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The X-ray emission of Intermediate Polars: the BeppoSAX view and the role of current missions

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Intermediate Polars (IPs) are the most intriguing systems among Cataclysmic Variables (CVs), as the X-ray spectral and temporal behaviour is not similar in all members. The simultaneous study of broad–band X-ray temporal and spectral properties is crucial to characterize the accretion geometry and the physical conditions of the accretion flow onto moderately (B<10-20 MG) magnetized white dwarfs. Thanks to the wide energy coverage, BeppoSAX observations of bright IPs have allowed to infer the accretion mode, the presence of complex patchy absorption in the pre–shock flow and of a Compton reflection component from the white dwarf surface as well as to measure simultaneously the temperature of the post–shock region and that of the irradiated poles of the white dwarf atmosphere. The observations show that accretion in these systems cannot be reconciled with a single scenario, accounting for their soft and hard X-ray behaviour. Many known systems and IP candidates still lack of X-ray characterization in both soft and hard bands, for which current X–ray missions are providing new and unprecedented results.

1. INTRODUCTION

Intermediate Polars (IPs) are the hardest X-ray and most complex behaving systems among Cataclysmic Variables (CVs), containing a fast asynchronously spinning (33 s–1 h) magnetized white dwarf (WD), which accretes material from a late type Roche-Lobe overflowing Main Sequence star. IPs typically populate the long period side of the CV orbital period distribution and were believed to evolve into the strong magnetized Polars (B∼ 10-230 MG) once the WD synchronizes. However, the ROSAT discovery of few systems, sharing properties (soft X-ray component, optical polarized radiation) similar to the Polars and with magnetic fields similar to the lowest field Polars (10-20 MG), suggests that IPs possess low field (B≤ 10 MG) WDs. Fig. 1 reports all IPs (confirmed and candidates) in the spin-orbit period plane, where it is apparent that the majority of known IPs populate the lower part of the plane traced by the spin-orbit period ratio of 10%. Spin equilibrium theories [1] predicted that systems below this line accrete via a disc, while above they should accrete without a disc. The observations, however, suggest that a disc is favoured also in IPs populating the upper part of the plane. Many new IP candidates have been recently discovered, some of them with a very weak degree of asynchronism [2]. These new systems fill the gap between IPs and Polars (the synchronism line),

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further exacerbating the evolutionary debate of magnetic CVs. It is then crucial to understand the role of magnetic field, mass accretion rate and system parameters in the accretion process and in their evolutionary status.

The X-ray regime is fundamental to assess not only the nature of the accreting object (magnetic or non-magnetic) but also to determine the accretion configuration at work and hence the emission properties of the accreting flow. In particular the study of temporal and spectral behaviour of IPs over a wide energy range can allow to simultaneously map the accretion flow and its effects on the WD atmosphere as well as to assess the energy balance of primary hard X-rays and re-processed soft X-ray emission. The BeppoSAX satellite has provided for the first time such opportunity and in particular has allowed the simultaneous study of broad–band temporal and spectral properties from 0.1 keV up to energies of 90 keV, this latter being an unprecedented detection thanks to the PDS instrument. Here we summarise the results obtained for four bright IPs observed with BeppoSAX and of a recently discovered faint ultra–short binary observed with XMM-Newton. They are shown in Fig. 1 and encompass different emission properties. RE 0751+14 and RX J0558+53 were discovered as soft X-ray IPs, while RX J0028+59, RX J1712-24 and RX J0757+63 were discovered as hard X-ray systems. We will henceforth call them RE 0751, RX J0558, RX J0028, RX J1712 and RX J0757.

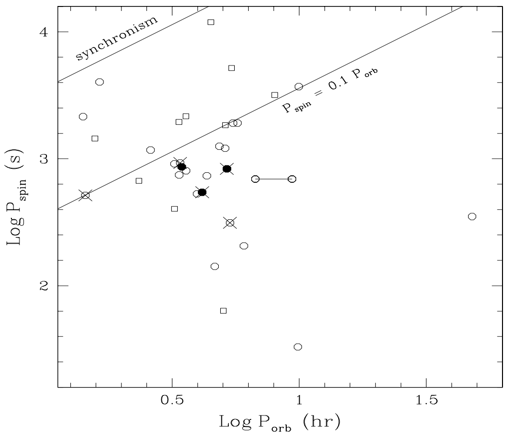

Figure 1. The spin-orbit period plane of IPs. Confirmed systems are marked with empty circles, soft X-ray IPs with filled circles, IP candidates with open squares. The IPs observed by BeppoSAX and XMM-Newton are further marked with crosses.

