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First IBIS results on the high energy emission of Cygnus X-2*

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Abstract. The bright low-mass X-ray binary Cyg X-2 was in the field of view of the IBIS telescope during the early Cygnus region observations, executed during the INTEGRAL Performance Verification Phase. The data presented are spanning about one week and cover the rising edge of one of the two peaks of the ≈82 day cycle of the Cyg X-2 light curve. The IBIS data in the energy range 20−40 keV exhibit flux variation correlated with the *RXTE*/ASM light curve. Two different main exposures, separated by ≈5 days are found to be characterized by sensibly different spectra, with significant softening and higher X-ray luminosity in the second part, coincident with the long-term cycle peak. At high energies, both measured spectra are very steep. The ratio of the 30−45 keV and 20−30 keV detected fluxes is ≈0.30, against a value of 0.95 expected for a Crab-like spectrum. No positive detection exists for $E \geq 45$ keV, with a flux upper limit (5σ) of $\sim 1.4 \times 10^{-10}$ erg cm^{-2} s^{-1} in the 45−100 keV band.

Key words. binaries: individual – stars:individual:Cyg X-2 – stars: neutron – X-rays: binaries

1. Introduction

Cyg X-2 is a well known, and one of the best studied binary systems. Being a bright persistent source, many X-ray spectral and timing properties have been established and the main binary parameters determined during recent years observations. Cyg X-2 is located at a distance of ≈8 kpc and is identified as a low-mass X-ray binary (LMXB), consisting of a weakly magnetized neutron star (NS) orbiting the late-type companion star V1341 Cyg with a 9.844 days orbital period (Cowley et al. 1979). Evidence for the NS nature of the compact object comes from the detection of type I X-ray bursts (Smale 1998) and from the optical measurement of the mass of the compact object, (1.78 ± 0.23) $M_\odot$ (Orosz & Kuulkers 1999). The short time duration (~5 s) X-ray bursts detected from Cyg X-2 are a challenge to the current theories. Short bursts are recognized as typical of accretion rates lower than $\sim 10^{-10}$ $M_\odot$/yr (Kuulkers et al. 2002 and refs. therein) so they are not expected from sources accreting at near-Eddington levels, like Cyg X-2. Currently, short type I bursts have been observed in at least three high luminosity sources: Cyg X-2, GX 17+2 (Kuulkers et al. 2002) and GX 3+1 (Den Hartog et al. 2003).

Cyg X-2 has a bright, highly variable X-ray emission. Its X-ray light curve has a clear pattern, showing two peaks repeating periodically with a cycle of ~82 days (Vrtilek et al. 2003, see also Wijnands et al. 1996 for a previous determination), as is also shown in Fig. 1. The X-ray luminosity changes regularly by a factor ~5 to 10 in time scales of hours to days (see e.g. Di Salvo et al. 2002; Piraino et al. 2002). Associated to these luminosity changes are important spectral variations. When represented in terms of colour-colour diagrams (Hasinger & van der Klis 1989) the spectral variations describe a Z-shaped track, with shape and morphology depending on the source intensity (Kuulkers et al. 1996). Distinct timing features (QPOs in the power spectrum) are found to be associated to the three different limbs of the Z (for a review see van der Klis 2000). This behaviour has also been seen in other five sources common to the bright LMXB class: GX 5-1, Sco X-1, GX 17+2, GX 340+0 and GX 349+2 (Sco X-2), forming the class of Z-sources. On short/medium time scales, (~hours) the spectral softness if found to be positively correlated to the X-ray luminosity, consistently with the overall spectral behaviour of LMXBs in the X-rays. However, the correlation of spectral/timing properties with accretion rate on long-term periods is still unclear. For example, the source may exhibit the same spectral softness and/or the same characteristic QPO frequencies while changing a factor of a few in X-ray luminosity. According to a recent interpretation (van der Klis 2001), this is compatible with a long-time scale averaged response to variations of the accretion rate. On the other hand, as far as the spectral modelling is

