The spectrometer SPI of the INTEGRAL mission

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Abstract. The spectrometer on INTEGRAL (SPI) is one of the two main telescopes of the future INTEGRAL observatory. SPI is made of a compact hexagonal matrix of 19 high-purity germanium detectors shielded by a massive anticoincidence system. A HURA type coded aperture modulates the astrophysical signal. The spectrometer system, its physical characteristics and performances are presented. The instrument properties such as imaging capability, energy resolution and sensitivity have been evaluated by means of extensive Monte-Carlo simulations. With the expected performances of SPI, it will be possible to explore the γ-ray sky in greater depth and detail than it was possible with previous γ-ray telescopes like SIGMA, OSSE and COMPTEL. In particular, the high-energy resolution will allow for the first time the measurement of γ-ray line profiles. Such lines are emitted by the debris of nucleosynthesis and annihilation processes in our Galaxy. Lines from these processes have already been measured, but due to the relatively poor energy resolution, details of the emission processes in the source regions could not be studied. With the high-resolution spectroscopy of SPI such detailed investigations will be possible.

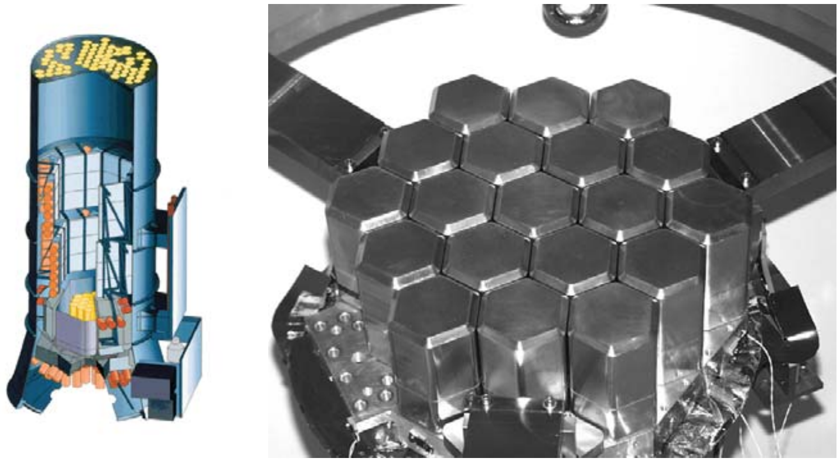

FIGURE 1. View of the spectrometer SPI (left) and its flight model Ge detector array (right).

DESIGN OF SPI

SPI will be aboard the INTEGRAL observatory which is an ESA's high-energy astrophysics mission to be launched on a Proton vehicle into a high eccentric orbit end 2001. Figure 1 (left) shows a view of the spectrometer. The detection plane is made of an array of 19 hexagonal cooled (85 K) high-purity Ge detectors providing a total area of $\approx$500 cm^2. The diameter and the thickness of detectors are 5.6 cm (flat to flat) and 7 cm respectively. Figure 1 (right) shows a view of the SPI flight-model Ge-detector array. It will be mounted on a beryllium plate and housed in a beryllium cryostat. A Pulse Shape Discrimination (PSD [1]) electronic system has been implemented in order to reduce the β decay background in Ge. The anticoincidence system consists of: (i) 91 bismuth germanate scintillator blocks that define the instrument field-of-view (FOV) and reduce the background, and (ii) a plastic scintillator underneath the coded-aperture in order to reduce the background originated in the mask. The coded aperture is 171 cm from the detection plane. It is made of 63 hexagonal 3 cm thick tungsten alloy elements. The design of the different parts of the spectrometer (shield thickness, detector nature...) has been optimised to reduce the instrumental background.

PERFORMANCES OF SPI

The anticipated performance for narrow-line spectroscopy is characterized by an energy resolution in the parts per thousand in the energy range relevant for nuclear astrophysics. The table below shows the SPI performance parameters.

Energy range	20 keV - 8 MeV
Energy resolution	2 keV at 1 MeV
Fully coded FOV	16 °
Partially coded FOV	35 °
Angular resolution	3. °
Point source location	<2 °

The sensitivity of the spectrometer is limited by the instrumental background induced by primary and secondary cosmic-ray particles and cosmic diffuse emission. The instrumental continuum background has been estimated using mainly the GEANT code and semi-empirical and empirical nuclear cross-sections. The physical effects inducing such background events are: the cosmic diffuse γ-ray emission, the radioactive decays in Ge, the spacecraft γ-ray and neutron emissions and the mask γ-ray emission. Figure 2 presents the point source narrow-line sensitivity that has been estimated using predicted background [2] and calculated efficiency which agrees with measurements [3]. Background reduction techniques (PSD, rejection of multiple events with a 511 keV signature) have been applied. Since positrons are induced by interaction of cosmic-rays in the instrument, a strong 511 keV background line limits the sensitivity at 2.8 10^{-5} photons cm^{-2} s^{-1} at this energy of astrophysical interest.

