Recent Advances in Star Formation: Observations and Theory
ASI Conference Series, 2012, Vol. 4, pp 165 – 172
Edited by Annapurni Subramaniam & Sumedh Anathpindika

Upcoming Indian facility: UVIT on ASTROSAT

Annapurni Subramaniam*
Indian Institute of Astrophysics, Bengaluru 560034, India

Abstract. An overview of the upcoming ASTROSAT mission with its five instruments on board is presented. UVIT instrument is discussed in detail along with the ground calibrations and plans for in-orbit calibrations. The UVIT filter system and their effective areas are presented. General science goals of UVIT are presented and some specific science goals related to star formation are discussed.

Keywords : telescopes – ultraviolet: stars

1. Introduction – ASTROSAT

ASTROSAT will be a multi-wavelength astronomy mission which will carry five astronomy payloads for simultaneous multi-band observations. The twin 38-cm Ultraviolet Imaging Telescopes (UVIT) will cover Far-UV to optical bands. Three units of Large Area Xenon Proportional Counters (LAXPC) cover the medium energy X-rays from 3 to 80 keV with an effective area of 6000 sq.cm. at 10 keV. A Soft X-ray Telescope (SXT) with conical foil mirrors and X-ray CCD detector, will cover the energy range 0.3-8 keV. The effective area will be about 200 sq.cm. at 1 keV. A Cadmium-Zinc-Telluride coded-mask imager (CZTI), covers hard X-rays from 10 to 150 keV, with about 10 deg field of view and 1000 sq.cm. effective area. The fifth payload is a Scanning Sky Monitor (SSM) consisting of three one-dimensional position-sensitive proportional counters with coded masks. The assembly will be placed on a rotating platform to scan the available sky once every six hours in order to locate transient X-ray sources. ASTROSAT will be a proposal-driven general purpose observatory, with main scientific focus on simultaneous multi-wavelength monitoring of intensity variations in a broad range of cosmic sources, Monitoring the X-ray sky for new transients, sky surveys in the hard X-ray and UV bands, broadband spectroscopic studies of X-ray binaries, AGN, SNRs, clusters of galaxies and stellar coronae and studies of

*email: purni@iiap.res.in

periodic and non-periodic variability of X-ray sources. The ASTROSAT website has more details: http://www.iucaa.ernet.in/ astrosat/

LAXPCs and the CZT arrays are the hard X-ray detector system on board the ASTROSAT. This is expected to cover a wide energy band of 2-100 KeV. In the high energy range, the proposed LAXPC detector array will be 5 times more sensitive than that of the present largest instruments on board RXTE and Beppo-SAX. The combination of the LAXPC with its unprecedented sensitivity in the hard X-ray band and the soft X-ray Telescope (SXT) with its low energy sensitivity and good spectral capability will make ASTROSAT a unique observatory in its time-frame. The UVIT will cover from far-UV to Visual range (130nm - 550nm). A wide variety of X-ray sources will be observed spanning various types of binaries, pulsars, magnetars, AGN and cluster of galaxies will be studied using these X-ray instruments.

2. Ultra Violet Imaging Telescope - UVIT

The UVIT instrument contains two 38 cm telescopes: one for the far-ultraviolet (130 - 180 nm : FUV); and the second for the near-ultraviolet (200-300 nm : NUV) and the visible (320 - 550 nm : VIS) ranges, which uses a dichroic mirror for beam-splitting. UVIT is primarily an imaging instrument, which simultaneously makes images with $\sim 1.8''$ resolution in a field of $\sim 28'$, in FUV, NUV and VIS channels. Each of these channels are divided into smaller pass bands, which can be selected using a set of filters. In addition, a slitless spectroscopic mode is available in FUV and NUV.

