SAX J2103.5+4545: BRIGHT AND FAINT STATES CHARACTERIZED WITH *INTEGRAL*

P. Blay[1], A. Camero[1], S. Martínez-Núñez[1], P. Connell[1], V. Reglero [1], P. Reig[2], I. Negueruela[3], A. Segreto[4], and C. Ferrigno[4]

[1]*Institut de ciència de Materials, Universitat de València, PO BOX 22085, 46071 Valencia, Spain*
[2]*Physics Department, University of Crete, 710 03 Heraklion, Crete, Greece*
[2]*Foundation for Research and Technology-HEllas, 711 10 Heraklion, Crete, Greece*
[3]*Dpto. de Física, Ingeniería de Sistemas y Teoría de la Señal, EPSA, Universidad de Alicante, PO BOX 99, 03080 Alicante, Spain*
[4]*IASF/INAF, Via Ugo La Malfa 153, 90146 Palermo, Italy*

ABSTRACT

The BeX system SAX J2103.5+4545 shows a set of peculiarities which make it different from the rest of BeXs. With a short orbital period compared to other BeXs (12.67 days) and a pulsating period of ∼350 s, it does not follow the Corbet relationship between P_{orb} and P_{spin} for BeX systems. It shows alternating bright and faint states. Bright states are characterized by luminosities of the order of 10^{36} erg s^{-1} and orbital modulation of the high energy emission. Faint states are characterized by low luminosities (10^{34} erg s^{-1}) and the absence of detectable orbital modulation. For the first time we present a detailed comparative analysis of the source in the bright and faint states with *INTEGRAL* data, showing clear evidence of different spectral behaviour in both states. The interactions of the Be star envelope and the compact companion in SAX J2103.5+4545 are briefly presented.

Key words: stars:Be – pulsars: individuals: SAX J2103.5+4545 – X-rays:binaries.

1. INTRODUCTION

SAX J2103.5+4545 was discovered with BeppoSAX in 1997, during a bright state (Hulleman et al. [6]). The modulated nature of the high energy emission plus the spectral shape of the source pointed to an accreting compact object in a binary system as the nature of the source (most likely a BeX system). A bright state (BS), with high luminosity and strong orbital modulation, and a faint state (FS), with low luminosity and weak or none orbital modulation, have been reported by Baykal et al. [1], see also Fig 1 and Fig 2. In the faint state the spectral shape was harder while in the bright state it was softer. Fig 2 shows a periodogram of both, faint and bright states of the source. A peak at a frequency in agreement with the measured orbital period is found only in the bright state periodogram. Based on RXTE/ASM count rate, we establish the onset of the BS when the source *RXTE*/ASM X-ray intensity increases above ∼0.5 count s^{-1}. During FS the source is too faint to be detected by *INTEGRAL* high energy instruments.

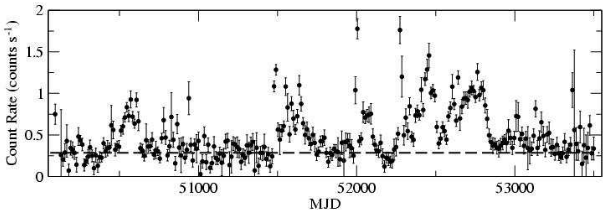

Figure 1. RXTE/ASM light curve showing the occurrence of bright and faint states.

During November-December 2002, within the *INTEGRAL* Performance and Verification phase (PV), SAX J2103.5+4545 was intensively monitored (see Blay et al. [2]). During 2003 and 2004, the source was repeatedly observed by *INTEGRAL*. The transient nature of the system and the observing strategy of *INTEGRAL* spacecraft meant that the amount of data and the time coverage were not adequate to perform a deep analysis of the source. In spite of these difficulties, some work has been done. Falanga et al. [5] carry out a detailed analysis of the pulse profile shape and energy dependence with *INTEGRAL* data from a private observation which took place in May 2003. Sidoli et al. [8] reported on the spin-up rates measured during the bright state observed by *INTEGRAL*. During the subsequent faint state, only a few observations are available. As a matter of fact, the source is so weak and that spectral or timing information can be obtained with the official OSA 5.1 software. Actually, in most of the observations during the faint state, only upper limits to the source flux can be given. A. Segreto and C. Ferrigno (SF)[1] developed an analysis software for the *INTEGRAL*/ISGRI instrument with the property of being able to perform spectral extraction directly from the event list, rather than from deconvolved images (which may fail for

