#164

THE IBIS TELESCOPE ON BOARD INTEGRAL

on behalf of the IBIS Consortium:

P. Ubertini
CNR - Via E. Fermi 23, 00044 - Frascati, Italy

G. Di Cocco
ITESRE, CNR - Via P. Gobetti 101, 40129 - Bologna, Italy

F. Lebrun
CEA - Saclay, 91191 Gif Sur Yvette Cedex, France

ABSTRACT

The International Gamma Ray Astrophysics Laboratory (INTEGRAL) mission was selected by ESA as part of the Agency's "HORIZON 2000" strategic plan and is a natural follow up on the remarkable discoveries of the Compton Gamma Ray Observatory and GRANAT SIGMA.

IBIS, one of the two core instruments on board INTEGRAL, is operative in the range 15 keV - 10 MeV and will perform spectroscopic and imaging studies of unprecedented resolution in the year 2001.

It features a coded aperture mask, active and passive shields and a novel multilayer pixellised detector which utilises 16,384 Cadmium Telluride (2600 cm^2) and 4,096 Cesium Iodide (3100 cm^2) elements.
These features will provide fine source location accuracy up to 1 arcmin, wide spectral response (15 keV to 10 MeV) and good resolution spectroscopy (8% at 100 keV) required to satisfy the mission's imaging and spectroscopic objectives.

A large international consortium, composed by 14 Institutes belonging to 9 countries is committed to develop, build and fly this instrument.

1. INTRODUCTION

The main scientific rational of the INTEGRAL Observatory is to address imaging, with arcminute positioning capability, and fine spectroscopy of celestial γ-ray emission either diffuse or from point sources[1].
These results will be fulfilled using a high resolution Imager (*IBIS)* and a high resolution Spectrometer (*SPI*) as main instruments, supplemented by two X-Ray and Optical monitors.

IBIS, (*I*mager on-*B*oard *I*NTEGRAL *S*atellite), is an essential element 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 galactic compact objects in binary systems to extragalactic sources.

2. SCIENTIFIC OBJECTIVES

The need for an Imager operative on a broad energy range has been indicated by the recent results of both CGRO and GRANAT. High angular resolution is necessary to disentangle the spectra of neighbouring sources in crowded regions such as the Galactic Center. A high localisation accuracy is needed to identify the sources of emission with objects seen at other wavelengths (radio, X-ray, optical).
The *IBIS* combination of wide energy range with moderate-to-high spectral resolution, imaging capability and consequently higher sensitivity with respect to previous instruments on board X and γ-ray satellites, will permit to measure detailed spectra overcoming source confusion limits from different types of systems.
Studies will be carried out on broad-band spectral phenomena associated with intense high energy radiation from the innermost region of compact stellar objects such as white dwarfs, neutron stars and black holes and from active galactic nuclei at the centers of galaxies, with the benefit of location accuracy better than 1 arcmin.

For an updated description of the basic *IBIS* scientific rationals see Ubertini et al., SPIE Denver 1995.

3. INSTRUMENT DESCRIPTION

The *IBIS* gamma ray detector is composed of two planes, a front layer made of 16,384 CdTe squared elements and a succeeding layer made of 4,096 CsI scintillators bars, providing the wide spectral range and high sensitivity continuum spectroscopy (with $E/\Delta E \geq 10$) required for the mission’s imaging objectives.
The telescope imaging is achieved using a coded mask aperture system held at 3.1 m above the upper detector layer. Images of the sky will be reconstructed by decoding the shadowgram with the mask pattern.

A passive shield is employed to limit the FOV (Field of view) and in turn the aperture flux at low energy.

In the following table are shown the *IBIS* "basic facts" as evaluated after the re-design of *IBIS* which followed the selection after the end of the Phase-A study.

