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Magnetic CVs in the UCT CCD CV Survey

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Abstract. An overview is given of all the magnetic CVs found in the UCT CCD CV Survey (Woudt & Warner 2001, 2002, 2003a). We have identified eight new candidate Intermediate Polars (IP), of which six are classical novae (RR Cha, DD Cir, AP Cru, V697 Sco, V373 Sct, and RX J1039.7-0507). The two other candidate IPs are Aqr1 (2236+0052) and RX J0944.5+0357. In addition, there are two probable Polars, namely V351 Pup (= Nova Puppis 1991) and FIRST J102347.6+003841.

1. The UCT CCD CV Survey

The UCT CCD CV Survey is an ongoing high-speed photometric survey of faint Cataclysmic Variable (CV) stars (Woudt & Warner 2001, 2002, 2003a) down to a magnitude limit of V $\sim$ 21. For this survey, we use the 1.9-m and 1.0-m telescopes of the South African Astronomical Observatory at the Sutherland site, in combination with the University of Cape Town (UCT) CCD camera (O'Donoghue 1995). In the past three years, an intensive observational campaign – mainly focused on old novae – has resulted in new orbital periods for 18 CVs, 12 of which are old southern novae.

2. Candidate Intermediate Polars

The objects listed in this section are candidate Intermediate Polars. In these systems we have either seen a second (consistent) photometric period in addition to the orbital modulation, e.g., DD Cir, or we have identified multiple photometric periodicities associated with a spin period (or its harmonic) and its orbital sidebands, e.g., RX J1039.7-0507. In the former case, confirmation of the suspected spin period in X-rays, or optical sidebands is needed to confirm its classification, whereas in the latter scenario, the orbital sidebands already secure the IP nature of the CV.

We will list each of the eight candidate IPs with a short description of their main characteristics. A summary is given in Table 1.

Aqr1: Listed in Downes et al. (2001) as Aqr1, this object is also known as 2236+0052 and was identified spectroscopically as a CV by Berg et al. (1992) in a bright QSO survey. We have observed Aqr1 during four nights in 2002 November; the light curves of Aqr1 (for two of the nights) are shown in Figure 1. The Fourier Transform (FT) of the combined data set, after subtracting

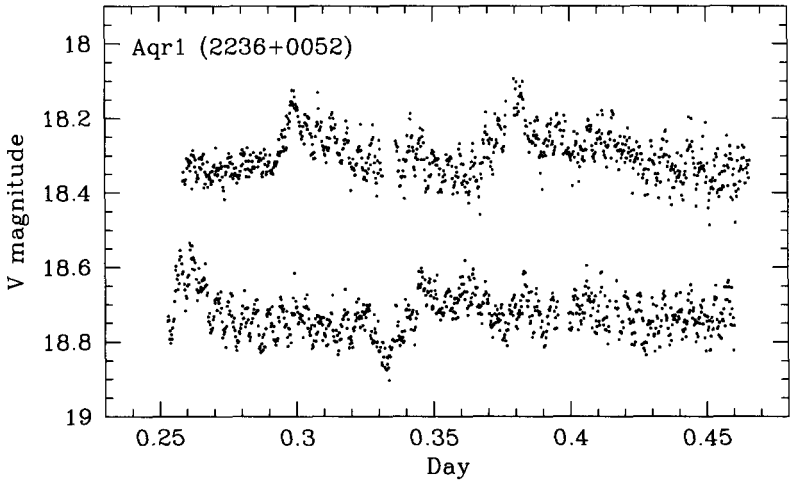

Figure 1. The light curves of Aqr1 (2236+0052) obtained on 2002 November 1 (upper light curve) and November 2 (lower light curve, displaced downwards by 0.4 mag).

the mean of each run, is shown in Figure 2. There is an unambiguous peak at $\omega = 2477.1$ μHz, which we infer to be the spin frequency. In addition, there are two prominent sidebands ($\omega - \Omega = 2391.2$ μHz and $\omega + \Omega = 2563.2$ μHz) – see also the blow up in the upper panel of Figure 2 – approximately equally spaced on either side of ω; the separation is 85.9 μHz and 86.1 μHz, respectively, for $\omega - \Omega$ and $\omega + \Omega$. The orbital frequency (Ω) cannot be determined unambiguously from these data, as the one day alias (towards lower frequency, i.e. a larger orbital period) cannot be excluded. The peak at low frequency in the lower panel of Figure 2 does not correspond to the orbital frequency, nor one of its aliases. A more thorough study of Aqr1 is needed in order to determine its orbital period. The classification as an Intermediate Polar, however, is secure due to the presence of the orbital sidebands.

