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counter (LE-GSPC)
calibration and system performance**

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The SAX low energy gas scintillation proportional counter (LE-GSPC) calibration and system performance

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ABSTRACT

The Low Energy Gas Scintillation Proportional Counter (LE-GSPC) is an imaging X-ray spectrometer. It is one of the narrow field instruments onboard the SAX satellite and covers the lower energy range from 0.1 to 10 keV. The low energy response of the detector is achieved by using a driftless gas cell and a thin multilayer polyimide foil as entrance window.

The overall design of the imaging GSPC for space application, will be described. Using unit level and system level calibration data, acquired at a synchrotron and a long beam X-ray source, the capabilities both in terms of energy and position resolution will be discussed. The overall efficiency of the instrument which includes the mirror's effective area, the entrance windows' transparencies, the detector's efficiency and electronics deadtime will be reviewed. Background rejection issues and the experiment's consequent sensitivity to the measurement of cosmic X-ray source spectra will be addressed.

Keywords: low energy, X-ray, imaging, GSPC, detector, astronomy

1 INTRODUCTION

SAX is an Italian/Dutch spacecraft that will be launched into low-Earth orbit by an Atlas G-Centaur in early 1996. During the expected lifetime of up to 4 years, SAX will be capable of making observations of cosmic X-ray sources over an extremely wide energy range of 0.1 – 200 keV. Descriptions of the mission are to be found in Spada,¹ Butler & Scarsi,² Piro,³ and Scarsi⁴ and only brief details of the mission are presented here.

The payload consists of a high pressure gas scintillation proportional counter (GSPC), a Phoswich detector system, two wide field cameras (WFCs) and four imaging GSPCs. 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. Each concentrator consists of 30 nested grazing incidence mirrors giving a double cone approximation to Wolter I. Each mirror module has a 185 cm focal length and 120 cm² geometric area. A detailed description of these modules can be found in Conti⁵ while the energy dependence of the effective area is shown in Figure 2. In order to extend the sensitive range of the imaging spectrometers to below 1 keV, one of the GSPCs, the LE-GSPC, is a new design of driftless gas scintillator

Instrument	Number of units	Energy range (keV)	Field of view (degree)	Effective area (cm ²)	Energy resolution
MECS	3	1.0 – 10.0	1.0	200 at 7 keV	8% at 7 keV
HPGSPC	1	3 – 120	1.0	300 at 6 keV 280 at 60 keV	10% at 6 keV 3% at 60 keV
PDS	1	15 – 200	1.5	680 at 20 keV 140 at 200 keV	17% at 60 keV
WFC	2	2 – 30	20x20	500 at 6 keV	20% at 6 keV

Table 1: SAX Instruments

with an ultra-thin entrance window. This instrument was developed by the Space Science Department of the European Space Agency (ESA). A small summary of the other SAX instruments is given in Table 1, each of them are described in more detail by Piro,³ Chiappetti,⁶ Giarrusso,⁷ Frontera,⁸ Jager⁹ and Mels.¹⁰

The main objective of the LE-GSPC is to extend the SAX response well below 1 keV and, particularly below 500 eV, provide a somewhat improved energy resolution than that currently available from other non-dispersive detectors such as CCDs. This characteristic will open up new areas of astrophysical interest. The general performance characteristics of the LE-GSPC are given in Table 2 while the total collecting area, including the mirrors is shown in Figure 3. Note the energy and angular resolutions are quoted for 6 keV photons and scale with energy as $E^{-1/2}$. In this detector the drift region has been dispensed with, allowing X-rays to convert directly in the scintillation region. Previous designs of GSPCs suffered from poor energy resolution at low energies since significant numbers of electrons, created in the photoabsorption process, are lost to the entrance window rather than being available for the production of scintillation light. This new design minimizes such losses resulting in a better overall performance. The improvement is most marked at energies lower than 0.5 keV where the energy resolution is better than that of current CCD devices. The LE-GSPC consists of Detector, Gas and Electronics Units and a schematic diagram is given in Figure 1.

