INTEGRAL

Announcement of Opportunity for Observing Proposals (AO-1)

INTEGRAL Manual

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1. Introduction

The **INTE**rnational **G**amma-**R**ay **A**strophysics **L**aboratory INTEGRAL is a 15 keV - 10 MeV gamma-ray observatory mission with concurrent source monitoring at X-rays (3 - 35 keV) and in the optical range (V, 500 - 600 nm). All instruments, co-aligned with large field of views, cover simultaneously a very broad energy range for the study of high energy astrophysical sources. The payload consists of the two main gamma-ray instruments, the spectrometer SPI, the imager IBIS and of two monitors, the X-ray monitor JEM-X and the optical monitor OMC. In addition a particle radiation monitor measures charged particle fluxes of the spacecraft orbital environment.

The scientific goals of INTEGRAL will be attained by high resolution spectroscopy with fine imaging and accurate positioning of celestial sources of gamma-ray emission. High resolution 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 summary the scientific topics will address:

i) **compact objects:** *white dwarfs, neutron stars, black hole candidates, high energy transients and GRB's*.
ii) **extragalactic astronomy:** *AGN, Seyferts, blazars, galaxies and clusters, cosmic diffuse background*.
iii) **stellar nucleosynthesis:** *hydrostatic nucleosynthesis (AGB and WR stars), explosive nucleosynthesis (supernovae and novae)*.
iv) **Galactic structure:** *mapping of continuum and line emission, ISM, cosmic-ray distribution*.
v) **Galactic Centre:** *cloud complex regions, mapping of continuum and line emission, ISM, cosmic-ray distribution*.
vi) **particle processes and acceleration:** *transrelativistic pair plasmas, beams, jets*.
vii) **identification of high energy sources:** *unidentified gamma ray objects as a class*.
viii) **unexpected discoveries**.

Each of the two main gamma-ray instruments, the spectrometer (SPI) and the imager (IBIS), has both spectral and angular resolution, but they are differently optimised in order to complement each other and to achieve overall excellent performance. The two monitor instruments (JEM-X and OMC) will provide complementary observations of high energy sources at X-ray and optical energy bands.

2. The spacecraft

2.1 Introduction

The Flight Model of the INTEGRAL spacecraft has been built under ESA contract by a European industrial consortium led by Alenia Spazio S.p.A. of Turin/Italy, acting as prime contractor. The INTEGRAL programme is strongly linked to the XMM-Newton programme by the requirement of commonality (see below).

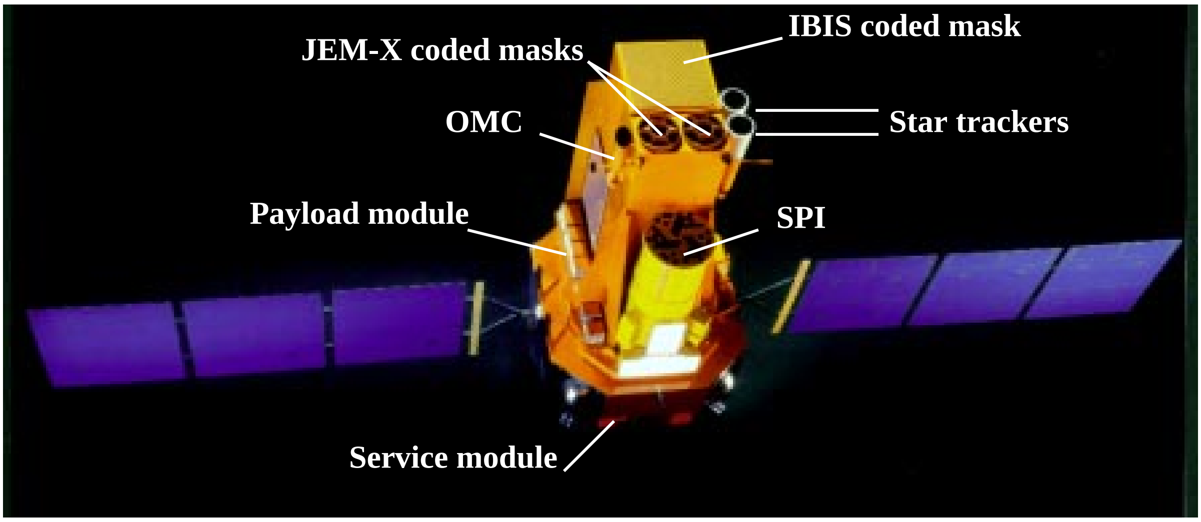

Figure 1. The INTEGRAL spacecraft with the payload module on top the service module. The coded masks for IBIS and JEM-X are located 3.2 m above the detection planes. IBIS and JEM-X detectors are inside the payload module structure. The overall dimensions of the spacecraft (excluding solar arrays which span 16 m) is ~4 m × 5 m (w × h). The sun direction is along the Z-axis (see Figure 2), i.e. the sun is illuminating the payload module on the IBIS side, while leaving SPI in the shadow.

The key characteristics of the spacecraft are:

Commonality with XMM-Newton: The commonality with XMM-Newton is achieved by the re-use of the XMM-Newton Service Module design including the use of recurrent XMM-Newton FM units, the re-use of the XMM-Newton Structural Thermal Model (STM) and Electrical Model (EM) for the INTEGRAL Integration and Verification Program.

Modifications necessitated by the specific needs of the INTEGRAL mission had to be introduced mainly in the Attitude and Orbital Control System (AOCS) and Reaction Control System (RCS) areas, which are specifically affected by the different orbital and launcher scenario.

Compatibility with Launchers: Different static and dynamic fairing envelopes and the different mechanical environment of the PROTON launcher were taken into account in the definitions of the satellite configuration and of mechanical launch loads, both for the XMM-Newton recurring units and the newly developed instruments.

Operational Orbits: With respect to the system design the choice of the operational orbits affected mainly the radiation protection. An Ariane-5 launcher for INTEGRAL was technically maintained as a back-up during the development programme. As an Ariane-based orbit has a higher radiation background, this was considered as a worst design case where the electronic units will be subjected to high radiation doses requiring radiation hardened parts and components.

Pointing and Alignment: The INTEGRAL s/c pointing and attitude requirements are less stringent than those on XMM-Newton, and analyses show that they can be fulfilled up to the end of the extended mission without relying on gyroscope information. These requirements and the instrument alignment requirements are listed in the summary tables below. The X, Y, Z axes (Table 1 and Table 2) describe the spacecraft orthogonal co-ordinate system (Figure 2) with origin at the centre of the separation plane between spacecraft and launch adaptor. The X-axis is perpendicular to this spacecraft/launcher separation plane, pointing positively from the separation plane towards the spacecraft (i.e. the X-axis is the “pointing direction”). The Z-axis is orthogonal to the solar array surface, pointing positively to the sun. The Y-axis completes the coordinate system (see Figure 2). **Note** that the values in Table 1, Table 2 and Table 3 represent requirements on the spacecraft design. Actual measurements on the hardware (to be repeated in-orbit) indicate that the performance values are better. Instruments’ source location capabilities (Table 7, Table 8) are described in the *Instrument Observer’s Manuals*.

Table 1: Pointing and attitude domain[a]

	Y, Z- axes	X-axis	Time interval
Absolute Pointing Error (APE)	5'	15'	-
Relative Pointing Error (RPE)	0.3'	1'	-
Absolute Pointing Drift (APD)	0.6'	2'	10^3 s
Absolute Measurement Accuracy (AMA)	1'	3'	10^5 s

a.Errors are 3σ

Table 2: Instrument alignment[a]

	Y, Z- axes	X-axis	Time interval
Overall Misalignment Error	1'	3'	-
Misalignment Variation	0.1'	0.3'	-
Misalignment Variation	0.3'	1'	10^3 s
Error of a-posteriori determination of misalignment	1'	3'	10^5 s

a.Errors are 3σ

The pointing and alignment requirements as specified in Table 1 and Table 2 are single axis values not referring to half or full cone opening angles. The half-cone direction angle R (= error radius) is obtained via:

$$R = \sqrt{Y^2 + Z^2}$$

and the results are shown in Table 3.

Table 3: Half cone direction R (3σ)

Pointing and attitude	**R**
Absolute Pointing Error (APE)	7.1'
Relative Pointing Error (RPE)	0.4'
Absolute Pointing Drift (APD)	0.8' over 10^3 s
Absolute Measurement Accuracy (AMA)	1.4' over 10^5 s
Instrument alignment	**R**
Overall Misalignment Error	1.4'
Misalignment Variation	0.1'
Misalignment Variation	0.4' over 10^3 s
Error of a-posteriori determination of misalignment	1.4'over 10^5 s

Autonomy and Ground Outage: The mission is designed to be a pre-planned real-time mission under continuous ground control. The spacecraft design takes into consideration that short term reactions (in less than 3 min.) have to be excluded and medium term reactions (in less than 30 min.) are to be minimised. The satellite is designed to cope with 36 hours of ground outage.

Instrument accommodation: The spacecraft design is driven by the gamma ray and X-ray instruments (SPI, IBIS, JEM-X) which are all based on the coded mask principle. The coded masks are positioned at a large distance (~ 3.5 m) from a position sensitive detector. To achieve and maintain the required relative position accuracy between each detector and its mask as well as the Instrument Line of Sight (ILS) w.r.t. the satellite star tracker reference axis requires a high degree of alignment and dimensional stability of the supporting structure under all environmental conditions foreseen from integration to the end of the mission. Field of view and mass distribution constraints had to be taken into account in the accommodation of all instruments.

These design requirements were implemented by applying a modular concept to the spacecraft: INTEGRAL is a three axis stabilized satellite consisting of two separate modules, the Service Module (SVM) and the Payload Module (PLM).

