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BeX systems, an INTEGRAL view

Pere Blay *
GACE - Image Processing Laboratory, University of Valencia, PO BOX 22085, 46071 Valencia, Spain
E-mail: pere.blay@uv.es

Silvia Martínez-Núñez
Inst. de Física Aplicada a las Ciencias y las Tecnologías, Universidad de Alicante, Alicante, Spain

Pablo Reig
IESL, FORTH, 711 10 Heraklion, Crete, Greece
Physics Department, University of Crete, 710 03 Heraklion, Crete, Creece

Paul Connell
GACE - Image Processing Laboratory, University of Valencia, PO BOX 22085, 46071 Valencia, Spain

José Miguel Torrejón
Inst. de Física Aplicada a las Ciencias y las Tecnologías, Universidad de Alicante, Alicante, Spain

Víctor Reglero
GACE - Image Processing Laboratory, University of Valencia, PO BOX 22085, 46071 Valencia, Spain

Public data of different types of High Mass X-Ray Binaries have been analyzed. We have developed a classification scheme based on their temporal variability and spectral properties. We find that the Be X-Ray binaries tend to show harder spectra than those of Supergiant X-ray Binaries and that the use of the statistical normalized variance seems to be a promising tool to identify source type.

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Source	Class	Source	Class	Source	Class
IGR J01363+6610	Be	H 1145-619	Be	GRO J2058+42	Be
RX J0146.9+6121	Be	PSR B1259-63	Be	SAX J2103.5+4545	Be
IGR J01583+6713	Be	SAX J1324.4-6200	Be	3A 0114+650	SG
V615 Cas	Be	H 1417-624	Be	3A 0726-260	?
EXO 0331+530	Be	SAX J1452.8-5949	Be?	Ginga 0834-430	?
X Per	Be	H 1553-542	Be?	IGR J16318-4848	SgB[e]?
1H 0521+373	Be?	SAX J1749.2-2725	Be?	IGR J16320-4751	SG
LMC X-3	Be	GRO J1750-27	Be?	IGR J17391-3021	SFXT
1A 0535+262	Be	Cep X-4	Be	4U 1807-10	?
1H 0556+286	Be	AX J1820.5-1434	Be	RX J1826.2-1450	SG
RX J0812.4-3114	Be	3A 1845-024	Be	Sct X-1	SG?
GRO J1008-57	Be	XTE J1858+034	Be	XTE J1855-026	SG
4U 1036-56	Be	XTE J1946+274	Be?	4U 1901+03	?
1A 1118-615	Be	KS 1947+300	Be	IGR J19140+0951	SG
IGR J11435-6109	Be	EXO 2030+375	Be	3A 2206+543	MSD[1]

[1] Main Sequence Donor

Table 1: List of sources used in this work. Wherever a question mark (?) is shown, it is an indication that, whether the classification is doubtful to some extent, or yet unknown. An extended version of this table can be found in Blay et al. 2008.

1. Introduction

We have used an initial sample of 32 BeX systems, all of them included in the INTEGRAL/ISGRI catalog (see Bird et al. 2007). They are shown in Table 1. Together with this set of Be X-ray binaries we have analyzed a small subset of High Mass X-Ray Binaries (HMXRB) including supergiant (SG) stars, as well as peculiar systems or systems with unknown optical counterpart. They are also shown in 1. They will serve, on the one hand, as testers to compare to the observed properties of the BeXs, and, on the other hand, for those with unknown optical counterpart, we will test the possibility to define to which group they will most likely belong (BeX or SG HMXRB). A representative of each of the newly defined classes of HMXRB (obscured sources and Super Fast X-ray Transients –SFXT–) have also been included, they are IGR J16318-4848 and IGR J17391-3021 respectively. This is an extension of the work presented by Blay et al. 2008.

