THE INTEGRAL SPECTROMETER SPI

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ABSTRACT

The International Gamma-Ray Astrophysics Laboratory (INTEGRAL) is conceived as the next logical step in γ -ray astronomy after the US Compton Gamma-Ray Observatory (CGRO) and the French/Russian SIGMA mission.

The INTEGRAL scientific payload consists of two main instruments (Imager and Spectrometer) and two monitor instruments (X-Ray Monitor and Optical Transient Camera). The INTEGRAL spectrometer (SPI) is optimized for detailed measurements of γ-ray lines and mapping of diffuse sources. It combines a coded aperture mask with an array of large-volume high-purity germanium detectors. The detectors make precise measurements of the γ -ray energies over the 20 keV - 8 MeV energy range.

This paper presents the instrument characteristics; these properties have been evaluated by means of Monte-Carlo calculations. With the characteristic features it will be possible to study γ -ray emission from compact objects or line profiles with a high-energy resolution and a very good angular resolution.

Keywords: γ-ray astronomy, γ-ray spectroscopy,
γ-ray telescope INTEGRAL.

1. INTRODUCTION

The importance of gamma-ray spectroscopy has already been demonstrated during the last decade thanks to very interesting γ-ray line detections obtained with:

balloons:

- SN 1987A, ^{56}Co radioactive decay lines (Matz et al. 1988 and Tueller et al. 1990), Galactic Center emission at 511 keV observed since 1970 (Johnson et al. 1972, Leventhal 1973).

satellites:

- OSO 7 - SMM:
  Solar γ -ray line (Chupp et al. 1973, Chupp 1990)
- HEAO-C - SMM:
  ^{26}Al and annihilation line from the central region of our galaxy (Mahoney et al. 1984, Share et al. 1985).
- CGRO:
  with OSSE:
  a) the first real 511 keV galactic distribution revealing different components (Kinzer et al. 1996).
  b) ^{57}Co decay lines in SN 1987A (Kurfess et al. 1992).

with COMPTEL :

a) first galactic map of ^{26}Al (Diehl et al. 1995)
b) another observation of SN radioactive element production: ^{56}Co lines from SN 1991T (Type Ia SN) (Morris et al. 1995)
c) ^{44}Ti observation from Cas A opening the field of young (few hundred years) SN remnant identifications in our Galaxy (Iyudin et al. 1994)
d) possible detection of C and O broad lines from the nearby molecular cloud ORION (Bloemen et al. 1994).

- SIGMA/GRANAT:

Broad and narrow features in γ-ray sources (galactic black-hole candidates) : 1E1740.7-2942 (Bouchet et al. 1991) and Nova Muscae (Goldwurm et al. 1992).

These different line detections were often at the limit of instrumental sensitivities. Therefore an improvement in fine spectroscopy with high-sensitivity instruments promises to provide adequate data for the study of following challenging astrophysical problems.

1.1. Gamma-ray lines from nucleosynthesis

a) Supernovae and Supernova remnants

The observation of SN 1987A clearly demonstrated that SN-models have to be revised, taking into account the early mixing of radioactive elements in the ejecta (e.g. the asymmetry of ^{56}Co ejection). This has led to extensive modifications in the models (Nomoto et al. 1988, Pinto & Woosley 1988, Bussard et al. 1989). But even with the most recent models the observed shape of the lines is not completely fitted (Tueller et al. 1990). The observation with INTEGRAL of SN explosions within a few 10 Mpc (Virgo Cluster, probably mostly of type Ia) would offer the opportunity to have more data on this exciting stage of the star life. The dynamic of the explosions is still to be studied and the models to be improved (for an overview see Hoffman et al. 1995, and Prantzos 1996).

Supernova remnants of galactic origin and not older than 200-300 years can be in principle detected with INTEGRAL by measuring the 1.157 MeV line from the ^{44}Ti decay, defining the recent rate of galactic SN explosion and connecting this information with a general description of the chemical evolution of our Galaxy. Already detected by COMPTEL from Cas A, ^{44}Ti is the most adapted tracer to achieve this goal. It is also very important for SN II models because its yield is a very sensitive function of the mass cut. For SN 1987A this line is expected to be at the limit of the SPI sensitivity (Timmes et al. 1996) but remains a prime objective.

b) ^{26}Al galactic distribution

Due to the long ^{26}Al half life (10^6 years), it is a good way to study recent galactic nucleosynthesis by tracing the galactic distribution of this element and identifying nearby hot spots through the emission of the 1.8 MeV. The galactic distribution of 1.809 MeV gamma-rays as determined by COMPTEL (Diehl et al. 1995, Oberlack et al. 1996) is interpretated to result from massive star nucleosynthesis as main source, from their supernovae or Wolf-Rayet winds ; this interpretation mainly is derived from the signature of spiral structure, and a general irregularity along the plane, with prominent emission regions far outside the inner Galaxy (Diehl et al. 1996, Knödlseder et al. 1996).

