High Energy Astrophysics with INTEGRAL

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Abstract. INTEGRAL is an ESA mission scheduled to be launched in 2001. Its four coaligned instruments will allow observations of cosmic sources from a fraction of a keV to several MeV plus source monitoring in the optical band. INTEGRAL will be operated as a space observatory and an Announcement of Opportunity to the astronomical community at large will be issued by ESA in the spring of the year 2000. Purpose of this paper is to illustrate INTEGRAL capabilities of the three X and Gamma Ray detectors plus optical monitor in order to help potential users to write observing proposals.

Keywords: Gamma-Ray Astronomy, X-Ray Astronomy, INTEGRAL, Astrophysics

1. Introduction

In less than a decade our understanding of the Gamma-Ray sky has experienced a revolution. From a handful of bright Gamma-Ray sources in the sky , we now have fluxes, positions and often spectra of more than one hundred sources, some of which appear to be violently variable, others explosive and others bright and quite steady. The impressive amount of data from NASA's Compton Gamma Ray Observatory (CGRO) and the French-Russian Granat have brought Gamma-Ray Astronomy to the same level of the other branches of Astronomy throught the electromagnetic spectrum. Some of the detected sources are galactic, and can be either diffused or associated to compact objects, others are of extragalactic nature. Unfortunately, because of lack of sensitivity and resolution, for some sources we are still unable to tell their spatial extent, and sometime even to locate them with sufficient accuracy to associate them to any plausible counterpart. Gamma-Ray Astronomy is in a blooming season and much is expected from the coming experiments to be flown in the near future. One of the major requirements for the new generation Gamma Ray Telescopes is an outstanding angular resolution over a wide field of view.

The "Gamma-Ray Astrophysics Laboratory" (INTEGRAL) is the next mission in line, being scheduled for launch in not more than two

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years time. In the following a concise account of what INTEGRAL will consist of and will be able to do will be given (for details see Bazzano et al. 1999) The aim of the paper is to provide a basic guide to help possible users to prepare to respond to ESA Announcement of Opportunity (AO) which will be issued in less than a year

2. INTEGRAL's telescopes

INTEGRAL will be dedicated to fine spectroscopy (to be performed with the spectrometer SPI; ΔE: 2 keV FWHM at 1.3 MeV) and fine imaging (by the imager IBIS; angular resolution: 12' FWHM) of celestial sources emitting high-energy photons in the range 15 keV - 10 MeV. The detection of narrow lines is SPI's main scientific objective. SPI high resolution spectroscopy (2 keV FWHM at 1 MeV) will be accomplished by an array of 19 high purity Germanium hexagonal detectors cooled to 85 K by 2 pairs of Stirling Coolers. The total SPI detection area is 500cm^2. 1.7 meters above the detector an hexagonal coded aperture mask allows imaging of a large area of sky (see Tab. 1). An active BGO veto shield around the detector assembly up to the coded mask, will keep a low background, further reduced by another plastic veto between mask and upper veto shield ring. SPI will provide high-resolution spectroscopy with superior sensitivity and will be able to study compact sources of long lived radioisotopes such as ^{26}Al as well as extended emission of the narrow e^-e^+ line. Since Gamma-Ray lines are the fingerprints of nuclear transitions and carry memory of high energy processes, Gamma-Ray spectroscopy is a powerful tool to identify the presence of exited nuclei, to quantitatively determine their abundances and provide a measure of the source temperature, density and gravitational or cosmological energy shift. This will further our knowledge of the source regions physical conditions. The fine spectroscopy and coarse imaging concept of the SPI instrument is particularly suited for nuclear astrophysics studies. In fact, for example, diffusion of radioactive isotopes into the interstellar medium often lead to narrow lines emitted on a broad angular scale whereas Gamma-Ray line emission from violent compact objects are more likely to be spectrally broadened.

A key feature for IBIS is good Spectral Resolution, while high Energy Resolution will be only moderatly high over the entire energy range. These goals are achieved applying inovative technologies. The first IBIS element is a Tungsten coded aperture mask located 3.2 m above a double layer detector. Angular resolution is limited by the spatial resolution of the detector array. A large number of spatially resolved pixels optimizes IBIS for high angular resolution imaging. The first detector plane uses 2600 cm^2 of 128x128 CdTe elements (4x4x2)mm each (ISGRI) working at room temperature. For an angular resolution of 12 arcmin and assuming no error in pointing axis reconstruction or other systematic effects ISGRI will locate a 30 sigma point-like source at better than one arcmin. A second plane of 3100 cm^2 CsI pixels (9x9x30)mm each (PICsIT) allows photon tracking in 3D as they scatter and interact with more than one element. The highest IBIS time resolution is equal to the intrinsic time resolution of the detector layers ISGRI and PICsIT, that is 250ns. However telemetry limits the information one can send to the ground, different time resolutions can be set according to the observation scientific goals. Below 1 MeV IBIS full timing capability will be 61μs while for $E > 200$ keV PICsIT will record arrival time for each photon with time resolution up to 1ms. In the $E < 200$ keV range data will be transmitted in photon by photon mode with full time information. A thin passive shield limits IBIS aperture. An active BGO veto shields the two IBIS detector layers all around and below. The 5 side BGO array is made out of 16 independent BGO modules made of two slabs per module and read-out by 32 PMTs. The choice of the large IBIS FOV ensures full compatibility with SPI and will allow joint observations as well as increasing the number of detectable sources which can be monitored as it seems to be mandatory in the X-Gamma domain.