2. Light Curves

We can distinguish two types of variability patterns in the INTEGRAL/ISGRI data of the HMXRBs analyzed in this work. In the first kind, repeated short outbursts are seen over a long time span (on the order of ∼1000 days, see Figure 1). The 20-40 keV light curves, with a time resolution of one INTEGRAL pointing (∼3 ks), do not give enough information to distinguish the various types of HMXRBs. The difference in behavior is only noticed in the case of BeX systems with a clear orbital periodicity or it is only spotted out when a more careful and finer resolution timing analysis is performed. However, the orbital periodicity present in the BeX systems may be

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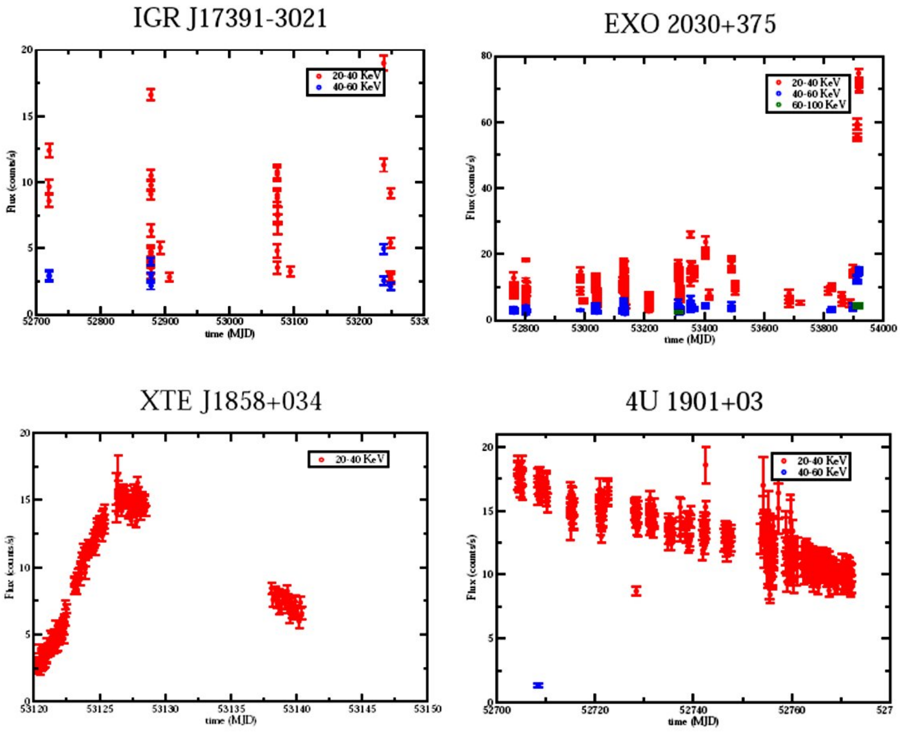

Figure 1: Upper plots: Example of long time span light curves (∼1000 days) showing a SFXT (left) and a BeX system (right). Lower plots: Example of short time span light curves (∼50 days). A BeX system (XTE J1858+034) and the unclassified system 4U 1901+03 are shown.

hidden by observational effects. The other type of variability is that of the BeX systems showing type II outbursts, with slower increases and decreases of flux on time scales on the order of 50 days. Only BeX systems are found to show this type of light curves. 4U 1901+03, a system with unknown counterpart, shows this latter type of variability (see Figure 1). Therefore the data strongly suggests that it is a BeX system.

3. Statistical parameters

We have obtained a set of temporal parameters using the 20-40 keV light curves. Our aim is to investigate whther it is possible to distinguish among the different types of HMXRBs by the values of these parameters. Some of these statistical parameters are shown in Table 2. No clear trend can be used to differentiate among types with any of the parameters shown in Table 2. We have, then, made use of the *normalized excess variance* as defined by Nandra et al. (1997). Figure 2 shows the normalized variance versus the source flux calculated for the HMXRBs analyzed in this work. BeX systems tend to be distributed along the lower values of the normalized variance. This is not yet conclusive, but may be an indication that this parameter could be used to segregate HMXRBs by type.

Source	det./point.	F_{av}	A. V. (%)	Source	det./point.	F_{av}	A. V. (%)
H 0115+634	62/751	54.5	4	3A 2206+543	16/160	4.6	30
EXO 0331+530	142/176	57	54				
X Per	2/2/7.6	3	-	3A 0114+650	104/652	4.5	56
1A 0535+262	2/35	6.9	4	XTE J1855-026	77/ 892	4.5	36
GRO J1008-57	60/777	1.2	29	IGR J16320-4751	220/1254	34.5	7
H 1145-619	19/796	0.7	21	IGR J19140+0951	81/1357	5.4	54
SAX J1324.4-6200	1/120	-	-				
H 1417-624	7/513	1.7	34	IGR J16318-4848	474/1297	7.0	71
AX J1749.2-2725	11/3276	1.1	27				
XTE J1858+034	178/1308	4.4	44	4U 1901+03	570/1423	12	17
KS 1947+300	49/345	2.6	33				
EXO 2030+375	595/1271	7.9	12	IGR J17391-3021	33/3286	7	57
SAX J2103.5+4545	183/855	1.4	30				

Table 2: Number of detections vs. number of pointings with the source in the FOV, average count rate (F_{av}), and amplitude of variability (A. V.) of the systems detected by INTEGRAL/ISGRI, in the 20-40 keV energy range. The BeX systems are grouped on the left and the rest of HMXRBs on the right. A more complete version of this table can be found in Blay et al. 2008.

