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Proposed UV-optical payload for the Indian astronomy satellite

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Abstract. The Ultraviolet Imaging Telescope is a part of the proposed Indian Multiwavelength Astronomy Satellite mission. The primary objective of the UV Imaging Telescope is an all-sky survey in two bands in the wavelength region 1200 to 3000 Å. The aperture of the telescope will be 50 cm and there will be two channels for simultaneous observations, one for the range 1200-1900 Å and the other longwards of 1800 Å. The goal for spatial resolution on the sky over a full field of 2° is ~ 2 seconds of arc. The detectors of choice are photon counting devices using MCP intensifiers and different photocathodes for the two channels. Each channel will have a filter changing mechanism, with a provision for upto 4 full size filters and 20 small (20 arc minutes) filters. It will also be possible to mount grisms for field spectroscopy.

The all-sky survey is expected to reach a UV (1500 Å) limiting magnitude of 20. After the all sky survey, deeper surveys over selected regions of the sky can also be done, interspersed with programs for the X-ray payload. A key area will be simultaneous UV / optical and X-ray observations of a variety of astronomical objects ranging from binaries to quasi-stellar objects and active galactic nuclei. The launch of the mission is expected between the years 2002 and 2004.

Keywords : telescope - ultraviolet - imaging - survey

1. Introduction

In the Presidential address yesterday we have heard a detailed account of the state-of-the-art in Indian satellite and launch capability and the encouragement this community has received from the Department of Space (DOS) for an Indian space mission fully devoted to astronomy. The Secretary DOS set up two Working Groups (WG), in August last year, to consider proposals in the areas of X-ray/γ-ray astronomy and UV/optical/IR astronomy and to come up with an integrated mission definition for a multi-wavelength satellite devoted to astronomy. In an earlier talk we have heard a description of payloads proposed by the WG for the high energy bands (X-ray/γ-ray). In this talk I shall report on the deliberations of the WG for UV/

Optical/IR bands and present the rationale for and a brief description of the Ultra-Violet Imaging Telescope (UVIT), which has emerged as the consensus payload of the WG.

The instruments for the astronomy mission would be mounted on the Indian Remote Sensing (IRS) satellite platform. The Polar Satellite Launch Vehicle (PSLV) rocket can be used to launch a total payload mass of 500 to 600 kg on the IRS bus to an orbital altitude between 600 and 800 km. To minimise the effects of charged particles background (which is high over the polar regions), it is highly desirable to have a low inclination orbit (with an inclination of ~ 28° to the equator). The three axis stabilised IRS bus presently achieves a pointing accuracy of 0.1° (6 arc minutes) about all three axes and this can be improved to better than 0.05°. The star sensors currently used allow a pointing stability of about 0.02°, with more accurate position error feedback (eg. from the UVIT detectors) this can be improved considerably. The solar panels on the IRS can generate upto 800 watts of power, of which about half can be made available for the scientific payloads. The projected lifetime for the astronomy mission using this bus would be around five years.

2. Scientific objectives

The overall objective of the astronomy mission is to provide a multi-wavelength platform for space-based observations with emphasis on the UV and X-ray wavelengths. The primary scientific objectives are to do an all-sky imaging survey in the ultraviolet and to do simultaneous UV and X-ray observations of certain classes of objects such as binary stars and AGN.

The UVIT proposal aims at a high resolution imaging survey of the entire sky in two bands in the wavelength region 1000 to 3000 Å. The TD-1 satellite had produced the first photometry in the ultraviolet for stars all over the sky; since then there have been several limited UV imaging experiments on rocket and balloon borne missions, but an imaging survey of the sky in the UV comparable to surveys in other wavelength bands has not yet been carried out. An excellent summary of past UV imaging experiments can be found in O' Connell 1991. The advantage in the UV band lies in the fact that the background of the night sky is substantially lower than that in the visible bands (at ground-based sites), going down to 26 mag/arcsec^2 at around 2000 Å (see O' Connell 1987). Keeping in mind that the energy output from 'hot' object peaks in the UV, with the resulting increase in contrast against the background of the far more numerous cool sources (cool stars both in the Galaxy and in other galaxies), it becomes apparent that even a modest aperture offers distinct gains for studies of UV-bright objects, comparable to 4 metre telescopes on the ground in the visible bands. The Ultraviolet Imaging Telescope, a 38 cm aperture telescope developed at the NASA Goddard Space Flight Centre (see Stecher et al., 1992) and flown on the ASTRO1 (1990) and ASTRO2 (1995) missions, produced UV images of a variety of sources (see the NASA and STScI web sites for images) dramatically demonstrating the scope of the UV for a variety of astrophysical problems, even with a modest aperture.

