

# The Integral Payload

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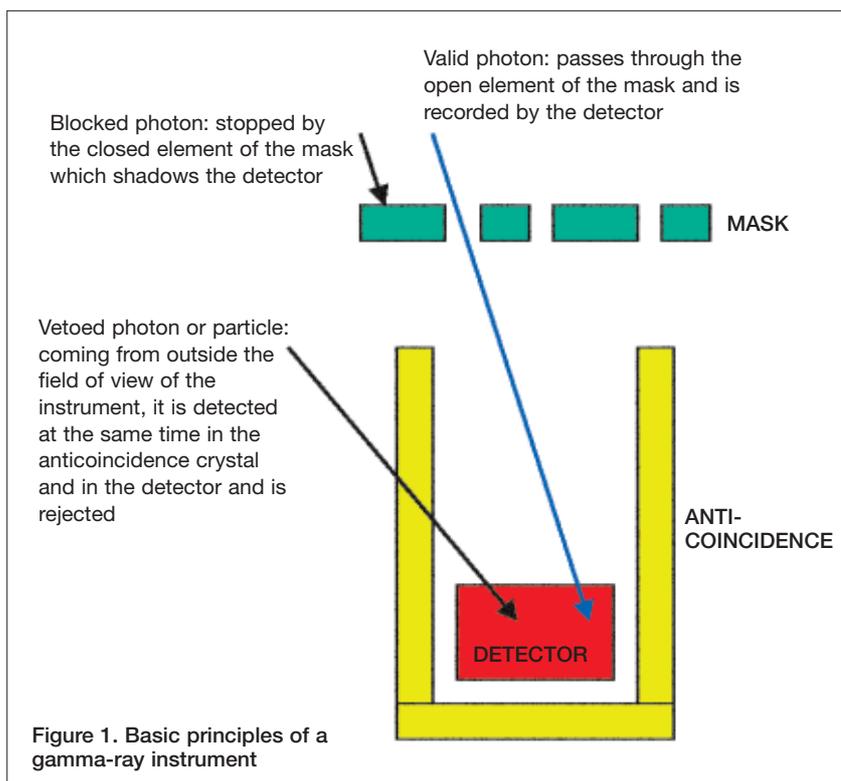
## Introduction

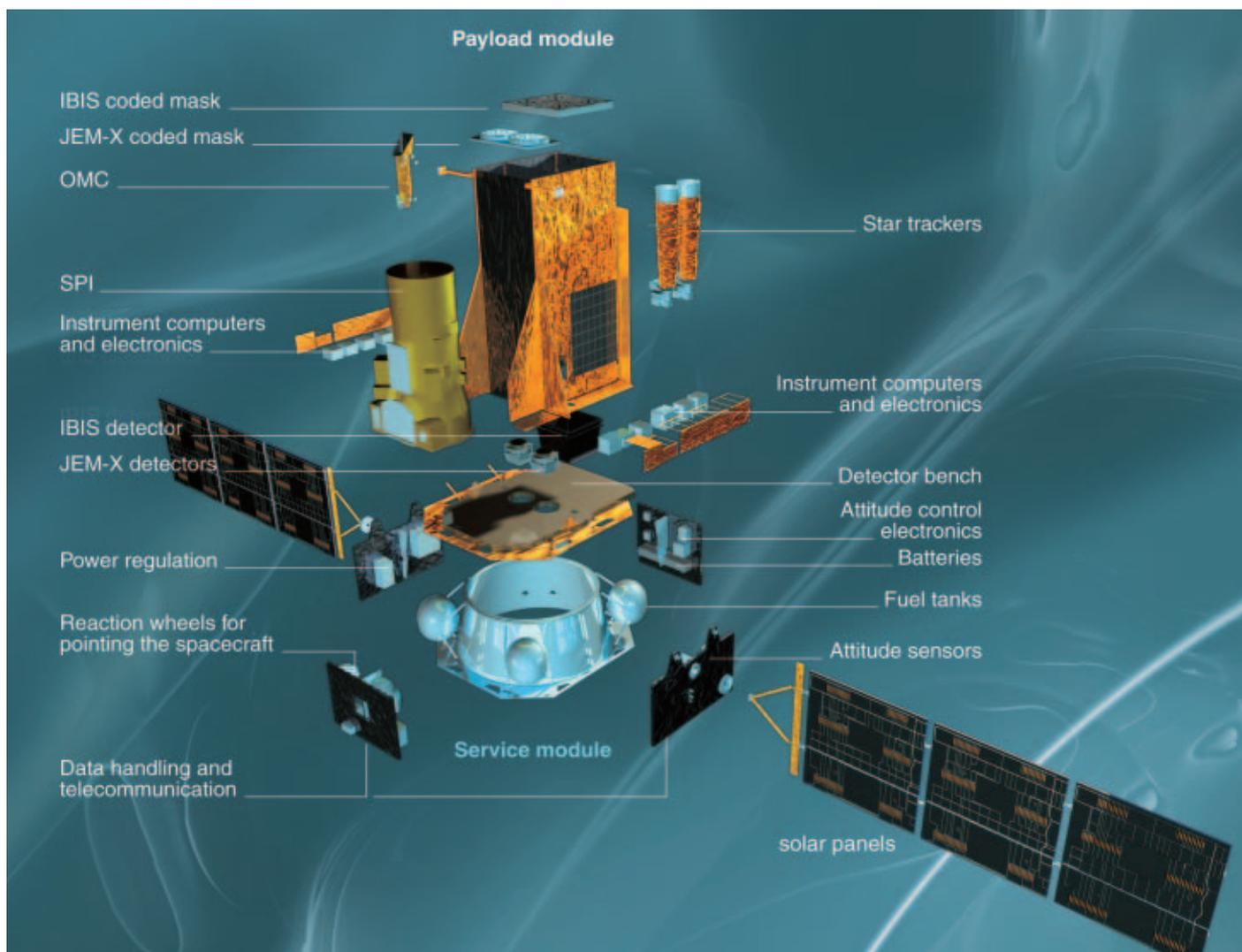
Gamma-ray astronomy is more complicated than other branches of astronomy because at high energies matter is transparent, and therefore source detection and imaging cannot be accomplished with standard optical-like technologies. In addition, the weakness of the source fluxes calls for instruments with large detector areas, which tends to make them large and heavy.

**Gamma-rays represent one of the most energetic forms of radiation in nature. They carry large quantities of energy radiated from some of the cataclysmic of all astronomical events, including exploding stars, colliding neutron stars, particles trapped in magnetic fields, and matter being swallowed by black holes. Integral's payload instruments – IBIS, OMC, JEM-X and SPI – will study these gamma-rays through detailed imaging and high-resolution spectroscopy, providing astronomers around the World with their clearest views yet of the most extreme environments in our Universe.**

The first problem to be solved is how to make an image of a source when the incoming light cannot be focussed, i.e. it passes through most materials without being deviated. The solution adopted for Integral is to use a method known as the 'coded-mask technique' (Fig. 1). The concept is simple, even if the associated mathematics is far from trivial. A coded mask can be seen as a chessboard where the black squares are made of very thick and heavy material with high atomic number, and the white squares are either empty or made of very light and thin material. The incoming gamma-ray radiation is stopped by the black elements, but is unaffected by the white elements. Any source will cast a shadow on the detector, placed a few metres below the mask. From the kind of shadow produced and knowing the geometric characteristics of the mask (the so-called 'code'), the position and shape of the source in the sky can be reconstructed on the ground. Of course, the presence of several sources in the sky, the effect of the external and internal backgrounds, and the fact that the geometry of the mask is much more complex than a simple chessboard, make the image reconstruction a complex mathematical exercise.

The second problem is how to image only what it is in the field of view of the instrument, and to exclude photons or high-energy particles reaching the detector from other directions. This could be achieved by surrounding the detector with a structure of material so thick and heavy that it is able to stop any undesired radiation. Unfortunately, this is not practical for two reasons: firstly, the structure will weigh several tons, and secondly too much material around the detector will create even more disturbance due to emissions of secondary radiation. The technique actually used is called 'active anti-coincidence' and the Anti-Coincidence System (ACS) is a key element of most gamma-ray instruments. The ACS consists of several blocks of thick crystal surrounding the detector, with the exception of the field of view. When the crystal is hit by a





particle or a photon, it generates a flash of light, which can be recorded in time. If the timing coincides with an event in the detector, the relevant particle or photon is considered as coming from outside the instrument's field of view and it is disregarded, or 'vetoed'.

