A Spotted Model of the Contact system BH Cas

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Abstract

New CCD B,V,R,I observations of the W UMa system BH Cas are presented. New ephemeris based on our times of minima and on recent photoelectric and CCD observations is given. The light curves are analyzed with the Wilson-Devinney program to derive the geometrical and physical parameters of the system. A small O'Connell effect, observed mainly in the V light curve, is explained by introducing a cool spot on the surface of the cooler component. The absolute elements of the system are used to study its evolutionary status. The results show that BH Cas is a fairly evolved W-type W UMa system.

1 Introduction

BH Cas (V=12.58^m, RA=00^{h}21^{m}21^s.4, DEC=+59°09′05″.2 (J2000)) is classified as a W UMa-type system, with a period near 0.5 days and an amplitude of 0.4 mag. The system was originally discovered by S.Beljawsky in 1928 (Beljawsky 1931). For a long time no observations were made of the system due to Ahnert and Hoffmeister (1943) who couldn't find any variability for BH Cas. Later, in 1994 Metcalfe took CCD images of the system that showed clearly its variability. Additionally, in 1999, he managed to obtain radial velocities for the system and determined the following ephemeris for the system:

$$J.D.hel.(MinI) = 2449998.6187 + 0.40589004 \times E \qquad (1)$$

More rescent observations, using the 1.22 m Cassegrain reflector at the Kryonerion Astronomical Station of the National Observatory of Athens, were made in 1998, 1999 and 2000. These observations provided us with complete light curves in B,V,R,I filters for further analysis. The history of BH Cas has been given by Zola et al. (2001).

2 The observations–New ephemeris

In the present work we use the observations obtained in October and November 2000 at the Kryonerion Astronomical Station of the National Observatory of Athens. A total of 173, 206, 253, 283 measurements in Bessell B, V, R and I filters, respectively, were obtained. The light curves clearly show a W UMa-type system. The magnitude difference between the two maxima MaxII-MaxI is almost negligible.

Three times of minima have been computed from our observations using the method of Kwee and van Woerden (1956). These minimum times together with 24 others, already observed either photoelectrically or with a CCD camera, were used to derive the following new linear ephemeris

$$J.D.hel.(MinI) = 2449998.6183(3) + 0.40589160(5) \times E \qquad (2)$$

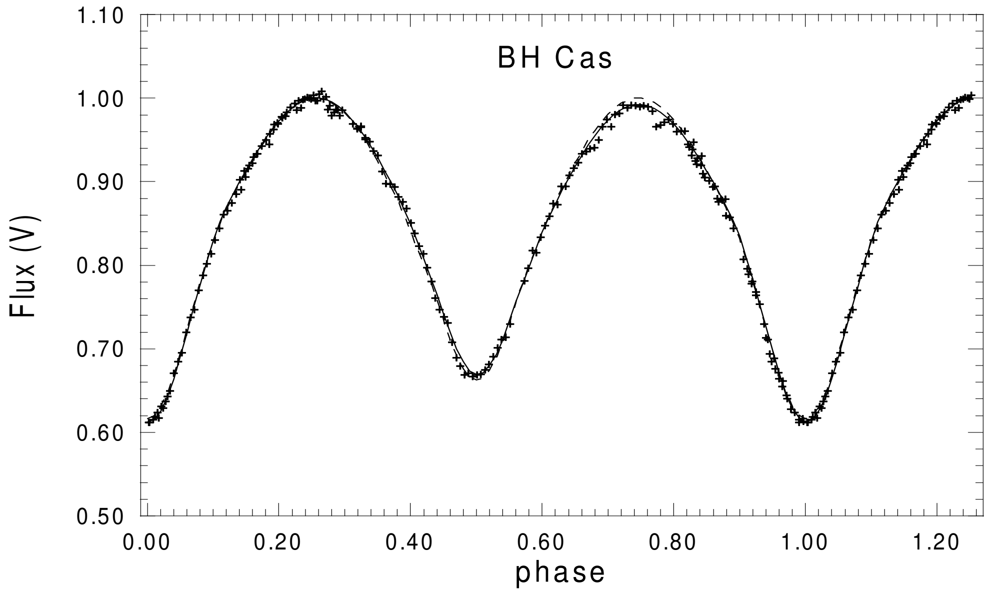

Figure 1: Observed and theoretical light curves of BH Cas in V filter. Observed points are shown by crosses, while theoretical curves by dashed lines (unspotted solution) and solid lines (spotted solution).

