Mon. Not. R. Astron. Soc. **000**, 000–000 (0000) Printed 28 October 1997

RX J 1914.4+2456: the first double-degenerate polar?

Mark Cropper, M. K. Harrop-Allin, K. O. Mason, J. P. D. Mittaz, S. B. Potter, Gavin Ramsay

Mullard Space Science Laboratory, University College London, Holmbury St. Mary, Dorking, Surrey RH5 6NT

Received:

ABSTRACT

RX J1914.4+2456 exhibits a light curve with a strong modulation at 569 sec: this period is characteristic of the white dwarf spin period in intermediate polar (IP) systems. However the X-ray light curve is difficult to reconcile with current models for IP emission. We argue that a simpler explanation is that the system is a polar with a degenerate secondary star, which would make it the first known system of its kind. As such it should contain the first example of a He-dominated radial accretion flow onto the white dwarf surface, and RX J1914.4+2456 would have the shortest known orbital period of any binary system.

Key words: Accretion, Cataclysmic variables, X-rays: stars, Stars: individual: RX J1914.4+2456.

1 INTRODUCTION

The cataclysmic variable (CV) RX J1914.4+2456 was identified by Motch et al. (1996) in a sample of *ROSAT* All-Sky Survey objects as a soft X-ray source subject to pronounced interstellar absorption ($N_H = 10^{22}$ cm^{-2}). The X-ray flux is strongly modulated at a period of 569 sec, which led Motch et al. (1996) to identify the source as a member of the recently-recognised class of soft X-ray bright intermediate polars (IPs) and the period as the spin period of the white dwarf. IPs are magnetic CVs where the latter stages of the accretion flow onto the white dwarf are controlled by its magnetic field (see Warner 1995). Unlike the polars, the white dwarf in IPs is not rotating synchronously with the orbital period of the binary. A disk usually forms in these systems, with accretion occuring from the magnetically excluded inner regions of the disk onto the magnetic pole. In general, the X-ray light curves of IPs show a quasi-sinusoidal variation of moderate amplitude which is thought to be caused by absorption or obscuration of the emitting region by the white dwarf. The group of soft X-ray bright IPs such as PQ Gem (Mason 1995) are distinguished from other IPs in that they have a very soft X-ray spectrum more reminiscent of polars, although the soft IPs are clearly non-synchronous.

Motch et al. (1996) were unable to identify the optical counterpart to RX J1914.4+2456 to a level of V=19.7. This is consistent with the significant reddening expected on the basis of the X-ray absorbing column.

2 OBSERVATIONS

RX J1914.4+2456 was observed in X-rays (0.1–2.0keV) using the *ROSAT* satellite on 4 occasions in the pointed mode. On

ROR	Instrument	Start Date UT	End Date UT	Duration sec
300337	PSPC	1993 Sep 28	1993 Sep 29	6982
300509	HRI	1995 Oct 13	1995 Oct 13	2385
300509	HRI	1996 Apr 30	1996 May 5	25941
300587	HRI	1997 Mar 25	1997 Mar 28	19442

Table 1. The log of *ROSAT* observations.

the first occasion it was observed using the PSPC (without Boron filter), while the rest used the High Resolution Imager (HRI) (see table 1). We used the `ASTERIX` data analysis package (Saxton 1992) to extract a background subtracted time series for RX J1914.4+2456. We have not made use of the shortest pointed observation lasting 2.4 ksec made in October 1995. Source photons were accepted from a region whose size was a compromise between sampling as many of the source photons as possible and optimising the signal-to-background ratio. The source was on-axis in both the PSPC and HRI observations. The background level was determined from a source-free region of sky then subtracted from the source counts with appropriate scaling for the solid angles involved.

The 1996 and 1997 HRI time series were subjected to a period analysis using a standard discrete Fourier transform (DFT) code. In Figure 1a and 1d we show the DFT amplitude spectra for the two runs. These show a dominant period at 569.38 sec as reported by Motch et al. (1996). There are clear harmonics at twice and three times the frequency in the amplitude spectrum. We have subtracted the best fitting sinusoids at these three periods from the time series and re-computed the amplitude spectrum (Figures 1b and 1e). The low-level peaks at 5700 and 2850 sec are at the orbital period of the satellite and its harmonic – they may prevent the detection of real low-level variations at these periods. No other significant periods are evident at either epoch.

