X-ray confirmation of the new intermediate polar RX J1238–38

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ABSTRACT

By finding a 2147-s X-ray pulsation in the recently identified ROSAT source RX 1238–38 we confirm that it is a member of the intermediate polar class of cataclysmic variable. We analyse the spectral changes over the white dwarf spin cycle, but are unable to distinguish between competing mechanisms for the cause of the pulsation. RX 1238–38 has an anomalous ratio of spin period to orbital period, similar to that of EX Hya.

Key words: accretion, accretion discs – binaries: close – stars: individual: RX J1238–38 – novae, cataclysmic variables – X-rays: stars.

1 INTRODUCTION

The X-ray satellite ROSAT has led to the discovery of many new magnetic cataclysmic variables (e.g. Beuermann & Burwitz 1995; Burwitz 1998) including several new intermediate polars (IPs) (e.g. Mason et al. 1992; Haberl & Motch 1995; Buckley et al. 1995). The latest possible IP, RX 1238–38, was announced by Buckley et al. (1998). Following their work, and further unpublished spectroscopy, the likeliest interpretation is that the orbital period of the white dwarf–red dwarf pair is either 85 min or its one-day alias 90 min, while the spin period of the magnetic white dwarf is 2147 s. Thus RX 1238–38 is, after EX Hya, only the second IP below the cataclysmic variable period gap. More recently, RX J0757.0+6306 has been suggested as a third IP below the gap, with an orbital period of 86.1 min and a spin period of 515 s (Tovmassian et al. 1998).

We have used ASCA and RXTE to make the first pointed X-ray observation of RX 1238–38, to look for an X-ray pulsation at the spin period and so confirm the IP classification. Our secondary aim, if the spin pulse was detected, was to continue our program of phase-resolved ASCA spectroscopy of IPs, investigating the mechanisms responsible for pulsing the X-rays. An investigation of the iron lines in this data set, along with those from other IPs, is reported in Hellier, Mukai & Osborne (1998).

2 OBSERVATIONS AND DATA

We observed RX 1238–38 between 1997 January 14 08:46 UT and 1997 January 16 00:15 UT in a simultaneous observation using the RXTE and ASCA satellites (see Bradt, Rothschild & Swank 1993 and Tanaka, Inoue & Holt 1994, respectively). ASCA recorded 58 ks of good data during this interval, in the energy range 0.6–10 keV. The count rate was 0.4 count s⁻¹ in each of the four instruments (SIS0, SIS1, GIS2, GIS3). To maximize the usable data we used relatively lax screening criteria, as detailed in Hellier et al. (1996). RXTE recorded 40 ks of data with the PCA instrument, 33.5 ks while all five PCUs were working, and 6.5 ks with four PCUs working. To maximize the signal-to-noise ratio (S/N) we used only the top xenon layer of PCA data, which after background subtraction using pcabackest v1.5 gave an average of 34 count s⁻¹ in the energy range 2–15 keV.

In Fig. 1 we show the combined 1–15 keV RXTE and ASCA lightcurve of RX 1238–38. This results from a process of normalizing the data from the different instruments to the same count rate and then merging the lightcurves. Since the instruments have different spectral responses this is a slightly dubious procedure, but for period searching the overriding consideration is to maximize the coverage of the data. Fig. 2 shows the Fourier transform of the lightcurve. There is a clear periodicity at 2144 ± 3 s, compatible with Buckley et al.’s (1998) 2147-s period, thus confirming that RX 1238–38 is an IP. There is no significant power at the orbital period or at the beat period between the spin and orbital cycles, or at the 1860-s period detected in optical photometry (Buckley et al. 1998).

When folded on the two possible orbital periods, the data show no departure of more than 10 per cent from the mean level.

When folded on the 2147-s period (Fig. 3) the lightcurve is nearly sinusoidal, with a greater pulse fraction at lower energies, which is typical of IPs. The pulse fraction (peak-to-trough as a fraction of the peak from fitting a sinusoid) is 36 ± 2 per cent at 0.6–2 keV, 23 ± 5 per cent at 3–5 keV and 15 ± 9 per cent at 6–10 keV. In principle the RXTE data could give the pulse fraction at higher energies, but the current uncertainty in the background subtraction for faint sources makes this unreliable.

3 SPECTRAL ANALYSIS

For spectral analysis we divided the data according to spin phase, choosing three phase bins as the best compromise between phase resolution and S/N per bin. These bins covered phases 0.90–1.13 (maximum); 0.26–0.70 (minimum); and the sum of phases 0.13–0.23 and 0.73–0.90 (medium). We also checked for spectral changes between the rising and falling parts of the medium bin.
by taking the ratio of the ASCA spectra in these intervals; it showed no significant trends.

We first tried combining the ASCA and RXTE data during the spectral analysis. However, the lower resolution of the RXTE data makes it beneficial only beyond the range of the ASCA data, and since it contained only \( \sim 1 \) source count s\(^{-1}\) above 10 keV the uncertainties in background subtraction (using current calibrations) are of the same order as the signal. Hence, for this paper, we present spectral analysis of the ASCA data only, fitting the four instruments (SIS0, SIS1, GIS2, GIS3) in each of the three phase bins.

The X-ray emitting accretion column in an IP is expected to consist of plasma shocked to temperatures of \( \sim 1–30 \) keV. We therefore fitted the data using the MEKAL plasma code (Mewe, Kaastra & Liedahl 1995) in XSPEC.

