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TAUVEX—UV observations from geosynchronous orbit

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Abstract. The TAUVEX Observatory consists of three identical co-aligned telescopes operating in several bands in the 1200 − 3500 Å bandpass from geostationary orbit. The major science objectives of TAUVEX are (a) searches for QSOs and AGNs based on their UV properties, (b) surface photometry of galaxies in the UV, (c) studies of stars and nebulae within the Galaxy, (d) the nature of the UV background, and (d) studies of variable sources in the UV domain. The Principal Investigators and TAUVEX Science Team have created a coherent observing programme to address several key science objectives that will constitute the Core Science Programme projects. Along with this project, which will contribute up to 85% of observing time, the Science and Core Group teams have identified a small number of more modest programmes to pursue. We present a description of the TAUVEX mission, including details of the instrument design and its estimated performance, assess the status of the mission development and describe in brief the main research categories. Additional information on the TAUVEX programme and development can be obtained on the World Wide Web at http://tauvex.iiap.res.in.

Keywords : space vehicles: instruments – ultraviolet: general – surveys

1. Introduction

The TAUVEX Observatory is a collaborative project between the Indian Institute of Astrophysics (IIA) and Tel Aviv University (TAU) to observe the ultraviolet (UV) sky.

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TAUVEX Observatory consists of a set of three identical co-aligned telescopes capable of imaging in the 120 to 350 nm range through a set of 5 different filters. The principal hardware and software developments for the TAUVEX instrument is carried out at ElOp (Electro-Optic Industries), the Israeli aerospace company, and after the ground calibrations the instrument will be shipped to ISAC (ISRO Satellite Centre) in Bangalore, India. The observatory will be launched as part of the GSAT-4 mission on a GSLV rocket from the Satish Dhawan Space Centre into a geostationary orbit in early 2008. The nominal mission life-time of the Observatory is 3 years, but a much longer life-time is expected.

Science planning for TAUVEX is being conducted by the personnel of the TAUVEX Core Group (TCG). All science planning activities will be based at TAUVEX Data Centre, IIA, Bangalore, India. The TCG will solicit observational and archival research investigations through *Calls for Proposals*, will organize technical and scientific reviews of proposals and select the approved investigations (based on the recommendations from a TAUVEX Science committee). In addition, the TCG will schedule all science observations (including calibrations), conduct pipeline processing of all TAUVEX data, develop and maintain software tools for higher-level analysis tasks, maintain the TAUVEX Webpage, and create an electronically accessible science data archive.

While the sky background at all wavelengths is much less in space, the sky background is particularly low in the UV. The advantages of observing in the ultraviolet have been well documented by O'Connell (1987); namely, the sky background in this spectral regime is 5 mag/arcsec^2 lower than in optical, allowing faint objects to be easily seen. However, despite its importance to many areas of astronomy, the UV sky is still largely unknown. There has been no full survey of the UV sky since the TD-1 satellite in the early 1970's, which had both low sensitivity ($11^{\rm m}$) and low spatial resolution ($1'$). Pointed-mode instruments such as the *IUE* and the *HST* have yielded a wealth of data but have only observed objects discovered in other wavelength bands.

More recently (Burgarella et al. 2003), a UV mission, the Galaxy Evolution Explorer (GALEX) was launched by NASA to investigate the evolution of galaxies at low redshifts. GALEX is comprised of one telescope with a dichroic, which splits the light into two different bands, one in the FUV (1300−1800 Å) and the other in the NUV (1800−3000 Å).

The TAUVEX Observatory will not only complement and supplement GALEX data, but also provide simultaneous observations in three wavelength bands in UV (see Fig. 1) with a greater sky coverage. TAUVEX mission planning will be done in such a way as to keep GALEX already observed areas in mind.

The Indian multi-wavelength satellite ASTROSAT will also contain an ultraviolet imager (UVIT) (see Pati & Rao 1998) but with a much smaller field of view and higher spatial resolution. TAUVEX will be an ideal precursor to ASTROSAT. Areas of sky selected on the basis of TAUVEX data can then be observed with much higher spatial resolution by UVIT.

