BROAD X-RAY SPECTRAL BAND STUDIES WITH ASTROSAT

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ABSTRACT

Astrosat is a broad spectral band Indian Astronomy satellite covering 0.5 - 100 keV X-rat region as well as ultraviolet and visible bands to carry out multi-wavelength observations of a variety of X-ray sources. This is achieved by means of 3 co-aligned X-ray astronomy instruments and one UV imaging instrument. This mission is aimed at high time resolution X-ray timing studies, low and medium resolution X-ray imaging and spectral measurements and simultaneous imaging and photometric observations in the UV and optical bands for different classes of X-ray and UV bright objects. Astrosat is well suited for studies of rapid variability like pulsations, kHz QPOs, Sporadic bursts etc. in X-ray binaries ,continuum X-ray spectral measurements of binaries, AGNs ,Cluster of galaxies etc. and also construct energy spectra of sources over five decades in energy from simultaneous measurements. It will have superior sensitivity in the hard X-ray band for detection of of cyclotron lines , measurements of non-thermal components in the spectra of black hole sources , supernova remnants , Cluster of galaxies etc. and also extend studies of QPOs to hard X-ray region. The Astrosat is planned for launch using Indian PSLV in a near equatorial orbit of 600 km altitude in 2007/2008. Characteristics of the instruments are briefly presented and science goals of the mission are highlighted baed on simulations.

1. INTRODUCTION

To understand the nature of cosmic sources, their radiation processes and environment, it is necessary to measure their emission over the entire electro- magnetic spectrum. Since intensity of several classes of cosmic sources varies with time, simultaneous observations in different wave-bands are required to construct their energy spectra as well as measure their variability. Most of the space observatories are designes for observations ina particular band e.g. X-ray, UV etc. Therefore, multiwavelength studies usually have to be made from coordinated observations with different satellites (Edelson et al.1996).The most efficient and effective way of multiwavelength studies is to have a dedicated satellite mission which will carry several co-aligned instruments covering the desired spectral bands.The proposal for Astrosat as an Indian multiwavelength Astronomy Satellite has been conceived to meet the long felt need for such a mission. The uniqueness of Astrosat lies in its wide spectral coverage extending over visible, ultraviolet, soft x-ray and hard x-ray regions with capability to observe a target source over a wide band with 4 co-aligned instruments simultaneously.

Astrosat is a collaborative effort of several Indian institutions, Canadian Space Agency and Univercity of Leicester, UK. These include Tata Institute of Fundamental Research (TIFR), ISRO Satellite Center (ISAC), Indian Institute of Astrophysics (IIA), Raman Research Institute (RRI), Inter-University Center for Astronomy and Astrophysics (IUCAA) and Physical Research Laboratory (PRL), all of which are involved in the development of hardware for this mission. Besides, several centers of Indian Space Research Organization (ISRO) are involved in the design and fabrication of various components and sub-systems of the 5 instruments. Several other Indian institutions will be involved in the development of science analysis software.

2. ASTROSAT SCIENCE GOALS

The Astrosat mission has been conceived with the principal objectives of (a). Multiwavelength studies of cosmic sources over a wide spectral band extending over low energy X-rays (0.3 - 8 keV), high energy X-rays (10-100 keV), UV (120 - 300 nm) and visible bands from simultaneous observations with co-aligned instruments. (b). Measure correlated intensity variations to investigate the origin and mechanism of the emission of radiation in different spectral bands. (c). X-ray studies of periodic (pulsations, binary light curves, QPOs etc) and aperiodic (flaring activity, bursts, flickering and other chaotic variations) variability by high time resolution (10 μsec) photometry in 0.3-100 keV band. Rapid variability studies, high and low frequency QPOs, kHz QPOs in soft and hard X-ray bands, probe astrophysical processes closest to the central source. (d). Broad band X-ray spectroscopy

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[*] On behalf of Astrosat collaboration.

of X-ray binaries, Supernova remnants (SNRs), Active Galactic Nuclei (AGNs) etc with moderate energy resolution (E/ΔE ∼ 30-50) X-ray CCD in Soft X-ray Telescope (SXT),low resolution (E/ΔE ∼ 6-10) LAXPCs covering 3-80 keV and CZT detector array with E/ΔE ∼ 10 to 20 in 10-100 keV. Astrosat is particularly well suited for investigating the non-thermal spectral component due to very large effective area above 20 keV. (e). Studies of cyclotron lines in the spectra of the X-ray pulsars to measure magnetic fields of neutron stars. (f). UV Studies of a variety of galactic sources including active stars, cataclysmic variables (CVs) , X-ray binaries , SNRs etc. (g). Ultraviolet imaging studies of nearby and distant galaxies and AGNs to probe their structure, spectral energy distribution, studies of starburst activity and ionized gas.

