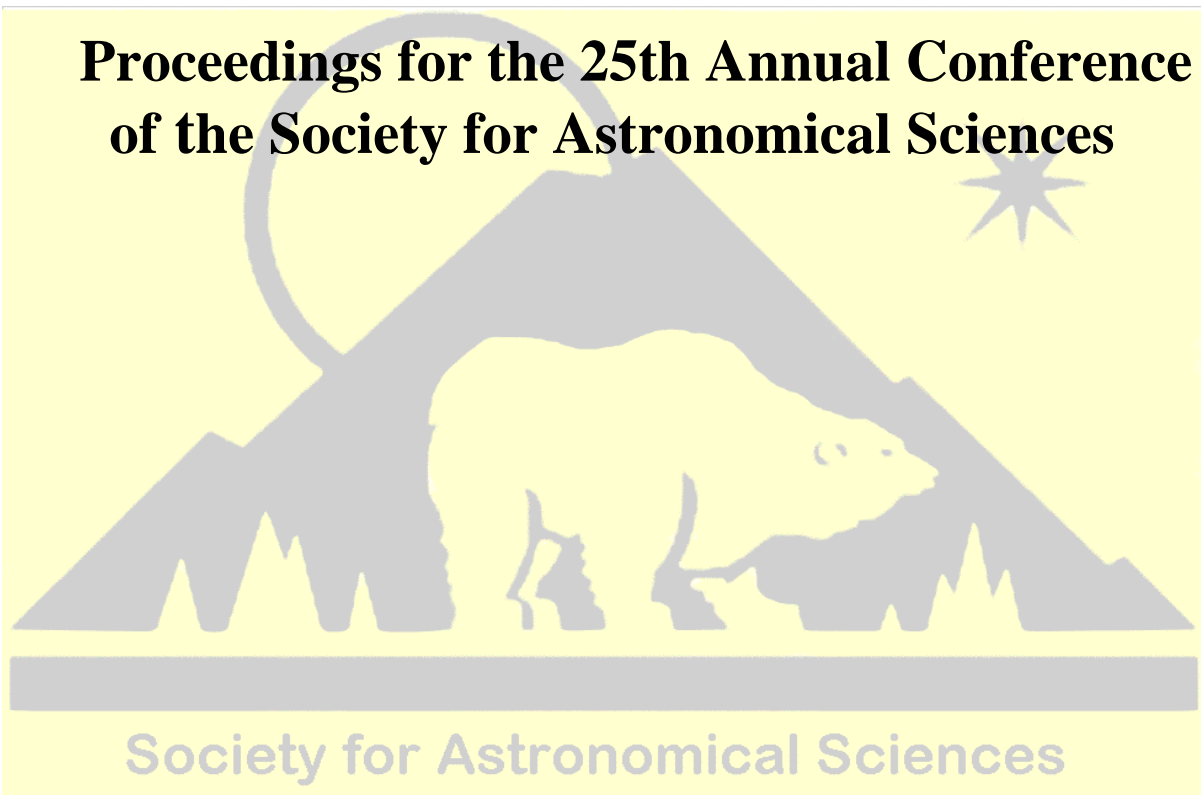

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The Detection of the WZ Sge-type Nature of the Dwarf Novae ASAS 023322-1047.0 and ASAS 102522-1542.4 by the Center for Backyard Astrophysics

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Abstract

We present the results of a detailed analysis of 13,116 time series CCD photometry observations of the cataclysmic variable stars ASAS 023322-1047.0 and ASAS 102522-1542.4, collected during

175.1 hours over 23 nights in early 2006 by 9 observers. We report also the detection of outburst orbital humps and common superhumps, establishing the variables as genuine new members of the rare class of WZ Sge-type dwarf novae. Our observations furthermore provide an excellent basis to illustrate how the pro-am partnership of the Center for Backyard Astrophysics is implemented in practice. © 2006 Society for Astronomical Sciences.

1. Introduction

On every clear night, there are an amazing number of CCD photometry projects waiting for exploration by dedicated and skilled amateur astronomers. They range from asteroid research to variable star observing and exoplanet studies. Many of those projects are vastly rewarding and have been inspired by professional astronomers seeking the active assistance from amateurs. Reversibly, some projects originate from a circle of highly motivated amateurs, and attract – through their scientific relevance – the attention of professional astronomers. In either case, the result often is a flourishing pro-am collaboration.

Our paper focuses on one such type of pro-am projects: CCD photometry of cataclysmic variables, and the related pro-am network called the Center for Backyard Astrophysics (CBA). The CBA is a multi-longitudinal network dedicated to studies of periodic phenomena in cataclysmic variable stars (Skillman (1993), mostly with CCD cameras mounted on small backyard telescopes. An example observatory is presented in Figure 1.

Early 2006, the ASAS3V instrument of the ASAS All Sky Automated Survey (Pojmanski (2002) discovered two new bright variable stars that were given the designations ASAS 023322-1047.0 and ASAS 102522-1542.4. Both objects became the subject of an intensive, worldwide CCD observing campaign, headed by the CBA.

