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New Light Curves and Orbital Period Investigations of the Interacting Binary System UV Piscium

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UV Psc is a typical RS CVn type system undergoing dynamic chromosphere activity. We performed photometric observations of the system in 2015 and secured new *BVR* light curves showing well-defined photometric waves. In this paper, we analyzed the light curves using Wilson-Devinney binary code and investigated the orbital period of the system. The combination of our light curve synthesis with the spectroscopic solution developed by previous investigators yielded the absolute parameters as: $M_1 = 1.104 \pm 0.042\ M_\odot$, $R_1 = 1.165 \pm 0.025\ R_\odot$, and $L_1 = 1.361 \pm 0.041\ L_\odot$ for the primary star, and $M_2 = 0.809 \pm 0.082\ M_\odot$, $R_2 = 0.858 \pm 0.018\ R_\odot$, and $L_2 = 0.339 \pm 0.010\ L_\odot$ for the secondary star. The eclipse timing diagram for accurate CCD and photoelectric timings showed that the orbital period may vary either in a downward parabolic manner or a quasi-sinusoidal pattern. If the latter is adopted as a probable pattern for the period change, a more plausible account for the cyclic variation may be the light time effect caused by a circumbinary object rather than an Applegate-mechanism occurring via variable surface magnetic field strengths.

Keywords: eclipsing variables, photometry, RS CVn type

1. INTRODUCTION

RS CVn type system is a detached binary showing very dynamic chromosphere activity (Hall 1976). These systems are composed of rapidly rotating late-type or giant stars (Kim et al. 2014). The light curves of RS CVn type systems show a distortion wave caused by stellar activity, particularly at outside eclipse phases. The wave changes continuously according to variations in cool spots. Moreover, angular momentum loss (AML) can occur via magnetized stellar winds induced by the chromospheric activity of the system, which finally decreases the orbital period. Therefore, long-term photometric observations of RS CVn type systems are important to more clearly understand these phenomena.

UV Psc, discovered by Huth (1959), is a representative RS CVn type system. The distortion wave was clearly observed in the previous light curves of this system (Oliver 1974; Sadik 1979; Vivekananda Rao & Sarma 1981, 1983a; Zeilik et al. 1982; Antonopoulou 1983, 1987; Han & Kim 1988). This phenomenon was interpreted as being caused by the existence of cool spots (Budding & Zeilik 1987; Han et al. 1996; Radhika & Vivekananda Rao 2001; Vivekananda Rao & Radhika 2002; Kjurkchieva et al. 2005). The radial velocity (RV) curves for both components were determined by Popper (1991, 1997), and Kjurkchieva et al. (2005) despite the fact that it is not easy to measure the spectral lines of the less massive component due to its fast rotation. The observed RV curves indicated that the mass ratio of this system falls within the range of 0.7 to 0.8.

Many investigations of variations in the orbital period have been performed to understand the dynamic properties

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of the UV Psc system, but the orbital period variation of this system remains controversial. Sadik (1979) and Kjurkchieva et al. (2005) suggested a decreasing orbital period, while Hall & Kreiner (1980) and Milano et al. (1986) proposed an increasing orbital period. Shengbang et al. (1999) suggested that the orbital period oscillates with a period of approximately 61 years and a semi-amplitude of 0.21×10^{-5} days.

In this study, we investigated the physical properties of UV Psc using new multiband photometric light curves obtained during the observing seasons in 2015. An overview of our observations is provided in Section 2. Sections 3 and 4 contain the investigations of the light curves and orbital period variation, respectively. Finally, we summarize the results presented in Section 5.

2. NEW OBSERVATIONS

New photometric observations of UV Psc were performed at Jincheon station of the Chungbuk National University Observatory (CBNUOJ) over 12 nights from October to November 2015 using the 60 cm reflector installed by the Korea Astronomy and Space Science Institute and operated by CBNUOJ. The telescope was equipped with an electronically cooled SBIG STX16803 4K CCD camera at a f/2.92 prime focus. A field of view of 72’ × 72’, and an image scale is 1.05 arcsec pixel^{-1}. Standard *BVR* filters were used during the observations with different exposures from 30 to 90 s according to the weather conditions for each observation. Further details regarding the telescope and instrument systems can be found in Han at al. (2015). The brightness values of the field stars were measured using aperture photometry and all images were corrected with bias, dark, and flat-field image. All reduction processes were performed using the IRAF package. TYC 26-70-1 and TYC 26-1046-1 in the UV Psc field were chosen as the comparison (C) and check (K) stars, respectively; further information is listed in Table 1. During the entire observation period, observational errors were calculated using the standard deviations of the differential *BVR* magnitudes between the K and C stars, were $0.^{m}013$, $0.^{m}014$, and $0.^{m}015$, respectively. A total of 2913 observations were obtained (973 in *B*, 972 in *V*, and 968 in *R*), and a representative sample data set is listed in Table 2.

Table 1. Star information from the Tycho-2 Catalog (Høg et al. 2000)

Name	RA. (J2000)	DEC. (J2000)	*B* [mag]	*V* [mag]
UV Psc	$01^{h}\,16^{m}\,55^{s}.119$	+06° 48’ 42”.11	9.73 (3)	9.01 (2)
TYC 26-70-1	01 16 18.491	+06 34 37.25	11.06 (8)	9.70 (3)
TYC 26-1046-1	10 17 41.429	+06 35 32.43	11.88 (13)	11.50 (14)

3. LIGHT CURVE SYNTHESIS

3.1 New Light Curves of UV Psc

Fig. 1 shows the *V* light curves calculated by the ephemeris (Kreiner 2004):

$$C = \mathrm{HJD}\ 2452500.0411(\pm 0.0007) + 0.^{\mathrm{d}}8610468(\pm 0.0000003)\,E, \tag{1}$$

where the black dot and red cross represent the data measured before and after HJD2457315, respectively. The light curve shows light variation of approximately $0.^{m}05$ at the primary eclipse where the more massive and hotter primary component is transited by the less massive and cooler secondary component. This value is larger than that of the observational error. In contrast, the brightness at the secondary eclipse remained unchanged. These facts may imply that the spot effect of the less massive component predominates in this light curve.

