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A SIMBOL-X view of microquasars

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Abstract. Based on spectral simulations, I show how focusing of the X-ray radiations above 10 keV will open a new window for the study of microquasars. With simulations of soft and hard state spectra of Galactic sources, I discuss how SIMBOL-X can help to precisely measure the spin of black holes. Spectral study on short ~ 1 s time scales will also allow the accretion-ejection connections to be accessed, and the formation of jets possibly witnessed in X-rays. I then turn to external galaxies, and demonstrate that spectral studies of hard sources will be possible up to at least ~ 1 Mpc. For such sources, subtle spectral signatures (e.g. a reflection bump) will clearly be detected. I finally discuss the implications that these original results will bring on the physics of microquasars and black holes.

Key words. Accretion, accretion disks – Black hole physics – X-rays: binaries

1. Introduction

Microquasars are X-ray binaries (XRB) in which ejections of material occur. They, therefore, are powered by the accretion of matter onto a central compact object (either a black hole, BH, or a neutron star). Their behaviour at X-ray energies is not different than the behaviour seen in other XRBs. The jets in those systems can occur under different forms: discrete ejections at speeds close to that of the light (e.g. Mirabel & Rodríguez 1994), or they can form a more compact jet (e.g. Fuchs et al. 2003). The quite short time scales of the accretion and ejection events (as compared to the quasars for example) make them excellent laboratories to study the accretion-ejection connections and the physics underlying those phenomena.

The X-ray spectra of microquasars/XRBs are usually composed of two main components: a thermal one peaking around 1 keV, and a hard X-ray tail (e.g. Remillard & McClintock 2006, for a review). The first is attributed to an accretion disc surrounding the compact object, and fed by the companion star. The latter emission is usually attributed to the inverse Comptonization of the disc photons on a population of hot electrons (thermalized or not), although alternative explanations have recently been proposed (e.g. Markoff, Nowak & Wilms 2005). On top of these main processes, signatures of fluorescent emission from iron around 6.5 keV or refection of hard photons on the accretion disc around 10–50 keV can also be seen.

Precise descriptions of the SIMBOL-X mission and the capabilities of the different instruments can be found in different papers in these proceedings (Ferrando 2007, Pareschi 2007, Laurent 2007, Lechner 2007). To summarize, SIMBOL-X is a formation

Send offprint requests to: J. Rodriguez flight whose payload is made of a single optics module (on the first satellite) focusing the X-rays on two detectors placed 20 m away, one above the second, on the second satellite. They both have spectro-imaging capabilities. It covers the ~0.5 to ~100 keV energy range. In their current versions, the Macro-Pixel Detector (MPD) is the upper detection layer and covers the ~ 0.5–15 keV range, while the lower detection layer the Cd(Zn)Te detector (CZT) covers the ~ 5–100 keV energy ranges. Note that all the simulations presented in this paper were done with the set of response files[1] and scripts provided by the organisers of the conference, under `XSPEC v11.3.2ad`. All spectra have further been rebinned in order not to be oversampled and to obtain a good statistics on each spectral bin.

In this paper, I present some results that will be obtained with SIMBOL-X, concentrating more particularly on points that are only achievable with the focusing of the hard X-rays, and the combination of excellent capabilities from a few tenth of keV to ~ 100 keV: the good angular resolution, extremely low background and high sensitivity of the detectors. In the next section, I study two aspects that will be possible with SIMBOL-X concerning two Galactic microquasars, namely XTE J1550−564 and GRS 1915+105. In the third section, I study the possibility of establishing broad band X-ray spectra of XRBs from external galaxies. All these original results and the physical implications expected from these studies will be discussed in the last part of the paper.

