BVR CCD photometry and light curve analysis of the eclipsing binary BF Virginis

K.D. Gazeas, V.N. Manimanis, P.G. Niarchos

University of Athens, GR 15784 Zographou, Athens, Greece

Abstract

New CCD light curves of the near-contact binary system BF Virginis with an A2 primary and a K1 secondary have been obtained in the B, V and R filters in March and April 2001 with the new 40-cm telescope of the University of Athens Observatory. The light curves are analyzed in order to determine the geometrical and physical parameters of the system with the W-D program. These parameters are used together with the available spectroscopic data to compute the absolute elements of the system in order to estimate its evolutionary status.

1 Introduction

BF Virginis (= BD+00°3102 = HD 120166 = SAO 139552 = PPM 179142) has been observed by various observers, but they were mainly concerned with times of minima and period study (Kwee 1952 and 1958, Whitney 1955, Fitch 1964, Mallama et al. 1977, Mallama 1980). Mallama & Witt (1976) have derived models of the system based on their own observations, but with the old (rectification) method. Russo & Sollazzo (1981) have re-analyzed the B light curve of BF Vir published by Mallama & Witt using the Wilson-Devinney (1971) program. Lately, Qian et al. (2000) have deduced changes in the orbital period of the system. BF Vir is one of those eclipsing binaries that cannot be easily classified as either near-contact or Algol-type systems. Brancewicz & Dworak (1980) include it in their *Catalogue of parameters for eclipsing binaries* as an Algol-type binary system. Shaw includes it in both his first (1990) and his second (1994) catalogue of near-contact systems as a system belonging to the subclass of FO Virginis, but with uncertainty. According to Shaw (1990), as FO Vir systems are defined those that have a primary component of normal size inside its Roche lobe and a 2 to 3 times oversized secondary at or near its Roche lobe. V1010 Oph are defined as those with a normal primary at or near its Roche lobe and an up to 1.5 times oversized secondary well inside its Roche lobe. Members of the latter subclass often show asymmetrical light curves, while the members of the FO Vir subclass never do. Therefore, we observed the system in order to determine its subclass and evolutionary state, analyzing for the first time its light curves for more than one colors simultaneously with the Wilson-Devinney program.

2 The observations

The CCD observations of BF Vir were made in March and April 2001 (March 4, March 14-16, and April 7, 19, 23 and 24); also in the night of January 10, 2001. The instruments used were the new 40-cm Cassegrain telescope of the University of Athens Observatory and a SBIG-8 CCD camera. The three Bessell B, V, R filters were used. The CCD images obtained were processed with the AIP4WIN photometry program of Berry & Burnell (2000). The stars BD+00°3103 (= HD 120266 = SAO 139561) and GSC 04967-00900 were used as comparison and check stars, respectively. In total, 347 red, 296 yellow and 357 blue observations were obtained during the nine nights. The probable error of a single observation was estimated at ± 0.015 mag in red, ± 0.01 mag in yellow and ± 0.04 mag in blue. Figure 1 shows all the observations made in the whole observing period.

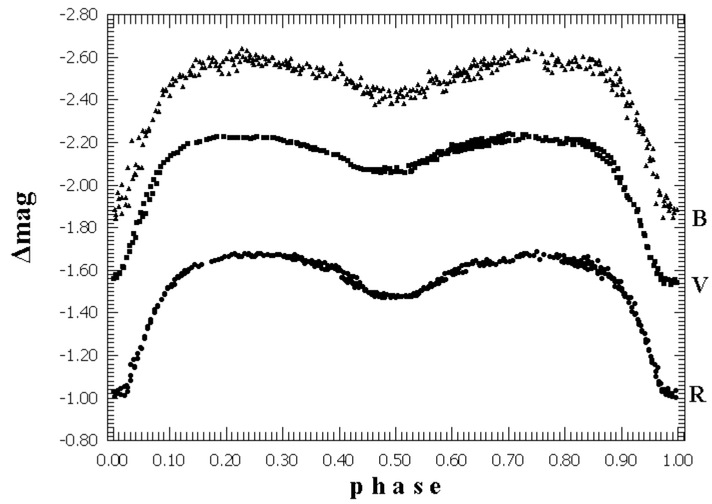

Figure 1. The observed light curves of BF Virginis (January, March and April 2001)

