









A New Stellar Outburst Associated with the Magnetic Activities of the K-type Dwarf in a White Dwarf Binary

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Abstract

ISWASP J162117.36+441254.2 was originally classified as an EW-type binary with a period of 0.20785 days. However, it was detected to have undergone a stellar outburst on 2016 June 3. Although the system was later classified as a cataclysmic variable (CV) and the event was attributed as a dwarf nova outburst, the physical reason is still unknown. This binary has been monitored photometrically since 2016 April 19, and many light curves were obtained before, during, and after the outburst. Those light and color curves observed before the outburst indicate that the system is a special CV. The white dwarf is not accreting material from the secondary and there are no accretion disks surrounding the white dwarf. By comparing the light curves obtained from 2016 April 19 to those from September 14, it was found that magnetic activity of the secondary is associated with the outburst. We show strong evidence that the L_1 region on the secondary was heavily spotted before and after the outburst and thus quench the mass transfer, while the outburst is produced by a sudden mass accretion of the white dwarf. These results suggest that J162117 is a good astrophysical laboratory to study stellar magnetic activity and its influences on CV mass transfer and mass accretion.

Key words: binaries: close – binaries: eclipsing – stars: individuals (ISWASP J162117.36+441254.2) – stars: winds, outflows – starspots – white dwarfs

1. Introduction

ISWASP J162117.36+441254.2 (= CSS J162117.3+441254 = SDSS J162117.35+441254.1, hereafter J162117) was originally identified as an EW-type eclipsing binary by several authors (Lohr et al. 2013; Palaversa et al. 2013; Drake et al. 2014a). The derived orbital period ($P = 0.207852$ days) places the system near the short-period limit of contact binaries (Rucinski 1992, 2007; Qian et al. 2017). An outburst was reported by Drake et al. (2016), which occurred on 2016 June 3 (UT = 10.8 hr). The pre-discovery observations given by Maehara (2016) from 2016 May 28 to June 3 revealed that the object was already in outburst at $V = 13.13$ mag on 2016 June 1 (UT = 14.78 hr). If the system is really a contact binary, the outburst could be explained as the beginning of a rare binary merger event similar to V1309 Sco (Tylenda et al. 2011; Zhu et al. 2016). However, the conclusion was ruled out by follow-up photometric monitoring and spectroscopic observations. Drake et al. (2016), using *GALEX* data as well, suspect that the outburst is more likely from an unusual cataclysmic variable (CV). Also, the spectroscopic emission lines observed by Scaringi et al. (2016) support that the outburst event is associated with accretion onto a compact object. Therefore, J162117 is possibly a long-period CV above the period gap. In addition to broad emission lines (Scaringi et al. 2016), the spectral observations obtained by Thorstensen (2016) show a strong contribution from a K-type secondary star. By analyzing the radial velocities, the masses of the compact object and donor star were estimated as $0.9 M_{\odot}$ and $0.4 M_{\odot}$, respectively.

After the report of the outburst from J162117 (Drake et al. 2016), the binary system was monitored continuously (Pavlenko et al. 2016; Zejda & Pejcha 2016; Zola et al. 2016;

Kjurkchieva et al. 2017). The phased light curve obtained by Zejda & Pejcha (2016) during the outburst showed deep primary eclipses and shallower secondary eclipses. At the time, the depth of the primary minima were decreasing, while the depth of the secondary minima were increasing as the outburst faded. Finally, the system returned to its quiescence state during 2016 June 14–16 with its light curve returning to a state similar to that of EW-type variability (Zola et al. 2016). A 0.052 day variability with an amplitude of 0.1 mag was reported by Pavlenko et al. (2016), which is superimposed on the out-of-eclipse light curve. These authors suspected that the variability could be related to the magnetic pole/poles of a white dwarf and that this could be a candidate of the intermediate polar system. The outburst, with an amplitude of about 2 mag in V band and the EW-type light curve in its quiescence state, makes J162117 a very interesting target for further investigation. Although we know that the outburst is associated with the accretion on a white dwarf and that the system may be an unusual CV, the physical reasons that produce this behavior are still unknown.