In the FUV telescope, primary mirrors have a working diameter of 375 mm. The detector has a diameter of $\sim$ 40 mm. The filters, each of diameter 50 mm, and the grating are mounted in a wheel at a distance of $\sim$ 40 mm from the detector. Optical layout of the NUV/VIS telescope is similar to the FUV telescope. The primary mirrors have a working diameter of 375 mm. A dichroic beam splitter is used for spectral division of the beam in NUV (reflection) and VIS (transmission). Photon counting detectors are used for FUV and NUV channels. MCP intensified detectors, with Star250 CMOS imager is used for recording frames at rates up to 29 frames/sec. In order to correct for drift of the satellite and achieve the required spatial resolution, short exposures are taken and are integrated through a shift and add algorithm on the ground. The shift is found by comparing successive images from VIS channel every second or so (cf. ASTROSAT hand book).

3. Detector and the filter system

The UVIT Detectors are of photon counting nature based on Micro Channel Plate (MCP) image intensifiers Technology. The photocathode deposited on the inside of a 40 mm window lies at the focal plane of the optical system. The photoelectrons released are accelerated across a gap (typically 100-200 μm) to a stack of two mi-

Table 1. FUV, NUV and VIS filters and gratings. The number denotes the filter number in the filter wheel. The gratings are denoted as Gr. There is a neutral density filter in the VIS channel, along with a BK7 window.

#	Filter	Pass band	#	Filter	Pass band	#	Filter	Pass band
FUV			NUV			VIS		
0	Block	-	0	Block	-	0	Block	-
1	$CaF2_2$	> 125	1	Silica	>200	1	VIS 3	400-530
2	BaF	> 135	2	NUV 15	200-23	2	VIS 2	370-410
3	Sapphire	> 142	3	NUV 13	230-260	3	VIS 1	325-365
4	Gr-1	> 125	4	Gr	>200	4	NDFilter	> 380
5	Silica	> 160	5	NUVB4	250-280	5	BK7	> 320
6	Gr-2	> 125	6	NUVN2	275-285			
7	$CaF2_2$	>125	7	Silica	>200			

crochannel plates. The resulting electron shower illuminates a phosphor with a fast decay time. The light from the phosphor is fed through a fiber-optic taper that is bonded to the surface of a Cypress Star250 CMOS detector, with 512×512 pixels. Each pixel is square in size with 25 μm a side. Each pixel extends $\sim 3{\times}3$ arcsec on the sky. A detected photon event produces a splash of light on the CMOS that covers several pixels. The exact coordinates of the photon event would be estimated through a centroid algorithm using the pixel values of the detector, to a much higher resolution than one CMOS pixel. The experimental studies done by Hutchings et al. (2007) shows that one photon event produces a light splash which follows roughly a Gaussian distribution with Full Width at Half Maximum (FWHM) of $\sim$ 1.5 pixels. The UVIT detectors are designed with the gap of 0.1–0.15 mm, between the photocathode and the MCP, to obtain a resolution of $\sim 1''$ ($\sim$23 μ on the photo-cathode). The intensified CMOS detectors can either be used in a high gain photon counting mode, or in a low gain integration mode (in which signal in a pixel of the CMOS detector could be contributed by multiple photons). The detector can also be used in window mode for observing partial fields to get faster frame rates (> 29/s). For a window size of 100×100 pixels (5.5×5.5 arcmin^2), a frame rate of 600 frames/sec is possible.

The UVIT has various filters in the three channels. The FUV and NUV filters and gratings, and VIS filters are tabulated in table 1. Each filter wheel also holds a block which will be used avoid bright objects and to protect the detector. The location of the filters in each wheel and the pass bands are also presented in table 1. The gratings have a resolution in the range 100-150.

4. Ground calibrations

The calibration of the UVIT instrument is achieved through ground-based as well as in flight tests. The individual components of the UVIT instrument are tested and calibrated in the ground. The performance of the integrated system is planned during the performance verification phase after the launch.