2. Detection of ASAS 023322-1047.0

ASAS 023322-1047.0 was detected by the ASAS3V instrument (telephoto lens 180/2.8, diameter 65mm on CCD with Johnson V filter) on 2006, Jan 20.12 UT [$JD +3756.3$] at $V = 12.08$ (Pilecki (2006). No object brighter than $V = 14$ was visible on an ASAS3V image of Jan 18.08 UT [$JD +3754.3$].

Precise astrometry of the new object was done using CCD images by D. Rodriguez (2006), Spain, and yielded a position of $RA = 02h33m21.41s$ and $Decl = -10^{\circ}47'04.09''$ (J2000.0). A star at mag $B = 18.18$ is visible at this location in the USNO-B1.0 catalog. The large amplitude of about six magnitudes,

combined with a location far from the galactic plane, already presented a first indication of the dwarf nova nature of the variable star.

Immediately following the outburst discovery, an international observing campaign was initiated by the CBA. The objective was to monitor the new object photometrically as intensively as possible, and to study periodic phenomena at different stages of the outburst cycle. The CBA is extremely well suited for this kind of research, given the range of terrestrial longitudes at which the network operates, allowing to reach very sensitive limits for the detection of periodic signals and to resolve ambiguities easily in daily cycle count.



Figure 1. CBA Belgium Observatory, one of the nodes of the CBA network, is remotely operated by Tonny Vanmunster. It features two CCD-equipped 0.35-m telescopes on computerized mounts

Observations collected by the CBA consist of differential photometry with respect to a nearby comparison star, mostly in unfiltered light. We measure photometric periods by splicing long light curves of

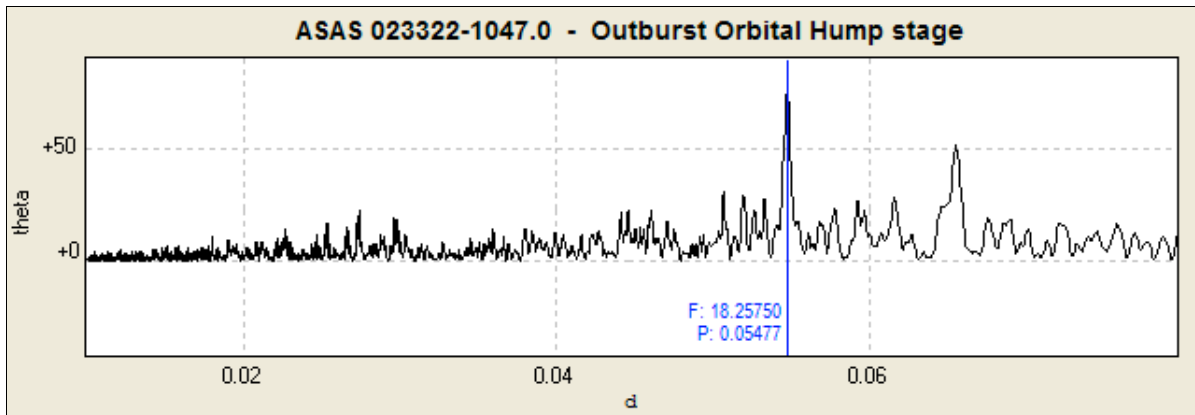


Figure 2. ANOVA Period Window of ASAS 023322-1047.0, displaying the outburst orbital hump period at 0.05477d.

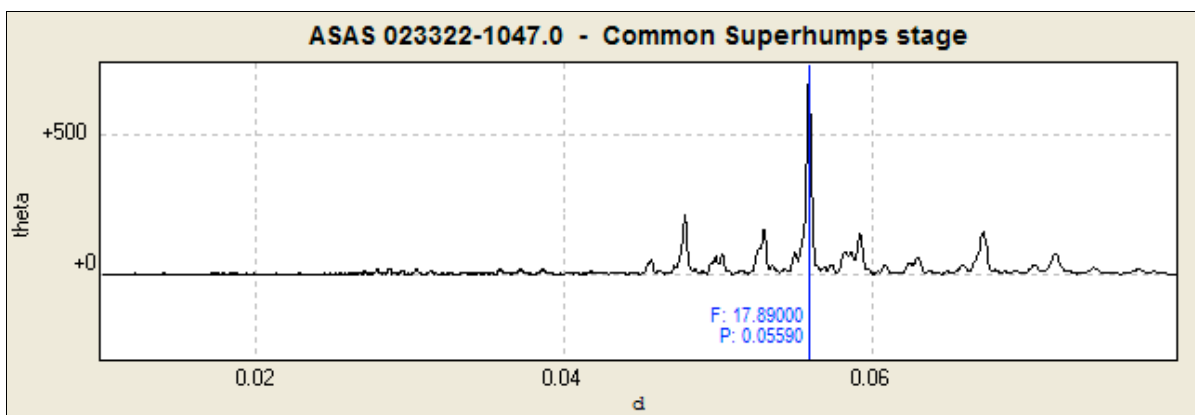


Figure 3. ANOVA Period Window of ASAS 023322-1047.0, displaying the common superhump period at 0.05590d.

differential magnitudes, and by calculating their power spectra or some other statistic (e.g., an Analysis of Variance) to evaluate the quality of a period fit.