Scientific Performance of *IBIS*

Parameter	Current *IBIS*
Energy Range	15 keV - 10 MeV
Sensitive Area	2600 cm^2 CdTe 3100 cm^2 CsI
Energy Resolution at 100 keV at 1 MeV	 8% 6%
Field of View Fully coded Partially coded FWHM Zero Response	 9x9 squared degree 19x19 squared degree 29x29 squared degree
Continuum Sensitivity 3σ, 10^6 s, at 100 keV 3σ, 10^6 s, at 1 MeV (ph cm^{-2} s^{-1} keV^{-1})	 3.8 10^{-7} 1.5 10^{-7}
Line Sensitivity 3σ, 10^6 s, at 100 keV 3σ, 10^6 s, at 1 MeV (ph cm^{-2} s^{-1})	 1.3 10^{-5} 7.5 10^{-5}
Angular Resolution	12 arcmin
Point Source Location Accuracy	1 arcmin 10σ Source 30 arcsec 30σ Source
Timing Resolution	0.1 ms (fast timing) 5 ms (stand. timing) ~20 minutes (imaging)

The expected scientific performance of *IBIS* has been computed using a combination of Monte Carlo simulation programs, scaling from other experiments and experimental tests on prototype detector units.

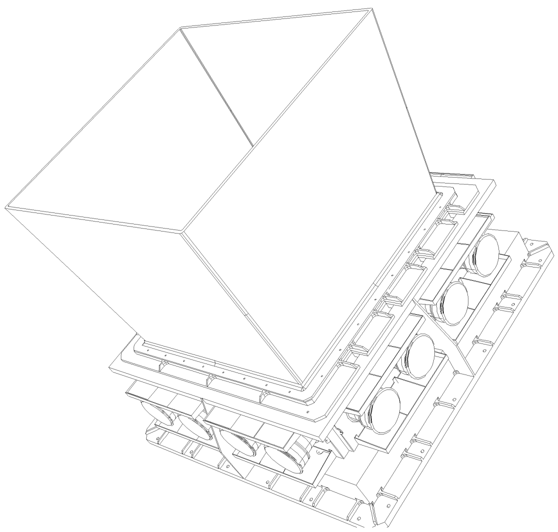

Figure 1: IBIS detector/hopper view

The *IBIS* telescope (the CAD drawing of the detector unit is schematically shown in figure 1.) will provide redundancy and modularity such that any single point failure cannot induce a science loss of more than 20 %.
In figure 2. is shown the payload complement: the two main instruments are visible as well as the two monitors and star trackers, all co-aligned.

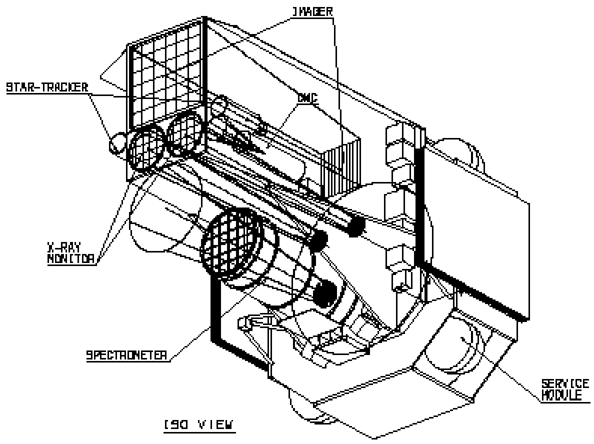

Figure 2: the payload complement

4. HARDWARE DESCRIPTION

4.1 Overall instrument

In the following paragraph a short description of the *IBIS* detection module will be provided. A full description of the whole instrument is available in the EID-B documentation delivered by the *IBIS* consortium to ESA.

The *IBIS* CdTe/CsI detector is coupled with a tungsten coded-mask imaging system in order to achieve a high angular resolution over a wide FOV. As diffraction is negligible at γ-ray wavelengths, the point source location accuracy (PSLA) of a coded mask telescope is limited by the spatial resolution of the detector array, while the angular resolution is driven by the mask pixel size. The *IBIS* is made of a large number of small, fully independent pixels.

