GROUND CALIBRATIONS OF THE MEDIUM ENERGY EXPERIMENT ON BOARD THE X-RAY ASTRONOMY SATELLITE SAX

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Abstract. The scientific instrumentation on board SAX (cfr. Piro et al. *these proceedings*) includes a Medium Energy Concentrator / Spectrometer (MECS), operating in the 1.3-10 keV energy range, which consists of three identical instruments, composed by a grazing incidence Mirror Unit with a focal length of 185 cm and by a position sensitive Gas Scintillation Proportional Counter. We give a brief description of the ground calibrations of the MECS, performed at the X-ray PANTER facility, and of their analysis. A more presentation can be found in Boella et al. (1995).

1. Introduction

The main objectives of the Medium Energy Concentrator / Spectrometer (MECS) on board SAX are: 1) broad band spectroscopy in the range 1.3-10 keV with a resolution of $E / \Delta E = 0.08 \times (E/6)^{-0.5}$, where E is in keV and ΔE is the FWHM; 2) imaging with angular resolution at the arcmin level; 3) study of time variability on time scales down to the millisecond. To reach the desired sensitivity levels with the allowed dimensions of the satellite, the MECS consists of three identical instruments, each composed by a Mirror Unit (MU) with a Xenon filled position sensitive Gas Scintillation Proportional Counter. In these proceedings we present a brief description of the ground calibrations of the MECS, performed at the X-ray PANTER facility (section 2), and of their analysis (sections 3,4,5,6).

2. The Ground Calibrations

The three flight MECS instruments, together with the LECS flight unit (Parmar et al., *these proceedings*) have been extensively calibrated at the 130 meter long X-ray PANTER facility of the Max-Planck-Institut für Extraterrestriche Physik in Munich, during a period of 7 weeks in October-November 1994. The limited size of PANTER beam did not allow a simultaneous calibration of all units, therefore two MECS instruments, hereafter named ME2 and ME3, were calibrated together during a first run and a third MECS unit, hereafter ME1, and the LECS were calibrated during a second run. The measurements were made at: 0.92 keV (Cu-Lα), 1.25 keV (Mg-Kα), 1.48 keV (Al-Lα), 1.74 keV (Si-Kα), 2.02 keV (P-Kα), 3.12 keV (Ag-Lα), 4.52 keV (Ti-Kα), 5.44 keV (Cr-Kα), 6.44 keV (Fe-Kα), 7.52 keV (Ni-Kα) and 8.1 keV (Cu-Kα). For each energy three main kind of measures were performed: 1) MUs (on-axis and off-axis); 2) flat fields of the detector units alone; 3) multipinhole scans of the detector units alone. The statistical quality of the data is very high, (e.g. typical MU acquisition runs contain about half a million events).

3. Spatial Gain Dependency

A dependency of the gain on the position is present in all three detectors and can be calibrated by analysing individual spectra of each spot of the multipinhole measurements. The core of each line has been fitted with a gaussian, and the peak position in channels has been associated to the spot position in pixels, obtaining a set of sparse values $G_i = G(x_i, y_i)$. For each run a gain map has been derived with a biquadratic interpolation of the above values. The values have then been normalized to the gain at the detector center, obtaining a relative gain map $g(x, y) = G(x, y)/G(x_0, y_0)$. We have found that the relative gain is extremely stable with energy, as well as unaffected by temporal variations of the absolute gain, therefore we have averaged the gain maps of all runs at all energies to produce a single high accuracy gain map per detector. The range of the relative gain (assuming 1.00 at the detector center) is 0.9-1.1 for ME1, 0.99-1.06 for ME2 and 0.96-1.03 for ME3. The rms error on the relative gain is extremely small, $< 0.2\%$ over almost all the field of view.

4. Absolute Gain and Spectral Calibration

The absolute gain was monitored continuously using the built-in Fe^{55} calibration sources. For the spectral calibration analysis we used data from the on-axis MUs runs, in order to minimize any dependence of the detector gain

