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NEAR INFRARED PHOTOMETRY AND FREE-FREE FLUXES OF 12 SOUTHERN OB SUPERGIANTS

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RESUMEN

Se presenta fotometría en el cercano infrarrojo (*JHKL*) para 12 estrellas OB supergigantes del hemisferio sur. La presencia de atmósferas extendidas es investigada por medio del análisis del posible exceso de color en las bandas *K* y *L*, el cual se espera sea causado por radiación libre-libre en la envolvente. La mayoría de las estrellas estudiadas muestran excesos de color significativos.

ABSTRACT

Near infrared photometry is presented for 12 OB supergiant stars in the southern hemisphere. The presence of extended atmospheres is investigated by means of an analysis of possible color-excess in the *K* and *L* bands, expected to be caused by free-free radiation in the envelope. Most of the studied objects show significant color-excess.

Key words: STARS-EARLY-TYPE – STARS-SUPERGIANTS – IR PHOTOMETRY

I. INTRODUCTION

Early-type stars with high mass-loss rates are expected to emit detectable free-free radiation from the expanding envelope (cf. Wright and Barlow 1975; Panagia and Felli 1975). In this paper, the near infrared photometry (NIR) of 12 southern OB supergiants is presented and their color-excesses in the *K* and *L* bands are derived. It is assumed that these color-excesses are produced by free-free radiation in the envelope. The sample consists of supergiant stars instead of very early O or Of-type stars because NIR excess is easier to detect in stars with high mass-loss rates, slow wind acceleration, and dense envelopes (e.g., Groot and Thé 1983). The two latter characteristics are not met by very early (O and Of) stars where fast accelerated winds with a rapid decrease in the particle density of the envelope are normally present. In section II the observations are presented, results are described in section III, and a brief general discussion is given in section IV.

II. OBSERVATIONS

Near infrared $J(1.25\,\mu m)$, $H(1.65\,\mu m)$, $K(2.2\,\mu m)$ and $L(3.5\,\mu m)$ photometry of the stars listed in Table 1 was obtained on the South African Astronomical Observatory (SAAO) 1.9-m telescope. The MK I near infrared photometer (Glass 1973) was used with focal plane chopping in a north-south direction with a throw of 70 arcsec; the aperture size was 12 arcsec. The *JHKL* magnitudes obtained are on the SAAO *JHKL* system which is based on a revision of the standards of Glass (1974). Filter characteristics are given elsewhere (López and Walsh 1984). Table 1 lists the HD numbers of the observed stars together with the observed *JHKL* magnitudes and their standard deviations.

TABLE 1

OBSERVED MAGNITUDES

HD	*J*	*H*	*K*	*L*
104565	8.40 ± 0.01	8.30 ± 0.01	8.21 ± 0.02	8.55 ± 0.12
122879	6.13 ± 0.01	6.08 ± 0.01	6.05 ± 0.01	6.03 ± 0.02
123008	7.95 ± 0.01	7.82 ± 0.01	7.73 ± 0.01	7.84 ± 0.05
146628	8.67 ± 0.01	8.47 ± 0.01	8.35 ± 0.01	8.67 ± 0.09
149038	4.69 ± 0.02	4.66 ± 0.02	4.63 ± 0.03	4.59 ± 0.02
151018	7.40 ± 0.02	7.17 ± 0.01	7.04 ± 0.01	7.00 ± 0.03
152003	6.16 ± 0.01	6.05 ± 0.02	5.96 ± 0.01	5.85 ± 0.03
152147	6.40 ± 0.02	6.27 ± 0.02	6.18 ± 0.01	6.16 ± 0.03
152249	5.98 ± 0.02	5.93 ± 0.02	5.86 ± 0.03	5.81 ± 0.03
152424	5.31 ± 0.01	5.20 ± 0.01	5.11 ± 0.02	5.06 ± 0.02
154368	5.13 ± 0.03	4.91 ± 0.01	4.81 ± 0.01	4.69 ± 0.01
154811	6.01 ± 0.02	5.90 ± 0.02	5.81 ± 0.01	5.73 ± 0.03