The detector features two layers that allows the paths of photons to be tracked in 3D as they scatter and interact with more than one element. Events can be classified, and the signal-to-noise ratio improved by rejecting those unlikely to correspond to real photons (e.g. towards the high end of the energy range) or which could not have passed through the mask (Compton mode). The detector aperture is restricted in the soft γ-ray range by a thin tungsten passive shield, covering the distance between mask and PSD (Position Sensitive Detectors) , and shielded in all other directions by an active Bismuth Germanate (BGO) scintillator veto system.

4.2 Energy range.

The lower energy end is limited by the transparency of the mask supporting structure and, to some extent, by the Front End Electronics noise.

The high energy cut-off is due to the limited efficiency of *IBIS* (total detection efficiency at 10 MeV ~10%) and to the dynamic range of the PICsIT (Pixellated Imaging Caesium Iodide Telescope) electronics chain (~45). The transparency of the Tungsten elements of the coded mask is shown in Figure 3. as a function of energy, and become important above 500 keV. This effect causes a worsening of the MeV sensitivity and could be minimised increasing the thickness of the Tungsten elements, so far limited to 14 mm for weight constraint (it will be revised provided the needed mass should become available to *IBIS*).

The *IBIS* energy range has been optimised to have broad band spectroscopic capability. The two detector layers have been designed to overlap around 150 keV. In this way the instrument is very sensitive from soft γ-rays to the gamma ray region. In particular, the CdTe array provides the best INTEGRAL sensitivity to the Cyclotron line region while the CsI layer is optimised to have the maximum sensitivity at about 511 keV. Figure 4. show the total detection efficiency of *IBIS* for on-axis sources. Furthermore, the spectrometric capabilities of the CdTe are such that it will provide the best INTEGAL narrow line sensitivity in the soft gamma ray range.

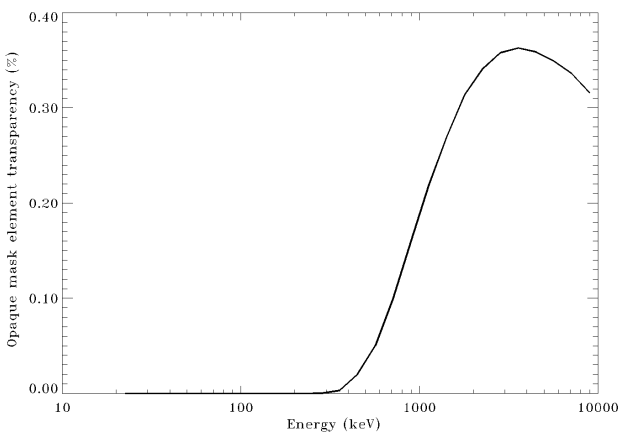

Figure 3: the mask "opaque" element transparency

4.3 The Coded Mask Assembly

The Coded Mask is an array of square tungsten elements, 14 mm thick, providing 80% transparency at 20keV and 65% modulation even at the minimum opacity at 3 MeV. The basic pattern is a 53x53 Modified URA (MURA). The Mask baseline design is a square graphite honeycomb sandwich with tungsten elements embedded inside to obtain the proper alignment and optical characteristics.

The Mask Structure provides the structural support to the Coded Mask in order to have the required strength and stiffness to withstand launch conditions, maintaining the stability of the Coded Mask pattern by holding the square tungsten elements. The mask detector axes will be aligned on ground by using laser/optical prism assemblies, the prism being mounted on the mask structure and the detector body. During flight operations the alignment will be guaranteed by the structure of the PLM, which will provide high rigidity and low thermal expansion. Mechanical jigs will be manufactured to keep the mask in the correct position during ground calibration end-to-end tests.