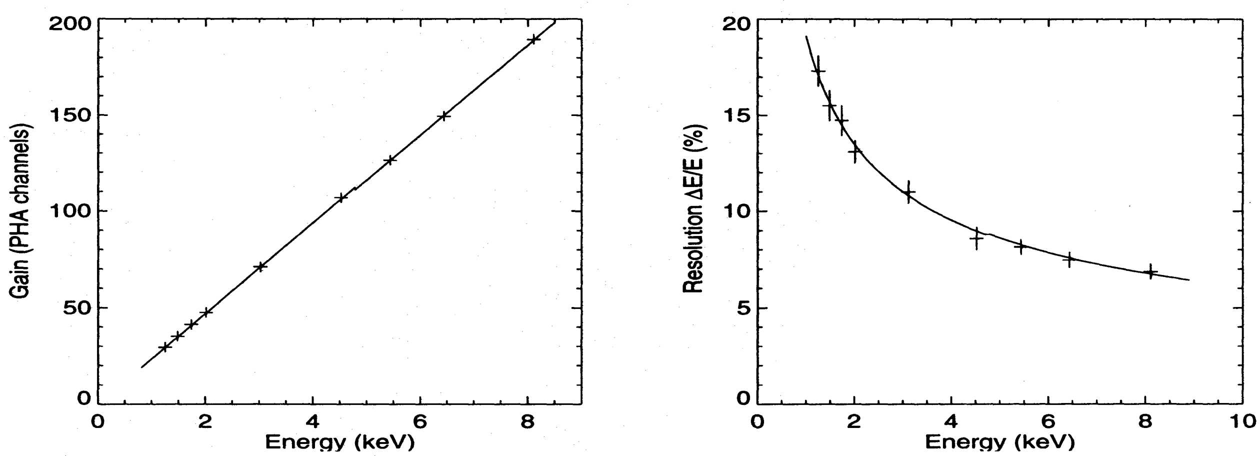

Fig. 1. a) and b): gain vs. energy relationship and spectral resolution vs. energy relationship for the ME3 unit.

from the position. The calibration lines were generally fitted using a single gaussian curve, although in some cases (e.g. the Titanium line) the presence of a secondary peak required a more complex model. From the results of this analysis, compensating for the time variations of the gain by using the built-in Fe^{55} sources, we calibrated the gain versus energy relationship (fig. 1a) and the spectral resolution versus energy relationship (fig. 1b).

5. Effective Areas

For this analysis we have used the MU and flatfield measurements, we have also corrected for the instrumental background by using background measurements. For each energy we have considered events from the entire detector, except those falling around two small areas were the calibration sources are located. In figure 2 we show the comparison between the theoretical behaviour, as derived from ray tracing simulations of a point source located at the same distance as the PANTER X-ray source, and the data for the ME1 unit. As can be seen the experimental points are in excellent agreement with the model, the largest deviations being of $\simeq 2\%$.

6. Spatial Calibration

The preliminary analysis of the MECS PSF which we have performed has been restricted in 3 ways: 1) by considering only the on-axis PSF; 2) by assuming only a radial dependence of the PSF; We have used a model for the PSF which is the sum of 2 components: a gaussian, $G(r) = c_g \exp(-r^2/2\sigma^2)$, and a generalized lorenzian, $L(r) = c_l[1 + (r/r_l)^2]^{-m}$, where r is the distance from the peak of the emission and c_g, c_l, σ, r_l and m are the parameters of the model which have been derived by fitting the radial profiles accumulated from the calibration data at the energies of: Mg, Al, Si, P, Ag, Ti, Cr, Fe and Cu. By imposing that the integral of the PSF over the entire plane be equal to unity, we have reduced the number of independent parameters to 4: σ, r_l, m and R, where $R = c_g/c_l$. The dependency of these 4 parameters on the energy has been reproduced through simple algebraic functions. The complete analytical expression for the PSF reads:

$$PSF(r,E) = \frac{1}{2\pi\left[R(E)\sigma^2(E) + \frac{r_l^2(E)}{2(m(E)-1)}\right]} \times \left\{ R(E)\exp\left(-\frac{r^2}{2\sigma^2(E)}\right) + \left[1 + \left(\frac{r}{r_l(E)}\right)^2\right]^{-m(E)} \right\}$$

where $R(E)$, $\sigma(E)$, $r_l(E)$ and $m(E)$ are algebraic functions of E.

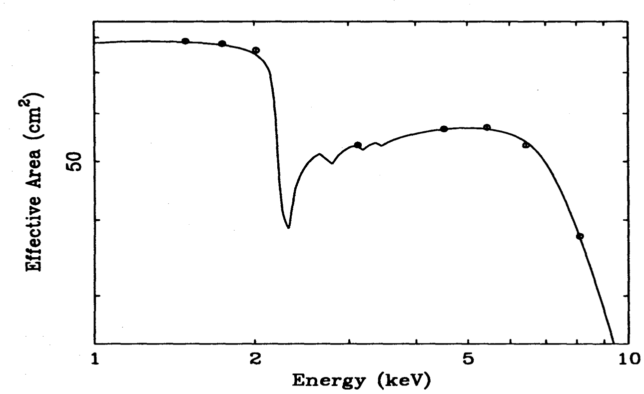

Fig. 2. On Axis Effective Area for the ME1: Panter Measurements vs. Ray-Tracing Simulation.