Some CVs, e.g., the nova-like VY Scl-type variables and the strongly magnetic CVs (polars), usually show sudden dips in their brightness at irregular intervals of weeks to months. Low-luminosity states have been explained as the coverage of dark spots near the L_1 point that then quench the mass transfer (Livio & Pringle 1994; King & Cannizzo 1998). Spots, produced at preferred longitudes, may be due to tidal forces, and were theoretically predicted by Holzwarth & Schüssler (2003). The Doppler image of the detached white dwarf binary V471 Tau was conducted by Hussain et al. (2006), who found that the side of the

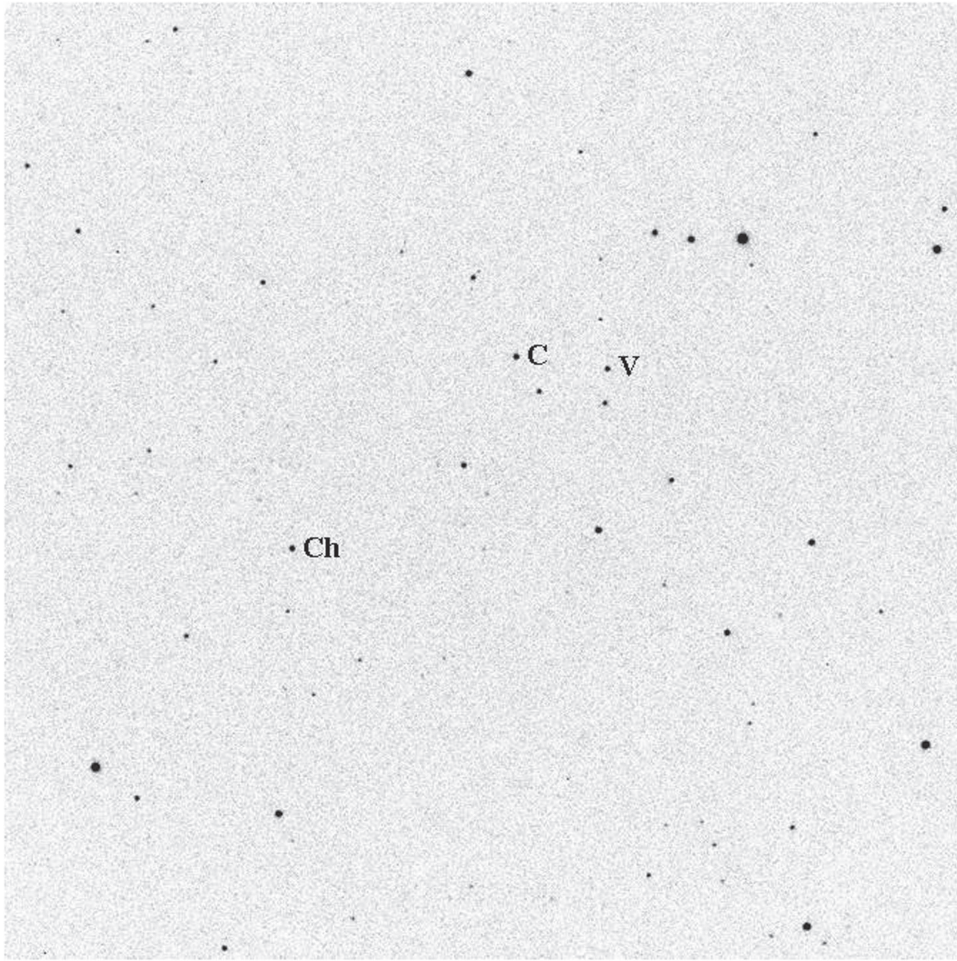


Figure 1. Finding chart of the variable star (J162117). “C” refers to the comparison star, while “Ch” refers to the check star.

