INTEGRAL
– The Next Major Gamma-ray Astronomy Mission?

G. Skinner[1], S. Bergeson-Willis[2], T. Courvoisier[3], A. Dean[4], Ph. Durouchoux[5],
N. Eismont[6], N. Gehrels[7], J. Grindlay[8], W. Mahoney[9], J. Matteson[10], B. McBreen[11],
O. Pace,[12], T. Prince[13], V. Schönfelder[14], R. Sunyaev[6], B. Swanenburg[15], B. Teegarden[7],
P. Ubertini[16], G. Vedrenne[17], G. Villa[18], S. Volonté[19], and C. Winkler[12]

[1] University of Birmingham, Edgbaston, Birmingham B15 2TT, UK
[2] Office of Technical Management, NASA GSFC, Greenbelt, MD, USA
[3] Observatoire de Genève, Sauverny, CH 1290 Switzerland
[4] University of Southampton, Southampton, SO9 5NH, UK
[5] CEN-Saclay, 91191 Gif-sur-Yvette, France
[6] IKI, Profsoyuznaya, 84/32, Moscow 117296, Russia
[7] Code 661, GSFC, Greenbelt, MD, USA
[8] Harvard Smithsonian Observatory, Cambridge, MA, USA
[9] JPL 169-327, Pasadena, CA, USA
[10] Center for Astrophysics, UCSD, La Jolla, CA, USA
[11] University College, Dublin, Ireland
[12] ESA/ESTEC, Noordwijk, The Netherlands
[13] Downs Lab. of Physics, Caltech, Pasadena, CA, USA
[14] MPE, Garching bei Munchen, Germany
[15] SRON/ROL, Leiden, The Netherlands
[16] Istituto di Astrofisica Spaziale, Frascati, Italy
[17] CESR, 9, Avenue du Colonel Roche, BP 4346 Toulouse, France
[18] CNR, IFCTR, 21033 Milano, Italy
[19] Directorate of Scientific Programmes, ESA, 8–10 rue Mario Nikis, Paris, France

ABSTRACT

The International Gamma-Ray Astrophysics Laboratory (INTEGRAL) is a proposed joint ESA/NASA/Russia gamma-ray astronomy mission which will provide both imaging and spectroscopy. It is currently at the final stages of an ESA phase-A study which it is hoped will lead to it being adopted during 1993 as the second 'medium-class' mission within ESA's Horizon 2000 plan. Launched in less than 10 years time it will be the successor to the current generation of gamma-ray spacecraft, NASA's Compton Observatory (GRO) and the Soviet-French Granat/Sigma mission. The proposed mission is the culmination of many years of study, being based on ideas originating in the European GRASP study and in the work on NAE within the US.

The baseline is to have two main instruments covering the photon energy range 15 keV to 10 MeV, one concentrating on high-resolution spectroscopy, the other emphasising fine imaging. In addition there will be two monitors – an X-ray monitor which will extend the photon energy range continuously covered down to a few keV, and an Optical Transient Camera which will search for optical emission from gamma-ray bursts.

The spacecraft will be launched into an highly elliptic orbit allowing extended periods of uninterrupted viewing. It will be operated as a single observatory with coordinated observations obtained simultaneously with all the instruments, which are coaligned and have similar fields of view. There will be an extensive Guest Observer programme with time allocated by a peer review process.

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1. INTRODUCTION

The current generation of gamma-ray astronomy missions – the French SIGMA instrument on the Russian Granat spacecraft and NASA's Compton Gamma-Ray Observatory (CGRO) – are producing dramatic new results. They are opening up the gamma-ray band as one in which it is possible to make unique observations. These are often of phenomena observable only in this part of the spectrum or for which gamma-rays provide a discriminating probe with which to confront theoretical models of the very high energy processes involved.

The remarkable advances being achieved with these instruments mean that they will leave in their wake a need for detailed observations to follow up the new discoveries. A mission aiming to fill this need must provide, for example, the capability of observing in detail the spectral lines which have been seen and so utilizing the enormous diagnostic potential of the line centroids, widths and shapes. It must also offer high sensitivity imaging on a variety of scales to study the structure and the location of the sources observed.

INTEGRAL (INTErnational Gamma-Ray Astrophysics Laboratory) is just such a mission, for which a Phase-A study has recently been conducted by the European Space Agency (ESA). If successful in the coming selection process (April–June 1993) INTEGRAL will be an international venture, building on the foundations established by SIGMA and CGRO. It will make available high resolution spectroscopy and fine imaging with unprecedented sensitivity in the energy range 15 keV to 10 MeV. INTEGRAL will be the first high resolution spectral imager to operate in this important region of the electromagnetic spectrum.

The key aspects of the INTEGRAL mission are summarized in Table 1. By the time it is operational in 2001, exploratory gamma-ray observations will have been completed by the SIGMA and CGRO missions. The situation will be ripe for an instrument with excellent spectral and imaging capabilities to make detailed measurements of, and hence understand more deeply, the objects already detected. In addition, many new objects and phenomena are expected to be discovered.