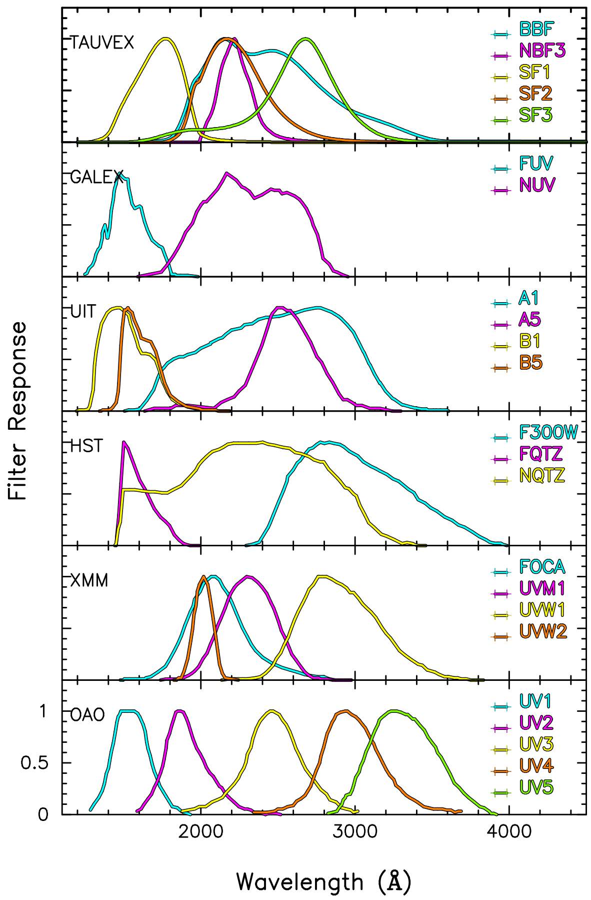

Figure 1. Comparison of TAUVEX with other UV missions spectral coverage.

We believe that we will obtain a unique science product with TAUVEX that will be widely used by Indian, Israeli, and international scientists and will complement existing ground observatories such as ARIES in Nainital and IAO in Hanle, and future space missions such as ASTROSAT.

2. TAUVEX main science goals

The main scientific goal will be to survey the sky over the mission lifetime combined with selected deep fields and observations of interesting targets. Our limiting magnitude will be on the order of 19 for the UV 3-band survey and 25 for the deep pointings. (Note that we quote magnitudes as per Hayes & Latham 1975.) We will certainly detect more than

10^7 galaxies with 3-band photometry plus a comparable number of stars and, perhaps most excitingly, several million quasars.

Perhaps the most important science issue to be addressed by TAUVEX is simply that of a deep census of a large fraction of the sky. Immense numbers of new objects will be discovered which will then be followed up from ground-based observatories in India and Israel for identification and further classification.

We will also obtain a measure of the diffuse galactic light over regions ranging from the Galactic plane to the poles. This is largely starlight scattered by interstellar dust about which little is known. Dust is important in many processes in our Galaxy and others, particularly in radiation transfer from starlight to the interstellar medium in which new stars are born. With its wide field of view, combined with the ability to reject stars because of its 2-dimensional imaging capability, TAUVEX will be able to trace the level of the astronomical diffuse radiation over the sky. There are other sources of radiation from the sky which have affected diffuse radiation measurements over the sky. The dark count rate from the instrument (the rate when no astronomical source is being observed) should be small and will be measured at intervals using a blocking filter. Terrestrial emission which often affects satellites in lower orbits will simply not be present at geostationary altitudes, except for the Lyman lines of hydrogen, where the specific choice of TAUVEX filters comes into account. The selected range of the filters cuts off the Lyman lines. And a unique possibility allows the study of the interstellar dust band at 217.4 nm; the two TAUVEX filters SF2 and NBF3 (see Table 2) are centered on this wavelength but have different widths. As the filters are located on different telescopes, it is possible to measure the same sky region in both filters simultaneously, deriving the equivalent width of the band for every star in the FOV.

TAUVEX is well-suited for UV variability studies because of the possibility of repeated scans. Because of the nature of a TAUVEX operations, the time scale at which variability may be investigated will depend on the source latitude and brightness. Here TAUVEX has the advantage over *GALEX* as *GALEX* does not study variability. In addition, multi-wavelength follow-up is critical for variable sources and will be coordinated by the TAUVEX Science Team.