The ASCA spectra (both phase averaged and phase-resolved) are poorly fitted by a single temperature model. A MEKAL with a best-fitting temperature of 9 keV gives an unacceptable fit to the data.
The multi-temperature model (with complex absorption) gave a \( \chi^2 \) of 1.00 when optimized for each instrument separately. However, to make further investigation manageable we enforced the same set of parameters for all four instruments. This gave a worse \( \chi^2 \) of 1.07, indicating small systematic or calibration uncertainties between the instruments (we did not make any allowance for these in the spectral error bars). Adding a Gaussian to represent a 6.4 keV iron line, as would arise from a reflected component, reduced the \( \chi^2 \) by a marginally significant 0.01, but we did not include it in the following analysis.

The question we then asked was, is the spin pulse caused by a change in the normalizations of the mekal components with phase (if, for instance, accretion regions pass over the white dwarf limb) or is it caused by changes in the absorption, or both? Allowing the three normalizations to change with phase, and including phase-invariant simple absorption, gave a good \( \chi^2 \) of 1.08 (Table 1). Complicating the absorption by including partial covering components made no difference, still giving \( \chi^2 = 1.08 \). Thus the spin pulse can be explained by normalization changes alone.

Trying the alternative, fixing the normalizations over spin phase but allowing the absorption to change, gave a poorer \( \chi^2 \) of 1.26 if the model contained only simple absorption. However, with complex absorption (one simple and two partial covering components) and with the columns and covering fractions free to vary with phase, the \( \chi^2 \) was again 1.07 (Table 1). Thus the spin pulse can also be explained by absorption changes alone.

Trying the third option, allowing changes in both normalization and absorption over spin phase, gave \( \chi^2 = 1.07 \) yet again. To summarize, using the ASCA data we cannot tell whether the spin

\begin{table}
\centering
\caption{Temperature normalizations (\( \times 10^3 \)) and absorbing columns from analysis of ASCA data in three phase bins. The basic model consists of three mekal plasmas and a fixed absorber. The spin pulse is reproduced by allowing the normalizations to vary (top), or by allowing the columns and covering fractions (CvF) of two absorbers to vary (bottom). We do not present errors because the ambiguities in the model are far greater: either method of reproducing the spin pulse, or hybrids of the two, is acceptable.}
\begin{tabular}{lccc}
\hline
\textbf{Varying normalizations} & \\
\hline
Fixed column \( n_H = 14.4 \times 10^{20} \text{ cm}^{-2} \) & Max & Mid & Min \\
\hline
0.76 keV & 0.68 & 0.61 & 0.25 \\
1.8 keV & 1.87 & 1.05 & 0.78 \\
13.7 keV & 11.1 & 10.0 & 8.88 \\
\( \chi^2 = 2619; \, \nu = 2430; \, \chi^2 = 1.08 \) \\
\hline
\textbf{Varying absorption} & \\
\hline
Fixed column \( n_H = 6 \times 10^{20} \text{ cm}^{-2} \) & Max & Mid & Min \\
\hline
0.84 keV & 0.73 & fixed & fixed \\
3.3 keV & 3.7 & fixed & fixed \\
19.4 keV & 9.3 & fixed & fixed \\
\( n_H (10^{20}) \) & 12 & 40 & 45 \\
CvF & 0.41 & 0.52 & 0.65 \\
\( n_H (10^{20}) \) & 0 & 3200 & 5800 \\
CvF & 0.11 & 0.20 & \\
\( \chi^2 = 2606; \, \nu = 2425; \, \chi^2 = 1.07 \) \\
\hline
\end{tabular}
\end{table}
pulse is caused by absorption, by occultation, or by both. The only secure statement is that if changing absorption is the sole cause then the absorption must include partial covering components.

Analysis of ASCA data of IPs has shown that AO Psc has a single-temperature spectrum with a spin pulse caused by variable absorption (Hellier et al. 1996); that EX Hya has a multi-temperature spectrum and a spin pulse probably caused by occultation of parts of the accretion column (Allan, Hellier & Beardmore 1998); and now that RX 1238–38 has a multi-temperature spectrum but a spin pulse whose origin is uncertain. Further work is thus needed to understand the range of pulse behaviours in IPs.

4 DISCUSSION

Having confirmed that RX 1238–38 is an IP, we compare its spin and orbital periods with those of other IPs (Fig. 4). Almost all systems are on or below the $P_{\text{spin}} = 0.1 P_{\text{orb}}$ line, on which systems reside when in equilibrium and accreting the specific angular momentum of the accretion stream (King & Lasota 1991). Systems above this line (of which there are two, EX Hya and RX 1238–38) cannot be both accreting from a disc and in equilibrium.

The lack of orbital or spin/orbit beat periods in the X-ray lightcurve of RX 1238–38 (Fig. 2) implies (provided we have identified the periodicities correctly) that the accreting material loses knowledge of orbital phase, and thus that RX 1238–38 does accrete predominantly through an accretion disc, with no evidence for a direct interaction of the accretion stream with the magnetosphere (e.g. Hellier 1991; Wynn & King 1992). Thus we predict that the white dwarf in RX 1238–38 will be spinning up towards the $P_{\text{spin}} = 0.1 P_{\text{orb}}$ line, as that in EX Hya is doing (e.g. Jablonski & Busko 1985; Hellier & Sproats 1992).

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