UVSTAR, AN IMAGING SPECTROGRAPH WITH TELESCOPE FOR THE SHUTTLE HITCHHIKER-M PLATFORM

Roberto STALIO
Department of Astronomy, University of Trieste & Center for Advanced Research in Space Optics - Area Science Park, Padriciano 99, 34016 - Trieste

Bill R. SANDEL, A. Lyle BROADFOOT
Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721

ABSTRACT

UVSTAR is an EUV spectral imager intended as a facility instrument devoted to solar system and astronomy studies. It covers the wavelength range of 500 to 1250 Å, with sufficient spectral resolution to separate emission lines and to form spectrally resolved images of extended plasma sources. Targets include the Io plasma torus at Jupiter, hot stars, planetary nebulae and bright galaxies. *UVSTAR* consists of a pair of telescopes and concave grating spectrographs that cover the overlapping spectral ranges of 500 - 900 and 850 - 1250 Å. The telescopes use two 30 cm diameter off-axis paraboloids having focal length of 1.5 m. An image of the target is formed at the entrance slits of the two concave grating spectrographs. The gratings provide dispersion and re-image the slits at the detectors, intensified CCDs. The readout format of the detectors can be chosen by computer, and three slit widths are selectable to adapt the instrument to specific tasks. *UVSTAR* has internal gimbals which allow rotation of ±3° about each of two axes. Dedicated finding and tracking telescopes will acquire and track the target after rough pointing is achieved by orienting the Orbiter. Responsabilities for implementation and utilization of *UVSTAR* are shared by groups in Italy and the U.S. *UVSTAR* is scheduled for flight in early 1995, timed for an opportunity to observe the Jovian system.

INTRODUCTION

UVSTAR, UltraViolet Spectrograph Telescope for Astronomical Research, is a spectrographic telescope for observations of astronomical and planetary sources; it operates in the 500-1250 Å waveband at ≈ 1 Å resolution. The experiment has capability for long slit spectral imaging of extended cosmic sources such as planets, planetary nebulae, supernova remnants, H II regions, and external galaxies. *UVSTAR* will fly as a Hitchhiker-M payload on the Shuttle (Figure 1). The experiment complement includes an independent companion instrument that will be provided by Darrell Judge (University of Southern California) to measure the absolute solar flux in selected extreme ultraviolet bands. The two experiments form the IEH (International EUV/FUV Hitchhiker) mission.

UVSTAR consists of a movable platform and an optical system. The platform will provide fine pointing (±5 arcsec) within ±3° from the nominal view direction, which is near the Shuttle +Y axis, i.e. perpendicular to the long axis of the Shuttle and in the plane of the wings. The optical system consists of a set of two telescopes and Rowland concave-grating spectrographs with intensified CCD detectors. The first spectrographic telescope (FUV) operates in the 850-1250 Å spectral range; the second (EUV) covers the 500-900 Å region. A number of pointed observations will be made of calibration targets, planets, ultraviolet stellar sources and extended objects. At any time the *UVSTAR* is pointed toward the hemisphere outward from the Earth and the Shuttle is on celestial lock, it is possible that a source of interest for UV astronomy will be within the pointing range. In this case, *UVSTAR* will operate in a ''serendipitous/target-of-opportunity'' mode; in this mode targets that will have been defined in advance will be acquired and observed.

UVSTAR has two nearly identical spectrograph channels (EUV and FUV) that will observe simultaneously the same target. Each channel consists of a telescope mirror, and a concave grating spectrograph with its own intensified CCD detector. The telescopes form images of the target at the entrance slit of the spectrographs. The concave gratings of the spectrographs both disperse and re-image the light from the target onto the 2-D detectors. Spatial resolution along the slit is preserved, so that in the cross-dispersion direction the detectors records many spectra corresponding to different part of the source simultaneously. The optical design is driven by the facts that at the EUV wavelengths of interest

- only reflective optics can be used,
- reflectivities are poor, which requires minimizing the number of reflections if weak sources are to be detected in a short period of time.

