Superhumps and post-outburst rebrightening episodes in the AM CVn star SDSS J012940.05+384210.4

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Abstract

We report unfiltered photometry of the first confirmed outburst of the AM CVn system SDSS J012940.05+384210.4 during 2009 December. At its brightest the star was magnitude 14.5, 5.4 magnitudes above mean quiescence. Although the first part of the outburst was not observed, six remarkable rebrightening events were observed during the course of the outburst. Forty-one days after the outburst was detected, the star was still 1.7 magnitudes above quiescence. Superhumps were observed during the outburst with a peak-to-peak amplitude of 0.06 mag and $P_{sh} = 37.9(2)$ min. We also used archival data to show that another AM CVn system, SDSS J124058.03-015919.2, has also undergone at least one outburst, with an amplitude of ~4.6 magnitudes.

Introduction

The AM CVn stars are a class of cataclysmic variables comprising two interacting white dwarfs. Due to their proximity, mass is transferred from one star (the secondary, or donor) and because the material has significant angular momentum it does not settle immediately on the primary, but instead forms an accretion disc around the primary. Spectroscopy has shown that these binaries are comprised largely, or completely, of helium. They have ultra-short orbital periods in the range ~10 to 65 mins. These systems are so compact that both binary components are degenerate (or semi-degenerate) and it is thought that the mass transfer is driven by gravitational radiation (1) (2).

Very few confirmed AM CVn stars are known: only about two dozen are suspected at the time of writing (3). Anderson *et al.* (2) examined spectra from the Sloan Digital Sky Survey (4) (5) (SDSS) in an attempt to find new AM CVn stars from their telltale helium-dominated optical spectrum. SDSS J012940.05+384210.4 was identified in this search from its broad Hel emission lines (2). Thus far, no orbital period has been published. SDSS lists magnitude g=19.81, r=20.04. Data from the Catalina Real-Time Sky Survey (CRTS) (6), shows that it varies between V= 18.9 and 21.1, with a mean of V= 19.9. The star is located in Andromeda at RA 01h 29min 40.05s +38deg 42min 10.4s.

The outburst of SDSS J012940.05+384210.4 discussed in this paper, which is the first on record, was discovered on 2009 Nov 29.045 by the authors (7) using the

Bradford Robotic Telescope (8) at an unfiltered magnitude of 14.5 as part of a programme to monitor cataclysmic variables for outbursts using small telescopes; this particular star has been monitored since 2009 January.

Photometry and analysis

The authors conducted 63 h of unfiltered photometry using the instrumentation shown in Table 1 and according to the observation log in Table 2. Images were dark-subtracted and flat-fielded prior to being measured using differential aperture photometry relative to the V-sequence given on AAVSO chart 3325juo (9). Heliocentric corrections were applied to all data.

Profile of the 2009 outburst

The overall light curve of the outburst is shown in Figure 1, based on the authors' photometry, supplemented with data from the AAVSO International Database (10), and CRTS. Expanded plots of some of the longer photometry runs are shown in Figure 2.

Unfortunately the beginning of the outburst is not well constrained due to gaps in the observational data and the plateau phase, assuming one was present, was missed. Only a single observation was made on discovery night (JD 2455164), when the star was at its brightest at magnitude 14.5; the previous recorded observation was made 12 days earlier when the object was fainter than magnitude 16.9. Two nights after the outburst was detected the star had faded to 14.8 and was undergoing a rapid decline at 2.7 mag/d (Figure 2a). This was followed by at least 6 rebrightening episodes at 3 to 5 day intervals (~ JD 2455169, 172, 176, 183, 188 and 203). Other rebrightenings might have been missed due to incomplete coverage. Based on an average quiescence brightness V=19.9, the outburst amplitude was therefore at least 5.4 magnitudes. The star was still ~1.7 magnitudes above mean quiescence 41 days after the outburst was first detected.

Detection of superhumps

Inspection of the light curve from JD 2455172, during one of the rebrightening episodes, clearly shows the presence of regular modulations which we interpret as superhumps (Figure 2 b). We performed a period analysis of the combined data using the Lomb-Scargle algorithm in Peranso (11), after subtracting the mean magnitude. This gave the power spectrum in Figure 3. The highest peak in the power spectrum is at 38.02(22) cycles/day, which we interpret as being due to the superhumps. This results in a superhump period, $P_{sh} = 37.9(2)$ min or 2274(12) sec. The error estimates were derived using the Schwarzenberg-Czerny method (12). The same signal was identified using several other algorithms in Peranso. Prewhitening the power spectrum with the 38.02 cycles/day signal left only weak signals, none of which has any significant relationship to the superhump period. A phase diagram of the data, folded on the proposed P_{sh} , is shown in Figure 4, where two

cycles are shown for clarity. This shows a classical saw-toothed superhump profile with a peak-to-peak amplitude of 0.06 mag.

