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High Energy behaviour of Neutron Star Low Mass X-ray binary systems

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We report on the study of the high energy emission of Neutron Stars in Low Mass X-ray Binary systems performed with INTEGRAL. We aim to study of the subclasses of the Atoll, Bursting sources selecting a sample of NS LMXBs in the Galactic Bulge: 4U 1608-522, 4U 1728-34, 4U 1722-30, 4U 1254-690, 4U 1820-30, 4U 1812-12 and XB 1832-330. The X and Gamma behaviour of the sources has been monitored through construction of light curves in different energy bands, then the hardness-intesity diagrams have been constructed, and finally we performed a fine spectral extraction to discern the physical parameters dominating the spectral variations. The deep survey of a large sample of sources of this class allowed to re-constructed the "Bursters Box", for all the source-spectral states detected, comparing the source luminosity in the energy bands 4-20 keV with the 20-200 keV ones. This allows to compare amongst themselves the sources sample.

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1. Introduction

A criterion to distinguish the black hole (BH) or neutron star (NS) nature of the compact object of the X-ray Binaries has been searched since ever. The optical observation and the *mass function* estimation represent the *sure* method to identify the nature of the compact star. Unluckily, it is only rarely possible to apply the optical method to the Galactic Binaries, especially for the Low Mass type most of which being located in the Galactic Bulge.

Before the *SIGMA* mission ($\sim$ 1990') it was suggested that the presence of the extension of the spectra in the high energy range was indicative of a BH nature for compact object. Later on, it was shown by Barret & Vedrenne (1994) [1] that also NS emit up to 100-200 keV in their hard state, demonstrating that the use of a high energy emission criterion alone was not valid as possible means of discriminating between BH and NS systems.

Barret et al. 1996, 2000, proposed a "luminosity criterion" to distinguish BH and NS systems. They measured the 1-20 keV and 20-200 keV luminosity of a sample of NS and BH systems (optically proved), showing that the X-ray Bursters are clustered in the *X-ray Bursters Box* at low luminosities ranges with respect to the BH systems [2] [3]

Later on it was noticed from the broad band spectral shape of the X-ray binaries that the electron temperature of the corona appeared to be systematically lower for the NS systems than for BHs ($kT_{\rm e} \leq$ 30 keV vs $\geq$ 50 keV) and this signature was suggested as possible parameter to distinguish the nature of the compact object [4] [5] [6].

The observations of NS LMXBs in the hard X-ray band with *BeppoSAX* and *RXTE* satellites and now with *INTEGRAL*, reject these criteria. In fact the observations show that the X-ray spectral parameters and shape, are similar for NS and BH candidate binaries. Moreover the detection of hard X-ray tail and high energy emission from the NS systems also, shows that the "luminosity criterion" is difficult to be applied.

The present work confirms that the NS system are high energy emitters with spectra extending above 100 keV, and their spectral state (especially the Hard state) are similar to the BH ones.

2. The bursters sample

During the last years we studied the high energy emission from a selected sample of Neutron Star Low Mass X-ray Binaries (NS LMXBs) with *INTEGRAL* data. The sample is composed by bursters and atoll with different characteristics, most of them are located in Globular Cluster, some are transients and some are persistents: 4U 1608–522, GX 354–0, 4U 1722–30, 4U 1820–30, 4U 1812–12, XB 1832–330 and also 4U 1254–690. Each source was analysed and studied individually in the past years and now we compare their behaviour through the luminosity characterizing each observed spectral state.

3. Behaviour of the sources

The sources 4U 1812–12, XB 1832–330 [7] and 4U 1254–690 [8] showed a persistent flux with a low level of variability ($<$ 25%) and without any spectral changes. In particular, 4U 1812–12 has been detected only in the Hard state up to now [9].

On the contrary we detected spectral changes from the sources 4U 1820–30 [10], 4U 1608–522 [11], 4U 1728–34 [12] and 4U 1722–30 [13]. These changes are associated to transient phenomena for two of them, with spectral hardening and softening occurring in a short time; the other ones showed continuum emission with high flux variations coupled to spectral transitions. In particular for the source 4U 1820-30 was detected for the first time an high energy emission characterized by the presence of a hard tail extended above 50 keV, during the hard state. This hard tail could be produced by a synchrotron emission correlated with radio emission from a jet, or more probably, by a thermal and also non-thermal comptonization emission [10]

4. Luminosity diagram

We derived the flux values from the best fit models of each sources state detected in two energy bands: the *soft*, 4-10 keV, and the *hard*, 20-200 keV. We estimated the luminosity in these two energy bands using the distances reported in the literature, giving priority to the values derived from burst with photospheric radius expansion whenever possible.

Figure 1 shows the luminosity diagram in the two energy bands for all the sources spectral-states.

