Part 7

Ultra-short Period Systems

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Ultra-Short Period Double-Degenerate Binaries

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Abstract. We review the current observational status of the *ROSAT* sources RX J1914.4+2456 and RX J0806.3+1527, and the evidence that these are ultra-short period (< 10 min) binary systems. We argue that an Intermediate Polar interpretation can be ruled out, that they are indeed compact binaries with a degenerate secondary, and that the period seen in the X-ray and optical is the orbital period. A white dwarf primary is preferred, but a neutron star cannot be excluded. We examine the capability of the three current double-degenerate models (Polar, Direct Accretor and Electric Star) to account for the observational characteristics of these systems. All models have difficulties with some aspects of the observations, but none can be excluded with confidence at present. The Electric Star model provides the best description, but the lifetime of this phase requires further investigation. These ultra-short period binaries will be strong gravitational wave emitters in the *LISA* bandpass, and because of their known source properties will be important early targets for gravitational wave studies.

1. Introduction

Binary systems consisting of interacting white dwarf pairs (double degenerate) have been known for some time. Smak (1967) was the first to suggest that AM CVn was such a system, and although many questioned this interpretation, it is now generally accepted. There are four AM CVn binaries in Warner's (1995) review, and approximately ten such systems are now known. They have been considered to be the double-degenerate analogues of Cataclysmic Variables, but with a degenerate rather than main sequence-type secondary, accreting by Roche Lobe overflow through a disk.

In the first Cape Workshop, Motch et al. (1995) reported the discovery of a soft X-ray source, RX J1914.4+2456 (now V407 Vul), from the *ROSAT* Galactic Plane Survey. They reported this as a new 'soft' Intermediate Polar. The X-ray emission was to be modulated with an amplitude of 100% at a period of 568s. Motch et al. (1996) searched for the optical counterpart, but were unable to identify any unusual object.

In followup observations of the 'soft' IPs, Cropper et al. (1998) were exercised by the shape of the X-ray modulation in this particular object, and by the fact that for half of the modulation phase there was no detectable X-ray emission. They noted that this was unlike the behaviour of all other IPs and proposed instead that the period was the orbital period of a rotationally sychronised white dwarf pair with a magnetic primary – the double degenerate analog of Polars. The implication of this was that at 568s (9.5 min) this was the shortest period binary system known.

Since then the optical counterpart has been identified (Ramsay et al. 2000) and significant progress has been made in elucidating the nature of the system. In 1999, another soft source, RX J0806.3+1527, was identified with a pulsation period of 321s (Israel et al. 1999, also Beuermann et al. 1999), again classified as an IP. In papers accepted within days of each other, Ramsay, Hakala & Cropper (2002a) and Israel et al. (2002) suggested that this system was similar to RX J1914.4+2456, so that the 321s (5.4 min) period was the orbital period of a double degenerate binary.

The X-ray light curves of these two systems distinguishes them from AM CVn systems, even though the binary components may be degenerate pairs in both cases. If the variations are taken to be the orbital period as proposed, these are shorter than those of any known AM CVn systems. Recently Warner & Woudt (2002) have suggested that ES Cet (KUV01584–0939, discovered in the KISO Schmidt UV Survey: Kondo, Noguchi & Maehara 1984) is a short period AM CVn. At 10.3 min this is only slightly longer than that of RX J1914.4+2456, but the system has characteristics that are more typical of AM CVns, including strong He emission lines in the spectrum (Wegner et al. 1987), double-peaked lines (Woudt – private communication) and a double-humped optical light curve which may be the result of a permanent superhump (Warner & Woudt 2002). This implies evidence for a disk, so ES Cet is therefore probably an AM CVn system with a period at the short extreme of the class. This categorisation is also supported by the fact that ES Cet was not detected in the *ROSAT* All Sky Survey or PSPC pointed observations (Voges et al. 2000).

In this paper we review the observed properties of the objects RX J1914.4-+2456 and RX J0806.3+1527 and the models currently applied to them. We then examine how well these explain their observed properties.

