IBIS: The Imaging Gamma-Ray Telescope on Board INTEGRAL

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Abstract. INTEGRAL (International Gamma Ray Astrophysics Laboratory) will be the follow up on the succesful high energy missions CGRO and GRANAT. The Scientific goal of INTEGRAL is to address the fine spectroscopy with imaging and accurate positioning of celestial X-ray emission as well as large scale diffuse emission studies. These achievement will be possible by means of a high spectral resolution Spectrometer (SPI) and a high angular resolution Imager (IBIS) supplemented by an X-ray monitor and an Optical Monitoring Camera. INTEGRAL, with 2 years nominal lifetime possibly extended to 5 years, will be an observatory-class mission. The observing time will be divided into a General Programme, open to the scientific community with scientific targets selected by a peer review committee, and a Core Programme which is guaranteed time for the INTEGRAL Science Working Team (ISWT).

INTRODUCTION

IBIS, (Imager on-Board INTEGRAL Satellite), is an essential element of the mission with its powerful diagnostic capabilities of fine imaging source identification and spectral sensitivity to both continuum and broadened lines. It will observe, simultaneously with the other instruments on board INTEGRAL, celestial objects of all classes ranging from the most compact galactic systems to extragalactic objects. IBIS features a coded aperture mask and a novel large area multilayer detector which utilizes both Cadmium Telluride and Cesium Iodide elements to achieve the fine angular resolution <12 arcmin, over a wide energy range (15 keV to 10 MeV) and good resolution spectroscopy (6%-7% 0.1-1 MeV) required to satisfy the mission's imaging objectives. A large international consortium, composed by 14 Institutes belonging to 9 countries is committed to develop, build and fly this instrument.

SCIENTIFIC RATIONALS

The results obtained in the last half decade in the gamma ray range have provided a new picture of the high energy sky. Of particular relevance are the data collected with both CGRO and GRANAT. The first one provids a large collecting area from keV to GeV but moderate (degree level) imaging capaility; conversely, GRANAT featurs a lower sensitivity with very good imaging capability up to a few MeV. The complementarity of these two missions have clearly shown the need to combine in a single instrument both sensitivity and imaging in order to perform a forward step in the understanding of the high energy sky. IBIS has been designed considering these requirements as essential. More recently, the must for high angular capability to disentangle the spectra of neighbouring sources in crowded regions such as the Galactic Center has been re-enforced by the unique results of the Wide Field Cameras on board the BeppoSAX (Bazzano el al., 1997a, 1997b, in 't Zand et al., 1997a), capable to study and monitor at the same time as much as 32 sources in the Galactic Central radian. Such an achievement is due to the capability of the position sensitive X-ray detector operated with a coded mask, providing high localisation accuracy over a wide field of view (Jager et al., 1997). IBIS will permit to extend imaging to the gamma ray domain assuring good spectral resolution over a wide energy range. This will overcome source confusion limits allowing to measure detailed spectra from different types of systems, as just demonstrated by the WFCs at energies up to ∼30 keV (Bazzano et al, 1997c, Heise, 1997, in 't Zand et al., 1997b, Ubertini et al., 1997a) and at lighter energy by SIGMA (Goldwurm et al., 1994, Vargas et al. 1997).