The detector is the core element of the telescope where the interactions with the photons take place and the relevant signals are generated. Three interaction mechanisms are involved: the photoelectric effect, Compton scattering and pair production, depending on the energy of the incoming photon. The higher the energy that has to be measured, the greater must be the stopping power of the detector, and therefore its thickness. The quality of the image generated by the telescope, i.e. its spatial resolution, depends on the number of elements constituting each detector, which in Integral's case ranges from a few tens to several thousands of crystals. As the goal of the Integral mission is precise imaging coupled with fine spectroscopy, the instrument detectors will also provide high-resolution line spectroscopy.

### Integral's instruments

The Integral payload consists of two main gamma-ray instruments, and two monitoring instruments operating in the X-ray and optical bands (Fig. 2). The two high-energy instruments are the SPI (SPectrometer on INTEGRAL), and the IBIS (Imager on-Board the INTEGRAL Satellite). The X-ray monitor is the JEM-X (Joint European Monitor for X-rays), and the optical instrument is the OMC (Optical Monitoring Camera). All four instruments have been designed with good scientific complementarity in mind in terms of energy range, energy resolution and imaging capability. Each of the two main instruments has imaging and energy-resolution capabilities, but whilst the IBIS is best for imaging, the SPI is optimised for spectroscopy. The two monitors will provide complementary, but still fundamental, observations of the high-energy sources at X-ray and optical wavelengths.

Also forming part of the payload is a small radiation monitor, which will continuously measure the charged-particle environment of the spacecraft, particularly the electrons and protons. This will provide essential information

Figure 2. The four Integral instruments are integrated on the upper structure of the satellite, known as the Payload Module (PLM) (illustration Medialab)

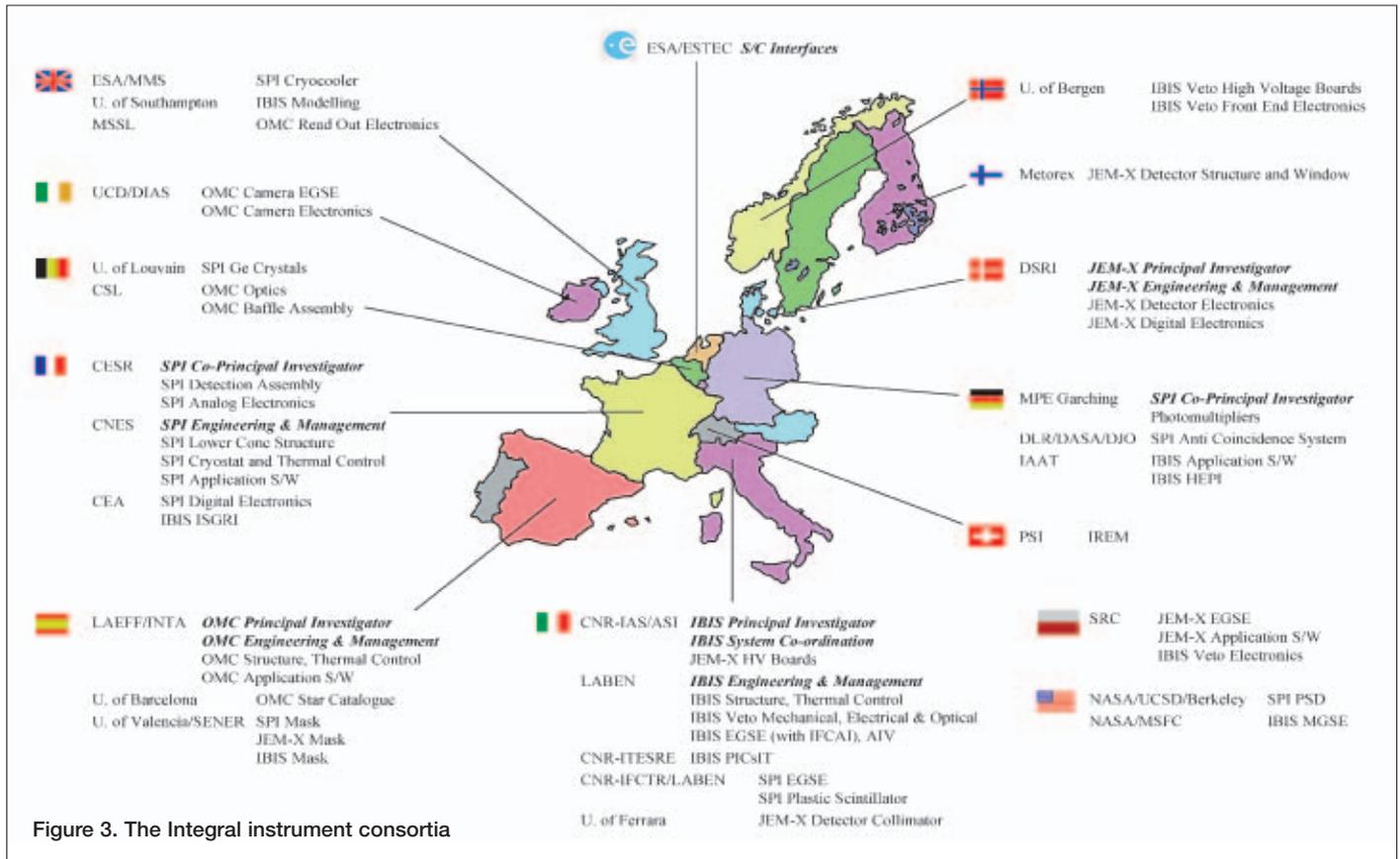


Figure 3. The Integral instrument consortia

Table 1. Summary of the Integral payload's main scientific performances

Parameter	SPI	IBIS	JEM-X	OMC
Energy Range	20 keV – 8 MeV	15 keV – 10 MeV	3 keV – 35 keV	V-filter (at 550 nm)
Detector Area	500 cm <sup>2</sup>	2700 cm <sup>2</sup>	1000 cm <sup>2</sup> (two units)	1.33 x 1.33 cm <sup>2</sup> 1024 x 1024 pixels 50 mm aperture diameter
Energy Resolution	2.4 keV @ 1.33 MeV	8% @ 100 keV 9% @ 1 MeV	16% E > 6 keV	12 bits, 4095 digital levels
Fully Coded Field of View	16°	9° x 9°	4.8°	5° x 5°
Partially Coded Field of View	35°	29° x 29° (zero response)	13.2° (zero response)	
Angular Resolution	2.8° (FWHM)	12 arcmin (FWHM)	3 arcmin	17.6 arcsec x 17.6 arcsec
Point Source Location	30 arcmin	30 arcsec (ISGRI)	30 arcsec	
Continuum Sensitivity 3 σ in 10 <sup>6</sup> sec	3 x 10 <sup>-7</sup> ph cm <sup>-2</sup> s <sup>-1</sup> keV <sup>-1</sup> @ 1MeV, δE=1 MeV	5 x 10 <sup>-7</sup> ph cm <sup>-2</sup> s <sup>-1</sup> keV <sup>-1</sup> @ 100 keV, δE=E/2 1.6 x 10 <sup>-7</sup> ph cm <sup>-2</sup> s <sup>-1</sup> keV <sup>-1</sup> @ 1 MeV, δE=E/2	1.3 x 10 <sup>-5</sup> ph cm <sup>-2</sup> s <sup>-1</sup> keV <sup>-1</sup> @ 6 keV 8 x 10 <sup>-6</sup> ph cm <sup>-2</sup> s <sup>-1</sup> keV <sup>-1</sup> @ 30 keV	
Line Sensitivity 3 σ in 10 <sup>6</sup> sec	2 x 10 <sup>-5</sup> ph cm <sup>-2</sup> s <sup>-1</sup> @ 1MeV	1.1 x 10 <sup>-5</sup> ph cm <sup>-2</sup> s <sup>-1</sup> @ 100 keV 5 x 10 <sup>-5</sup> ph cm <sup>-2</sup> s <sup>-1</sup> @ 1 MeV	1.7 x 10 <sup>-5</sup> ph cm <sup>-2</sup> s <sup>-1</sup> @ 6 keV 5 x 10 <sup>-5</sup> ph cm <sup>-2</sup> s <sup>-1</sup> @ 30 keV	
Timing Accuracy 3 σ	160 μs	120 μs – 30 min	122 μs	2 ms (frame transfer time) 3 s (time resolution)
Limiting Magnitude				17.6 (10 x 100 sec, 3 σ) 18.2 (50 x 100 sec, 3 σ)
Sensitivity to Variations				m <sub>v</sub> < 0.1, for m <sub>v</sub> < 16 (15 x 100 sec, 3 σ)

to the payload in cases where high particle backgrounds (radiation belts, solar flares) are being encountered, allowing instrument high voltages to be switched off and on as appropriate, and will also provide background information for sensitivity estimates.

