Mon. Not. R. Astron. Soc. **000**, 000–000 (0000) Printed 8 September 1997

RX J0744–52: A probable new Intermediate Polar

Gavin Ramsay[1],⋆ David A. H. Buckley[2] & Mark Cropper[1]
[1] *Mullard Space Science Laboratory, University College London, Holmbury St.Mary, Dorking, Surrey, RH5 6NT*
[2] *South African Astronomical Observatory, PO Box 9, Observatory 7935, South Africa*

submitted: 16 May 1997, submitted in revised format:

ABSTRACT

We present optical and X-ray data of the Cataclysmic Variable RX0744–52 discovered using *ROSAT* by Motch et al. High resolution spectroscopy centred on the Hα line indicates a probable orbital period of 3.60 hrs. From its distance (obtained using polarimetry), its X-ray luminosity, its X-ray colour and its X-ray/UV+Opt ratio, we suggest that RX0744–52 is an new Intermediate Polar. The absence of a significant coherent modulation in the X-ray light curve suggests that RX0744–52 has either a low inclination or that the rotational and magnetic axes must be closely aligned. This is consistent with its small radial velocity amplitude.

Key words: Stars: accretion, accretion discs - stars: individual: RX J0744–52 - novae, cataclysmic variables - white dwarfs - X-rays: stars

1 INTRODUCTION

Among the many new X-ray sources detected using the *ROSAT* satellite (0.1–2.5 keV) were a number of Cataclysmic Variables (CVs). These are close binary stars in which material accretes onto a white dwarf through Roche-lobe overflow from a dwarf secondary star. In some systems the magnetic field of the white dwarf is sufficiently strong to disrupt the flow of material in the disk (Intermediate Polars) or prevent the formation of a disk entirely (Polars, or AM Her systems), (see Warner 1995 for a comprehensive account). One of these new X-ray sources was RX J0744–52 which was identified as a CV from its optical spectrum (Motch et al 1996). This relatively bright object (V ∼15) would probably have been identified much sooner had it not been only 1$'$ distant from a V=8.3 star. Motch et al (1996) noted that the Equivalent Width of the HeII emission lines are consistent with those of a dwarf nova. To investigate this source in more detail we have obtained new optical data and analysed unpublished archival *ROSAT* data. Table 1 shows the dates of these observations and the telescopes used.

Data	Dates	Telescope
X-ray	1992 Dec 2–6	*ROSAT*
Optical Polarimetry	1996 Oct 13	SAAO 1.9m
Optical Photometry	1997 Jan 25–29	ESO 0.9m
Optical Spectroscopy	1997 Feb 8	ESO 3.6m
Optical Spectroscopy	1997 Feb 11–15	SAAO 1.9m
Optical Spectroscopy	1997 Apr 11–14	SAAO 1.9m

Table 1. The observation log of RX0744–52.

2 OPTICAL OBSERVATIONS

2.1 Photometry

Photometry was obtained between 1997 Jan 25–29 using the ESO/Dutch 0.9m telescope at La Silla, Chile. The exposure time was 20 sec and the dead time was 12 sec. Differential photometry was performed using stars in the immediate field and standard stars were used to bring these magnitudes onto the standard system. The light curve of RX0744–52 is shown in Figure 1. Over 5 days, the range in brightness was V=14.4–15.2. A sequence lasting ∼2 hrs was also obtained in I (figure 1).

To investigate the time variability we have used a discrete Fourier Transform (DFT: Deeming 1975, O'Donoghue, Warner & Cropper 1992) to compute an amplitude spectrum of the V band light curve. A first order polynomial was fitted to the data. The data were normalised using the polynomial and the resulting mean value of unity subtracted, so that the resultant amplitudes are fractional. No cosine tapering was applied. The amplitude spectrum is shown in the upper panel of figure 2. The strongest peak in the amplitude spectrum is at ∼160 mins (=2.67 hrs), with peaks also seen at 62, 52 and 24 mins, although none of them are likely to be significant.

