PRELIMINARY RESULTS OF A NEW STUDY OF THE INTRINSIC PROPERTIES OF WOLF-RAYET STARS

David G. Turner
Department of Physics and Astronomy
Laurentian University
Sudbury, Ontario, P3E 2C6, Canada

ABSTRACT. Results are presented of a semi-empirical investigation of the transformation relations between colors and magnitudes in Lindsey Smith's narrow band photometric system for WR stars and their corresponding parameters in the broad band UBV system. A preliminary application of these relations to the study of WR stars in open clusters indicates that the intrinsic colors of WR stars are slightly bluer than the values tabulated by Smith, and that single WN stars are less luminous than previously supposed.

The present paper describes a new attempt to determine intrinsic colors and luminosities for that sample of galactic Wolf-Rayet stars which are members of open clusters or associations. This study is a collaborative effort with Dr. Lindsey Smith, and is not yet complete. However, I will describe here some of the results which have been obtained so far.

The first step has been to reexamine the transformation relations between colors and magnitudes in the broad band UBV system and similar parameters in Lindsey Smith's narrow band system. These were derived previously by Smith (1968) and by Lundström and Stenholm (1979) using approximations to the interstellar reddening law and calculated effective wavelengths for the various filters involved. However, it is now possible to investigate these relations in a semi-empirical manner using the large number of stars that have been observed in both systems.

For input data I have used normal Population I stars observed in the narrow band system and contained in the lists of standards and cluster members observed by Lundström and Stenholm (1980), in the list of standards observed by Smith (1968), and in an unpublished table of Sco OB1 stars also observed by Lindsey Smith. The broad band UBV data for these stars have been taken either from the literature or from my own unpublished observations.

Unfortunately, the filters and photomultipliers which were used by

C. W. H. de Loore and A. J. Willis (eds.), Wolf-Rayet Stars: Observations, Physics, Evolution, 57–61.

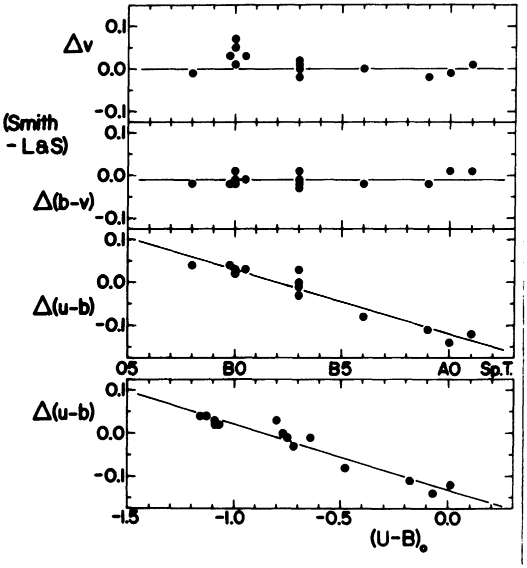

Figure 1. Differences between the narrow band observations of Smith and those of Lundström and Stenholm (L&S) for standard stars in common to both programs.

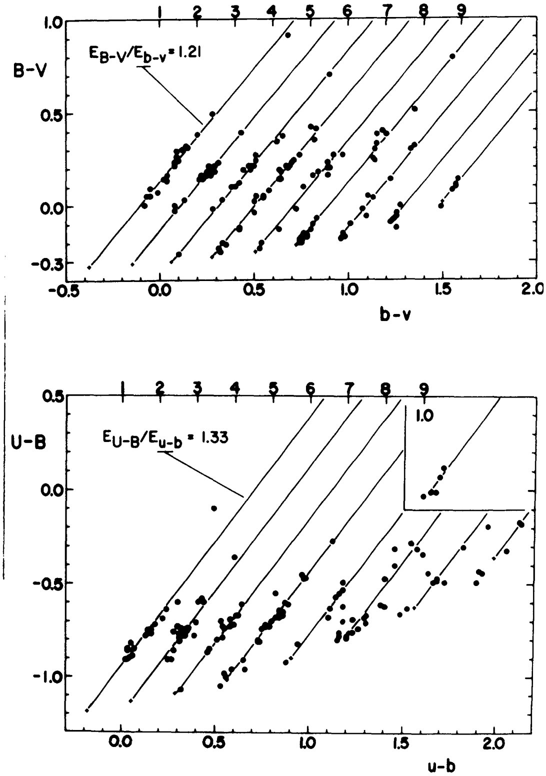

Figure 2. Comparison of broad band and narrow band colors for stars of approximate spectral type O5 (1), O8 (2), B0 (3), B1 (4), B2 (5), B3 (6), B5 (7), B7 (8), and A0 (9).