SCIENTIFIC OBJECTIVES

The energy range, spatial and spectral resolution of SPI are optimised for the measurement of astrophysical γ-ray lines. Such lines are emitted by radioactive nuclei produced in supernovae (^{56}Co, ^{57}Fe, ^{44}Ti, ^{26}Al, ^{60}Fe), in novae (^{22}Na, ^{7}Be) and WR stars (^{26}Al). The measured characteristics (intensity, shape, location) of these

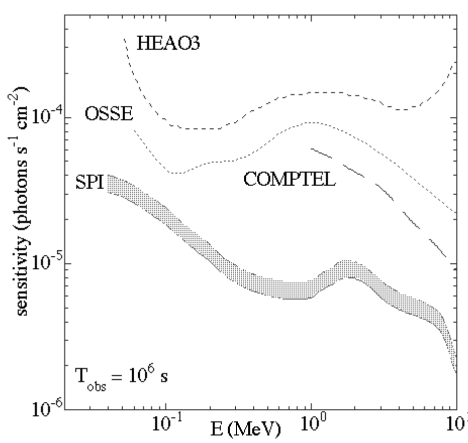

FIGURE 2. SPI on-axis point source narrow-line sensivity (3σ) for an observation time of 10^6 s (≈11 days). Sensitivities of existing experiments are also shown.

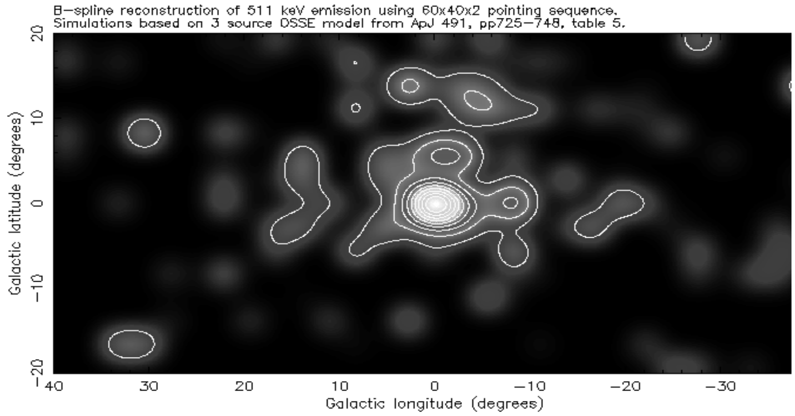

FIGURE 3. Simulated images of a possible 511 keV galactic emission model (see text) for the Galactic Center Deep Exposure ($\approx$ 56 days) of INTEGRAL.

γ-ray lines yield valuable information on the physics (e.g. SNIa explosion mechanism [4], mass-cut in core-collapse supernovae...) involved in the nucleosynthesis sites and their distribution in our Galaxy. Gamma-ray lines are also produced in the interstellar medium (ISM) such as the 511 keV emission due to annihilation of galactic e^+, that has been observed since the early 1970s. Figure 3 shows a simulated SPI observation of this emission based on a particular model [5]. Spectroscopic analysis of the e^+e^- line will provide insight into the physical conditions (temperature, density) of the annihilation regions, and its spatial distribution will provide clues for the e^+ origin. Nuclear de-excitation lines from energetic particle interactions with the ISM nuclei are also expected but remain to be discovered.

Although designed for γ-ray line observation, SPI will also be able to provide constraints on models of continuum emission from hard X-ray and γ-ray sources such as galactic center sources and active galactic nuclei. Other continuum emissions of interest are the galactic continuum emission and cosmic γ-ray background (CGB). In the 300 keV to 3 MeV range, the CGB may be due to the cumulative emission of cosmological SNIa. Its spectrum would contain edge features with amplitude depending on the cosmological parameter values. With its expected performances, the scientific objectives of SPI will cover a large field of astrophysical investigation such as stellar nucleosynthesis, physic of compact objects and of ISM, Galaxy structure and cosmology.

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