INTEGRAL

Announcement of Opportunity for Observing Proposals (AO-2)

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 (4 - 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 are 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 permits 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 permits 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) 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 was 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 development programme was strongly linked to the XMM-Newton programme by the requirement of commonality.

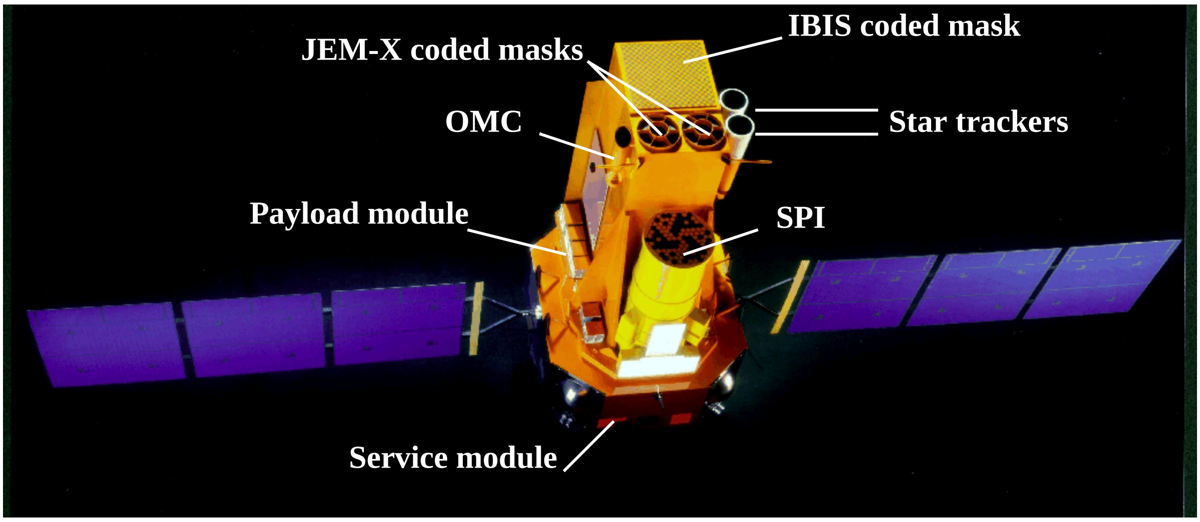

Figure 1. The INTEGRAL spacecraft with the payload module on top the service module. The coded masks for IBIS and JEM-X are located 3.2 m above the detection planes. IBIS and JEM-X detectors are inside the payload module structure. The overall dimensions of the spacecraft (excluding solar arrays which span 16 m) is ~4 m × 5 m (w × h). The sun direction is along the Z-axis, 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 was achieved by the reuse of the XMM-Newton Service Module design including the use of recurrent XMM-Newton FM units, the reuse 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 orbit affected mainly the radiation protection. Although an operational orbit above the proton belts was selected, the electronic units are still subject to high radiation dose 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 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. Note that the values in Table 1, Table 2 and Table 3 represent the requirements on the spacecraft design. Actual measurements on the hardware (both inflight and on the ground) demonstrated that the actual 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 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 and the Payload Module.

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 for torque actuation and momentum storage. The AOCS also controls the Reaction Control System, which with its thrusters provides the capability of reaction wheel momentum dump and for orbit maintenance. A hard-wired Emergency Sun Acquisition Mode 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, distribution 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, one on the service and the other on the payload module, for data acquisition from peripheral units. Spacecraft telemetry is down-linked in real-time; there is no on-board data storage. Early in the mission after it was confirmed that the link RF margin was sufficiently large, it was decided to increase the telemetry clocking frequency and thus to increase the bit rate by ~20%. The data rate for science data was increased from 86 kbps to 108 kbps.
- *Launcher Adapter:* it connected the service module with the Russian PROTON launcher. A special adapter was designed, which included 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 detector bench provides the interface to the service module cone upper flange and carries the spectrometer (SPI) units, the IBIS detector and the relevant electronic and data processing units. System units (Payload module power distribution unit and remote terminal unit) 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*.

