The Hidden Population of AM CVn Binaries in the Sloan Digital Sky Survey

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Abstract

We present results from a spectroscopic survey designed to uncover AM Canum Venaticorum (AM CVn) binaries hidden in the photometric database of the Sloan Digital Sky Survey (SDSS). The discovery of only 7 new AM CVns in the observed part of our sample suggests a lower space density than previously predicted. Based on the complete $g \leq 19$ sample, we calculate an observed space density for AM CVns of $(5 \pm 3) \times 10^{-7}$ pc^{-3}. We also compare the cataclysmic variables (CVs) discovered via this survey to those found in the SDSS spectroscopy, and we discuss SBSS 1108+574, an unusually helium-rich CV that has a spectroscopically confirmed orbital period of 55 minutes, well below the CV period minimum (∼80 min). SBSS 1108+574 may represent an AM CVn forming via the 'evolved CV' formation channel.

Keywords: cataclysmic variables - dwarf novae - binaries: close - stars: individual: SBSS 1108+574.

1 Introduction

The AM Canum Venaticorum (AM CVn) binaries are a rare group of hydrogen-deficient, ultra-compact, mass-transferring white dwarf binaries. They have orbital periods in the range 5 – 65 minutes, well below the observed period minimum of hydrogen accreting cataclysmic variables (∼80 min, Gänsicke et al. 10).

Three formation channels have been proposed for the AM CVn binaries, each characterised by the donor. The donor can be (1) a second, lower mass, white dwarf – these systems have the shortest minimum periods, beginning mass-transfer at periods as short as a few minutes [9, 22]; (2) A semi-degenerate helium star [12, 31]; or (3) an evolved main sequence star [23, 32, 34, 36]. The third channel is known as the 'evolved CV' channel, and has generally been considered to be unimportant in comparison to the double white dwarf and helium star channels.

The evolution of these systems is thought to be governed by gravitational wave radiation [e.g. 22], causing the mass accretion rate to be a steeply decreasing function of orbital separation. This gives rise to a strong dependence of their observational properties on the orbital period. The shortest period systems are expected to undergo direct impact accretion, and no disc forms [19, 28]. For systems with $10 \lesssim P_{\rm orb} \lesssim 20$ min, the accretion disc is in a stable high-state, with spectra showing helium absorption from the optically thick disc [e.g. 21]. AM CVns with periods greater than ∼40 min, are thought to be in a stable low-state, the spectra of these systems are characterised by emission lines from the accretion disc [e.g. 30]. In the intermediate period systems ($20 \lesssim P_{\rm orb} \lesssim 40$ min), an instability occurs in the accretion disc, and their appearance varies between that of the high-state and the low-state systems, similarly to the hydrogen-rich dwarf novae [14, 24].

In the past 10 years, the known population of AM CVns has quadrupled, largely as a result of dedicated surveys using the Sloan Digital Sky Survey (SDSS; York et al. 37), and the Palomar Transient Factory [16, 17]. Here we discuss estimates of the AM CVn space density, and results from our spectroscopic survey designed to uncover new AM CVn binaries amongst colour-selected objects from the SDSS photometric database [6, 25, 29].

2 The Serendipitous SDSS AM CVns

The first AM CVn binaries were discovered in a variety of different ways, and only 10 were known prior to the burst of discoveries over the last decade. Roelofs et al. [26] and Anderson et al. [1, 2] discovered a total of six new AM CVn systems in the SDSS spectroscopic database via their helium emission dominated spectra. This provided the first sufficiently complete and homogeneous sample of AM CVn systems that a study of the population became possible.

Roelofs et al. [27] used these 'serendipitous SDSS AM CVns' to estimate the observed space density of AM CVn binaries – a crucial quantity for calibration of predictions from binary evolution theory. They calculate the completeness of the SDSS spectroscopy as a function of colour and galactic latitude, and using an assumed magnitude distribution for AM CVns, determine the number and distribution of systems that would be expected from Nelemans et al. [20]'s population synthesis. These numbers are then compared to the number of systems found in the SDSS, giving a value for the AM CVn space density of 1–3 $\times$ 10^{-6} pc^{-3}, an order of magnitude lower than the expected value at the time (2 $\times$ 10^{-5} pc^{-3}, Nelemans et al. 20). Roelofs et al. [27]'s study also indicated that there should be at least 50 AM CVns in total in the SDSS photometry, most of them 'hidden' due to the absence of spectroscopic data.