Lundström and Stenholm in their program do not match those employed originally by Lindsey Smith. The consequences of this can be seen in Figure 1, which is a comparison of magnitudes and colors on the narrow band system for stars in common to both programs. As indicated here, the v magnitudes and b-v colors are in excellent agreement, with only a small difference evident in b-v. The u-b colors exhibit an obvious color dependence, however, and in the analyses that follow I adjusted all of Lundström and Stenholm's colors to their calculated equivalents in Lindsey Smith's system. The u-b corrections were based upon the broad band $(U-B)_0$ colors of the stars, since the differences exhibited minimum scatter when plotted as a function of this parameter.

Reddening differences were examined by separating the stars into 9 groups based upon similarity in intrinsic broad band color. Plots of broad band versus narrow band B-V and U-B colors are shown in Figure 2, where offsets in narrow band b-v and u-b colors have been made to separate the groups. Reddening slopes were derived for each group by the method of least squares, and the assumption was made that uncertainties

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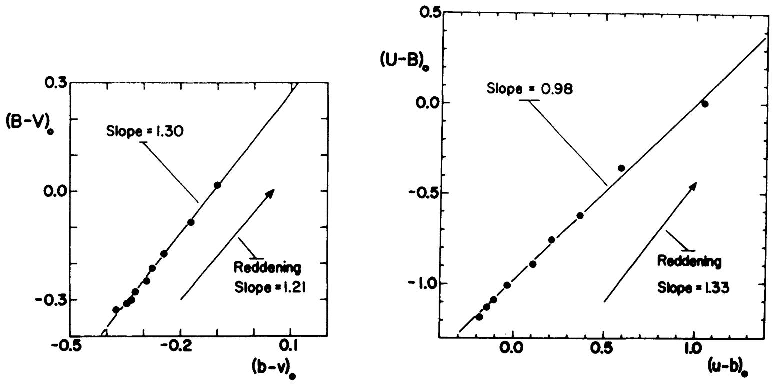

Figure 3. Intrinsic color relationships.

in color in both systems are identical. The adopted reddening relations plotted here are a weighted mean of individual results for groups 1 to 7, since reddening seems to be unimportant in the last two groups. The ratios of broad band to narrow band color excesses were calculated to be E(B-V)/E(b-v) = 1.212 ± 0.013 and E(U-B)/E(u-b) = 1.332 ± 0.032, respectively. By way of comparison, Smith (1968) calculated the slope E(B-V)/E(b-v) to be 1.20, and Lundström and Stenholm (1979) derived a value of 1.21.

Using the above values and a reddening slope of E(U-B)/E(B-V) ≃ 0.75 for the Milky Way, I find a narrow band color excess ratio of E(u-b)/E(b-v) = 0.683. This agrees with the observationally-derived value of 0.69 given by Smith (1968), but disagrees with the value 0.60 found by Lundström and Stenholm (1979).

The relationships between intrinsic colors in the two systems are shown in Figure 3. The effects of temperature differences are very

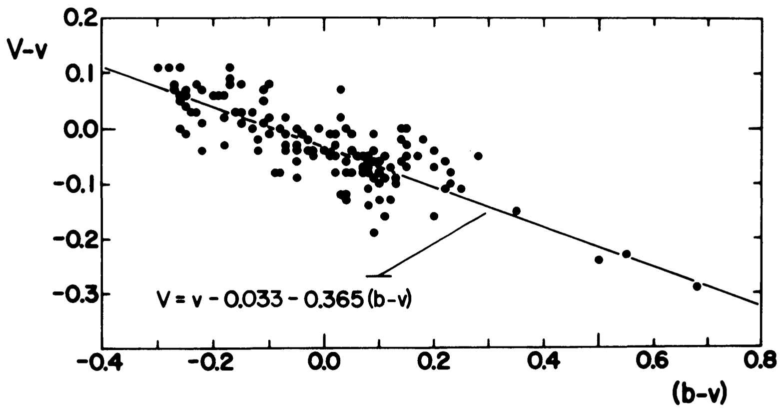

Figure 4. Functional dependence of the magnitudes V and v.