3. ASTROSAT INSTRUMENTS

The instruments chosen for realizing the science goals of Astrosat are:

3.1. Large Area X-ray Proportional Counters (LAXPCs):

LAXPC will be used for the timing and spectral studies covering broad energy band (3-80keV). This is a cluster of 3 identical co-aligned proportional counters in a multi-layer geometry with 1^o X 1^o field of view (FOV). The X-ray detection volume is 15 cm deep consisting of 60 anode cells each 3.0 cm X 3.0 cm arranged in 5 layers surrounded on 3 sides with veto cells of size 1.5 cm x 1.5 cm for rejection of non-cosmic X-ray background. Each LAXPC is filled with 90% Xenon + 10% Methane at 1600 torr pressure to provide an average detection efficiency of 100% below 15 keV and ∼ 50% up to 80 keV. A 25μ thick aluminized Mylar film supported against pressure by a honeycomb shape collimator serves as the X-ray entrance window. The FOV collimator is made by gluing layers of tin,copper and aluminium. The total effective area of 3 LAXPCs is about 6000 cm^2 below 20 keV and about 5000 cm^2 at 45 keV making it the largest effective area hard X-ray detector ever flown in a satellite mission (Fig.1). This will provide high sensitivity for the timing observations in the hard X-ray band.

3.2. Cadmium-Zinc-Telluride Imager (CZTI):

Medium resolution spectroscopy and low resolution imaging (0.1 degree) in 10-100 keV is achieved by CZTI. The CZT array has a geometrical area of 1024 cm^2 made up of 16384 pixels each 2.5 mm x 2.5 mm X 5 mm thick read out by 128 ASICs each having 128 channels. This will provide position and energy of each detected X-ray. The imaging will be realized by a coded aperture mask(CAM) of tantalum with 17^o x 17^o FOV placed above the CZT plane. The CZT detector will be operated in -0^oC to -20^oC range by passive cooling using a radiator plate of appropriate area. The CZT has superior energy resolution compared to the LAXPCs, above 40 keV with expected resolution of about 7% at 60 keV. Compton scattering produced background in the CZT will be eliminated to a great extent by using a 2.5 cm thick Caesium Iodide detector immediately below the CZT plane operated in anticoincidence mode.

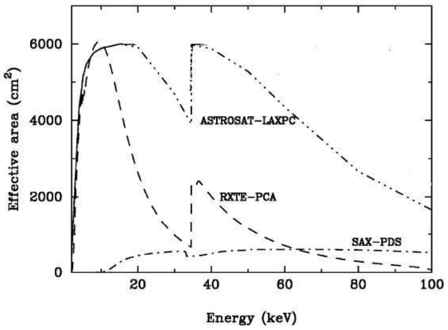

Fig. 1. Effective area as a function of energy for LAXPC Instrument

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3.3. Soft X-ray Imaging Telescope (SXT):

SXT will carry out moderate resolution (3’) imaging, and medium resolution (E/Δ E ∼20 to 50) spectroscopy in 0.3 to 8 keV based on the use of conical foil mirrors of 2 meter focal length with X-ray CCD as the detector. The conical foil X-ray mirrors and CCD detector have been used successfully in the ASCA mission (Tanaka et al. 1994). The gold coated X-ray reflecting mirrors made by nesting 41 conical shells, have been formed by replication process similar to the one used for the Japanese Astro-E2. An open gate, frame transfer CCD of 600 x 600 pixels of 40μ x 40μ size having an image section and a store section, developed by Leicester University (LU) for the Swift mission, will be used for the SXT. The CCD camera will be developed in collaboration with the LU group. The CCD will be cooled to about -80^oC by a thermoelectric cooler coupled to a passive radiator plate. The optical bench as well as the entire SXT housing cylinder will be fabricated using CFRP. The CCD will be read out in imaging, timing and photon counting modes with maximum intensity for a point source of ∼100 mCrab without pile up.The CCD will have an energy resolution of about 130 eV at 6 keV and an effective area of about 200 cm^2 at 2 keV dropping to 25 cm^2 at 6 keV. The expected count rate of SXT is about 1.4 cps per mCrab.

3.4. The Ultraviolet Imaging Telescope (UVIT):

The UVIT instrument consists of two identical telescopes each with 38 cm aperture primary and 14 cm secondary and uses three channel plate multiplier and CCD/CMOS based photon counting detectors. It will have angular resolution of about 2”, a circular filed of 0.5^o, time resolution of about 1 s and sensitivity to detect a 21 magnitude star in 1000 sec exposure in 50 nm pass band. One telescope will cover 120 -180 nm far-uv (FUV) band while the second telescope will have a dichroic beam splitter to provide two pass bands, 180-300 nm near-uv (NUV) band and the 350-650 nm visible band. In addition several filters with pass band of 10 to 50 nm centered at UV lines, will be mounted in a filter wheel in each telescope for narrow band imaging and photometry. The mirrors will be made from light weighted Zerodur with aluminium reflecting surface protected by a layer of magnesium fluoride. The telescopes will have suitable baffles above them to reduce background due to stray light. The three Photon Counting Detectors (PCDs), 2 for the 2 UV and one for the Visible channel, are being made in collaboration with the Canadian Space Agency (CSA). The CCD/CMOS frames are read out at a suitable rate to obtain the position of the photons to construct an image of the sky under observation.

