THE INTEGRAL MISSION

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Abstract. **INTEGRAL**, the **Inte**rnational **G**amma-**R**ay **A**strophysics **L**aboratory, to be launched in 2001, is the second medium-size scientific mission (M2) of the ESA long term programme "Horizon 2000". INTEGRAL addresses the fine spectroscopy and accurate positioning of celestial gamma-ray sources in the energy range 10 keV to 10 MeV. The observational requirements will be met by a payload utilising coded mask imaging in combination with detector pixel arrays (*Imaging*) and cooled Germanium detectors (*Spectroscopy*). INTEGRAL is an ESA led mission in collaboration with Russia and USA. Most of the observing time will be made available to the general scientific community.

1. Scientific Objectives

The scientific goals of INTEGRAL - the International Gamma-Ray Astrophysics Laboratory - address the fine spectroscopy with imaging and accurate positioning of celestial sources of gamma-ray emission. The fine spectroscopy over the entire energy range will permit spectral features to be uniquely identified and line profiles to be determined for physical studies of the source region. The fine imaging capability of INTEGRAL within a large field of view will permit the accurate location and hence identification of the gamma-ray emitting objects with counterparts at other wavelengths, enable extended regions to be distinguished from point sources and provide considerable serendipitous science which is very important for an observatory class mission.

In the 15 keV - 10 MeV region, line-forming processes such as nuclear excitation, radioactivity, positron annihilation, cyclotron emission and absorption become important, and when used as astrophysical tools, are almost certain to lead to fundamental new discoveries. Unique astrophysical information is contained in the spectral shift, line width, and line profiles. Detailed studies of these processes require the resolving power ($E/\Delta E = 500$) of a Germanium spectrometer such as that employed on INTEGRAL. Lower resolution spectrometers (e.g. SIGMA, OSSE, COMPTEL) do not have sufficient energy resolution to study the parameters of these lines. The

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last high resolution space instrument on HEAO-3 in 1979-80, was 100 times less sensitive than INTEGRAL. Solid observational and theoretical grounds already exist for predicting detectable emission from such varied celestial objects as the Galactic Centre region, the interstellar medium, compact objects, novae and supernovae and a variety of active galactic nuclei. The scientific objectives are wide-ranging and include:

- The diffuse emission of the Galaxy will be mapped on a wide range of angular scales from arc minutes to degrees in both discrete nucleosynthesis lines, e.g. 1.809 MeV from Al^{26} and 511 keV, as well as the wideband continuum.
- INTEGRAL will provide the tools for using gamma-rays as a sensitive probe of the astrophysical processes going on within a few hundred parsec of the centre of our Galaxy.
- INTEGRAL will image compact objects in unprecedented detail at high energies and the spectroscopic capabilities of the mission will provide the first detailed physical diagnostics of these systems at gamma-ray energies.
- Measurements with INTEGRAL of the shapes of the line profiles of radioactive heavy elements, created by explosive nucleosynthesis during supernova events, will provide information about the expansion velocity and density distribution inside the envelope, whilst the relative intensities of the lines provide direct insight into the physical environment at the time of the production.
- INTEGRAL will monitor the Galactic plane regularly in order to detect high energy transient sources, determine their duty cycle and their luminosity function. Gamma-ray bursts will be studied using the very broad energy range provided by the two main instruments and the two x-ray and optical monitors.
- Because of the greatly improved sensitivity of INTEGRAL, sub-degree resolution imaging is absolutely essential to avoid source confusion from the large population of AGN and to associate gamma-ray sources unambiguously with their optical, infrared and radio counterparts.

2. Design Reference Model Payload

During the Phase A study (1992-1993) a design reference model payload has been defined: INTEGRAL consists of two main instruments (Table 1), a Germanium SPECTROMETER and a Caesium iodide IMAGER, each of which has both spectral and angular resolution but they are differently optimised in order to complement each other and to achieve overall excellent performance. The SPECTROMETER uses cooled hyperpure n-type Germanium detectors providing high spectral resolution, high line sensitivity, mapping of diffuse source emission and medium (degree) imaging capabili-

Fig. 1. The INTEGRAL spacecraft in flight configuration (multi-layer insulation not shown) and cut-away view of the payload module as studied in Phase A. Overall size of the spacecraft (bus and payload module) is 4 m x 3 m x 6 m (width x depth x height). With the solar arrays being deployed, the spacecraft spans about 16 m.

ty. The IMAGER is a high angular resolution gamma-ray telescope using a 3-dimensional detector array of CsI pixels, providing accurate source positioning, high continuum and good broadline sensitivity and medium (10's of keV) spectral capability.

In addition, two monitor instruments will provide complementary observations in other wavebands: the X-Ray Monitor (XRM) will extend the continuous spectral coverage of the payload down to 4 keV – 100 keV and will provide the best position information ($3'$ angular resolution), and an Optical Transient Camera (OTC) (550 nm – 850 nm) will search for, locate ($20''$) and study the optical counterparts (12^m for 1 s) of gamma-ray bursts.

Continuum and narrow line sensitivities of the high energy instruments are shown in Figure 2.

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 because for any particular source direction the detector pixels can be considered to be split into two intermingled subsets, those capable of viewing the source and those for which the flux is blocked by opaque mask elements. Effectively the latter subset provide an exactly contemporaneous background measurement for the former, made under identical conditions.

