Overview of the AstroSat mission

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AstroSat is the first dedicated astronomy mission of India aimed at simultaneous multi-wavelength observations of celestial sources in X-ray, ultraviolet and limited optical spectral bands. The satellite was launched from Satish Dhawan Space Centre, Sriharikota on 28 September 2015 by PSLV-C30 (XL) in its 30th consecutive successful flight. The satellite was placed in an orbit with an altitude of 650 km and 6° orbital inclination. Currently, all the payloads are operational and observations are underway. The mission life is expected to be 5 years.

Keywords: Astronomy mission, celestial sources, multi-wavelength observations, payloads.

Introduction

Need for multi-wavelength observations

UNDERSTANDING the universe requires the study of radiation emitted by the celestial objects. The characteristics of this radiation and its interpretation provide knowledge of physical parameters of the radiation-emitting regions, like flux emitted, temperature, magnetic field, etc. These in turn can be inputs to construe the processes occurring at the source or its surrounding environment. Ground-based observatories can access optical, radio and limited portions of infrared wavebands. The Earth's atmosphere absorbs other wavebands of electromagnetic (EM) radiation like ultraviolet (UV), X-ray and parts of gamma rays. It is due to this reason that space-based observatories are necessary to measure emission over the entire EM spectrum and for a comprehensive understanding of the celestial objects.

Experiments (termed as 'payloads' in space terminology) on AstroSat

AstroSat carries on-board five payloads, namely Ultraviolet Imaging Telescope (UVIT), Soft X-ray Telescope (SXT), Scanning Sky Monitor (SSM), Large Area X-ray Proportional Counter (LAXPC), Cadmium–Zinc–Telluride Imager (CZTI) and an auxiliary payload Charged Particle Monitor (CPM) (Figure 1). The scientific payloads span the far UV (FUV; 130–180 nm), near UV (NUV; 200–300 nm), visible (320–550 nm), soft and hard X-ray (0.3–100 keV) regimes.

Each of these payloads employs different techniques for the detection of incoming radiation.

Special features of AstroSat

The main strength of AstroSat is its capability to simultaneously observe in UV and X-ray wavebands.

In the international scenario, the Swift mission of NASA has the primary objective to detect gamma ray bursts (GRBs) and can slew swiftly towards the GRBs for finding their location, to enable as many observatories, both ground- and space-based, to observe these short-lived events. With its X-ray and UV/optical telescopes, it can observe the afterglows in UV and X-ray wavelengths. ESA's XMM-Newton mission has X-ray and UV/optical telescopes along with cameras and spectrometers, and can observe the sources in UV and optical bands. However, both these satellites do not observe in the FUV region.

On AstroSat, we have both NUV and FUV coverage, and in addition large area for detectors in X-rays for performing excellent timing studies. The effective area of LAXPC is ~6000 sq. cm @ 15 keV. The effective area is 4–5 times greater than that of Proportional Counter Array (PCA) on the Rossi X-ray Timing Explorer (RXTE) above 30 keV. It is the only instrument currently

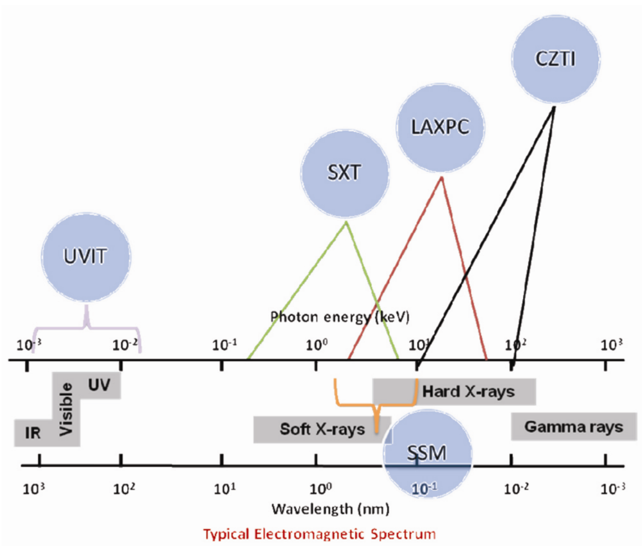

Figure 1. AstroSat wavelength coverage.

