

First results of the INTEGRAL spectrometer SPI

J. Knödlseher ^a,

^a*Centre d'Etude Spatiale des Rayonnements, 9, avenue du Colonel-Roche, B.P. 4346, 31028 Toulouse, Cedex*

Abstract

This paper presents first results obtained by the SPI telescope aboard the INTEGRAL gamma-ray observatory. Science highlights comprise the rapid localisation and observation of gamma-ray bursts, high-resolution spectroscopy of compact objects, the determination of the morphology and spectral shape of the galactic 511 keV positron annihilation line, and the determination of the spectral shape of the 1809 keV decay line from radioactive ²⁶Al.

Key words: gamma-ray telescopes and instrumentation, spectroscopy, gamma-ray, nucleosynthesis

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1 Introduction

ESA's International Gamma Ray Laboratory, INTEGRAL, has been launched successfully on October 17th, 2002 from the Russian launch site at Baïkonour using a Proton rocket. INTEGRAL is dedicated to a large variety of scientific topics, such as the study of compact objects, active galactic nuclei, pulsars, diffuse galactic emission, positron creation and annihilation, nucleosynthesis, and gamma-ray bursts (see e.g. Winkler 1997 for a comprehensive review of the scientific objectives). INTEGRAL is composed of two main instruments, the imager IBIS and the spectrometer SPI, accompanied by two monitor instruments, JEM-X for the soft X-ray domain and OMC for the visible waveband. IBIS has been optimised to provide high angular resolution, allowing for the precise localisation and identification of gamma-ray sources, in particular of point sources such as black hole or neutron star binaries. Complementary, SPI has been optimised to provide high spectral resolution, allowing for studies of gamma-ray line profiles, either from point or diffuse sources. While this paper emphasizes the first science results obtained by the spectrometer SPI,

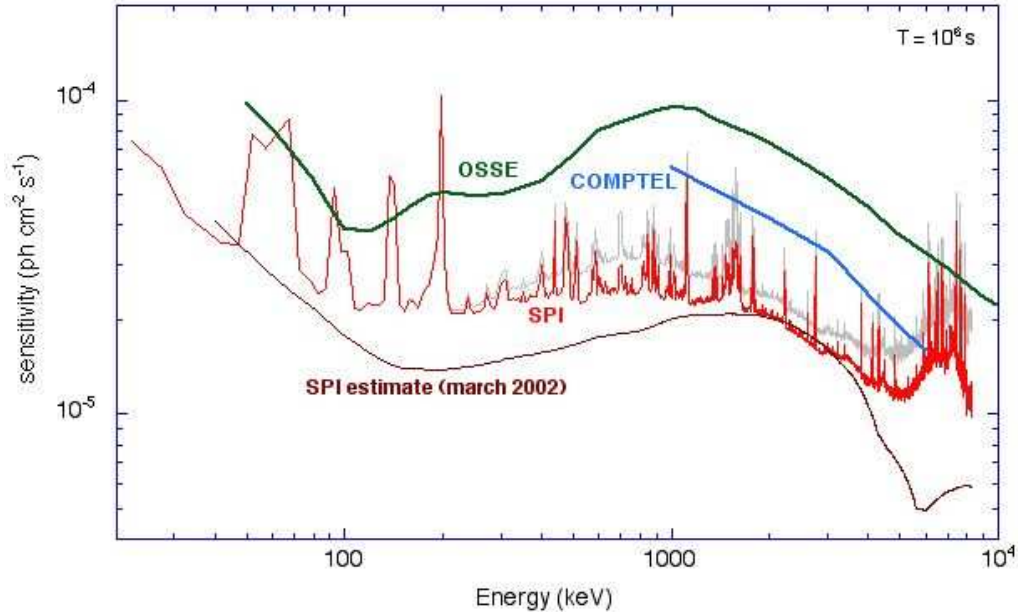


Fig. 1. SPI narrow line sensitivity for an observation duration of 10^6 seconds (Roques et al. 2003).

an accompanying paper by C. Winkler presents INTEGRAL observatory and mission characteristics and first science results at the observatory level.