There are numerous fine details to this enterprise, For example, before merging data we usually subtract the mean and (linear) trend from each night's time series since it greatly reduces the low-frequency noise arising from erratic night-to-night variability. We also tend to verify that a periodic signal displays no color dependence, so the data can be merged with no great loss of integrity. This is quite important, because we always merge time series data from disparate sources. Since unfiltered light suffers from differential extinction (the blue CV is fainter at large air mass than the redder comparison star), we often discard observations obtained at large air mass.

3. The Outburst Orbital Hump Stage of ASAS 023322-1047.0

On Jan 23, 2006, T. Vanmunster (2006a) announced the detection of *outburst orbital humps*,

sometimes also called *early superhumps*, in the light curve of ASAS 023322-1047.0 based on unfiltered time series CCD photometry obtained at CBA Belgium Observatory using a 0.35-m f/6.3 telescope and ST-7XME CCD camera. Outburst orbital humps have a typical double-peaked waveform (Figure 5) and were first identified in the 1978 outburst of WZ Sge. They mostly appear within one day of the outburst, maintaining an essentially constant double-humped waveform, and then are replaced by a common superhump, which develops in a normal manner. Outburst orbital humps are still of an uncertain nature (Patterson (2002) but are now considered a standard signature of WZ Sge-type dwarf novae. Our observations thus established ASAS 023322-1047.0 as a genuine new member of the rare class of WZ Sge-type dwarf novae.

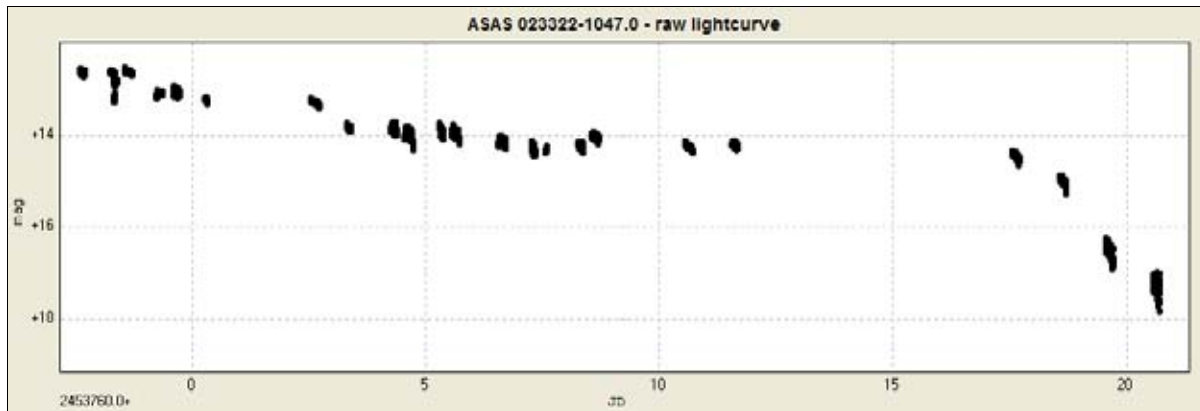


Figure 4. Raw lightcurve of ASAS 023322-1047.0, depicting the entire outburst interval, and combining 4971 CCD observations collected by the authors.

This class of dwarf novae is a subclass of the SU UMa-type dwarf novae and is particularly interesting since WZ Sge-type variables have very rare and long-lived eruptions (Bailey (1979) and show few or no normal outbursts. The latter phenomenon can not be fully explained yet with today's mass transfer models of dwarf novae, turning WZ Sge-type cataclysmic variables into very interesting research targets.

The dwarf nova nature of ASAS 023322-1047.0 was furthermore independently detected through spectroscopic observations by C. Aguilera, using the SMARTS 1.5-m telescope at Cerro Tololo Interamerican Observatory on behalf of Howard E. Bond and F. Walter of the Space Telescope Science Institute (Bond (2006a)). A spectrum taken on 2006, Jan 22.12 UT, covering 3550-5300 angstroms (\AA), showed broad, shallow absorption lines of the hydrogen Balmer series and He I 4471 \AA , which is typical of a dwarf nova at maximum light.

Further CCD time series observations were collected by CBA and AAVSO photometrists Tom Krajci, David Boyd, Berto Monard, Michael Armstrong, Tim Crawford, and Diego Rodriguez. In all, we accumulated 2222 CCD observations over 28.2 hours covering a time span of 5.8 days [from JD +3757.6 till JD +3763.4], i.e. the entire initial outburst stage of ASAS 023322-1047.0 (Table 1).