*For correspondence. (e-mail: seetha@isro.gov.in) operating in the wide X-ray regime of 3–80 keV, for fast timing studies, with a timing resolution of 10 μs. The image resolution of UVIT is ~1.5″ in NUV compared to ~6″ of Galaxy Evolution Explorer (GALEX) mission. UVIT is one of the best UV telescopes with a good position resolution and large field of view (FOV) of about half a degree, in both FUV and NUV bands.

A special aspect of AstroSat is that all the payloads detect the incoming radiation in the form of individual photons, and the data are also recorded in terms of arrival time, position, and where applicable, energy of the individual photons.

Requirements of pointing of payloads

Since exposure to solar radiation is detrimental to all the experiments, the angle between payload-pointing axis and the Sun has to be a minimum of 45°. At present, this angle is maintained at 65° considering further safety aspects.

RAM angle (the angle between the payload axis to the velocity vector direction of the spacecraft) needs to be more than 12° to avoid impingement of orbital particles on the optical elements of the payloads.

Terminator angle between payload-pointing axis and Bright Earth limb is more than 12°. The angle between star sensor and the Sun is to be maintained more than 50°.

Since multi-wavelength observations are the main objective here, four payloads, namely UVIT, SXT, LAXPC and CZTI are co-aligned in one direction. SSM, on the other hand, is meant to cover as much of the sky as possible and hence is mounted on a rotating platform.

Spacecraft axes definition

AstroSat is meant for observations of specific celestial targets whose positions in the sky are identified by the right ascension (RA) and declination (Dec) of the object.

AstroSat is a three-axis stabilized spacecraft. In order to enable four of the payloads to view the same celestial source, they are mounted on the top deck of the satellite with their view axis aligned in the same direction. This axis is termed the +ROLL axis. Two deployable solar panels consisting of triple junction solar cells generate about 2.2 kW power. The panels are rotatable and oriented normal to the Sun in order to generate maximum power. The axis around which the solar panels can rotate is known as the pitch axis. The other perpendicular axis is termed as Yaw axis. Since the Sun is not to be in the FOV of any of the payloads, the satellite is pointed such that the Sun is most of the time around the negative yaw axis. Two Li-ion batteries supply power to the spacecraft when the solar panel produces less power than required (Figure 2).

The orientation of the spacecraft towards any source is maintained by the Attitude and Orbit Control System (AOCS) with the help of four reaction wheels and three magnetic torquers. Thrusters are used only in case of emergency, to avoid likelihood of contamination of the UV optics.

Two star sensors operating in closed loop with the controls along with gyro wheels enable maintenance of the attitude of the satellite within ~2 arcmin. Finer attitude determination is done by the UVIT payload inherently, by associating each of the photons with the source position.

Pointing accuracy is better than 0.05° (three-sigma) in each axis, attitude drift rate is 3×10^{-4} deg/s and jitter is <0.3 arcsec.

Payload data transmission is by two X-band carriers using the phased array antennae. A solid-state recorder with 200 Gb storage capacity is used for on-board storage of data. The spacecraft Bus Management Unit (BMU) integrates the main bus functions, including AOCS, telemetry, command and sensor processing, etc.

The lift-off mass of AstroSat is ~1513 kg with the payload mass of ~855 kg.

Payload axes definition

The view axis of the three X-ray instruments, namely SXT, LAXPC, CZTI and the UVIT are co-aligned and pointed along the positive roll axis. SSM is mounted on a rotating platform, with its central detector view axis pointed towards the positive yaw axis, and the other two SSMs canted away by 45° and tilted so as to make an included angle of 24°. A rotation of the platform is made in step and stare mode about the positive yaw axis.

Hence one more specific requirement of AstroSat is to avoid the Sun both along the positive roll and the positive yaw axes even for manoeuvres.

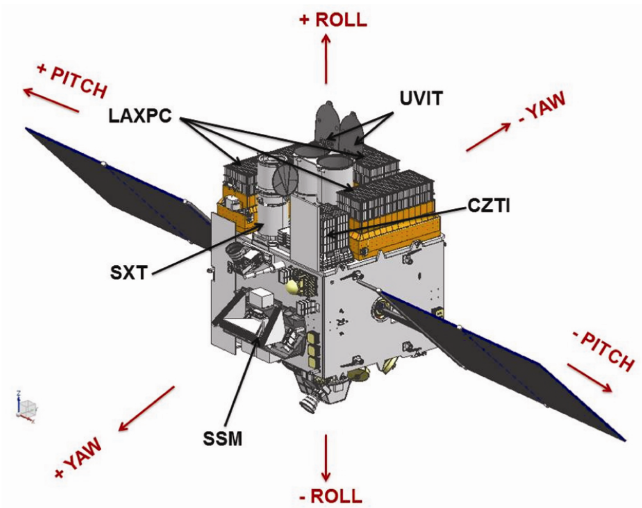

Figure 2. Spacecraft axes definition.

