A first look at cataclysmic variable stars from the 2dF QSO survey

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Abstract. The 2dF QSO survey is a spectroscopic survey of 48,000 point-sources selected by colour with magnitudes in the range $18.35 \leq B \leq 20.95$. Amongst QSOs, white dwarfs, narrow-line galaxies and other objects are some cataclysmic variables. This survey should be sensitive to intrinsically faint CVs. In the standard picture of CV evolution, these form the majority of the CV population. We present the spectra of 6 CVs from this survey. Four have the spectra of dwarf novae and two are magnetic CVs. We present evidence that suggests that the dwarf novae have period $P < 2$ h and are indeed intrinsically less luminous than average. However, it is not clear yet whether these systems are present in the large numbers predicted.
1. Introduction

The standard picture of cataclysmic variable (CV) evolution was developed to explain three outstanding features of the orbital period distribution of CVs: (1) the cutoff for $P \gtrsim 10$ h, (2) the dearth of systems with $2 \lesssim P \lesssim 3$ h (the “period gap”) and (3) the cutoff for $P \lesssim 80$ min. The theory involves magnetic braking at long periods, gravitational radiation braking at short periods, and a hiatus in between when the magnetic braking is disrupted resulting in the period gap. Degeneracy of the donor stars at short periods leads to the period minimum.

This theory suffers from several problems. First, single star studies provide no support for either the magnitude of magnetic braking assumed in CV studies or its disruption when the donor star becomes fully convective (Andronov, Pinsonneault, & Sills 2001). Moreover, an excess of systems is expected close to the period minimum, but is not observed (Kolb & Baraffe 1999; also Kolb, King, this volume). Associated with this is a prediction that most (99%) systems should be of short period ($P < 2$ hrs), whereas the observed number is more like 50% (Kolb 1993). This is also seen in the observed space densities which are consistently lower than theoretical predictions (see Gänsicke, this volume).

A possible reason for the absence of an excess of short period systems is that they exist, but just have not been discovered. The only way for this to be the case is if they never, or very rarely, go into outburst. The uncertainty over accretion physics is large enough that no one is competent to say whether or not this is possible, and so it must at least be admitted as a possibility. If so, then we need to search for such systems without relying on gross changes in brightness. In this paper we present the first spectra of targets found in a search based upon selection for ultraviolet excess. We start by describing the survey and why we expect it to turn up intrinsically faint CVs. We then present the first spectra of the 6 targets and discuss the evidence that suggests that they are indeed of low luminosity. We finish by discussing whether these systems can solve the problem of the missing submerged iceberg of the CV population outlined above.

2. The 2dF QSO survey

The 2dF (2-degree field) spectrograph on the 3.9m Anglo-Australian Telescope is a prime-focus, fibre-fed spectrograph that can obtain up to 400 spectra at once covering a two-degree-wide field of the sky. Two large projects have been running on this instrument since it was commissioned: the 2dF Galaxy & QSO surveys. The 2dF QSO survey (Boyle et al. 2000; Croom et al. 2001), which is still taking place (2001), will obtain spectra of $\approx 48,000$ sources which appeared star-like on archive blue photographic plates, selected by colour and magnitude to exclude stars in the Milky Way. The survey covers 740 sq. deg, in two strips, one near the equator, and the other at $\delta \approx -30^\circ$ at the South Galactic Pole. CVs display ultraviolet excesses, thus they are also included in the target list, and can be identified once spectra are obtained. Such identification is in any case essential because only about 60% of the targets are expected to be QSOs.

Fig. 1 shows the locations of the CV candidates in the colour selection plot used to select targets for the 2dF QSO survey. The plot does not indicate any
Figure 1. Colour/colour plot of CV candidates from the 2dF QSO survey. The region in the upper-right is occupied by normal stars and is rejected. Most of the CV candidates are located well away from this region, essentially because of their $u' - b_J$ colours. The numbers along with the cross & circle symbols correspond to the targets we observed. Arrows indicate upper limits (no red detection). For our targets, $u' \approx U - 0.24$, $b_J \approx B - 0.1$, and $r \approx R$. The very red colour of target 6 indicates that it was in outburst when the red plate was taken in March 1985.

build-up of candidates towards the excluded zone, which would have suggested significant incompleteness.