2. Observational Characteristics

2.1. X-ray Spectrum

These objects were first classified as IPs because of their short but stable X-ray periodicities, but their spectra were completely atypical of IPs. Rather than a hard ($>$ 1 keV in this context) optically thin continuum without any soft ($<$ 1 keV) optically thick component, their spectra showed *only* a soft optically thick component. Even 'soft' IPs such as PQ Gem show a hard component (Duck et al. 1994). No hard component was evident in the *ROSAT* data (Motch & Haberl 1995). Much deeper hard X-ray observations of RX J1914.4+2456 were carried out by Ramsay et al. (2000) with *ASCA*: they measured an upper limit of the bolometric luminosity of this component of 10^{-7} with respect to the soft component. Recent stringent upper limits using *Chandra* have also been reported by Israel et al. for RX J0806.3+1527 (these proceedings).

2.2. Frequency Analysis of Light Curves

When Cropper et al. (1998) performed a Fourier analysis of their *ROSAT* HRI data of RX J1914.4+2456, only one period (with its harmonics) was evident in the data, with the value of 569.38s reported by Motch & Haberl (1995). The same was found in the optical by Ramsay et al. (2000). A similar analysis of RX J0806.3+1527 X-ray data by Israel et al. (1999) and optical data by Israel et al (2002) and Ramsay et al. (2002a) also found only one period with its harmonics (but see below for further discussions). Again this was atypical of IPs, which generally show a multiplicity of periods at combinations of the orbital and white dwarf rotation periods.

2.3. X-ray Modulation Profile

The folded X-ray light curves (on the detected period) are remarkably similar in both systems (Cropper et al. 1998, Burwitz & Reinsch 2001) – see Figure 1. These are approximately sawtooth, with a more rapid rise than decline. In more detail, they show a sharp rise, followed by a slower rise to maximum, then a slower decline, with a final smaller drop back to minimum. There are *no* detected X-rays for approximately half of the period. At different epochs the light curves of RX J1914.4+2456 change slightly (Ramsay et al. 2000), but the sawtooth profile remains. The shape of the X-ray modulation profile is unlike that seen in any other IP, 'soft' or normal.

Cropper et al. (1998) argued that the shape of the X-ray emission, and its absence over half of the period, required a small emission region moving into and out of view. The accretion had to be far from symmetric about the rotation axis in order to prevent a lower region rotating into view as the upper rotated over the limb of the star; they considered absorption could not be the cause, and that pole-switching would not be possible on the observed short timescales in the system.

2.4. Long-term Light Curves

Ramsay et al. (2000) examined the long-term brightness of RX J1914.4+2456 and found that its measured brightness varied between 0.03 and 0.3 HRI cts s^{-1} in the X-ray and between $I = 16.6$ and $I = 18.2$ in the red over a period of 6 years. Such variability in X-rays is also evident in RX J0806.3+1527 (Israel et al. 1999) and in the optical even on short time scales (Ramsay et al. 2002a, Israel et al. 2002).

These results indicate that the emission processes in these systems are highly variable, indicative of accretion or similar mechanism.

2.5. Optical/IR Colours

In order to characterise the nature of the secondary in RX J1914.4+2456, Ramsay et al. (2000) obtained optical and infrared photometry. Their $H-K/I-K$ and $J-H/I-K$ colour-colour diagrams located the source away from the main sequence tracks, for all reddening values. The best description of the spectrum