3 Light curve solution

Since the light curves were symmetrical, without any O' Connell effect (unequal maxima) present, we solved the light curves assuming that there are no spots on the components of the system. 150 normal points were formed from the individual observations and assigned weight equal to the number of observations per point. The subscripts 1 and 2 refer to the star being eclipsed at primary and secondary minimum, respectively. The 1996 version of the Wilson-Devinney (WD) program was used for the light curve analysis. A q-search with the WD program gave a starting value of q = 0.5. A preliminary set of input parameters was found using *Binary Maker 2.0* (Bradstreet 1993); the results converged with all the modes of the program that were tried, namely Modes 2, 4 and 5. The adjustable parameters were: the conjunction phase , the inclination i, the temperature T_2 of the secondary, the non-dimensional surface potential Ω_1 (Mode 5), or Ω_2 (Mode 4) or both Ω_1 and Ω_2 (Mode 2), and the non-normalized monochromatic luminosity L_1. The fixed parameters were: the mass-ratio $q = M_2/M_1$ and the temperature T_1 (from spectroscopy). Assumed values for limb darkening, gravity darkening and bolometric albedos, according to the spectral types of the components, were used. Third light was assumed to be zero. The results are given in Table 1. The errors given are the calculated standard deviations.Theoretical light curves based on the model and observed ones (normal points) are shown in Fig. 2. A three-dimensional model of the system is given in Fig. 3.

4 Evolutionary state

From our Mode 2 solution and the spectral type of the system, we obtained the following absolute elements in solar units:

$R_1 = 2.00 \pm 0.03$ $\quad R_2 = 1.57 \pm 0.04$
$L_1 = 26.29 \pm 0.97$ $\quad L_2 = 1.35 \pm 0.10$
$M_1 = 2.55 \pm 0.17$ $\quad M_2 = 1.35 \pm 0.09$

and the bolometric absolute magnitudes: $M_{bol(1)} = 1.20$ and $M_{bol(2)} = 4.42$

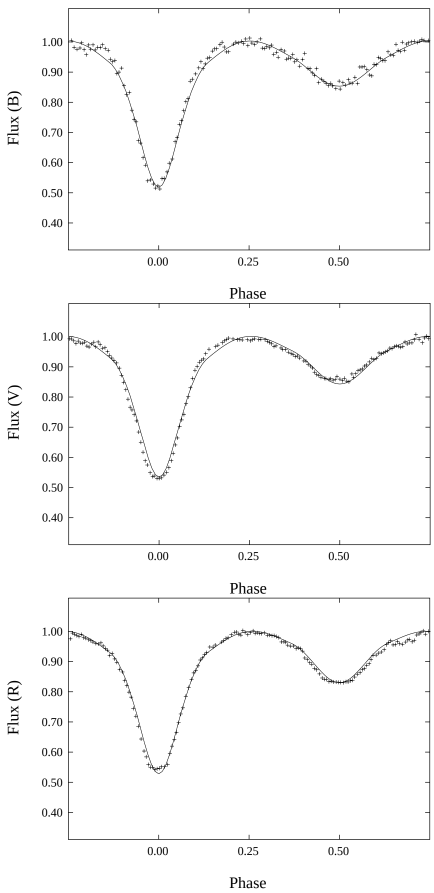

Figure 2. Normal points and theoretical light curves (Mode 2)