The four scientific instruments have been provided by separate scientific consortia, each led by a Principal Investigator, or PI (Fig. 3). They are nationally funded, with ESA contributing the Data Processing Electronics (the dedicated onboard computers), the cryo-cooler, and high-reliability electronic components. The pre-processing and distribution of the scientific data to the science community will be the responsibility of the Integral Science Data Centre (ISDC), which is also nationally funded via a PI-led consortium. A summary of the Integral payload's main scientific performances and spacecraft resource allocations is given in Tables 1 and 2.

**SPI (Spectrometer on Integral)**

PIs: J.P. Roques (formerly G. Vedrenne) (CESR, Toulouse) and V. Schönfelder (MPE, Garching)

The SPI is a spaceborne spectrometer designed to perform high-resolution gamma-ray spectroscopy (Fig. 4). The instrument will explore the most energetic phenomena that occur in the Universe, such as neutron stars, black holes, supernovae and the most fundamental problems in physics and astrophysics, such as nuclear de-excitation, positron annihilation, and synchrotron emission. To meet its scientific objectives, the instrument has to satisfy very challenging measurement requirements. It has thus been designed to provide good angular resolution and an excellent energy resolution in the range 20 keV – 8 MeV, with imaging and accurate positioning of point sources (~2.8°) or extended celestial gamma-ray emissions. The SPI's detection, shielding and imaging capabilities for high-energy photons rely on three main features: a 19-detector focal plane, an active shielding telescope and a passive coded mask.

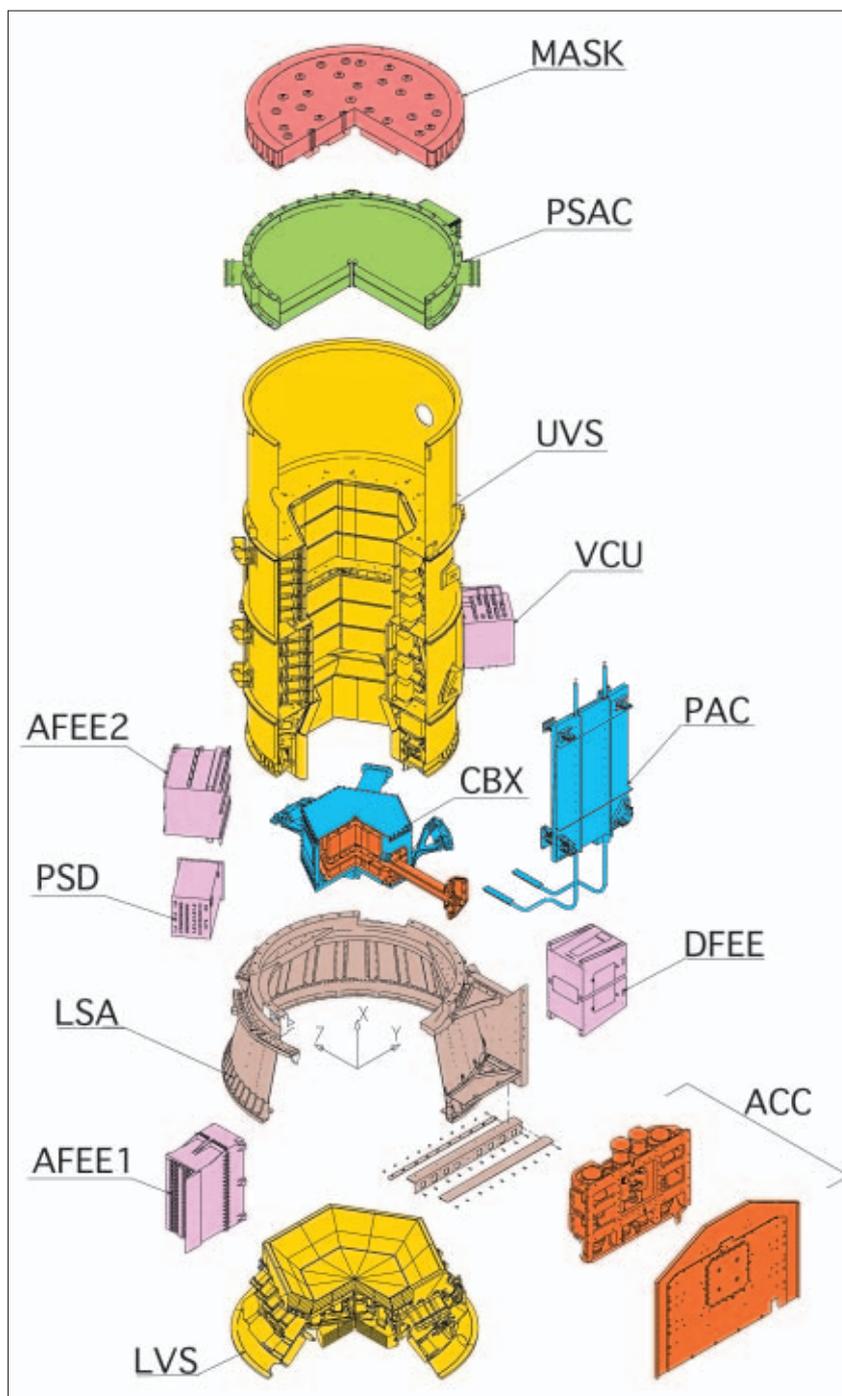


Figure 4. Exploded view of the Spectrometer (SPI), with the core of the instrument, the detector element, housed in a cryostat (courtesy of CNES)

Table 2. Summary of spacecraft resources allocated to the Integral payloads (including DPE)

Instrument	SPI	IBIS	JEM-X	OMC	Total	% of spacecraft resources
Mass	1273 kg	731 kg	76 kg	23 kg	2103	53 %
Peak power in sunlight	384 W	234 W	68 W	26 W	712 W	45 %
Average power in eclipse	159 W	8 W	8 W	17 W	192 W	26 %
Data rate	Up to 20 kbps	Up to 60 kbps	Up to 8 kbps	Up to 2 kbps	Up to 86 kbps	95 %

The mask, located on the top of the SPI, holds a coded motif of tungsten blocks (63 opaque elements and 64 transparent elements). The tungsten stops gamma-rays in the energy range 20 keV – 8 MeV with an effective blocking power greater than 95% at 1 MeV. Similarly, the ‘holes’ have a 60% transparency at 20 keV and 80% at 50 keV. The Plastic Scintillator Anti-Coincidence (PSAC) sub-assembly located below the mask reduces the background due

to the mask’s 511 keV secondary radiation emission. It is composed of a plastic scintillator enclosed in a light-tight box with photo-multiplier tubes that convert the light flashes into electrical pulses. The signals are processed by the PSAC electronics, which send a synchronous veto signal associated with the detected events to the active shielding control electronics (Veto Control Unit).