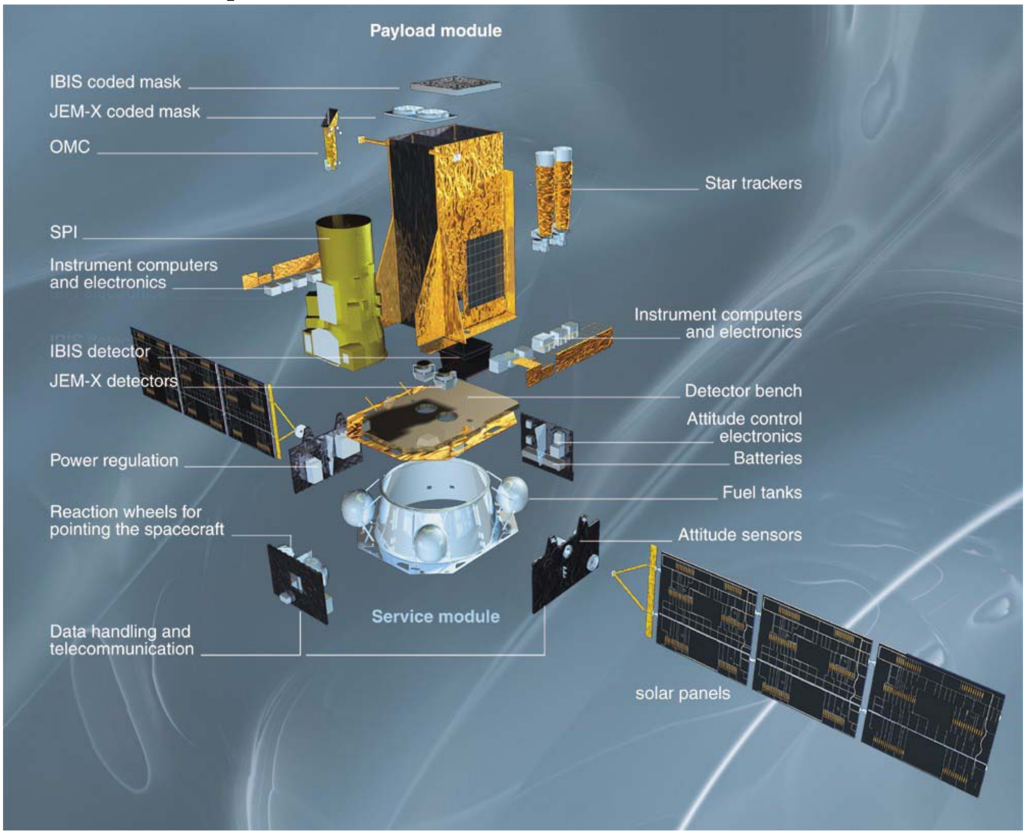

Figure 2. Exploded view of INTEGRAL service and payload modules.

3. The launcher and INTEGRAL orbit

INTEGRAL was launched with a PROTON launcher from Baikonour/Kazachstan on October 17, 2002 at 06:41 UTC. The PROTON launcher had four stages. The first three stages brought the satellite into an intermediate 192x690 km orbit. The upper stage injected the satellite into a transfer orbit with apogee height of the operational orbit. INTEGRAL's own propulsion system brought the satellite into its 72 hours operational orbit. The initial orbital parameters are summarized in Table 4.

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. For critical operations (like orbital manoeuvres) simultaneous coverage from two stations is required. The orbital period is 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. 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) the Solar Aspect Angle of the spacecraft is SAA = +/- 40^o and will be decreased 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.

The scientific observations are performed between an altitude of 40,000 km (ascending leg of the revolution) and 60,000 km (descending leg of revolution). The operational altitudes are determined by the higher level of the radiation environment below these altitudes. 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, instrument operation is interrupted in case of a higher radiation environment, e.g. during a strong solar flare.

The perigee height varies throughout the mission between the initial 9000 km and 12,400 km,

Table 4: INTEGRAL operational orbit (BOM)

Parameter	
Launch:	2002-Oct-17
Epoch:	2002-Nov-01 @ 20:15:00 UT (Orbit after completion of all orbital manoeuvres at end of LEOP)
Orbital period:	72 hours
Perigee height:	9049.6 km
Apogee height:	153657.2 km
Eccentricity:	0.8245
Inclination:	52.246^o
R.A. of ascending node:	103.07^o
Argument of perigee:	301.72^o
True anomaly:	180.0^o

reaching the peak approximately in November 2006, while apogee height decreases down to 150,300 km. The inclination increases constantly and reaches 85^o at the end of the extended mission (December 2007). The percentage of available observation time of a revolution (neglecting small operational windows, such as reaction wheel biases or station handovers) are listed for different phases of the mission and different critical altitudes in Table 5. The currently used critical altitudes (40000km ascending and 60000km descending) for begin/end of science operation yield 62.6 hours for science operation per revolution equivalent to 87.3% of the orbital period

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 INTEGRAL orbit the longest solar eclipse does not exceed 1.2 hours. All eclipses 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 achieved 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 EOM respectively, together with the eclipse regions. Simultaneous visibility from Redu and Goldstone exists during a large part of the orbit.