Table 1. Unspotted light curve solutions of BF Vir

Parameter	Mode 2	Mode 4	Mode 5
ϕ_0	0.0051 ± 0.0002	0.0048 ± 0.0002	0.0051 ± 0.0002
i (degrees)	76.59 ± 0.57	76.49 ± 0.17	76.80 ± 0.35
g_1	1.00^*	1.00^*	1.00^*
g_2	0.32^*	0.32^*	0.32^*
T_1 (K)	9230^*	9230^*	9230^*
T_2 (K)	4961 ± 69	5193 ± 54	5059 ± 63
A_1	1.0^*	1.0^*	1.0^*
A_2	0.5^*	0.5^*	0.5^*
Ω_1	3.0795 ± 0.0363	2.9235^*	3.0370 ± 0.0323
Ω_2	2.9602 ± 0.0292	2.6446 ± 0.0030	2.8722^*
$q = M_2/M_1$	0.5304 ± 0.0155	0.4330 ± 0.0030	0.4981 ± 0.0155
$L_1/(L_1+L_2)(B)$	0.9722 ± 0.0071	0.9620 ± 0.0039	0.9684 ± 0.0051
$L_1/(L_1+L_2)\ (V)$	0.9511 ± 0.0087	0.9373 ± 0.0044	0.9461 ± 0.0060
$L_1/(L_1+L_2)\ (R)$	0.9237 ± 0.0104	0.9070 ± 0.0045	0.9176 ± 0.0068
$X_1(bolo)$	0.641^*	0.641^*	0.641^*
$X_2(bolo)$	0.578^*	0.578^*	0.578^*
$X_1\ (B)$	0.607^*	0.607^*	0.607^*
$X_2\ (B)$	0.862^*	0.862^*	0.862^*
$X_1\ (V)$	0.531^*	0.531^*	0.531^*
$X_2\ (V)$	0.759^*	0.759^*	0.759^*
$X_1\ (R)$	0.429^*	0.429^*	0.429^*
$X_2\ (R)$	0.621^*	0.621^*	0.621^*
r_1(volume)	0.4074 ± 0.0022	0.4167 ± 0.0024	0.4087 ± 0.0032
r_1 (pole)	0.3869 ± 0.0034	0.3967 ± 0.0004	0.3887 ± 0.0029
r_1 (point)	0.4580 ± 0.0060	0.4616 ± 0.0015	0.4561 ± 0.0047
r_1 (side)	0.4062 ± 0.0040	0.4168 ± 0.0006	0.4080 ± 0.0033
r_1 (back)	0.4270 ± 0.0043	0.4352 ± 0.0008	0.4277 ± 0.0035
r_2(volume)	0.3195 ± 0.0025	0.3370 ± 0.0023	0.3203 ± 0.0025
r_2 (pole)	0.3001 ± 0.0086	0.3081 ± 0.0018	0.2995 ± 0.0024
r_2 (point)	0.3902 ± 0.0528	–	0.4288 ± 0.0828
r_2 (side)	0.3127 ± 0.0104	0.3245 ± 0.0023	0.3126 ± 0.0026
r_2 (back)	0.3426 ± 0.0164	0.3733 ± 0.0048	0.3451 ± 0.0025
$\Sigma(\text{res})^2$	0.0003530	0.0003715	0.0003566

*assumed

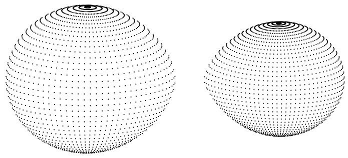

Figure 3. Three-dimensional model of BF Virginis at phase 0.25

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 the secondary component seems to have evolved halfway between the ZAMS and the TAMS lines, occupying an intermediate position among the secondaries of the sample of Hilditch et al. (1988). More extreme are the positions of both the primary and the secondary in the M-L diagram, indicating two totally unevolved stars (always assuming solar metallicities). 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 beyond the TAMS line.

5 Summary and conclusions

From the results obtained using the WD program it seems more probable that the system of BF Vir is detached, with the secondary almost filling its inner Roche lobe. The primary must also be near the limits of its lobe, because the code tended to give values for the Ω_1 potential close to the Ω_{in} value for the final mass ratio we derived. The solution from Mode 5 of the WD program could also be used, since the $\Sigma(\mathrm{res})^2$ was only slightly larger than in the case of Mode 2. Then it would be assumed that the secondary exactly fills its Roche lobe. Either way, we can conclude that the system is an FO Virginis system. It is therefore interesting that Qian et al. (2000) have deduced changes in its orbital period, since, if the generalization by Shaw (1990) is true, it shouldn't change its period. From the evolutionary point of view, the similarity with the A-type W UMa contact binaries, as supported also by this study, suggests that the FO Vir near-contact systems are either precursors or temporarily detached stages of the A-type W UMa systems.

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