RR Cha: RR Cha (Nova Chamaeleontis 1953) is an eclipsing system (P_{orb} = 3.362 h) which shows both positive and negative superhumps (Woudt & Warner 2002). In two independent data sets (2001 February and 2001 May) we identified a photometric periodicity at 1950 s, suggesting that this might be either the spin period of the white dwarf, or the reprocessed period. It is not detected in the ROSAT X-ray survey (G. Israel, private communication), but recent polarimetric observations of RR Cha (Rodríguez-Gil & Potter, in prep.) revealed circular polarisation at the 1950 s periodicity, supporting the classification as an IP.

DD Cir: DD Cir (Nova Circini 1999) is an eclipsing system (Woudt & Warner 2003a) with $P_{orb} = 2.339$ h and eclipses ~ 0.6 mag deep. It has a mean

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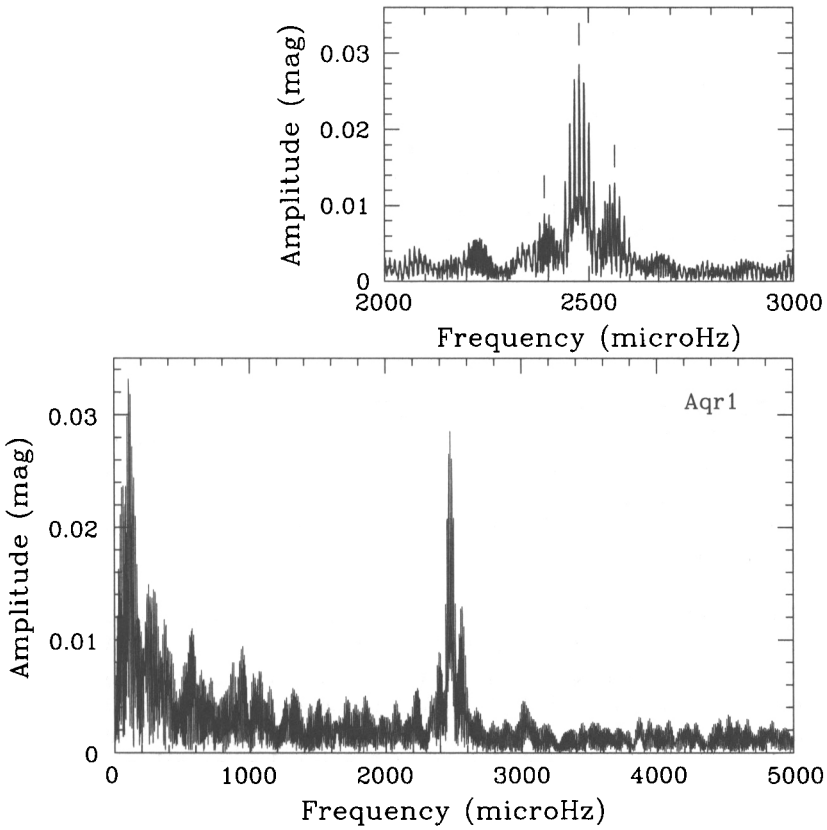

Figure 2. The Fourier transform of Aqr1 (2236+0052) of the 2002 November data.

magnitude out of eclipse of V $\sim$ 20.1 mag. The light curve of DD Cir reveals a number of interesting features: (i) there is a reflection effect of amplitude $\sim$ 0.3 mag, indicative of a recent nova outburst in a system where the disc does not dominate the luminosity of the system (a short orbital period and high inclination both favour such reflection effect), (ii) there is evidence for a secondary eclipse, and (iii) there is a consistent photometric modulation at $\sim$ 670 s which is either the spin period of the white dwarf, or its orbital sideband.

AP Cru: AP Cru was Nova Crucis 1936 and is currently at V $\sim$ 18. An uncharacteristic CV spectrum (absorption spectrum of a K7 star with strong narrow Hα emission superimposed) was observed for AP Cru (Munari & Zwitter 1998), when the system was 0.6 – 0.9 mag fainter than our observations. We suggest that the star was at a very low (or zero) mass transfer rate then. We find an orbital period of 5.12 h, and in the FT there is a persistent signal at 1837 s, suggestive of AP Cru being an IP (Woudt & Warner 2002). There is

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no X-ray emission observed from AP Cru; its large distance and low Galactic latitude (2°) make it improbable that it would be detected in X-rays.

