Ultraviolet Imaging Telescope on AstroSat

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The AstroSat satellite is designed for multi-wavelength astronomy for observations covering a spectral range from soft and hard X-rays to the ultraviolet. The Ultraviolet Imaging Telescope (UVIT) is the only non-X-ray telescope on AstroSat and it provides the long lever arm to the multi-wavelength observations. In addition to the simultaneous multi-wavelength studies in coordination with the X-ray telescopes on-board AstroSat, UVIT is used to study a large variety of objects with arcsecond-level spatial resolution. During the first year of observations, UVIT has obtained images in many filter bands in the wavelength range 130–300 nm over a field of ~28′, which are being used to study a variety of hot stars, nebulae, stellar clusters and galaxies.

Introduction

THE Ultraviolet Imaging Telescope (UVIT) has been designed for widefield imaging in the ultraviolet (UV) with high spatial resolution. It provides a unique combination of spatial resolution of ~1.5″, a field of ~28′ and a choice of multiple filters to select spectral bands in the wavelength range 130–300 nm. Slitless spectroscopy with low spectral resolution is also provided for. The ultraviolet wavelengths are covered by two detectors (far ultraviolet (FUV) and near ultraviolet (NUV)), and a third detector is used to provide images in the visible to provide accurate information on aspect drift of the satellite. All three channels cover the same field and operate simultaneously. Figure 1 illustrates the configuration of UVIT, while Table 1 shows its key specifications. Compared with a similar recent UV mission called GALEX[1], UVIT has a much wider selection of spectral bands and a spatial resolution better by a factor ~3, but has a field of view smaller by a factor ~6 in solid angle. For more details regarding instrumentation, the reader is referred to Tandon *et al.*[2]. The two UV detectors work in photon-counting mode with full-field readouts every ~35 ms providing positions of all detected photons, which are corrected for distortions in the detectors. Stacking of these positions from many such frames would give an image of the object. However, the pointing of the satellite has a typical drift of ~1″/s which can increase to ~4″/s during some periods; so the stacking is done after shifting positions of the photons in each frame to nullify the drift (see ref. 3). The required shifting is estimated by images taken with the visible (VIS) detector every ~1 s, in which individual stars can be seen to estimate the drift. The estimate of the drift is possible with the UV data for some fields where there are sufficient UV-bright stars.

The processes involved in observations with UVIT and analysis of the data to obtain standard images are quite complex. To facilitate optimization of the observations and analysis of the data, a Payload Operating Centre
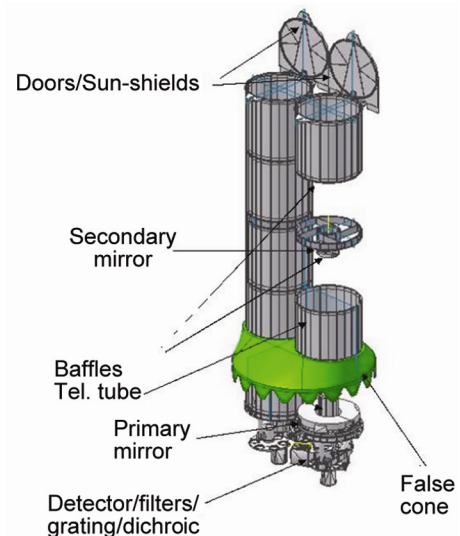

Figure 1. Configuration of the Ultraviolet Imaging Telescope (UVIT). Two co-aligned *f*/12 Ritchey–Chrétien telescopes with aperture of ~375 mm are used for simultaneous imaging in far ultraviolet (FUV), near UV (NUV) and visible (VIS). One of the two telescopes is used for FUV, and the other for NUV and VIS in which a dichroic beam splitter splits NUV and VIS. Sets of filters are provided, to select narrower bands, on wheels in front of each detector. For FUV and NUV gratings are also provided on the wheels for low-resolution spectroscopy. The two telescopes are mounted on a false cone which also provides mechanical interface to the satellite.

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Table 1. Key specifications of the Ultraviolet Imaging Telescope

Parameters	Far ultraviolet	Near ultraviolet	Visible[a]
Telescope aperture[b] (mm)	375	375	375
Wavelength range (nm)	130–180	200–300	320–550
Spectral bands[c]	4	5	4
Field of view	28′	28′	28′
Spectral resolution[d]	~80	~80	
Spatial resolution (FWHM)[e]	~1.5″	~1.5″	~2.5″
Zero AB-magnitude[f]	18.08	20.0	

[a]VIS images are only used for tracking drift of the satellite on a timescale of ~1 s.

