Development of a CZT array detector

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Abstract

A large area CZT array detector is being developed for the *Astrosat* satellite. The science background and objectives are described here. The strategy adopted to develop a full system in a short time is outlined.

Key-words : X-ray detectors, hard X-ray astronomy, instrumentation

1 Introduction

The Indian Multi-wavelength Satellite, *Astrosat*, has been proposed with broad-band X-ray spectroscopy as one of its major objectives. Several of the problems dogging the field of hard X-ray continuum spectroscopy like background measurement, limited energy bandwidth, limited degrees of freedom for spectral fitting due to poor energy resolution can be effectively tackled by incorporating the new generation near-room-temperature solid state devices like Cadmium Zinc Telluride (CZT) detector arrays. It is proposed that a large area (1000 cm^2) CZT detector will be developed for inclusion in *Astrosat*. These detectors have very good detection efficiency (close to 100% up to 100 keV) and have a superior energy resolution ($\sim$3% at 60 keV) compared to scintillation and proportional counters. Their small pixel size also facilitates medium resolution imaging in hard X-rays.

2 Science objectives

X-ray spectroscopy is a powerful tool which can be used to probe sites where high energy phenomena are taking place. Several of the potential promises of X-ray spectroscopy, however, remain largely unfulfilled. The major reasons for this are:

a) The bulk of the emission from non-thermal processes is in hard X-rays (above 10 keV). Due to the non-availability of focusing techniques in this region, the sensitivity is quite inferior compared to that available for the low energy X-rays. The only way to improve the sensitivity is to build large area detectors. This further hinders X-ray spectroscopic measurements because of the fact that the currently available large area X-ray detectors have poor energy resolution.

b) Except in cases where copious cold matter surrounds the acceleration sites and gives rise to emission from photo-ionized plasma, X-ray emission from a large variety of objects is mostly in continuum. Extracting the parameters from the X-ray continuum spectroscopic methods requires that the detectors are of sufficiently large area to collect enough number of photons in each of the spectral bins, response of the detectors are known to a high degree of accuracy and there is sufficient bandwidth to constrain the multiple continuum components.

It is a technical challenge to meet these requirements. The *Astrosat* satellite aims to do this by using a judicious mix of different types of X-ray detectors. Since the low energy thermal components of the X-ray emission in astrophysical sources will be well understood from the vast amount of data coming from (and expected to be obtained) from *Chandra* and *XMM*, the problem of X-ray continuum spectroscopy boils down to building of sensitive detectors above 10 keV along with medium resolution detectors for low energy X-rays.

Since most of the astrophysical sources have steep power-law spectrum, at low energies (2 – 8 keV), a modest collecting area along with medium energy resolution (~100 - 200 eV) will be required to identify specific spectral features and quantify the thermal component in the spectrum. In the 2 – 20 keV range, a large area conventional detector would be extremely useful for timing studies and time-resolved X-ray spectroscopy. Above 10 keV, the observations are background dominated and hence a large area detector with good energy resolution and a facility to reduce Compton induced background will be required. With these objectives in mind, a combination of an X-ray CCD at the focal plane of a focusing detector (SXT), a large area proportional counter (LAXPC) and a CZT array detector with an efficient Compton-induced background rejection mechanism is planned for *Astrosat*.

3 Detector specifications

Proportional counters and scintillating crystals are the commonly used hard X-ray detectors in X-ray astronomy. Though they can be made in large areas, they have poor energy resolution. The typical energy resolution possible in such detectors are shown in Figure 1, along with the resolution possible with the near room temperature solid state detector CZT. The improved energy resolution, particularly at higher energies, and better detection efficiency of the CZT detectors are evident from the figure.

To optimally utilize the imaging and spectroscopic characteristic of CZT detectors a 1000 cm^2 detector with a pixel size of 2.5 mm $\times$ 2.5 mm is planned. The salient features of the telescope is given in Table 1. The detector plane will be pixelated and to exploit this property a Coded Aperture Mask will define the field of view. The purpose of the mask is primarily to remove source confusion and to simultaneously measure the background contribution. The field of view is energy dependent to effectively reduce the cosmic diffuse X-ray background. A one inch thick CsI crystal will be used in an anti-coincidence mode to reject Compton-scattered background from gamma-rays. The detectors would be used in a spectroscopic mode in the energy range of 5 – 100 keV and above this energies the detectors would be operating as a all-sky gamma-ray detector with very limited imaging capability.