4.1 Ground calibration tests

1. Detectors: The CMOS detectors used in the three UVIT channels are tested at the Canadian facility in the University of Calgary. The tests performed on the detector include tests for sensitivity, response as a function of wavelength, spatial variation of sensitivity, tests to estimate the centroid of the photons detected, gain as a function of MCP voltage etc. Some results of the above tests are summarised in Postma, Hutchings & Leahy (2011). The quantum efficiency of the detectors are estimated at the CREST facility. Details of the set up, analysis and the results of the estimation are presented in the Technical report (Narra et al. 2011a). This will soon be published as part of the Complete UVIT calibration paper.

2. Filters and gratings: The EM and the FM filters and gratings were tested and calibrated at the CREST, Hosakote facility. The parameters estimated here are the transmission of each filter as a function of wavelength, spatial variation of sensitivity, parallelism of the sides, shift in focus due to the filters. The images using these filters are taken using an SBIG camera and the hence the parameters estimated are for the filters alone. Details of the experiment, analysis and results for the filters are presented in technical report (Shankarasubramanian et al. 2011). The report containing the results on grating (Narra et al. 2011b) and the report on filters will be published together with the rest of the calibration results.

The following parameters of the detectors, filters and gratings will be calibrated in the ground. Main results of the ground calibration tests are available in the UVIT-CDR documents (http://www.iiap.res.in/Uvit).

1. Effective wavelength and bandwidth of the filters
2. Response and sensitivity
3. Spatial variation of sensitivity with position as a function of wavelength
4. Photometric non-linearity in Photon counting mode
5. Effects of window mode on sensitivity
6. Gain vs MCP voltage in integration mode
7. Distortions on the detector
8. Efficiency, wavelength coverage of gratings
9. Length of spectra on the detector plane
10. Shift between the object position in the image and the zeroeth order spectrum

The deliverable from the calibration tests will be presented in the form of a tables

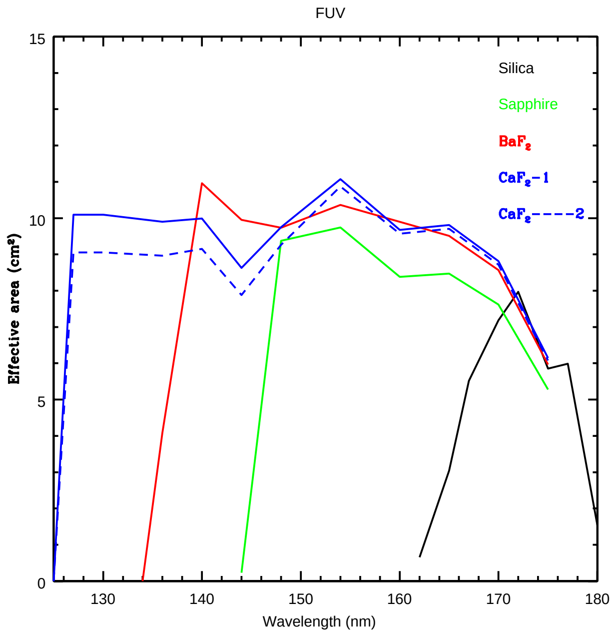

Figure 1. The effective area curves for the filters in the FUV channel

or plots. One such deliverable is the effective area for various filters. The ground calibrations are integrated to estimate the effective area for all the filters in the three channels. These effective area curves for the FUV, NUV and VIS are shown in the Figs 1–3 respectively. This is being incorporated in the exposure time calculator developed by the Canadian team. The exposure time calculator is available in the website: http://oryx.ras.ucalgary.ca/UVIT/ This will be updated with the latest ground calibration outputs. The calculator estimates the expected counts/sec for any object, when one provides its magnitude and the spectral energy distribution (or equivalent).

