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ASTROSAT observations : complementary studies from ground

P. Sreekumar*
ISRO Satellite Centre, Bangalore 560 017, India

Abstract. Since the advent of the satellite era, X-ray astronomy and UV astronomy have advanced tremendously. The discovery of intense X-ray emission from accreting compact objects has permitted very detailed timing and spectral studies, leading to the important discovery of neutron stars and black holes as likely candidates driving these systems. Today, with the Rossi X-ray Timing Experiment (RXTE), Chandra x-ray Observatory (CXO) and XMM-Newton telescopes, X-ray astronomy provides the ideal tool to study regions of strong gravity, high magnetic field and high density in the Universe. Building on the success of earlier Indian piggyback space astronomy experiments, ASTROSAT is now being designed as India's first dedicated multiwavelength astronomy satellite to provide a broad-band space platform ranging from optical to hard X-ray. However significant advancements in the ASTROSAT studies of many of the compact objects are expected from a wider multiwavelength observation platform including ground-based facilities at radio, infrared, optical and TeV bands.

Keywords : UV, X-rays, ASTROSAT, AGN

1. Introduction

Initial studies in X-ray astronomy began with the investigations of the Sun. In 1949 using simple X-ray detectors on a rocket, Herb Friedman and his team found that the Sun does emit X-ray but the X-ray intensity was one-millionth of the visible light from the Sun. Subsequently, a US team led by Riccardo Giacconi discovered strong X-ray emission from the Scorpius constellation during a rocket flight in 1962. Unlike the Sun,

*e-mail: pskumar@isac.ernet.in

this source, Sco X-1 had an X-ray intensity 600 times the emission in visible light. Thus we had the first case of an astronomical source which emitted most of its energy at X-ray wavelengths, giving birth to X-ray astronomy as a new field of astronomical research. Today these studies are important to understand some of the most energetic phenomena in the Universe occurring in regions of strong gravity ($> 10^{11}$ g), strong magnetic fields ($> 10^8$ Gauss) and high temperature ($>10^6$ C). Currently, there are three major X-ray satellites in orbit (RXTE - high-resolution timing studies, CXO - high-resolution spectroscopy and high-angular resolution imaging and XMM-Newton - high-throughput, simultaneous spectroscopy and imaging) which will soon be joined by ASTRO-E2, adding large collection area at higher energies to this armada of X-ray satellites. The X-ray instruments on ASTROSAT do not address high angular resolution or spectroscopy at low-energies, instead focus on high-resolution timing studies and broad-band moderate-resolution spectroscopic coverage from 0.3 keV to 100 keV (large effective area upto 80 keV which is nearly 4-5 times the RXTE capability at high energies).

Space-based UV astronomy has also developed considerably, although not to the level of X-ray astronomy due to the limited number of UV missions launched so far. The IUE satellite with more than a decade of operation, made UV spectroscopic studies of hot stars, galaxies, chromospheric and transition region of active late type stars, accretion disk emission from novae and active galactic nuclei (AGN) and contributed to the understanding of the outer atmospheres of stars and the environment of the galaxies. The only UV sky survey carried out about three decades ago with TD1 satellite, detected more than 30,000 sources. The current GALEX mission will carry out a sensitive UV sky survey that is expected to result in a catalog of millions of UV objects. There is thus a vast scope for imaging, photometric and spectroscopic studies of cosmic sources in the 110 to 300 nm band due to the paucity of observations so far in the UV region.

2. ASTROSAT

Beginning with the Aryabhatta satellite, many opportunities to conduct astronomical studies from a space platform have been provided by ISRO. More recently, these include the gamma-ray burst experiment on SROSS-C2, Indian X-ray Astronomy Experiment (IXAE) onboard IRS-P3, and the Solar X-ray experiment on GSAT-/2. Following the success of IXAE on IRS-P3, it was felt nationally that the time was ripe for a major initiative in space astronomy. This led to the concept of a dedicated multiwavelength astronomy mission named ASTROSAT.

To understand the nature of cosmic sources, their radiation processes and environment, it is necessary to measure their emission over the entire electromagnetic spectrum. Since intensity of most cosmic sources varies with time, the variability being wavelength dependent, it is necessary to make simultaneous observations in different wavebands. Most of the current space astronomy observatories are dedicated to a particular waveband e.g. X-ray, UV etc and therefore, usually multiwavelength studies have to be made from coordinated observations with different satellites. There are logistical problems in making simultaneous and coordinated studies of a specific object from different satellites and ground-based telescopes. As a result, despite a large number of such multiwavelength observation campaigns, very few sources have so far been studied over wide spectral band leading to poor understanding of the underlying physical processes. The most efficient and effective approach is to have a dedicated satellite such as ASTROSAT with several co-aligned instruments covering the desired spectral bands so that simultaneous observations in all the desired wavebands is possible.

