Transient low mass X-ray binaries seen by INTEGRAL: the already known sources and the new IGRs

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Abstract

We report here on the study of the hard X-ray energy emission of two samples of sources detected by the INTEGRAL survey: the first one is composed by Neutron Stars in Low Mass X-ray Binary systems, with different characteristics; the second one consists of two new sources discovered by IBIS (IGRs) during the INTEGRAL monitoring of the sky over the last six years. For the first sample, the X and Gamma behaviour has been monitored through light curves in different energy bands to look for the temporal variability, then the hardness-intensity diagrams have been constructed, and finally a fine spectral extraction has been performed to discuss the physical parameters dominating the spectral variations. For the two unknown IGRs a temporal and spectral study has been performed with a multi-wavelength approach whenever possible, to try to understand their nature.

Key words: X-ray binaries — LaTeX2.09: style file — instructions

1. New IGR sources

The fourth IBIS/ISGRI soft Gamma-ray survey catalog (Bird et al. 2010) lists more than 700 sources and of this about 60 % are new INTEGRAL sources (IGRs) of which more than a half are still unidentified. Between the new unidentified IGRs there are about 100 sources that show a transient behaviour[1] both on short and long timescale.

Here we report in the following sections on the study of two of these sources at X-ray using different data set in the attempt to define their nature.

1.1. IGR J18284–034

IGR J18284–034 is a unknown source discovered by IBIS and JEM-X on 18-19 March 2009 (Blancard et al. 2009). The peak of the outburst reached 10 mCrab and 6 mCrab in the 3-10 keV and 20-40 keV band respectively. Figure **??** (left) shows the IBIS 18-60 keV light curve of the whole available public data up to 2008 March.

Two days after the discovery, the source was observed by Swift/XRT that allowed to refine the coordinates of the source at RA:18h28m30s, 03d45m43s.2 (error box of 4″). The spectrum was as a typical highly absorbed source with $N_H = 2.4 \times 10^{22}$ cm^{-2}, $kT_{\rm bb}$=2.9 keV, $F_{2-10keV}$=3.2×10^{-11} erg s^{-1} cm^{-2} (Alpern et al. 2009). The absorption is consistent with the Galactic one ($N_H = 2.4\times10^{22}$ cm^{-2}) so we can assume the source distance at 8.5 kpc. The source position does not allow to constrain the Low Mass X-ray Binary (LMXB) or High Mass X-ray Binary (HMXB) nature. The Swift much better error box allowed to search the possible counterpart also in optical wavelengths but it was not detectable (Alpern et al. 2009). The lack of optical counter part in this no Galactic central position decreases the chance of a HMXB nature of the system.

Searching in the XMM-Newton data archive we found that IGR J18284–034 falls in the field of view of the instrument on 22 March 2005 for a 25 ks observation. In Figure 1 (right) we show the XMM image in which a source detected at the position RA=18h:28m30.1s Dec=–03d:45m:44s is consistent with the Swift error box of IGR J18284–034. The source extrapolated flux from the XMM-Newton spectrum was of the low value of $F_{2-10\rm keV}$= 4×10^{-13} erg s^{-1} cm^{-2} corresponding to a luminosity of 4×10^{32} erg s^{-1}, suggesting that was detected in a quiescent state. According with the study of Campana et al. 2001 this quiescent luminosity value seems too high to be associated with X-ray binary with a Black Hole (BH) as compact object, while is consistent with a X-ray binary hosting a Neutron Star (NS) (see Campana et al. 2001: a luminosity of 10×10$^{32-33}$ erg s^{-1} is for NS systems while a luminosity of ×10$^{30-31}$ erg s^{-1} is for BH).

*1 statistics performed by the use of the catalog (Bird et al. 2010) and the page maintained by J. Rodriguez & A. Bodaghee http://irfu.cea.fr/Sap/IGR-Sources/

