The distance to the luminous blue variable HR Carinae*

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Abstract. The distance of the LBV or hot S Dor type star HR Car has been determined with the reddening distance method of field stars close around HR Car. With $E(B-V)_J \sim 0.9$ the distance amounts to $r = 5$ kpc $\pm$ 1 kpc. The corresponding luminosity $M_{bol} \sim -8.9$ is now more in accordance with the luminosity of other LBV’s.

Key words: photometry – variable stars – supergiants – star: HR Car – distance

1. Introduction

The star HR Car (HD90177) is a luminous blue variable (LBV), or a hot S Dor-type star of spectral type B and a visual magnitude $V_J \sim 8$ (at present). The distance is not well known. Usually the distance is taken to be $\sim 2.5$ kpc, assuming that it belongs to the Carina complex, just like AG Car (Viotti 1971). However, the line of sight to HR Car is almost tangential to the Carina spiral arm, so the luminous stars near the Carina complex may have a very large range in distances. For AG Car the distance based on various methods appeared to be much larger than the canonical distance of 2.5 kpc, making its luminosity more in agreement with that of other LBV’s (Humphreys et al. 1989; Hoekzema et al. 1992). This revised distance removed an important obstacle with respect to the theoretical interpretation of the LBV’s, as being stars close to their Eddington limit.

The luminosity of HR Car, based on the 2.5 kpc distance is too low with respect to other LBV’s. Applying Wolf’s (1989) amplitude-luminosity relation, the distance could be of the order of 6 kpc (van Genderen et al. 1990, hereafter called Paper XI).

In this paper we determine the distance of HR Car by means of the reddening-distance method by multicolour photometry of field stars around HR Car. The same method appeared to be successful for AG Car, because its position is right into the direction of the Carina spiral arm (Hoekzema et al. 1992) just like HR Car. The present paper describes the observations and the results of which a preliminary note is presented at the IAU Symposium 143 at Bali (van Genderen et al. 1991).

2. The observations and reductions

The observations were made with the 90 cm Dutch telescope at the ESO, La Silla, Chile, equipped with the Walraven $VBLUW$ photometer.

Roughly 100 stars within an area of radius $\sim 10''$ around HR Car were selected and measured in one to three nights in the interval April/June 1989 through a 16'' aperture. The limiting magnitude is about 14.5. Integration times for stars as well as for the sky background varied between 2 and 6 min. The extinction coefficients and the calibration constants are based on a large number of standard stars measured each night.

Dependent on the brightness of the star, most of the standard deviations ($\sigma$) varied between 0.005 and 0.050 in $V$, 0.005 and 0.030 in $V-B$ and $B-L$, and 0.010 and 0.050 in $B-U$ (all in log intensity scale). Due to the low signal in the $W$ channel ($\lambda_{eff} = 3235$ A), the colour index $U-W$ could only be applied for blue stars brighter than $\sim 13$th mag. For these ones most of the standard deviations were of the same order as for $B-U$.

Figure 1 shows the identification chart of the field stars around HR Car (= HD90177). A few bright stars also have HD numbers: HD 90087 (= star 1), HD90245 (= star 5) and HD90313 (= star 6).

Table 1 lists the photometric data in the $VBLUW$ system (in log intensity scale) and the $UBV$ parameters $V_J$ and $(B-V)_J$, transformed from the equivalent $V$ and $V-B$ values using the formulae of Pel (1987):

$$V_J = 6.886 - 2.5[V + 0.033(V-B)]$$

$$B - V_J = 2.571(V-B) - 1.020(V-B)^2 + 0.500(V-B)^3 - 0.9010$$

A number of stars marked on the chart are omitted in Table 1 due to bad photometric results (inclusion of optical components, bad centering, etc.) and they are therefore rejected.