We also performed a Lomb-Scargle period analysis on the data from the rebrightening episodes of JD 2455178 (Figure 2c) and 183 (Figure 2d). In both cases the star was fading rapidly (3.1 and 2.3 mag/d respectively), so we first subtracted the linear trend from the data and found signals at 38.16(91) and 37.94(90) cycles/day respectively. These values are consistent with the value for $P_{\rm sh}$ measured on JD 2455172 as described above. By contrast, when we analysed the data from JD 2455166, corresponding to the first observed rapid fade (Figure 2a), we only found very weak signals, none of which appeared to be related to the signals at around 38 cycles/day which were found later in the outburst (however, we note that Kato *et al* (13). report a signal in data from JD 2455166 at around 26 mins which they interpret as $P_{\rm sh}$). Unfortunately our time series data from the other nights were too noisy, due to the faintness of the star, for satisfactory period analysis to be carried out.

Identification of a further outbursting AM CVn system: SDSS J124058.03-015919.2

We note the similarity of the probable orbital period of SDSS J012940.05+384210.4 (~37 min) to that of SDSS J124058.03-015919.2 (37.355(2) min) (14). The latter was identified as an AM CVn system by Roelofs *et al.* (14) with a low mass transfer rate, although they could not rule out outbursts. We examined CTRS data (6) and found that in quiescence SDSS J124058.03-015919.2 varies between V= 19.1 and 21.4, with a mean of V= 19.9. The star appears to have undergone an outburst in 2005: ASAS-3 (15) (All Sky Automated Survey) detected the outburst on 2005 March 15 and March 17 at V=13.53(04) and 13.78(5) respectively. CRTS also appears to have caught the tail of this outburst at V = 17.03(4) on 2005 April 4 and it was still above quiescence (V=18.3) some 77 days after detection. The outburst light curve is shown in Figure 5.The outburst amplitude was 4.6 magnitudes above mean quiescence. Thus SDSS J124058.03-015919.2 is the seventh confirmed outbursting AM CVn system.

Discussion

AM CVn systems have been classified into 3 broad groups, based on their observed characteristics, as a function of increasing orbital periods (1) (14):

- (i) The short-period, high state systems which are permanently bright and have high mass transfer rates, with $P_{\text{orb}} \lesssim 20$ min, such as AM CVn and HP Lib
- (ii) The longest period, low state, systems that are believed to be in a stable state of low mass transfer, with $P_{\text{orb}} \gtrsim 40$ mins, such as GP Com and CE315

(iii) The intermediate period outbursting systems, with 20 $^{\lesssim}$ P_{orb} $^{\lesssim}$ 40 mins. Thus far only 5 such systems have been confirmed (16): CR Boo, KL Dra, V803 Cen, CP Eri and V406 Hya (previously known as 2003aw).

The stars in group (iii) have exhibited superhumps, where the superhump period excess, $\epsilon = (P_{sh} - P_{orb})/P_{orb}$, is in the range 0.003 to 0.020 (see Table 3). Therefore our measurement of $P_{sh} = 37.9(2)$ min for SDSS J012940.05+384210.4 suggests that its P_{orb} is probably ~37 min. The outbursting nature of SDSS J012940.05+384210.4 which we report in this paper clearly makes this system the sixth member of the group (iii) described above.

The group (iii) AM CVn systems have been described as the helium cousins of the hydrogen-dominated dwarf novae (16). Patterson *et al.* (17) and Gaensicke *et al.* (18) analysed P_{orb} as a function of P_{sh} for a large sample of SU UMa hydrogen dwarf novae and found a strong correlation between the two parameters; unfortunately such a correlation does not presently exist for superhumping AM CVn systems as so few have been observed. It is hoped that as more surveys are conducted, more such systems will be identified.

One of the most remarkable features of the outburst light curve of SDSS J012940.05+384210.4 is the rebrightening events. A very similar behaviour was observed by Kato et al. (19) in the AM CVn system, V803 Cen, during its 2003 June outburst, when at least 7 rebrightening events were observed. Rebrightenings (sometimes called "echo outbursts") have also been reported in several members of the WZ Sge family of hydrogen dwarf novae, including WZ Sge itself (20). WZ Sge systems are a highly evolved sub-set of the SU UMa family, which have very short orbital periods and low mass transfer rates.

