FOLLOW UP OBSERVATIONS OF SDSS AND CRTS CANDIDATE CATAclySMIC VARIABLES

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ABSTRACT

We present photometry and spectroscopy of 11 and 35 potential cataclysmic variables, respectively, from the Sloan Digital Sky Survey, the Catalina Real-Time Transient Survey, and vsnet alerts. The photometry results include quasi-periodic oscillations during the decline of V1363 Cyg, nightly accretion changes in the likely Polar (AM Herculis binary) SDSS J1344+20, eclipses in SDSS J2141+05 with an orbital period of 76 ± 2 minutes, and possible eclipses in SDSS J2158+09 at an orbital period near 100 minutes. Time-resolved spectra reveal short orbital periods near 80 minutes for SDSS J0206+20, 85 minutes for SDSS J1502+33, and near 100 minutes for CSS J0015+26, RXS J0150+37, SDSS J1132+62, SDSS J2154+15, and SDSS J2158+09. The prominent He ii line and velocity amplitude of SDSS J2154+15 are consistent with a Polar nature for this object, while the absence of this line and a low velocity amplitude argue against this classification for RXS J0150+37. Single spectra of 10 objects were obtained near outburst and the rest near quiescence, confirming the dwarf novae nature of these objects.

Key words: binaries: close – novae, cataclysmic variables – stars: dwarf novae

1. INTRODUCTION

The observational identification of close binaries involving mass transfer from a late main-sequence star to a white dwarf (cataclysmic variables or CVs) has always been hampered by selection effects. The first wide-field surveys such as Palomar–Green (Green et al. 1982) concentrated on bright (<16 mag) blue objects and found many high-accretion, novalike-type systems. The Hamburg Survey (Hagen et al. 1995) used low-resolution spectra to identify emission line objects (targeted for quasars) and was able to reach fainter (<17.5 mag) objects with strong emission lines. The Sloan Digital Sky Survey (SDSS; York et al. 2000) pushed to 21st–22nd mag in five filters and to about 20th mag in medium-resolution spectra and was able to reach the faintest, shortest period dwarf novae as well as extremely low-accretion systems with magnetic white dwarfs (summary in Szkody et al. 2011), while the latter survey and its follow up on individual objects provided a means to counter previous biases to brightness and provide a test of population models. Besides photometric colors and emission lines, the other way to characterize CVs is by their variability, both long term via outbursts and high/low states in novalikes, and short term via orbital variability due to hot spots, eclipses, and flickering (a summary of general properties of CVs can be found in Warner 1995). This aspect is being pursued with the recent and ongoing Catalina Real-Time Transient Survey (CRTS; Drake et al. 2009a) which uses three different telescopes: a 0.7 m Schmidt in the Catalina mountains (CSS), a 1.5 m Cassegrain on Mt. Lemmon to cover the northern skies, and a 0.5 m Schmidt at Siding Springs for the south. The CRTS also avoids the galactic plane, but accomplishes long term light curves down to about 20th–21st mag. The candidate CVs are made public by the CRTS on their Web site.8 Two other all-sky surveys that use small wide-field cameras, but only reach objects that brighten at outburst are the All Sky Automated Survey (ASAS; Pojmanski 1997), and the Mobile Astronomical System of the Telescope Robots (MASTER; Lipunov et al. 2010). Information about the CV systems discovered in these surveys is usually dispersed via vsnet alerts.9

While these surveys provide the database to identify CV candidates, the confirmation and specific nature of the type of CV requires detailed follow up observations using spectroscopy and orbital light curves. These follow up data determine whether an accretion disk or the underlying stars contribute most of the light, whether the system is a high excitation novalike showing He ii, if it contains a magnetic white dwarf (Polar) showing cyclotron or Zeeman splitting features, and if the orbital period is long or short. This type of information for a large unbiased all-sky survey allows a comparison of observed numbers of CVs in each period range and each category with expectations from population models.

Several groups are now accomplishing follow up studies of the available candidate CVs. Woudt et al. (2012) and Coppejans et al. (2014) have published their photometry of 40 southern objects, Thorstensen & Skinner (2012, hereafter TS) have published spectra and photometric colors of 36 northern systems, and Breedt et al. (2014, hereafter B14) accomplished

8 crts.caltech.edu/
9 http://ooruri.kusastro.kyoto-u.ac.jp/pipermail/vsnet-alert/
spectroscopic identification of 85 additional systems along with a discussion of the CRTS light curves. Since many of the candidates were discovered during outbursts, most are relatively faint for follow up at quiescence. TS and B14 compared the available results from CRTS to the SDSS and Ritter–Kolb samples and concluded that the CRTS is biased toward large outburst amplitudes, missing objects that are not dwarf novae. However, the large number of new discoveries shows that there are still many CVs being missed.

Our group has continued to obtain follow up photometry and spectroscopy of both the SDSS sample and the CRTS and vsnet alerts to further the task of identifying the nature of the large number of available CV candidates. Our results from 2010 to 2013 are presented here, which include photometry of 11 CVs (8 from SDSS, 1 from CRTS, and 2 from vsnet) and spectroscopy of 35 (8 with SDSS spectra, 14 from CRTS that have only SDSS photometry, and 13 from CRTS, MASTER, and ASAS that are not in the SDSS database). Time-resolved spectra of eight objects were obtained, with tentative fits to a sine-curve solution available for seven. Our observations have six objects that overlap with objects studied by TS: we have spectra of three objects that TS has only photometric colors, while their spectral studies of the other three occurred during different years/outburst states. As done by the other groups, for simplicity we identify all objects by their 2000 right ascension (R.A.) and declination (decl.) coordinates in Tables 1 and 2 (which allows them to be found in their respective databases) and abbreviate these coordinates in the following discussion.

