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THE EVOLUTIONARY STATUS OF η CAR BASED ON HISTORICAL AND MODERN OPTICAL AND INFRARED PHOTOMETRY

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Abstract. We present a photometric study of the luminous early-type star η Car. The star's secular brightness increase is due largely to the expansion of the Homunculus. η Car is a LBV with a possible B0.5V companion. The combined effect of Balmer-line emission, and of warm and cold dust radiation explains the star's other light variations.

1. Introduction

η Carinae is a strong emission-line source surrounded by a pure reflection nebula, the Homunculus. It is one of the brightest IR sources in the sky. Its vital statistics are as follows: distance = 2.8 kpc; $L = 6 \cdot 10^6 L_{\odot}$; $T_{eff} = 30000$ K; $M \simeq 100 - 150 M_{\odot}$.

2. Observations

We used photometric data from different observers covering the period 1935 - 1992 to reconstruct η Car's long-term light curve (de Vaucouleurs and Eggen, 1952; Feinstein, 1967; Feinstein and Marraco, 1974; van Genderen and The, 1984; Manfroid *et al.*, 1991, 1993). As an example, Walraven VBLUW photometry covering the period 1974 - 1991 is shown in Figure 1.

Quite apart from several short-term variations in brightness, the light curve shows a secular rise which is shown in Fig. 2. Observations were averaged over each observing season, corrected for aperture effects, and transformed to Johnson V (V_J). This gives a homogeneous light curve for the period 1952 - 1992. The 1935 - 1952 period is covered by photographic observations transformed to V_J taken from O'Connell (1956).

The secular rise in brightness since 1952 cannot be explained by evolutionary effects because these predict $\Delta V = 0.^m025/\text{century}$ (Maeder and Meynet, 1987), whereas the observed rise is $2.^m46/\text{century}$.

Fig. 1. Walraven VBLUW light curves, 1974 - 1991. Note (i) the different kinds of long and short time scale variations; (ii) the gradually rising mean brightness (secular light variation).

The expansion of the Homunculus at $\sim 750 \text{ km s}^{-1}$ causes a decrease of the circumstellar extinction (CSE) which can be calculated assuming that each layer expands homologously. The resulting light curve is also shown in Fig. 2. The CSE curve fits the observations very well. However, considering the colour variations of η Car, while these go in the right direction (i.e. η Car is getting bluer) they do show some abnormalities which are probably due to the varying influence of emission lines (see below).

η Car also shows S Dor-type light variations with some differences as follows: (i) η Car has outbursts on a shorter time scale of 1 to 3 years only; (ii) η Car's outbursts have smaller amplitude of $\sim 0.^m2$ only; (iii) η Car's outbursts show flux excess in the L and U bands. We conclude that η Car is either an S Dor variable or an LBV, with some additional source of variation in the ultraviolet.

3. Tentative Explanation

Due to continuous mass loss of the LBV, a nearby emission region is replenished continuously but at a variable rate. This emission region surrounds either the LBV or a companion. In the latter case a hot spot may be part of the system. An optically thin disk will radiate mostly in spectral lines with a $T_{\text{eff}} < 10000 \text{ K}$. An optically thick disk will radiate mostly in the continuum with a $T_{\text{eff}} > 10000 \text{ K}$. Thus, it is possible that the physical state of the emission region is changing as a function of the amount of infalling matter.

Bath's (1979) model of η Car has an accreting massive main-sequence star in a binary with $L_{\text{disk}} \simeq 10^{29} - 10^{32}$ if $\dot{M} = 10^{-6} - 10^{-2} M_{\odot} \text{ yr}^{-1}$. This is similar

Fig. 2. η Car's secular light variation; 1962 - 1992: seasonally averaged photoelectric photometry; $\diamond$: m_{vis} from de Vaucouleurs and Eggen (1952); pre-1952 dots: adapted photographic observations of O'Connell (1956); +: light curve due to the decrease in circumstellar extinction (CSE) according to the text.