2. X–RAY TEMPORAL PROPERTIES

Differently from the Polars, IPs are characterized by a wide range of periodicities such as the WD rotation, the orbital period and their sidebands. The majority of known systems are strongly modulated at the spin (ω) frequency, indicating that most of these systems accrete via a truncated disc at the magneto-spheric radius. This because the circulating disc material loses memory of the orbital motion. Hence, disc–fed accretion is a common configuration in IPs, where material flows onto the magnetic poles via an arc–shaped curtain [3]. However, in some systems, the presence of additional frequencies, such as the orbital Ω and the beat (or synodic) $(\omega-\Omega)$, indicate a disc–overflow accretion [4]. On the other hand, systems dominated by the beat frequency should be pure stream–fed accretors, similar to the Polars. Therefore, X-ray power spectra are powerful diagnostics of the accretion mode. We report in Fig. 2 the 1–10 keV power spectra of the four IPs observed with BeppoSAX [5,6] and of RX J0757 with XMM-Newton [7]. These show that all but one are disc–fed systems, RX J1712 being, the unique case known to date of a beat dominated system. It hence should accrete directly from the stream of material from the secondary star. In the disc–fed systems, different proportions of the signals at higher harmonics are observed indicating structured light curves. The folded light curves at the dominant periodicity (Fig. 3) reveal different morphologies which are energy dependent in most cases. The hardness ratios from 0.1 up to 10 keV are also different in our sample. The disc–fed systems RX J0028 and RX J0757 show a hardening at pulse minimum but with different

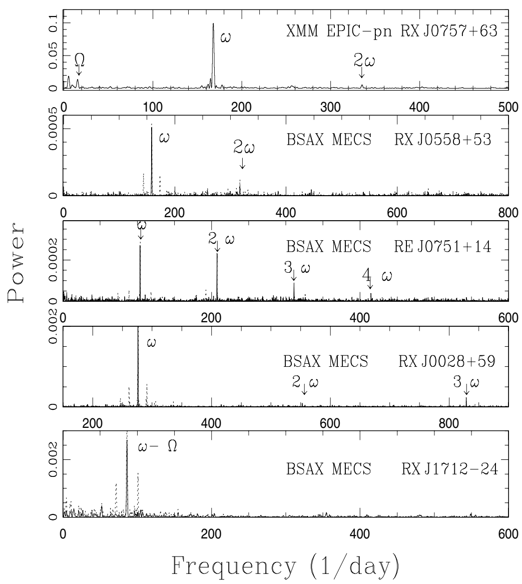

Figure 2. The 1-10 keV power spectra of the four IPs observed with BeppoSAX and of a new faint IP by XMM-Newton. Spurious signals due to the BeppoSAX orbit are removed by the CLEAN algorithm.

hard X-ray behaviour. In RE 0751 and RX J0558, the hardness ratios are different from each other. RX J1712 shows a softening at spin minimum which is typical of the Polars. A hardening at spin minimum is typical of many hard X-ray IPs and is consistent with photo-electric absorption within the accretion curtain, where optical depth is larger along the field lines. Thus when the curtain points towards the observer it has the lowest projected area (spin minimum) and the absorption is largest. This is opposite to Polars, which are accreting via a filled and less extended columns. Here absorption is maximum at pulse maximum when the column points towards the observer. The different behaviour of the two soft IPs is not easy to be reconciled with an unique scenario. RX J0558 does not change its spectral shape along the spin cycle, implying that the observed modulation is due to changes in the normalization of hard X-rays. In RE 0751, the highly structured spin pulsation is due to an intervening phase–dependent material which produces a strong dip as well as to photo-electric absorption within the curtain.

3. X-RAY SPECTRAL PROPERTIES

The X-ray emission of IPs is hard (tens of keV) and optically thin arising from the post-shock region above the magnetic pole. The spectra are however highly absorbed by material with column densities up to $10^{23}\,cm^{-2}$. The hard X-rays are expected to be reflected and partially absorbed by the WD atmosphere. For the majority of IPs the re–processed component was not detected except for the small group of soft X-ray IPs.
Thanks to the wide energy coverage of the BeppoSAX satellite it has been possible to detect for the first time X-ray emission up to 90 keV and simultaneously characterise the soft and hard X-ray spectrum. Indeed this is especially important to assess whether a soft X-ray black–body component due to the reprocessing of hard X-rays in the WD atmosphere is present in IPs or it is a peculiarity of a few systems. The presence of a Compton reflection component in the continuum is suggested by the large (EW$\sim$ 150-290 eV) equivalent widths of iron Kα line observed in these systems. This is extremely important as the inclusion of a Compton reflection continuum in the study of X-ray spectra allows to obtain lower temperatures and EWs of the fluorescent iron line, which otherwise would be overestimated.
We have analysed the phase–averaged spectra with a composite model consisting of a black–body and an optically thin plasma and two absorbers (the galactic and a partial covering) plus a reflection component and a gaussian centred on 6.4 keV. We find that only RX J1712, RE 0751 and RX J0558 require a black–body component, with temperatures of 56-100 eV. These are higher than those observed in Polars (20-50 eV), indicating hotter and likely smaller reprocessing areas. This re-inforces the recent finding with XMM-Newton that some hard X-ray IPs may possess a soft X-ray black–body but highly absorbed [8]. The temperature of the post–shock