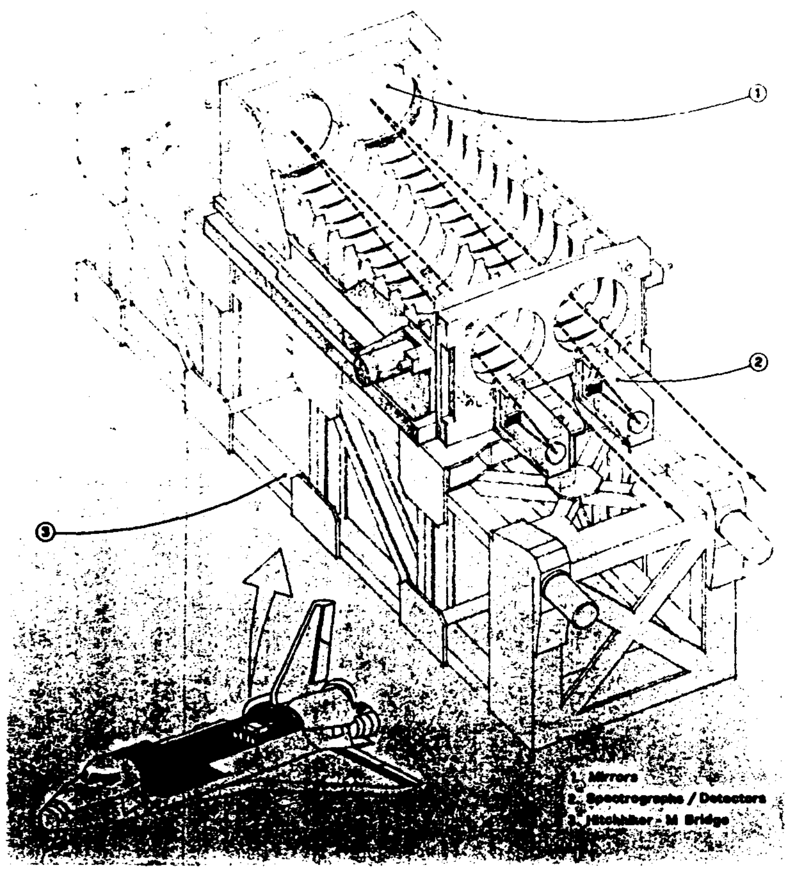

Figure 1: Sketch of the opto-mechnical configuration of *UVSTAR*

TELESCOPES

The telescope mirrors are off-axis paraboloids of 30 cm diameter and 1.5 m focal length. They are SiC coated for maximum reflectivity; are made by Zerodur to prevent defocussing due to thermal changes; are joined to the spectrographs by rods of a carbon composite material of about zero thermal expansion coefficient along its length.

SPECTROGRAPHS

Each spectrograph employs a single concave, holographic grating to disperse the radiation and focus it on the detector. Holographic ruled gratings can achieve aberration correction and a flat focal plane over a length of 8 mm in the cross-dispersion, and 15.4 mm in the dispersion directions. The 70 × 100 mm gratings have a radius of curvature of 275 mm. To maintain good focus over a range of temperatures, the gratings will be fabricated on Zerodur blanks. The grating cell is mounted to permit small motions relative to the spectrograph housing. The position of the grating relative to the entrance slit and detector is established by invar rods that extend from the grating cell to fixed positions near the entrance slit and detector.

The two spectrographs cover overlapping spectral ranges, 500-900 Å and 850-1250 Å. In each case the spectrum of about 400 Å is dispersed along 1152 pixels, giving a dispersion of ≈ 0.35 Å per pixel. The array is 298 pixels wide. In the image mode the spectral/spatial images are comprised of 2 ×1152 × 298 pixels, that is, nearly 7×10^5 pixels or 1.4×10^6 bytes if each pixel is digitized to 16-bit accuracy. The read out format is controlled by computer so that it can be matched to the needs of a particular experiment.

