Introducing UVIT

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Summary. The Ultraviolet Imaging Telescope (UVIT) is a collaborative project between the Indian and Canadian space agencies. It is expected to be launched in 2009, for a 5-year minimum mission, along with X-ray instruments as part of the ASTROSAT orbiting observatory. ASTROSAT will measure the flux of celestial objects in various high energy bands. The science objectives are broad, extending from individual hot stars, neutron stars, star-forming regions, to active galactic nuclei, addressing fundamental questions about stellar and galactic evolution and cosmology. We summarize the instrument capabilities, detail some of the science objectives, and present flux simulations for hot stars to be studied with UVIT.

1 The ASTROSAT mission

ASTROSAT is a multi-wavelength space borne observatory that will be launched in 2009 for a five year minimum lifetime mission. It is the first completely scientific satellite developed by the Indian Space Research Organization (ISRO). In 2004, the Canadian Space Agency (CSA) and ISRO agreed to collaborate in the Ultraviolet Imaging Telescope (UVIT) project. This instrument will be flying on board ASTROSAT together with four co-aligned X-ray telescopes of different kinds: LAXPC (large area X-ray proportional counter), CZT (cadmium-zinc-telluride), SXT (soft X-ray imaging telescope), and SSM (scanning sky X-ray monitor).

ASTROSAT will have a near equatorial orbit with an inclination of 10° and an altitude of ~ 650 km above sea level. A single ground station located in Hyderabad (India) will gather all the data from the satellite and produce scientific calibrated images through a pipeline.

2 Ultraviolet Imaging Telescope

UVIT consists of two telescopes with a primary mirror of 375 mm in diameter each. These telescopes will feed three imaging detectors which are photon-counting devices with photocathodes sensitive in the wavelength ranges 120-180 nm (far-UV), 180-300 nm (near-UV), and 300-550 nm (visible). The visible channel will primarily provide pointing information to allow the UV images to be built up with sub-arcsecond precision. The three detectors consist of a channel plate multiplier system with a CMOS readout. UVIT aims to provide flux calibrated images at a spatial resolution in the range $1''$-$1.5''$ per pixel with a $30'$ field of view, as shown in Figure 1. For each wavelength bandpass there will be a set of carefully selected filters, mounted on three filter wheels.

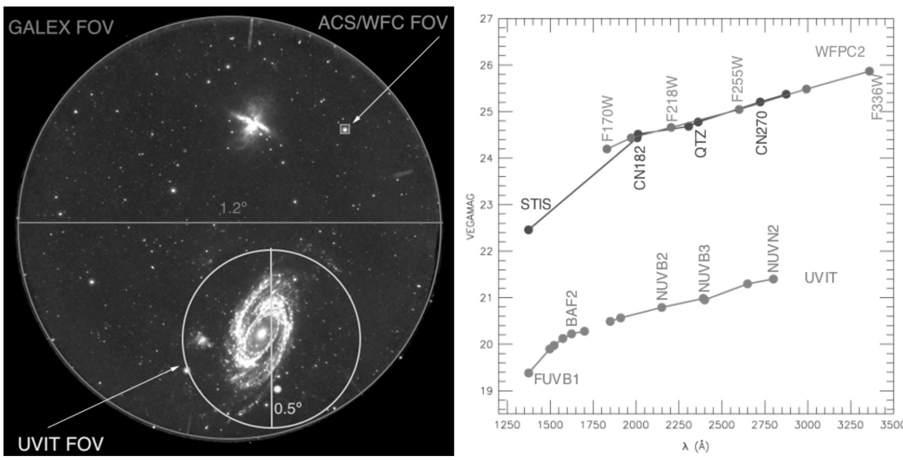

Fig. 1. [Left] Messier 81 and Messier 82 as imaged in the UV by GALEX. The diameter of the image on the sky is 1.2°. We show the FOV of UVIT (below) and for comparison the FOV of ACS/WFC (above). [Right] Estimated limit magnitudes (in the VEGAMAG system) of an O5 dwarf observed using STIS, WFPC2 onboard HST, and UVIT onboard ASTROSAT. A four magnitude difference between both missions is due to the different size of the primary mirrors.

3 Numerical Simulations

In order to understand the future performance of UVIT onboard ASTROSAT, we performed some numerical simulations using a tailored version of SYNPHOT within STSDAS. The SYNPHOT package simulates photometric data and spectra as they are observed with the Hubble Space Telescope (HST), but it can be customized for other optical configurations. We used SYNPHOT as a tool to answer the following question: how faint can we go in a 30 minute observation of an O5 V star if we want 30 % photometric accuracy? We created transmission functions for all the proposed UVIT filters and we modified some SYNPHOT tables to include this instrument and its optical configuration. For an O5 V star, we assumed $T_{\rm eff} = 45\,000$ K, $\log(g) = +4.04$, and $Z = Z_{\odot}$, and we used the corresponding synthetic spectrum from the Kurucz library within SYNPHOT. We estimated the magnitudes in all the available UVIT filters in the VEGAMAG system. For comparison, we calculated the magnitudes using some WFPC2 and STIS filters in the UV. The results are shown in Figure 1. We observe a four magnitude difference between the two telescopes, as expected from the different size of the primary mirrors. However, UVIT will provide a much larger field of view in comparison to HST/WFPC2.