Table 1
Information of J162117: The Comparison and Check Stars

	Variable	Comparison Star	Check Star
Name	CSS_J162117.4+441254	LAMOST241916119	LAMOST241916114
R.A.(2000)	245.322395	245.352570	245.433867
Decl.(2000)	+44.215008	+44.220438	+44.181152
U	15.980(± 0.010)	16.815(± 0.014)	15.710(± 0.013)
B	16.000(± 0.007)	16.116(± 0.006)	15.730(± 0.016)
V	15.217(± 0.005)	15.182(± 0.004)	15.142(± 0.008)
R	14.606(± 0.005)	14.658(± 0.006)	14.805(± 0.008)
I	14.050(± 0.005)	14.188(± 0.005)	14.411(± 0.005)
J	13.462(± 0.027)	13.513(± 0.026)	13.975(± 0.024)
H	12.875(± 0.023)	13.095(± 0.025)	13.540(± 0.029)
K	12.763(± 0.025)	12.943(± 0.025)	13.504(± 0.036)

star facing the white dwarf (around the L_1 point) was heavily spotted. These properties, that spots are more preferred near the L_1 point, were also observed in a few CVs (e.g., Watson et al. 2006). However, we know relatively little about the influence of magnetic activity on the mass transfer and accretions in CVs. In this paper, we present the monitoring of photometric data of J162117 from 2016 April 19 to September 14. We show that the mass accretion in J162117 is ceased by dark spots near the L_1 point before and after the outburst, while the outburst may be produced by an intermittent mass accretion on the white dwarf that is caused by the local magnetic activity of the secondary.

These properties indicate that it may be a new type of optical outburst associated with the stellar activity.

2. Photometric Monitoring and the Stellar Outburst of J162117

Due to its unusually short period and it showing EW-type light variation (Palaversa et al. 2013; Lohr et al. 2013; Drake et al. 2014b), J162117 was included in our observational list of contact binary stars below or near the short-period limit (Qian et al. 2014a, 2015b, 2015c; Jiang et al. 2015). We started to observe the binary on 2016 March 19, by using the 84 cm

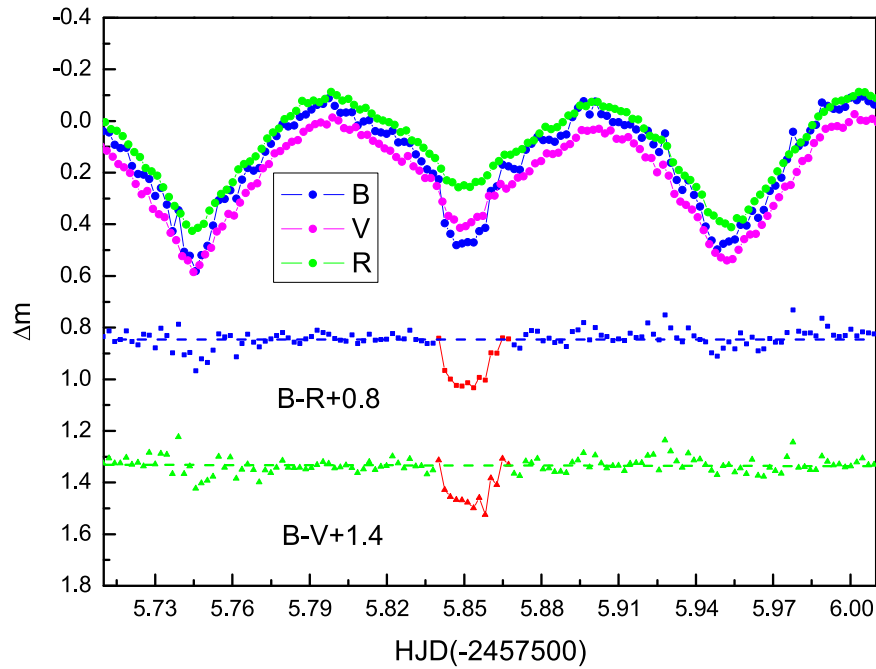


Figure 2. Photometric light curves in the *BVR* bands observed on 2016 April 27. Also shown in the figure as squares and triangles are the $B - R$ and $B - V$ colors, respectively. Two shoulders in the B and V band light curves are clearly seen at both sides of the brightness minimum around HJD 2457505.85, indicating that there are no accretion disks surrounding the white dwarf. This is supported by the $B - R$ and $B - V$ color curves (see the text for details). The BVR light curves are asymmetrical and some of the small optical flares in the B -band light curves are visible.