[b]The payload is configured as twin co-aligned telescopes of Ritchey–Chrétien optics with aperture of 375 mm.

[c]A filter wheel is provided for each detector. The wheels carry multiple filters for selecting full or partial wavelength range for observation.

[d]Gratings, also mounted in the filter wheels, can be selected for slitless spectroscopy.

[e]Spatial resolution depends on the drift and distortion corrections achieved, and the filter used.

[f]Zero AB-magnitude is the AB-magnitude of the star which gives 1 c/s in the full band.
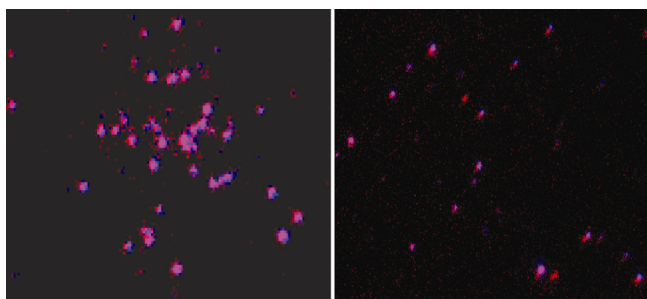

Figure 2. Parts of the images of the Small Magellanic Cloud. (Left) Combined image of FUV in Baf2 filter (blue colour) and NUV in F-6 filter (red colour) for ~70″ × 70″ in the inner part of the field. The close matching (better than 0.5″) of blue and red images is evidence for good relative astrometry. Further, sources within 3″ of each other appear quite distinct. (Right) Combined image for 140″ × 140″ near one corner of the field. A gradual worsening of the overlap between the two images near outer parts of the field is apparent.
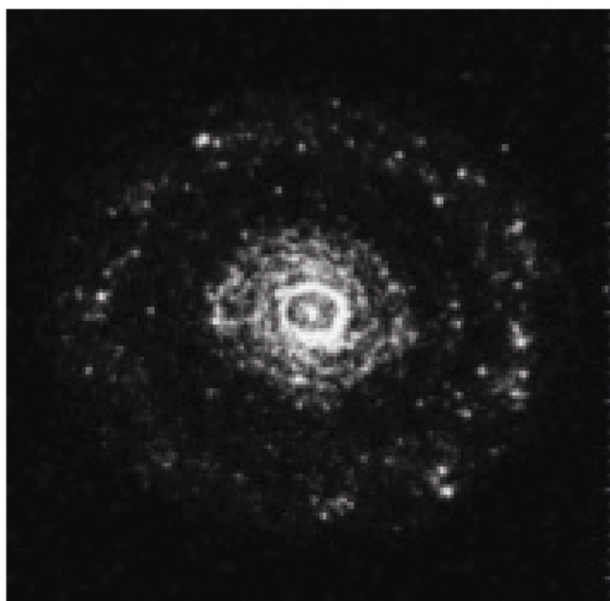

Figure 3. NUV image of the galaxy NGC 7217. Multiple rings of star-formation activity are seen. The outermost ring is ~2.5′ in size.

(POC) has been established at Indian Institute of Astrophysics (IIA), Bengaluru. Performance of UVIT can suffer permanent deterioration due to two possible causes: (i) development of blind areas in the detectors by exposures to excessively bright sources and (ii) reduction in transmission/reflectivity of the optical parts by the deposition of contaminants in minute amounts from the low-level degassing which continues to occur in the spacecraft for very long periods. The POC, in cooperation with the Mission Group of Indian Space Research Organisation (ISRO), also monitors the operations for avoidance of such deterioration in the performance of UVIT. So far, the performance has not shown any detectable deterioration[2].

In general, the targets of interest for observations with UVIT are any objects which have hot regions within them. Objects with X-ray emissions are one such important class and are interesting targets to be observed simultaneously with UVIT and X-ray telescopes on-board AstroSat, for studying the time variations and physical processes responsible for the emissions. Beyond the X-ray sources, some of the categories of targets for study with UVIT include: hot stars, evolved stars, planetary nebulae, supernova remnants, star clusters, star-forming galaxies, active galactic nuclei, clusters of galaxies and star-formation history in the distant universe.

At this stage, the calibrations are in the process of being completed and there are very few finished results. In order to give an idea of the potential of astronomy with UVIT, we shall present processed data from some observational programmes carried out so far.