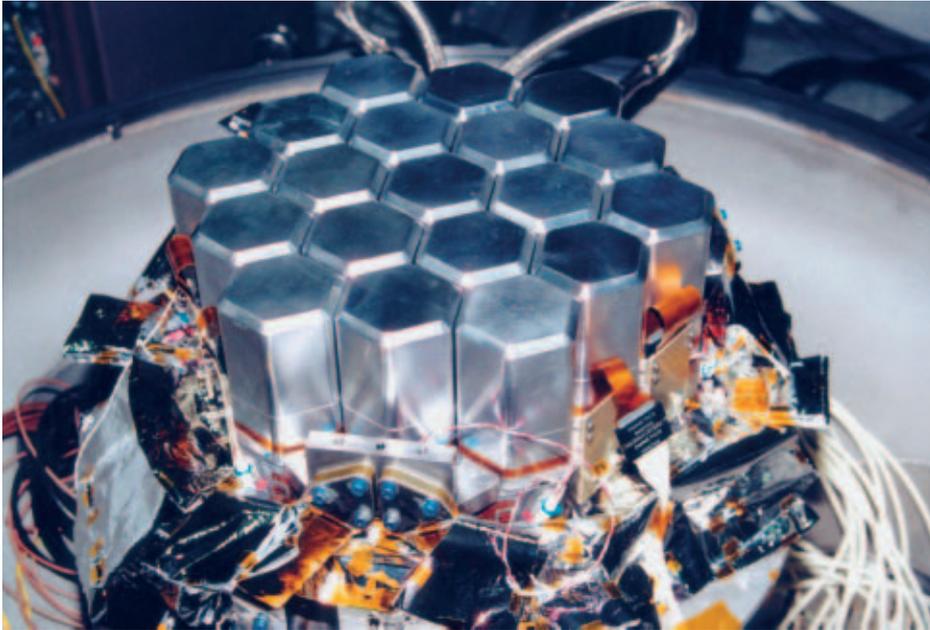


Figure 5. The SPI detectors, consisting of 19 encapsulated germanium crystals mounted on a cold plate, which is nominally maintained at 90 K by four Stirling mechanical coolers (courtesy of CESA)

The detection plane is made of 19 encapsulated, hexagonal, high-purity germanium detectors mounted on a ‘cold plate’ cooled to 90 K (Fig. 5). The detection plane is itself placed in a thermally insulated ‘cold box’ (CBX), whose temperature is maintained at approximately 210 K by passive cooling. Wherever possible, the box’s structure has been manufactured from beryllium (limiting the generation of secondary radiation background noise in the detectors). The cooling of the detectors is achieved via the Cold Bus Bar linking the cold plate to the Active Cooling (ACC) sub-assembly composed of two pairs of cryocoolers (four compressors and four displacers). The cryocoolers are fixed onto a radiator, itself mounted on the structure (LSA) supporting the instrument active shielding and other

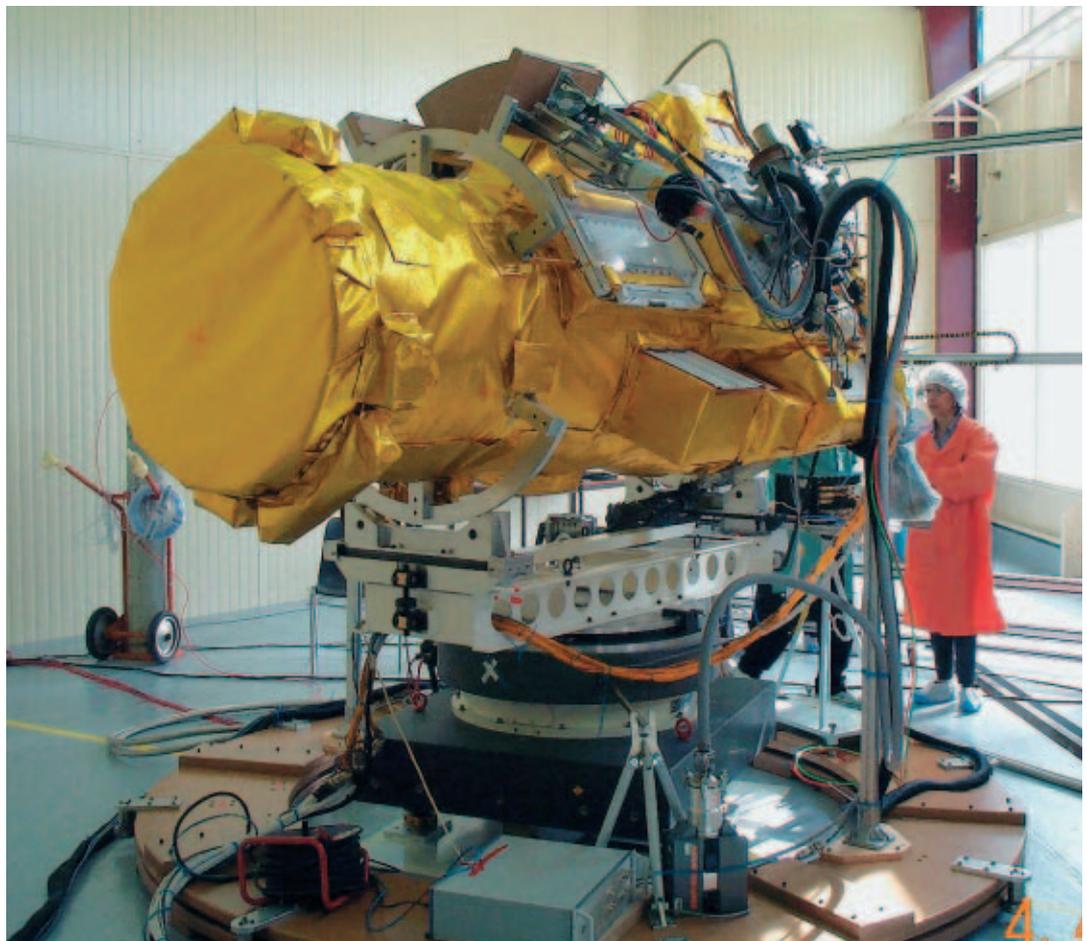


Figure 6. The SPI during calibration activities at the Centre d'Etudes Atomiques in Bruyères le Chatel (F) (courtesy of CESA/CEA/CNES)

electronics. A radiator (PAC) mounted on the structure of the active shielding performs passive cooling of the cold box via two ammonia heat pipes. Each pair of cryocoolers is controlled by a separate Cooler Drive Electronics (CDE) unit located on the Payload Module platform near the SPI (Fig. 6).

The bias voltage of each germanium detector is programmable up to 5000 V. Dedicated high-voltage filters (located on the cold plate) and charge-sensitive amplifiers (operating at 200 K) amplify the signal produced by each detector. A pulse-shape amplifier and pulse-height analyser located in the Analogue Front-End Electronics (AFEE 1) process this signal further. The low-voltage supplies for the 19 amplification chains as well as the germanium-detector high-voltage power supplies are located in AFEE 2.

The Anti-Coincidence System is made up of scintillator crystals (bismuth germanate oxide), photomultiplier tubes (182 PMTs) with the associated electronics (91 FEE) and a shielding Veto Control Unit (VCU). The key function of the active anti-coincidence sub-assembly is to protect the detection plane against the background (photons and charged particles) from sources located outside the field of view. To that end, the scintillator crystals encircle 60% of the telescope's height, as well as enclosing the back of the detection plane. The crystals convert all incoming events into photons of approximately 480 nm wavelength. The light flashes produced are converted by the photomultiplier tubes into electrical pulses. These, in turn, are sorted, normalised and summed by the ACS electronics. The VCU is responsible for the proper functioning and health of the ACS, performing the overall monitoring and control.

The task of the Pulse Shape Discriminator (PSD) is to actively reduce the instrumental background in the 200 keV – 2 MeV energy range by pulse-shape discrimination. It digitises the current pulses from single detector events that correspond to photon energies in the above-specified range. The observed current pulses are then compared on-board with a library of single-site current-pulse templates stored in the sub-assembly, to distinguish single-site from multiple-site interactions within the germanium detectors. By rejecting single-site and retaining only multiple-site events, active background reduction is achieved, leading to a sensitivity improvement of about a factor two within the PSD energy range.

