A LOW ENERGY GAS SCINTILLATION PROPORTIONAL COUNTER FOR THE SAX-X-RAY ASTRONOMY SATELLITE

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Abstract. The payload of the italian/Dutch satellite SAX will include a set of four concentrators each with a geometric area of 90 cm^2. Imaging GSPCs will be located at the focal planes of the concetrators. The Space Science Department of ESA will provide one of these GSPCs which will be sensitive to X-rays with energies between 0.1–10 keV. In order to achieve such a low-energy energy response, a driftless configuration and a thin plastic window have been adopted. At 6 keV the collecting area will be 50 cm^2 and the energy and angular resolutions 8% and $1.6'$ FWHM, respectively.

1. Introduction

The Italian/Dutch satellite Sax is scheduled for launch into a 600 km equatorial orbit in December 1993. This orbit ensures a relatively constant, low particle background. During the 2 year mission the instruments will make imaging, spectral and timing studies of a wide range of X-ray sources in the energy range 0.1–200 keV (Scarsi 1983; Perola 1983). The payload of scientific instruments includes a high pressure GSPC, a phoswich detector system, two wide field cameras (WFCs) and four imaging GSPCs (Spada 1983). All the instruments are coaligned except for the WFCs which point in opposite directions along an axis perpendicular to the other instruments. The imaging GSPCs are located at the focal planes of four X-ray concentrators each with a geometric area of 90 cm^2. In order to extend the sensitive energy range of the concentrator spectrometers below 1 keV, one of these GSPCs will be a new design of low-energy gas scintillation proportional counter (LEGSPC). This instrument is being provided by the Space Science Department of ESA. It will have energy resolution comparable to prototype CCDs at low energies and a factor of ~ 2 better than proportional counters at iron K (6.4 keV). Its high sensitivity, imaging capability and low background will allow detailed spectral and timing studies of both point and extended sources to be made.

2. The SAX LEGSPC

The general performance characteristics of the LEGSPC are given in Table I. The low energy response requires the use of a thin plastic window since the low-energy cut-off of a conventional 50μ beryllium window is $\gtrsim 1$ keV. The current solution for this window is 1μ polypropelene with a thin Lexan coating, although an alternative approach involving a diamond coated polyimide foil is presently under development at Outokumpu OY, Finland. Impurities due to outgassing from the window and detector (the detector cannot be baked at high temperature because of the presence of the polypropelene) are removed by a passive getter.

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TABLE I
The LEGSPC 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	$40'$
Time Resolution	16μs
Maximum Throughput	2000 events s^{-1}
Background Rejection	98%

Xenon was chosen as the filling gas because its scintillation spectrum closely matches available photomultiplier entrance windows. Since the penetration depth of low energy X-rays in xenon is low, a conventional drift region would unacceptably degrade the energy resolution of the detector because of the loss of electrons to the front window (Inoue *et al.* 1979). This problem is overcome in the LEGSPC since the X-rays are absorbed directly into the high field scintillation region. The absence of a drift region and the associated drift/scintillation grid leads to an intrinsically better performance (Simons *et al.* 1985), but does cause a dependance of pulse height on penetration depth that has to be considered in the signal processing.

The first prototype SAX LEGSPC detector is described in Smith, Peacock, and Kowalski (1987). In later designs a cylindrical geometry was chosen in order to overcome field non-uniformities and the electric field near the window was more carefully controlled. Two detectors of this design were built by SIRA Ltd, UK under contract from ESA. These early detectors were found to be sufficiently sensitive to allow the study of various aspects of GSPC gas physics including the light emission process, electron drift velocity and longitudinal diffusion, and the Fano factor (Favata *et al.* 1990; Smith, Favata, and Kowalsky 1989; Kowalsky, Smith, and Peacock 1989). After improvements and increased confidence in the reliability of the entrance window a larger (2 cm) diameter was chosen which lead to the final design as shown in Figure 1. Two Fe^{55} radioactive sources constantly illuminate regions of the detector that do not see the sky allowing the position and energy gains to be constantly monitored. The first SAX engineering model detector is presently being built to this design by AEG Inc. Ulm, FRG.