Extragalactic light has long been the Holy Grail of diffuse studies but is hampered by Galactic light in most spectral regions. We will be observing Galactic poles as part of our survey, where we will be able to obtain the best observations of the extragalactic light. Through these observations we will be able to significantly constrain cosmological models.

3. Main research categories

For the first three years of TAUVEX science operations, in recognition of the time spent on the development of the instrument, its operational planning and science planning, the TAUVEX observational time will be predominantly restricted to Indian and Israeli participation. There are three main categories of observing time with TAUVEX: Core Science Programme, which has the Guaranteed Time Observations (GTO) status; First Science Survey (FSS), and General Observations Programme. In addition, any researcher from the general scientific community may apply for the Archival Research Programme through the proposals sent to TAUVEX PIs. The proposals will be evaluated according to the guidelines delineated in the *Pre-Launch Call for Proposals.*

3.1 TAUVEX Core Science Programme

85% of the observing time will be dedicated to the Core Science Programme, which is created in recognition of the importance of the space UV astronomy in India and Israel and its impact on the future development of astrophysics in both countries. The Core Science Programme participation is restricted to the Indian and Israeli scientific community and has a GTO status. The programme constitutes several broad key science areas, defined by the TAUVEX Science Team. The Lead Investigators of each key science area are responsible for the creating of a detailed respective science plans and the TAUVEX Science Committee is responsible for incorporating these plans into a final Core Science Programme plan. There are six key science areas with equal share of the Indo-Israeli leadership. These areas are *Stellar UV Astronomy*, *UV Studies of Galaxies*, *Diffuse UV Radiation and Dust*, *Studies of Active Galaxies*, *UV Deep Surveys*, *Galactic Astronomy.* Each area will have specifically defined projects, abstracts of which will be available on the TAUVEX web pages.

3.2 General observations

15% of the observing time is reserved for proposals that are outside the Core Science Programme key areas but, nevertheless, may constitute important scientific contribution to the UV science. In these projects the PIs have to be from India or Israel but co-investigators need not be. Examples of such topics are:

Project title	Principal investigator
UV flushes from planetary collisions	C. Sivaram, IIA
UV observations of ULXs	M. Safonova, IIA
Detecting pulsars in UV	Gangadhara, IIA

3.3 First Science Survey (FSS)

The First Science Survey (FSS) is intended to provide an early examination of the UV sky. It will be conducted in the first months from the start of TAUVEX observations by the TAUVEX Core Group. The primary purpose is to provide an early and representative sample of reliable UV data that will enable effective and efficient planning of TAUVEX observing programmes. The Survey will characterize both high- and low-latitude regions of the sky, and will access the effects of zodiacal emission. The FSS will include both Galactic and extragalactic components.

3.4 Archival research

Data from TAUVEX observations will enter the public (password-protected) archive immediately upon obtaining, however, it will be predominantly restricted to the core science programme projects. General Observations projects will have access to their archival data through their passwords. Any researcher from the general scientific community may apply for the Archival Research Programme through the proposals sent to the TAUVEX PIs.

4. Science team members

TAUVEX is a Principal Investigator (PI) class Observatory with a Science Team composed of Indian and Israeli scientists at academic and governmental institutions. The PIs of the TAUVEX mission are Jayant Murthy of the Indian Institute of Astrophysics and Noah Brosch and Hagai Netzer of the Tel Aviv University. In addition, members of the TAUVEX Core Group (TCG), who contribute to the instrumental development, operational planning, science planning, and science operations of TAUVEX will also actively participate in the utilization of data obtained with instrument observing time. Members of the TAUVEX science team are listed in Table 1.

5. The TAUVEX observatory

5.1 The instrument

TAUVEX consists of a three-telescope array mounted on a single bezel and enclosed in a common envelope. Each telescope is a reflecting Ritchey-Chrétien design, with field-flattener corrector lenses. The clear aperture of each telescope is 20 cm.

The systems are designed for imaging the same 0.9° field in the UV spectral band from 120 nm to 350 nm. Therefore, the corrector optics is manufactured from high quality

Table 1. TAUVEX Science Team (list not exhaustive).