3 Light curve analysis and spot modelling

As mentioned before, there is almost no O'Connell effect visible in the light curve. However, there is a small asymmetry around maximum II, thus we decided to introduce a cool spot on the surface of the cooler component. For this system the spectroscopic mass-ratio is available, so we proceed to our analysis in two ways. First, we keep the mass- ratio fixed in its spectroscopic value, and, second, we let the mass-ratio parameter to be free. Whichever the case is, two solutions are presented when analyzing simultaneously the four light curves: the unspotted and the spotted solution.

3.1 Unspotted solution

The 1996 version of the Wilson-Devinney (Wilson 1993) synthetic light curve code was used for the light curve solution. Normal points were used and assigned weights equal to the number of observations per normal. Specifically, we calculated 87, 98, 98 and 99 normal points in B, V, R, I, respectively. In the unspotted solution there are no spots on the components of the system. Assuming that the small asymmetry and the inappreciable decrease of brightness around maximum II is due to a spot, we have to exclude this part of the light curve. For this purpose we excluded the observations in the phase interval 0.66-0.81.

In the subsequent analysis we use all available information of the system, so the following assumptions were made: a mean surface temperature $T_1 = 6000$ K is set, according to the assumed spectral type F8($\pm$2) and the calibration published by Harmanec (1988); bolometric albedos and gravity darkening coefficients were assigned values typical for stars with convective envelopes, which are 0.5 and 0.32, respectively; linear and bolometric limb darkening coefficients were taken from Diaz-Cordoves et al. (1995) and Claret et al. (1995) tables. Third light was assumed to be $l_3 = 0$. The spectroscopic mass-ratio is $q(= m_2/m_1) = 2.105$, where the subscript 1 refers to the hotter component (less massive) and the subscript 2 to the cooler one (more massive).

The following parameters have been treated as free: the temperature of the secondary star, the potentials of the components and the primary component's

Table 1. Light curve solutions of BH Cas

Parameter	unspotted solution	spotted solution
ϕ_0	0.0007 ± 0.0001	0.0006 ± 0.0001
i (degrees)	71.48 ± 0.49	71.81 ± 0.42
$g_1 (= g_2)$	0.32^*	0.32^*
T_1 (K)	6000^*	6000^*
T_2 (K)	5606 ± 5	5611 ± 4
A_1 $(= A_2)$	0.5^*	0.5^*
Ω_1 $(= \Omega_2)$	5.2648 ± 0.0018	5.6280 ± 0.0052
$q = m_2/m_1$	2.1050^*	2.3584 ± 0.0040
$L_1/(L_1 + L_2)$ (B)	0.4201 ± 0.0007	0.4041 ± 0.0007
$L_1/(L_1 + L_2)$ (V)	0.4005 ± 0.0006	0.3865 ± 0.0006
$L_1/(L_1 + L_2)$ (R)	0.3900 ± 0.0005	0.3752 ± 0.0005
$L_1/(L_1 + L_2)$ (I)	0.3804 ± 0.0004	0.3658 ± 0.0004
x_1 $(= x_2)$ (B)	0.766^*	0.766^*
x_1 $(= x_2)$ (V)	0.659^*	0.659^*
x_1 $(= x_2)$ (R)	0.585^*	0.585^*
x_1 $(= x_2)$ (I)	0.504^*	0.504^*
x_1 $(= x_2)$ (bolo)	0.571^*	0.571^*
% overcontact	22%	20%
r_1 (pole)	0.3074 ± 0.0002	0.2970 ± 0.0002
r_1 (side)	0.3226 ± 0.0002	0.3112 ± 0.0002
r_1 (back)	0.3636 ± 0.0003	0.3512 ± 0.0003
r_2 (pole)	0.4297 ± 0.0001	0.4375 ± 0.0005
r_2 (side)	0.4595 ± 0.0002	0.4686 ± 0.0007
r_2 (back)	0.4919 ± 0.0003	0.4994 ± 0.0010
$\Sigma_(\mathrm{res})^2$	0.0040	0.0066
$\mathcal{M}_1/\mathcal{M}_\odot$		0.35 ± 0.07
$\mathcal{M}_2/\mathcal{M}_\odot$		0.73 ± 0.15
$R_1/R_\odot$		0.78 ± 0.06
$R_2/R_\odot$		1.09 ± 0.05
$\log(L_1/L_\odot)$		0.72 ± 0.09
$\log(L_2/L_\odot)$		1.01 ± 0.07

