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The INTEGRAL mission – an overview

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Abstract. The ESA observatory INTEGRAL (International Gamma-Ray Astrophysics Laboratory) is dedicated to fine imaging and spectroscopy in the energy range 15 keV to 10 Mev with concurrent X-ray (3-35 keV) and optical monitoring. It was launched on October 17, 2002 and has been succesfully operating ever since. Its two main instruments the spectrometer SPI – optimized for high resolution spectroscopy – and the imager IBIS – optimized for for high resolution imaging – are complemented by the X-ray monitor JEM-X and the optical monitor OMC. All the high energy instruments use coded mask techniques, allowing imaging in the gamma-ray range and combining wide fields of view with high spatial resolution. The presentation gives an overview of the unique properties of INTEGRAL.

Keywords. gamma rays: observations, X-rays: stars.

1. Introduction

The gamma-ray observatory INTEGRAL (INTErnational Gamma-Ray Astrophysics Laboratory) is ESA's second gamma-ray mission after COS-B in 1975. It was selected in June 1993 as the next medium-size scientific mission within ESA's "Horizon 2000" programme, with important contributions from Russia (PROTON launcher) and NASA (Deep Space Network ground station).

INTEGRAL has been operating very succesfully since its launch on October 17, 2002. The ESA Science Programme Committee has approved a rolling mission extension, beyond the first two years, until at least 2008. Efforts are ongoing to extend the mission life further; at the current rate of consumption consumables would hold for >10 more years.

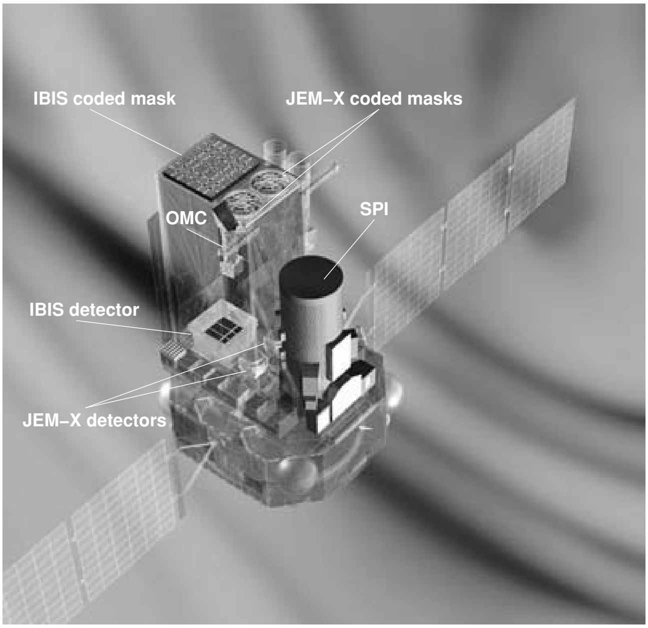

Figure 1. Artists impression of the INTEGRAL spacecraft. The dimensions are 5×2.8×3.2 m; the deployed solar panels are 16 m across.

2. Mission Overview

The spacecraft (Jensen *et al.* 2003) consists of a service module (bus) containing all spacecraft subsystems and a payload module containing the scientific instruments. The service module has been developed in parallel for two ESA scientific missions, INTEGRAL and XMM-Newton. The spacecraft has been built under ESA contract by a large industrial consortium, led by Alenia Spazio as prime contractor. The total launch mass was about 4 t.

Launched by a four-stage PROTON from Baikonur/Kazakhstan on 17 October 2002, INTEGRAL was inserted into a geosynchronous highly eccentric orbit with high perigee in order to provide long periods of uninterrupted observation with nearly constant background and away from trapped radiation (electron and proton radiation belts). The initial orbital parameters are: 72-hour orbit with an inclination of 52.2°, a height of perigee of 9000 km and a height of apogee of 154 000 km. Owing to background radiation effects in the high-energy detectors, scientific observations are carried out while the satellite is above a nominal altitude of 60 000 km (approaching radiation belts) and above 40 000 km (leaving radiation belts). This means that >80% of the time – or about 60 hours per orbit – can be used for scientific observations (real-time, 108 kbps science telemetry).