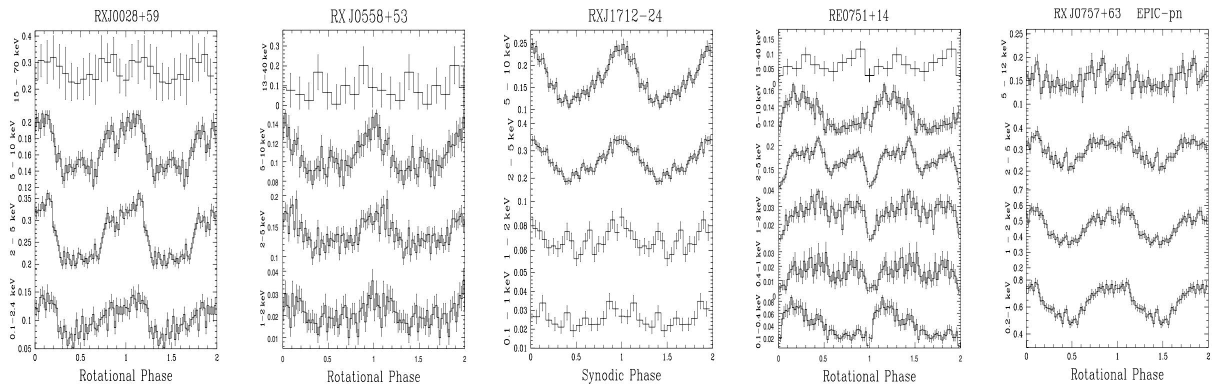

Figure 3. Folded light curve at the dominant period of the five IPs in selected energy bands.

region is well constrained (14-28 keV) and reflection is definitively present in RE 0751, RX J0558 and RX J0028 for which BeppoSAX PDS data are available. The EWs of iron fluorescent line are found to vary at the spin period, suggesting that reflection originates at the WD surface [5]. We note that for RX J0757+63 such component is not required, as also suggested by the very weak iron line (42 eV). The partial covering absorber is ubiquitous in all IPs and covers $\sim$ 40% the X-ray sources with column densities a few $\times 10^{22}\,\mathrm{cm}^{-2}$. Only RX J1712 possesses a very dense partial covering material with $N_H \sim 1 \times 10^{23}\,\mathrm{cm}^{-2}$. From spectral fits at pulse minimum and maximum we find that this material is responsible for the pulse phase behaviour of RX J0028, RE 0751, RX J0757, RX J1712 but not in RX J0558. The phasing of the partial covering absorbing material at maximum and minimum is however different in RE 0751 and RX J1712. While BeppoSAX data are not of enough quality to determine a multi–temperature structure, XMM-Newton can easily detect cooling flows as found in RX J0757 [7]. However, recent Chandra data of a few bright IPs [9], show that cooling flows are not a general property, thus requiring further investigation in all known IPs.

4. CONCLUSIONS

The IPs presented here show that while these systems share global similarities, they are different from each other. Only one system is a stream–fed IP with pulse spectral characteristics similar to those of Polars. The others are accreting via a disc but only one has spin spectral characteristics which can be reconciled with the generally accepted accretion curtain scenario. For the others modification of optical depths are required. In the three IPs showing a soft X-ray component, the soft-to-hard bolometric flux ratio is at most unity, implying that reprocessing of hard X-rays in the WD atmosphere is a viable solution.

REFERENCES

1. Woudt P., Warner B., 2003, IAU Coll. 190, ASP Conf. Ser., in press.
2. King A., Lasota P.J., 1991, ApJ 378, 674.
3. Rosen S., Mason K.O., Cordova F., 1988, MNRAS 231, 549.
4. Hellier C., 1991, MNRAS 251, 693.
5. de Martino D., Matt G., Mukai K., et al., 2001, A&A 377., 499.
6. de Martino D., Matt G., et al. 2003, A&A, submitted
7. de Martino D., Matt G., et al., in preparation
8. Haberl F., 2002, ASP Conf. Ser. 261, p. 151.
9. Mukai K. et al. 2003, ApJ 586, L77.