*assumed

luminosity. In these parameters the mass-ratio is added when we determine q photometrically (q_{ptm}). In this case we set the resulting parameters, derived from the solution with the mass-ratio fixed, as starting ones for this search. A preliminary set of the system parameters was obtained with the Binary Maker 2.0 (Bradstreet 1993). The system parameters from the unspotted solution are given in Table 1.

3.2 Spotted solution

Having determined the system parameters from the unspotted solution, we tried to explain the observed light curve asymmetry by assuming one cool spot on the surface of the cooler component. The Binary Maker 2.0 program was used to obtain the preliminary best fit by adjusting the spot parameters: colatitude $b = 90°$, longitude $l = 269°$, angular radius $R = 10.8°$ and temperature factor $T.F. = 0.90$. Then we proceeded with the differential correction search using the entire light curves and as input values those of the parameters derived from the unspotted solution. The system parameters from the spotted solution are also given in Table 1.

A comparison between theoretical and observed light curves of BH Cas in V filter, where the O'Connell effect is larger, is given in Figure 1. Theoretical light curves correspoding to the solutions are presented by lines, while observations by crosses. As one can see, the fit is almost perfect in the unspotted solution (dashed line), with only small departures in maximum just before the primary minimum, and it is even better in spotted solution (solid line). Similar results are obtained in B, R, I filters.

4 Summary and conclusions

New, accurate measurements of the contact binary star BH Cas have been acquired in the B, V, R, I filters. We have chosen a comparison star with colors very close to those of the target star, thus minimizing the effects of the colour extinction term. Our light curves show no significant O' Connell effect. Nevertheless, we introduce one cool spot on the surface of the cooler component, trying to explain the small asymmetry around maximum II.

By using the parameters, derived from the light curve analysis, and the spectroscopic elements of the system given by Metcalfe (1999), we determined the absolute elements listed in Table 1. By using these absolute parameters of BH Cas we can estimate its evolutionary status via the mass-radius (MR), mass-luminosity (ML) and HR diagrams of Hilditch et al. (1998). In all the three diagrams the primary component of BH Cas lies beyond the Terminal-Age Main Sequense (TAMS) and it is oversized and overluminous for its ZAMS mass. This is the possition where primaries of some other W-type W UMa systems (such as AB And, RZ Com, U Peg) are found. This is also the case for the secondary component which occupies the same possition with the secondaries of other W-type W UMa systems (AE Phe, SS Ari, U Peg). The secondary of BH Cas has slightly larger radius and luminosity than expected for its ZAMS mass. These results show that BH Cas is a fairly evolved W-type W UMa system.

W UMa binaries systems are strong coronal X-ray emission sources with their luminosities range from 10^{29} to 10^{30} erg.s^{-1}. Especially, Choi & Dotani (1998) used the ROSAT Position Sensitive Proportional Counter to carry out a spectral survey of 7 X-ray bright W UMa contact systems and found that their luminosities are in the range from 4.4×10^{29} to 3.3×10^{30} erg.s^{-1}. These luminosities are 10^2-10^3 times higher than that of a typical solar flare and it is caused , probably, by the reconnection of the emerging flux with an overlying coronal magnetic field (Priest, Parnell & Martin 1994). X-ray observations for BH Cas showed that the luminosity is less than about 1.1×10^{30} erg.s^{-1} which is inside the above range.

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