2.2 The service module

The service module of the INTEGRAL spacecraft is a re-build of that developed for the XMM-Newton project and is composed of the following key sub-systems:

- *Mechanical Structure:* It consists of the primary structure (central cone and shear panels) supporting primarily the launch loads and a secondary structure basically consisting of panels carrying the sub-system units and the tanks.
- *Thermal Control System:* The thermal control is achieved by means of active (heaters etc.) and passive (MLI) means.
- *Attitude and Orbital Control Subsystem (AOCS):* This subsystem provides control, stabilisation, and measurements about the 3 satellite axes using star and sun sensors for primary attitude measurements and Reaction Wheels (RW) for torque actuation and momentum storage. The AOCS also controls the Reaction Control System (RCS), which with its thrusters provides the capability of RW momentum dump, delta-V manoeuvres for final orbit injection and maintenance. A hard-wired Emergency Sun Acquisition Mode (ESAM) is implemented to acquire a safe sun-pointing attitude in case that an AOCS failure results in uncontrolled attitude conditions.
- *Electrical Power System:* It comprises the functions of power generation (solar arrays), storage (batteries), control and conditioning (MRU), distribution (SVM PDU – PLM PDU is accommodated on the PLM) to provide all users with the required power on a regulated 28 V main and redundant power bus.
- *Radio Frequency Function:* This subsystem ensures the permanent up- and down-link of telecommands and telemetry using a quasi omni-directional antenna and two redundant S-band transponder.
- *Data Handling System:* This sub-system provides the capability to acquire, process and format data for the down-link. It consists of a single failure tolerant Command and Data Management Unit (CDMU – the central on-board computer) and two Remote Terminal Units (RTUs), one on the SVM the other on the PLM, for data acquisition from peripheral units. Spacecraft telemetry is down-linked in real-time (90 kbps including 86 kpbs science and instrument housekeeping); there is no on-board data storage.
- *Launcher Adapter:* To connect the service module with the Russian PROTON launcher a special adapter was designed, which includes the separation system.

2.3 The payload module

The INTEGRAL payload module consists of an equipment platform accommodating the detector assemblies and an empty box supporting the “upper floor” at a height of about 3.5 m. There the so-called coded masks are installed, a key feature of INTEGRAL's instruments. The backbone supporting the instruments in the payload module is an H-shaped structure. It is made of strong and stiff composite material and ensures that the instruments will have the structural stability necessary for their accurate pointing.

The detector bench provides the interface to the SVM cone upper flange and carries the spectrometer (SPI) units, the IBIS detector and the relevant electronic and data processing units. System units PLM-PDU and PLM-RTU are accommodated on the lower side. The vertical panels carry the OMC, IBIS calibration unit, the IBIS lead shields and the star trackers. They also support the IBIS mask and the JEM-X mask support panel. Sun acquisition sensors (part of AOCS) are accommodated on dedicated brackets. The detailed instrument descriptions can be found in the *Instrument Observer's Manuals*.

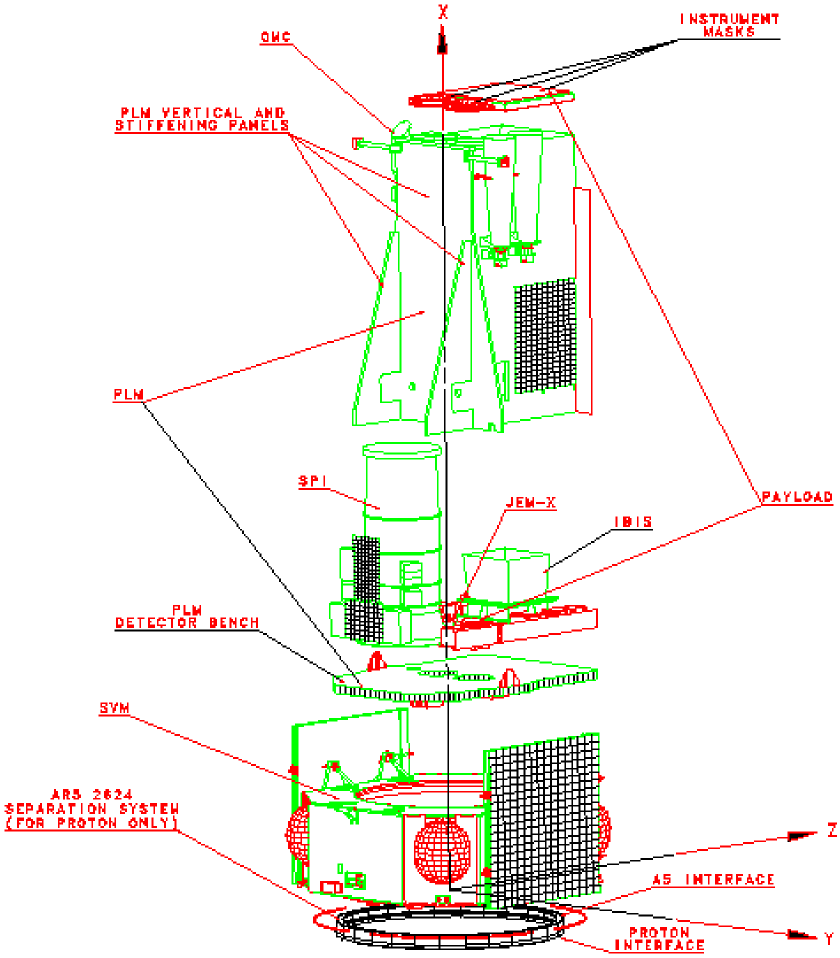

Figure 2. Exploded view of INTEGRAL service and payload modules (solar arrays stowed).

3. The launcher and INTEGRAL orbit

INTEGRAL will be launched with a PROTON launcher from Baikonour/Kazachstan. The PROTON launcher has four stages. The first three stages will propel the composite of fourth stage and INTEGRAL into a 192 × 690 km orbit. The upper stage will put the composite into transfer orbit with apogee height of the operational orbit. Satellite separation from the PROTON upper stage will occur shortly after perigee. Injection from the transfer to the operational orbit will be performed by INTEGRAL's own propulsion system to reach the initial perigee altitude of 10,000 km of the operational 72 hours orbit (Table 4).

The INTEGRAL orbit scenario has to comply with requirements and constraints dictated not only by science objectives but also by ground segment configuration, satellite and launcher capabilities.

In order to allow undisturbed scientific measurements and guarantee maximum science return, it is required to optimize the time spent outside the Earth's radiation belts (proton and electron belts).

The real-time nature of the INTEGRAL mission requires full ground station coverage of the operational orbit above 40,000 km with maximum use of available coverage below. In addition scientific observations will be possible up to the end of the extended mission and hence the orbit will be stable for 5.2 years following the launch, restricting basically the perigee height evolution.

The requirement for maximum visibility from ESA's European ground stations imposes high inclination and an apogee position in the northern hemisphere. After commissioning the number of needed ground stations will be minimised, while for critical operations (like orbital manoeuvres) simultaneous coverage from two stations is required. The orbital period will be a multiple of ~24 hours (i.e. 23^h 56^s) to keep an optimal coverage pattern for all revolutions and to allow repetitive working shifts on ground.

The satellite requirements on the orbital scenarios are dictated by power, thermal and operational considerations. In order to guarantee sufficient power throughout the mission, the Solar Aspect Angle (SAA) has to be constrained (see below for details, however). The maximum duration of eclipses (umbra plus penumbra) shall not exceed 1.8 hours for thermal and energy reasons.

During the nominal mission life (i.e. launch + 26 months) and outside eclipse seasons the Solar Aspect Angle of the spacecraft is SAA = +/- 40^o and it decreases to +/- 30^o for the duration of the extended mission life (years 3 to 5). This viewing constraint implies that the spacecraft cannot point to celestial sources which are closer than 50^o (60^o) to the sun and to the anti-sun during nominal mission (extended mission) respectively. However, during eclipse seasons of the nominal mission the SAA is also constrained to +/- 30^o (see Chapter V).

The assumption also is made that scientific observations will be performed above a nominal altitude of 40,000 km only. However, the on-board radiation monitor provides continuous monitoring of the local spacecraft environment in order to help assessing the background, hence sensitivity and performance of the payload. Based on data from the radiation monitor, collection of science data at altitudes below 40,000 km is possible provided the feasibility of the elevation profile of the ground station coverage.

A reference orbit providing optimum coverage from the ground stations at Redu and Goldstone has been defined for the beginning of the launch window in April 2002. Its initial osculating parameters in Mean Earth Equator 2000 are shown in Table 4.

Table 4: INTEGRAL operational orbit (BOM)

Parameter	
Launch:	2002-04-22
Epoch:	2002-05-05 @ 08:02:29 UT (entry into operational orbit after 5 LEOP revolutions)
Orbital period:	72 hours
Perigee height:	10,000 km
Apogee height:	152,600 km
Eccentricity:	0.813
Inclination:	51.6^{o}
R.A. of ascending node:	106.2^{o}
Argument of perigee:	300.0^{o}
True anomaly:	180.0^{o}

The perigee height varies throughout the mission between the initial 10,000 km and 12,750 km, reaching the peak approximately in December 2005, while apogee height decreases down to 150,000 km. The inclination increases constantly and reaches 85^{o} at EEM (July 2007). Based on this, the percentages of time above 60,000 km and below 40,000 km were calculated (Table 5):

Table 5: Orbital time

	Mission time (y)	**Hours above 40,000 km (% of the orbital period)**	**Hours above 60,000 km (% of the orbital period)**
Begin of Mission (BOM)	0	65.2 (90.8 %)	60.6 (84.4 %)
End of Nominal Mission (ENM)	2.2	65.0 (90.5 %)	60.2 (83.8 %)
End of Extended Mission (EEM)	5.2	65.2 (90.8 %)	60.6 (84.4 %)

For the selected reference orbit the longest solar eclipse will not exceed 1.2 hours. All eclipses will occur at altitudes below 40,000 km, either shortly before perigee (in summer) or shortly after (in winter).

Ground station coverage of the orbit above 40,000 km is achievable by the combined use of Redu (ESA station) and Goldstone (NASA DSN station). Figure 3 and Figure 4 indicate the individual visibility arcs of the orbit from these stations, at BOM and ENM respectively, together with the eclipse regions. Simultaneous visibility from Redu and Goldstone exists during a large part of the orbit.