Figure 1: LE-GSPC instrument schematic

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'
Time Resolution	16 μ s
Maximum Throughput	2000 events s ⁻¹
Background Rejection	98%

Table 2: The LE-GSPC Performance

Figure 2: Concentrators' theoretical effective area, from 0.1 to 10 keV.

Figure 3: Effective collecting area of the instrument, including mirrors

2 INSTRUMENT DESCRIPTION

2.1 Detector unit

The method of operation of the detector is similar to that of a conventional GSPC, see Davelaar,^{11,12} Inoue.¹³ An X-ray which is absorbed in the detector cell gas liberates a cloud of electrons. A uniform electric field produced between the window kept at -20 kV and a grounded grid causes scintillation of the xenon gas as the electrons travel towards this grid. The UV light from these scintillations is detected by a photo-multiplier tube (PMT) mounted at the rear of the cell. The amount of light produced is proportional to the energy of the incident X-ray but, unlike a conventional GSPC, also depends on the depth at which the X-ray photon was absorbed. This depth is determined by measuring the duration of the scintillation light and is referred to as the “burstlength”. An X-ray absorbed directly below the entrance window will have a long burstlength whereas one absorbed deeper into the cell will have a shorter burstlength. The negative potential on the window coupled to the high electric field ensure that electrons created by low energy X-rays absorbed close to the window effectively enter into the scintillation process.

The detector unit consists of the scintillation gas cell, a PMT, front-end electronics and two high-voltage supplies. The detector top is protected by an aluminium cap (top cover) on which a shutter mechanism is

mounted which will be opened once in orbit. The front chamber is protected against space plasma ingress by a plasma protection window located just beneath the shutter and meander like venting filters. The window has a multilayer construction similar to, but even thinner than that of the entrance window and a hexagonal polyimide support grid. The top cover also has a thin beryllium disk mounted on its interior upper surface to avoid additional X-ray background induced by electron emission from the detector top plate. The detector also contains two ^{55}Fe radioactive sources which constantly illuminate regions of the detector that do not see the sky allowing the position and energy gains to be continuously monitored. These sources provide Mn K- α and K- β X-rays (about 5.9 and 6.5 keV respectively) at a rate of 20 counts/s in October 1994 with a half-life of 2.7 years.

The gas cell is a 114 mm diameter ceramic cylinder of depth 50 mm with a metallic top disk and lower flange. The exit quartz window is in close proximity with the PMT. A titanium support for the entrance window and calibration sources is mounted on the top disk. The cell is filled with very pure Xe at a nominal pressure of 1.1 bar. A passive getter continuously absorbs gas impurities. It can be activated by a current source, once it has reached saturation. The gas cell has, as a key feature, a very thin multi-layer entrance window, the structure of which is shown in Figure 4. The aluminium/aluminium-nitride layers act as gas permeation barriers while the polyimide provides the mechanical support. The strength to support a differential pressure of over 1 bar, is provided by a fine grid structure and a strongback, both made of tungsten, as shown in Figure 5.

Figure 4: Detector entrance window cross section

Figure 5: Entrance window support grid and strongback structure

The high voltage (HV) power supplies provide power to the scintillation cell and to the PMT. The cell voltage is commandable in 31 steps between -12 kV and -20 kV. That of the PMT is programmable between 0.8 and 1.5 kV in 255 steps. The power supplies are based on a flyback converter followed by an 8 stage Cockcroft-Walton multiplier. The output voltages are then filtered by a triple resistive-capacitive network to produce less than 0.1% (peak to peak) ripple.

The PMT is a ruggedized Hamamatsu R5218 tube with a 2.8 mm thick quartz entrance window of 76 mm diameter contained in a mu-metal housing to shield it from external magnetic fields. Nine anodes, each $13 \times 13 \text{ mm}^2$ are positioned in a 3×3 square configuration with a separation of 1 mm. The anodes, each read out separately, are operated as an Anger camera to provide spatial information, see Anger,¹⁴ Hoan.¹⁵ The cathode is a special bi-alkali with a spectral response from 160 to 600 nm. The amplification is provided by 15 proximity mesh dynodes.