2. Bright sources: microquasars in our own Galaxy

2.1. Introduction on spectral states

Transient microquasars are detected when entering into an outburst. Based on the shape of the spectra, the relative contributions of the emitting media, the level of rapid (< 1 s) variability, the presence and type of quasi-periodic oscillations, one can distinguish several spectral states (e.g. Homan & Belloni 2005; Remillard & McClintock 2006, for precise definitions). Two canonical ones are the Soft State (SS, also referred to as the thermal dominant state) and the hard state (LHS). In the former the X-ray spectra are dominated by the emission from a thermal disc, and the power law tail is soft (its index Γ is usually greater than 2) and has almost no contribution (less than 25% of the total 2–20 keV unabsorbed flux) to the spectrum (for example, in the classification of Remillard & McClintock 2006). In the latter the disc is cold (~ 0.1 keV), its contribution to the 2–20 keV unabsorbed flux less than 20%, and $1.4 < \Gamma < 2.1$. An exponential cut-off is also often observed at energies 20–100 keV.

As these states already correspond to bright phases of an outburst, there is no doubt about the feasibility of their study with SIMBOL-X as exemplified by the huge amount of archival data from any X-Ray satellite that is available today. The great advantage of having a very sensitive telescope above 10 keV brings, however, very interesting possibilities for the study of BHs in particular, as I show below.

2.2. States dominated by the thermal component: the thermal state

It is thought than during the SS, the disc is a "pure" α-disc, and that it reaches the last stable orbit around the BH. Hence if we are able to measure its value, we will be able to access the spin of the BH which is a key parameter to the understanding of those objects. While at first sight current observatories (e.g. RXTE, INTEGRAL, Chandra or XMM-Newton) may be able to do it, they either lack sufficient sensitivity at soft X-rays (RXTE, INTEGRAL) or lack hard X-ray telescopes (XMM, Chandra). A recent controversy on the value of the spin of GRS 1915+105 (McClintock et al. 2006; Middleton et al. 2006) has shown how important is the identification of "pure" α-disc states.

The advantage of SIMBOL-X over XMM-Newton or Chandra (besides the high degree

[1] MPD_Ref2.rmf and MPD_TB_200_OA0.arf for the soft X-ray detector MPD, and CZT_Ref2.rmf and CZT_TB_200_OA0.arf for the hard X-ray detector CZT.

of pileup in those instruments) is the wider energy coverage. Indeed to precisely access the parameters of the disc component during the SS, precise estimates of the power law parameters are needed to avoid as much as possible mixing of the two components. This is done by extending the energy range to a domain where the disc emission is completely negligible, i.e. above ~20 keV, and by detecting the faintest tails.

To perform the feasibility of such a study and its pertinence I used the published parameters of a SS of the microquasar XTE J1550−564 during its 1998 outburst (Sobczak et al. 1999), as seen with RXTE. This observation took place on November 4^{th}, 1998. It was choosen because the spectrum was so soft (the disc accounted for 92% of the total 2–20 keV flux) that the source was not detected above 20 keV with RXTE/HEXTE (Sobczak et al. 1999).

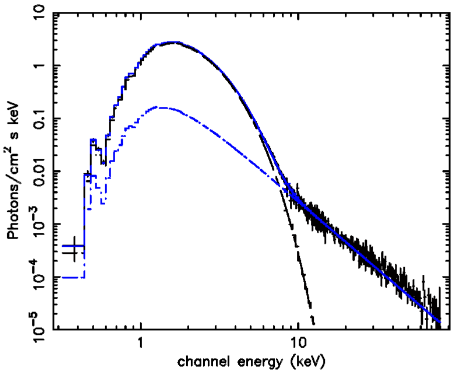

Fig. 1. 1 ks simulated MPD+CZT photon spectrum of XTE J1550−564 during a SS. The best fitted model is superposed as a line, while the individual components are represented with a dash-dotted line.