⋆ Formerly: Astronomical Institute, University of Utrecht, The Netherlands

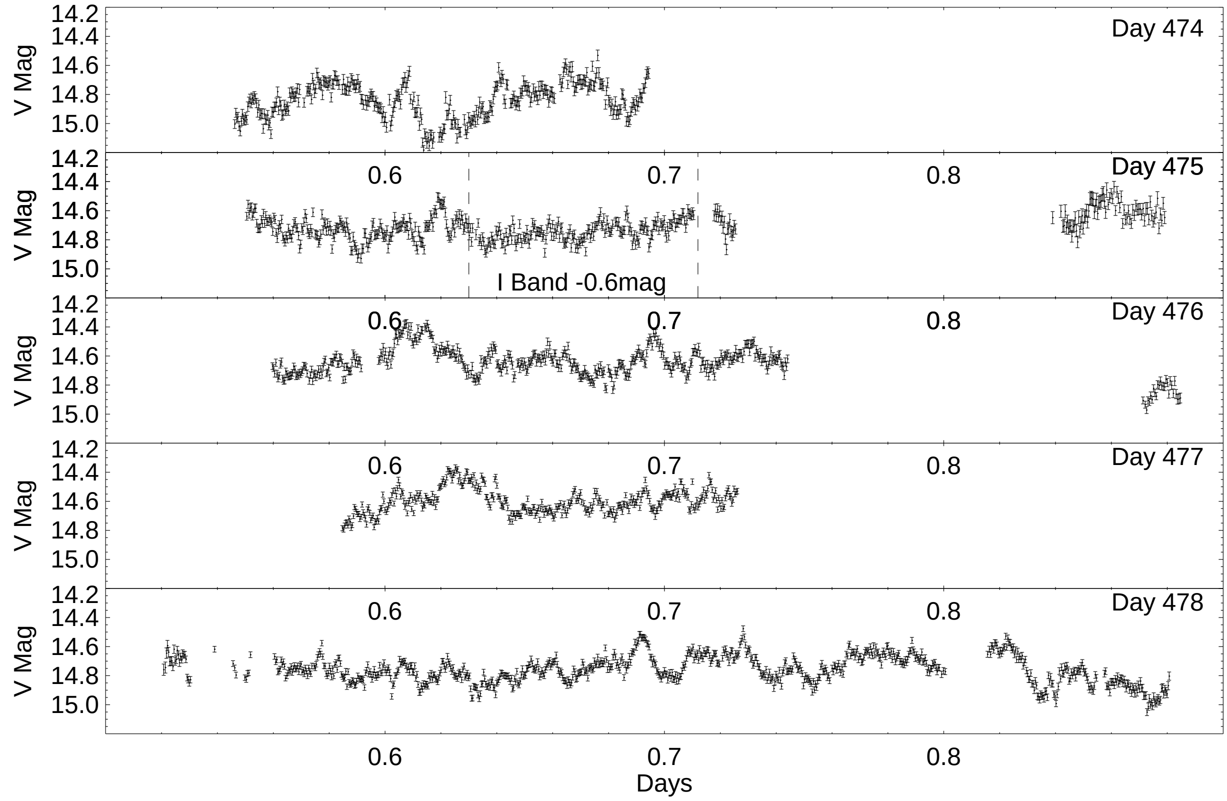

Figure 1. Photometry of RX0744–52 taken using the ESO/Dutch 0.9m telescope at La Silla, Chile. The day is the JD-2450000.0. For the *I* band data taken in day 475 we have subtracted 0.6 mag from the *I* band magnitude to bring it into line with the *V* band data.

2.2 Polarimetry

RX0744-52 was observed on 1996 Oct 13 for approximately 40 mins using the SAAO 1.9m telescope and UCT Polarimeter (Cropper 1985) with an unfiltered GaAs photomultiplier. Conditions were photometric. Polarised and non-Polarised standard stars (Hsu and Breger 1982) and calibration polaroids were observed at the beginning of the night to set the position angle offsets and efficiency factors. The data were reduced in the standard way (eg Cropper 1997).

The circular polarisation is consistent with zero. There is an apparent trend in the position angle data, but this should be viewed with caution as experience has shown the ease with which such trends appear in low signal-to-noise data of faint sources with low levels of polarisation, despite care being taken over the sky subtraction (see also the discussion on statistical effects in Clarke and Stewart 1986). Averaging over the 26 integrations each of 1 minute yields a linear polarisation of 0.92 ± 0.31 percent at 48 ± 10 degrees and a circular polarisation of -0.28 ± 0.22 percent. This low level of polarisation probably rules out RX0744–52 being a Polar. Further, in the absence of a significant modulation of the polarisation flux, it is likely that this linear polarisation is interstellar in origin.