2.1 Primary science objectives of ASTROSAT

- Understand the production processes that lead to the broadband x-ray emission spectrum in cosmic sources.
- Study correlated intensity variations over time in the visible, UV, soft and hard X-ray bands to address the origin of radiation in different wave bands.
- Search for black hole sources by limited surveys in the galactic plane.
- Measure magnetic fields of neutron stars by detection and studies of cyclotron lines in the X-ray spectra of X-ray pulsars.
- Detect and locate new transient X-ray sources.
- Multi-band all-sky or limited sky survey covering Ultraviolet band from 130300 nm and X-ray band from 0.3 100 keV in six months. The all-sky UV survey will be the most sensitive survey in UV going down to the 20th magnitude or better.

These primary science objectives of ASTROSAT are being met with 5 science payloads. They are :

1. three identical large area xenon-filled proportional counters (LAXPC) instrument covering 3 – 100 keV region
2. Cadmium-Zinc-Telluride Imager (CZTI) with coded mask aperture, sensitive in 10 – 100 keV
3. a soft x-ray imaging telescope (SXT) using x-ray reflecting mirrors and x-ray CCD for imaging and spectral studies in 0.3 – 8 keV
4. A Scanning Sky Monitor (SSM) for detection and monitoring of new and known X-ray sources in 2 – 10 keV region.
5. An Ultra Violet Imaging Telescope (UVIT) consisting of two identical telescopes, one covering the Far UV (FUV) band (130 – 200 nm) and the second sensitive in Near UV (NUV) (200 – 300 nm) and Visible bands.

The important parameters of the ASTROSAT instruments are listed in the table.

Table 1. Important characteristics of ASTROSAT payload instruments.

	UVIT	SXT	LAXPC	CZTI	SSM
Detector	photon counting CCDs	X-ray CCD	Prop. counter	CdZnTe array	Position-sensitive prop. counter
Optics	Twin RC system	conical foil	collimator	2-D coded mask	1-D coded mask
Energy range	1300–3000 Ang	0.3–8 i keV	3–100 keV	10–100 keV	2–10 keV
Effective area (cm^2)	60 (depends on filter)	125 @ 0.5 keV 200 @ 1–2 keV	6000 @ 5–30 keV	500	40 @ 2 keV 90 @ 5 keV
FOV	0.50°dia	0.35°(FWHM)	1°× 1°	17°× 17°	6°× 90°
Energy Resolution		2%@ 6 keV	9%@ 22 keV	5%@ 10 keV	18%@ 6 keV
Angular Resolution	1.8 arcsec	3–4 arcmin (HPD)	5 arcmin (scan mode only)	8 arcmin	5–10 arcmin
Detection Sensitivity(σs) (Obs. time)	23^{rd} mag (5σ) (1800 s)	10 μCrab (5σ) (10000s)	0.1 mCrab (3σ) (1000 s)	0.5 mCrab (3σ) (1000 s)	$\sim$ 30 mCrab (3σ) $<$ 5 min
Sensitivity in mJy	.001mJy	2.45×10^{-6}mJy @ 1 keV $1.3 \times 10^{-5} mJy$ @ 5.2 keV	$1.3 \times^{-4} mJy$ @ 5.2 keV 2.2×10^{-5}mJy @ 30 keV	6.4×10^{-4}mJy 5.2 keV 1.1×10^{-4}mJy @ 30 keV	.04 mJy @5.2 keV

3. Relevance of ground-based observations for ASTROSAT

The broad-band coverage of ASTROSAT from optical to UV to X-ray energies can be further complemented with additional ground observations at radio, IR, optical and TeV energies. Due to paucity of space, we examine a specific source class viz., the blazar class of active galactic nuclei to demonstrate the value addition from ground observations. Blazars are characterised by broad band emission ranging from radio to TeV gamma rays. These sources where it is believed that the line-of-sight is very close to the relativistic jet direction, show strong temporal variability throughout the electromagnetic spectrum. An important science question that has been the intensely pursued for the last two decades is "What is the origin of the jet emissions and what is its composition?". Various scenarios proposed include relativistic electrons and protons, relativistic electrons and positrons or relativistic protons interacting with the magnetic and radiation fields to produce the observed emission.

It is very clear that a deeper understanding of the jet composition and emission processes can arise from time evolution studies of the broad-band spectral emission from blazars. ASTROSAT with its simultaneous optical/UV and X-ray observational capability can provide excellent simultaneous sampling of the synchrotron and inverse Compton processes in a blazar such as 3C279 (see Fig.1) where the synchrotron emission cuts-off near the EUV region. However, studies have revealed the presence of a near-continuum of synchrotron cutoff energies from IR to hard X-ray energies (Fossati et al., 1999). In many of the High-frequency Peaked Quasars (HPQs) the inverse Compton emission is primarily detected at TeV energies. Further, long-term monitoring of the source can be carried out from ground at radio, IR and optical energies using GMRT, Gurushikhar and Kavalur/Hanle/IUCAA/ARIES telescopes. These observations are most relevant for ASTROSAT since it is hoped that observational programs involving long-term monitoring of specific AGNs will be taken up as a key project during the mission.