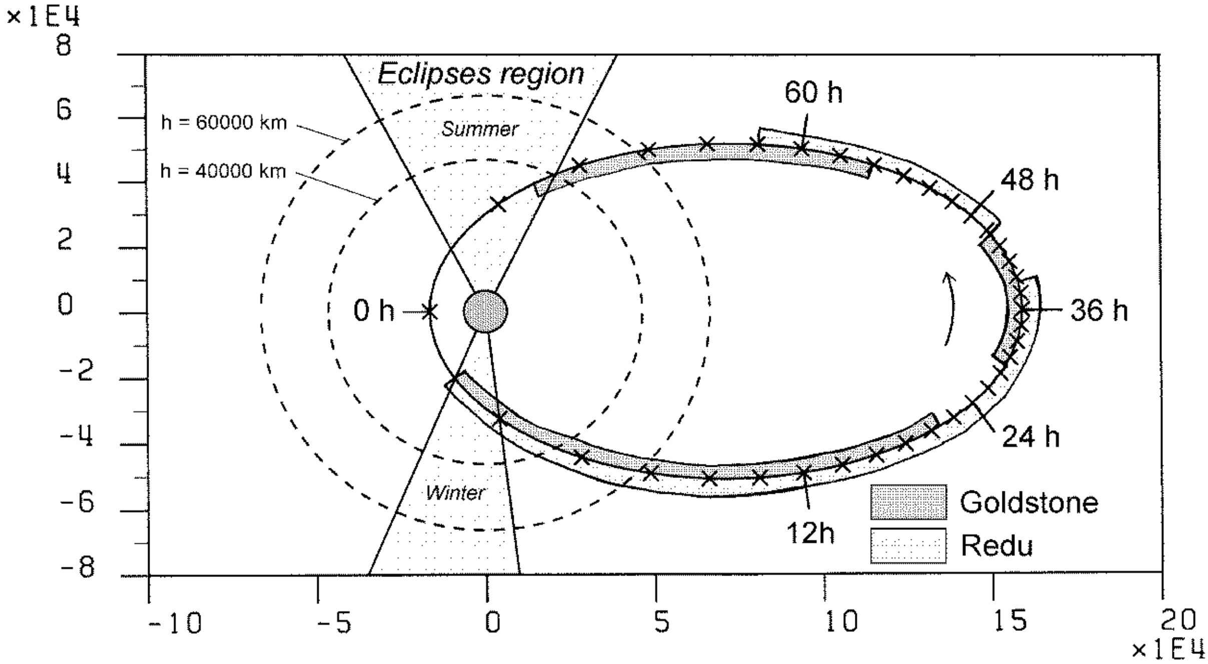

Figure 3. Coverage from Redu and Goldstone and eclipse regions at Begin of Mission (BOM). Axes are in units of km.