A tool to detect bright sources in the field of view of the telescope, around the object of interest, is being developed. This would alert the observer about the presence of a star brighter than the specified limit, in the field of view around the target to be observed. Srivastava, Prabhudesai & Tandon (2009) performed some simulations to study the imaging characteristics of the UVIT. A simulation tool which can be used to create expected images from the UVIT instrument is available. This can be downloaded from the following website: http://www.iiap.res.in/Uvit

5. In-orbit calibrations

UVIT-in flight calibration is designed to allow automated processing of UVIT data by the pipeline with the goal of producing a calibrated set of images and spectra

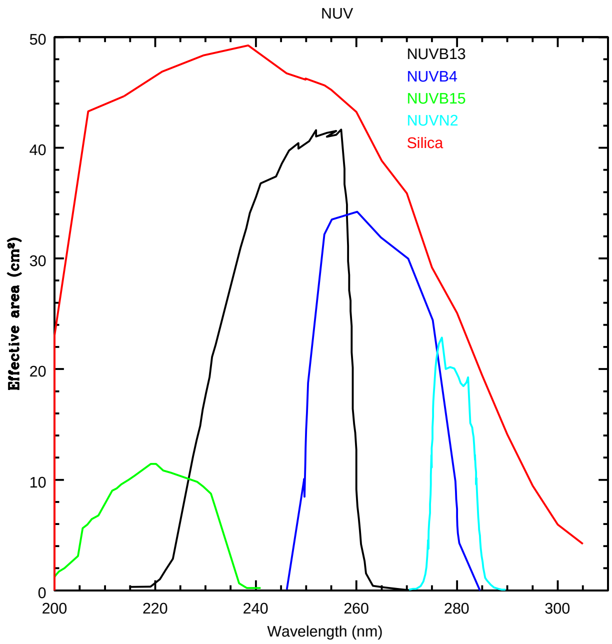

Figure 2. The effective area curves for the filters in the NUV channel

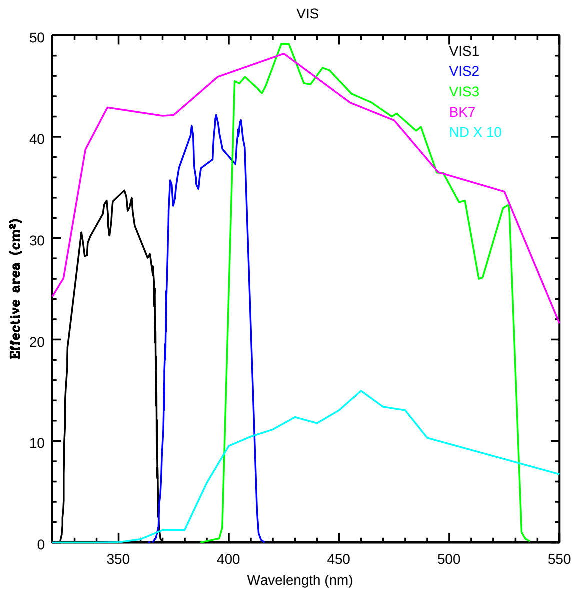

Figure 3. The effective area curves for the filters in the VIS channel

which can be used for quantitative data analysis in order to achieve the scientific objectives. The planned activities pertain to three types of calibrations. Photometric calibration is a measurement of broadband source-independent flux. Calibration will yield a conversion of a measured count rate into a broadband flux and the conversion of ratios of count rates into broadband colours. The spectroscopic calibration consists of estimation of wavelength coverage, wavelength and flux calibrations. Astrometric calibration is the measurement of the relation between a point on the detector based on the image created by the telescopes and the absolute position in the sky.

The performance verification (PV) phase of the UVIT is of approximately one month duration. The in-flight calibration tasks will be performed during the PV phase and repeated at regular intervals to monitor the performance of the system as well as to improve the already estimated parameters.

Various calibration tasks planned to be taken up during the PV phase are:
Photometric zero-point (FUV, NUV, VIS), Secondary photometric calibration (FUV, NUV, VIS) Flux calibration of the grism, Dispersion and wavelength calibration of the grism, Astrometric positional calibrations, Astrometric angular separation estimations, Linearity of response and bright star limits, PSF estimations, Timing calibrations, Estimation of background.