V697 Sco: We observed V697 Sco (Nova Scorpii 1941) during two nights in 2001 May, and four nights in 2002 June (Warner & Woudt 2002). It is faint (V $\sim$ 20) and located in a star-crowded region. The orbital frequency and its first harmonic are very distinctly present in the FT (P_{orb} = 4.49 h), but after prewhitening at these frequencies, a set of peaks remain which can be explained in terms of ω (and its harmonics), and orbital sidebands. The spin period ($2\pi/\omega$) of V697 Sco is 3.31 h, and hence the model that emerges for V697 Sco is that of an asynchronous magnetic rotator, similar to IPs like EX Hya and V1025 Cen, but with a much larger P_{orb}. For a detailed discussion of V697 Sco, see Warner & Woudt (2002).

V373 Sct: V373 Sct (Nova Scuti 1975) was observed by us on three nights in 2002 April. The light curves show great activity but no orbital modulation. The only significant modulation in any of the three light curves was a narrow spike at 258.3 s seen in one of the runs (S6361, see Woudt & Warner 2003a). More observations are needed in the optical and X-ray regions to confirm its possible IP classification.

RX J0944.5+0357: Spectroscopic observations of RX J0944.5+0357 by Jiang et al. (2000) showed H I and He I emission lines typical of a CV. Additional spectroscopy by Mennickent et al. (2002) confirmed the previously determined (spectroscopic) orbital period of 3.581 h reported to them by Thorstensen & Fenton. High speed photometry of RX J0944.5+0357 by Mennickent et al. (2002) revealed large amplitude variations ($\sim$ 0.5 mag), but no coherent signal was reported in their data.

Our high speed photometry of RX J0944.5+0357, taken in 2002 March and April, revealed a repetitive brightness modulation with a period of $\sim$ 2000 s. This feature has a double humped profile, with the two humps varying independently and rapidly in amplitude. One of our light curves illustrating this most clearly is shown in Figure 3. The best period (from the Fourier Transform of the entire data set) is 2162 s and is shown in Figure 3 as the lower vertical bars. RX J0944.5+0357 is similar to canonical IPs such as FO Aqr and TV Col, however, it most resembles YY Dra (e.g., the double-humped light curve). A more extensive discussion of our observations can be found in Woudt & Warner (2003b).

RX J1039.7-0507: RX J1039.7-0507 was identified by Appenzeller et al. (1998) as a CV at V = 18.5. Our photometry of RX J1039.7-0507 (Woudt & Warner 2003c) showed a strong reflection effect of amplitude $\sim$ 1.1 mag (peak-to-peak), and we deduced that RX J1039.7-0507 must have been a recent nova (within the past decade or so). As such it is the first in a class of relatively recent 'overlooked' novae. The light curves show a nearly sinusoidal intensity modulation at a period of P_{orb} = 1.574 h.

The FT (of intensities) of the entire data set, prewhitened at the orbital period and its first harmonic, is dominated by peaks at 1932.5 s and 721.9 s,

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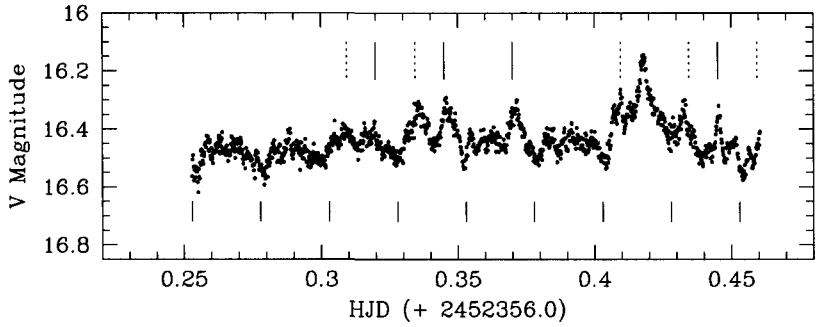

Figure 3. The light curve of RX J0944.5+0357 obtained on 2002 March 22. The 2162 s periodicity is marked by the lower vertical bars; the pairs of peaks of variable amplitude are marked by the upper bars (dotted bar for the first peak, solid bar for the second peak).

which we associate with $\omega - \Omega$ and 2ω, respectively. There are lower amplitude peaks at the ω (P_{spin} = 1444 s) and $2\omega + \Omega$ frequencies. Only this association produces a sensible model (*i.e.* an IP with orbital sidebands and two-pole accretion) for the observed photometric modulations. RX J1039.7-0507 is a good candidate for an extended pointed observation in X-ray and UV bands.

Table 1. Candidate Intermediate Polars, optical modulations only.