2. OBSERVATIONS

Most of the photometric observations were conducted on the Kitt Peak National Observatory (KPNO) 2.1 m telescope during 2011 May and June. The STA2 CCD was used with either a V or a BG39 filter. Data were also acquired on three nights during 2013 July and October with the UW 0.76 m telescope at the Manastash Ridge Observatory (MRO) using a Spyder CCD with a BG40 filter. The data are summarized in Table 1. Reductions were accomplished using IRAF10 routines under ccdproc to flat-field and bias correct the images. Magnitudes of the variables and comparison stars on the same images were then measured using aphot and used to construct differential light curves on each night. Due to relatively long readout times and the faintness of the targets, the time resolution of most of the light curves is on the order of a minute.

Spectroscopy was primarily accomplished during 2010–2013 using both the KPNO 4 m telescope and the 3.5 m telescope at the Apache Point Observatory (APO). At KPNO, the RC Spectrograph was used with the 2048 CCD T2KA and a 1′′ slit. The second order of grating KPC-22b produced a focused spectrum over 3800–4900 Å with a resolution of 0.7 Å pixel$^{-1}$. FeAr lamps were used to calibrate the wavelengths and flux standards were observed. At APO, the Double-Imaging Spectrograph was generally used in its high-resolution mode to provide simultaneous blue and red spectral coverage with a resolution of 0.6 Å pixel$^{-1}$ for blue wavelengths of 3900–5000 Å and red wavelengths of 6000–7200 Å. On one night (2010 October 2), the low-resolution gratings were used, resulting in a resolution of 1.2 Å from 3400 to 9500 Å. Flux standards and HeNeAr lamps were used for calibration. On another night (2010 September 18), the Double Beam Spectrograph on the 5 m telescope at Mt. Palomar provided a spectrum with a resolving power of 7700 in the blue and 10,000 in the red, with wavelength coverage of 3500–5000 Å in the blue and 6200–6800 Å

### Table 1

| UT Date       | Object | Type, $P$ (hr)$^a$ | Obs. UT | Exp(s) | Filter | State  |
|---------------|--------|--------------------|---------|--------|--------|--------|
| 2011 May 12   | V1363 Cyg | DN | KPNO | 10:52–11:46 | 10 | BG39 | Outburst |
| 2011 May 13   | V1363 Cyg | DN | KPNO | 09:16–11:48 | 10 | BG39 | Outburst |
| 2011 May 24   | V1363 Cyg | DN | KPNO | 09:16–11:26 | 20 | BG39 | Decline |
| 2013 Oct 29   | CSS/SDSS215427+155938 | P, 1.6 | MRO | 05:44–07:46 | 60 | BG40 | Low |
| 2011 Jun 28   | CSS/SDSS215815+094709 | DN, 1.7 | KPNO | 07:59–11:21 | 240 | V | Quies |
| 2013 Oct 29   | RXS015017+375614 | DN, 1.7 | MRO | 08:14–11:20 | 35 | BG40 | Quies |
| 2011 May 12   | SDSS121913+204938 | DN | KPNO | 04:33–06:06 | 30 | BG39 | Quies |
| 2011 May 13   | SDSS121913+204938 | DN | KPNO | 05:15–06:02 | 30 | BG39 | Quies |
| 2011 May 26   | SDSS121913+204938 | DN | KPNO | 04:49–05:36 | 30 | BG39 | Quies |
| 2011 May 27   | SDSS121913+204938 | DN | KPNO | 03:28–07:56 | 60 | BG39 | Quies |
| 2011 Jun 5    | SDSS134441+204408 | P, 1.7 | KPNO | 04:00–06:25 | 30 | V | Quies |
| 2011 Jun 6    | SDSS134441+204408 | P, 1.7 | KPNO | 03:35–05:59 | 30 | V | Quies |
| 2011 Jun 10   | SDSS134441+204408 | P, 1.7 | KPNO | 03:46–07:12 | 30 | V | Quies |
| 2013 Jul 26   | SDSS160450+414328 | ... | MRO | 08:26–09:44 | 60 | BG40 | Quies |
| 2011 May 25   | SDSS160501+203056 | DN, 1.3 | KPNO | 04:58–05:3 | 50 | BG39 | Quies |
| 2011 May 25   | SDSS160501+203056 | DN, 1.3 | KPNO | 08:01–10:02 | 50 | BG39 | Quies |
| 2011 May 26   | SDSS160501+203056 | DN, 1.3 | KPNO | 07:51–09:58 | 50 | BG39 | Quies |
| 2011 May 27   | SDSS160501+203056 | DN, 1.3 | KPNO | 08:13–09:54 | 50 | BG39 | Quies |
| 2011 Jun 8    | SDSS160501+203056 | DN, 1.3 | KPNO | 07:43–08:53 | 50 | BG39 | Quies |
| 2011 Jun 10   | SDSS160501+203056 | DN, 1.3 | KPNO | 07:27–09:28 | 50 | BG39 | Quies |
| 2013 Jul 26   | SDSS165951+192745 | ... | MRO | 06:07–08:14 | 60 | BG40 | Quies |
| 2013 Jul 28   | SDSS165951+192745 | ... | MRO | 06:09–07:49 | 60 | BG40 | Quies |
| 2013 Oct 29   | SDSS205252−023952 | E, 1.4 | MRO | 03:44–05:22 | 60 | BG40 | Quies |
| 2011 Jun 29   | SDSS2141140+050729 | E, 1.3 | KPNO | 09:00–11:20 | 60 | V | Quies |
| 2011 Jun 30   | SDSS2141140+050729 | E, 1.3 | KPNO | 07:19–09:15 | 60 | V | Quies |