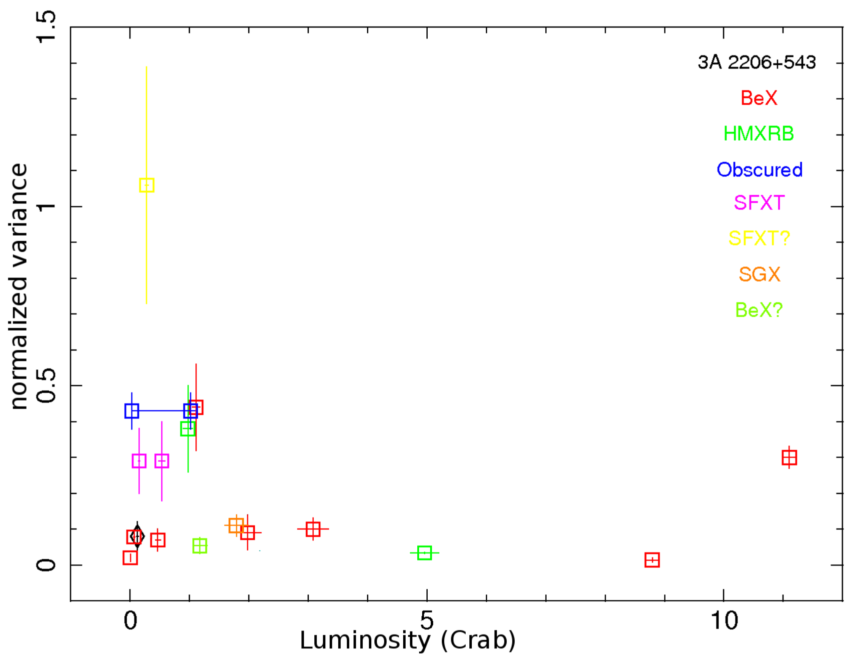

Figure 2: Normalized variance for the sources detected by ISGRI in the 20-40 keV energy range.

4. Spectral Characterization

As seen in Table 3, spectra for most of the detected sources have been extracted in the 20-100 keV energy range. For the shake of comparison, the same spectral model have been used to fit all the spectra. A simple power-law have been used, modified by a cutoff whenever the power-law by itself could not yield a good fit. For those sources showing spectral absorption features (i.e., Cyclotron Scattering Resonant Features –CRSF– in most of the cases), Gaussians in absorption have been used to help obtaining a good continuum fit. Our goal is not to analyze the details of the spectral features, but to compare the continuum, that is, the spectral shape, with the aim to check for systematic differences between types of HMXRBs.

Two clearly visible trends can be seen in the data shown in Table 3:

A) The BeX systems tend to have lower values of the photon index, while the SG systems have values of the photon index above 2.5.

B) The BeX systems admit a cutoff as improvement of the spectral fit, however for the wind-fed systems (SG HMXRBs plus the peculiar system 4U 2206+54) a cutoff will not improve the spectral fit.

The suggestion that systematic differences in the spectral shape are reflecting the mechanism of mass transfer present in the system is strong. We have made the addition to our set of two sources with SG companions but in which the accretion is mediated by an accretion disk, as this is also the case in the BeX systems, namely Cyg X-1 and SMC X-1. These two systems present a photon index similar to that of the BeX system and also admit the addition of a cutoff to the spectral fit. As expected, the accretion mechanism present in the system strongly affects the shape of the spectrum of the source.