Conclusions

The AM CVn system SDSS J012940.05+384210.4 was found to be in outburst in 2009 December, the first confirmed outburst on record. We report unfiltered photometry obtained during the outburst. At its brightest the star was magnitude 14.5, 5.4 magnitudes above the mean quiescence level of V = 19.9 found in data from the Catalina Real-Time Sky Survey (6). Although the first part of the outburst was not observed, six remarkable rebrightening events were observed during the course of the outburst. The star was still 1.7 magnitudes above quiescence 41 days after the outburst was detected. Superhumps were observed during the outburst, confirming it to be a superoutburst, with a peak-to-peak amplitude of 0.06 mag and P_{sh} = 37.9(2) min.

SDSS J012940.05+384210.4 is thus confirmed to be a sixth member of the outbursting group of AM CVn stars. The observed rebrightening episodes are similar to those seen during the 2003 June outburst of the AM CVn star, V803 Cen. Moreover, they are reminiscent of the echo outbursts shown by many members of the WZ Sge family of hydrogen dwarf novae.

We also used archival data to show that another AM CVn system, SDSS J124058.03-015919.2, and which likely has a similar P_{orb} to SDSS J012940.05+384210.4, has also undergone at least one outburst, in 2005 March. The outburst amplitude was at least 4.6 magnitudes.

Rather few AM CVn stars are known and the characteristics of the outbursting systems are not well studied. Thus we encourage further monitoring of SDSS J012940.05+384210.4 and SDSS J124058.03-015919.2 with the aim of identifying and studying future outbursts.

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Observer	Telescope	CCD		
Shears	0.28 m SCT	Starlight Xpress SXVF-H9		
Brady	0.4 m reflector	SBIG ST-8XME		
Koff	0.25 m SCT	Apogee AP47		
Goff	0.4 m reflector	SBIG ST-8		
Boyd	0.35 m SCT	Starlight Xpress SXV-H9		

Table 1: Instrumentation used

Start time	End time	Duration	Observer
JD	JD	(h)	
2455166.304	2455166.463	3.8	Shears
2455166.416	2455166.489	1.8	Boyd
2455166.514	2455166.881	8.8	Koff
2455166.615	2455166.886	6.5	Goff
2455172.214	2455172.328	2.7	Shears
2455172.441	2455172.737	7.1	Brady
2455176.493	2455176.772	6.7	Brady
2455178.449	2455178.717	6.4	Brady
2455183.479	2455183.705	5.4	Brady
2455184.529	2455184.702	4.2	Brady
2455188.485	2455188.691	4.9	Brady
2455203.478	2455203.495	0.4	Brady
2455206.462	2455206.644	4.4	Brady

Table 2: Log of time series observations

Name	P _{orb}		P _{sh}		3
	(s)	(min)	(s)	(min)	
CR Boo	1471	24.5	1487	24.8	0.011
KL Dra	1500	25.0	1530	25.5	0.020
V803 Cen	1612	26.9	1618	27.0	0.003
CP Eri	1701	28.4	1716	28.6	0.009
2003aw	2028 (21)	33.8	2042	34.0	0.007

Table 3: Orbital and superhump periods of outbursting AM CVn systems

Data are from Nelemans (1) unless otherwise stated

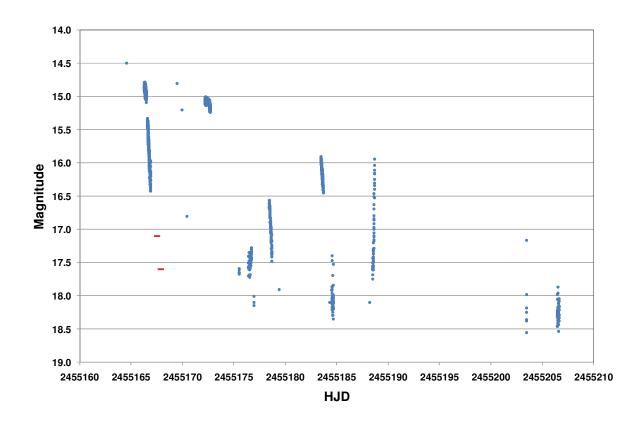
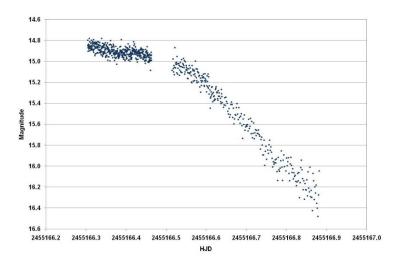
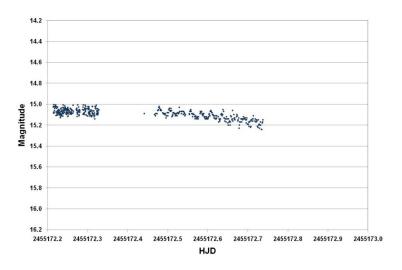