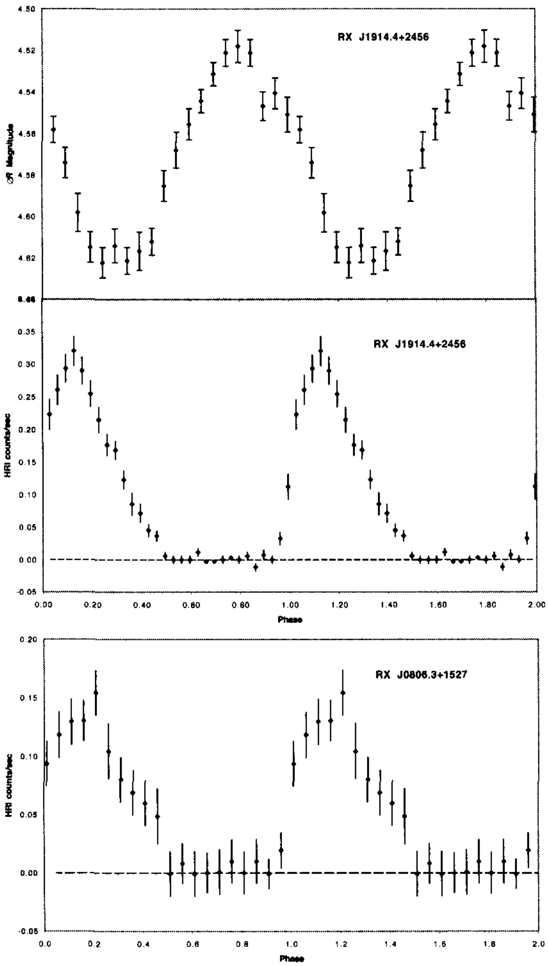

Figure 1. The *ROSAT* HRI X-ray light curves of RX J1914.4+2456 (middle, adapted from Cropper et al. 1998) (1996 April) and RX J0806.3+1527 (bottom, adapted from Burwitz & Reinsch 2001) (1994 October and 1995 April) phased on the principal periodicity in each case. Also shown on the top panel is the $R-band$ light curve for RX J1914.4+2456 on the same phase reference from Ramsay et al. (2002b) where the magnitudes are with respect to Star 'B' of Motch et al. (1996).

is a highly reddened ($E(B-V)\sim 1$) hot blackbody ($>10^4$K) (Ramsay et al. 2002b). This reddening is consistent with the measured X-ray absorption from cold material using *ASCA* and *ROSAT* data. If little reddening is assumed, then

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a cooler spectrum is permitted, approaching 5000K. In this case, the discrepancy between the X-ray and optical absorption requires explanation.

The situation is much clearer in the case of RX J0806.3+1527 as this system is much less reddened in X-rays and the optical (Israel et al. 2002) and has a spectrum characteristic of a hot blackbody ($> 4 \times 10^4$K).

2.6. Phasing of X-ray and Optical Light Curves

Ramsay et al. (2000) were able to co-phase the X-ray and optical light curves in RX J1914.4+2456 and found that the X-ray and optical variation was almost anti-phased (Figure 1). The centre of the X-ray bright phase (but not the maximum brightness) is at $\phi \sim 0.25$ in their data, while the optical maximum is at $\phi \sim 0.85$ (in contrast to the X-rays, the optical/IR variation is quasi-sinusoidal), so that the optical lags the X-rays by ~ 0.6. A similar value is reported in these proceedings for RX J0806.3+1527 by Israel.

The difference in phasing between the X-ray and optical is most naturally explained by re-processing in a binary star model. Here the variation in the optical emission is caused by the heating from the soft X-ray emission from small spots on the primary (as inferred from the X-ray light curve) (see Figure 2).

2.7. Optical Spectrum

Despite several attempts, obtaining a spectrum of RX J1914.4+2456 was frustrated by the presence of nearby companions. The first optical spectrum was presented in Ramsay et al. (2002). By this time Israel et al. (2002) had obtained VLT spectra of RX J0806.3+1527. These showed an almost featureless continuum rising to the blue. On close inspection, the high S/N data indicated the presence of weak $\sim 5\%$ emission lines, which they attributed mostly to the Pickering series of He, with some C and Ne. The lines were broad, with velocities of ~ 1000 km s^{-1}. Norton, Haswell &Wynn (2002) claim that the even terms of the Pickering series lines in the spectra presented in Israel et al. (2002) are stronger, indicating the presence of *some H*, and therefore ruling out a degenerate primary. This deserves further quantification.