**Note.** $^a$ Provisional type of dwarf nova (DN), Polar (P), eclipsing (E), and orbital period if determined.
### Table 2
Summary of Spectroscopic Observations

| UT Date      | Coords       | Type, P (hr)* | Source          | Obs     | UT start | Exp(s) | State   |
|--------------|--------------|---------------|-----------------|---------|----------|--------|---------|
| 2010 Sep 12  | 000025+332543| DN CRTS, SDSS | KPNO            | 08:27   | 900      | Outburst|
| 2010 Sep 18  | 000025+332543| DN CRTS, SDSS | Pal             | 09:26   | 1200     | Decline|
| 2013 Sep 3   | 001133+045122| DN ASASSN-13ck| KPNO            | 09:38   | 900      | Outburst|
| 2013 Oct 3   | 001133+045122| DN ASASSN-13ck| APO             | 04:37   | 600      | Outburst|
| 2010 Sep 14  | 001538+263657| DN, 1.7 CRTS  | KPNO            | 09:04   | 900      | Quies   |
| 2011 Aug 26  | 001538+263657| DN, 1.7 CRTS  | KPNO            | 11:10   | 900 × 3  | Quies   |
| 2011 Aug 29  | 001538+263657| DN, 1.7 CRTS  | KPNO            | 10:29   | 600 × 8  | Quies   |
| 2010 Sep 15  | 005153+083503| DN CRTS       | KPNO            | 08:27   | 1200     | Quies   |
| 2013 Jan 16  | 050825+283004| DN CRTS, SDSS | APO             | 02:01   | 900      | Quies   |
| 2013 Sep 3   | 010411-031341| DN CRTS, SDSS | KPNO            | 10:45   | 1200     | Outburst|
| 2011 Aug 26  | 001538+263657| DN, 1.7 CRTS  | KPNO            | 09:38   | 900      | Quies   |
| 2011 Aug 29  | 001538+263657| DN, 1.7 CRTS  | KPNO            | 10:29   | 600 × 8  | Quies   |
| 2010 Sep 15  | 034420+093006| SDSS CRTS     | KPNO            | 09:01   | 1200     | Quies   |
| 2013 Jan 16  | 035318-034847| DN CRTS       | KPNO            | 03:13   | 900      | Outburst|
| 2011 May 15  | 075415+222253| DN CRTS, SDSS | APO             | 03:40   | 600      | Outburst|
| 2011 May 15  | 113215+624900| DN, 1.7 SDSS  | APO             | 04:39   | 600 × 8  | Quies   |
| 2011 May 16  | 122405+184102| SDSS CRTS     | KPNO            | 03:50   | 600 × 12 | Quies   |
| 2011 Jun 12  | 123255+222209| SDSS CRTS     | KPNO            | 03:56   | 900 × 3  | Quies   |
| 2011 May 15  | 134441+204048| P, 1.7 SDSS   | KPNO            | 04:40   | 900 × 3  | Low     |
| 2011 Jun 9   | 134441+204048| P, 1.7 SDSS   | KPNO            | 04:14   | 900      | High    |
| 2011 Jun 10  | 134441+204048| P, 1.7 SDSS   | KPNO            | 04:06   | 900 × 2  | High    |
| 2011 Jun 13  | 150240+334323| DN, 1.4 SDSS  | CRTS            | 04:09   | 600 × 4  | Decline |
| 2011 Jun 14  | 150240+334323| DN, 1.4 SDSS  | CRTS            | 03:48   | 480 × 8  | Decline |
| 2011 May 16  | 151915+064529| SDSS CRTS     | KPNO            | 03:28   | 600      | Quies   |
| 2011 Jun 11  | 151915+064529| SDSS CRTS     | KPNO            | 03:49   | 600 × 5  | Quies   |
| 2013 May 5   | 174033+414756| DN CRTS       | APO             | 05:49   | 600 × 5  | Outburst|
| 2013 Jun 12  | 174033+414756| DN CRTS       | APO             | 05:52   | 900      | Decline |
| 2013 Oct 3   | 174033+414756| DN CRTS       | APO             | 01:59   | 900 × 2  | Quies   |
| 2013 Jun 12  | 191501+071847| DN PNV        | APO             | 06:38   | 300      | Outburst|
| 2013 Oct 3   | 210016+024258| DN CRTS, SDSS | APO             | 04:13   | 900      | Outburst|
| 2013 Sep 1   | 215427+155713| P, 1.6 CRTS   | SDSS            | KPNO    | 09:49    | 1200    | Out     |
| 2013 Sep 5   | 215427+155713| P, 1.6 CRTS   | SDSS            | KPNO    | 09:18    | 600 × 8 | Out     |
| 2010 Oct 2   | 215636+193242| DN CRTS, SDSS | APO             | 03:26   | 900      | Quies   |
| 2010 Sep 14  | 215815+094709| DN, 1.7 CRTS  | SDSS            | KPNO    | 08:26    | 900 × 2 | Quies   |
| 2010 Sep 16  | 215815+094709| DN, 1.7 CRTS  | SDSS            | KPNO    | 07:07    | 600 × 12| Quies   |
| 2010 Oct 2   | 224348+080927| DN CRTS       | APO             | 03:48   | 900      | Quies   |
| 2010 Oct 2   | 232551-014024| DN CRTS, SDSS | APO             | 05:17   | 600      | Quies   |
| 2010 Sep 12  | 233849+281955| DN CRTS, SDSS | KPNO            | 10:18   | 900      | Decline |
| 2010 Sep 13  | 235503+420010| DN MASTER     | KPNO            | 09:57   | 1200 × 2 | Outburst|