A detailed period analysis using the ANOVA method (Schwarzenberg-Czerny (1996) of the software package *Peranso* (<http://www.peranso.com>), reveals an outburst orbital hump period $P_{\text{orb}} = 0.05477 \pm 0.00010\text{d}$ (Figure 2). This is one of the shortest orbital periods of WZ Sge-type dwarf novae presently known. A phase diagram of the dominant signal clearly reveals the double-peaked outburst orbital hump waveform, with average amplitude just below 0.05 mag. (Figure 5). We subtracted the dominant signals and studied the residual time series but did not find significant weaker periodic signals.

Our findings for this stage of the outburst were confirmed shortly afterwards by H. Maehara (2006a) based on observations by VSOLJ (Variable Star Observers League of Japan) members K. Nakajima, S. Kiyota and H. Maehara.

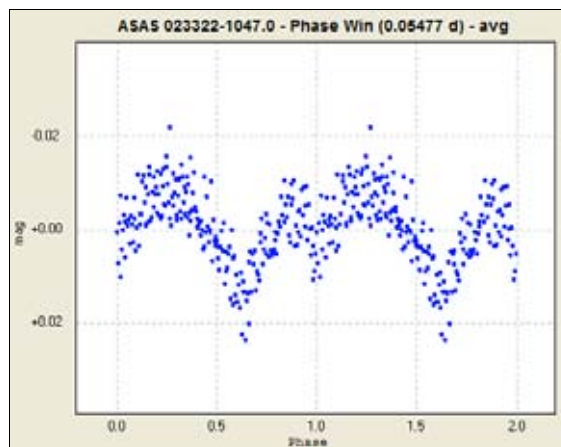


Figure 5. Phase diagram of ASAS 023322-1047.0, obtained by folding all observations from the outburst orbital hump stage over a period of 0.05477d, and displaying the average value for each bin of 10 observations.

4. The Common Superhump Stage of ASAS 023322-1047.0

Following the detection of outburst orbital humps in ASAS 023322-1047.0, the object entered its main outburst stage on Jan 28th [JD +3764] (Figure 4), trading in outburst orbital humps for *common superhumps*: the periodic wave increased very rapidly in amplitude and became single peaked (Figure 6). Common superhumps are a feature of all SU UMa-type dwarf novae in superoutburst and result from the light coming from the rim of the precessing elliptical accretion disc (Hellier (2001)).

Common superhumps with an amplitude of 0.2 mag were first announced by H. Maehara (2006b) based on CCD observations obtained on Jan 28.4 UT [$JD +3763.9$]. CCD observations by T. Vanmunster (2006b) half a day earlier, on Jan 27.9 UT [$JD +3763.4$], were still showing outburst orbital humps with an amplitude of 0.05 mag. The transition from the outburst orbital hump stage to the common superhump stage therefore must have been fast and quite spectacular.

A total of 2012 time series CCD observations were collected over 34.2 hours by CBA members during the common superhump stage of the outburst, covering a time span of 7.4 days between Jan 28.7 UT and Feb 5.2 UT [from $JD +3764.2$ till $JD +3771.7$]. Using the ANOVA method of *Peranso*, we find a common superhump period $P_{sh} = 0.05590 \pm 0.00005d$ (Figure 3), and an average amplitude of 0.16 mag (Figure 6). The P_{sh} value is one of the shortest superhump periods found in WZ Sge-type dwarf novae. The superhump period excess value $P_e = (P_{sh} - P_{orb}) / P_{orb}$ of ASAS 023322-1047.0 equals 2.1%, a value that is in line with expectations for dwarf novae with an orbital period of 1.3 hours (Hellier (2001)).

5. Rapid Fading Stage of ASAS 023322-1047.0

Around Feb 11th [$JD +3778$], ASAS 023322-1047.0 entered its rapid fading stage, when the magnitude of the system dropped by an average of 0.99 mag per day. CBA member Tom Krajci monitored this outburst stage with 737 unfiltered CCD observations obtained during 14.0 hours, covering a time span on 3.1 days between Feb 11.1 UT and Feb 14.2 UT [from $JD +3777.6$ till $JD +3780.7$].

A detailed analysis of the light curve at this stage of the outburst shows weak humps that are roughly anti-phased (shifted in phase by $\sim 180^\circ$) with the common superhumps (i.e. hump maxima occur where minima would be expected). These are called *late superhumps*. The transition from common superhumps to late superhumps in dwarf novae is currently not yet understood (Hellier (2001)).

Finally, it should be noted that no rebrightenings have been reported for ASAS 023322-1047.0 (see also Figure 4).

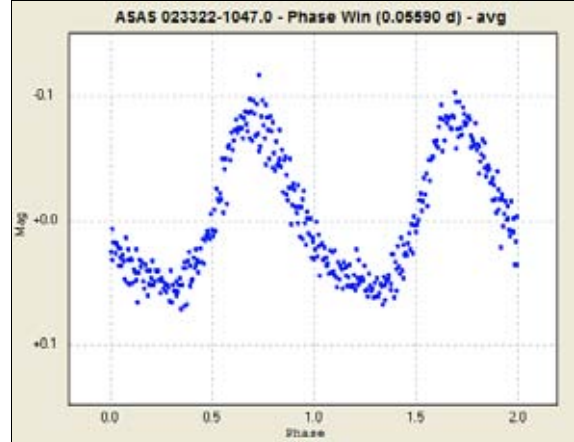


Figure 6. Phase diagram of ASAS 023322-1047.0, obtained by folding all observations from the common superhump stage over a period of 0.05590d, and displaying the average value for each bin of 10 observations.