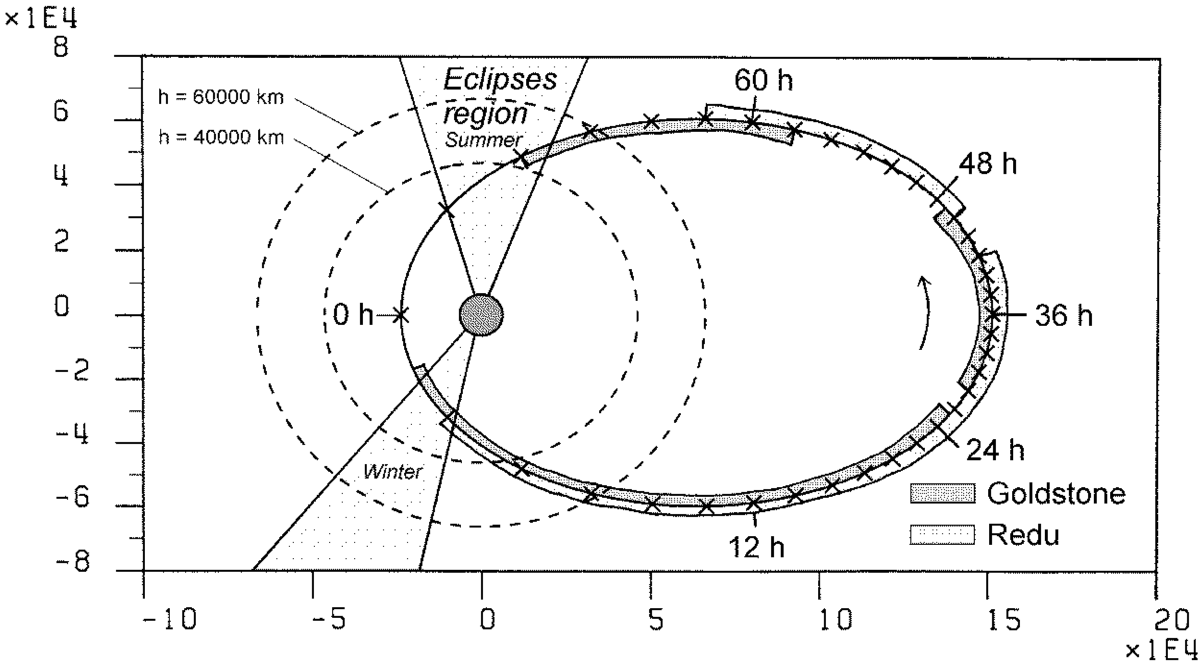

Figure 4. Coverage from Redu and Goldstone and eclipse regions at End of Nominal Mission (ENM). Axes are in units of km.

4. Overview of scientific capabilities

The design of the instruments was 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	18 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	4 - 35 keV	Source identification
		X-ray monitoring of high energy sources

Table 6: INTEGRAL science and payload complementarity

Instrument	Energy range	Main purpose
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 are addressed by the different instruments.

Table 7: Key performance parameters SPI & IBIS

	SPI	**IBIS**
Energy range	18 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)	3 keV @ 1.7 MeV	8 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)	<200 μs[b]	<200 μs[b]
Mass (kg)	1309	746
Power [max/average] (W)	385/110	240/208

Table 8: Key performance parameters JEM-X & OMC

	JEM-X	**OMC**
Energy range	4 keV - 35 keV	500 nm - 600 nm
Detector	Microstrip Xe/CH_4-gas detector (1.5 bar)	CCD + V-filter
Detector area (cm^2)	500 for each of the two JEM-X detector [a]	CCD: (2061 × 1056) pixels Imaging area: (1024 × 1024) pixels
Spectral resolution (FWHM)	2.0 keV @ 22 keV	--
Field of view (fully coded)	4.8^o	$4.98^o \times 4.98^o$
Angular resolution (FWHM)	3'	25"
10σ source location (radius)	< 30"	6"
Absolute Timing accuracy (3σ)	<200 μs[b]	> 1 s
Mass (kg)	65	17
Power [max/average] (W)	50/37	20/17

a.at the moment only one of the two JEM-X camera is operated at one time.
b.the absolute timing was verified using the Crab Pulsar to be better than 200 μs

4.1 Scientific topics spectrometer SPI

Scientific topics 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 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 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 observes 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 provides 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 four 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 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. Note that a sequence of observations separated by a time interval (e.g. three observations, with the observations separated by 2-3 weeks) are considered as fixed time observations as well. The proposer has to make sure, that this is flagged when submitting a proposal and that the *Observation Type* is set to *Fixed Time* in the *Observation Details Pane*l of PGT.

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 (grade A) by the TAC.

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 <u>rules and guidelines</u> are applicable for TOO proposals:

- The ISWT has prepared a list 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 priorization 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 via the dedicated ISOC TOO Web page (see below), 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 for TOO observations are made by submitting a “Target of Opportunity Notification” using the ISOC Target of Opportunity Alert Web page (**http://www.rssd.esa.int/Integral/isoc/html/too/my_too_alert.html**). The Project Scientist or an appointed deputy is then responsible for the submission of that request 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 Project Scientist 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 or other high priority observations. In such situations the Project

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.

Scientist will determine priorities. The Project Scientist will inform the science community and the INTEGRAL Science Working Team on declared (approved) TOO observations.

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 one event per month occurs inside the FOV.

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 processes the near real-time science telemetry stream in order to detect and localize GRB events. Location information and where possible flux estimates derived from this process are broadcasted to the scientific community at large via the ISDC-GRB alert system. 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 support the IPN analysis. Further details are provided in the *Instrument Observer's Manual (SPI)*.

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

Dedicated payload calibration observations are occasionally executed during the normal operation phase. Observations of the Crab are intended every visibility period. After the initial Crab calibration campaign in February 2003, the duration of future Crab calibration observations will significantly be reduced to about 2 revolutions consisting of on- and off-axis observations. Crab observations are required to continuously assess, verify and to complete the database describing the scientific performance of the instruments, specifically after annealing of the SPI detectors or after strong solar flare events. OMC flat field calibration sequences are performed about once a month with a duration of ~4.5 hours to characterize the OMC flat field response.

Proposers should take note of this planning by preparing open time proposals which should avoid duplicating these observations.

