THE NEAR INFRARED PROPERTIES OF SELECTED WN STARS IN THE LARGE MAGELLANIC CLOUD

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I. INTRODUCTION

We report here on preliminary infrared photometry of six WN stars in the Large Magellanic Cloud. Besides R136, the central object of the 30 Doradus Nebula, the sample includes three stars (R139, R140, R145) located near the center of the region (within ∿ 1 arcmin) and two more stars (R144, R147) at a distance of ∿ 5 arcmin from R136.

Our results do not confirm the extreme infrared colours of magellanic WN star reported by Hyland et al (1978) but, on the contrary, indicate their similarity to galactic WN stars in the continuous energy distribution from the visible to the infrared. From the present data we derive the parameters of the stellar wind. The computed mass loss rates compare well to those found for galactic WN stars.

2. THE OBSERVATIONS

Measurements in filters J(λ_{eff}=1.25μm),H(λ_{eff}=1.65μm) and K(λ_{eff}=2.2μm) of the programme stars were obtained during two nights on March 23 and 24, 1981, with the new infrared photometer on the 3.6 m telescope of the European Southern Observatory, La Silla, Chile. The standard dual beam technique with a 10 arcsec aperture and 20 arcsec throw was used. The observed magnitudes, relative to BS 2015 (J = 3.86, H = 3.74, K = 3.70) are given in Table 1. The stars are identified by the Radcliffe number (Feast et al, 1960) and by HD/HDE designation, when available. Spectral types are from Breysacher (1981).

The observations were corrected for interstellar reddening according to the relations $A_V:A_J:A_H:A_K$=1:0.28:0.16:0.12. The E_{B-V} values quoted in Table 1 for four stars were derived from the measurements and the mean intrinsic colours given by Smith (1968). For R 139 and R 140, since no direct information was found in the literature, the range between the galactic foreground value E_{B-V}=.07 in the direction of LMC (e.g. Isserstedt, 1975) and E_{B-V} = .3, was considered.

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3. DISCUSSION

The dereddened H-K colours of the programme stars (Fig. 1) appear to be very close to those found for galactic WN stars (Allen et al, 1979). Since for galactic WN stars J magnitudes are not available, comparison of J-H colours is not possible. On the other hand, also the v-H colours of WN stars in the LMC compare well with those of galactic ones, both for single and binary stars (Panagia et al, 1981). These results suggest that in galactic and magellanic WN stars the overall continuum distribution has essentially the same characteristics.

Fig. 1 shows that single WN stars are definitely redder than galactic O-type stars (Tanzi et al, 1981) whereas binary systems (WN + O) have intermediate colours. The locus of binary systems in the two colours diagram of Fig. 1, is shown for different values of the ratio of luminosity in the J band of the components (i.e. $L_J(WN)/L_J(O)$). This curve was computed adopting the mean colours $\overline{(J-H)}_{WN}=+.15$, $\overline{(H-K)}_{WN}=+.25$ and $\overline{(J-H)}_{O}=-.10$, $\overline{(H-K)}_{O}=-.05$. In this diagram R 136, albeit exceptionally bright (cf. Table 1; see also Cassinelli et al, 1981), appears to be a normal binary system, dominated by the WN component. On the other hand, R 139, whose spectral type is reported as uncertain between WN and Of (Breysacher, 1981), turns out to be either a single O-type star or, if binary, heavily dominated by its O-type component

In Figure 2 the solid line labelled "bb" represents the colours of black body radiators at different temperatures. The black body colours closest to those of magellanic WN stars pertain to temperatures near 7.5×10^3K. However, this temperature is much lower (near a factor of four) than the effective temperature of the stars, and by far too high for a conceivable circumstellar dust. Considering that emission lines contribute negligibly to the observed infrared colours of WN stars (Williams, 1982), the most natural interpretation is therefore in terms of free-free emission from expanding gaseous envelopes, i.e. mass loss.