3.5. Scanning X-ray Sky Monitor (SSM):

This is similar in design to that of the highly Successful All Sky Monitor (ASM) on the RXTE. It is based on the use of a one dimensional Position Sensitive Proportional Counter (PSPC) sensitive in 2-10 keV with an aluminium coded mask aperture of 6^o X 90^o FOV placed above it. The SSM will consist of 3 coded mask cameras with PSPCs, mounted suitably on a boom with rotation capability to scan the sky. Each PSPC has 8 anode cells of 1.2 cm x 1.2 cm,has a 25μ thick Mylar window and will be filled with a mixture of Argon,Xenon and Methane at 800 torr. The position of the incident X-ray is measured by charge division technique to an accuracy of about one mm. The position of a source will be measured along the scan direction to an accuracy of 6’ to 8’ depending on the source intensity.

A summary of the characterstics of all the Astrosat instruments is given in table 1.

4. ASTROSAT MISSION DETAILS

The Astrosat will be a three axis stabilized satellite with orientation maneuvers and attitude control done by using reaction wheels and magnetic torquers which get input from 3 gyros and 2 star sensors. It will have pointing accuracy of about one arc second. A solid state recorder with 120 Gb storage capacity will be used for on board storage of data .The data will be transmitted by two carriers,once in all the visible orbits, at a rate of 105 Mb / sec. The total mass of Astrosat observatory is estimated to be 1600 kg including 868 kg mass of the scientific instruments. It will be launched in a circular orbit of about 600 km altitude with orbital inclination of 8 degree by well proven Indian Polar Satellite Launch Vehicle (PSLV)

Table 1. A summary of the characterstics of all the Astrosat instruments

	UVIT	LAXPC	SXT	CZTI	SSM
Detector	Photon Counting, CPM + CCD based UV and optical detectors	Multilayer Proportional Counters	X-ray CCD (at the focal plane) of Wolter-1 conical foil mirrors	CdZnTe detector array	Position-sensitive proportional counter
Optics	Twin Ritchey Chretian optics with 38 cm aperture primary	Collimator	Conical foil mirrors (∼Wolter-1)	2-D coded mask	1-D coded mask
Band Width	128-180nm uv 180-300nm 350-650nm	3-80 keV	0.3-8 keV	10-100 keV	2-10 keV
Effective Area (cm^2)	∼25 in 120-300nm 50 in 350-650nm	6000 @ 5-30keV 5000 @ 50keV	125 @ 0.5keV, 200 @ 1-2keV, 25 @ 6keV	500 ($E \leq 10$ keV)	∼40 @ 2keV 90 @ 5keV (Xe gas)
Field of View	0.50^o diameter	1^o x 1^o	0.35^o (FWHM)	17^o x 17^o	6^o x 90^o
Energy Resolution (FWHM)	≤100 nm (filters dep.)	10% @ 22 keV	∼2% - 3% @ 6keV	5% @ 60keV	19% @ 6keV
Angular Resolution	2 arcsec	∼1-5 arcmin (scan mode only)	3 arcmin (HPD)	8 arcmin	∼ 5-10 arcmin
Time Resolution	1 S	10μsec	2.6 s, 0.3 s, 1 ms	1 ms	1 ms
Sensitivity (Obs.Time in ks)	20 magnitude (4σ)in 50 nm band	0.1 mCrab (3σ) (1K)	10 mCrab(5σ) (10 K)	0.5 mCrab (5σ) (10K)	∼30 mCrab (3σ) (0.3 K)
Total Mass (KG)	290	390	90	50	48

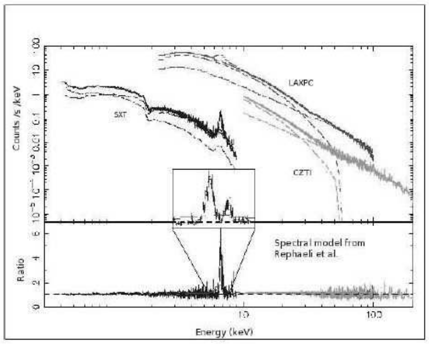

Fig. 2. Simulated wide band X-ray spectrum from the Coma cluster

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from Shriharikota range in India in 2007/2008. The Astrosat will have a minimum mission life of 5 years.