III. RESULTS

In deriving the free-free fluxes, a procedure similar to the one described by López and Walsh (1984) for the supergiant star ζ^1 Sco has been followed. Relations (2) and (3) from Barlow and Cohen (1977) have been used to compute the *K* and *L* colors that are predicted in the case of no excess flux. The $(V-K)_0$ and $(V-L)_0$ intrinsic color indices have been calculated for each particular spectral type with relation to A5 and A6 of the same authors. The effective temperature and $(B-V)_0$ scale for the observed stars has been adopted from Table 2 of Böhm-Vitense (1981). The T_{eff} used corresponds to

TABLE 2

PREDICTED *K* AND *L* MAGNITUDES

HD	Sp. type	$-M_V$	*V*	*B–V*	$E(B-V)$	*K*	*L*
104565	O9.7 Ia	6.3	9.25	0.34	0.57	8.57	8.60
122879	B0 Ia	6.2	6.37	0.04	0.26	6.54	6.60
123008	O9.5 I	5.9	8.79	0.36	0.60	8.06	8.08
146628	O9.5 Ia	5.8	9.98	0.64	0.88	8.45	8.44
149038	B0 Ia	6.9	4.89	0.08	0.30	4.95	5.00
151018	O9.5 I	6.1	8.71	0.62	0.86	7.24	7.23
152003	O9.7 Iab	6.5	7.03	0.41	0.64	6.16	6.17
152147	O9.7 Ib	6.2	7.27	0.40	0.63	6.42	6.44
152249	O9.5 Iab	6.3	6.48	0.15	0.39	6.34	6.39
152424	O9.7 Ia	7.1	6.32	0.45	0.68	5.33	5.35
154368	O9.5 Iab	7.1	6.13	0.52	0.76	4.94	4.95
154811	O9.7 Iab	6.6	6.92	0.38	0.60	6.13	6.15

the mean values of the temperature scales derived from spectral type and $(B-V)_0$ for the cases of O9.5 and B0, respectively, whereas the value for O9.7 is a linear interpolation of these scales. The values adopted are: 26250 K and $(B-V)_0 = -0.24$ for O9.5; 24850 K and $(B-V)_0 = -0.23$ for O9.7, and 23450 K and $(B-V)_0 = -0.22$ for B0. It is noted that differences of the order of 1000 K on the adopted T_{eff} have no significant consequences in the overall procedure. A standard reddening law with R = 3.1 has been assumed. The selective absorptions in the infrared have been scaled according to the van der Hulst curve No. 15 (Johnson 1968). The predicted *K* and *L* (black body) magnitudes are listed in Table 2 together with the M_V, *V*, and $(B-V)$ magnitudes, the $E(B-V)$ color excess and the corresponding spectral types. The photometric *V* and $(B-V)$ data was taken from Humphreys (1978) for HD 146628, HD 149038, HD 152249 and HD 152003; and from Schild, Garrison and Hiltner (1983) for all the rest. The absolute magnitudes M_V were also either obtained from Humphreys (1978) in all possible cases or derived from Klare and Neckel (1977). Table 3 lists the predicted and observed *K* and *L* magnitudes corrected for interstellar extinction. The difference between the de-reddened, observed and predicted magnitudes is assumed to be due to free-free emission. To obtain the flux densities, S_K and S_L, the calibration of Wilson *et al.* (1972) has been adopted.

It is considered that the S_K and S_L values can be biased by the following factors: (a) The well-known photometric variability shown by all early-type supergiants (cf. Rosendhal 1973). Different sources report different photometric *V* and $(B-V)$ values for most of the stars observed, differences being typically of the order of ±0.05 mag in *V*. An effort has been made here to quote values only from two recent sources. (b) The lack of an updated reference calibration system of standard NIR colors. (c) The intrinsic uncertainties associated with the observations. It is estimated that after weighting the different possible contributions from the factors mentioned above only color differences in Table 3 corresponding to values greater than ∿ 0.05