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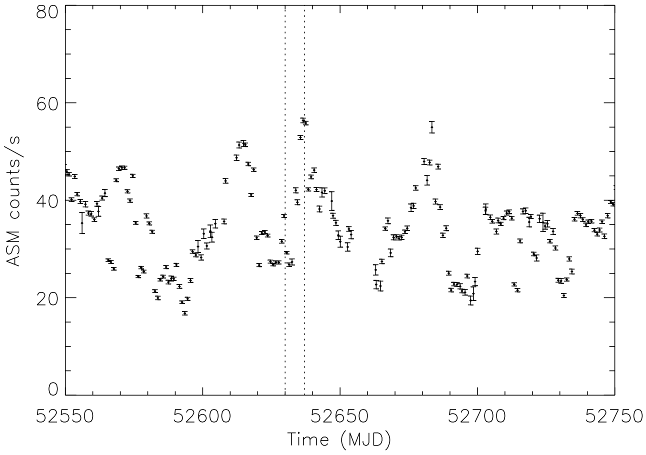

Fig. 1. A light curve of the 2−10 keV intensity of Cyg X2 (data are courtesy of the *RXTE/ASM* team), showing the double peak structure typical of the ~82 days long term cycle. Dotted lines indicate the epoch of the IBIS observations reported here.

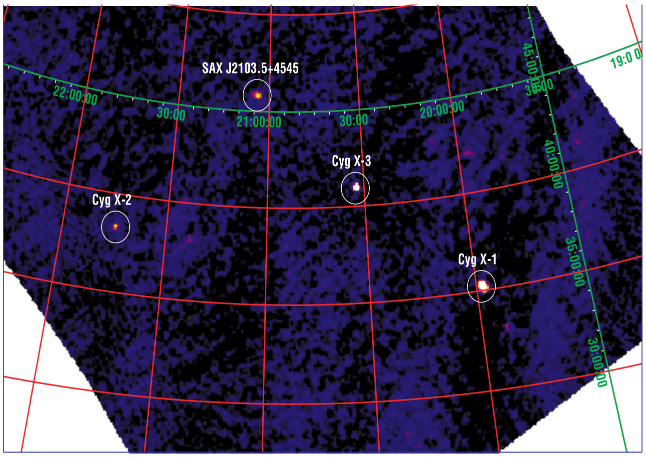

Fig. 2. IBIS/ISGRI mosaic image obtained from an observation of a field near to the Cygnus region, in the energy range 20−30 keV. Cyg X-2 is clearly visible at the left, appearing at a significance level of 23 σ. The other three sources visible, Cyg X-1, Cyg X-3 and SAX J2103.5+4545 are detected at 190, 126 and 24 σ, respectively.

concerned, the most recent studies have converged to a generally agreed scheme, in which the soft component is described by a Planckian type law, i.e. blackbody or disk blackbody (see Mitsuda et al. 1984), whereas the hard component, luminous up to a few tens of keV is described by a thermal Comptonization spectrum (Titarchuck 1994). This model, with the addition of an emission Fe Kα line and, in some cases, other lines for $E \approx 1$ keV (Kuulkers et al. 1997) is capable of providing a good description of the X-ray spectrum of Cyg X-2 (for a recent discussion, see Done et al. 2002 and refs. therein). In case of bright LMXBs, the Comptonization spectrum is generally characterized by a relatively low (≤10 keV) temperature of the electron plasma, whereas for atoll sources and most of the low luminosity LMXB X-ray bursters, $kT_e \sim 50$ keV (Barret et al. 2000). This is currently explained as an effect of cooling of the Comptonizing plasma, caused by a strong soft X-ray irradiation.

Despite these latest developments, however, the picture of the origin of hard X-ray emission from Cyg X-2, as well for the other Z sources, is not yet clear. Recent spectral measurements at high energies have detected a possible, further spectral component which is needed to explain an observed hard tail. Modelled by a power law, this hard tail has a photon spectral slope Γ as hard as ~2 (Di Salvo et al. 2002), or being in the range ~2.5–3.2 (Piraino et al. 2002). A similar hard tail has been also detected from other Z sources, namely GX 17+2 (Di Salvo et al. 2000), GX 349+2 (Di Salvo et al. 2001) and Sco X-1 (D'Amico et al. 2001; Strickman & Barret 2000). Hard tails in these sources are found to be highly variable, with many cases of non-detection.

2. Observations and data analysis

The IBIS instrument on board *INTEGRAL* has been observing the Cygnus region extensively during the fall of 2002. In particular, in observations when Cyg X-1 was pointed off-axis, Cyg X-2 was in the partially coded field of view of the IBIS telescope. Within these observations we have selected IBIS/ISGRI data from 16 *science windows*, each corresponding to an exposure time of ≈2150 s.