Fig. 1 shows the MPD and CZT spectra simulated with an accumulation time of 1 ks. The source is clearly detected up to 80 keV. Further simulations showed that it was even detected when accumulating the spectra on 100 s only. The best fit model is superposed to the spectra. It consists of a disc component, a power law and an iron emission line modified by interstellar absorption. All these components are required to obtain a good fit. The iron edge component that was input in the simulation is, however, not required in the fit. All other spectral parameters are compatible with those reported in Sobczak et al. (1999), and even more precise. In particular the photon index is $2.41^{+0.03}_{-0.04}$ (vs. 2.36±0.06 with RXTE) and the disc radius R_{in} = 46.3 ± 0.2 km (vs. 46.4±0.6 km). The fit on a broader band spectrum helped in increasing the precision of the spectral parameters.

2.3. Rapid X-ray variations: the possibility of spectral studies on a second time scale

Systematic multi wavelength monitorings of microquasars in outburst have revealed a clear but complex association between the accretion seen at X- and Gamma-ray energies, and the jets seen in radio/infra red. This has first been seen in GRS 1915+105 (e.g. Mirabel et al. 1998), with ejections of ¨bubbles¨following sequences of dips terminated by spikes at X-ray energies. This result has recently been generalised: in GRS 1915+105 ejections of ¨bubbles¨will always occur provided a sequence of a hard X-ray dip (i.e. a dip during which the X-ray spectrum is dominated by the power law tail, and the disc is cold) of a duration longer than 100 s ended by a short spike takes place (Rodriguez et al. 2006, 2007a). Such sequences are dubbed ”cycles” due to their repeated occurences. Rodriguez et al. (2006, 2007b) have suggested, based on a spectral analysis of these sequences, that the ejected material was the corona. While their analysis makes use of data above 20 keV for the first time, they accumulated spectra over times on which the source spectrum may evolve, typically tens of second.

SIMBOL-X spectra were simulated using the parameters obtained by Rodriguez et al. (2006) from their INTEGRAL observations at two moments during a cycle as illustrated in Fig. 2 left panel. The integration time of the simulations were 1 s for each spectra. The

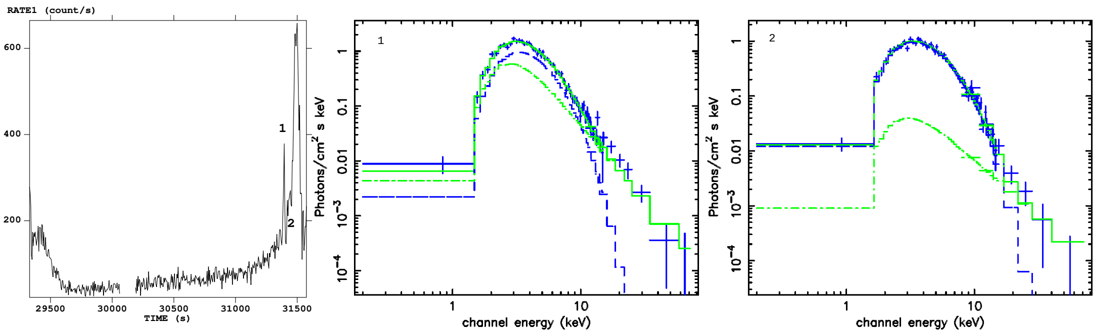

Fig. 2. Left: 3–13 keV (JEM-X) light curve of GRS 1915+105 dip-spike during a cycle. **Middle:** 1 s MPD+CZT photon spectra of the peak labeled 1 in the left panel. **Right:** Same as in the middle panel for the dip labeled 2 in the left panel. In both latter cases the best fit model and individual components are superposed as lines.

spectra were fitted with simple a model of a thermal disc and a powerlaw modified by absoprtion. The spectral fits to those spectra yielded $kT_{disc} = 1.48\pm0.09$ keV, and $R_{in} = 380\pm60$ km Γ=2.8±0.4 at moment 1,and $kT_{disk} = 1.74 \pm 0.07$ keV, $R_{in} = 255^{+40}_{-12}$ km, and $\Gamma = 2.1 \pm 1.2$ at moment 2. In addition during moment 1 the fluxes of the infdividual components followed $F_{disc}^{1-100keV} \sim F_{pl}^{1-100keV}$, while in moment 2, $F_{disc}^{1-100keV} \sim 10\times F_{pl}^{1-100keV}$.

