Recent observational progress in AM CVn binaries

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Abstract. We present the results of some recent research on AM CVn systems. We present: X-ray/UV observations made using XMM-Newton; the X-ray grating spectrum of RX J1914+24; preliminary results of a search for radio emission from AM CVn binaries, and discuss the strategy and first results of the RATS project, whose main aim is to discover AM CVn systems.

1. AM CVn binaries

Most cataclysmic variables (CVs) consist of a white dwarf accreting material from a late-type main sequence star via Roche lobe overflow. However, in some CVs, the mass donor is hydrogen deficient - either a semi-degenerate star or a white dwarf. These binaries are called AM CVn systems or ultra-compact binaries since they have orbital periods less than ~70 mins. Currently there are 17 confirmed systems with another 2 candidate systems. This paper presents: the main results of a survey of these systems using XMM-Newton; an initial study of the high resolution X-ray spectrum of RX J1914+24; the results of a search for radio emission from RX J0806+15 and RX J1914+24, and we also present initial results of the RApid Temporal Survey (RATS) project whose aim is to detect new AM CVn systems.

2. Observations of AM CVn binaries using XMM-Newton

Until the launch of XMM-Newton, AM CVn systems had been little studied in X-rays - only 3 of the then known systems were detected in the ROSAT all-sky survey. With the greater sensitivity of the EPIC X-ray detectors on board XMM-Newton, coupled with the optical/UV telescope (the OM) it was possible to study these systems in way that was not previously possible.

One of our goals was to search for evidence for a coherent modulation in the X-ray intensity of these systems. Of the 7 systems which we have so far
observed (excluding RX J0806+15 and RX J1914+24), none show any evidence for pulsations in their light curve. This suggests that we have not detected the spin period of the accreting white dwarf, and implies that they do not have strong magnetic fields. The sources did, however, show variability (cf Figure 1).

A second goal was to determine the nature of their X-ray emission. We found that they were best modelled using optically thin thermal plasma models with highly non-solar abundances. On top of their hydrogen deficiency, many systems showed significant nitrogen over abundances.

Our third goal was to determine their energy balance for the first time. We showed that a large fraction of their accretion energy was emitted at UV wavelengths. In particular, the UV luminosity was greatest at shorter periods where the accretion disc dominates. Moreover, with parallaxes for these systems now available (Roelofs et al 2006) we showed that their observed luminosity agrees remarkably well with the accretion luminosity predicted by gravitational wave losses. Our results are presented in detail in Ramsay et al. (2005b, 2006c).

3. The candidate systems RX J0806+15 and RX J1914+24

The X-ray sources RX J0806+15 (HM Cnc) and RX J1914+24 (V407 Vul) have been the subject of much interest. If their periods (321 sec and 569 sec respectively) can be confirmed as their orbital period, then their orbital periods will be the shortest among known binary systems. Here we concentrate on two aspects - the nature of the X-ray spectrum of RX J1914+24 and a search for radio emission from RX J0806+15 and RX J1914+24.
The X-ray spectrum of RX J1914+24 is complex. It cannot be well fit using a simple absorbed blackbody or absorbed optically thin thermal plasma model. Rather, other model components (such as an absorption edge or Gaussian line) have to be added to achieve good fits to the XMM-Newton EPIC spectra (Ramsay et al. 2005a, 2006a). It is not clear if these extra components are physically realistic.

To investigate this in more detail we have extracted a spectrum of RX J1914+24 using the Reflection Grating Spectrometer detectors on-board XMM-Newton. We summed up the data from both RGS detectors and from data taken in XMM-Newton orbits 0718, 0721 and 0880. (RGS data from orbit 0882 has various issues which we are still investigating). We show the spectrum in Figure 2. We find that an absorbed thermal plasma model plus broad Gaussian feature centered at 0.68 keV gives a significantly better fit than either a model which replaces the Gaussian component with an edge or a model consisting of a blackbody (plus Gaussian or edge).

Determining if RX J1914+24 has an optically thick or thin X-ray spectrum has important consequences for its luminosity. Ramsay et al. (2006a) show that the optically thin emission model gives a luminosity 2–3 orders of magnitude less than the optically thick based models. If the emission layer is hotter than the optically thick atmosphere beneath, then the spectrum would be expected to show emission lines. There is some evidence for line features in Figure 2. However, only a spectrum with a longer exposure would be able to verify the presence of such lines. The physical origin of the feature, to which we have fitted a Gaussian, is not clear. Could it be some feature produced by a high magnetic field? For instance broad absorption (rather than emission) features in X-ray spectra of isolated neutron stars have been interpreted as due to cyclotron features from which magnetic fields of $10^{13}$ G have been inferred (e.g. Haberl 2004).

The unipolar-inductor model (Wu et al. 2002) predicts that radio emission should be produced due to electron-cyclotron maser emission (Willes & Wu 2004; Willes, Wu & Kuncic 2004). If we observe the system at an appropriate viewing which should detect strongly circularly polarised radio emission. A search was made using the VLA in Sept 2005 to detect emission from both RX J0806+15 and RX J1914+24 at 6cm. Each observation lasted a total of 3 hrs. We did not detect RX J1914+24 (3σ upper limit of 42 µJy/beam), but detected RX J0806+15 at a level of 96 µJy (a 5.0σ detection). For comparison we did not detect ES Cet (an accreting AM CVn system with $P_{orb}=10.4$ min) using ATCA at 6cm (3σ upper limit of 74 µJy/beam) We have further observations of RX J0806+15 approved with the VLA.