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

4. Spacecraft observing modes

The INTEGRAL spacecraft provides 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 consists 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 flexible in the range between 0.5 hour to 1 hour. The integration time is adjusted in a way so that always multiples of a complete dither pattern are executed for each observation. The spacecraft will continuously follow one dithering pattern throughout one observation. Two different dither patterns and a staring mode (no dithering) are used as operational baseline:

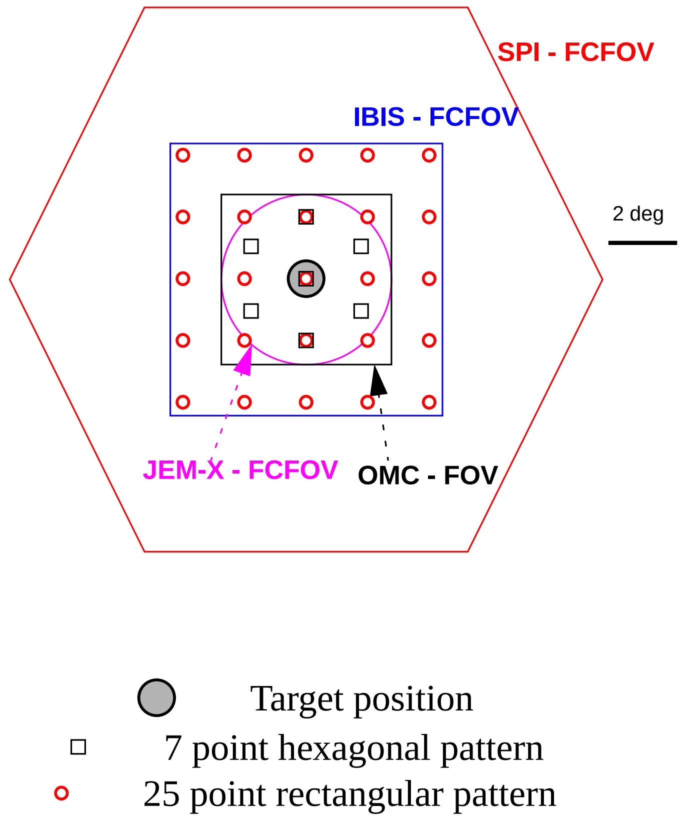

Figure 5. Schematic view of dithering patterns and instrument fully coded field of views.

- 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 should generally only be used for a single known point source, where no significant contribution from out-of-view sources is expected** (Figure 5); Experience from earlier observations has shown that this is not very often fulfilled (e.g. because of transient sources) and the observers are generally discouraged to use this mode. see 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 is 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.

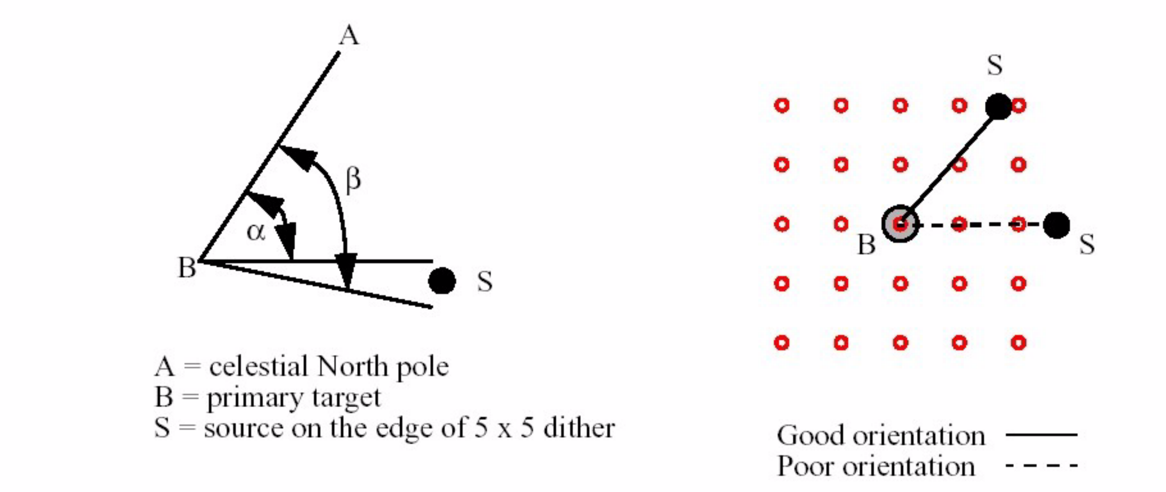

Figure 6. Sketch illustrating the preferred orientation for 5 × 5 dither pattern

- 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. Therefore it is quite possible that more than one approved observation (source) can be covered in the same field of view. The ISOC has 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

ISOC will generate a list of proposed amalgamations from the TAC-recommended programme. These will be presented to the TAC chair for endorsement. 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.