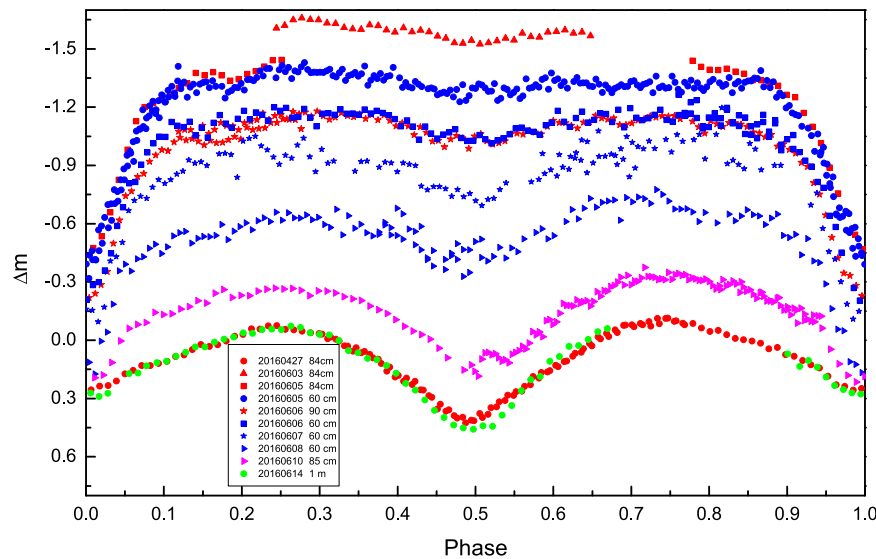


Figure 3. Comparison of the light curves in R band obtained during the outburst and outside the outburst from 2016 April 27 to June 14. The light curves during the outburst are varying rapidly, while those obtained before and after the outburst are nearly overlapping and are showing as asymmetrical (O'Connell effect).

telescope in Mexico. The observations were carried out with the 0.84 m $f/15$ Ritchey–Chrétien telescope at OAN-SPM Baja California, the Mexman filter-wheel, and the *SpectralInstruments* CCD detector (a deep depletion e2v CCD42-40 chip that has a 2048×2048 $13.5 \mu\text{m}$ square pixel array, a gain of $1.32 e^-/\text{ADU}$, and a readout noise of $3.4 e^-$). 2×2 binning was used during all of these observations with exposure times set at 60 s for the filter B integrations, 30 s for V , and 20 s for R , respectively. Flat field and bias frames were also acquired during all of the observing runs. Original CCD images were reduced using the PHOT (aperture photometry on a list of stars) of the aperture photometry package of the IRAF.

As shown in Figure 1, two stars near J162117 were chosen as the comparison and check stars, respectively. Their coordinates and the calibrated magnitudes, together with the corresponding errors, are listed in Table 1. On 2016 March 19 and 21, only data around the eclipses were obtained, while the complete light curves in the BVR bands were observed and are shown in Figure 2. Also displayed in the figure are the $B - V$ and $B - R$ color curves. These pre-outburst light and color curves are very useful for understanding the properties of J162117. The data displayed in Figure 2 are available online.⁷

