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INTEGRAL long term monitoring of 4U 1722–30: evidence for spectral state variations

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We report on the 2003-2005 *INTEGRAL* observations of the Neutron Star Low Mass X-ray Binary 4U 1722–30 (also known as GRS 1724–30) located in the Globular Cluster Terzan 2. The JEM-X and IBIS light curves show the source with a persistent yet variable flux. The Hardness-Intensity diagrams highlight the behaviour of a typical Atoll source: 4U 1722–30 repeatedly moves in the diagrams from the Banana (Soft state) to the Island (Hard state). We report on the detailed spectral analysis of Soft and Hard states and, for the first time, also of an Intermediate state. The Hard spectra reveal a Comptonised corona emission up to 200 keV characterized by a high temperature of 40 keV and optical depth of 0.5. In the Soft state the main emission is from the accretion disk (with $kT_{in} \sim 0.5$ keV) whereas the Comptonised emission decreases showing an optically thick and cold corona ($\tau \sim 9$, $kT_e \sim 2$ keV). During the hardening there is an increase of the inner radius of the accretion disk suggesting a system expansion during the spectral transition. This behaviour is reminescent of the Soft X-ray transient sources though 4U 1722–30 never reaches a real "quiescent" state.

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1. Introduction

4U 1722–30, also known as GRS 1724-30, is a bright LMXB located in the Globular Cluster Terzan 2 [1]. The observed Type 1 X-ray bursts indicate that the compact object is a weakly magnetized neutron star [1], [2]. The timing properties outlined with *RXTE* observations suggest that its timing properties are typical of an atoll source [3]. 4U 1722–30 is a persistent though variable source, and it is one of the first neutron star systems from which hard X-ray emission (E $>$35 keV) was detected by SIGMA with a power law spectrum with photon index $\Gamma \sim$1.65 extending above 100 keV [4]. Previous EXOSAT observation didn't reveal flux above 10 keV [5]. *BeppoSAX* and *RXTE* allowed a broad band observations, detecting the source with a Comptonized spectrum extending up to 200 keV, plus an additional soft componenet (below 3 keV), described by a blackbody emission.

2. The INTEGRAL monitoring

We monitored the sources with *INTEGRAL* during the period October 2003 - April 2005, collecting a total of 883 pointing for IBIS and 256 pointings for JEM-X. Because of this long term monitoring, *INTEGRAL* detected the source in different spectral states and for the first time a detailed spectral analysis of different spectral states has been performed.

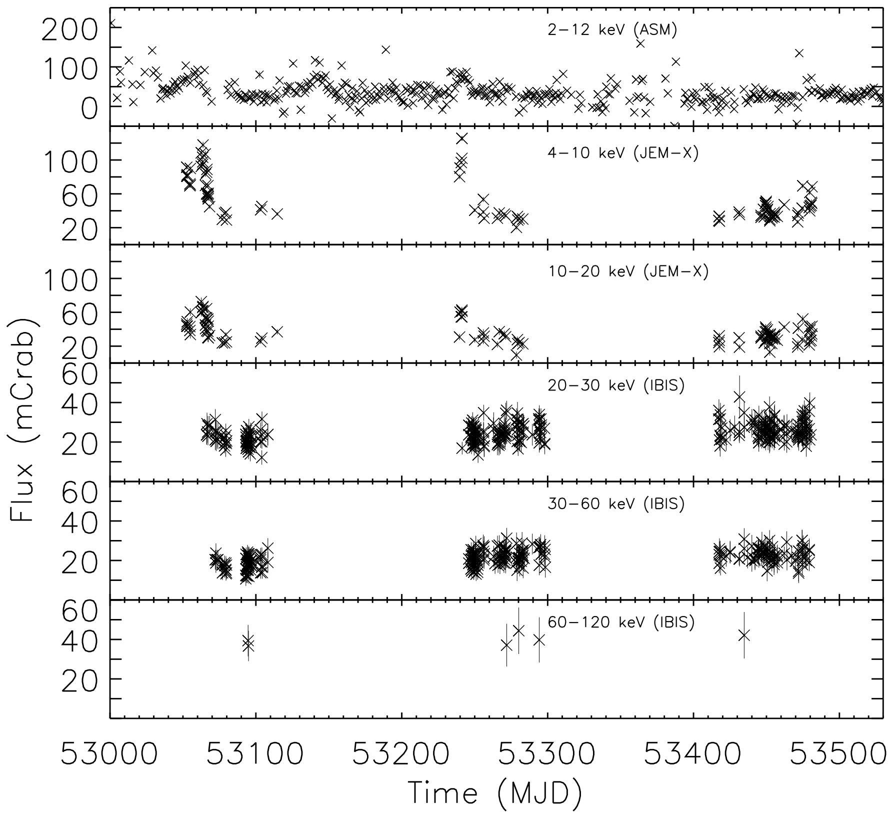

Figure 1: *INTEGRAL* and ASM/*RXTE* light curves of 4U 1722–30.