6. The Detection of ASAS 102522-1542.4

The outburst of ASAS 023322-1047.0 was still in full development when yet another ASAS discovery was announced by Grzegorz Pojmanski (2006), Warsaw University Astronomical Observatory, based on observations of 2006, Jan 26.25 UT [$JD +3761.8$]. The ASAS3V instrument this time found an object of $V = 12.219$, that was not visible on images of Jan 23.26 UT [$JD +3758.8$], down to a limiting magnitude of $V = 14$. The new variable star, designated ASAS 102522-1542.4, is located at RA = 10h25m22.24s and Decl = $-15^\circ 42' 22.030''$ (J2000.0). Also this time, there was an USNO-1B star close to this position, at mag B = 19.32, denoting a large-amplitude outbursting object.

Again, an international observing campaign was set up by a few CBA members in conjunction with the already ongoing CBA campaigns initiated by our mentor, Prof. Dr. Joe Patterson.

The dwarf nova nature of ASAS 102522-1542.4 was revealed through spectroscopic observations obtained by A. Pasten on behalf of F. Walter and Howard E. Bond of the Space Telescope Science Institute (Bond (2006b)), on 2006, Jan 29.18 UT, using the SMARTS 1.5-m telescope at Cerro Tololo Interamerican Observatory. His spectrogram, covering 3500-5300 Å, showed broad, shallow absorption lines of the Balmer series and He I 4471 Å, typical for a dwarf nova at maximum light.

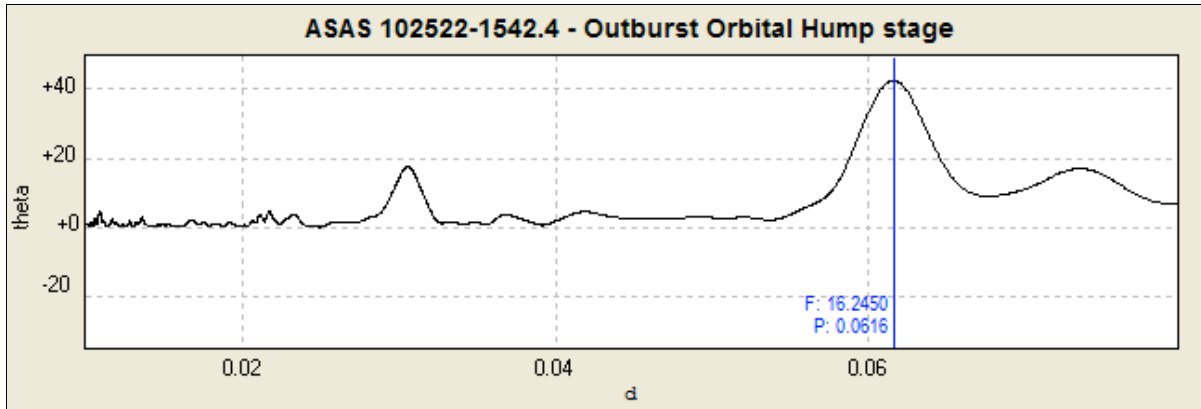


Figure 7. ANOVA Period Window of ASAS 102522-1542.4, displaying the outburst orbital hump period at 0.0616 d.

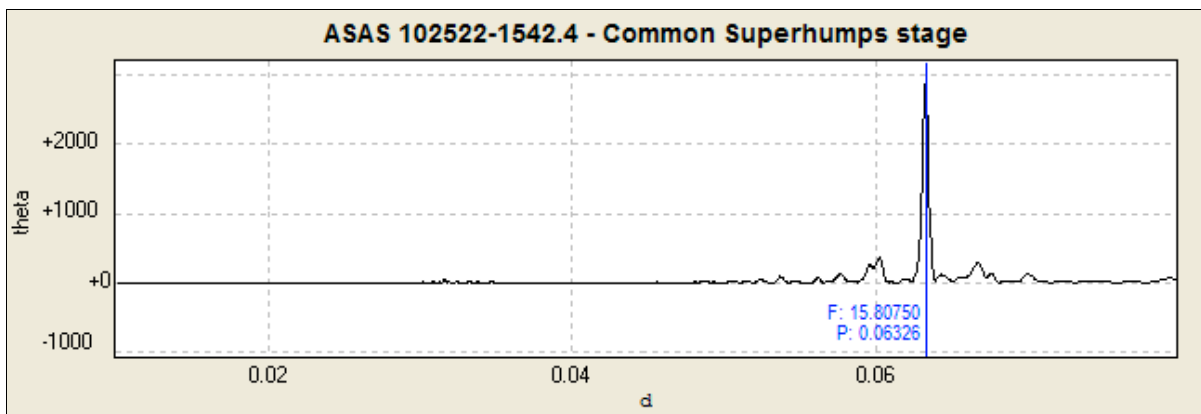


Figure 8. ANOVA Period Window of ASAS 102522-1542.4, displaying the common superhump period at 0.06326 d.