SLIT SELECTOR

Each of the spectrographs is equipped with a mechanism for selecting among three entrance slits. All slits have the same length of 0.25° but differ in width. The slits widths and their uses are:
- Narrow slit (3 pixels, 9 arcsec). This slit will provide about 1 Å resolution and will also have spatial resolution it.
- Medium slit (13 pixels, 39 arcsec). This slit will give global images of extended sources (planetary nebulae, SN remnants, Jupiter's disk) at the wavelengths of most intense emissions. Resolution is 4.5 Å.
- Wide slit (33 pixels, 100 arcsec). This aperture will allow the whole image of the Io plasma torus to be dispersed into its major emissions and re-imaged with a resolution of 12 Å.

DETECTORS

The intensified CCD (ICCD) detectors consist of standard proximity-focused image intensifier tubes that are fiber-optically coupled to CCDs. They have successfully flown in previous missions. Both image intensifiers are windowless. Charge from photoevents is amplified by the microchannel plate and electrostatically accelerated to a phosphor screen on a fiberoptic window. The visible-wavelength image from the phosphor is transferred to the CCD by fiber optics for readout. A special position of the slit changing mechanisms seals the spectrograph enclosures to protect the detectors and gratings from contamination. Each spectrograph is equipped with a small ion pump to assure a satisfactory vacuum environment for operating the windowless intensifiers on orbit.

SENSITIVITY

The ICCD detectors of *UVSTAR* are 2-D detectors with photon-counting capability. Thus the overall instrument performance is related to the rate at which photoevents are generated at the photocathode of the detector. For the imaging spectrographs, Table I gives the sensitivity for two kinds of source, namely a point source of continuum emission, and an extended source of monochromatic emission. The wavelengths are in Å, the area of the telescope mirror (A) is in cm^2, Ω is the solid angle, measured in sr, corresponding to the field of view of a single pixel, δ (Å/pixel) is the spectral dispersion, σ is the reflective-dispersive efficiency of the grating, ε the quantum efficiency of the photocathode, μ the reflective efficiency of the telescope, R is the response for a point source in units counts/pixel/s per photon/cm^2/s/Å, S is the response for monochromatic emission of brightness I Rayleighs; the units are counts/pixel/s per Rayleigh.

GUIDING & OTHER CHARACTERISTICS

UVSTAR includes capabilities for independent target acquisition and tracking. The spectrograph package has internal gimbals that allow angular movement of ±3° from the central position. Rotations about the azimuth axis (parallel to the Shuttle Z axis) and elevation axis (parallel to the Shuttle X axis) will actively position the field of view to center the target of interest in the fields of the spectrographs.

Two dedicated visible imagers (Finder and Tracker) having different fields of view, and a quadrature diode, provide guiding information.The Finder has 60 mm focal length and f/1.4 optics giving a field of view of 6° × 8°. The system, fully planned and constructed at CARSO, works in two modes:

Finder mode:
From a coarse knowledge of the pointing direction (± 3°), the system recognizes autonomously the acquired stellar field and point to the chosen direction within ± 5''.
Tracker mode:
After having reached the wanted direction, it operates with three different techniques:
1) same as the *finder mode*: at every acquisition, the system repeats the star field identification routine. In this mode the algorithm requires, on the average, a processing time of 300 ms (on a 386/387 at 25 MHz).
2) *Triangulation mode:* the system chooses three stars out of the stars selected in the *finder mode* and by means of a triangulation procedure, calculates the position of the center of the sensor which concides with the chosen pointing direction. In this case the algorithm needs a few ms of processing time.
3) *Star pointing mode:* the target star is at the center of the sensor. We correct its position at every acquisition keeping it at the center. The algorithm takes only few ms of processing time.

As an alternative to the above mentioned routines we have developed another procedure (planet mode) which doesn't use any identification procedure, but simply searches for the brightest object in the FoV, brings it at the sensor center and tracks it with the algorithm 3.

The Tracker is a 75 mm diameter cassegrain telescope with a focal length of 1.5 m and a field of view of 0.24° × 0.32°. Finder and Tracker have their own ICCD detector, 384 × 288 pixel arrays. The tracker ICCD will have the same plate scale as the spectrograph. In addition the tracker telescope will also be equipped with an intensified quadrature diode which will track a 8-9 magnitude star with negligible processing time. The diameter of the photodiode is 3 mm and the star image will be 1 mm. The tracking accuracy will be better than ±5''.

