High-speed photometry of faint cataclysmic variables - IX. Targets from multiple transient surveys.

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ABSTRACT
We present high-speed photometric observations of 25 cataclysmic variables detected by the All Sky Automated Search for Super-Novae (ASAS-SN), the Mobile Astronomical System of the TElscope-Robot (MASTER) and the Catalina Real-Time Transient Survey (CRTS). From these observations we determine 16 new orbital periods and 1 new superhump period. Two systems (ASASSN-14ik and ASASSN-14ka) have outburst periods of approximately 1 month, with a third (ASASSN-14hv) having outbursts approximately every 2 months. Included in the sample are 11 eclipsing systems, one probable intermediate polar (ASASSN-15fm), 1 SW Sex-type star (MLS 0720+17), 1 WZ Sge-type star (ASASSN-17fz) and one system showing different photometric and spectroscopic periods (ASASSN-15kw).

Key words: stars: cataclysmic variables - stars: dwarf novae - binaries: eclipsing - methods: observational - techniques: photometric - techniques: spectroscopic

1 INTRODUCTION
We present the latest results of photometric follow-up of faint cataclysmic variables (CVs; see Warner 1995 for a review on CVs) that are accessible from the southern hemisphere. This work is the last in series of papers (see Coppejans et al. 2014 and references therein) aimed at the characterisation of newly discovered CVs, including the determination of their orbital periods, a search for sub-orbital periodicities and the discovery of interesting targets for possible in-depth studies. Previous papers in the series focused on faint nova remnants and CVs identified by the Sloan Digital Sky Survey (SDSS; see Szkody et al. 2002, Szkody et al. 2003), attention then shifted to CVs discovered by the Catalina Real-Time Transient Survey (CRTS; see Drake et al. 2009). In this paper we present observations of 25 faint CVs identified in the All Sky Automated Search for Super-Novae (ASAS-SN; see Shappee et al. 2014), the Mobile Astronomical System of the TElscope-Robot (MASTER) node situated in Sutherland (MASTER-SAAO; see Lipunov et al. 2010), as well as from CRTS. The ASAS-SN survey is a dedicated all-sky survey focusing on the search for supernovae. It is made up of five units, each consisting of four 14-cm robotic telescopes, located at the Halealula, Cerro Tololo, South African Astronomical Observatory (SAAO) and McDonald stations of the Las Cumbres Observatory (LCO1); and in Chile. Together, these telescopes are able to observe the entire night sky. The MASTER GLOBAL Robotic Net is a Russian collaboration of robotic telescopes distributed across the globe whose goal is the observation of the entire sky each night up to 20-21 mag with the aim of answering questions about Gamma Ray Bursts (GRBs), dark energy and exoplanets. CRTS is a transient survey, covering 33,000 square degrees of the sky between -80° and 70° declination, whose main goal is the discovery of rare and interesting transients. With all data being publicly accessible, CRTS provides valuable long-term light curves for many sources. In this paper Section 2 summarises the observations and data reduction. Sections 3 - 6 contain the results of each individual CV, grouped by type: eclipsing systems (Section 3), non-eclipsing systems in quiescence (Section 4); non-eclipsing CVs in outburst (Section 5), and CVs for which no period could be determined (Section 6). Section 7 contains a summary of the data and discussion of the results.

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2 OBSERVATIONS

Most photometric observations presented in this paper were obtained at the SAAO site in Sutherland. Differential photometry was performed using the Sutherland High-speed Optical Camera (SHOC; see Gulbis et al. 2011; Coppejans et al. 2013) mounted on the 74- and 40-in reflector telescopes of the SAAO. Additional observations were obtained with SHOC mounted on the SAAO’s new 1-m telescope, Lesedi (Worters et al. prep). Making use of a frame-transfer, thermoelectrically-cooled, back-illuminated CCD, SHOC allows for high-quality, high-speed photometry. A dead time of 6.7 ms and sub-second exposure times makes SHOC an ideal instrument to use in the search of short periods in brighter objects. This includes searching for Dwarf Nova Oscillations (DNOs, with a range of 5-40s), longer period DNOs (lpDNOs, with approximately 3-5 times the period of DNOs) and Quasi-Periodic Oscillations (QPOs, with a range of 50-1000s) during outburst (Warner & Woudt 2004). Observations were taken with 1 MHz readout, in conventional mode (electron-multiplying not enabled), with exposure times ranging from 1 to 120 seconds.

No filters were used and data were calibrated using PSF images from either SkyMapper (Keller et al. 2007) or PANSTARRS (Kaiser et al. 2002), unless stated otherwise. The catalogue magnitudes used to calibrate each system are given in Table 1. As found by Coppejans et al. (2014), the r-band is a close approximation to white light (WL - no or clear filter) for bluer sources (2r0.2 to 1.0). Since CVs are typically blue sources, we can use the r magnitude as an estimate of the WL magnitude; this calibration is good to ∼r-1 mag. The data were reduced using standard IRAF packages (such as the phot and mkapfile commands) to perform aperture-corrected photometry. Frequency spectrum analysis of the data was done using Eagle, a program written by Darragh O’Donoghue for time-series analysis of unevenly spaced data containing large data gaps. A phase dispersion minimisation (Stellingwerf 1978), in which the sum of the variance in each bin for the folded light curve is minimised, was used to verify the periods found in eclipsing system and calculate the eclipse times. For MLS 0720+17, photometric observations were taken with an Andor camera on the 1.3m telescope at MDM Observatory on Kitt Peak, Arizona. The MDM observations were taken with a GG420 filter, which suppresses light with wavelengths < 4200 Å. A log of all observations is presented in Table 1. Only the first 10 lines are shown here, with the full version available online.