6. ASTROSAT Science goals

Distinguishing Features of Astrosat payload is its multiwavelength capability. ASTROSAT has the capability from the hard X-ray to visible using five co-aligned instruments. Most astronomy missions cover single spectral band (XMM-Newton, Swift being exceptions). Hard X-ray capability is expected to be better than earlier missions. The coverage in the UV, along with the Visual is a unique capability to probe physical processes in a variety of science targets.

Broad UVIT Science goals

Broad Science Drivers for the UVIT are summarised below:
Solar Stellar Connection (Chromospheric, Transition region lines; T-Tauris)
Auroral Emissions from Planets (Jupiter , Saturn : Lyman-a, H2 bands)
Hot stars (WD, CV, WR, LBV, β-Cephei, time variability)
Imaging the emission nebulae and supernova remnants
Hot stars in nearby galaxies (LMC, SMC, M31, M33)
UV Morphology of galaxies (blue dwarf galaxies, $z > 0.5$)
Quasars and active galactic nuclei (deep survey : discover faint QSOs)
Lyman surveys(stripped gas in galaxy clusters)
Deep surveys and rate of star formation ($1.3 < z < 2$)
Monitoring of X-ray Sources & GRB afterglows
UV Sky Survey of limited areas (5000 sq. deg., 20th magnitude).

A few science cases to study star formation: Young stellar objects in the accretion phase are expected to be bright in the UV. It is now accepted that classical T Tauri stars are accreting mass from their disks via magneto-spheric accretion. In this process, the stellar magnetic field truncates the circumstellar disk and channels gas near the truncation radius onto the stellar surface where an accretion shock forms. The spectrum produced by the accretion shock on the stellar surface peaks in the UV, so UV flux excesses over the stellar fluxes are the most direct measure of the accretion luminosity from which the mass accretion rate can be derived. These stars also have active chromospheres which produce UV emission and the contribution to the UV flux from the above two mechanisms is a function of disk evolution. In contrast, indicators of chromospheric activity, e.g., the X-ray luminosity, stay approximately constant in the age range 1–10 Myr during which disks evolve significantly (Ingleby et al. 2011).

UVIT, with its multiple filters in the far and near UV will be able to sample the flux in the UV better than the GALEX. These will help to model the magneto-spheric accretion vs chromospheric activity of T-Tauri stars. Observations of YSOs in various stages of formation will help in understanding the evolution of UV-excess. A complete sample of YSOs in selected star forming regions observed using the UVIT can bring out significant impact in the understanding of the YSOs, as well as in narrowing down the accretion models. The filters systems in the NUV channels can be used to separate YSOs in various stages of evolution. We plan to produce various diagnostic tools using the FUV-NUV colours for the T-Tauri stars and YSOs, which will help in planning the observations and interpreting the results. UV grism spectra of T-Tauri stars, in combination with the photometry can be made into a powerful tool to explore the UV-excess of these stars.

Acknowledgements

We thank the UVIT team and the UVIT calibration team. We thank the IIA for all the support in successfully holding this star formation meeting.

References

Hutchings J. B., Postma J., Asquin D., Leahy D., 2007, PASP, 119, 1152
Ingleby L., Calvet N., Hernandez J., et al., 2011, AJ, 141, 127
Narra S. V., Stalin C. S., Sriram S., Amit K., Tandon S. N., Determination of Quantum Efficiency of UVIT Flight Model Detectors, June 2011a
Narra S.V., Stalin C. S., Sriram S., Pradeep R., Tandon S. N., Calibration of Engineering and Flight model gratings for the Ultraviolet Imaging Telescope (UVIT), June 2011b
Postma J., Hutchings J. B., Leahy D., 2011, PASP, 123, 833
Sankarasubramanian K., Sreejith P., Vaishali S., Sreekumar P., Sriram S., Tandon S. N., Pradeep, June 2011, Technical Report on UVIT Filter Calibration
Srivastava M. K., Prabhudesai S. M., Tandon S. N., 2009, PASP, 121, 621