SCIENCE PROGRAM

1 ASTRONOMY

The ''pointed'' observations from *UVSTAR* will be of 25±5 astronomical sources per flight. A similar number of pointed observations will be available to the planetary physics program. At the end of the program we will have observed 100 to 150 astronomy sources. About 40% of them will be 1) calibration, 2) EUV, and 3) extended sources.

Predicted sensitivity curves for point sources and examples of source observability are displayed in Figures 2, 3 and 4. The sensitivity curves are presented under the form of fluxes which can be observed in 25 minutes with S/N = 6 in the two channels, EUV and FUV. Two observing modes, full resolution and reduced resolution (about 6 Å, IUE-like), are considered. In Figure 2 are also displayed the energy distribution of two important UV sources: HZ 43, a nearby subdwarf, which is among the few stars observable in the 500 - 912 Å band and the bright quasar 3C273. Both are well observable from *UVSTAR*, even if, at the shorter FUV wavelengths, the signal to noise ratio of 3C273 will be slightly less than 6 using the "standard" exposure time of 25 minutes. Figure 3 gives compares the FUV sensitivity curves with energy fluxes of two representative cataclysmic variables; Figure 4 does the same for two important Seyfert galaxies. In this last case both continuum fluxes and line fluxes are reported.

The effects of interstellar extinction on exposure times are presented in Figure 5 for full resolution spectra. With the IUE-like resolution one gain a little bit less than 2 magnitudes. The effects also include the absorption for molecular hydrogen. The FUV interstellar reddening curve and the H_2 absorption have been discussed in a previous study of low resolution data from the Voyager UV Spectrometers (ref. 1).

The EUV program will be fundamentally different from that at longer wavelengths because of the opacity of neutral hydrogen in the interstellar medium. In general we will be able to observe only within a few tens of parsecs from the Sun; however, in those directions where the ISM has low density, we will go farther and possibly observe some stars. In general only a few hot white dwarfs are listed as candidates. However, the recent results by ROSAT and EUVE indicate that a substantial number of sources would be observable. As an example, among the EUV sources detected by ROSAT WFC (at 100 and 137 A) in a 60 x 60 degree field centered at $\alpha = 14^h$ and $\delta = 10°$ are the low X-ray binaries Sco X-1 and Her X-1, the FUV source Spica (B1V star), 3C273 (

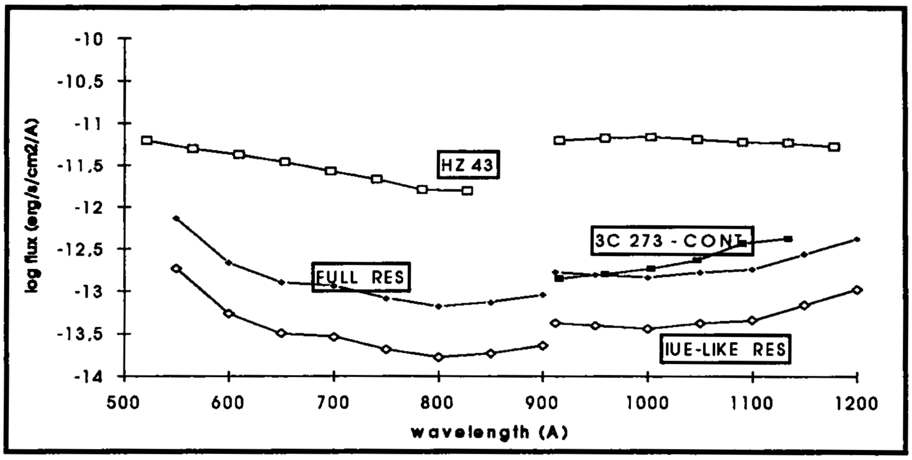

Figure 2: Sensitivity curves for point sources and EUV/FUV fluxes of HZ43 and 3C273