References

Boella et. al in *Proceedings of the SPIE Conference on X-ray and EUV/FUV Spectroscopy and Polarimetry held in San Diego 11-12/9/95.*

Parmar et. al *these proceedings.*

Piro et. al *these proceedings.*

The Low-energy Concentrator Spectrometer Onboard the SAX X-ray Astronomy Satellite

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Abstract. The payload of the Italian/Dutch satellite SAX includes a set of four X-ray concentrators each of geometric area 120 cm^2 together with imaging gas scintillation proportional counter detectors located at the focal planes. One of these detectors is sensitive to X-rays in the energy range 0.1–10 keV, while the other three cover the narrower energy range of 1.3–10 keV. In order to achieve this extended low-energy response, a new design of gas scintillation proportional counter has been developed.

1. Introduction

SAX is an Italian/Dutch spacecraft that will be launched into low-Earth orbit by an Atlas G-Centaur in Spring 1996. The nominal orbit is circular at a height of 600 km with an inclination of < 3 degrees to the equator in order to take maximum advantage of the shielding of the Earth's magnetic field. During the expected lifetime of up to 4 years, SAX will make 2000–3000 observations of cosmic X-ray sources over the extremely wide energy range of 0.1 – 300 keV. Descriptions of the mission are to be found in Spada (1983), Butler & Scarsi (1990) and Scarsi (1993). The scientific objectives of the mission include broad band spectroscopy ($E/\Delta E \sim 12$) in the energy range 0.1–1.0 keV with imaging resolution of $1'$, non-imaging spectroscopy ($E/\Delta E \sim 5 - 20$) in the energy range 3–300 keV and variability studies of X-ray source intensities and spectra on timescales from milliseconds to months. Mission operations will be conducted from Rome and are designed to allow a flexible response to any targets of opportunity.

The SAX payload consists of a high pressure gas scintillation proportional counter (GSPC), a Phoswich detector system, two wide field cameras (WFCs) and four imaging GSPCs. The instruments have been developed by a consortium of Italian and Dutch scientific institutes and by the Space Science Department of ESA (SSD). All the instruments are coaligned except for the WFCs which point in opposite directions along an axis perpendicular to the other instruments. Each imaging GSPC is located at the focal plane of an X-ray concentrator.

In order to extend the sensitive range of the imaging spectrometers to below 1 keV, one of the GSPCs is a new design of driftless GSPC with an ultra-thin entrance window. This instrument, the LECS, was developed by SSD and is described here. The main objective of the LECS is to provide better low-energy energy resolution then currently available non-dispersive detectors and so open up new areas of astrophysical interest.

2. The SAX LECS

2.1. Rationale

The mid-1990's have proved to be an exciting time for X-ray astronomy with the launches of of a number of new missions. The ASCA payload consists of both imaging CCD and GSPC detectors (Tanaka et al. 1994). The ASCA CCD detectors provide an energy resolution of 100–150 eV over a ~ 0.5–10 keV energy range and the GSPCs provide 8% resolution at 6 keV in the energy range 1.0-10.0 keV. XTE concentrates on timing studies in the 2–200 keV energy range. While CCD development is still proceeding at a rapid pace it is worth comparing their properties with those of GSPCs:

- The resolution of a typical GSPC detector at iron K of 500 eV is about a factor 4 worse than a CCD. However, since it scales as $E^{1/2}$ it becomes comparable to that of a CCD at $\lesssim 0.5$ keV.
- GSPC detectors provide extremely good time resolution of up to a few microseconds. This should be compared with a typical time of 2s needed to read out a typical CCD.
- In X-ray astronomy CCD detectors are used in photon counting mode which can place severe constraints on the maximum source strengths allowed.

2.2. The mirror system

Each SAX mirror unit consists of 30 nested coaxial and confocal mirrors with a double cone approximation to Wolter I geometry (Citterio et al. 1985). The geometric area is 120 cm^2 and the mirror diameters range from 16.2 to 6.8 cm. The shell thicknesses range from 0.4 to 0.2 mm and the nominal focal length is 185 cm. The total length of each mirror shell is 30 cm. The mirrors were produced using a replication technique by nickel electroforming from super-polished mandrels.

