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Astrosat: The First Indian Astronomy Satellite with Multiwavelength Capability.

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Astrosat observatory under development in India will be the first full-fledged Indian Astronomy mission to be launched by Indian Space Research Organization (ISRO) in late 2007 for multiwavelength studies of cosmic sources. Astrosat will carry 4 X-ray astronomy instruments and one UV imaging instrument consisting of 2 identical telescopes for visible and UV studies. This mission will carry out simultaneous observations for high resolution timing, spectral and imaging studies with all the co-aligned instruments over a spectral band covering visible, near-UV and far-UV bands and X-ray band from 0.3 - 100 keV. A Scanning Sky X-ray Monitor (SSM) will continuously monitor known sources and detect new X-ray transients. Major scientific goals of the Astrosat mission will be presented and a summary of the instruments and their characteristics will be described.

1. Introduction

X-ray astronomy has grown and matured in last 30 years due to successful operation of a series of X-ray observatories with progressively improved imaging and spectral resolution capabilities. Superior sub-arc second X-ray imaging capability of Chandra and high spectral sensitivity of XMM-Newton are producing spectacular X-ray images and spectra of a range of objects in 0.1-10 keV band [1],[2],[3] Large collecting area and high time resolution capability of RXTE has resulted in the discovery of high frequency QPOs (kHz QPOs) from X-ray binaries which enables one to probe inner most region of the accretion disc close to the neutron star surface and event horizon of the back holes [4]. Space-based ultraviolet astronomy has also developed considerably with the IUE and FUSE having spectroscopic capability [5]. Recently launched Galex mission is carrying out a sensitive UV sky survey which is expected to result in a catalog of millions of UV objects [6].

To understand the nature of cosmic sources, their radiation processes and environment, it is necessary to measure their emission over the entire electromagnetic spectrum from simultaneous observations in different wavebands.The most efficient and effective way of multiwavelength studies is to have a dedicated satellite mission which will carry several instruments covering the desired spectral bands. Astrosat has been conceived to meet the long felt need for such a mission with its unique wide spectral coverage extending over visible, ultraviolet, soft x-ray and hard x-ray bands with 4 co-aligned instruments. Astrosat is a collaborative effort of several Indian institutions that 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) , Physical Research Laboratory (PRL) etc.

2. Scientific objectives of ASTROSAT

Some of the principal scientific objectives of ASTROSAT are :

(a) Multiwavelength studies of different types of cosmic sources over a wide spectral band extending over visible, UV (120 - 300 nm), low energy X-ray (0.3 - 8 keV) and high energy X-ray (10-100 keV) bands from simultaneous observations with different instruments. (b) Correlated time variations of intensity in visible, UV, soft and hard X-ray bands to investigate the origin and mechanism of the emission of radiation in different wave bands. (c) Studies of periodic (pulsations, binary light curves, QPOs etc) and aperiodic (flaring activity, bursts, flickering and other chaotic variations) variability by high time resolution ($\sim$10 μsec) photometry over the spectral band 0.3-100 keV. (d) Broad band X-ray spectroscopic studies from 0.3-100 keV for X-ray binaries, Supernova remnants (SNRs), CVs, Stellar Coronae, AGNs etc. This will be done using moderate energy resolution (E/ΔE) $\sim$30-50 of X-ray CCD in Soft X-ray Telescope (SXT),low resolution (E/ΔE) $\sim$ 6-10 of LAXPCs in 3-80 keV band and moderate resolution CZT detector array with resolution of $\sim$10 to 20 in 10-100 keV band. (e). Measuring magnetic fields of neutron stars by detection and studies of cyclotron lines. (f) UV Studies of a variety of galactic sources including (I) late type active stars e.g.RSCVn stars, dMe stars and T Tauri stars to understand the role of rotation and magnetic field in stellar activity (II) hot white dwarfs, sub-dwarfs in globular clusters (III) spectral energy distribution of cataclysmic variables and X-ray binaries. (IV) UVlight curves of Beta Cephei and Wolf-Rayet stars and (V) Mapping of the ionization structure across emission nebulae and supernovae remnants from UV imaging observations. (f) UV imaging studies of nearby and distant galaxies and AGNs to probe their structure and spectral energy distribution, to detect regions of starburst activity and ionized gas.

3. ASTROSAT Instruments

The Astrosat will have four coaligned instruments mounted on its top deck and an X-ray sky monitor.

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

For timing and low resolution spectral studies over a broad energy band (3-80 keV) a cluster of 3 identical co-aligned Large Area X-ray proportional counters (LAXPCs),with a multi-anode,multi-layer configuration having FOV of 1° x 1° will be used. The X-ray detection volume consists of 60 anode cells each of cross-section 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 the background. copper wires spaced 3 mm apart., enclosed in a housing filled with 90% Xenon and 10% methane at a pressure of about 1600 Torr. This will achieve an average detection efficiency of close to 100% below 15 keV and about 50% up to 80 keV. The total effective area of 3 LAXPCs will be $\sim$ 6000 cm^2 below 20 keV and about 5000 cm^2 at 50 keV This will be the largest effective area for 20-80 keV region ever flown in a satellite mission and provide unprecedented sensitivity for the timing and spectral observation in the hard X-ray band.