3. Payload

INTEGRAL carries two main gamma-ray instruments, the spectrometer SPI (Vedrenne *et al.* 2003) – optimized for the high-resolution gamma-ray line spectroscopy (20 keV-8 MeV), and the imager IBIS (Ubertini *et al.* 2003) – optimized for high-angular resolution imaging (15 keV-10 MeV). Two monitors, JEM-X (Lund *et al.* 2003) in the (3-35) keV X-ray band, and OMC (Mas-Hesse *et al.* 2003) in optical Johnson V-band complement the payload. An on-board particle radiation monitor allows an assessment of the radiation environment local to the spacecraft.

Table 1. Key parameters of the INTEGRAL payload.

Parameter	SPI	IBIS
Detector	19[a] Ge detectors (6×7 cm) cooled to 85 K	16384 CdTe pixels (4×4×2 mm) 4096 CsI pixels (8.4×8.4×30 mm)
Detector area (cm^2)	500	2600 (CdTe), 2890 (CsI)
Spectral resolution (FWHM)	3 keV @ 1.7 MeV	8 keV @ 100 keV
Field of view (fully coded)	16° (corner to corner)	9° × 9°
Angular resolution (FWHM)	2.5° (point source)	12’
Source location radius	$\leqslant$ 1.3°	$\leqslant$1’ (10σ sources)
Absolute timing accuracy	$\leqslant$200 μs	$\leqslant$200 μs
Mass (kg)	1309	746
Parameter	**JEM-X**	**OMC**
Energy range	4 keV – 35 keV	500 nm – 600 nm (V-filter)
Detector	Microstrip Xe/CH_4-gas detector (1.5 bar)	CCD (2061×1056 pixels) 1024×1024 pixels iaging area
Detector area (cm^2)	500 per detector[b]	
Spectral resolution (FWHM)	2 keV @ 22 keV	–
Limiting magnitude	–	17.8 (3σ, 5000 s)
Field of view (fully coded)	4.8° (corner to corner)	5° × 5°
Angular resolution (FWHM)	3’	25”
Source location radius	$\leqslant$30”	6”
Absolute timing accuracy	$\leqslant$200 μs	$\geqslant$1 s
Mass (kg)	65	17

[a] At the time of writing two detectors have failed

[b] Currently only one of the two JEM-X detectors is being operated

The spectrometer, imager and X-ray monitor share a common principle of operation: they are all coded aperture mask telescopes. The coded mask technique is the key for imaging, which is all-important in separating and locating sources. It also provides good background subtraction because for any particular source direction the detector pixels can be considered to be split into two intermingled subsets, those capable of viewing the source and those for which the flux is blocked by opaque mask elements. Effectively the latter subset provide an exactly contemporaneous background measurement for the former, made under identical conditions.

The payload was extensively calibrated pre-launch on instrument and system level. During the early mission phase, the in-flight calibration was initially performed on Cyg X-1, and empty fields, and completed later using the Crab nebula and pulsar. Further in-flight calibration refinement is being done via regular observations of the Crab twice per year.

All instruments (Fig. 1 and Table 1) are co-aligned with overlapping fully coded field-of-views ranging from 4.8 diameter (JEM-X), 5 (OMC), to 9 (IBIS) and 16 corner-to-corner (SPI) – see also Fig. 3 – and they are operated simultaneously, so, an observer receives all data from all four instruments, allowing to combine data across instruments. Alternatively, many users with different scientific goals, e.g., point sources vs. diffuse emission, can make use of the same data.

4. Ground Segment

The ground segment consists of two major elements, the Operations Ground Segment (OGS) and the Science Ground Segment (SGS). The OGS, consisting of the ESA and NASA ground stations and the Mission Operations Centre at ESOC, implements the observation plan within the spacecraft system constraints into an operational command sequence. In addition, the OGS performs all standard spacecraft and payload operations and maintenance tasks. The SGS itself consists of two components, the INTEGRAL Science Operations Centre (ISOC, Much *et al.* 2003) and the INTEGRAL Science Data Centre (ISDC, Courvoisier *et al.* 2003). The ISOC processes the accepted observation proposals into an optimised observation plan which consists of a time line of target pointings plus the corresponding instrument configuration. ISOC is also responsible for the implementation of Target of Opportunity observations within the pre-planned observing programme. The ISDC receives the science telemetry plus the relevant ancillary spacecraft data from the OGS, usually within seconds of the actual data taking onboard. Final data products are distributed to the observer with a usual time delay of 10–12 weeks and archived for later use by the science community.