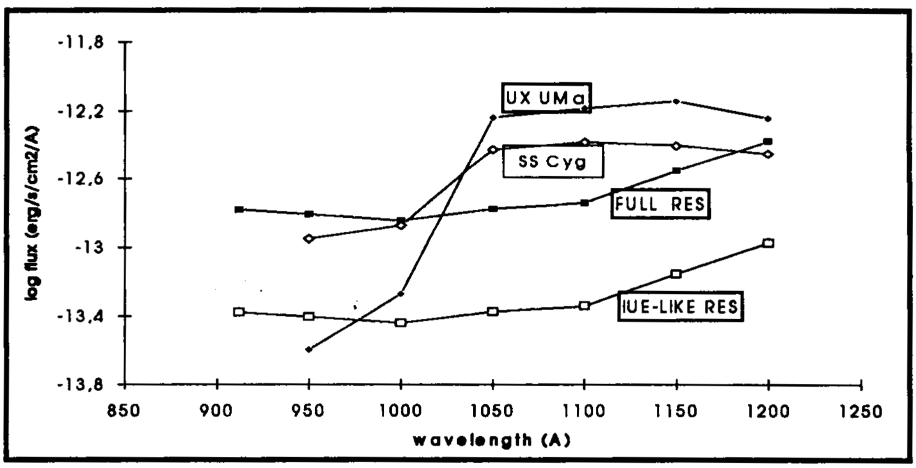

Figure 3: Same as Figure 2 for cataclysmic variables.

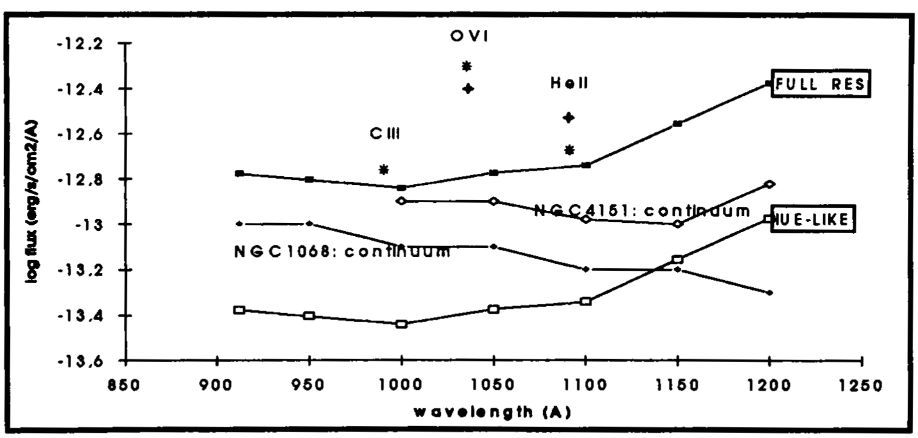

Figure 4: Same as Figure 2 for the Seyfert galaxies NGC 1068 and NGC4151. The symbol ✚ refers to line intensities of NGC 4151; the symbol ✱ to NGC 1068

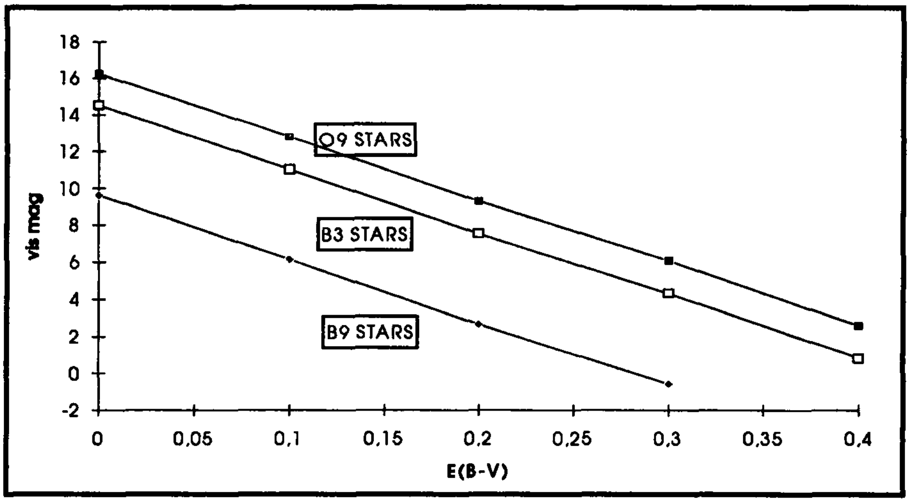

Figure 5: The diagram shows the limiting magnitude reachable for a S/N = 6 at full resolution in 25 minutes for different spectral types and different E(B-V). The effect of molecular hydrogen absorption is also included