The observatory, with the addition of X-Ray (Jem-X) and Optical (OMC) Monitors will provide the astronomical community with an unprecedented combination of instruments for imaging and spectroscopical analysis for studying a large number of cosmic sources. Jem-X plays a crucial role in the combined observations as it will image the Gamma-Ray sources under investigation in the 3-35 keV band with 3' angular resolution.Two identical high pressure imaging microstrip gas chambers filled with Xenon at 5 bar, will be looking at the sky through a coded aperture mask located 3.2 m above the 1000 cm^2 detector plane.

OMC is an optical telescope consisting of a (1024 x 2048) pixels cooled CCD in the focal plane of a 50 mm lens. One half of the CCD will be used for imaging, the other half for image transfer before readout. The OMC will observe the optical emission of the sources in the SPI and IBIS Field Of View (FOV). Variability as short as 1s can be monitored. The limiting magnitude of 19.7^{m_v} corresponds to about 40 photons cm^{-2} s^{-1} keV^{-1} (at 2.2 eV)

The observatory, operated by ESA, will benefit of contributions from Russia, which will provide a Proton launcher, and NASA, which will provide ground station support through the Deep Space Network. An

Table I. INTEGRAL telescopes key parameters

	SPI	IBIS	JEM-X	OMC
Energy Range	20 keV - 8 MeV	15 keV - 10 MeV	3 keV - 35 keV	(500-600)nm
Spectral Resolution FWHM (keV)	2 (at 1.3 MeV)	7 (at 100 keV) 60 (at 1 MeV)	1.5 at 10 keV	
FOV	16^o	9^o x 9^o	4.8^o	5.0^o x 5.0^o
Angular Resolution	2^o FWHM	12' FWHM	3' FWHM	17.6"/pixel
Continuum Sensitivity (3σ, 10^6 s)	7 x 10^{-8} at 1 MeV	4 x 10^{-7} at 100 keV	1 x 10^{-5} at 6 keV	19.7^{m_v} ($3\ \sigma$, 10^3 s)
Line Sensitivity (3σ, 10^6 s)	5 x 10^{-6} at 1 MeV	1 x 10^{-5} at 100 keV	2 x 10^{-5} at 6 keV	

inovative feature for an ESA mission, a Science Data Centre (ISDC), based in Versoix, Switzerland, operated with contributions from various countries, not all ESA member states, will assist observers throught the mission duration and keep a data archive. The key parameters of the four telescopes are summarized in Table 1.

INTEGRAL with its payload mass of 2019 kg and a total launch mass of about 4000 kg, will be launced in April 2001. Uninterrupted observations with nearly constant background and away from geomagnetic belts trapped radiation are envisaged to overcome the low photon flux at high energies. Such observations will be possible thanks to the highly eccentric orbit with high perigee. At the present stage of project development the predicted orbit parameters are: 72 hours period, 51.6^o inclination with initial perigee height of 10 000 km and initial apogee height of 153 000 km. The estimated average observation efficiency is 85% per year and the real-time scientific data rate 86 kbps.

Because of imaging deconvolution required by the spectrometer SPI a series of off-source pointings (known as "dithering") will be performed.The dithering pattern will consist of a series of pointings at sky positions, separated by 2^o, around the nominal target position. Two dither patterns will be employed: a 7 point hexagone and a 5 x 5 point raster both centred on the target position. A 20 minutes exposure time per point is required, however observers may ask for dithering disable.

3. INTEGRAL scientific objectives

SPI fine spectroscopy from 15 keV to 10 MeV will allow unique identification of spectral features and determination of line profiles. These are basic quantities to determine physical parameters of the source region. The large field of view fine imaging capabilities of IBIS will provide positional parameters for accurate source location and hence identification. Multiwavelength information, including the optical band, will provide instantaneous information on the Gamma-Ray source nature and extent (point versus extended source). Furthermore the long exposure times will allow variability studies to be made at least at low energies. In summary the scientific topics INTEGRAL will address are:

(i) Studies of galactic compact objets
(ii) Stellar nucleosynthesis
(iii) High energy transients
(iv) Maps of the diffuse continuum and line emission
(v) A detailed study of the Galactic Center
(vi) Studies of particle processes and acceleration
(vii) Studies of plasmas with highly relativistic electron-positron pairs
(viii) AGNs, nearby galaxy nuclei, clusters of galaxies
(ix) High energy sources and the diffuse cosmic background
(x) New unexpected discoveries

The Galactic Center region will receive particular attention in fact it has been included as the main objective of the "Core Programme". Our present knowledge of the Galactic Center is based on what SIGMA on board the Russian satellite Granat and COMPTEL and OSSE, on board the CGRO have told us. At INTEGRAL energies the center of our galaxy seen by SIGMA is rich of X-Gamma-Ray variable point sources, seen by COMPTEL it appears to be an extended source of diffused emission at 1.8 MeV of Al^{26} and seen by OSSE as a similar source but emitting at 511 keV.