⁷ <http://search.vbscn.com/J162117.Fig2data.txt>

Table 2
Log of the Photometric Monitoring of J162117 in 2016

Date	Filters	Start Time	Duration (hr)	Telescopes
Mar 19	<i>BVR</i>	−33.0620	2.40	84 cm
Mar 21	<i>BVR</i>	−31.0632	1.37	84 cm
Apr 27	<i>BVR</i>	5.7052	7.35	84 cm
Jun 03	<i>BVR</i>	42.8993	2.05	84 cm
Jun 05	<i>BVR</i>	44.8811	2.35	84 cm
Jun 05	<i>R</i>	45.3309	5.88	60 cm
Jun 06	<i>BVR</i>	46.4068	5.80	90 cm
Jun 06	<i>RI</i>	46.3275	5.84	60 cm
Jun 07	<i>RI</i>	47.3293	5.73	60 cm
Jun 08	<i>RI</i>	48.3292	5.68	60 cm
Jun 10	<i>BVR</i>	50.0813	5.71	85 cm
Jun 12	<i>RI</i>	52.3853	3.67	60 cm
Jun 13	<i>RI</i>	53.3548	5.07	60 cm
Jun 14	<i>RI</i>	54.3376	3.83	60 cm
Jun 14	<i>BVR</i>	54.0518	3.83	1 m
Jun 15	<i>VR</i>	55.1051	5.32	85 cm
Jun 15	<i>RI</i>	55.3347	4.47	60 cm
Jun 17	<i>RI</i>	56.5216	0.64	60 cm
Jun 18	<i>R</i>	58.3403	5.69	60 cm
Jun 22	<i>R</i>	62.3363	5.76	60 cm
Jun 23	<i>RI</i>	63.3405	5.44	60 cm
Jun 23	<i>BVR</i>	63.1080	3.10	1 m
Jun 24	<i>BVR</i>	64.1550	3.02	1 m
Jun 24	<i>RI</i>	64.3538	5.18	60 cm
Jun 25	<i>R</i>	65.3344	1.78	60 cm
Jun 26	<i>R</i>	66.3477	0.42	60 cm
Jun 27	<i>VR</i>	67.4406	2.31	60 cm
Jun 28	<i>R</i>	68.3431	5.42	60 cm
Jun 29	<i>VR</i>	69.3880	1.89	60 cm
Jun 29	<i>R</i>	69.3110	1.23	1 m
Jul 01	<i>VR</i>	71.3350	5.78	60 cm
Jul 04	<i>VR</i>	74.3348	4.01	60 cm
Jul 05	<i>VR</i>	75.3315	5.97	60 cm
Jul 08	<i>BVR</i>	78.0390	1.59	1 m
Jul 09	<i>BVR</i>	79.0334	4.35	1 m
Jul 24	<i>BVR</i>	94.0791	1.72	1 m
Aug 19	<i>BVR</i>	120.0268	2.43	70 cm
Aug 23	<i>BVR</i>	124.0096	3.3	1 m
Sep 13	<i>VR</i>	144.9973	0.68	1 m
Sep 14	<i>VR</i>	146.0052	2.33	1 m

Note. Start time is HJD-2457500.

Although the light curves resemble those of EW types, the details are quite different. The ingress and egress of the shallower eclipsing minima are visible in the *B*- and *V*-band light curves. The two shoulders around the minimum are more visible in the *B*-band light curve and its bottom is nearly flat. These properties indicate that this minimum is caused by the eclipse of a compact object by a normal cool star, revealing that it is a white dwarf-main sequence binary system. This is consistent with the conclusion derived by previous investigators (Drake et al. 2016). Meanwhile, as shown in Figure 2, the eclipse minimum in the *B* band is deeper than those in the *V* and *R* bands, indicating that the white dwarf is hotter than its main-sequence companion. Therefore, this shallower minimum should be the primary one that corresponds with the eclipse of the primary component, i.e., a white dwarf. During the outburst, it becomes deeper, while the other one nearly disappears.

Because of the peculiar observational properties of J162117, after the outburst was reported on 2016 June 3 by Drake et al.

(2016), we continued to monitor the target using the 84 cm and 90 cm telescopes in Mexico. The comparison of the light curves obtained from April 27 to June 14 is shown in Figure 3. The data obtained on June 3 indicate that the secondary minimum became shallower and nearly disappeared. To get more photometric data, J162117 was then monitored continuously using several small telescopes in the Czech Republic and China. The log of the photometric monitoring for the system is shown in Table 2 where the dates and the filters used are listed in the first and the second columns, respectively. Those listed in the third and the fourth columns are the start time (in HJD-2 457 500) and the duration of the observations, respectively. As shown in Figure 3, during the outburst the primary eclipses are very deep, while the secondary minima are shallow. As reported by Zejda & Pejcha (2016), the depth of primary minimum decreases, while the depth of secondary minimum increases as the outburst fades. The system returned to a quiescence state on 2016 June 14, and the light curves obtained before and after the outburst are nearly overlapping.