Colour-selected surveys are nothing new, some 30 CVs having turned up in the PG survey (Green, Schmidt, & Liebert 1986; Ringwald 1996). However, the 2dF survey reaches much fainter apparent magnitudes than did the PG survey. 2dF targets are selected to have $18.25 < b_J < 20.85$ ($\approx 0.1$ mags fainter still in $B$), so even the brightest targets are fainter than the faintest PG CVs at $B \approx 16$. Of course, the area covered by the 2dF survey is smaller than the PG survey’s 10,700 sq. deg., but it nevertheless has a larger effective volume at faint absolute magnitudes.

Assuming a particular absolute magnitude, galactic scale-height and local space density, one can calculate the number of objects expected in a given survey. We compare the effectiveness of PG and 2dF surveys as a function of absolute magnitude in this manner in Fig. 2. The PG survey is, as expected, more effective at bright magnitudes because of its large area. The 2dF survey on the other hand wins at absolute magnitudes $M > 9.5 - 10.5$, depending upon the scale height assumed. In principle the accretion luminosity of CVs could
The number of systems detectable, assuming they all have the same absolute magnitude, as a function of that magnitude in the PG and 2dF surveys for two different scale heights in the disk. We assume the local space density from Ringwald (1996) of $6 \times 10^{-6}$ pc$^{-3}$. The dot-dash line in the lower left shows the same for halo CVs assuming a space density $10^4$ times smaller but an (arbitrary) 8 kpc scale height.

descend to even fainter magnitudes than indicated on the plot, however in such cases it is the magnitude of the white dwarf that matters and those observed so far in CVs have always satisfied $M < 13$. For example, at $\log g = 8$, white dwarfs have absolute magnitudes of $M_V = 12.1$ for a temperature $T = 10,000$ K (Bergeron, Wesemael, & Beauchamp 1995), corresponding to the coolest white dwarf observed in any CV (Szkody, this conference). Thus the 2dF survey is sensitive to the faintest magnitudes known for any CV so far. (The possibility of cooler white dwarfs should not be dismissed however, because such systems may fail to appear in the 2dF and similar UV excess surveys, thus the failure to find any cooler white dwarfs in CVs may be a selection effect.)

3. The Spectra

As part of the survey classification, the 2dF spectra were checked by eye. It was this that led to the identification of 19 CV candidates. We observed 6 of these over three dark nights on the 4.2m William Herschel Telescope (WHT) in the Canary Islands in February 2001. We used the ISIS spectrograph to cover blue and red simultaneously. On the blue arm we covered 3460 – 5350Å at
3.5Å FWHM resolution, while on the red arm we covered 6150 – 9116Å at 5.8Å resolution.

Table 1. Target details.

| Target | RA (J2000) | Dec  | $b_J$ | Type$^3$ | Orbital period |
|--------|------------|------|-------|----------|----------------|
| 1      | 11 25 55.73 | -00 16 38.9 | 19.64 | DN       | 0.0613 d       |
| 2      | 12 10 05.30 | -02 55 43.9 | 20.72 | DN       | —              |
| 3      | 13 04 41.76 | +01 03 30.8 | 20.73 | DN       | —              |
| 4      | 14 22 56.32 | -02 21 08.7 | 19.54 | Mag.     | 0.1404 d$^\dagger$ |
| 5      | 14 24 38.94 | -02 27 39.9 | 19.52 | Mag.     | 0.1555 d$^\dagger$ |
| 6      | 14 35 00.18 | -00 46 06.9 | 18.58 | DN       | 0.072727 d$^\dagger$ |

§ Classified from spectra alone.
† Several 1 cycle/day aliases possible as well.
‡ From Vanmunster, Velthuis, & McCormick (2000).

Details of the targets are shown in Table I, and their mean spectra are shown in Fig. 3. As yet we have no photometry of any of our targets beyond the target selection plates, and so we do not know their outburst behaviour (except target 6 which has outbursts of $\approx$ 4 mags, Vanmunster, Velthuis, & McCormick 2000 and Fig. I). However, the spectra are characteristic enough that we can make identifications of the CV type with confidence. Targets 1, 2, 3 and 6 have the spectra of quiescent dwarf novae, while we identify targets 4 and 5 as “magnetic” (polar or intermediate polar) because of their narrow lines and strong HeII 4686, and because the M-type donor star is visible in each of them (each shows NaI 8200 and TiO bandheads at 7200 and 7500Å). Novalike variables can also show HeII 4686, but have broader lines and are bright enough to drown out M-type donor stars. There is direct evidence of cyclotron emission in target 5, visible in the red spectrum in Fig. 3 and in time-resolved spectra.

