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The periods of the intermediate polar RX J0153.3+7446

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ABSTRACT

We present the first optical photometry of the counterpart to the candidate intermediate polar RX J0153.3+7446. This reveals an optical pulse period of 2333 ± 5 s. Reanalysis of the previously published *ROSAT* X-ray data reveals that the true X-ray pulse period is probably 1974 ± 30 s, rather than the 1414 s previously reported. Given that the previously noted orbital period of the system is 3.94 h, we are able to identify the X-ray pulse period with the white dwarf spin period and the optical pulse period with the rotation period of the white dwarf in the binary reference frame, as commonly seen in other intermediate polars. We thus confirm that RX J0153.3+7446 is indeed a typical intermediate polar.

Key words. binaries: close – stars: white dwarfs – stars: individual: RX J0153.3+7446

1. Introduction

Intermediate polars are cataclysmic variables, characterised by pulsed X-ray emission which reflects the rotation period of an accreting magnetic white dwarf. Over two dozen confirmed systems are currently known (for a recent list see Norton et al. 2004a) and of these, around a quarter were discovered by *ROSAT* during its all sky survey. In an important paper, Haberl & Motch (1995) reported the first *ROSAT* observations of six intermediate polar candidates. Five of these systems have gone on to be well studied. RE0751+14 (PQ Gem; see Duck et al. 1994, Potter et al. 1997), RX J0028.8+5917 (V709 Cas; see Norton et al. 1999, de Martino et al. 2001) and RX J0558.0+5353 (V405 Aur; see Allan et al. 1996, Evans & Hellier 2004) are now confirmed as typical intermediate polars with a wealth of published observations; RX J1712.6–2414 (V2400 Oph; see Buckley et al. 1997, Hellier & Beardmore 2002) is the first confirmed stream-fed intermediate polar; and RX J1914.4+2456 (V407 Vul; see Cropper et al. 1998, Ramsay et al. 2002, 2005; Norton et al. 2004a) has excited much controversy as a possible ultra-compact binary, although its nature is still in doubt.

However, the sixth object reported by Haberl & Motch (1995), namely RX J0153.3+7446, has been virtually ignored ever since. They showed an X-ray pulse profile of the system, claiming the pulse period as 1414 s, and mentioned that a publication on optical observations of the object was in preparation. Such a publication has never appeared, although the on-line cataclysmic variable catalogue (Downes et al. 2001) lists an optical counterpart in Cassiopeia with $V = 16.4$ at RA 01:53:20.9, Dec +74:46:22 and mentions an orbital period of 0.16415 d credited to a private communication from John Thorstensen. The only published observation of RX J0153.3+7446 is an identification spectrum by Liu & Hu (2000) which confirms its cataclysmic variable nature by virtue of the typical emission line spectrum.

Optical photometry of intermediate polars usually shows modulation at the X-ray pulse period (i.e. the spin period of the white dwarf in most cases) and/or the beat period (i.e. the spin period of the white dwarf in the binary reference frame). The latter modulation, where seen, is presumed to be due to reprocessed X-ray emission originating from the illuminated surface of the donor star or some other structure fixed in the binary reference frame. An orbital photometric modulation is often seen as well, presumably depending on the inclination angle of the system.

2. Observations

In an attempt to confirm the nature of RX J0153.3+7446, we have carried out optical photometric observations of its 16th magnitude counterpart. The unfiltered photometry was carried out on the night of 2005 November 24th using the 40 cm Alan Cooper Telescope, a Meade LX200 Schmidt Cassegrain telescope at the Open University's George Abell Observatory in Milton Keynes, UK. We obtained over 350 exposures, each of 30 s, between 19:08 UT and 22:54 UT. There is a deadtime of ~5 s between each exposure whilst the full frame was read out. Images were acquired using an SBIG STL1001E CCD camera, giving an image scale of 1.24 arcsec per pixel. The counterpart to RX J0153.3+7446 is clearly detected with a signal-to-noise ratio of typically ~20 on each frame, separated from a nearby 11th magnitude star (TYC 4322-169-1) by around 12 arcsec

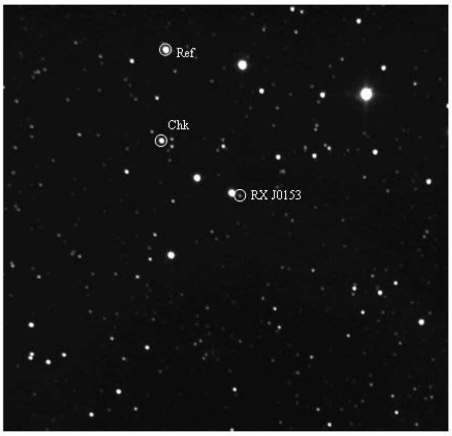

Fig. 1. The field of RX J0153.3+7446. The reference star and check star used for the photometry are indicated. The field shown here is about 12 arcmin across, North is up and East to the left.