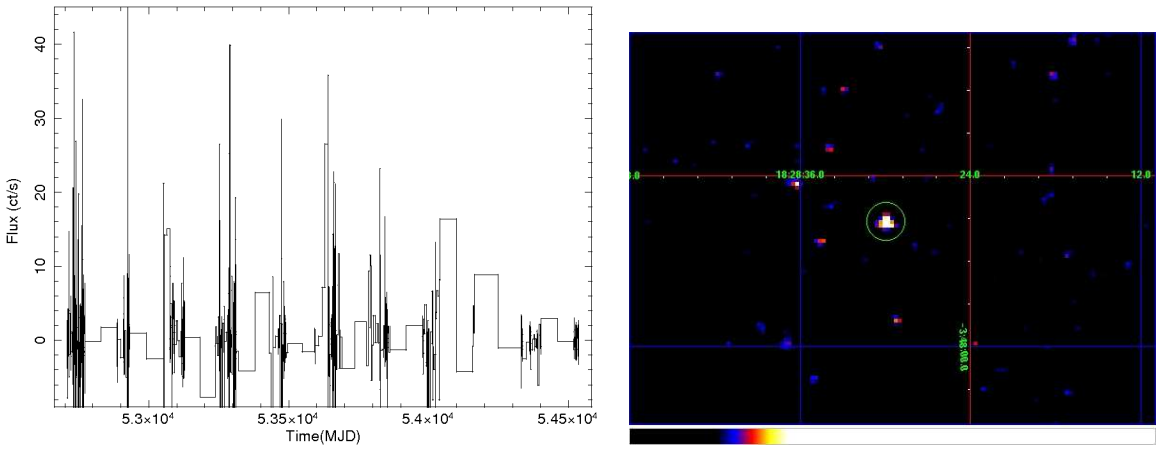

Fig. 1. *Left:* IBIS 18-60 keV light curve of IGR J18284–034. *Right* XMM-Newton 2-10 keV image of IGR J18284–034.

1.2. IGR J17419–2802

IGR J17419–2802 is a unknown source discovered by IBIS on 29 September 2005 (Grebnev et al. 2005). It showed two outburst in the IBIS data: the first on 01 October 2005 and the second in 22 February 2006. We report here results of the first outburst. The Figure 2 (top) shows the 18-60 keV IBIS light curve and the Figure 2 (bottom) shows the 109 ks IBIS mosaic images of IGR J17419–2802. The source was detected in the mosaic image with 13.4 sigma in the 20-40 keV (left panel); and with 4 sigma in the 40-80 keV (right panel).

The source was observed also with other satellites. Figure 3 (left) shows an observation performed by Swift immediately after the discovery in 2005. The refined XRT position of the source is: R.A.=17h41m56.0s, Dec=-28d01m54s.5 (J2000) (error box of 8″) (Kong 2006). This position is consistent with a 2MASS source. The source shows a $F_{2-10\mathrm{keV}}$=3.6×10^{-11} erg s^{-1} cm^{-2} (Kennea et al 2005). The power law XRT spectrum results with a Γ of 1.6±0.3, and a N_H=1.4×10^{22} cm^{-2} that is compatible with Galactic Centre value distance of 8.5 kpc.

On 2008-05-16 the source falls in the field of view of a 3 ks CHANDRA observation. The 2- 10 keV image showed in Figure 3 (right) shows that it is not detected in the CHANDRA data in fact it was in quiescent state during this observation. The detected upper limit flux (2-10 keV), assuming a distance of 8.5 kpc, gives L < 2×10^{32} erg s^{-1} that is consistent with the quiescent luminosity of a BH binary (Campana et al. 2001).

From the observations obtained for these new source we than suggest IGR J18284–034 could be a NS and IGR J17419–2802 could be a BH, but it is necessary to perform furthermore study to confirm this hypothesis.

2. The Luminosity Diagram

A second part of this work is dedicated to the study of a sample of bursters, Atoll and Z sources. In particular we populated the Luminosity diagram, showed in Figure 4, with bursters transient sources plus a sample characterized with persistent behaviour from the IBIS survey.

The flux values for the bursters are derived 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. The luminosity in these two energy bands has been derived using the distances reported in the literature and selecting the better estimates values as derived from burst with photospheric radius expansion whenever possible.

In the Luminosity diagram for each source it is shown the spectral states detected, joined with a line for the same source. The blue boxes represent the Soft states, the orange one the Hard states and the red boxes the Hard state with hard power law tail. The Intermediate states belong to the near spectral state-group. For the persistent source the averaged luminosity value is reported. Also for the Z sources GX 17+2, Gyg X-2 and GX 13+1 we used average value even if they are very variable sources.

The Soft states are 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, high optical depth of 2-9 and input photons with temperature of 0.2.-1.2 keV. During the Hard state the soft black body component is of lower intensity and in some cases is not even detected, while the Comptonizing corona shows a higher electron temperature (6-60 keV) and a lower value of the optical depth (0.4-3).