ISGRI is the soft γ-ray, CdTe detector of *INTEGRAL*/IBIS, operative in the energy range 15−1000 keV with an active area of 2600 cm^2. Its on-axis sensitivity (5σ) in the range 15−50 keV is better than ≈2 mCrab with an exposure time of 10^5 s. Due to the large field-of-view, ISGRI is an excellent monitor instrument for sources in regions extensively observed by *INTEGRAL*, in particular for sources at low Galactic latitudes. For a detailed description of IBIS and ISGRI we refer to Ubertini et al. (2003) and Lebrun et al. (2003), respectively.

For the purpose of data selection, we required the source offset ≤12 deg from the telescope axis, in order to reduce the sensitivity losses and the unknown systematic effects which could arise, in this early phase, by very large offset angles. The selected observations are reported in detail in Table 1. The total IBIS exposure time for these pointings is 32.8 ks and is splitted in two main exposures, separated by a time gap of 5.5 days, whereas the offset of the source was always in the range 11.2−11.8 deg. The very low spread of offset values is essentially due to the INTEGRAL observing strategy based on *dithering* around a given target (Winkler et al. 2003), which was also adopted for part of the in-flight calibration observations.

Cyg X-2 was detected in all but the first two pointings. In Fig. 2 we show a *mosaic* image in the energy band 20−30 keV, built using the total available exposure time. Cyg X-2 is visible together with other bright, known sources: from right to left, Cyg X-1, Cyg X-3 and the transient SAX J2103.5+4545, respectively (for the latter, we refer the reader to Lutovinov et al. 2003). The data were processed by means of the IBIS off-line analysis S/W (Goldwurm et al. 2003), version 1.1. For each pointing we have extracted the count-rate flux measured after processing the related image. In Fig. 3, bottom panel, the light curve of the

Table 1. Summary of the *INTEGRAL*/IBIS pointings used for the analysis. For every pointing it shows the related start time, duration, pointing coordinates RA, Dec (equinox 2000), and offset angle respect to Cyg X-2.

Start time (MJD, days)	Duration (s)	RA (deg)	Dec (deg)	Offset (deg)
52629.63110	604	311.762	39.058	11.260
52629.63965	2164	311.663	39.116	11.335
52629.88000	2158	311.818	41.113	11.374
52629.90662	2157	311.988	43.109	11.748
52630.65271	2146	311.989	43.109	11.748
52630.67932	2283	311.818	41.113	11.374
52630.94812	2148	311.664	39.116	11.335
52631.21423	2147	311.818	41.113	11.374
52631.24084	2159	311.988	43.109	11.748
52636.66309	2246	325.154	49.879	11.580
52636.70850	2147	316.810	47.486	11.428
52637.22803	2095	311.901	42.113	11.521
52637.25476	2058	311.735	40.117	11.315
52637.49548	2100	311.593	38.120	11.444
52637.74109	2590	311.744	40.115	11.308
52637.77271	2092	311.907	42.115	11.517

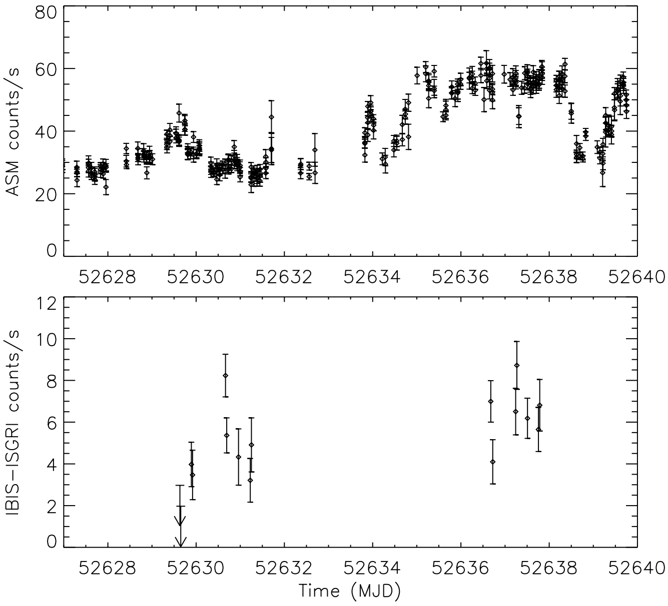

Fig. 3. Light curves of Cyg X-2 obtained on November 2002, for *RXTE*/ASM (data are courtesy of *RXTE*/ASM team) in the energy range 2−10 keV (top) and from IBIS/ISGRI in the range 20−40 keV (bottom). The first two IBIS measurements are 2 σ upper limits. Note that the unit used for ISGRI as counts/sec are, to a certain extent, arbitrary (see text).