The Digital Front-End Electronics (DFEE) performs the real-time acquisition, assembly, time-stamping and intermediate storage of the

various events detected by the Spectrometer. It first compensates for the differential delays that may occur in the different electronics chains. After this 'time alignment', the AFEE and PSD events observed in one or more detectors are recorded, with their time of occurrence, relative time, AFEE energy, and PSD identifier (single- or multiple-site interaction). Whenever the ACS activates the veto signal, events that occurred in that time period are marked as vetoed and handled separately. The DFEE delivers the annotated lists of AFEE or PSD non-vetoed events to the Digital Processing Electronics (DPE) for inclusion in the telemetry packets.

The DPE, located on the Payload Module close to the instrument, acts as the functional interface between the instrument and the Service Module. It performs the instrument commanding (operating modes) and monitoring (house-keeping management), as well as the scientific data management (i.e. building the spectra and transmitting the data packets to the spacecraft's data-handling system for transmission to ground).

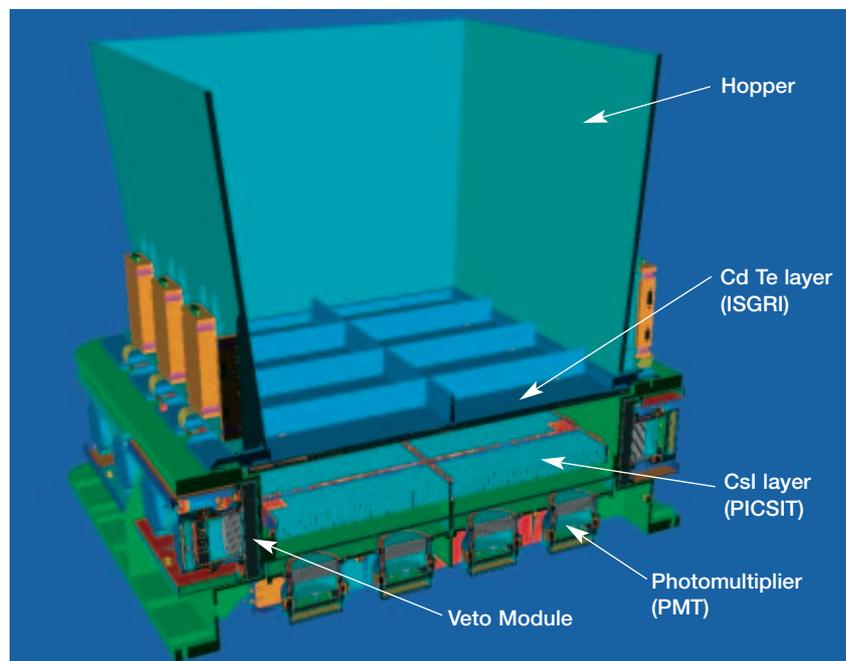
#### *IBIS (Imager on-Board the Integral Satellite)*

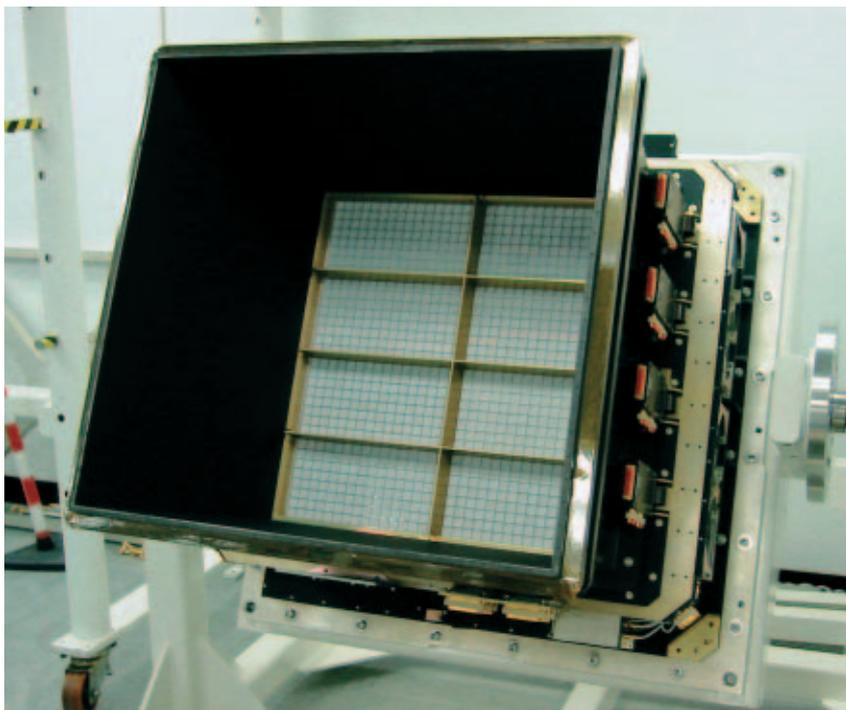
*PI: P. Ubertini (CNR-IAS, Rome)*

*Co-PIs: F. Lebrun (CEA, Saclay) & G. Di Cocco (CNR-ITESRE, Bologna)*

The IBIS will provide high-resolution images of celestial objects of all classes, ranging from the most compact galactic systems to extragalactic objects (Fig. 7). Better than any previous imaging instrument operating in the gamma-ray range between 15 keV and 10 MeV, IBIS will achieve an angular resolution of 12 arcmin and a spectroscopic resolution of 8–9 % over the range 0.1–1 MeV.

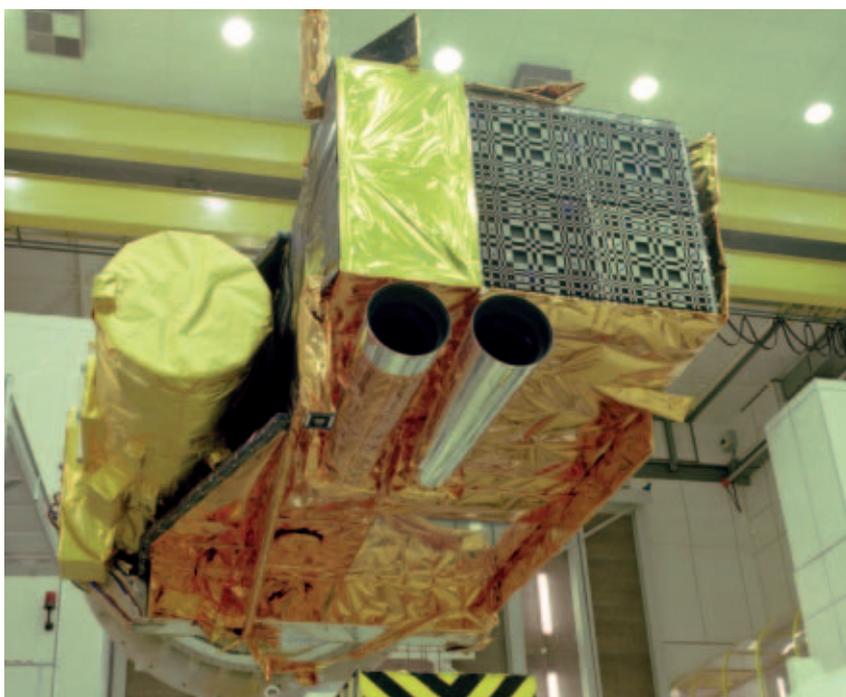
**Figure 7. Cut-away view of the IBIS detector unit. The two crystal layers, the ISGRI (low-energy detection) and the PICSIT (high-energy detection), are surrounded by the veto modules of the anticoincidence system. The collimator (hopper) is made of CFRP covered by a layer of tungsten (courtesy of Laben)**





**Figure 8.** The IBIS detector unit. The eight modules of the upper detector layer can be seen at the bottom of the collimator. Each module is made up of 2048 sensing elements. (courtesy of CNR-IAS/CEA and Laben)

**Figure 9.** The IBIS mask on top of the Integral Payload Module. The two JEM-X masks are covered by the thermal blanket. The baffle of the OMC is visible in the upper part of the picture, and the two star trackers in the lower part. On the left is the SPI



The imaging capability of the instrument is provided by casting a 'shadowgram' of a coded-mask aperture onto a two-layer position-sensitive detector (Fig. 8). The energy of the incoming gamma-ray photon, transferred to charged particles, is dissipated and measured with two parallel pixellised detector planes surrounded by an active anti-coincidence scintillation system. A total of 16 384 independent semiconductor crystals, made of cadmium telluride, constitute the upper layer of the detection unit, designed to cover the lower gamma-ray energy range from 15 keV to 0.5 MeV. High-energy photons are detected by the lower layer, made with 4096

caesium-iodide crystal scintillators. Time-coincident events in both planes resulting from Compton scattering are also analysed.

