

AstroSat: a decade of frontline astronomy

Kulinder Pal Singh* and S. Seetha

India's first dedicated multi-wavelength space observatory, AstroSat, completed a decade in orbit on 28 September 2025. Over the past ten years, it has demonstrated the country's capability to design, build, and operate an advanced space astronomy observatory. Observations carried out by the astronomy community in India and abroad have established AstroSat as a powerful platform for frontier research, enabling discoveries comparable to those made with the world's leading space observatories. AstroSat has observed a diverse range of celestial objects, including ordinary stars, novae, supernovae, binary systems containing white dwarfs, neutron stars and black holes, as well as distant galaxies seen as they existed billions of years ago. These observations have resulted in numerous discoveries and significantly advanced our understanding of some of the hottest, most energetic, and most enigmatic objects in the universe. The present article highlights the major scientific achievements of AstroSat during its first decade of operations and its enduring contributions to modern astronomy.

Keywords: Active galactic nuclei, galaxies, multiwavelength astronomy, stars, X-ray binaries

ASTROSAT, India's first space-based astronomical observatory, has marked more than 10 years of successful operations, observing the universe in the ultraviolet and X-ray bands. Weighing ~ 1.5 tonnes, AstroSat was launched aboard the PSLV-C30 XL on 28 September 2015. More than 50% of the satellite's total mass was dedicated to scientific payloads. It has five main payloads for observations: Ultra-Violet Imaging Telescope (UVIT) with two parallel optics, one for near ultra-violet (NUV) in 2000–3000 wavelength range, and one for far ultra-violet (FUV) in 1300–1800 Angstrom's band (developed by the Indian Institute of Astrophysics, Bengaluru); a Soft X-ray Telescope (SXT) (developed by the Tata Institute of Fundamental Research [TIFR], Mumbai) operating in the X-ray energy band 0.3–8 keV; three Large Area X-ray Proportional Counters (LAXPC) (developed by TIFR, Mumbai) operating in the 3–80 keV band; a Cadmium Zinc Telluride Imager (CZTI) (developed by TIFR Mumbai with the Physical Research Laboratory, Ahmedabad) operating in the 20–100 keV band and three Scanning Sky Monitors (SSM) operating from 2.5 to 10 keV (developed by the U. R. Rao Satellite Centre [URSC], Bengaluru). In addition, a Charge Particle Monitor (CPM) developed by TIFR Mumbai is mounted on the satellite to help identify times and regions of high particle background. The UVIT, SXT, LAXPCs and CZTI are all co-aligned to observe the same source simultaneously. The three X-ray instruments with overlapping energy bands provide a broad band spectroscopic capability to study cosmic X-ray sources. The LAXPCs have an excellent time resolution of 20 microseconds for timing studies, while the UVIT provides high-resolution imaging in UV with multiple filters with an overall resolution of about 1.4 arcsec that is 3–4 times

better than the earlier satellite known as Galaxy Evolution Explorer (GALEX) of the National Aeronautics and Space Administration (NASA). Detailed descriptions of the instruments have been published previously¹. All instruments were made operational within a period of a week to three months after launch. Launched into a near-equatorial and near-Earth circular orbit (6 degrees inclination and altitude of 650 kms), AstroSat has far exceeded its designed life of five years, and its operations are continuing to date. Its success is reflected in the pioneering scientific results it has enabled, leading to more than 539 publications in international journals and inspiring over 39 doctoral theses based on AstroSat observations and data².

Operations

The satellite has been operated continuously by the operations team at the ISRO Telemetry, Tracking and Command Network (ISTRAC), Bengaluru, under the guidance of the mission team at URSC, Bengaluru³. AstroSat incorporates several safety features, including specially developed two-axis sun avoidance manoeuvres that protect the satellite during transitions between observational targets. The first six months of operations constituted the Performance Verification (PV) phase, during which the instruments were operated in various observational modes determined exclusively by the instrument developers, under the guidance of their respective payload and programme managers. Upon completion of the initial six-month onboard commissioning phase, the instrument teams were granted one year of Guaranteed Time (GT) for exclusive observations. Subsequently, access to the observatory was progressively extended to the wider

