Science with INTEGRAL in Perspective

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Abstract. The ESA-Mission INTEGRAL (International Gamma-Ray Astrophysics Laboratory) is the next step in low-energy gamma-ray astronomy (up to 10 MeV) and will be launched in 2002. Its two main instruments, the spectrometer SPI and the Imager IBIS complement each other: SPI is dedicated to high-resolution line spectroscopy ($\Delta E = 2.5$ keV FWHM at 1.3 MeV) and IBIS to fine imaging (angular resolution : 12' FWHM). These two co-aligned main instruments are complemented by two monitors in the X-ray (3 - 35 keV) and optical (V, 550 nm) range. With this combination of instruments unprecedented sensitivities will be achieved for the study of astrophysical continuum and line emitting processes in compact and extended source regions. INTEGRAL will be an Observatory-type mission. Most of the observing time will be awarded to the scientific community (65 % during the first year of the mission). The remaining time is reserved for the INTEGRAL Science Working Team.

INTRODUCTION

The International Gamma-Ray Astrophysics Laboratory (INTEGRAL) of ESA will be the next step in space-borne gamma-ray astronomy after the successful missions of SIGMA on GRANAT and the Compton Gamma-Ray Observatory. INTEGRAL will be devoted to high-resolution spectroscopy and fine source imaging in the energy range 15 keV to 10 MeV, and in addition, will allow parallel monitoring of the observed gamma-ray sources in the neighbouring X-ray band and at optical wavelengths (Winkler and Hermsen, 1999; and Winkler 1999).

INTEGRAL was selected in 1993 as a Medium Size Mission of the ESA programme. It is worth mentioning that the present concept of INTEGRAL differs somewhat from that proposed to ESA in 1993. Most of the changes were made after it became clear that a major involvement of the US could not be realized and when the UK decided not to participate in the building of the scientific payload.

INTEGRAL is expected to be launched in 2002 by a Russian PROTON rocket, which will bring the laboratory into a 72 hour elliptical orbit (inital perigee 10 000 km, apogee: 153 000 km) of 51.6° inclination. The nominal mission life time will be 2 years. An extension by three additional years is possible. INTEGRAL will be operated as an observatory: most of its observation time will be made available to the scientific community.

THE SCIENTIFIC PAYLOAD

INTEGRAL will carry four instruments: the two main instruments SPI (Spectrometer INTEGRAL) and IBIS (Imager on-Board the INTEGRAL Satellite), and the two monitors

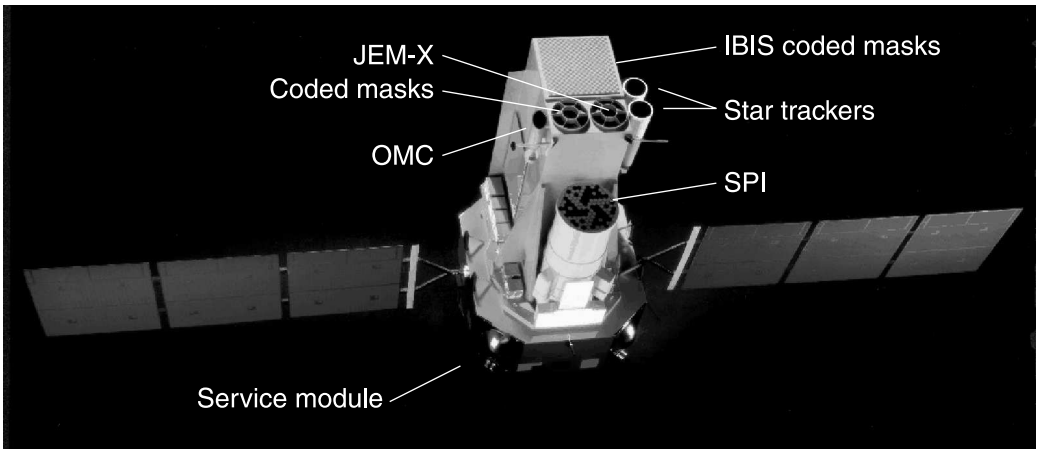

FIGURE 1. Schematic View of INTEGRAL with its four instruments.

JEM-X and OMC.