In order to reject background events as energetic particles, the sides of both planes as well as the back face are shielded by an active anti-coincidence system made of bismute germanate oxide (BGO) crystal scintillator blocks coupled with photomultipliers. A truncated carbon-fibre pyramid covered with a thin tungsten layer is placed on top of the detector as a collimating system to reduce the low-energy X-ray background. An on-board Calibration Unit (CU), consisting of a  $^{22}\text{Na}$  radioactive source in combination with a scintillator-based coincidence strobe generator, is included within the instrument as a known reference for in-flight calibration.

The coded mask is obtained from a pattern of  $95 \times 95$  elements, covering a total area of  $1064 \times 1064 \text{ mm}^2$ . Half of the elements are made of 16 mm-thick tungsten, offering 70% opacity at 1.5 MeV; the remaining elements are open and consequently transparent to photons (Fig. 9).

The upper detection layer, the Integral Soft Gamma-Ray Imager (ISGRI), is made of eight identical, modularly organised detection units, providing a total sensitive area of  $2621 \text{ cm}^2$ . Each module contains 2048 independently operated CdTe detectors,  $4 \times 4 \times 2 \text{ mm}^3$  in size. Due to the high number of pixels, specially developed Application-Specific Integrated Circuits (ASICs) convert the electrical charges into proportional voltage signals. Each ASIC is designed to support four pixels, and so 4096 ASICs have been manufactured for the IBIS flight model. Final processing of the analogue parameters is done by eight electronics units accommodated in two ISGRI Electronics Boxes (IEB 1 and 2).

The upper energy range of 200 keV – 10 MeV is covered by the Pixellated Imager Caesium-Iodide Telescope (PICsIT), which is located 90 mm below ISGRI. Like the ISGRI, the layer is modularly organised with eight rectangular detector units, each consisting of 512 tallium-doped caesium-iodide crystal scintillator bars of  $8.35 \times 8.35 \text{ mm}^2$  with a thickness of 30 mm. The bars are optically coupled and readout by custom-made low-leakage silicon photodiodes. 32 ASICs inside each module, containing pre-amplification, pulse shaping, amplification, signal discrimination, peak detection, and analogue storage, analyse the signals from the photo-diodes. Two separate PICsIT Electronics Boxes (PEB 1 and 2) process the detector signals and convert them into digital event-

position and photon-energy information.

16 Veto Detector Modules (VDMs), each made of BGO scintillator crystal and analysed by two photomultipliers, function as anti-coincidence detectors for ISGRI and PICsIT events to reduce the detector background. Eight BGO modules are located below the two detector layers, and eight are placed around them. The signals from the photomultipliers are routed to the Veto Electronics Box (VEB), in which the analogue signals are discriminated by programmable thresholds to generate binary veto signals. The VEB also controls the onboard Calibration Unit. The veto event signals are used directly by the ISGRI and PICsIT in order to reject coincident events.

During times of high photon fluxes, the IBIS may generate more events than can be transferred to ground with the allocated telemetry rate. A special pre-processing unit has therefore been built to enhance the spacecraft DPE's capabilities. It will accumulate data into onboard histograms, reconstruct multiple or Compton events, and calculate energy amplitude corrections using dedicated calibration tables.

#### *JEM-X (Joint European X-Ray Monitor)*

*PI: N. Lund (DSRI, Copenhagen)*

In order to have a comprehensive understanding of physical phenomena in the celestial sources observed by the SPI and IBIS, it is important to extend the energy range of the observations to the lower X-ray energy band. Therefore an X-ray monitor was needed in Integral's payload complement. JEM-X will provide images with an angular resolution as low as 3 arcsec in the 3 – 35 keV energy band (Fig. 10).

The instrument consists of two identical high-pressure micro-strip gas chambers, which view the sky through two identical coded masks (Fig. 11). For each of the two JEM-Xs, the X-ray photons entering the instrument's field of view pass through the holes in the coded mask, which is located about 3.4 m above the detector entrance window. Inside the detector, which is filled with a mixture of 90% xenon and 10% methane, the photons are absorbed by the xenon gas. This photon absorption process

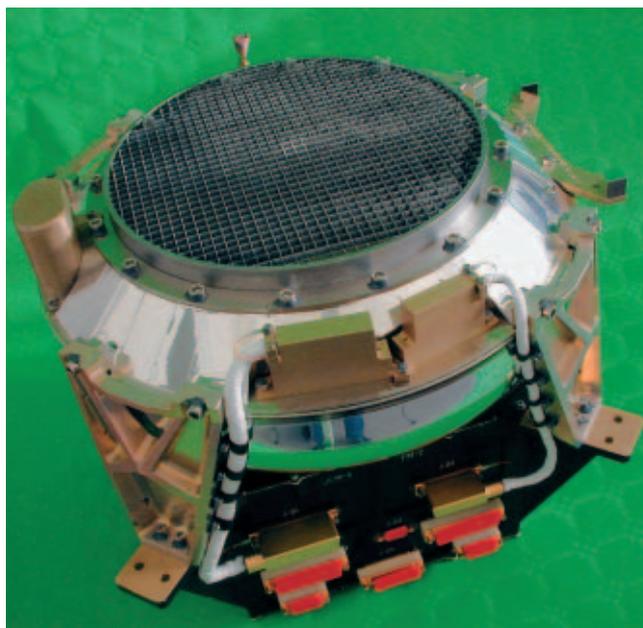


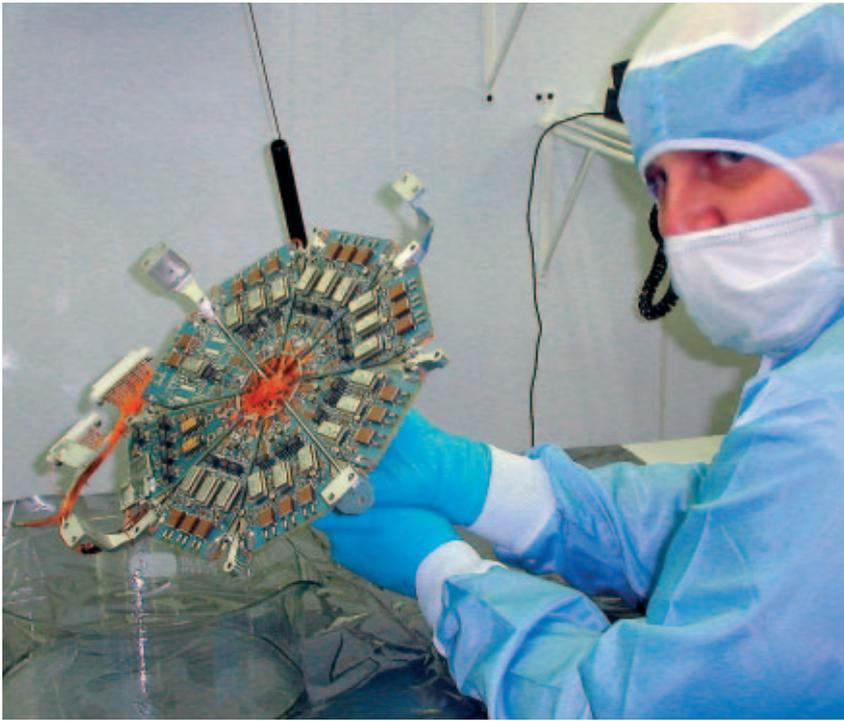
Figure 10. The JEM-X detector assembly. The upper element is the detector vessel, whilst the lower, black element is the Digital Front-End Electronics (DFEE). The square pattern of the collimator can be seen on the top of the detector vessel (courtesy of DSRI)



Figure 11. The JEM-X mask is made from a thin tungsten plate. The coded pattern is provided by a regular combination of small hexagonal holes. Supporting ribs are provided to carry the launch loads (courtesy of Univ. of Valencia/Sener)

is mainly photoelectric and the emitted electrons ionise the other atoms, thereby generating an ionisation cloud. The cloud is amplified whilst drifting towards the detection plane, thanks to an electric field applied between the detector entrance window and the detection plane itself. The avalanche of ionisation is eventually detected by the micro-strip plate, which constitutes the detector focal plane (Fig. 12). The resulting electrical signal is proportional to the energy of the incoming photon. The position is determined by knowing on which anode/cathode group the charge is collected.

