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Transient neutron star X–ray binaries with Simbol-X

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Abstract. We present a brief overview of test-bed observations on accreting neutron star binaries for the Simbol-X mission. We show that Simbol-X will provide unique observations able to disclose the physical mechanisms responsible for their high energy emission.

Key words. Accretion, accretion disks — Stars: neutron

1. Introduction

Low mass X–ray binaries (LMXBs) are binary systems composed by a compact object (here we consider only neutron stars, NS) and a low mass companion. These systems are the brightest X–ray emitters in the Galaxy, mainly distributed in the central regions and in the galactic bulge. These sources come in two different flavours. There are persistent sources which shine at a steady (but variable) luminosity in the 10^{36} – 10^{38} erg s^{-1} range and transient sources which alternate intervals (lasting weeks to months) during which they rival in brightness with persistent sources to longer (years to decades) quiescent periods (characterized by luminosities 10^{32} – 10^{33} erg s^{-1}).

Bright persistent sources are variable on short timescales, with variation by a factor of a few on a daily timescale. Historically, in an X–ray color-color diagram they trace out either a Z (Z sources) or a C pattern (atoll sources, see van der Klis 1995 for a review). Z sources are the brightest NS X-ray binaries, do not show (Type I) X–ray bursts and display strong quasi-periodic oscillations (QPOs). Atoll sources are dim by a factor of $\lesssim 10$, show X–ray bursts and display less intense QPOs. Transient NS binaries when in outburst show properties very similar to atoll sources.

The overall spectra of Z sources are soft (Barret & Olive 2002, and references therein) and can be described by the sum of a cool (~ 1 keV) black body and a Comptonized emission from an electron plasma (corona) of a few keV. Instead, atoll sources undergo strong spectral changes: when bright, they can have soft spectra (similar to Z sources) but they switch to low/hard spectra at low luminosities (Barret & Vedrenne 1994). Observationally, the soft and hard spectra of atoll sources are very different in the hard X–ray energy band: the ratio between the hard (13–80 keV) to the soft luminosity (2–10 keV) may increase by a factor of $\sim$ 10 (van Paradijs & van der Klis 1994, see Fig. 1). Further studies showed that there exists a limiting luminosity at which this change occurs, around a level of $\sim 4 \times 10^{36}$ erg s^{-1}, and this spectral change is also common to black hole binaries (Maccarone 2003). Observationally, the Componized emis-

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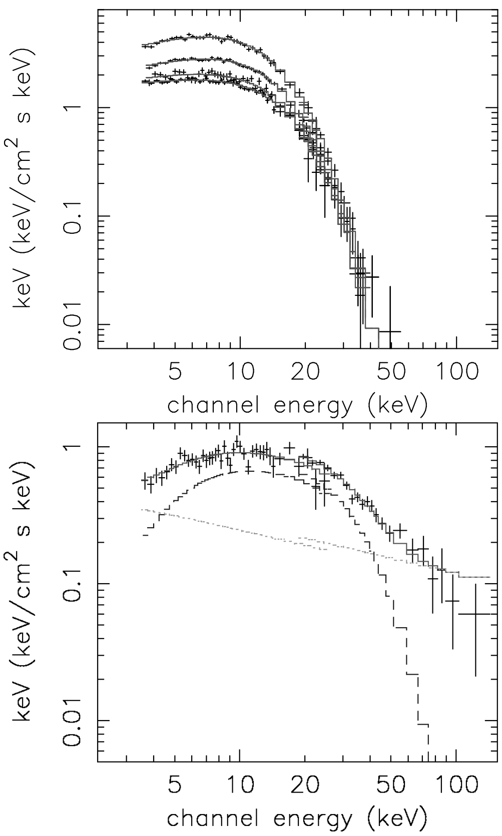

Fig. 1. Data and models of the soft spectra (top) and the hard spectrum (bottom) of 4U 1820–30 as observed by INTEGRAL during 2003-2005. The spectra were fitted by thermal Comptonization models without and with a power law component, respectively (taken from Tarana et al. 2007).

sion changes from a few keV in the soft state to a few tens of keV in the hard state.