Name	P_{spin} (s)	P_{orb} (h)	Sidebands	Class	<V>
V373 Sct	258.3		No	CN	18.6
Aqr1	403.7	3.23:	Yes		18.3
DD Cir	670:	2.339	No	CN	20.1
RX J1039.7-0507	1444	1.574	Yes	CN:	18.4
AP Cru	1837	5.12	No	CN	18.0
RR Cha	1950	3.362	No	CN	18.4
RX J0944.5+0357	2162	3.581	No		16.5
V697 Sco	11916	4.49	Yes	CN	20.0

CN = Classical Nova, ':' denotes uncertain values.

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3. Candidate Polars

To date, the UCT CCD CV Survey has resulted in the detection of two probable Polars, Nova Puppis 1991 (V351 Pup), and FIRST J102347.6+003841.

V351 Pup: The light curves of Nova Puppis 1991 (V351 Pup) are so similar to V1500 Cyg (Nova Cygni 1975), that it suggests that V351 Pup, like V1500 Cyg, is a polar. An argument in favour of this is the very large reflection effect observed in V351 Pup (Woudt & Warner 2001) of $\sim$ 1.2 mag (see also RX J1039.7-0507), that is typical of a recent nova in which the disc does not dominate the luminosity of the system. In the case of RX J1039.7-0507 the short orbital period implies a small disc; in the case of V1500 Cyg (P_{orb} = 3.35 h) there is no disc. With an orbital period of 2.837 h in V351 Pup, the latter would be required, i.e., no disc, to show such large reflection effects. G. Schmidt (private communication) has observed V351 Pup and detected no circular polarisation to a 3σ upper limit of 1%, but at the time of observation V351 Pup was far earlier in its recovery from its eruption than when V1500 Cyg was observed to be polarised, and hence much more unpolarized light is probably present in V351 Pup. At V $\sim$ 19, V351 Pup will be an ideal target for spectropolarimetric observations with large telescopes.

FIRST J102347.6+003841 (FIRST): This is the first CV to be discovered from radio emission (Bond et al. 2002). Our photometry of FIRST during 2003 January is shown in Figure 4. The light curves taken by us are in sharp contrast to those shown by Bond et al. (2002). There is some flickering on top of what is otherwise a very regular light curve. The light curves are modulated at a period (P_{orb}) of 4.75 h (the light curves shown in Figure 4 are phased on this period). In the FT the fundamental and the first harmonic of the 4.75 h periodicity are present, but no other stable period is seen (unlike RX J1039.7-0507). The light curve has the characteristics of a reflection effect (peak-to-peak amplitude $\sim$ 0.45 mag), so in analogy to V351 Pup and RX J1039.7-0507, FIRST could have been a recent nova (in the past few decades) that was overlooked. FIRST is located far from the Galactic Plane ($\ell = 243°$, $b = +46°$) – only $\sim$ 10° away from RX J1039.7-0507 – and could have been easily missed by nova searches.

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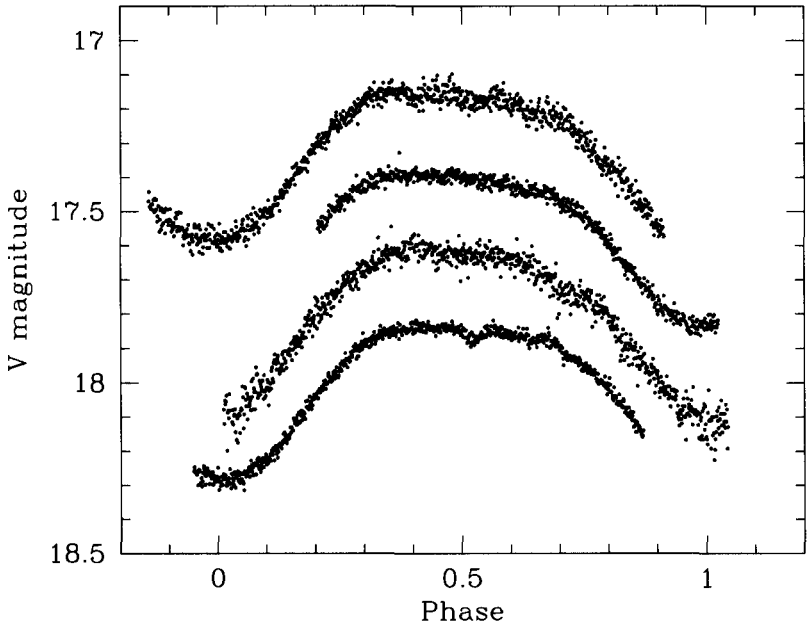

Figure 4. The light curves of FIRST J102347.6+003841, phased on the orbital period of 4.75 h. The top light curve is at the correct brightness (V $\approx$ 17.3), the other three have been displaced vertically for display purposes.

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