Images of the Small Magellanic Cloud (a small galaxy close to our galaxy, i.e. Milky Way), shown in Figure 2, illustrate the spatial resolution and astrometric accuracy (linear reproduction of the space-angles). The spatial resolution in these images ranges from 1.3″ to 1.6″ FWHM, and the astrometric accuracy within the field is 0.5″ rms. The images have been provided by John Hutchings and Joe Postma who will use the data of multiple UV bands to

study properties of the hot stars, characterize evolved stars and binaries of a globular cluster of Milky Way (which is in front of Small Magellanic Cloud), and UV spectral properties of white dwarfs of Milky Way halo in the field.

Figure 3 shows an image of galaxy NGC 7217 in NUV (with the filter covering 230–260 nm). This is an interesting galaxy with multiple rings of enhanced star formation. The image has been provided by Swarna Ghosh who will use the images taken in multiple UV bands to study hot stars in the rings.

Figure 4 show a part ($\sim$100″ × 100″) of the NUV (in the filter covering 200–300 nm) image of Chandra Deep Field South, provided by Kanak Saha. The images will be analysed by Saha and colleagues to determine the luminosity function of the galaxies and their star-formation history. Given the much smaller PSF (spread of the image for any point source), many more galaxies are expected to be resolved as compared to those resolved by Galex.

One of the important scientific aims is to correlate temporal variability of X-ray bright sources in X-ray and UV wavelengths. As an illustration of the capability of UVIT for studying time variability, we show in Figure 5 a time series for source for the magnetic Cataclysmic Variable FO Aquarii. The source is a well-known intermediate polar with a white dwarf spinning at a rate $\sim$21 min/rotation. These data are from observations by P. C. Agrawal and colleagues, who are analysing the data from the X-ray telescopes and UVIT to derive the physical properties of the source.

Lastly we present the first fully analysed result from UVIT which has been published by Subramanian *et al.*[4]. The images of the old open cluster, NGC 188, taken by UVIT revealed a blue straggler star which has a companion from which it has been accreting material. Although 'blue stragglers' were first identified 62 years ago, astronomers are yet to converge on an evolutionary scenario to explain them. These stars appear to stay young, defying aging, or evolution, whereas, in general, blue stars have a short lifetime.

The most popular explanation is that a smaller star accretes the material out of an evolving bigger companion star to become a blue straggler. The smaller star becomes hotter and bluer, which gives it the appearance of being young, while the aging companion burns out and collapses to a stellar remnant. Earlier studies based on the Hubble Space Telescope found blue stragglers to have a white dwarf (a stellar remnant) as companion, which suggested that the blue stragglers probably acquired mass from the progenitor of the white dwarf some time ago.

The multi-band UV data from UVIT show that the blue straggler has accreted mass very recently. The companion is still going through aging and has not yet become a remnant. The companion is hot and large, therefore also very bright in the UV, but not so bright in the optical. So, previous studies of the blue straggler in the optical could

not detect the companion. Previous studies in the UV could not find its exact stage of aging or evolution. Figure 6 shows an analysis of the properties of the stars in this binary system. For more details the reader is referred to Subramaniam *et al.*[4].

These precise measurements from UVIT helped identify and study the companion. The authors combined UVIT data with those from other UV space missions as well as many ground-based data. They have generated an unprecedented spectral sampling covering UV to infrared. This confirmed that the target star is indeed a vampire star and the companion is a luminous, aging large star, called post-asymptotic giant branch star, on its way to becoming a stellar remnant. Therefore, the blue straggler has recently acquired mass from the evolved companion.
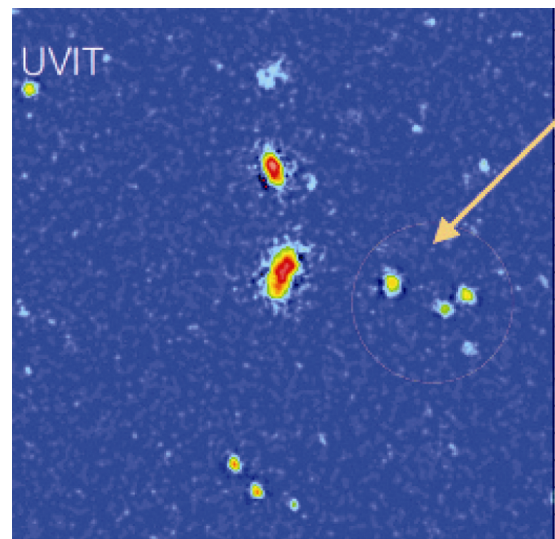

