

## Discovery of two new faint cataclysmic variables<sup>★</sup>

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**Abstract.** We report on the discovery of two new faint cataclysmic variables. The objects were selected as candidates from two different imaging surveys aimed at the discovery of such faint systems. One survey used color and variability while the other used color and H $\alpha$  emission as selection criteria. We present our spectra of the two new variables and discuss their properties. A discussion of the implication of these discoveries on the space density of faint cataclysmic variables is presented.

**Key words.** stars: novae, cataclysmic variables

### 1. Introduction

Cataclysmic variables (CVs) are an important class of binary stars as they contain one of the most populous stars in the universe, a white dwarf. The other star in a CV is a low mass object, generally 0.8–0.1  $M_{\odot}$ , which loses mass via Roche Lobe overflow toward the more massive primary. A review of the general properties of CVs is given in Warner (1995).

Recent theoretical work (e.g., Howell et al. 2001; Kolb 2001) has predicted that the majority of present day CVs will have very short orbital periods (<2 hours) and be of low luminosity ( $M_V < 11$ ), i.e., they will be TOADs (Tremendous Outburst Amplitude Dwarf novae; Howell et al. 1995). These predictions are based on binary evolution models using the accepted, long held paradigms of CV evolution theory. However, recent new ideas related to the level at which magnetic fields drain orbital angular momentum, and if and when they cease to be important for the mass donor star, have been proposed (King et al. 2002; Howell et al. 2000). Additionally, the idea of circumbinary disks as an orbital angular momentum sink has been proposed (Taam & Spruit 2001, 2002), observationally searched for (Sanghi et al. 2002) and possibly discovered (Mouchet et al. 2002). If these new theoretical ideas are shown to be correct, the predicted plethora of short period, faint CVs may not really exist. However, it may be that the oldest systems no longer resemble CVs at all (e.g., Harrison et al. 2002).

Other imaging surveys with spectroscopic follow-up (SDSS, Szkody et al. 2002; 2dF, Marsh et al. 2002; HQS, Gänsicke et al. 2002) use different candidate selection criteria but also are discovering new CVs in the magnitude range of 16 to ~21. The initial estimated space density of CVs from

these surveys do not support the predicted large faint CV population. However, as we will see below, our survey type and candidate selection are based on different methods and we go to fainter magnitude limits. Fainter candidate search techniques are in line with theoretical predictions for a larger space density of low luminosity CVs (Politano et al. 1998). In any case, observational identification and study of faint CVs are needed in order to test our long held ideas about cataclysmic variables and to prove or eliminate the existence of a large group of faint CVs. The results of such programs also have a direct bearing on the white dwarf and binary star production within the Galaxy.

We present here our initial search for faint CVs by using candidate sources identified from two imaging surveys. These two surveys have been undertaken to provide candidate CVs for follow up spectroscopic confirmation. The Faint Sky Variability Survey (Groot et al. 2002) used the wide-field camera on the 2.5-m Isaac Newton telescope to provide candidate sources based on blue color ( $B - V$ ,  $V - I$ ) and intrinsic variability on time scales of minutes, hours, days and up to 1 year (see Huber et al. 2002). The FSVS has observed ~20 square degrees and presents multi-color data on point and extended sources from  $V = 16.5$  down to  $V \sim 24$ th magnitude. A second survey (Davenhall et al. 2001; Clowes et al. 2002) used UK Schmidt plates in  $B$ ,  $R$ , and H $\alpha$  to identify faint sources which are both blue ( $B - R$ ) and likely to be H $\alpha$  sources. These candidates are of  $B$  magnitude 18 to >22. Details of the selection criteria for faint CV candidates from both of these surveys are discussed in the references given above.

### 2. Observations

Our observations were performed using the ESO New Technology Telescope (NTT) and the ESO Multi-Mode Instrument (EMMI) on the nights of 9-10 August 2002. We used EMMI in RILD (Red Imaging, Low Dispersion) mode

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<sup>★</sup> Based on observations obtained at ESO La Silla (ESO Proposal 69.D-0142(A)).