5. EXPECTED SCIENCE FROM ASTROSAT:

Multiwavelength studies will be a unique capability of Astrosat that will improve understanding of the radiation processes and the environment in the vicinity of the central compact objects in the AGNs. Observations of binaries with neutron star, black hole or white dwarf as X-ray source will lead to understanding of the nature, environment, site and geometry of X-ray and UV emission of these objects. Variability studies over a wide spectral and time domain are crucial for probing the nature of the sources and the cause of variability (van dar Klis 2000). Detection and detailed studies of kHz QPOs in hard X-rays is an almost unexplored area that is important to probe the accretion flows closest to the compact source. One will be able to successfully search QPOs from the X-ray sources with LAXPC in the kHz range if the source intensity rises above 50 mCrab. The X-ray spectral measurements of the continuum and lines in 0.5-100 keV interval from simultaneous observations will reveal origin of the different components of the spectra and parameters of the radiation processes.

Simulated wide band X-ray spectra of Coma Cluster of galaxies are shown in Figure 2 for the SXT, LAXPC and the CZT.The X-ray spectrum of Coma cluster measured by Rephaeli et al. (1999) with the RXTE was used in simulation.

With an exposure of 1 day LAXPCs will provide spectrum with good statistical significance for a 0.1 mill Crab intensity X-ray source. The CZT Imager will be able to detect a source of 0.5 milliCrab in 1000 s and obtain a good spectrum in one day of observation. The cosmic X-ray sources, that will be observed with these detectors, range from the nearby solar-mass Galactic X-ray binaries to the largest structures in the universe, the clusters of galaxies. The sensitivity of the LAXPCs and the CZT array for measurement of magnetic field of nutron stars is unmatched by any other existing experiment. Using the cyclotron line fluxes detected from the X- ray pulsar in 4U0115+63 with RXTE, a simulation of the expected signal in the LAXPC array is shown in Figure 3 along with the actual observed spectra from RXTE-PCA and BeppoSAX PDS (Heindel et al. 1999, Santangelo et al. 1999). It is obvious that the cyclotron lines will stand out very clearly in the LAXPC spectrum compared to shallow dips in the PCA and PDS spectra. Spectroscopy of hot thin collisional plasmas in galaxies, clusters of galaxies, supernova remnants and stellar coronae, and photo-ionized matter in accreting white dwarfs, neutron stars, black-holes and AGNs would be carried out with SXT. With energy resolution that is 10 to 50 times better than that of the proportional counters, SXT will separate the line emission and absorption components from the continuum in all known varieties of objects.

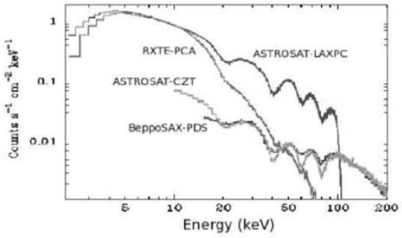

Fig. 3. Simulated X-ray spectrum of the pulsar 4U0115+63 for the LAXPC and CZT showing cyclotron absorption features

Figure 3. Simulated X-ray spectrum of the pulsar 4U0115+63 for the LAXPC and CZT showing cyclotron absorption features

The imaging UVIT observations with ∼2 arc sec angular resolution will measure the morphology and energy distribution of galaxies in the local region i.e. at the present epoch and compare them with those at the high red shift. The UVIT will detect first burst of star formation in low surface brightness blue dwarf galaxies from morphological studies by deep imaging observations. It will also study star bursts in distant galaxies and map the ionized gas in them. The UV colours will provide a measure of the properties of the dust in normal and starburst galaxies. It will map the Galactic H II regions, planetary nebulae and supernova remnants in our Galaxy well as those in the nearby galaxies in various emission lines e.g. CII (235 nm), CIII (190.9 nm), CIV (155 nm), O II (247 nm) etc. to map the elemental distribution and the physical condition of the gas. By studying early type hot OB stars in our Galaxy and their distribution in nearby galaxies one will be able to obtain the star formation histories and enrichment of gas.

The Astrosat observatory with 4 co-aligned X-ray and UV instruments and an X-ray sky monitor will be a powerful tool to probe the astrophysical processes and environment of all kinds of astronomical sources. With its broad spectral coverage in the X-ray band and simultaneous UV and visible observation capability, it is expected to bring about a qualitative change in the multi-wavelength astronomy.

ACKNOWLEDGMENTS:

I acknowledge the valuable inputs provided by my colleagues in the Astrosat project. I am especially grateful to R.K.Manchanda, B.Paul , A.R.Rao, S.Seetha, P. Sreekumar, K.P.Singh , S.N.Tandon and N.K.Rao for their contributions to the science aspect of the Astrosat mission discussed in this paper. Finally I thank Parag Shah for help in preparing the manuscript.

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