The readout photomultiplier is a Hamamatsu 3 × 3-anode tube R2488. The anodes are arranged in a square configuration providing 9 separate signals for each observed X-ray. These are combined to produce pulse height, burst length, X_{pos}, Y_{pos} and veto signals (see Favata and Smith 1989). Each signal is then converted to a digital value via an ADC and then handed to the digital electronics and microprocessor system. This is based around an 80C86 microprocessor with 32 kbytes of ROM and 104 kbytes of RAM memory and is presently under development at MBB

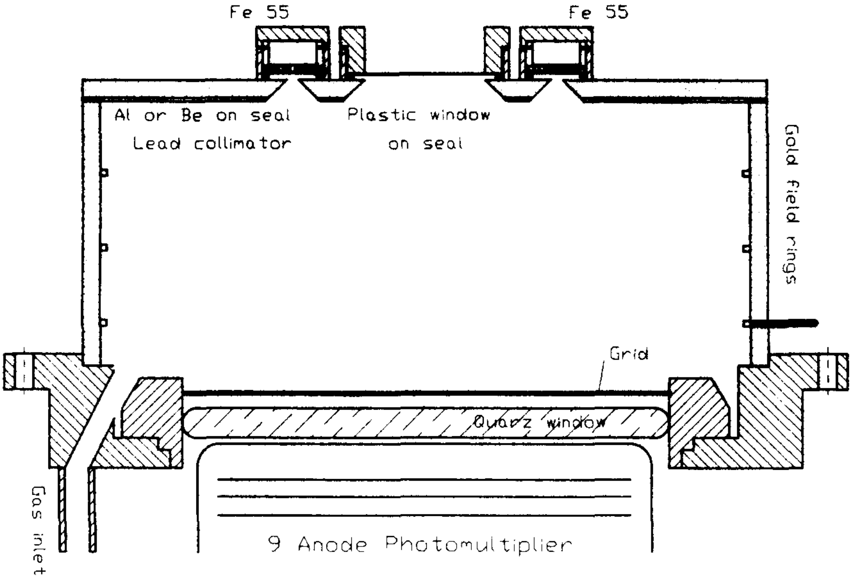

Fig. 1. Schematic of the SAX LEGSPC gas cell.

Ottobrunn, FRG. There are a number of commandable modes. In Direct mode, the energy, time, position, burst length and veto state of each event is passed to the on-board data handling system. Various Indirect modes exist in which either spectra and/or images of selected regions of the field of view may be accumulated on-board prior to transmission to the ground in order to reduce the telemetry load. In both modes the correction to pulse height due to varying penetration depth of the X-rays can be performed in flight and/or during ground analysis.

3. Scientific Objectives

The mid-1990's will be an exciting time for X-ray astronomy with the launches of SAX, Astro-D, XTE and Spectrum-X-Γ expected within a short interval. Astro-D and Spectrum-X-Γ will use CCD detectors to provide a resolution of 100–150 eV over a $\sim$ 0.5–10 keV energy range while XTE will concentrate 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 the LEGSPC 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 low ($\lesssim$ 1 keV) energies.
- The LEGSPC provides extremely good time resolution of up to 16μs.

This should be compared with a typical time of 2s needed to read out a typical TV format CCD.