4 Scientific Programs

The advantages of space-based observations are very well known for some time now. They allow access to the full range of electromagnetic radiation without the fading or even blocking produced by the Earth's atmosphere. This has been proved by several space missions which carried instruments that studied objects of astronomical interest in different wavelength ranges. Of special interest in space observations is the UV part of the spectrum because that radiation is completely blocked by the Earth's atmosphere. In the past forty years, space missions like Copernicus, the International Ultraviolet Explorer (IUE), HST, FUSE, and GALEX, among others have carried UV instruments and they have shown that high quality science (both photometry and spectroscopy) can be performed in this interesting part of the spectrum.

The wide field of view and the high spatial resolution of UVIT are two essential characteristics that will allow the scientific community to pursue major scientific programs in the ultraviolet, both new projects as well as follow-ups of recent discoveries. In the following section we briefly describe some of the scientific programs that can be pursued with UVIT onboard ASTROSAT.

4.1 Individual hot stars

Stars that are born with masses $\geq 8 M_{\odot}$ end their lives as core-collapse supernovae [11]. These *massive stars* are extremely rare: for every 20 $M_{\odot}$ star in the Milky Way there are roughly a hundred thousand solar-type stars [18]. However, they are probably the most important stars for several reasons: through the actions of their strong stellar winds and eventual disruption as supernovae, they provide most of the mechanical energy input into the interstellar medium. They also generate most of the UV ionizing radiation in galaxies, and power the far-infrared luminosities through the heating of dust. They are a primary source of enrichment of heavy elements of the interstellar medium. Their evolution is difficult to model due to their rapid rotation and high mass loss throughout their short lives, and they tend to be highly unstable and variable. Since they emit most of their radiation in the UV part of the spectrum, UVIT will be able to observe large numbers of massive O and B stars in young, nearby star clusters such as the Carina Nebula. UVIT will search for the periodic variable signature of a large number of stars simultaneously in its wide field of view.

UV observations of the central cores of Galactic globular clusters using HST and GALEX have proved to be extremely helpful in discovering peculiar objects such as: *blue stragglers, interactive binaries, white dwarfs,* and *horizontal branch stars* (e.g. Ferraro in these proceedings; [3, 14, 6]). Pulsating white dwarfs may be studied by comparing pulsation amplitudes at UV and visible wavelengths.

The ASTROSAT mission, with a group of aligned UV and X-ray telescopes, will be most suitable to study *X-ray binaries* and all of their associated phenomena [15]. In particular UVIT can study the interaction of the accretion disk with the neutron star magnetosphere, and the flow of material through the magnetosphere on the surface of the neutron star.

Planetary nebulae show characteristic emission lines in the UV part of the spectrum and UVIT will have an adequate set of filters to isolate those emissions and obtain flux calibrated images of the nebulae. Their central star will be a suitable candidate for UV studies [9].

4.2 Individual cool stars

Flare stars are active M dwarfs which experience luminosity bursts in the visible, UV, and X-rays on time-scales of minutes to hours [20]. With UVIT we will be able to build light curves, continuing previous studies performed using GALEX.

Some G and K dwarfs have *activity cycles* similar to the 22-year solar cycle, and this feature has been studied using Ca II H and K photometry. These lines are often ambiguous because of the weakness of the emission, buried at the bottom of a deep photospheric feature. UVIT can observe the stronger Mg II h and k lines in the near-UV where the stellar continua are much weaker. Astronomers have tried to establish empirical relationships between the period of the cycle and some stellar parameter like the rotation period or effective temperature (e.g. [10] and [1]).

In 1979, Linsky & Haisch [17] used UV and X-ray observations from IUE and the Einstein observatory and discovered that the Hertzsprung-Russell diagram presents a *dividing line* separating solar type stars with a coronal wind and non-coronal stars with a cool massive wind. These investigations require both UV and X-ray observations and ASTROSAT is perfectly suitable for these kind of studies.

4.3 Extinction studies

The understanding of how interstellar dust extinguishes light is of absolute importance in both spectroscopy and photometry studies.

The research of Cardelli, Clayton, & Mathis [2] shows that most of the variation in Milky Way extinction curves could be described by an empirical relationship based on the single parameter R_V. This was a major step forward in our understanding of dust properties. R_V is a measurement of how steep is the overall extinction slope; it is close to 3.1 for most sightlines, but it can range between 2 and 5.5, with higher values being typical in some H II regions. An interesting feature of these extinction laws is the presence of the 2175 Å bump which is thought to be associated with small carbonaceous grains. Besides our own Galaxy, there are extinction-law studies in the Magellanic Clouds.