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Distribution of AstroSat Observations (Total: 1713)

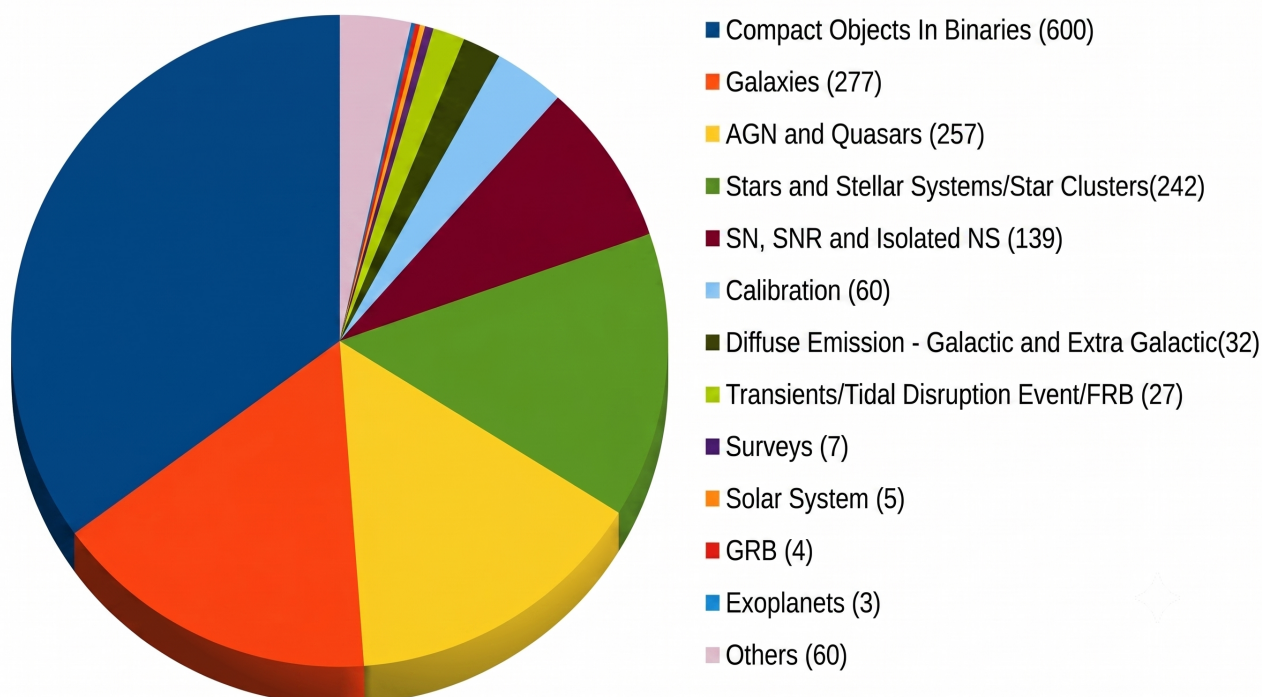


Figure 1. Different categories of cosmic objects observed during the first decade of AstroSat.

Indian and international astronomical communities through Announcements of Opportunity (AOs) issued by the Indian Space Research Organisation (ISRO). The AstroSat Proposal Processing System (APPS) was developed to receive and process observation proposals. These proposals were assessed for scientific merit by the AstroSat Time Allocation Committee (ATAC) and for technical feasibility by the AstroSat Technical Committee (ATC) constituted by ISRO. Proposals approved by both committees were subsequently scheduled for observations using software developed by teams at URSC and implemented at ISTRAC. AstroSat, India's first space observatory operated through an open call for scientific proposals, receives observational data at the ISRO Space Science Data Centre (ISSDC). The data are initially pre-processed at ISSDC and then forwarded to the respective Payload Operations Centres (POCs) for quality verification and validation. Subsequently, the POCs generate higher-level data products and return them to ISSDC for long-term storage, archiving and dissemination.