We have then folded the three datasets on the 569.38 sec period to show in Figure 2 the mean X-ray light curve at each epoch (Haberl & Motch 1995 show the PSPC data in a slightly different bandpass). We have chosen the start of the rise to peak flux to define phase zero. The light curve

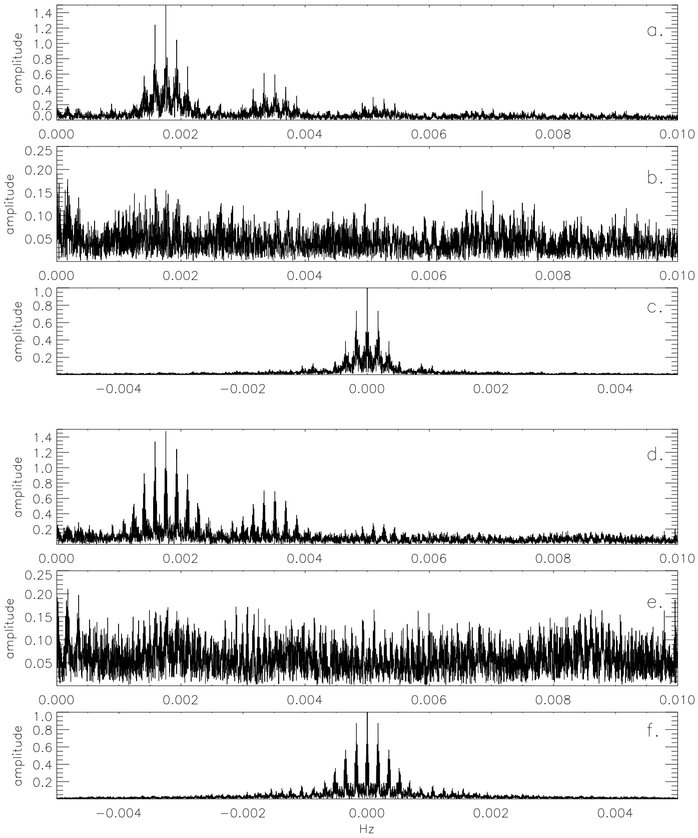

Figure 1. (a) The amplitude spectrum of the 1996 April data. (b) The amplitude spectrum after prewhitening with the principal 569.38 sec period. (c) The power spectral window. (d) to (f): as for (a) to (c) but for the 1997 March data.

is characterised by a steep rise to and a slower decline from maximum. The HRI countrates imply that the system was a factor of ~ 3 fainter at the time of the PSPC observations. The most significant aspect of the phased data is that for half of the period the observed flux is consistent with zero. This is unlike any other IP system.

We fitted a blackbody absorbed by a cold H column to the PSPC spectrum. In agreement with Motch et al. (1996) we obtain a best fit of $N_H = 1.1 \times 10^{22}$ cm^{-2} with a blackbody temperature of 40eV (reduced $\chi^2 = 1.1$). This translates to a bolometric luminosity of 1×10^{36} erg sec^{-1} for 100 pc (the lower limit suggested by Motch et al 1996). If we take the lower limit for the H column implied by the