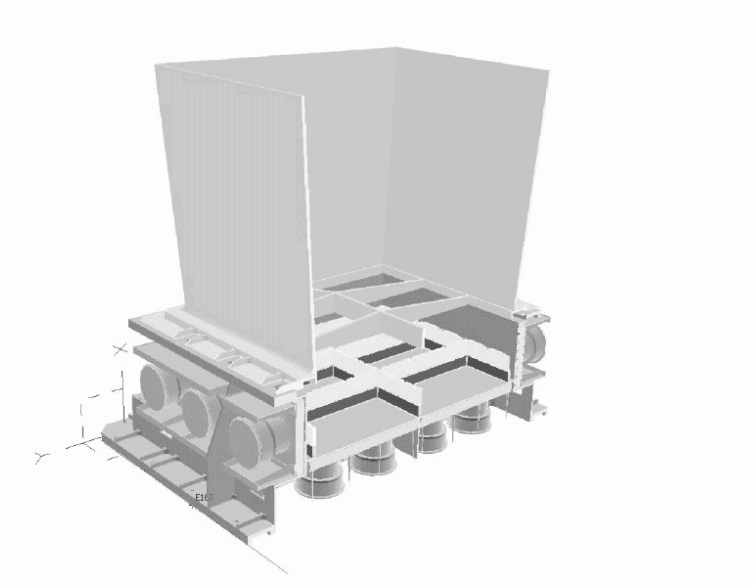

FIGURE 1. IBIS detector/hopper view.

INSTRUMENT DESCRIPTION

The basic concept of the IBIS gamma ray detector is to have two pixellised arrays: a matrix of 128x128 CdTe elements as a front layer coupled with a matrix of 64x64 CsI bars. This set up provides a wide spectral range and high sensitivity spectroscopic capability. The detector aperture is restricted by a thin tungsten passive shield, covering the distance between the mask and the Position Sensitive Detector (PSD), and is shielded in all other directions by an active Bismuth Germanate (BGO), 20 mm thick, Veto system, as shown in Figure 1. The imaging is obtained projecting on the PSD a shadowgram provided by the use of a 15 mm thick tungsen based a coded mask positioned 3100 mm above the top detector plane. Sky images, spectrally resolved, will be obtained with standard deconvolution processes (Caroli et al., 1987). The two detector layers allow the paths of photons to be tracked in three dimensions as they scatter and interact with more than one element/plane. In this way the detector is operated as a photoelectric detector at lower energies and as a Compton detector/telescope at higher energy thus improving the signal-to-noise ratio and in turn the high energy sensitivity.

The CdTe Array. The Cadmium Telluride (CdTe) is used in order to achieve a good spatial and spectral resolution in the lower end of the detector energy range. In fact the possibility to have detectors thickness of a few mm optimises their use in the low energy domain. The IBIS CdTe, with 2 mm thick chrystals, will provide a 50% efficiency at 150 keV and will assure a good detection sensitivity down in the X-Ray domain at energy lower than 15 keV. The CdTe spectroscopic capability and variation with energy is relatively well represented with the relationship: $\Delta E/E = 2E^{-0.7}$E in keV (Lebrun et al. 1995). This result is an upper limit to the spectral resolution. In fact, the optimum operative temperature for these detectors is around 0 ^{o}C (both for the FWHM and the peak to valley ratio), while the data in the figure has been collected at room temperature ($\sim 20^{o}$).

The CsI Layer. The CsI array is a matrix composed by 64x64 elements, 30 mm thick, that is placed 100 mm underneed the CdTe layer in order to achieve a good stopping power up to several MeV, till maintaining a high spatial resolution and good spectral capability. The large sensitive area, exceeding 3000cm^2, is designed for optimal performance at 511 keV. The CsI layer is divided, as the CdTe one, in eight rectangular modules of 512 detector elements each. This design provides a high degree of modularity having the CsI modules the same cross-sectional shape as those of the CdTe ones. The design and construction of the detector elements have been studied in order to optimize the low energy threshold, resolution, and signal-to-noise ratio (Labanti et al., 1996, Di Cocco et al., 1996).

The spectroscopic capabilities of the CsI array at different energies are summarised as follows: $\Delta E/E$ (FWHM) %: 9.5 at 511 keV, 7.7 at 662 keV and 5.2 at 1275 keV.

The Veto Shield. The sides and rear of the detector planes are surrounded by an active Bismuth Germanate (BGO) veto shield consisting in a 5 side BGO array made out of 16 independent BGO slabs read-out by 32 photomultipliers (PMT). The high density and mean Z of BGO ensures that a thickness of 20 mm is very efficient to reduce the detector background due to leakage through the shielding of Cosmic Diffuse Background and gamma-rays produced in the spacecraft. The 16 BGO crystals are viewed by two PMT which provide veto signals to the detector electronics. Analog signals from the Veto and Calibration System are collected, after preamplification, in Veto Electronics Boxes and used by the detector layer electronics for event rejection or tagging. Particular care was devoted to obtain a detection lower thresholds for the BGO array down to 50 keV, in order to optimise the rejection of BGD events. In Figure 2 are shown preliminary results obtained from a Development Model of a BGO unit. As can be seen the lower threshold is close to the required 50 keV.