But even if SN Type II can explain the observed ^{26}Al γ-ray line fluxes, the COMPTEL distribution does not allow to exclude definitively the role of WR stars. As Wolf-Rayet stars are not expected to produce ^{60}Fe, while core-collapse supernovae co-produce ^{26}Al and ^{60}Fe in the same regions (Hoffman et al. 1995), a measurement of ^{60}Fe lines at 1.173 and 1.332 MeV from 1.809 MeV ^{26}Al source regions could disentangle those two ^{26}Al candidate source types. This detection seems possible with INTEGRAL even if the expected fluxes are a factor of 5 to 10 lower than the ^{26}Al γ-ray fluxes. Moreover with its better sensitivity and its higher energy resolution (positioning the ^{26}Al line at the level of a few tenth of keV depending of course on the intensity of the line) it might be possible to better identify the emitting foreground regions and the features connected to the galactic spiral structure.

c) Galactic annihilation line

The general features of the annihilation-line distribution along the galactic plane have been measured with OSSE (Kinzer et al. 1996) although this instrument has no imaging capabilities. Two components are identified: an extended one along the galactic plane mainly between -40° and +40° longitude; another one more concentrated in the galactic Center region : a sort of spherical bulge with an extension of 11° FWHM (Kinzer et al. 1996). This distribution is significantly different from that of ^{26}Al, which means that their origin cannot be completely identified. The ^{26}Al decay chain can only contribute for 15 % or less to the annihilation galactic distribution (the extended one) (Chan & Lingenfelter 1993). The emission concentrated in the bulge might be connected to nova (via ^{22}Na decay) or to Type Ia SN (via ^{56}Co or ^{44}Ti decay) but, in the most central part of the bulge, point sources such as 1E1740.7-2942 (Ramaty & Lingenfelter, 1994) may also contribute to the emission of the annihilation line. The sensitivity and imaging capability of the INTEGRAL spectrometer will allow a more precise determination of this annihilation-line distribution. A possible annihilation-line contribution from point sources such as 1E1740.7-2942 or Nova Muscae which clearly show a transient feature at 480 keV (signature of a possible redshifted annihilation line) will be better determined. Nevertheless after the observations of SIGMA (Malet et al. 1995) and OSSE the presence of a variable point source at the Galactic Center first suggested by HEAO-C observations seems to be unrealistic and not necessary to explain the observed emission. The imaging capability and sensitivity of IBIS and SPI can help to solve definitively this problem.

Concerning the extended galactic disc emission, Ramaty & Lingenfelter (1991) have shown that pulsars and cosmic-ray interactions are not significant components in the production of positrons. After COMPTEL results dominating sources of ^{26}Al appear to be core collapse supernovae. A fraction of the positrons produced in the ^{26}Al ejecta can leave the supernova remnants and, for 10^5 years, move in the interstellar medium before they finally annihilate. Nevertheless, a major difficulty to estimate this contribution is a realistic evaluation of the fraction of positrons which can escape from the SN remnant and reach the interstellar medium for annihilation. In fact, a more significant source of galactic positrons could be ^{44}Sc synthesized as ^{44}Ti in supernovae (Clayton 1973, Woosley & Pinto 1988, Signore & Vedrenne 1988). Even if the nucleosynthesis of ^{44}Ti remains uncertain, more recently Timmes et al. (1996) do not exclude the possibility that a significant fraction (if not most) of the smooth 511 keV emission comes from the annihilation of ^{44}Ti positrons (for a complete discussion on the positron sources from supernovae, see Chan & Lingenfelter 1993). A more accurate knowledge of this broad 511 keV distribution would help to approach its origin and to possibly connect it to the ^{26}Al extended distribution.

d) Novae : another site of nucleosynthesis

We have envisaged the role of novae in the production of positrons and the annihilation line in the galactic bulge via a possible ^{22}Na decay adding its contribution to Type Ia SN via ^{56}Co and ^{44}Ti decay. Early estimates of radioactive nuclei production (Clayton and Hoyle 1974) have been refined with more accurate nova models and nuclear networks (Hernanz et al., 1997): ^{22}Na appears today as the most interesting γ-ray line to look for at 1.275 MeV. A COMPTEL search for this gamma-ray line at the locations of recent novae was negative, with 2 sigma upper limits for neon-type novae in the Galactic disk of the order of 3 10^{-5} ph./(cm^2.s) (Iyudin et al. 1996). In particular, the two nearest novae observed both by COMPTEL and OSSE (Nova Her 1991 and Nova Cyg 1992) lead to 2 sigma upper limits of 3.3 and 2.3 x 10^{-5} ph/(cm^2.s), respectively, well below the predicted values. SPI on INTEGRAL will be able to decrease these limits significantly, and possibly achieve a positive detection. This will contribute to constrain the present nova models.