3.2 Binary Modeling and Absolute Dimensions

In this light curve investigation, we used the *BVR* data acquired before HJD2457315. To model the *BVR* light curves of UV Psc, Wilson-Devinney binary code (Wilson & Devinney 1971; WD) mode 2 for the detached binary systems was used. The temperature of the more massive star (T_1) and mass ratio ($q = M_2/M_1$) were fixed as 5780 K and 0.733, as determined by Popper (1997) and Kjurkchieva et al. (2005), respectively. Considering that RS CVn type system consists of two late-type main-sequence stars with convective envelopes, the gravity darkening coefficients and bolometric albedos for both components were assumed to be $g_1 = g_2 = 0.32$ and $A_1 = A_2 = 0.5$, respectively (Lucy 1967; Rucinski 1969). The limb-darkening coefficients obtained using the logarithmic law were adopted from the table developed by van Hamme (1993). The projected rotation velocities of the primary and secondary components measured by Kjurkchieva et al. (2005) were $v_1 \sin i = 66$ and $v_2 \sin i = 54$ km/s, respectively, while the synchronized rotation velocities calculated by the absolute parameters in Kjurkchieva et al. (2005) were $v_{1,\mathrm{syn}} = 67.0 \pm 2.3$ km/s and $v_{2,\mathrm{syn}} = 49.9 \pm 5.3$ km/s, respectively. Because the projected rotation velocities are in excellent agreement with the synchronized velocities within the errors, we assumed the rotation parameters to be $F_1 = F_2 = 1$. In addition, the

Table 2. CCD photometric observations of UV Psc

B		*V*		*R*	
HJD	*Δm*	HJD	*Δm*	HJD	*Δm*
2457301.0266	−1.328	2457301.0255	−0.664	2457301.0259	−0.336
2457301.0287	−1.325	2457301.0275	−0.651	2457301.0279	−0.342
2457301.0348	−1.345	2457301.0295	−0.656	2457301.0299	−0.341
2457301.0388	−1.332	2457301.0315	−0.667	2457301.0320	−0.342
2457301.0408	−1.333	2457301.0336	−0.663	2457301.0340	−0.342
2457301.0428	−1.336	2457301.0356	−0.660	2457301.0360	−0.334
2457301.0467	−1.333	2457301.0376	−0.659	2457301.0380	−0.346
2457301.0487	−1.325	2457301.0396	−0.660	2457301.0400	−0.339
2457301.0506	−1.341	2457301.0416	−0.656	2457301.0420	−0.341
2457301.0526	−1.322	2457301.0436	−0.658	2457301.0440	−0.345
2457301.0545	−1.337	2457301.0455	−0.661	2457301.0460	−0.350
2457301.0565	−1.330	2457301.0475	−0.652	2457301.0479	−0.339
2457301.0585	−1.342	2457301.0495	−0.655	2457301.0499	−0.343
2457301.0604	−1.336	2457301.0514	−0.660	2457301.0518	−0.344
2457301.0624	−1.328	2457301.0534	−0.666	2457301.0538	−0.347
2457301.0643	−1.336	2457301.0553	−0.654	2457301.0557	−0.345
2457301.0266	−1.328	2457301.0573	−0.647	2457301.0577	−0.339
…	…	…	…	…	…

The full version is available on our website (http://binary.cbnu.ac.kr/).

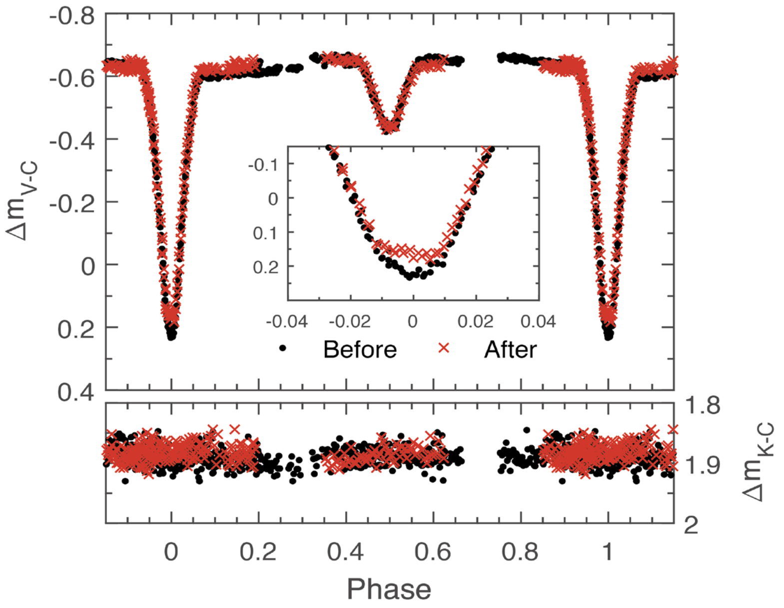

Fig. 1. *V* light curves for UV Psc (top) and the differential magnitude between the comparison and check stars (bottom). The inset in the upper inner panel is a zoomed-in view of the primary eclipse curve. The black circles and red crosses represent data obtained before and after *HJD2457315*, respectively.

adjustable parameters were the initial epoch (T_0), orbital period (P), inclination (i), temperature of the secondary component (T_2), surface potentials (Ω_1 and Ω_2), relative luminosity of the primary component (l_1), and third light (l_3).