For two sources, ASASSN-15kw and MLS 0720+17, we include time-series spectroscopy from the 2.4m Hiltner telescope at MDM Observatory on Kitt Peak, Arizona, USA. We used the ‘modspec’ spectrograph. For ASASSN-15kw, the CCD covered from 4340 to 7500 Å at 3.5 Å resolution FWHM, with severe vignetting toward the red end of the range. For MLS 0720+17, a 2048 × 2048 STeP CCD that covered 4210 to 7500 Å with 3.6 Å resolution was used. MLS 0720+17 set early in the night, limiting the observable hour-angle range. The calibration, reduction, and analysis protocols followed the same steps described by Thorstensen et al. (2016) and Thorstensen & Halpern (2013). Table 2 gives a journal of these observations.

3 ECLIPSING SYSTEMS

This section contains the details of the eclipsing systems presented in this paper. These systems are listed in alphabetical order and our average light curves, except for ASASSN-14ka, are shown in Figure 1. Eclipsing systems play an important role in the study of CV evolution through the modeling of eclipse profiles (Hardy et al. 2017). With the exception of ASASSN-14ka and ASASSN-15fm which have shallow eclipses, the eclipsing systems in this paper show narrow eclipses, ranging from 0.2 to 2 mag in depth. A table listing eclipse times for each system presented in this paper is available online.

3.1 ASASSN-14hq

ASASSN-14hq shows evidence of previous outbursts, as well as eclipses, in the CRTS data. It was identified as a CV candidate by the ASAS-SN survey on 2014 September 24, when it went into outburst reaching $V = 13.97$ mag (Shappee et al. 2014). ASASSN-14hq shows a characteristic light curve of an eclipsing dwarf nova in quiescence. Our average light curve is shown in Figure 1, and shows deep, narrow eclipses of more than 1 mag in depth during quiescence. ASASSN-14hq has an orbital period of 0.074327(±9) d and the eclipse ephemeris is

$$HJD_{\text{min}} = 2456975.5967(±2) + 0.074327(±9) E$$

(1)

With an orbital period below the period gap, we expect this system to have superoutbursts. Although the archival data of CRTS does show outbursts, there is inadequate coverage to determine whether these are normal outbursts, or in fact superoutbursts. Archival data from ASAS-SN however, show evidence of regularly occurring normal outbursts and superoutbursts.

3.2 ASASSN-14ka

ASASSN-14ka, was announced as a CV candidate by the ASAS-SN survey on 2014 September 15, when it underwent an outburst peaking at $V = 15.06$ mag (Shappee et al. 2014). It was also reported by the Gaia Photometric Science Alerts (Wyrzykowski et al. 2012) in 2017 as Gaia17anx. Archival data from the ASAS-SN survey team (Shappee et al. 2014), displayed in Figure 2, show regular outbursts occurring approximately once a month. Our SHOC light curves obtained are displayed in Figure 2, each being vertically offset for display purposes. During runs S8495, S8498, S8501 and S8503, the system was still in a brightened state, with a resulting eclipse minimum of 18.4 mag. During the three later runs (S8549, S8551 and S8592), the system had returned to quiescence and showed a slightly deeper eclipse minimum of 18.7 mag. ASASSN-14ka has an orbital period of 0.17716(±1) d and the eclipse ephemeris is

$$HJD_{\text{min}} = 2456975.3854(±2) + 0.17716(±1) E$$

(2)

Evidence of a modulation with an amplitude of 0.6 magnitude at half the orbital period can be seen in the bottom...
3.3 ASASSN-15fm

ASASSN-15fm, was announced as a CV candidate by the ASAS-SN survey on 2015 March 15, when it went into outburst with a peak magnitude of $V = 16.26$ mag (Shappee et al. 2014). The Fourier Transform (FT) of the three longest runs, displayed in Figure 3, shows that ASASSN-15fm is a probable intermediate polar (IP). The highest peak in the FT is most likely the orbital period (represented by $\Omega$), while the spin of the white dwarf, along with the interaction between these two periods, appears as the two smaller peaks highlighted by the dashed lines. The two smaller periods at 18.57 (±1) and 20.37 (±1) mins are separated by twice the orbital frequency, but the duration of our data is insufficient to distinguish which is the spin period of the white dwarf. A more detailed study at higher cadence is needed to determine the spin period of the white dwarf. Our average light curve is shown in Figure 1. The orbital ephemeris for minimum light is

\[
\text{HJD}_{\text{min}} = 2457134.708(\pm 5) + 0.289(\pm 1) E
\]  

