## 3A. Ultraviolet Astronomy (Non-IUE)

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### I. INTRODUCTION

Results from the IUE satellite, summarized in the section which follows this one, continue to dominate the literature for research topics which rely on observations in the ultraviolet. This trend may be accentuated in the near future, as we experience the natural attrition of papers based on results from previous major missions which are no longer operating, such as TD-1, Copernicus, ANS and BUSS. The Challenger accident on January 28, 1986 abruptly halted flights of new orbital facilities which depend on the Space Shuttle and has created long and somewhat indefinite postponements in the eventual manifesting of payloads ranging in size from simple experiments in Getaway Special (GAS) and Spartan carriers, to telescopes of intermediate size on Spacelab (such as those which were to fly on the Astro mission in March 1986) to the Hubble Space Telescope. Suborbital missions, i.e., sounding-rockets and balloons, will probably dominate the extra-IUE uv astronomy scene until there is a re-establishment of a vigorous launch schedule for expendable vehicles and/or the Space Shuttle.

### II. OPERATING MISSIONS

The ultraviolet spectrometers (20.032.579) on Voyagers 1 and 2 continue to deliver spectrophotometric scans of stars over the wavelength range 500 -1700Å at a resolutions of 15-30Å. These observations provide important information on the fluxes from hot sources over wavelength ranges not covered by IUE (38.131.253), and a catalog of observations of some 300 objects has been created (41.002.032). The UFT experiment on the high-apogee Astron satellite has an 80-cm diameter telescope and a spectrometer with three channels which scan from 1100 to 3500Å (37.035.022; 39.051.066; 42.035.005). On a flight of the Columbia Space Shuttle in January 1986 (STS-61C), two spectrometers [one built by U. C. Berkeley (38.035.079), the other by Johns Hopkins U. (Tennyson, et. al. COSPAR XXVI)] were flown in GAS canisters for the UVX mission to monitor the diffuse cosmic background emissions from 600 to 3200Å and to obtain more definitive measurements of the background emission associated with the shuttle glow reported from a previous uv imaging mission (38.142.007).

Payloads launched on sounding rockets include instruments which recorded stellar spectra in the windowless ultraviolet (i.e. below 1150Å) at resolving powers $\lambda/\Delta\lambda$ = 60,000 (U. Colorado) and 200,000 (Princeton U). The primary objectives were to observe interstellar lines toward $\delta$ and $\pi$ Sco, respectively. A payload built at U. C. Berkeley to record EUV line emissions between 80 and 650Å was flown on a rocket in 1986 (38.035.080; 42.035.141; 42.106.059).

### III. SPECTRA OF STARS

#### 1. Absolute Photometry and Stellar Spectral Features

Catalogs of fluxes over a bandpass 1200-1600Å for stars in Cygnus and Sagittarius have been presented by Carruthers and Page (37.155.042; 37.155.079), who used wide-field images recorded by an electrographic camera during the Apollo 16 mission. Savage, Massa and Meade (40.131.228) published a catalog of uv fluxes for 1415 stars of spectral type B7 or earlier for the 5 passbands between 1500 and 3300Å of the ANS satellite. They analyzed this ANS color survey to study the relationships at different wavelengths for uv extinctions by dust grains.

Absolute spectrophotometry of (mostly) normal, early-type stars has been reported by Tanaka, et al. (37.142.056), Woods, Feldman and Bruner (39.113.041), and Carruthers, Heckathorn and Opal (39.114.014). Faraggiana and Malagnini (38.114.018) outlined some discrepancies between S2/68 and OAO-2 measurements of

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fluxes at 2740Å for stars with spectral types earlier than F8. Hua, et al. (42.114.152) discuss a factor of 3 discrepancy in the flux of an O8f star, compared with earlier measurements. However Polidan, Carone and Campbell (39.115.027) caution that most stars of spectral type B5 or earlier have fluxes at $\lambda < 1100$Å which vary over periods of several days. Polidan and Holberg (40.114.085) stated that at these wavelengths main sequence stars are variable (also see Polidan and Stalio 41.114.142), but subluminous stars have stable fluxes whose distributions are smooth extrapolations of spectral distributions measured at longer wavelengths. This conclusion underscores Holberg's suggestion (39.113.067) that subluminous stars are the most desirable photometric standards.