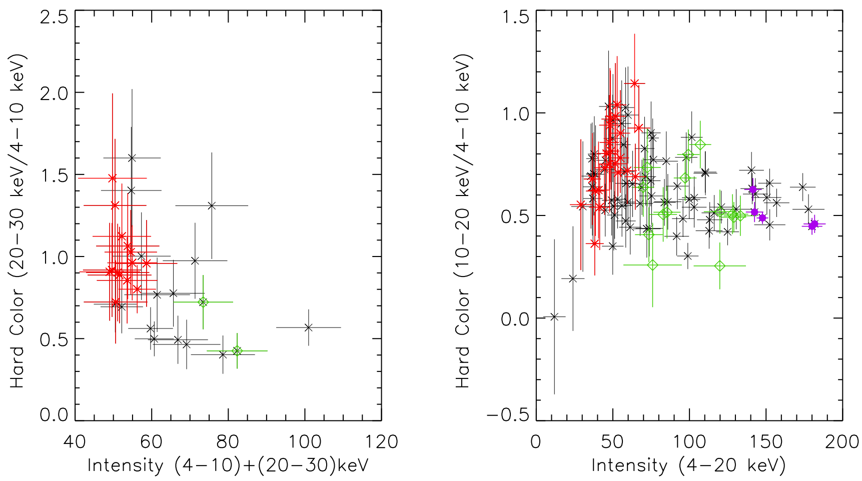

Figure 2: *Left:* IBIS-JEM-X Very hard color–intensity diagram. *Right:* JEM-X hard color–intensity diagram. The colors identify the spe1 (purple), spe2 (green) and spe3 (red) data sets (see Table 1).

3. The light curves and hardness-intensity diagrams

The JEM-X and IBIS light curves in different energy bands are shown in Figure 1. Each INTEGRAL point correspond to a single pointing lasting about 2000 seconds. In the top panel are reported the ASM/*RXTE* one-day monitoring during the same period. The source reveals a flux variation (similar to outbursts) in the soft band (<20 keV), while in the hard ones (>20 keV) it is more rarely significantly detected and the flux changes to a minor extent.

We constructed two hardness-intensity diagrams, the first one with the JEM-X data and the second one with IBIS and JEM-X simultaneous data. Both are shown in Figure 2, with indication on the Intensity and Color bands used. The source moves through the diagram showing spectral changes. We show with different color the different spectral data sets for which observations log is reported in Table 1. The purple data set refers only to the JEM-X/JEM-X hardness intensity diagram because of the lack of high energy detection by IBIS. This data set correspond in fact to a Soft (banana) spectral state. The green and red pointings correspond to a hardening of the sources that enters the Hard (island) spectral state. These pointings are reported in both the hardness-intensity diagrams. The mass accretion rate increases during the softening with a corresponding decreasing of the inner accretion disk radius (see discussion for details).

Table 1: The log of the *INTEGRAL*/IBIS and JEM-X data used for spectral fitting of 4U 1722–30.

Data set	Time start (MJD)	Exposure (ks) IBIS ; JEM-X	Spectral state
spe1 (purple data)	53239.0	9.6 ; 24.4	Soft
spe2 (green data)	53241.2	66.1 ; 25.9	Hard/Intermediate
spe3 (red data)	53431.2	116.1 ; 65.5	Hard

4. The spectral evolution

Spectral analysis was performed by collecting the data corresponding to the same spectral state as shown in the Hardness-Intensity diagram of Figure 2.

4.1 Soft state

For the spe1 data (see Table 1) the best fit model is represented by a black body model (or also simple black body model) [6] plus a Comptonization model [7] with parameters showed in Table 2. Changing the diskbb model with the simple black body model the fit doesn't change.