3.4 ASASSN-15pb

The CRTS light curve provides no evidence of previous outbursts or eclipses for ASASSN-15pb due to sparse coverage. ASASSN-15pb was listed as a CV candidate by the ASAS-SN survey on 2015 September 1, when it went into outburst with $V = 16.48$ mag (Shappee et al. 2014). Our average light curve is shown in Figure 1, and shows eclipse depths of more than 1.5 mag in quiescence. ASASSN-15pb has an orbital period of 0.09329(±2) d, just above the period gap minimum of 2.15(±0.03) hrs (Knigge et al. 2011), and the eclipse ephemeris is

\[
\text{HJD}_{\text{min}} = 2457312.349(\pm 1) + 0.09329(\pm 2) E
\]
Figure 1: Our average light curves of eclipsing systems presented in this paper, duplicated over 2 orbital cycles. The system’s name and orbital period is shown in the plot. For ASASSN-14hq, runs S8825 and S8831 are excluded due to bad weather, and the target being in a brighter state (possibly on the rise of a normal outburst) respectively. Due to lack of data, phase 0.19-0.3 is not plotted for CSS 0524+00. Due to lack of data, phase 0.35-0.4 is not plotted for MLS 0720+17 and only runs obtained in Sutherland, denoted with run names containing ‘S’, are included. Many of these systems show strong orbital humps in their light curves.

3.5 ASASSN-15pw

ASASSN-15pw shows evidence of previous outbursts, but no eclipses, within the CRTS data. It was listed as a CV candidate by the ASAS-SN survey on 2015 September 22, when it went into outburst with $V = 16.07$ mag (Shappee et al. 2014). Our average light curve is shown in Figure 1, and shows eclipses with a depth of around 1 mag. ASASSN-15pw has an orbital period of 0.1834(±3) d and the eclipse ephemeris is

$$ \text{HJD}_{\text{min}} = 2457316.589(\pm 1) + 0.1834(\pm 3) \ E $$

3.6 CSS 0524+00 (CSS131106:052412+004148)

Since the discovery of CSS 0524+00 by CRTS on 2013 Nov 6 (Drake et al. 2009), ample coverage shows evidence of multiple eclipses and outbursts. With evidence of eclipses, Hardy et al. (2017) observed CSS 0524+00, finding a period of 0.17466647(±0.0002) d. We find a period of 0.1747(±3) d, in agreement with that found by Hardy et al. (2017). Our average light curve, folded on the ephemeris $\text{HJD}_{\text{min}} = 2456651.4295(\pm 3) + 0.1747(\pm 3) \ E$, is shown in Figure 1; and shows eclipse depths of around 1.2 mag.

3.7 MASTER 0014–56 (MASTER OT J001400.25–561735.0)

CRTS data of MASTER 0014–56 show evidence of eclipses, along with a possible outburst. MASTER 0014–56 was discovered by MASTER-SAAO when it went into outburst with an amplitude of more than 3.7 mag (Gress et al. 2015). Our average light curve is shown in Figure 1, and shows deep, narrow eclipses of ~ 2 mag depth in quiescence. MASTER 0014–56 has an orbital period of $0.0715295(\pm 6) \ d$ and the eclipse ephemeris is

$$ \text{HJD}_{\text{min}} = 2457245.5459(\pm 1) + 0.0715295(\pm 6) \ E $$

MNRAS 000, 1–14 (2019)
Figure 2: Top: Long term light curve of ASASSN-14ka obtained from the ASAS-SN survey team. The grey triangle indicate upper limits, while the red lines show when the observation presented in this paper where taken. Bottom left: Individual light curves of ASASSN-14ka. The light curve for run S8495 is displayed at the correct brightness; the vertical offset for each light curve thereafter, is given in brackets. The figure clearly shows the structure present in quiescence, as well as the changing eclipse profile as the system was declining from outburst. Bottom right: Individual light curves from runs S8501, S8503 and S8549, folded on the ephemeris given in equation 2. Run S8501 vertically offset by 0.5 mag for display purposes. This plot highlights the modulation seen in ASASSN-14ka at half the orbital period.

3.8 MLS 0720+17 (MLS101226:072033+172437)

After the discovery of MLS 0720+17 by CRTS, Drake et al. (2009) interpreted the variability seen in the light curve as eclipses. Hardy et al. (2017) confirmed the presence of eclipses when they obtained a short observation, in which they observed part of an eclipse. Oliveira et al. (2017) later obtained a spectrum of MLS 0720+17. They concluded that the spectrum was typical of a polar, with the eclipse seen by Hardy et al. (2017) being a modulation due to cyclotron emission, and the narrow emission lines seen in the spectrum inconsistent with an eclipsing disc system. Our individual light curves and time-resolved spectroscopy are shown in Figure 4 and Figure 5 respectively, while our average light curve is shown in Figure 1. Our observations confirm MLS0720+17 as an eclipsing system. From the four eclipses in the 2015 SAAO light curves, we found a preliminary period of 0.1504 d, which we constrained further using the 2013 eclipse from SAAO and the October and January eclipses from MDM. No sign of a coherent pulsation, as would be expected for an IP, was seen. The eclipse ephemeris is

$$HJD_{\text{min}} = 2457072.2590(\pm 7) + 0.150408(\pm 7) E$$

(7)