2. SCIENTIFIC OBJECTIVES

Although gamma-rays have been seen from spacecraft at energies extending to the GeV part of the spectrum (and at even higher energies from ground based observations of their interaction in the atmosphere) the spectral region from 15 keV–10 MeV is especially important for several reasons.

It is at these energies that processes such as nuclear excitation, radioactivity, positron annihilation, and cyclotron emission all produce emission lines. Observations of these lines provide important and detailed information about the regions and processes which give rise to them. Unique information is contained in the spectral shift, line width, and line profiles, but such studies require the resolving power ($E/\Delta E=500$) of a Germanium spectrometer such as that employed on INTEGRAL. Instruments like the scintillation detectors on Granat and CGRO have insufficient energy resolution. Until now the only high resolution gamma-ray astronomy performed from space was with HEAO-3 in 1979-80, using an instrument 100 times less sensitive than INTEGRAL.

Some gamma-ray lines have already been observed: 511 keV ($e^+ + e^-$), 1809 keV (^{26}Al), 847, 1238 & 2599 keV (^{56}Co) and 122 keV (^{57}Co)[1–16]. Since the time of HEAO-3, the only high spectral resolution observations have been from balloon flights of necessarily limited duration and have used instruments with fields of view comparable with that of HEAO-3 *i.e.* $\gtrsim$100 square degrees. The only cases where the origin of the lines has been clearly established have been when there was only one possible source (the lines from SN1987A)[10–16] or where the lines were strong enough to have been observed with the very limited energy resolution of SIGMA (lines from Nova Muscae and from 1E1740.7−2942)[17–20]. With INTEGRAL, not only is there the prospect of examining lines such as these in enough detail to exploit their full diagnostic potential, but there are solid observational and theoretical grounds for expecting other lines and for anticipating detectable line emission from a variety of celestial objects. For example the 68 and 78 keV lines of ^{44}Ti

INTEGRAL Mission Summary	
Objectives:	Gamma-Ray Astronomy 15 keV → 10 MeV using High Resolution Spectroscopy and Fine Imaging. Concurrent Monitoring in X-Ray and Optical bands
Payload:	Main Instruments: Germanium Spectrometer Caesium Iodide Imager Monitors: X-Ray Monitor (XRM), Optical Transient Camera (OTC)
Field of View (fully coded):	5.6° to 3.2° (main instruments)
Field of View (part.coded):	13° to 22° (main instruments)
Angular Resolution:	$<20'$ to $>10°$ (Main instruments, according to mode)
Spectral Resolution:	$E/\Delta E \sim 500$ @ 1 MeV
Source Location (20σ source):	$1'$
Continuum Sensitivity (3σ):	3×10^{-8} ph cm^{-2} s^{-1} keV^{-1} in 10^6 s @ 1 MeV
Narrow Line Sensitivity (3σ):	1.5×10^{-6} ph cm^{-2} s^{-1} in 10^6 s @ 1 MeV
Polarization Sensitivity (3σ):	$\sim$ 10 mCrab in 10^6 s, $\phi \sim$ degrees
Orbit and Launcher:	Highly Eccentric Orbit (HEO) Launcher: PROTON D 1-e Period: 72 h, Inclination: 51.6° Perigee: 48000 km, Apogee: 115000 km or: Highly Eccentric Orbit (HEO) Launcher: TITAN III/TOS Period: 48 h, Inclination: 28.5° Perigee: 4000 km, Apogee: 117000 km backup: Highly Eccentric Orbit (HEO) Launcher: ARIANE 5 Period: 24 h, Inclination: 65° Perigee: 4000 km, Apogee: 68000 km
Ground Stations:	Villafranca, Canberra and/or Goldstone
Spacecraft:	Three-axis Stabilized Bus Common with XMM
Absolute Pointing Error:	$\leq 15'$ (95%)
Launch Mass:	3643 kg (PROTON), 3804 kg (TITAN), 3839 kg (ARIANE)
Science Instrument Mass:	1942 kg
Total Payload Mass:	2314 kg
Total Payload Power:	568 W
Total Spacecraft Power:	1268 W
Telemetry:	40 kbps Science Data
Dimension (Payload):	Diameter: 3 m, Height: 4 m
Operational Mode:	Observatory
Nominal Mission Lifetime:	2 years
Design Lifetime:	5 years

Table 1. The INTEGRAL mission – Summary Table

from SN1987A[21] and from galactic supernovae within the last ~500 years, a 1275 keV ^{22}Na line[22] and 478 keV ^{7}Be line[23,24] from novae, and lines at 1173 keV and 1332 keV[25] from decay of ^{60}Fe should all be detectable.

