The INTEGRAL spectrometer SPI

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ABSTRACT : The INTEGRAL spectrometer SPI features a compact array of high purity Germanium detectors cooled by a Stirling cooler system and shielded by a BGO anticoincidence system. A coded mask modulates the astrophysical signal. In the energy range between 20 keV - 8 MeV SPI will perform spectral analysis of high-energy sources such as supernovae remnants, novae, compact Galactic sources, annihilation sites, Active Galactic Nuclei etc. The anticipated performance for narrow line spectroscopy is characterized by an energy resolution in the parts per thousand range, an angular resolution of order 2.5° within a fully coded field of view of 16°, and a sensitivity 3-7$\cdot 10^{-6}$ ph cm^{-2} s^{-1} in the energy range relevant for nuclear astrophysics.

KEYWORDS: instrumentation; high-resolution gamma-ray spectroscopy; INTEGRAL; SPI

SPI hardware

Germanium detectors : The detector array consists of 19 n-type Germanium detectors, with a total geometric detection area of 500 cm^2 (Fig. 1). Each detector has a hexagonal shape, 3.2 cm on a side, 7 cm deep, and a center-to-center distance of 6 cm. They are mounted inside partially pressurized Al capsules. The preamplified signal of each detector is fed into an analog front-end electronics (AFEE) system where it is amplified, filtered and converted in 32000 channels in two energy ranges. In order to reduce internal background produced by β decays inside the Ge detectors, a Pulse Shape Discrimination (PSD) system also receives the preamplified signal. By distinguishing single site interactions (predominantly caused by β decays) and multiple interactions (primarily produced by gamma rays), the PSD improves the sensitivity by about a factor of two between 200 keV and 1.5 MeV. The information of the PSD and

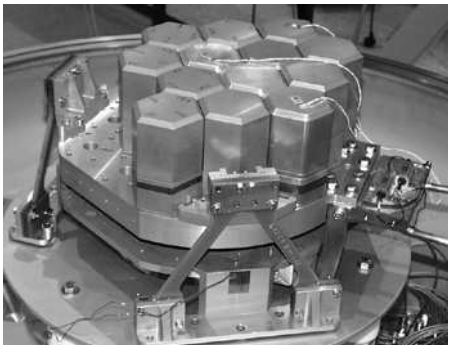

FIGURE 1 : The Ge-detector array

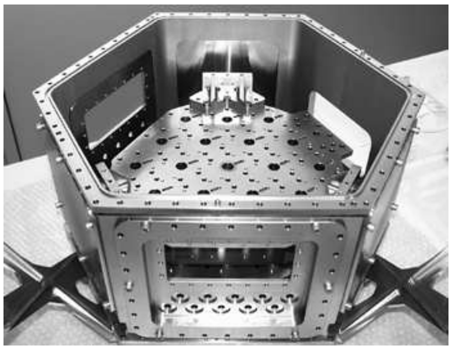

FIGURE 2 : The Beryllium cryostat

AFEE are then time-tagged and formatted by the digital front end electronics (DFEE) before being sent to the digital processing electronics (DPE). At CESR Toulouse (France), the detector array and analog front-end electronics are being developed, while CEA Saclay (France) provides the digital front-end electronics. The Ge crystals are produced by Union Minière (Olen, Belgium) under the leadership of the University of Louvain (Belgium). The PSD is developed by UC Berkeley and UC San Diego, USA.

Cryostat : The Ge detector array is mounted on a Beryllium plate and cooled to an operating temperature of 85 K (Fig 2.). A Be cold finger carries heat through the BGO shield towards the Stirling cryocoolers on the outside of the instrument. The Ge detector assembly is housed in a Beryllium cryostat, which is thermally isolated and passively cooled to 210 K. This is achieved by a radiator connected to the cryostat via ammonia-filled heat pipes. The use of Beryllium for the cryostat will help to reduce the background due to passive material inside the shield, while ensuring the highest possible transmission for gamma rays from astrophysical sources. CNES Toulouse (France) is developing the cryostat as well as being responsible for the mechanical, thermal, software and electrical design, general design specifications, both internal and external interfaces, and SPI integration activities. The cryocoolers are provided by ESA.

Coded mask : The aperture system providing the imaging capabilities of the instrument is a coded mask 171 cm above the detector. The mask pattern is a hexagonal uniformly redundant array (HURA) with 127 elements. The 63 opaque mask elements are 3 cm thick tungsten hexagons, 6 cm center-to-center. They assure a signal modulation of more than 90% over SPIs energy range. The 64 transparent elements are characterized by the honeycomb mounting plate which absorbs less than 10% of the signal at 50 keV. The tungsten mask is developed by the University of Valencia (Spain).

BGO shield : The anticoincidence subsystem (ACS) shields the detector assembly and defines an aperture of 25° FWHM. It consists of a massive hexagonal container protecting the detector and two hexagonal collimator rings,