The source shows this spectral state during the soft "outbursts" clearly evident in the JEM-X light curve, when it isn't detected above 30 keV.

The spectrum, model and residuals are showed in Figure 3. The unabsorbed bolometric luminosity during this spectral state corresponds to 1.8×10^{38} ergs s^{-1}, i.e. L/L_{Edd}=0.9 (assuming a source distance of 9.5 kpc [8]).

Table 2: Spectral fitting results for the JEM-X and IBIS broad-band spectra of 4U 1722-30. The model is CompTT for spe3 and CompTT + diskbb for spe1 and spe2.

parameters	spe1	spe2	spe3
kT_0 (keV)[a]	0.40	1.33	0.81
kT_e (keV)	$2.21^{+0.20}_{-0.09}$	$11.37^{+1.31}_{-0.56}$	$40.36^{+47.03}_{-15.06}$
τ	$9.06^{+9.65}_{-3.40}$	$1.33^{+0.19}_{-0.09}$	$0.48^{+0.42}_{-0.35}$
$\mathrm{norm}_{\mathrm{CompTT}}$	$0.46^{+0.09}_{-0.18}$	$1.19^{+0.27}_{-0.42}\times10^{-2}$	$3.79^{+2.78}_{-3.79}\times10^{-3}$
kT_{in}	$0.46^{+0.10}_{-0.15}$	$0.54^{+0.02}_{-0.02}$	–
norm_{diskbb}	$2.13^{+4.93}_{-0.42}\times10^{4}$	$1.42^{+0.40}_{-0.32}\times10^{3}$	–
χ^2_r(d.o.f)	1.27(30)	1.03(41)	0.70(55)
$F_{4-20\mathrm{keV}}$[b]	2.8×10^{-9}	8.1×10^{-10}	6.4×10^{-10}
$F_{20-200\mathrm{keV}}$	3.7×10^{-11}	1.5×10^{-10}	3.3×10^{-10}

[a] Fixed parameters
[b] The Fluxes are in units of erg s^{-1} cm^{-2}

4.2 Hard and Hard/Intermediate state

The green and red spectral data sets corresponds to the hardening of the source. The Intermediate state is detected just after the soft "outburst" shown in the light curve, and the Hard state follows soon after this.

The Hard/Intermediate state is well represented by the diskbb model plus a Comptonisation model. For the Hard state, the best fit is a simple Comptonisation and the fit doesn't improve by adding a diskbb component. The plasma temperature rises with the hardening, while the optical depth decreases, as indicated in Table 2.

In the Hard state the plasma temperature is not constrained very well and there is the indication of a lack of cut-off, similarly to the Hard state of the atoll 4U 1608-522 [9]. A reflection component is not necessary. The spectra, model and residuals are shown in Figure 3 (panel spe2, spe3). The bolometric luminosity of the Intermediate state corresponds to 1.2×10^{38} ergs s^{-1}, that yields a 0.6 $L_{\rm Edd}$. The bolometric luminosity of the Hard state corresponds to 1.4×10^{37} ergs s^{-1}, i.e. a $L_{\rm Edd}$ ratio of 0.07.