The Passive Collimating System and the Shielding Tube. The current collimating system of IBIS is made of two subsystems mechanically independent based on tungsten as passive material. The first one is an hopper structure on the top of the ISGRI layer that is a truncated pyramid with an height of 550 mm and a profile that ideally joins the detector perimeter to the active mask sides. The second one is a structure made of four walls (two vertical and two inclined) closing the aperture down to the hopper level. This set up was chosen in order to reduce as much as possible the Cosmic X-Ray Background flux up to 150-200 keV within the limited mass constraint (Natalucci and Caroli, 1996).

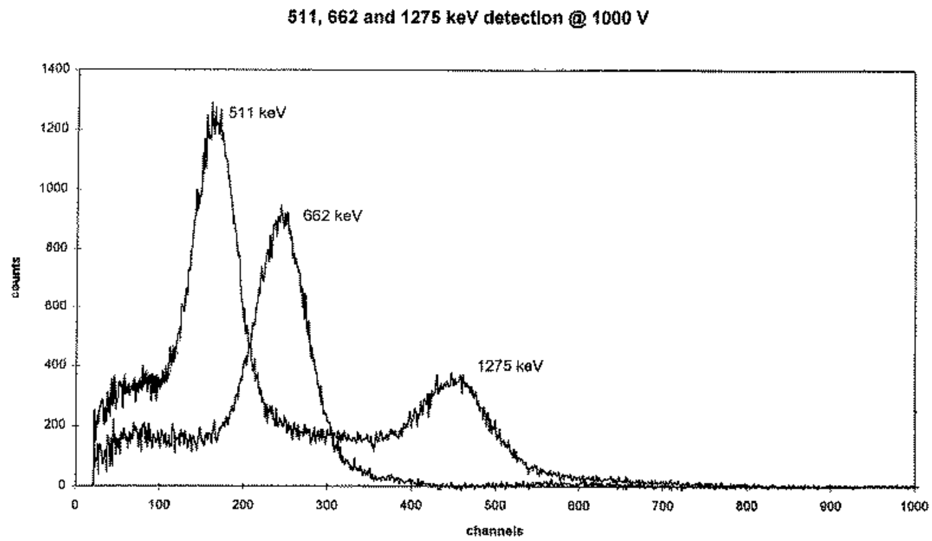

FIGURE 2. Preliminary spectral results of a slab of BGO 340x75x20 mm (DM) seen by a single 3 inches photomiltiplier. The line are 511, 662 and 1275 keV.

The Coded Mask Assembly. The Coded Mask is an array of squared tungsten elements (densimet D18), 15 mm thick, providing 80% transparency at 20 keV and 70% opacity (minimum) at 3 MeV. The basic pattern is a 53x53 Modified URA (MURA). The Mask assembly is a square graphite honeycomb sandwich with tungsten elements embedded inside to obtain the required alignment (better than a fraction of mm) and optical characteristics. The mask will be aligned on ground by using laser/optical prism assemblies. In flight the alignment will be guaranteed by the structure of the PLM, which will provide high rigidity and low thermal expansion. A proper Mechanical Ground Support Equipment (MGSE) and jigs will be manufactured to keep the mask in the correct position during ground calibration planned at instrument level. The transparency of the IBIS mask support structure for on-axis and off-axis sources (19 degrees) is respectively: 68% and 52% at 15 keV, 80% and 70% at 20 keV and 88% and 84% at 50 keV.

The on Board Calibration System. On-board calibrations are necessary in order to monitor and control the instrument in flight performances. The response function of the instrument will be refined through comparison of predicted performances obtained by modelling and ground calibration with in-orbit measurements. The calibration system will use a ^{22}Na radioactive source that produces, for each single disintegration, an opposed pair of 511 keV photons (100%), and one 1.275 MeV photon (96.6%). This set up will permit the measurement and check of the quantum efficiency as a function of energy and time, the monitoring of the gain changes and energy resolution as a function of energy and time.