**Table 1.** Faint CV candidates.

Source	RA(2000)	DEC(2000)	UT(h)	$B^a$	Int Time (s)	ID
2002 Aug. 09 UT						
FSVSJ1626+2657	16:26:27.10	+26:57:58.8	23:34	16.4	2x180	sd F, G star
FSVSJ1632+2107	16:32:36.32	+21:07:22.4	23:55	18.6	350	F, G star
2002 Aug. 10 UT						
H $\alpha$ 0231–3140	2:31:09.1	–31:40:34	07:53	20.5	1000	A, F star
H $\alpha$ 0233–3101	2:33:36.0	–31:01:00	06:57	19.9	800	A, F star
H $\alpha$ 0236–3058	2:36:40.9	–30:58:22	07:42	20.4	20 <sup>b</sup>	compact galaxy
H $\alpha$ 0237–3024	2:37:08.1	–30:24:07	09:04	19.3	800	QSO
H $\alpha$ 0240–2836	2:40:46.8	–28:36:02	08:17	20.6	1000	F, G star
H $\alpha$ 0241–3045	2:41:30.1	–30:45:37	07:17	20.1	800	QSO
H $\alpha$ 0241–2923	2:41:47.3	–29:23:40	06:07	19.4	800	QSO
H $\alpha$ 0242–2802	2:42:34.8	–28:02:43	09:57	19.0	2x700	CV
H $\alpha$ 0247–3159	2:47:07.1	–31:59:49	06:36	19.7	800	blue cont.
H $\alpha$ 0249–2748	2:49:30.5	–27:48:09	08:41	19.4	800	QSO
H $\alpha$ 0251–2837	2:51:23.9	–28:37:52	09:24	19.4	800	QSO
H $\alpha$ 0254–3224	2:54:25.8	–32:24:29	05:31	19.9	600	A, F star
FSVSJ1722+2733	17:22:17.09	+27:33:21.2	01:01	20.5	800	A, F star
FSVSJ1722+2723	17:22:43.96	+27:23:55.7	00:15	20.6	2x900	CV
FSVSJ1722+2714	17:22:55.72	+27:14:14.6	00:48	19.3	350	F, G star
FSVSJ1725+2729	17:25:09.04	+27:29:03.9	01:55	20.9	2x1000	A, F star
FSVSJ1727+2737	17:27:54.09	+27:37:43.4	02:35	18.8	250	F, G star
FSVSJ1728+2736	17:28:04.43	+27:36:57.6	01:23	17.1	230	H $\alpha$ em. cores, narrow ab. lines
FSVSJ2159+2743	21:59:18.92	+27:43:29.8	03:40	20.7	600	F, G star
FSVSJ2159+2737	21:59:51.39	+27:37:06.2	03:58	18.0	350	H $\alpha$ em. cores, narrow ab. lines
FSVSJ2200+2729	22:00:44.19	+27:29:10.6	04:22	21.4	2x1500	double, red+blue stars
2002 Aug. 11 UT						
FSVSJ2341+2726	23:41:21.52	+27:26:28.9	07:59	18.4	350	blue cont., no/weak lines
FSVSJ2348+2826	23:48:16.01	+28:26:29.3	08:12	18.4	350	blue cont., no/weak lines

<sup>a</sup> The  $B$  magnitude is from the imaging survey observations.

<sup>b</sup> Image only, no spectrum obtained.

with a 360 l/mm grism (grism #3) providing 2.3 Å spectral resolution and wavelength coverage from 3400 to 9200 Å. The grism efficiency drops blue-ward of 3800 Å and red-ward of 9000 Å. Minor second order overlap from 3400 Å to about 4200 Å occurred but since the sources of interest were faint and blue, and the grism efficiency in second order at the overlap (red) wavelengths is only 20% of first order, we used no order sorting filter for these observations. This decision provided maximum throughput for the spectrograph.

