NEAR-INFRARED PHOTOMETRY OF SOUTHERN GALACTIC WOLF-RAYET STARS *

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1. INTRODUCTION

Allen et al. (1972) observed 40 WR stars in the |1.6μ| and |2.2μ| bands, and found evidence of interstellar dust emission in the WC9 stars Ve 2-45, AS320 and HD 313643. Hackwell et al. (1974) reported 2.3 to 23 μ photometry of 19 WR stars and concluded that the excess infrared radiation from the Wolf-Rayet stars (except for the WC9 stars) could be explained by free-free emission from a hot circumstellar shell. Gehrz and Hackwell (1974) found from 2.3 to 23 μ photometry that three out of four WC stars appear to be embedded in thick circumstellar dust (graphite) shells, and concluded that WC9 stars may form a distinct Wolf-Rayet class. Cohen et al. (1975) derived energy distributions of 23 Wolf-Rayet stars from 3μ-11μ scanner spectrophotometry and infrared photometry, and concluded that WN stars show only free-free emission whereas only WC stars show dust. The excesses in WC9 stars are interpreted as thermal emission by graphite grains.

We here report results from 1μ-5μ photometry of some WR stars of the Southern Hemisphere.

2. THE OBSERVATIONS

In 1980 the authors started an infrared observing program at the European Southern Observatory, Cerro La Silla, Chile, using the 1.00m telescope equipped with an InSb-photometer developed by the Max Planck Institut für Radioastronomie, Bonn (ESO, 1979). The 1μ-5μ observations have been collected during three nights in May 1980. Chopping was used at a frequency of 30 Hz with a throw of 13".

The observations have been reduced in the classical way, using at least two measurements of each of the 10 standards of the list of Wamsteker (1980a) to transform the measurements to the Johnson system.

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* based on observations made at La Silla.

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3. DISCUSSION

All of the observed WR stars emit excess infrared radiation. This is illustrated by the H-L, v-L diagram in figure 1. The reddening line taken from Hackwell et al. (1974), corresponds to a colour temperature of 30000 K at v, reddened using the reddening law derived by Whitford (1958). The colour-excess ratios for Van de Hulst's curve n°15 (Johnson, 1968) and the ratios $A_V = 4.1\ E_{b-v}$; $A_V = 3.0\ E_{B-V}$ and $E_{B-V} = 1.23\ E_{b-v}$ (van der Hucht et al., 1981) were used to determine the corrections for interstellar reddening; $A_J = .21\ A_V$, $A_H = .10\ A_V$, $A_K = .07\ A_V$, $A_L = .03\ A_V$, $A_M = .01\ A_V$. The intrinsic (b-v) colours listed by van der Hucht et al. (1981) have been used.

