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Evolution of 2MASS J16211735+4412541 light curve in the quiescent state

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Abstract. We report follow-up multifilter observations of the binary 2MASS J16211735+4412541 taken in BVRI colors in 2017 and 2018. We present the evolution of the shape of the light curve, as well as the preliminary results from modelling the system. Based on these and a spectrum showing double peaked Balmer emission lines, we infer that the system still contains an accretion disk and not a bare white dwarf.

Key words: stars:individual: 2MASS J16211735+4412541 – binaries:eclisping – cataclysmic variables

1. Introduction

2MASS J16211735+4412541 is a short-period eclipsing binary (P=0.21^d) which was classified as a contact system based on its light curve as gathered by large surveys. In June 2016 it unexpectedly brightened by about 2 magnitudes and stayed in this high state for about 2 weeks. The shape of the light curve changed during the outburst, but within a week the system returned to its pre-outburst state. Following the initial alert by Drake et al. (2016), this event drew much attention from observers and resulted in the posting of several pieces of information about its properties in the Astronomer's Telegrams (Maehara (2016); Scaringi et al. (2016); Zejda & Pejcha (2016); Thorstensen (2016)). Less than two weeks later, on June 12, the light curve taken in the R filter displayed the usual, pre-outburst shape, typical of an eclipsing binary system with a close configuration (Zola et al., 2016).

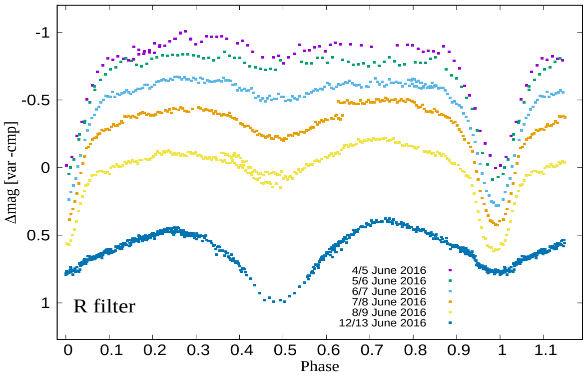

Figure 1. Changes of the light curve shape during the 2016 outburst. Only R filter data are shown here.

We monitored the outburst starting from June 4, first with the 35 cm Maksutov telescope in Krakow, and from June 6 also with the 50 cm telescope at the same site and the 60 cm at the Mt. Suhora observatory. In Fig. 1 we show the light curve of the system taken at outburst (June 4-8, 2016) and that taken on June 12, when the system returned to its low state. During the outburst, the depths of the minima were reversed, with the one which was shallower in the low state becoming the deeper one. The shape of the light curve appeared distorted, and changing rapidly while the system brightness was declining. The depth of the deeper (outburst) minimum was decreasing and once the system returned to the low state it again became the less deep one, as observed in the pre-outburst state. Furthermore, the decline was so fast that it was impossible to match the level of the light curve at the same phase taken at the beginning and the end of a night (see Fig. 1).

The first model of the system was published by Kjurkchieva et al. (2017), who analyzed the system light curve and arrived at the conclusion that due to enhanced mass transfer, a temporary disk was being created around the white dwarf which, after some time, entirely accreted leaving the system consisting of a main sequence star and a bare white dwarf. A diskless model of the binary in quiescence was also proposed by Qian et al. (2017) with brightening being due to mass transfer bursts. The study by Zola et al. (2017) based on photometry, spectroscopy and data taken by SWIFT concluded that this cataclysmic type variable does harbour an accretion disk even more than a year after the outburst. Kimura et al. (2018) arrived at a similar model of a high inclination system with an accretion disk in both high and low states.

2. Spectroscopic Observation

Two spectra were obtained with the Double Imaging Spectrograph on the Apache Point Observatory 3.5m telescope on April 17, 2018, using 10 min exposures for each. The grating settings, calibration and reduction were identical to those in Zola et al. (2017). The red spectra (Fig. 2) show deep doubling of the Balmer lines, clearly indicative of an accretion disk viewed at relatively high inclination.