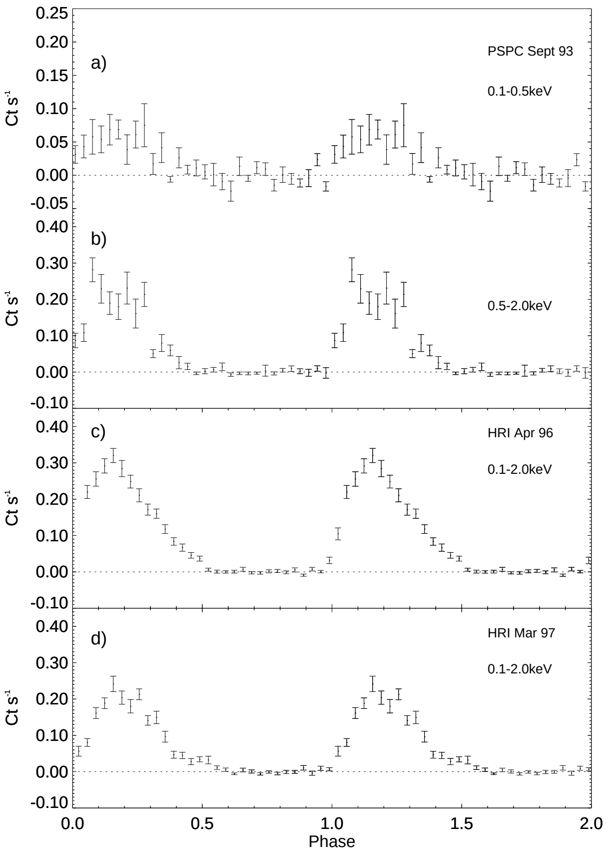

Figure 2. RX J1914.4+2456 folded on the 569.38 sec period: (a) The 1993 Sept PSPC 0.1 to 0.5 keV band data; (b) The 1993 Sept PSPC 0.5 to 2.0 keV data; (c) the 1996 April HRI data; (d) the 1997 March HRI data.

absorption in the optical ($N_H = 1 \times 10^{22}$ cm^{-2}; Motch et al 1996) then the minimum luminosity consistent with the spectrum at the 90 percent confidence level is 1×10^{35} erg sec^{-1}.

3 DISCUSSION

3.1 Identification of the optical counterpart

Motch et al. (1996) were unable to identify the optical counterpart of RX J1914.4+2456 down to a limit of V = 19.7 within their 20 arcsecond error circle. Using the HRI data we have obtained tighter constraints on the position of RX J1914.4+2456. Within the HRI field we have detected (at greater than 5σ significance) three other X-ray sources close to the position of RX J1914.4+2456. Two of these sources can be identified unambigously with optical counterparts. We have used the HST Guide Star coordinates of these counterparts to correct the HRI position of RX J1914.4+2456 to the HST Guide Star frame separately for the two HRI observations. We find a shift of -2 arcsec in R.A. and -0.8 arcsec in declination for the first field and -3.8 arcsec in Right Ascension and -4.2 arcsec in Declination for the second. These corrections resulted in positions from the two HRI fields which agree to within 1.5 arcsec. In order to determine the optical counterpart we have then averaged these two positions to arrive at the final position of RA 19 14 26.1 and Dec +24 56 40.0 (J2000) with an estimated error of 2 arcsec radius. This position is very close to the candidate stars A and B in Motch et al. (1996) and is closest (within 3 arcsec) to candidate H. The close proximity of RXJ1914.4+2456 to candidate H together with the identification of stars A and B as field stars (Motch et al. 1996) implies that candidate H is the counterpart of RXJ1914.4+2456. In line with the estimated extinction of the system ($A_V \sim 5.6$) candidate H is extremely red, having only been detected in the I band with a magnitude of 16.6. The inferred unreddened I magnitude is then ~ 13.

3.2 Difficulties with an IP interpretation

Although the folded X-ray data are similar in shape to those of the prototype soft-IP PQ Gem (Mason 1995), the absence of any X-ray flux for half of the period is unique among IPs and is difficult to reconcile with current models of IP accretion. It would be necessary to invoke complete absorption of the flux from the accretion region at the lower magnetic pole, for example by the accretion disk viewed at high inclination. A duty cycle of 50 per cent also requires that the inclination of the system is approaching 90 degrees: lower inclinations will cause the accretion region at the magnetic pole on the upper hemisphere to be in view for more than 50 per cent of the period. However, any spatial extent of the accretion region will make it even more difficult to accommodate the 50 percent duty cycle even if high inclinations are assumed, and in any case there is no evidence of eclipses in the HRI data. Reducing the duty cycle will therefore depend on phase-dependent absorption of the *upper* accretion region as well as screening of the lower region. Given our limited understanding of the trajectories of the accreting material in IPs this additional absorption could perhaps be accommodated. In this case, we would expect to see less modulation in the harder PSPC band than in the softer. For example, in an outburst of the IP XY Ari, Hellier, Mukai & Beardmore (1997) find that the modulation depth of the folded light curve (their figure 4) increases as the outburst progresses, which they interpret as greater obscuration of the lower accretion region. Even here, the modulation is sinusoidal and at every phase there is significant flux. The 0.5 to 2.0 keV PSPC band in Figure 2(b) is too soft to draw any strong conclusions, but it is clear that the modulation in this higher PSPC band is no less than that of the 0.1 to 0.5 keV band.