The total light curves in the *R* band observed from 2016 March 19 to September 14 are displayed in Figure 4, where the blue dots refer to the light curves obtained during the outburst and the green dots refer to those observed outside of the outburst. As shown in Figure 4, the amplitude of the outburst in the *R* band is larger than 1.71 mag. It takes about 11 days for the system to return to the quiescence brightness state. Before and after the outburst, the brightness levels are nearly the same. All of the *R*-band photometric data displayed in Figure 4 are available online.⁸

3. Discussions and Conclusions

During the outburst of J162117, the spectral observations showed some properties of CVs, i.e., the broad, two-peaked emission lines H_{α} (FWHM corresponding to 1500 km s^{-1}), H_{β} , and $\text{He II } 4686$. These are indications of the accretion on a white dwarf (Scaringi et al. 2016). Moreover, the strong rotational disturbance of the emission lines in the eclipse indicates the presence of a rapidly rotating disk (Thorstensen 2016). Therefore, after ruling of the merging of a contact binary as an explanation of the outburst of J162117, this event was attributed to a dwarf nova outburst (Scaringi et al. 2016; Kjurkchieva et al. 2017). However, in comparison with known CVs, J162117 shows several peculiarities (Kjurkchieva et al. 2017), namely a deeper eclipse at the outburst than at the quiescence state (by a factor 2.8) and outburst amplitudes at the lowest limit of dwarf nova eruptions. These properties reveal that J162117 is not a normal CV.

The binary system was monitored photometrically from 2016 April 19 to September 14, using several small telescopes in the world. We were lucky to obtain several high-precision light curves before the outburst. As shown in Figure 2, there are two shoulders around the primary minima in the *B*- and *V*-band light curves. The two minima show a clear U-type shape and that their bottoms are nearly flat. The color curves plotted in the figure also show a U-type shape around the primary minima, while the color curves are flat outside the eclipses. All of these properties suggest that there are no accreting disks around the white dwarf and thus, the white dwarf is not accreting material from the cool secondary at the pre-outburst quiescent state.

⁸ <http://search.vbscn.com/J162117.Fig4data.txt>

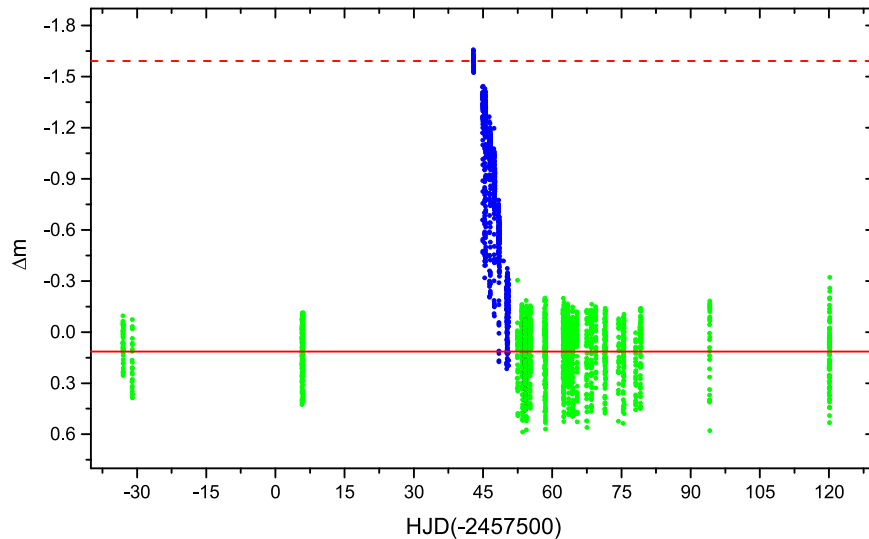


Figure 4. Brightness variation of J162117 in the R band observed from 2016 March 19 to September 14. The blue dots represent the brightness change during the outburst, while the green dots refer to the brightness outside of the outburst.

