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Photometry of the eclipsing cataclysmic variable SDSS J152419.33+220920.0★ (Research Note)

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ABSTRACT

Aims. We present new photometry of the faint ($g \sim 19$ mag) and poorly studied cataclysmic variable SDSS J152419.33+220920.0, analyze its light curve and provide an accurate ephemeris for this system.

Methods. Time-resolved CCD differential photometry was carried out using the 1.5 m and 0.84 m telescopes at the Observatorio Astronómico Nacional at San Pedro Mártir.

Results. From time-resolved photometry of the system obtained during six nights (covering more than twenty primary eclipse cycles in more than three years), we show that this binary presents a strong primary and a weak secondary modulation. Our light curve analysis shows that only two fundamental frequencies are present, corresponding to the orbital period and a modulation with twice this frequency. We determine the accurate ephemeris of the system to be $\mathrm{HJD}_{\mathrm{eclipse}} = 2\,454\,967.6750(1) + 0.06531866661(1)$ E. A double-hump orbital period modulation, a standing feature in several bounce-back systems at quiescence, is present at several epochs. However, we found no other evidence to support the hypothesis that this system belongs to the post-minimum orbital-period systems.

Key words. novae, cataclysmic variables – stars: individual: SDSS J152419.33+220920.0

1. Introduction

The discovery of the cataclysmic variable SDSS J152419.33+220920.0 (hereafter SDSS 1524) was announced in the seventh CV release of the Sloan Digital Sky Survey (SDSS; Szkody et al. 2009). The complete SDSS optical spectrum of this object is shown in Fig. 1. It shows a blue continuum with strong double-peaked Balmer emission lines, which is typical of high-inclination systems, and, as Szkody and collaborators pointed out, a candidate for showing deep eclipses of the white dwarf by the secondary star. No spectroscopic features from the donor star are detected in the red part of the spectrum. The object, at quiescence, has a magnitude of $g \sim 19$ mag; two outbursts have been detected by the Catalina Real-Time Transient Survey (CRTS; Drake et al. 2009). The first one[1] was reported first on March 30 2009 by the Variable Star Network (VSNET, see Kato et al. 2004)[2] and was subsequently confirmed by the Center for Backyard Astrophysics. The latter pointed out that the object was previously followed at quiescence for some weeks and showed deep eclipses with a period of 0.065317 days[3]. On March 31 2009 the AAVSO Cataclysmic Variable Network confirmed the presence of superhumps[4], and of a 1.5 mag eclipse when the system was at magnitude 15. The second outburst on January 18 2012 was also detected by the CRTS and by the VSNET[5]. This outburst had a confirmed magnitude of ∼15.5 but no other observations have been reported.

An analysis of the 2009 outburst showed positive superhumps with a period of 0.06711 days (Kato et al. 2009). These authors also provided ephemeris of the eclipses during outburst: Min(BJD) = 2 454 921.5937(1) + 0.0653187(1) E. Gänsicke et al. (2009) included SDSS 1524 in a large study of faint newly discovered SDSS CVs, concluding mainly that the orbital period distribution statistics have greatly improved thanks to the nearly 140 objects. This new faint sample, not surprisingly, favours detection of short-orbital-period systems. Southworth et al. (2010), based on two eclipses observed on 6 May 2009, using the WHT in service mode, derived the following ephemeris: Min(HJD) = 2 454 957.6499(1) + 0.06500(32) E. The light curve of their second eclipse shows evidence of an occultation of the hot spot and the white dwarf.

★ Photometry described in Table 1 is only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsarc.u-strasbg.fr/viz-bin/qcat?J/A+A/554/A25

[1] http://nesssi.cacr.caltech.edu/catalina/20090329/903291210784144089p.html

[2] VSNET-alert 11133.

[3] http://cbastro.org/communications/news/messages/0635.html

[4] cvnet-outburst/message/3029.

[5] VSNET-alert 14121.

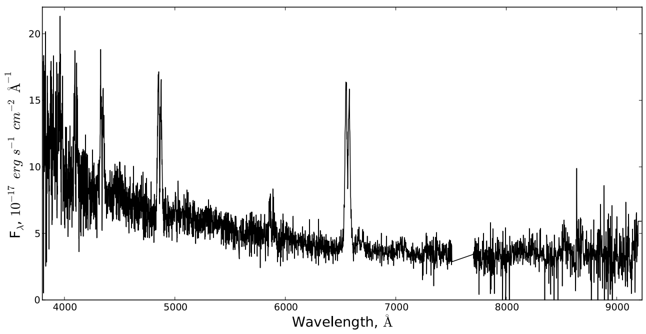

Fig. 1. Spectrum of SDSS 1524. Data are taken from the SDSS database.

