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An X-ray Perspective on a Gamma-Ray Mission

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Abstract The most recent astrophysics mission of ESA is INTEGRAL, a mission dedicated to gamma-ray astronomy (Winkler et al. 2003). INTEGRAL carries two gamma-ray instruments: the imager, IBIS, and the spectrometer, SPI, and in addition an optical monitor, OMC, and an X-ray monitor, JEM-X. INTEGRAL is an observatory mission with 70% of the observation time available to the general astronomical community through a peer-reviewed selection process. This paper describes the INTEGRAL mission primarily as seen from the JEM-X perspective.

Key words: techniques: Coded mask telescopes – stars: X-ray and gamma-ray sources – stars: individual: Crab Nebula

1 INTRODUCTION

INTEGRAL was launched on October 17, 2002. It operates in an elliptical 3 day orbit permitting about 65 hours of observation outside the Earths radiation belts per orbit. The orbital insertion was achieved with a minimal usage of fuel and the satellite performs extremely well so both with respect to electrical power and attitude control fuel there is ample margin for achieving a lifetime of five years or more.

INTEGRAL carries four instruments, two large gamma-ray instruments and two smaller monitors — one operating in the optical V-band, and one in the X-ray band from 3 to 35 keV. The main technical characteristics of the four instruments can be found in Table 1.

Table 1 INTEGRAL Instrument Characteristics

	SPI	IBIS	JEM-X	OMC
Energy Range (keV)	20 – 8000	14 – 10000	3 – 35	V-band
Energy Resolution	0.2% @ 1 MeV	8% @ 100 keV	9% @ 22 keV	
Field of view†	16° (35°)	$9^\circ \times 9^\circ$ ($29^\circ \times 29^\circ$)	5° (12°)	$5^\circ \times 5^\circ$
Angular Resolution	2.7°	12 arcmin	3 arcmin	17 arcsec
Detector Area (cm^2)	500	2300	900	(5 cm lens)

† Numbers outside parentheses: Fully coded, inside parentheses: partially coded field

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The primary aim of SPI, the spectrometer is detailed spectral studies of point and diffuse sources of line emission, mostly nuclear deexcitation lines from radioactive isotopes (Vedrenne et al. 2003). The IBIS instrument is designed to provide the most detailed imaging yet achieved in the hard X-ray range combined with the first large scale application of room temperature semiconductor detectors in X-ray astronomy (Ubertini et al. 2003). This gives the IBIS instrument some unique properties which have already led to the discovery of several new sources with unusual spectra. JEM-X provides the extension to lower energies of the source spectra and adds finer localization capability to the instrument complement (Lund et al. 2003; Brandt et al. 2003a). The Optical Monitor Camera on INTEGRAL is described in Mas-Hesse et al. 2003.

A key element in the INTEGRAL observatory complex is the INTEGRAL Science Data Center (ISDC) in Geneva. ISDC receives the raw INTEGRAL data and performs a number of common processing tasks before delivering the data to the observers (Courvoisier et al. 2003a). An essential task for ISDC is the quick-look analysis of the data which is the basis for early detection of transient sources. The INTEGRAL Burst Alert System, IBAS, providing teal time alerts for gamma-ray bursts is also one of the software tasks being executed from ISDC (Mereghetti et al. 2003).

2 INTEGRAL OBSERVATION TECHNICALITIES

The three high-energy instruments are all "coded mask" instruments, this fact is important both for understanding the way the observations are performed and for appreciating the complexity of the data analysis.

The 19 high resolution detectors of SPI does not in a single observation provide enough information to separate the contributions from multiple sources in the field of view — multiple sources is a quite common situation. To overcome this difficulty observations are normally performed as a sequence of individual pointings in a raster pattern around the primary target. The pattern preferred by SPI is a 5 by 5 raster with 2 degree separation between points. Unfortunately, due to the more restricted field of view of JEM-X, the use of the 5 by 5 raster means that JEM-X will view the primary target effectively only during a fraction of the raster. Continous light curves in the JEM-X energy range are therefore difficult to recover when this raster pattern is used. An alternative raster, with only 7 points in a hexagonal pattern, is much better for JEM-X, but limits the SPI capabilities for handling many sources. The choice of raster pattern is of smaller significance for IBIS since the field of view is large enough to accomodate the full 5 by 5 pattern; still the raster movements complicates the IBIS analysis both regarding spectral extraction and light curve recovery. The choice of raster pattern must be done by the observer at proposal time, and should be carefully considered according to the purpose of the observation.

3 INSTRUMENT PERFORMANCE

All four instruments on INTEGRAL are working fine and are returning excellent results. There have been a number of initial problems — higher background than expected, insufficient telemetry capacity to cope with the higher count rates, and, in the case of JEM-X, a problem with detector erosion due to the cosmic ray bombardment. But, one by one, these problems have been brought under control, and recently even the telemetry bandwidth have been increased, ensuring that all data can be retrieved in the future.