Rogerson has supplemented earlier uv spectral atlases recorded at high resolution by Copernicus for $\tau$ Sco (20.114.542), $\iota$ Her (27.114.062), and $\beta$ Ori (32.002.005) with those for two new stars, $\gamma$ Peg (39.002.059) and $\alpha$ CMa (Ap. J. Suppl 63, 369). All of these papers contain line identifications except the one for $\tau$ Sco; identifications of features for this star have been published by Rogerson and Ewell (39.114.131). Rogerson is currently preparing an atlas for $\alpha$ Lyr. Peters and Polidan (40.114.075) have combined Voyager fluxes and Copernicus line scans to evaluate new effective temperatures, surface gravities and element abundances for $\iota$ Her and $\tau$ Sco. Oegerlie and Polidan (38.112.083) have analyzed Copenicus spectra of rapidly rotating B stars and concluded that not all Be stars display shell lines in the ultraviolet, contrary to some earlier findings. They state that uv shell lines appear only in "classical" shell stars and are formed in low-velocity, outflowing, flattened disk structures. Boyarchuk, et al. (37.035.022) studied spectra of several stars recorded by the UFT on Astron to derive velocity shifts of C IV and Al III lines caused by mass loss. They also examined spectra of Ap stars for features from heavy elements (Pb, Th, U).

Various classes of stars have been monitored by the UVS on Voyager: the Be stars $\zeta$ Tau and $\alpha$ Eri (39.112.116; 39.112.117; 40.114.118), the symbiotic star AG Peg (41.117.124), the $\beta$ Cep variable BW Vul (37.122.200; 39.122.163), the eclipsing binaries $\mu$ Sag and $\beta$ Lyr (39.117.017), and several cataclysmic variables [see Polidan and Carone (Astr. Space Sci. 130, p235) for a brief summary] - primarily SS Cyg, U Gem, and VW Hyi (37.117.196; 37.117.261; 39.117.217; 39.117.224; 39.124.382; 41.117.086; Polidan and Holberg, MNRAS 225, p131). Models of dwarf nova outbursts have benefited substantially from the contributions by Voyager which supplemented observations of these phenomena at other wavelengths (Carone, Polidan and Wade 42.117.293; Pringle, et al. MNRAS 225, p73).

The observations by Voyager permit the spectral energy distributions derived by IUE to be expanded to shorter wavelengths, permitting more accurate determinations of effective temperatures of very hot objects. The combined observations are less prone to errors from absolute flux calibrations and reddening corrections. Studies using such combined observations have improved our understanding of subdwarf B stars (Wesemael, et al. 40.114.126), subdwarf O stars (Drilling, Holberg and Shonberner 39.126.002 and 38.126.042), the DA white dwarfs Sirius B (Holberg, Wesemael and Hubeny 37.126.082) and CD −38°10980, (Holberg, et al. 39.126.092), and an x-ray source (H1504+65) thought to be a metal-rich, near degenerate object with a temperature of order 160,000 K (Nousek, et al. 42.126.052).

## 2. Interstellar Absorption Lines

de Boer, et al. (41.131.092) analyzed Interstellar lines between 2000 and 3000Å for 22 stars observed by the BUSS echelle spectrograph and telescope which flew on a balloon, and they derived abundances of Mg, Cr, Mn, Fe and Zn along the lines of sight. Bruhweiler, et al. (38.131.246) studied Mg I and Mg II lines in Copernicus and IUE spectra in 5 stars ranging from 2 to 40 pc from the Sun to investigate the local interstellar medium. Both of these teams made use of the expected abrupt increase in Mg I abundance caused by the onset of dielectronic

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recombination at T > 5000 K to derive the amount of gas above this temperature.

Federman (42.131.288) has performed a general study of an unidentified spectral feature near 1088Å in Copernicus spectra of many stars. He concluded that this feature is caused by Cl I.