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

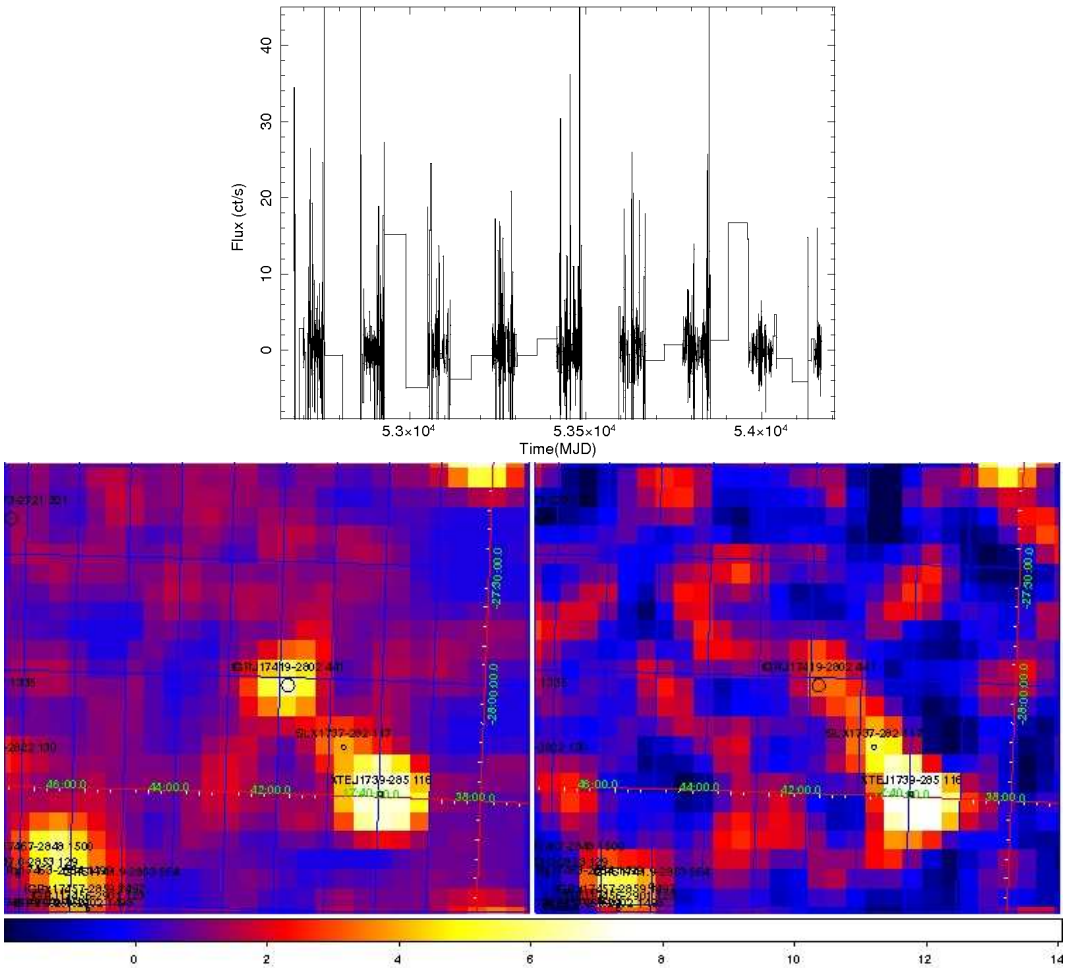

Fig. 2. *Top:*IBIS 18-60 keV light curve; *Bottom:* IBIS 20-40, 40–80 keV image of IGR J17419–2802.

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) (Tarana et al. 2007, 2011).

Comparing the luminosity between different spectral states it is clear that they are positioned in different zones. The Soft states are all localized at $L_{soft} > 6\times10^{36}$ erg s^{-1} and $L_{hard} < 1.4\times10^{36}$ erg s^{-1} (blue boxes). On the contrary the Hard states are located all at L_{soft} $<6\times10^{36}$ erg s^{-1} and $L_{hard} > 0.7\times10^{36}$ 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 can selected if the Intermediate state is associated more to a group than to the other one. In fact the Intermediate state of both 4U 1722–30 and 4U 1728–34 is more similar to the Hard state, while the Intermediate state of 4U 1608–522 belongs to the Soft state group. As an example we report in the next section the spectral evolution of the transient source 4U 1722–30.