Apart from the eclipse of the white dwarf component, the BVR light curves shown in Figure 2 are dominated by ellipsoidal variability in a binary star as well as the magnetic activity of the K-type secondary. As displayed in Figure 2, some small flare-like events are visible in the B -band light curves, while these events are not seen in the V and R band light curves. These are general properties of optical flares (e.g., Qian et al. 2012). Moreover, as shown in Table 1, the errors of the B -band magnitudes for J162117 and the comparison star are about ± 0.006 , indicating that those B -band flares are true. The light curves in the figure are asymmetrical, displaying the O’Connell effect. Meanwhile, the depth of the secondary minimum (at phase 0.5) is deeper than that of the primary one (at phase 0.0). These observed properties could be explained by the secondary being covered by dark spots near the inner Lagrange point L_1 where the mass is expected to flow onto the primary. The fact that regions near the L_1 point are heavily spotted has been observed in the pre-CV V471 Tau and in a few CVs (e.g., Hussain et al. 2006; Watson et al. 2006). This type of dark spots, that may be caused by tidal forces and produced at preferred longitudes, was theoretically predicted by Holzwarth & Schüssler (2003). The coverage of dark spots around the L_1 region could cease the mass transfer and thus quench the mass accretion of the white dwarf (e.g., Livio & Pringle 1994; Qian et al. 2014b, 2015a, 2015d). This is the reason why there are no accreting disks around the white dwarf before the outburst.

The comparison of some R -band light curves, observed outside the stellar outburst from 2016 March 18 to July 9, is shown in Figure 5. The light curves are nearly overlapping and there are no noticeable changes in their shape. All of them are asymmetrical (the O’Connell effect) and are showing deeper secondary minima. Meanwhile, the variation of the O’Connell effect (the magnitude difference between the two maxima) is displayed in Figure 6, where the red solid dots refer to the data observed during the outburst, while the green dots refer to those obtained outside the outburst. The magnitudes at the two maxima were determined by averaging the data around phases 0.25 and 0.75, respectively. As shown in the figure, the

O’Connell effect is varying rapidly during the outburst, while it is stable outside the outburst within the error. All of the observations of J162117 reveal that there are dark spots near the L_1 point at those quiescent states. The dark spots on the K-type secondary cease the mass accretion on the white dwarf as well as cause those deeper secondary minima and the O’Connell effect. During the outburst, the dark spots at the L_1 point may disappear, and the sudden mass accretion on the white dwarf causes the stellar outburst. The observed broad, two-peaked emission lines (e.g., H_α) and the strong rotational disturbance of the emission lines during the outburst could be explained by the accretion of the white dwarf component.

Here we speculate that the K-type secondary is only marginally filling the critical Roche lobe. The coverage of dark spots on the secondary could cause it to expand (e.g., Chabrier et al. 2007) and cause materials of the cool secondary to overflow from the Roche lobe. However, J162117 was monitored for many years by the SuperWASP project and had a stable light curve showing the O’Connell effect, as observed in the pre-outburst light curves in Figure 2. This implies magnetic spot coverage for a long time prior to the outburst, indicating that the expansion may be a long-term property of the cool secondary. After it expands to fill the Roche lobe completely, the white dwarf is then suddenly accreting mass from the secondary and producing the outburst. During the outburst, the dark spots around the L_1 region disappear because of the overflow of material onto the hot white dwarf. Finally, the shrinking of the secondary due to the disappearance of the dark spots causes the accretion rate to decrease, and the system returns to its quiescent state. Meanwhile, dark spots near the L_1 region are produced again due to tidal forces, as predicted by Holzwarth & Schüssler (2003).