A cool spot was proposed as an explanation to interpret the distortion wave of the light curve, as suggested by Budding & Zeilik (1987), Han et al. (1996), Radhika & Vivekananda Rao (2001), Vivekananda Rao & Radhika (2002), and Kjurkchieva et al. (2005). To interpret the distortion wave in our light curves, we adopted the cool spot on the secondary component, but an appropriate model was not calculated. Therefore, an additional cool spot on the primary component was adopted because the primary component also has a convective envelope. The final WD solution of UV Psc is listed in Table 3 and the synthetic *BVR* light curves are shown in the upper panel of Fig. 2 as solid lines. The spot radii of the primary and secondary components are 15.00 and 35.71 deg, indicating that both components are the sources of the distortion wave in UV Psc. The temperature of the secondary component is T_2 = 4756 ± 4 K. The orbital inclination was modelled as i = 90.10 ± 0.18 deg, implying that the line of sight is almost parallel to the orbital plane and UV Psc may have a retrograde orbit. From the i, the model light curves in Fig. 2 show the total eclipse at the secondary eclipse for approximately 27 min. The third light parameter l_3 was adjusted but not detected. To figure out the effect of the spots, theoretical light curves were calculated without considering the spots in Table 3 and are shown as dashed lines in the upper panel of Fig. 2. The residuals corresponding to presence and absence of the spots are plotted in the lower panel of Fig. 2 as the black and gray circles, respectively. Fig. 2 shows that the light depression from phase 0 to 0.3 was affected mainly by the cool spots, which existed actively on the surfaces of both components during the observation period.

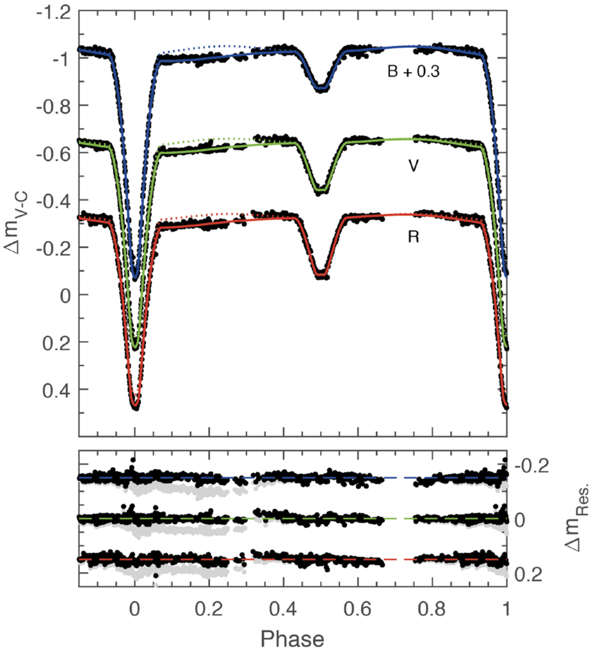

Fig. 2. *BVR* light curves of UV Psc (top) and residuals between the observation and model data (bottom). The black circles represent the observation data, and the gray circles in the bottom panel indicate the residuals for the non-spot model. The solid, dotted, and dashed lines represent the spot model, non-spot model, and zero lines, respectively. The blue, green, and red lines indicate the *BVR* filters.

To calculate the absolute parameters of UV Psc, we used the photometric solution in Table 3 and the semi-amplitude of the RV curves (K_1 and K_2) from Kjurkchieva et al. (2005). The masses, radii, and luminosities of both components were obtained as follows: M_1 = 1.104 ± 0.042 and M_2 = 0.809 ± 0.082 $M_\odot$; R_1 = 1.165 ± 0.025 and R_2 = 0.858 ± 0.018 $R_\odot$; and L_1 = 1.361 ± 0.041 and L_2 = 0.339 ± 0.010 $L_\odot$, respectively. These values are similar to those reported by Popper (1997) and Kjurkchieva et al. (2005).

Table 3. Light curve parameters for UV Psc

Parameter	Primary	Secondary
T_0 [HJD]	2452500.0148 (56)	
P [day]	0.8610515 (10)	
$q = M_2/M_1$	0.733	
i [deg]	90.10 (18)	
Ω	4.828 (3)	5.192 (3)
T [K]	5780	4756 (4)
X_{bol}	0.195	0.305
Y_{bol}	0.520	0.383
$L_1/L_{\mathrm{total,B}}$	0.8807 (10)	0.1193
$L_1/L_{\mathrm{total,V}}$	0.8447 (9)	0.1553
$L_1/L_{\mathrm{total,R}}$	0.8123 (9)	0.1877
r_{volume}	0.2464	0.1815
r_{pole}	0.2429 (2)	0.1799 (1)
r_{point}	0.2513 (2)	0.1838 (1)
r_{side}	0.2461 (2)	0.1812 (1)
r_{back}	0.2497 (2)	0.1832 (1)
Spot parameters:		
Co-Latitude θ [deg]	51.97 (52)	16.97 (31)
Longitude λ [deg]	289.32 (34)	166.86 (1.51)
Spot radius r_s [deg]	15.00 (9)	35.71 (24)
Temperature factor T_s/T_*	0.796 (4)	0.705 (23)
$\Sigma W(O-C)^2$	0.00915	
Absolute parameters:		
M [$M_\odot$]	1.104 (42)	0.809 (82)
R [$R_\odot$]	1.165 (25)	0.858 (18)
L [$L_\odot$]	1.361 (41)	0.339 (10)