[1]http://www.pa.iasf.cnr.it/ ferrigno/*INTEGRAL*software.html

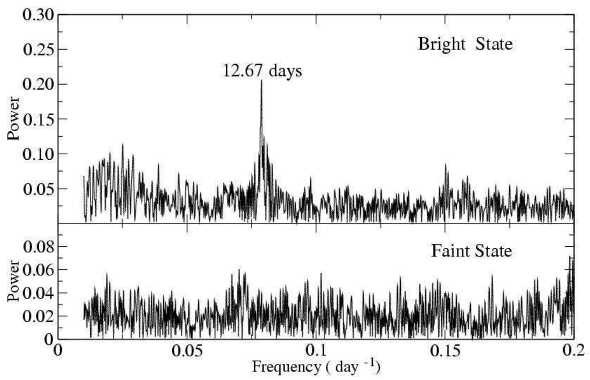

Figure 2. Power spectrum of SAX J2103.5+4545 RXTE/ASM light curve during bright and faint states.

very low luminosity sources). The software is described in the poster by Segreto el al. (these proceedings).

2. SPECTRAL ANALYSIS.

With the available OSA 5.1 ISGRI detections in three energy bands (25–40 keV, 40–60 keV and 60–80 keV) we have built SAX J2103.5+4545 hardness ratios (HR) defined by HR=$\frac{H-L}{H+L}$. with H and L the count rates in the higher and lower bands. The resulting HRs are shown in Fig 3 as a function of count rate in the 25–40 keV energy band. We notice that above 1.5 counts s^{-1}, that is, during BS, the hardness ratio remains constant. Hence, we expect no spectral variations during the BS, as confirmed by previous publications (Baykal et al. [1]). Therefore, we can safely use an average spectrum to characterize the spectral properties of SAX J2103.5+4545 during the BS. Left pannel of Fig 4 shows the combined JEM-X and ISGRI spectra during the BS. A powerlaw with photon index of Γ= 1.1±0.2 and a cut off at E_{CUT}=7±5 keV, with a folding energy of E_{FOLD}=25±2 keV , yields the best fit to the data, in very well agreement with previous estimates (see Baykal et al. [1] and Blay et al. [2]).

We have used the SF software in order to extract spectra at three different FS periods: a) from revolution 181 up to revolution 202, b) revolutions 210–243, and c) revolutions 242–259. Middle pannel of Fig 4 shows ISGRI spectra, extracted for these epochs, together with the BS spectrum for comparison.

While the average ISGRI BS spectrum can be fitted with a single powerlaw, we need to add a cutoff in order to fit the FS spectra. The results of the fit are shown in Table 1. We forced a cutoff in the BS spectrum in order to make comparison easier. We find evidence of spectral evolution in all the spectral parameters, with the suggestion of a possible intermediate state (revolutions 181–202).

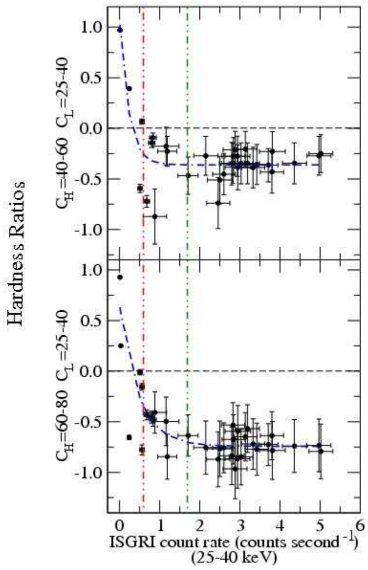

Figure 3. Hardness ratios from ISGRI data by using OSA 5.1 software .

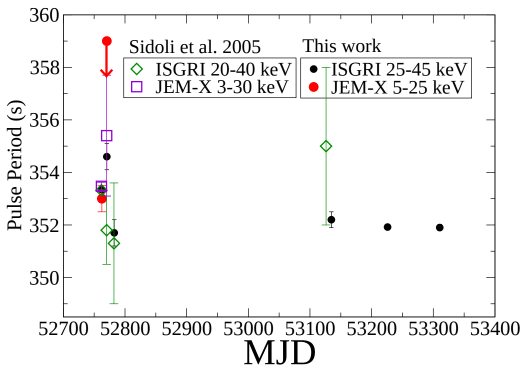

Figure 5. Pulse period history of SAX J2103.5+4545. While during BS the data suggest some pulse period evolution, during the FS some stability is achieved.

3. PULSE PERIOD ANALYSIS.

Fig 5 shows the pulse period evolution of SAX J2103.5+4545 with *INTEGRAL* data. It shows evidence of spin ups and downs, contrary to the general spin-up trend found in the literature. In contrast, during FS, the spin period remains quite stable. During BS (MJD < 5300), although the errors are large, we notice that the data suggest a fast spin up of the Neutron Star (NS), from ∼355 s pulse period down to ∼352 s, preceded by a possible spin down (from 353 s up to 355 s). From MJD∼5300 on, the data suggest very little changes in the pulse period with a very stable value around ∼352 s.