In addition, explosive hydrogen burning in novae can produce ^{7}Li. Hernanz et al. (1996) have computed the ^{7}Li production. In the decay of ^{7}Be to ^{7}Li a photon with an energy of 478 keV is emitted. For an ejected mass of 10^{-5} Solar Mass with an abundance by mass of X (^{7}Be) = 8 x 10^{-6} the ^{7}Be line would be detectable by SPI just after the outburst if the nova is closer than 500 pc. But the ejected mass might be higher by a factor of 10 or more (Hernanz et al. 1996).
From INTEGRAL we may learn if C-O novae are able to produce ^{7}Li, which is underproduced in the standard big-bang nucleosynthesis with respect to solar abundances by more than an order of magnitude.

1.2. Nuclear interaction lines

In addition to these important sources of nucleosynthesis lines, COMPTEL has shown that another field might be of high interest for γ-ray spectroscopy: the interaction of low-energy cosmic-rays with matter and gas in dense molecular clouds as e.g. the nearby molecular cloud complex of ORION (Bloemen et al. 1994).

This field of investigation no longer deals directly with the death of stars, even if strong shock waves in recent SN explosions can be the source of the accelerated ions needed to explain the high intensity of the observed lines around 4.4 and 6.1 MeV. COMPTEL observations of broad features support the idea of a deexcitation of ^{12}C and ^{16}O nuclei. The excitation of the accelerated elements might be due to collisions with the gas and dust of the molecular clouds.

Lot of work is in progress thanks to better statistics accumulated on this emission which surprisingly is not accompanied by emissions in the 1 - 3 MeV range nor by strong emission in the EGRET energy range above 100 MeV. Depending on the detailed mechanism of low-energy cosmic-ray production, one would however expect other excitation lines (from Mg and Ne) to result in emission in the 1-3 MeV band not seen by COMPTEL. This has been interpreted as being due to a peculiar composition of cosmic-ray seed nuclei (Ramaty et al. 1995). For associated work on this topic see also Cowsik & Friedlander 1995, Fields et al. 1996, Clayton et al. 1995.

INTEGRAL with SPI and IBIS can help to identify with a better sensitivity some active regions in such clouds, in order to find out if this broad emission cannot be the superposition of narrower lines which can constrain the conditions and the dynamics of the emission. The observed Orion emission has been interpreted as splitting of the C and O lines due to the anisotropy of the photon emission in the rest frame of the excited nuclei, which occurs even if the distribution of the fast emitting nuclei is isotropic (Bykov et al. 1996).

1.3. Lines from X and γ-ray sources

This field has just been evoked for the galactic distribution of the annihilation line because transient nova-type sources, such as Nova Muscae or 1E1740.7-2942, might contribute to such an emission.

The strength and transient character of the Nova Muscae redshifted annihilation line (not the only explanation for this line) demonstrates the need for increasing the sensitivity of instruments with respect to SIGMA. The goal of the INTEGRAL mission is to develop instruments with such better sensitivities and, with the two telescopes IBIS and SPI, this annihilation line can be investigated in great detail. It will be possible to find out whether this line is narrow, broad and blue or redshifted. Accretion in the presence of a magnetic field accompanied by the emission of two jets are realistic configurations found in the radio range by Mirabel et al. (1992) for 1E1740.7-2942, and are proposed to explain the blazar sources seen at high energy by EGRET (von Montigny et al. 1995). Such a geometry is favourable to explain broad emission lines at 511 keV connected to a high-temperature plasma of pairs, and also a narrow emission line through the interaction of the jet with the surrounding colder matter. Other effects such as Compton reflection have been introduced to obtain a better fit with the observed spectra. But here again these observations are often at the limit of the instrument sensitivities and are subject to controversy. INTEGRAL and its two main instruments could contribute to a clear confirmation of these observations.

Cyclotron absorption features are also of great interest due to their signature of strong magnetic fields (teragauss) around neutron stars in X-ray binary systems. One of the most recent observation comes from OSSE with the detection of a feature at 110 keV from A0535+26 (Grove et al. 1994). This observation has been interpreted as a cyclotron scattering in a near critical field of about 10^{13} Gauss (Araya & Harding 1996). SPI and IBIS with their improved sensitivity and their extended energy range towards the lower energy (10-20 keV) will be well adapted to identify all the harmonics of this kind of feature.