In a recent Mission Performance Review it was concluded that the mission is performing so well that we shall now seek to get the mission life extended from two to five years.

So, despite some initial difficulties and data complications INTEGRAL promises to be a very productive mission, it is still young, and the instrument teams are working hard to optimize the data analysis software.

4 EXAMPLES OF EARLY JEM-X OBSERVATIONS

4.1 Core Programme and Calibration Observations

The available observation time is divided into two parts: 70% goes to the "General Observation Programme" (based on proposals from the general community), and the remaining 30% is reserved for the "Core Programme", which is decided by the INTEGRAL Science Team (the hardware and software providers). The Core Programme has three parts:

– The Galactic Plane Scans — every 12 days the accessible parts of the Galactic plane is scanned to detect new transients and monitor the state of the known sources.
– The Galactic Central Radian Deep Exposure — the central $20° \times 60°$ area of our Galaxy observed for a total time of 4.7×10^6 s per year.
– Pointed observations — for instance follow-up on transients.

Figure 1 shows the distribution of the 56 sources detected by JEM-X during the Core Programme observations of the first half year of the mission. Only the sources identified in analyses of individual pointings (each of about 30 minutes duration) are shown. More sources are bound to appear once a combined analysis of several science windows are undertaken. The names and characteristics of the sources of Fig. 1 are listed in Table 2.

Figure 2 illustrates the use of JEM-X for securing the identification of new sources discovered with INTEGRAL. In March 2003 IBIS detected a new source, IGR J17464-3213, in the constellation of Scorpius. The initial IBIS error circle had a diameter of 6 arcminutes. Within this error circle a new radio source was detected by VLA. During subsequent INTEGRAL observations, where the source was within the JEM-X field of view, the position derived from JEM-X matched the VLA candidate position to within the precision of the then known JEM-X alignment errors.

The Crab nebula and pulsar was observed as part of the instrument calibrations during February. These data are public. We have performed a timing analysis which demonstrate the good timing stability of the INTEGRAL data analysis chain. The analysis of the absolute timing of the Crab pulsar main pulse in the X-ray signal with respect to the corresponding peak observed in radio by Jodrell Bank brought to light an erroneous time shift of about 900 μs in the ground segment which also affected the timing for XMM. This error has now been corrected.

The position resolution of JEM-X is sufficient to demonstrate the fact that the Crab pulsar is offset from from the centroid of the nebular emission. The offset is seen as a phase dependent shift of the centroid of the total pulsar plus nebula signal, Fig. 3. The measured shift decreases with increasing energy, it is 14.4 ± 1.4 arcsec in the energy interval 3 to 8 keV and 10.5 ± 1.0 arcsec in the interval 13 to 25 keV (Brandt et al. 2003b).

JEM-X has observed a number of bright X-ray bursts. An example is shown in Fig 4. At high energies this burst exhibit two peaks. This is likely caused by radial expansion of the pulsar photosphere causing a reduction of the effective temperature during the maximum of the burst.

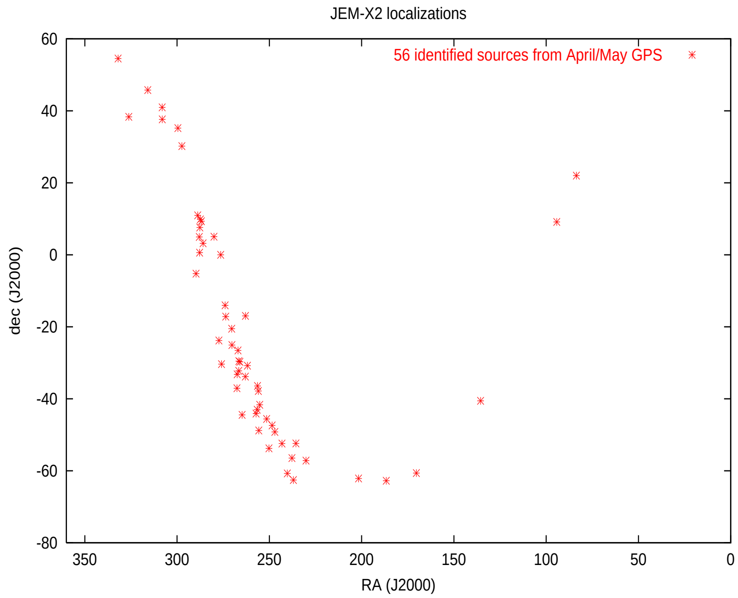

Fig. 1 Sources detected by JEM-X in single pointings during April and May 2003.