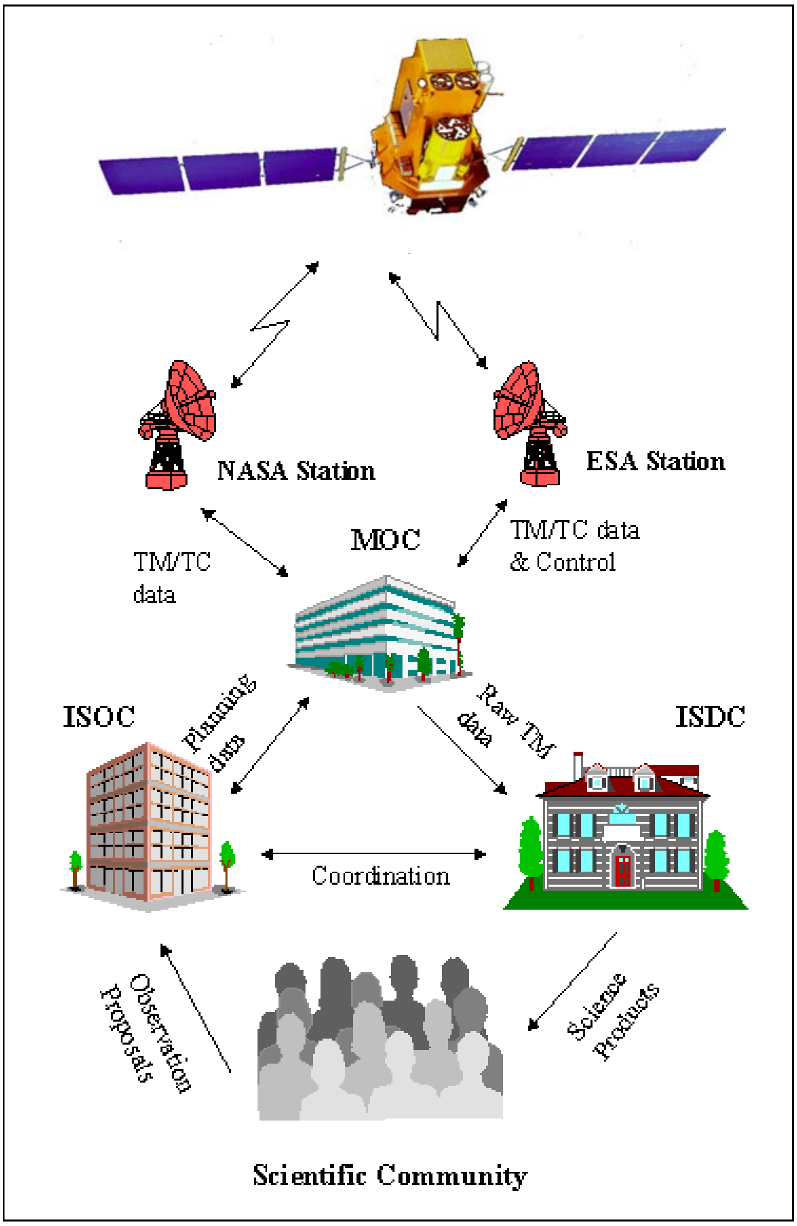

Figure 7. The INTEGRAL ground segment

Basically, the ISOC receives observing proposals and processes the accepted proposals into an optimised observation plan which consists of a time line of target pointings plus the corresponding instrument configurations. The ISDC receives 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 converts these raw data into physical units and generates standard data products. ISDC archives the data and products and distributes them to the science community. ESA also maintains a copy of this archive at the ISOC.

2. Science ground segment support for proposers and observers

The INTEGRAL ISOC WWW pages at **http://www.rssd.esa.int/Integral/** provides 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
  - Scheduling Information
  - Long and short term scheduling
  - Approved Target List
  - ISDC data archive
- INTEGRAL Helpdesk and Frequently Asked Questions

There is one central help-desk handling all questions (received via e-mail at **inthelp@rssd.esa.int**) 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 are handled by ISOC staff and questions on INTEGRAL data, instrument calibration and data shipment are 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.