(ll). Cadmium-Zinc-Telluride Imager (CZTI)

For medium resolution spectroscopy in hard X-ray band (10-100 keV) and low resolution imaging ($\sim$0.1 degree), it is proposed to use an array of pixilated Cadmium-Zinc-Telluride (CZT) detectors that have superior energy resolution and are now commercially available. The CZT array will have a geometrical area of 1024 cm^2 made up of 2.5 mm x 2.5 mm pixels with thickness of 5 mm. Thus there will be 16384 pixels and charge from each will be read out by 128 ASICs each having 128 channels. This will provide position and energy of each absorbed X-ray photon. The imaging will be realized by a coded aperture mask (CAM) placed suitably above the CZT detector plane. The CZT detector can be operated at temperature of about 0° C to -20°C without significant leakage current. The cooling of the CZT array will be done passively by using a radiator plate of appropriate area. Compton scattering of low energy gamma-rays in the CZT results in X-ray-like background events that will be eliminated to a great extent by placing an anticoincidence detector of 2.5 cm thick Caesium Iodide below the CZT plane.

(III) Soft X-ray Imaging Telescope (SXT)

Moderate resolution (about 3 arc minute) imaging and medium resolution (E/ΔE ∼20 to 50) spectroscopic studies of X-ray sources in 0.3 to 8 keV band will be done by a Soft X-ray Imaging Telescope (SXT) based on the use of conical foil mirrors for X-ray reflection with an X-ray CCD as the focal plane detector as done in the ASCA mission [7]. The gold coated X-ray reflecting mirrors, with focal length of 2 meter and made by replication process, will have 41 nested conical shells of 100 mm length. An open gate frame transfer CCD with 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°C by mounting it on a thermoelectric cooler that will radiate its heat through a passive radiator plate coupled by heat pipes. The estimated point spread function (PSF) of the SXT is about 3 arc minutes. The CCD will be read out in imaging, timing and photon counting modes. The effective area of SXT will be about 200 cm^2 at 2 keV and will drop to about 25 cm^2 at 6 keV. The expected count rate of SXT is about 1.4 cps per milliCrab.

(lV) The Ultraviolet Imaging Telescope (UVIT) :

For Ultraviolet (120-300 nm) and visible (350-650 nm) bands, a two telescope configuration Ultraviolet Imaging Telescope (UVIT) has been chosen that has two similar telescopes, each with 38 cm aperture primary and 14 cm diameter secondary and uses three channel plate multiplier and CCD/CMOS based photon counting detectors. It will have angular resolution of ∼2', a circular filed of 0.5 degree, a time resolution of about 1 second, and will be able 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, one covering 180-300 nm near-uv (NUV) band and the second with visible band of 350-650 nm. 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 to do narrow band imaging and photometry. The mirrors will be made from light weighted Zerodur material with aluminium reflecting surface protected by a layer of magnesium fluoride. The three Photon Counting Detectors (PCDs), 2 for the 2 UV and one for the Visible channel, are being realized in collaboration with the Canadian Space Agency (CSA). The PCDs are based on the use of a channel plate multiplier (CPM) with coating of a suitable photocathode followed by a phosphor coupled through optical fiber to a CCD / CMOS device that provide the position of the photons to construct the image of the sky under observation.

(V) Scanning X-ray Sky Monitor (SSM) :

The Scanning X-ray Sky Monitor (SSM) for Astrosat is based on the use of a one dimensional Position Sensitive Proportional Counter (PSPC) with a coded mask aperture placed above it. The PSPC is used to measure the positions and the intensities of the shadow patterns cast by the X-ray sources within the FOV from which the directions and intensities of the sources may be inferred. The main features for a sky monitor are large sky coverage (wide field of view (FOV)), good position resolution (a few arc min) and sensitivity of a few mCrab in about half an hour observation. The SSM will consist of 3 coded mask cameras with PSPCs, mounted suitably on the satellite deck, so as to scan the sky when other instruments on Astrosat are pointed towards a specific source. Each PSPC sensitive in 2-10 keV band will have field of view of 6° x 90°. The position of a source will be measured along the scan direction to an accuracy of 6' to 8' depending on the source intensity.

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, to provide one arc second pointing capability. A solid state recorder with 120 Gb storage capacity will be used for onboard 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 with 1600 kg mass including 868 kg mass of the scientific instruments, will be launched in a circular orbit of about 650 km altitude with orbital inclination of 8° by well proven Indian Polar Satellite Launch Vehicle (PSLV) from Shriharokota range in India in the later half of 2007. The Astrosat will have a minimum mission life of 5 years.

5. Expected Science from Astrosat and Conclusion

Multiwavelength studies will be a unique capability of Astrosat that will vastly improve understanding of the radiation processes and the environment in the vicinity of the central compact objects. Periodic and aperiodic time variability studies for all classes of X-ray and UV bright sources will be done with Astrosat instruments over a wide spectral region and wide time domain. Energy spectra of all classes of X-ray sources will be measured by Astrosat over 0.3-100 keV from simultaneous observations. The magnetic field strength of the X-ray pulsars will be measured by detection of cyclotron absorption lines. The imaging UVIT observations with 1.8 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 gas.

The Astrosat observatory with its complement of 4 different coaligned 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 multiwavelength astronomy.

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