Hard tails were historically observed also in Z sources, but only sporadically. The first detection was in the spectrum of Sco X-1 dominating the above 40 keV (Peterson & Jacobson 1966). More recently the presence of a variable hard tail in Sco X-1 was confirmed by OSSE and RXTE observations (Strickman & Barret 2000; D'Amico et al. 2001). BeppoSAX and INTEGRAL observations led to much progresses in this field. A hard component has been observed in several Z sources (see Di Salvo & Stella 2002; Paizis et al. 2006) indicating that this is a common feature. This hard component, fitted by a power law with photon index in the range 1.9-3.3, contributes up to 10% to the source bolometric luminosity.

A further step in the understanding the LMXB hard tails is provided by radio studies. A coupling between (hard) X–rays and radio properties of NS LMXBs has been proven to exist (Migliari & Fender 2006; Migliari et al. 2007). This can be seen in Fig. 2, showing the coupling between the radio jet emission and the position in the X–ray hardness-intensity diagram. In addition, a positive correlation between the radio flux density and the X–ray flux in the hard-tail power law component has been found. These observations were interpreted as evidence for the formation of a radio jet associated with the Flaring Branch-to-Normal Branch X–ray state transition in the Z pattern (Migliari et al. 2007).

A close parallel between NS and black hole transients exists based on the connection between radio and hard X–ray emission. Black hole transients are better studied with a detection of A0620-00 at an X–ray luminosities as low as $10^{-8.5}$ times the Eddington limit (Gallo et al. 2006). These observations favour a model for quiescence in which a radiatively inefficient outflow accounts for a sizable fraction of the missing energy. This has not proven to be true in NS transient yet. NS transients in quiescence are characterized by X–ray spectra made by a soft component (interpreted as emission coming from the cooling of the neutron star atmosphere) and a power law tail (not present in all systems and accounting for up to 50% of the flux) of unknown origin (e.g. Campana 2001). In addition, in some well studied sources this tail has been shown to undergo substantial variations of unknown origin (Campana & Stella 2003).

In the last few years it has become clear that the quiescent spectra of NS transients containing an accreting ms X–ray pulsar during outburst (e.g. SAX J1808.4–3658 and similar sources) lack of the soft component, being a dimmer (~ 10) and showing only a power law tail (Campana et al. 2004a; Wijnands et al. 2005; Heinke et al. 2007). The physical na-