SPI (20 keV to 8 MeV) will be devoted to high-resolution spectroscopy with modest imaging. Within its fully coded field-of-view of 16° FWHM, its angular resolution is about 2.5° FWHM (Vedrenne et al., 1999). SPI will build upon the results which OSSE and COMPTEL obtained in the field of gamma-ray line spectroscopy. It will be able to measure the profiles of gamma-ray lines to an accuracy of about 2 keV. This is its most important aspect. The knowledge of the line profile allows a detailed study of the physical conditions of the sky regions in which the lines are produced, like temperature, expansion velocity, ionization degree, and emission geometries. A similar experiment (called GRSE) was also originally planned for the Compton Gamma-Ray Observatory, but was never realized.

The imager IBIS (15 keV to 10 MeV) will have an excellent angular resolution of 12 arc min within its fully coded field-of-view of 9° FWHM (Ubertini et al., 1999). IBIS may be considered as the follow-on step after SIGMA on GRANAT, which had practically the same angular resolution, but which was less sensitive by about a factor of 10.

The two monitor instruments will allow parallel monitoring of the gamma-ray sources in the adjacent X-ray band and at optical wavelengths. JEM-X (3 keV to 35 keV) has an excellent angular resolution of 3 arc min in its 4.8° FWHM field-of-view (Lund et al., 1999). The optical monitor camera OMC (500 to 600 nm) has a pixel resolution of 16.6 arc sec within its 5.0° x 5.0° field-of-view (Giménez et al., 1999).

SPI, IBIS and JEM-X are all based on the coded aperture imaging technique. SPI uses germanium detectors, IBIS CdTe and CsI detectors, and JEM-X microstrip Xenon gas detectors. OMC consists of a passively cooled CCD in the focal plane of a 50 mm lens.

THE INTEGRAL SENSITIVITIES

The scientific return of the INTEGRAL mission will mainly depend on the sensitivities of its instruments. The actual sensitivities will only be known after launch, when the in-orbit background is known. Much effort has been invested to predict the background from