Within the Front-End Electronics (FEE), each of the nine PMT anodes are fed to separate charge-sensitive amplifiers with a $60 \mu\text{s}$ time constant. The amplified signals are then combined to provide the Energy (S_a), position X (S_x) and Y (S_y) and Veto (S_v) signals. Defining A_i to be the output of the i^{th} anode's pre-amplifier, gives:

$$S_a = A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7 + A_8 + A_9 \quad (1)$$

$$S_x = A_1 + A_4 + A_7 - A_3 - A_6 - A_9 + 0.5S_a \quad (2)$$

$$S_y = A_1 + A_2 + A_3 - A_7 - A_8 - A_9 + 0.5S_a \quad (3)$$

$$S_v = A_5 \quad (4)$$

As their names suggest, S_x and S_y provide position information while S_a is used for amplitude measurement, and provides event energy information. The Veto signal, S_v , provides a measure of the light distribution in the detector and is used to distinguish particle events (which typically appear extended) from true X-ray events which are more point-like. The four signals are buffered and passed to the Electronics Unit for further processing.

The DU also includes a pressure transducer for monitoring the cell pressure, a thermistor to monitor the PMT temperature, two micro-switches to determine the open or closed position of the shutter mechanism and analog monitors of the two HV outputs.

2.2 Electronics unit

The electronics unit (EU) provides the electrical interface between the instrument and the spacecraft. The 8 kg box, located about 1 meter from the DU-GU assembly, contains 13 printed circuit boards connected by a bus. To perform its multiple tasks, the unit contains 2 micro-processors. One is dedicated to the communications with the spacecraft, using the European Space Agency's (ESA) standard On Board Data Handling (OBDDH) protocol. Communication between the two processors is via a dual port RAM. The main processor, a radiation-tolerant 80C86, runs with 64 kBytes of data RAM and 32 kBytes of program memory (PROM). An additional 32 kBytes of RAM are available for future software patches.

The EU performs many functions. The analog signals provided by the FEE all pass through optimized pulse shapers with $5.6 \mu\text{s}$ time constant. These also include a pole-zero cancellation of the FEE's $60 \mu\text{s}$ time constant. Additionally, the amplitude signal is fed through a $1.5 \mu\text{s}$ pulse shaper for the pulse length determination. The output of the filters are sampled at their peaks. The position, veto and pulse length signals are then normalized by the amplitude signal. At this stage, qualification of the signals occurs, based on programmable amplitude windows. In case of a qualified event, all the signals are converted to digital values by means of Wilkinson type converters, providing excellent integral and differential linearity. The measured differential non-linearity of the Energy channel is less than 3.5% of a Least-Significant-Bit. The amplitude channel is converted to a 10 bits value, all other channels are 8 bits. Between the moment the unit detects an event and its conversion, the acquisition chain is blocked to prevent new pulses from distorting the measurement in progress. The time the input board is inhibited for new events is accumulated in a "deadtime" counter. Whenever a non-qualified event is detected, the analog-to-digital conversion process is aborted in order to reduce the dead-time to a minimum. Since the converters are Wilkinson types, i.e. integrating, the deadtime for each event depends upon its amplitude and is in the range $64 \mu\text{s}$, for a non-qualified event, to $250 \mu\text{s}$ for a full-scale event.

In addition, the unit is responsible for house-keeping and science data collection, processing, packetization and transmission to the spacecraft data handling system for re-transmission to the ground. Both processors are involved in the reception, processing and distribution of both ground and on-board generated commands within the instrument. Finally, active instrument protection is achieved by supervising temperatures, pressures, currents and event rates.

The on-board software is written in "C" and assembler language, for the time critical tasks. The system runs under the control of a real-time operating system (RTMS), which schedules the tasks for instrument monitoring, command processing, command execution, instrument protection, data processing and packetization. Event processing and telemetry transmission are interrupt triggered. Whenever an event is detected, i.e. has an energy larger than a programmable trigger level, the analog electronics process the different signals and convert Energy, Position, Veto and Burst Length to digital values as described above. An on-board counter, synchronized to the spacecraft's ultra-stable clock, time-tags the event with 16 μ s resolution. The complete data set is then retrieved by the main processor and packetized for transmission to ground, this constitutes the "direct science" mode. Additionally, the data can be processed on-board, for instance, two so-called "indirect science modes" are available which can accumulate images and spectra in parallel to the standard "direct" mode.