Observations and results

During its 10 years of operation, AstroSat has observed 1,713 targets of diverse nature (Figure 1) within our galaxy and beyond. With its simultaneous broadband wavelength coverage, AstroSat is comparable to NASA's Swift

Observatory. While Swift has high manoeuvrability and observations are usually short exposures of many targets in a day, AstroSat provides us with a long look capability of observations lasting for several days. This has led to some pioneering deep surveys with UVIT in and around the targets of interest that range from many types of stars and stellar clusters to galaxies and clusters of galaxies. An early observation of AstroSat UV Deep Field (AUDF), the deepest UV field ever imaged, led to the discovery of a clumpy galaxy named ADUFs01 at $z = 1.42$, emitting Lyman continuum radiation crucial for understanding the re-ionisation era and galaxy formation processes. Additionally, AstroSat's simultaneous broadband coverage, particularly the overlapping wideband coverage in the X-ray region, has led to some very significant results, a few of which are outlined below.

UV astronomy

UVIT observations have identified several new blue straggler stars and post-asymptotic giant branch stars in various globular clusters. The existence of hot luminous stars above the turn-off point in Hertzsprung-Russell diagrams (Blue Stragglers) suggests unusual stellar evolution processes (especially those involving binaries with one of the components being an extremely low-mass white