Assuming the observed polarisation is interstellar in origin, we can use the relationship (for $b < -10^\circ$, P/d=1.1%/kpc) of Barrett (1996) to obtain an approximate distance to RX0744–52 of 820pc with a range of 540–1090pc. (The error in the distance does not take into account any uncertainty in the polarisation-distance scale – for instance changes in the magnetic field orientation for different lines of sight).

2.3 Optical Spectra

Two low resolution (~15Å) spectra were taken on 8 Feb 1997 using EFOSC1 on the ESO 3.6m telescope. The red spectrum covered 6000-9500Å while the blue coverage was 3800–6800Å. The blue spectrum is shown in figure 3. No secondary star features were visible in the red spectrum. Images of the field taken immediately before the spectra suggest that it was at V ~14.8 - similar to that observed using the ESO/Dutch 0.9m telescope 1 week previously. The flux over the range 4000-9000Å was $\sim 1.3 \times 10^{-11}$ ergs s^{-1} cm^{-2}.

A series of 132 medium-low resolution (~1.5–2.5Å) spectra were obtained between 1997 Feb 11–15 at SAAO with the 1.9m telescope using the Cassegrain spectrograph employing the two-channel Reticon photon counting system (RPCS). The longest coverage on one night was 260 mins. The exposures were 300 sec and calibration arc spectra were obtained every ~1200 sec. Between April 11–14 1997 68 higher resolution (~1Å) spectra were obtained at SAAO with the 1.9m telescope using the Cassegrain spectrograph with the newly commissioned SITe#2 CCD detector. The spectra were centred on Hα and the exposures were 300 or 600 sec.

The most prominent lines in these spectra, (Hα, Hβ and Hγ), were fitted with a single Gaussian to derive radial velocities, Equivalent Widths and line fluxes. In Hα the γ

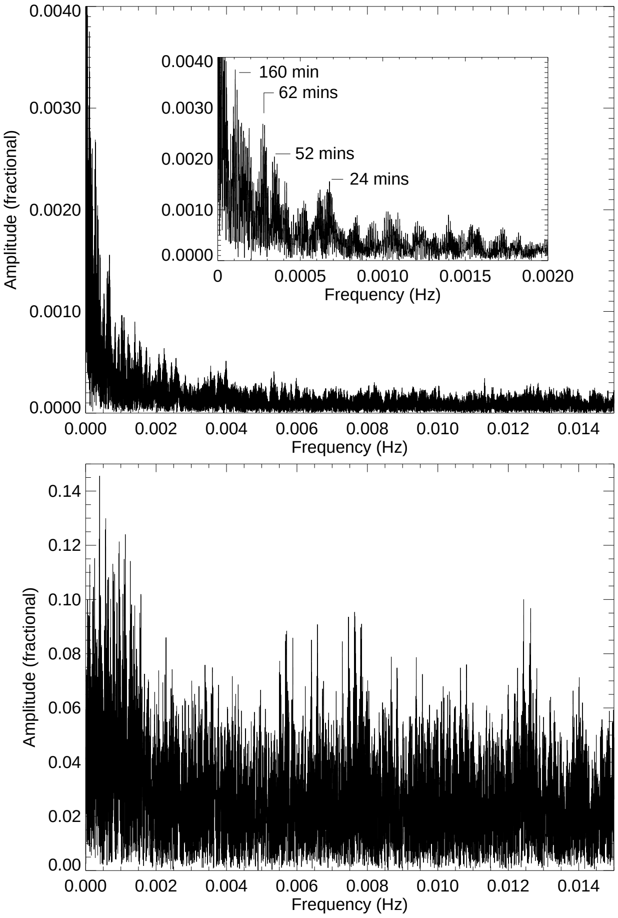

Figure 2. Top panel: the DFT amplitude spectrum of the V band time series shown in figure 1, bottom panel: the amplitude spectrum for the full X-ray light curve covering 0.1-2.0keV.