The radial velocities, determined using the convolution method described by Schneider & Young (1980), do not independently determine the period due to the limited time span, but they do show a strong modulation consistent with the known period. We fit the velocities with a sinusoid of the form

$$v(t) = \gamma + K \sin(2\pi(t - t_0)/P)$$

(8)

using linear least squares, with the period P fixed at the value derived from the eclipses. This yielded $t_0 = 2457141.698(\pm 0.003)$, $K = 299(\pm 23)$ km s$^{-1}$, and $\gamma = 88(\pm 19)$ km s$^{-1}$. The radial velocities, folded on the eclipse ephemeris, are shown in Figure 5 with the sinusoidal
Figure 3: FT of three longest runs (S8638, S8640, S8643) for ASASSN-15fm. The dashed lines show the orbital period (Ω), the spin of the white dwarf, and a 2nd side band.

fit superposed. There is a phase difference between the radial velocity fit and eclipse phase of 0.175(±0.031) cycles, a hallmark of a subclass of CVs, the SW Sextantis (SW Sex) stars. First classified by Thorstensen et al. (1991). These are nova-like CV stars that exhibit a suite of properties as follows: (1) Absorption in the Balmer and He I lines appears near orbital phase 0.5; (2) An S-wave absorption feature in the emission of H α is often observed; (3) In cases in which the true orbital phase is known from eclipses, the zero phase of the radial velocities lag behind the eclipses if they were to trace the white dwarf’s motion; in other words, at eclipse, the Balmer line velocities have not yet decreased to their mean value; (4) The orbital periods of SW Sex stars are clustered from the 3 hour upper limit of the period gap up to about 4 hours (Rodríguez-Gil et al. 2009).

In many SW Sex stars, the HeI and Balmer absorption features appear around phase 0.5, opposite the eclipse. This is not apparent in the present data, most likely due to low signal-to-noise. Further studies are necessary to determine whether the absorption feature appears. The spectrum seems to show 2 additional traits of SW Sex stars: signs of a HeII 4686 + Bowen blend, and singly peaked emission lines. The bottom panel of Figure 5 shows a grey-scale representation of the H α line as a function of phase. The velocity shifts are readily apparent. There is an artificial brightening of the intensity of the H α line during eclipse (phase 0 and 1) because the line is normalized to the continuum, boosting the line when the continuum is eclipsed. SW Sex stars’ eclipses are often deeper in the continuum than in the lines (Dhillon 1998). Groot et al. (2001) showed that this effect is a result of the emission lines forming above the disc.

3.9 SSS 0522–35 (SSS111126:052210–350530)

SSS 0522–35 was discovered by CRTS on 2011 Nov 11, with a peak outburst amplitude of 2.53 mag (Drake et al. 2009). CRTS data show evidence of high variability and outbursts roughly 5-6 months apart. Our average light curve is shown in Figure 1, and shows eclipse depths of around 1.5 mag.

Figure 4: Differential photometry in V (approximated by the shift in white light by the comparison star) of MLS 0720+17 as a function of orbital phase. Each light curve is offset by ΔV = 3 respectively. The first four nights’ data were taken with SHOC without a filter. The V-shaped eclipse is another trait of SW Sex stars.

Figure 5: (Upper) Mean spectrum of MLS 0720+17 from MDM data taken April 2017. (Mid) H α radial velocities folded on the eclipse ephemeris given in equation 7. There is an apparent 0.175(±0.031) cycle phase shift. (Lower) H α plotted as a function of phase.
SSS 0522–35 has an orbital period of 0.0622(±5) d and the eclipse ephemeris is
\[ \text{HJD}_\text{min} = 2455913.4377(\pm 2) + 0.0622(\pm 5) \times E \]  

3.10 SSS 0945–19 (SSS130413:094551–194402)

Suspected as a variable by Kukarkin et al. (1981) (known as NSV4618), the CRTS light curve of SSS 0945–19 shows evidence of deep eclipses, as well as previous outbursts. Ellipses and an orbital period of 0.065769264(±2) d was reported by Kato, T. through the vsnet collaboration (vsnet-alert 15615). Hardy et al. (2017) observed a single eclipse, noting it to have clear white dwarf and bright spot features. Our average light curve is shown in Fig. 1. SSS 0945–19 has an orbital period of 0.0657693(±3) d, in agreement with the period reported by Kato, T., and the eclipse ephemeris is
\[ \text{HJD}_\text{min} = 2456421.3609(\pm 1) + 0.0657693(\pm 3) \times E \]

3.11 SSS 1340–35 (SSS120402:134015–350512)

After its discovery by CRTS (Drake et al. 2009), and first observed by Coppejans et al. (2014), SSS 1340–35 was found to be eclipsing with an orbital period of 0.059(±1) d. With our new observations, the orbital period has been refined to be 0.0598(±1) d. Our average light curve is shown in Fig. 1. The eclipse ephemeris is
\[ \text{HJD}_\text{min} = 2457073.5424(\pm 8) + 0.0598(\pm 1) \times E \]

4 NON-ECLIPSING SYSTEMS IN QUIESCENTНЕ

This section contains the details of individual non-eclipsing systems, for which orbital periods were found. These systems are listed in alphabetical order and our average light curves are shown in Figure 6.