4. ORBITAL PERIOD VARIATION INVESTIGATION

To investigate the orbital period variation of UV Psc, we determined 17 times of minimum light (primary: 10, secondary: 7) from measurements by Han & Kim (1988), Heckert (2012), and CBNUOJ using Kwee & van Woerden (1956) method. We also collected the times of minimum light from previous studies, the O – C gateway (http://var.astro.cz/ocgate/), and the database compiled by Kreiner et al. (2000). The same epoch data collected from the same literature were calculated as a weighted mean value. All data used in this investigation are listed in Table 4. The eclipse timing diagram of UV Psc was calculated using Eq. (1) and is shown in Fig. 3, where the timings are differentiated by assorted symbols according to the observational method. From the diagram, the CCD and photoelectric (O – C) residuals after 1966 clearly varied in a continuously

Table 4. The times of minimum lights of UV Psc

HJD	Error	Me.[1]	Type[2]	Epoch	Ref.[3]	HJD	Error	Me.[1]	Type[2]	Epoch	Ref.[3]
2414666.490	-	P	I	–43939.0	(1)	2429531.608	-	P	I	–26675.0	(3)
2414981.630	-	P	I	–43573.0	(1)	2429626.313	-	P	I	–26565.0	(1)
2415372.539	-	P	I	–43119.0	(1)	2429639.270	-	P	I	–26550.0	(3)
2415434.532	-	P	I	–43047.0	(1)	2429878.592	-	P	I	–26272.0	(1)
2415668.769	-	P	I	–42775.0	(1)	2429896.728	-	P	I	–26251.0	(1)
2415763.479	-	P	I	–42665.0	(1)	2429937.609	-	P	II	–26203.5	(1)
2416059.660	-	P	I	–42321.0	(1)	2430175.640	-	P	I	–25927.0	(1)
2416134.584	-	P	I	–42234.0	(1)	2430201.536	-	P	I	–25897.0	(3)
2416746.774	-	P	I	–41523.0	(1)	2430207.511	-	P	I	–25890.0	(1)
2416859.545	-	P	I	–41392.0	(1)	2430318.598	-	P	I	–25761.0	(1)
2417212.630	-	P	I	–40982.0	(1)	2430648.377	-	P	I	–25378.0	(1)
2417969.477	-	P	I	–40103.0	(1)	2431358.734	-	P	I	–24553.0	(1)
2418227.781	-	P	I	–39803.0	(1)	2431687.639	-	P	I	–24171.0	(1)
2418687.563	-	P	I	–39269.0	(1)	2431725.544	-	P	I	–24127.0	(1)
2419009.636	-	P	I	–38895.0	(1)	2431738.461	-	P	I	–24112.0	(3)
2419683.783	-	P	I	–38112.0	(1)	2431845.247	-	P	I	–23988.0	(3)
2420484.565	-	P	I	–37182.0	(1)	2432804.431	-	P	I	–22874.0	(1)
2420768.722	-	P	I	–36852.0	(1)	2432879.373	-	P	I	–22787.0	(1)
2421909.633	-	P	I	–35527.0	(1)	2432885.387	-	P	I	–22780.0	(3)
2422621.712	-	P	I	–34700.0	(1)	2433888.484	-	P	I	–21615.0	(3)
2422993.710	-	P	I	–34268.0	(1)	2433894.508	-	P	I	–21608.0	(3)
2423327.731	-	P	I	–33880.0	(1)	2433914.335	-	P	I	–21585.0	(2)
2424134.574	-	P	I	–32943.0	(1)	2433970.263	-	P	I	–21520.0	(1)
2424165.546	-	P	I	–32907.0	(1)	2434607.510	-	P	I	–20780.0	(3)
2424789.796	-	P	I	–32182.0	(1)	2435369.482	-	P	I	–19895.0	(3)
2425527.755	-	P	I	–31325.0	(1)	2435691.542	-	P	I	–19521.0	(3)
2426678.503	-	P	II	–29988.5	(1)	2436075.550	-	P	I	–19075.0	(3)
2426985.525	-	P	I	–29632.0	(2)	2436850.510	-	P	I	–18175.0	(3)
2427004.430	-	P	I	–29610.0	(2)	2439388.8736	-	PE	I	–15227.0	(4)
2427034.608	-	P	I	–29575.0	(1)	2439406.9565	-	PE	I	–15206.0	(4)
2427061.293	-	P	I	–29544.0	(3)	2439407.8167	-	PE	I	–15205.0	(4)
2427313.533	-	P	I	–29251.0	(2)	2440466.9057	-	PE	I	–13975.0	(4), (5)
2427994.633	-	P	I	–28460.0	(1)	2440854.351	-	VI	I	–13525.0	(6)
2428038.563	-	P	I	–28409.0	(3)	2440860.4014	-	PE	I	–13518.0	(7)
2428067.798	-	P	I	–28375.0	(1)	2440953.384	-	VI	I	–13410.0	(2)
2428080.735	-	P	I	–28360.0	(1)	2441163.4933	-	PE	I	–13166.0	(8)
2428107.428	-	P	I	–28329.0	(3)	2441276.281	-	VI	I	–13035.0	(9)
2428126.362	-	P	I	–28307.0	(2)	2441282.304	-	VI	I	–13028.0	(9)
2428156.519	-	P	I	–28272.0	(1)	2441301.250	-	VI	I	–13006.0	(10)
2428164.288	-	P	I	–28263.0	(3)	2441319.340	-	VI	I	–12985.0	(10)
2428366.643	-	P	I	–28028.0	(1)	2441350.333	-	VI	I	–12949.0	(10)
2428373.499	-	P	I	–28020.0	(3)	2441534.609	-	VI	I	–12735.0	(11)
2428373.546	-	P	I	–28020.0	(1)	2441565.610	-	VI	I	–12699.0	(11)
2428398.464	-	P	I	–27991.0	(3)	2441571.630	-	VI	I	–12692.0	(11)
2428423.435	-	P	I	–27962.0	(3)	2441598.333	-	VI	I	–12661.0	(12)
2428429.502	-	P	I	–27955.0	(1)	2441610.374	-	VI	I	–12647.0	(12)
2428453.555	-	P	I	–27927.0	(3)	2441616.407	-	VI	I	–12640.0	(12)
2428761.830	-	P	I	–27569.0	(1)	2441622.433	-	VI	I	–12633.0	(12)
2428837.622	-	P	I	–27481.0	(1)	2441623.303	-	VI	I	–12632.0	(12)
2429110.557	-	P	I	–27164.0	(3)	2441648.263	-	VI	I	–12603.0	(12)
2429156.647	-	P	II	–27110.5	(1)	2441888.4942	-	PE	I	–12324.0	(13)
2429166.529	-	P	I	–27099.0	(3)	2441894.526	-	VI	I	–12317.0	(14)
2429230.243	-	P	I	–27025.0	(3)	2441900.555	-	VI	I	–12310.0	(15)
2429267.275	-	P	I	–26982.0	(1)	2441989.241	-	VI	I	–12207.0	(16)
2429486.859	-	P	I	–26727.0	(1)	2442020.223	-	VI	I	–12171.0	(17)
2429514.403	-	P	I	–26695.0	(3)	2442026.268	-	VI	I	–12164.0	(17)
2429514.420	-	P	I	–26695.0	(1)	2442044.339	-	VI	I	–12143.0	(17)