Orbit

Low Earth-orbiting satellites at altitude 600–2000 km experience high intensity of energetic charged particle background of trapped protons and electrons at specific regions in the orbit, which is greater for higher altitudes and for higher inclination angles of the orbit. In addition, there exists the South Atlantic Anomaly (SAA) region of the Van Allen belt caused by the anomaly in the Earth's magnetic field. SAA at altitudes above ~600 km spans approx –50° to 10° lat and –90° to +40° long (Figure 3). The extent of this region also changes with activity of the Sun. The exposure to enhanced charge particle flux may damage the detectors, create glitches in the data and cause aging effect in the X-ray instruments. Hence the ingress and egress of the satellite into this region has to be monitored, and appropriate action for switching OFF/lowering the high voltages for the payloads have to be taken, either through commands or automatically through a sensor. Both these provisions exist for this satellite.

AstroSat has a Charged Particle Monitor (CPM) to measure the count of charged particles at the satellite location in the orbit. CPM senses entry of the satellite into SAA, by means of counts measured above a threshold, and provides alert in the form of an electrical signal to other payloads. CPM is sensitive to protons above 1 MeV.

In order to minimize the effect of charged particle radiation, and at the same time have visibility of the satellite at the ground station in Bengaluru, AstroSat is placed in an orbit with an inclination of 6°.

Neutral thermosphere is the region of the Earth's atmosphere which contains neutral atmospheric constituents and is located from 90 km to several hundreds of kilometres, depending upon the solar activity. Atomic oxygen is the major constituent of the lower thermosphere region, whereas hydrogen and helium dominate the upper regions. Due to photo-dissociation of diatomic oxygen, oxygen exists predominantly in the atomic form. The exposure to atomic oxygen may deteriorate many spacecraft materials and optics. Hence a 650 km orbit with 6° inclination is chosen for AstroSat to minimize the impact of both charged particles and atomic oxygen.

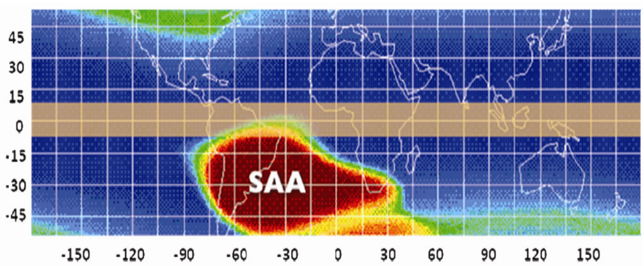

Figure 3. South Atlantic Anomaly and orbital trace of AstroSat.

Switch ON sequence and mission operations

After the launch of AstroSat on 28 September 2015 and stabilizing it in the designated orbit, the payloads were switched ON in a sequence.

Initially, the electronics of the payloads were powered ON one after another, and the health was monitored. Venting operation for SXT and LAXPC purification was done. This was followed by powering ON the high voltages and detectors. All the house-keeping parameters and temperatures were monitored and found to be within limits. The SXT and UVIT telescope door opening was carried out when all other functioning was verified, and also allowing for sufficient time for outgassing of spacecraft elements.

After the initial checks, the payloads went through a series of performance verification tests where it observed different blank sky coordinates, standard sources and sources of interest. These tests led to the on-orbit calibration, and estimation of payload performance and characteristics.

The AstroSat pointing accuracy was found to be dependent upon two factors – the settling of gyro drift behaviour and lack of updates of the star sensor during the Earth albedo region. Both sensors were studied on-orbit for a whole month and procedures were built to counter their effects. Gyro base temperature affects gyro drift and therefore a tight control on base temperature was exacted by controlling Sun-pitch and Earth-pitch angles. This solved the gyro drift problem. Similarly, the star sensor and updates of gyro were supplemented by extensive modelling on ground. Subsequently, the procedure was incorporated into the payload programming software and automated for current operations.