The all-sky survey will be done simultaneously in two channels, one in the far UV (FUV 1300-2000 Å) and the other in the near UV (NUV 2000-3000 Å). The filter bandwidths will be in the range 400-500 Å. The effective integration time would be ~ 20 minutes, reaching a limiting magnitude m_{1500}~ 20. The filter wheels in each channel will have additional slots, both to cover the full field of view (fov) of 2° as well as for smaller fields of ~ 20 arc minutes. Careful selection of filters will allow deep, multiband surveys over limited fields aimed at discriminating different classes of objects eg. QSOs or AGNs in different redshift ranges. The survey will thus yield a valuable image data base which will provide new insights into physical processes in a wide variety of objects :

* Hot stars have flux maxima in the UV, allowing a factor of ~ 10 more sensitivity in determining temperatures using UV-V colours. This class of objects includes young clusters, star forming complexes, starbursts, PN central stars, post AGB, HB and EHB stars, metal poor stars in the Galactic halo, white dwarf and hot binary stars. The survey would yield upto **several times** 10^4 **objects**.

* Normal galaxies, even of types E or SO have $m_{uv} - m_v$ in the range –1 to –2 and blue dwarf galaxies are still bluer. Faint galaxy counts yield ~ 200-300 galaxies /deg^2/mag at B~20. We expect to detect a **few times** 10^7 **galaxies** in the survey.

* Quasars and AGN have very blue UV-V colours. At B~20, one expects ~30 - 40 QSOs/ deg^2/ mag. The 'big blue bump' in the energy distribution of quasars peaks in the 1000-2000 Å region, making for easier detection in the UV. Many of them also have a soft X-ray excess which shows up in the UV for certain redshift ranges. The Lyman break gets shifted into the UV region, allowing for detection of high redshift objects using UV colours. We expect to detect ~ 10^6 **objects in the survey**.

After the initial all sky survey, which is expected to be completed in about eight months, the UVIT will be used for targetted programs in the pointed mode. The primary programs among these will be multi-wavelength monitoring (X-ray/UV) of X-ray binaries, cataclysmic variables, novae, supernovae, AGNs and QSOs. Other programs of interest to various groups are (but not limited to); star formation processes (young cluster and starbursts), studies of old metal poor stars and hot stars in the halo, mapping of HII regions, properties of the interstellar medium, polarisation in UV of different classes of objects, metallicity gradients in galaxies, deep imaging surveys for number counts of galaxies, redshifts from multiband colours and grism spectra, studies of gravitational lensing in the UV, monitoring the afterglow of gamma ray burst sources, diffuse UV emission from possible neutrino decay in clusters of galaxies, studies relating to the nature and distribution of the UV sky background.

3. UVIT concept

The performance goals of UVIT have been specified taking account of the primary objective of an all-sky survey as well as scientific programs projected by different groups. The baseline proposal specifies an aperture of 50 cm, with an image scale around 60 arcsec/mm and 80% energy concentration within 1 arcsec for a full field of 2°. A beam splitter divides the light into the FUV and NUV channels. Each channel is to have a filter wheel for full size broad band filters and smaller size narrow band filters. The filter wheels can also accommodate optical elements for polarisation studies as well as grisms for spectroscopy. The telescope configuration is constrained by the volume and mass limit restrictions on the payload.