Potential sources of line emission include the Galactic Centre region, the interstellar medium, compact objects, novae and supernovae (lines from Type Ia supernovae anywhere in the Virgo cluster should be strong enough to be observed)[26] and perhaps active galactic nuclei.

The 15 keV–10 MeV region is also the band in which Active Galactic Nuclei (AGNs) emit most of their energy. Although it is now clear from CGRO results that these objects have a variety of spectral shapes and slopes, in almost every case the peak energy per decade falls within the INTEGRAL band. Some models of the central engines in these objects involve pair plasmas in which electrons, positrons and photons are in equilibrium and it may or may not be a coincidence that the band in which the peak of AGN emission occurs encloses the energy 511 keV, which is characteristic of the creation or annihilation of electrons or positrons. The study of active galaxies with both fine and broadband spectroscopy will yield unprecedented insight into the particle interactions which take place in the region where the central engine's energy meets the galaxy's matter. Because of the greatly improved sensitivity of INTEGRAL, sub-degree resolution imaging is absolutely essential to avoid source confusion from the large population of AGNs and to associate gamma-ray sources unambiguously with their optical, infrared and radio counterparts.

One of the most important scientific objectives of INTEGRAL is the study of compact objects, *e.g.* neutron stars and black holes. The rotating magnetized neutron stars in fast pulsars emit throughout the gamma-ray spectrum, while it has recently been found that low-mass X-ray binaries, which are thought to contain low magnetic field neutron stars, sometimes exhibit hard tails to their spectra extending up to low gamma-ray energies[27,28]. In the case of black holes, it is increasingly apparent that a signature of probable black hole binary sources is that, while they often have ultra-soft spectra at X-ray energies, the spectrum extends up to hundreds of keV with a characteristic shape thought to be associated with Comptonization[29]. INTEGRAL will image these objects in unprecedented detail at high energies and the spectroscopic capabilities of the mission will provide the first detailed physical diagnostics of such systems at gamma-ray energies.

Transient sources in the gamma-ray region display unprecedented variability in both the temporal and spectral domains. The enigmatic gamma-ray bursts (GRBs) could originate in sources in our Galaxy or even in other galaxies at cosmological distances[30]. The origin of these bursts is a major unsolved problem in astrophysics. On other timescales, too, the gamma-ray sky is an ever-changing one. A remarkable flare has been observed from a source 1E1740.7−2942, less than a degree from the galactic centre, in which a spectrum with a very strong line feature around 500 keV appeared for about a day[19,20]. Transient sources, usually located in the Galactic plane, flare on timescales of less than a day with the outburst often persisting for several weeks. INTEGRAL will monitor the Galactic plane regularly in order to detect transient sources, and to determine their duty cycle and luminosity function.

3. THE MISSION

INTEGRAL will be placed in a geosynchronous High Eccentric Orbit (HEO) with high perigee in order to provide long (>40 hour) uninterrupted observation periods at nearly constant background, away from trapped radiation and from the gamma-ray 'glow' of the earth's atmosphere. Two alternative launchers are proposed, either (a) a PROTON D 1-e, provided by Russia in exchange for data, providing a 72 hour orbit with 51.6° inclination and 48000/115000 km perigee/apogee, or (b) a TITAN III plus TOS (or equivalent), giving a 48 hour, 28.5° inclination, 4000/117000 km orbit. As a backup, an Ariane-5 launch into a 4000/68000 km, 24 hour orbit (inclination 65°) is also possible. All of these orbits are good for INTEGRAL and any of the three launchers could be used.