3. XRBs in external galaxies

With the advent of high imaging resolution and high sensitivity X-ray telescopes, such as XMM-Newton and Chandra, many XRBs have aso been detected in other Galaxies, and their Soft X-ray (0.1–10 keV) spectral behaviour studied. The limited energy range has, however, hampered a complete study of state changes in those sources, and therefore has limited the study of the interplay between the different emitting media in sources found in other Galaxies. This topics is more developped in other papers in these proceedings, especially from the imaging point of view. I briefly show here what importance can have a very sensitive hard X-ray detector, and assume that the simulated source does not suffer from confusion with other sources. Here again X-ray telescopes as Chandra and XMM-Newton have shown that many XRBs (and other ultra luminous X-ray sources) wer active in other Galaxies. Being sensitive in the soft X-rays, however, they detected mostly sources that have their bulk of energy in that band (i.e. under 10 keV) or that are very bright. In addition to continue to study those, SIMBOL-X will allow us to study sources that have their bulk of emission above 10 keV (in the LHS for example), allowing us to precisely follow spectral state changes, better characterise source population by adding the less luminous sources to the populations, and either discover intrinsically absorbed sources in external galaxies.

Rather than just a $3-\sigma$ detection (over the whole energy range of SIMBOL-X) I tried to see until approximately what distance a decent spectrum could be obtained. To do so I used spectral parameters similar to those of XTE J1550−564 while in the LHS as seen during its 2000 outburst (Rodriguez et al. 2003), i.e. a cutoff powerlaw with $\Gamma = 1.49$ and a cut-off at 33.8 keV for an intrinsic 0.1–100 keV luminosity of 7×10^{37} erg cm^{-2} s^{-1}. The spectra were simulated at two typical distances and absorption columns, that of LMC (at 50 kpc, $N_H = 0.682\times1021$ cm^{-2}) and that of M33 (795 kpc, $N_H = 0.558\times1021$ cm^{-2}), for respective integration times of 10 ks for the former and 50 ks for the latter.

Fig. 3 shows the result in the case of the M33 source. While fitting the joint MPD+CZT spectrum with a simple absorbed power law

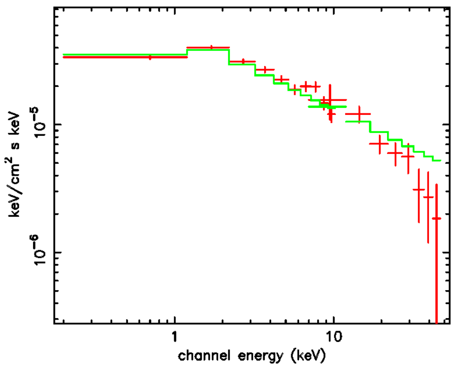

Fig. 3. 50 ks joint MPD+CZT spectrum of a LHS source in M33. The lines represent a simple absorbed power law model. A significant deviation with the spectrum can be seen above ∼ 20 keV.

shows residual above ∼ 20 keV, adding a cutoff improves the fit significantly. An F-test indicates a chance probability of 5 × 10–5. The spectral parameters are quite accurate and close to the feed parameter for the simulation: $N_H = 0.050.02 \times 10^{22}$ cm^{-2}, $E_{cut} = 33^{+24}_{-10}$ keV, and $\Gamma = 1.5 \pm 0.1$. Beside the detection of hard sources, the detection of a spectral break in the energy spectrum of an external XRB will be the first.