Table 1. Log of photometric observations.

Date (UT)	HJD begin +2 450 000	HJD end +2 450 000	No. of images	Exposure time (s)
May 16 2009	4967.71141	4967.98379	181	100
May 21 2009	4972.91246	4973.00072	72	100
May 22 2009	4973.64853	4973.99673	286	100
May 20 2011	5701.69035	5701.99199	187	120
Jun. 07 2011	5719.66400	5719.92770	173	120
Aug. 08 2012	6147.64344	6147.79328	113	100

Since this object requires a comprehensive photometric analysis, we decided to observe it at different epochs and collect enough information to improve on its light curve, eclipses, and ephemeris. Thus, in this paper we present new time-resolved photometry of SDSS 1524 and the results of its light curve behaviour, as well as an improved ephemeris. We discuss the possible membership of this object to post-minimum-orbital-period systems.

2. Observations

We obtained white-light time-resolved photometry of SDSS 1524 during 16, 21 and 22 May 2009 at the 1.5 m telescope of the Observatorio Astronómico Nacional at San Pedro Mártir. Additional observations were obtained with the 0.84 m telescope on 20 May and 7 June 2011 and 8 August 2012. In all runs we used the Blue-ESOPO CCD detector on a 1024 × 1024 pixel configuration (Echevarría et al. 2008). The exposure times were between 100 and 120 s. In total, the object was monitored for ~30 h and nearly 24 complete eclipses were measured. Data reduction was performed with the IRAF[6] software. The images were corrected for bias and were flat-fielded before aperture photometry was carried out. An estimate of the uncertainty of the CCD photometry of SDSS 1524 is about 0.02 mag outside eclipse. Differential photometry was obtained using star C1 as shown in Fig. 2. The log of observations is presented in Table 1.

3. Period analysis

The photometric data of SDSS 1524 were analysed for periodicities using the discrete Fourier transform (DFT) code implemented in the *Period04* (Lenz & Breger 2005) programme. The

[6] IRAF is distributed by the National Optical Observatories, operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

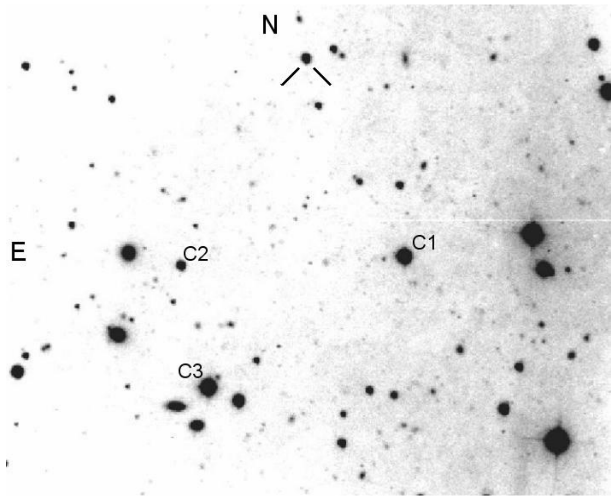

Fig. 2. Finding chart for SDSS 1524. The field is ~4 × 3.5 arcmin. The differential photometry was made with respect to star C1 (SDSS J152415.99+220804.0, g = 17.77), while stars C2 (SDSS J152422.53+220753.5, g = 19.23) and C3 (SDSS J152421.46+220705.7, g = 16.97) were used as references to check that C1 was not a variable as well.

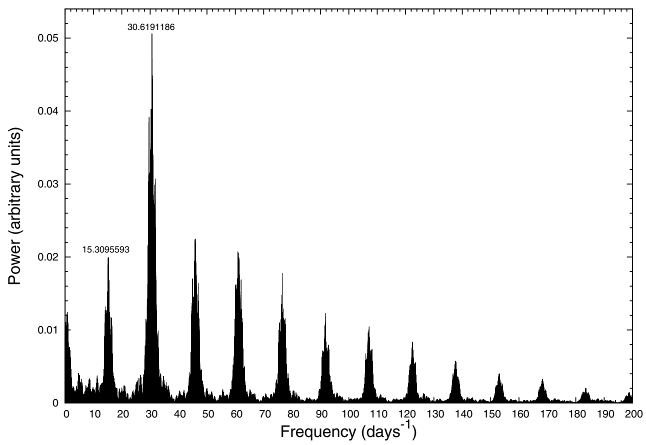

Fig. 3. DFT analysis for SDSS 1524. The power spectrum shows the strongest peak at f = 30.6191 d^{-1}, while the orbital period correspond to f = 15.3096 d^{-1}. All other peaks are harmonics of these two fundamental frequencies.

power spectrum, shown in Fig. 3, shows the strongest peak at f = 30.6191 d^{-1}, because of a strong primary eclipse and a shallow secondary eclipse. The primary eclipse alone gave a clear peak at f = 15.3095593 d^{-1} corresponding to an orbital period of P = 94.06 min, as shown in Fig. 3. The other peaks are harmonics of this frequency. To fit the overall light curve, we used *Period04* to calculate the phase and amplitude of its first 15 harmonics. The fit is shown as solid lines in Figs. 4 and 5.