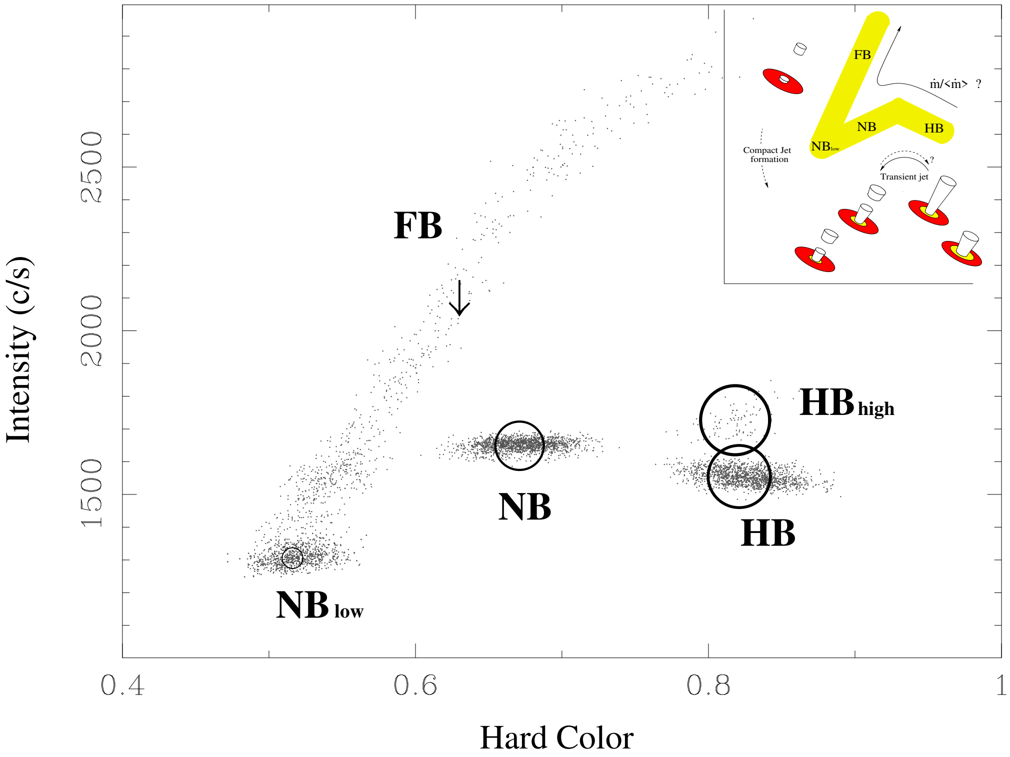

Fig. 2. Hardness intensity diagram of GX 17+2 (main panel), with a sketch of the jet/X-ray state coupling (top-right panel) to include the formation of a compact jet at the FB-to-NB transition. In the main panel, the gray dots represent the HID of 16 s of observation. The open circles indicate the mean radio flux density of the source observed in the different branches: the bigger the circle, the higher the observed radio flux density. The arrow in the FB indicates an upper limit on the radio flux density. The radio emission is strongest in the HB_{high} and, following the HID track, decreases towards the NB_{low}, until it is not detectable anymore in the FB (from Migliari et al. 2007).

ture of these tails is basically unknown (see Campana et al. 1998 for some possibilities).

2. Simbol-X on the scene

Simbol-X will produce a revolution in the hard X–ray research field. Simbol-X will disclose the faint population of hard X–ray sources as the Einstein satellite did in the soft energy band, following the Uhuru satellite. The main characteristics of Simbol-X are:

- the broad band capabilities with an effective energy range of 0.5–80 keV and possibly up to 100 keV;
- the very large effective area at low (rivaling with XMM-Newton) and high energies;
- a good timing capabilities without problems of pile-up and/or storage problems, allowing for long observations of $\sim$ 0.5 Crab sources;
- a very low background allowing for the detection and study of very dim sources.

3. Simbol-X and compact objects

In order to assess the potentialities of the Simbol-X mission we consider here a few test cases.

3.1. Study of hard tails in persistent neutron star sources

We consider first an atoll source with an 0.5–20 keV X–ray flux of 10^{-9} erg cm^{-2} s^{-1} (i.e. about 60 mCrab), being a typical source of $\sim 10^{37}$ erg s^{-1}, at the Galactic center distance. The source spectrum can be recovered extremly well even in 5 ks observation (see Fig. 3). The plasma temperature and optical depth can be obtained with a 90% error of $\sim 5\%$. These numbers testify for the extreme spectral accuracy that can be obtained and open the window of the study of spectral variability looking directly at the physical parameters of the models.

Furthermore, we simulate the addition of a very faint hard tail in the spectrum of a bright Z source. For a source flux we took 2×10^{-9} erg cm^{-2} s^{-1} (i.e. about 120 mCrab) and for the tail we took a flux of 6×10^{-12} erg cm^{-2} s^{-1}, i.e. 0.1% of the main flux. Even at this faint level, the tail can be recovered in a 40 ks observation. Observations of Z sources can therefore shed light on the presence of these tails and on their evolution as the source moves along the color-color diagram.

3.2. Study of hard tails in quiescent neutron star sources

In order to exploit the Simbol-X capabilities we address here the study of the hard energy tails in quiescent LMXB transients. These sources have received a boost of interest after Chandra and XMM-Newton, the first two instruments able to provide detailed spectral information at these low quiescent fluxes.

Recent data show that these hard tails are not present in all transient sources in quiescence. Their overall behaviour shows a hint of an anti-correlation of the hard tail luminosity with the total quiescent luminosity, even if more data are needed (Jonker et al. 2004). In addition, works on the brightest sources have shown that spectral changes are occurring in quiescence and these can be (also) interpreted as variations in the hard tail (Rutledge et al. 2001; Campana & Stella 2003).