The INTEGRAL science analysis software is available together with documentation and test data for download from the ISDC Web page at **http://isdc.unige.ch/index.cgi?Soft+download.** 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

- is preparing AOs for observations, receives the 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
- decides 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).
- keeps 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 30% of INTEGRAL time (for the second 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 70% of INTEGRAL time (for the second 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) 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 observation duration) and also a scientific justification. The TAC will evaluate each proposal against the entries entered with the Proposal Generation Tool (PGT). Each proposal is evaluated against the observation duration entered by the PGT and not what is written in the scientific justification. In case zero or unrealisticly small observation durations (so called “hitch-hicker” observations) are specified, the scientific goals won’t in general be achievable and the proposal would have to be rejected; This applies also to “survey proposals”, which are of the nature “*I want the data of all observations with sources from the supplied list/or from all observations with sources of type X in the FOV, but do not request any extra observation time*”, unless the proposer has a very convincing justification, why this kind of research cannot be done using public data from the archive. Each requested observation for each target of a proposal must be entered into the proposal by the PGT, otherwise it is not considered by the TAC for evaluation.

This means, **targets only listed in the scientific justification and not entered into the proposal by PGT are not considered during the TAC evaluation.** General Observers (i.e. the PIs) can request a PGT compatible version of their own proposal submitted in response to an earlier AO via the INTEGRAL helpdesk. This is very useful in case of long lists with targets and saves re-entering all the observation information.

3.3 Proposal generation tools

ISOC makes available through its WWW pages (**http://www.rssd.esa.intl/Integral**) 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. The Principle Investigators can request a PGT compatible version of their own proposal submitted in response to an earlier AO via the INTEGRAL helpdesk.

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://www.rssd.esa.int/Integral**) where proposers - via the helpdesk using e-mail to **inthelp@rssd.esa.int** - 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 and Time Allocation Committee (TAC)

After the deadline for an AO, ISOC will perform a technical feasibility of the submitted proposals using the Target Visibility Predictor and the Observing Time Estimator, and forward the proposals to the Time Allocation (TAC) for scientific assessment.

The proposals are reviewed by a single international Time Allocation Committee (TAC). This committee consists of four panels, covering the four scientific topics addressed with INTEGRAL:

- Compact objects: including black hole candidates and neutron star binaries, pulsars, isolated neutron stars and galactic jet sources.
- Active Galactic Nuclei: including AGN, Seyferts, Blazars, quasars, but also normal galaxies, clusters of galaxies and cosmic background.
- Nucleosynthesis: including supernovae, supernova remnants, novae, Wolf-Rayet stars, diffuse (line) emission and interstellar phenomena.

• Miscellaneous: including gamma-ray bursts, gamma-ray burst sources and anything not in the three categories given above.

Based on the results of the 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.

The TAC will be advised to accept only a limited number of proposals for Targets of Opportunity (about 1 per month). The reason for this is that the scheduling of TOO observations will reduce the efficiency of the mission, since it upsets the preplanned schedule of the observatory.

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 generates and maintains detailed observing schedules based on the approved observations (both from the Core Programme and the General observing Programme), and delivers these schedules to MOC for uplink and execution. The ISOC scheduling takes 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 has to schedule them as several separate exposures. In addition, both ISOC and MOC 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, is generally implemented by MOC in the next revolution following the request from ISOC, assuming that this revolution will start more than 8 hours in the future.

When an exposure has been performed on-board the spacecraft, MOC forwards 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 regularly informs 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 ships 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 and maintain 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 receives 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 also processes 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 receives the telemetry of the INTEGRAL spacecraft in real-time from the MOC at a rate of ~ 113 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 is 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 receives 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 is 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, if available flux estimates and duration) are made available to interested astronomers via the GCN circulars. An alert distribution through internet socket for robotic telescopes is available as well. For further details the ISDC Web page can be consulted (**http://isdc.unige.ch/index.cgi?Soft+ibas**).

Within a few hours of receipt, the data are 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 are 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 performs a Standard Analysis (SA) of each observation. This analysis results 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 are 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 results in about 17 Gbytes of uncompressed data products per revolution. These data are 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 are 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 is cut into a series of contiguous “science windows”. A science window usually corresponds to a pointing (30-60 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 were performed before launch, during the commissioning phase, during an extensive Crab calibration in February 2003 and regularly during the mission (see Chapter II, Section 3.) The instrument teams analyse the calibration data and their results are used by the ISDC data processing. All calibration and response files are 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, contains 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 are on-line and accessible both via an archive browse utility with a dedicated WWW interface and more directly through 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 hard media (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 via Internet transfer (FTP) or on hard media (DVD or DLT tapes). Experience has shown that the typical download rate for data from ISDC is 1 Gbyte/hour via FTP and that the data transfer via FTP is generally smooth.