5. Conclusions

We have performed an extensive analysis of more than 5 years of INTEGRAL/ISGRI data of the BeX systems included in the ISGRI catalog, as well as a few SG HMXRBs. We have seen that regarding to timing properties, only after a detailed analysis of the outburst properties the nature of the source can be suggested, but timing analysis is not conclusive by itself. The patterns of variability are similar in terms of time-scale and amplitudes except for the case of BeX system showing only type II outbursts. In this case we propose the system 4U 1903+01 to be a BeX system, as the only INTEGRAL/ISGRI detection of the source shows the tail of an outburst very similar to the type II outbursts of the BeX systems (such as XTE 1858+035, or H 0115+63). The normalized variance deserves to be investigated in deeper detail when applied to HMXRBs as we have shown indications that it can be used to differentiate types of HMXRBs.

Spectral analysis seems to be a more promising tool to infer the physics of the accretion mechanism present in the system. We have seen that those systems with a spectral photon index above 2.5 and which do not allow a cutoff in the spectral fit are very likely to be SG HMXRBs (win-fed systems). On the other hand, systems with harder photon index and admitting a cutoff in their spectral fits will very likely be accreting via an accretion disk (they can be BeX systems or Roche-Overflow SG systems).

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Source	Γ	Ecut	Efold	χ^2_{red}	DOF	gabs	notes
XTE J1858+034*	0.8^{+1}_{-3}	22^{+2}_{-4}	8^{+4}_{-4}	1.4	13		
EXO 0331+530*	$1.3^{+1.0}_{-1.0}$	32^{-2}_{+2}	7^{-2}_{+2}	1.3	11	$29^{+0.2}_{-0.2}$,50^{+1}_{-1},60^{+1}_{-1}	
Cyg X-1**	1.5^{+1}_{-1}	175^{+40}_{-41}					**(a)**
SMC X-1**	$1.5^{+0,9}_{-0.8}$	24^{+2}_{-2}		1.1	17		**(b)**
SAX J2103.5+4545*	$1.7^{+0.6}_{-0.5}$	26^{+8}_{-5}	38^{+36}_{-12}	0.9	45		
X Per*	$1.8^{+0.2}_{-0.2}$			1.1	47		
KS 1947+300*	$2.2^{+0.2}_{-0.2}$	57^{+6}_{-6}	23^{+7}_{-7}	1.5	20		
IGR J19140+0951*	$2.32^{+0.08}_{-0.11}$	52^{+5}_{-8}	56^{+11}_{-11}	1.3	20		
4U 1901+03*	$2.4^{+0.6}_{-1.2}$	$24.9^{+0.4}_{-0.6}$	12^{-2}_{+2}	1.8	20		
EXO 2030+375*	$2.5^{+0.2}_{-0.1}$			1.2	24		
IGR J17391-3021	$2.57^{+0.09}_{-0.11}$						
3A 0114+650	$2.6^{+0.2}_{-0.2}$			1.02	13	45 $^{+6}_{-3}$,90^{+12}_{-25}	
GRO J1008-57*	$2.7^{+0.2}_{-0.2}$	43^{+14}_{-8}	10^{-2}_{+2}	0.6	20		
IGR J16318-4848	$2.7^{+0.3}_{-0.3}$	43^{+4}_{-4}	26^{+6}_{-4}	0.6	3		**(c)**
XTE J1855-026	$2.74^{+0.12}_{-0.11}$			1.9	22		
H 1145-619*	$2.8^{+0.2}_{-0.2}$	45^{+50}_{-7}		1.7	15	70^{+5}_{-4}	
H 0115+634*	$2.88^{+0.05}_{-0.08}$	28^{+2}_{-1}	32^{+1}_{-1}	0.6	21		
3A 2206+543	$3.1^{+0.8}_{-0.4}$			1.8	2	30^{+1}_{-4}	**(c)**
IGR J16320-4751	$3.50^{+0.12}_{-0.11}$			1.8	5		**(c)**

* BeX systems

** Supergiant systems with Roche-Lobe overflow

(a) Bouchet et al. 2003 **(b)** From INTEGRAL revolutions 94-95 **(c)** From mosaic

Table 3: The INTEGRAL/ISGRI 20-100 keV spectra for some of the detected sources of our sample. Two SG systems with accretion driven by the presence of an accreting disk have been added to the sample, namely Cyg X-1 and SMC X-1.

This methodology seems to be promising to characterize the different types of HMXRBs, however an improvement in the spectral analysis (increased sensitivity or more detections) is needed in order to reduce uncertainties and allow a better estimation of spectral parameters. A more complete follow up of these sources in energies above 20 keV (in order to detect obscured sources) would improve the statistics needed to perform the normalized variance analysis.

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