2.1. Spectral evolution of the transient source 4U 1722–30

4U 1722–30, also known as GRS 1724-30, is a bright LMXB located in the Globular Cluster Terzan 2 (Grindlay et al. 1980). The observed Type 1 X-ray bursts indicate that the compact object is a weakly magnetized neutron star (Grindlay et al. 1980, Swank et al. 1977). The *RXTE* observations suggest that its timing properties are typical of an atoll source (Olive et al. 1998). 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. In fact the spectrum was consistent with a power law of photon index $\Gamma \sim 1.65$ extending above 100 keV (Barret

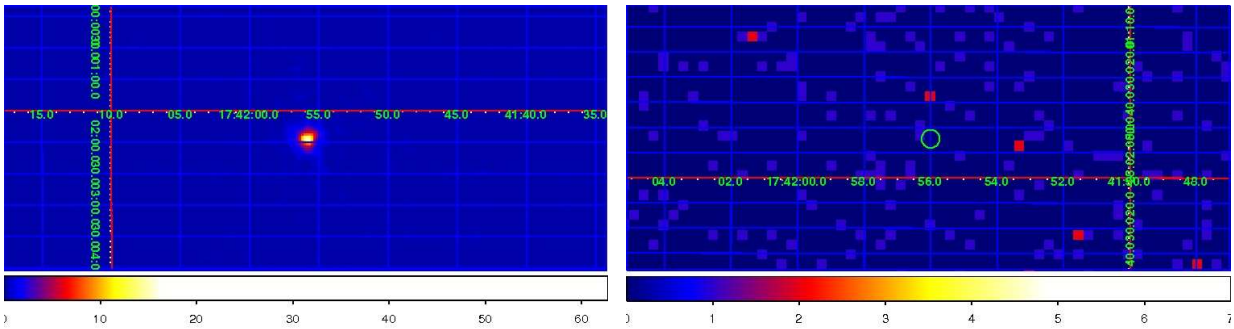

Fig. 3. Swift (*left*) and Chandra (*right*) image of IGR J17419–2802.

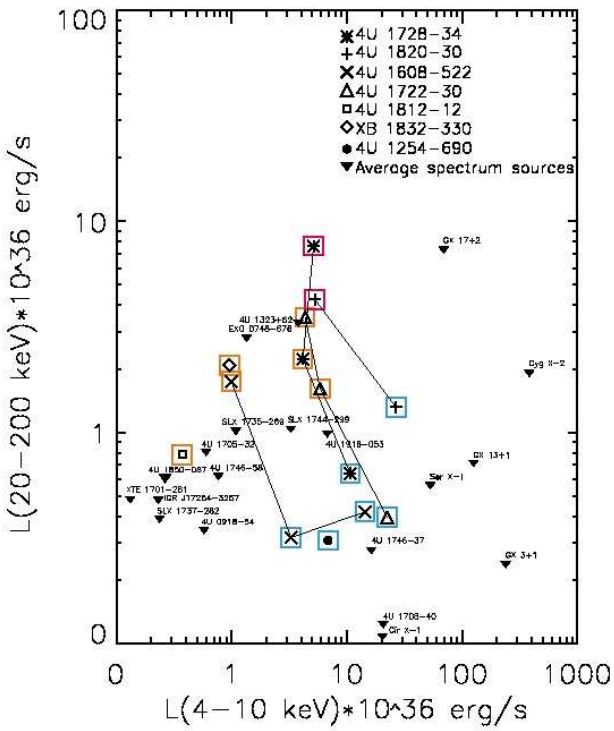

Fig. 4. Luminosity diagram.

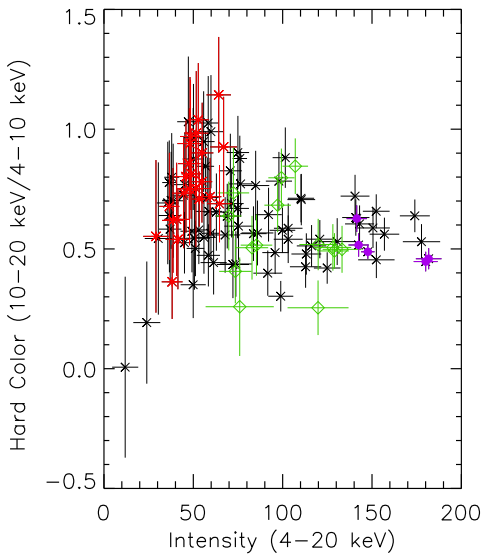

Fig. 5. JEM-X hard color–intensity diagram of 4U 1722–30. The colors identify the spe1 (purple), spe2 (green) and spe3 (red) data sets.