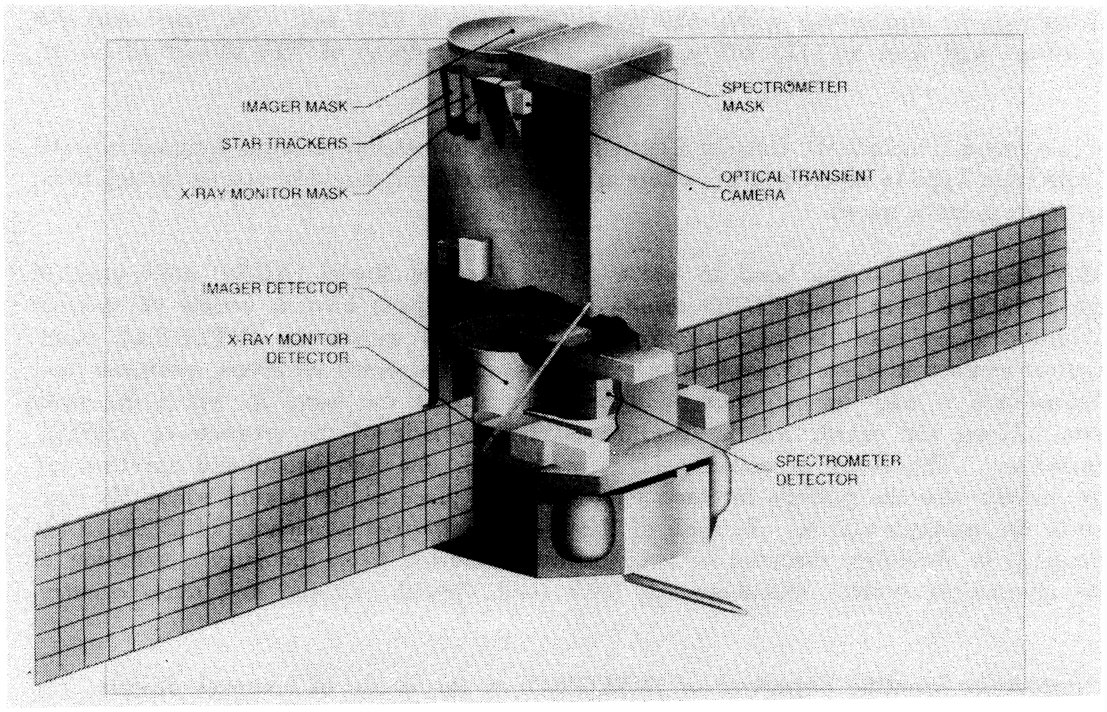

Figure 1. The INTEGRAL payload mounted on the XMM bus.

ESA will be responsible for providing the overall spacecraft, for integration and for spacecraft operations. Considerable cost savings are made possible by using a duplicate of the spacecraft being built for the ESA XMM mission (Fig. 1).

The instruments are mounted on a separate science payload module which will be integrated and tested independently and later incorporated onto the spacecraft as a single unit. The interface to the satellite bus has been designed to be as simple as possible to reduce complexity, timescales and cost.

4. THE MAIN INSTRUMENTS

The conclusion of the phase-A study is that a conservative approach is to baseline two main instruments (Table 2), each of which has both spectral and angular resolution but differently optimized in order to complement each other. Through the use of various new technologies, each can be considerably more powerful than preceding instruments. Between them the two instruments, termed here the '*SPECTROMETER* ' and the '*IMAGER*', meet all the various requirements imposed by the scientific objectives. Together they provide a very powerful combination. The predicted sensitivities are shown in Fig. 2. The two main instruments are supported by two monitors (section 5), an X-ray monitor (*XRM*) and an Optical Transient Camera (*OTC*).

The *SPECTROMETER* , *IMAGER* and *XRM* share a common principle of operation – they are all coded-mask telescopes. The coded-mask technique is the key which allows imaging, which is all-important in separating and locating sources. It also provides near perfect background subtraction. The differences between the instruments are in the designs of the detector and mask dictated by the optimization for different capabilities.

4.1 The *SPECTROMETER*

The gamma-ray detectors planned for use in the *SPECTROMETER* are large-volume (68 mm diameter by 80 mm long) reverse-electrode n-type Germanium detectors. Nine such detectors are arranged in a 3 by 3 array (Fig. 3) to provide the fine spectroscopic capability of INTEGRAL ($E/\Delta E \sim 500$). The detectors are individually encapsulated in separate hermetically sealed containers to avoid contamination and are

Parameter	*SPECTROMETER*	*IMAGER*
Energy range	15 keV → 10 MeV	70 keV → 10 MeV
Detector area	327 cm^2	2500 cm^2
Spectral resolution (E/ΔE @ 1 MeV)	~500	~25
Field of view	5.6° fully coded 13° partially coded 10° FWHM	3.2° fully coded 22° partially coded 6° FWHM < 300 keV
Angular resolution	1.4° FWHM	17′ FWHM
Point source location (20σ source)	10′	1′
Continuum sensitivity (3σ in 10^6 s @ 1 MeV, $\delta E = 1$ MeV)	6×10^{-8} ph cm^{-2} s^{-1} keV^{-1}	3×10^{-8} ph cm^{-2} s^{-1} keV^{-1}
Line sensitivity (3σ in 10^6 s @ 1 MeV)	Narrow (2 keV) line 1.5×10^{-6} ph cm^{-2} s^{-1}	Broad (20 keV) line 1.2×10^{-5} ph cm^{-2} s^{-1}
Polarimetry sensitivity (3σ)		10 mCrab ϕ ~ degrees
Timing accuracy (3σ)	0.1 ms	0.1 ms