First light observations were obtained with the CPM on 29 September, followed by the CZTI on 5 October, SSM on 12 October, three LAXPCs on 20 October, SXT on 26 October and the visible and UV telescopes on 30 November 2015.

The high voltages of LAXPC, SSM and CZTI payloads were stepped down just before entering the SAA region and stepped up after exit. The SAA entry/exit timings were predicted on ground and also by the CPM counts. UVIT was operated only during eclipse. Sun avoidance manoeuvre was implemented on-board to avoid the Sun entering the FOV of payloads during transition from one source to another.

Currently, all the payloads are operational. The health of the spacecraft and payloads are monitored for all the 14 orbits in a day with Telemetry, Tracking and Command (TTC) support from the Bengaluru station. A dedicated 11-m antenna is utilized for this purpose.

Mission Operations Complex, ISRO Telemetry Tracking and Command Network (ISTRAC) is operating the satellite, and the data are processed, archived and distributed by the Indian Space Science Data Centre (ISSDC).

Payload data are collected in 11 or 12 orbits over a day. AstroSat payloads generate about 700 GB data every month.

Phases of operation

The observation time is divided into various phases – performance verification (PV) phase for the first six months, guaranteed time (GT) up to the third year and announcement of opportunity (AO) cycle observations for Indian and international research communities. About 5% of the time is allotted for targets of opportunity (TOO) and 2% for calibration.

The PV phase began in October 2015 and ended on 31 March 2016. The targets were provided by the respective payload instrument teams. The performance of all the payloads conformed to the design parameters.

April to September 2016 was provided as GT for the payload teams in which science observations were done. After one year, GT for the instrument teams was reduced to 50% and 35% was made available to Indian scientists/researchers affiliated to institutes/universities/colleges. The announcement was released in June 2016 through the ISRO website. Currently, the AO proposals are being executed. From the third year onwards, the observatory will be open to the international scientific community for a fixed fraction of the available observing time.

Proposal for AstroSat observatory time

AstroSat is a proposal-driven space observatory. ISRO releases calls for proposals periodically through its website (for further details visit http://www.isro.gov.in/astrosat-0).

The proposal submission and review are done on-line through AstroSat Proposal Processing System (APPS) software designed by scientists at the Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune for this purpose. APPS is a web application which automates the process of preparation, submission and evaluation of proposals. It is hosted at the ISRO Space Science Data Centre (www.issdc.gov.in/astro.html). Associated details are provided by the AstroSat Science Support Cell hosted at IUCAA (visit http://astrosat-ssc.iucaa.in/).

One can submit: (i) A regular proposal – One pointed observation for one or more targets. (ii) Monitoring proposal – Multiple observations of a single target. (iii) An anticipated TOO proposal – Interesting phenomenon is foreseen, but exact timing is unknown.

In addition, the TOO proposals can be submitted any time, when an interesting phenomenon is announced, and calibration proposals are submitted by the instrument teams. Proposals can be submitted under different scientific categories like star and stellar system, compact objects in binaries, supernova, supernova remnant and neutron stars, diffuse emission – galactic and extragalactic, active galactic nuclei, quasars, galaxies, etc.

In order to submit a proposal, the proposer has to make a science case or a problem for which she/he needs a solution or further understanding, and has to select a suitable target(s) of observation for the same. The Principal Investigator (PI) of the proposal then has to use various tools like exposure time calculator, web/pimms, to estimate the duration of observations required. Astroviewer tool has to be used to verify whether the target is visible to AstroSat considering the mission constraints, at the time proposed for observations. For UVIT proposal, Bright Source Warning Tool (BSWT) and mandatory checks are necessary to ensure that the target is safe for UVIT observations. Science and technical justification needs to be clearly submitted for every proposal.

These proposals are reviewed by the AstroSat Time Allocation Committee (ATAC) and AstroSat Technical Committee (ATC) for their scientific merit and technical feasibility, and a list of selected proposals is provided to the mission. The observations are then planned according to the mission scheduling. The PI will be informed after completion of successful observation, for the downloading of processed Level-1 data from the designated directory at ISSDC.

Proprietary period, during which the data remain with the PI, starts from the day Level-1 data are made available to him/her. For the first year of PV (selected sources) and GT observations, a proprietary period of 18 months and for observations thereafter, a proprietary period of 12 months is applicable. Any PI of a proposal can, however, reduce the above time-frame for his/her data. At the end of the proprietary period, the archived data will be open to registered users and will be available at ISSDC.

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