Fig. 3. Amplitude (A) versus $1/\lambda$ for η Car during the period 1971-1992 (fat line, broken at $\lambda > 3\mu\text{m}$). The dotted curve represents the increase in amplitude caused by the central emission regions.

to our above figures for η Car with the observed variations in the L, U and W bands of $\sim 3 \cdot 10^{29}$ W fallin within the above predicted range.

Fig. 4. a: A schematic model of the η Car system; b: details of the central binary. Note that the radius of the Homunculus is ≈ 23000 AU, extending far beyond this picture.

4. Could η Car be a Binary?

A close inspection of the light curve shows ten minima of short duration (a few days?) which are most pronounced ($\sim 0.^m1$) in the UV and sometimes invisible at optical wavelengths. Analysis gives $JD_{min} = 2447631.39 + 52.^d38E$ with a standard error in JD_{min} of $\simeq 6.^d7$.

There are, however, a few problems with the binary model: (i) relatively large errors in the O-C values of JD_{min} occur; (ii) the minima vary in depth from one to the other; (iii) some predicted minima are not observed; (iv) a monitoring campaign October, 1992, to July, 1993, did not show any of the predicted minima.

From the depth of the 'eclipses' in the various pass-bands one deduces that the eclipsed body must be a star with spectral type $\sim B0.5V$; i.e. $R=10 - 20 R_{\odot}$, $M \sim 12M_{\odot}$, $\log T_{eff} \simeq 4.45$ and $M_{bol} \simeq -6.2$, at a separation of 1.4 AU.

5. Other Light Variations

In addition to the decrease in circumstellar extinction, we note other variations in brightness. η Car's total brightness variation shows the following differences with respect to the variation resulting from a decrease in CS extinction only: (i) there is excess radiation due to Balmer-line emission at $\lambda \sim 4000 \text{ \AA}$; (ii) there is excess radiation at $\lambda \sim 2\mu\text{m}$; (iii) there is a decrease in intensity at $\lambda > 4 \mu\text{m}$. This is clear from Fig. 3 which shows the total light amplitude (A) versus $1/\lambda$ for η Car during the period 1971-1992 (fat line, broken between the near-IR L and M pass-bands).

We identify the excess at $\lambda \sim 4000 \text{ \AA}$ with either the H II halo, an accretion disk, or a hot spot. The excess at $\lambda \sim 2 \text{ }\mu\text{m}$ is from either a warm-dust halo, the H II halo, or an accretion disk. See Fig. 3 where the dotted curve represents the increase in amplitude caused by the central emission regions. The decrease of the intensity beyond $4 \text{ }\mu\text{m}$ would be due to the expansion of the Homunculus; a 13% increase in the radius of the Homunculus between 1974 and 1992 causes a 27% decrease in the luminosity of the cold dust over the same period.

Reflected optical light also decreases due to Homunculus expansion. This is represented by the line labeled "reflection" in Fig. 3.

The sum of all these effects is capable of explaining the secular brightness increase of η Car.

Further particulars of this investigation will appear in A&A (van Genderen *et al.*, 1993).

References

- Bath, G.T., 1979, *Nature* 282, 274
- Feinstein, A., 1967, *The Observatory* 87, 287
- Feinstein, A., Marraco, H.G., 1974, *AA* 30, 271
- O'Connell, D.J.K., 1956, *Vistas in Astron.* 2, 1165
- Maeder, A., Meynet, G., 1987, *AA* 182, 243
- Manfroid, J. et al., 1991, ESO Scientific Report No. 8
- Manfroid, J. et al., 1993, ESO Scientific Report No. 12
- de Vaucouleurs, G., Eggen, O.J., 1952, *PASP* 64, 185
- van Genderen, A.M., The, P.S., 1984, *SpScRev* 39, 31
- van Genderen, A.M., de Groot, M., The, P.S., 1993, *AA* (in press)