2 SPI inflight performances

SPI is equipped with 19 cooled germanium detector crystals that are arranged in a hexagonal pattern and that act as the camera of the telescope. A coded mask situated 1.71 metres above the camera modulates the incoming gamma radiation, and provides an angular resolution of $\sim 2.5^\circ$ within a fully-coded field of view of 16° . Inflight, SPI reaches an energy resolution of ~ 2.5 keV at 1 MeV with a narrow line sensitivity of $(2 - 3) \times 10^{-5}$ $\text{ph cm}^{-2}\text{s}^{-1}$ for an observation time of 10^6 seconds (Roques et al. 2003; see also Fig. 1). The energy resolution degrades with time due to particle irradiation in space which create electron trapping sites in the detector crystals. To recover the degradation, an annealing system has been implemented that allows rising the detector temperature from the nominal 85 – 90 K up to 106° C. A first such cycle, conducted in February 2003, demonstrated the efficiency of the process (the baking time amounted to 37 hours). A second annealing was performed in July 2003. It is expected that an annealing is required each six months in order to maintain the excellent detector resolution over the duration of the mission.

In order to reduce instrumental background, SPI is equipped with an active anticoincidence shield, made of 91 BGO crystals. The threshold of this system

has been set to ~ 75 keV, reducing the background in the detectors by a factor of 20. The deadtime of the entire detection system, which is dominated by the anticoincidence shield deadtime, amounts to about 12%.

3 First science highlights

3.1 *Gamma-ray bursts*

The first gamma-ray source that has been detected by the INTEGRAL observatory was a gamma-ray burst, GRB021027. It has been detected using SPI's anticoincidence system (ACS), which is composed of 500 kg of BGO crystals which primarily serve to veto charged particle interactions within the instrument. The ACS counting rates provide a direct measurement of GRB lightcurves with 50 ms time resolution, which in combination with the lightcurves obtained by other satellites within the Interplanetary Network (IPN), allows for burst localisation via triangulation (Hurley 2001). Today, SPI contributes to the IPN with a rate of one burst every 3.4 days (Hurley, private communication).

Due to INTEGRAL's real time telemetry stream, rapid burst localisation using onground data processing is feasible for bursts that occur accidentally within the large fields of view (FOV) of IBIS and SPI. So far, about one GRB is localised per month within the FOV, where the most rapid position has been obtained for GRB030501 only 30 seconds after burst occurrence. For FOV bursts, the full spectral resolution power of SPI may be exploited to precisely determine the spectral shape and to search for possible gamma-ray line signatures.

3.2 *Galactic X-ray binaries*

Due to its low energy threshold of about 20 keV, SPI is well suited to study the spectral shape of galactic X-ray binaries. The PV phase observations provided first high resolution spectra and lightcurves for the well known systems Cyg X-1 and Cyg X-3, in addition to data on the transient pulsar EXO2030+375 which luckily flared-up during the observation period (Bouchet et al. 2003). A contemporaneous observation of Cyg X-1 using the RXTE telescope allowed for an inter-instrument comparison that demonstrated the validity and high accuracy of the pre-flight SPI response matrix. With the acquired exposure of 600 ks, Cyg X-1 is detected up to energies of about 1 MeV, illustrating the SPI imaging capabilities at MeV energies. The search for spectral signatures

