Large Scale Extinction Maps with UVIT

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Abstract

The Ultraviolet Imaging Telescope (UVIT) is scheduled to be launched as a part of the ASTROSAT satellite. As part of the mission planning for the instrument, we have studied the efficacy of UVIT observations for interstellar extinction measurements. We find that in the best case scenario, the UVIT can measure the reddening to an accuracy of about 0.02 magnitudes, which combined with the derived distances to the stars, will enable us to model the three-dimensional distribution of extinction in our Galaxy. The knowledge of the distribution of the ISM will then be used to study distant objects, affected by it. This work points the way to further refining the UVIT mission plan to best satisfy different science studies.

Keywords GALEX: — space missions: UVIT, SDSS, interstellar medium: extinction

1 Introduction

It is very difficult to model the three-dimensional distribution of interstellar matter (ISM) in our Galaxy because of the general lack of distance information. One of the few ways to probe the distance of the interstellar gas and dust is through absorption line measurements (in the case of gas) or through extinction (in the case of the dust), but these have been limited to a relatively small number of directions. This has impacted studies of extragalactic objects, not to mention the extragalactic background, because of the unknown effects of interstellar dust in the Milky Way.

The most reliable means of determining the amount of dust in a given line of sight is through observations of the extinction along the line of sight to stars across the sky. This originally involved comparing similar stars and measuring the difference between their spectra, but stellar models have now become sufficiently accurate so that they can be used for comparison instead, greatly extending the utility of this procedure (Fitzpatrick & Massa 2007). Further, if the distance to a star is known, then, in principle, the distance to the actual scattering dust may be inferred. This method traditionally required spectral observations of moderate resolution and has been limited to those specific sight lines where such observations existed.

A much wider coverage was achieved by Burstein & Heiles (1982) who combined observations of 21 cm emission with the gas-to-dust ratio of Bohlin et al. (1978) to provide reddening maps over the sky. This was supplanted by Schlegel et al. (1998) who used the infrared emission from the Infrared Astronomy Satellite (IRAS) and the Cosmic Orbiting Background Explorer (COBE) to estimate the extinction over the entire sky. Both methods are model-dependent and, moreover, can only estimate the integrated dust column density. This can be overcome by using modern photometric surveys which observe large areas of the sky in multiple bands. Amongst these are Marshall et al. (2006), who have used the Two Micron All Sky Survey (2MASS) to model the extinction in the Galactic plane, and Finkelman et al. (2008), who have used SALT data combined with Sloan Dig-
ital Sky Survey Data (SDSS) to study extinction at high galactic latitudes. These surveys yield both the extinction along any line of sight and the distance to the background star and so may be used to develop a three-dimensional map of the dust in our Galaxy.

We report here on our plans to use data from the Ultraviolet Imaging Telescope (UVIT) aboard the ASTROSAT mission to probe the extinction across the entire sky. This mission has been in development since 2000 (Agrawal 2001) and is expected to be launched on a Polar Satellite Launch Vehicle (PSLV) rocket by the Indian Space Research Organization (ISRO) in 2013. The UVIT instrument is being developed at the Indian Institute of Astrophysics (IIA) and includes three telescopes, two in the ultraviolet (FUV and NUV) and one in the visible, each including a filter wheel with a number of different filters (Kumar et al. 2012). We have run a series of simulations to determine which filters are best suited for our purpose and will use these results in planning our observations with the UVIT.

2 Data and Simulations

The standard operating procedure of UVIT will be to observe selected targets with a nominal exposure time of about 1000 seconds. Although, due to the multi-wavelength nature of the ASTROSAT mission (there are four other instruments on board, covering the entire X-ray range, apart from the UVIT) and the need to accommodate all the instruments in the time planning, there will be a number of different operating modes. The standard data products will consist of FITS binary tables with a time ordered photon list, FITS images of each field, and a catalog of astrometrically and photometrically corrected point sources. We will start our work with that catalog, and match the UVIT sources with SDSS and GALEX sources. The UVIT filter set covers a broad range of UV to visible spectral region from about 1200 to 5500 Å dividing the range into 12 narrow and broad bands. We considered 5 filters in the FUV telescope (CaF$_2\_1$, CaF$_2\_2$ and BaF$_2$, Silica and Sapphire), 4 filters in the NUV channel (NUVB2, NUVB4, NUVB13, NUVB15) and 3 filters in the visible channel (VIS1, VIS2 and VIS3). The effective areas of these filters, together with GALEX and SDSS bands, are shown in Fig. 1. These filters were chosen for their scientific utility for different programs, with one (NUVB15) selected especially to study the 2175 Å extinction bump. However, because the visible imager was chosen primarily for registration purposes and the data may not be complete or photometrically accurate, we have used only the UV filters in this work. Combining these with the two GALEX bands and the five SDSS bands, we will have a total of 16 photometric magnitudes from the FUV through to the near infrared (1400 – 9000 Å), if the data are available in all bands (Table 1).