Notes:

- Provisional type of dwarf nova (DN), Polar (P), eclipsing (E), and orbital period if determined.
- For multiple observations, denotes spectrum shown in Figure 1.

In the red. Standards and FeAr and HeNeAr lamps were used for calibration. In all cases, IRAF tasks under `ccdproc`, `apall`, and `onedspec` were used to correct the images, extract the spectra to one dimension, and calibrate them. For the time-resolved spectra, velocities of the Balmer emission lines were measured with the centroid e routine in `splot` and an IDL program was used to find the least-squares fit to a sine curve. A summary of the spectroscopic observations is given in Table 2 and the radial velocity fits are summarized in Table 3. A montage of the useful spectra available is shown in Figure 1. As both the KPNO and APO data cover the blue region of the spectrum, Figure 1 is plotted for the region that is common to all spectra.

### 3. RESULTS FOR SYSTEMS WITH LIGHT CURVES

The following sections provide the photometric and spectroscopic results obtained for the 11 systems with observed light curves (Table 1).
Figure 1. Blue region spectra of sources listed in Table 2. The vertical axes are $F_\lambda$ in units of $10^{-15}$ erg cm$^{-2}$ s$^{-1}$ Å$^{-1}$. Objects are labeled with the first digits of R.A. and decl. as given in Table 2.

| Object       | Line | $P$ (minutes) | $\gamma$ (km s$^{-1}$) | $K$ (km s$^{-1}$) | $\sigma$ (km s$^{-1}$) |
|--------------|------|---------------|-------------------------|-------------------|-------------------------|
| 001538+26    | H$\beta$ | 103           | $-66 \pm 3$            | $71 \pm 10$       | 19                      |
| 001538+26    | H$\gamma$ | 99            | $-53 \pm 2$            | $78 \pm 9$        | 16                      |
| 015017+37    | H$\alpha$ | 103           | $96.9 \pm 0.4$         | $54 \pm 3$        | 5.5                     |
| 015017+37    | H$\beta$ | 103$^a$       | $88 \pm 1$             | $38 \pm 11$       | 21                      |
| 020633+20    | H$\beta$ | 81            | $-58 \pm 2$            | $58 \pm 8$        | 18                      |
| 113215+62    | H$\alpha$ | 100$^a$       | $-0.7 \pm 0.5$         | $34 \pm 6$        | 11                      |
| 113215+62    | H$\beta$ | 100$^a$       | $-7.2 \pm 0.5$         | $20 \pm 7$        | 12                      |
| 113215+62    | H$\gamma$ | 102           | $-4.8 \pm 0.8$         | $29 \pm 9$        | 15                      |
| 150240+33    | H$\beta$ | 84.83$^a$     | $6 \pm 2$              | $104 \pm 26$      | 36                      |
| 150240+33    | He$\upbeta$ | 84.83$^a$     | $1 \pm 1$              | $142 \pm 14$      | 19                      |
| 215427+15    | He$\upbeta$ | 97$^a$        | $-44.4 \pm 0.1$        | $311 \pm 10$      | 17                      |
| 215427+15    | H$\beta$ | 97$^a$        | $-2 \pm 1$             | $293 \pm 51$      | 89                      |
| 215815+09    | H$\beta$ | 100–120$^a$   | $-4–14$                | $71–76$           | 27–21                   |

Table 3
Radial Velocity Fits

Note. $^a$ Period fixed at this value.

3.1. V1363 Cyg

This CV has a peculiar nature that has defied classification. It was classified as a dwarf nova when it was discovered (Miller 1971), but the light curve was peculiar in showing long periods at quiescence near 17.5 mag and also what appeared to be standstills about 1 mag below maximum light that would classify it as a Z Cam star (Warner 1995). Bruch & Schimpke (1992) obtained spectra which showed the typical Balmer emission lines of a CV. Outbursts are relatively rare and have not been well studied in the past. In 2011 May, V1363 Cyg underwent its first outburst since 1952 as reported by vsnet (Oshima 2011a). Quasi-periodic oscillations (QPOs) from 8.5–10.5 minutes and an amplitude of 0.05 mag were reported from May 8 to June 1. On May 30, a longer QPO at 28.8 minutes was observed (Oshima 2011b). Our light curves in May (Figure 2) show the QPOs, with changes in amplitude noticeable in the longer light curves of May 13 and 24.
3.2. RXS0150+37