3 The Search for the Hidden Population

Since the completeness of the SDSS spectroscopy in the area of colour space occupied by the AM CVns is low, and this area is sparsely populated (see Fig. 1), Roelofs et al. [29] began a dedicated spectroscopic survey of objects in this region, intended to uncover the ~40 AM CVns that were expected [27]. Fig. 1 shows the low density of sources in the SDSS photometry in the colour region occupied by the AM CVn binaries. Also shown are the ~2000 candidates selected from the SDSS DR7 database by applying the colour cuts given in Roelofs et al. [29].

Our targeted region of colour space selects those AM CVns with emission line spectra – the longer period systems. As AM CVns should spend only a few percent of their lifetime as mass-transferring systems at orbital periods below 30 minutes, our selection should include the vast majority of AM CVns in the SDSS footprint [6]. This region of colour space is also occupied by DB white dwarfs, which are the most significant contaminant in our survey.

To date we have taken low-resolution, low signal-to-noise ratio spectra of ~70% of these candidates, uncovering 30 CVs and 7 new AM CVns (see Carter et al. 6 for more details).

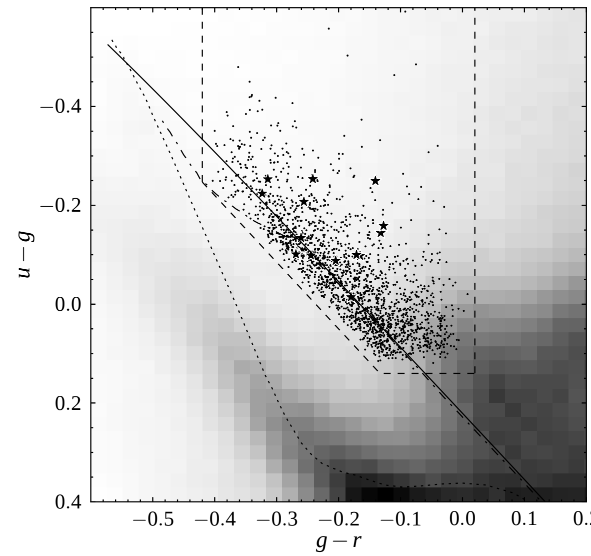

Figure 1: The greyscale represents the density of sources in the SDSS photometric database as a function of colour, to a limiting magnitude $g = 20.5$ (dereddened). The long period SDSS AM CVn binaries are indicated by star symbols. The solid line marks the blackbody cooling track, the dotted and dot-dashed lines indicate model cooling sequences for DA and DB white dwarfs. The dashed lines indicate the colour cuts given by Roelofs et al. [29], and the dots indicate the candidates selected.

4 The CV Population

Spectra of the CVs discovered in our survey were presented in Carter et al. [6]. We compare this sample to the SDSS CV population [33, these proceedings] by plotting the equivalent widths (EWs) of their Hα and He I 5875 emission lines, see Fig. 2. The distributions of the two populations appear similar, with the strongest Hα emitters falling outside our survey colour box. There are two obvious outliers visible in Fig. 2, CSS 1122-1110 (SDSS J1122-1110; Breedt et al. 5) from the Sloan sample, and SBSS 1108+574 (SDSS J1111+5712; Carter et al. 7) from our sample, both having much stronger helium emission compared to hydrogen than the majority of CVs. The $P_{\rm orb} = 59$ min CV, V485 Cen [3] is also shown in Fig. 2 for comparison.

Followup phase-resolved spectroscopy of SBSS 1108+574 reveals an orbital period of 55.3 ± 0.8 minutes [7], consistent with independent photometric and spectroscopically determined periods [13, 18]. This is clear evidence for the evolved nature of the donor, which has been stripped of most of its hydrogen by, or prior to the onset of, mass-transfer. SBSS 1108+574 and the similar systems, CSS 1122-

1110 [5] and CSS 1740+4147 (Chochol et al., these proceedings), may be evolving along the 'evolved CV' evolutionary pathway toward AM CVn binaries.