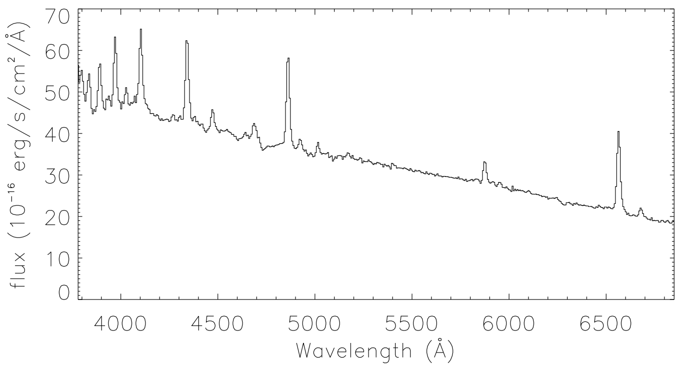

Figure 3. A low-medium resolution spectrum of RX0744–52 taken using EFOSC1 and the ESO 3.6m telescope.

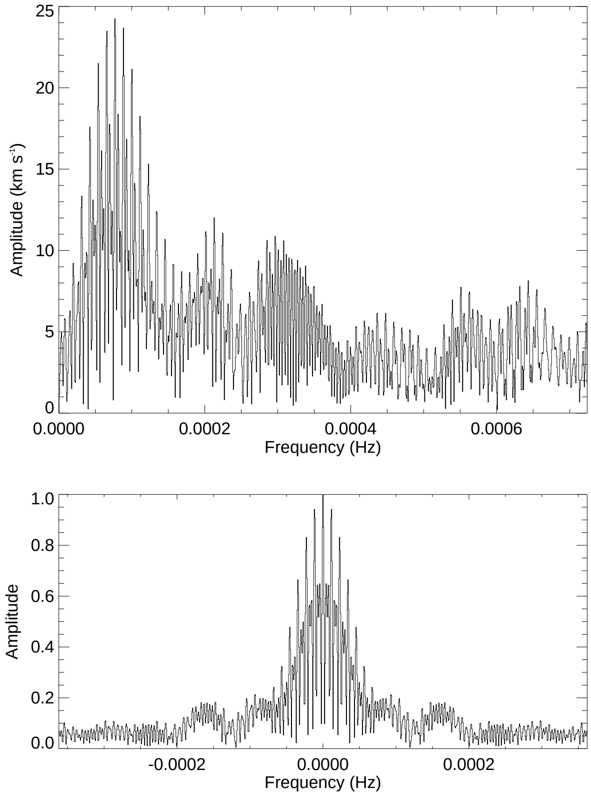

Figure 4. Top panel: The DFT amplitude spectrum of the SAAO Hα spectra taken over 1997 April 11–14. Bottom panel: its window function.

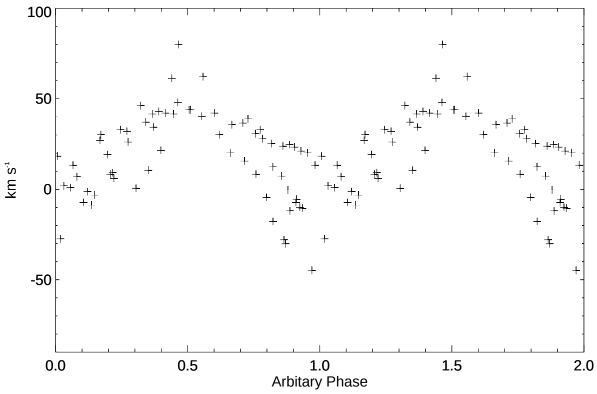

Figure 5. The Hα radial velocity data obtained in April 1997 folded on a period of 3.60 hrs.

velocity was +18 km s^{-1}. We used the DFT mentioned in §2.1 to obtain amplitude spectra for the fitted parameters: a first order polynomial fit was subtracted from the data. The top panel of figure 4 shows the amplitude spectrum for the high resolution Hα radial velocity data. The most significant peak is centred at 0.1497 days (=3.60 hrs). The window function shown in the bottom panel of figure 4 indicates that the peaks on either side of the 3.60 hour period (0.1304 days = 3.13 hrs and 0.1761 days = 4.22 hrs) are due to the sampling. Figure 5 shows the Hα data folded on the 3.60 hour period. Similar peaks in the radial velocity amplitude spectra were also seen in the Hβ and Hγ data but with lower significance. In one spectrum there was evidence for a double peak in the Hγ component which was not evident in other lines (eg Hβ).