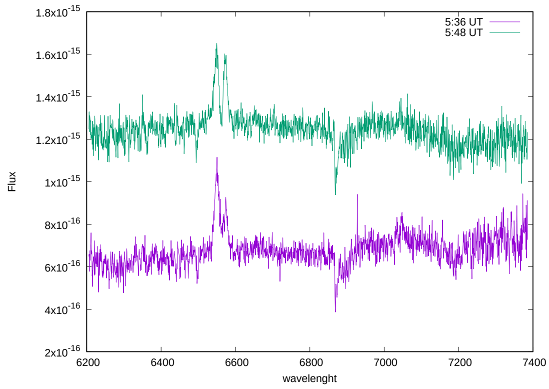

Figure 2. Spectra of 2MASS J16211735+4412541 obtained with the APO 3.5m telescope (red) on April 17, 2018. The shape of the H_α line changed between the two consecutive spectra taken at 5:36 UT (top) and at 5:48 UT (bottom). The top spectrum is offset for clarity.

3. Photometric Observations and Light Curve Modeling

In the beginning and ending of the 2017 and 2018 observing seasons we collected a complete multicolor light curve of J1621 using two telescopes: the 50 cm telescope at the Astronomical Observatory of the Jagiellonian University in Krakow and the 60 cm telescope at the Mt. Suhora Observatory of the Pedagogical University. Both telescopes are equipped with Apogee CCDs and a set of wide-band filters. Light curves in B and V filters were taken at the Mt. Suhora observatory, while those in R and I filters at the Krakow site. A series of calibration images were taken every night. Reduction of observations were performed in a standard way, with calibration images for bias, dark and flatfield (taken on sky) done with the IRAF package, while extraction of magnitudes with the CMunipack package (an interface to the DAOPHOT program) using the aperture method. The resulting light curves (phase versus differential magnitudes) gathered in 2017 and 2018 are shown in Figs. 3 and 4. Note the different depths of the primary (phase 0) minima between May 2017 and August 2018 (the most recent observations). On all dates, the depth of the primary minimum grows toward shorter wavelengths and in the U filter this minimum becomes deeper (see the left panel of Fig. 4) than the secondary one. The most recent light curves in R and I filters may be taken as typical of a close or contact system.

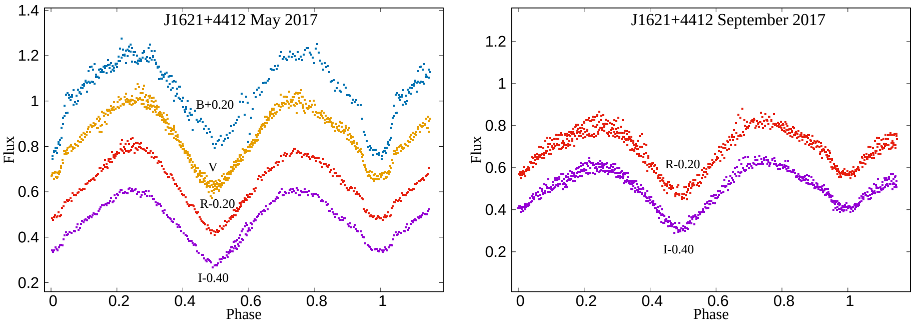

Figure 3. The light curves of 2MASS J16211735+4412541 taken in May (left panel) and September (right panel) 2017.

We phased the newly gathered light curves and recalculated magnitude differences into flux normalizing it to 1 at the first quadrature. We also analyzed the BVR light curves published by Qian et al. (2017). The ephemeris listed in Zola et al. (2017) was used for phasing and the primary minimum corresponds to the minimum which was deeper during the outburst. While doing light curve modelling, we applied the disk model and followed the same procedure as outlined in Zola et al. (2017). The program we used for light curve simulation is a modified Wilson-Devinney code altered by adding a phenomenological disk model that surrounds the star eclipsed at phase 0. The disk is assumed to be optically thick and its vertical thickness grows linearly with radius. The secondary star is assumed to fill in the Roche lobe. This model accounts for effects due to the presence of the disk, e.g. obscuration of primary and secondary stars by the disk, self obscuration of the disc face. The search for the best fit is done by the Monte Carlo search method. Further details were given in Zola (1991) and Zola (1992).

The theoretical model lines and the observed data (gathered in April 2016 and March 2018) are shown in Fig. 5.