Table 2. Key characteristics of the main gamma-ray instruments

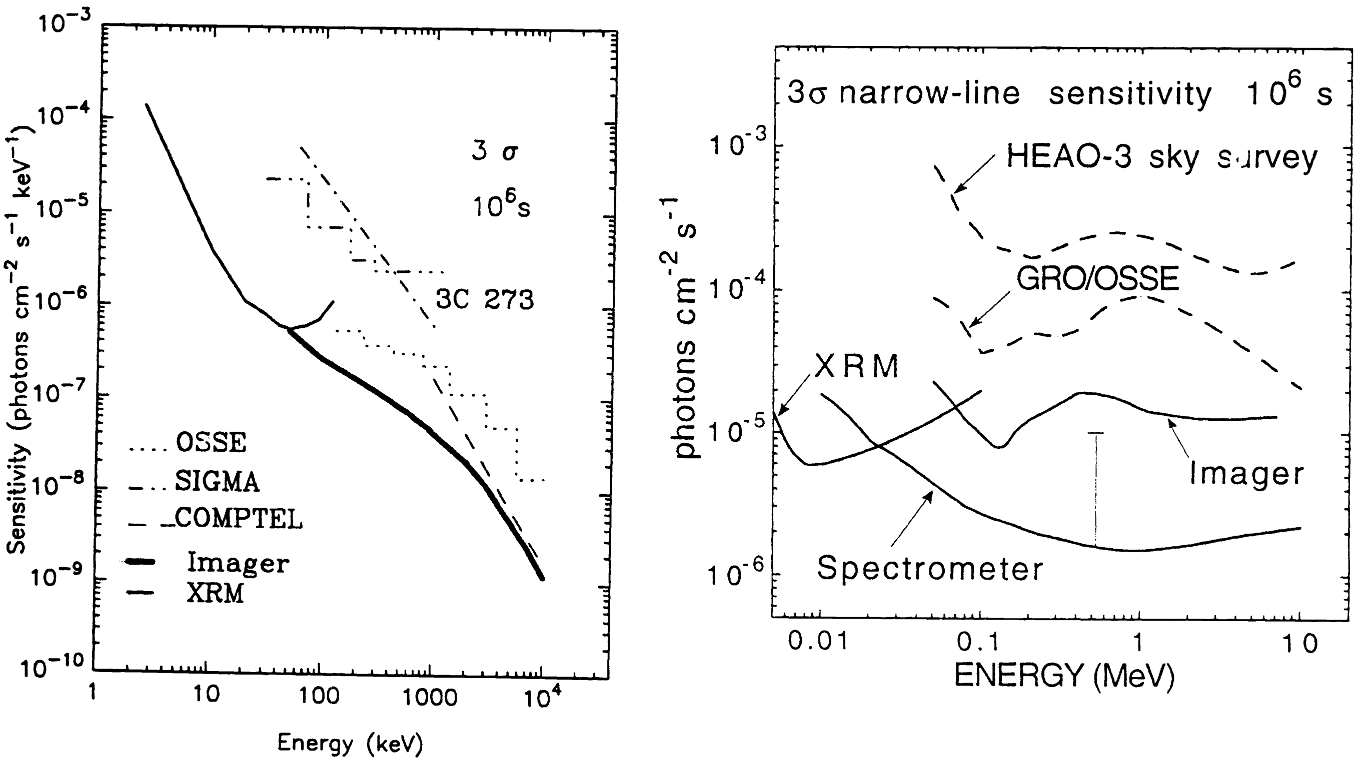

Figure 2. The predicted sensitivities of the INTEGRAL X-ray and gamma-ray instruments compared to other instruments. (a) Imager continuum sensitivity ($\Delta E = E$) (b) Narrow line sensitivity.

enclosed in a cryostat cooled to 75–85 K by a pair of Stirling-cycle mechanical coolers. A second pair of coolers is provided for redundancy. The load on the coolers is reduced by the use of a passively cooled intermediate 215 K shroud in the cryostat, which also provides a sink for the cooled preamplifier front-end FETs.

Considerable efforts have been made to find ways of minimizing the background in the detectors. A heavy 'veto' shield made of Bismuth Germanate (BGO) scintillator will surround the detector array. A thickness of 75 mm provides good shielding even at ~5 MeV (the worst energy). Within such a shield β-decay of ^{75}Ge produced from ^{76}Ge or ^{74}Ge by particle interactions can be an important component of the residual background. External segmentation to remove single-site events will be combined with the use of Germanium enriched to $> 90\%$ in ^{70}Ge at the expense of the background inducing isotopes[31]. Between them, these techniques are expected to remove almost all the β-decay background. Both techniques have been tested in balloon flights during 1992.