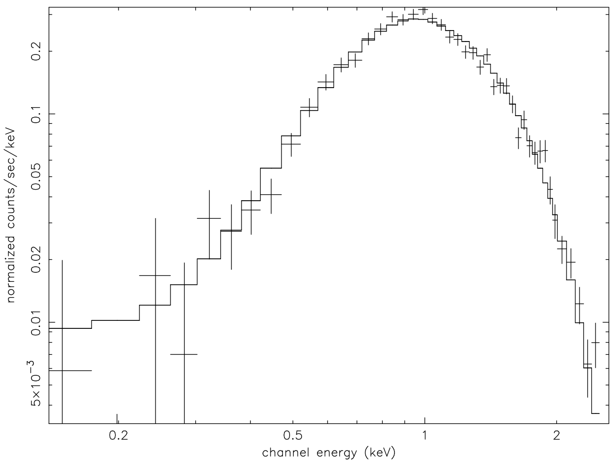

Figure 6. The inferred photon spectrum of RX0744–52. The model is an absorbed thermal bremsstrahlung with kT=1.45keV.

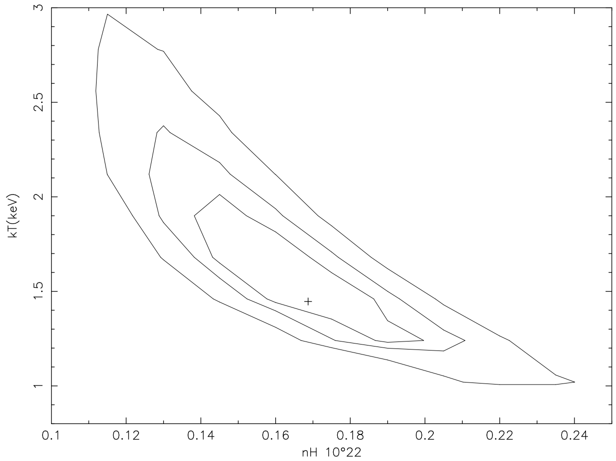

Figure 7. The 68%, 90% and 99% confidence contours in the kT, N_H plane.

3 X-RAY DATA

The *ROSAT* satellite carries an X-ray telescope with a PSPC detector operating in the 0.1–2.5 keV energy range (see Pfeffermann et al 1986 for more details). RX0744–52 was observed on-axis for nearly 22 ksec between 1992 Dec 2–6. We followed the reduction procedure of Ramsay et al (1994). The mean count rate was 0.27 ct s^{-1} over the 0.1–2.0keV energy range (corrected for vignetting and dead time). The light curve exhibits flickering typical of CVs. To search for any significant periodicity in the X-ray light curve we used the DFT described in §2.1. The highest peak in the power spectrum is at 41.9 min, but is not significant (lower panel of figure 2). We can place an upper limit of ∼10% for a coherent modulation in the X-ray data – this estimate is from a visual inspection of figure 2.

A binned integrated spectrum covering the full energy range was extracted and fit using XSPEC (see fig 6). A good fit was obtained using an absorbed thermal bremsstrahlung: $N_H = 1.7 \times 10^{21}$ cm^{-2}and kT=1.45keV (χ^2_ν=1.06: 41 dof). (To account for the uncertainty in the *ROSAT* PSPC response matrix, a 5 percent systematic error was added to the data). Figure 7 shows the confidence contours in the kT, N_H plane: the fitted temperature lies between 1.0$< kT <$ 2.1 keV at the 90% confidence level. A similar fit and temperature was achieved using an absorbed Raymond-Smith thermal plasma model.

As the absorption to the edge of the Galaxy is $N_H \sim 1.1 \times 10^{21}$ cm^{-2}(Stark et al 1984), most of the absorption occurs in the binary system. This is consistent with one view of IPs which have accretion curtains above the magnetic poles which can absorb X-rays. However, such absorption phenomena are not unique – evidence for internal absorption in VY Scl and non SU UMa systems was presented by van Teeseling, Beuermann & Verbunt (1996).

4 DISCUSSION

4.1 Orbital Period

The amplitude spectrum of the Hα radial velocity data indicates a probable orbital period of 3.60 hours. This places RX0744–52 above the period gap and is typical of Intermediate Polars. This period rules out RX0744–52 being an SU UMa sub-class of dwarf novae (all have periods less than 3 hours).