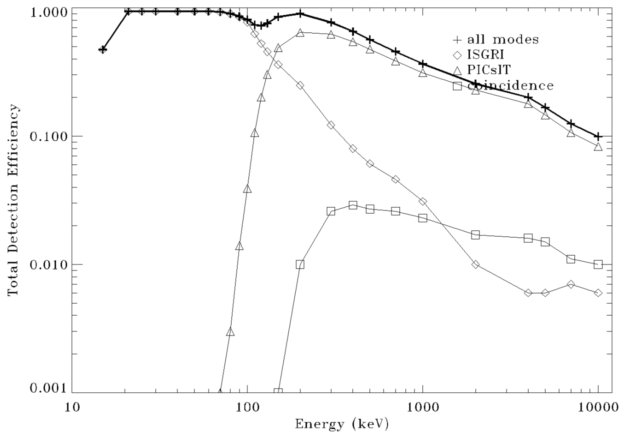

Figure 4.: Total detection efficiency of IBIS for on-axis sources. The profiles associated with ISGRI (INTEGRAL Soft Gamma-Ray Imager) alone, PICsIT (Pixellated Imaging Caesium Iodide Telescope) alone, and coincidence events are shown.

4.4 The Passive Collimation and the Shielding Tube

The passive shielding is designed to reduce the celestial diffuse background component as much as possible within the mass constraint. The shield of the tube system has been designed to be opaque up to about 200 keV.

In order to maintain the low energy response of *IBIS*, despite the dithering needed to implement the SPI observation philosophy, the collimating system is made of two subsystems, mechanically independent, based on tungsten as passive material:

i) a "*hopper*" structure on the top of the ISGRI layer that is a truncated (at 550 mm height) pyramid with a profile that ideally joins the detector perimeter to the active mask sides

ii) a "*tube*" made of four walls (two vertical and two inclined) closing the aperture down to the hopper level. This design has been chosen to cope with interface requirements with the spacecraft and to ensure easier handling of *IBIS* during AIV.

4.5 The CdTe Layer

The Cadmium Telluride is a II-VI semiconductor operating at ambient temperature; 0-10 ^{0}C is the optimum range. With their small area, the CdTe detectors are ideally suited to build up a pixellized imager with good spatial resolution. On the other hand, their small thickness restricts their use to the low energy domain (50% efficiency at 150 keV). Providing spectral performances intermediate between that attained the cooled germanium spectrometers and those of the scintillators, the CdTe can be used down into the X-ray domain (E > 15 keV).

The spectroscopic capabilities of the CdTe array are shown in Figure 5. The data are obtained with a high quality crystal exposed to a mix of ^{57}Co and ^{133}Ba radioactive sources. No rise time selection has been applied.
The scale of the plot for the data above 160 keV is multiplied by a factor of 30 to allow a better visibility of the spectral details.

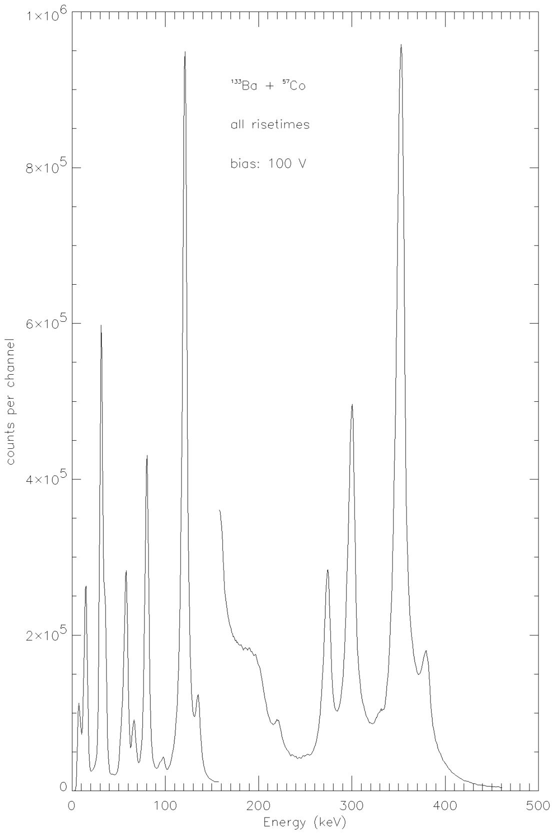

Figure 5.