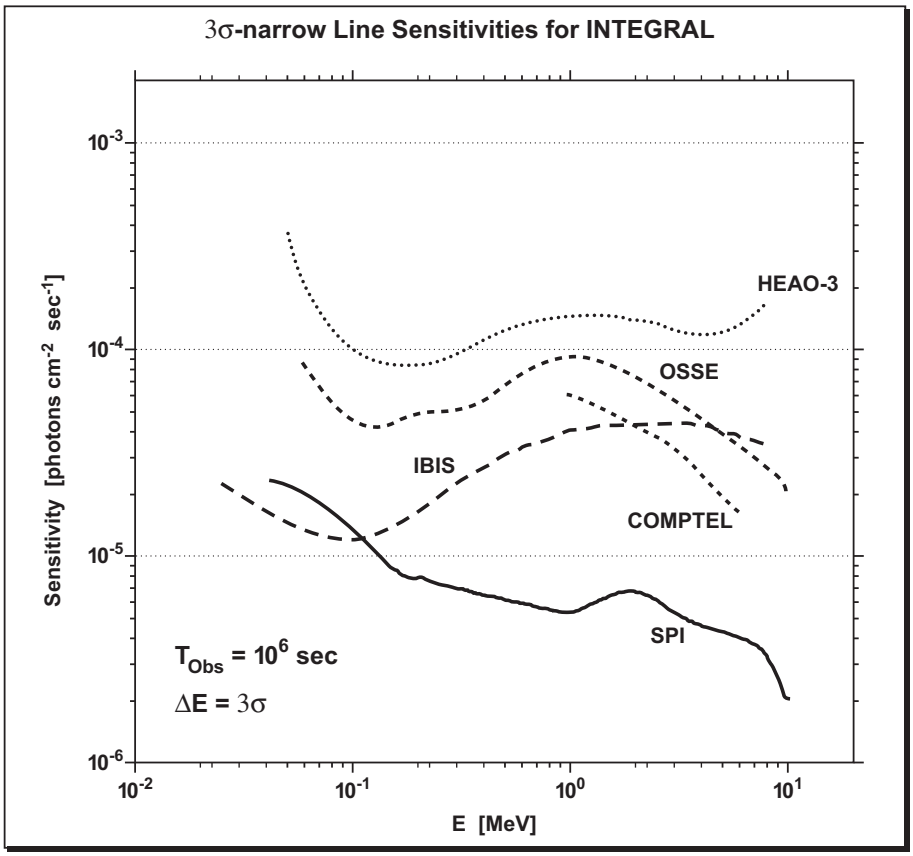

FIGURE 2. Point source sensitivity (3σ) for narrow line detections with SPI and IBIS for 10^6 sec observation time in comparison with the sensitivities of HEAO-3, OSSE, and COMPTEL.

previous missions and to derive realistic sensitivity estimates for the instruments.

Figure 2 shows the expected 3σ narrow line sensitivity of SPI and IBIS for an observation time of 10^6 sec in comparison with that of HEAO-3 and COMPTEL and OSSE on the Compton Gamma-Ray Observatory. The term "narrow" is defined to be identical to the energy resolution of the instruments (2.5 keV FWHM for SPI at 1.3 MeV, about 6 to 7 % FWHM for IBIS, 3 keV FWHM for HEAO-3, 10 % FWHM for COMPTEL, and 5 to 6 % FWHM for OSSE). SPI will be by far the most sensitive narrow gamma-ray line instrument ever flown. For broadened gamma-ray lines, the SPI sensitivity is somewhat degraded. The dependence of the degradation factor on the width of the line is illustrated in Fig. 3.

The IBIS, SPI and JEM-X 3σ continuum sensitivities (again for an observation time of 10^6 sec and for an energy interval $\triangle E = E/2$) are shown in Fig. 4, and are compared with the SIGMA sensitivity. Below 1 MeV, the point source detection sensitivity level is in the range between 0.5 to 20 m Crab strengths. Above 1 MeV, SPI and IBIS have comparable sensitivities (at the 100 m Crab level).

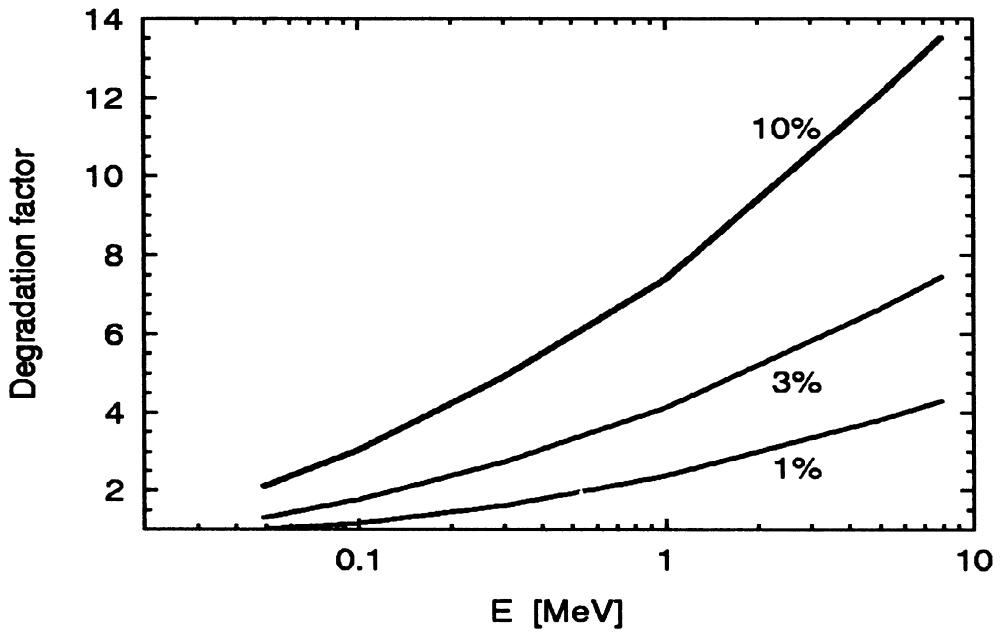

FIGURE 3. Degradation of SPI sensitivity for broadened lines. The degradation factor is plotted for line widths of 1 %, 3 %, and 10 % FWHM of the line energy.