4.2 Optical Spectrum

From its optical spectrum RX0744–52 is unlikely to be a Nova-like system as HeII(4686)/Hβ is rather low for these systems (see Warner 1995, p221). The optical spectra are similar to those of dwarf novae in quiescence (Warner 1995, p127) and also to those of the IPs (ibid, p400), as is the FWZI of the lines (Hβ=3200kms^{-1}). Motch et al (1996) in their discovery paper of RX0744–52 suggested a dwarf nova classification on the basis of its low Equivalent Width (3.2Å) of the HeII (4686) line. The Equivalent Width measured from the ESO 3.6m spectra was 5.5Å. This is similar to that found in some IPs (eg 6Åin AO Psc: Hellier, Cropper & Mason 1991).

Only one of the spectra taken in Feb 1997 at SAAO shows the Hγ line to be double peaked. Dwarf novae tend to show double peaked lines throughout their orbital period. Double peaked lines have been seen in several IPs for a limited part of their orbit: for instance, the IP EX Hya shows double peaked emission lines at certain orbital phases (this is taken as evidence for accretion from a truncated accretion disk; Hellier et al 1987). In another IP, AO Psc is seen to show double peaked lines at some phases, but this is thought to be due to absorption in the line centres (Hellier, Cropper & Mason 1991).

4.3 X-ray luminosity

From the observed flux over 0.5–2.5keV of 3.4×10^{-12} ergs s^{-1} cm^{-2}we obtain L_X (0.5–2.5keV) $= 4.1 \times 10^{30} d^2_{100pc}$ ergs s^{-1}. Using the distance determined in §2.2 we find that

$L_X = 2.7(1.2 - 4.9) \times 10^{32}$ ergs s^{-1}. Comparing this X-ray luminosity with Figure 8 of Verbunt et al (1997) (which shows the X-ray luminosity over 0.5–2.5keV, uncorrected for absorption, for various sub-classes of CV), we find that the X-ray luminosity of RX0744–52 is comparable with the upper range of the IPs. All the other sub-types of CVs, show significantly lower luminosities than RX0744–52: the nearest sub-type is the SU UMa systems, the most luminous system having $L_X = 6 \times 10^{31}$ ergs s^{-1}. However, we showed earlier (§4.1) the orbital period is inconsistent with those of SU UMa type systems. The next most luminous sub-class of CV is the U Gem systems whose most luminous system has a luminosity of $L_X = 2 \times 10^{31}$ ergs s^{-1}. To equal this luminosity, RX0744–52 would have to lie only 220 pc distant – it is unlikely that the polarisation-distance relationship in the direction of RX0744–52 discussed in §2.2 differs to this extent from the mean relationship of Barrett (1996).

4.4 X-ray to UV+Optical ratio

We now compare the X-ray to UV+Optical ratio of RX0744–52 to that determined for non-magnetic CVs by van Teeseling, Beuermann & Verbunt (1996). Using their formula to obtain the UV+Optical flux ($\log(F_{UV+Opt})$=–0.4m_v–4.32) we obtain F_{UV+Opt}=5.75 $\times 10^{-11}$ ergs s^{-1} cm^{-2}for V=14.8 (the mean magnitude determined from the ESO photometry). This figure is consistent with the flux determined from the low-resolution spectra taken in Feb 1997 at ESO: (1.3×10^{-11} ergs s^{-1} cm^{-2}, between 4000–9000Å). The unabsorbed bolometric X-ray flux determined using the integrated *ROSAT* spectrum is 1.1×10^{-11} ergs s^{-1} cm^{-2}. Bearing in mind that the optical and X-ray data are not simultaneous and that the UV component is based on an estimate of the V magnitude, we find a ratio F_X/F_{UV+Opt} ∼0.2. Comparing this value with Figure 6 of van Teeseling, Beuermann & Verbunt (1996) (which shows the bolometric X-ray/UV+Optical ratio, corrected for absorption, as a function of orbital period), we find that for a system with an orbital period of 3.6 hrs, RX0744–52 has a F_X/F_{UV+Opt} ratio much greater than typically found for non-magnetic CVs. It occupies the area in the diagram usually filled with IPs. Non-magnetic CVs which have temporarily lower mass accretion rates will have similar F_X/F_{UV+Opt} ratios to that of IPs. There is no reason to suppose that RX0744–52 was in a low accretion state during the optical observations – examining the Deep Sky Survey image of this field shows that RX0744–52 was at a similar brightness compared to Feb 1997 (V ∼14.9), while Motch et al (1996) found V=13.3 & 15.5 in two observations.