The imaging principle is the same as for the two other main instruments and is based on the coded-mask technique. The main hardware elements of the JEM-X are therefore the mask, the detector (with its key constituents the collimator, the pressure vessel with entrance window, and the micro-strip plate), the Digital Front-End Electronics for signal processing, and the dedicated onboard computer (DPE).



**Figure 12.** The micro-strip plate and its associated electronics are the core elements of the JEM-X detector. Due to their extreme sensitivity to contamination, all assembly operations have been carried out in an extra-clean environment (courtesy of DSRI)

The coded mask is a plate of tungsten 0.5 mm thick and with a diameter of about 0.5 m. Due to its thinness, it behaves like a membrane, and the titanium supporting structure has a pre-tensioning system to help keep the natural frequency above the forcing frequencies that will be experienced during launch. The mask elements are hexagonal and 3.3 mm in size, and the holes are produced by electrical erosion. The collimator, located on top of the detector vessel, reduces the background and limits the instrument's field of view to about 6 deg, which is also driven by the detector-mask combination. Its cells are square in shape and it is made of molybdenum. Four small radioactive sources mounted on the collimator will serve as references for the in-flight calibration of the instrument. The collimator also has a structural function, which is to protect the very thin entrance window against the internal detector pressure and the launch loads.

The entrance window must be as thin as possible and is made from a metal with a low atomic number to allow good transmission of the low-energy (3 keV) X-rays. A 0.25 mm-thick beryllium foil has been selected. The detector micro-strip plate and its basic conditioning electronics are contained in a stainless-steel vessel. The gas inside the vessel has a nominal pressure of about 1.4 bar. The micro-strip plate is the sensing element of the detector and is the equivalent of the wires in a classical multiwire proportional chamber. It is made up of a pattern of alternating cathode and anode strips with a pitch of 1 mm, built on a glass-plate substrate. This pattern gives one coordinate in the detection plane, and the

orthogonal coordinate is given by a set of pickup electrodes on the rear surface of the glass plate. The micro-strip plate is surrounded by a veto electrode, which is used to suppress events caused by charged particles entering the detector from the side.

The instrument electronics are physically distributed in three locations. The detector vessel hosts the first level, whose purpose is analogue signal processing and high-voltage distribution to the micro-strip sensors. The second level is a dedicated box called the Digital Front-End Electronics, which performs the digital elaboration of the signals. It also generates, controls and distributes the high voltage and the secondary voltages to the instrument. The last element is the Data-Processing Electronics, which is also a separate unit provided and controlled by the satellite. Its functions are data reception from the front end, data compression, and the management of all telemetry and telecommand interfaces with the satellite.

Three JEM-X flight units have been manufactured, two flight units and one flight spare. The two JEM-X units on the spacecraft will be operated independently and simultaneously, thereby making the instrument fully redundant with respect to any possible failure.

**OMC (Optical Monitoring Camera)**

*PI: M. Mas-Hesse (formerly A. Gimenez) (LAEFF/INTA, Madrid)*

The Integral model payload was designed to study simultaneously high-energy sources in a wide field of view over many decades in energy, and thus to make a major contribution to short-time-scale high-energy astrophysics. The OMC (Fig. 13) observes the optical emission from the prime targets of the two gamma-ray instruments with the support of the X-ray monitor. This capability provides information on the nature and the physics of the sources over a broad wavelength range. Multi-band observations are particularly important in high-energy astrophysics, where variability is typically rapid, unpredictable and of large amplitude. The main scientific objectives with OMC are therefore to:

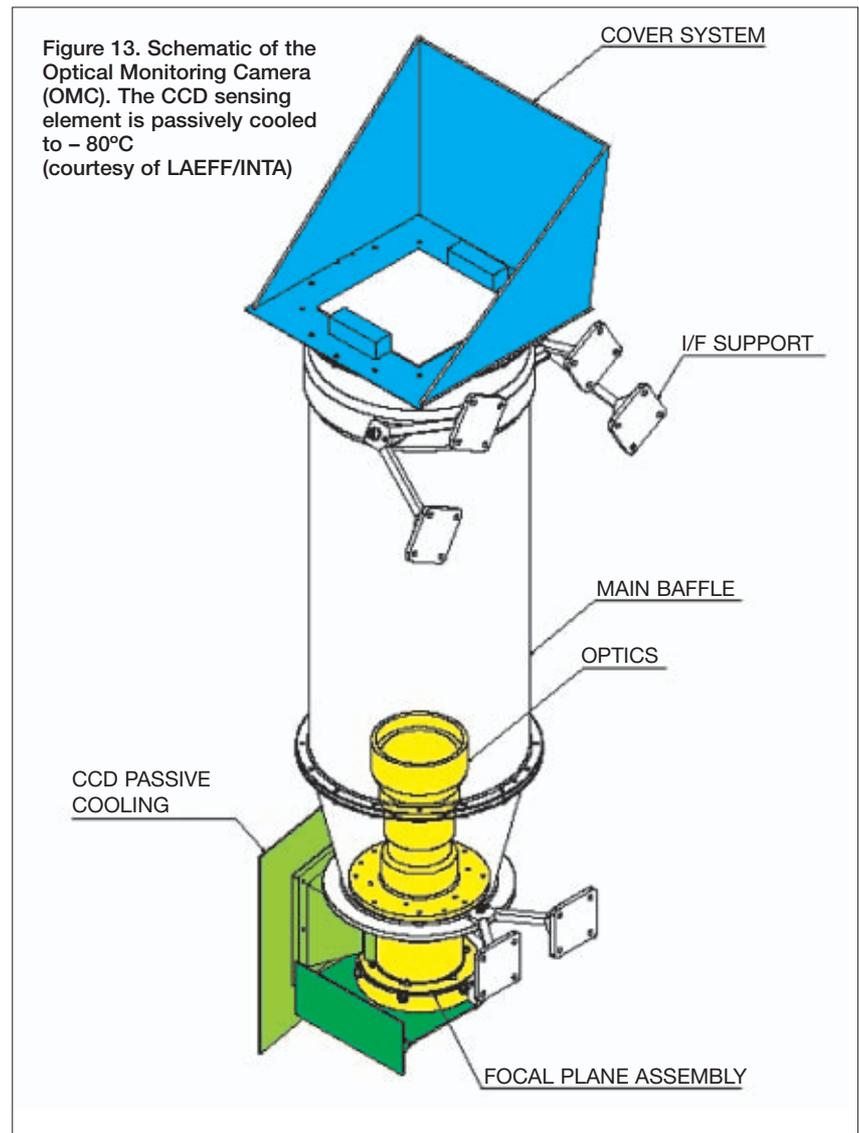
- monitor the optical emission of all high-energy targets within its field of view, simultaneously with the high-energy instruments
- provide simultaneous and calibrated standard V-band photometry of the high-energy sources, to allow comparison of their high-energy behaviour with previous or future ground-based optical measurements
- analyse and locate the optical counterparts of high-energy transients detected by the other instruments, especially gamma-ray transients

– monitor any other optically variable source within the OMC field of view which may require long periods of continuous observations for their physical understanding.

The OMC is also designed to provide data for the estimation on the ground of the precise pointing of the observatory with an accuracy of a few arcseconds. This information allows the Imager, Spectrometer and X-ray monitor images to be reconstructed on the ground with maximum angular resolution.