Table 4. Continued

HJD	Error	Me.[1)]	Type[2)]	Epoch	Ref.[3)]	HJD	Error	Me.[1)]	Type[2)]	Epoch	Ref.[3)]
2442272.524	-	VI	I	−11878.0	(18)	2445323.214	-	VI	I	−8335.0	(42)
2442291.470	-	VI	I	−11856.0	(18)	2445335.266	-	VI	I	−8321.0	(42)
2442365.517	-	VI	I	−11770.0	(19)	2445341.300	-	VI	I	−8314.0	(2)
2442385.315	-	VI	I	−11747.0	(20)	2445613.392	-	VI	I	−7998.0	(43)
2442423.214	-	VI	I	−11703.0	(21)	2445632.332	-	VI	I	−7976.0	(43)
2442429.231	-	VI	I	−11696.0	(21)	2445681.410	-	VI	I	−7919.0	(2)
2442435.265	-	VI	I	−11689.0	(21)	2445987.5131	-	PE	II	−7563.5	(44)
2442680.663	-	VI	I	−11404.0	(22)	2446004.3008	-	PE	I	−7544.0	(44)
2442681.523	-	VI	I	−11403.0	(22)	2446023.250	-	VI	I	−7522.0	(45)
2442738.348	-	VI	I	−11337.0	(23)	2446043.0488*	0.0002	PE	I	−7499.0	(46)
2442738.353	-	VI	I	−11337.0	(22)	2446054.244	-	VI	I	−7486.0	(47)
2442776.240	-	VI	I	−11293.0	(24)	2446059.412	-	VI	I	−7480.0	(2)
2442782.262	-	VI	I	−11286.0	(25)	2446322.4592	-	PE	II	−7174.5	(44)
2442806.268	-	VI	I	−11258.0	(25)	2446326.3344	-	PE	I	−7170.0	(44)
2443041.442	-	VI	I	−10985.0	(26)	2446331.5004	-	PE	I	−7164.0	(44)
2443053.4926	0.0003	PE	I	−10971.0	(3), (27)	2446413.298	-	VI	I	−7069.0	(48)
2443079.3230	-	PE	I	−10941.0	(4)	2446745.2367	-	PE	II	−6683.5	(44)
2443080.1840	-	PE	I	−10940.0	(4)	2446753.4130	-	PE	I	−6674.0	(44)
2443123.2362	-	PE	I	−10890.0	(4)	2446760.305	-	VI	I	−6666.0	(49)
2443400.4951	0.0007	PE	I	−10568.0	(27)	2447057.365	-	VI	I	−6321.0	(50)
2443406.5225	0.0001	PE	I	−10561.0	(27)	2447082.329	-	VI	I	−6292.0	(50)
2443425.4660	0.0002	PE	I	−10539.0	(27)	2447094.3875	-	PE	I	−6278.0	(51)
2443428.4807	0.0004	PE	II	−10535.5	(3), (27)	2447113.326	-	VI	I	−6256.0	(52)
2443445.2691	-	PE	I	−10516.0	(4)	2447125.386	-	VI	I	−6242.0	(2)
2443446.1302	-	PE	I	−10515.0	(4)	2447410.3944	-	PE	I	−5911.0	(51)
2443452.1564	-	PE	I	−10508.0	(4)	2447434.5021	-	PE	I	−5883.0	(51)
2443463.3493	-	PE	I	−10495.0	(28)	2447553.328	-	VI	I	−5745.0	(53)
2443734.582	-	VI	I	−10180.0	(29)	2447856.4240	-	VI	I	−5393.0	(2)
2443772.471	-	VI	I	−10136.0	(30)	2448531.4756	-	PE	I	−4609.0	(54)
2443785.3834	0.0002	PE	I	−10121.0	(3), (27)	2448541.3770	-	PE	II	−4597.5	(54)
2443791.408	-	VI	I	−10114.0	(30)	2448594.3328	-	PE	I	−4536.0	(54)
2443803.472	-	VI	I	−10100.0	(30)	2448888.3754	0.0007	PE	II	−4194.5	(55)
2443805.1877	-	PE	I	−10098.0	(4)	2448897.4161	0.0007	PE	I	−4184.0	(55)
2443809.489	-	VI	I	−10093.0	(30)	2448913.3461	0.0006	PE	II	−4165.5	(55)
2443821.548	-	VI	I	−10079.0	(31)	2449003.330	-	VI	I	−4061.0	(56)
2443835.324	-	VI	I	−10063.0	(31)	2450003.4397	0.0013	PE	II	−2899.5	(57)
2443841.345	-	VI	I	−10056.0	(31)	2450007.3112	0.0005	PE	I	−2895.0	(57)
2443848.241	-	VI	I	−10048.0	(32)	2450333.6434	0.0001	PE	I	−2516.0	(58)
2443849.0996	-	PE	I	−10047.0	(4)	2450334.5051	0.0002	PE	I	−2515.0	(58)
2443861.1542	-	PE	I	−10033.0	(4)	2450652.6656	0.0001	PE	II	−2145.5	(58)
2444144.445	-	VI	I	−9704.0	(33)	2450655.6767	0.0001	PE	I	−2142.0	(58)
2444157.345	-	VI	I	−9689.0	(33)	2450715.5266	0.0011	PE	II	−2072.5	(59)
2444168.551	-	VI	I	−9676.0	(2)	2450731.4506	0.0004	PE	I	−2054.0	(59)
2444201.275	-	VI	I	−9638.0	(33)	2450756.4201	0.0001	CCD	I	−2025.0	(60)
2444212.460	-	VI	I	−9625.0	(34)	2451031.9560*	0.0002	PE	I	−1705.0	(61)
2444225.3790	-	PE	I	−9610.0	(35)	2451397.9015*	0.0005	PE	I	−1280.0	(61)
2444603.386	-	VI	I	−9171.0	(36)	2451400.9157*	0.0002	PE	II	−1276.5	(61)
2444831.552	-	VI	I	−8906.0	(37)	2451403.9295*	0.0002	PE	I	−1273.0	(61)
2444869.447	-	VI	I	−8862.0	(2)	2451510.6989	-	PE	I	−1149.0	(62)
2444913.358	-	VI	I	−8811.0	(38)	2451523.6140	-	PE	I	−1134.0	(62)
2444913.363	-	VI	I	−8811.0	(38)	2451821.5362	0.0004	CCD	I	−788.0	(63)
2444931.438	-	VI	I	−8790.0	(38)	2452478.9453*	0.0005	PE	II	−24.5	(61)
2444932.2966	-	PE	I	−8789.0	(39)	2452607.6729	0.0001	CCD	I	125.0	(64)
2445241.415	-	VI	I	−8430.0	(40)	2452853.9313*	0.0003	PE	I	411.0	(61)
2445265.5228	-	PE	I	−8402.0	(41)	2452874.5969	0.0009	CCD	I	435.0	(65)
2445282.3144	-	PE	II	−8382.5	(41)	2452875.4627	-	VI	I	436.0	(66)
2445322.356	-	VI	I	−8336.0	(2)	2453225.9032*	0.0006	PE	I	843.0	(61)