4.5 X-ray colours

To make a comparison with *ROSAT* observations of other CVs which were observed in the all-sky survey (Verbunt et al 1997), we obtained count rates using the pointed observation of RX0744–52 in the bands defined by Verbunt et al. We found the following count rates in the various bands – channels 11–41: 0.006 cts s^{-1}, 52–201: 0.245, 52–90: 0.077, 91–201: 0.168 (to make an approximate conversion from channels to keV, divide the channel number by 100). Figure 8 shows those systems which had non-zero counts in all of the

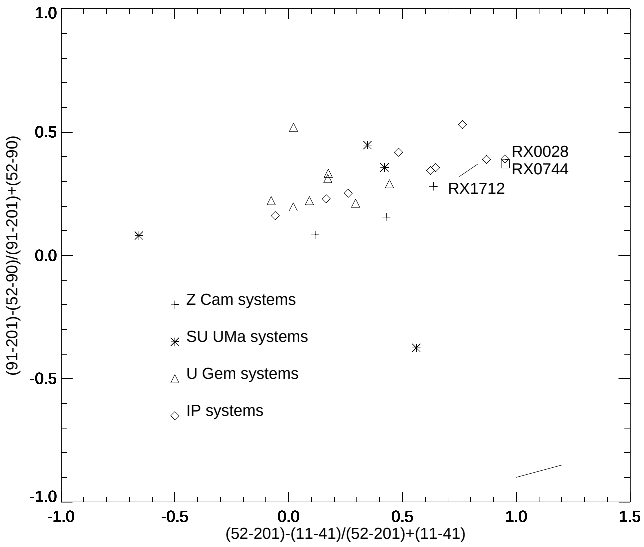

Figure 8. The *ROSAT* data of various sub-classes of dwarf novae and IP systems were taken from Verbunt et al (1997) and plotted in the counts in channels (52–201)-(11–41)/(52–201)+(11–41) vs counts in channels (91–201)-(52–201)/(91–201)+(91–201) plane. For 2 new IPs (RX0028+59 and RX1712–24) data were extracted from the *ROSAT* pointed data archive. The location of RX0744–52 is shown as a square. The approximate reddening line is shown in the lower right hand corner.

above bands in an X-ray colour diagram. We have added the data of two IPs discovered using *ROSAT* (RX0028+59 and RX1712–24; Haberl & Motch 1995) by extracting data from the *ROSAT* data archive. RX0744–52 falls in the same location in this diagram as a number of IPs. We should caution, however, that the effects of absorption has not been taken into account. Increasing absorption will have the effect of shifting the X-ray colour to the right: therefore systems with high absorption will be to the right hand of the diagram. This is consistent with the high absorption derived from the X-ray spectral fit.

4.6 X-ray temperature

In IPs the temperature at the accretion shock is 10–20keV (eg AO Psc: Hellier et al 1996). However, we expect to observe a distribution of temperatures since the plasma cools as it nears the surface of the white dwarf (eg Cropper, Ramsay & Wu 1997). As the *ROSAT* PSPC covers an energy range of 0.1–2.5keV, we expect to detect only the emission from plasma close to the surface of the white dwarf. This is consistent with our fit to the integrated X-ray spectrum where we find a temperature of ∼1–2.5 keV. (A thermal bremsstrahlung with a fixed temperature of kT=10keV gives a poor fit: χ^2_ν=2.67).

To compare this temperature derived from *ROSAT* with that of other IPs, we extracted *ROSAT* data of several IPs from the public archive and fitted their integrated spectrum with an absorbed thermal bremsstrahlung model as before. We found a range in the goodness of fits (from bad to good) and in the fitted temperatures. For instance, a reasonable fit could be obtained for AO Psc with a temperature of 10 keV, while for the two IPs which had X-ray colours very similar to RX0744–52 (RX1712–24 and RX0028+59: figure 8), good fits were obtained with temperatures between 2.5 and 5.5 keV.

To investigate this in more detail we modelled the integrated X-ray spectrum using a stratified post-shock region (only applicable to magnetic CVs) together with a warm absorber (Cropper, Ramsay & Wu 1997) plus cold absorber. We find that for a shock temperature of kT=30 keV we get a good fit (χ^2_ν=0.97) and for a shock temperature of kT=15 keV a slightly poorer fit (χ^2_ν=1.36). We conclude that a simple thermal bremsstrahlung model together with cold absorption is not a useful method of obtaining temperatures of IPs using *ROSAT* data and that the X-ray spectrum of RX0744–52 is consistent with that of other IPs.