The spectrum of RX J1914.4+2456 in Ramsay et al. (2002) also appeared almost featureless, with a red continuum consistent with the reddening. No emission lines were evident in this lower S/N spectrum, but there was an absorption feature at 5200Å. The absence of strong emission lines in a system accreting through Roche lobe overflow was a surprising result, and entirely atypical of the spectrum of known IPs.[1]

2.8. Polarisation

Ramsay et al. (2000) obtained $I-$band polarisation measurements of the object RX J1914.4+2456 and concluded that there was no circular polarisation detected

[1]Steeghs (private communication) has recently reported optical spectra of RX J1914.4+2456 taken with *Gemini N*. This shows absorption lines characteristic of the interstellar medium and an overall spectrum which appears typical of a K star. The implications of these results are being investigated by Steeghs et al.

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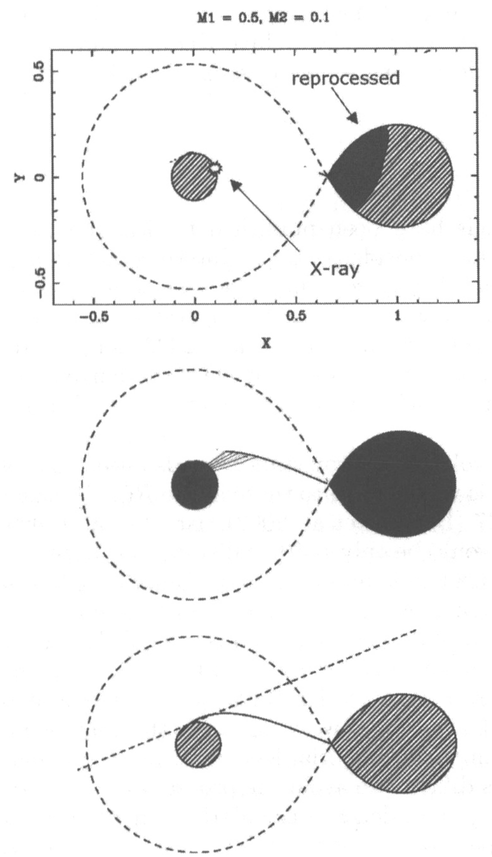

Figure 2. Schematic diagrams representing the optical re-processing by the secondary of the X-rays from a small region on the primary (top), the double-degenerate Polar model (centre) and the Direct Accretor model (bottom). In the Direct Accretor, the horizon is shown from the location of impact region, and the grazing angle of the impact is evident. All diagrams are for a system with a period of 9.5 min as in RX J1914.4+2456, and the primary and secondary masses shown. Note the large size of the primary relative to its Roche lobe. In the Electric Star model, the secondary does not fill its Roche lobe. Diagrams adapted from Marsh & Steeghs (2002).

on the modulation period. The instrument used prevented a high precision measurement of the absolute level of polarisation, but absolute levels exceeding 0.5% and amplitudes exceeding 0.2% could be excluded.

2.9. Period Changes

Strohmayer (2002) examined the change in the 568s X-ray period of the same object RX J1914.4+2456 using the archive *ROSAT* and *ASCA* data. He found that the period was decreasing at the rate expected from gravitational losses.

3. Models

Currently four models have been published to describe these systems. Both systems were originally considered to be Intermediate Polars; Cropper et al. (1998) suggested that they were double-degenerate analogs of Polars; Ramsay et al (2002b) and Marsh & Steeghs (2002) suggested that they might be double-degenerate Direct Accretors and Wu et al. (2002) suggested that they might be double-degenerate systems powered by electrical current. It should be noted that three of the four models involve a magnetic white dwarf. We discuss these in turn below.