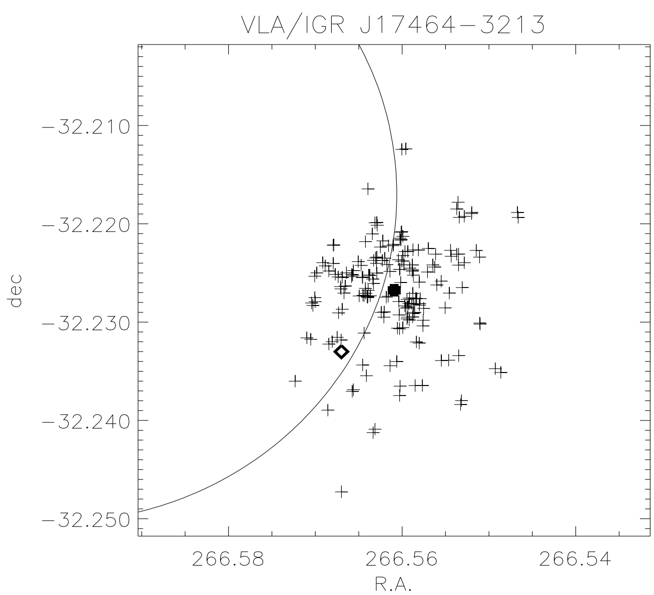

Fig. 2 JEM-X confirmation of suggested VLA radio-counterpart (open circle) of new source found by IBIS. The instrument alignment was not final at this time.

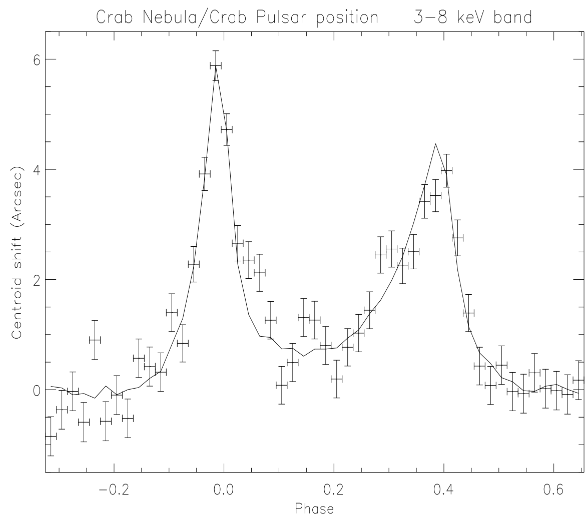

Fig. 3 Phase resolved oscillation of the centroid of the Crab X-ray position.

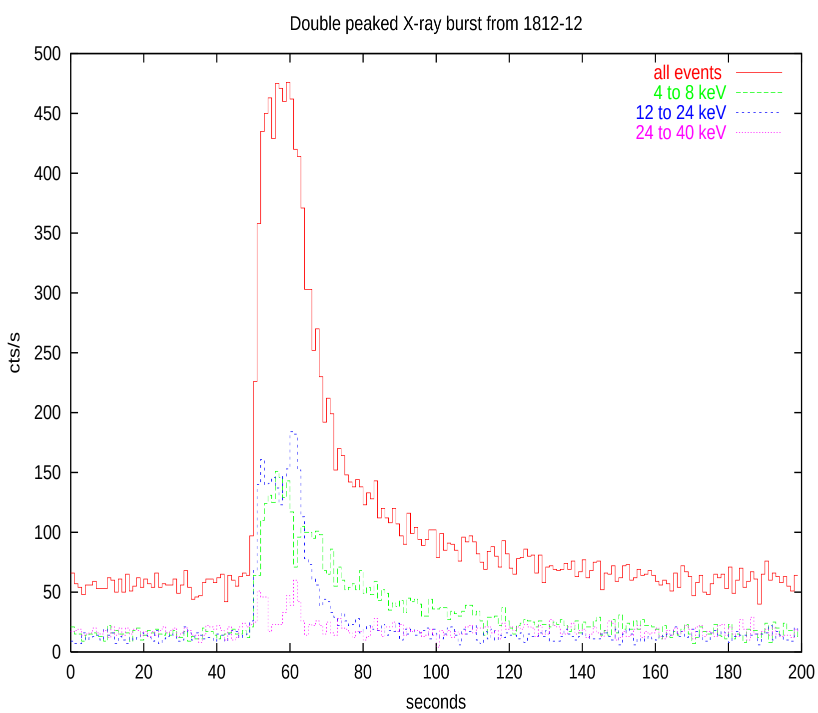

Fig. 4 X-ray burst from 1812−12. Note double peak at highest energies.

