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A photometric study of the W UMa-type binary DF Canum Venaticorum

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ABSTRACT

We present new photometric observations for the eclipsing binary DF CVn, and determined five light minimum times. By using the Wilson–Devinney code, two sets of photometric solutions were deduced from our observations in 2009. The asymmetric light curves obtained on 2009 March 5 were modeled by a dark spot on the more massive component. The results indicate that DF CVn is a W-type weak-contact binary, with a mass ratio of $q \sim 0.28$ and an overcontact degree of $f \sim 20\%$. From the $O-C$ curve of minimum times, it is found that there exists a cyclic variation, whose period and semi-amplitude are $P_3 = 17.2(\pm 0.9)$ year and $A = 0.^d0070(\pm 0.^d0008)$, respectively. This kind of cyclic oscillation may possibly result from the light-time effect due to the presence of an unseen third body. This kind of additional body may extract angular momentum from the central system. The low-amplitude changes of the light curves on a short-time scale (e.g., half a month) may be attributed to the dark spot activity, which may result in angular momentum loss via magnetic breaking. With angular momentum loss, the weak-contact binary DF CVn will evolve into a deep-contact configuration.

1. Introduction

DF CVn (=GSC 3021-2642 = NSV 5904, $\alpha_{J2000.0} = 12^h43^m37.^s241$ and $\delta_{J2000.0} = +38°44'15.''67$) was discovered as a suspected variable star by Weber (1963) from the photographic survey of selected areas in the northern hemisphere. Then it was catalogued in the New Suspected Variable Stars (Kholopov, 1982). From the visual observations, Vandenbroere (1999) confirmed its light variability with an apparent period of $0.^d16345$. However, Vandenbroere et al. (2001) doubled its period to be $0.^d326890$. They classified DF CVn as an EW-type binary, with the magnitude range from $10.^m96$ to $11.^m46$ and a color index of $B-V = 0.78$. Acerbi et al. (2005) obtained 317 individual observations in V band using a 0.2 m Cassegrain telescope. Based on new light minimum times, they obtained a linear ephemeris as follows,

$$\text{Min.I} = \text{HJD } 2450571.1994 + 0.3268956 \times E. \qquad (1)$$

From their observations, a preliminary photometric solution with spot was deduced. The mass ratio and overcontact degree are $q = 0.3475(\pm 0.0007)$ and $f = 9.1\%(\pm 0.1\%)$, respectively. Therefore, the weak-contact binary DF CVn was included in our observing program to study late-type contact binaries with magnetic activity.

2. Photometric observations

CCD photometry of DF CVn was performed on 2009 March 5 and 22 (i.e., LC_1 and LC_2), using the 85-cm telescope and the 60-cm telescope at the Xinglong Station (XLS) of the National Astronomical Observatories of China (NAOC). For the *85*-cm telescope, a standard Johnson–Cousin–Bessel photometric system was mounted on the primary focus (Zhou et al., 2009). The PI 1024 BFT camera has 1024 × 1024 square pixels, each subtending a projected angle on the sky of 0.''96 and resulting in a field of view of 16.'5 × 16.'5. The 60-cm telescope was equipped with a PI 1024 × 1024 CCD, giving a field of view of 17' × 17'. The CCD cameras are equipped with UBVRI filters. All CCD images were reduced by means of the IMRED and APPHOT packages in IRAF. Zero and flat-fielding corrections were applied to the images. Extinction corrections were small and were not made to the observations.