We were able to obtain fits of reasonable quality to all quiescent light curves within the disk model. Even the fit derived to the sparse U filter data resembles the observations pretty well. Comparing the current system parameters with those obtained during the outburst, its is obvious that both the accretion disk and the accreting white dwarf are cooling, plausibly as a result of decreasing mass transfer rate. The temperature of the accreting component, the accretion

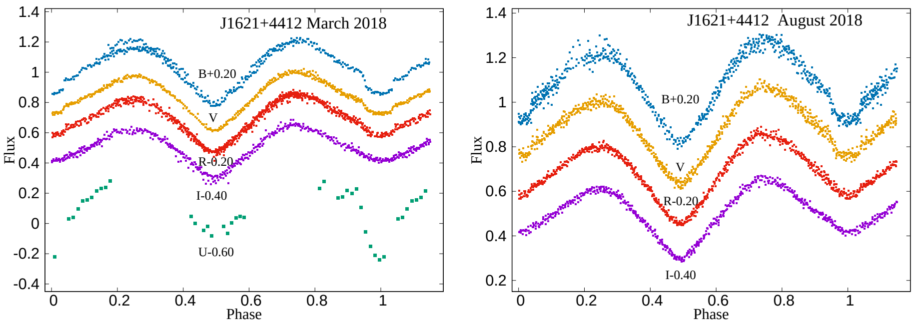

Figure 4. Light curve of 2MASS J16211735+4412541 gathered in March (left panel) and in August 2018 (right panel).

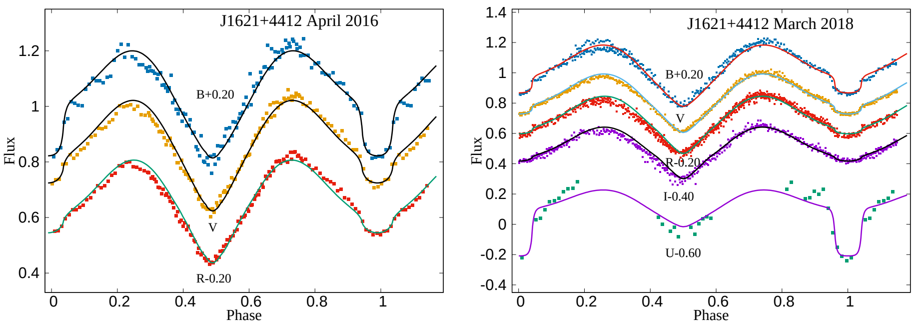

Figure 5. Model light curves (continuous lines) plotted along observed ones (square symbols). The pre-outburst (April 2016) LC is shown in the left panel, while that taken in March 2018 in the right one.

disk size (in units of components separation) and its light contribution to the system total light (at phases of full accretion disk visibility) derived from modelling are presented in Table 1.

4. Conclusions

– We have gathered multicolor light curves of J16211735+4412541 during quiescence twice in the 2017 and 2018 observing seasons. The most recent one was taken in August 2018, more than 2 years after the 2016 outburst. One can notice the decreasing depth of the primary minimum with time, especially well seen in the B filter, indicating cooling of the accreting white dwarf and the surrounding accretion disk.

Table 1. White dwarf temperature, the size of an accretion disk and the disk light contribution in B and R filters.

Date	T_1 [K]	r_d	l_d [B]	l_d [R]	remarks
Apr 2016	11 360	0.32	16%	5%	this work
Jun 6 2016	44 600	0.39	53%	44%	Zola et al. 2017
Aug 2016	14 350	0.45	10%	7%	Zola et al. 2017
Mar 2017	28 180	0.44	5%	10%	this work
May 2017	16 830	0.34	16%	6%	this work
Sep 2017	11 440	0.28	–	4%	this work
Mar 2018	16 850	0.29	4%	1%	this work
Aug 2018	11 430	0.33	9%	2%	this work

– The light curves are asymmetric, exhibiting an O'Connell effect with a lower level of the first quadrature. A cool spot located on the surface of the secondary, mass losing star could be the reason. An additional, smaller in quantity, rise of the flux in the descending part of the primary minimum may be due to a hot spot on the accretion disk.

– The properties of the target light curve and clearly visible double peaked Balmer emission lines lead to the conclusion that there is an accretion disk still present in the system two years after the outburst. A similar shape of the pre-outburst light curve indicates that it was presumably also present in April 2016, about two months before the outburst.

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