and V represent the density and velocity of the outflow in the expanding atmosphere at a distance (R_e) of the emission line region from the centre of the star. To determine the required elemental abundances, and also electron densities in the WR atmosphere, the escape probability model (EPM) of Castor and Van Blerkom (1970)

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TABLE I

Star	N_e (density) (cm^{-3})	Expansion velocity ($\mathrm{km\ s}^{-1}$)	$\log(L/L_\odot)$	$\log(T_{\mathrm{eff}})$	$\log\dot{M}$
FD13	5.00×10^{11}	3870	4.80	4.380	-4.219
FD12	3.64×10^{11}	2290	5.22	4.531	-4.582
FD23	2.63×10^{11}	2300	5.27	4.556	-4.578
FD24	3.27×10^{11}	3220	5.55	4.579	-4.481
FD70	1.15×10^{11}	2520	5.93	4.462	-5.037
FD71	2.21×10^{11}	2100	6.13	4.556	-4.836
FD5	1.60×10^{11}	3210	4.65	4.579	-4.792
FD37	5.80×10^{11}	3890	4.99	4.568	-4.149
FD46	3.50×10^{11}	3920	4.90	4.477	-4.365

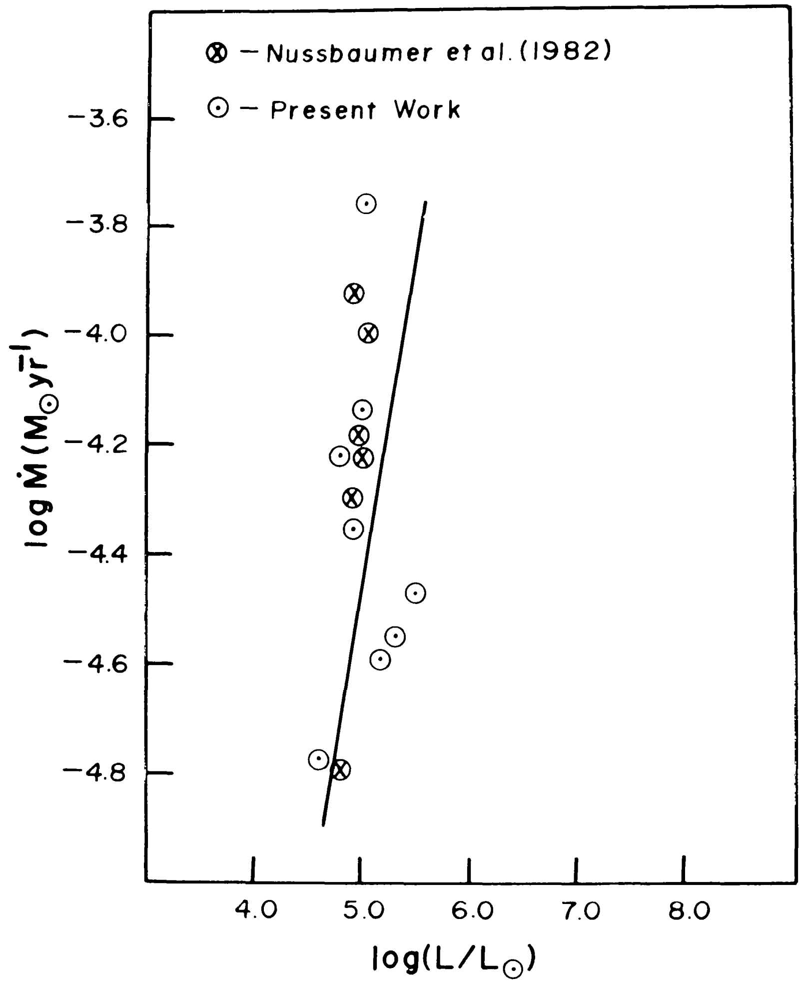

Fig. 1. A plot of derived mass loss vs luminosity for Wolf–Rayet stars.

was used, assuming that the emission lines are formed in a spherical, homogeneous, and expanding medium, surrounding a continuum-emitting stellar core. The radii of the emission line regions (R_e) were determined from the ratio of the optically thick He II lines that couple the levels $n = 3, 4, 5$ (Castor and Van Blerkom, 1970). A very similar value of $R_e = 60\ R_\odot$ was found by Nussbaumer *et al.* (1982) for galactic WN 4, 5, 6 and WC 5, 6, 7 and the same value for the WN 7 and WN 8 subclass. The same value of $R_e = 60\ R_\odot$ has been used in our calculations for mass loss rate. Expansion velocity and average number density of electrons for individual stars were borrowed from Smith and Willis (1983) and are shown in Table I.