Finally the high sensitivity of SPI and IBIS above a few 10 keV will allow to observe the continuum of these different X and γ-ray sources and especially the binary compact sources containing a BH or a NS. The observation of these objects from a few keV with JEM X, to 10 MeV with SPI and IBIS, can help to understand, among other properties, what are the true criteria to choose between these two types of objects, when we do not know their mass function. In fact it will be for the first time that an observatory will cover such an energy range. SIGMA, CGRO, ASCA, XTE, SAX cover the low-energy range (below 500 keV).

2. GENERAL DESCRIPTION OF THE INSTRUMENT

The goal of the INTEGRAL spectrometer SPI is to image the sky in the 20 keV - 8 MeV energy range with an unprecedented energy resolution. To meet this objective, a detector with an energy resolution in the parts per thousand range with a sensitivity of the order of 2 to 5 10^{-6}ph/(cm^2.s) is needed. The detectors able to achieve the required energy resolution are cooled high-purity Ge crystals. These detectors have to be efficiently shielded to obtain the best possible sensitivity. The imaging will be achieved by a coded aperture mask designed to have at the same time a good angular resolution for point-source identification and a wide field-of-view for the mapping of extended regions.

The main performance parameters of the SPI spectrometer are summarized in Table 1.

Table 1

Energy range	20 keV - 8 MeV
Energy resolution	2 keV at 1 MeV (E/ΔE ≈ 500)
Angular resolution	point sources ≈ 2°
Field-of-view	≈ 16° Fully coded
Narrow line sensitivity	≈ 3. 10^{-6} ph/(cm^2.s) at 1 MeV
Timing	100 µs (absolute U.T.)
Detector area	500 cm^2

The spectrometer concept evolved all along phases A and B (Figure 1), and improvements were achieved thanks to an important effort of tests and simulations performed both by the scientific and technical teams.

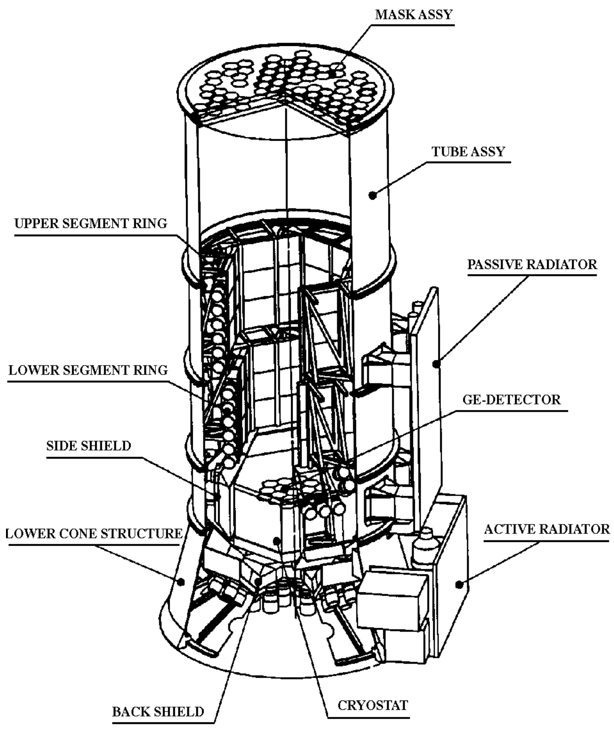

Figure 1 : Schematic view of the SPI telescope.

The central element of SPI is a detector array made of 19 independent large-volume Ge detectors, arranged in a hexagonal geometry. These detectors are placed into a cryostat and cooled down to ≈ 85 K by the association of passive and active cooling systems.

The detector array is surrounded by a massive BGO (Bismuth Germanate) anticoincidence shield optimized to minimize the background (Lichti et al., 1996). The field-of-view is modulated by a passive coded-aperture mask placed at 1.71 m from the top of the detector plane. The Pulse Shape Discrimination (PSD), a specific electronic system designed to increase the sensitivity in the 200 keV - 2 MeV range by a factor of ≈ 1.5 to 4.5, depending on the deposited energy of the particles (Slassi-Sennou et al., 1996), will be connected to the detectors.

Each subsystem of the SPI spectrometer is described in detail in the following chapters.

2.1. The Ge detector assembly

The Ge detector assembly consists of 19 reverse-electrode n-type Ge detectors, grown from natural Ge. The detectors have a hexagonal shape; they have a side length of 3.2 cm and a height of 7 cm. Each crystal has a central hole (6 mm in diameter, and 6 cm in length) and is individually mounted inside a Beryllium capsule pressurized to 0.3 atm. with a chemically pure passive gas.