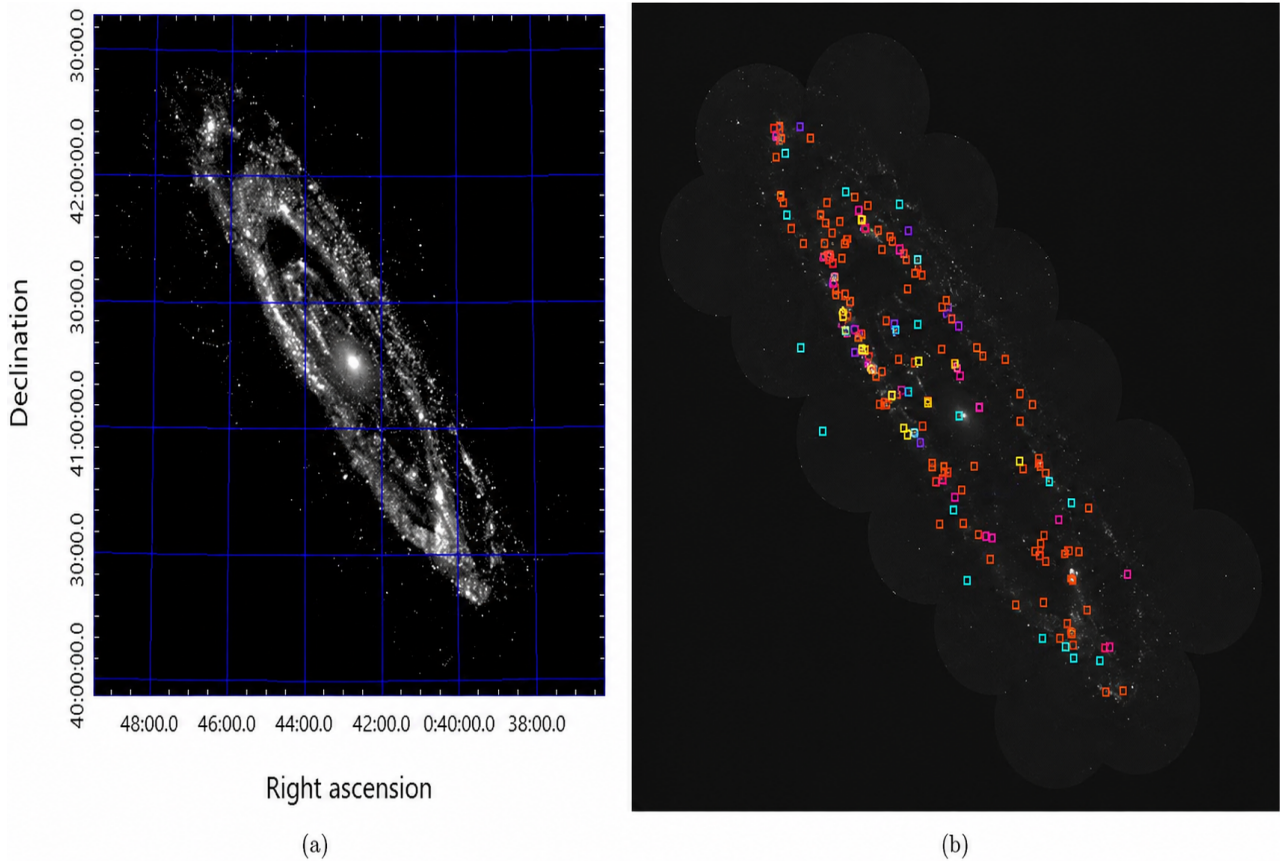


Figure 2. (a) Far-ultraviolet (FUV; F148W) mosaic image of M31. (b) Distribution of the 177 supernova remnants (SNRs) overlaid on the FUV mosaic. Red squares represent SNRs detected in the optical, aqua squares in X-rays, purple squares in both the optical and radio, pink squares in both the optical and X-rays, and yellow squares in the optical, radio, and X-rays⁴.

dwarf) operating in these stars, challenging the theoretical constructs. UVIT has studied the impact of interactions in galaxies, revealing new star-forming regions and the effects of galaxy mergers on their shapes/morphologies. It has studied galaxy clusters containing hundreds to thousands of galaxies with hot X-ray gas in the intra-cluster medium influencing star formation activity. A number of galaxies with distorted morphologies have been discovered, some of which have shapes resembling jellyfish and are named thus. These shapes result from processes like strangulation and ram-pressure stripping. These processes take place as the galaxies move from outer parts of the clusters into the central parts and can thus suppress star formation in them. The evolution of stars in galaxies leads to explosive end points known as novae and supernovae. Several supernova remnants (SNRs) (Figure 2) and novae (Figure 3) have been identified in deep images of the Andromeda galaxy (M31) covered with multiple UVIT observations.

A catalogue of the point sources observed by UVIT based on observations of 428 fields in the FUV and 54 fields in the NUV band, in 5 filters and covering an area of about 63 square degrees, has been made. This catalogue

contains 102,773 sources with the faintest magnitude (AB) of ~ 21.3 in a broad-band FUV filter that has the largest number of detections and with the limiting magnitude at around ~ 23 in the NUV. Several other catalogues going much deeper are in the making. For example, in the 28 arcmin diameter field surrounding an active galactic nucleus (AGN), IC 4329A, where UVIT goes as faint as 26.2 mag in NUV and 25.7 mag in FUV, a total of 4437 and 456 sources have been detected (above 5 sigma) in the NUV and FUV, respectively, containing many new sources. A cross-matching of this catalogue with Gaia-DR3 and XMM-Newton DR12 catalogues shows 651 optical and 97 X-ray counterparts.

Broad-band X-ray astronomy and multi-wavelength astronomy

AstroSat has advanced the study of X-ray binaries and their emission processes. It has measured cyclotron resonant scattering features in several neutron star binaries, thus leading to magnetic field determination on their surfaces. AstroSat/LAXPC has discovered X-ray emissions