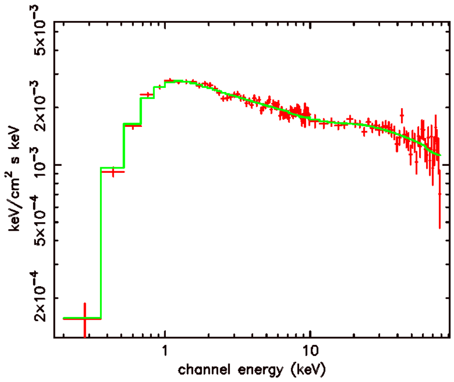

Fig. 4. 10 ks joint MPD+CZT spectrum of a LHS source in the LMC, with a reflection feature. The reflection bump at ∼ 20 keV is obvious.

The last point and the important constraints on the models of emission led me to study whether or not more subtle features visible in the X-ray spectra above 10 keV will be seen with SIMBOL-X in external galaxies. I simulated a 10 ks exposure Cyg X–1 like spectrum for a source in the LMC (thermal Comptonisation with kT_{inj} = 0.2 keV, kT_e = 67 keV, and reflection with a scaling factor 0.25, for a 0.1–100 keV flux of ∼ 2.3 × 10–10 erg cm^{-2} s^{-1}). The joint MPD+CZT simulated spectrum and the best fit model is reported in Fig. 4. A simple absorbed Comptonised component represents the spectrum rather well, although some deviation in the 15–30 keV region can be seen. Adding a reflection component improves the fits with an F-Test probability of 8×10^{-9} chance improvement. The fitted parameters are close to the feed parameters of the simulation with N_H = 0.05 ± 0.02 × 10^{22} cm^{-2} a reflection coefficient of 0.22 ± 0.06, $kT_{inj} = 0.21^{+0.03}_{-0.02}$ keV, $kT_e = 59.51^{+13}_{-9}$ keV. The reflection bump is evident in the spectrum (Fig. 4).

4. Conclusions

The great advantage of SIMBOL-X compared to the current X-ray satellites is that in addition it couples excellent spectro-imaging capabilities below and above 10 keV. As I showed in the previous sections, this will allow us to access some physics of accreting compact objects that is still subject to debate, poorly known or that has even never been studied so far.

- The detection of very weak corona during the SS in Galactic sources, will enable us to obtain the most accurate possible spectral parameters for the accretion disk, and hence access one of the key physical parameters for a BH: its spin. The actual controversy, examplified by the case of GRS 1915+105 (Middleton et al. 2006; McClintock et al. 2006), shows how crucial the determination of the disc parameters is.
- The possibility of performing time resolved spectroscopy on short (∼ 1 s)

time scale will permit us to precisely follow the evolution of the source immediately after the jet has been launched in GRS 1915+105 like sources. We may thus witness the formation of the ejecta at X-ray energies. Such sources present the great advantage to vary very rapidely, and show repeated occurences of accretion-ejection linked processes. Hence, the chance of observing such phenomena is greater than in any other sources.

– In the case of external galaxies, a completely new window will be opened. By detecting hard sources, non-biased population study will be rendered possible. As showed here it should be possible to precisely characterise the spectral state up to about 1 Mpc using the $>$ 10 keV domain for the first time.
– The possibility of performing phenomenological as well as physical fits will allow us to access the physics of accreting sources in other galaxies, in order to know whether they show similar behviour than in our Galaxy (e.g. outbursting sources), and search for possible relations with the type of the galaxy.
– Studying BH in other galaxies will also increase the number of such sources (only 20 are confirmed BH in our Galaxy Remillard & McClintock (2006)) which will help us constrain the physics of accretion, and that of BHs.

Clearly SIMBOL-X will have a major role in future studies of accreting-ejecting objects. By opening a complete new window in the hard X-rays, it will allow us to answer key questions on BHs, but also on the physics of accretion and its link with the ejections. Precise population studies will be possible while unveiling sources that are faint below 10 keV and emit their bulk of emission above 10 keV. Additionally the hard X-rays emitted by quiescent Galactic sources will also be accessed for the first time, with great implication for the emission models, and sources evolution through outbursts.

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