source in the energy band 20−40 keV is shown. The intensity values, referred as ISGRI counts/s, are uncorrected for systematic effects due to the source offset and hence, cannot be compared directly to other on-axis measurements or to observations with significantly different offsets. The reported intensity probably underestimates the ISGRI counts/s for an on-axis source by a factor ~1.5. On the other hand, values of fluxes reported hereafter have been derived by comparing the ISGRI intensities by the intensity measured from the Crab nebula during the calibration observations, at a close value of offset position (9.6 deg). So they are corrected, to a large extent, from this type of systematics. The light curve obtained from *RXTE* All Sky Monitor (ASM) data in the energy band 2−10 keV is also shown. The IBIS intensities are found to be correlated to the ASM data, eventhough the high energy flux shows less variation. The period spanned by the data corresponds to the X-ray flux increasing approximately from the minimum to the maximum of one of the two peaks in the long-term cycle. Since the low energy data shows more intensity change, there is straightforward evidence from Fig. 3, for the spectrum to become softer in the second series of pointings.

For this reason and also due to the significant separation of the two data sections, we consider two different exposures (see Table 2). In order to estimate hardness ratios we choose two contiguous energy bands, 20−30 keV and 30−45 keV. Reconstructed sky images were computed separately for the two exposures. From these images, and by cross-calibration with the Crab offset exposure we estimate average flux values, as reported in Table 2. In this preliminary phase of the calibration, we have allowed a 10% systematic error in these flux estimates (for details see Goldwurm et al. 2003).

The ratios of the 20−30 keV to the 30−45 keV count rates are, after offset correction, (2.89 ± 0.56) and (3.33 ± 0.59) for the two observations. Therefore, the softening of the spectrum is evident only by comparison with the ASM data.

Table 2. Flux values measured during the two main exposures (see text). For both exposures it shows: the related time interval, as values of MJD-52000; the energy band, in keV; the measured flux, in units of 10^{-11} erg cm^{-2} s^{-1}. Errors in flux values allow a 10% systematic error.

Time interval (days, MJD-52000)	Energy band (keV)	Flux (10^{-11} erg cm^{-2} s^{-1})
629.888–631.266	20–30	30 ± 4
629.888–631.266	30–45	9.2 ± 1.9
636.633–637.798	20–30	37 ± 5
636.633–637.798	30–45	9.7 ± 1.9

3. Conclusions

We have reported on the first results of a monitoring of Cyg X-2 performed during $\sim$10 days in December 2002. Due to the large offset angle of the source and its steep spectrum, the observations were much limited in sensitivity. A joint analysis of the IBIS/ISGRI and *RXTE*/ASM light curves reveals a softening of the X-ray spectrum on a time scale of $\approx$1 week, corresponding to the rising from one low intensity phase of the long term cycle of $\approx$82 days. During the softening, the $20-40$ keV luminosities changed only from ≈ 3.5 to $\approx 4.2 \times 10^{36}$ erg s^{-1} (assuming a distance of 8 kpc) against a change of luminosity of a factor of $\sim$2 in the $2-10$ keV band. During the second exposure, the $2-10$ keV luminosity was $\sim 10^{38}$ erg s^{-1} or even more. The hard X-ray spectrum is found to be very steep. The *luminosity* hardness ratios for the energy bands $30-45$ keV and $20-30$ keV are ≈ 0.30 or even less, indicating a spectral slope significantly greater than ~ 3.5 (when this is approximated by a power law). Such a steep spectral slope is consistent with the shape of the high energy tail of the thermal comptonization spectrum observed from Cyg X-2. There is no evidence, instead, of a hard tail extending beyond 40 keV, with a 5σ upper limit of 1.3×10^{-3} ph cm^{-2} s^{-1}.

We note that the lack of detection of a hard tail is not contradictory with other observations of such feature in the spectrum of Cyg X-2, as this component could be variable or sporadic. Further monitoring and spectral observations by INTEGRAL will help clarifying the nature of the high energy emission from this source.

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