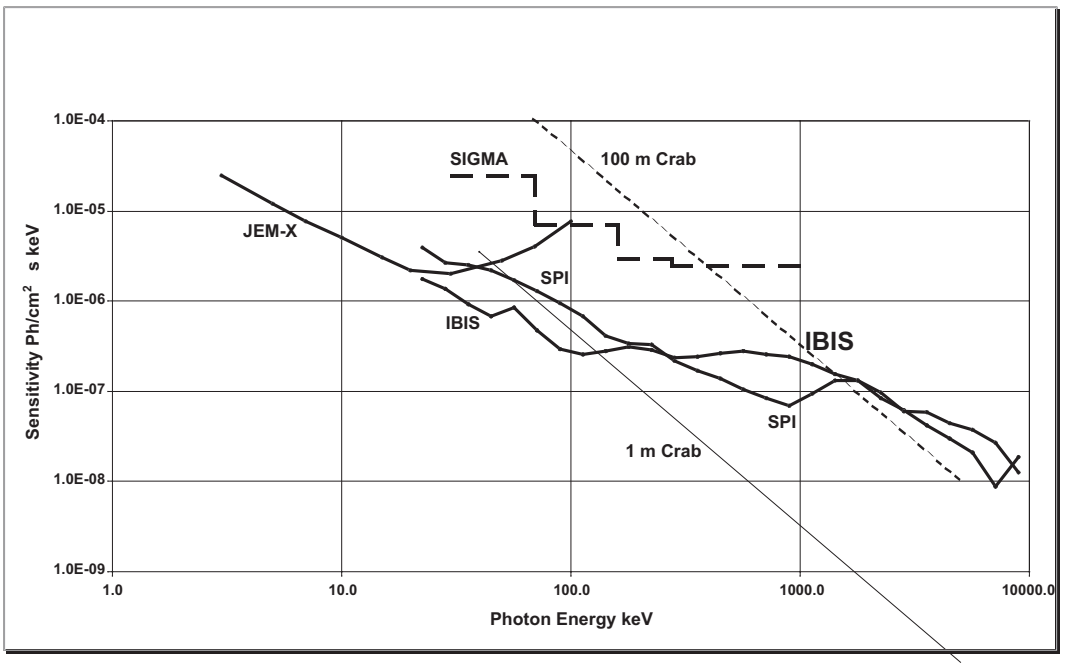

FIGURE 4. INTEGRAL continuum sensitivity (3σ) for an observation time of 10^6 sec and energy bins $\triangle E = E/2$ in comparison with the SIGMA sensitivity.

SCIENCE WITH INTEGRAL IN PERSPECTIVE

Considering the improvements in sensitivity - as illustrated in Fig. 2 and 4 - the most important and spectacular results from INTEGRAL can be expected in the field of gamma-ray line spectroscopy and in the study of continuum gamma-ray sources in the sub-MeV range. The key objects to be studied by INTEGRAL will be

- **compact objects**, like neutron stars, stellar black hole candidates, high-energy transients (X-ray novae), galactic micro-quasars, and gamma-ray bursters
- **stellar nucleosynthesis sites**, especially novae, supernovae, supernova remnants, but also hydrostatic nucleosynthesis sites like AGB and Wolf-Rayet stars
- **the interstellar medium** (mapping in continuum and gamma-ray line emission)
- **the Galactic center region**
- **external galaxies**, especially Seyfert galaxies and gamma-ray blazars
- **the cosmic gamma-ray background** (its spectral and spatial structure)
- **the unidentified gamma-ray sources** (especially from the EGRET source catalogue).

SPI's main research field is that of gamma-ray line spectroscopy. Here the key topics are twofold: first, the study of the broad-scale interstellar emission of the electron-positron annihilation line, the 1.809 MeV ^{26}Al line, the 1.17 and 1.33 MeV ^{60}Fe lines, and the 1.275 MeV ^{22}Na line. Of prime interest are the profiles of these lines. Second, the study of individual gamma-ray line sources: Candidates are the two supernova remnants Cas-A and RX 0852-46, from which the signature of the 1.157 MeV ^{44}Ti line was found, and other still to be discovered ^{44}Ti line sources, whose (broad) line profiles are expected to be measured by SPI for the first time (the latter of these two sources may also be identified as a 1.809 MeV line source), any nearby (< 15 Mpc) supernova that may occur after the launch of INTEGRAL to search for ^{56}Co and ^{57}Co gamma-ray line emission (1 or 2 such supernovae are expected over the life time of the mission), any nearby (≤ 1 kpc) nova to search for the 478 keV and 1.275 MeV lines from ^{7}Be and ^{22}Na decay, and possible 511 keV annihilation line sources, especially in the Galactic center region.

