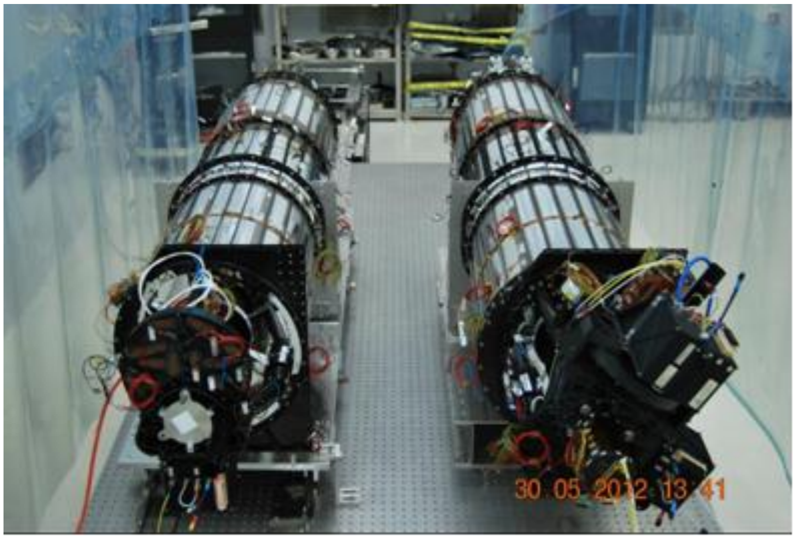
AstroSat – PAYLOADS

1. Ultra Violet Imaging Telescope (UVIT)



The Ultra-Violet Imaging Telescope (UVIT), is a remarkable 3-in-1 imaging telescope. Weighing all of 230 kg, the UVIT can simultaneously observe in the visible, near-ultraviolet (NUV) and far-ultraviolet (FUV). UVIT comprises of two separate telescopes. One of them works in the visible (320-550 nm) and the NUV (200-300 nm). The second works only in the FUV (130-180 nm) band. Remember that the famous Lyman-α line of Hydrogen is at 121.6 nm, at the far end of the FUV, and even beyond that is the X-ray band covered three experiments on-board AstroSat.

UVIT has a spatial resolution of 1.8 arcsecond and a field of view of 0.5 degree. In comparison, GALEX, an ultraviolet telescope by NASA had a larger field of view of 1.2 degree but a spatial resolution of about 5 arcsecond.

Each of the two Ritchey-Chretien type telescopes of UVIT have a primary mirror of 37.5 cm diameter, specially coated for efficiently reflection of ultraviolet photons. These mirrors, are hyperbolic in shape to minimise optical errors, reflect the incoming light to a secondary mirror, which in turn focuses the light onto a filter wheel and the detector.

Just as optical telescopes typically have filters to image the sky in different wavebands UVIT has filters to image the sky in NUV and FUV (and the visible) in different narrow wavelength bands. These filters are mounted on wheels which can be spun to bring whichever filter the astronomer wants into the light path.

After the filters, the actual detectors are mounted. These are photon counting detectors (CMOS Cameras) and can measure the location on the detector and time of incidence of each photon individually. The cameras can also operate in the integration mode (like a CCD camera). The visible channel is mostly operated in integration mode. Objects are far fainter in the ultraviolet than in the visible and hence each photon is first hugely amplified before it is allowed to fall on the 0.25 Megapixel camera. The UVIT sensitive enough to detect a single ultraviolet photon and time of its arrival to within 5 millisecond accuracy! The UVIT can image a field of view 30 times a second (and in special cases, even 200 times a second).

UVIT was a challenging instrument to design and build. It had to deal with the unique problems of ultraviolet astronomy, incorporate modern technology and also withstand the intense mechanical vibrations during launch and the thermal and radiative extremes of outer space.

