SAX J2103.5+4545, A PECULIAR HMXRB OBSERVED BY INTEGRAL

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ABSTRACT

We present an INTEGRAL data analysis of the X-ray transient SAX J2103.5+4545 during December 2002. The source showed two type-I outbursts in this period. The INTEGRAL location agrees with the position of the recently proposed optical counterpart. A power-law model was fitted to the 10–100 keV spectrum and a photon index of 2.5±0.1 was derived. The X-ray luminosity in the 10-100 keV energy range was 3.5×10^{36} erg s^{-1}. These results indicate that the source was in a bright state. A 355-second pulse period was measured.

Key words: INTEGRAL – binary systems – neutron star – accretion – HMXRB – BeX.

1. INTRODUCTION

SAX J2103.5+4545 was discovered with BeppoSAX in 1997 during a bright outburst, see Hulleman et al (1998). X-ray pulsed emission with a 358.61 second period was detected. The best fit to the spectra was an absorbed power-law of index 1.27. Two more detections are reported in the literature, in October 1999 and March 2001 (Baykal et al. 2000; 2002). The orbital parameters of the system were found by means of pulse time analysis, yielding a 12.65±0.25 day orbital period and an eccentricity of e=0.4±0.2. The presence of pulsations and spectral properties indicated that most likely the source was a High Mass X-ray Binary system (HMXRB) with a neutron star as the source of the X-ray emission. The orbital modulation of the X-ray emission suggested that the system is a BeX-ray binary. In these systems the pulsed X-ray emission is produced by the accretion of matter pulled from the dense envelope of the Be star onto the magnetic poles of the compact companion. Accretion is enhanced every time the neutron star passes through the periastron, producing the periodic, orbital-modulated, outbursts which are typical in BeX systems, called type-I outbursts.

Although an attempt was made to identify a close-by early-type B8 star, namely HD 200709, as the optical counterpart to the system, it was only recently that the optical companion was identified with a B0V star (Reig et al, 2003; 2004).

Lutovinov et al (2003) and Del Santo et al (2003) reported the detection of SAX J2103.5+4545 during December 2002 and January 2003 with INTEGRAL data.

2. OBSERVATIONS AND DATA REDUCTION

During December 2002 the Cygnus X-1 region was intensively monitored, with both staring and dithering observation modes. Several sources were detected, among them Cyg X-1 itself, SAX J2103.5+4545, Cyg X-3, and EXO 2030+375. SAX J2103.5+4545 showed two type-I outbursts during these observations. We found that the source was visible with a periodicity in coincidence with the modulation seen in the simultaneous RXTE-ASM observations during December 2002 (see Fig. 1).

Images, spectra, and light curves from ISGRI, SPI and JEMX were obtained by using the Integral Science Data Center (ISDC) official software release (OSA version 3.0). The software analysis is described in Goldwurm et al. (2003), Diehl et al. (2003) and Westergaard et al. (2003).

3. DATA ANALYSIS

3.1. Imaging

ISGRI detects the source in a total of 280 pointings, giving the best quality imaging for 60 of them. SPI detects the source from revolutions 19 up to revolution 23. JEMX, with its twin instruments, JEMX1 and JEMX2, only gives us positive detections of the source for 10 pointings spread in revolutions number 23 and 25. This is due to the small field of view of JEMX and the dithering patter used.

Best ISGRI position is 21h 03m 31s of right ascension and 45^o 45' 00" of declination, with a 1 arcmin error radius. Best JEMX source location is 21h 03m 37s of R.A. and 45^o 45' 03" of declination, with an error radius of 30 arcseconds. These values represent a considerable improvement with respect to the ~2 arcmin error radius of the Wide Field Camera on board BeppoSax.

