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HD 167971: A BRIGHT MASSIVE CLOSE ECLIPSING BINARY SYSTEM

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ABSTRACT

A combined V light curve of a recently discovered bright massive close eclipsing binary system HD 167971 has been analyzed by Wilson-Dewinney code. Because of a very low amplitude variation in light, no unique solution for the physical and geometrical elements could be obtained. However, evidences are found that the contact or almost contact component stars have comparable masses around 50 M_0 each, and the inclination of the orbit is about 65°. There may be a third component star in the system.

1. INTRODUCTION

Althought extensively observed since 1960's, a bright, luminous, Of-type supergiant HD 167971 has only recently been discovered (by Stahl et al. 1985) to be a close eclipsing binary system. Its brightness in Hiltner's (1965) catalogue of OB stars is $7^m.50$ in standard V filter. Independent UBV photometry has been carried out e.g. by Johnson and Borgman (1963), Johnson (1965) and Moffet and Vogt (1975). The star has been classified as O 7.5 I (f) by Conti and Alschuler (1971) and as O 8 Ib(f)p by Walborn (1972). Yamashita et al. (1977) adopted HD 167971 as an 08 I b(f) standard star for spectral classification, since no spectral peculiarity is exhibited distinguishing this star from other extremely luminous hot stars.

HD 167971 is a member of the well-studied open cluster NGC6604 (e.g. Humphrey 1978). Humphrey's value for the distance of NGC6604 is about 2 kpc. (V_0—Mv = 11.5) which leads to an absolute visual magnitude of $\backsim -7^m.2$ for HD 167971 The average Mv value for the spectral type O 8 I b stars is $\backsim -6^m.2$ which is one magnitude less than Mv based on cluster membership for HD 167971. Such large discrepancy in Mv called attention on this puzzling star. In the IR and visual observations, Leitherer and Wolf (1984) found variability of HD 167971 by $0^m.3$ (see also Leitherer et al. 1984 for UBV and Strömgren photometry). Subsequent observations by Stahl et al. (1985) showed that HD 167971 is a W UMa type eclipsing binary.

In 1985, three observatories (Mount John; Kit Peak; and ESO) joint the observational campaign and all the measurements were combined together after transforming in the usual way from instrumental magnitudes and colours in the UBV (RI) and Strömgren systems (Strupat, 1986). The combined V light curve is shown in Figure 1.

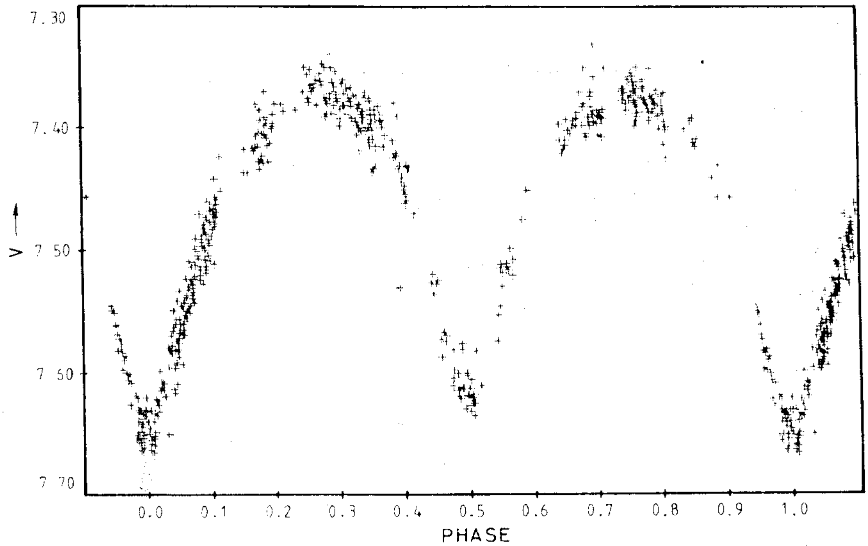

Figure 1 V light curve of HD 169771

In order to better understand the nature of this massive binary I analyzed the V light curve by Wilson-Dewinney (1971) code. In the following section, interpretation of the light variation in terms of the physical and geometrical elements of the system, the results of the light curve analysis and discussions on the results were given.