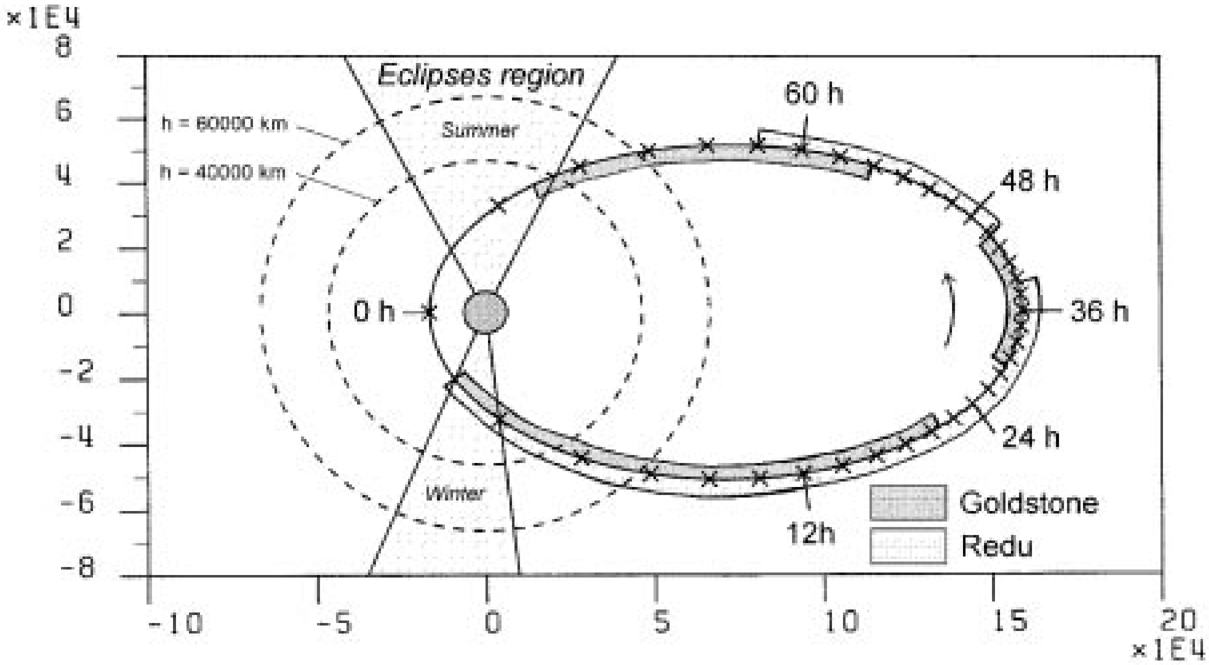

Figure 3. Coverage from Redu and Goldstone and eclipse regions at Begin of Mission (BOM). Axes are in units of km.

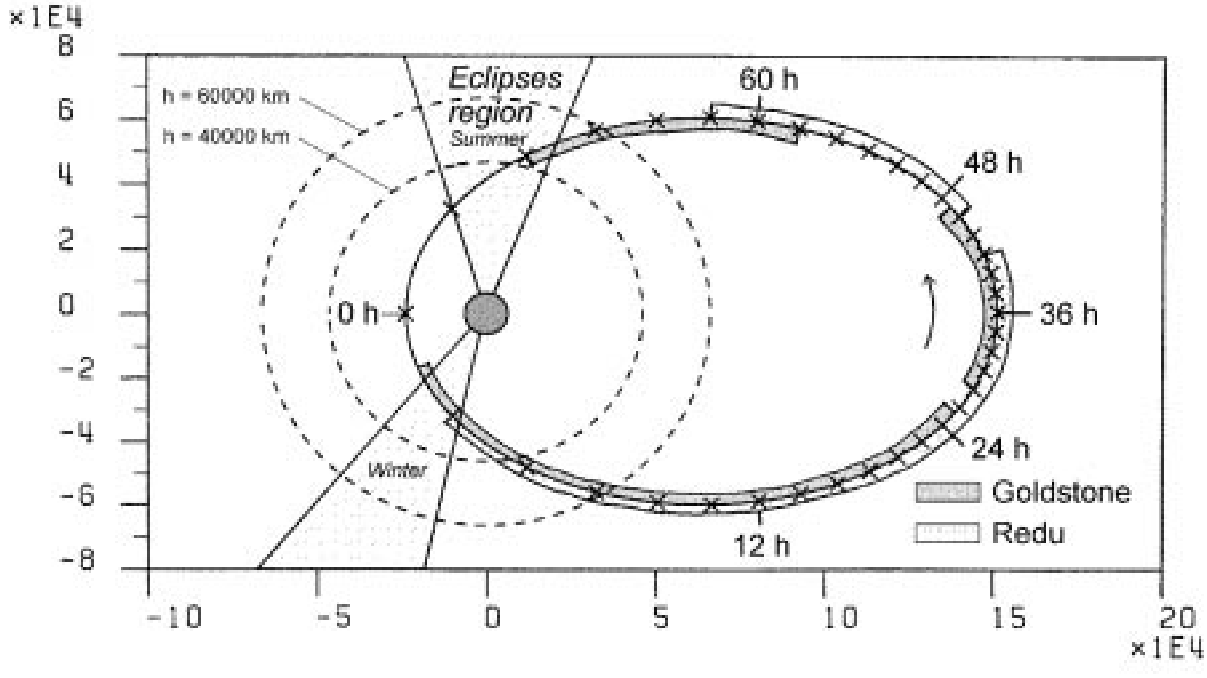

Figure 4. Coverage from Redu and Goldstone and eclipse regions at End of Nominal Mission (ENM). Axes are in units of km.

4. Overview of scientific capabilities

The design of the instruments is largely driven by the requirement to establish a payload of scientific **complementarity**. Each of the main gamma-ray instruments (SPI, IBIS) has both spectral and angular resolution but they are differently optimised in order to complement each other and to achieve overall excellent performance. The payload complementarity is summarised in Table 6.

Table 6: INTEGRAL science and payload complementarity

Instrument	Energy range	Main purpose
Spectrometer SPI	20 keV - 8 MeV	Fine spectroscopy of narrow lines
		Study diffuse emission on >1^o scale
Imager IBIS	15 keV - 10 MeV	Accurate point source imaging
		Broad line spectroscopy and continuum
X-ray Monitor JEM-X	3 - 35 keV	Source identification
		X-ray monitoring of high energy sources
Optical Monitor OMC	500 - 600 nm (V-band)	Optical monitoring of high energy sources

The key performance parameters of the payload are summarized in Table 7 and Table 8 below, for details of the instruments and the sensitivities we refer the reader to the *Instrument Observer's Manuals*. The following subsections give a non-exhaustive list of the scientific topics which will be adressed by the different instruments.

Table 7: Key performance parameters SPI & IBIS

	SPI	**IBIS**
Energy range	20 keV - 8 MeV	15 keV - 10 MeV
Detector	19 Ge detectors (each 6 × 7 cm), cooled @ 85K	16384 CdTe dets (each 4×4×2 mm), 4096 CsI dets (each 9×9×30 mm)
Detector area (cm^2)	500	2600 (CdTe), 3100 (CsI)
Spectral resolution (FWHM)	2.3 keV @ 1.3 MeV	9 keV @ 100 keV
Field of view (fully coded)	16^o (corner to corner)	$9^o \times 9^o$
Angular resolution (FWHM)	2.5^o (point source)	12'
Source location (radius)	< 1.3^o (depending on source strength)	< 1' (for 10σ source)
Absolute timing accuracy (3σ)	129 µs	92 µs
Mass (kg)	1309	746
Power [max/average] (W)	385/110	240/0
Data rate[a] (kbps)	15.8	59.8

a.Allocation for solar maximum

Table 8: Key performance parameters JEM-X & OMC

	JEM-X	**OMC**
Energy range	3 keV - 35 keV	500 nm - 600 nm
Detector	Microstrip Xe/CH_4-gas detector (1.5 bar)	CCD + V-filter
Detector area (cm^2)	2 × 500	CCD: (2061 × 1056) pixels Imaging area: (1024 × 1024) pixels
Spectral resolution (FWHM)	1.2 keV @ 10 keV	--
Field of view (fully coded)	4.8^o	$5^o \times 5^o$
Angular resolution (FWHM)	3'	25"
10σ source location (radius)	< 30"	6"
Absolute Timing accuracy (3σ)	122 µs	> 1 s
Mass (kg)	65	17
Power [max/average] (W)	50/0	15/5
Data rate[a] (kbps)	7.9	2.2

a.Allocation for solar maximum

4.1 Scientific topics spectrometer SPI

Scientific topics to be addressed by the Spectrometer:

- Nucleosynthesis Processes and Supernova Dynamics
  - Astrophysics of supernovae
  - Historical supernovae and recent massive star formation
  - Nucleosynthesis in massive stars and the mapping of sites of star formation
  - Extragalactic supernovae
  - Astrophysics of novae
  - Cosmological abundances and the nucleosynthesis of light elements
- Interstellar Processes
  - Diffuse galactic 511 keV emission
  - Energetic particles: nuclear de-excitation lines
- Compact Objects
  - Galactic centre sources
  - The astrophysics of candidate black hole systems
  - The astrophysics of magnetized neutron stars
  - Superluminal sources
  - Transients
- Active Galactic Nuclei
  - Seyfert galaxies
  - Blazar-type AGNs
- Cosmic Diffuse Background Radiation
- Cosmic Gamma-Ray Bursts
- Diffuse Continuum Emission
  - Galactic continuum emission
  - Continuum from cosmic-ray -- interstellar matter interactions

4.2 Scientific topics imager IBIS

Scientific topics to be addressed by the Imager:

- Galactic Astrophysics
- The Galactic Centre
  - Compact objects:
  - Cataclysmic variables
  - Neutron stars (radio pulsars, cyclotron lines from X-ray binaries, hard X-rays from LMXBs)
  - Black hole candidates
  - BH candidates vs neutron stars
- Explosive (supernovae and novae) and hydrostatic nucleosynthesis
- Long lived isotopes, mapping of diffuse emission
- Nuclear interaction gamma-ray lines
- High energy transients and gamma-ray bursts
- Extragalactic astrophysics:
  - Active Galactic Nuclei (Seyferts, blazars, other galaxies)
  - Clusters of galaxies
  - log N-log S and cosmic diffuse background

4.3 Scientific topics X-ray monitor JEM-X

The scientific topics to be addressed by JEM-X are those which take full advantage of the strengths of JEM-X such as its broad spectral coverage. The source categories include:

- Active Galactic Nuclei
- Accreting X-ray pulsars
- X-ray transients
- Black hole candidates

4.4 Scientific topics optical monitor OMC

The OMC will observe the optical emission from the prime targets of the INTEGRAL main gamma-ray instruments and the X-Ray Monitor JEM-X. The OMC offers the first opportunity to make long observations in the optical band simultaneously with those at X-rays and gamma-rays. This capability will provide invaluable diagnostic information on the nature and the physics of the sources over a broad wavelength range. Multi-wavelength observations are particularly important in high-energy astrophysics where variability is typically rapid. The wide energy band covered by INTEGRAL is unique in providing for the first time simultaneous gamma-ray, X-ray and optical observations over seven orders of magnitude in photon energy for some of the most energetic objects in the Universe, including AGN, Supernova explosions, active binary systems, black hole candidates, high energy transients, serendipitous sources and gamma-ray bursts.

II. Observing with INTEGRAL

1. Introduction

All 4 instruments on-board INTEGRAL are co-aligned (Figure 1, Figure 2) and are operated simultaneously. Observers receive from the ISDC (see Chapter III), in general, all data from all instruments pertinent to their observation together with auxiliary data including output from the particle radiation monitor. Typical INTEGRAL observations will range in duration from ~1 day to a few weeks, the former being for studies of the softer (< 500 keV) end of the spectrum, the latter for narrow - line studies and at MeV energies. A proposal may contain several observations.

Details of the observation types, spacecraft modes and amalgamation of observations are described below.

The reader is further referred to the AO document (annexe) on *INTEGRAL Science Data Rights*.

2. Observation types

There are three classes of INTEGRAL observations which can be applied for in the open time of the General Programme (see Chapter III, Section 3.2). Each class has implications for the science operations of INTEGRAL.

2.1 Normal observations

These are the majority of scientific observations which do not require any special boundary conditions apart from the normal ones, e.g. constraints on sky visibility. These observations lead to the most efficient observing schedules.

2.2 Fixed time observations

Fixed time observations have special scheduling requirements - for example, phase dependent observations of a binary system, or co-ordinated observations with other (ground- or space-based) facilities. The exact scheduling requirements for a fixed time observation may not be known at the time of proposal submission. Once the proposal is approved, ESA will liaise with the observer to determine the best time when to schedule such an observation. Fixed time observations reduce the observing efficiency since INTEGRAL is forced to observe a particular region of the sky at a particular time and they tend to drive the schedule. These observations cannot be guaranteed to be scheduled unless they are awarded the highest scientific grade (1) by the TAC. It is strongly recommended, that long ($> 2.3 \times 10^5$ s) fixed time observations be entered into PGT (see Chapter III, Section 3.3) as a number of shorter ($[1 \text{ to } 2] \times 10^5$ s) individual fixed time observations. ISOC mission planners will then take care to schedule all of them as a single block.

2.3 Targets of Opportunity (TOO)

TOO observations are observations in response to ''new'' phenomena, like X-ray novae in outburst, AGN flaring, SNe, galactic microquasar in high state. TOOs can be already known sources (e.g. 3C 279, GRS 1915+105, GROJ 0422+32...) or unknown sources (supernovae, novae...), i.e. identified by class. It is pointed out that the Core Programme (guaranteed time observations, see AO document on *INTEGRAL Guaranteed Time*) covers a number of TOO candidates and should as such not be duplicated (see below). TOO observations require interruption of the pre-planned schedule, re-pointing of the spacecraft and schedule re-planning (see Chapter III for further details including TOO turn-around time). They imply therefore a very heavy load on the scheduling system and, like fixed time observations, reduce significantly the mission efficiency. In general, the following rules and guidelines are applicable for TOO proposals:

- The ISWT has prepared a list of types of TOO events (as part of the Core Programme [guaranteed time] pointed observations) which are considered as approved proposals and, when executed, will be accounted to the Core Programme time. This list is published as part of the Core Programme in the AO (see AO document on *INTEGRAL Guaranteed Time*).
- Proposals[1] for TOO observations other than those included in the ISWT list, or covering different scientific objectives for those listed TOOs can be made in response to this AO.
- The Time Allocation Committee (TAC) is advised to accept no more than a few proposals for TOO observations per year, although no prioritization shall be given for standard observations vs TOO ones; all proposals shall receive a standard ranking.
- A TOO observation will displace another observation, which can be rescheduled by the ISOC and MOC if at all feasible. In some cases the displaced observation has to wait for a next AO-round.
- It is up to the proposer to request[1] a TOO observation if their trigger event occurs. When a TOO event of an accepted proposal is discovered by the ISDC in the routine scrutiny of the INTEGRAL data, the ISDC PI or an appointed deputy shall inform ISOC and the proposer.
- When a potential TOO event is discovered by the ISDC in the routine scrutiny of the INTEGRAL data and there is no accepted proposal for such an event, the ISDC PI or an appointed deputy shall request a TOO observation.
- Requests[1] for TOO observations are made by contacting the ESA Project Scientist (PS). (Details may be found on the ISOC WWW at **http://astro.estec.esa.nl/Integral/isoc/**). The PS or an appointed deputy is then responsible for submission of that request to ISOC to be included in the ISOC proposal database. This will allow tracking and documenting TOO requests and including them in the time-line, as for the normal proposals accepted by TAC during the AO cycle.
- The ESA PS or an appointed deputy will decide on the declaration of a TOO, after determining whether the overall science of the mission will be enhanced by the TOO. It is possible that the TOO observation would conflict with a time-critical observation and/or another TOO observation. In such situations the PS will determine priorities. The PS will inform the science community and the ISWT on declared (approved) TOO observations.

1. A ***proposal*** for a TOO observation can be submitted during the normal AO process, in anticipation of the event. A ***request*** for TOO observation is understood to be made after a scientific event occurred which may justify an INTEGRAL TOO observation. The occurrence of this event may or may not match an existing proposal.

In principle, gamma-ray bursts (GRBs) are considered as a subset of TOOs. GRBs occur randomly in time and space, therefore both inside and outside the FOVs of the instruments. Data of GRB events **inside** the FOV (e.g. light curve, location & trigger time (see also Chapter III, Section 5.1), spectra, data related to afterglow that can be detected etc.) will be contained in the normal science data of INTEGRAL instruments operating in the modes selected for the on-going observation and belong either to observer(s) with accepted open time GRB proposal(s), like accepted TOO proposals, or are treated as serendipitous sources in the FOV (see AO documents on *Policies, Procedures and Forms* and on *INTEGRAL Science Data Rights* for further details concerning GRB proposals and data rights). Typically a few events per month would be expected.

Concerning **GRB follow-up** observations initiated from GRB events detected by INTEGRAL or suggested from other missions, it has to be kept in mind, with the current knowledge on GRBs, that these events are of rather short duration ($\sim 10^{-2}$ s to $\sim 10^{+2}$ s) compared to other TOOs with typical decay time scales of ~days to ~weeks or more. Afterglow or counterpart observations with INTEGRAL to follow up a GRB detection are possible if (i) the GRB event occurs inside the FOV of the on-going observation and will be covered during the on-going nominal dithering manoeuvres, or (ii) if the event occurs outside the FOV but the spacecraft will dither onto that position during the nominal dithering manoeuvre of the observation during which the event occurred[1]. An interruption of the on-going dither pattern in order to prevent the GRB location from moving out of the FOV and/or an extra near real-time slew manoeuvre onto the GRB position within a short time scale (of typically one hour) are not foreseen as this does **not** constitute the operational baseline of the mission for observation re-planning.

The ISDC will routinely process the near real-time science telemetry stream in order to detect and localize GRB events. Location information derived from this process will be broadcast to the scientific community at large via the ISDC-GRB alert system, very similar to the successful GCN/BACODINE alert system used for the CGRO mission. This location information and its rapid (near real-time) dissemination to the scientific public is crucial for GRB follow up and afterglow observations at other wavelengths. Scientists interested in receiving these alerts from INTEGRAL should subscribe to the GRB alert mailing system by contacting the ISDC (see Chapter III, Section 5. for further details).

GRB data from events occurring "**outside**" the INTEGRAL field of view can be obtained from the anti-coincidence shield of the SPI instrument. These time series will support the IPN analysis. Further details are provided in the *Instrument Observer's Manual (SPI)* and in Chapter III, Section 5.

More information on the handling of GRB events by the Science Ground Segment is provided in Chapter III, Section 5.

Concerning data rights, in particular for TOOs including GRBs the reader is referred to the AO document (annexe) on *INTEGRAL Science Data Rights*.

1.Note that in case (i) all three high energy instruments and OMC (Chapter III, Section 5.) will provide data, while in case (ii) data will be provided by SPI, IBIS, and JEM-X.

3. Calibration observations

In-orbit calibration of the scientific payload through observations of celestial targets will take place during about five weeks of the so-called ''payload performance verification phase'' which is included in the ''commissioning phase'' following immediately the launch and early operations (see also breakdown of observing time in AO document on *INTEGRAL Guaranteed Time*). The commissioning phase will last two months followed by the normal operations phase.

However, dedicated payload calibration observations will also occasionally occur during the normal operations phase. This is required to continuously assess, verify and to complete the data-base describing the scientific performance of the instruments, for instance after annealing of the SPI detectors or after strong solar flare events.