Field of View and Point Source Location Accuracy (PSLA). The imaging capability over a wide field of view is a key parameter for IBIS and for the INTEGRAL Mission as a whole. In order to ensure a full compatibility of the IBIS field of view with the Spectrometer one allowing for joint observations of any region of the sky, we have choosen a FOV of 9x9 degree Fully Coded, 19x19 degree FWHM and 29x29 degree Zero Response. Such an extended FOV will also enable a better sky coverage increasing the number of detectable sources, and allow a monitoring as frequent as possible of sources, which is mandatory due to the high variability of the X-gamma ray sky. The angular resolution of the telescope is 12 arcmin. Simulations have shown that assuming no error in pointing axis reconstruction and/or other systematic effects, IBIS will locate in the sky a strong pointlike source (30 sigma) with an accuracy of better than 30 arcsec. This value is substantiated by the actual results obtained with the SIGMA telescope on the Galactic Centre (Goldwurm, 1995).

THE OBSERVING PROGRAMME

INTEGRAL is an observatory-class mission lead by the European Space Agency with the payload complement instrumentation provided by four European cosortia, including USA contributions. The observatory has a two years nominal life time, to be eventually extended to five years (Winkler, 1997). The observing time will comprise a General Programme and a Core Programme (Gehrels et al., 1997). The General Programme will constitute 65% of the time of the first year and will increase to 75% in later years. It will be open to the scientific community, with observations selected from peer-reviewed proposals. The Core Programme will constitute the rest of the time and will be dedicated to key investigations devoted to regular surveys of the Galactic Plane and deep sky fields. The Core Programme is planned and carried out by the INTEGRAL Science Working Team, chaired by the INTEGRAL Project Scientist and will be dedicated to three key investigations: Deep observation of the Central Radian of the Galaxy, the Galactic Plane Survey and Transient monitoring, by means of weeky scans, and pointings at selected sources and fields.

The Central Radian of the Galaxy. One of the main scientific objectives of the deep survey of the central radian of the Galaxy is to map and resolve at arcminute level the continuum emission of the galactic ridge and, at the same time, map line emission from nucleosynthetic radioiosotopes. It will also be possible to perform deep imaging and spectroscopic studies of the Galactic Centre region resolving isolated gamma-ray point source with an accuracy of < one arcminute and provide spectral information with outstanding resolution of ∼2 keV. At least 90 sources known as X and gamma ray emitters are contained in this region at low energy (<10 keV). Spectra are available for about 40 objects associated with X-ray pulsars, black hole candidates, X-ray sources in Globular clusters showing burster behaviour and transient. In Figure 3 are shown the persistent and transient sources in the GC region amenable to study within a single IBIS pointing. In the Figure 4 is shown a reconstructed image of a simulated observation of the Galactic Centre, in the

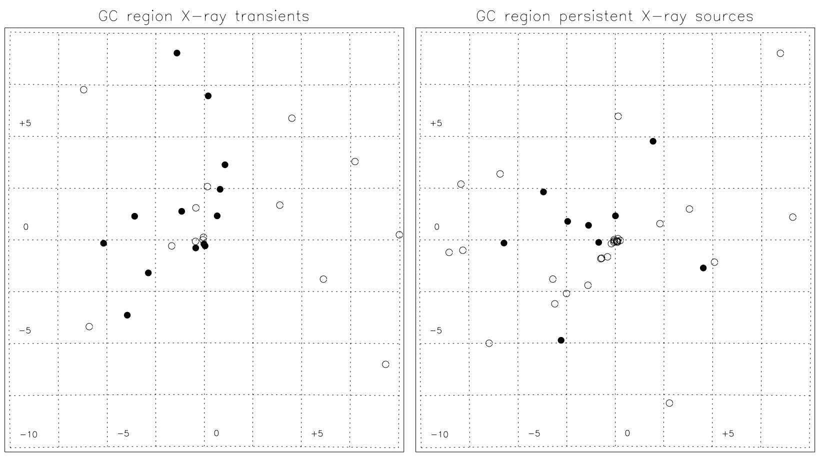

FIGURE 3. Galactic Centre Region Transients and Persistents Sources Distribution. Dots indicate sources emmitting at energy > 30 keV (From Bazzano et al., 1997d).