The 19 encapsulated detectors are mounted, with a center-to-center distance of 6 cm, on a Be cold plate, connected to two pulse tubes through copper braids. The cold plate is placed inside a cryostat made of Russian Beryllium (Figure 2).

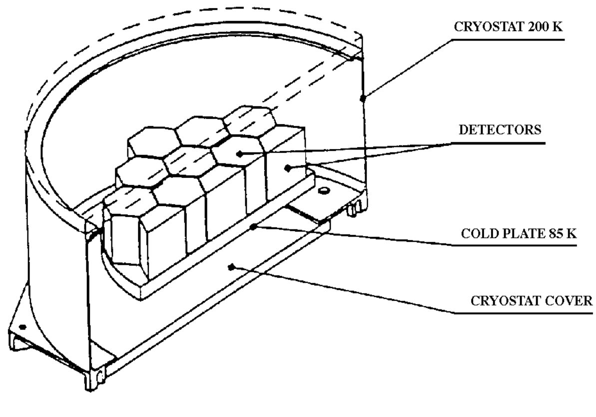

Figure 2: Cut view of the cryostat

This Beryllium, poor in radioactive residuals (< 5 ppm of Uranium) in order to reduce the background, will be also used for the capsules and the cold plate.

The cooling down of the Ge crystals to < 85 K is achieved by a two-fold cooling system:

- a passive radiator with ammonia-driven heat pipes cools the cryostat down to a temperature of ≈ 205 K
- two double compressors connected to the pulse tubes cool the cold plate to the required temperature of < 85 K.

Ge crystals are sensitive to radiation damages. Protons and neutrons from cosmic origin or induced by cosmic rays in the close environment of the detectors induce trapping centers in the crystals which decrease the energy resolution proportionally to the received radiation dose or crystal temperature. It is of first importance, to maintain the detector temperature as low as possible (< 85 K), to decrease the effects of radiation damage (see Koenen et al., 1995).

Nevertheless, crystals can be regenerated by an annealing process which consists of heating them to 373 K for 24 hours. The cold plate is thus equipped with heaters to be used periodically for the annealing process. The expected frequency of such a process is 6-12 months depending on the available orbit for INTEGRAL.

In order to minimize the background for the detector, all mechanical parts in its close environment (parts situated inside the BGO shield) are built with as low as possible Z-value materials. Because of this and despite the complexity and cost of Be metallurgy, this material is planned to be extensively used. All other necessary metals as Copper, Aluminium, Stainless-steel, etc… are reduced to their possible minimum, carbon fiber is favoured for mechanical structures inside the veto shield.

2.2. The Anticoincidence Subsystem

To protect the detector array against background radiation, and to define the needed field-of-view, a thick active anticoincidence shield surrounds the cryostat. It consists of a massive hexagonal container surrounding the Ge detector array, topped by two hexagonal collimator rings.

The BGO thickness has been optimized by means of Monte-Carlo simulations (see Georgii et al., 1996 and P. Jean et al., 1996) in order to minimize the detector background. Two components relating to the veto shield contribute to the detector background :

- the shield leakage which decreases when the BGO thickness increases.
- the secondary particles induced in the shield itself by nuclear interactions and producing delayed reactions in the Ge. This component increases with the BGO thickness.

The best compromise for these two components has been found between 4.5 and 6 cm (figure 3). A thickness of ≈ 5 cm has been chosen for the rear and side shields of the detector array. The collimator rings limit the field-of-view to ≈ 25° FWHM. Their thickness decreases with the distance to the Ge detectors but, taking into account the angles of the line of sight, the effective thickness as seen by the detectors remains constant at ≈ 6 cm. The distance between the detector plane and the top of the last ring is ≈ 1 m. In order to increase the shield efficiency it is planned to set the energy threshold detection at 50 keV for the container around the detector array. This seems to be achievable although the moderate light yield of BGO and the poor light-collection efficiency due to crystals geometry lead only to few photoelectrons at 50 keV. At this level of the study, the BGO shield is made of 90 independent crystal blocks each one being viewed by two photomultiplier tubes for redundancy.

Since the total counting rate of the anticoincidence shield is expected to be of the order of ≈ 65 000 events/s. at solar maximum and ≈ 130 000 events/s. at solar minimum, the veto signal duration for each event will be optimized to maintain the dead time value at a reasonable level (less than ≈ 8 %).