TABLE 3

DE-REDDENED MAGNITUDES AND FREE-FREE FLUX DENSITIES

HD	Sp. type	K_{obs} (mag)	K_{pre} (mag)	L_{obs} (mag)	L_{pre} (mag)	S_K (Jy)	S_L (Jy)
104565	O9.7 Ia	8.05	8.41	8.47	8.52	0.11	0.01
122879	B0 Ia	5.98	6.47	5.99	6.56	0.91	0.46
123008	O9.5 I	7.56	7.89	7.75	7.99	0.15	0.04
146628	O9.5 Ia	8.11	8.21	8.54	8.31	0.03	– 0.03
149038	B0 Ia	4.55	4.87	4.55	4.96	2.40	1.33
151018	O9.5 I	6.80	7.00	6.88	7.11	0.20	0.09
152003	O9.7 Iab	5.78	5.98	5.76	6.08	0.51	0.35
152147	O9.7 Ib	6.01	6.25	6.07	6.35	0.49	0.24
152249	O9.5 Iab	5.75	6.23	5.75	6.33	1.11	0.58
152424	O9.7 Ia	4.92	5.14	4.96	5.25	1.22	0.68
154368	O9.5 Iab	4.60	4.73	4.58	4.84	1.01	0.88
154811	O9.7 Iab	5.64	5.96	5.64	6.06	0.88	0.50

Jy, in the S_K and S_L fluxes can be regarded as a reliable indication of the presence of an infrared color-excess, attributable to free-free emission from the envelope. There is, however, the case of HD 104565 which according to the above criterion does not show a significant S_L flux density. Nevertheless, López and Walsh (1983) have shown that this star (a member of the OBC group) has an extended envelope revealed by a conspicuous emission in Hα. In this particular case, the small value of S_L is most probably due to the low photometric accuracy of the *L* observation (see Table 1). HD 152249, HD 152424 and HD 154811 also belong to the OBC group, whose members have expanding atmospheres (López and Walsh 1983) where infrared free-free emission and mass loss processes are apparent.

IV. DISCUSSION

The results presented in Table 3 indicate that most of the stars in the sample show significant color-excesses and, correspondingly, free-free flux densities, S_ν(f-f). This is a result to be expected for these highly luminous early-type supergiants that presumably undergo high mass-loss rates and have developed an extended envelope. It is interesting to compare, however, with the case of ζ^1 Sco (B1.5 Ia^+) where the detected color-excesses in the *K* and *L* bands and the corresponding S_ν(f-f) (López and Walsh 1984) are much larger than in any of the cases here analysed. The color excess in the near infrared that is attributable to free-free radiation can be related to the stellar mass-loss rate. However, the true detection and relation of the flux density of free-free radiation in the NIR to the mass-loss rate is not as straightforward as it is in the radio regime (cf. Abbot, Bieging, and Churchwell 1982). In the NIR, emission comes from a region where the wind is still being accelerated and, then, one should know the wind's velocity law, v(r). This is not an easy relation to determine, since in some cases where even several good quality spectroscopic *UV* observations are available, the determination of the velocity law proves to be evasive (cf. Wolf and Appenzeller 1979). This is mainly due to the growing knowledge of the variable nature of the stellar wind of early-type stars which precludes determination of smooth, monotonic velocity laws.

Furthermore, no good standard absolute color calibration in the NIR exists yet for early-type stars. Neverless, the method has been shown to be fairly successful in estimating mass-loss rates of a number of OB stars (e.g., Barlow and Cohen 1977; Leitheler *et al.* 1982; Persi, Ferrari-Toniolo, and Grasdalen 1983; López and Walsh 1984) and has stimulated a more thorough study of the general structure of stellar winds (cf. Barlow 1982). One of the most important parameters to determine for an expanding envelope is the spectral index α, where $S_\nu \propto \nu^\alpha$. The knowledge of this parameter together with the distance to the star, allows a good determination of the mass-loss rate and permits to estimate the distribution of particle density and wind velocity through the envelope, without an explicit knowledge of the velocity law. Measurements at several wavelengths in the radio-NIR range ($\sim$ 6 cm-2.2 μm) are needed for a reliable determination of α. The recent availability of radio observations with enough sensitivity, of early-type stars with the VLA and the forthcoming results of the IRAS satellite should produce a wealth of data that are expected to yield significant new information on the structure of the expanding envelopes of OB stars.

In this paper no attempt has been made to derive the mass-loss rate of the sample stars since not enough information exists for most of the objects to work out either the velocity law or the spectral index of the envelope. Instead, it is intended that the data presented here will serve as basis for future studies of the mass-loss processes and envelope structure of OB supergiants.

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