4. The RATS project

Less than 20 AM CVn systems are currently known. However, models predict that many more systems should be easily detectable using current instrumentation. For instance, Nelemans et al. (2004) predict that nearly 4000 systems with periods shorter than 25 mins should be brighter than $V=22$. These shorter period systems show modulation periods in the optical band up to 0.1-0.2 mag.
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Figure 2. The X-ray spectrum of RX J1914+24 taken using the XMM-Newton RGS detectors. The data from both detectors and data from XMM-Newton orbits 0718, 0721 an 0880 have been combined. The fit was made using an absorbed thermal plasma model of variable abundances plus a broad Gaussian feature centered at 0.68 keV.

There are a number of projects whose aim is to discover new AM CVn systems. The strategy of the RApid Temporal Survey (RATS) is to use wide field cameras on medium sized telescopes to detect stellar sources which vary in their optical intensity on periods shorter than $\sim 80$ min. A series of short ($\sim 30$ sec) exposures are obtained for a given field over the course of 2–3 hrs (Ramsay & Hakala 2005). Candidate systems are then subject to followup spectroscopy to determine their nature.

4.1. Results from our pilot study

Our pilot study was obtained using the Isaac Newton Telescope on La Palma with the Wide Field Camera. We obtained data of 12 fields which gave a coverage of 3 square degrees. A total of 46 objects were found to vary in their optical brightness. Details of our analysis and results are given in Ramsay & Hakala (2005). Many of the objects were contact binaries (also known as W UMa stars). However, 4 sources showed variability with periods on timescales less than $\sim 70$ mins. Followup spectroscopy and photometry revealed their nature. Three of these systems are SX Phe or dwarf Cepheid stars - only $\sim 20$ of these pulsating stars were previously known outside stellar clusters. The object showing the shortest period, 374 sec, is a rare pulsating sdB star (also known as EC 14027 stars). Its high pulsation amplitude is consistent with its location at the cool end of the EC 14026 instability strip (see Ramsay et al. 2006b for details).

4.2. Latest results

Since our pilot survey we have obtained data covering 12 fields using the ESO 2.2m telescope in Chile and 8 fields using the INT in La Palma, both in June
2005. Our analysis of the data from ESO is complete. Excluding those fields which included globular clusters, we found over 150 new variable objects. Similar to our pilot survey, many of these are contact binaries (based on their light curves) and around 10% of these variables showed modulation periods of less than \( \sim 80 \) min (we show the light curves of two such systems in Figure 3). A similar number of systems were found to be eclipsing systems. We have spectra of the brighter systems using the SAAO 1.9m telescope.

It is also of interest to determine the number of ultra-compacts located in globular clusters. This would give insight into how their formation process was sensitive to the density of their environment. We obtained data of M4 and M22 using the 2.2m telescope in La Silla, and M71 using the INT. We had to adapt our software to suit the more crowded fields. However, the cluster centers (up to the core radius) were too crowded for aperture photometry to perform well – a future study will develop tools which utilises profile fitting photometry. We found a total of 24, 70 and 80 variable sources in clusters M4, M22 and M71 respectively. A significant proportion of the sources are within the cluster tidal radius and therefore may be cluster members. We have discovered more than 40 eclipsing systems and more than 10 systems which show variations on periods less than 60 min.

We have obtained spectra of the variable sources in M4 and M22 using AAOmega at the Anglo Australian Telescope in the summer of 2006. In the red arm we used the 385R grism and in the blue the 580V grism. The seeing was moderate to poor so we did not obtain useful spectra for the fainter targets. There was no evidence for any ultra-compact binaries in either cluster. However, we did detect emission lines in one system, RAT J162324–262622 which showed H\( \alpha \)-H\( \gamma \) in emission along with emission lines of forbidden N II on the blue and red side of H\( \alpha \) (Figure 4). Such a spectrum is more similar to planetary nebulae. RAT J162325-262911 shows emission in the core of an absorption line at H\( \alpha \), while RAT J162342-264255 shows deep Balmer absorption lines.
Figure 4. The spectra of 3 variable sources discovered in the globular cluster M4 using data obtained from the 2.2m telescope at La Silla. The spectra were obtained using AAOmega and the AAT.

4.3. Future strategy

So far, we have not found any AM CVn systems in the RATS survey. At face value this suggests that the models of Nelemans et al. (2001, 2004) overestimate the space density of AM CVn’s. However, the size of our survey is relatively small (6 square degrees have been currently analysed in full) and secondly, the models predict that they should be concentrated in the Galactic plane. Future field selections will be strongly biased towards the Galactic plane ($|b| < 10^\circ$). However, we have shown that our strategy is a good means for discovering rare pulsating systems, some of which may eventually become white dwarfs.

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