4.1 ASASSN-14eq

ASASSN-14eq appears in both the CRTS, as well as the All Sky Automated Survey release 3 (ASAS-3; Pojmanski & Maciejewski 2004). The combined survey light curves show evidence of previous outbursts, some of which resemble superoutbursts. It was announced as a CV candidate by the ASAS-SN survey on 2014 July 28, when it underwent an outburst reaching a of V = 13.53 mag (Shappee et al. 2014). Our average light curve is shown in Figure 6. The observations presented in this paper were taken: 1) nearly 4 months (S8508 - S8517); and 2) over a year (S8533 - S8545), after the outburst recorded by Kato et al. (2015). The system was in quiescence during all of these observations. Kato et al. (2015) found a superhump period of 0.079467 d. Observations of ASASSN-14eq show an orbital period of 0.0813(±3) d. This results in a negative superhump excess of -0.02, consistent with the expected value for such an orbital period (Hellier 2001, Fig. 6.19). The orbital ephemeris for maximum light is
\[ \text{HJD}_\text{max} = 2457240.5088(\pm 1) + 0.0813(\pm 3) \times E \]

ASASSN-14eq shows flickering on the order of 0.1 mag, with no evidence of other periods found.

4.2 ASASSN-14hv

ASASSN-14hv was announced as a CV candidate by the ASAS-SN survey on 2014 September 27, when it underwent an outburst with a peak of V = 14.16 mag (Shappee et al. 2014), and shows outbursts, including superoutbursts, approximately once every 2 months. Our observations, excluding runs S8846 and S8847 in which the system appear to be declining from outburst, were taken when the system was in quiescence. From run S8847, we determine a superhump period of 0.082(±2) days. Our average light curve in quiescence is shown in Figure 6. With an orbital period of 0.079095(±7) d, ASASSN-14hv shows a superhump excess of 0.04 consistent with the expected value (Hellier 2001). The FT of the earlier runs (from Nov 2014) and the later runs (from May 2017) are shown in Figure 7. The orbital period and its harmonic can be seen in the FTs, but with the power changing between the orbital period and the harmonic. The orbital ephemeris for maximum light is
\[ \text{HJD}_\text{max} = 2456981.6068(\pm 7) + 0.079095(\pm 7) \times E \]

4.3 ASASSN-15kw

With a possible outburst in the CRTS, ASASSN-15kw was announced as a CV candidate by the ASAS-SN survey on 2015 June 10, when it went into outburst with a peak magnitude of V = 14.44 mag (Shappee et al. 2014). Campbell et al. (2015) obtained a spectrum of ASASSN-15kw, confirming its classification as a CV. Our average light curve is shown in Figure 6. Individual light curves show flickering with an amplitude on the order of 0.3 mag. The ephemeris for maximum light is
\[ \text{HJD}_\text{max} = 2457217.3939(\pm 1) + 0.137(\pm 6) \times E \]

Our mean spectrum, shown in Figure 8, is typical of dwarf novae at minimum light. The emission lines are almost double-peaked, with typical FWHM near 2000 km s$^{-1}$; the emission equivalent widths of H$\beta$ and H$\alpha$ are respectively ~80 and ~115 Å. The Hz radial velocities show a significant modulation at an unambiguously-determined period of 0.05924(±10) d, or 85.3 min; a sinusoidal fit in the form of equation 8 gives $t_0 = 2457845.891(±1)$ BJD, $v = -36(±6)$ km s$^{-1}$, and $K = 75(±9)$ km s$^{-1}$ at this period. It is likely that the 85-min period is $P_{\text{orb}}$, and the 3.28-hour photometric period arises from some other phenomenon. We do not have a ready explanation for these two periods, but note that Woudt & Warner (2002) found a similar discrepancy in another short-period dwarf nova, GW Lib; its orbital period is 1.28 h, but they found a significant photometric modulation at 2.09 h, and they note similar disparate periodicities in FS Aur and V2051 Oph.

4.4 ASASSN-15ls

ASASSN-15ls, not covered by the CRTS, was announced as a CV candidate by the ASAS-SN survey on 2015 June 19, when it went into outburst with a peak magnitude of V = 16.33 mag (Shappee et al. 2014). Our average light curve is shown in Figure 6. The orbital ephemeris for maximum light is
\[ \text{HJD}_\text{max} = 2457240.2242(±1) + 0.051(±8) \times E \]
Figure 6: Our average light curves of non-eclipsing systems in quiescence presented in this paper, duplicated over 2 orbital cycles. The system name and orbital period are shown in the plot. Only the later five runs (S8533 - S8545) are shown for ASASSN-14eq.