The total sensitive area (2621 cm^2) consists of 16,384 square CdTe detectors (4 x 4 x 2 mm^3). Each detector has its own front end electronic chain. These chains are grouped by 4 on an ASIC circuit. The detector is highly modular: it is divided in eight rectangular modules of 128 polycells, each polycell containing 16 detectors (pixels). Both the rise time and the height of each pulse are measured to allow an off-line correction of the charge loss in the CdTe detectors (Lebrun et al. 1995).

4.6 The CsI Layer

The total sensitive area (3100 cm^2) consists of 4,096 square CsI detectors (8.7 x 8.7 x 30 mm^3). The CsI(Tl) bars are optically bonded to custom made low leakage silicon PIN photodiodes. The detector array has been designed for optimal performance at 511 keV.
The design provides a high degree of modularity. The CsI layer is divided in eight rectangular modules of 512 detector elements, each module is integrated into a stand-alone testable sub-system. Modules may be assembled into the layer.
The CsI modules have the same cross-sectional shape as 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. This resulted in a specification of doping level, surface finish and a housing which maximizes light collection.

Figure 6 shows the spectrum obtained with a ^{22}Na source illuminating a single CsI detector.

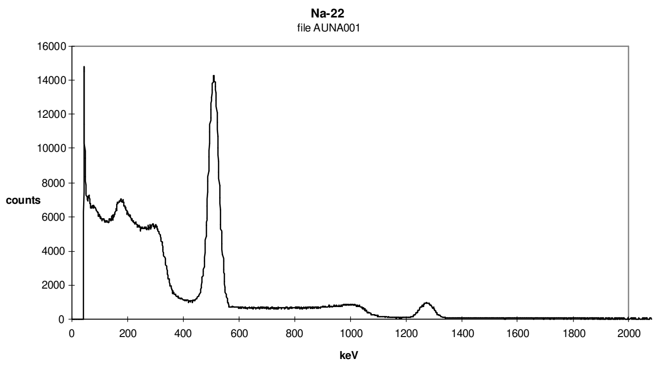

Figure 6: Na^{22} spectrum (511 and 1275 keV). The branching ratio for the 511/1274 keV lines is modified by the different efficiency of the CsI bar at the two energies and by the use of a single CsI bar.

The *IBIS* sensitivity to continuum and narrow lines emission is shown in Figure 7 and Figure 8 (3σ, 10^{6}s).

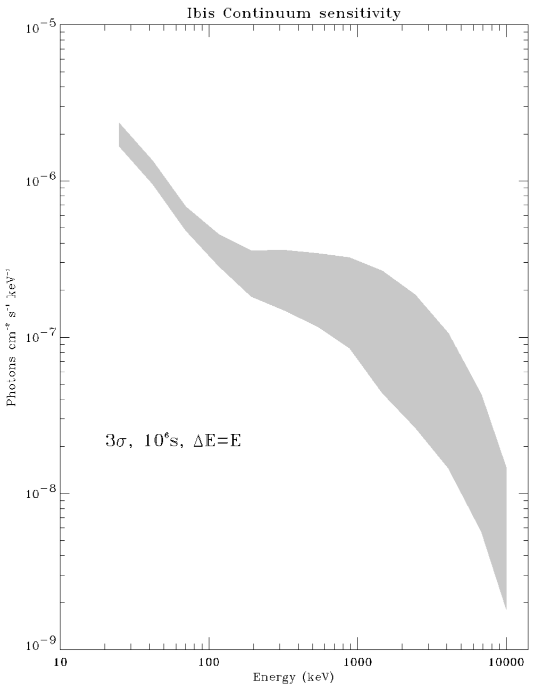

Figure 7: IBIS continuum sensitivity. The band shows the uncertainty due to the background evaluation and to the different cosmic rays behaviour due to solar minimum and maximum.