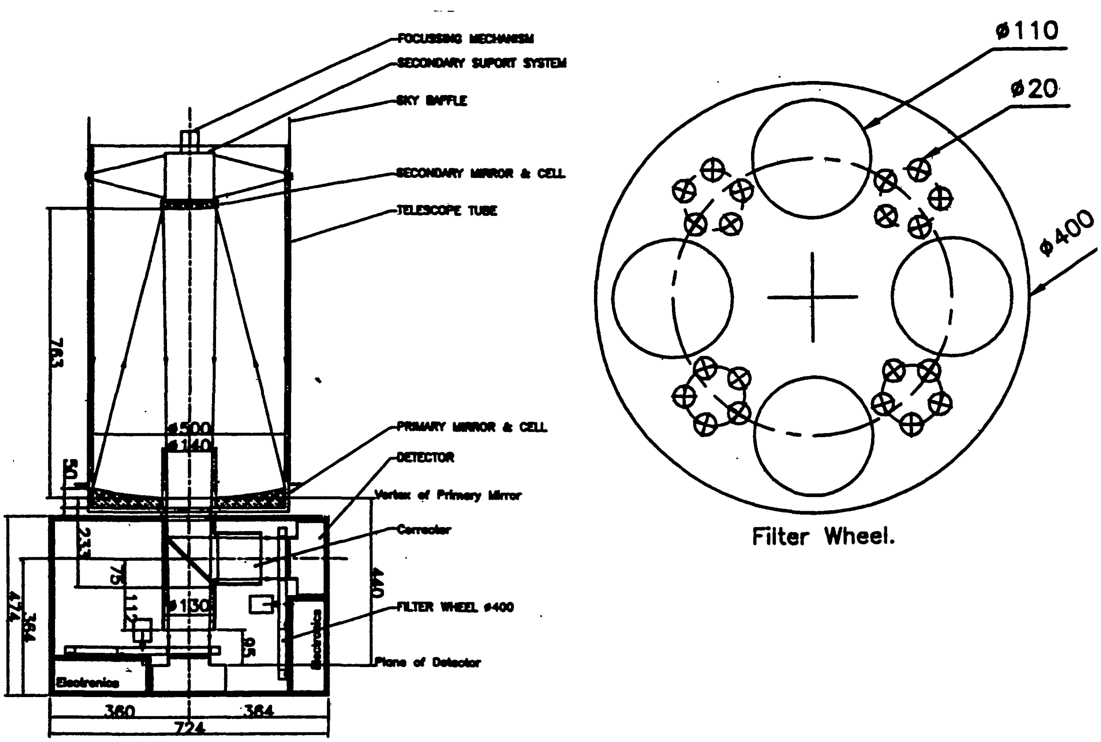

Figure 1. Details of the UVIT baseline configuration. This is a Ritchey Chretien configuration using correctors. All the necessary baffles, wavelength cutt-off filters etc are not shown (dimensions in mm). The layout of the filter wheel is shown alongside.

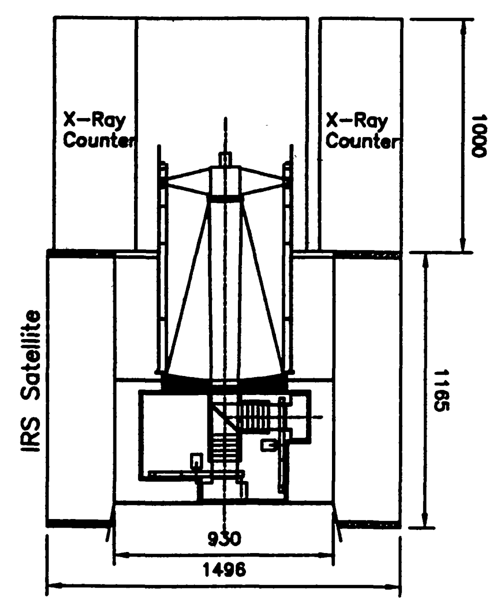

Figure 2. Cross section of IMAS showing the UVIT concept mounted on the IRS bus along with the X-ray detectors (dimensions in mm)

Fig. 1 shows a first concept for the telescope, employing a Ritchey-Chretien configuration with correctors. The primary mirror has ϕ=50 cm F/2.4 and the final focal ratio is F/6.78 with a relative obscuration of 0.2. The mirrors are to be of low expansion Zerodur, with an aluminium and magnesium fluoride (Al+MgF_2) coating. The beam from the secondary is split into the FUV (reflected) and NUV (transmitted) channels by a beam splitter with appropriate multilayer coatings. The corrector elements for the two channels will also have coatings optimised for the wavelength region of interest. The final design optimization has to be done taking account of the filters and detectors. The FUV channel will have a cutoff filter in front of the detector to avoid geocoronal Lyman-alpha (Lyα) radiation. A layout showing the filter wheel and available slots is also shown in Fig. 1, Fig. 2, shows schematically, the UVIT mounted in the IRS satellite along with the proposed X-ray detectors.

Detectors for the FUV and NUV channels is a critical area for UVIT. Optimal sampling of the image size as specified above, required a pixel size of 16 to 17 microns (μ). For imaging a field of 2° a detector of ϕ ~ 120 mm is required. Further, operation of the detector in both the scan mode as well as stare mode is desirable. The critical aspects of detector performance are high efficiency in the UV (and no sensitivity at longer wavelengths), large dynamic range, low background, low image distortion, durability and stability in the orbital environment. The detectors of choice are photon counting microchannel plate (MCP) detectors which have been flown successfully on several missions (eg. The Hopkins Ultraviolet Telescope, the NASA Goddard Ultraviolet Imaging Telescope, the Extreme Ultraviolet Experiment). These detectors use different image readout schemes ranging from photographic film for the UIT to delay line readout for the EUVE. Another interesting readout option is used in the Precision Analog Photon Address (PAPA) detector, which employs an optical readout (see Papaliolios et al., 1985). There are several other readout methods using array detectors (eg. electron bombarded CCDs, charge injection devices) being developed by different groups.

The **total mass** of UVIT including all subsytems is expected to be around 230 Kg and the **power** requirement is estimated at 210 watts, well within the constraints of the overall payload repertoire. Several other areas such as instrument control, data acquisition, on-board data processing, telemetry, post processing, archiving etc. have been deliberated upon during discussions of the WG and cannot be addressed here for want of time. It can be pointed out here that photon counting detectors used in scan mode for the survey will generate photon event lists, which would be a much sparser data set compared to full images generated in stare mode. For pointed programs using stare mode imaging it may be necessary to have an on-board memory of ~ 500 Mb to accumulate images between data dumps to a single ground station.

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