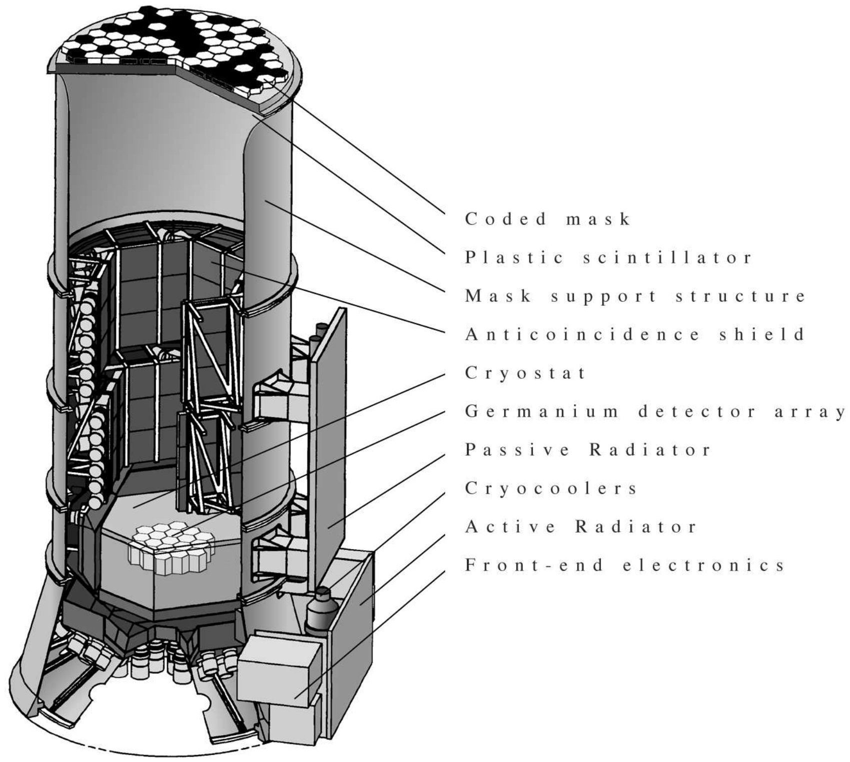

FIGURE 3 : Cutaway view of SPI and its subsystems

both made from bismuth germanate (BGO) scintillators. The BGO thickness is equivalent to 5 cm in all shielded directions. It has been optimized in order to minimize the detector background : whereas photons are rejected more efficiently with a thicker shield, the internally produced background, mainly due to nβ activations, is enhanced in a more massive shield. A total of 191 photomultiplier tubes are optically coupled to the BGO blocks to detect their scintillation light. A sophisticated read-out electronics of the total shield counting rate allows the measurement of the arrival time of a gamma-ray burst with a 50 ms time resolution. The anticoincidence shield and electronics are provided by MPE Garching (Germany).

Plastic scintillator : A thin plastic scintillator placed below the tungsten mask will significantly reduce the background produced in the mask, particularly in the 511 keV line. The plastic scintillator is the responsibility of IFCCNR Milan (Italy) which is also responsible for the electronic ground support equipment (EGSE) for the whole instrument.

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

TABLE 1 : Summary of scientific objectives

Performance and Objectives

Spectroscopy : The detection of narrow lines is SPI's main scientific objective and is made possible by the excellent energy resolution of the Ge detectors: 2 keV FWHM at 1 MeV. SPI's narrow line sensitivity is presented by N.Diallo et al. in these proceedings. The 511 keV line sensitivity for an on-axis point source in $T_{obs}=10^6$ sec is $2.8\cdot 10^{-5}$ $ph\ cm^{-2}s^{-1}$. During the Galactic plane survey, a point source brighter than $2.2\cdot 10^{-5}$ $ph\ cm^{-2}s^{-1}$in the inner galaxy will be detected at more than 3 standard deviations. The sensitivity estimates have been performed by teams of CESR Toulouse (France), CEA Saclay (France) and GSFC Greenbelt (USA), by exposing comprehensive computer models of the spectrometer and spacecraft to simulated conditions of the radiation environment encountered outside the magnetosphere. The performance estimates are based on a background model that has been verified by accelerator tests and balloon borne spectrometer data (CESR Toulouse, CEN Saclay, University of Louvain). More detailed descriptions of the spectrometer SPI can be found in P.Mandrou et al. (1996) and G.Lichti et al. (1996).

Imaging : The coded mask, together with the detector plane, define an angular resolution of about 2.5° within a fully coded field of view of 16 x 16. The partially coded field of view is 34°× 34° while the anticoincidence shield defines a hexagonal aperture of ~25° FWHM. The point source location is better than 2° and improves with source intensity and exposure time. An example of SPI's imaging capabilities is presented in the paper of A.Strong et al. (these proceedings). The calculations of SPI's imaging performance are performed at the University of Birmingham (UK) and at MPE Garching (Germany).

Scientific objectives : SPI will provide high-resolution spectroscopy with superior sensitivity and will cover a wealth of scientific objectives ranging from compact sources to hot-spots of long-lived radioisotopes, such as ^{26}Al, or to the extended emission of the narrow e^-e^+ line. Gamma-ray lines are the fingerprints of nuclear transitions, carrying the memory of high-energy processes in the Universe. Gamma-ray spectroscopy is thus a unique tool to identify the presence of excited nuclei, to quantitatively determine their abundances, and to provide insight into the physical conditions of the source regions (temperature, density, gravitational or cosmological energy shifts). The fine spectroscopy / coarse imaging concept of SPI is particularly appropriate for nuclear astrophysics since phenomena such as the diffusion of radioactive isotopes into the interstellar medium often lead to narrow lines emitted on a broad angular scale, whereas gamma-ray line emissions from violent compact objects are more likely to be spectrally broadened. SPI will also further increase our understanding of compact objects - galactic and extragalactic - for example through the observation of spectral features such as cyclotron lines.

ACKNOWLEDGMENTS The authors would like to thank the technical staff of their laboratories. They also are grateful for important support from their national space agencies, namely CNES, DLR, INTA, ASI, and NASA.

REFERENCES

N. Diallo et al., 1998, these proceedings

G. Lichti et al., 1996, SPIE proc, Vol. 2806, p.217 (ed. Ramsey B.D and Parnell T.A)

P. Mandrou et al., 1997, ESA Symp. Proc. The Transparent Univers, SP-382, 591

A. Strong et al., 1998, these proceedings