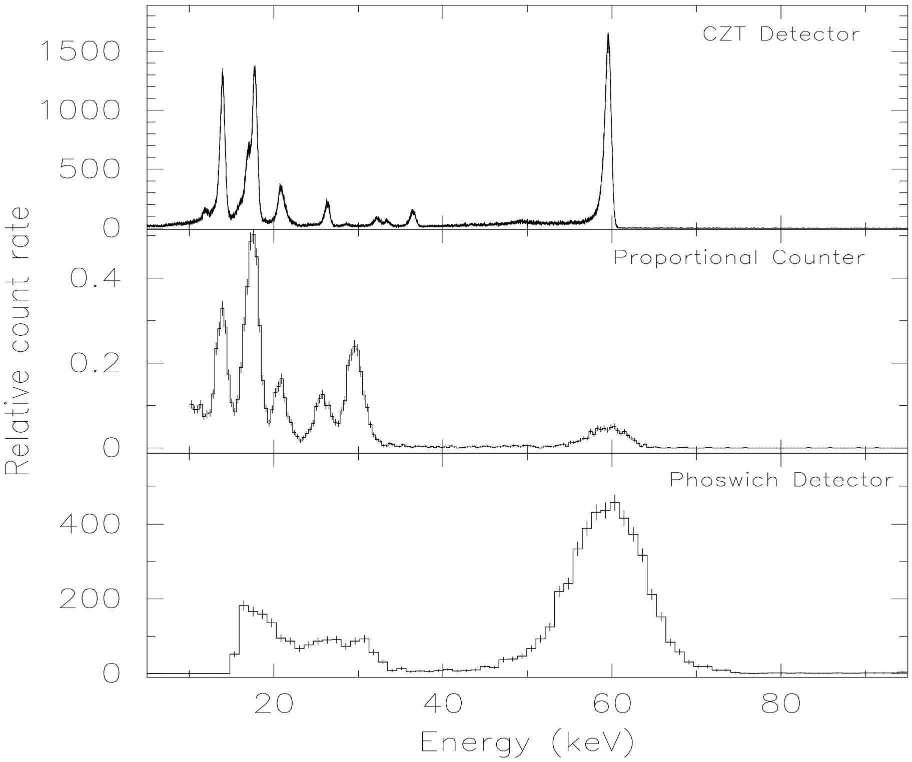

Figure 1: X-ray spectrum using various detectors for ^{241}Am radio-active source

Table 1. Details of CZT array detector

Total area	:	1024 cm^2
Number of pixels	:	16384
Pixel size	:	2.5 mm $\times$ 2.5 mm
	:	(5 mm thick)
Read-out system	:	ASIC based
	:	(128 chips of 128 channels)
Imaging method	:	Coded Aperture Mask (CAM)
size	:	1024 cm^2
element size	:	2.5 mm $\times$ 2.5 mm
material	:	Tungsten
thickness	:	1 mm
Field of view	:	17° $\times$ 17° (CAM)
	:	5° $\times$ 5° (25 – 100 keV)
	:	1° $\times$ 1° (5 – 25 keV)
Angular resolution	:	8'
Energy resolution	:	3% at 60 keV
Detection efficiency	:	100% in 5 – 100 keV band
Sensitivity	:	5 σ detection of 0.5 mCrab
	:	source in 10^4 s

4 Development plan

It has been recognized that CZT is the hard X-ray detectors of the future and several groups are actively working in this field (see Bloser et al. 2001 and references therein). A large area (5200 cm^2) CZT detector array is being developed for the swift mission (Barthelmy 2000) and a wide field hard X-ray survey telescope, EXIST, is in the early planning stage (Grindlay et al. 2000). These telescopes attempt to exploit the imaging capability of CZT detector and are used in a wide field of view mode and hence are background dominated. The CZT detector being developed for *Astrosat* will be the first such detector to fully exploit the spectroscopic characteristics and is operated in a low background pointed mode.

The primary difficulty in developing a large area CZT detector is the requirement of a large number of amplifiers (one for each pixel for good spectroscopy) and the time and effort required to develop a good quality low noise ASIC for this purpose. This is overcome for the *Astrosat* by an attempt to qualify and characterize ASICs already developed for some other applications. IMARAD Imaging Systems, Israel, is developing CZT arrays for medical applications and these detectors are being characterized for X-ray spectroscopic applications for *Astrosat*. The background reduction will be achieved by the use of a large area CsI detector used in anti-coincidence. It is estimated that by this method low background rates would be obtained and a detection sensitivity of 0.5 mCrab (5 σ detection) in an observation time of 10^4 s would be achieved.

It is proposed to initially develop a small CZT array of about 16 cm^2 area, with its front-end and signal processing electronics. The small CZT array has been procured and is being tested. A hard X-ray imager will be developed and will be tested in a balloon flight to measure the background count rates and other detector parameters by studying Crab Nebula and other cosmic X-ray sources. Based on the experience from this effort a full fledged large area CZT array detector will be developed for *Astrosat*.

5 Conclusions

The CZT array with its superior energy resolution (about 10% at 6 keV and 3% at 60 keV) will carry out the spectral measurements (in conjunction with the SXT and the LAXPC detectors) in the 2-100 keV band with an accuracy which will be unmatched by any existing or planned mission in the 2005 time frame. The CZT detector array will have the merit of (a) measuring the contribution of the non-cosmic X-ray background from 5 keV to 100 keV, simultaneously with the source intensity measurements, (b) enable a simultaneous spectral fit to the X-ray spectra so as to get a measure of systematic errors in the data, and (c) allow us to measure the contribution from confusing neighboring sources.

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References

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