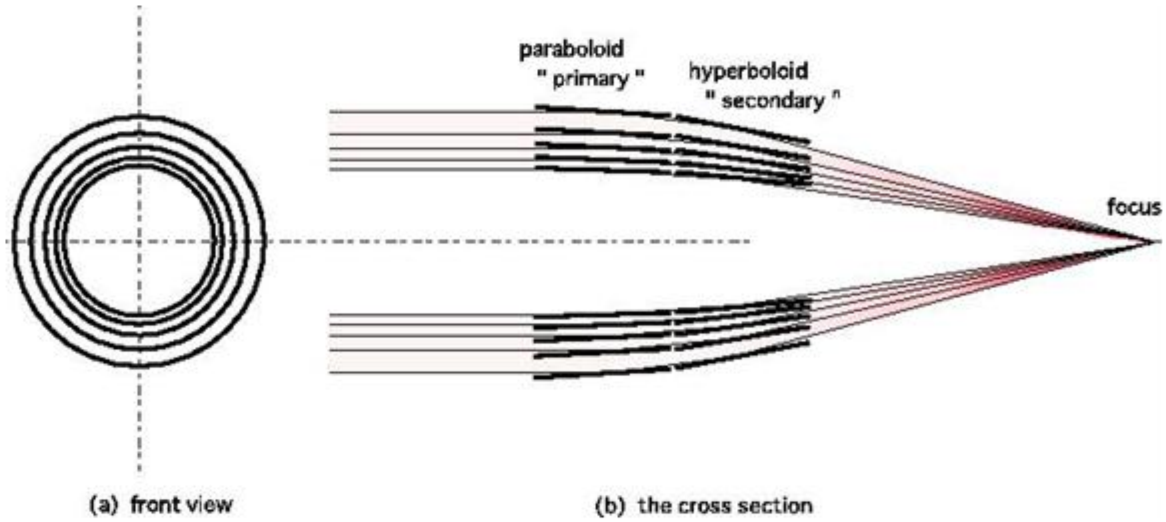
The intensified CMOS detector works by converting incoming photons to electric charges. Hence, the UVIT can be permanently damaged if it is exposed to very bright light. Sunlight scattered from the satellite, the light reflected from the Earth's surface, emission from molecules (like O2) in Earth's outer atmosphere when excited by the Sun and even sunlight scattered off the dust in the solar system can threaten the safety of UVIT. Hence, the telescope will make observations only at night, and has a number of electronic and mechanical features to safeguard its sensitive components, to ensure that it produces path-breaking science.

The geometric area and mass of UVIT are 1250 cm2 and 231.8 kg respectively. Indian Institute of Astrophysics (IIA), Bangalore and Inter University Centre for Astronomy & Astrophysics (IUCAA), Pune in collaboration with Canadian Space Agency (CSA) has developed UVIT payload.

2. Soft X-ray Telescope (SXT)

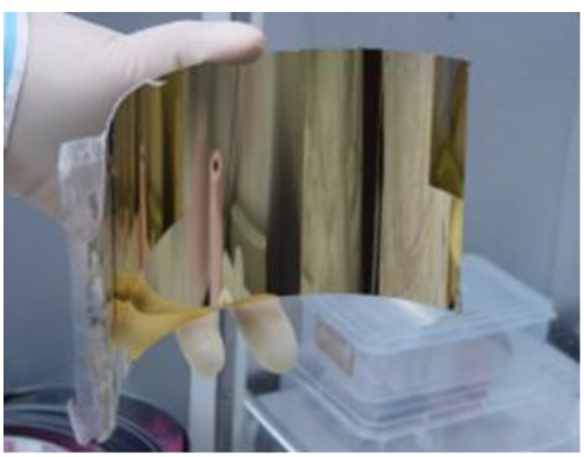
SXT is an X-ray focusing telescope operating in the energy range of 0.3-8.0 keV (X-rays are often detected as individual photons. They are quantified in terms of their energy rather than their wavelength, purely due to initial development of X-ray detectors without optics. One keV photon is approximately 1.2 nm (for comparison, a blue light photon has an energy of about 3 eV).

At normal incidence, silver and aluminium reflect over 90% of all visible light which is why metallic coatings are applied to visible light telescope mirrors made of glass. The amount reflected increases at grazing angles of incidence. However, X-rays do not reflect off mirrors the same way that visible light does. Because of their high-energy, X-ray photons penetrate into the mirror in much the same way that bullets slam into a wall. X-rays are either completely absorbed or pass right through the material at normal incidence depending on their energy. However, these X-ray photons reflect off the surface of few materials at very shallow angles called grazing incidence. This principle is used in construction of X-ray telescopes.



Wolter-I geometry

The SXT uses one such geometry, the Wolter Type I geometry Here the X-rays are reflected twice, first by a paraboloid mirror section and then by a hyperboloid mirror section before being focused. The mirrors are made as conical approximation to these cross sections using gold coated Aluminium foils and can achieve resolution of few arcminute. This allows the telescope to be lighter than the much heavier but more accurate telescopes like Chandra and XMM-Newton. The word 'soft' is used to imply that the telescope can focus X-rays of relatively at low energies, in the range 0.3 - 8.0 keV. The length of SXT is nearly 2.5 m while the telescope envelope diameter is 38.6 cm. The telescope has 320 nested mirror foils to increase the collecting area of X-rays. Each foil is thickness 0.2 mm made of aluminium and coated with gold for enhanced reflectivity.