The search for nuclear interaction lines from interstellar space is another interesting topic for SPI. However, according to presently existing predictions, observation times much in excess of 10^6 sec will possibly be needed to detect such lines.

For IBIS Galactic binaries with compact objects like neutron stars, black-hole candidates, and transients are of special interest. Their observations will allow us to compare the spectral behaviour of these objects, to perform timing analysis and to search for transient spectral features like those observed near 511 keV from Nova Musca and the 1E 1740-2942 source. IBIS is expected to largely enhance our knowledge about transient source types discovered and investigated by SIGMA. Especially the Galactic center region is rich in such objects.

In the field of gamma-ray bursts 10 to 20 events will be detected within the fields-of-view of SPI and IBIS each year. Strong bursts will be located to an accuracy of better than 1 arc min, and high-resolution spectroscopy measurements of the burst will be possible. The location of the bursts will be made available to the world-wide community in less than 5 minutes. Follow-up observations of a burst as target-of-opportunity will be

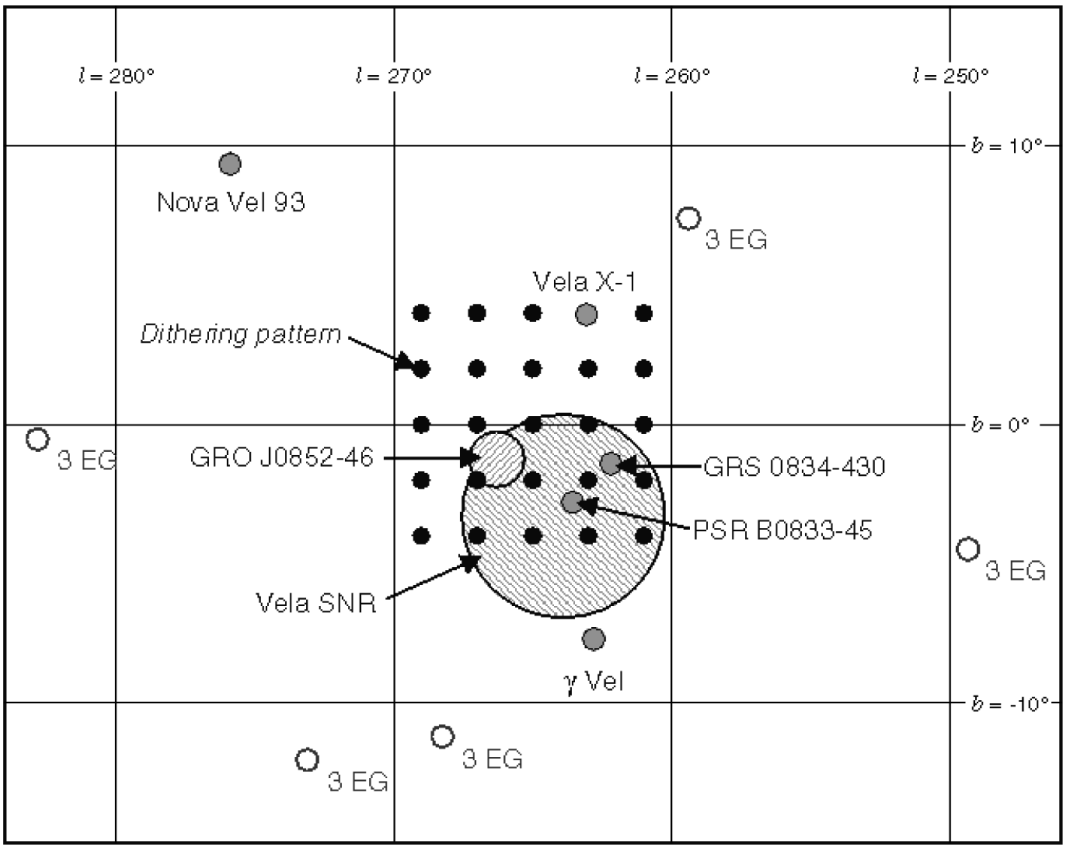

FIGURE 5. The Vela region will be used by INTEGRAL as a showcase for Galactic gamma-ray sources.

possible 36 hours after the initial event. The anticoincidence system of SPI will be used as part of the interplanetary network to locate bursts to about 10 arc sec.