Absorption aside, an IP model may still be possible if there is effective beaming of the X-ray emission, although we have no idea how such beaming of the soft X-rays could be produced. Another possibility may be to identify the 569.38 sec modulation as the beat period in a low-inclination pole-switching system in which accretion takes place directly from the accretion stream instead of the disk. This assumes that during the half-cycle in which accretion occurs onto the lower pole the emission is completely obscured while at the same time there is no residual accretion onto the top pole. However it is unlikely that the latter condition will be satisfied when the travel time of the accreting material is of the same order as the 569.38 sec period, or that the pole-switching can produce the sharp risetimes in Figure 2.

3.3 Classification as a polar

The folded data are strongly reminiscent of the orbital light curves of the synchronously rotating polar systems, particularly those, such as ST LMi or VV Pup where the accretion takes place preferentially at one magnetic pole. In addition, the X-ray spectrum of RX J1914.4+2456 is inferred to be soft by Motch et al. (1996), as for polars. Being synchronously rotating, polars are characterised by only a single period (plus harmonics) in their power spectra, as is seen in Figure 1. Thus the absence of any combination of orbital and synodic periods in the power spectrum is consistent with this interpretation. We note that studies of the power spectra of IPs (Hellier, Garlick & Mason 1993, Norton, Beardmore & Taylor 1996) found that all IPs studied had evidence of more than one period.

Based on the shape of the light curve and the existence of only a single underlying period, the simplest explanation is that RX J1914.4+2456 is a polar rather than an IP and that the 569.38 sec period is the *orbital* period. If this scenario is correct, this would make it the first known strongly magnetic double degenerate binary, the analog of the AM CVn stars in the non-magnetic CVs. As such it would represent a hitherto unidentified endpoint of mCV evolution. Furthermore, this would be the shortest orbital period known for any binary star system.

3.4 Implications

The most significant implication of this interpretation is that the orbital period is far too short for that of a binary with a main sequence secondary, where the minimum period is around 80 min. If the 569.38 sec (9.5 min) X-ray period in RX J1914.4+2456 is the orbital period of the system, and the secondary is Roche lobe-filling, the secondary must be He-rich. A non-degenerate, He-burning secondary is excluded by Iben & Tutukov (1991) who find that the minimum orbital period for such a CV is ~ 13 minutes. However, if the secondary is a *degenerate* He white dwarf and the primary a carbon-oxygen white dwarf, orbital periods in the range 6 to 50 min are permitted (Tutukov & Yungelson 1996). In this case, the secondary's mass is $\sim 0.2\,\mathrm{M}_\odot$ (if allowances are made for departures from thermal equilibrium). The predicted mass transfer rate of the system is $\sim 1\times10^{-7}\,\mathrm{M}_\odot\,\mathrm{y}^{-1}$ (Warner 1995). This is consistent with a mass transfer rate inferred from the best fit blackbody to the PSPC spectrum (see Section 2) of $5\times10^{-8}\,\mathrm{M}_\odot\,\mathrm{y}^{-1}$ calculated by assuming all the accretion luminosity is liberated in the soft X-ray component and using a white dwarf mass of $0.7\,\mathrm{M}_\odot$. If we adopt the lowest luminosity limit to the spectral fit, the inferred mass transfer rate is $5\times10^{-9}\,\mathrm{M}_\odot\,\mathrm{y}^{-1}$. (However, these mass transfer rates are also consistent with that of a long-period IP, Patterson 1994). At the inferred high mass transfer rate the system would evolve rapidly to larger orbital periods; the mass transfer rate will decrease as the system evolves.

The magnetic field of the primary in RX J1914.4+2456 is likely to be weak: in the model of Li, Wu & Wickramasinghe (1994) a field strength of 70 MG completely surpresses magnetic braking in a system with an orbital period of 5 h and a primary mass of 0.7 $M_{\odot}$. Thus the evolution of the orbital period is driven by gravitational radiation alone in high field systems and they are not expected to evolve into contact within the age of the Galaxy (Warner 1995). Therefore under the assumptions of the Li, Wu & Wickramasinghe (1994) reduced magnetic braking model, a primary magnetic field strength $\geq$ 70MG is excluded if RX J1914.4+2456 has evolved close to or beyond the period minimum.