Other models involving neutron stars have also been considered, as the thermal X-ray spectrum is very similar to those in the *ROSAT* isolated neutron stars such as RX J1856–37 (Burwitz et al. 2002). Israel et al. (1999) concluded that such a neutron star would be only $\sim$ 10 pc distant, but both they and Ramsay et al. (2002a) reported negligible proper motion. Burwitz & Reinsch (2001) argued that the absence of hard emission precluded an neutron star interpretation for general Roche lobe overflow accretion. Ramsay et al. (2002b) also considered a neutron star model, in this case for RX J1914.4+2456, and concluded that this may be viable if low rates of accretion (but higher than those expected from the accretion of interstellar material) were assumed: this may be possible if the neutron star was accreting from material left over from a previous phase of stellar evolution. It remains difficult to avoid the production of a hard tail of emission, however, and pending more detailed calculations, models in which the primary is a neutron star appear to be less favoured.

3.1. Intermediate Polar

The IP interpretation is the only one of the four white dwarf primary models with a main sequence companion. Cropper et al. (1998) argued against such an interpretation on the grounds that the X-ray light curve, and particularly the absence of flux for half of the period and the sharp rise to maximum could not be explained in the framework of an IP model, even if pole switching was occurring. As noted above, further observations, for example the absence of emission lines, the absence of a hard X-ray spectral component and the infrared colours (the last seemingly excluding a main-sequence secondary), also militate against an IP interpretation.

Norton et al. (2002) resuscitated the IP model by investigating the pole-switching timescales using single particle hydrodynamic (SPH) calculations for the stream. They concluded that the rapid transitions in the X-ray light curves could indeed be generated by pole switching in a face-on system. They did not however address the optical/infrared colours, and the presence of mostly He lines in the optical spectrum of RX J0806.3+1527 was not satisfactorily explained.

One argument against the IP model was the absence of any other periodicities in the power spectra of these systems. These are upper limits, and other periods may be unearthed in more sensitive future data. Indeed, despite careful analysis, Ramsay et al. (2002a) were unable to decide whether a low-level signal in their power spectra of RX J0806.3+1527 at 4800s was real or not. The power spectra of Israel et al. (2002) also show an enhancement at this period (although the resolution in their plots is lower) which may mean that the periodicity is real. In this case, asynchronous models (all except for the first below) would be favoured, with the longer periods reflecting the orbital period or some combination of the orbital and primary rotation periods.

Strohmeyer (2002) notes that the decrease in the 568s period in RX J1914.4-+2456 could be associated with the spin-up of the primary in an IP model.

3.2. Double-Degenerate Polar

Because of the difficulties of the IP interpretation, and the softness of the X-ray spectrum of RX J1914.4+2456 and the similarity of its X-ray light curve to those Polars accreting at one visible pole only, and the presence of only one significant periodicity in the system, Cropper et al. (1998) suggested that the system may be the first of the double-degenerate analogs of Polars, so that the 569s period was the orbital period of a rotationally synchronised pair of white dwarfs (Figure 2).

Cropper et al. (1998) noted that for such a compact system, the magnetic field of the primary did not need to be as strong as that of normal Polars in order to achieve synchronism. The predictions from the model were that there may be detectable levels of optical circular polarisation and that the accretion flow should be mostly He. The model successfully predicted the optical/IR colours in the two systems (Ramsay et al. 2000), and the He emission (Israel et al. 2002) but the absence of strong emission lines from an accretion stream was a surprise. In retrospect, the small dimensions of these systems renders the stream to be small, and this and the hotter white dwarf secondary could cause the line emission from the stream to be feeble by comparison with normal Polars.

The absence of circular polarisation was also seen as a possible difficulty for the double-degenerate Polar model by Ramsay et al. (2002b). However they point out that magnetic fields less than a few MGauss would not generate the high levels of polarisation seen in usual Polars.

While the ratio of soft X-rays to hard in some Polars can be high (see Ramsay & Cropper, these proceedings), in general some optically thin hard component from the post-shock region is detected. The absence of any detection of a hard component (Ramsay et al. 2000, Israel et al., these proceedings) therefore poses some difficulties. One possibility is that the flow between the secondary and primary is subsonic all of the way (a 'settling solution'). If this is the case the temperature structure within the stream should be evident as it appears over the limb of the star; moreover, in this case it is difficult to imagine how X-ray emission is absent for half of the orbital period, even if most of the emission is near the base of the accretion flow onto the white dwarf.