Table 4. Continued

HJD	Error	Me.1)	Type2)	Epoch	Ref.3)	HJD	Error	Me.1)	Type2)	Epoch	Ref.3)
2453228.9176*	0.0003	PE	II	846.5	(61)	2455483.5683	0.0008	CCD	I	3465.0	(74)
2453273.6972	0.0002	CCD	II	898.5	(67)	2455850.3760	0.0008	CCD	I	3891.0	(75)
2453283.5936	0.0003	CCD	I	910.0	(67)	2455889.9824	-	CCD	I	3937.0	(76)
2453286.6058	0.0010	CCD	II	913.5	(67)	2456152.6003	0.0004	CCD	I	4242.0	(77)
2453288.7592	0.0004	CCD	I	916.0	(67)	2456208.1410	-	CCD	II	4306.5	(78)
2453289.6211	0.0004	CCD	I	917.0	(67)	2456962.4148	0.0009	CCD	II	5182.5	(79)
2453294.7887	0.0006	CCD	I	923.0	(67)	2456974.0400	-	CCD	I	5196.0	(80)
2453298.6607	0.0006	CCD	II	927.5	(67)	2457287.4603	0.0002	CCD	I	5560.0	(81)
2453307.7029	0.0002	CCD	I	938.0	(67)	2457301.2381*	0.0001	CCD	I	5576.0	(82)
2453311.5756	0.0010	CCD	II	942.5	(67)	2457305.1121*	0.0002	CCD	II	5580.5	(82)
2453336.9771	-	CCD	I	972.0	(68)	2457308.1267*	0.0001	CCD	I	5584.0	(82)
2453953.9182*	0.0005	PE	II	1688.5	(61)	2457311.1406*	0.0006	CCD	II	5587.5	(82)
2453984.4866	0.0004	CCD	I	1724.0	(69)	2457326.2085*	0.0001	CCD	I	5605.0	(82)
2453990.5121	-	CCD	I	1731.0	(70)	2457327.0696*	0.0001	CCD	I	5606.0	(82)
2454040.0240	-	CCD	II	1788.5	(71)	2457330.0831*	0.0004	CCD	II	5609.5	(82)
2454097.2835	0.0013	CCD	I	1855.0	(66)	2457343.4300	0.0011	CCD	I	5625.0	(83)
2454369.3737	0.0002	CCD	I	2171.0	(72)	2457356.3420	0.0020	CCD	I	5640.0	(84)
2454845.9623	-	CCD	II	2724.5	(73)	2457677.0862	-	CCD	II	6012.5	(85)
2455143.0244	-	CCD	II	3069.5	(73)	2457682.6812	0.0010	CCD	I	6019.0	(86)

* The times of minimum light newly calculated using photometric data from the literature.

1) VI, visual; P, plate; PE, photoelectric; CCD, charge-coupled device.

2) I, Primary time of minimum light; II, Secondary time of minimum light.