2. ANALYSIS OF THE V-LIGT CURVE AND DISCUSSION ON THE RESULTS

The overall-shape of the combined V light curve shown in Figure 1 is well represented although some additional points were desirable around certain phases. The light elements used in phase calculation are given by Strupat (1986), as

$$\text{Min I} = \text{JD}2445937.00 + 3^{d}.3213 \times E \qquad 2.1$$
$$\pm 0.03 \qquad \pm 0.0001$$

First glance shows that the light variation is a W UMa type with secondary minimum differs from primary by only $0^m.03$ The amplitude of variation in primary minimum is $\sim 0^m.29$. The mean scatter of individual measurements around the mean light curve is about $0^m.01$ and for some points this scatter is as large as $0^m.1$. The lower brightness seen in Figure 1 around phases 0.2 and 0.7 (just after the primary and secondary eclipses) are probably related to the mass transfer in the system. Such lower levels of brightness may also be caused by purely systematic instrumental error. The collective observations at different vawelengths showed that the colours B-V, U-B, V-R, V-I, V-J, V-H, V-K and V-L are all constant (i.e. phase independent) as expected in contact binaries. Thus, such property of colour curves together with the shape of the light curve imply that the binary HD 167971 is a contact (or almost contact) binary where the transfer of energy through the common envelope equalize the temperatures of the component stars. The binary being in very early spectral type (08 I) should be an A-type in Binnendijk's (1970) classification and thus the primary eclipse is a transit: fainter and smaller (in size) component is eclipsing (in front) star in the perimary eclipse. The brighter primary component being supergiant most probably filled its Roche Lobe and its effective temperature should be 33000–35000°K. The very low amplitude of light variation implies that very shallow (or probably no) eclipse is present. The inclination i of the orbit should also be very low (lower than 70°). It is well known that under such conditions, derived elements through the analysis of the light curves are very much less reliable and especially the mass ratio q is an indeterminate parameter. For further discussion of this problem see e.g. Leung and Schneider (1978). This parameter for HD 167971 should be obtained spectroscopically before the photometric analysis. Such a work has been attempted in a recent paper by Letherer et al. (1987) which appeared after my study was completed. Letherer et al. observed two variable weak component lines at the wings of stationary He II λ 5411 line and interpreted the weak lines as due to a close O-type eclipsing binary with components of comparable masses ($q \simeq 1$), and the stationary lines as due to a O 8 Ib type luminuous third component in the system.

With the hope to determine the physical and geometrical parameters of HD 167971, the V-light curve shown in Figure 1 have been analyzed by using Wilson-Dewinney (1971) code. Above mentioned restrictions on different parameters have been adopted in different modes of light curve solution. To facilitate the solutions, not original observations but