3.3. Double-Degenerate Direct Accretor

The double-degenerate Direct Accretor (sometimes loosely called double-degenerate Algol) model was proposed independently by Marsh & Steeghs (2002) and Ramsay et al. (2002b). In this case, neither of the white dwarfs is magnetic, and mass is lost from the secondary by Roche Lobe overflow in a ballistic stream. The larger relative size of the primary and its Roche Lobe in these compact systems is such, however, that the stream impacts directly onto its surface, ahead of the line of centres (Figure 2). For smaller (more massive) primaries, the stream may miss the surface and intersect with itself, circularising and forming an accretion disk as in the standard AM CVn systems.

The above papers used slightly different constraints for determining the allowed parameter space for such a model to be viable, but both agreed in their analysis that the primary mass could not exceed $\sim 0.55\ M_{\odot}$. Marsh & Steeghs (2002) took the point of view that this was consistent with known primary masses in interacting binaries, while Ramsay et al. (2002b) considered the restricted parameter space to be a concern, searching as they were for other models which avoided the restricted magnetic field in the double-degenerate Polar model.

It should be noted that unless the primary is substantially less massive than $0.55\ M_{\odot}$, the stream impacts on the far side of the primary from the secondary, and the impact is at an oblique angle. In this case, the secondary is below the horizon, and it cannot be the source of the optical modulation through reprocessing of the X-ray flux. In this case Marsh & Steeghs (2002) suggested that the optical modulation results from the cooling material downstream of the X-ray heated region (the non-magnetic primary would not be synchronised). The implications of this are that there is no fixed relationship between the X-ray and optical phasing: this would differ for different accretion rates; it would be different from system to system, depending on the rotation rate of the primary; there should be a systematic advancement in the phasing of the optical/IR light curves towards longer wavelengths, and because of the prograde rotation of the primary, the X-ray light curve should have a slow rise and steep decline, together with a strong X-ray spectral signature. On most of these points such an explanation can be excluded, so that this model requires a very low mass primary.

3.4. Electric Star

In response to the difficulties with all of the models above, Wu et al. (2002) suggested that RX J1914.4+2456 was powered by electrical current. They noted that a white dwarf secondary star moving in the magnetic field of the primary would develop an electrical potential across its diameter. Should there be any ionised material between the two stars, an electrical circuit would be set up each side of the orbital plane: down the magnetic field lines from one side of the secondary to the primary and back down field lines to the other side. The major source of resistance in this circuit is in two small regions where the magnetic field lines intersect the surface of the primary near the magnetic poles. This is where almost all of the energy is dissipated.

This unipolar inductor system was based on the one that was observed directly in the Jupiter-Io interaction (Clarke et al. 1996) and proposed white dwarf-planet interactions (Li, Ferrari & Wickramasinghe 1998) but scaled up to take account of the much shorter orbital period, potentially much larger primary magnetic field and relatively much larger secondary in the double-degenerates. Wu et al. (2002) found that the total energy dissipated at the spots in the white dwarf primary atmosphere exceeded 10^{32} erg s^{-1} for a fractional asynchronism of 0.001 between the rotation of the primary and that of the orbit. The energy reservoir in the system is the revolving and rotating binary pair; gravitational radiation robs the orbit of energy, so that the orbital separation shrinks and the period shortens, but does not act significantly on the stellar rotation. The primary is therefore being continually spun up through the Lorentz torques caused by the electrical currents, and from the point of view of the secondary it moves slowly retrograde. However, the foot points of the field lines remain locked in the frame of the binary as the primary rotates, as they are the lines which thread the secondary.