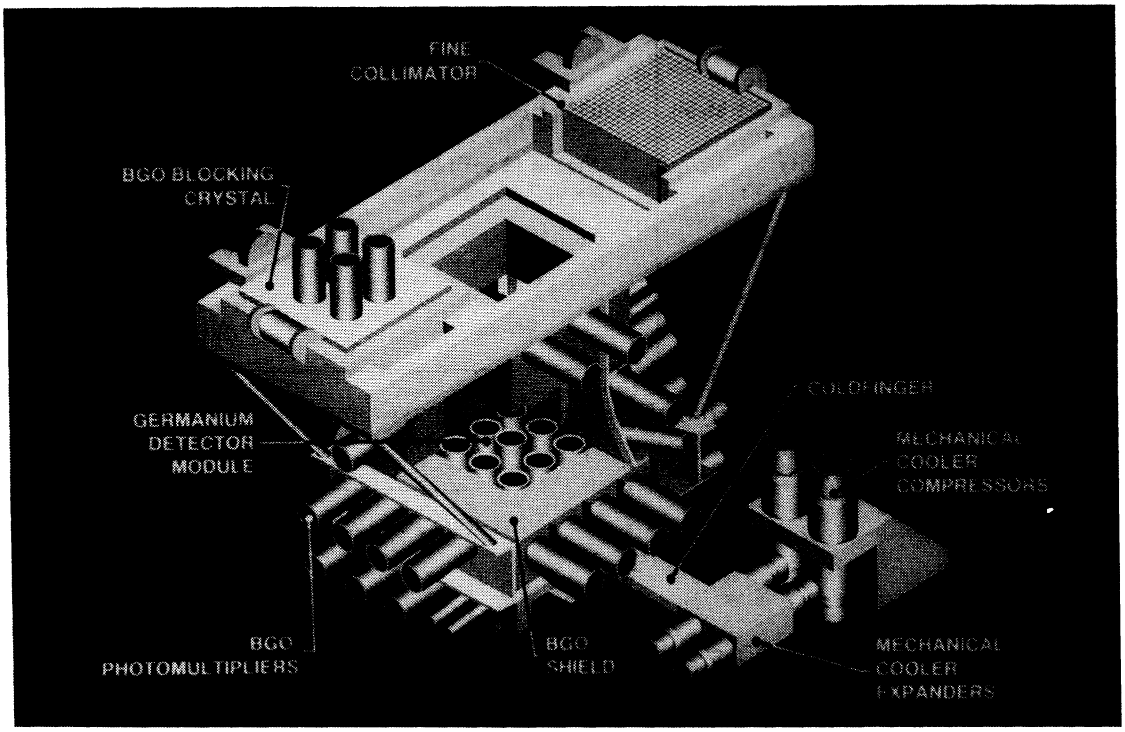

Figure 3. The INTEGRAL *SPECTROMETER* detector

Imaging with 1.4° resolution is obtained by the use of a fixed coded-mask (7×7 mask elements, located about 4 m above the detection plane. To minimize the amount of passive material 'seen' by the Germanium detectors the closed elements are active; each is a 100 mm square by 50 mm thick block of BGO scintillator, viewed by a photomultiplier. To eliminate background systematic effects and to improve the imaging, shadows of different parts of the mask will be projected onto the detector plane by changing the spacecraft pointing direction by a small amount (~ 1°) every ~ 10 minutes.

Efficient observations of diffuse fluxes on larger angular scales are made possible using a 50 mm thick BGO blocking crystal. This is carried by a mechanism which allows it to chop the incoming gamma-rays across the full 10° FWHM field defined by the apertures in the shield through which the detectors look.

Finally, a removable fine collimator is provided to restrict the field of view at low energies (<100 keV) to 1° x 1°, in order to reduce source confusion and the diffuse cosmic gamma-ray background.

4.2 The *IMAGER*

The CsI scintillator *IMAGER* has a separate mask optimized for good angular resolution while providing high sensitivity continuum spectroscopy with moderate resolution ($E/\Delta E \sim 25$).

At gamma-ray wavelengths, the angular resolution of a coded-mask telescope is limited only by the spatial resolution of the detector array. The *IMAGER* design takes advantage of this by utilizing a detector with a very large number of pixels. The pixels are in fact physically distinct elements and thus as independent of each other as possible.