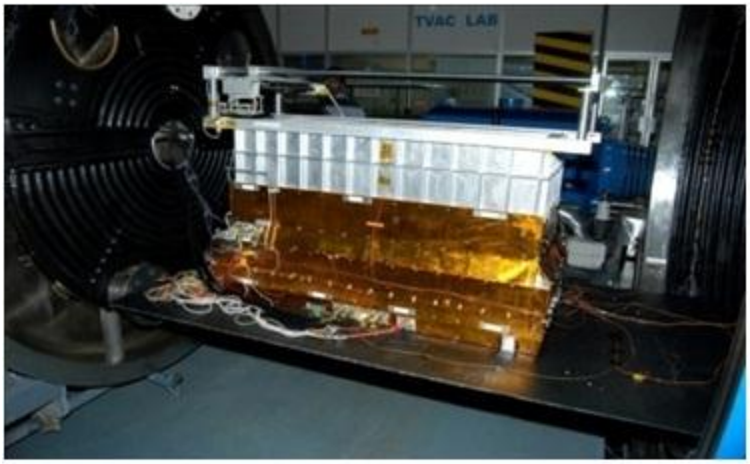
A shaped and gold coated foil segment

The focused X-ray photons are collected by a cooled charge-coupled device (CCD) with 600 x 600 pixels. The total field-of-view is 41.3 minutes of arc across. The CCD is cooled to a temperature lower than -80 °C to avoid stray noise photons being generated. This is particularly important since the rate of X-ray photons from astronomical objects are very few in number in contrast to longer wavelengths such as optical or infrared. The SXT-CCD can also separate X-ray photons of different energies between 0.3 - 8.0 keV, and so simultaneously provides a spectral resolution of about 150 eV at 6 keV.

The geometric area and mass of SXT are 250 cm^2 and 73.6 kg.

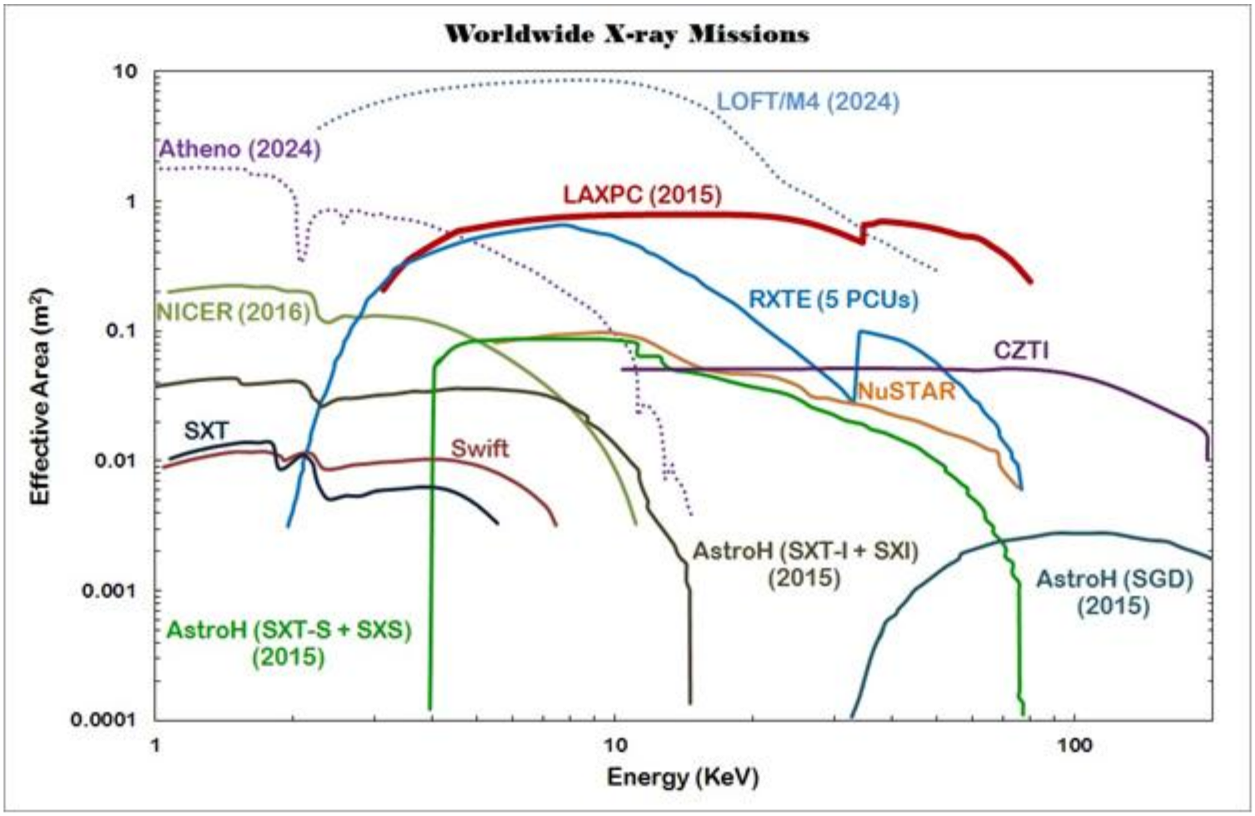
This payload is developed by Tata Institute of Fundamental Research (TIFR), Mumbai. The focal plane camera with a cooled CCD is from University of Leicester, UK.