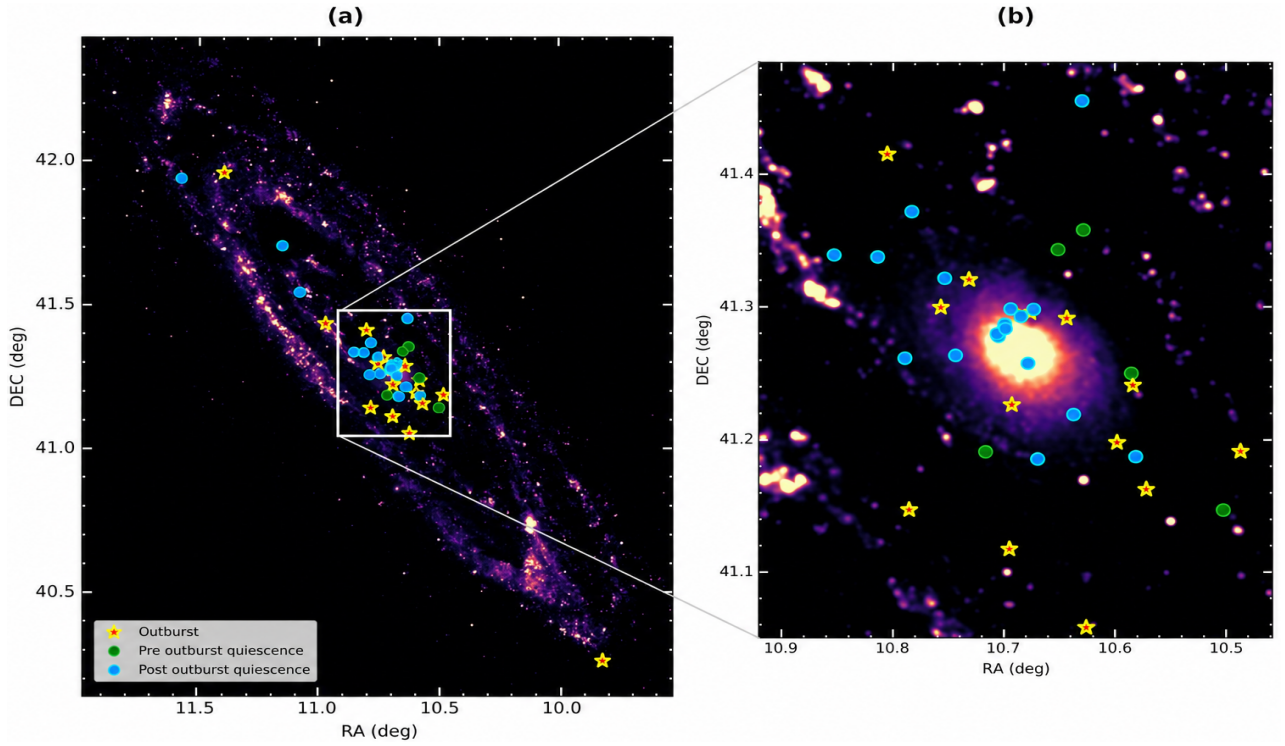


Figure 3. (a) Ultra-Violet Imaging Telescope (UVIT) FUV (F148W) mosaic image of M31 showing the locations of 42 novae, most of which were detected in the central region owing to the high spatial resolution of UVIT. The novae, observed at different stages of activity, provide insights into the evolution of accreting white dwarfs. (b) Zoomed-in view of the central region of M31 (ref. 5).