Figure 1: Outburst light curve of SDSS J012940.05+384210.4

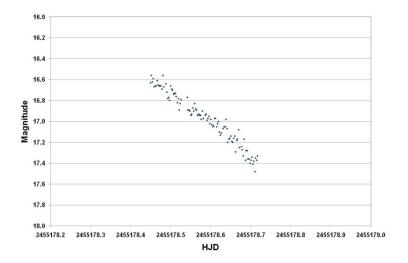
The red dashes indicate "fainter than" observations



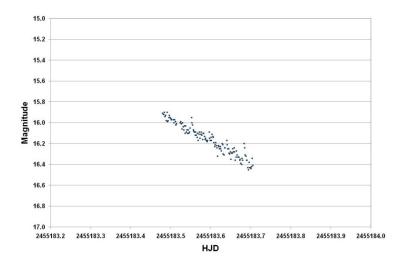
(a) JD 2455166



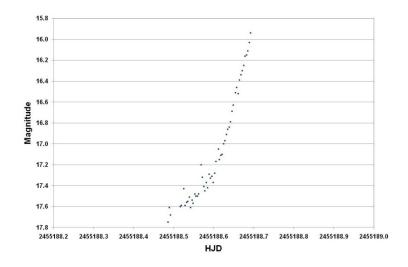
(b) JD 2455172



(c) JD 2455178



(d) JD 2455183



(e) JD 2455188

Figure 2: Light curves from time resolved photometry

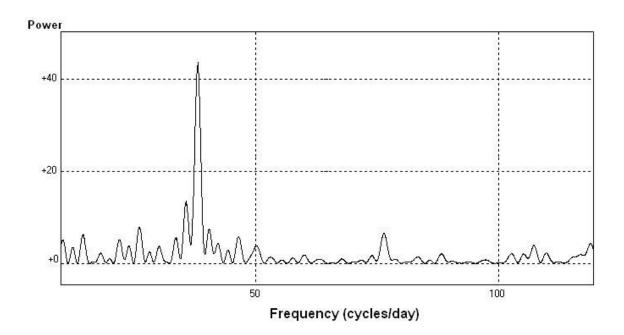


Figure 3: Power spectrum of data from JD 2455172

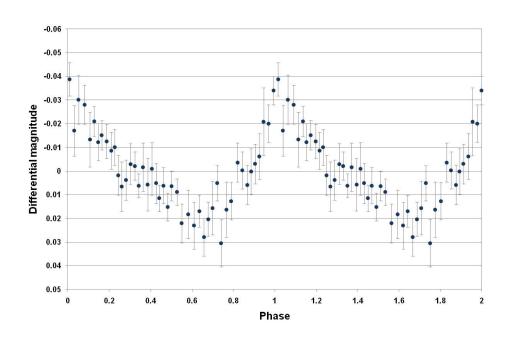


Figure 4: Phase diagram of data from JD 2455172 folded on P_{sh} = 37.9 min Each data point is the mean of 10 individual measurements

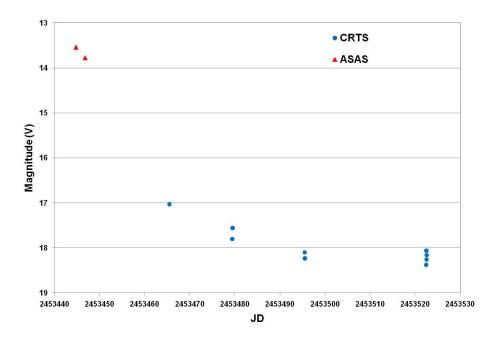


Figure 5: The 2005 outburst of the AM CVn system SDSS J124058.03-015919.2

The first data point is on 2005 March 15. Data are from ASAS-3 and CRTS are as indicated