Table 1. Spectra extraction summary. Values for a power-law fitting for all 3 instruments, JEMX, ISGRI and SPI. One revolution lasts for ~3 days, revolution 19 started at MJD 52617.86

	Rev.	Energy range (keV)	Γ	$\chi^2_{\rm red}$	DOF
JEMX	19	–	–	–	–
	20	–	–	–	–
	21	–	–	–	–
	22	–	–	–	–
	23	10-25	1.7±0.2	0.99	88
	24	–	–	–	–
	25	–	–	–	–
ISGRI	19	25-70	2.6±0.5	1.3	6
	20	–	–	–	–
	21	–	–	–	–
	22	–	–	–	–
	23	20-100	2.5±0.1	1.1	24
	24	–			–
	25	25-70	2.7±0.6	1.4	6
SPI	19	20-100	2.4±0.3	1.1	12
	20	–	–	–	–
	21	–	–	–	–
	22	–	–	–	–
	23	20-100	2.8±0.2	1.3	12
	24	–	–	–	–
	25	–	–	–	–

3.2. Timing

In Fig. 1 one day averaged fluxes from RXTE-ASM (2-12 keV), JEMX (5-25 keV), ISGRI (20-40 keV) and SPI (20-40 keV) are shown, with normalised flux units. The time span of the observations range from MJD 52615 up to MJD 52640, i.e., the whole Performance Verification (PV) phase. ISGRI and JEMX detections are in coincidence with peaks in the orbital-modulated SPI and RXTE-ASM light curves. These peaks show the occurrence of the two type-I outbursts through which SAXJ2103.5+4545 went during this period.

From MJD 52617.86 until 52620.43, ISGRI data show the peak of an outburst. The detection extends up to MJD 52623.43, but the significance of the detection lies bellow 3σ level A second outburst peak was detected by ISGRI during the period from MJD 52629.40 to MJD 52632.40. In this chance the source was well inside the FOV, moreover, in about a dozen pointings, it was inside the fully coded field of view (FCFOV) of ISGRI.

We have folded INTEGRAL data using the period and ephemeris published by Baykal et al. (2000). Figure 2 shows ISGRI and SPI folded data together

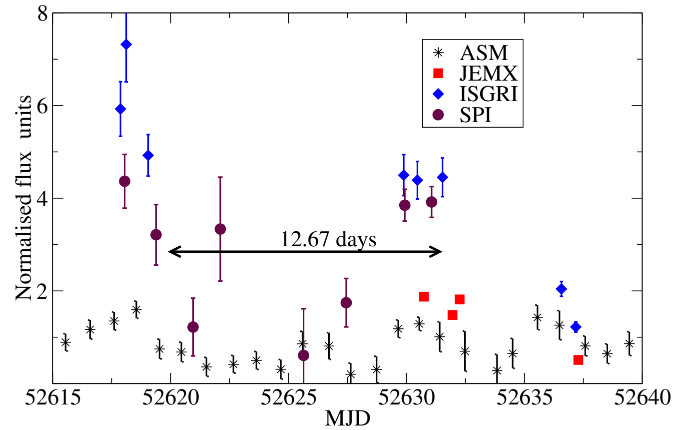

Figure 1. ISGRI, SPI, JEMX and ASM light curve. Each data point represents an averaged one day flux for all the instruments. Units are arbitrarily normalised flux units.

with RXTE-ASM observations. Both ISGRI and SPI fluxes correspond to the energy range 20-40 keV. According to Baykal et al. (2000) periastron passage corresponds to phase 0.4, while the peak of the outburst was observed 3 days later, i.e., at around phase 0.7. RXTE-ASM and INTEGRAL measures follow very nicely this trend, but Fig. 2 shows that there is some remnant emission between phases 0.0 and 0.2, very close to apastron.

3.3. Pulse Period

Pulse period analysis is hampered by the weakness of the source. ISGRI software for light curve extraction in sub-science window time-scales does not give yet very good results for off-axis and weak sources. Only data from pointings for which the source was in the FCFOV were used. That makes a total of 17 pointings. An average power spectrum is shown in Fig. 3. This power spectrum was obtained by averaging the Fast Fourier transformed light curves of each pointing. The maximum power is found for the frequency 0.00281 Hz, consistent with the known pulse period of the system.

Once we ensured the presence of pulsations we carried out an epoch folding analysis of the entire 1-s binned light curve of revolution 23. The time-span of these observations is almost 2 days. The resulting pulse period is 354.9±0.5 seconds, in excellent agreement with that reported by Inam et al. (2004) of 354.794 seconds.