Comparing the luminosity among different spectral states show the position in different zones. The Soft states are all localized at $L_{soft} > 6 \times 10^{36}$ erg s^{-1} and $L_{hard} < 1.4 \times 10^{36}$ erg s^{-1} (blue boxes). On the contrary the Hard states are located all at $L_{soft} < 6 \times 10^{36}$ erg s^{-1} and $L_{hard} > 0.7 \times 10^{36}$ erg s^{-1} (orange and red boxes). The Intermediate states observed are located between the Soft and Hard states. By the closeness to the Soft state group or the Hard group we could say that the Intermediate state is associated more to a group than to the other one. As examples, the Intermediate state of 4U 1722–30 and 4U 1728–34 is more similar to the Hard state, while the Intermediate state of 4U 1608–522 to the Soft state group.

The Luminosity diagram seems to be a good clue to characterize the Soft or Hard nature of the source spectral states.

We indicate with red boxes the Hard states with the power law tail i.e. with an electron population with hybrid thermal and not thermal velocity distribution. These correspond to high value of L_{soft}, $\simeq 5 \times 10^{36}$ erg s^{-1} and to the highest value of L_{hard}, $> 4 \times 10^{36}$ erg s^{-1}.

We investigated the existence of a different luminosity correlation between Soft and Hard states using the Luminosity ratio $R = L_{soft}/L_{hard}$. R values ranges from 7.2 to 56.5 for the Soft states, while for the Hard states R values are in the range to 0.45 to 3.64.

With respect to the Burster Box reported by Barret et al. 2000 [3], our diagram has in addition the information of the spectral changes, being the luminosities not an averaged value but computed for the different spectral states detected from the same source. The sources in our sample also indicate the existence of a critical value for L_{hard} below which the NS systems are positioned in the Bursters Box as reported by Barret et al. 2000 (L_{crit} 1.5×10^{37} erg s^{-1}).

5. Sample observed spectral states

The performed spectral analysis can be summarized with the existence of three types of spectral states for the Atoll sources: Soft, Hard and Intermediate state.

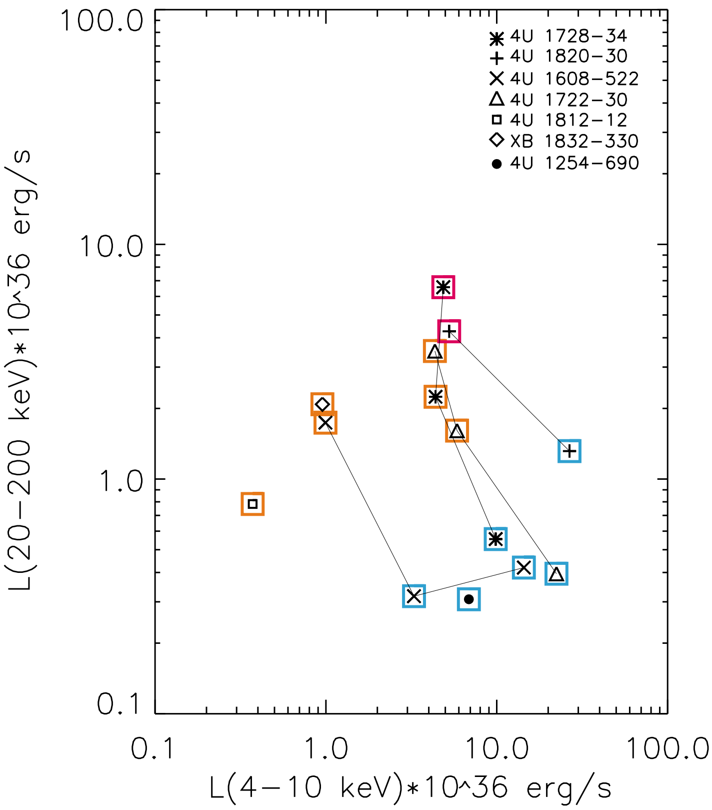

Figure 1: Luminosity diagram of the source sample analysed. For each source it is shown the spectral states detected, joined with a line for the same source. The blue boxes show the Soft states, the orange one the Hard states and with red boxes the Hard state with hard power law tail. The Intermediate states belong to the nearing spectral state-group.

5.1 Soft state

This state (also called "banana" state) is characterised by a strong black body component with temperature of 0.4-0.6 keV plus a Comptonized component with a low electron temperature ranging from 2 to 5 keV and high optical depth of 2-9. The input photons of the Comptonization have a temperature of 0.2.-1.2 keV.

The Soft state of transient sources is characterized by a stronger soft component compared to that of the other persistent sources (as example 4U 1608–522 compared to 4U 1254–690). This could be explained by the high flux level reached during the outburst (high luminosity) that implies higher accretion rate and, in turn, high luminosity.

5.2 Hard state

The soft black body component during the Hard state (also known as "island" state) is of lower intensity and in some cases is not even detected. The Comptonizing corona shows a higher electron temperature (6-60 keV) and a lower value of the optical depth (0.4-3) than the soft state ones.

The *main results of this paper* is that the Hard states show two different type of behaviour:

In the first one, the corona temperature is high and the spectra extends up to 200 keV, and in some cases without a clear high energy cut-off (as for 4U 1608–522 and 4U 1722–30).