4.7 Lack of X-ray modulation

Finally we turn to the lack of any significant modulation in the soft X-ray light curve (at the 10% level). This may simply be due to fact that the modulation is hidden in the noise of our X-ray power spectrum. In general Intermediate Polars show rich power spectra (Norton, Beardmore & Taylor 1996) including orbital sideband frequencies and their harmonics. This contrasts with the less rich dwarf novae power spectra. However, in some systems (eg TV Col: Hellier 1993), the spin period, although seen in X-rays, has not been seen in the optical. It is not clear why this should be the case. One reason for the absence of a significant modulation may be that it has a low inclination (the same would be true for a system in which the rotation and magnetic axes were closely aligned). Such a system would also show low radial velocity variations, which is what we see in RX0744–52 (figure 5). Further, this low inclination is consistent with the internal absorption determined from the X-ray spectrum being caused by an accretion curtain – for all but low inclination systems an accretion curtain would be expected to lie in the line of sight to the accretion region and cause an X-ray modulation.

5 CONCLUSIONS

We have presented X-ray and optical data of RX0744–52 discovered by Motch et al (1996). We can confirm that it is a Cataclysmic Variable with a probable orbital period of 3.60 hrs. RX0744–52 has the following properties:

- Its F_X/F_{UV+Opt} ratio is typical of IPs and much greater than dwarf novae of similar orbital period,
- Its X-ray colour is typical of IPs but not of dwarf novae: indeed it is very similar to two of the hard IPs discovered by Motch et al (1996),
- Its X-ray luminosity is comparable with that of IPs, but higher than dwarf novae.

These properties suggest that RX0744–52 is a new member of Intermediate Polar sub-class of CVs. The absence of significant modulation in the X-ray light curve indicates that it has either a low inclination or the rotational and magnetic axes are closely aligned. This is consistent with its small radial velocity amplitude.

6 ACKNOWLEDGEMENTS

We would like to thank both ESO and SAAO for their allocation of observing time and their support during the observing runs. We would like to thank Darragh O'Donoghue for the use of his Fourier transform software. This paper is based partly on data extracted from the UK *ROSAT* data archive in Leicester. We would like to thank the referee for their helpful comments.

REFERENCES

Barrett, P., 1996, PASP, 108, 412
Clarke, D., Stewart, B. G., 1986, VA, 29, 27
Cropper, M, 1985, MNRAS, 212, 709
Cropper, M, 1997, in press
Cropper, M, Ramsay, G, Wu, K., MNRAS, in press
Deeming, T. J., 1975, ApSS, 36, 137
Haberl, F., & Motch, C., 1995, A&A, 297, L37
Hellier, C., 1993, MNRAS, 264, 132
Hellier, C., Mason, K. O. Rosen, S. R., Cordova, F. A., 1987, MNRAS, 228, 463
Hellier, C., Cropper, M., Mason, K. O., 1991, MNRAS, 248, 233
Hellier, C., Mukai, K., Ishida, M., Fujimoto, R., 1996, MNRAS, 280, 877
Hsu, J. -C. & Breger, M., 1982, ApJ, 262, 732
Motch, C, Haberl, F, Guillout, P, Pakull, M, Reinsch, K, Krautter, J, 1996, A&A, 307, 459
Norton, A. J., Beardmore, A. P., Taylor, P., 1996, MNRAS, 280, 937
O'Donoghue, D., Warner, B., Cropper, M., 1992, MNRAS, 258, 415
Pfeffermann, E., et al 1986, Proc SPIE, 733, 519
Ramsay, G., Mason, K. O., Cropper, M., Watson, M. G., Clayton, K., 1994, MNRAS, 270, 692
Stark, A., Heiles, C., Bally, J., Linke, K., 1984, privately distributed tape
van Tesseling, A., Beuermann, K., & Verbunt, F., 1996, A&A, 315, 467
Verbunt, F., Bunk, W. H., Ritter, H., Pfeffermann, E., in press, A&A
Warner, B., 1995, Cataclysmic Variable stars, Cambridge Astrophysics Series, Vol 28, CUP