4.5 CSS 0353-03 (CSS111231:035318-034847)

After its discovery on 2011 Dec 31 (Drake et al. 2009), Szkody et al. (2014) obtained a spectra of CSS 0353-03 during the 2013 Jan outburst. The spectrum showed a flat blue continuum. CRTS data show evidence of outbursts occurring roughly once a year. Our average light curve is shown in Figure 6. The orbital ephemeris for maximum light is

\[ \text{HJD}_{\text{max}} = 2456247.5218(\pm 2) + 0.0582(\pm 1) E \]  \hspace{1cm} (16)

4.6 CSS 2144+22 (CSS100520:214426+222024)

CSS 2144+22 was discovered by CRTS on 2010 May 20, with a peak outburst amplitude of 2.41 mag (Drake et al. 2009). The CRTS light curve shows evidence of previous outbursts, as well as a possible superoutburst. Hardy et al. (2017) observed CSS 2144+22, confirming no eclipses. Our average light curve is shown in Figure 6. The orbital ephemeris for maximum light is

\[ \text{HJD}_{\text{max}} = 2456564.3701(\pm 3) + 0.154(\pm 1) E \]  \hspace{1cm} (17)

5 NON-ECLIPSING SYSTEMS IN OUTBURST

This section contains the details of individual systems which were observed during outburst, and for which superhump periods were found. Our average light curves are shown in Figure 9. Our observations for ASASSN-17fz are shown in Figure 10, to show the overall shape of the observed outburst.

5.1 ASASSN-15hm

ASASSN-15hm was observed during outburst after it was announced as a CV candidate by the ASAS-SN survey on 2015 April 18, (Shappee et al. 2014). ASASSN-15hm was also detected a month later by Gaia Photometric Science Alerts (Wyrzykowski et al. 2012) as Gaia15aeu. Campbell et al. (2015) obtained a spectrum of ASASSN-15hm, but classified it as a stellar object due to its redness and strong, narrow Na\,D absorption. Kato et al. (2016) reported a superhump period of 0.056219 d. Using the two longest runs (as these were the cleanest with multiple orbital cycles) presented in this paper (S8649 and S8651), a superhump pe-
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5.2 ASASSN-15hn

ASASSN-15hn was observed during outburst after it was announced as a CV candidate by the ASAS-SN survey on 2015 April 18, (Shappee et al. 2014). We obtained 4 runs, the later three runs (S8647, S8653 and S8657) overlap with the data presented by Kato et al. (2016). These runs provided limited coverage, and a superhump period of 0.06(±1) d was found using them. Kato et al. (2016) reported a superhump period of 0.06189 d. Our average light curve of run S8653, folded on the ephemeris \(\text{HJD}_{\text{max}} = 2457147.20394(±1) + 0.06(±1) E\), is shown in Figure 9.

5.3 ASASSN-17fz

ASASSN-17fz was observed during a superoutburst after it was announced as a CV candidate by the ASAS-SN survey on 2017 May 5, (Shappee et al. 2014). Our observations of ASASSN-17fz are shown in Figure 10. A single observation obtained by D. L. Holdsworth on the SAAO 1-m with SHOC on 12 Dec 2017 placed an upper limit of 21 mag on the brightness of the system. With a quiescent magnitude of >21, the amplitude of the observed superoutburst is more than six magnitudes. The superoutburst also showed a slow decline of ~ 0.13 mag per day for the duration of the observing period, classifying ASASSN-17fz as a WZ Sge-type star. Our average light curve is shown in Figure 9. A superhump period of 0.05757(±5) d was found during the outburst with an ephemeris for maximum light during outburst given by

\[ \text{HJD}_{\text{max}} = 2457888.40859(±1) + 0.05757(±5) E \] (18)

5.4 SSS 0553-52 (SSS111213:055349-525045)

Since its discovery by CRTS (Drake et al. 2009) on 2011 Dec 13, there has been sparse coverage of SSS 0553-52 within CRTS. Our average light curve is shown in Figure 9. The orbital ephemeris for maximum light is

\[ \text{HJD}_{\text{max}} = 2455910.4994(±1) + 0.0718(±2) E \] (19)

6 CVs For Which No Periodicity Could Be Determined

This section contains the details of individual systems in for which no persistent periods were found. Some of the individual light curves for these systems are shown in Figure 11. Our observations of the 2014 Nov outburst of ASASSN-14ik are displayed in Figure 10, to show the overall shape of the observed outburst.
Figure 9: Our average light curves of systems in outburst presented in this paper duplicated over 2 orbital cycles. The system name and superhump period is shown in the plot. Only the longest two runs (S8649 and S8651) are shown for ASASSN-15hm.

Figure 10: Multiple runs showing the magnitude of systems observed in outburst. Top: All observations of ASASSN-17fz presented in this paper. Bottom: Observations of ASASSN-14ik showing the general shape of the Nov 2014 outburst.