5. Observing programme

INTEGRAL was conceived from its initial study phase in 1989 as an observatory-type mission (nominal lifetime 2 years,extensions up to 5 years possible). Most of the total observing time (65% during year 1, 70% year 2, 75% year 2+) is awarded as the General Programme to the scientific community at large. Typical observations last from 100 ksec up to about two weeks. Proposals for observations are selected on their scientific merit only by a single Time Allocation Committee (TAC). These selected observations make up the general programme. The first call (AO-1) for observation proposals was issued on 1 November 2000; at the time of writing INTEGRAL is executing the AO-3 programme which will cover observations until mid August 2006.

As a return to those scientific collaborations and individual scientists who contributed to the development, design and procurement of INTEGRAL and who are represented in the INTEGRAL Science Working Team (ISWT), a portion of the total scientific observing time, the guaranteed time, is being used for their Core Programme (Winkler 2001) observations. Since the third year of operations, the share of guaranteed time is 25%. This split is agreed up to 2007, for 2008+ the share between guaranteed and open time is still to be discussed.

The Core Programm for the current AO-3 consists of several elements: scans of the Galactic Plane (2.1 Ms); surveys of the Galactic Center region (1.3 Ms), the Norma and the Scutum arm (0.8 and 1.4 Ms); a survey of an extragalactic field around 3C 273 (1 Ms); specific scans in the GC region from galactic latidue $b = -30$ to $b = +30$ in order to map the diffuse emission latidude profile (1.3 Ms) and 1.1 Ms for specific Target of Opportunity (ToO) follow-up observations.

Due to the highly variable nature of X-ray and gamma-ray sources, Target of Opportunity observations generally play an important role in INTEGRAL's observation programme. In many cases corresponding proposals have been submitted during the AO process and accepted by the TAC; these include cases of unknown and new sources. Some cases are also covered by the Core Programme as mentioned above. Finally it is always possible to request directly a ToO observation for an interesting astronomical object via the ISOC WWW pages (`http://integral.esac.esa.int/`). In all cases, the final decision to interrupt the current programme for the ToO lies with the Project Scientist. Until August 2005 there have been 23 ToO targets with ∼5 Ms total observing time.

Gamma-ray bursts falling into the FOV of INTEGRAL are considered a special class of ToO objects. While no dedicated follow-up observations are done, succesful proposers can obtain data rights to the relevant INTEGRAL data around the burst for their scientific purposes.

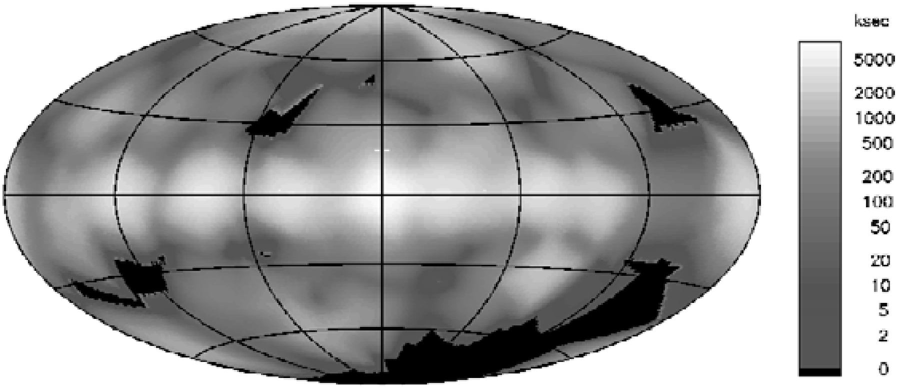

Figure 2. INTEGRAL exposure map in galactic coordinates after 1000 days in orbit (July 13, 2005) based on the IBIS partially coded FOV. Courtesy of E. Kuulkers (ESA-ESAC).

6. Gamma-Ray Burst detection

INTEGRAL has no on-board GRB detection capabilities, but still manages to detect bursts and disseminate positions with arcminute precision within less then a minute of the start of the burst. This is achieved via the INTEGRAL Burst Alert System (IBAS) running at the ISDC and analyzing the real-time data stream from the satellite, which usually arrives within seconds (Mereghetti & Gotz 2005).

Since its activation in December 2002 up to July 2005 IBAS has detected 30 GRBs within the FOV, corresponding to ~1 burst per month, consistent to pre-launch estimates. 21 of these alerts have been disseminated rapidly (tens of seconds), the remaining are mostly from the early mission. The standard position uncertainty is 3' (90% error radius). The bursts detected by INTEGRAL are among the faintest for which good localization exists (see Fig. 3). In addition to the bursts in the FOV, 1–2 bursts per day are registered by the SPI anticoincidence shield. Lightcurves for ACS are also available at the ISDC and a catalogue has been published by Rau *et al.* 2005.