2.3 Gas unit

The original specification on the detector entrance window's leak-rate was sufficiently high to require a gas filling system. As mentioned earlier, the final design is virtually leak tight and the gas unit will only be used for renewing the cell gas that becomes contaminated due to exposure to air.

Although the gas unit can operate autonomously by actively controlling the gas cell pressure, keeping it at a programmable value (between 800 and 1200 mbar) with a hysteresis of 50 mbar, it is disabled under normal operations since the measured cell leak rate is less than 10^{-6} mbar $\cdot$ l/s. The unit can also be used to vent the gas cell completely and refill it. It consists of two identical 0.5 liter titanium high pressure reservoirs containing 20 bars of xenon. A non-latching input valve allows gas to enter the cell. It can be actuated in pulse mode from the EU. The pulse duration is programmable to minimize the number of actuations. A non-latching vent valve allows gas to escape from the cell into free space. A high pressure transducer monitors the remaining gas pressure in the reservoirs and a thermistor monitors the unit's temperature.

3 CALIBRATION

The calibrations of the instrument were carried out as a series of campaigns at the European Space Agency Research and Technology Center (ESTEC) in Noordwijk, the Berlin synchrotron facility BESSY and the long-beam X-ray facility of the Max Planck institute PANTER, near Munich. All measurements reported here were performed in vacuum with the nominal voltages of -20 kV on the cell and 1082 V on the PMT. Work is still ongoing on the ray-tracing program which will include all the aspects of the instrument. Here, only spatial and temperature gain variations, entrance window and plasma protection window transmissions will be discussed. Energy gain and resolution discontinuities are discussed in detail by Bavdaz.¹⁶

3.1 Gain map

Many instrument functional tests were carried out using our own dedicated X-ray beam source. During these tests, the flight instrument was mounted behind a pin-hole plate and illuminated with Al (1.5 keV) and Fe (6.4 keV) radiation from a Kevex source located 5 meters away. The pin-hole plate is made of 0.5 mm thick aluminium sheet through which 1 mm holes were drilled, forming a rectangular grid with 4 mm pitch. Figure 6 shows a typical image obtained with an Fe K- α illumination. The two in-situ calibration sources, which are in the upper left and lower right corners, provide, as will be shown, an accurate measure of the detector's gain. Each functional test consists of 4 consecutive 1800 seconds background accumulation, an Fe illumination, an Al illumination and again a background acquisition. In this context, the gain will be defined as the ratio of pulse

Figure 6: Multi pin-hole array image, Fe exposure. The calibration sources are the bright spots in the upper left and lower right corners. The circles delimit the areas used for gain mapping.

Figure 7: Pulse height amplitude versus temperature for the 2 ^{55}Fe calibration sources

height amplitude (PHA) to the average amplitude of the 2 calibration sources.

3.1.1 Temperature dependence

Since all tests were performed without temperature control, the measurements also revealed the gain behaviour with temperature. The integrated DU thermistor was used as temperature sensor since this will be the only reference in orbit. The temperature scale reported here is the digital read-out of the EU. The data files cover the range from 67 to 80 digital units, corresponding to between 27.7 and 22.1°C.

Each data file was broken into segments of constant temperature and for each of these segments the average PHA generated by each of the calibration sources was determined. The results are plotted in Figure 7. The two data sets differ only by a scaling factor and show a linear dependence with a temperature coefficient of $-1.4\%/^{\circ}\text{C}$. The scatter in the figures can be attributed to the resolution of the temperature measurement which amounts to 0.4°C in the region around 25°C . The same procedure was followed to check this coefficient in the field of view and was found to be independent of position and energy (Fe and Al exposures). The effect of temperature on the absolute gain of the detector can therefore be taken into account by referring all amplitudes to that of the calibration sources.