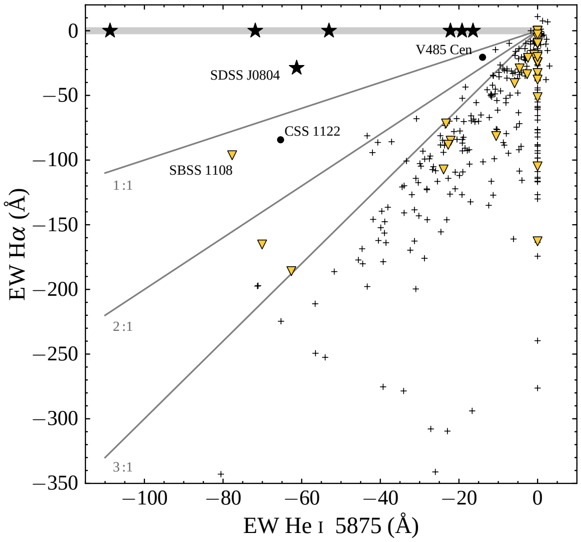

Figure 2: EW of He I 5875 versus Hα for our CV sample (triangles), and the CV population from the SDSS (crosses). The star symbols represent the AM CVns from our sample, which fall on the EW(Hα) = 0 line. Also plotted are lines showing Hα to He I 5875 EW ratios; CVs with unusually low EW ratios are labelled, V485 Cen is shown for comparison. The position of the AM CVn SDSS J0804+1616 is due to strong He II 6559 emission.

5 The AM CVn Space Density

Roelofs et al. [27]'s observed space density, 1–3 $\times$ 10^{-6} pc^{-3}, corresponds to $\sim$40 AM CVns in our survey sample. We have found 7 new AM CVns in the $\sim$70% of the sample that has been observed, suggesting that either there is some bias that we have not considered, or the space density is lower than previously estimated.

Biases in the survey are discussed in detail by Roelofs et al. [29] and Carter et al. [6]. They show that due to the distribution in colour space of the spectroscopic observations from the SDSS, it is unlikely that a large number of AM CVns lie outside the selected colour box. There is a slight bias in our survey observations towards the easier to observe brighter objects, but there is no significant colour bias, and the edges of our colour box are well explored. We therefore consider it likely that a lower space density is required to explain our results.

Since our survey is essentially complete down to a g-band magnitude of 19, we use this smaller sample to recalibrate the population synthesis results. Following the method described in Roelofs et al. [27] we calculate the expected magnitude distribution of AM CVn binaries in the SDSS photometric database. The Roelofs et al. [27] space density corresponds to 11 AM CVns with $g \leq 19$. In our essentially complete to $g = 19$ sample there are 4 known AM CVns, scaling the space density to match this number, we obtain a value of $(5 \pm 3) \times 10^{-7}$ pc^{-3} [6].

6 Summary

The SDSS has significantly increased both the numbers of AM CVn stars known, and our understanding of the population. Our spectroscopic survey of colour-selected objects from the SDSS photometric database has uncovered a further seven new AM CVns.

We have also identified a helium-rich CV, SBSS 1108+574, follow-up observations of which reveal an orbital period of 55 minutes, well below the CV period minimum. SBSS 1108+574 and similar helium-rich systems may be examples of AM CVns forming via the 'evolved CV' pathway.

Discovering only seven new AM CVns in the observed sample likely indicates a significantly lower space density than previously predicted. We use the essentially complete, brighter part of our sample to estimate the observed space density to be $(5 \pm 3) \times 10^{-7}$ pc^{-3}.

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DISCUSSION

NATALY KATYSHEVA: Do you classify SBSS 1108+574 as an AM CVn or an SU UMa star?

PHILIP CARTER: We do not classify SBSS 1108+574 as an AM CVn because the AM CVn classification is classically applied only to objects in which no hydrogen is seen; we decided to refer to it simply as a helium-rich CV. Since this system is clearly below the CV period minimum it does not seem entirely appropriate to group it with normal CVs either. Whilst it is not certain whether it will become sufficiently hydrogen-depleted to become a 'true' AM CVn, it is clear that SBSS 1108+574 and similar systems lie between the classical definitions of these two classes.

KOJI MUKAI: Is your survey sensitive to AM CVn systems with high-state discs, which would have absorption lines, or to direct impact accretors?

PHILIP CARTER: ES Ceti is a border-line direct impact accretor, showing emission lines [8], and does fall within our colour box. We would have been able to detect systems similar to ES Cet. Those systems showing absorption lines from a high-state disc would appear indistinguishable from DB white dwarfs at the low S/N employed in our survey, and so we are not sensitive to them. However, such systems are expected to be a small minority of the total population, and our conclusion about the space density takes this into account.

CHRISTIAN KNIGGE: I know the numbers are still small, but have you started to look at the period and magnitude distribution of your systems and checked how they compare to the theoretical predictions?

PHILIP CARTER: We have not yet investigated this in detail, and there are still a few systems for which we do not yet have an orbital period. In a magnitude limited sample, the expected period distribution peaks at ∼50 min, with approximately similar numbers above and below this peak [27]. We have found more systems in the SDSS with periods below 50 min, than above, but the numbers are still too small to draw any strong conclusion from this.