3.4. Spectral Analysis

The total number of good spectra was 19 for the three instruments. For ISGRI and JEMX spectra are

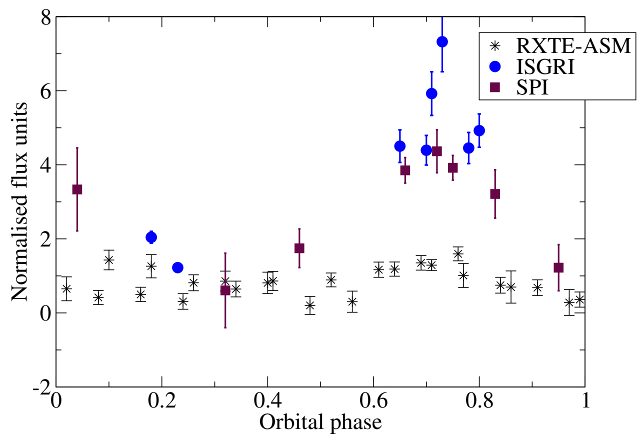

Figure 2. ISGRI, SPI, and ASM folded light curve. A period of 12.67 days have been used. MJD 51519.3 has been taken as orbital ephemeris (Baykal et al. 2000).

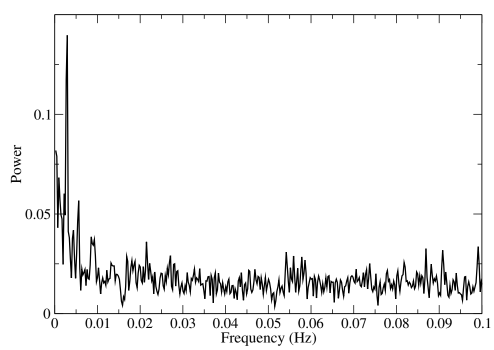

Figure 3. Power-spectrum for positive detections of SAXJ2103.5+4545 inside the FCFOV of ISGRI during revolution number 23. The maximum power is achieved at ~ 0.00281 *Hz.*

extracted for individual pointings. Three averaged spectra for MJD 5268.73, 52630.71 and 52636.69 were extracted for ISGRI, the former and latter ones being of bad quality. In the case of JEMX, a mean spectrum at MJD 52630.71 was obtained. For SPI, to increase the S/N, an averaged spectrum for the whole PV phase is used. Table 1 shows a summary of the spectral extraction for all the instruments per INTEGRAL revolution (one revolution lasts for ∼3 days, revolution 19 started at MJD 52617.86).

We have searched for spectral variations on ∼1 day time scale using ISGRI data. We see in Table 1 that there are no significant changes, within errors, in the spectral parameters in the whole period.

A 10-100 keV spectrum using all three instruments for SAX J2103.5+4545 is shown in Fig. 4. We have plotted together a mean spectrum of ISGRI and JEMX for MJD 52630.71. However, in the case of SPI an averaged spectrum for all PV phase is used. Bellow 10 keV no data from JEMX is considered, because of known vignetting and Response Matrix Function (RMF) problems in the JEMX software included in the official INTEGRAL software release (OSA version 3.0). The best-fit parameters for the energy range 10-100 keV are shown in Table 2. We have fitted a power-law model. In order to check for consistency with previous results, we also added a high energy cut-off with fixed paramteres $E_{\rm cut} = 7.89$ keV and $E_{\rm fold} = 27.1$ keV (Baykal et al. 2002). The flux of 6.8×10^{36} erg s^{-1} and the spectral photon index of 1.2 ± 0.1 are in excellent agreement with those of Baykal et al. (2002) and indicate that the source was in the bright state during the INTEGRAL observations.

While ISGRI and JEMX spectra are means for MJD ∼52630.71 (during the second outburst), the SPI data contains also information from the previous outburst (at MJD ∼52619.15). Thus, we have performed an independent analysis using only data from ISGRI and JEMX, to check for possible deviations in the spectral parameters derived when SPI data from other period were included.Table 2 compares the result of the spectral fitting when SPI data were and were not included.

Table 2. Best-fit parameters for the joint spectra using: A) JEMX, ISGRI and SPI data ; B) JEMX and ISGRI data. For both cases the forced cut-off is at 7.89 keV and the forced folding energy is 27.1 keV.