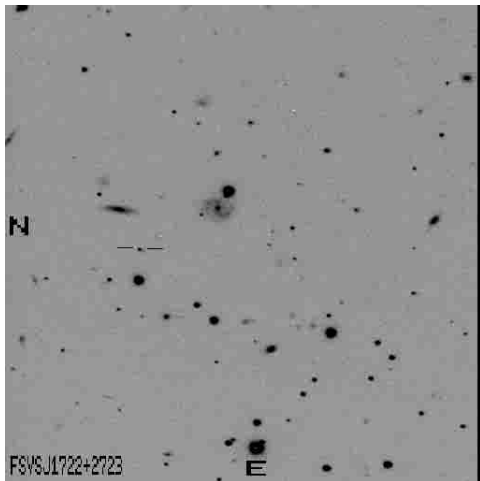
The seeing was excellent on both nights, being between 0.4 to 0.6 arcsec for almost all times and sources. Sources at higher airmass (the northern sky sources had  $X = 1.4$ – $2.0$ ) had slightly degraded seeing, near 0.8 arcsec. We used a 1.0 arcsec slit for all observations, thus all the source light entered the spectrograph. We observed spectrophotometric standards at the start and near the end of each night, and bias, flat, and wavelength calibration arcs were obtained prior to and after each night of observing. EMMI is a Nasmyth focus instrument, so spectrograph flexure throughout the night does not occur. Our calibrated spectra have a wavelength scale uncertainty of 0.2 Å rms and typical flux uncertainties are of order 10% over most of the range, degrading rapidly near the ends.

Candidate stars were chosen from the FSVS fields centered near RA 16–17h and DEC +21–28 and RA 21–0 and DEC +27 (see Groot et al. 2002). H $\alpha$  candidates were selected from a

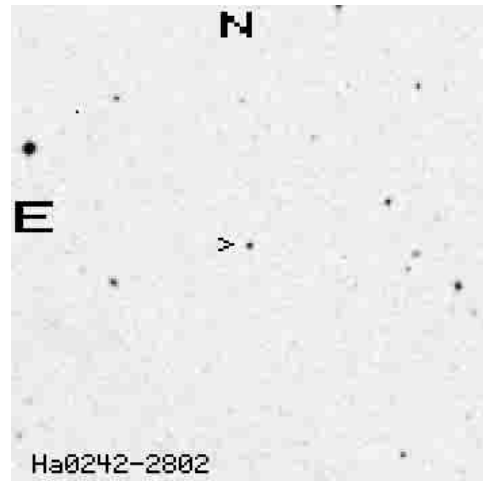
Schmidt field centered near RA 2:20, DEC –30 (see Clowes et al. 2002). In all, we observed 13 FSVS candidates that were known to be “CV-like” variables and bluer than  $B - V = 1.0$ , and  $V - I = 1.2$ , the CV color range (see Huber et al. 2002). We also observed 12 H $\alpha$  candidates (Clowes et al. 2002) that were bluer than  $B - R = 1.0$  and in fact showed no appreciable H $\alpha$  emission (except for the discovered CVs and 1 red-shifted QSO line). This initial survey work was designed to explore the sensitivity of our selection criteria and has revealed that some emission is probably variable, our  $R$ ,  $B$ , and H $\alpha$  source matching is not yet optimal, and/or there is a broader main sequence component than we expected. From our initial small sample of 25 candidates, we discovered two new CVs, two stars with emission cores in H $\alpha$ , and six extragalactic objects. The five QSOs observed will be discussed in detail in Clowes et al. (2002). Table 1 presents an observing log for the candidates and their identification.

### 3. Discussion

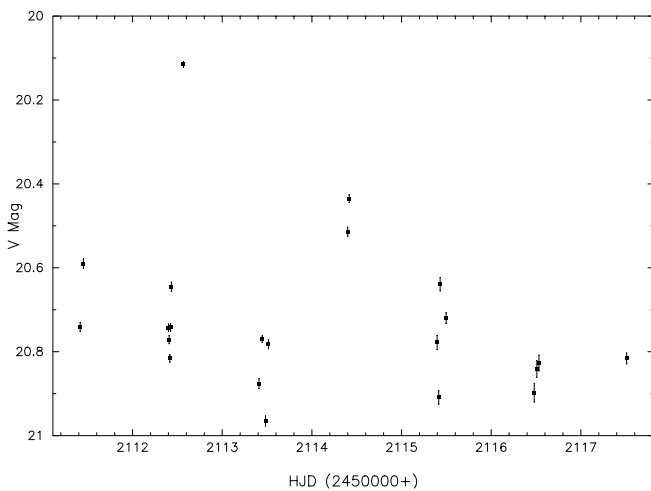
Both imaging surveys provide accurate positions and magnitudes for the candidates. We present finding charts for the new CVs in Figs. 1 and 3, our FSVS V-band light curve in Fig. 2, and the EMMI spectra in Fig. 4. Table 2 provides some details of the properties of the new CVs along with magnitude information obtained from the imaging surveys.