The ISWT is currently defining the targets for in-orbit calibration. With a 22 April 2002 launch date the following calibration observations during ''commissioning phase'' (May - June 2002) are envisaged:

- a total of 2×10^6 s exposure on the Cygnus region, including: a number of Cyg X-1 on- and off-axis pointings up to 13.2^o (staring mode) , hexagonal dither observation with Cyg X-1 on-axis, and three 5×5 dithering observations, centred on (l, b) = (74^o, $+3^o$), (74^o, $+10^o$), (81^o, $+3^o$), see Section 4. for details on observing modes. The main objectives are to calibrate the imaging performances for point sources, for crowded field regions, imaging performances for extended diffuse and line emission regions, background studies and spectral cross calibration of IBIS, SPI and JEM-X below a few hundred keV.
- a total of 6×10^5 s exposure on ''empty fields'' located at (l, b) = (240^o, $+40^o$), (60^o, -45^o) (to be confirmed) for background studies, both in staring and 5×5 dither mode.
- a sample scan (~12 h duration) of the Galactic plane as planned for the Core Programme.

Because of the April launch date, the Crab region is not visible for INTEGRAL during commissioning phase. However, in-orbit calibration using Crab is mandatory in order to perform an absolute flux calibration, to determine the energy response at higher (MeV) energies, and to verify the absolute timing. Therefore a calibration observation of Crab will be scheduled at a later date with a total exposure of about 10^6 s. This observation would achieve, in the 2.5 MeV to 5 MeV band, a detection significance of 10σ (SPI) and 6σ (IBIS-PICsIT), respectively, with higher significances at lower energies, see *Instrument Observer's Manuals* for details. This observation would be done during nominal mission (normal operations) phase at the earliest opportunity (August 2002) so that observers could as early as possible be provided with response information at higher energies. Further improvement of the instruments' high energy response will be achieved through additional (cumulative) Crab observations during nominal mission.

Proposers should take note of this planning by preparing open time proposals which should avoid duplicating these observations. It is the intention to cross-check the proposal database with the final in-orbit calibration planning during the TAC evaluation period in order to avoid duplicate observations.

Proposers are referred to the AO document on *INTEGRAL Science Data Rights* which specifies the proprietary data rights for calibration observations conducted during commissioning phase and during normal operations phase.

4. Spacecraft observing modes

The INTEGRAL spacecraft will provide stable pointings with pointing characteristics as described in Chapter I.

In order to minimize systematic effects due to spatial and temporal background variations in the spectrometer (SPI) detectors, a controlled and systematic spacecraft dithering manoeuvre is required (see also *Instrument Observer's Manual (SPI)*). This manoeuvre will consist of several off-pointings of the spacecraft pointing axis from the target in steps of 2 degrees. The integration time for each pointing (all instruments) on the raster is 30 minutes. The spacecraft will continuously follow one dithering pattern throughout one observation. Two different dither patterns and a staring mode (no dithering) are foreseen as operational baseline:

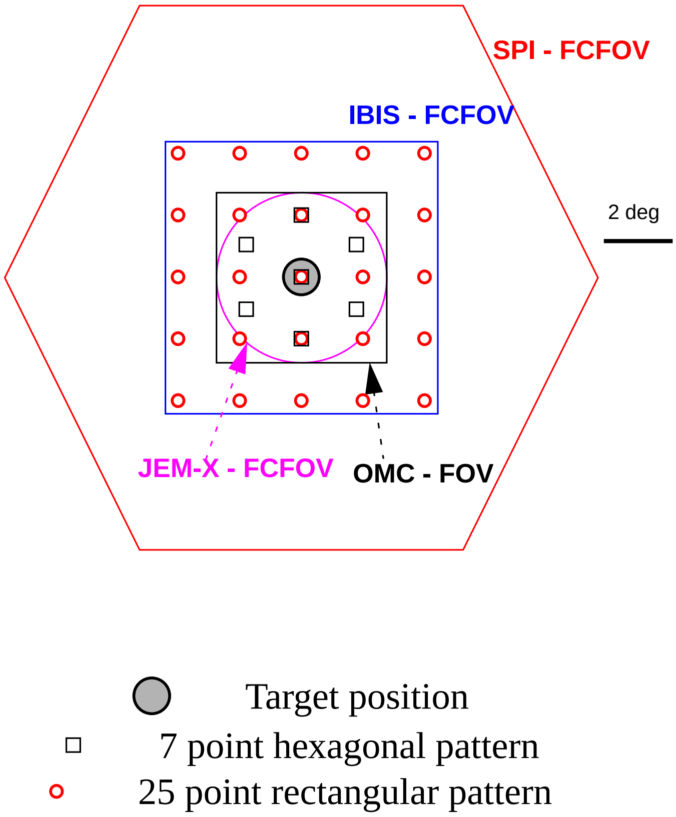

Figure 5. Schematic view of dithering patterns and instrument fully coded field of views.

- Hexagonal dithering

This mode consists of a hexagonal pattern centred on the nominal target location (1 source on-axis pointing, 6 off-source pointings, each 2^{o} apart, in a hexagonal pattern). This mode will be used for a **single** known point source, where **no** significant contribution from out-of-view sources is expected (Figure 5); see, however, the *SPI Instrument Observer's Manual* for further details.

- Rectangular dithering

This mode consists of a square pattern centred on the nominal target location (1 source on-axis pointing, 24 off-source pointings, each 2^o apart, in a rectangular pattern). This mode will be used for multiple point sources in the FOV, sources with unknown locations, and extended diffuse emission which can also be observed through combination ("mosaic") of this pattern. It is recommended to use this mode as **default** for observations (Figure 5).

In case that strong sources are located near the edges of the 5×5 square pattern, the observer should define a preferred orientation of the dither pattern such that those sources be located inside the IBIS FCFOV rather than inside its PCFOV. Therefore the observer may specify (see PGT) two angles α and β as shown in Figure 6 below. Note that (even for point-like sources) α should differ from β to allow some flexibility in scheduling as the pattern rotates with ~ 1^o/day. The default values for α and β are 0^o and 360^o, in other words no preferred orientation.

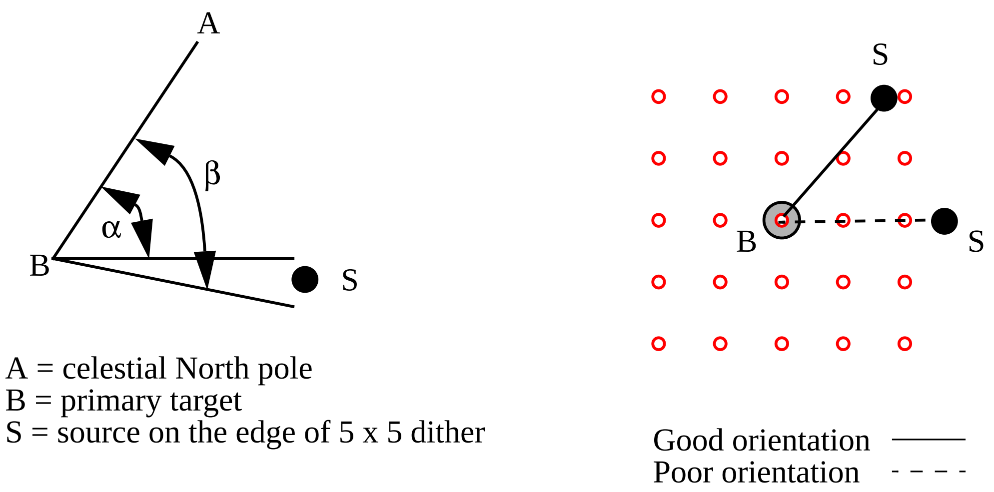

Figure 6. Sketch illustrating the preferred orientation for 5 × 5 dither pattern

- Staring observations

If scientific requirements exist to observe a source with a single pointing position for long uninterrupted periods of time (e.g. for studies of time variability or QPOs) then the dithering modes can be disabled ("staring mode"). Observers should be aware that in this mode the SPI imaging capabilities are strongly compromised, consequently IBIS must be the prime instrument for these observations.

5. Amalgamation

The (prime) INTEGRAL instruments have large FOVs and show generally very little off-axis degradation of sensitivity and resolution, at least in the fully coded FOV (see *Instrument Observer's Manual (SPI)*, however). Therefore it is quite possible that more than one approved observation (source) can be covered in the same field of view. The ISOC have the capability to combine (''amalgamate'') these into a single observation, thus saving observing time and increasing operational efficiency (decreasing oversubscription), while still respecting the original goals of each approved observation (instrument modes, signal-to-noise ratio).

Basically, amalgamation is the process by which several (independent) observations with similar attributes (sources in the same FOV, instrument configuration etc.) can be linked within the ISOC database such that the scheduling of one single observation, the ''core observation'', is regarded as the scheduling of all of the originally approved observations.

The following criteria and steps to create a proposed amalgamation will be used by ISOC:

- during the TAC process, the proposal database will be scanned to find candidates for amalgamation.
- the target (pointing or dither) for the ''core observation'' is that for the longest observation of a group of candidates.
- the duration of the ''core'' observation is that requested for the longest candidate, and is sufficiently long so that off-axis corrected durations for all observations (included in the amalgamation) are consistent with their requested on-axis duration, i.e. there will be no degradation in signal-to-noise.
- the TAC recommended scientific grade of the ''core'' observation will be as high as or higher than the grades of all other observations in the amalgamation.
- all sources are within the fully coded FOV for the main instruments (SPI, IBIS).
- there are identical modes for all four instruments (JEM-X: primary mode only), except where the observer has set "data not required" or deselected ''prime'' (see Proposal Generation Tool PGT in Chapter III). Then the selected mode for that observation and instrument can be ignored.
- there are restrictions in the combination of dither patterns which can be amalgamated with each other. They are described in Table 9.
- fixed time observations may not be amalgamated with each other.
- the rectangular (5×5) dither pattern is only allowed if all sources are within a configurable distance of each other and their requested orientations are compatible

During the TAC process the ISOC will generate a list of proposed amalgamations from the TAC-recommended programme. These will be presented to the TAC chair and panel chairs for endorsement. Only TAC-endorsed amalgamations will be implemented. However, it should be noted that during routine operations, the ISOC may have to de-amalgamate observations if an observing mode of an observation has been modified and then re-amalgamate afterwards. Proposers will be notified by the ISOC if their observations have been amalgamated. The reader is also referred to the AO document (annexe) on *INTEGRAL Science Data Rights* for data rights on multiple sources in the FOV.