6.1 ASASSN-14ik

CRTS data of ASASSN-14ik show evidence of previous outbursts, possible superoutbursts, and high variability during quiescence. ASASSN-14ik was announced as a CV candidate by the ASAS-SN survey on 2014 October 1, when it underwent an outburst reaching $V = 14.15$ mag (Shappee et al. 2014), and has shown regular outbursts, occurring approximately once a month, since its discovery. Our observations in November, 2014 saw ASASSN-14ik undergoing a normal outburst, with a 2 mag amplitude and duration of 5 days. The shape of the outburst is shown in Figure 10. No DNOs or QPOs were found during the outburst. Our individual light curves of two long runs (S8494, taken just before the Nov 2014 outburst, and S8505, taken after the outburst) are shown in Figure 11. ASASSN-14ik shows flickering with an amplitude of $\sim 0.1$ mag, as well as large flaring with an amplitude of $\sim 0.5$ mag which is seen most clearly after the outburst. However, no persistent period was found in the data. A longer term study while the system is in quiescence is needed to confirm the presence or absence of any persistent periods.
6.2 ASASSN-15ev

ASASSN-15ev was announced as a CV candidate by the ASAS-SN survey on 2015 March 16, when it went into outburst with a peak magnitude of $V = 14.71$ mag (Shappee et al. 2014). The individual light curves of the longest two runs (S8632 and S8635) are displayed in Figure 11, each being vertically offset for display purposes, and shows flaring of ~ 0.5 mag. Matches to GALEX (Bianchi et al. 2018) and Swift (Evans et al. 2013) show the presence of UV and X-ray emission from ASASSN-15ev. The observations presented in this paper were taken over a month after the outburst recorded by Kato et al. (2016), once the system was in quiescence. Using the relation between superhump period and orbital period of $P_{\text{orb}} = 0.9162(\pm 0.052)P_{\text{SH}} + 5.39(\pm 0.052)$ mins, found by Gänsele et al. (2009), an estimate of the orbital period can be made using the superhump period found by Kato et al. (2016). With a reported superhump period of 0.057961 d, we predict an orbital period of around 0.056847 d. No evidence of the predicted orbital period, or any other periods, was found during quiescence.

6.3 ASASSN-15fo

ASASSN-15fo was announced as a CV candidate by the ASAS-SN survey on 2015 March 20, when it went into outburst with a peak magnitude of $V = 14.57$ mag (Shappee et al. 2014). The individual light curves are displayed in Figure 11, each being vertically offset for display purposes. The observations presented in this paper were taken a month after the outburst recorded by Kato et al. (2016), once the system was in quiescence. Using the relation between su-
perhump period and orbital period found by Gänsicke et al. (2009), we predict an orbital period of around 0.058991 days from the superhump period of 0.060301 d report by Kato et al. (2016). No evidence of the predicted orbital period, or any other periods, was found during quiescence.

6.4 MASTER 2220–74 (MASTER OT J222049.51–740240.9)

MASTER 2220–74 was discovered by MASTER-SAAO when it went into outburst with an amplitude of more than 3.5 mag (Shumkov et al. 2015). Archival data from CRTS show evidence of variability. Our individual light curves of the two longest runs are shown in Figure 11. MASTER 2220–74 shows flickering with an amplitude on the order of 0.4 mag and a possible suggestion of a very long orbital period of over 9 hrs.

7 DISCUSSION AND CONCLUSIONS

We observed 25 CVs with the aim of classifying them, determining their orbital periods, searching for sub-orbital periodicities and highlighting interesting targets for possible in-depth studies. This sample consists of 15 CVs detected by ASAS-SN, 2 by MASTER and 8 by CRTS. A summary of the results are shown in Table 3.

Eleven of the systems (ASASSN-14hq, ASASSN-14ka, ASASSN-15fm, ASASSN-15pb, ASASSN-15pw, CSS 0524+00, MASTER 0014–56, MLS 0720+17, SSS 0522–35, SSS 0945–19, SSS 1340–35) were found to be eclipsing, most with eclipse depths ≥ 1 mag. Systems with clearly defined eclipse components (bright spot, accretion disc, white dwarf and donor star) can be modelled to accurately determine the systems parameters, such as masses and radii of the stellar components. This information contributes towards completing the sample distribution of CV parameters (such as orbital period distribution or white dwarf mass distribution) and plays an important role in understanding their evolution (Hardy et al. 2017). ASASSN-14ik and ASASSN-14ka have outburst periods of ~1 month, while ASASSN-14hv has outbursts approximately every 2 months, along with superoutbursts.

The light curve and periodogram of ASASSN-15fm indicate that this system is likely an IP; but further observations are needed to confirm the spin period of the white dwarf. With an orbital period within the period range of known SW Sex CVs, and a radial velocity phase shift of 0.175 ± 0.031 cycles with respect to the orbital phase, it is likely that M3 0720+17 is a SW Sex-type CV. Although S-waves are not visible in our spectra, this is most likely due to low signal-to-noise. Higher S/N observations are also needed to confirm the presence of the phase 0.5 absorption feature seen in most SW Sex CVs. ASASSN-15kw was found to have different photometric and spectroscopic periods, similar to GW Lib and 3 other dwarf novae. The cause of this phenomenon is still unknown, but the addition of ASASSN-15kw has increased the number of the systems showing this phenomenon to 5.