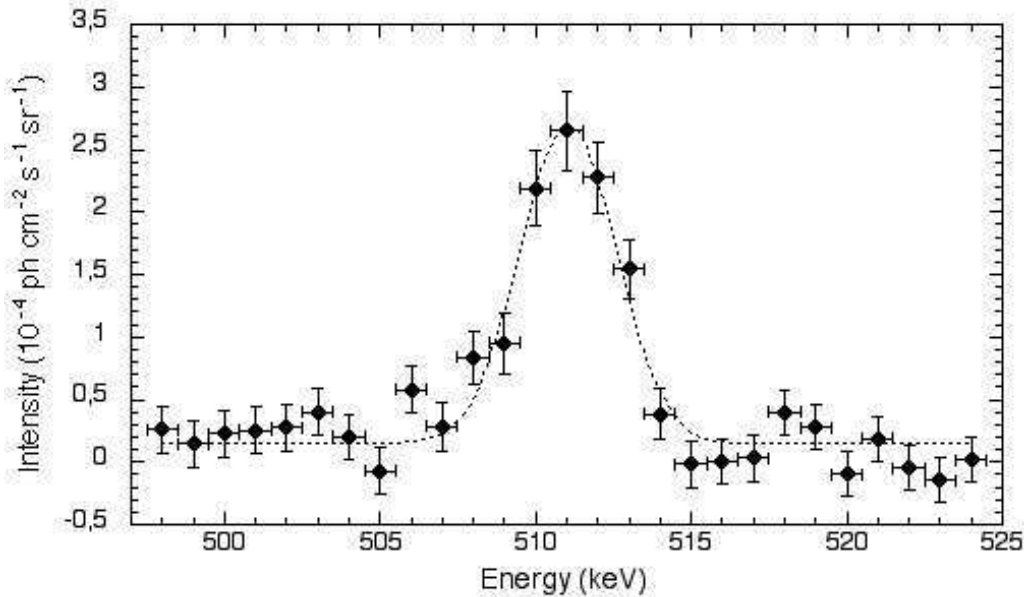


Fig. 2. Spectrum of the 511 keV annihilation line towards the galactic centre (Jean et al. 2003).

such as cyclotron lines or positron annihilation features is underway.

The preliminary analysis of the GCDE data has revealed a wealth of point-like sources towards the inner Galaxy. The comparison of IBIS and SPI skymaps indicates that the SPI analysis is limited in this area by source confusion rather than sensitivity. Within these limits, SPI has detected so far more than 20 sources during the GCDE. Most of the sources are only seen up to 50 keV, while a few extend to energies of at least a few 100 keV. A detailed spectral analysis of the sources has just started.

3.3 511 keV positron annihilation line

The strongest gamma-ray line within the INTEGRAL energy range is the 511 keV line that arises from the annihilation of positrons. Although the source and distribution of the galactic positrons is yet unknown, it is well known since the 70s that an intense annihilation signal is present towards the centre of our Galaxy.

Figure 2 shows the spectrum of the 511 keV line as detected by SPI through the GCDE observation (Jean et al. 2003). The line centroid of $511.06^{+0.17}_{-0.19}$ keV is compatible with the electron rest mass energy, the intrinsic line width of $2.95^{+0.45}_{-0.51}$ keV (FWHM) indicates a modest broadening that is clearly resolved by SPI. The line flux of $(0.99^{+0.47}_{-0.21}) 10^{-3} \text{ ph cm}^{-2} \text{ s}^{-1}$ still obeys a large uncertainty, which is dominated by the uncertainty about the spatial distribution of the emission. The data exclude with high significance models in which the