This counterpart to an X-ray object in Andromeda was found by MASTER and reported by Denisenko (2013a) with archival images showing variability from 15th–19th mag. A further alert (Denisenko 2013b) reported unusual behavior at a mid-state between 2013 September 16–25 that could be indicative of an active Polar. Our 2.8 hr of photometry on 2013 October 29 (Figure 3) show a double-humped modulation at a period of 109 minutes. The velocities measured from our 1.5 hr of APO time-resolved spectra on 2013 October 2 give a best fit to a sinusoid with period of 103 minutes and a semi-amplitude of 54 km s$^{-1}$ (Table 3 and Figure 3). The lack of a high excitation line of He$\text{II}$, combined with the low semi-amplitude of the radial velocity curve, argue for this object being a normal low-inclination dwarf nova rather than a Polar.

3.3. SDSS1219+20

This 19th mag CV was observed in order to search for possible white dwarf pulsations, as its SDSS spectrum (Szkody et al. 2011) showed broad Balmer absorption lines flanking the emission lines. This type of spectrum is typical in the 16 known accreting white dwarf pulsators. However, our four light curves in 2011 May did not reveal any periodic feature that could be ascribed to either pulsation or orbital motion.

3.4. SDSS1344+20

The SDSS spectrum of this 17th mag object showed weak Balmer emission lines and a broad hump feature near 5200 Å that implied an origin as a cyclotron harmonic from a magnetic white dwarf (Szkody et al. 2011). Time-resolved spectra revealed a large (∼400 km s$^{-1}$) semi-amplitude variation of the H$\alpha$ and H$\beta$ lines with orbital periods of 110 and 122 minutes, respectively, which was consistent with a Polar nature. Our three nights of photometry in 2011 June shown in Figure 4 corroborate this Polar identification, but also show interesting changes during the week timespan. On June 5, a very large (2 mag) hump is visible. This feature is typical of an accretion pole passing through the line of sight, such as occurs in the Polar VV Pup (Warner & Nather 1972; Liebert et al. 1978), but the light increases after the passage of the pole. The next night, June 6, shows the hump with less amplitude but longer duration, while
four days later, on June 10, the system has transitioned to most of the time spent in the bright state. This is somewhat reminiscent of the light curves of the Polar CSS071126+440405 (Thorne et al. 2010), which was interpreted as sporadic mass transfer. If the increased mass transfer moves the accretion zone so that it is no longer eclipsed by the white dwarf, the light curve would not have the low segment visible on June 5. The changes in the light curve make the determination of a photometric orbital period difficult, but the features present on June 5 and 6 are most consistent with a period near 100 minutes.

The spectra obtained in 2011 May and June (Table 2 and Figure 1) also reveal significant changes in accretion. On May 15, the system was in a low state with a featureless spectrum, while the spectra on June 9 and 10 show a flux increase by a factor of two as well as increased Balmer line strengths over those in the SDSS spectrum. If the broad hump around 4200 Å is a cyclotron hump, its presence together with the one at 5300 Å in the SDSS spectrum would imply a field strength of $\sim 65$ MG for harmonics of 4 and 3 (Wickramasinghe & Ferrario 2000).

3.5. SDSS1604+41

While the SDSS spectrum of this $g = 17.7$ mag source shows strong He II (Szkody et al. 2005), the light curve obtained over 1.4 hr on 2013 July 26 shows no prominent feature, only flickering of a few tenths in magnitude.

3.6. SDSS1605+20

The SDSS spectrum of this 19.9 mag object (Szkody et al. 2009) shows Balmer absorption surrounding its emission lines. The five nights of photometry in 2011 May–June (Figure 5) show a broad feature with an amplitude near 0.08 mag and a period of 75–78 minutes.

3.7. SDSS1659+19

This $g = 16.8$ mag system also shows a prominent He II line in its SDSS spectrum (Szkody et al. 2006). Its light curve on two nights in 2013 July (the longest timespan is shown in Figure 6) shows a 10% amplitude flickering as well as a possible hump, but further photometry is needed to determine if this is a periodic occurrence.

3.8. SDSS2052−02

This object was discovered in outburst at $V = 14$ as ASASSN-13cg on 2013 August 27 and matched with a blue SDSS $g = 18.3$ object (Stanek 2013), while later vsnet posts suggested
Figure 3. Light curve of the dwarf nova RXS0150+37 on 2013 October 29 (top) and the radial velocity curve (bottom) from 2013 October 3. The velocity curve is phased with a period of 103 minutes and best-fit sine curve is shown with parameters from Table 3.

a possible AM CVn object. Observations by Littlefield reported by Kato (2013b) revealed a superhump period of 1.4 hr and shallow (0.1 mag) eclipses. Our light curve obtained two months later (2013 October 29) near quiescence (Figure 7) shows some variability near 37 minutes with an amplitude of 0.4 mag, although better signal-to-noise ratio (S/N) and a longer timespan will be needed to ascertain if this is related to the orbital period.

3.9. SDSS2141+05

This g = 18.9 mag CV appears in DR10 of the SDSS III release. The SDSS spectrum is shown in Figure 8. The deep absorption in the Balmer lines, along with the broad absorption flanking the emission, is indicative of a system at high inclination and with a low mass transfer rate. Our follow up photometry during 2011 June (Figure 9) confirms the high inclination by showing two eclipses on each night. While the eclipses are not well resolved at our time resolution of 194 s between exposures, the combination of the two nights yields an orbital period of 76 ± 2 minutes.