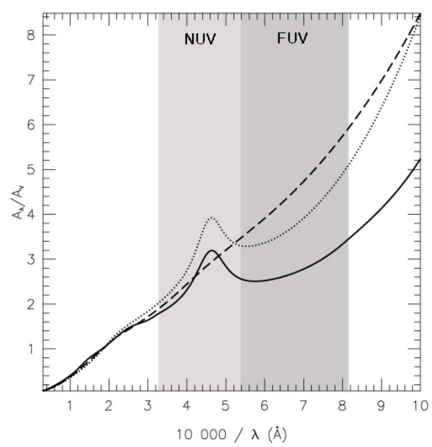

Fig. 2. Comparison of three extinction laws: A Galactic law from [2] using $R_V = 3.1$ (solid line), the SMC law from [8] (dashed) and the LMC law from [19] (dotted). UVIT detectors will be sensitive in the wavelength ranges labeled with NUV and FUV.

The UV extinction curve of dust in the Small Magellanic Cloud (SMC) has been mesaured in the direction of four blue supergiant stars with IUE data (e.g. [8]). For three of these stars, the extinction curves follow a roughly linear rise from the optical to the far-UV with no 2175 Å bump. The peculiar SMC extinction curve is often considered as evidence for a specific dust composition associated with the low metallicity of this galaxy ($Z = 0.1Z_\odot$).

Using IUE observations, Misselt and collaborators [19] have analyzed the Large Magellanic Clouds (LMC) UV extinction. They found that there is a group of stars with very weak 2175 Å bumps that lie in or near the region occupied by the supergiant shell LMC 2, on the southeast side of 30 Dor. The average extinction curves inside and outside LMC 2 show a very significant difference in 2175 Å bump strength, but their far-UV extinctions are similar.

Current extinction laws vary significantly in the UV part of the spectrum as can be appreciated in Figure 2, and with UVIT we will be able to test and improve the UV part of these laws. UVIT observations will provide the extinction properties of nearby galaxies and they will allow us to study the effects of metallicity and dust composition in different environments.

4.4 Nearby galaxies

GALEX observations of nearby galaxies have shown that the UV morphology of even normal galaxies looks quite different from the visible spectrum. This is simply because the UV probes the young stellar population, while longer wavelengths are dominated by the flux of older and less massive stars.

Most of the galaxies in the Local Group have an angular size which is smaller than the field of view of UVIT, with few exceptions such as Andromeda and the Magellanic Clouds. UVIT observations will therefore provide a complete UV survey of all galaxies in the Local Group with a spatial resolution four times better than GALEX. These observations will map the distribution of hot stars, free of crowding by cool stars in the visible in the nearest galaxies. Some of them will be resolved, most probably in nearby OB associations and giant H II regions. This in turn will allow a measurement of the star formation rate and the stellar mass function in galaxies.

4.5 Distant galaxies

When individual stars can not be resolved anymore in more distant galaxies (see Figure 3), we need to rely on population synthesis codes to study the different stellar populations from the galaxy's integrated flux. UVIT observations can be combined with synthesis codes such as LavalSB [4] or Starburst99 [16] in order to derive galaxy properties such as star formation rate, initial mass function, age, mass, and metallicity.

Some galaxies present clear evidence of the existence of globular clusters. These extragalactic objects have been studied using different wavelengths, from the near-infrared to the UV (e.g. [13, 5, 12]). Some of them show different properties than their Galactic counterparts, even for similar metallicities. Most UV observations in the past few years have been carried out using GALEX and HST, and UVIT will continue to address their study.

GALEX has shown from FUV and NUV observations that some spiral galaxies present an extended UV disk [7]. It is now clear that this phenomenon is due to young stars associated with low-mass stellar associations located at large galactocentric distances. UVIT will follow up these recent discoveries with high spatial resolution observations.

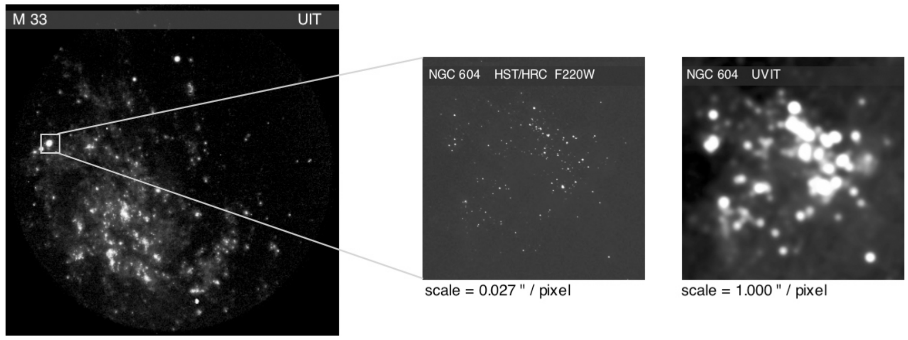

Fig. 3. [Left] UV image of M 33 obtained using the Ultraviolet Imaging Telescope (UIT). [Center] A detailed UV image of starburst region NGC 604 obtained with HST/HRC. [Right] A resampled version of the same region as would be observed by UVIT with a spatial resolution of $1''$ per pixel.

UVIT will pursue other scientific programs related to distant galaxies, such as the study of the UV properties of early type galaxies, age-metallicity degeneracy problems in elliptical galaxies, and the investigation of ultra compact dwarf galaxies, quasars, and active galactic nuclei.

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