THE OBSERVATION PROGRAM OF INTEGRAL

In the first year of the mission 65 % of the INTEGRAL observation time will be awarded to the scientific community in general (this is called the "open time"). The remaining fraction will be reserved for the INTEGRAL Science Working Team (called the "Core Programme"). In later years of the mission the fraction of the open time will further increase.

The core programme is well defined and consists of three elements (Winkler et al., 1999): a deep exposure of the Galactic central radian, weekly scans of the Galactic plane, and pointed observations.

The purpose of the deep exposure of the Galactic central radian is to map the Galactic ridge in continuum and line emission, in order to perform deep imaging and spectroscopic studies in that region. For each point along the plane in the central radian, the 10^6 sec sensitivity level (shown in Fig. 2 and 4) will be achieved after the first year.

The purpose of the Galactic plane scans is to discover transient sources (like e.g. Nova

Musca). For continuum sources around 100 keV the sensitivity limit of the plane scan is at the 20 m Crab intensity level for one single scan. The sum of all weekly scans over 1 year results on average in a 1-day exposure for each point along the Galactic plane, and can thus be used to build maps of the plane in continuum and line emission.

The pointed observations are of three different kinds: first, follow-up observations of transient events detected during the Galactic central radian deep exposure and the weekly Galactic plane scan; second, follow-up observations of externally triggered transient events; and third, observation of persistent sources. Candidates for the follow-up observations are X-ray novae, superluminal jet sources, supernovae, classical novae, and AGN outbursts. The time left in the Core Programme for the observation of persistent sources is only 10^6 sec. The INTEGRAL Science Team has decided to devote this time to the observation of the Vela region, which contains several exciting and spectacular objects (see Fig. 5). Among these are RX 0852-46, the closest historical supernova remnant in the Galaxy; γ^2-Velorum; the closest Wolf-Rayet star; the Vela pulsar; the Vela supernova remnant; Vela X-1; GRS 0834-430: an unusual Be-star binary accreting pulsar; Nova Vel 93: a black-hole X-ray nova in quiescence, and a few unidentified EGRET sources.

The INTEGRAL data first will arrive at the INTEGRAL Data Centre, which is located at Versoix, near Geneva. Its main task will be the data processing, quick-look analysis, instrument performance monitoring, target-of-opportunity recognition and gamma-ray burst alerts, standard science analysis, and archiving of the science data. All INTEGRAL data will be released for public use one year after they have been given to the individual observers.

REFERENCES

Giménez, A. et al., 1999, Proc. of 5th Compton Symposium, ed.: M.L. McConnell, and J.M. Ryan, AIP **510**, 732 (2000)

Lund, N. et al., 1999, Proc. of 5th Compton Symposium, ed.: M.L. McConnell, and J.M. Ryan, AIP **510**, 727 (2000)

Winkler, C. and Hermsen, W., 1999, Proc. of 5th Compton Symposium, ed.: M.L. McConnell, and J.M. Ryan, AIP **510**, 676 (2000)

Winkler, C., 1999, Proc. 3rd INTEGRAL Workshop, Astrophys. Letters & Communications **39**, 309

Winkler, C. et al., 1999, Proc. 3rd INTEGRAL Workshop, Astrophys. Letters & Communications **39**, 361

Ubertini, P., 1999, Proc. of 5th Compton Symposium, ed.: M.L. McConnell, and J.M. Ryan, AIP **510**, 684 (2000)

Vedrenne, G. et al., 1999, Proc. 3rd INTEGRAL Workshop, Astrophys. Letters & Communications **39**, 325