7. The Outburst Orbital Hump Stage of ASAS 102522-1542.4

The initial outburst stage of ASAS 102522-1542.4 was very well covered by CBA time series observations from Tom Krajci, Lew Cook, and Tonny Vanmunster (Table 2). A total of 1236 observations was used in our analysis, revealing double-peaked outburst orbital humps with an amplitude of 0.03 mag (Figure 9). The duration of this stage may have been fairly short: the discovery by ASAS3V was made on Jan 26.2 UT, and outburst orbital humps lasted till Jan 28.5 UT. An analysis of this part of the light curve, using the ANOVA method of *Peranso*, yields an outburst orbital hump period $P_{orb} = 0.0616 \pm 0.0018$ d (Figure 7).

Clearly, the detection of outburst orbital humps in ASAS 102522-1542.4 (Vanmunster (2006c), and the accurate determination of their characteristics, would never have been possible on the basis of data accumulated by just one observer. For example, the double-hump structure has a second (minimal) peak amplitude of less than 0.01 mag, and this second peak

becomes visible only by combining the time series observations of the three above mentioned CBA stations. The unfavorable location of the variable in the evening sky furthermore mandated observations by geographically dispersed observatories to resolve the cycle count problem.

Our findings for this stage of the outburst are well in line with conclusions derived by H. Maehara (Maehara (2006c), based on observations by VSOLJ members K. Nakajima, S. Kiyota, and H. Maehara obtained on Jan 27th and 28th.

8. The Common Superhump Stage of ASAS 102522-1542.4

Time series CCD observations, obtained by T. Vanmunster at CBA Belgium Observatory shortly after Jan 29.2 UT [$JD + 3764.3$], showed the appearance of single-peaked common superhumps with an amplitude just below 0.1 mag (Vanmunster (2006d). These observations, combined with the detection of outburst orbital humps, clearly established ASAS 102522-1542.3 as a new member of the WZ Sge-type

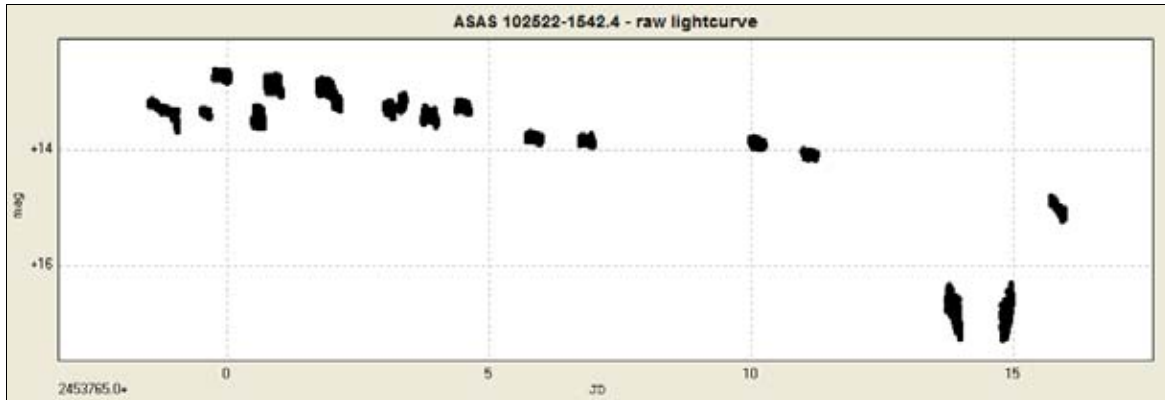


Figure 11. Raw lightcurve of ASAS 102522-1542.4, depicting the entire outburst interval, combining 8145 CCD observations collected by the authors.

dwarf novae, a conclusion that furthermore was confirmed by the appearance of echo outbursts (see section 9).

A total of 5973 CCD observations was collected between Jan 29.2 UT and Feb 4.5 UT [from JD +3764.3 till JD +3771.7], by CBA members Tom Krajci, Pierre de Ponthiere, Lew Cook, Berto Monard, and Tonny Vanmunster. An ANOVA-based period analysis using *Peranso* reveals a common superhump period $P_{sh} = 0.06326 \pm 0.00007$ d (Figures 8, 10). Common superhumps grew from an amplitude of less than 0.1 mag on Jan 29.0 UT to over 0.25 mag by Jan 30.5 UT.

Based on the above outburst orbital hump and common superhump period, we find a superhump period excess value $P_e = 2.8\%$, a value that is very well in line with expectations for a system with an orbital period of about 1.5 hours (Hellier (2001).



Figure 9. Phase diagram of ASAS 102522-1542.4, obtained by folding all observations from the outburst orbital hump stage over a period of 0.0616d, and displaying the average value for each bin of 10 observations.