Since end 2004, IBAS also delivers alerts for bursts from known X-ray bursters, Soft Gamma-ray Repeaters and Anomalous X-ray Pulsars.

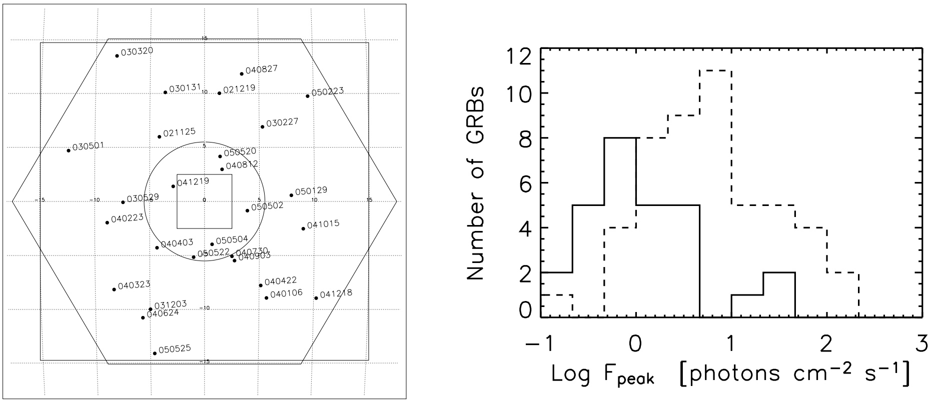

Figure 3. Left: positions of the GRBs localized with IBAS within the FOV of the INTEGRAL instruments: IBIS (large square), SPI (hexagon), JEM-X (circle) and OMC (small square). Right: Distribution of the peak fluxes for the GRBs detected with IBAS (solid line) and BeppoSAX (dashed). Both figures taken from Mereghetti & Gotz (2005).

7. Public data archives

The main archive for INTEGRAL data is located at the ISDC. A copy of the public data is available via the ISOC Science Data Archive using a different user interface similar to that used for other ESA missions.

The ISDC also provides access to summary scientific results with maps, lightcurves and spectra for ∼180 sources based on the public data. In addition, the INTEGRAL Bright Source Catalog is maintained as collaboration between HEASARC and the ISDC. Optical lightcurves from the OMC can also be obtained via a specialized data archive at LAEFF/INTA.

PI led programs include, e.g., the Galactic Bulge Monitoring Program (Kuulkers *et al.* 2005) with quick-look results in near real time or the monitoring program on accreting X-ray pulsars (Sidoli *et al.* 2004).

For links to these services and more see: `http://integral.esac.esa.int/services.html`

8. Conclusions

Due to its sensitivity in the hard X-ray and gamma-ray bands, INTEGRAL's view of the universe is not affected by the interstellar absorption that can shroud sources from X-ray satellites. This ability has already led to, e.g., the detection of a new class of heavily absorbed sources and to new insights on the high energy emission for source classes like AXP's and accreting ms pulsars.

In comparison with previous gamma-ray missions, the high imaging resolution allows to disentangle close sources and avoid source confusion. At the same time, a wide field of view gives good coverage of areas not directly targeted leading to a large number of serendipitous detections.

These abilities are brought to good use in several survey programs both in the Core Programme and in the Open Time, besides the various studies of individual sources.

INTEGRAL's unique capaibilities concerning observing diffuse gamma-ray line emission have resulted in many important observations including the first 511 keV all-sky map (Knoedlseder *et al.* 2005).

In summary, the mission performs well and produces the scientific results it was built to do, in the important window of the hard X-ray to gamma-ray range. The prospects for more interesting results in the future are promising.

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Discussion

Garcia: 1. Why is only 1 X-ray telescope run, when there are 2?
2. How fast are ToOs done?

Kretschmar: 1. To save the 2nd XRT for future use. There were instrumental problems at activation.
2. In ∼1 – 2 days.

Lipunov: 1. Did you include in statistic of the detection GRB alerts from Soft Gamma Repeaters?
2. How much GRB alerts come from low galactic latitude

Kretschmar: 1. No.
2. You can find this information on the INTEGRAL website.