Table 1. The LECS Performance

Parameter	Value
Energy Range	0.1–10.0 keV
Energy Resolution at 6 keV	8% FWHM
Angular Resolution at 6 keV	1.6′ FWHM
Effective Area at 6 keV	50 cm^2
Field of view	40′ (circular)
Time Resolution	16μs
Maximum Throughput	2000 events s^{-1}

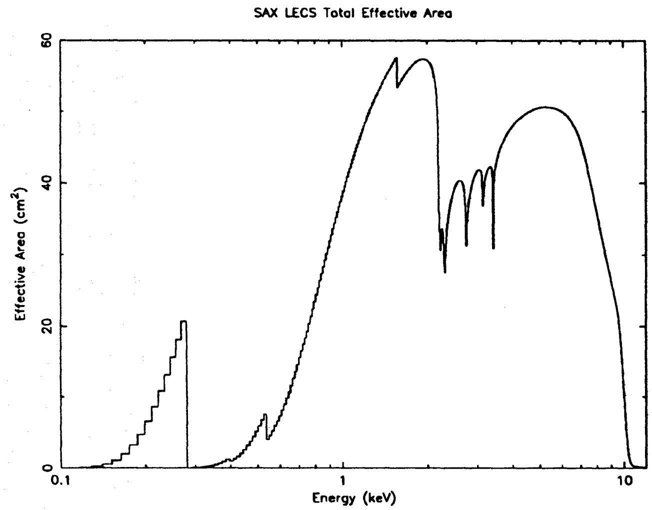

Fig. 1. The effective collecting area of the LECS versus energy

2.3. The Detector system

The LECS consists of Detector, Gas and Electronics Units (see e.g. Martin et al. 1995). The overall performance of the instrument is summarized in Table 1 and the effective area illustrated in Figure 1. The Detector Unit consists of the gas cell, an imaging photomultiplier tube, high-voltage power supplies and associated electronics. The detector is protected against space plasma ingress by a protection window. Two ^{55}Fe radioactive sources illuminate regions of the detector that do not see the sky, allowing the position and energy gains to be continuously monitored. The gas cell has an ultra-thin multilayer entrance window with a cross-section consisting of 1.25μ of Polyimide sandwiched between layers of Al and AlN. To support a differential pressure of over 1 bar, the window is supported by a fine grid structure and a strongback. The Gas Unit is used to replenish gas lost by diffusion through the entrance window. The Electronics Unit controls the operation of the other units, conditions and processes the incoming X-ray events and passes them to the spacecraft data bus for transmission to Earth.

A conventional GSPC consists of separate drift and scintillation regions. X-rays are photo-absorbed in the low-field drift region and then produce light in the high-field scintillation region. This ensures that the distance through which a detected X-ray causes scintillation, is independent of its absorption depth. Unfortunately, a significant fraction of X-rays which are absorbed at low depths in the gas cell are lost to the entrance window resulting in a degraded signal, especially at low-energies (Inoue et al. 1979). In the LECS the drift region has been dispensed with, allowing X-rays to convert directly in the scintillation region. This minimizes the above losses resulting in a better overall performance. The Gaussian line profile observed at C (0.28 keV) illustrates how well the instrument works at low-energies since loss of electrons to the window would give a "tail" towards low-energies, which is not seen (Fig 2.) This figure also shows the effects of penetration at higher energies (Cu_K at 9.0 keV), where a substantial "tail" towards lower energies is visible. This is due to X-rays that penetrate deeply into the gas cell before being photo-absorbed. The effect can be corrected for by combining a measure of the duration of scintillation with the observed energy for each event.

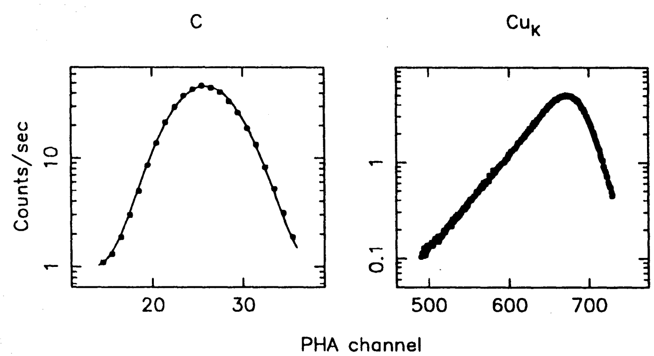

Fig. 2. The response of the LECS to monochromatic radiation at 0.28 keV (left panel) and 9.0 keV (right panel).

References

Butler R.C., & Scarsi L. 1990, SPIE, 1344, 46

Citterio O., Conti G., Mattaini E., Sacco B., & Santambrogio E. 1985, SPIE, 597, 102

Inoue H., Koyama K., Matsuoka M., Ohashi T., & Tanaka Y., Nucl. Instr. & Meth., A, 157, 295.

Martin D.D.E., Bavdaz M., Peacock A., Vacanti G., & Parmar A.N. 1995, SPIE, submitted

Parmar A.N., Smith A., & Bavdaz M. 1990, In Observatories in Earth Orbit and Beyond. Kluwar. p457

Scarsi L. 1993, A&AS, 97, 371

Spada G.F.L. 1983, In Proceedings of the Workshop on Non-thermal and Very High Temperature Phenomena in X-ray Astronomy, Rome, p217.

Tanaka Y., Inoue H., & Holt S.S. 1994, PASJ, 46, L37