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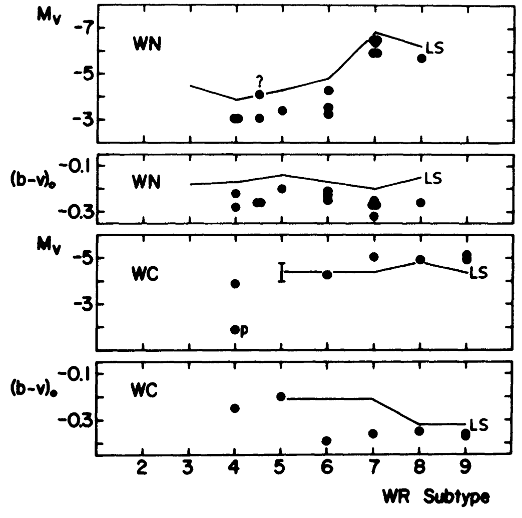

Figure 5. Derived luminosities and intrinsic colors for WR stars which are members of open clusters or OB associations. The relations marked "LS" refer to the values listed by Smith (1973). Other symbols refer to HD 219460 ("?") in the poorly-studied cluster Markarian 50, and to the peculiar WC or WO star ST 3 ("p").

similar to those of reddening for the B-V color, but are less similar for the U-B color.

The difference between the magnitudes V and v is color dependent, as demonstrated in Figure 4. The best fitting regression line plotted here is similar to one given previously by Conti and Smith (1972). The slope enters into the determination of the ratio of total-to-selective extinction for the narrow band system. The value of R' = A(v)/E(b-v) is 4.00 for R = 3.0, 4.12 for R = 3.1, and 4.24 for R = 3.2.

These relations have been used with the data for stars in open clusters and associations containing Wolf-Rayet stars in order to derive reddenings and luminosities for these objects. Results obtained to date are shown in Figure 5. It should be noted that corrections have been made to the luminosities to correct for the effects of early-type companions in many of these systems. It is premature to draw too many conclusions from these data, but two features seem evident — namely that the intrinsic colors of galactic Wolf-Rayet stars are somewhat bluer than the values given by Smith (1968, 1973), and single WN stars are less luminous than previously supposed.

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DISCUSSION

Williams: Can you tell us anything about the intrinsic colours of the OVI stars; especially ST 3 which may be a member of the cluster Dolize 7 (= Berkeley 87) ?

Turner: Unfortunately, I have only broad band photometry for ST 3 and obviously this is contaminated by the strong emission lines in its spectrum. I do have a reddening and distance for this object from its membership in Berkeley 87, and have included it in Figure 5 with a rough estimate of its luminosity. However, until I get information of its intrinsic colours, I cannot tell you anything about its intrinsic colour.

Massey: Aren't you worried about the effect of emission lines ?

Turner: Yes ! However, as you have noted, the contamination problem is less severe for (b-v) than (u-b), and less important for the WN stars as well. I think another problem worth noting is the fact that many of the WN stars used here are composite systems containing O-stars and the colours have not been corrected for the presence of companions in the systems. The reason I have not attempted this is that the derived intrinsic colours are redder than the expected colours for O stars, and any attempt at correcting for the companions yields unnaturally red intrinsic colours for the WN stars. Presumably this problem also originates from the effects of contamination of the colours by emission lines.

Lundstrom: There are no problems with the influence of emission lines in the reddening ratios, since these are derived from ordinary early-type stars. For the intrinsic colours, however, the strong influence of CII emission in the B-filter for late WC stars makes them very blue.

Turner: Yes.