Eder (39.132.032) analyzed high resolution Copernicus spectra of λ and υ Sco to work out the geometry, ionization equilibrium and local densities of gas ionized by radiation from λ Sco. A comparison of the two lines of sight indicates that there are fluctuations in local densities. A more definitive analysis of this region was performed by Eder and York (42.131.140) who deconvolved separate velocity components in the spectra. Ionized material in a much lower density regime was analyzed in the spectrum of β CMa by Gry, York and Vidal-Madjar (40.131.099). Most of the path to this star contains H II material with $n \sim 0.1$ $cm^{-3}$ or a diffuse coronal gas.

There have been several, more specific studies of neutral gas. Meyers, et al. (39.131.074) isolated a low velocity (~10 km/s) shock toward the ρ Oph cloud and concluded that the post-shock gas has greater element depletions and more molecules than the material ahead of the shock. Snow, McClintock and Voels (Ap. J., in press) analyzed $H_2$ lines in a high-resolution spectrum of δ Sco recorded by a spectrograph on a sounding rocket. They concluded that lines from different J levels all have identical radial velocities and thus are not created in an expanding circumstellar shell. Snow, Lamers and Joseph (PASP, in press) have used BUSS results to refine a previous analysis of abundances along the line of sight to ζ Per.

IV. PHOTOMETRY AND IMAGERY OF EXTENDED OBJECTS

Onaka, et al. (38.131.296) observed the Orion reflection nebulosity using a rocket-borne photometer which performed a raster scan of the region and recorded fluxes in 5 wavelength channels between 1300 and 2000Å. These observations are complementary to the pictures in 4 colors between 1400 and 2620Å of dust reflection in Orion obtained earlier by Bohlin, et al. (31.134.009) from an image tube on a rocket. Onaka, et al. derived values for the albedo and scattering asymmetry of the dust at different wavelengths, although the results are very dependent on the assumed distribution of the dust with respect to the stars.

Two wide-field cameras were flown on Spacelab-1 to obtain images of extended objects in the ultraviolet. Both experiments were badly compromised by background light associated with the Shuttle orbit. One, the FAUST experiment, obtained pictures of the Cygnus Loop and the galaxy cluster Abell 2634 from 1300 to 1800Å (Bixler, et al. 38.142.007). The other, an all-reflecting uv Schmidt camera, obtained photographs of the Large and Small Magellanic Clouds in 3 passbands between 1650 and 2530Å (Courtes, et al. 38.142.006; Viton, et al. 39.156.015). The uv images of the clouds highlighted hot stars in Shapley's wing of the SMC, along a bridge of matter to the LMC. Pierre, et al. (41.156.001) used the uv fluxes as a sensitive way to confirm the correctness of the luminosity and initial mass functions for stars in the SMC based on UBV photometry from the ground.

An image intensifier on a sounding rocket recorded images (1' resolution) at 1500 and 1900Å of associations in the LMC and enabled Smith, Cornett and Hill (Ap. J., in press) to model the sequence of star formation at different locations in the system's spiral structure. Carruthers and Page (37.142.086) show uv pictures of the LMC in their general summary of results from the S201 mission.

Bohlin et al. (39.154.029) derived the uv brightnesses of 144 stars stars in the M5 globular cluster, using a rocket-borne telescope which was a prototype for the UIT facility to fly on the Astro Spacelab mission (see also 33.154.044 and

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34.157.151). In conjunction with stellar evolution models, the results for 50 horizontal-branch stars allowed them to infer an initial helium abundance and distance modulus for the cluster, along with a minimum mass for stars in the horizontal branch.