3.1.2 Spatial gain map

Spatial gain maps are obtained by computing the gain, as defined above, at each of the pin-hole positions. The region used for each position evaluation is indicated by the circles in Figure 6. For each pixel in the field of view, the gain is estimated by means of a spline interpolation. In order to smooth out statistical fluctuations, the exposures for each source were summed. Temperature effects were removed by breaking up the data files into constant temperature segments and using the average calibration source PHA to normalize the amplitude of each individual X-ray event. The best peak position was determined by fitting the data with a Gaussian plus background. The interpolated gain maps are shown in Figure 8 for Fe K- α , and Figure 9 for Al K- α X-rays. The two gain maps only differ by a scaling factor of 0.2382. Note the Al/Fe energy ratio is 0.2344.

Figure 8: Gain map at 6.4keV. The cross indicates the center of the field of view.

Figure 9: Gain map at 1.5keV. The cross indicates the center of the field of view.

Additional multi pin-hole measurements were taken at PANTER, where other sources were available (especially C at 0.28 keV). During this campaign, the pin-hole array was stepped in the XY plane, parallel to the focal plane, to increase the spatial sampling. These measurements confirm the smooth surfaces and extend the calibration to the lower and higher energy range. Again, the spatial gain maps are well behaved, differing only by a scaling factor approximately equal to the energy ratios.

3.2 Plate scale

This section describes the coordinate transformation required to translate the raw pixel coordinates into absolute position in the focal plane. The data used here was collected at PANTER using a multi pin-hole mask (MP) of 4 mm pitch, which is stepped in the XY plane. Due to the finite distance of the source (about 130 m), the actual distance between consecutive pinholes projected on the focal plane is magnified by about 1%. This effect is taken into consideration in the analysis. The reproducibility of XY positions at PANTER is in the range 10 to 100 μm . By comparing the positions of the pin-hole images in different exposures with identical XY encoder positions, the absolute error is estimated to be closer to the upper limit of 100 μm . The data used for this analysis was obtained at energies of C (0.28 keV), Al (1.5 keV) and Fe (6.4 keV). For each exposure, a correspondence can be established between pixel coordinates and pin-hole position, as shown in Figure 10. Based on this data, the coordinate transformations required to assign to each pixel (RAWX, RAWY) its true distance along the X and Y axis, from the physical center of the field of view have been determined. A cubic polynomial has been fitted to the data:

$$D^{x,y} = a_0^{x,y} + a_1^{x,y} \cdot p_x + a_2^{x,y} \cdot p_y + a_3^{x,y} \cdot p_x p_y + a_4^{x,y} \cdot p_x^2 + a_5^{x,y} \cdot p_y^2 + a_6^{x,y} \cdot p_x^2 p_y + a_7^{x,y} \cdot p_x p_y^2 + a_8^{x,y} \cdot p_x^3 + a_9^{x,y} \cdot p_y^3. \quad (5)$$

Here, $D^{x,y}$ is the distance in mm from the physical center of the field of view, along the X and Y axis; $p_x = (\text{RAWX} - \text{RAWX}_0)$; $p_y = (\text{RAWY} - \text{RAWY}_0)$; $a_i^{x,y}$ are the fitted coefficients (one set for each axis). The constants RAWX_0 and RAWY_0 are the pixel coordinates corresponding to the physical point from which all distances are measured. These were taken to be the pixel coordinates of the pinhole closest to the center of the image when the MP's physical coordinates were set to (0,0).

The physical center of the field of view, i.e. the point where X-rays coming from the PANTER source (assumed to be on-axis) strike the detector when the mirror unit (MU) is mounted, is found at slightly different pixel coordinates. This is because of the slight misalignment of the LE-GSPC, the MU and the MP on the XY tables at PANTER. The shift will be reflected in the fact that $a_0^{x,y}$ in equation 5 is not equal to 0 (see Table 3).

Figure 10: Correspondence between pixel (left panel) and physical (right panel) space. Each data point represents the position of one pinhole.

The coefficients $a_i^{x,y}$ do not depend on energy and combining all the data we obtain the transformation summarized in Table 3. Distances in physical space are obtained in mm. Pixel space axes cover the range 0 – 255, with (0,0) being the lower left corner of the image. In physical space, the frame of reference is translated so that (0,0) is the center of the field of view.