The secondary star in the electric star model does not fill its Roche lobe, and there is no accretion. The model therefore naturally explains the absence of strong emission lines as may be expected from a stream: any lines that are evident will be produced by the heated secondary, and ought therefore to be rotationally broadened. The magnetic field required on the primary is moderate, ~ 1 MG, and there is no shock, so the levels of optical circular polarisation should be small and there should be no hard X-rays produced. There are natural instabilities in the system caused by induced magnetic fields (from the large currents flowing in the circuit) that modify the field of the primary: these could be the origin of the long- and short-term variability seen in the systems. Such detached white dwarf pairs in which one of the stars has a moderate magnetic field will be natural end-points of many binary systems, and the extreme mass ratios required for Roche Lobe overflow are not required in this model. Furthermore, the steep rise and more shallow decline in X-ray brightness is in the right sense as (unlike the Direct Accretor) the primary is rotating retrograde.

Strohmeyer (2002) notes that the binary period will decrease in the absence of conservative mass transfer (Wu et al. 2002), but increase if conserved mass transfer takes place (Rappaport, Joss & Webbink 1982). The observed decrease in period consistent with gravitational radiation losses therefore favours a non-accretor interpretation and hence the Electric Star model.

The Electric Star model appears to be consistent with the observational facts for RX J1914.4+2456 and RX J0806.3+1527 but Wu et al. (2002) note that the lifetime of this phase would be short at $\sim 10^3$ years. Marsh & Steeghs (2002) considered this a serious difficulty given the space density that can be inferred from two systems. However, this difficulty may be overcome, as the system may be oscillating between a unipolar inductor phase and an accreting phase many times through the lifetime of the binary, which may last $10^6 - 10^7$ years.

3.5. Comparison

We summarise in Table 1 the degree with which the different models are consistent with the observational characteristics of the two systems.

Of the four models, the IP interpretation has the most difficulties. The absence of strong emission lines, the optical/IR colours (particularly in RX J0806.3-+1527 where the uncertainties introduced by the reddening are not important)

	Intermediate Polar	DD Polar	DD Direct Accretor	Electric Star
Absence of hard X-rays	×	∼	√	√
Only one modulation period	×	√	√	√
Optical/IR colours	×	√	√	√
Phasing of X-ray and optical	∼	√	∼	√
Shape of X-ray modulation	√	√	∼	√
Absence of Polarisation	√	∼	√	√
Absence of H	∼	√	√	√
Absence of strong emission lines	×	∼	∼	√
Long-term variability	√	√	√	√
Period change	√	×	×	√
Lifetime	√	√	√	∼

Table 1. Model comparison for the four models containing a white dwarf primary. ×, ∼ and √ symbols indicate increasing degrees of compliance with the observational data.

and the absence of a hard optically thin X-ray component all appear to be insurmountable difficulties, even if the claim by Norton et al. (2002) that the shape of the X-ray light curve can be caused by pole switching is accepted.

The double degenerate Polar and Direct Accretor models provide a reasonably good description of the observed data. Both are inconsistent with the period change in RX J1914.4+2456 measured by Strohmayer (2002), who points out that although there may be other factors affecting the period, those identified in normal CVs are generally absent when the secondary is degenerate. Period changes will become increasingly evident as time passes, especially in the case of RX J0806.3+1527, and this promises to be a powerful way to discriminate between the accreting and Electric Star models.

Both the double degenerate Polar and Direct Accretor models ought to have some signature of the accretion stream at a low level. It remains to be seen whether the lines seen by Israel et al. (2002) in RX J0806.3+1527 can be explained fully by emission from the heated face of the secondary, or whether they require an additional component from the stream. This can be solved using Doppler Tomography.

The Direct Accretor model suffers from the requirement that the primary star needs to be relatively low mass, and, if a re-processing model is accepted for the optical component, the primary mass is uncomfortably low in order for the secondary to be illuminated by the X-ray emitting regions. The suggestion by Marsh & Steeghs (2002) that the optical is the cooling tail of the X-ray emitting region on the primary is not particularly satisfactory on the grounds of the X-ray modulation profile, the absence of phase shifts between the different optical/IR bands and the constant phase difference at different accretion rates; also the similar X-ray/optical phasing observed in the two systems (Ramsay et al. 2000, Israel 2004, these proceedings). On the other hand, the absence of polarisation in the double degenerate Polar model may not be too significant, given the modest field strengths required to achieve synchronism.