et al. 1991). Previous EXOSAT observation didn't report any flux above 10 keV (Parmar et al. 1989). Later on *BeppoSAX* and *RXTE* allowed a broad band observations and the source showed a Comptonized spectrum extending up to 200 keV, plus an additional soft componenet (below 3 keV) described by a blackbody emission (Guainazzi et al. 1998).

The INTEGRAL observations of 4U 1722–30 allow us to follow the hard X-ray behaviour of this source that is very similar to a X-ray transient, though a real "quiescent" state is never reached. We monitored the sources with *INTEGRAL* during the period starting from October 2003 to April 2005, collecting a total of 883 IBIS pointing and 256 JEM-X pointings (Tarana et al. 2008).

2.1.1. Hardness-intensity diagram

JEM-X Hardness-Intensity diagram is shown in Figure 5. Each point corresponds to a single pointing lasting about 2000 seconds. The Intensity is in mCrab flux and the total energy range considered is 4–20 keV keV. The Hardness is defined as the mCrab flux ratio between 10–20 keV/4–10 keV energy bands. 4U 1722–30 moves through the diagram and shows spectral changes. We indicated with different color the different spectral data sets: Spe1 (purple data) is Soft spectral state; Spe2 (green data) is the Hard/Intermediate state; Spe3 (red data) is Hard spectral state.

Table 1. 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
$kT_{\rm e}$ (keV)	$2.21^{+0.20}_{-0.09}$	$11.37^{+1.31}_{-0.56}$	$40.36^{+47.03}_{-15.06}$
τ	$9.06^{+9.65}_{-3.40}$	$1.33^{+0.19}_{-0.09}$	$0.48^{+0.42}_{-0.35}$
$\rm norm_{CompTT}$	$0.46^{+0.09}_{-0.18}$	$1.19^{+0.27}_{-0.42}\times10^{-2}$	$3.79^{+2.78}_{-3.79}\times10^{-3}$
$kT_{\rm in}$	$0.46^{+0.10}_{-0.15}$	$0.54^{+0.02}_{-0.02}$	–
$\rm norm_{diskbb}$	$2.13^{+4.93}_{-0.42}\times10^{4}$	$1.42^{+0.40}_{-0.32}\times10^{3}$	–
χ^2_r(d.o.f)	1.27(30)	1.03(41)	0.70(55)
$F_{4-20\rm keV}{}^b$	2.8×10^{-9}	8.1×10^{-10}	6.4×10^{-10}
$F_{20-200\rm keV}$	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}

2.1.2. 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 5. Spectral fitting results for JEM-X and IBIS joined spectra of 4U 1722–30 is reported in Table 1. The model is CompTT (Titarcuk 1994) for spe3 and CompTT plus a disk black body (diskbb) (Mitsuda et al. 1984) for spe1 and spe2.

During the Soft state, at high soft flux level, the source does not show emission above 30 keV, and the spectrum is well described by a cold and optically thick Comptonized corona (τ ~9 and kT$_{\rm e}$ ~2 keV) plus a soft black body emission (kT$_{\rm in}$ ~0.46 keV) coming from either the accretion disk or the neutron star.

Otherwise 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 (τ ~0.5 and kTe$_{\rm e}$ ~40 keV), without evidence of an energy cut-off.

We estimated the inner radius of the accretion disk in the soft and hard/intermediate state and we found an increasing in its value (from 5 to 20 km) that suggests an extension of the inner radius during the hardening.

The spectrum, model and residuals are shown in Figure 6. The unabsorbed bolometric luminosity during the soft 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 (Kuulkers et al. 2003)). The bolometric luminosity of the Intermediate state corresponds to 1.2×10^{38} ergs s^{-1}, that yields a value of 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.

3. Discussion and conclusion

The new detected unidentified IGR transient sources are the most difficult to identify because of their limited information and lack of better constrain to on their position. Often the outbursts detected by IBIS are very short or too faint for source information characterization (detailed spectra, light curves etc.). The sky position of the objects give us a hint of their nature: Galactic Bulge and Plane contain more likely XRBs; at high Galactic latitude we observe more likely AGNs. The location of the new sources studied by us is consistent with a Galactic nature.