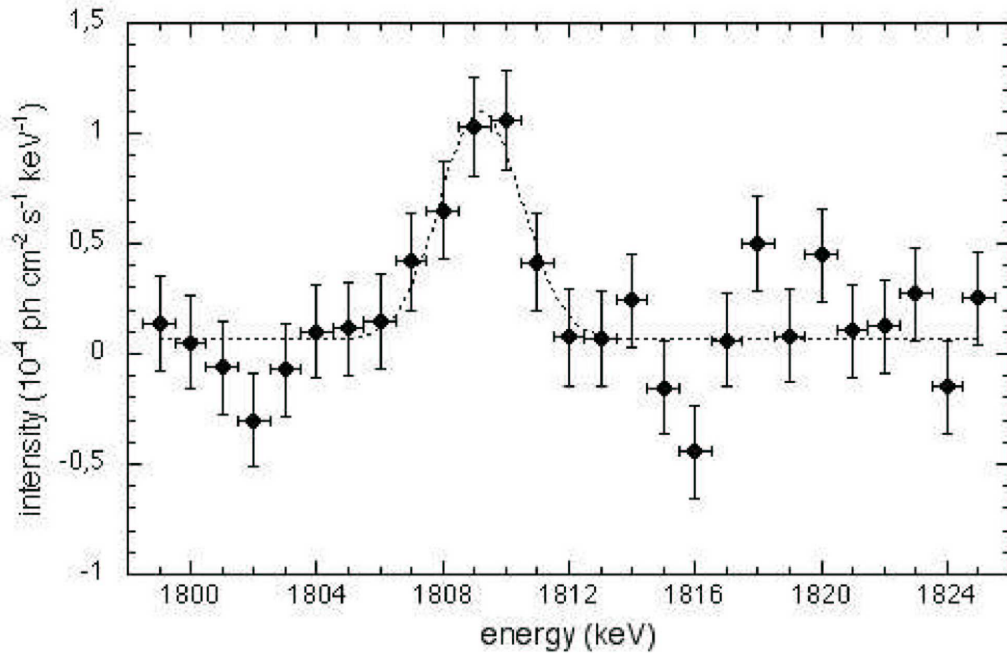


Fig. 3. Spectrum of the 1809 keV line towards the galactic centre (Diehl et al. 2003).

source is relatively compact; for a Gaussian source centred at $l=0^\circ$, $b=0^\circ$ the 2σ limits on the FWHM are 6° and about 18° . So far, there is no indication of a significant emission asymmetry with respect to the galactic centre, in particular towards regions above the galactic plane where previous observations using the OSSE telescope reported an emission enhancement (Purcell et al. 1997).

3.4 Galactic radioactivity

A major scientific objective of the INTEGRAL mission is the study of nucleosynthesis by observations of gamma-ray lines that arise from the decay of radioactive isotopes, such as ^{26}Al or ^{60}Fe . The most intense of these lines, the 1809 keV line from the decay of ^{26}Al , has been clearly detected by SPI (Diehl et al. 2003). Towards the galactic centre, SPI shows a narrow line feature (see Fig. 3) that is compatible with the instrumental resolution of 3.1 keV (FWHM), in contradiction with earlier balloon observations using the GRIS telescope that suggested a substantial broadening (Naya et al. 1996), yet in agreement with recent observations using the RHESSI solar observatory (Smith 2003). 1809 keV emission has also been detected towards the Cygnus region, confirming earlier findings that massive star associations in this area substantially enriched the interstellar medium by heavy elements in the recent past (Knödlseeder et al. 2002).

During this conference, Smith (this volume) announced the detection of the

1173 and 1333 keV gamma-ray lines from the radioactive decay of ^{60}Fe towards the galactic centre direction by the RHESSI observatory at a significance level of 3σ . The flux he found in each of the lines amounts to 16% of the galactic 1809 keV flux, which is of the order of upper limits that have been reported previously (e.g. Naya et al. 1998). Ongoing analysis of the SPI data taken during the GCDE show so far no indication of the ^{60}Fe decay lines, yet the actual statistical upper limits in each of the lines amount to $\sim 20\%$ of the 1809 keV flux, hence are still compatible with the RHESSI detection. Improvement of the analysis techniques and the inclusion of more data taken in the near future should considerably reduce this upper limit, allowing for a verification of the RHESSI result and permitting a detailed study of galactic ^{60}Fe production.

4 Conclusions

The SPI spectrometer aboard INTEGRAL is working properly, providing high quality spectroscopic data that for the first time will allow a deep study of gamma-ray line shapes. In particular, the high spectral resolution is maintained throughout the mission by regular annealing cycles that remove crystal defects in the Germanium detectors created by the permanent high energy particle bombardment in space. A first annealing cycle conducted in february 2003 has demonstrated the efficiency of this procedure.

Among the first science results of SPI figure the rapid localisation and spectroscopy of gamma-ray bursts that coincidentally have been detected in the field of view of the telescope, the high-resolution spectroscopy of the numerous compact objects that have been detected towards the inner Galaxy, the determination of the morphology and the spectral shape of the galactic 511 keV gamma-ray line emission that arises from the annihilation of positrons within the interstellar medium, and the determination of the spectral shape of the 1809 keV gamma-ray arising from the radioactive decay of ^{26}Al in the interstellar medium.

The analysis of the SPI data is still in a very preliminary state, facing the many difficulties that are typical for the gamma-ray domain, and that are related to the intense instrumental background that largely dominates the registered events. Yet, the first results are very promising, illustrating that the background can be modelled sufficiently well, although many details still have to be understood. The knowledge about background handling and reduction will necessarily improve with experience about the instrument behaviour in space, allowing for more detailed and sensitive analyses in the future.

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