The OMC consists of a charge-coupled-device camera unit (Fig. 14) connected to a single electronics unit. The core of the unit is a large-format CCD (2048 x 1024 pixels) working in frame-transfer mode (1024 x 1024 image area) to avoid the need for a mechanical shutter. The CCD resides in the focal plane of a refractive system (Fig. 15) with an entrance pupil of ~50 mm and a field of view of 5.0 x 5.0 deg<sup>2</sup>. It will be passively cooled by means of a radiator to an operational temperature range of -100 to -70°C. The complete system covers the wavelength range between 500 and 850 nm. A V-filter is included to allow for photometric calibration in a standard system. An optical baffle guarantees the necessary stray-light reduction for diffuse background. A once-only deployable cover mounted on a specially designed fore-baffle will protect the optics from contamination during ground and early in-orbit operations. The fore-baffle, besides accommodating the cover mechanism, will also protect the main baffle entrance from direct solar irradiation.

The CCD read-out electronics, residing in the OMC Electronics Unit, has multiple functions. On



**Figure 14. The OMC Camera Unit during its final acceptance testing. The square element close to the focal-plane region is the radiator for the CCD (courtesy of LAEFF/INTA)**

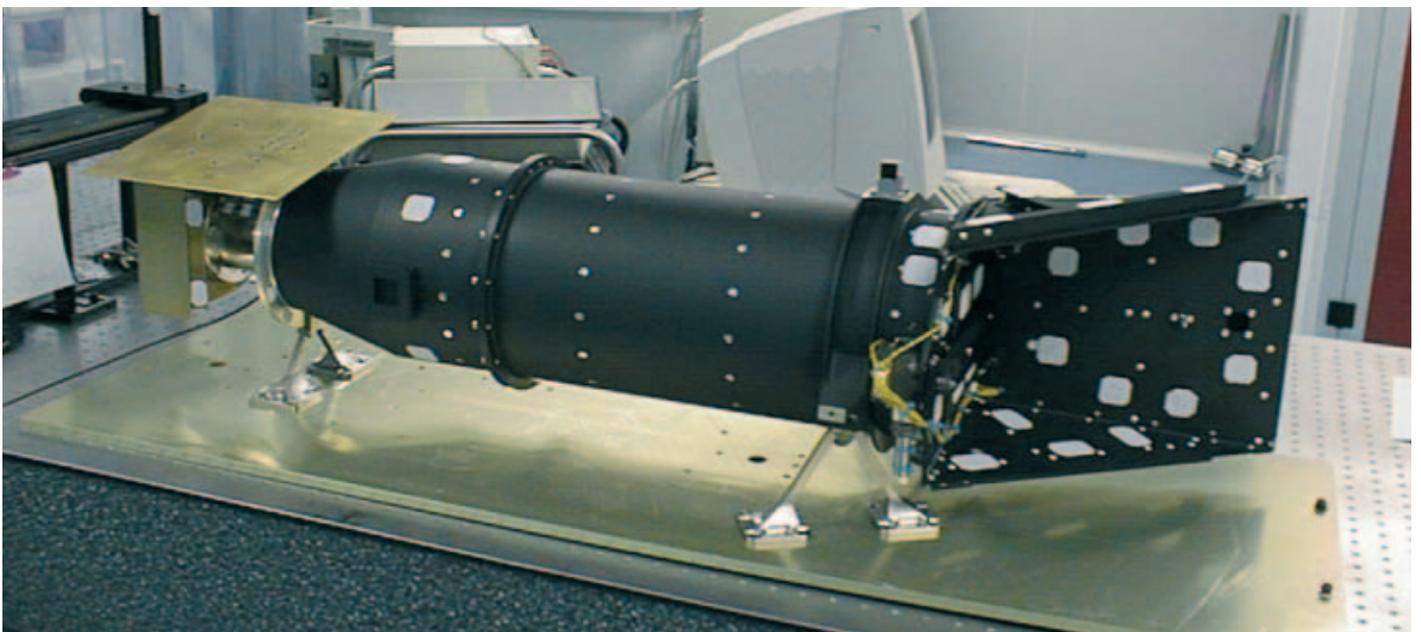
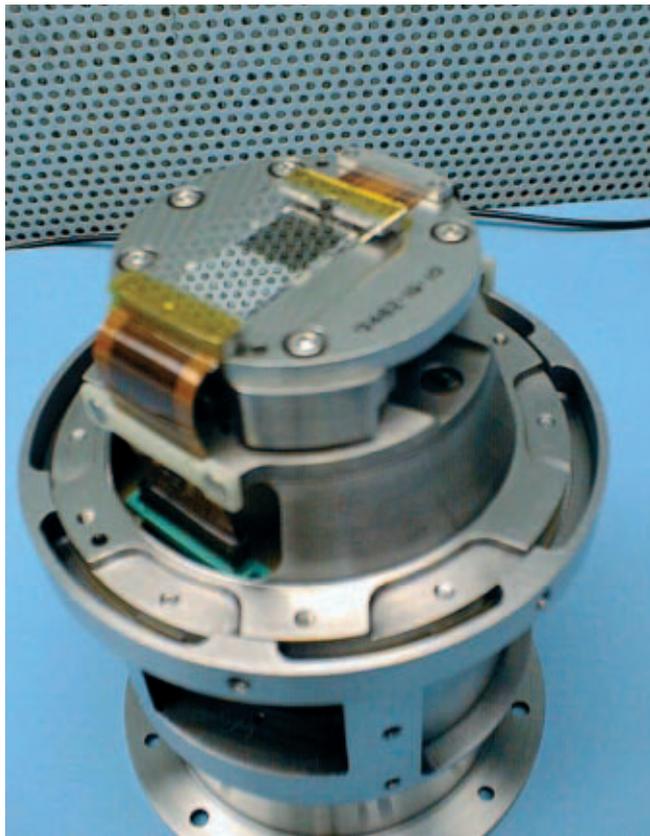


Figure 15. The OMC focal-plane assembly, showing the CCD at the top (courtesy of LAEFF/INTA)



OMC will take images of the full field of view every 1 to 255 sec, depending on the integration times for the different targets. The baseline is to follow a given sequence of different integration times within these limits in order to monitor both bright and faint sources in the field of view. This sequence is configured just before the Science mode is entered, using a dedicated imaging command. The target stars are selected from a sky catalogue (the OMC Catalogue) using a software tool provided by the OMC team to the Integral Science Operations Centre.

Other operating modes for specific investigations are the Fast Monitoring sub-mode, which will allow the monitoring of rapidly variable sources down to 1 sec periodicity, and the Trigger sub-mode, which will allow the monitoring of new sources with a short response time.

the one hand it will control and command the CCD, and on the other it will digitise the read-outs and process the data for transmission to ground via the DPE and the spacecraft telemetry system. Within the CCD cavity of the camera, there are two LEDs for calibration purposes. When activated they illuminate the image area of the CCD. The differential response of each pixel to this known illumination pattern is used to build a flat-field correction matrix, which is needed for the photometric calibration of the images (ground processing). This system is intended to determine the relative quantum efficiency of each CCD pixel to an accuracy of better than 1% in a period of less than 1000 sec. New flat-field images will be taken with a periodicity of the order of CCD degradation once Integral is in orbit. For comparison, dark-current measurements will be performed using masked CCD pixels. Periodic dark-current measurements and flat-field images will also contribute to the absolute photometric calibration performed on the ground using the standard photometry stars imaged in 'Science Mode'.

During the nominal mission phase, scientific data will be acquired repetitively when the satellite is in a stable pointing mode. The OMC is then in its standard operating mode, called the 'Science' mode. The instrument does not provide images whilst the spacecraft is slewing, but is ready to accept new imaging commands for the next acquisition. In Science mode, the

## Conclusions

Seven years after the kick-off of its design phase (Phase-B), the Integral satellite is now ready to fly. As confirmed by the recently concluded Instrument Flight Acceptance Review, the performances of the four payloads are as good or even better than those foreseen during the Phase-A study.

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