4. Improved ephemeris

Shortly after the publication by Szkody et al. (2009), we started to observe SDSS 1524 and obtained a total of 24 orbital cycles spanning more than three years. We have followed a consistent observational and reduction method throughout all epochs. Because of the symmetry of the eclipses, we fitted Gaussian profiles to determine the mid-eclipse timing. This allowed us to

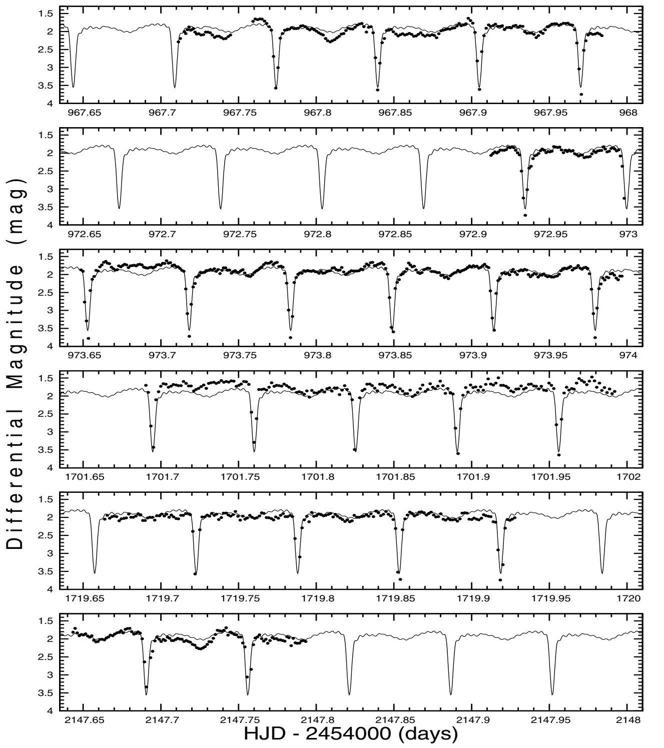

Fig. 4. Differential photometry for SDSS 1524 with respect to star C1 (circles) and the DFT fit (solid line) for all six runs (*from top to bottom*). See text for details of each observation.

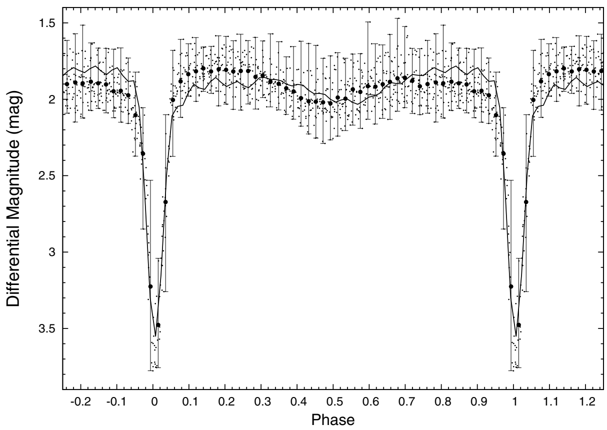

Fig. 5. Folded photometry for SDSS 1524. The original data (dots) were binned in intervals of 0.02 in phase (open squares), the bars represent the extreme points in that phase interval. The solid line is the fit discussed in the text.

calculate the improved ephemeris using only the data described in Sect. 2,

$$\mathrm{HJD_{eclipse}} = 2\,454\,967.6750(1) + 0.06531866661(1)\,E, \qquad (1)$$

where phase zero correspond to the mid-eclipse by the secondary star.