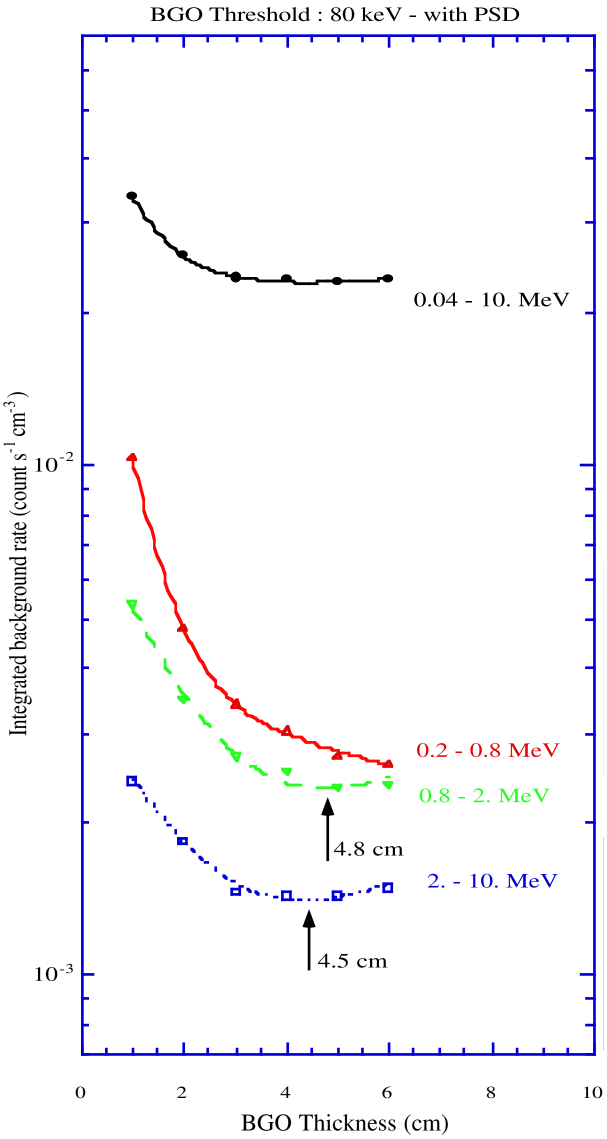

Figure 3: Optimization of background as function of the BGO thickness using simulation software.

2.3. The passive mask

The mask associated to the detector to provide the imaging capability of the spectrometer is a hexagonal array of 127 elements among which 63 are opaque, and 64 transparent. The pattern is from Hexagonal Uniformly Redundant Array (HURA) type. The opaque pixels, made of 3 cm-thick Tungsten blocks, are placed following a center-to-center distance of 6 cm (equal to that of Ge detectors blocks). They are supported by a honeycomb carbon-fiber sandwich structure, at a distance of 1.71 m from the detector plane. This light structure gives a transparency of the transparent elements of the order of ≈ 80 % at 20 keV, 90 % at 50 keV and better for higher energies, for on-axis photons. The transparency is important as the difference between opacity and transparency of mask elements at a given energy is directly connected to the contrast of the shadowgram projected by a source, and thus is an important parameter of the sensitivity.

This detector/mask arrangement results in a hexagonal field-of-view with the following characteristics :

- fully coded (maximum sensitivity)
  - ≈ 14° flat to flat
  - ≈ 16° on the long axis
- partially coded (decreasing sensitivity versus pitch angle)
  - ≈ 30° flat to flat (zero sensitivity)
  - ≈ 34° on the long axis (zero sensitivity)
- Angular resolution to point sources
  - ≈ 2° flat to flat axis
  - ≈ 2.7° on long axis

These values are adapted to the detection of diffuse emissions. As the needed exposure time to reach the best sensitivity is long, it is important to collect large sky area contribution within this time.

2.4. The Pulse Shape Discrimination

One important source of background in the detectors results from the β^+, β^- radioactive daughters induced by primary protons or secondary neutrons. The β^- contribution peaks in the 200 keV - 2 MeV range. The β^+ component is situated above 1 MeV. An electronic device able to recognize the β^-signals in the 19 detectors will be associated to SPI, increasing the sensitivity in the 200 keV - 2 MeV range by a factor of ≈ 1.5 to 4.5 (figure 4). By analyzing the shape of the pulse, this device is able to discriminate the single or multiple interactions in the Ge crystals. Single interactions correspond to photoelectric interactions or β^- emission; multiple interactions correspond to multiple Compton effect and thus are associated to a photon.