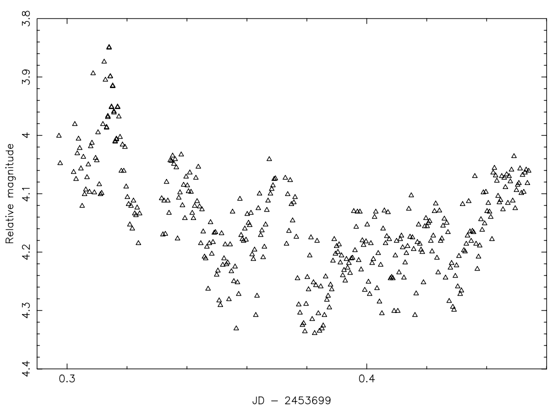

Fig. 2. The unfiltered optical lightcurve of RX J0153.3+7446. The magnitudes are relative to that of TYC 4322-255-1 which has V = 12.058, B = 13.005 according to *Vizier*.

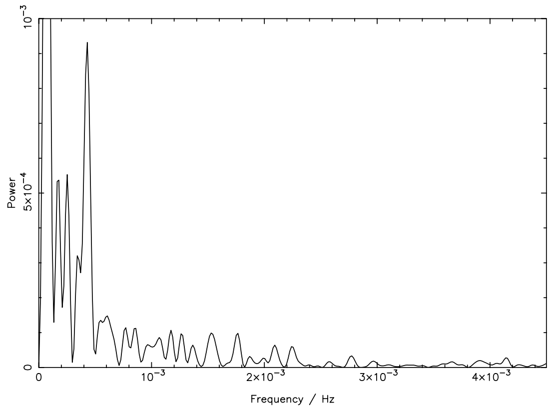

Fig. 3. The power spectrum of the RX J0153.3+7446 optical lightcurve. Significant power is seen at a frequency of 4.286×10^{-4} Hz, corresponding to a period of 2333 s.

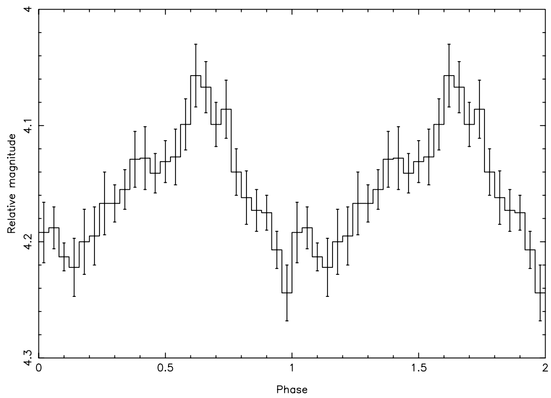

Fig. 4. The optical lightcurve of RX J0153.3+7446, folded at 2333 s and binned into 25 phase bins. Magnitudes are relative to TYC 4322-255-1 and the phasing is arbitrary.

(see Fig. 1). The seeing was very stable at ~2.5 arcsec throughout the observations.

Using the MaximDL (v4) software, all images were bias and dark current subtracted, then flat fielded using dome flats. Aperture photometry was performed with respect to the nearby star TYC 4322-255-1 which has V = 12.058, B = 13.005 according to *Vizier*. Comparison with a check star (for which also see Fig. 1) confirmed that the magnitude of the reference star was constant for the duration of the observations.

3. Results

The optical lightcurve of RX J0153.3+7446, spanning almost 4 h, is shown in Fig. 2. A long term modulation is clearly present, consistent with the 3.94 h orbital period listed in the Downes et al. (2001) catalogue. Superimposed on top of this are around 6 cycles of a further modulation, with an amplitude of ~0.1 mag. A Fourier transform of the lightcurve reveals a strong peak at 4.286×10^{-4} Hz, see Fig. 3. The period of this additional modulation is therefore 2333 s, with an uncertainty of ~5 s. The lightcurve folded at this period, and binned into 25 phase bins, is shown in Fig. 4. Error bars represent the standard error on the mean within each bin, averaged over typically 15 observations each.

There is no sign of a modulation at the previously reported X-ray pulse period of 1414 s, and nor is the period we see a harmonic or sideband of that and the reported orbital period.

Although these are the first photometric observations to be reported from the George Abell Observatory, following its recent refurbishment, the performance of the telescope plus CCD system was verified a few days prior to these observations when we observed another of the intermediate polars from Haberl & Motch's original paper. On 2005 November 19th we obtained ~2.5 h of unfiltered photometry of the 14th magnitude intermediate polar V405 Aur. The lightcurve of those observations clearly shows the well established (Allan et al. 1996) double peaked pulse profile with a 545s pulse period and peak-to-peak amplitude of ~0.1 mag. Hence we are confident in the stability and reliability of our observing system.