Of all the currently envisaged scenarios, the Electric Star model matches the observations most closely. The main disadvantage of the model is that the lifetime is predicted to be too short given the observed space density. However, the calculation in Wu et al. (2002) used magnetic field strengths and departures from asynchronism which aimed primarily to demonstrate that sufficient power was available from these systems, rather than using parameters which maximised the lifetime given an observed luminosity. How much the lifetime is a difficulty also depends on how many close white dwarf pairs are expected from evolutionary calculations, which at present are not sufficiently constraining. Further open issues of the model are that it relies on an initial disturbance into asynchronism, and that the effects of the induced currents on the magnetic field of the primary still need to be calculated. Perhaps the main difficulty faced with the model is one of unfamiliarity in the context of accreting binaries, thus requiring an extra burden of proof.

4. Gravitational Radiation

Ramsay et al. (2000) made the point that the accretion in these systems was driven by gravitational radiation. Wu et al. (2002) estimated that the power of the gravitational radiation in such systems can easily reach $\sim 10^{36}$ erg s^{-1}. A number of authors (for example Strohmeyer 2002) have pointed out that they will radiate at frequencies $2/P_{orb}$ at the centre of the band at which the proposed *LISA* mission will be sensitive. Because of the large gravitational radiation power, the large strain amplitudes ($\sim 10^{-21}$) they generate in this band and their proximity will cause these systems to be the brightest presently known constant sources in the gravitational wave sky, and as such they will be among the first to be observed. Moreover, these will be sources with relatively well-known properties (masses, orbital periods) and will therefore be fundamentally important in early gravitational wave studies.

5. Conclusions

With the discovery of RX J0806.3+1527, so similar to RX J1914.4+2456, it now appears more clear that the secondary in these systems is a degenerate dwarf, and that the main period in these systems is the orbital period. The uncertainties on the nature of the secondary introduced by the reddening correction to the optical/IR colours in RX J1914.4+2456 are negligible in RX J0806.3+1527, and the shorter period makes it impossible to squeeze in a main sequence star. The similar phasing between the X-ray and optical in the two systems and its stability from epoch to epoch suggests that the source of the optical variation is reprocessing from the secondary. This again argues for a binary model.

A neutron star primary is not entirely excluded as a possibility, but because of the gravitational bending of the emission into fan-shaped beams, the sharp X-ray pulse profiles are difficult to generate if these are assumed to arise in hot polar caps. The systems need to be extremely close in order to attain the measured X-ray intensities from small regions on a neutron star: the reddening in RX J1914.4+2456 and the lack of proper motion of RX J0806.3+1527 (Ramsay et al 2002a, Israel et al. 2002) makes this unlikely. The absence of a hard component rules out accretion onto a neutron star, except possibly for a very narrow parameter regime.

For these reasons models with a white dwarf primary are preferred. Of the four models considered so far, it would be unwise to exclude any except the IP interpretation. Of these, the Electric Star model provides the best agreement with the observed characteristics of these systems, but their short lifetimes remain an issue given the space density that can be inferred from two systems.

Looking forward, progress in understanding these systems will depend on more being found. All of the double-degenerate models are viable and together with the disk-accreting AM CVn systems, it may be that larger samples indicate that there is a melange of double degenerate systems with ultrashort binary periods. It may even be possible for individual binaries to move from Electric Star to accreting systems, as alluded to above, or from double-degenerate Polars to double-degenerate IPs. One of the main discriminants between the models is the presence and extent of an accretion stream, and Doppler tomography will be an important tool in identifying if a stream contributes to the line emission. A further important tool, as pointed out by Strohmayer (2002) is the investigation of the period changes in these systems; more constraints on their space density from evolutionary models will also prove valuable.

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