**Fig. 1.** Finding chart for FSVSJ1722+2723 made from the EMMI image obtained prior to the spectroscopic observation. This image is approximately  $V + R$ , is a 20 s exposure, and is 2.3 arcmin on a side.



**Fig. 3.** Finding chart for H $\alpha$ 0242-2802 made from the first generation POSS red plates. The chart is 5 arcmin on a side.



**Fig. 2.** FSVS V-band light curve for FSVSJ1722+2723. Note the rapid variability suggestive of a short orbital period.

### 3.1. H $\alpha$ 0242-2802

H $\alpha$ 0242-2802 has the  $B - R$  color of a mid- to late A-star, similar to the short period TOADs, WZ Sge and GO Com. In fact, the spectrum obtained for H $\alpha$ 0242-2802 (Fig. 4) has an appearance reminiscent of WZ Sge (also shown in Fig. 4) with strong, double peaked emission lines of H and He (the central absorption extending to near or below the local continuum for the He lines and later Balmer lines), and evidence for white dwarf absorption in the later Balmer lines. We also note that in H $\alpha$ 0242-2802 and WZ Sge the Paschen series lines are in emission as well. The continuum appearance, the white dwarf absorption, and the emission line structures in general are indicative of a high inclination, short orbital period, low mass transfer CV. A determination of the orbital period for H $\alpha$ 0242-2802 is needed and, if similar to WZ Sge as well, would provide confirmation of these inferences. Making a tentative guess, based on the assumed similarity with WZ Sge, we take the  $M_V$  of H $\alpha$ 0242-2802 to be near 12 yielding a  $z$  height of 250 pc.

### 3.2. FSVSJ1722+2723

FSVSJ1722+2723 is a blue object with  $B - V = -0.147$  and  $V - I = 1.092$ , similar to the colors of the nova-like CV, UU Aqr. The emission lines are single peaked (see Fig. 4), He I (4471, 5876 Å) is fairly strong and the Balmer decrement ( $H\alpha/H\beta$ ) appears to be inverted. The continuum emission rising toward the blue and the high He I excitation level generally indicate a fairly high mass accretion rate. However, the weakness of the He II emission and the Balmer reversal are unusual. If FSVSJ1722+2723 is confirmed as a high mass transfer rate dwarf novae, then we can assume  $M_V \sim 7-9$  which would imply a large distance to FSVSJ1722+2723, in excess of  $z = 1000$  pc.