3) (1) Strohmeier & Bauernfeind (1968), (2) Kreiner et al. (2000), (3) Hall & Kreiner (1980), (4) Vivekananda Rao & Sarma (1983b), (5) Oliver (1974), (6) Diethelm & Locher (1970), (7) Kizilirmak & Pohl (1971), (8) Pohl & Kizilirmak (1972), (9) Diethelm et al. (1972a), (10) Diethelm et al. (1972b), (11) Diethelm et al. (1972c), (12) Diethelm et al. (1972d), (13) Kizilirmak & Pohl (1974), (14) Diethelm et al. (1973a), (15) Aeberli et al. (1973), (16) Diethelm et al. (1973b), (17) Diethelm et al. (1974a), (18) Carnevali et al. (1974), (19) Diethelm et al. (1974b), (20) Carnevali et al. (1975a), (21) Carnevali et al. (1975b), (22) Baumann et al. (1975), (23) Isles (1976), (24) Diethelm et al. (1976), (25) Behagle et al. (1976), (26) Boninsegna et al. (1976b), (27) Aslan (1978), (28) Al-Naimiy et al. (1978), (29) Boninsegna et al. (1978), (30) Boninsegna et al. (1978), (31) Agnesoni et al. (1979), (32) Agnesoni et al. (1979), (33) Andrakakou et al. (1979), (34) Agnesoni et al. (1980), (35) Milano L. et al(1986), (36) Boistel et al. (1981), (37) Andrakakou et al. (1981a), (38) Andrakakou et al. (1981b), (39) Ibanoglu (1987), (40) Boistel et al. (1982), (41) Pohl et al (1983), (42) Diethelm et al. (1983), (43) Boninsegna et al. (1983), (44) Pohl et al (1987), (45) Boninsegna et al. (1984), (46) Han & Kim (1988), (47) Boller et al. (1985), (48) Acerbi et al. (1986), (49) Blättler et al. (1987), (50) Blanchart et al. (1988), (51) Keskin & Pohl (1989), (52) Blättler et al. (1988), (53) Andrakakou et al. (1989), (54) Wunder & Wieck (1992), (55) Jassur & Kermani (1993), (56) Acerbi et al. (1993), (57) Albayrak et al. (2000), (58) Deeg et al. (2003), (59) Selam et al. (1999), (60) Agerer et al. (1999), (61) Heckert (2012), (62) Sowell et al. (2001), (63) Agerer & Hübscher (2002), (64) Nelson (2003), (65) Zejda (2004), (66) Brat et al. (2007), (67) Ogloza et al. (2008), (68) Nagai (2005), (69) Dogru et al. (2007), (70) Csizmadia et al. (2006), (71) Nagai (2007), (72) Liakos et al.(2014), (73) Nagai (2010), (74) Zasche et al. (2011), (75) Hübscher & Lemann (2012), (76) Nagai (2012), (77) Zasche et al. (2014), (78) Nagai (2013), (79) Samolyk (2015), (80) Nagai (2015), (81) Juryšek et al. (2017), (82) CBNUOJ, (83) Hübscher (2017), (84) Paschke (2015), (85) Nagai (2017), (86) Samolyk (2017).

decreasing pattern, although this pattern does not appear in the residuals for earlier plate timings because of their large short-term scattering. Therefore, we fitted all $(O - C)$ residuals to a downward parabolic ephemeris using a least-square fitting method. The resultant ephemeris is as follows:

$$(O-C) = -0.^{d}38(\pm 3.65)\times 10^{-4} + 1.^{d}33(\pm 0.74)\times 10^{-7}E - 2.^{d}16(\pm 0.72)\times 10^{-11}E^{2}. \qquad (2)$$

In this calculation, the weights of plate (P), visual (VI), photoelectric (PE), and CCD measurements were assigned values of 0.01, 1, 10, and 10, respectively. The black dashed line in the first panel of Fig. 3 was drawn using Eq. (2), indicating that the equation is in good agreement with CCD and PE data. The second panel shows only the residuals ($(O - C)_{\mathrm{res},1}$) of PE and CCD timings from Eq. (2). The standard deviations from all timings and those from the PE and CCD timings are $\sigma_{\mathrm{ALL},1} = 0.0144$ and $\sigma_{\mathrm{CCD,PE},1} = 0.0016$, respectively. The coefficient of quadratic term in Eq. (2) gives an orbital period decrease of $1.83(\pm 0.06) \times 10^{-8}$ days year^{-1}.

As mentioned in Section 1, Shengbang et al. (1999) proposed a cyclic orbital period variation. If we assume that the continuously decreasing variation in the $(O - C)$ residuals of the PE and CCD timings in Fig. (3) is a part of a sinusoidal variation, the residuals could be fitted to a sine curve ephemeris using an iterative least-squares method. The equation was obtained as follows:

$$(O-C) = -0.^{d}89(\pm 1.55)\times 10^{-3} + 4.^{d}14(\pm 1.64)\times 10^{-7}E + 2.^{d}26(\pm 1.68)\times 10^{-3}\times \sin[2.74(\pm 0.66) + 2.03(\pm 1.12)\times 10^{-4}E]. \qquad (3)$$

The blue solid curve in the first panel of Fig. 3 was generated from Eq. (3), and the residuals ($(O - C)_{\mathrm{res},2}$) of the PE and CCD timings from Eq. (3) are shown in the bottom