3.10. CSS/SDSS2154+15

An outburst of this CRTS CV on 2013 June 4 at 17.5 mag was reported by vsnet (Kato 2013a). A light curve showed a prominent single hump feature with a period of 96.9 minutes. Our light curve shows a similar feature four months later (Figure 10). The large amplitude (1.5 mag) is indicative of a Polar nature for this object.

Our KPNO spectra obtained on 2013 September 5 (Figure 1) shows a prominent He II line. The velocities from the 82 minute time-resolved spectra were fit to a sine curve with the period fixed at 96.9 minutes (Figure 10). The resulting large K amplitudes near 300 km s⁻¹ (Table 3) are consistent with a Polar. The SDSS photometry obtained in 2009 October gives a fainter magnitude (g = 18.65) and blue colors (u − g = 0.10, g − r = 0.02), which are not consistent with the usual red colors of a Polar. However, the system may have been in a low state at the time of the SDSS observations, similar to the low state in EF Eri when the white dwarf dominates the optical light (Wheatley & Ramsay 1998). Polarimetric measurements would confirm that this object harbors a magnetic white dwarf.

3.11. CSS/SDSS2158+09

The CSS light curve of this object shows a bright measurement at 13.2 on 2010 June 15. The rest of the time it resides near 17.6 mag, with a large scatter indicative of orbital variability. This object exists in the SDSS photometric database with blue colors (g = 17.51, u − g = 0.08, g − r = −0.10). Calibrated V, R, I images by TS provide a comparable V magnitude of 17.48 and V − R = 0.13. Our KPNO spectra obtained in 2010 September (Figure 1) show prominent deep central absorption in the Balmer emission lines, indicative of a high inclination. Our KPNO photometry obtained nine months later (Figure 11)
reveals a large-amplitude (0.3 mag) hump feature followed by dips (near UT times of 9 and 10.7 hr) that hint at eclipses, but the 4 minute integration times do not allow resolution of this feature. A periodogram of these data gives a period of 104 minutes. Using the 12 time-resolved spectra obtained over 2 hr on 2010 September 16, we attempted a radial velocity solution using centroids, Gaussians, and the line wings of H$\beta$. Due to the complexity of the line shape and the less than ideal S/N, a good solution could not be determined. The values obtained by fixing the period at values between 100–120 minutes are listed in Table 3. The semi-amplitudes are typical for dwarf novae but improved data will be needed to pin down the period. Spectra in the red can determine if the secondary is visible.

4. TIME-RESOLVED SPECTRA OF SYSTEMS WITHOUT LIGHT CURVES

In addition to the time-resolved spectra for the three objects with light curves described above, radial velocities were also obtained for five other systems.

4.1. CSS0015+26

Drake et al. (2009b) identified this 18th mag ROSAT source as a CV when the CSS measured it at 13.3 mag in 2009 September. Our KPNO blue spectra over 73 minutes reveals a typical dwarf nova (Figure 1) with a period near 100 minutes and a $K$ semi-amplitude near 70 km s$^{-1}$ (Figure 12, Table 3).

4.2. CSS/SDSS0206+20

The CSS identifies a 1 mag variation in this $g = 15.58$ mag SDSS object. The blue colors ($u-g = 0.06$, $g-r = 0.10$) are consistent with a CV. The KPNO blue spectra obtained in 2013 September show the strong Balmer emission lines of a dwarf nova and the 11 time-resolved spectra over 113 minutes on September 6 are fit with a period near 80 minutes and a $K$ semi-amplitude near 60 km s$^{-1}$ (Table 3, Figure 13). While the photometric amplitude is very low, the other characteristics are typical of a dwarf nova. It is possible that the variation caught by CSS was not an outburst but merely a sporadic accretion event, as objects with such short orbital periods often have outburst frequencies that are tens of years.

4.3. SDSS1132+62

This $g = 18.5$ system showed strong Balmer emission lines in its SDSS spectrum (Szkody et al. 2004). Our 82 minutes of time-resolved spectra on 2013 February 5 reveals a low $K$ semi-amplitude and an orbital period near 100 minutes (Figure 14, Table 3).
4.4. SDSS1224+18

The SDSS spectrum of this bright 16th mag system shows broad absorption with central narrow emission and was suggested as a possible pre-CV (Szkody et al. 2011). Our 126 minutes of time-resolved spectra on 2011 May 16 showed no significant radial velocity variation during that interval. The system likely has a long orbital period and/or a low inclination.

4.5. SDSS/CSS1502+33

This object was identified in the SDSS spectra at quiescence (Szkody et al. 2006) as a high-inclination, eclipsing system with a period of 84 minutes. A vsnet alert by Maehara (2011) reported the CSS detection of this system at an outburst mag of 15 (2.5 mag brighter than quiescence) on 2011 June 11. We obtained four spectra on June 13 and eight on June 14 in order
to search for a line component that could be from the irradiated secondary star and yield the velocity amplitude of the secondary. The spectra (Figure 1) show much stronger Balmer lines and a much larger flux in the He II line than the quiescent spectra. The Hβ/He II flux and equivalent width ratios on June 13 were 1.25 and 1.29, respectively, whereas they were 15 and 7 in the quiescent SDSS spectra. On June 13, the He II line does show a prominent red peak when the Balmer lines have a prominent blue peak (Figure 1). However, the four spectra were not enough to resolve a velocity curve, and the next night the peaks in the lines are similar in phase. The radial velocity curves from June 14 (Table 3) have higher amplitudes than the quiescent data (a factor of two for Hβ), implying an origin closer to the white dwarf.