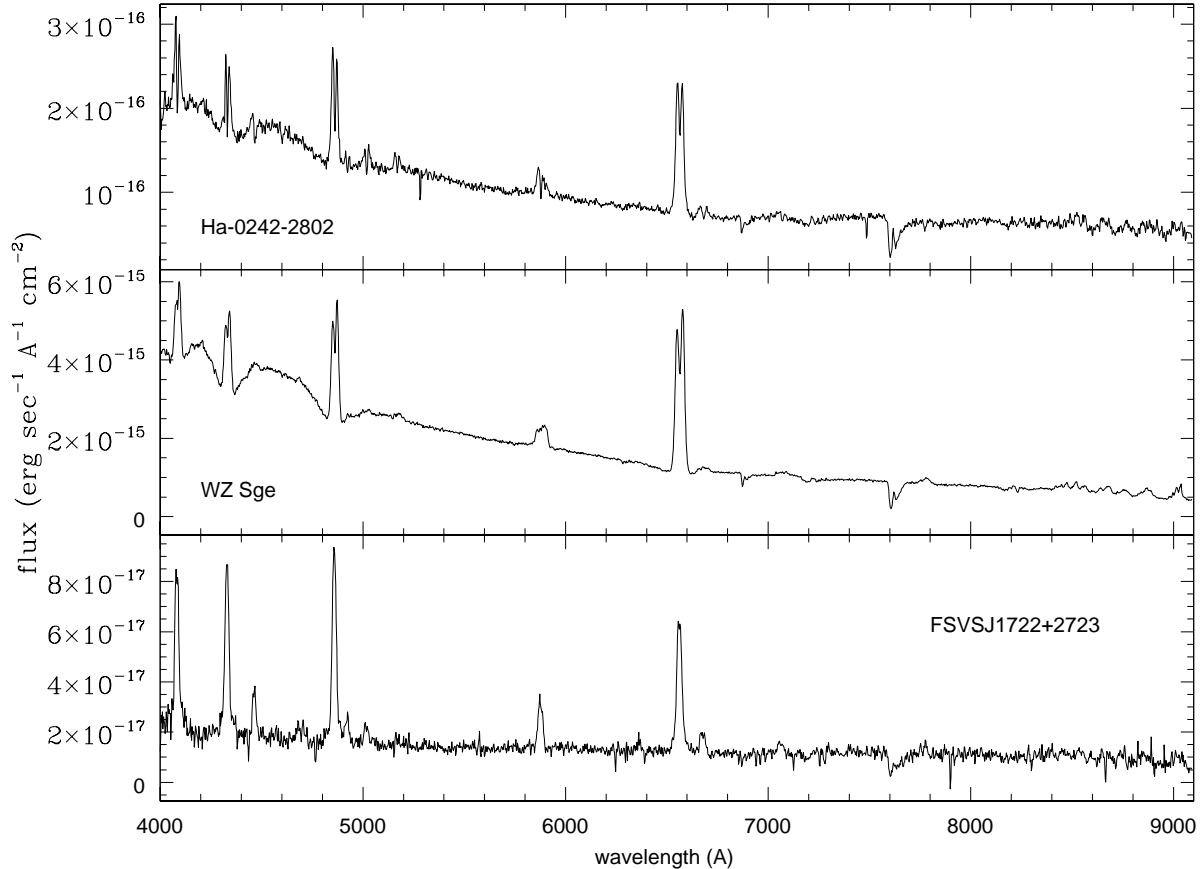
## 4. Conclusion

Using our initial small sample of CV discoveries from two different surveys, we can estimate the total number of faint CVs which may be lurking in the remaining bulk of the datasets. We did not explicitly choose the most obvious or brightest candidates (given our ability to observe them at the NTT with EMMI) from our source lists as a starting point. Thus, our sample should be relatively unbiased in selection from the candidate lists but clearly biased in overall selection criteria as is true of every survey. The FSVS candidates were chosen as blue, variable sources and we found 1 CV out of 13 sources,  $\sim 7\%$  success. The H $\alpha$  survey candidates, picked by blue color and expected H $\alpha$  emission, netted 1 new CV out of 12 candidates, again  $\sim 7\%$  success. The FSVS has produced a list of  $\sim 1200$  CV candidates from the entire dataset (23 sq. degrees) covering the magnitude range of  $V = 16.5-23$  (see Huber et al. 2002) while the H $\alpha$  survey candidate list of CVs contains  $\sim 500$  candidates in three regions (RA, DEC's 2:30, -30 and 10:40, +5, +10). Taking the  $\sim 7\%$  value as indicative of the success rate for each survey, we estimate that  $\sim 100$  additional CVs await discovery within our two survey candidate lists. This large number of low luminosity CVs within our survey areas, *if in fact realized*, would provide a space density consistent with the large

**Table 2.** New CV candidate properties.

Source	<i>B</i>	<i>V</i>	<i>R</i>	<i>I</i>	Spectroscopic Properties
Ha0242–2802	19.0	–	18.6	–	Double peaked emission lines of H, He, Strong He I (5876 Å)
FSVSJ1722+2723	20.6	20.4–21.0 <sup>a</sup>	–	19.6	Strong Em lines of H, He, $\delta V_{20-21}$

<sup>a</sup> FSVSJ1722+2723 varies on few hour to day time scales (see Fig. 2).



**Fig. 4.** Discovery spectra of Ha0242–2802 and FSVSJ1722+2723 obtained at the NTT. Also shown is the spectrum of the well known TOAD WZ Sge obtained with the same instrumental setup on the same night and presented for comparison. Note that Ha0242–2802 appears very similar to WZ Sge and that FSVSJ1722+2723 has strong He I emission and an inverse  $H\alpha/H\beta$  decrement.

(undiscovered) population predicted by theory (e.g., Howell et al. 2001). However, many additional candidates from these two imaging surveys as well as detailed phase-resolved spectroscopy must be obtained before such claims can be verified.

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