Table 1 Effective wavelengths and predicted $m_{AB}$ in different filters for a B0V type star.

| Filter   | Effective Wavelength (Å) | $m_{AB}$ |
|----------|--------------------------|----------|
| GALEX FUV | 1511.2                   | 3.145    |
| GALEX NUV | 2203.1                   | 3.418    |
| UVIT CaF$_2\_1$ | 1483.5           | 3.122    |
| UVIT CaF$_2\_2$ | 1487.5           | 3.126    |
| UVIT BaF$_2$ | 1514.7             | 3.147    |
| UVIT Sapphire | 1591.4           | 3.189    |
| UVIT Silica  | 1701.9              | 3.181    |
| UVIT NUVB15 | 2175.7             | 3.347    |
| UVIT NUVB13 | 2412.0             | 3.47     |
| UVIT NUVB4  | 2618.1              | 3.376    |
| UVIT NUVN2  | 2790.9              | 3.656    |
| SDSS u     | 3515.7              | 4.02     |
| SDSS g     | 4568.5              | 4.352    |
| SDSS r     | 6093.5              | 4.854    |
| SDSS i     | 7048.5              | 5.224    |
| SDSS z     | 8833.7              | 5.57     |

We will compare the model spectral energy distributions (SEDs) with data observed by the UVIT. In this work, we have created the model SEDs for stars of different spectral types reddened by interstellar dust. The stellar SEDs are based on the model spectra of Castelli & Kurucz (2004), provided as fluxes as a function of temperature. Each spectrum was reddened by an extinction curve, based on the standard Milky Way curve of Draine (2003), and then convolved with the all filter curves to produce a magnitude for each of the 16 bands. This is illustrated in Fig. 2 where we have plotted the spectra of an unreddened B0V and an unreddened A0V star with effective fluxes in each of the bands. Note that the points do not always fall on the stellar spectrum because the integration was done over the entire filter band. Fig. 3 shows the effective fluxes for an A0V star for three different values of the interstellar reddening.

We have performed Monte Carlo simulations to estimate the uncertainty expected from the UVIT observations. Each simulation consisted of a series of 100 independent runs for a 20th magnitude star, with different combinations of temperature and $E(B − V)$ with an assumed error of 0.1 magnitudes in each of the bands.
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Fig. 1.— In this plot we have combined the effective area curves of the UVIT filter set: FUV filters in cyan, NUV filters in light blue, visible filters in dark blue. We also show for comparison GALEX effective area curves (green dashed) and the throughput functions of SDSS filter set (red dotted). Note that SDSS curves are given as a throughput function in %, not as effective areas.

Fig. 2.— The stellar spectra of an unreddened B0V star (solid line) and an unreddened A0V star (dashed line – right axis) are plotted with diamonds and squares marking respectively the effective flux in each of the GALEX FUV (at 1557 Å) and NUV bands (at 2261 Å) in red, 9 UVIT bands in green and 5 SDSS filters in blue. Note that the effective wavelength is dependent on both the stellar spectrum and the filter response.

The deviations of the derived $E(B-V)$ from the actual values are plotted in Fig. 2 as a function of the stellar temperature. We are best able to reproduce the original values for A and F stars, with a deviation in $E(B-V)$ of 0.02 magnitudes with an upper limit of 0.05 magnitudes, for stellar temperatures of about 20,000 K. The cooler stars (G type and later) have no detectable UV emission and, hence, are not detectable with the UVIT.

The best possible case would be if we had multiple observations of the same field through each of the combinations of FUV and NUV filters. However, in most cases, we will not have multiple observations of any given location, and thus we have to optimize the choice of filters to maximize the science output, which implies, in this case, the minimization of the $\Delta E(B-V)$.

We have simulated different combinations of FUV and

Fig. 3.— The effective flux in each of the filters for an A0V star with $E(B-V) = 0$ (red); $E(B-V) = 0.1$ (black); and $E(B-V) = 0.3$ (blue). Asterisks represent the flux in the two GALEX bands, circles – in the UVIT bands and crosses – in the SDSS bands.
NUV filters, and calculated the standard deviations for different spectral types and reddening values. The standard deviations for three different spectral types are shown in Fig. 5, assuming a reddening \((E(B-V))\) of 0.5 magnitudes. In all cases, the best fit to the data (the lowest deviations) are for the NUVB15 filter in the UVIT NUV telescope. We are much less sensitive to the FUV telescope, where any of the choices are acceptable.

Fig. 4.— Standard deviations in the \(E(B-V)\) derived from Monte Carlo simulations of the observed fluxes through the GALEX, UVIT and SDSS bands.

Fig. 5.— The deviations in the derived \(E(B-V)\) are shown for each of the different filter combinations. ALL means that all filters were used (see Fig. 2). Three FUV filters, CaF\(_2\)_1, CaF\(_2\)_2 and BaF\(_2\) are quite similar (see Fig. 1) and we show here the results for only one, CaF\(_2\)_1. Note that the SDSS data alone cannot constrain the reddening effectively.

3 Conclusions

We have begun the process of observational mission planning for the UVIT instrument by calculating the flux in each of the UVIT bands to maximize the science. In this work, we describe our plans to make a three-dimensional dust map over the sky using the UVIT point source catalog, combined with GALEX and SDSS observations. We have determined the best filter combination for this extinction work as NUVB5 filter with any of the the FUV filter, but since observations are generally serendipitous in nature, we will use all the UVIT data for our purpose. The process of observational mission planning for UVIT will include the optimization of filters combinations for all scientific objectives. For example, we will calculate SEDs for different scientific programs (such as, for ex., stellar astrophysics, observations of globular clusters, AGN, etc.) and select the optimal filters.

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