The first photometric analysis of the near-contact eclipsing binary V370 Cygni

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Abstract

The first complete CCD light curves of the eclipsing binary system V370 Cygni with an A0V primary have been obtained in the B, V, R and I filters during 5 consecutive nights in 2005 with the 122-cm telescope at the Kryoneri Station of the National Observatory of Athens. The light curves are analyzed with the W-D program in order to determine the geometrical and physical parameters of the system. These parameters are used to compute the absolute elements of the system. The analysis indicates a semi-detached configuration.

1. Introduction

The binary system V370 Cygni (GSC 02660:02075) was discovered as a variable star by Gengler (1928). Afterwards, it was mainly observed in order to obtain times of minima, as by W. Moschner (in Agerer & Hübscher 1997), Safăr & Zejda (2000) and Hübscher et al. (2005). Shaw (1994) includes it in his second catalog of near-contact binary systems, and Budding et al. (2004) included it in their tables of Algol systems (2004).

2. The observations

The CCD observations of V370 Cygni (Niarchos & Manimanis 2006) were made on five consecutive nights, 9 through 13 July 2005, at Kryoneri Observatory, Greece. The instruments used were the 122-cm Cassegrain telescope of the Kryoneri Observatory and a CCD camera with 528 × 528 pixels binned to 264 × 264 and field of view 2.5′ × 2.5′. The four Bessell B, V, R and I filters were used. An uncatalogued fainter star 1.5′ SSE of the variable was used as comparison star. In total, 281 blue, 282 yellow, 282 red and 284 infrared observations were obtained during the five nights. The probable error of a single observation was estimated to be ± 0.008 mag in infrared and red, ± 0.010 mag in yellow and ± 0.014 mag in blue. One new time of minimum was obtained from our observations.

3. Light curve solutions

We solved the light curves assuming that there are no spots on the components of the system, since no asymmetry indicative of spots is present. All observational points for each color were used in the analysis. The subscripts 1 and 2 refer to the star being eclipsed at primary and secondary minimum, respectively. The PHOEBE 0.28 version (Prša & Zwitter 2005) of the Wilson-Devinney program was used in the light curve analysis.

Since no double-line spectroscopy was available, initial values for the mass ratio (q = 0.42), for the inclination (i = 83°) and for the secondary temperature (T_2 = 6000 K from the spectral type, F9 IV, given) were adopted from the tables by Budding et al. (2004). The fixed value of the temperature T_1 (10000 K) was obtained from the spectral type, A0V, given by Shaw (1994); also, assumed values for gravity darkening coefficients and bolometric albedos according to the spectral types of the components were used. The values of the limb darkening coefficients are automatically interpolated step-by-step by the PHOEBE program according to the Van Hamme (1993) tables. The solutions converged with the Modes 2, 4 and 5 of the program, and they are shown in Table 1; the best fit (minimum χ^2 value averaged for all filters) was achieved with Mode 2, indicating that none of the members fills its Roche lobe. However, this solution gave an unacceptably low value for Ω_2 , i.e. $\Omega_2 < \Omega_{in} = 0.7501$ for q = 0.43572, a value that was used to calculate the radii and luminosities for the Mode 2 solution in Table 1. On the other hand, the Mode 4 (primary fills its Roche lobe) solution has q > 1, indicating that the program has switched star 1 with star 2. Therefore, both Mode 2 and Mode 4 solutions, each in its own way, can be said to point to the Mode 5 solution as the correct one. Therefore, we deduce that, although its χ^2 fit is slightly worse than the Mode 2 fit, the Mode 5 solution gives the true configuration of this binary system, i.e. the secondary does fill its Roche lobe.

The theoretical light curves of our Mode 5 solution, along with the observed ones, are shown in Figure 1. A three-dimensional model of the system and a surface outline are shown in Figure 2. The relatively short distance between the two stars supports the assertion that this is a near-contact system, and therefore it was correctly included by Shaw (1994) it in his second catalog of such binary systems.