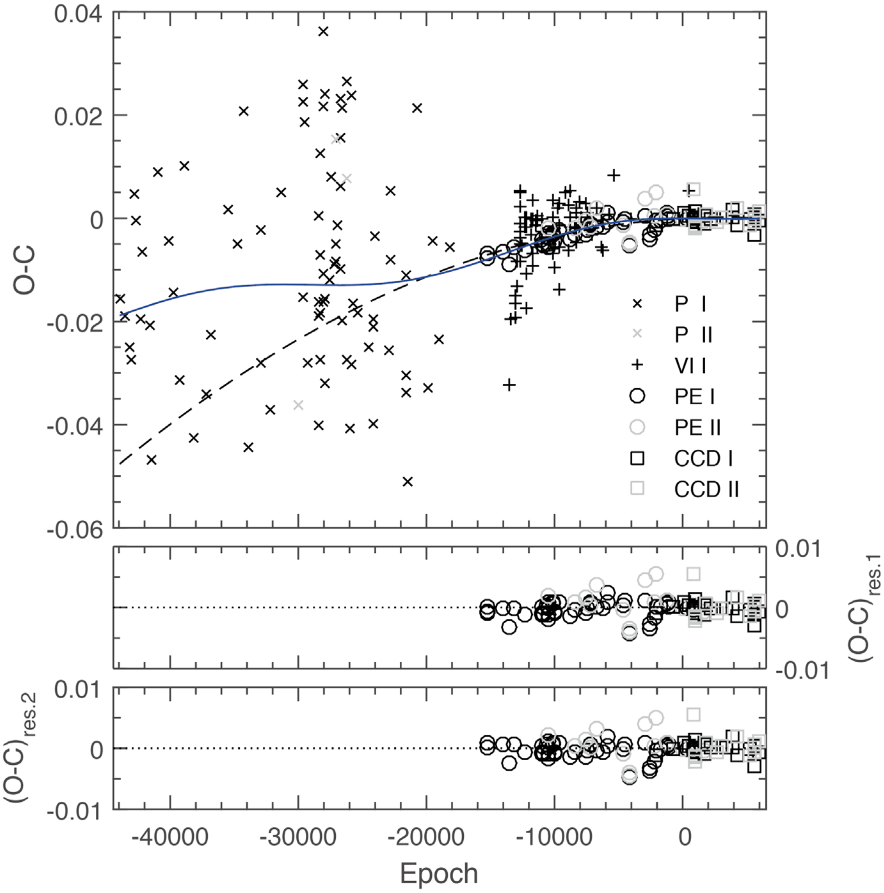

Fig. 3. The eclipse timing diagram of UV Psc (top) and residuals of Eqs. (2) and (3) (middle and bottom). The black dashed line and blue solid line were plotted using Eqs. (2) and (3), respectively.

panel. The standard deviation of the $(O - C)_{\mathrm{res},2}$ ($\sigma_{\mathrm{CCD,PE},2}$) is the same as the $\sigma_{\mathrm{CCD,PE},1}$ of 0.0016 days, while the standard deviation of all timings was $\sigma_{\mathrm{ALL},2} = 0.0121$ day, slightly smaller than that of $\sigma_{\mathrm{ALL},1}$, which was 0.0144 day. Therefore, based on the present timing database, it is more acceptable that the orbital period of UV Psc exhibits a cyclic variation rather than a decreasing variation. The cyclic variation of the modulating period and amplitude were determined to be $P_{\mathrm{mod}} = 73$ (±42) years and $K = 2.3\ (\pm 1.7) \times 10^{-3}$ days, respectively.

For completeness, we attempted to fit all $(O - C)$ residuals to a combined ephemeris of a quadratic term and a sine curve ephemeris. However, we could not find any suitable solution for this case.

In general, the periodic $(O - C)$ variation of UV Psc can be explained by the light time effect (LTE; Irwin 1952, 1959) caused by a circumbinary object or by the Applegate-mechanism (Applegate 1992). If the third body in the UV Psc system causes of the $(O - C)$ variation, its minimum mass is calculated to be $m_3 = 0.035\ \mathrm{M}_{\odot}$ from the following mass function (Mayer 1990):

$$f\left(m_3\right) = \frac{m_3^3 \sin^3 i_3}{\left(M_1 + M_2 + m_3\right)^2} = \frac{\left(a_{12} \sin i_3\right)^3}{P_{mod}^2}, \tag{4}$$

where a_{12} and i_3 are the semi-major axis of the center of mass of UV Psc and inclination of the third body, respectively. The calculated m_3 was much smaller than masses of the primary and secondary components, which is likely the reason why we could not detect l_3 in the light curve synthesis.

In contrast, assuming that the variation was caused by the Applegate-mechanism, the subsurface magnetic field strengths of the primary and secondary components were calculated to be 4.6 and 8.4 kG, respectively. These values are approximately twice the 2.0 and 4.6 kG of the primary and secondary components, respectively, predicted by Feiden & Chaboyer (2013) using the magnetic Dartmouth stellar evolution code. Therefore, it is reasonable to conclude that the periodic variation in the orbital period of UV Psc is caused by a circumbinary object.

5. SUMMARY AND CONCLUSION

BVR photometric observations of UV Psc were performed at CBNUOJ in 2015, and new light curves were obtained. The light curves varied on a short-term scale of less than a month, indicating that stellar activities are strong. The WD light curve synthesis suggested that the UV Psc is a typical RS CVn type system with M_1 = 1.104 ± 0.042 $M_\odot$, M_2 = 0.809 ± 0.082 $M_\odot$, R_1 = 1.165 ± 0.025 $R_\odot$, R_2 = 0.858 ± 0.018 $R_\odot$, L_1 = 1.361 ± 0.041 $L_\odot$, and L_2 = 0.339 ± 0.010 $L_\odot$. In addition, the eclipse timing diagram of UV Psc exhibited downward parabola variation. Our orbital period investigation showed that the downward parabola is part of the sinusoid and the LTE is more suitable than the AML and Applegate-mechanism for interpreting the variation. However, since the UV Psc is an RS CVn type system, we cannot completely rule out a secular decrease of the orbital period caused by AML. Therefore, further observations of the times of minimum light and new light curves for this system are required to resolve the issues highlighted above.

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