low energy band (40-80 keV). The image shows the 30% sensitivity FOV of the telescope, with an exposure time of about 2 days. The sources intensity were simulated using the results obtained with the SIGMA telescope (Goldwurm et al., 1997). The inner rectangular box represents the SIGMA telescope FOV, with similar sensitivity of $\sim$30%.

Frequent Galactic Plane Scans. One of the expected outcome of the INTEGRAL Mission will be the regular survey of the Galactic Plane. The two goals of these regular scans are the production of a time and spatially resolved maps of the Galaxy over a wide energy band (15 keV up to 5 MeV), even if with a modest exposure, and the search for sources in outburst in order to trigger target of opportunity observations if warranted. As part of this study a number of Galactic Transients will be detected and possibly deep follow-on observations provided by means of pre-planned target of opportunity (see Ubertini et al., 1997b, for more details).

Pointings at Selected Sources. In order to complement the Galactic Central radian deep exposure and the Galactic Plane scans a few dedicated observations will be performed on gamma-ray sources of particular astrophysical interest to solve key open issues. Because of the limited amount of time available for these investigations in the Core Programme few of them will have a long exposure, typically 10^6s while few of them could be shorter snap-shots of about 10^5s on particularly bright sources amenable for studies at lower energies ($\sim$100-500 keV).

An example. IBIS will be particularly suited for the study and definition of the high energy spectral shape of AGNs; we expect that over 200 Seyfert type objects will be visible by IBIS above the 5 sigma level up to 100 keV in a typical 1 day exposure; 20 objects can be detected up to 500 keV thus allowing spectral studies to be performed on quite large sample of sources

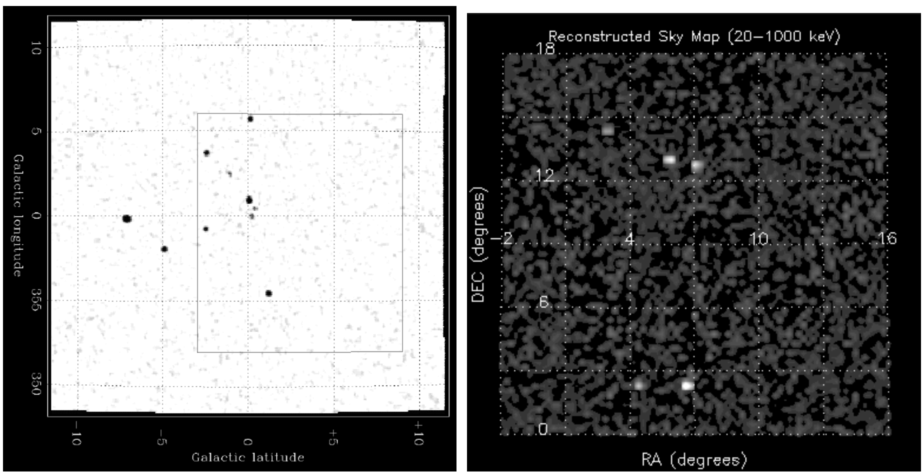

FIGURE 4. a, simulated observation of the Galactic Centre; b, simulated observation of the region containing 3C273 (50-150 keV band).

(Di Cocco et al., 1997). At higher energies the main investigations will be focussed on Blazars whose spectra extends to MeV energies, with the main aim to determin the spectral characteristics. In order to achieve the required sensitivity typically 10^6 sec observations are necessary and we expect to detect a number of serendipitous sources from each exposure. In the Figure 4b is shown a simulated IBIS observation of the extragalactic sky region (12 x 12 degree) containing the high energy source 3C273 in the 50-150 keV band: a number of sources of various classes (Seyfert 1, 2, QSOs) are visible above 10σ (Malizia et al., 1997).

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