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X-ray emission from accreting white dwarfs: recent results and future perspectives

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Abstract. Our view of the X-ray sky has dramatically changed thanks to the recent hard X-ray surveys conducted with the *INTEGRAL* and *Swift* satellites. Among the large number of detected galactic X-ray sources, a non-negligible fraction is constituted by accreting white dwarf binaries, indicating a potentially important population of galactic X-ray sources. A brief summary of the results from recent X-ray follow-ups to characterize new candidates is presented as well as the role of future X-ray missions to study in details temporal and spectral properties over a broad energy range.

Key words. Stars: binaries:close – Stars: Cataclysmic Variables – X-rays: binaries

1. Introduction

Our view of the hard X-ray sky has dramatically changed thanks to the deep surveys above 20 keV conducted by the *INTEGRAL* and *SWIFT* satellites. More than 700 X-ray sources in the 20-100 keV range have been detected so far (Bird et al. 2010; Cusumano et al. 2010). The *INTEGRAL*/IBIS extensive survey of the galactic plane has surprisingly shown that our knowledge of X-ray binaries was very poor, revealing a new class of supergiant X-ray binaries, doubling fast X-ray transients and detecting Low Mass X-ray Binaries (LMXBs) and Cataclysmic Variables (CVs). Most of the CVs were found to be magnetic of the Intermediate Polar (IP) type with a handful of Polar systems (Barlow et al. 2006; Bonnet-Bidaud et al. 2007, 2009; de Martino et al. 2009). To date magnetic CVs (mCVs) represent $\sim$ 5% of the *INTEGRAL*/IBIS and $\sim$ 6% of the *SWIFT*/BAT white dwarf (WD) binaries detected at these energies. The negligible absorption in the hard X-rays and the flux limits of *INTEGRAL*/IBIS and *SWIFT*/BAT surveys can allow one to detect systems up to $\sim$1.5 kpc and hence to obtain the first volume-limited sample of these magnetics.

Systematic optical follow-ups of many unidentified hard X-ray sources have shown CV-like spectra with emission lines suggesting a magnetic nature (Masetti et al. 2008, 2009, 2010) making these systems a potentially important class of hard X-ray sources. That mCVs of the IP type may represent a significant fraction of the galactic background was proposed by Muno et al. (2004) and further corroborated by recent studies of the galactic X-ray ridge emission (Revnivtsev et al. 2008, 2009). While this is a new exciting result, it also reflects a poor knowledge of close binary evolution and exhacerbates the the long-

Send offprint requests to: D. de Martino standing problem of the high incidence of magnetism in WDCVs ($\sim$ 25% of the whole CV class harbour a magnetic WD) against that of single WDs ($\sim$ 5%). If magnetics are so numerous because of selection effects (bright sources in X-ray surveys) or because of longer evolutionary time scales linked to the WD magnetic field (Wickramasinghe & Ferrario 2000) it has still to be established.

A few more *INTEGRAL* and *SWIFT* detections of WD accreting binaries have surprisingly shown that other types, most Symbiotic stars, are hard X-ray emitters. The lack of magnetic field signatures in these systems indicates that these binaries harbour very massive WDs with two of them at near Chandrasekhar values (Kennea et al. 2009). Given the relatively low quiescent X-ray luminosity, deep wide area surveys above 10 keV will reveal the true population of these hard X-ray binaries. The importance of Symbiotics as one of the most viable progenitor channel to type Ia SNe makes the investigation of these systems a critical issue.

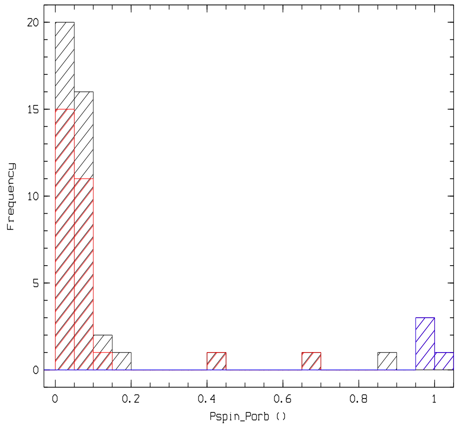

Fig. 1. The distribution of the spin-orbit period ratio (degree of asynchronism) of confirmed asynchronous mCVs (black) together with that of the *INTEGRAL* and *Swift* detected IPs (red) and Polars (blue). Most hard systems are concentrated below 0.1.