Table 9: Allowed combinations of dither patterns in amalgamation

S/c observing mode	**Hexagon**	**Rectangular**[a]	**Staring**	**No preference**[b]
Hexagon	No	No	No	**Yes**
Rectangular[a]	No	**Yes**	No	**Yes**
Staring	No	No	**Yes**	**Yes**
No preference[b]	**Yes**	**Yes**	**Yes**	**Yes**

a.Note that rectangular dithers may only be amalgamated if there is **no position angle constraint requested** by the observer.
b.''No preference'' means that the observer has not specified a dither pattern or staring mode. Although this is technically possible it may not be useful from a scientific point of view.

III. The INTEGRAL Science Ground Segment

1. Introduction

The INTEGRAL science ground segment consists of the ISOC and ISDC and is shown in the lower part of Figure 7.

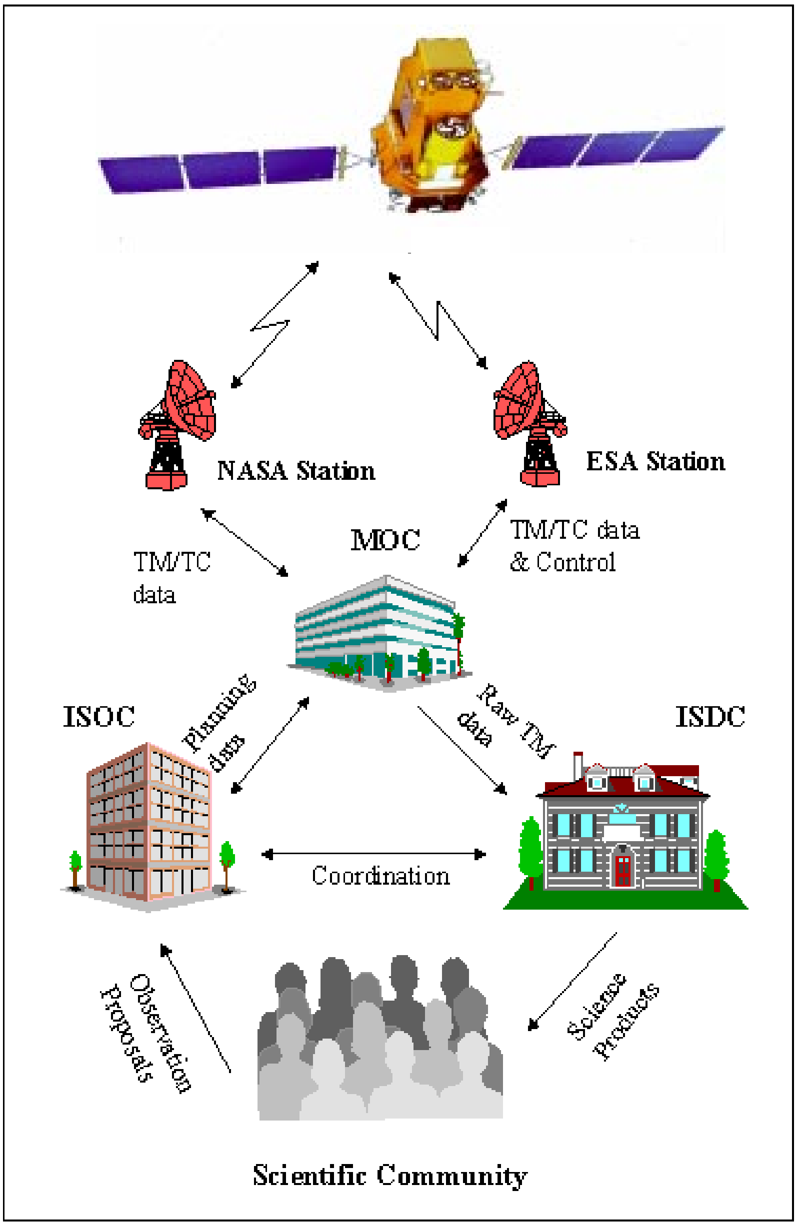

Figure 7. The INTEGRAL ground segment

Basically, the ISOC will receive observing proposals and will process the accepted proposals into an optimised observation plan which consists of a time line of target pointings plus the corresponding instrument configuration. The ISDC will receive the science telemetry plus the relevant ancillary spacecraft data from the Mission Operations Centre (MOC). MOC's prime responsibility is the operations of the spacecraft and payload. Taking into account the instrument characteristics the ISDC will convert these raw data into physical units and generate standard data products. ISDC will archive the data and products and distribute them to the science community. ESA will also maintain a copy of this archive at the ISOC.

2. Science ground segment support for proposers and observers

The INTEGRAL ISOC WWW pages at **http://astro.estec.esa.nl/Integral/isoc/** provide access to important information for proposers and observers, in particular on:

- INTEGRAL Announcement of Opportunity (AO)
  - AO Announcement
  - AO Documentation
  - Proposal support tools: Proposal Generation Tool (PGT), Observing Time Estimator (OTE), Target Visibility Predictor (TVP), see Section 3.3 and Section 3.4 for details
  - Links to astronomical catalogues
- INTEGRAL Target and Scheduling Information
  - Approved target list
  - Long and short term scheduling
  - Observation log
  - ISDC data archive
- INTEGRAL Helpdesk

There is one central help-desk handling all questions (received via e-mail at **inthelp@astro.estec.esa.nl**) related to the INTEGRAL mission. The INTEGRAL help-desk is organized such that those questions on proposals, observing modes, scheduling and on INTEGRAL in general will be handled by ISOC staff and questions on INTEGRAL data, instrument calibration and data shipment will be handled by ISDC staff. This split is transparent to the user of the help desk, however. A list of frequently asked questions (FAQ) will be maintained on the ISOC and ISDC WWW pages.

An observation data simulator (OSim) has been developed by the ISDC to generate simulated data for the high energy instruments SPI, IBIS and JEM-X. The Osim will be used at ISDC to test the scientific (standard and quick-look) analysis tools. It can, however, also be used by proposers to get familiar with the INTEGRAL capabilities and the data products. Currently, visitors to ISDC have access to the Osim and to the prototype analysis tools at the ISDC with some support. Based on this experience, parts of the Osim and of the protoype analysis software may be distributed in a near future through the ISDC WWW pages at **http://isdc.unige.ch/.** Further information on ISDC user support is provided in Section 4.10.

3. From proposal to observation: ISOC

3.1 ISOC responsibilities

The INTEGRAL Science Operations Centre ISOC, located at ESTEC, Noordwijk, the Netherlands, is responsible for the definition of scientific operations including the instrument configuration for each observation, the mission planning and implementation of the observing programme. In summary, ISOC

- will prepare AOs for observations, will receive proposals and assess their technical feasibility and makes technical assessments available to the Time Allocation Committee.
- is responsible for the mission planning (scheduling) and implementation of the observing programme.
- is responsible for the definition of scientific operations including the instrument configuration for each observation
- will decide on TOO follow-up observation upon the receipt of an alert for Targets of Opportunity in order to change/interrupt the observing program (responsibility of Project Scientist).
- will keep an archival copy of all scientific data as created and maintained by the ISDC.

3.2 Proposals

Scientific observations performed by INTEGRAL are requested by submitting observing proposals. There are two kinds of proposals; for ''Guaranteed Time'', corresponding to 35% of INTEGRAL time (for the first year of operations) reserved for the ISWT. This is known as the ''Core Programme'' (CP), see AO document on *INTEGRAL Guaranteed Time*. ''Open Time'', corresponding to 65% of INTEGRAL time (for the first year of operations) is available to the scientific community at large, who may apply as General Observer (GOs) to perform INTEGRAL observations. General Observers submit their proposals in response to a Call for Observing Proposals (''AO'') issued by ESA (ISOC) with further AOs at regular intervals during routine in-orbit operations. Proposals written in response to an AO must reach ISOC before the calendar deadline announced in the AO documentation; the only exception is for requests to observe newly identified ''Targets of Opportunity'' which can be submitted to the ESA Project Scientist at any time (see Chapter II, Section 2.3). An observing proposal must contain details of the proposed observations (target information, instrument modes requested) and also a scientific justification. Proposers should make sure that they request a **Proposer ID** from ISOC as early as possible (see AO document on *Policies, Procedures and Forms* for details).

3.3 Proposal generation tools

ISOC makes available through its WWW pages (**http://astro.estec.esa.nl/Integral/isoc**) the Proposal Generation Tool (PGT) software which is required to draft, edit and submit proposals to ISOC at ESA. PGT **must** be downloaded to the users' local environment as it will run on the users local computer. Proposals can be submitted to ESA **only** through the PGT interface.

3.4 Supporting software tools

Through the same ISOC WWW page the following additional software tools are available to the proposer:

- The Target Visibility Predictor (TVP)
- The Observation Time Estimator (OTE)

Note that, prior to and during the TAC review of proposals, the ISOC technical verification of proposals makes use of the OTE to verify proposed durations of IBIS and SPI observations. The use of OTE is therefore **strongly** recommended to the proposers when integration times are estimated.

As it cannot be excluded that PGT, as well as TVP and OTE, will have to be updated during the proposal preparation phase, **proposers are strongly recommended to verify** that they always work with the latest version of this software in addition to the latest versions of the entire AO documentation. Details on latest versions (software and documentation) can be found on the ISOC WWW pages (**http://astro.estec.esa.nl/Integral/isoc**) where proposers - via the helpdesk using e-mail to **inthelp@astro.estec.esa.nl** - can also sign into an e-mail distribution list in order to get immediately notified by ISOC about updates on AO documentation and software.