INTEGRAL will provide images and spectra of the known sources and of many new ones so far undetected by the less sensitive SIGMA. Repeated observations will monitor flux and spectral variations in the optical, X and Gamma bands. Continuum characteristics of Neutron Stars versus Black Hole candidates will also be measured and detailed studies of bright individual sources will be possible. The maps of diffused radiation will be on large angular scales but "hot spots" will be identified and studied in both continuum and line emission. Cosmic Ray-Dust ratio will also be measured and isotopes determined. Timing and polarisation of variable sources will also be possible.

The extragalactic scenario is just as intense but most of it will be created by single observers. In fact very few extragalactic observations are included in the core programme. Broad band spectra of AGNs and Blazars can of course provide better constraints on current unified models. Monitoring of Balazars covering INTEGRAL energy bands will be extremely valuable for both deriving physical parameters and modelling source dynamics.

One interesting aspect of the observatory is the large field of view (see Table 1) of the high energy instruments. At any chosen pointing a number of non target sources will also be observed, with careful planning specific sources may be included. This will allow monitoring of a large number of objects for any exposure and the scientific return of each observation will be maximized.

4. Mission operation

INTEGRAL service module (the same as the one designed for ESA XMM) will contain spacecraft subsystems, while the payload module will contain the scientific instruments described in the previous session. Structural and thermal tests (STM) have succesfully been completed and electrical tests (EM) are well underway.

The Operations Ground Segment (OGC) will consist of ESA and NASA ground stations. At Esa's Mission Operation Centre (MOC), located in ESOC (Germany) the INTEGRAL observation plan, received from the INTEGRAL Science Operation Centre (ISOC), will be implemented within the spacecraft system constraints into an operational command sequence. OGS will also perform:

- all classical spacecraft operations
- real-time contacts with the spacecraft and payload
- maintenance tasks
- anomaly checks, including payload critical health and safety

MOC will determine the spacecraft orbit and attitude and provide raw science data to the Science Ground Segment (SGS) which will consist of two parts: the INTEGRAL Science Operation Centre (ISOC) mentioned above and the INTEGRAL Science Data Centre (ISDC) located in Versoix and mentioned earlier. ISOC is provided by ESA and is located at ESTEC; it will issue the INTEGRAL AO for observing time and will handle the incoming proposals. The accepted observing proposals will then be processed, at ISOC, into an optimized observation plan consisting of target pointings timeline and corresponding instrument configuration. The elaborated observation plan will then be forwarded to MOC and uplinked to the spacecraft. ISOC will also validate parameter changes defining on-board instrument configuration and will keep a copy of the scientific archive produced at ISDC. ESA Project Scientist, at ISOC, will decide on the generation of Target of Opportunity (TOO) alerts and consequently request an update and reschedule of the observing programme.

The ISDC has a Principal Investigator (PI) responsable for its operations and is considered, in all respects as the fifth INTEGRAL instrument. At ISDC will arrive the complete raw science telemetry plus the relevant ancillary spacecraft data from the OGS/MOC. Science data will be processed according to instrument characteristics and row data will be converted into physical units. ISDC will routinely monitor instrument science performance and produce quick-look science analysis using the incoming science row data and housekeeping information. Most of the TOO will be detected at ISDC during the routine scrutiny of the data and will be reported to ISOC. To the observer data will be distributed as obtained by processing with standard analysis tools. Data will also be archived for science community use at later times.

5. INTEGRAL Observing Programme

The nominal lifetime of the INTEGRAL observatory mission is 2 years but an extension of 3 more years is technically possible. In the first year of operation 65% of the observing time (70% in the second and 75% in the third and subsequent years) will be awarded to proposals from the general scientific community as General Programme. Standard AO process will be applied, proposals will be evaluated according to their scientific merit by a single Time Allocation Committee. Observations may last from 10's of minutes to two weeks. The first call for observing proposals is scheduled for release at the end of 1999. Observers will receive data from all four coaligned INTEGRAL instruments simultaneously operating during the whole observation.

The remaining fraction of the observing time (35%, 30% and 25% for the first, second, third and subsequent years respectively) will be reserved as guaranteed time for the INTEGRAL Science Working Team for its contribution to the mission. The Core Programme will be devoted to:

- Galactic Plane Survey
- A deep exposure of the central radian of the Galaxy
- Pointed observations of a few selected targets (point sources or extended regions or TOO followup)

The Core Programme in full will be described in the first AO. All scientific data, in accordance with ESA policy, will be made public, and therefore available to the whole scientific community at large, one year after they have been released to the original observer. This guarantees the use of the scientific data for different investigations beyond the aim of a single proposal.

For up to date information on any aspect of INTEGRAL please see the web page *http : //sci.esa.int/integral*

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