5. Light curve behaviour

The photometric data are shown in Fig. 4 together with the fit discussed in Sect. 3. The data are separated into the six observing runs for clarity, as presented in Table 1. Although SDSS 1524 at first sight appears to have a regular photometric behaviour with an almost constant difference of two magnitudes with respect to C1 and deep eclipses of more than 1.5 mag, we point out that the deep eclipses mask a variety of light curves, some of them similar to those observed in WZ Sge (Patterson et al. 1998, hereafter PEA98). At some stages (first, third, and sixth run) the object shows a clear hump before primary eclipse in some cycles, with a decreased magnitude at the egress, similar to that in PEA98 Fig. 1, middle-panel and to the photometry reported in Southworth et al. (2010). This is typical of high-inclination systems with a bright spot, which are self-obscured by the accretion disc at this orbital phase (e.g. Warner 1995). At other stages (cycles in fourth and fifth runs), the system shows a double cycle variation with the orbital period, similar to those in PEA98 (Fig. 1 upper-panel), where the ingress and egress have comparable brightness. The difference in contrast between these two objects arises because the eclipses in WZ Sge are not very deep; and is most certainly due to the difference in the inclination angle, which in WZ Sge is ~75° (Smak 1993), while in SDSS 1524 it is ~83° (Southworth et al. 2010; Smak 2010).

The strength of the secondary minimum is variable from cycle to cycle, with a highest depth of about 0.4−0.5 mag (third cycle, first run) to almost an absence of it (e.g. fifth run). Its strength is not tied to the hump prior to eclipse, as show for example in the variety of the eclipses in the first run. Its position in phase also appears to shift (almost up to $\phi = 0.6$). This is very clear in Fig. 5, where we have folded the data with the orbital period. The small dots correspond to all observed points, while the open squares correspond to the data binned in 0.02 phase intervals. The error bars represent the highest and lowest values at that interval. The solid line is the fit discussed in Sect. 3. While the binned data show a minimum closer to phase 0.5, the fit favours a minimum closer to phase 0.6. This is probably due to the variation of brightness and location of a hot spot. The double cycle variation is more evident in Fig. 5. The secondary minimum is also present in the observations presented in Southworth et al. (2010). The presence of the humps or the secondary minimum may be tied to the outbursts. This is evident, for example, in the first 2009 March outburst. Our observations in 2009 May show a strong activity in the light curves, while in our 2011 May run there seems to be a more quiet behaviour. Although we only have two nights around the 2012 outburst there is at least an indication of a lower activity prior to outburst than after.

6. A bounce-back system?

A large number of short-period cataclysmic variables have been found in the Sloan Digital Sky Survey, confirming the prediction of an accumulation of systems close to the orbital period minimum in the 80−90 min range (Gänsicke et al. 2009). Of these, a few have been confirmed as moving away from this period minimum, the so-called bounce-back systems (Zharikov et al. 2010; Savoury et al. 2011). A great interest pertains to the observation of these binaries because they confirm the secular evolution of cataclysmic variables at the short-end of the orbital period range (e.g. Kolb & Baraffe 1999, and references therein), and also because of the physical study of brown dwarfs, here defined as stars that have lost mass up to the point where they can no longer produce nuclear reactions, but are still semi-detached binaries and are losing enough mass to produce an accretion disc.

SDSS 1524 shows a double-hump orbital period modulation, a characteristic feature in several bounce-back systems at quiescence as described in Zharikov & Tovmassian (2009) and Zharikov et al. (2010). These authors proposed that double-humps at quiescence might be an indication of a permanent

2:1 resonance in the accretion disc, which would require an extreme mass ratio ($q \leq 0.1$). In SDSS 1524, this modulation has the strongest peak in our DFT analysis. Although the deep primary eclipses mask this modulation, it is clearly present in the binned data shown in Fig. 5. From their models of the light curve during primary eclipse, Southworth et al. (2010) derived very similar results for SDSS 1524 and SDSS J115207.00+404947.8.

However, while SDSS J115207.00+404947.8 shows a shallow absorption in H_β and other higher order Balmer lines, SDSS 1524 shows only a marginal absorption, and that only in H_β. The presence of strong and broad Balmer lines in absorption (presumably coming from the white dwarf) are a strong feature in bounce-back systems. This is clearly the case in SDSS J103533.02+055158.3 (Southworth et al. 2006). However, other candidates such as SDSS J123813.73-033933.0 (Zharikov et al. 2006) and SDSS J080434.20+510349.2 (Szkody et al. 2006) show a less prominent white dwarf. In fact, SDSS J123813.73-033933.0 shows a variable contribution of the white dwarf at different epochs (Avilés et al. 2010). It is possible that a similar behaviour might be found in SDSS 1524 and that the white dwarf will become visible. However, the high inclination of SDSS 1524 implies that we are viewing a more edge-on disc, which can hide the white dwarf contribution. More spectra are required and simultaneous photometry is strongly suggested to confirm if the brightness and appearance of the double-hump are correlated with spectral changes in this system. Kato et al. (2009) found the mass ratio from their superhump excess relationship to be $q = 0.138$. Although their observations are scant and the actual light curve is not shown in their paper, their results and the fact that the secondary eclipse and hump is not always present argue strongly against a bounce-back object.

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