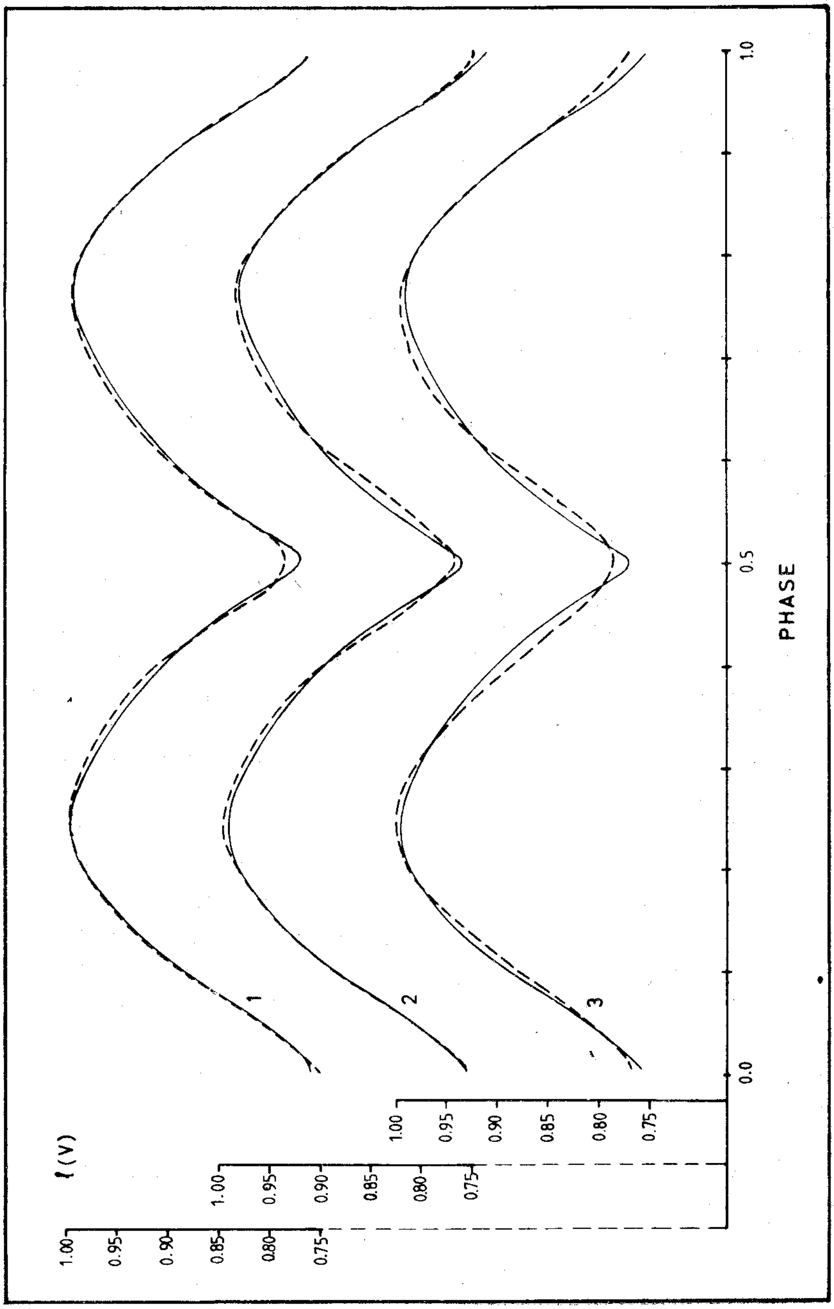

Figure 2 The mean free hand curves (continuous lines) representing the V-observations, and best fit theoretical model light curves (dashed lines) for different set of initial parameters. The best fit parameters for the theoretical curves are given in Table 1 together with the χ^2 values of the respective fits.

discrete points on the mean free-hand curve representing the observations have been fitted by model light curves. For the theoretical light curves q is fixed to different values between 0.2 and unity. It was found that with the present photometric data the light curve solution can not fix the size (the surface potentials $\Omega_{1,2}$ in Wilson-Dewinney code) of the components. Slightly detached, semidetached, contact and even overcontact models are all possible (see Figure 2 and Table 1). However it becomes not possible to fit the shape of the secondary minimum with large inclination $i \geq 70°$ The theoretical curves of secondary minimum comes out to be always broader and less deep in comparison to observational curve, and moreover such discrepancy between theoretical and observed light curves diminishes for smaller values of i (not smaller than 60°) and larger values of q. It is thus fare to conclude that the masses of the component stars of HD 167971 are comparable, and $60° \leq i \leq 70°$.

Table 1. The best fit parameters for the theoretical curves shown in Figure 2

	1 Semi-detact	2 Contact	3 Overcontact
q*	1.0	0.6	0.2
i	64°.25	64°.00	63°.5
Ω_1*	3.750	3.063	2.137
Ω_2	3.390	3.063	2.137
T_1(°K)*	34500	33000	34000
T_2(°K)	30040	31000	32350
L_1	0.553	0.603	0.768
L_2	0.447	0.397	0.232
χ^2	0.00026	0.00025	0.00033

*Mark stands for tbe fixed parameters in the iterative solutions.

Existence of a third component was also allowed by leaving the fractional luminosity l_3 of this component as adjustable parameter in the iterations. The l_3 increases to large values through the iterations but fit does not improve in the secondary eclipse although χ^2 diminishes up to 0.0002. It is interesting however to realize that the larger $q = M_2 / M_1$ and smaller i in the mass function given by

$$f(M_1) = M_1^3 Sin^3 i / (M_1 + M_2)^2 = 1.035{*}10^{-7}\ K_2^3\ P \qquad 2.2$$

requires larger value of M_1. The mass function f $(M_1) = 9.3\ M_0$ for P = 3.32 days and $K_2 = 300$ km / sec from the spectroscopic data (Letherer et al. 1987). Further assumption as q = 1 and $M_1 = M_2 = 50\ M_0$ in Equation 2.2 yield i = 65° which agrees well with the results of photometric analysis. The binary model of HD 167971 with massive components of about 50 M_0, each is supported by the spectroscopic work of Leitherer et al. (1987). They introduced O 8 Ib type luminuous star as a third component. The binary components having very much weaker He II λ 5411 lines should be hotter and thus in earlier spectral type probably late A or early O type main sequence stars.

To make better sense of the physical and geometrical model drawn in this section for the puzzling system HD 167971, further well behaved photometric and high resolution spectroscopic observations are needed.

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