Figure 4. A part of the image of Chandra Deep Field South taken in NUV (200–300 nm). Many galaxies are seen in this frame of $\sim$100″ × 100″. Inclusion of more exposures would show many more fainter galaxies.
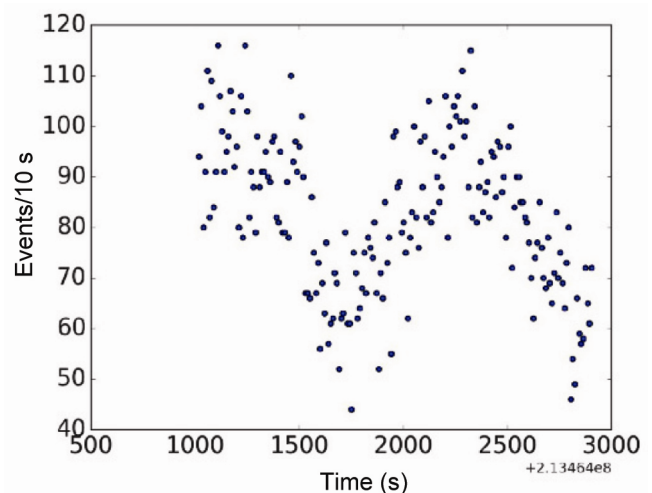

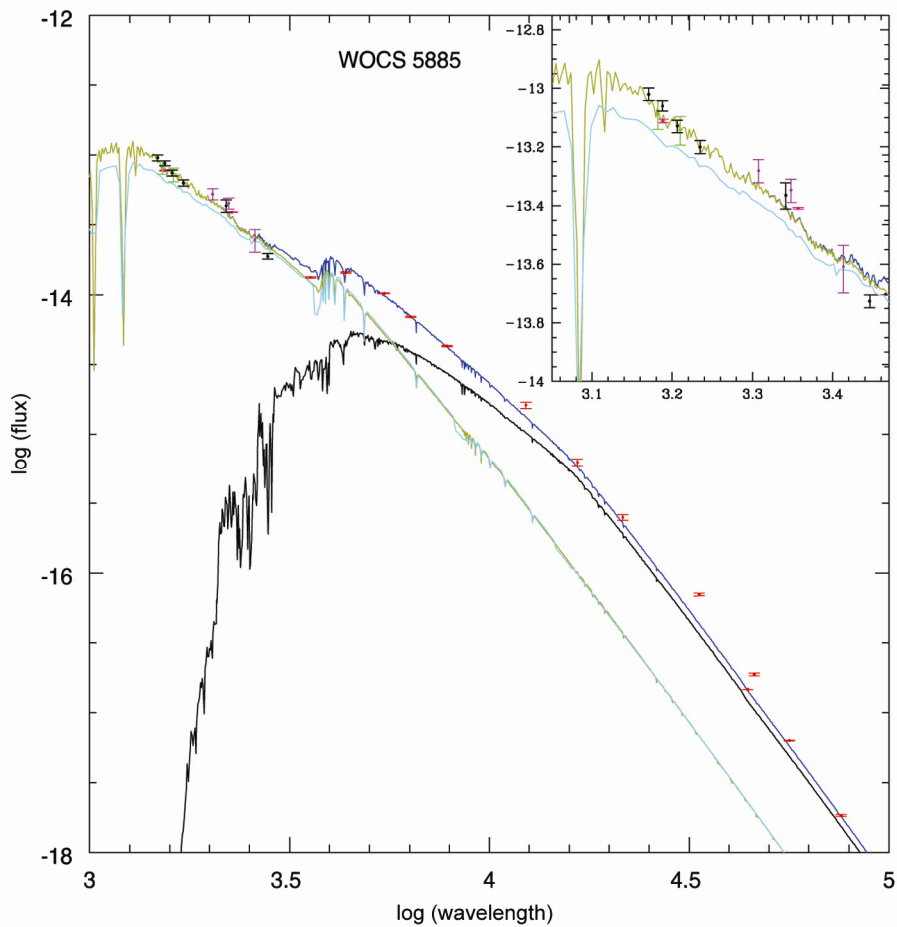**Figure 5.** Time series of FUV counts for FO Aquarii.

Figure 6. The extinction-corrected spectral energy distribution of the blue straggler WOCS 5885. The black (UVIT), magenta (GALEX), green (UIT) and pink (UVOT) points indicate the UV fluxes (shown in the inset as well); all other flux measurements are shown in red. Kurucz model spectra (log(g) = 5.0) for the separate components are shown in gold (17,000 K) and black (6000 K), with the composite spectrum in blue.

This pair is a unique example to study details of the formation of blue straggler stars. As the accreted material from the aging star will be enriched with elements processed within it, this blue straggler will throw light on the kind of nuclear processing that happens in aging stars[4].

Many other observations and analyses are under way, and the UVIT payload is proving to be a versatile instrument of wide interest.

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