The residuals between the data and the fit along X and Y are approximately $55\,\mu\text{m}$. This corresponds to about half a pixel and is of the order of the systematics inherent to the experimental set up.

	X	Y
a_0	$-7.084 \cdot 10^{-1}$	$5.573 \cdot 10^{-1}$
a_1	$1.254 \cdot 10^{-1}$	$3.408 \cdot 10^{-3}$
a_2	$-5.786 \cdot 10^{-3}$	$1.255 \cdot 10^{-1}$
a_3	$-1.982 \cdot 10^{-5}$	$7.484 \cdot 10^{-6}$
a_4	$4.157 \cdot 10^{-5}$	$5.508 \cdot 10^{-7}$
a_5	$1.437 \cdot 10^{-5}$	$-2.612 \cdot 10^{-5}$
a_6	$9.160 \cdot 10^{-8}$	$2.049 \cdot 10^{-6}$
a_7	$2.000 \cdot 10^{-6}$	$-5.029 \cdot 10^{-7}$
a_8	$1.463 \cdot 10^{-6}$	$-9.026 \cdot 10^{-8}$
a_9	$1.395 \cdot 10^{-7}$	$2.059 \cdot 10^{-6}$
RAW0	136.78	119.07
(MP center)		
RAW	131.44	124.12
(MU center)		

Table 3: Coefficients required to map pixel space into physical space (equation 5). Distances in physical space are obtained in mm. The transformation is independent of energy.

3.3 Entrance window X-ray transmission

The transmission of the DU cell's entrance window which is a critical item with respect to the interpretation of the low energy astronomical data, was measured separately at BESSY. Two sets of data were taken. The first is a precision energy scan at 5 positions in the central window region. Since the window consists of Carbon, Hydrogen, Oxygen, Nitrogen and Aluminium, and is therefore transparent above 2 keV, 500 energy points were taken between 0.1 to 1.8 keV, with energy steps as small as 0.2 eV around the absorption edges of the constituents. The second set, with low energy resolution, scanned 8 by 8 positions in each of the 3 by 3 central strongback squares. Only 18 to 30 energies were used for these scans. Absolute errors on the order of 1% on the transmission are to be expected, some discussion on these can be found in Bavdaz.¹⁷

Comprehensive tables of X-ray cross sections are published in the literature about every 10 years. The X-ray cross sections used by Bavdaz¹⁷ were derived from tables contained in Veigel.¹⁸ Another, more recent, set of coefficients has been published by Henke¹⁹ it differs from the former one mainly around the absorption edges and will be used throughout this discussion.

The usual approach to modelling X-ray transmission (T) through an absorbing layer, as explained for instance by Zombeck,²⁰ is to use the following formula:

$$T(x, E) = \exp(-\mu \rho x) \quad (6)$$

where E is the X-ray energy, ρ the density, x the thickness and μ the mass absorption coefficient, which for compounds is given by:

$$\mu = \sum_i \mu_i f_i \quad (7)$$

where μ_i is the mass absorption coefficient of element i and f_i its fractional weight. By defining a_i as the area density of element i , we can write:

$$\sum_i \mu_i f_i \rho x = \sum_i \mu_i \rho_i x = \sum_i \mu_i a_i \quad (8)$$

Using the measurements at different energies, we can obtain the area densities required to describe the X-ray properties of the window. Unfortunately the chemical state and thickness of the absorber displaces the edge energies, see Barden,²¹ and Equation 7 is only a good approximation away from the edges. As example, Figure 11 shows the actual transmission around the oxygen edge compared to the exponential model with the old (dashed) and new (crosses) mass absorption coefficients.