The present investigation indicates that J162117 is not a normal CV and that the stellar eruption detected on 2016 June 3 is not a dwarf nova outburst, because no lasting accretion disks are around the white dwarf. It is shown that the magnetic activity of the secondary may be associated with the outburst. During the quiescent states, the local dark spots near the L_1 point cease the accretion onto the white dwarf, while the optical outburst is

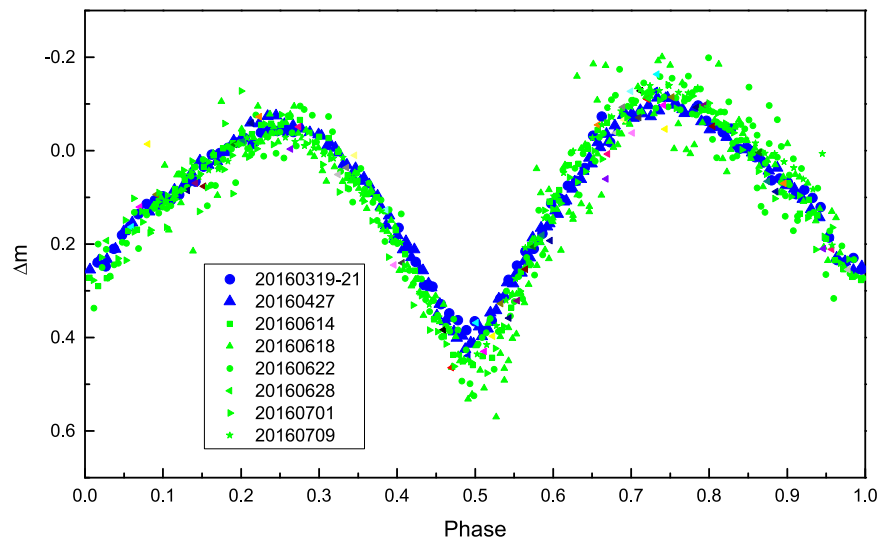


Figure 5. Comparison of several light curves in the R band obtained from 2016 March 18 to July 9. All of the light curves were observed outside the stellar outburst. Those light curves are stable and are showing asymmetry (O’Connell effect).

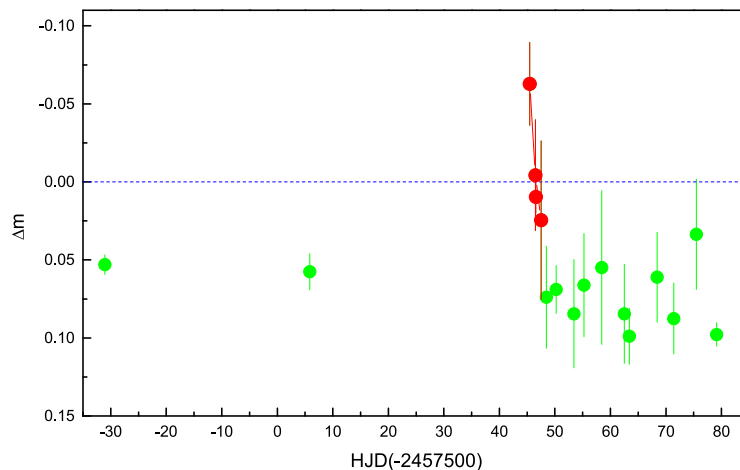


Figure 6. Variation of the magnitude difference between the two maxima (the O’Connell effect). The red solid dots refer to the data obtained during the outburst, while the green dots refer to those observed outside of the outburst. It is shown that the O’Connell effect varies rapidly during outburst, while it is stable outside of the outburst within the error.

produced by an intermittent mass accretion. The mass accretion during the outbursts may be caused by the expansion of the secondary via the presence of the dark spots. In this way, both of the eclipses of the outburst, rather than those of the quiescence state or the low-amplitude outbursts (which are only about 2 mag), could be explained. The eruption event in J162117 may be a new optical outburst associated with the stellar activity. These results make J162117 a very interesting target for future investigations on stellar magnetic activity and its influence on CV mass transfer and mass accretion.

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