3.5 Proposal handling

After the deadline for an AO, ISOC will perform a technical feasibility of the submitted proposals, and forward the proposals to the Time Allocation (TAC) for scientific assessment. Based on the results of these assessments, TAC will recommend approval of either an entire proposal (i.e. all requested observations), or part of a proposal (some of the requested observations, and possibly with reduced observation time), or rejection of the entire proposal. In addition, TAC will recommend scientific ''grades'' for the approved observations. Following the TAC assessment, and endorsement of the TAC recommended observing programme by the ESA Director of Science, a data base of approved observations and associated details is created and maintained by ISOC. This data base contains both GO and Core Programme observations. A subset of these data is made available to the ISDC. ISOC will communicate to the proposer the ESA endorsed decision of the TAC, and in particular, for the successful proposer, ISOC will communicate the TAC approved observations.

3.6 Scientific mission planning

This section describes the scientific mission planning including execution of observations, scheduling and re-scheduling.

During routine observations, ISOC will generate and maintain detailed observing schedules based on the approved observations (both from the Core Programme and the General observing Programme), and deliver these schedules to MOC for uplink and execution. The ISOC scheduling will take into account: celestial viewing constraints; the need for high efficiency (i.e. time spent usefully observing versus slewing); the need for high scientific value observations (as determined by the TAC-assigned grade); and any special requirements (e.g. fixed-time observations). One important feature is that a number of INTEGRAL observations may be rather long, in fact too long to be scheduled as an unbroken block of time, and ISOC will have to schedule them as several separate exposures. In addition, both ISOC and MOC will provide details of the ’’live’’ schedules to ISDC.

Re-scheduling is usually associated with the need to drastically change the pre-planned sequence of observations/operations which is foreseen in cases of:

- instrument/spacecraft anomaly
- declaration of a TOO
- previously unforeseen (planned) ground station outages

Re-planning at MOC is foreseen at a maximum frequency of once per orbit. The MOC reaction time of (typically) 8 hours from receipt of the ISOC request and execution of the related command schedule applies only for replanning due to TOO’s (see Section 4.) and anomalies. Any other re-planning, e.g. optimization of instrument configuration, will be implemented by MOC in the next orbit following the request from ISOC, assuming that this orbit will start more than 8 hours in the future.

When an exposure has been performed on-board the spacecraft, MOC will forward the telemetry to ISDC for processing. There is a return loop for ISDC to inform ISOC if any or all of a scheduled exposure did not yield useful scientific data, in which case re-scheduling can be considered by ISOC; also ISOC will regularly inform ISDC which fraction of a full observation has been completed by successful exposures. When a certain fraction of an observation (usually the whole) has been completed, and the data have been processed, ISDC will ship those data to the observer.

An observer has sole proprietary data rights to his/her source for one full year after those data have been shipped (see also AO document (annexe) on *INTEGRAL Science Data Rights* for further details). After that period, the data are public and anyone may request access to them via the ISDC archive.

4. From observation to data products: ISDC

4.1 Introduction

The INTEGRAL Science Data Centre (ISDC) (**http://isdc.unige.ch/**) is the link between the scientific output of the instruments on board INTEGRAL and the astronomical community. It has the task to receive, analyse and archive all INTEGRAL data and to distribute them to the observers worldwide.

The ISDC has been based in Versoix, near Geneva, Switzerland since 1996. Its staff consists of about thirty scientists and engineers funded by an international consortium of twelve institutes with support from the European Space Agency (ESA). The ISDC works in close collaboration with the INTEGRAL instrument teams to ensure that the software they develop is integrated in a coherent data analysis system. The ISDC is also in contact with the INTEGRAL Science Operations Centre (ISOC) at ESTEC, Noordwijk, the Netherlands and with the Mission Operations Centre (MOC) in Darmstadt, Germany.

4.2 ISDC responsibilities

The ISDC will receive all the INTEGRAL telemetry and auxiliary data. One of its tasks is to detect gamma-ray bursts and to alert interested scientists. The ISDC is also responsible for monitoring the scientific instruments on board INTEGRAL and for finding solutions with the instrument teams to problems that might occur. By performing a quick-look analysis of the data, the ISDC is able to inform the astronomical community about the detection of unexpected features and events.

The ISDC is responsible for the calibration and conversion of raw data products into physical units. It shall also process the observed data with the best set of instrumental responses in order to derive source properties in the form of images, spectra and light-curves. Finally, the ISDC is responsible for the archiving and distribution of all data and for supporting users of INTEGRAL data.

4.3 Data flow

The ISDC will receive the telemetry of the INTEGRAL spacecraft in real-time from the MOC at a rate of ~ 90 kbits per second. This on-line telemetry is used for the real time and the quick-look analysis (Section 4.4). Every few days, the telemetry will be sent again to the ISDC on CD-ROM, as so called ’’consolidated data’’ in which all telemetry problems (e.g. at station handover) that can be corrected for, have been corrected. The consolidated data are used for the standard scientific analysis (Section 4.5). Apart from the telemetry, the ISDC will receive auxiliary data and in particular the current observing plan from the ISOC.

4.4 Real time and quick-look analysis

The INTEGRAL Burst Alert System (IBAS) is designed to detect and locate gamma-ray bursts in the field of view of the instruments within a few seconds (see also Section on “Gamma-ray burst (GRB) handling” on page 35). Should the burst occur in the field of view of the Optical Monitoring Camera (OMC), the calculated position of the gamma-ray burst will be used to modify the read-out windows of the OMC in order to observe a possible optical counterpart with the

OMC (Section 5.). Gamma-ray burst alerts (positions, trigger times) will be distributed to a list of interested astronomers. The exact procedure for subscribing to receive gamma-ray burst alerts is not yet defined. More information about this procedure will be given in a coming issue of the "ISDC-Astrophysics Newsletter" (**http://isdc.unige.ch/Newsletter/**).

Within a few hours of receipt, the data will be used for instrument monitoring and a scientific quick-look analysis (QLA). The QLA compares the INTEGRAL data with the expected position and flux of known sources. The aim of the QLA is to rapidly detect bright transient sources, large flux changes in known sources and instrument anomalies. QLA results will be communicated to the observers/owners of that particular observation (see *INTEGRAL Science Data Rights*). The ISOC will be contacted if the detected event might be of interest for an INTEGRAL Target of Opportunity (TOO) follow-up observation (see Section 2.3 in Chapter II).

4.5 Data analysis

The ISDC will perform a Standard Analysis (SA) of each observation. This analysis will result in deconvolved images of the gamma-ray sky in pre-defined energy bands, spectra of individual sources and light-curves of variable objects. The SA is designed as an automatic process, which should be completed within three weeks after consolidated data have been received by the ISDC. It is based on high level analysis software especially developed in collaboration with the INTEGRAL instrument teams and integrated into the ISDC system in order to function automatically. The results of the SA will be included in the INTEGRAL Archive (see Section 4.8).

4.6 INTEGRAL data

An INTEGRAL revolution of three days (72 hours) results in a telemetry volume of 2.7 GBytes. This telemetry stream is processed and analysed at the ISDC and will result in about 17 Gbytes of uncompressed data products per revolution. These data will be stored in FITS files and consist of:

- **raw data** (4.5 GBytes), which are reformatted data with the same information content as the telemetry sent by the spacecraft,
- **prepared data** (7.2 GBytes) including additional timing information,
- **corrected data** (2.7 GByte) including gain corrected event energy, and
- **high-level products** (2.7 GBytes). which are the results of the scientific analysis in the form of images, spectra, light curves etc.

All these data will be distributed in a compressed format (~ 9 Gbytes per revolution) to the observers (Section 4.9). Proposers should be therefore aware that they need more than 10 Gbytes of disk-space to store INTEGRAL observations that last about one revolution.

The INTEGRAL data flow will be cut into a series of contiguous "science windows". A science window usually corresponds to a pointing (30 minutes in dither modes) or a slew of the spacecraft. An entire observation consists usually of the order of some 10's to some 100's distinct science windows. Raw and prepared data are stored by science window, whereas corrected data, intermediate results of the analysis and high level data products are stored per observation. The instruments generate many types of data during each science window: these will use the hierarchical grouping convention of FITS, which is transparent to the ISDC data analysis system. Since the data will be stored in FITS files, they are not only accessible through the ISDC scientific software, but also through any other astronomical software package, provided that the data organization and the above convention are well understood.

4.7 Calibration overview

Although the ISDC has to deliver well calibrated results, the instrument teams are formally responsible for the calibration of their instruments. Calibrations will be performed before launch, during the commissioning phase and regularly during the mission (see Chapter II, Section 3.). The instrument teams will analyse the calibration data and their results will be used by the ISDC data processing. All calibration and response files will be accessible through the INTEGRAL Archive (Section 4.8). Concerning data rights on calibration data, the reader is referred to the AO document (annexe) on *INTEGRAL Science Data Rights*.

4.8 INTEGRAL archive

The INTEGRAL archive, located at the ISDC, will contain all INTEGRAL data from raw telemetry to the results of the SA (Section 4.5), as well as calibration and response files, auxiliary data and catalogues of sources.

Public data in the complete INTEGRAL archive will be on-line and accessible both via an archive browse utility based on a WWW interface and by anonymous FTP. For FTP data retrieval, the exact name or location of the archived data has to be known. The WWW interface allows indirect querying of the ISDC database by specifying object names, coordinates, time intervals or similar parameters to identify corresponding sets of data. These data are then extracted from the archive in tar files, compressed and made ready for FTP retrieval. Data might also be distributed on tapes (Section 4.9). Private science data will not be accessible from the INTEGRAL archive until they become public after the proprietary period of one year (see AO document (annexe) on *INTEGRAL Science Data Rights*).

4.9 Data distribution

Guest observers, at the time of proposal submission, can choose if they want to receive their data on hard media (probably DLT tapes) or to have them staged for Internet transfer. The use of DLT tapes (or similar hard media) is required because of the large size of the INTEGRAL data (Section 4.6.) For tape distribution, a single set of tapes will be sent to the PI. Tape redistribution is not foreseen unless the media is defective or was lost in the mail.