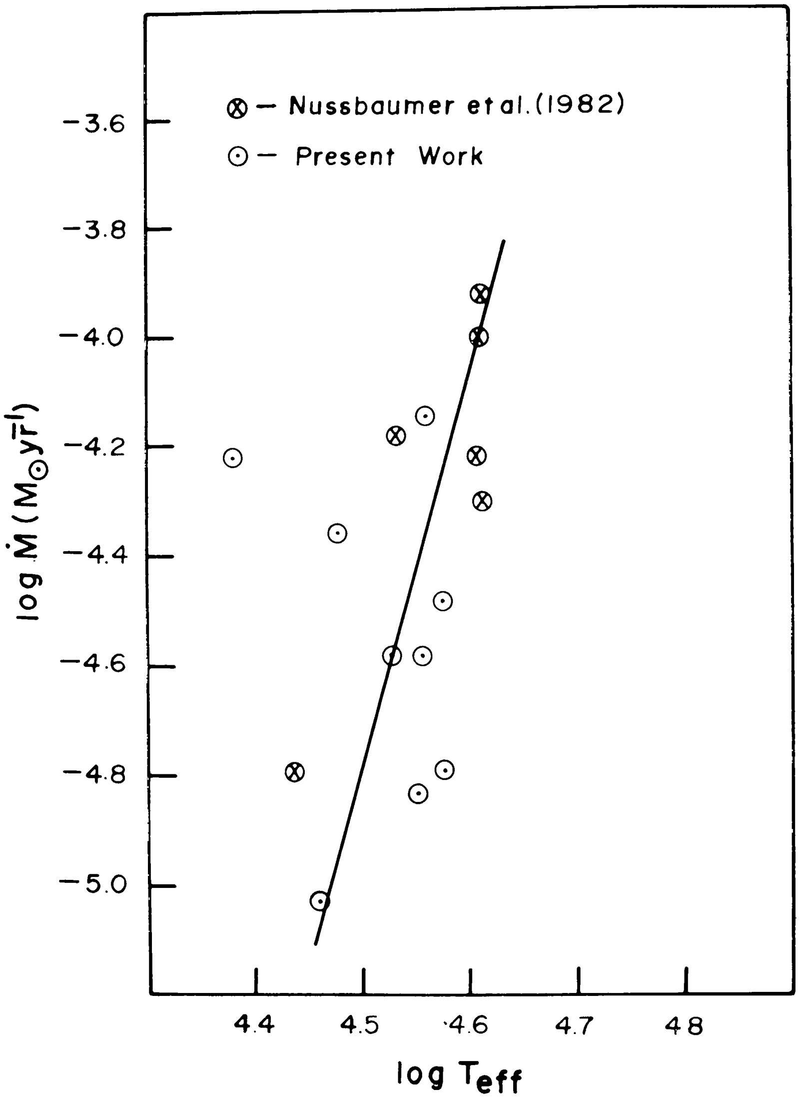

Fig. 2. A plot of derived mass loss rate vs effective temperature for Wolf–Rayet stars.

3. Result and Discussion

A good correlation between bolometric luminosity L_{bol} and $\dot{M}$ by Abbott *et al.* (1981) has been observed for OB stars. Ultraviolet determinations of $\dot{M}$ for stars which are too faint to be studied by Garmany *et al.* (1981) show that the ($\dot{M}$, L_{bol}) power law relation holds for a range of $\log L_{\mathrm{bol}}$ from 4.6 to 6.5 (Abbott, 1982). A similar type of correlation between mass loss rate and luminosity for O stars has been observed by Snow (1978). However, Bieging *et al.* (1982) have noted no such correlation on the basis of observations taken in the radio region. Conti and Garmany (1983) have derived mass loss rates for a number of unevolved O-type stars and a few WN stars from IUE UV observations. They found that the relationship between $\log \dot{M}$ and M_{bol} is broad rather than linear, suggesting that the line-radiation-driven stellar wind theory may not be sufficient to explain the mass loss. Here we have plotted $\log \dot{M}$ versus log(Luminosity) and $\log \dot{M}$ versus $\log(T_{\mathrm{eff}})$ shown in Figures 1 and 2 to see whether there is any correlation between the two. From Figures 1 and 2, it is clear that there is a good correlation for both cases. The mass loss rates obtained by Nussbaumer *et al.* (1982) have also been plotted in Figures 1 and 2, and they fit well.

Contrary to Snow (1978), in our case there seems to be a better correlation for $\log \dot{M}$ versus $\log(T_{\mathrm{eff}})$ than for $\log \dot{M}$ versus log(luminosity). The points show appreciable scatter (Figure 2); however, a monotonic increasing trend is perceptible which is also supported by theoretical expectations. An almost constant mass loss rate for a narrow range of luminosity is apparent from Figure 1. The same type of relation has also been observed by Bieging *et al.* (1982). In order to confirm it, more observational data are necessary for a wider range of luminosities

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