There are, however various ways of improving this last figure. One of these is

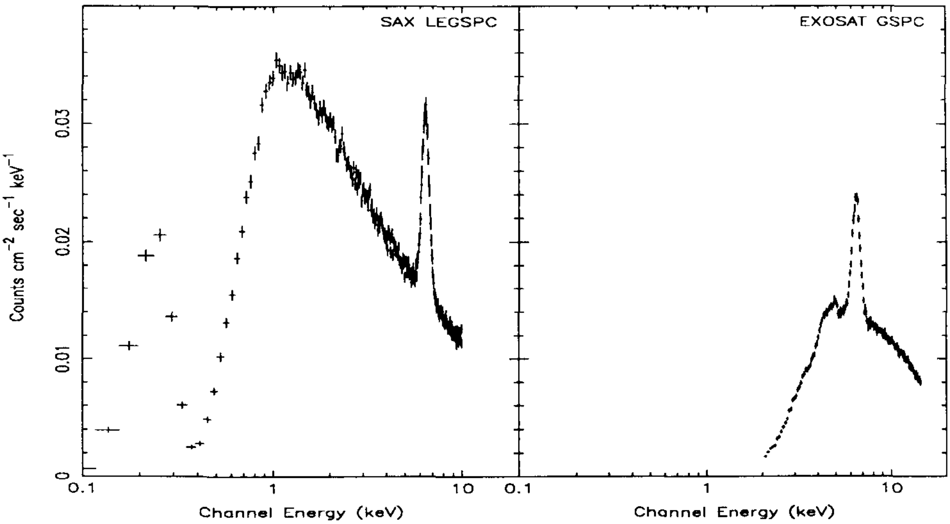

Fig. 2. The same source observed by the LEGSPC and EXOSAT GSPC instruments

to read out the CCD continuously, the spatial distribution of the observed X-rays then represents timing information.

– In X-ray astronomy CCD detectors are used in photon counting mode. This means that the mean arrival rate should be < 0.1 photons/pixel/frame which can place severe constraints on the maximum source strengths allowed. There are no such problems with the LEGSPC which has a maximum throughput of 2000 counts s^{-1}.

– The energy resolution of GSPCs is known to be extremely stable, whereas there are still uncertainties as to the effects of large radiation doses on CCDs (e.g., Holland, Lumb, and Castelli 1989).

The instrumentation on SAX is ideally suited to the study of the brighter time-varying sources such as X-ray transients. These sources were first discovered as bright sources that appeared in previously source free locations and then slowly decayed. The brightest known to date, Nova Mon 1975, reached a flux 50 times that of the Crab Nebula. Transient outbursts above 50 mCrab are roughly estimated to occur at a rate of 5×10^{-4} deg^{-2} yr^{-2}. X-ray transients can be divided into three classes; pulsing sources with hard spectra, many of which are identified with Be star companions; bursting sources with soft spectra; and the ultra-soft transients. SAX with its WFCs monitoring large regions of sky will detect and study some 10–30 bright transient events per year. Optical identifications of many of these sources will lead to important further information. The combination of the wide energy range of the SAX instruments and the large field of view of the WFCs makes SAX ideally suited for detecting these sources and especially for carrying out detailed follow-up studies over a wide luminosity range. These studies will provide important new insights into the nature of the accretion process onto both neutron stars and black holes.

Some idea of the quality of the spectra that will be obtained using the LEGPSC is shown in Figure 2. A spectrum with an equivalent hydrogen column density of 10^{20} atoms cm^{-2}, a power-law photon index of 0.61, and a 6.4 keV iron line of 0.2 keV FWHM width and 0.85 keV equivalent width (the flux in a line divided by the strength of the continuum under the line) was assumed. The assumed 2–10 keV flux of 1.7×10^{-9} erg cm^{-2} s^{-1} is typical of bright transient sources. The significantly better resolution of the LEGSPC compared to the EXOSAT GSPC (Peacock *et al.* 1981) results in a narrower line with higher peak counts. The loss in efficiency of the SAX mirrors above 10 keV means that the EXOSAT GSPC is more sensitive at $\gtrsim$ 10 keV. At low energies, the different window construction and improved design of the detector allows the LEGSPC to observe the hypothetical source down to 0.1 keV.

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