The material transferred from a degenerate secondary star to the magnetic primary will be predominently He. In polars, the infalling material forms a standoff shock (see for example Lamb & Masters 1979) before cooling in a subsonic flow and settling on the surface of the white dwarf. The temperature and density structure of the post-shock flow determines the characteristics of the hard X-ray spectrum from the system, and the continuum slope and line strengths provide important diagnostics for the accretion rate, white dwarf mass *etc.* (see for example Cropper, Ramsay & Wu 1997, Wu, Chanmugam & Shaviv 1994, Fujimoto & Ishida 1995). RX J1914.4+2456 may be the first example of a radial accretion flow which is predominantly He. Such a composition will have significant effects on the cooling mechanisms (particularly the ratio of bremsstrahlung to cyclotron cooling) and on optical depth. More detailed X-ray spectroscopic studies of this He-dominated flow will be rewarding.

4 CONCLUSIONS

We have identified the optical counterpart to RX J1914.4+2456 as star H in the finding chart in Motch et al (1996).

We have concluded that the most likely explanation for the X-ray behaviour of RX J1914.4+2456 is that it is a double-degenerate polar system rather than an IP as currently suggested (Motch et al. 1996). It would then be the first magnetic counterpart of the non-magnetic AM CVn class of CVs. This has evolutionary implications. Moreover the X-ray flux emanates from a He-dominated accretion flow, which will have different characteristics from the H-dominated flows seen in polars. At less than 10 min, RX J1914.4+2456 would have the shortest known orbital period of any binary system.

It remains a possibility through a combination of absorptions that RX J1914.4+2456 is indeed an IP. The key to resolving this will be a medium energy X-ray light curve of good quality, the detection of substantial polarisation in the infrared and the absence of Hydrogen in the far red or infra-red spectrum.

5 ACKNOWLEDGEMENTS

We are grateful both to Fred Ringwald and to the referee for pointing out that if the 569 sec period is the orbital period then it is the shortest known period for a binary system. We thank Darragh O'Donoghue for the use of his EAGLE DFT software used for Fig. 1 and Andrew Norton and Christian Motch for useful discussions. MKHA acknowledges funding support from University College London (Graduate Schools Research Scholarship), the Committee of Vice Chancellors and Principals (Overseas Research Students' Award) and the University of Cape Town (Max & Lillie Sonnenberg Scholarship). SBP acknowledges the support of a PPARC studentship. We have made use of *ROSAT* data obtained from Max Planck Institute (Garching) and from the Leicester Database and Archive Service at the Department of Physics and Astronomy, Leicester University, UK.

REFERENCES

Cropper, M., Ramsay, G., Wu, K., 1997, MNRAS, in press

Fujimoto, R., Ishida, M., 1996, ApJ, 474, 774

Haberl, F., Motch, C., 1995, A&A, 297, L37

Hellier, C., Garlick, M. A., Mason, K. O., 1993, MNRAS, 260, 299

Hellier, C., Mukai, K., Beardmore, A. P., 1997, MNRAS, in press

Iben I., Tutukov A., 1991, ApJ, 370, 615

Lamb, D. Q., Masters, A. R., 1979, ApJ, 234, L117

Li J., Wu K., Wickramasinghe D.T., 1994, MNRAS, 268, 61

Mason, K. O., 1995, in Cape Workshop on Magnetic Cataclysmic Variables, eds Buckley D. A. H., Warner B., ASP Conf Ser, 85, 225

Motch, C., Haberl, F., Guillout, P., Pakull, M., Reinsch, K., Krautter, J., 1996, A&A, 307, 459

Norton, A., Beardmore, A. P., Taylor, P., 1996, MNRAS, 280, 937

Patterson, J., 1994, PASP, 106, 209

Saxton, R., 1992, PPARC Starlink User Note, 98

Tutukov A., Yungelson L., 1996, MNRAS, 280, 1035

Warner, B., 1995. *Cataclysmic Variable Stars,* CUP

Wu, K., Chanmugam, G., Shaviv, G., 1994, ApJ, 426, 664