Following Panagia and Felli (1975) and Tanzi et al (1981), theoretical colours for stars with strong mass loss have been computed assuming:

i) Both photospheric radiation temperature and electron temperature in the wind are taken to be 2.5×10^4 °K.

ii) Stellar radii of $R_* = 15\ R_\odot$

iii) Power law velocity $v = v_o\ (r/R_*)^\gamma$, with $v_o = 400$ km s^{-1} and $\gamma = 0, 0.5, 1, 2, 3$.

iv) Helium rich gas ($\mu_e^2/Z = 2.25$)

The resulting curves for $\dot{M}=2\times10^{-5}\ M_\odot yr^{-1}$(curve A)and $\dot{M}=4\times10^{-5}\ M_\odot yr^{-1}$(curve B), as well as for the asymptotic case $\dot{M} \to \infty$ (curve C) are displayed in Figure 2. Inspection of this figure reveals that in order to explain the observations, the velocity of the wind must increase slowly with radius i.e.$0<\gamma<1$. It follows that the high terminal velocity observed in WR stars ($\sim$2000 km s^{-1}; e.g. Willis, 1980) requires relatively high initial velocity, (several 10^2kms^{-1}).

Table 1: J, H, K magnitudes of programme stars; 1σ uncertainties are quoted in brackets.

R	HD/HDE	Sp. Type	J 1.25μm	H 1.65μm	K 2.2 μm	E_{B-V}
136	38268	WN 5-6 + OB	9.18(.04)	8.98(.04)	8.78(.04)	.29
139		WN / Of	11.62(.05)	11.65(.05)	11.75(.05)	-
140		(WN4 + WN5)	11.32(.05)	11.16(.05)	10.98(.05)	-
144	38282	WN7	10.96(.05)	10.88(.05)	10.70(.05)	.11
145	269928	WN7	11.32(.04)	11.17(.04)	10.96(.04)	.28
147	38344	WN6	12.08(.05)	11.88(.05)	11.59(.05)	.29

For all the magellanic WN stars studied here the mass loss rate must be equal to, or greater than, 2×10^{-5} $M_\odot$ yr^{-1}, value very similar to that found for galactic WN stars. This result is remarkable in view of the lower metal abundance in the LMC which would simplistically suggest lower mass loss rates for radiatively driven winds.

In the particular case of R 136, whose radius is about six times the value assumed in the present calculations (Cassinelli et al, 1981), the mass loss rate must be a factor $6^{1.5}$ higher, i.e. $\dot{M}$(R 136) $\gtrsim 3 \times 10^{-4}$ $M_\odot yr^{-1}$. Finally we note that the extinction $A_V = 2^m$ mag proposed by Cassinelli et al (1981) would move R 136 far below the curves of both Figures 1 and 2. This indicates that the value $A_V = 1^m$ (Smith, 1968) adopted here could be more appropriate.

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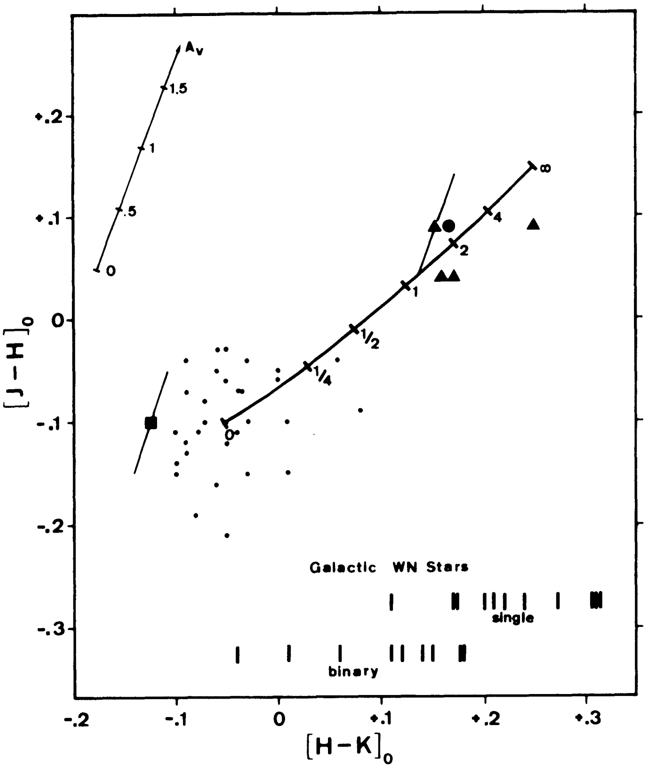