2. X-ray follow-ups

X-ray follow-ups are of key importance to characterize the newly discovered hard X-ray sources, thus to allow statistical studies of true samples and to identify outliers. In this context we are carrying out a programme with the *XMM-Newton* satellite to confirm newly identified CV candidates whose magnetic nature is suggested by their optical spectra. The great potential of *XMM-Newton* is to obtain timing and spectral parameters for faint sources that would not be possible otherwise. The detection of X-ray pulses at the WD rotational period (from tens of sec to mins) is the key signature of an IP. An interesting case of mis-identification is the hard X-ray source XSS J12270-4859. It was wrongly classified as a magnetic CV of the IP type in previous *RXTE* data, but a follow-up with *XMM-Newton* instead revealed a peculiar highly variable low-luminosity Low Mass X-ray Binary (LMXB) that we also found to be associated to the Fermi/LAT source 1FGLJ 1227.9-4852 (de Martino et al. 2010).

To date there are 44 confirmed systems of the IP type, with 16 out of 18 observed with *XMM-Newton*. This group of mCVs counts with about half the Polars ($\sim$80 systems). IPs are believed to harbour weakly magnetized accreting WDs ($\leq$10 MG), whilst the Polars contain strongly magnetized (B$\sim$10-240 MG) WD primaries. Basic differences are the asynchronous WD rotation (P_{spin} $\sim$mins) and the hard optically thin ($kT_{brem.}$ $\sim$20-40 keV) X-ray emission in the IPs, whilst the Polars have orbitally-locked ($P_{spin=orb}$ $\sim$hrs) WDs and also possess a strong soft X-ray optically thick (kT_{bb} $\sim$30-50 eV) emission. Interestingly, only four Polars have *INTEGRAL* and *Swift* detections and three of them have desynchronized WD primaries (Rana et al. 2005; Shafter et al. 2008). Hence asynchronism seems to be a common property of hard X-ray emitting mCVs.

Magnetic accretion produces a strong shock above the WD magnetic poles below which the flow cools by hard X-rays (bremsstrahlung) and cyclotron radiation. This emission is partially thermalized and re-emitted in the soft X-rays and/or EUV/UV domains (Konig et al. 2006). The relative im-

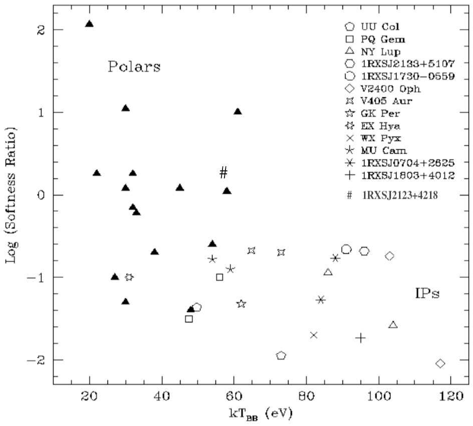

Fig. 2. The soft-to-hard X-ray luminosity ratio versus soft blackbody temperature of mCVs. Polars show on average a higher ratio but a small temperature range. IPs instead reveal a wider spread of temperatures (from Anzolin et al. (2008); de Martino et al. (2009)).

portance of these mechanisms depends on the magnetic field strength: cyclotron cooling gets increasingly efficient in high field systems such as the Polars and is able to suppress high gas temperatures (Fischer & Beuermann 2001). It is therefore likely that in the low-field systems the higher temperature post-shock flow makes these systems to preferentially emit in the hard X-rays. If desynchronization (i.e. low spin-to-orbit period ratio) is a signature of low-field systems, most hard X-ray CVs are expected to be asynchronous, i.e. of the IP type, as indeed seems to be the case. Many of the hard X-ray detected IPs have long orbital periods ($\geq$5 hr) with a high degree of asynchronism (Bonnet-Bidaud et al. 2006; de Martino et al. 2006a, 2008), suggesting weak-field magnetic accretors. An attempt to relate the hard X-ray emission with the spin-orbit period ratio as a signature of magnetic field strength (Scaringi et al. 2010) fails when including hard X-ray detected Polars (Fig.1). Hence, additional parameters other than the magnetic field strength likely play a role in the emission properties of these CVs (e.g. WD mass, mass accretion rate).

3. X-ray spectral properties

The X-ray emission of IPs, is known to extend up to about 90 keV and it is generally described by multi-temperature optically thin plasma, from few keV up to 30-40 keV. Broad-band spectra, using combined *XMM-Newton* and *INTEGRAL* data (Anzolin et al. 2009) have allowed to identify of complex spectral properties, including multi-temperature emission components and high density (N_H up to $10^{23}\,cm^{-2}$) absorbers partially covering the X-ray source, located in the pre-shock flow. Interestingly, most systems do not follow a power law multi-temperature profile as expected for the post-shock region above the polar caps. The high sensitivity of *XMM-Newton* has furthermore allowed to detect an absorption edge corresponding to OVII at 0.74 keV, related to the presence of ionized absorbing material as found in LMXBs (de Martino et al. 2008). This material should be also located in the pre-shock flow.