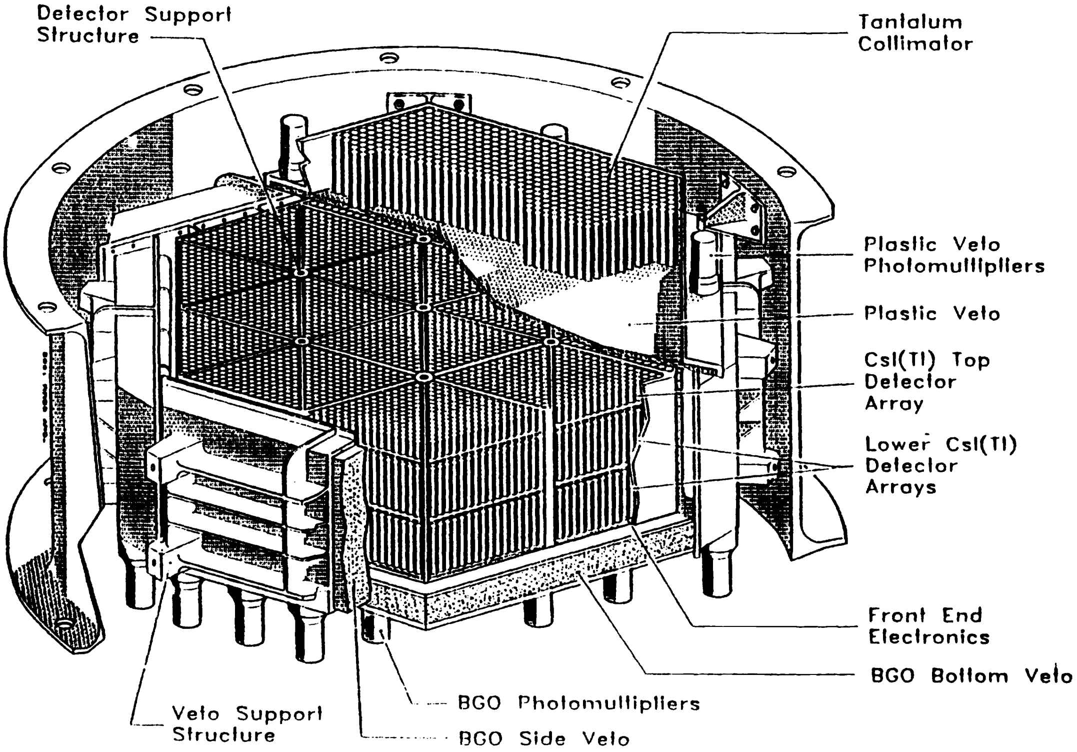

Figure 4. The INTEGRAL *IMAGER* detector

The detector has 3 planes (Fig. 4), each plane containing 2500 CsI bars (area 1 cm^2 each) in the sensitive volume. Every bar is optically bonded to a separate custom-made low-leakage PIN silicon photodiode connected to readout electronics. The division into three layers provides a way of tracking in 3-d the path of photons which scatter and interact in more than one element. This allows discrimination against events unlikely to correspond to real photons.

The CsI bars in the front plane are 10 mm long, while those in the rear two layers are 30 mm. This optimizes the light collection and minimizes the background in the front layer (where most of the photons below $\sim$ 300 keV are absorbed) while providing a large total volume for stopping the more penetrating high energy gamma-rays. For manufacturing efficiency all the detector elements within a layer are identical; indeed the only difference between the three layers is that those in the front layer elements are shorter. The design provides a high degree of modularity, with 24 interchangeable triangular modules of 120 detector elements forming a layer and with each layer being a separate testable assembly.

As with the *SPECTROMETER*, the sides and rear of the stack of detector planes in the *IMAGER* are surrounded by an active BGO veto shield. In the case of the *IMAGER* , though, the optimization leads to a large area with many resolution elements and a comparatively thin active shield. 20 mm of BGO is sufficient to reduce the background from leakage through the shielding of cosmic diffuse gamma-ray background

(CDB) emission and of gamma-rays produced in the spacecraft to less than the sum of all other background contributions.

The CDB from sky just outside the field of view cannot be stopped by an active veto shield of a reasonable size but is blocked by a collimator of stacked tantalum tubes, matched to the field of view of the mask system. The CDB has a steeper spectrum than that of other detector background contributions and is relatively unimportant at high energies. Consequently the collimator is designed to become increasingly transparent at photon energies greater than a few hundred keV, thus reducing the inevitable attenuation of photons from sources towards the edge of the field of view.

The pixel detector design is made possible by the use of multichannel Application Specific Integrated Circuits (ASICs) to handle the signals from the photodiodes. The ASIC chip has been designed and a trial device is currently being prototyped on silicon. It provides 16 channels, each with amplification, pulse shaping matched to the leakage current of the photodiodes and to the decay constant of the scintillator, peak-level detection, discrimination and analogue memory.

The noise level will be such that it should be possible to set a low energy threshold of about 50 keV, though to allow for pixel to pixel variations and for conservatism it has been assumed that *IMAGER* observations do not extend below about 70 keV (imaging at lower energies is with the *XRM*, see below).

Unlike the situation with the *SPECTROMETER*, gamma-ray line background produced in the mask is relatively unimportant in the *IMAGER*, so the mask elements can be passive. In practice the mask will be an hexagonal array of hexagonal 15 mm thick tungsten elements, built into a carbon fibre honeycomb sandwich assembly.

Studies have shown that potentially serious effects could arise from (a) shadows of the structure and of the forward parts of other instruments cast by gamma-ray sources well outside the field of view coded by the mask, and (b) variations due to different sensitivity and/or threshold in the detector elements and associated read-out channels. Both of these effects, as well as those of any variations across the detector of the background rejection efficiency, can be eliminated by making observations both with a given mask pattern and with the same pattern reversed – transparent elements becoming opaque and *vice versa* – and using a differencing method. The mask pattern chosen is such that this can be achieved by a 60° rotation of the mask[32].

Simulations show that rotating the mask in 60° steps reduces the effects of spurious modulation to a negligible level.

5. THE MONITOR INSTRUMENTS

5.1 The X-RAY MONITOR

An X-Ray Monitor *(XRM)* will extend the continuous spectral coverage of the payload down to, and including, the ~6 keV line of highly ionized iron. It will also provide the best position information.