A) JEMX, ISGRI and SPI data

POWERLAW

E. Range (keV)	Ph. Ind	Flux erg cm^{-2} s^{-1}	χ^2_{RED}	DOF
10-100	2.6± 0.1	6.8×10^{-10}	1.4	124

POWER-LAW + CUT OFF

E. (keV)	Ph. Ind	Flux erg cm^{-2} s^{-1}	chi^2_{RED}	DOF
10-100	1.2± 0.1	6.9×10^{-10}	1.6	124

B) JEMX and ISGRI data

POWER-LAW

E. Range (keV)	Ph. Ind	Flux erg cm^{-2} s^{-1}	χ^2_{RED}	DOF
10-100	2.3± 0.1	6.3×10^{-10}	1.5	92

POWER-LAW + CUT OFF

E. Range (keV)	Ph. Ind	Flux erg cm^{-2} s^{-1}	χ^2_{RED}	DOF
10-100	1.2± 0.1	6.2×10^{-10}	1.1	92

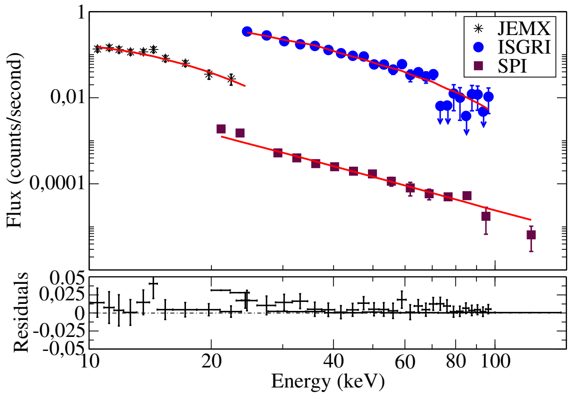

Figure 4. Fit to joint JEMX, ISGRI and SPI spectrum. JEMX and ISGRI spectra are mean spectra for revolution 23. For SPI a mean spectrum for December 2002 is used.

4. DISCUSSION AND CONCLUSION

We have shown a timing and spectral analysis of the two outbursts which SAX J2103.5+4545 underwent during December 2002. The capabilities of the INTEGRAL mission to perform a complete study of this kind of sources are shown. Our results are in very good agreement with previous ones, showing the source to be in a bright state. Inam et al. (2004) analyzed RXTE and XMM data for December 2002 and January 2003, contemporaneous to the period analyzed in this work. They found a pulse period of 354.794 seconds and spectral parameters compatible with a bright state. Their calculated unabsorbed 2-10 keV flux of (6.6×10^{-10} erg cm^{-2} s^{-1}) is equivalent to the one we find (6.8×10^{-10} erg cm^{-2} s^{-1} for 10-100 keV). Using a distance of 3.2 kpc, as in Inam et al. (2004), we find a luminosity of 8×10^{35} erg s^{-1}. If we used, instead, 6.5 kpc (Reig et al., 2004) calculated from the amount of absorption to the system (estimated to be $A_V = 4.2 \pm 0.2$), then we find a luminosity of 3.5×10^{36} erg s^{-1}. Both values are compatible with the bright state and type I outburst.

The measured 355 seconds period is compatible with a series of spin-up episodes undergone by SAX J2103.5+4545. Although a short spin-down phase was found by Baykal et al. (2002), it seems that the source has been continuously accelerated by the in-falling accretion of matter. The change in pulse period would be compatible with a continuous spin-up of 2.5×10^{-13} Hz s^{-1} ever since 1999. The source seems to be far from the equilibrium period (Reig et al, 2004). Then, in an scenario like the one at SAX J2103.5+4545, the $P_{orb} - P_{pulse}$ relationship (Corbet 1986) actually does not stand.

The long time-scale variations of intensity of the outbursts, as shown in Baykal et al. (2002), are related to the Be star envelope dynamics. Further studies and simultaneous observations in the optical and high-energy bands are needed to disentangle the connection between the changes in the Be star envelope and the behaviour in the high-energy bands. This system, with the shortest period known for a BeX, shows itself as the perfect laboratory to test all these theories.

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