A surprising result is the presence of a non-negligible soft X-ray blackbody emission in an increasing number of systems (Anzolin et al. 2008, 2009; de Martino et al. 2009). The *ROSAT* satellite could detect only four IPs with a substantial soft X-ray component (soft IPs), that were thought to be the ”true” Polar progenitors (i.e. similar magnetic field systems but still to evolve into synchronism). The current roster of soft IPs amounts to 14 systems (Anzolin et al. 2008; de Martino et al. 2009) further exacerbating the debate on evolution and magnetic field strengths of CVs. We found that IPs cover a much wider range of blackbody temperatures (from 30 eV to 100 eV) with respect to the Polars (Fig. 2), which poses the key question on the role of hard X-rays and cyclotron irradiation onto the WD atmosphere. Furthermore, the soft-to-hard X-ray luminosity ratio is much smaller than that found in the Polars, indicating that the additional (blobby) accretion mode, occurring in most Polars, is not active in the IP systems.

Another key feature of X-ray spectra is the strong fluorescent Fe K_α line at 6.4 keV indicative of reflection from cool material. A

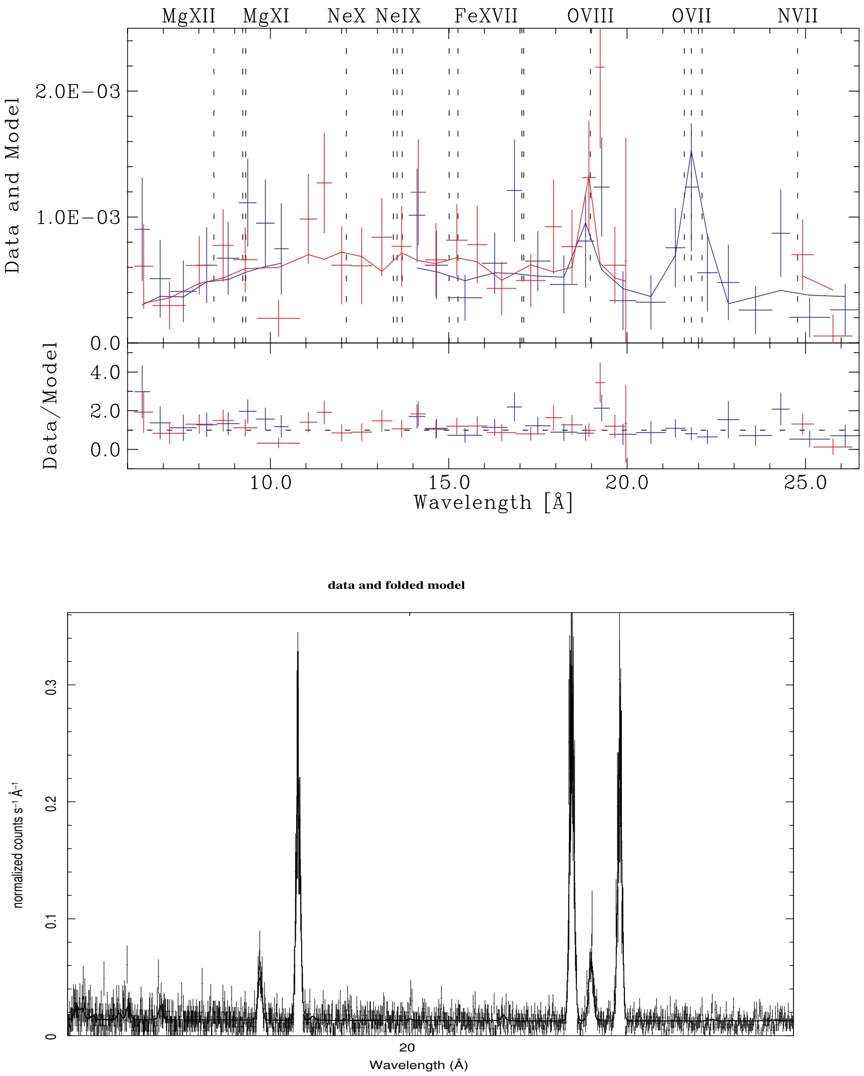

Fig. 3. *Top*: The *XMM-Newton*/RGS spectrum of the faint mCV UU Col in the region of the O VII He-like triplet and the O VIII Ly$_\alpha$. The line intensity ratio indicates a temperature of 0.2 keV. The forbidden, resonance and intercombination line components are difficult to be resolved at these flux levels. *Bottom*: A simulated *IXO*/XGS spectrum of the same source around Oxygen lines using the same exposure time as that of the *XMM-Newton* observation. The spectral parameters used were derived from the fits to the broad-band EPIC spectrum (from de Martino et al. (2006b). Note the improvement in the spectral quality.