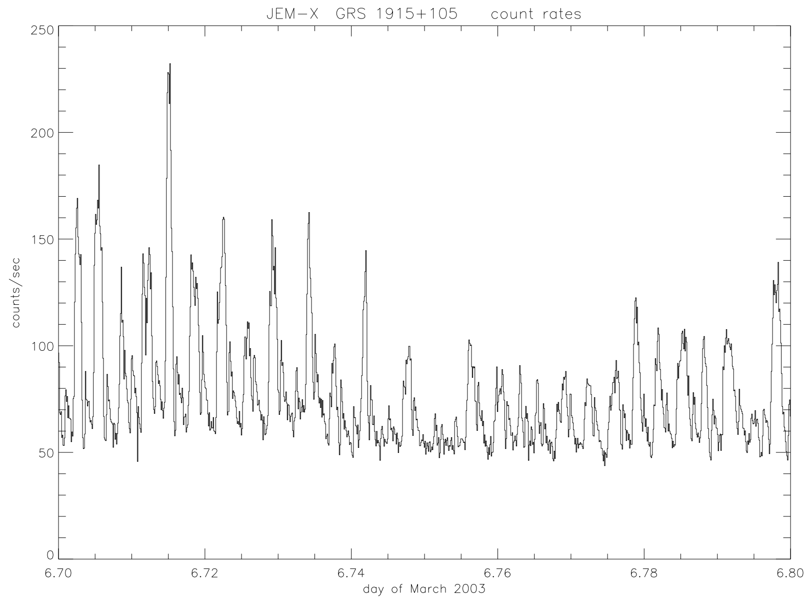

Fig. 5 Light curve of GRS 1915+105 during early March 2003.

4.2 Open Time Programme Observations

One of the prime targets during the early part of the INTEGRAL mission is the Galactic "microquasar", GRS 1915+105. This object is observed both during the Core programme and as part of a general observation proposal. During the first observing session in March 2003 the source was found to be in its strongly varying state previously also observed with RXTE (Hannikainen et al. 2003). The light curve from this first observation is shown in Fig. 5. In later observations the source has been equally bright, but much more stable. An extensive multiwavelength campaign was undertaken in April during which also radio and infrared data was obtained (Fuchs et al. 2003).

In January 2003 the black hole source XTE J1720−318 was observed in a flaring state with the All-Sky Monitor on RXTE. A target of opportunity observation was initiated with INTEGRAL. At the time of the INTEGRAL observation in late February the source intensity was much reduced and the spectrum was found to be very soft so only JEM-X could detect it with certainty. Figure 6 shows the observed energy spectrum compared with that of the Crab.

Although JEM-X is modest in size it is capable to observe relatively weak sources and also to provide some spectral information. As an example we may mention the observation of 3C 273 (T. Courvoisier et al. 2003b). For isolated sources JEM-X can of course not compete with much larger instruments like the PCA on RXTE, but in crowded field the ability to separate the contributions from individual sources may be a decisive advantage.

5 CONCLUSION

INTEGRAL is a wonderful new tool for multifrequency studies, and I can only recommend you to use it to its full capabilities.

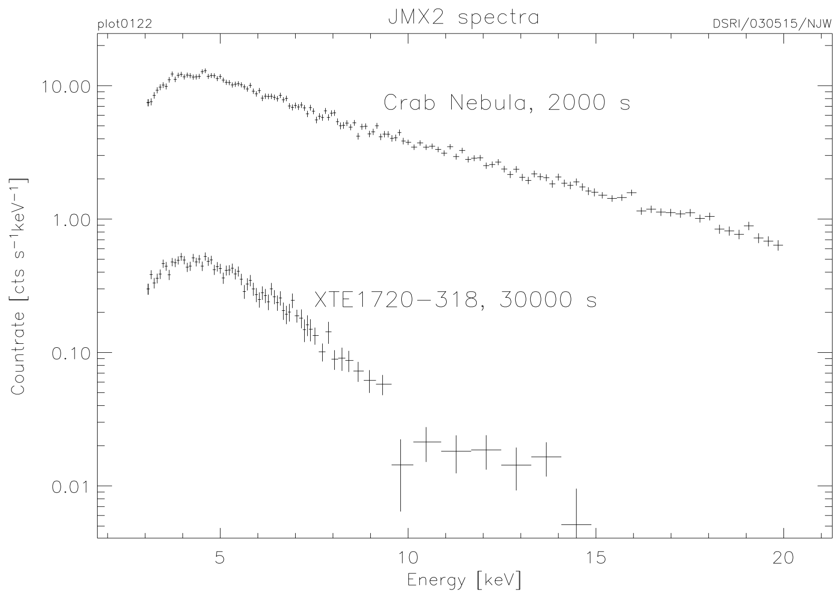

Fig. 6 Energy spectrum of black-hole XTE J1720−318 during late February 2003.

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