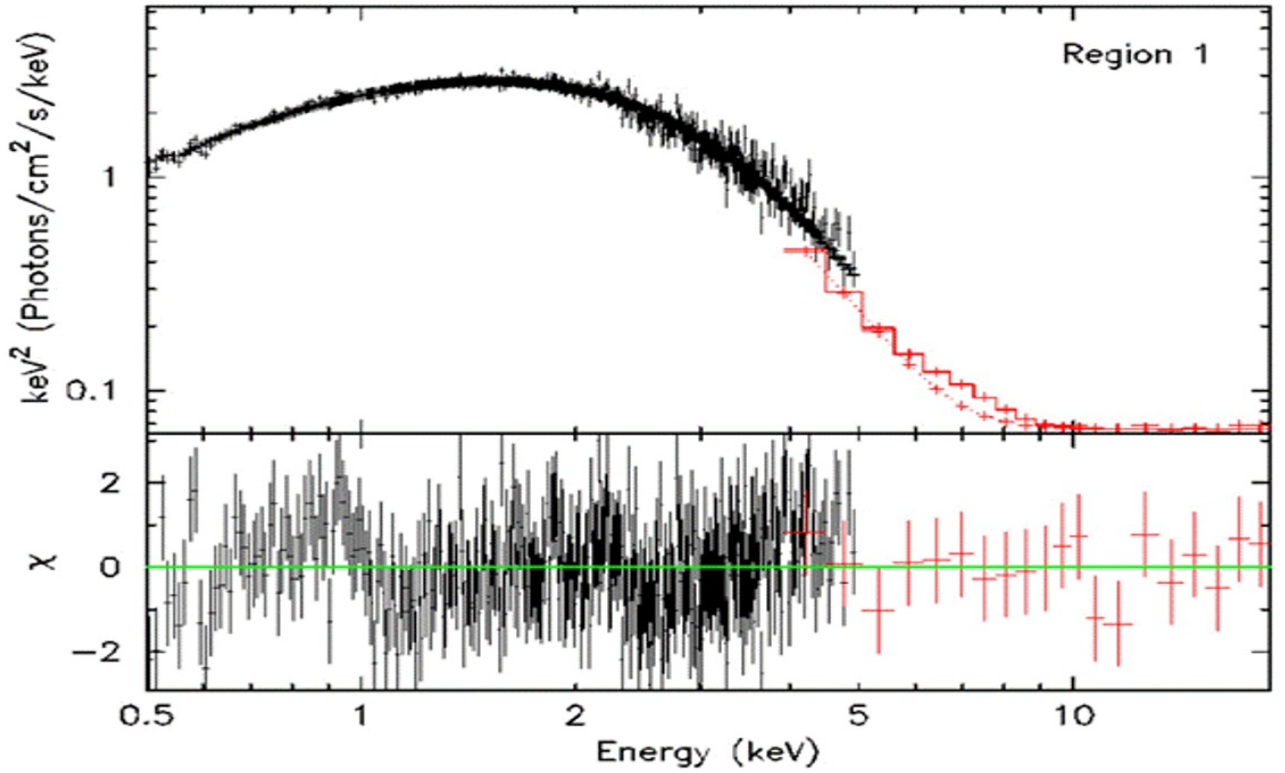


Figure 4. Unfolded spectrum of the MAXI soft X-ray transient MAXI J0637-430, obtained with the Soft X-ray Telescope (SXT; black) and Large Area X-ray Proportional Counters (LAXPC; red), fitted with a common spectral model⁶.

that exhibit rhythmic spin and orbital periods, as well as irregular fluctuations, high-frequency quasi-periodic oscillations (QPOs) in low-mass X-ray binaries, a correlation between QPO frequency and the inner accretion disk radius of a black-hole binary system, and the understanding of thermonuclear bursts and novae in binary systems. Type-I bursts occur in neutron star binaries, characterised by rapid increases in X-ray intensity. Joint observations using SXT and LAXPC (Figure 4) are a very powerful tool to study the spectral evolution in the X-ray binaries containing compact accreting objects like black holes, neutron stars and white dwarfs. Energy-dependent cross-correlation studies and spectral modelling using SXT and LAXPC together are able to constrain the size of the inner corona around the neutron star to between 30 and 100 kms in an X-ray binary known as GX 17+2. Observations of a recurrent nova (recurrence period of 28 years) V3890 Sgr captured the emergence of a super-soft X-ray source following a nova eruption using the SXT. Short-term variability of X-ray emissions during these events remains an area of ongoing research.

AstroSat has made significant strides in measuring X-ray polarisation, a challenging aspect of X-ray astronomy. The CZTI instrument performed polarisation measurements of the Crab pulsar, revealing variations during different rotation phases. These findings challenge existing theories of X-ray production in pulsars. Polarisation estimates in gamma ray bursts (GRBs) detected by CZTI are also providing important inputs towards understanding GRB processes.

AstroSat has facilitated multi-wavelength observations of AGN to understand their emission processes. AGN are powered by super-massive black holes (SMBH) and emit radiation across the electromagnetic spectrum. Observations of Seyfert galaxies and blazars have shown variability in UV and X-ray emissions. The UV emission from the inner accretion disk around an SMBH is modified by the corona and soft X-ray excess, and time-lag measurements with AstroSat have provided new insights into disk structure and dynamics. AstroSat observations combined with data from various national and international observatories

in radio, optical, UV and X-ray and theoretical efforts have contributed to new insights into the emission mechanisms in the inner regions around SMBH and powerful jets coming from some of these objects. Particle acceleration in jets is driven by shocks and turbulence, complicating the understanding of emission mechanisms. For example, AstroSat observations with UVIT, SXT and LAXPC of the blazar OJ 287 exhibited different flux states on yearly time scales, revealing insights into the spectral evolution of its jet.

To summarise, a decade of successful operation of AstroSat has been very productive, leading to several discoveries and leading to new insights into the science of almost all types of astronomical objects. Four of its co-aligned instruments (UVIT – FUV channel only, SXT, one LAXPC unit out of three and CZTI) are still working well, and we look forward to many more science results from AstroSat.

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