In the second one, the corona has a lower temperature and the Comptonization component contributes to the spectrum up to 50-60 keV, while at higher energy a hard power law with photon index of 2-2.3 dominates (as for 4U 1820–30 and 4U 1728–34). In this last case, the Hard state could be also interpreted as a Comptonization with a hybrid thermal-nonthermal plasma with high temperature (20-30 keV), and a power law at higher energy ($>$50 keV).

5.3 Intermediate state

These is the state in which sources spend a short time just in coincidence with a spectral state transition. Only a detailed spectral analysis correlated with a photometric and temporal study makes possible to detect these kind of short time behaviour and spectra.

The spectral parameters have intermediate values between the Soft and Hard ones. Nevertheless, it is possible to understand when it is Soft-like or Hard-like by the comparison with the values of the parameters for the two main states.

6. Physical interpretation

From our analysis it is clear that there is a strong variation in the spectral shape between the island and banana states of the Atoll sources, probably due to changes in the accretion flow geometry and coupled with variations in the mass accretion rate.

In spite of the difficulty to precisely determine the soft parameters because of the used limited instrumentation band-width (often available only for E$>$ 4 keV), we can still draw some remarks and explanations.

The observed "soft component" is modelled either by the `diskbb` or by `bbody` emission, and we don't manage to discern the origin of this component that could be originate either in the optically thick and geometrically thin accretion disk or NS surface or optically thick boundary layer between the disk and the NS (i.e. western or eastern model). In general we privilege the accretion disk emission origin.

The input seed photons necessary for the Comptonization process could in general have the same origin of the soft photons. This hypothesis is not confirmed by us since we never observed the same temperature value, suggesting a different origin for the seed photons.

During the Hard state the observed disk black body emission is either not detected or has a low temperature value compared to that of the Soft state. This implies a larger extension of the inner radius of the accretion disk, as $R_{\rm in} \propto T^{-3/4}$ [14]. The input seed photons have higher temperature compared to the inner disk temperature implying a smaller emission region. As a consequence they could originate from the NS surface or from the inner part of the disk such as the optically thick boundary layer[14] . The seed photons interact in a hot and optically thin plasma supposed to be around or inside the extended accretion disk, and causing the high energy Comptonized component observed in our sample.

During the Soft state the disk extends downwards to the NS surface as showed by the high values of the inner disk temperature observed e.g. in 4U 1608-522 ($R_{\rm in}$ changes from 20 km during the soft state to 120 km during the hard state) [11]. In this case, Comptonization takes place in an optically thick cold plasma and the seed photons have a low temperature and could originate from the outer part of the disk. Because of the extension of the disk close to the NS, the boundary layer is optically thick and could be the region that gives rise to the Comptonization.

The Hard and Soft states observed in our sample correspond to various ratios of Luminosity to the Eddington Luminosity. In fact, calculating the bolometric luminosity of each source (see the corresponding reference for each source) the L/L_{Edd} ranges from 0.01 (for 4U 1812–12) to 0.9 (for 4U 1722-30 in Soft state), as expected for the Atoll sources (assuming a L_{Edd} of 1.9×10^{38} erg s^{-1} for a NS of $1.4M_{\odot}$). Moreover this ratio decreases from the Soft to the Hard states, implying changes in the mass accretion rates.

All these informations are clues that the spectral behaviour between the NS systems and BH system are very similar, especially in the Hard state during which high temperatures of the corona are detected and the spectra extends up to 200 keV. This confirms that the "corona temperature" method is not a valid tool to discern from BH and NS systems.

References

[1] Barret, D. & Vedrenne, G. ApJSS 92, 505, 1994.

[2] Barret, D., McClintock, J. E., & Grindlay, J. E. 1996, ApJ, 473, 963

[3] Barret, D., Olive, J. F., Boirin, L., Done, C., Skinner, G. K., & Grindlay, J. E. 2000, ApJ, 533, 329

[4] Tavani M. & Barret D. AIP 410, 75, 1997

[5] Zdzdiarski A. A., et al. MNRAS 301, 435, 1998

[6] Churazov E., et al. Adv Space Res. 19, 55, 1997

[7] Tarana, A., Bazzano, A., Ubertini, P. et al. 2006, ESA SP, 622

[8] Tarana, A. et al. proceeding of the 'The Extreme Universe in the Suzaku Era' Kyoto, Japan, 2006

[9] Tarana, A., Bazzano, A., Ubertini, P., Cocchi, M., Götz, D., Capitanio, F., Bird, A. J., Fiocchi, M. 2006 A&A 448, 335

[10] Tarana A., Bazzano B., Ubertini P. & Zdziarski A.A., ApJ 654, 494, 2007

[11] Tarana A., Bazzano A., Ubertini P., ApJ 688, 1295, 2008.

[12] Tarana A., Belloni T., Homan J., Mendez M., Bazzano A., Ubertini P. in preparation.

[13] Tarana A., Bazzano A., Ubertini P. proceeding of "The X-ray Universe" Granada, Spain, 2008.

[14] Frank J., King A.R., Raine D.J., *Accretion power in astrophysics*, Cambridge University Press, Cambridge