3. The reddening and the distances

The method used here is more or less similar to the one used for the field stars of AG Car (Hoekzema et al. 1992). We shall describe it in short here. The three two-colour diagrams enabled an unambiguous determination of the average reddening and spectral type for most of the main sequence stars (Table 2). A few objects are likely supergiants and due to the large uncertainty in their luminosity they are not useful for our purpose. They are also listed

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in Table 2. Due to the relatively large errors in the colours of the faint stars, the reddening and spectral type determination were not always simple: it was sometimes difficult to decide to which part of the main sequence they actually belong. For these cases the reddening-independent two-colour diagrams $[B-L]/[B-U]$ based on Kurucz (1979) models, were consulted (Lub & Pel 1987; Hoekzema et al. 1992). These diagrams reveal temperature and gravity. The gravity is an indication for the luminosity class. Sometimes this method gave a more or less decisive answer, sometimes it did not. For a few stars of the latter case two possibilities were used and listed in Table 2, the others were rejected because of too large uncertainties.

From $V-B$ and $(V-B)_0$ (the latter is corrected for the reddening $E(V-B)$) resulted $(B-V)_y$ and $(B-V)_y$, respectively, and consequently the reddening $E(B-V)_y$, which is listed in Table 2. With the extinction law $R = 3.1$ the extinction could be derived and thus $V_{y0}$. Table 2 also lists the estimated spectral types and luminosity classes derived from the location of the stars in the colour-colour diagrams. With the aid of Schmidt-Kaler's (1982) tables, $M_{V}$ was derived for each star from the estimated spectral type and luminosity class and hence the distance $r$.

4. The reddening-distance diagram

Figure 2 shows the $E(B-V)_y$/log $r$ diagram ($r$ in kpc also indicated) for most of the measured field stars around HR Car. For a few stars two possibilities are plotted and connected by a dotted line. In order to give an impression of the average uncertainty in the distances, some specimen are shown with their individual error bar. The average uncertainty in the reddening is $±0.05$. The error bar for one star with a much larger uncertainty is drawn also.

A hand drawn smooth curve is fitted to the data points, suggesting that HR Car's tentative distance of $~6$ pkpc (Paper XI) is probably of the right order. We shall adopt $r = 5$ kpc ($±1$ kpc).
The reddening of HR Car is not precisely known; possibly it is in the order of 1.0 (Paper XI). Because of a possible flatter energy distribution than normal supergiants due to the extended atmosphere, we shall adopt $E(B-V)_J = 0.9 \pm 0.1$.

5. The HR diagram. Discussion

Figure 3 shows the top of the HR diagram for eight LBV's. For Eta Car we adopted the luminosity of the primary object (Davidson & Humphreys 1986). Bracketed numbers are the quasiperiods (P, in days) of their intrinsic micro variations (Paper XI).

For HR Car $M_{bol} = -8.9$ adopting $V_{r,min} = 84^m, E(B-V)_J = 0.9$, an extinction law $R = 3.1, f = 5$ kpc, and the $BC = 1$ based on $T_{eff} = 14000$ K (Paper XI). The $P$ of PCyg ($\sim 18^d$) is deduced from de Groot's (1989) light curve, adopting that two long time scale waves in the light curve (time scale ~4 months) are caused by small LBV eruptions and that the short time scale oscillations superimposed on them are the intrinsic micro oscillations (van Genderen 1991). However this tentative assumption need to be confirmed. Anyway this preliminary value for $P$ fits the $P = const.$ lines for variable supergiants (the four oblique dotted lines) of Maeder (1980) reasonably well, just like those of HR Car, AG Car and R71.

The reasonably good fit of HR Car is also a support for the larger distance, although the temperature determination was based on an empirical relation between the size of the variations of the colour curves and the temperature (Paper XI). An independent temperature determination is highly necessary. More support that the $PLT_{eff}$ relation also holds for LBV's and that the fit of the four specimen in Fig. 3 is no coincidence, has to come from quasiperiods and distances of more objects from this class of variables.

Although the uncertainties are still large, the present evidence supports the higher luminosity of HR Car, necessary to accommodate theoretical considerations.
Fig. 2. The reddening-distance diagram of the stars in the field of HR Car

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