3. Large Area X-ray Proportional Counters (LAXPC)



The LAXPC comprises of three large area proportional counters to carry out timing and broad band spectroscopy over an energy band of 3-80 keV X-rays for studying variable astrophysical sources. Proportional counters are made of large enclosures filled with gas and two electrodes held at a potential difference. The entry of a X-ray photon is marked by its absorption in the gas with the creation of photoelectrons. This then triggers further multiplication due to the potential difference by ionising the atoms of the gas and producing further electrons. This results in a charge pulse between the electrodes that is detected, converted to voltage, amplified and measured. The amplitude of the pulse is therefore proportional to number of electrons and ions produced and can be used to derive the energy of the original X-ray photon. The number of such events gives the count rate detected and therefore the strength or brightness of the celestial source. Combining the two, one can measure the flux and continuum spectrum of the source.

LAXPC has three co-aligned proportional counters with a total effective area of about 8000 cm^2 at 5-30 keV. The inert gas mixture contains predominantly Xenon and a small percentage of Methane at a pressure of 1520 torr (~2 atmospheres). Most of the gas is inert to avoid both absorption of electrons as well as chemical reactions with detector components. A small amount of methane is added to absorb photons produced during the ionisation of Xenon atoms by the X-ray. The field of view of each proportional counter is 1 degree, and this is determined by a mechanical collimator placed on the detector.



Comparison of effective area of LAXPC with international X-ray missions

The special feature of the LAXPC instrument is its ability to measure X-ray spectra at very short time scales. Not only can these spectral measurements be made over periods as short as few milliseconds if the source is bright enough, up to few hundreds of seconds, but these spectra can extend over a large range of energies viz. 3-80 keV. The LAXPC can even look at how the brightness of a celestial source varies over tens of microseconds! Hence, this is the perfect instrument to study a wide variety of celestial objects that undergo sudden outbursts.

The Rossi X-ray Timing Explorer (RXTE) was an X-ray telescope launched by NASA. The LAXPC of AstroSat is more sensitive than RXTE's Proportional Counter Array at high energies (> 25 keV). Due to its large collecting area, the LAXPC is also expected to be a superior instrument for precise timing measurements.

The geometric area and mass of LAXPC are 10,800 cm^2 and 415.5 kg.

Tata Institute of Fundamental Research (TIFR), Mumbai has developed this payload.

4. Cadmium-Zinc-Telluride Imager (CZTI)

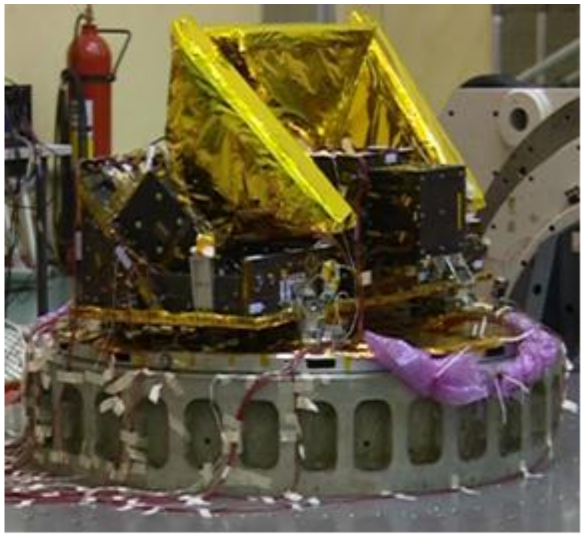
Cadmium - Zinc - Telluride Imager (CZTI) is truly a hard X-ray imaging instrument in the energy range 10-100 keV with a collecting area of 976 cm^2. This is a solid state detector and the entire detector assembly is divided into four identical and independent quadrants. In each quadrant, 16 CZT modules each of area 15.25 cm^2 are used. CZT modules are pixelated with a pixel size of 2.46 mm x 2.46 mm and 5 mm thickness. Individual pixels are connected with an electronic assembly to detect the incident X-ray photons as output voltage. Very high energy particles can simply pass through the CZT detector with a partial energy deposition and is a source of background noise. A Cesium - Iodide - Thallium [CsI(Tl)] crystal is used just under the CZT detector panel for background rejection (Veto layer). An X-ray photon in the energy range 10-100 keV deposits the full energy only in the CZT whereas a high energy charged particle deposits energy both in the CZT and the CsI detectors. This can be used to separate events due to X-ray photons and due to charged particles. The detector has a detection efficiency of 95% in 10-100 keV range.