4. Absolute elements and evolutionary state

Since no double-line spectroscopy is available, the only way to estimate absolute parameters is to make assumptions about the absolute magnitude or the mass of the primary and use the q obtained photometrically. Assuming that the primary has a mass of 3.16 solar masses, the value for a normal MS star of type A0V, we get the following absolute elements for V370 Cygni in solar units:

$$R_1 = 2.067 \pm 0.008 \quad R_2 = 1.732 \pm 0.010$$
$$L_1 = 38.48 \pm 1.19 \quad L_2 = 3.575 \pm 0.044$$
$$M_1 = 3.16 \quad M_2 = 1.07 \pm 0.08$$

and the bolometric absolute magnitudes:

$$M_{bol(1)} = 0.785 \text{ and } M_{bol(2)} = 3.37$$

According to them, the primary component is located relatively close to the ZAMS line (for stars of solar metallicity) in the mass-radius diagram, indicating an only slightly evolved star, while in contrast the secondary component seems to have evolved clearly beyond the TAMS line, a fact not uncommon among the **near-contact systems**, as was shown by Niarchos & Manimanis (2002); it can be explained by the expanded volume (and thus radius) of the component because of the large tidal forces exerted by the more massive star and their rapid rotation. Equally extreme are the positions of both the primary and the secondary in the mass-luminosity diagram, indicating in the case of the primary a totally unevolved star, while in the case of the secondary a fully evolved star slightly beyond the TAMS line (always assuming solar metallicities). Again, though, they fall within the region occupied by the 16 near-contact systems studied by Niarchos & Manimanis (2002). The reason is what we have called "reflection displacement", which the reflection effect causes in the M-L diagram, moving the cooler (secondary) star up on the L axis and the hotter (primary) star down from its true position on the same axis.

On the other hand, in the H-R diagram the primary lies almost exactly part way between the ZAMS and TAMS lines, and the secondary clearly beyond the TAMS line. In the H-R diagram the "reflection displacement" is also present, but it does not alter the evolutionary position of the stars. An immediate conclusion strengthened from these results is that BF Virginis is definitely a **FO Virginis-type near-contact system** as defined by Shaw (1994), in accordance with the photometric property of having equally bright maxima.

5. Discussion and conclusions

From the results obtained using the W-D program it follows that the system of V370 Cygni is most probably a semi-detached, with the secondary star almost filling its inner Roche lobe. The primary must be clearly detached, because the code gave values for the Ω_1 potential 20.8 % larger than the Ω_{in} value for the final mass ratio we derived. Nevertheless, we can conclude that the system is a FO Virginis-type near-contact binary. Thus, if the generalization by Shaw (1990) holds true, it should not exhibit a period change. As far as the evolutionary state of the system is concerned, the similarity with the A-type W UMa contact binaries suggests that the FO Vir near-contact systems are either precursors or temporarily detached stages of the A-type W UMa systems.

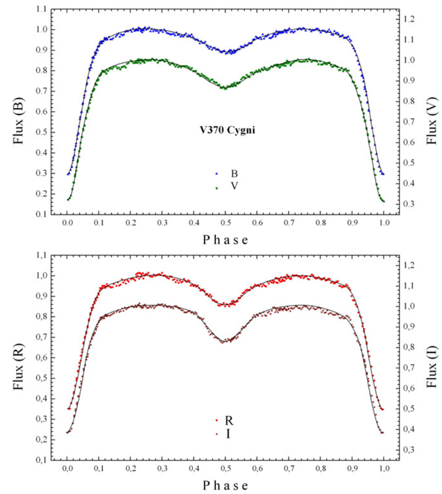

Figure 1: *The observational points and the theoretical light curve fitting for our model (Mode 5).*

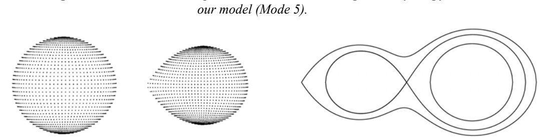

Figure 2. *Left: A 3-dimensional model of V370 Cyg at phase 0.25. Right: Cross-sectional surface outline of the system for our Mode 5 solution. (Both figures were made with the* Binary Maker 2.0 *program, Bradstreet 1993).*

Table 1: Our V light curve solutions

Parameter	Mode 2 solution	Mode 4 solution	Mode 5 solution
i (°)	83.90 (7)	86.16 (18)	89.03 (37)
T_1 (K)*	10000	10000	10000
T_2 (K)	6012 (5)	5219 (14)	6028 (6)
Ω_1	3.4218 (95)	4.3479* ≡ Ω_{in}	3.2403 (57)
Ω_2	2.7091 (103)	6.0511 (597)	2.6834* ≡ Ω_{in}
$q = m_2/m_1$	0.4357 (38)	1.3816 (160)	0.4026 (24)
$L_1/(L_1+L_2)$ (V)	0.8795 (12)	0.9772 (12)	0.8933 (9)
r_1 (volume)	0.3425 (11)	0.4072 (24)	0.3603 (9)
r_2 (volume)	0.3082 (7)	0.2158 (9)	0.3019 (7)
χ^2	0.04995	0.11432	0.05272

*** assumed**

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