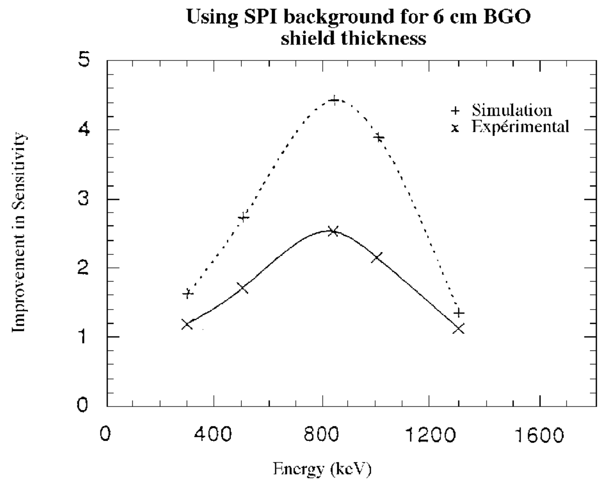

Figure 4: PSD efficiency in the 200 keV - 2 MeV range

Eliminating the single events decreases slightly the photon detection efficiency. But above 200 keV the Compton effect is predominant in Ge, thus the β^- elimination, of first importance for the background decrease in this range, favours the gain in sensitivity by an important factor.

3. INSTRUMENT PERFORMANCES

The prediction of the instrument performances results from both Monte-Carlo simulations and experimental measurements. Monte-Carlo simulations are useful to calculate the in-flight background and study the imaging aspects. Experimental measurements on the detector prototype are of great importance to check the validity of the technical concept.

3.1. The energy resolution

An engineering model of the detector has been built, and mechanically and electronically tested to check the validity of the concept. Measurements on the energy resolution have been performed using several nuclear γ-ray lines distributed in the energy range of the SPI instrument. The results of these measurements are shown in Figure 5. In Figure 6 we give an example of a spectrum obtained with this model for the capture (n, γ) reaction on Fe, where we can see the spectroscopy performance on some doublet lines.

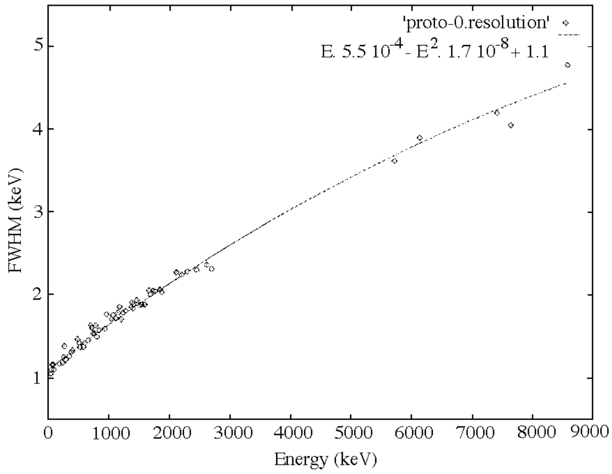

Figure 5: Detector energy resolution

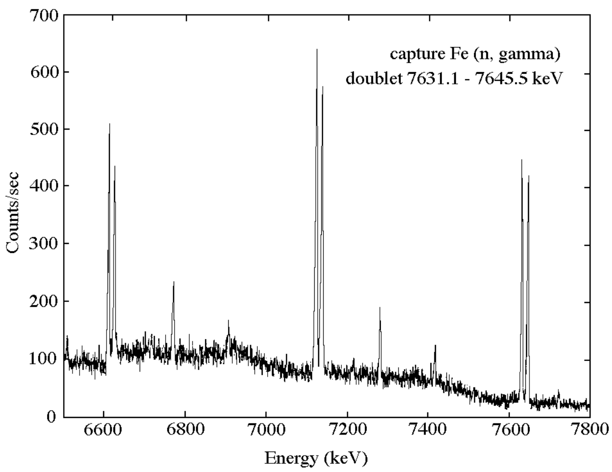

Figure 6: Example of spectrum obtained in the laboratory with the detector prototype

3.2. The sensitivity

The sensitivity is driven by several parameters: energy resolution, detector efficiency, effective area, etc… but the most important one is the background. The spectrometer will operate in an environment where high-energy charged particles from cosmic origin are dominant. The interaction of these particles with the telescope as well as with the masses of the spacecraft induces secondary radioactive nuclei increasing the primary background sources effects.
Thus, the background depends on the primary radiation, the position of masses around the telescope and materials surrounding the detectors.

In order to estimate the SPI background, a simulation software based on Monte-Carlo simulations using the GEANT code has been developed. In parallel, accelerator tests on materials being used have been performed to check the validity of some interaction cross-sections (Jean et al., 1996). The model built for these simulations is representative of the geometry and masses.

The software follows the primary particles in their interactions, as well as their produced daughters up to their detection in the Ge crystals. The work of the PSD subsystem is also simulated to obtain the true response of the instrument.

This software provided us with the estimated background on the expected orbit. The validity of the result has been checked by applying the simulation model to previous experiments and comparing the result to the measured background.