(quasar), NGC 4152 and MRK 478 (Seyfert galaxies) and the EUV source HZ43. ROSAT list includes many other sources in the same general area: spiral galaxies, white dwarfs and late type stars. EUVE has recently observed intense EUV emission from the B2 II star ε CMa in the 500-740 Å and 345-605 Å bands (Ref. 2).

2 PLANETARY PHYSICS

Io's plasma torus is a natural laboratory for investigations of plasma physics. It is our best-studied example of an astrophysical plasma, having been probed by both in-situ and remote sensing techniques. The full implication of early measurements revealing neutral sodium and ionized sulfur near Io's orbit was not realized until the discovery, by the *Voyager UVS*, of an intense hot plasma ($T_e \approx 10^5$ K), forming a complete toroidal cloud about Jupiter, near Io's orbit. As a consequence of the high electron temperature, the dominant emissions from S II, S III, S IV, and O II are in the EUV and FUV spectral regions, the brightest feature being near 685 Å. About 2× 10^{12} W is radiated in the EUV; this is the dominant mechanism for energy loss from the torus. Although ground-based studies of the visual wavelength torus emissions have added to our knowledge of this plasma, measurements in the EUV are a more direct method of studying processes in the torus. To date, studies of the plasma torus have demonstrated that measurement in the EUV spectral region is essential, full spectral coverage in this region is required, and morphological studies, i.e. imaging of the whole system are necessary.

UVSTAR will complement and extend observations of Jupiter and Io's plasma torus made by the *Galileo* spacecraft orbiting around Jupiter. *Galileo*'s orbital geometry limits its opportunities for viewing the plasma torus with the UV instruments, and especially with the EUV spectrograph, which is most diagnostic of torus conditions. *UVSTAR* will provide observations of the Jupiter system at improved spectral resolution. The imaging spectrographs will measure the intensity of several important emission lines of S II, S III, S IV, and O II as a function of position in the torus, measure the H_2 band emissions of Jupiter'sdayglow and aurora, and clarify the coupling of Jupiter's aurora and the torus. The H Ly-α dayglow intensity will be correlated with the absolute solar flux measurements taken with the companion instrument of the University of Southern California. Spectral dispersion with simultaneous imaging makes the most efficient use of observing time and photon collecting ability. No photons within the bandpass of the instrument are wasted. These capabilities open the way for a far more thorough investigation of torus EUV morphology and dynamics than is possible with other existing or planned instrumentation.

The spectrographs, when operating in the wide-slit configuration, form two-dimensional images of a target within the slit. Images at different emission lines are displaced in the dispersion direction. The spectral dispersion is great enough to separate monchromatic images of the torus in several wavelengths. Several of these will be strong enough to be analyzed as a snapshot of emission morphology. The spatial resolution over the disk of the planet will separate polar and equatorial emissions of H and H_2.

REFERENCES

1. R. Longo, R. Stalio, R.S. Polidan, and L. Rossi, *"Intrinsic UV Spectral Energy Distributions of OB Stars"*, Astrophysical J. 339 (1989) 474-80.

2. J.V. Vallerga, P.W. Vedder, and B.Y. Welsh, *"Intrinsic EUV Emission from the B Star ε CMa"*, Center for EUV Astrophysics (1993), Preprint No. 532.

TABLE I: SENSITIVITY CALCULATIONS

λ	A	Ω	δ	σ	ε	μ	R	S
600	700	2.10^{-10}	.35	.11	.4	.35	3.7	.000017
1000	700	2.10^{-10}	.35	.15	.2	.45	3.3	.000015