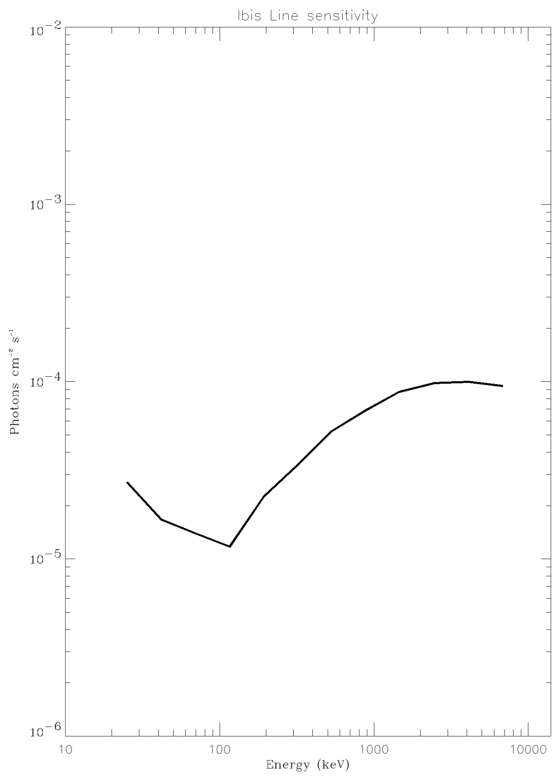

Figure 8: IBIS narrow line sensitivity (ΔE /E=2, photopeck efficiency)

4.7 The Veto Shield

The sides and rear of the stack of detector planes are surrounded by an active Bismuth Germanate (BGO) "veto" shield. Like the detector array, the veto shield will be modular in construction. The high density (713) and mean Z of BGO ensures that a thickness of 20 mm is very efficient in reducing the detector background due to leakage through the shielding of Cosmic Diffuse γ-ray Background (CDB) and γ-rays produced in the spacecraft.

The BGO crystals are each viewed by two photomultipliers (PMT) which provide veto signals to the detector electronics. The lower threshold level will be set around 100 keV. The Veto system gain will be monitored using the onboard calibration system, described in the next paragraph.

Cosmic-ray (protons) deposit at least 1.8 MeV in the CdTe layer far above the upper threshold. This very clear cut signature can be used to exclude those event and reduce the data throughput due to the background.

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. The possibility to use the same signal for the CdTe layer as well is under study. Accepted Calibration Source disintegration generate a tagging strobe which is sent to both the CdTe and CsI electronics for source events tagging.

4.8 The On-board Calibration System

On-board calibrations are necessary in order to monitor and control the instrument in-flight performances and to reach the limit sensitivity on weak astronomical sources to be studied. The response function of the instrument will be refined through comparison of predicted performance 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%).

The ^{22}Na nuclide is embedded in a BGO shield/collimator read-out by two independent 3 inches photomultipliers in order to obtain 511 and 1274 keV tagged photons in the two detector layers.

This set up will permit the measurement and verification of the

1) quantum efficiency as a function of energy and time,
2) monitoring of the gain changes and
3) energy resolution as a function of energy and time.

ACKNOWLEDGEMENTS

The authors acknowledge the IBIS Consortium and System Team support. In particular we are grateful to L. Bassani, A. Bazzano, A.J. Bird, K. Broenstad, E. Caroli, J. Cretolle, S. Di Cosimo, M. Denis, A. Goldwurm, G. La Rosa, C. Labanti, P. Laurent, P. Lavocat, G. Malaguti, I.F. Mirabel, L. Natalucci, E. M. Quadrini, F. Perez, B. Ramsey, V. Reglero, L. Sabau, B. Sacco, A. Spizzichino, R. Staubert, J.B. Stephen, L.Vigroux, R. Volkmer, M.C. Weisskopf, A. Zdziarski, A. Zehnder, the IBIS technical staff and the Laben Team for the continuous support to the programme.

REFERENCES

1. Bergeson-Willis et al., INTEGRAL, Report on the phase A study, SCI(93)1, April 1993.

2. Ubertini P. et al., SPIE Vol. 2806, 246, 1996.

3. Lebrun F., Leray J.P., Laurent P., De Antoni, P. and Blondel C., 1996, NIM A, in Press.