The comparison and check stars were GSC 3021-2613 ($\alpha_{J2000.0} = 12^h43^m45^s.36$ and $\delta_{J2000.0} = 38°48'22.''2$) and GSC 3021-451 ($\alpha_{J2000.0} = 12^h43^m07^s.72$ and $\delta_{J2000.0} = 38°42'20.''0$). The typical exposure times for V and R bands were 15s and 10s for the 85-cm telescope, and 30s and 20s for the 60-cm telescope, respectively. All observations (i.e., 260 in V band and 259 in R band for LC_1, and 198 in V band and 199 in R band for LC_2) are available on request. The errors of individual points do not exceed $0.^m01$ mag in VR bands. Two sets of complete light curves (i.e., LC_1 and LC_2) are displayed in both panels of Fig. 1. The amplitudes of light variation are $0.^m50$ for V band and $0.^m46$ for R band, respectively. For LC_1, Max.I of is brighter than Max.II up to $0.^m025$ for V band and $0.^m026$ for R band. Therefore, there exists a typical O'Connell effect (Milone, 1968; Davidge and Milone, 1984). However, the unequal heights of LC_2 disappeared. This implies that light curves of DF CVn change during a short-time interval of 17 days. From the observations in 2009, four light minimum times were determined by the K–W method (Kwee and van Woerden, 1956).

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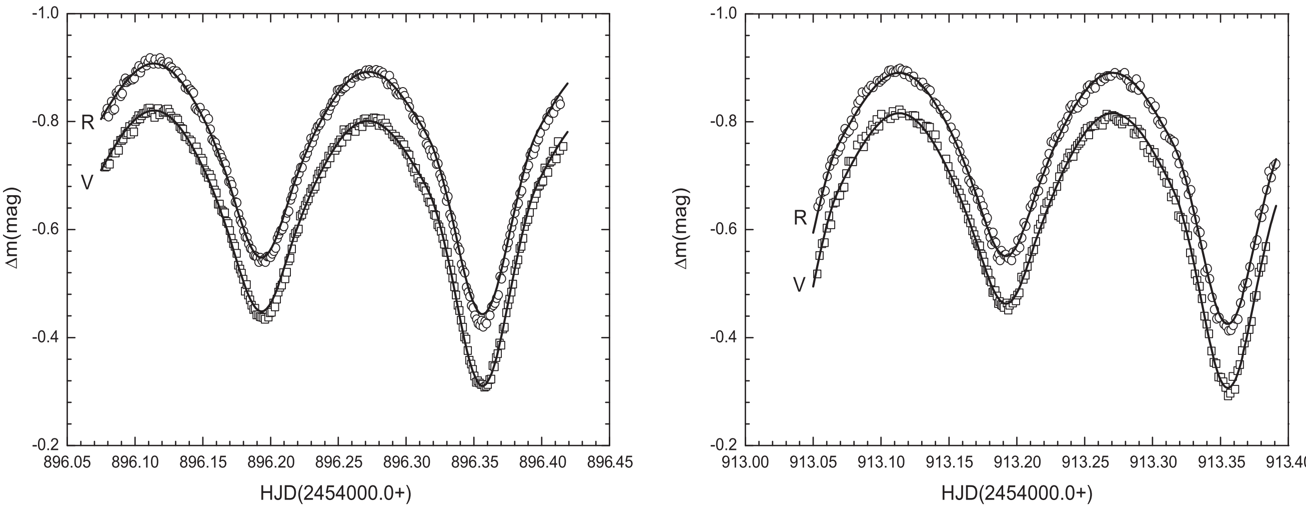

Fig. 1. *VR* observations of the eclipsing binary DF CVn, made on 2009 March 5 (i.e., LC_1; *left hand panel*) and 22 (i.e., LC_2; *right hand panel*). The solid lines in both panels were calculated from our photometric solutions.

Additionally, another secondary eclipse timing for DF CVn was observed on 2010 May 21, using the 60-cm telescope at the Yunnan Observatory (YNAO) in China. All those times of eclipses with their errors are listed in Table 1.

3. Orbital period changes

For the eclipsing binary DF CVn, all published light minimum times from the literature, such as IBVS, BBSAG, and VSOLJ, are available at the website of http://astro.sci.muni.cz/variables/ocgate/. Together with five new eclipsing times, we have compiled a total of 97 light minimum times, including 36 visual, 8 photoelectric and 53 CCD measurements to study the period changes. Using the linear ephemeris Eq. (1), we can calculate the values of $O-C$. The $O-C$ curve was constructed in the *left hand panel* of Fig. 2, where the crosses refer to the visual observations, while the filled circles represent the photoelectric or CCD ones.