One of the aims of our observations was to measure orbital periods (from variations in the emission lines) to test whether these systems were indeed part of the predicted majority of short period systems. We have been partly successful, and were helped by the discovery that target 6 (our brightest, and also discovered in the Large Bright Quasar Survey, Berg et al. 1992) was eclipsing (Vanmunster, Velthuis, & McCormick 2000). We failed to find periods for targets 2 and 3. We had only three spectra of target 3, while target 2 failed to show significant variability in the 10 spectra we acquired (total of 4 hours exposure). However, we suspect that, like targets 1 and 6, targets 2 and 3 are also short period ($P < 2h$), because there are no obvious donor star features while at the same time the presence of broad absorption wings shows that the white dwarf is visible. In addition, the lack of large radial velocity shifts in target 2, even though its emission lines are clearly double-peaked (i.e. it is not of low inclination), suggests that its donor is of low mass, as expected at short orbital periods.

$^1$A rather remarkable fact, given that only 100-odd magnetic systems are known, is that the two magnetic systems found here are within half a degree of each other!
Figure 3. The average spectra of the six 2dF CV candidates observed.
The short periods of the dwarf novae support the theory, but given that 65 out of 121 dwarf novae with known period have $P < 2.5$ h, no great significance can be attached to this (Ritter & Kolb 1998). Of rather more interest are the broad absorption wings from the white dwarf in targets 1, 2 and 3, suggesting $9 \lesssim M_V \lesssim 13$. In addition these systems show steeper-than-typical Balmer decrements and clear double-peaked lines, indicative of relatively cool disks of low optical depth. The Hα and Hβ equivalent widths are compared in Fig. 4 with those listed in the compilation of Echevarria (1988). Targets 1, 2 and 3 lie in a region of fairly average Hβ flux, but strong Hα, not occupied by the systems in Echevarria’s list (although there are stars such as GD552 and LL And that would probably be in a similar position).

4. Discussion

The 2dF CVs show signs of being of low intrinsic luminosity, but it is too early to say whether they match expectations in all respects. Certainly target 1, with a period of 88 min could be a “post period-bounce” system, but precise periods are required for targets 2 and 3 as well. An interesting point to note about these systems is that it may well be the white dwarfs that dominate rather than accretion light. Thus searches for “flickering” may prove disappointing as a means of detecting low-$L$ systems. On the other hand a subset of them should show brief and deep eclipses, so variability searches are still worthwhile, if sufficient area can be covered.
The 2dF survey is about 2/3rd complete. At the moment there are about 20 CV candidates. Not all of these will be confirmed as CVs perhaps, but others may be found, and so a total of 30 seems reasonable. This is consistent with the PG survey for Ringwald’s (1996) space density, a scale-height of 250pc, and a CV luminosity function dominated by systems with $M_B \approx 10$. A lower scale height would require a higher space density (see Fig. 3) approaching the region implied by theory. At this stage one might say that the uncertainties are such that there is little evidence for any discrepancy between observations and theory. However, the key test will be provided by their periods, because we expect the “missing majority”, if they exist, to cluster close to the period minimum. Confirming or refuting this is our long term aim.

5. Conclusions

We have presented spectra of 6 cataclysmic variables discovered in the 2dF QSO survey. Four are dwarf novae, two are magnetic. Three of the dwarf novae show white dwarf absorption wings, steep Balmer decrements and double-peaked line emission, with no sign of their donor stars. All are characteristics of low-luminosity, short-period systems. One of the three has a confirmed period of 88 mins, but further measurements of orbital periods are needed to see if these systems cluster near the orbital period minimum. The fourth and brightest dwarf nova has a period 105 mins; it is an eclipsing system very similar to OY Car and Z Cha. We point out that very low luminosity CVs are likely to be dominated by light from their white dwarfs rather than their accretion disks or stream/disk impact regions.

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