Jayant Murthy (PI)	Indian Institute of Astrophysics
Noah Brosch (PI)	Tel Aviv University
Hagai Netzer (PI)	Tel Aviv University
Elhanan Almoznino (TCG)	Tel Aviv University
Rekhesh Mohan (TCG)	Indian Institute of Astrophysics
Margarita Safonova (TCG)	Indian Institute of Astrophysics
P. Gopakumar (TCG)	Indian Institute of Astrophysics
Kameswara Rao	Indian Institute of Astrophysics
Harish Bhatt	Indian Institute of Astrophysics
Prajval Shastri	Indian Institute of Astrophysics
Annapurni Subramaniam	Indian Institute of Astrophysics
G. C. Anupama	Indian Institute of Astrophysics
U. C. Joshi	Physical Research Laboratory
G. Maheswar	ARIES
Ram Sagar	ARIES
Ananda Rao	Physical Research Laboratory
Swara Ravindranath	IUCAA
Gopal Krishna	NCRA
Sandip Chakrabarty	S N B N C S
Paul Groot	Radboud University
Ashok Pati	Indian Institute of Astrophysics
K. P. Singh	TIFR
Kiran Baliyan	Physical Research Laboratory
Ranjan Gupta	IUCAA
Gajendra Pandey	Indian Institute of Astrophysics
Asoke K. Sen	Assam University
B. Kumar	ARIES
B. Shylaja	J. N. Planetarium, BASE
N. V. Sujatha	Indian Institute of Astrophysics
P. Shalima	Indian Institute of Astrophysics

CaF_2, as well as the filter substrates and detector windows. The image quality is 6-8 arcsec (FWHM), depending on the spectral band of observation.

The primary and secondary mirrors are both lightweighted zerodur coated with Al + MgF_2 with an effective reflectivity of better than 90% over the wavelength region of interest. In addition, two doublet lenses, made of CaF_2, correct the field of view for aberrations and serve as Lyman α blockers. A schematic of the telescope structure with the internal baffles is shown in Fig. 2. The structure is cut away in one of the telescopes to show the carbon fibre (CFRP) metering support. CFRP expands very little due to temperature and so the entire telescope will stay in focus over a wide temperature range.

The detectors are photon-counting imaging devices, made of a CsTe photocathode on

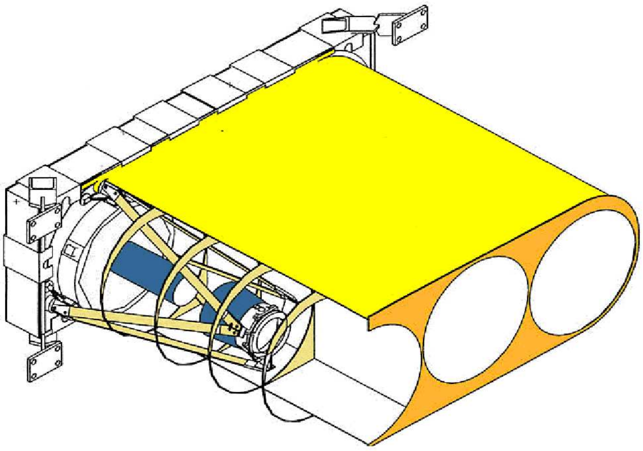

Figure 2. A schematic of the TAUVEX optical module structure is shown. One of the telescopes is cut away to show the internal baffles and mirrors.

the inner surface of the entrance window, a stack of three multi-channel plates (MCP), and a multi-electrode anode of the wedge-and-strip (WSZ) type. The photons detected by the instrument are treated by an electronic chain that calculates their arrival positions on the anode plate. The MCP chain gives a final spatial resolution of about 60 μm on the plate. Table 2 lists basic instrument parameters.

Table 2. Instrument parameters.

Mirrors (2)	:	zerodur substrate, Al+MgF_2 coating
Optics	:	2 doublet CaF_2 lenses; F/8 Ritchey-Chrétian
Diameter	:	20 cm aperture each
Detectors	:	3 chain microchannel plates with 25 mm CsTe photocathode
TAUVEX weight	:	37.5 kg
		Locations of the filters
Telescope:		Filters:
T1	:	SF1; SF2; BBF
T2	:	SF1; SF3; NBF3
T3	:	SF2; SF3; BBF

The observatory will be mounted on a rotating plate, called the Mounting Deck Plate (MDP), on the east face of GSAT-4. Nominal operation involves scanning the sky along a fixed declination and then change the platform orientation after the full revolution with complete sky coverage achieved by rotating the MDP from $-90°$ to $+90°$. However, the observable part of the sky is decided by various constraints that are discussed in details in the *TAUVEX Observer's Manual*. This document will be updated regularly by the TAUVEX Core Group and is available on the TAUVEX web pages.