Note that ISDC cannot assume any responsibility for the public network capacity that might (or might not) be available to support very large data volume transfers.

4.10 User support and communication

The ISDC will provide support to the observers with their data analysis. It is foreseen to distribute analysis software to be run locally at the observer’s institute. Alternatively, observers are welcome to visit the ISDC for local support and direct access to data analysis tools.

The ISDC software will include scripts to repeat the standard analysis and applications to visualize the data and to manage off-line analysis. The software will be available for SUN/Solaris and, as far as possible, ported on Linux. Due to limited resources, it is not possible to provide software running on other operating systems.

After launch, the ISDC plans to organize regular INTEGRAL data analysis workshops. Their aim is to discuss issues on calibration and on data analysis methods, software and results. These specialists workshops may also be combined with the well-known series of INTEGRAL scientific workshops organised by ESA and the ISWT in the tradition of the past four INTEGRAL workshops which took place since 1993.

The ISDC newsletter (**http://isdc.unige.ch/Newsletter/)** is the main communication link between the ISDC and the users community. Subscription to the distribution list receiving information about new releases can be done via the WWW pages.

5. Gamma-ray burst (GRB) handling

This section describes how gamma-ray burst (GRB) events will be handled by the INTEGRAL ground segment. The entire data from GRBs (Chapter II) are collected and treated as any TOO event described previously, however three areas connected with the GRB phenomenon are treated explicitly:

- GRB position and trigger time to facilitate rapid follow-up observations,
- GRB time histories from the SPI ACS subsystem to support the Interplanetary Network (IPN), and
- Fast uplink of special OMC subwindow.

These areas are described below in more detail.

5.1 GRB position and trigger time

INTEGRAL will not have a GRB detection and triggering system on board. However, it will downlink its acquired data continuously to Earth allowing for constant, near real-time, monitoring. At the ISDC all data will be automatically analysed to detect any transient events. In addition, a fast analysis will be performed by the INTEGRAL Burst Alert System IBAS. This “on ground” approach to detection not only allows for the application of larger computational power than available on-board a spacecraft, but also permits the implementation of several detection algorithms running in parallel.

After receiving the INTEGRAL telemetry at ISDC, the IBAS relevant data is extracted and fed into the attitude determination and into the several detection processes running in parallel. As soon as a GRB candidate event is detected, it must pass a verification process and a final screening, which is additionally in charge of spawning a more detailed off-line analysis of the burst. The GRB position and trigger time then reach the alert generation process, and the information is broadcast electronically. The expected number of GRBs per year is about 20 within the IBIS and SPI FOVs. Localization accuracy is a function of the event’s S/N ratio, the spacecraft attitude and stability, the instrument to star-tracker alignment, the angular resolution, and whether the event took place in the fully or partially coded FOV. Naturally, the first alert broadcast message will have rather crude information, e.g. the positional information will be based on predicted attitude information rather than the reconstituted one. Therefore it is planned to send also subsequent alert messages to subscribers with improved information, both on position and source characteristics.

Observers are invited to subscribe to the ISDC GRB alert system in order to receive routinely the GRB trigger alerts from the ISDC similar to the well-known BACODINE/GCN system. For this purpose scientists should contact the ISDC (http://isdc.unige.ch/) directly.

5.2 GRB data from the SPI anti-coincidence (veto) subsystem

In the relevant time frame of 2002 and beyond, INTEGRAL seems to be the satellite best suited as the Interplanetary Network’s near-Earth node providing large area detectors. As an optimised input to the IPN, SPI’s anti-coincidence shield (ACS, see *Instrument Observer’s Manual (SPI)* for more details) will collect GRB data in time bins of 50 ms, time-tagged to an accuracy of

1 ms at energies above ~ 50-100 keV. Thus the data of about 300 (5σ) bursts per year, located mainly perpendicular to the instruments' FOV can usefully contribute to the IPN.

These time series (contained in the instrument housekeeping data stream) will also be provided via the ISDC GRB alert system to the scientific community (see above for subscription) and are as such **immediately publicly available**.

5.3 OMC window handling in case of a GRB alert

Due to the limitation of the downlink data rate, it is not possible to down-load all OMC data. Thus it is necessary to pre-define specific OMC CCD sub-windows for routine observations (see *OMC Observer's Manual* for details). It is possible that a GRB (detected by IBIS via the ISDC alert system) is in principle observable by the OMC as it is taking place in its FOV, but that the pre-selected sub windows (selected prior to the observation) do not cover it. To enable GRB monitoring by the OMC it is necessary to rapidly command one special sub-window (covering the GRB location) that replaces all pre-defined sub-windows for the <u>duration of the on-going (dither) pointing only</u> (i.e. <= 30 minutes), i.e. until the next set of pre-defined OMC sub-window commands (for the next dither pointing) will be uplinked. Because GRB events are short-term events, the number of involved ground-segment elements has to be minimized in this process.

In order to allow a near real-time implementation of the required new OMC window commands the required functions are split between ISDC and MOC only. In summary the ISDC software will

- identify a GRB from IBIS near real-time science data
- identify a GRB location within IBIS detector co-ordinates
- convert IBIS detector co-ordinates to OMC detector co-ordinates
- check whether location is within OMC FOV
- provide necessary input to MOC only if previous check is positive

Upon receipt of this message, MOC will

- accept and check (syntactical) correctness of input
- generate necessary telecommands
- uplink necessary telecommands

The size of the new uplinked OMC sub-window is (100×100) pixels. The data collected from all other pre-defined sub windows during that pointing (only) are lost. It is estimated that the new OMC sub-window will be effective about one minute after the detection of the event (nominal case). It is noted that this mechanism has been established only to provide the described functionality for the OMC. As it violates some of the basic mission principles including safety related features it can not be applied for other cases. No other commands (especially to AOCS) are being sent in response to a GRB.

6. TOO turn-around time

Within the INTEGRAL ground segment (ISDC, ISOC, MOC) the detection of a potential TOO is performed at the ISDC by screening the incoming science telemetry. Alerts are being forwarded to the Project Scientist at ISOC who decides on declaring a TOO observation. Implementation of the updated command schedule following ISOC's request will be performed by MOC. It is to be noted that the ISDC and ISOC are not manned outside normal working hours. The same does apply for those MOC staff involved in re-planning activities. However, the ISDC has an automatic TOO detection system and ISDC scientists are available on call outside working hours. Also ISOC and MOC provide an on-call service outside working hours and during weekends and non-working days.

The analysis of various situations involving all elements of the ground segment leads therefore to a typical turn-around time for TOO (follow-up) observations, from detection until re-pointing of the spacecraft, ranging from 20 hours to a maximum of 36 hours. This turn-around time estimate is also approximately valid for TOOs reported from external triggers, i.e from observations from other missions or observatories. Here the event is reported directly to the Project Scientist who may initiate a TOO follow-up observation, see Chapter II for further details.

IV. Overview of INTEGRAL Observing Modes

Table 10 summarizes the instrument observing modes which are available to the observer. For details and choices to be made by proposers, readers are referred to the *Instrument Observer's Manuals* for details.

Table 10: INTEGRAL observing modes

Instrument	Modes
SPI	Photon-by-photon
IBIS-ISGRI IBIS-PICSIT	Photon-by-photon Histogram
JEM-X	Full Imaging Restricted Imaging Spectral Timing Timing Spectrum
OMC	Normal Fast

V. Sky visibility

1. Introduction

In principle, any point on the sky is visible for INTEGRAL, however due to some constraints listed below, not at any point in time. The targets Sun, Earth and Moon are always excluded.

1.1 Sun and anti-sun viewing constraints

As described in Chapter I, during the nominal mission life (i.e. until launch + 26 months) and outside of the eclipse seasons the solar aspect angle of the spacecraft is SAA = +/- 40^o which decreases to +/- 30^o for the duration of extended mission life (years 3 to 5). This viewing constraint implies that the spacecraft cannot point to sources which are closer than 50^o (60^o) to the sun and to the anti-sun during nominal life (extended life), respectively. However, during eclipse seasons of the nominal mission the SAA is also constrained to +/- 30^o. As a consequence of this constraint, the sun cannot be observed, at any time.

1.2 Earth and Moon viewing constraints

In order to protect the spacecraft star trackers (see Figure 2) co-aligned with the instruments pointing axis, the spacecraft has to point at least 15^o away from the Earth and Moon limbs. Both targets can therefore not be observed.

1.3 Other constraints

Nominally, scientific observations will be carried out while the spacecraft is at least at an altitude of 40,000 km. However, analysis of the on-board radiation environment monitor will be used in order to possibly lower this limit if deemed possible due to a lower than expected background. Consequently, however, this nominal altitude limit may also become larger in case of high background. No observations will be performed from 30 minutes before an eclipse until 30 minutes after an eclipse.

1.4 Target visibility tool

As pointed out in Chapter III, the INTEGRAL ISOC WWW (**http://astro.estec.esa.nl/Integral/isoc**) can be used to access the Target Visibility Prediction (TVP) tool. This tool can be used to calculate visibility constraints for each celestial source taking the above constraints into account.

VI. Extended mission

The nominal (operational) mission has a duration of 24 months, starting at the end of the post launch, in-orbit, commissioning phase of 2 months duration. Therefore, nominal mission life will end at launch + 26 months.

The spacecraft and payload are required to technically support an extended mission phase of 3 years duration beyond nominal mission lifetime. The nominal mission has been fully approved by ESA in 1993.

Pending ESA's budget approval of the extended mission phase and technical status of the spacecraft including payload, scientific observations would continue during the extended mission phase with a Core Programme (guaranteed time for ISWT) using 25% (TBC) and a General Programme (open time for the scientific community at large) using 75% (TBC) of the total observing time.

A final share of the observing time for ISWT and General Observers including General Observers sponsored from agencies other than ESA, NASA and Russia for this extended mission phase will be defined by the Agency in co-ordination with the ISWT and the participating partners in due course.