In general to identified new sources are important the study of:

- Multiwavelength observations (radio–IR–optical–soft-X): combining the available information in soft X-ray band and whenever possible in radio band, together with the optical spectroscopy of the putative counterparts of the hard x-ray sources.

- Quiescent flux searching: the counterpart searching is difficult, in fact these sources spend a lot of time in quiescence thus the archival data are often un-useful to this aim and even dedicated observations could often observe the source when in quiescence. Nevertheless the luminosity value during quiescent state could give hint of the source nature as suggested by Campana et al. 2001.

- X-ray outburst behaviour and temporal characteristics in general: the detection of type-I X-ray bursts indicates the NS nature of the compact object.

Different is the approach for the already known NS systems. When they are transient shows a well know behaviour:

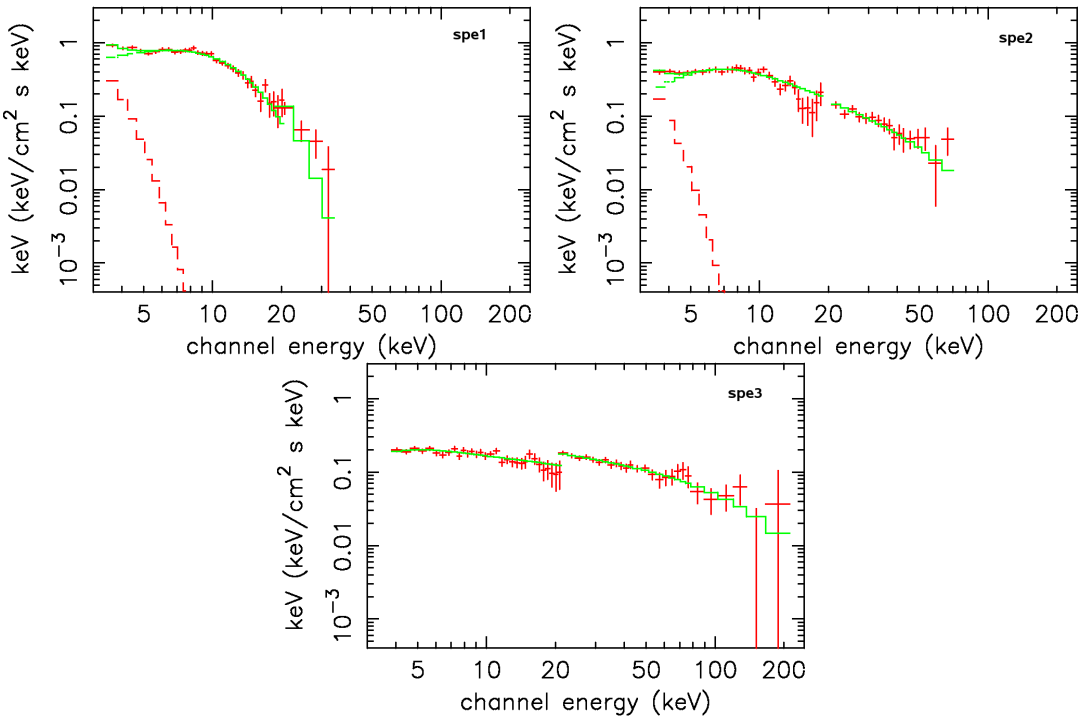

Fig. 6. 4U 1722–30. The colors identify the spe1 (purple), spe2 (green) and spe3 (red) data sets (see Table 1).

- Most of the time in quiescent state (L=$\times 10^{31-33}$ erg s^{-1})
- Outbursts with different time scale (d–m–y) and different temporal and spectral behaviour
- Spectral states changes during the outbursts (expecially in binary systems).

For a sample of already known sources of transient and persistent nature we have performed a study of their temporal and spectral characteristics. The construction of a *Luminosity diagram* gives us a good clue to understand the Soft or Hard nature of the source spectral states. The populations of the diagram is increasing with other sources.

The authors wish to thank the IBIS survey team to make data available to us. The authors thanks M. Federici for the continuous effort to update the *INTEGRAL* archive and software in Rome and L. Natalucci for the scientific and data analysis support. We acknowledge the ASI financial support via grant ASI-INAF I/008/07.

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