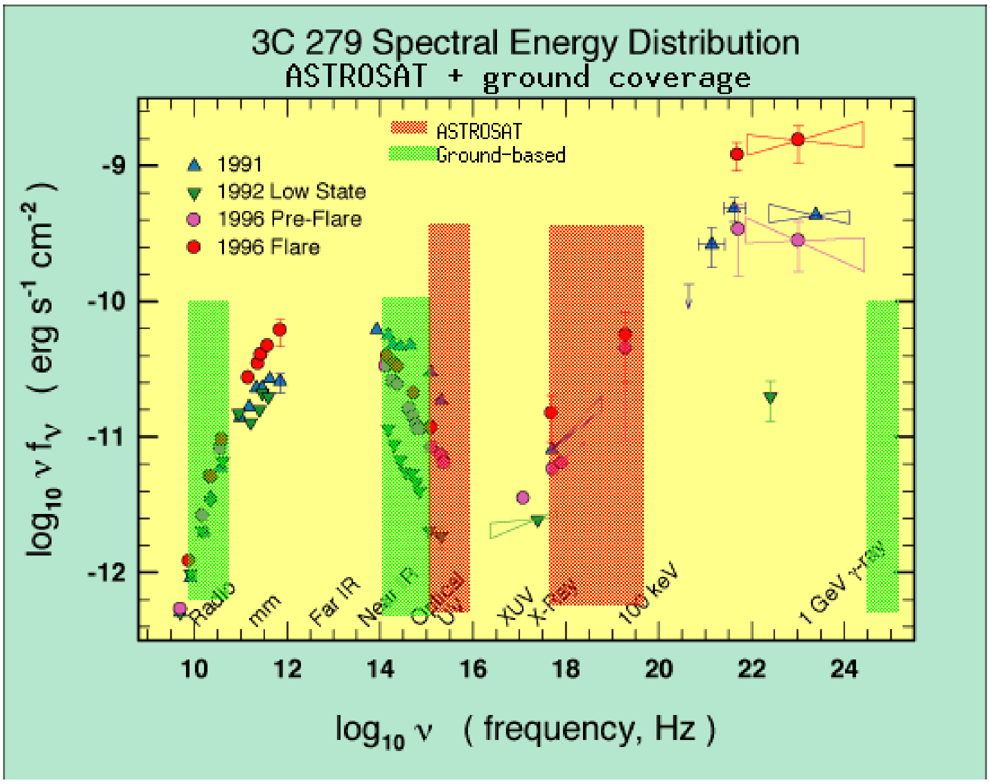

Figure 1. Spectral Energy Distribution of blazar 3C279 showing the energy ranges covered by ASTROSAT and complemented by ground-based instruments (adapted from NASA/GSFC - Heasarc.

4. Mission details

ASTROSAT is scheduled to be launched in 2007 using PSLV from SHAR center into a low-inclination (<10°), 650 km circular orbit. The nominal mission duration is 5 yrs. The payload data of 30 Gbit per orbit will be stored on a solid state recorder. As many as 4 orbits at a stretch are not visible over the data reception centre. Therefore it is planned to use a 120 Gbit solid state recorder. The data from satellite to the ground station are transmitted in X-band (two carriers). Each chain transmits data at a rate of 105 Mbps. Some of ASTROSAT's unique requirements include continuous data acquisition, large P/L data rates, 3-axis stabilized pointing to targets and the need to carry out constant monitoring of charged-particle levels in orbit. A separate data reception station for X-band payload data reception and pipeline processing of payload data is being planned.

In addition to many ISRO centers/units, the following outside institutes have significant roles in the ASTROSAT payload development.

- Tata Institute of Fundamental Research (TIFR), Mumbai
- Indian Institute of Astrophysics (IIA), Bangalore
- Inter University Centre for Astronomy & Astrophysics (IUCAA), Pune
- Raman Research Institute (RRI), Bangalore
- Physical Research Laboratories (PRL), Ahmedabad
- Bhaba Atomic Research Centre (BARC), Mumbai
- Centre for Space Physics (CSP), Kolkotta
- Canadian Space Agency (CSA)

The ASTROSAT will be a National Observatory which will be available for astronomical observations to any researcher in India. Although most of the observing time will be for the use of Indian researchers, a part of the ASTROSAT observing time will also be made available to International astronomical community on a competitive basis. ASTROSAT as a major astronomical mission is expected to bring together numerous scientific institutes and universities and provide much needed inspiration to the young students of the country to undertake careers related to understanding nature in its full glory.

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