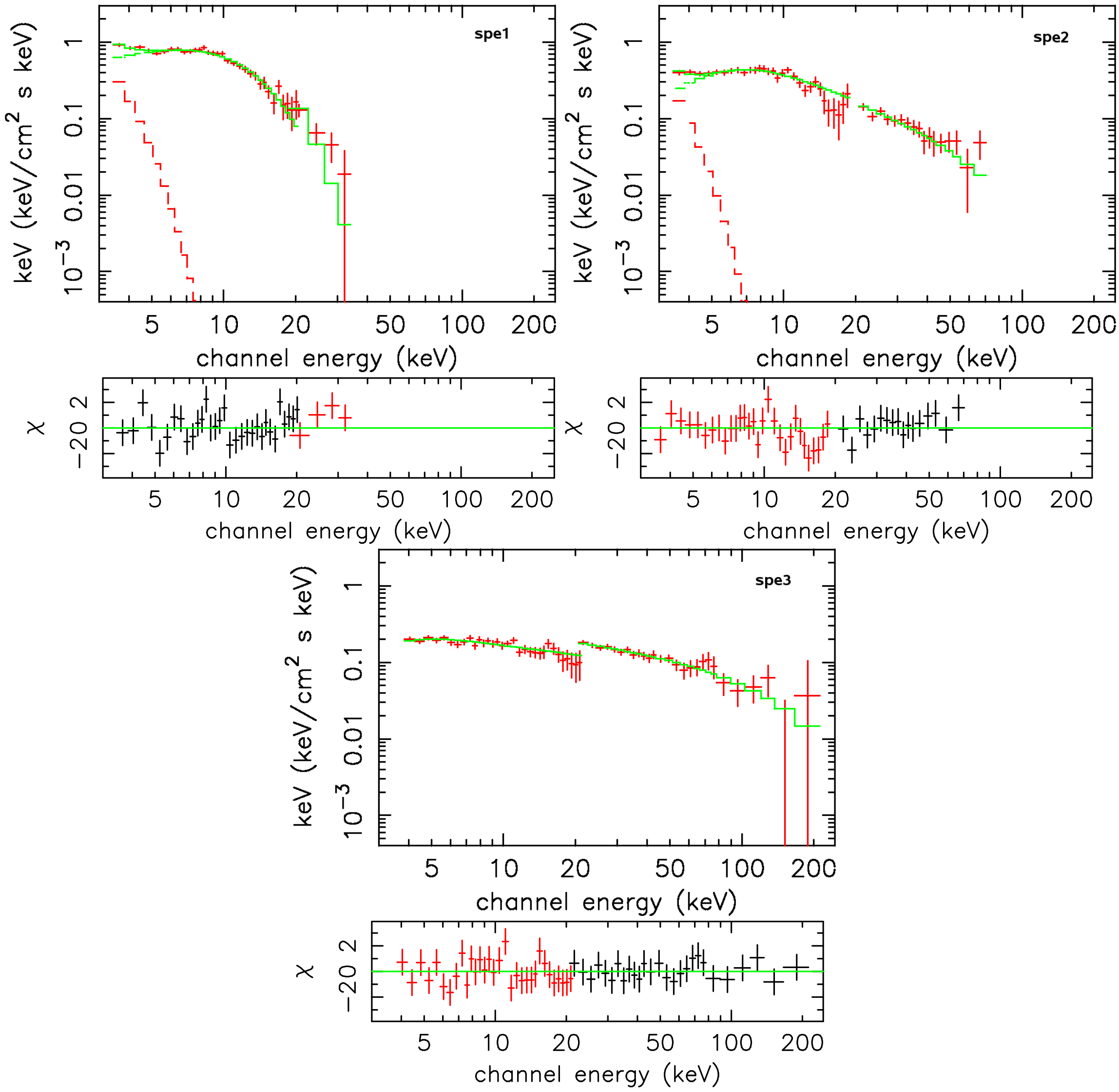

Figure 3: IBIS and JEM-X energy spectra of 4U 1722–30, with the residuals of the data to the model. Spe1 corresponds to the Soft spectral state; spe2 to the Hard-Intermediate; spe3 to the Hard. The models applied are the blackbody plus a Comptonization for spe1 and spe2 data sets and only a Comptonization for spe3. The best fit parameters are reported in Table 2.

5. Discussion and conclusion

The INTEGRAL observations of 4U 1722-30 allow us to follow the X-ray behaviour of this source that is very similar to a X-ray transient, though a real "quiescent" state is never reached. The outbursts are clearly visible in the INTEGRAL light curves, with spectral changes typical of transient sources as also confirmed by the color-intensity diagrams, such as the ones for the transient source 4U 1608-522 [9].

At high soft flux level the source was in Soft state, followed by a hardening. During the Soft state the source doesn't show emission above 30 keV, and the spectrum is well described by a cold and optically thick Comptonized corona ($\tau \sim 9$ and $kT_e \sim 2$ keV) plus a soft black body emission ($kT_{in} \sim 0.46$ keV) coming from either the accretion disk or the neutron star.

During the hardening (at low accretion rate) the contribution of the soft component decreases, with a corresponding increase of the hard X-ray emission (up to 200 keV) described by a hot and optically thin Comptonizing corona ($\tau \sim 0.5$ and $kT_e \sim$40 keV), without any evidence of an energy cut-off.

We estimated the inner radius of the accretion disk in the soft and hard/intermediate state and derived an increase from 5 to 20 km, suggesting an extension of the inner radius during the hardening as also shown by the transient source 4U 1608-522 [9].

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