As hardmedia DVDs and DLT tapes are possible. Because of the large size of the INTEGRAL data (Section 4.6.) DLT tapes are more appropriate. 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. The data distribution occurs after ISDC has received the consolidated data from ESA, processed and archived these data off-line. The whole process takes about one month.

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.

It is possible for observers **visiting the ISDC** to have a first view of the data from their observations within few hours. The ISDC can indeed (with the permission of ESA, note that in the case of amalgamated observations ESA will request the approval of all PIs) provide the observers access to the data of their observation at the ISDC. This possibility can be used by any observer wishing to have a first view of the data content before the distribution of the data.

4.10 User support and communication

The ISDC provides support to the observers with their data analysis. The INTEGRAL science analysis software is available together with documentation and test data for download at the ISDC Web pages at **http://isdc.unige.ch/index.cgi?Soft+download.** Alternatively, observers are welcome to visit the ISDC for local support and direct access to data analysis tools.

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

ISDC intends 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 are 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, trigger time, if available duration and flux estimate 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 has no GRB detection and triggering system on board. However, it continuously downlinks its acquired data to Earth allowing for constant, near real-time, monitoring. At the ISDC all data are automatically analysed to detect any transient events. In addition, a fast analysis is performed by the INTEGRAL Burst Alert System IBAS. This “on ground” approach to detections 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 are 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 rate of GRBs is about one burst per month within the IBIS and SPI FOVs. Localization accuracy is a function of the event’s S/N ratio, the spacecraft attitude and stability (e.g. during slews), the angular resolution, and whether the event took place in the fully or partially coded FOV. Naturally, the first alert broadcast message has rather crude information, e.g. the positional information is based on predicted attitude information rather than the reconstituted one. Therefore subsequent alert messages are sent out to subscribers with improved information, both on position and source characteristics.

Alerts with the coordinates of GRBs are distributed through internet sockets for robotic telescopes using the UDP transport protocol. The required software can be requested from ISDC. Email alerts are distributed via GCN circulars. The typical uncertainty is smaller than a few minutes. The IBAS GRB detection and alert distribution are mostly based on automatic processes. The interactive analysis, to confirm the event and to derive the most accurate GRB position, is generally performed within a few hours after the automatic delivery of the first alert message(s) with the preliminary coordinates.

In operating an automatic GRB alert system, one is faced with the trade-off between the requirement to react in the shortest possible time and the desire to get the most accurate results (e.g. reality of the event, dimension of error region, etc.). Considering that the main users of the IBAS Alerts are robotic telescopes with large fields of view, specifically devoted to GRB afterglow searches, the fast alert time requirement is favoured. Users must be aware that this implies that some of the IBAS alerts might subsequently be found not to be related to real GRB events. Users not interested in the fastest reaction time can decide to subscribe only to particular Alert Types.

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

INTEGRAL is a 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) collects 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 usefully contribute to the IPN.

These time series (contained in the instrument housekeeping data stream) are also provided via the ISDC GRB alert system to the scientific community 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 duration of the on-going (dither) pointing only (i.e. <= 60 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 whole process has already been successfully tested in flight.

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 (via the INTEGRAL TOO Notification Web page) 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 (via the INTEGRAL TOO Notification Web page, http://www.rssd.esa.int/Integral/isoc/html/too/my_too_alert.html) 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*. This especially applies to JEM-X due to the adjusted operation strategy with one JEM-X camera operated at any time.

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) 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. 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 10^{o} away from the Moon limb. 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. This has happened to the critical altitude at the end of revolution, which because of high radiation is currently set to 60000 km.

No observations will be performed from 30 minutes before an eclipse until 30 minutes after an eclipse.

A special constraint is imposed on the scheduling of observations by IBIS. If a very bright source (Crab, Cyg X-1 and Galactic Center) is positioned 30-50 degree off axis within a narrow azimuth angle range around the spacecraft -z-axis the bright source casts a shadow of the SPI mask onto the IBIS detectors. This so called SPIBIS effect can be avoided for the specific observation by excluding time periods from scheduling, where the bright source lays within the critical area. Currently, the ISOC avoids scheduling observations during periods where the SPIBIS effect occurs. More details can be found in the *Instrument Observer’s Manual (IBIS).*

1.4 Target visibility tool

As pointed out in Chapter III, the INTEGRAL ISOC WWW (**http://www.rssd.esa.int/Integral**) 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 with exception of the SPIBIS effect, which is only considered at the scheduling level.

VI. Extended mission

The nominal (operational) mission has a duration of 24 months and commenced two months after launch on December 17, 2002. Therefore, nominal mission life will end at launch + 26 months on December 16, 2004.

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.