5. SPECTRA AT OUTBURST

Ten of the objects listed in Table 2 and shown in Figure 1 were observed close to their maximum reported brightness. Most of the ones near outburst peak show the typical optically thick accretion disk that is the signature of outburst, with a rising blue continuum and shallow Balmer absorption (ASAS0011+04, CSS0514+08, SDSS0754+38, SDSS0757+22, PNV1915+07, MASTER2355+42). Of these, only CSS0514+08 shows the presence of He II. TS have three spectra from 4700 to 6700 Å for this object taken in 2011 January at quiescence which show Hα and Hβ in emission. Three other systems (CSS0353−03, SDSS0518−02, and SDSS2100−02) have flat or decreasing continua in the blue, which may be indicative of large reddening. The presence of emission cores in the Balmer lines of SDSS0518−02 indicates that the disk is not at the peak outburst state.

The most interesting outburst spectrum exists for CSS0104−03. The CSS has one recorded outburst of this system in 2009, but Ohshima (2013) reported an ASAS detection at 16.4 (about 3 mag above the SDSS and CSS quiescent magnitudes) on 2013 August 27. The CSS light curve does not cover this period of time, but the large spread of magnitudes at quiescence indicates a possible eclipsing system. Our KPNO spectra on 2013 September 3 show strong emission lines when the system was still brighter than quiescence.

6. SYSTEMS WITH STRONG HE II

Figure 1 shows five systems with strong He II emission lines (SDSS0756+30, SDSS1232+22, SDSS1502+33, SDSS1519+06, CSS2154+15). Previous sections have discussed SDSS1502+33 and CSS2154+15. The remaining three systems were first presented in Szkody et al. (2011). Additional spectra were taken to determine any changes that would indicate the nature of these objects. All spectra are similar to the past SDSS data, with weak broad Balmer and He II emission lines.
Figure 9. KPNO data from 2011 June showing two eclipses and two egresses from eclipse in SDSS2141+05.

7. COMMENTS ON THE REMAINING SPECTRA

7.1. CSS/SDSS0000+33

CSS found an outburst of this object on 2010 September 10. Our KPNO spectrum on September 12 shows the typical Balmer absorption lines of an accretion disk at outburst while the Palomar spectrum on September 18 shows the lines in emission, indicating that it was a short outburst and that the system was already declining to quiescence. The SDSS quiescent g magnitude is 20.5. While the integration time is long, so there is likely velocity smearing, the asymmetric nature of the lines may indicate a prominent hot spot, but a larger telescope is needed for orbital resolution.

7.2. CSS0051+20

The spectrum of this system near quiescence shows an interesting sharp peak in the broad Balmer emission lines. This could be indicative of irradiation of the companion or a hot spot on the accretion disk.

7.3. CSS/SDSS0058+28, CSS0650+41, and CSS1740+41

While these objects are very faint at quiescence, the broad lines of Hβ and Hγ are visible. The quiescent g magnitude of SDSS0058+28 is 19.2.

7.4. SDSS0344+09

Szkody et al. (2011) identified this object as a possible CV but with very narrow Balmer lines and a very blue continuum. The KPNO spectrum is very similar to the SDSS one, but extends blueward by 100 Å. It is possible that this system is a hot star with an irradiated companion.

7.5. CSS/SDSS0422+33

The asymmetric line shape with a sharp narrow component is typical of CVs with a prominent hot spot. The SDSS quiescent g magnitude is 19.8.

7.6. CSS0501+20

This object also displays the asymmetric profiles and peaks associated with a hot spot component. TS have time-resolved red spectra obtained four months after our KPNO data from which they obtained an orbital period of 1.8 hr.

7.7. CSS0647+49

TS obtained time-resolved red spectra in 2011 March that determined an orbital period of 8.9 hr. Our spectrum shows the blue wavelengths of this source.
Figure 10. MRO light curve of the likely Polar CSS/SDSS2154+15 obtained on 2013 October 29 (top) and the velocity curve from 2013 September 5 (bottom), phased with a period of 97 minutes and showing the best-fit sine curve with parameters from Table 3.

Figure 11. KPNO light curve of the dwarf nova CSS/SDSS2158+09 obtained on 2011 June 28, showing a possible orbital period near 104 minutes with hints of eclipses.
Figure 12. Velocity curves of H$\beta$ and H$\gamma$ obtained for the dwarf nova CSS0015+26 on 2011 August 26. H$\beta$ is phased with a period of 103 minutes and H$\gamma$ with a period of 99 minutes. The best-fit sinusoids are shown with parameters listed in Table 3.

Figure 13. H$\beta$ velocity curve of the dwarf nova CSS/SDSS0206+20 obtained on 2013 September 6, phased with a period of 81 minutes and showing the best-fit sine curve with parameters from Table 3.

