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Photoelectric photometry of the unusual eclipsing binary system FF Aquarii

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Abstract. FF Aqr is the first eclipsing binary (P = $9^d.2$) containing a hot subdwarf (sdOB) and a chromospherically active cool giant component classified as a G8-K0 III star. We observed the system in U, B, V and R filters during 2002, 2003 and 2004 observing seasons using two different telescopes and detectors. We obtained a total of 1171 observational points in each colour. The light curve reveals that FF Aqr has a totality in the primary eclipse, which lasts about $13^h\ 02^m$. The shape of the light curve indicates that FF Aqr is an Algol type binary. The light curves display an asymmetrical wave-like distortion at outside of the eclipse which has a minimum at about $0^P.46$ and a light amplitude of $0^m.050$, $0^m.204$, $0^m.277$, $0^m.282$ in the U, B, V, and R bands, respectively. This variation can not be explained by the reflection effect alone. We used the Wilson-Devinney code for the geometric and physical parameters of the system. The asymmetry at outside of the eclipse light variation and the results obtained from the light curve analysis were discussed.

Key words. Stars: eclipsing binary – Stars: spots, hot subdwarf

1. Introduction

FF Aqr is the first eclipsing binary (P=$9^d.2$) containing a hot subdwarf (sdOB) and a chromospherically active cool giant component classified as a G8-K0 III star. Hot subdwarf stars are generally believed to be the helium burning stars (the mass of He core is about 0.50 solar masses), covered with a very thin hydrogen shell (about 0.02 solar masses). sdB and sdOB stars are thought to be extremely blue horizontal branch stars, which evolved (like HBB stars) from red giants. They form a relatively narrow sequence at the blue end of the horizontal branch (HB), and are therefore often referred to as Extended Horizontal Branch Stars (EHB). The major difference to normal HB stars is the fact that they do not evolve to the asymptotic giant branch. sdO stars are in a post asymptotic giant branch phase of evolution. Another evolutionary scenario predicts hot subdwarf stars as the product of two-merged white dwarf stars. Generally, hot subdwarfs are immediate progenitors of white dwarfs. Nowadays there are a few systems contain a hot subdwarf and a cool giant component. One of them is FF Aqr. The observations of these systems are very important for the evolution of the hot subdwarf, studying the activity of cool giant stars and also for testing the evolution models.

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2. Observations

We observed the system photoelectrically in UBVR filters during three observational seasons in 2002, 2003 and 2004. The observations were carried out mainly with the 48-cm Cassegrain telescope equipped with a high-speed three-channel photometer (HSTCP), using three cooled Hamamatsu R1463P PMTs. Because of the optical design of HSTCP we could use only one comparison star. Therefore, some observations were made with the 30 cm Schmidt-Cassegrain telescope equipped with SSP-5 photometer (including Hamamatsu R4457 PMT) at Ege University Observatory to check whether the light of the comparison star changes or not. We used BD -03^o 5361 (B=10^m.7, V=9^m.4, Sp. K0) and BD -03^o 5353 (B=9^m.7, V=9^m.2, Sp. F2) as the comparison and check stars, respectively. These observations indicated that the light of the comparison star was constant. We obtained 1171 data points in each filter during two observational seasons. Following traditional reduction procedure, we obtained differential magnitudes, in the sense variable minus comparison, and then corrected for atmospheric extinction. The extinction coefficients were calculated for each band using the observed magnitudes of the comparison star. The times were also reduced to the Sun‘s center. The shape of the light curve indicates that FF Aqr is an Algol type binary. The light curve reveals that FF Aqr has a totality in the primary eclipse, which lasts about 13^h 02^m. The ingress and egress take 25 minutes. The duration of eclipse is 13^h 52^m. The depths of eclipse in U, B, V and R filters are 1^m.20, 0^m.26, 0^m.09 and 0^m.06, respectively. We determined the new light elements using the times of ingress and egress as follows:

$$MinI = HJD2452844.8186(7) + 9^d.207763(3) \times E \quad (1)$$

We calculated the orbital phases using this ephemeris. The light curves obtained in each filter display an asymmetrical wave-like distortion at outside of the eclipse. This distortion has a minimum at phase 0.46 and the amplitudes of the wave are 0^m.050, 0^m.204, 0^m.277, 0^m.282 in the U, B, V, and R filters, respectively.

3. Analysis of the light curves

The analysis was made by the Wilson-Devinney code, first presented in 1971 by Wilson-Devinney (1971) and revised by Wilson (1994). The light curves obtained in 2003 were analysed simultaneously in U, B, V and R filters. We derived the temperature of the cool component, using B-V colour in totality, as T_c=4441 K (Allen 2000). Thus, the first adopted parameter is T_c. The other adopted parameters for the analysis are the limb darkening coefficients (X_h=0.242 and X_c=0.962 (U), X_c=0.932 (B), X_c=0.844 (V) and X_c=0.728 (R), respectively (Diaz-Cordoves et al. 1995)), gravity darkening coefficients (g_h = 1 and g_c = 0.32 (Lucy 1967)) and albedo values (A_h =1 and A_c = 0.5 (Rucinski 1969)). The adjustable parameters are the mass ratio (q), the orbital inclination (i), the effective temperature of hot star (T_h), the potential of the components (Ω_h and Ω_c) and the monochromatic luminosity of hot star (L_h) (the Planck function was used to compute the luminosity). The system consists of two different components having very different temperatures. The hot component has maximum contribution on short wavelengths, while the cool giant is dominant on the long wavelengths. Therefore, we used Mode 0 of the DC program for the analysis. The phase of the light minimum at out-of-eclipse appears to occur on the average about 0^p.1 later in 2003 than in 2002. These light variations are very similar to the quasi-sinusoidal photometric waves commonly observed for RS CVn-type variables, which appear to arise from an uneven distribution of subluminous regions (starspots) over the surface of the rotating star (Hall 1976). Therefore, assuming the difference of the light curves obtained in two observing seasons is due to the temperature inhomogenities on the surface of the cool component, such as starspots, we solved the light curves assuming two spots located on the cooler component. The computed light curves are compared with the observations in Fig. 1. The parameters found for spotted solution are given in Table 1.