In an enviroment dominated by the amount of matter present in the circumstellar disk around the Be star (as it seems to be the case of SAX J2103.5+4545), spin up and spin down phases are not rare, and will depend on the

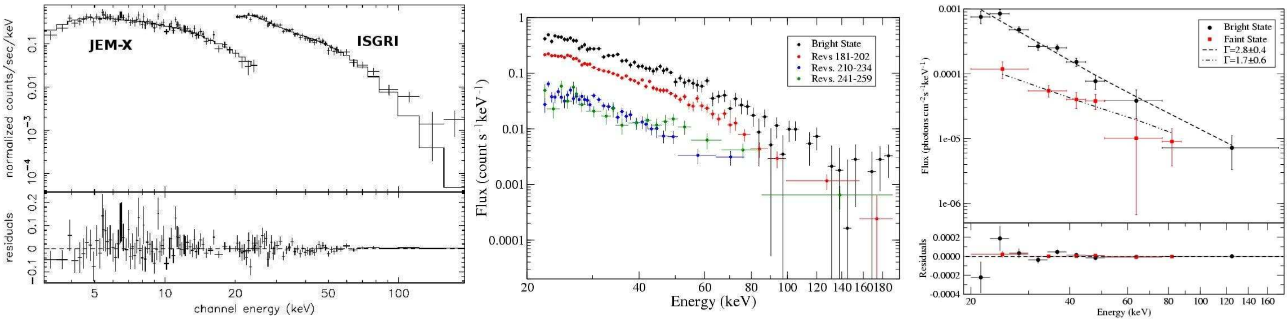

Figure 4. Left: Combined JEM-X and ISGRI spectra averaged for the whole bright state, a powerlaw fit with its residulas is shown. Middle: Comparison of the averaged ISGRI spectra for the bright state and the extracted spectra during faint state at three different epochs. Right: Comparison of bright and faint state spectra as extracted with SPI software.

Table 1. Results of the fit to the spectra shown in middle pannel of Fig 4. Data from revolutions up to 180 were used for BS spectral analysis. For FS A data from revolutions 181-202 were included and for FS B revolutions 210–234 were analised. Fluxes are given in units of 10^{-10} erg cm^{-2} s^{-1}

	BS	BS+cut-off	FS A	FS B
Photon Index	2.58±0.08	$1.7^{+0.6}_{-0.5}$	$1.5^{+0.5}_{-0.8}$	$1.0^{+0.6}_{-1.0}$
E_{CUT} (keV)		26^{+8}_{-5}	27±4	30^{+3}_{-2}
E_{FOLD} (keV)		38^{+36}_{-12}	29^{+11}_{-10}	13^{+6}_{-2}
χ^2_{RED}	1.3	0.9	0.9	1.3
Flux (20–100 keV)	7.2	6.8	3.2	0.6

matter available for accretion and its angular momentum. For example, if an accretion disk is formed, and its inner boundary layer is close to the co-rotation radius of the NS, changes in the accretion rate can result in positive or negative torques exerted on the NS magnetosphere. During the BS the Be disk is expected to be thick and large (see Blay et al. [3]) . This very dense disk contains matter with enough angular momentum to affect the NS rotation. During the FS, when we expect the Be star disk to be very small and thin, the NS will not be affected by the disk matter (with very low angular momentum) and the spin period will remain very stable.

4. CONCLUSIONS

We have been able, for the first time for SAX J2103.5+4545, to compare the source behaviour in both the faint and bright states with *INTEGRAL* data. Although this study is still preliminary, we can already notice the important differences in both the spectral shape and the pulse period evolution of the source between the two states. On one hand, we have seen that the spectral state of the source changes from a softer spectrum during the BS to a harder spectrum during the FS, with the possible presence of an intermediate state during the transition from BS to FS. On the other hand, data suggest that, while during BS there is an interesting pulse perid evolution, during FS the pulse period remains quite stable and around ∼352 s, the last value measured during the BS. This behaviour is compatible with the BeX interpretation and the peculiarity of the closeness of the NS to the Be star in SAX J2103.5+4545 (see Reig et al [7], Blay et al [3], [4]). As more data become available through the *INTEGRAL* Galactic Plan survey scans, and with the next onset of the BS, we will be able to confirm or discard these trends, and to perform a deeper analysis of both states and the transition from one to the other.

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