Compton reflection component is also detected in the hard X-rays (de Martino et al. 2001), although difficult to constrain (Anzolin et al. 2009). Whether this feature arises from the irradiated WD surface or from the pre-shock material has still to be assessed.

The inclusion of the reflection component also mitigates the problem of high (sometimes unconstrained) shock temperatures as derived from the broad-band analysis. However, most of the coverage above 10 keV lacks of the sensitive range where the Compton reflection continuum peaks. To this regard, the masses as derived using the post-shock maximum temperature are generally biased towards high values (Brunschweiger et al. 2009).

4. Future perspectives in the X-rays

The perspectives of X-ray astronomy are rich of new missions. Approved X-ray missions include both survey and pointed observatories. The *eROSITA* aboard the russian *SRG* is expected to be launched in 2012. It will provide the first imaging survey of the whole sky in the 0.5-10 keV range at a sensitivity $\sim 10^{-13}\, erg\, cm^{-2}\, s^{-1}$. This mission is expected to discover thousands of WD X-ray binaries in our Galaxy and Local Group and hence will provide volume limited samples of different types of WD binaries. Among approved observatory missions, *NuSTAR* will be a focusing high energy (5-80 keV) X-ray mission expected to be launched at the end of 2011 with a sensitivity two orders of magnitude higher than *INTEGRAL*/IBIS. Furthermore the Japanese, *ASTRO-H* mission, expected to be launched in 2013 will uncover the soft and hard x-ray ranges with a sensitivity four times higher than *Chandra*/MEG.

Under study there are several missions, among which the *NHXM*, with large Italian participation, that will cover a broad 0.2-80 keV X-ray range at about twice the sensitivity of *XMM-Newton*. It will also allow first X-ray imaging polarimetry for bright objects that will revolutionize our knowledge of magnetic fields in compact objects. A further mission under study is *LOFT*, with high X-ray timing capabilities over a wide energy range (2-30 keV) and also with a large Italian participation. This will push the time-domain to a few μsec allowing to study in details fast variabilities.

These missions will be pathfinders to the proposed large ESA-NASA *IXO* mission that will uncover a broad energy range from 0.2 keV to 40 keV at an unprecedented sensitivity (twenty-thirty times that of *XMM-Newton*) and will also allow X-ray polarimetry for faint objects. The *IXO* capabilities will allow one to study in great details faint soft-to-hard X-ray sources and hence to perform high resolution and timing spectroscopy over a broad energy range.

For accreting WD binaries, the *IXO* unique capabilities will allow one to study in great details the soft X-ray emission from the hot WD in Novae and Super-Soft X-ray sources up to the Local Group; to infer the accretion flow structures in both non-magnetic and mCVs as well as to infer the details of the iron complex. In non-magnetic WD hard X-ray binaries, the study of the fluorescent Fe K_α line will allow one to measure for the first time the WD gravitational redshifts and hence a direct measure of massive primaries in these systems. The determination of the key parameters, the mass and mass growth, will eventually allow one to identify the true progenitors of type Ia SNe.

Furthermore, for magnetic systems time-resolved spectroscopy will allow to diagnose both post-shock and pre-shock flows above the polar regions. It will be possible to infer the true temperature, velocity and density profiles by using emission lines of different species and ionization states and hence to determine departures from the Aizu model. To show the unique capabilities, a simulated *IXO*/XGS spectrum is shown in Fig. 3 for the faint mCV UU Col using spectral parameters derived from *XMM-Newton* data (de Martino et al. 2006b).

It will be also possible to study in details the reflection component using the fluorescent Fe 6.4 keV line and the Compton reflection continuum via phase-resolved spectroscopy to determine whether this component originates at the WD surface or in the pre-shock flow. In the former case it will help to understand irradiation processes onto the WD atmosphere including the origin of the soft X-ray component in IPs. A further very important aspect is the polarimetry capabilities of *IXO* to detect variable polarized emission in high field mCVs.

All these aspects will be challenges to improve our knowledge of accretion processes onto WD binaries as well as to understand the role of different populations of X-ray binary sources.

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