Figure 14. H$\alpha$ velocity curve of the dwarf nova SDSS1132+62 obtained on 2013 February 5, phased with a period of 100 minutes and the best-fit sine curve with parameters from Table 3.
7.8. CSS/SDSS2156+19

The spectrum shows prominent, very broad, and doubled Balmer emission, indicating a fairly high-inclination system. TS obtained four images on 2011 June at $V = 20.83$ showing very blue colors ($B - V = -0.96$). The SDSS photometry shows $g = 18.5$.

7.9. CSS/SDSS2243+08, CSS/SDSS2325−01, and CSS/SDSS2338+28

One year after their outbursts, these objects display typical CV spectra with strong, broad Balmer emission. The SDSS photometry provides $g$ magnitudes of 19.6, 18.9, and 18.5 for these three objects.

8. CONCLUSIONS

Our photometric and spectroscopic observations of CV candidates discovered from SDSS, CRTS, and vsnet alerts have resulted in the confirmation of objects as dwarf novae, novalikes, or Polars as well as the determination of unusual properties of a few systems. Our photometry revealed QPOs following the outburst of V1363 Cyg, eclipses in the short-period system SDSS2141+05, and likely eclipses in CSS/SDSS2158+09. Our spectra confirm the Polar nature of CSS/SDSS2154+15, show interesting nightly changes in the accretion of the likely Polar SDSS1344+20, and refute the Polar classification of RXS0150+37. These results present systems where further detailed follow up is necessary to understand the physical parameters of the binaries. This work also portends the impending problems in accomplishing the necessary follow up for future, ever larger surveys such as LSST. It will be very difficult to determine the precise nature of the CVs discovered without obtaining both time-resolved spectra and photometry. A single spectrum at quiescence can confirm the CV nature through the Balmer emission lines and the width of the lines and their single- or double-peaked nature gives information about the inclination, while the strength of He II indicates a high excitation novalike or a magnetic white dwarf. However, the time-resolved data are necessary for the determination of the orbital period through the periodic presence of a hot spot or eclipses in the light curves, or its determination through radial velocity curves which also provide the masses of the underlying stars. These physical parameters are necessary for formulating the correct evolution and population model for close binaries.

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REFERENCES

Breedt, E., Gänsicke, B. T., Drake, A. J., et al. 2014, MNRAS, 443, 3174 (B14)
Bruch, A., & Schimpke, T. 1992, A&AS, 93, 419
Coppejans, D. L., Woudt, P. A., Warner, B., et al. 2014, MNRAS, 437, 510
Denisenko, D. V. 2013a, vsnet-alert 16406
Denisenko, D. V. 2013b, vsnet-alert 16457
Drake, A. J., Djorgovski, S. G., Mahabal, A., et al. 2009a, ApJ, 696, 870
Drake, A. J., Djorgovski, S. G., Mahabal, A., et al. 2009b, ATel, 2210
Gänsicke, B. T., Dillon, M., Southworth, J., et al. 2009, MNRAS, 397, 2170
Green, R. F., Ferguson, D. H., Liebert, J., & Schmidt, M. 1982, PASP, 94, 560
Hagen, H. J., Groote, D., Engels, D., & Reimers, D. 1995, A&AS, 111, 195
Kato, T. 2013a, vsnet-alert 15803
Kato, T. 2013b, vsnet-alert 16302
Liebert, J., Stockman, H. S., Angel, J. R. P., et al. 1978, ApJ, 225, 201
Lipunov, V. M., Kornilov, V., Gorbkovskoy, E., et al. 2010, AdAst, 2010, 349171
Maehara, H. 2011, vsnet-alert 13412
Miller, W. J. 1971, Spec. Vat. Ric. Astron., 8, 167
Oshima, T. 2011a, vsnet-alert 13289
Oshima, T. 2011b, vsnet-alert 13357
Ohshima, T. 2013, vsnet-alert 16294
Pojmanski, G. 1997, AcA, 47, 467
Stanek, K. 2013, vsnet-alert 16272
Szkody, P., Anderson, S. F., Brooks, K., et al. 2011, AJ, 142, 181
Szkody, P., Anderson, S. F., Hayden, M., et al. 2009, AJ, 137, 4011
Szkody, P., Henden, A., Agüeros, M., et al. 2006, AJ, 131, 973
Szkody, P., Henden, A., Fraser, O., et al. 2004, AJ, 128, 1882
Szkody, P., Henden, A., Fraser, O. J., et al. 2005, AJ, 129, 2386
Thorne, K., Garnavich, P., & Mohrig, K. 2010, IBVS, 5923
Thorstensen, J. R., & Skinner, J. N. 2012, AJ, 144, 81 (TS)
Warner, B. 1995, Cataclysmic Variable Stars (Cambridge: Cambridge Univ. Press)
Warner, B., & Nather, R. E. 1972, MNRAS, 156, 305
Wheatley, P. J., & Ramsay, G. 1998, in ASP Conf. Ser. 137, Wild Stars In The Old West: Proceedings of the 13th North American Workshop on Cataclysmic Variables and Related Objects, ed. S. Howell, E. Kuulkers, & C. Woodward (San Francisco, CA: ASP), 446
Wickramasinghe, D. T., & Ferrario, L. 2000, PASP, 112, 873
Woudt, P. A., Warner, B., de Baar, D., et al. 2012, MNRAS, 421, 2414
York, D. G., Adelman, J., Anderson, J. E., Jr., et al. 2000, AJ, 120, 1579