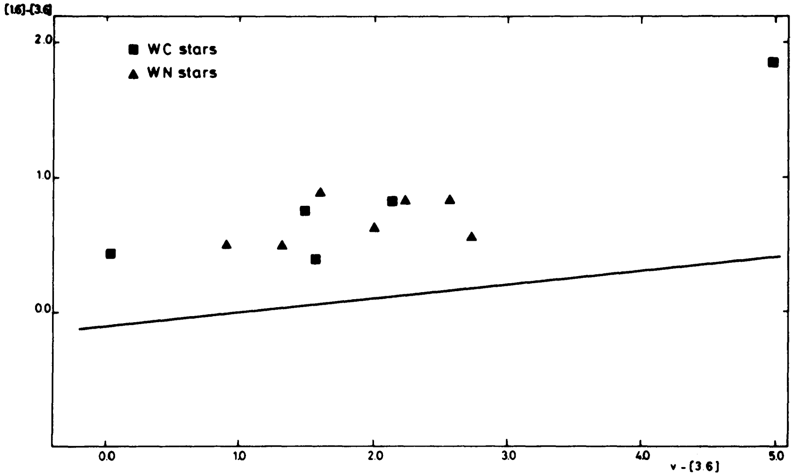

Figure 1. H-L, v-L diagram for the observed WR stars

Decomposing the observed spectral distribution of a WR star by subtracting the Rayleigh-Jeans tail of the black body energy distribution and interpreting the obtained difference spectrum in terms of free-free emission from a hot interstellar shell or a cool black body is a classical procedure used by many investigators (Allen et al., 1972; Hackwell et al., 1974; Gehrz and Hackwell, 1974; Cohen et al., 1975; Williams et al., 1978; Williams and Antonopoulou, 1979; Persi et al., 1979). Even long-period infrared light variations have been interpreted by Hackwell et al. (1976) in terms of a secular decrease in the electron densities, radii and mass loss rates of the circumstellar shells of their stars using a free-free emission model.

The procedure however contains a number of uncertainties: the observational errors on the photometric indices, the fit of the Rayleigh-Jeans tail of the black body energy distribution representing the stellar spectrum in the infrared, the interstellar reddening corrections, and the eventual contamination of the observed photometric indices by emission lines in the infrared part of the spectrum. We briefly discuss the consequences of these uncertainties.

1) Observational errors

Table 1 lists the procentual errors of the absolute flux calibration of the JHKLM system as derived from Wamsteker (1980b)(for the error in v the indicated quantity for V was taken), the standard deviation of a single observation in v (from $\sigma(b) = .02$, $\sigma(b-v) = .01$; Smith (1968b)) and in the infrared colours (from Engels et al., 1981), and the resulting mean error in log (λF_λ) for a star of magnitude 7 in all colours. The table clearly indicates that the errors on log (λF_λ) increase with wavelength. Since the Rayleigh-Jeans tail of the stellar energy distribution near J, H and K lies closer to the measured stellar distribution, the larger error at M does not matter so much. A difference of .04 in $\log(\lambda F_\lambda)$ at J or K however will significantly change the blue tail of the difference spectrum and its interpretation in terms of an optically thin free-free curve or a black body curve.

$\lambda(\mu)$	% error in F_λ	σ (phot)	$\sigma \log(\lambda F_\lambda)$
.516	1.1	.020	.01
1.25	1.9	.025	.02
1.65	1.7	.019	.02
2.2	2.5	.018	.03
3.6	3.1	.021	.02
4.9	8.7	.028	.05

Table 1. Procentual errors of the absolute flux calibration, standard deviations of the observed colours, and resulting standard deviation of log (λF_λ).

2) The representation by a black body curve of the stellar energy distribution in the near infrared

It is generally accepted that the v(.516) magnitude represents the continua of WN stars very well (Westerlund, 1966), but the contribution of the emission lines in the visible part of the spectra of WC stars to the measurements in the narrow-band photometric system cannot be fully avoided (Westerlund, 1966).

Hence the fit of the red tail of a black body curve through the observed v point is a doubtful procedure in the case of WC stars. An upward shift of one mean observational error in $\log(\lambda F_\lambda)$ may sometimes reduce the infrared excess at J to 0. Such a shift will also influence the blue wing of the difference spectrum. It should be stresses that the only acceptable way to determine an unbiased position of the Rayleigh-Jeans tail of the stellar energy distribution is to fit the curve to flux values derived from scanner measurements in the visual, as has been done by Cohen et al. (1975). The continuum should be defined using emission-line free portions of the scanner data.

3) The interstellar reddening corrections

Although one may conclude that only one mean interstellar reddening law exists for our galaxy (Hackwell and Gehrz, 1974; Schultz and Wiemer, 1975; Sneden et al., 1978), extreme care has to be taken in adopting the ratio of total to selective extinction R. Gehrz and Hackwell (1974), using R = 3.40 from Hackwell and Gehrz (1974), obtained completely different values for the ratios A_λ/A_V, than those used in this investigation. The importance of this effect is clearly illustrated in figure 2, where the energy distribution of HD 168206 taken from different sources are shown.