With the aim of improving the model, the following empirical function has been used:

$$T = \exp(-\sum_i \mu_i a_i) \times T_{fudge} \quad (9)$$

where the fudge function is defined as the ratio of the measured data to the exponential model fitted outside the edge regions :

$$T_{fudge} = T_{data} / \exp(-\sum_i \mu_i a_i) \quad (10)$$

This fudge function is derived from the average of the 5 high resolution energy scans and is plotted in Figure 12. The area densities for each of the 5 constituents were fitted at each position by minimizing the quality factor “ Q ”:

$$Q \equiv \sum_j (T_{data}^j - T_{exp}^j)^2 \quad (11)$$

$$T_{exp}^j = \exp(-\sum_{k=1}^5 \mu_k^j a_k) \quad (12)$$

Figure 11: Transmission around the O–K edge. The predictions of the exponential model are shown for the old (solid) and the new (dotted) mass absorption coefficients. The measured data is shown as crosses.

Figure 12: The fudge function used to model the transmission of the entrance window around the absorption edges.

where the index “ j ” denotes the energy dependence where care was taken to exclude the absorption edges, and “ k ”, the constituents, H, C, N, O and Al. Table 4 summarizes the theoretical composition, based on the design of Figure 4, and a typical area density fit. Figure 13 shows the transmission of the multilayer entrance window and compares it with a $10\mu\text{m}$ thick Be window. The fitted curve matches the data well but is not superposed for clarity reasons. Finally, additional data analysis is being performed to include the tungsten fine grid and strongback absorption.

Figure 13: Transmission of the multilayer entrance window. Also shown is the transmission of a $10\mu\text{m}$ Be window for comparison. Arrows at the bottom mark astrophysically important emission lines.

Element	Predicted Area Density ($\mu\text{g}/\text{cm}^2$)	Predicted Thickness (μm)	Fitted Area Density ($\mu\text{g}/\text{cm}^2$)
H	4.8		4.9
C	126		130
N (total)	17.3		17
O	31		38
Al (total)	19.4	0.044	13
AlN	11.4	0.035	
PI	175	1.25	

Table 4: Predicted and nominal fitted compositions of the entrance window.

3.4 Plasma protection window X-ray transmission

This protection window was also measured separately at BESSY, with a high resolution energy scan (500 energy points between 0.1 and 1.8 keV) at the center of the window and a high position resolution scan at 3 energies (0.28, 0.9 and 1.55 keV). The scans revealed less than 1% (r.m.s.) spatial variations of the transmission coefficient. Since this window is located about 5 cm above the focal plane, the small inhomogeneities will be

smoothed out. The model therefore assumes a uniform absorption across the surface. The actual absorption of the window has been modelled in a similar way as for the entrance window but also includes the absorption of the tungsten support grid. The resulting function is plotted in Figure 14.

Figure 14: The response function of the plasma protection window. Points outside the range 0.1–1.8 keV are extrapolated from the model.

4 BACKGROUND REJECTION

The minimum detectable source count rate depends upon the number of background events which can be either cosmic X-rays, particles, stray light or scattered solar X-rays. The cosmic X-rays can only be reduced by selecting a proper detection cell which will typically be 8.3' radius to allow 95% of the C-K line to be included. Although the entrance and plasma protection windows provide excellent UV filtering, some optical leakage through these windows is to be expected for bright stars and will result in background in the lowest energy channels. This effect will be calibrated for after launch. Solar X-rays, scattered off the residual Earth atmosphere, are seen as “real” events and will contribute to between 0.012 and 1.8 counts/s. The particle background, which in a traditional GSPC can be reduced considerably by selecting in burstlength, is more difficult to remove in this design. Figures 15 and 16 show a Burstlength versus Energy diagram for two monochromatic illuminations taken at BESSY. An energy of 4.77 keV, i.e. just below the Xe L-III edge, was used in Figure 15 where one can clearly see the penetration effect (label 1) due to the absence of a drift region, and pile-up events (label 3). Figure 16 is an exposure at 4.79 keV, just above the edge. Clearly the penetration feature (label 1) is reduced and instead, replaced by escape photons (label 2). A further discussion of these data can be found in Bavdaz.¹⁶

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Figure 15: Burstlength-Energy diagram for 4.77keV incident photons, i.e. just below the Xe L-III edge.

Figure 16: Burstlength-Energy diagram for 4.79keV incident photons, i.e. just above the Xe L-III edge.

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