We simulated the quiescent spectrum of the well known transient Aql X-1. The source is well detected up to 80 keV in a 100 ks observation. This will allow us to search for spectral variability on a shorter timescale at low (as already observed in Cen X-4, Campana et al. 2004b) and high energies. In addition, we can gain insight on the presence of a high energy cutoff, opening the possibility of a physical characterization of these tails.

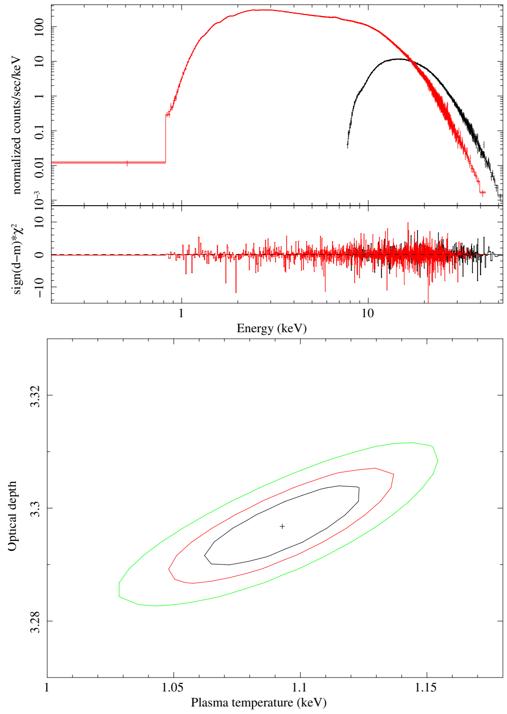

Fig. 3. Simulated spectrum of a typical atoll source as observed with Simbol-X. The upper figure shows the simulated spectrum for 5 ks exposure and for a source flux of 10^{-9} erg cm^{-2} s^{-1} (0.5–20 keV). The lower figure shows the countour plot of the plasma temperature and the optical depth of the best fit spectrum, highlighting the very small errors on these parameters.

We also investigated the observability of the hard tail in the SAX J1808.4–3658. The best fit quiescent spectrum comes from a deep XMM-Newton observation, confirming the hardness of the spectrum (photon index $\Gamma = 1.8$, Heinke et al. 2007). In a 100 ks exposure we can have a detection up to 50 keV (as well as an extremely detailed spectrum at low energies and the possibility to search for

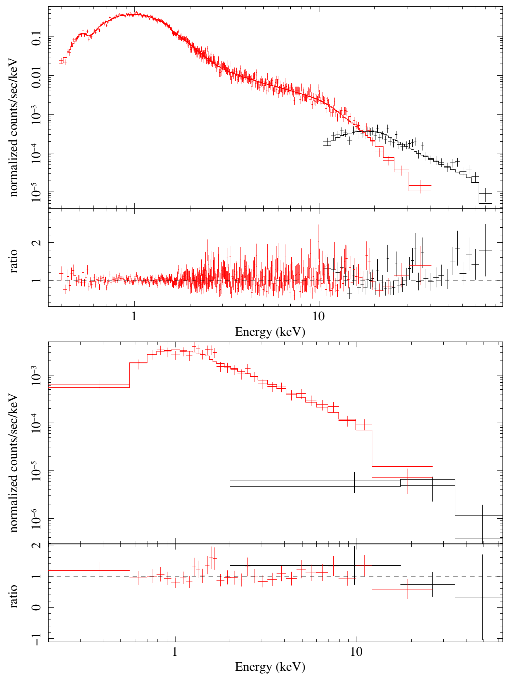

Fig. 4. Upper panel: simulated spectrum of Aql X-1 in quiescence as observed by Simbol-X with 100 ks exposure. Lower panel: simulated spectrum of SAX J1808.4–3658 as observed by Simbol-X in 100 ks assuming as template the XMM-Newton spectrum.

X–ray pulsations in quiescence). As above, this extension in energy band can lead us to a better understanding of the physics of these sources.

4. Conclusions

Simbol-X is the first observatory able to disclose the high energy part of the spectrum at very high S/N and for persistent and transient sources, making possible a thorough study of the emission mechanisms through monitoring the variability.

Different mechanisms for explaining the transition to and the quiescent emission of NS X–ray transient have been proposed. Simbol-X observation will allow us to approach the problem from the point of view of physics.

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