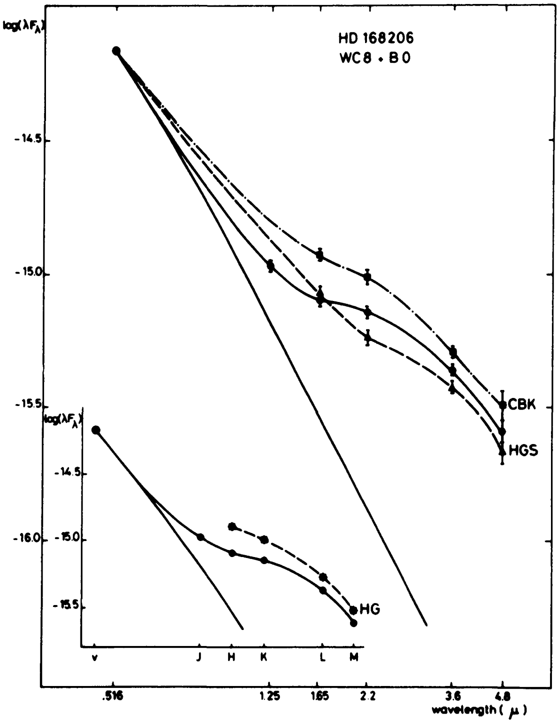

Figure 2. Energy distributions of HD 168206 taken from different sources

The upper curves show the dereddened energy distributions obtained by Cohen et al. (1975), Hackwell et al. (1974) and the dereddened energy distributions obtained from our data. All λF_λ values were normalized to yield a common value at v. The black body stellar energy distribution longward of v is also shown. It should be stressed that the large differences between the energy distributions are not purely due to observational errors and to the procedures used. The standard deviations of a single observation calculated from the data of Cohen et al. (1975), Hackwell et al. (1974) and this paper are $\sigma(H) = 0\overset{m}{.}06$, $\sigma(K) = 0\overset{m}{.}09$, $\sigma(L) = 0\overset{m}{.}04$, $\sigma(M) = 0\overset{m}{.}09$, which exceed the errors given by Engels et al. (1981) by about a factor of three, which might point to infrared light variations in HD 168206. For the sake of comparison Smith's (1968b) intrinsic (b-v) colours for WN and WC stars were used for the construction of this figure. The inset represents (on a reduced scale) the dereddened energy distributions obtained from the measurements of table 1 using the calibration of Wamsteker (1980b), applying the interstellar extinction corrections of Gehrz and Hackwell (1974)(open squares) and the results obtained in this investigation. The difference spectra obtained from these curves will differ at least 50% in H to 10% in M.

4) Contamination of infrared photometric indices by emission lines

Kuhi (1968) studied the near-infrared spectra of WR stars in the .8-1.1μ region at resolutions of 10 Å. The WC stars were found to exhibit emission lines arising from H, He I-II, and C II, C III, C IV. WN stars show only emission lines of He I - He II. In WN stars only a small fraction (10-30%) of the total flux is carried by emission lines in that region, whereas in WC stars this line flux is 30-50% of the total. Cohen et al. (1975), extrapolating from these data, concluded that the contribution of emission lines to the measurements in the infrared broad bandpass filters is negligible. Barnes et al. (1974) reported spectroscopy of γ^2 Vel (HD 68273, WC7+O7) in the region .9-1.7μ and found numerous emission features for the WC component of this star. Bernat et al. (1977) extended the spectroscopy of WN stars to 1.7 μ using HD 50896 and HD 151932 and identified emission lines of He I and He II. Cohen and Vogel (1978) presented 2 to 4 μ spectrophotometry of WC 7-9 stars and listed He I-II, C IV and N III emission lines. Williams et al. (1980) found that low resolution spectra of WR stars in the 1.4 to 2.5 μ region are dominated by He I and He II blends at 1.87 μ and in the WC stars only by a He I line at 2.06 μ. WC stars also show strong unidentified features at 1.7 and 2.4 μ.

These facts clearly indicate that there is no reason to believe that the broad passband JHKLM photometry is not contaminated by the emission lines present.

The observational results and their discussion will be published elsewhere.

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