Out of the 5 systems that were previously observed in outburst, we were able to confirm the superhump period for 2 of the systems and obtained an orbital period for a third system while in quiescence (ASASSN-15eq). With a superoutburst amplitude of more than 6 mag, and a superoutburst duration ≥ 46 days (assuming a constant decline of 0.13 mag per day and an upper limit of 21 mag for quiescence), ASASSN-17fz is classified as a WZ Sge-type star (see Kato 2015 for a review). Superoutburst are rare in WZ Sge-type stars, with recurrence times on the order of 1000’s of days. Although a period could not be determined for MASTER 2220–74, a suggestion of a very long orbital period, ≥ 9 hrs, is seen in the light curves. Long-term observations are needed to determine the orbital period.

In the final paper of this series on high speed photometry of faint cataclysmic variables we reflect briefly on nearly two decades of this survey. In the nine survey papers we have presented high speed photometry of 124 CVs, with an initial focus on faint southern nova remnants and a later focus on faint CVs discovered in optical transient surveys, probing the underlying orbital period distribution of CVs. In the last three papers alone (Woudt et al. 2012; Coppejans et al. 2014, and this paper) we presented photometry of 65 CVs resulting in 43 new photometric periods. Highlights from the survey include the discovery of a fair number of new AM CVn systems including the 10-min binary ES Ceti (Warner & Woudt 2002), and new insights in the nature of dwarf nova oscillations and quasi-periodic oscillations in CVs (Warner 2004).

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Table 3: Summary of results.

| Object        | Type | $P_{\text{orb}}$ | $P_{\text{SH}}$ | $r$ | Remarks                  |
|---------------|------|------------------|------------------|-----|--------------------------|
| ASASSN-14eq   | SU   | 0.0813(±3)       | 0.079467         | 15.6 - 18.5 | Negative superhump excess |
| ASASSN-14hq   | DN   | 0.074327±9       | -                | 18.8 - 21.7 | Eclipsing                |
| ASASSN-14hv   | SU   | 0.079095±8       | 0.082(±2)        | 17.7 - 18.5 | Outburst ~ once every two months |
| ASASSN-14ik   | DN   | -                | -                | 17.0 - 18.1 | Outburst ~ once a month |
| ASASSN-14ka   | DN   | 0.17716(±1)      | -                | 16.3 - 17.8 | Eclipsing; outburst ~ once a month |
| ASASSN-15ev   | SU   | -                | 0.057961         | 18.0 - 20.3 | Eclipsing; outburst ~ once a month |
| ASASSN-15fm   | IP   | 0.286(±1)        | -                | 19.4 - 20.4 | Eclipsing; probable intermediate polar |
| ASASSN-15fo   | SU   | -                | 0.060301         | 18.7 - 23.0 | Eclipsing; probable intermediate polar |
| ASASSN-15hm   | SU   | -                | 0.0562±1, 0.056219 | 14.7 | Eclipsing; probable intermediate polar |
| ASASSN-15hn   | SU   | 0.06(±1)         | -                | 14.3 | Eclipsing; probable intermediate polar |
| ASASSN-15kw   | DN   | 0.05924(±10)     | -                | 16.8 - 17.8 | Longer photometric period present alongside spectroscopic orbital period. |
| ASASSN-15ls   | DN   | 0.051(±8)        | -                | 16.6 - 17.7 | Eclipsing                |
| ASASSN-15pb   | DN   | 0.09329(±2)      | -                | 18.2 - 21.1 | Eclipsing                |
| ASASSN-15pw   | DN   | 0.1834(±3)       | -                | 16.8 - 20.3 | Eclipsing                |
| ASASSN-17fx   | WZ Sge | -                | 0.05757(±5)     | 21.5, 14.7 | Superoutburst of ≥ 6 mag, slow decline |
| CSS 0353-03   | DN   | 0.0582(±1)       | -                | 17.7 - 18.9 | Eclipsing                |
| CSS 0524+00   | DN   | 0.1747(±3)       | -                | 17.4 - 18.9 | Eclipsing                |
| CSS 2144+22   | SU   | 0.154(±1)        | -                | 16.4 - 17.3 | Eclipsing                |
| MASTER 0014-56 | DN  | 0.0715296(±6)   | -                | 19.1 - 22.9 | Eclipsing                |
| MASTER 2220-74 | DN  | 0.39277(±6)     | -                | 16.9 - 18.7 | Eclipsing                |
| MLL 0720+17   | SW Sex | 0.150409(±7) | -                | 17.9 - 21.1 | Eclipsing                |
| SSS 0522-35   | DN   | 0.0622(±5)       | -                | 17.9 - 20.3 | Eclipsing                |
| SSS 0553-52   | DN   | 0.0718(±2)       | -                | 16.9 - 17.4 | Eclipsing                |
| SSS 0945-19   | SU   | 0.0657693(±3)    | -                | 16.43 - 19.4 | Eclipsing                |
| SSS 1340-35   | DN   | 0.0598(±1)       | -                | 18.42 - 19.5 | Eclipsing                |

Notes: DN: dwarf nova; SU: SU Ursae Majoris; IP: intermediate polar; $^a$: quiescent magnitude range; $^b$: peak outburst magnitude; $^c$: period determined by Kato et al. (2015); $^d$: period determined by Kato et al. (2016); $r$: $r$ magnitude of the system in quiescence. This magnitude is an estimate and is accurate to 0.1 mag.
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