The layout of the payload has been conceived in terms of a separate science payload module containing the instruments. This 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

TABLE I
Key performance parameters of SPECTROMETER and IMAGER as studied during Phase A

Parameter	*SPECTROMETER*	*IMAGER*
Energy range:	15 keV $\rightarrow$ 10 MeV	70 keV $\rightarrow$ 10 MeV
Detector area:	327 cm^2	2500 cm^2
Spectral resolution		
(E/ΔE @ 1 MeV):	$\sim$500	$\sim$25
Field of view:	5.6° fully coded	3.2° fully coded
	13° partially coded	22° partially coded
	10° FWHM	6° FWHM ($<$ 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,		
δE = 1 MeV):	6×10^{-8} ph cm^{-2} s^{-1} keV^{-1}	3×10^{-8} ph cm^{-2} s^{-1} keV^{-1}
Line sensitivity	Narrow (2 keV) line	Broad (20 keV) line
(3σ in 10^6 s @ 1 MeV):	1.5×10^{-6} ph cm^{-2} s^{-1}	1.2×10^{-5} ph cm^{-2} s^{-1}
Polarimetry sensitivity (3σ):	–	10 mCrab, $\phi \sim$ degrees
Timing accuracy (3σ):	0.1 ms	0.1 ms

simple as possible to reduce complexity, timescales and cost.

3. Mission Scenario

The spacecraft will consist of a service module (bus) containing all spacecraft subsystems and a payload module containing the scientific instruments (Figure 1). The bus will be identical for the two scientific missions INTEGRAL and XMM. The Phase A study has shown that a common service module is feasible for both missions with only very minor adaptations for the INTEGRAL bus due to the different payload.

INTEGRAL (with a total launch mass of 3.6 tons) will be launched early 2001 into a geosynchronous High Eccentric Orbit (HEO) with high perigee in order to provide long uninterrupted observation periods at nearly constant background and away from trapped radiation. As the baseline, a Russian PROTON will launch the spacecraft into a 72 hour orbit with 51.6° inclination, height of perigee of 48000 km, and 115000 km apogee. As backup, an ARIANE 5 can launch the spacecraft into a 48 hour orbit with 60° inclination with almost the same apogee (following a recent change in the XMM

Fig. 2. INTEGRAL continuum (left) and narrow-line (right) sensitivity of the instrument configuration as studied during Phase A. The significance is 3 σ in 10^6 s of observation. Comparison with other missions is shown.

baseline.) Due to background radiation effects in the high energy detectors, scientific observations will be carried out while the satellite is above an altitude of 40000 km. This means, that 100% of the time spent on the PROTON provided orbit can be used for (real-time, 67 kbps) scientific observations, while the spacecraft will stay apx. 83% of its time above 40000 km on the 48 hour (ARIANE 5) orbit. ESA will be responsible for the overall spacecraft and mission design, procurement of bus and payload module, instrument integration into the payload module, integration of the spacecraft, system testing, spacecraft operations and acquisition and distribution of telemetry data. The PROTON launcher will be provided by Russia "free-of-charge" in exchange for observing time, or - as backup - an ARIANE 5 launcher will be provided by ESA. NASA will be responsible for one or possibly two ground stations in order to achieve full real time coverage of science data and will contribute to the scientific instruments and the data centre. Scientific instruments will be provided by the European science community through their national funding agencies and by the US science community through NASA. The INTEGRAL science operations centre (ISOC) will be provided by ESA, the INTEGRAL science data centre (ISDC) will be provided by the European science community through national funding.

4. Science Operations and Observing Programme

INTEGRAL will be an observatory type mission. Most of the observing time, the "general programme", will be awarded to the scientific community at large. Typical observations last from few minutes up to two weeks. Proposals will be selected on their scientific merit by a single review committee. A small fraction (i.e. 30% to 35%) of the total mission duration of nominal 2 years will be reserved for institutes which have developed and delivered instruments and the data centre (guaranteed PI time) and - to a smaller extent - for Mission Scientists. This fraction, the "core programme" will be devoted to (i) a survey of the Galactic plane to map its gamma-ray emission in order to detect as of yet unknown persistent sources (e.g. recent Galactic supernovae) and to facilitate the study of transient sources, and (ii) pointed observations yet to be determined by the PI's and Mission Scientists. The INTEGRAL science data centre (ISDC) will monitor the instrument performance, perform data pre-processing and spot potential targets of opportunity. INTEGRAL will be able to respond to such targets within 24 hours. All scientific data will be assembled by the ISDC into an archive and will be made available (via ISDC or ESA) to the scientific community one year after they have been collected. This guarantees the use of the scientific data for different investigations beyond the aim of a single proposal.

5. Programmatic Aspects

After selection of INTEGRAL by the ESA Science Programme Committee on 03 June 1993 as the next ESA medium-size scientific mission (M2), an Announcement of Opportunity has been issued by ESA on 01 July 1994 asking for proposals for scientific instruments and the ISDC to be provided by the science community via Principal Investigators (PI's), and for proposals for Mission Scientists. Proposals are due by 05 December 1994. After proposal evaluation and selection of instruments, ISDC and Mission Scientists (June 1995), Phase B will start 1995/1996 with a scheduled launch date of April 2001.

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