In Figure 7 the expected SPI 3σ sensitivity for an observation time of 10^6 s. to astrophysical narrow lines is shown, and in Figure 8 for continuum emission of celestial sources.

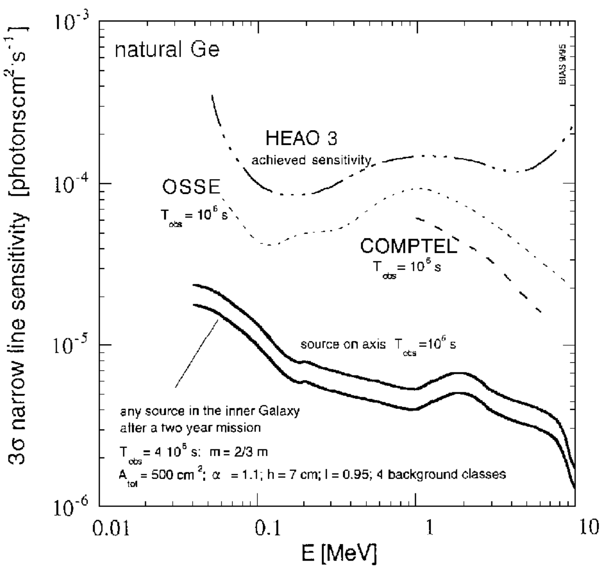

Figure 7: SPI sensitivity for astrophysical narrow lines

The sensitivity in the 511 keV line is specific and calculated independently. The background intensity in the 511 keV line results from four components :

- continuum-background component deduced from the previous calculations,
- passive-material component mainly due to β^+ radioactivity induced in materials surrounding the detectors which correspond to an emission of one 511 keV photon detected by the Ge and the second photon is either absorbed in the passive material or goes through the shield without triggering it.
- shield-leakage component where 511 keV photons produced in the spacecraft have a probability to interact in the Ge detectors without detection by the anticoincidence subsystem.
- mask component, due to e^+ produced by cosmic rays and high-energy photons in the Tungsten.

Taking into account these components, the 3σ sensitivity in the 511 keV line for 10^6 s. exposure time has been estimated to be : (1 to 2) 10^{-5} ph/(cm^2 s.).

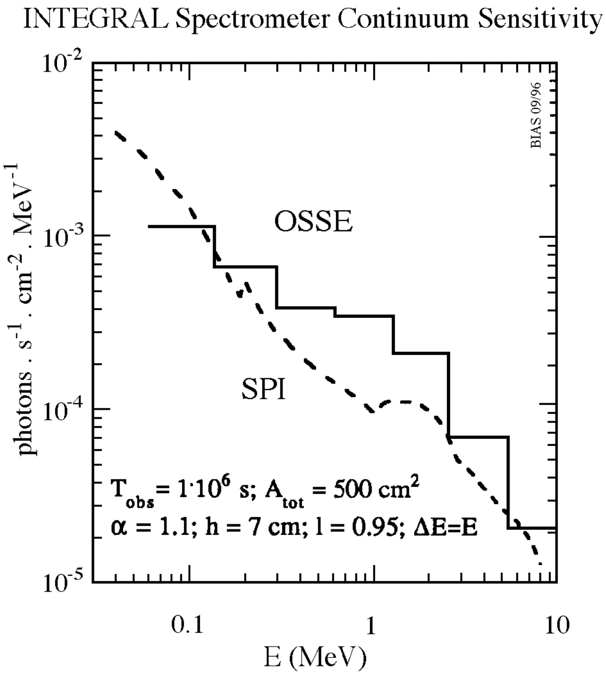

Figure 8: SPI sensitivity for continuum

3.3. Imaging quality improvement

The imaging performance depends on the contrast between illuminated and shadowed detector cells. These counting-rate differences are used to derive the location and intensity of the γ-ray sources in the field-of-view of the telescope. The problem of the SPI telescope is the small number of cells (19) available to derive the emission characteristics of all pixels in the field-of-view (≈ 156), especially if the possible variation of the background of the 19 independent detectors is considered.

The solution to this problem, the so-called dithering concept, consists in changing the orientation of the telescope within the field-of-view to vary the figure of the illuminated and shadowed detector cells when observing a sky region (Covault et al., 1991; Willmore et al., 1992, Skinner and Ponman, 1994).
Thus the telescope axis will be re-pointed following a regular grid of points separated by the angular resolution, located around the direction of sky to be observed. Each observation will last typically 20 or 30 minutes depending on the background behaviour.

Simulations performed to check the performances of the dithering technique show a clear increase in the image quality on the observation of both point sources and extended regions of emission of the sky.

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