Fig. 1

Dereddened colours of selected WN stars in the LMC. (▲ :R 140, R 144, R 145 and R 147. ■ :R 139. ● :R 136). For R 139 and R 140, a bar encompasses the considered range of reddening correction. Small dots represent galactic O-type stars as from Tanzi et al., 1981. The solid curve is the locus of binary systems (WN + O) as described in the text; ticks are labelled with values of $L_J(WN)/L_J(O)$. H-K colours of galactic WN stars (Allen et al., 1972) are represented by vertical bars.

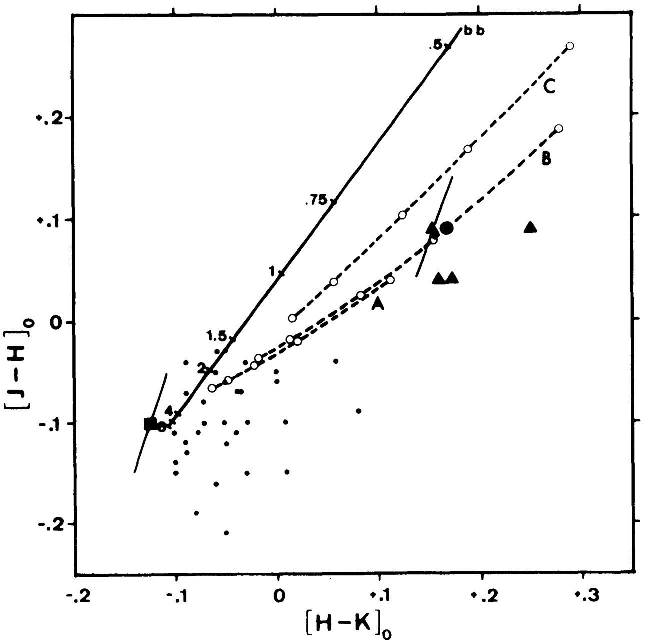

Fig. 2

Same data as in Fig. 1. The solid line labelled "bb" represents the colours of black body radiators; ticks indicate the temperature in units of 10^4°K. The dashed curves give the theoretical colours of a star for different mass loss rates: $\dot{M}=2\times10^{-5}M_\odot yr^{-1}$(curve A), $\dot{M}=4\times10^{-5}M_\odot yr^{-1}$(curve B) and $\dot{M} \rightarrow \infty$ (curve C). Open circles along each curve mark different values of the velocity slope: from the top γ = 0,0.5, 1, 2, 3 (see text)

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DISCUSSION

Tapia: 1) Could you show us what the observational error bars are on your two-colour diagrams ?

2) How large would the uncertainties in mass loss rate determinations be due to these observational errors ?

Panagia: The observational uncertainty in both colours is around $\pm$ 0.06 mag. for all stars. Then by comparing observations with theoretical curves we can safely derive lower limits to the mass loss rate of about 2×10^{-5} $M_\odot$/y for all "bone fide" WN stars observed. The actual values must be much higher but probably not more than twice the lower limit.

Cassinelli: From your data point of R136a in your $\dot{M}$ diagram I read $\dot{M} \sim 4 \times 10^{-5}$. Is it true that we should conclude that the star has a mass loss rate that small ?

Panagia: The curves of infrared colours for different values of $\dot{M}$ were computed assuming a stellar radius of $15 R_\odot$. For a given IR excess the mass loss rate scales with radius as $\dot{M} \propto R^{1.5}$. Therefore adopting for R136a a radius of $\sim 80 R_\odot$ the mass loss rate derived from the IR colours turns out to be about 3×10^{-4} $M_\odot$/y.

Garmany: Concerning the spectral type of R139, Conti and I have concluded that it is an Of star, based on both visual and UV (IUE low resolution) spectra.

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