9. The Echo Outburst Stage of ASAS 102522-1542.4

ASAS 102522-1542.4 entered a rapid decline phase shortly after Feb 10.0 UT [JD +3776.5] (Figure 11). CBA member Tom Krajci obtained unfiltered time series CCD observations on Feb 12.2 UT [JD +3778.7], when ASAS 102522-1542.4 had an average magnitude of 16.7, and showed common superhumps (not late superhumps) with an amplitude of 0.4 mag superimposed over a declining trend of approx. 1.9 mag/day. Later that day, H. Maehara reported the object at mag 17.5 (Maehara (2006d).

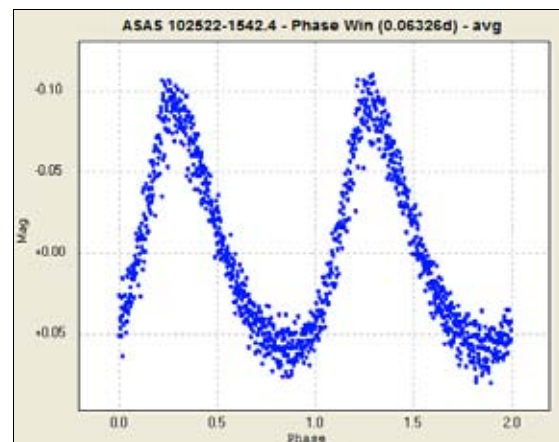


Figure 10. Phase diagram of ASAS 102522-1542.4, obtained by folding all observations from the common superhump stage over a period of 0.06326d, and displaying the average value for each bin of 10 observations

One night later, between Feb 13.26 UT [JD +3779.77] and Feb 13.46 UT [JD +3779.97], a brightening or *echo outburst* was observed in

Time series ID	Observer	Equip.	Start HJD	End HJD	Duration (d)	Total Obs
Outburst Orbital Hump stage						
ObsSet #7	Michael Armstrong	(6)	2453757.6011	2453757.6961	0.10	79
ObsSet #6	Berto Monard	(4)	2453758.2518	2453758.3408	0.09	249
ObsSet #10	Diego Rodriguez Perez	(5)	2453758.3180	2453758.3570	0.04	34
ObsSet #4	David Boyd	(8)	2453758.3181	2453758.3921	0.07	97
ObsSet #3	Tom Krajci	(2)	2453758.5492	2453758.7220	0.17	453
ObsSet #1	Tonny Vanmunster	(1)	2453759.2236	2453759.2582	0.03	42
ObsSet #2	Tonny Vanmunster	(1)	2453759.2584	2453759.3748	0.12	140
ObsSet #5	Tom Krajci	(2)	2453759.5921	2453759.7342	0.14	385
ObsSet #9	Tim Crawford	(7)	2453759.5985	2453759.6939	0.10	96
ObsSet #8	David Boyd	(10)	2453760.2803	2453760.3362	0.06	72
ObsSet #11	Tom Krajci	(2)	2453762.5476	2453762.7214	0.17	473
ObsSet #12	Tonny Vanmunster	(1)	2453763.3068	2453763.3926	0.09	102
Common Superhumps stage						
ObsSet #1	Tonny Vanmunster	(1)	2453764.2551	2453764.3879	0.13	150
ObsSet #2	Tom Krajci	(2)	2453764.5520	2453764.7253	0.17	340
ObsSet #4	Tonny Vanmunster	(1)	2453765.2937	2453765.3831	0.09	109
ObsSet #3	Tom Krajci	(2)	2453765.5505	2453765.7200	0.17	353
ObsSet #5	Tom Krajci	(2)	2453766.5550	2453766.7165	0.16	207
ObsSet #6	Tonny Vanmunster	(1)	2453767.2583	2453767.3559	0.10	110
ObsSet #8	Tom Krajci	(2)	2453767.5515	2453767.5988	0.05	58
ObsSet #7	Tonny Vanmunster	(1)	2453768.2652	2453768.3694	0.10	130
ObsSet #9	Tom Krajci	(2)	2453768.5523	2453768.7109	0.16	198
ObsSet #10	Tom Krajci	(2)	2453770.5532	2453770.7069	0.15	200
ObsSet #11	Tom Krajci	(2)	2453771.5526	2453771.6878	0.14	157
Decline stage						
ObsSet #1	Tom Krajci	(2)	2453777.5579	2453777.7008	0.14	185
ObsSet #2	Tom Krajci	(2)	2453778.5569	2453778.7115	0.15	200
ObsSet #3	Tom Krajci	(2)	2453779.5592	2453779.7061	0.15	185
ObsSet #4	Tom Krajci	(2)	2453780.5635	2453780.7011	0.14	167

Table 1. Log of observations for ASAS 023322-1047.0. **Equipment legend** : (1) 0.35-m f/6.3 telescope, ST-7XME unfiltered; (2) 0.28-m f/10 telescope, ST-7 unfiltered; (3) 0.20-m f/10 telescope, ST-7XMEI unfiltered; (4) 0.32-m f/3.7 telescope, ST-7XME unfiltered; (5) 0.20-m f/8.5 telescope, ST-9E unfiltered; (6) 0.25-m f/6.6 telescope, ST-7XME V filter; (7) 0.30-m telescope, ST-9 V filter; (8) 0.35-m f/5.3 telescope, SXV-H9 V filter; (9) 0.44-m telescope, TI TC-245 unfiltered; (10) 0.35-m f/5.3 telescope, SXV-H9 unfiltered.