5.2 Filters

There are four filters per telescope offering a total of five different UV bands for observation. The filter complement consists of a broad-band filter (BBF), which provides a blue cutoff for wavelengths shorter than 200 nm, three intermediate band filters (SF1, SF2 and SF3) and a narrow band filter (NBF3). Filters effective areas are given in Fig. 3 and filters properties are given in Table 3.

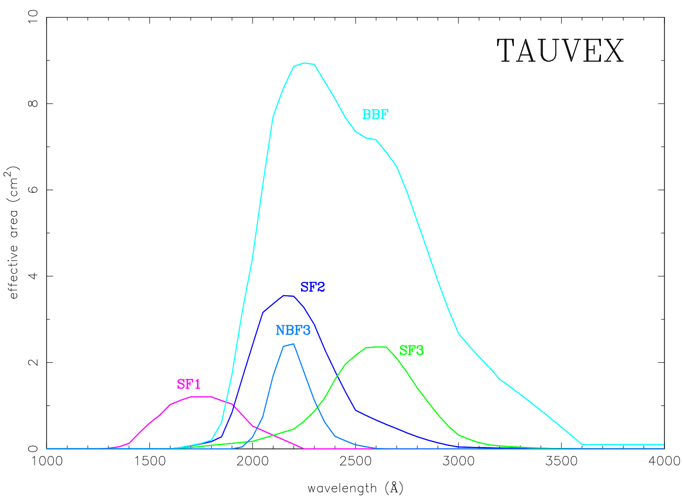

Figure 3. The spectral range of the TAUVEX filters.

In the standard mode of operation, we plan to use one fixed filter per telescope to give effective bands of 1700 ± 250 Å, 2150 ± 210 Å, and 2530 ± 225 Å, but will maintain the capability to change filters should it be desired on programmatic or scientific grounds.

6. Status

The ground calibrations are scheduled for April 2007 at El-OP, Israel. The TAUVEX Science Team has developed several comprehensive scientific objectives for the TAUVEX operations that constitute the Core Science Programme for the first three years of TAUVEX flight. TAUVEX Core Group has completed the schedule for the observational Stage One and the *Pre-Launch Call for Proposals*, *TAUVEX Data Agreement and Policies* and *TAUVEX Observer's Manual Update* documents are going to be released to the public after the ground calibrations. TAUVEX Core Group has created online science tools

Table 3. Observatory parameters.

Wavelength coverage	: 1250 − 3500 Å	
Angular resolution	: $6'' - 10''$ (depending on λ)	
Field of View (FOV)	: 0.9°	
Time resolution	: 128 milliseconds	
Observational mode	: Scanning	
Minimal exposure time*	: 216 seconds	
Filters central wavelengths and bandpasses		
Filter:	Wavelength (Å)	Width (Å)
NBF3	: 2200	: 200
SF1	: 1750	: 500
SF2	: 2200	: 400
SF3	: 2600	: 500
BBF	: 2300	: 1000
Bright limit (point source, BBF)	: $F_\lambda = 1.3 \times 10^{-11}$ erg cm^{-2} s^{-1} Å^{-1}	
Point source sensitivity (200 s)	: (For an O type star)	
BBF	: $V \approx 22.2$	
SF3	: $V \approx 20.2$	
SF2	: $V \approx 20.8$	
SF1	: $V \approx 20.3$	
NBF3	: $V \approx 19.2$	

*this exposure time is for $\delta = 0°$; it increases with declination and reaches theoretically $\sim$ 86000 seconds on the Pole ($\delta = \pm 90°$)

library for the preparation of the observations with TAUVEX and the first stable version of the pipeline is released on the TAUVEX Web Page. The Core Group is preparing to conduct the next TAUVEX Science Meeting—Observational Planning Workshop—in September 2007.

7. Acknowledgements

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Note added in Proof: Please, check our website *http://tauvex.iiap.res.in* for the latest information. Some of the dates and details have been updated.