A collimator, made of 0.07 mm thick Tantalum sheet sandwiched between 0.2 mm thick Aluminum with a field of view 4.6^o x 4.6^o, is placed above the CZT detector assembly allowing nearly parallel incidence of photons onto the detectors. A Coded Aperture Mask (CAM) made of 0.5 mm tantalum is placed above the collimator. The CAM consists of predetermined pattern of rectangle/square holes matched with the size of the CZT pixel straight down to it and the CAM casts a shadow onto the detector with 50% transparency (roughly equal number of close and open cells). The exact position of the source above the detector can be determined from the pattern of the shadow that it casts. CZT modules perform best in the temperature range 0^{o}-15^{o}C and hence the heat generated by the detector assembly is drained out continuously by a radiator panel assembly.

The geometric area and mass of CZTI are 976 cm^2 and 56 kg.

This payload is developed by Tata Institute of Fundamental Research (TIFR), Mumbai and Vikram Sarabhai Space Centre (VSSC), Trivandrum and IUCAA, Pune.

5. Scanning Sky Monitor (SSM)



The Scanning Sky Monitor (SSM), as the name indicates, is to scan a portion of sky away from sun to look for any transient behaviour in X-ray sources. In any space mission such an instrument is mandatory because it can scan a large portion of the sky in a few hours. SSM is good for detecting and locating any transient event in outbursting phase in the energy range 2.5-10 keV. Also, at the output of SSM, if some interesting source is found in a particular location, other instruments on-board AstroSat as well as ground based observatories can be alerted to conduct detailed observation towards that position. Hence SSM needs to have large field of view (FOV) and good angular resolution. SSM consists of three nearly identical one dimensional position sensitive proportional counters each having a FOV of about 22^o x 100^o. The assembly is mounted on a rotating platform to scan the sky. The working principle of the detector of SSM is similar to the proportional counter for LAXPC but in this case the anode wire is position sensitive and therefore functions as a 1-D position sensitive detector. The charge is proportionally divided to the two ends of the anode wire and therefore provides an estimate of where the incident X-ray created the charge cloud. The position resolution along the wire is 0.7 mm at 6 keV. The top part of each of the three SSM instrument consists of different coded aperture mask (CAM) patterns which forms the imaging element, which is joined sideway and the image of the shadow casted by the mask is deconvolved (same as for CZTI) using software application to find the location of the source in the sky. The angular resolution of SSM is ~12 arcmin (1^o = 60 arcmin) in the coding direction and across is ~ 2.5^o.

The geometric area is 57.6cm^2 per SSM unit and total mass is 75.5 kg.

This payload is developed by ISRO Satellite Centre (ISAC), Bangalore and IUCAA.

In addition, there is a **Charged Particle Monitor (CPM)** to detect high-energy particles during the satellite orbital path and alert the instrumentation.

Charged Particle Monitor (CPM)

CPM is a Scintillator Photodiode Detector (SPD) with a Charge Sensitive Preamplifier for detecting charged particles. Even though the orbital inclination of the satellite close to 6 degree, in about 2/3rd of the orbits the satellite will spend a considerable time (15 - 20 minutes) in the South Atlantic Anomaly (SAA) region which has high fluxes of low energy protons and electrons. The high voltage will be lowered or put off using data from CPM when the satellite enters the SAA region to prevent damage to the detectors as well as to minimize ageing effect in the Proportional Counters.

The mass of the payload is about 2kg.

This instrument is from Tata Institute of Fundamental Research (TIFR), Mumbai.