Table 1. The results of the photometric solutions.

Fixed parameters		
T_c	$4441K$	
A_h	1.0	
A_c	0.5	
g_h	1.0	
g_c	0.32	
X_h	0.242	
X_c	0.962(U)	
	0.932(B)	
	0.844(V)	
	0.728(R)	
Adjusted parameters	**UBVR**	
i	82°.54 ± 0.02	
q	4.026 ± 0.002	
Ω_h	255.92 ± 18.47	
Ω_c	17.01 ± 0.01	
T_h	32 774 ± 3376 K	
$L_h/(L_h+L_c)$	0.647 (U)	
	0.228 (B)	
	0.092 (V)	
	0.041 (R)	
$L_c/(L_h+L_c)$	0.382 (U)	
	0.818 (B)	
	0.931 (V)	
	0.985 (R)	
r_h(pole)	0.004	
r_h(point)	0.004	
r_h(side)	0.004	
r_h(back)	0.004	
r_c(pole)	0.230	
r_c(point)	0.233	
r_c(side)	0.231	
r_c(back)	0.232	
$\sum W(O-C)^2$	0.0547	
Spot parameters	S_1	S_2
Latitude (°)	102	59
Longitude (°)	43	304
Radius (°)	54	56
Temperature factor	0.938	0.953

4. Results and Discussion

FF Aqr is one of the few systems, which consists of the hot subdwarf and cool giant components. We observed this interesting system using U, B, V, and R filters during 2002, 2003 and 2004 observing seasons, and we found that;
- the system has a totality in the primary

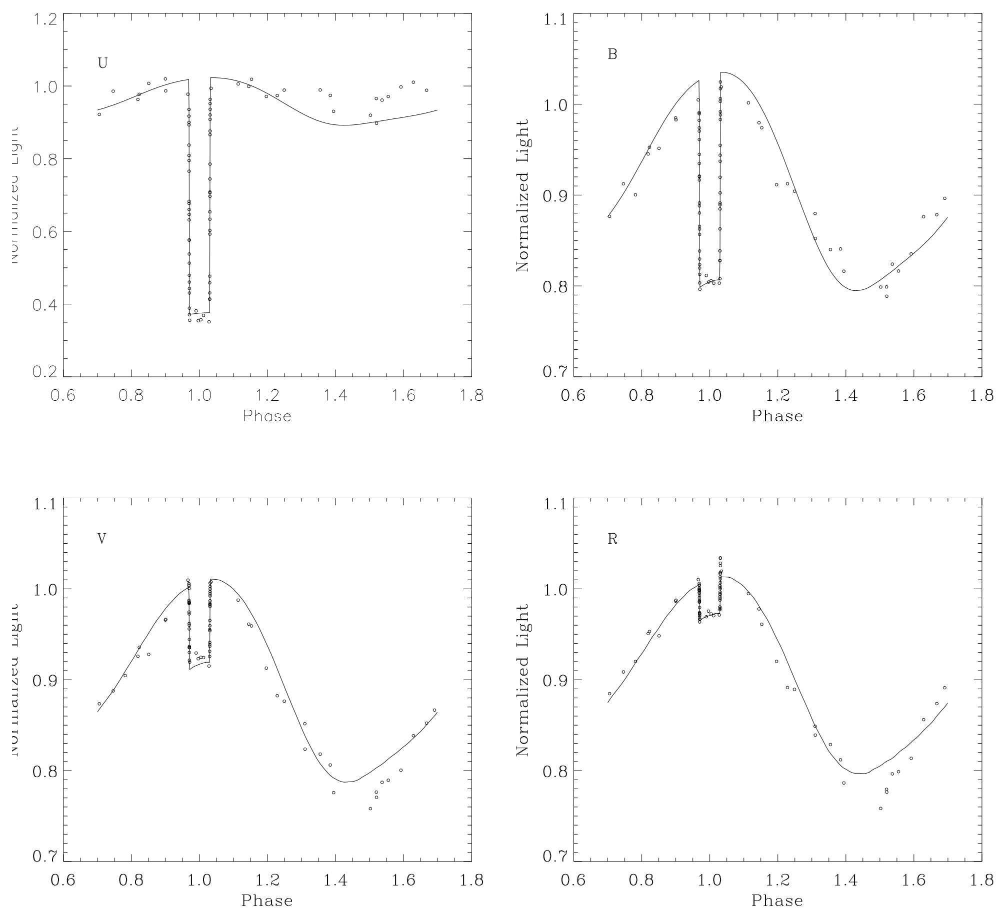

Fig. 1. The observed and the theorical light curves obtained by using the Wilson-Devinney code for each colour of FF Aqr.

eclipse, which lasts about 13^h. Ingress/Egress takes about 25^m. The increasing minimum depth with decreasing wavelength is due to the colour difference between the hot subdwarf and the giant star. The secondary minimum is not appear.

- the light curves show the wave-like distortion at outside of the eclipse. The phase of the wave minimum was changed in three observing seasons. We supposed that this observed asymme-

try in the light curves is due to the cool spots on the cooler component in binary.
- the parameters of the system obtained from light curve analysis reveals that the giant component is K1-2 III.

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