Krajci’s observations, when ASAS 102522-1542.4 rose by a rate of approx. 2 mag / day (average magnitude 16.8) and still showing common superhumps with an amplitude of 0.4 mag. A period analysis for both nights using the ANOVA method of *Peranso*, yields a common superhump period $P_{sh} = 0.06305 \pm 0.00014d$. This value is 1.4% shorter than the common superhump period derived during the main stage of the outburst. Such a reduction in P_{sh} during an outburst is not uncommon. The explanation for it is probably the gradual emptying of the accretion disc, which causes its radius to shrink (Hellier (2001).

The appearance of small eruptions, called *echo outbursts*, during the return to quiescence is a phenomenon that has been observed in only a few WZ Sge-type cataclysmic variables so far. The best-studied cases are EG Cnc (Patterson (1998) and WZ Sge (Patterson (2002)). Echo outbursts are of uncertain origin but somewhat resemble the normal outbursts of dwarf novae. Several ideas have been pro-

posed to explain echoes. The most common explanation (Osaki et al. (1997, 2001) is that after the main superoutburst, enough matter resides in the outer torus of the accretion disk to drive subsequent thermal instabilities. However, the emptying torus and the declining viscosity become quickly insufficient to power further outbursts.

The variable continued to rebrighten to approx. mag 15 on Feb 14.2 UT [$JD +3780.7$], as is apparent from the last set of observations in Figure 11. A more detailed view of that segment of the light curve indicates that humps are completely absent now, and the only thing left is a linear decline at a rate of approx. 1.1 mag / day.

10. Conclusion

The discovery of two new dwarf novae within less than one week in early 2006, and the subsequent detection of their WZ Sge-type nature, is probably unique in the history of cataclysmic variable star

Time series ID	Observer	Equip.	Start HJD	End HJD	Duration (d)	Total Obs
Outburst Orbital Hump stage						
ObsSet #2	Tonny Vanmunster	(1)	2453763.5110	2453763.6801	0.17	204
ObsSet #1	Tom Krajci	(2)	2453763.7517	2453764.0502	0.30	718
ObsSet #3	Lew Cook	(9)	2453763.9385	2453764.0543	0.12	314
Common Superhumps stage						
ObsSet #3	Tonny Vanmunster	(1)	2453764.5099	2453764.6635	0.15	178
ObsSet #1	Tom Krajci	(2)	2453764.7373	2453765.0405	0.30	700
ObsSet #5	Pierre de Ponthiere	(3)	2453765.4908	2453765.6422	0.15	359
ObsSet #4	Tonny Vanmunster	(1)	2453765.5096	2453765.6974	0.19	224
ObsSet #2	Tom Krajci	(2)	2453765.7339	2453766.0336	0.30	759
ObsSet #9	Tom Krajci	(2)	2453766.7303	2453767.0308	0.30	706
ObsSet #7	Lew Cook	(9)	2453767.0436	2453767.1597	0.12	289
ObsSet #6	Lew Cook	(9)	2453768.0107	2453768.1612	0.15	492
ObsSet #10	Berto Monard	(4)	2453768.2717	2453768.3969	0.13	330
ObsSet #8	Tom Krajci	(2)	2453768.7275	2453768.9971	0.27	604
ObsSet #11	Berto Monard	(4)	2453769.3732	2453769.6267	0.25	717
ObsSet #13	Tom Krajci	(2)	2453770.7187	2453770.9920	0.27	351
ObsSet #12	Tom Krajci	(2)	2453771.7267	2453771.9831	0.26	308
Decline stage						
ObsSet #1	Tom Krajci	(2)	2453778.7281	2453778.9724	0.24	315
ObsSet #2	Tom Krajci	(2)	2453779.7689	2453779.9677	0.20	257
ObsSet #3	Tom Krajci	(2)	2453780.7142	2453780.9648	0.25	320

Table 2. Log of observations for ASAS102522-1542.4. Equipment legend : see Table 1.

observing. More important, however, was the intensive monitoring of the two objects throughout their outburst cycle, revealing an interesting mix of features observed in other WZ Sge-type variables, and features that are still rare (e.g., echo outbursts).

The results that we obtained for ASAS 023322-1047.0 and ASAS 102522-1542.4 are a nice illustration of the fact that the CBA, despite its informal structure, is capable of consistently delivering high quality output. What's more, that data is often obtained by amateurs who are endowed with the same curiosity about cataclysmic variables shown by the best of professional scientists. Since its start in the 1970s, the CBA has been highly respected by the astronomical community. It now is the world's most powerful machine for finding periods in cataclysmic variable stars. Evidently, it's a tremendous experience to be part of the CBA and to actively contribute to scientific CCD photometry projects.

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