4. Re-analysis of the *ROSAT* observations

In an attempt to shed light on the discrepancy between our optical photometric period and the X-ray period reported by Haberl & Motch (1995), we have re-analysed the original *ROSAT* observations of RX J0153.3+7446. These comprise two

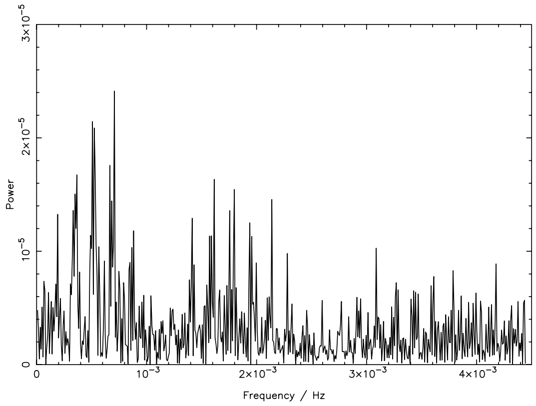

Fig. 5. The power spectrum of the RX J0153.3+7446 *ROSAT* X-ray lightcurve. Significant power is seen at frequencies of 7.05×10^{-4} Hz (i.e. 1414 s) and at 5.06×10^{-4} Hz, corresponding to a period of 1974 s.

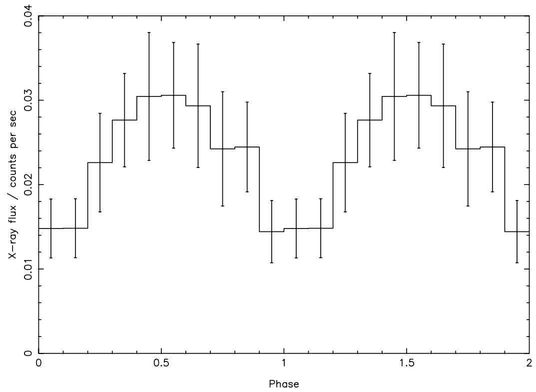

Fig. 6. The X-ray lightcurve of RX J0153.3+7446, folded at 1974 s and binned into 10 phase bins. The phasing is arbitrary.

observations, each of ~8000 s on-source exposure, obtained in 1991 and 1992. As noted by Haberl & Motch, the first observation is not suitable for period determination as it comprises many short segments, spread over a year. The lightcurve of the observation from 1992 March is more suitable for period determination, but even so it comprises a total of only 186 photons from RX J0153+7446, distributed over six satellite orbits and spanning ~58 ks.

The power spectrum of this lightcurve is shown in Fig. 5. Although the highest peak in the power spectrum (at 7.05×10^{-4} Hz) does indeed correspond to a period of ~1414 s, as reported by Haberl & Motch, the power spectrum is understandably noisy. Moreover, the second highest peak (at 5.06×10^{-4} Hz) is clearly an alias of the 1414 s period, and only marginally less preferred. This corresponds to a period of 1974 ± 30 s. The X-ray lightcurve folded at this period is shown in Fig. 6. If we assume that 1974 s is the true X-ray pulse period of RX J0153+7446, then the optical photometric period which we have found is harmonically related to this and the proposed orbital period via:

$$\frac{1}{P_{\rm spin}} - \frac{1}{P_{\rm orb}} = \frac{1}{P_{\rm beat}} \frac{1}{(1974 \pm 30)\,{\rm s}} - \frac{1}{3.94\,{\rm h}} \sim \frac{1}{(2333 \pm 5)\,{\rm s}}. \quad (1)$$

This is the usual way in which the white dwarf spin period, orbital period and beat period are related in intermediate polars, and reflects the fact that the dominant optical photometric modulation is due to reprocessing of the X-ray pulse from a site fixed in the binary reference frame, such as the face of the companion star.

5. Conclusions

We have detected a strong optical photometric modulation from RX J0153+7446 at a period of 2333 ± 5 s. Having reanalysed the *ROSAT* X-ray observation of the source, we find that the true X-ray pulse period is probably 1974 ± 30 s. Assuming that the X-ray period represents the white dwarf spin period and the optical period represents the rotation period of the white in the binary reference frame, then the two are in agreement with the reported orbital period for this system of 3.94 h. RX J0153+7446 is thus confirmed as an intermediate polar.

The spin to orbital period ratio of RX J0153.3+7446 is therefore 0.14, which is one of the highest amongst intermediate polars above the period gap. From the results presented in Norton et al. (2004a) we can estimate the magnetic moment of the white dwarf in this systems as $\sim 6 \times 10^{33}$ G cm^3. This places RX J0153.3+7446 at the high end of the intermediate polar magnetic moment distribution and suggests it may be a candidate for exhibiting polarized emission and also episodes of stream-fed accretion. Further X-ray observations are encouraged to confirm and refine the X-ray pulse period and orbital period of this system.

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