In the fitting procedure, weight of 1 and 5 were attributed to visual data and photoelectric or CCD measurements. Assuming that the orbital period continuously varies for the short-time scale observations, the general trend of $O-C$ shows a wavelike oscillation. Therefore, a linear equation and a sinusoidal curve were tried as a fit the $O-C$ curve. A weighted least-squares fitting method leads to the following equation,

$$O-C = 0.0137(\pm0.0015) + 0.0070(\pm0.0008) \times \sin[3.27(\pm0.17)E + 3.3521(\pm0.1887)]. \quad (2)$$

The corresponding residuals are shown in the *right hand panel* of Fig. 2. The solid line in the *left hand panel* of Fig. 2 is given by Eq. (2). Using the relation of $P_3 = 2\pi P/\omega$ with $\omega = 3.27(\pm0.17)\times10^{-4}$, the period of the cyclic variation can be determined to be $P_3 = 17.2(\pm0.9)$ year, where P is the orbital period in year.

Table 1
New light minimum timings of DF CVn.

JD (Hel.)	Min.	Error	Filter	Telescope
2454896.19457	II	±0.00013	V	85-cm (XLS)
2454896.19452	II	±0.00011	R	85-cm (XLS)
2454896.35674	I	±0.00013	V	85-cm (XLS)
2454896.35632	I	±0.00017	R	85-cm (XLS)
2454913.19242	I	±0.00017	V	60-cm (XLS)
2454913.19272	I	±0.00024	R	60-cm (XLS)
2454913.35543	I	±0.00022	V	60-cm (XLS)
2454913.35536	I	±0.00028	R	60-cm (XLS)
2455338.15528	I	±0.00014	R	60-cm (YNAO)

4. Photometric solution

Two sets of light curves of DF CVn, observed on 2009 March 5 and 22 (i.e., LC_1 and LC_2), were respectively analyzed by using the 2003 version of the Wilson–Devinney code (Wilson and Devinney, 1971; Wilson, 1979, 1990). According to the color index of $B-V = 0.78$ (Vandenbroere et al., 2001), the mean effective temperature of $T_1 = 5220$ K for Star 1 was adopted (Drilling and Landolt, 2000). The corresponding logarithmic bolometric (i.e., X and Y) and monochromatic (i.e., x and y) limb-darkening coefficients were interpolated from van Hamme's (1993) tables. Following Lucy (1967), Rucinski (1973), the gravity darkening coefficients of both components and their bolometric albedo coefficients were set at the values of $g_{1,2} = 0.32$ and $A_{1,2} = 0.5$, which are appropriate for stars with convective envelopes. The adjustable parameters employed are the orbital inclination, i, the mass ratio, q, the mean effective temperature of Star 2, T_2, the potential of both components, $\Omega_{1,2}$, the monochromatic luminosity of Star 1, L_1. The relative brightness of Star 2 was calculated by a stellar atmosphere model (Kurucz, 1993).

For the eclipsing binary DF CVn, Acerbi et al. (2005) deduced the preliminary elements from a V-band light curve with much larger scatter. By lack of a spectroscopic mass ratio, it is necessary to search for a reliable mass ratio from the symmetric light curves, LC_2. A series of solutions were carried out for assumed mass ratios from 0.5 to 6.0. For each mass ratio, the calculation started from mode 2 (i.e., detached configuration), but the solution always converged to mode 3 (i.e., overcontact configuration). A minimum value of $\sum(O-C)_i^2$ is achieved at $q = 3.5$. This indicates that DF CVn is a W-type contact binary, rather than an A-type one (Acerbi et al., 2005). After some iterations, we obtained the photometric solution without a spot (i.e., Sol. 2), which is listed in Table 2. The theoretical light curves from Sol. 2 are plotted in the *right hand panel* of Fig. 1 as solid lines. For the asymmetric LC_1 of DF CVn, there exists a unequal height between two maxima up to more than $0.^m02$. Therefore, a dark spot on the more massive component (i.e., the primary) was assumed. To avoid correlations among the adjusted parameters, its colatitude $\phi = 90^\circ$ was fixed. The mass ratio of 3.5 was chosen as an initial input parameter. The final photometric