The detector baselined for the *XRM* is a high-pressure (5 bar) Xenon-filled imaging Multi-Wire Proportional Counter (MWPC), with an area of ~1000 cm^2, with efficiency higher than 10% over the band 3–120 keV

The high pressure ensures both adequate quantum efficiency in the vicinity of the Xenon K-edge at $\simeq$ 35 keV, where the gas is most transparent and good overlap with the *SPECTROMETER* and *IMAGER*. It will be operated in a fluorescence-gated mode wherein those events for which a Xenon K fluorescence photon is produced and detected within the sensitive volume are tagged and analysed separately to give low-background and high-resolution[33].

The imaging capability of the instrument will be provided by a self-supporting coded-mask system made from a 1 mm Tungsten sheet, etched with a pattern based on a Uniformly Redundant Array. As with the two main instruments, the mask will be ~4 m in front of the detector. The good spatial resolution possible with a MWPC, even at moderately high energies, means that the mask elements can be much smaller than for the main instruments. 4 mm holes will provide an angular resolution of 3′.

A passive collimator will be employed to limit the field of view to $6° \times 6°$(FWHM) to reduce the background from cosmic diffuse emission.

The sensitivity achievable with the *XRM* is shown in Fig. 2. It is such that sources with typical spectra which are detectable with the main instruments will readily be detectable. Thus as well as providing simultaneous complementary low energy data, the *XRM* will be able to position at X-ray energies the objects observed with the main instruments at higher energies. For moderately strong sources ($\gtrsim 20\sigma$) it will be possible to position sources to 20″.

5.2 The OPTICAL TRANSIENT CAMERA

The main gamma-ray instruments on INTEGRAL will be sensitive detectors of gamma-ray bursts (GRBs). A few times per year there will be burst within the imaged fields of view of the *SPECTROMETER* and *IMAGER* and very detailed studies will be possible. But much more frequently (more than once per day) GRBs will be detected in the BGO shields of these instruments.

To date there has been no simultaneous detection of a GRB and an optical transient coming from the same direction in the sky. INTEGRAL provides an ideal opportunity to simultaneously measure optical, X-ray and gamma- ray emission from GRB sources.

The *OTC* consists of a 30 mm $f1.0$ lens system with a large format (2048 by 1024) CCD at the focus. A reduction in scattered light by more than seven orders of magnitude is afforded through the use of a standard two-stage baffle. The frame transfer CCD will have a sensitive area of 18.4 mm by 18.4 mm and will be divided into (1024 by 1024) pixels, with a pixel size of 1.8′ and overall field of view of 32° × 32°. The CCD will be operated at a temperature of −80° C which will be achieved by use of a cold finger attached to a radiator.

The normal mode of operation will be to accumulate CCD images every second. These images will be stored in memory in such a way as to provide both a *post facto* history of the GRB fields and sensitivity to both short term (frame to frame) and long term (100 s) variability/flaring of stars within the field. In the absence of a GRB trigger only very limited information associated with possible transients/flare stars (*e.g.* a small sub-image of 10× 10 pixels around the star) will be transmitted to ground. In the case of a GRB trigger from the *IMAGER* or *SPECTROMETER*, data prior to the burst will be retained as well as a logarithmically timed image sequence after the burst. These frames will be transmitted to ground in full over the next few hours.

The sensitivity is such that, for a 1 second integration time, 12^{th} magnitude transients accompanying a gamma-ray burst will be detectable.

6. OBSERVATIONS

INTEGRAL will be operated as an observatory with the majority of the time allocated by an international Time Allocation Committee. A Science Operations Centre and two Science Data Centres, one in Europe and one in the US, will be set up. The SDCs will be responsible for providing the scientific community with the data products and the required analysis software, and also for archiving the data for future use. The European and US centres will share the preparatory work to avoid duplication of effort, but each of them will be able to fully support its user community.

As well as the "general programme" a small fraction of the observing time will be allocated to a "core programme", which will largely comprise a systematic survey of the galactic plane. Some of the integration time necessary for the survey will be accumulated through a regular monitoring of the galactic plane which will be accomplished in a series of short pointings separated by 6°. In this way the whole of the galactic plane (or as much of it as possible when the sun constraints mean that parts are unavailable) will be surveyed for new transient sources every 1–2 days. It will be possible to redirect the spacecraft to look at 'targets of opportunity' detected in this way within about 24 h of discovery.

7. THE WAY FORWARD

Within ESA, a decision will be made in June 1993 on which of four missions which have undergone Phase-A studies to adopt as the next 'medium-scale' mission. Assuming INTEGRAL is successful in this selection and corresponding approval for the funding of the NASA contribution to the mission, the launch is expected to be early in the year 2001. The nominal mission lifetime is 2 years, but consumables will be flown to make possible an extension to 5 years.

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