From a lack of discrete sources in a rocket uv image of the bulge of M31, Bohlin et al. (40.157.146) concluded that the upturn of flux in the uv is caused by unresolved, post-AGB stars, rather than a young stellar population. This same group has also obtained two-color uv images of M33, and detected several hundred sources (Landsman, et al. 39.157.191). Israel, de Boer and Bosma (42.157.054) measured fluxes (dominated by OB associations) in the 5 ANS bands (1550 -3300Å) within selected 2.5X2.5 arc min fields covering M31, M33, M81, M101, NGC 2403 and a number of compact (Zwicky) galaxies. In a follow up of an earlier investigation using OAO-2 results (Donas and Deharveng 38.157.145), Donas, et al. (Astr. Ap. 180, 12) used images recorded by a balloon telescope to determine the 2200Å fluxes from 149 spiral and irregular galaxies. They concluded that the star formation rates in these galaxies are well correlated with total gas contents, and they studied variations in this relationship as a function of morphological type. Holberg and Barber (39.160.072) used upper limits for the flux between 912 and 1150Å from the Coma Cluster measured by the Voyager spectrometer to place lower limits for the lifetimes of neutrinos decaying into massless products.

V. DIFFUSE BACKGROUND

Recent observations of the uv diffuse background (excluding contributions from stars) show a correlation of measured fluxes with column densities of neutral hydrogen. At some wavelengths, fluorescence from molecular hydrogen may be important, while backscattering from dust is important over the entire spectrum above the Lyman limit. From the slope of this relationship shown in their UVX results, Hurwitz, Martin and Bowyer (42.131.350) concluded that the albedo times (1-g) for dust scattering from 1450 to 1850Å is of order 0.07. Jakobsen, et al. (38.142.040) observed the background with a telescope on an Aries sounding rocket and found intercepts at N(H) = 0 of 550 and 900 phot $cm^{-2}$ $s^{-1}$ $sr^{-1}$ $Å^{-1}$ over bandpasses 1450-1780 and 1610-1950Å, respectively. Although the wavelengths are somewhat different, it seems difficult to understand why these results contrast so sharply with Holberg's (42.142.041) upper limit toward the north galactic pole of 100-200 phot $cm^{-2}$ $s^{-1}$ $sr^{-1}$ $Å^{-1}$ over the range 500-1150Å, obtained from a spectrophotometric scan by Voyager 2 over a very long integration time. (The latter measurement supercedes by a large margin Bixler, Bowyer and Grewing's (38.131.181) upper limit of 9700 phot $cm^{-2}$ $s^{-1}$ $sr^{-1}$ $Å^{-1}$ at 1060Å.)

A sounding rocket instrument described by Labov, Bowyer and Martin (42.035.141) was flown by Labov and Bowyer (42.106.059) to study diffuse emission between 80 and 650Å. In addition to detecting the interplanetary He I 584Å emission, they registered some broad, unidentified emission features centered on 110 and 190Å (plus a weaker, narrow feature at 630Å). Martin and Bowyer (42.131.351) identified C IV λ1550, O III] λ1663, and O IV or Si IV λ1400 diffuse emission in data accumulated by the UVX experiment. Martin and Bowyer conclude the C IV emission originates from collisionally excited gas in the galactic halo, since it is too bright to be of local origin (without an unreasonably high gas pressure) and it is anti-correlated with H I column densities (i.e., the accompanying dust causes foreground absorption).

Finally, Opal and Weller (38.155.025) reported a flux of $1.4X10^5$ phot $cm^{-2}$ $s^{-1}$ $Å^{-1}$ over the band 912 -1050Å registered by a photometer aboard the STP 72-1 satellite. This flux is primarily from O and B type stars in Gould's Belt, and its magnitude is somewhat higher than most previous estimates. This measurement is an important datum for calculating photoionization and photodissociation rates in the local interstellar medium.

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## 3B. UV: International Ultraviolet Explorer

W. Wamsteker

The continued functioning of the International Ultraviolet Explorer (IUE), supported by the funding Agencies NASA, ESA and the SERC has been very important for Astronomy in quite unanticipated ways. After the serious launcher problems encountered over the reporting period a shortage of observing capabilities for space astronomy, especially in the UV, could be foreseen. The extended life of IUE has clearly softened the impact of this problem. The IUE presents an interesting first in space astronomy, by being the first pointed space telescope with an incomplete inertial reference system (only 2 gyroscopes of the original six remain operational) which retains its full three-axes stability. The continued availability of IUE cannot be expected to fill the gap caused by the delays in the launch of the next major UV facility: the Hubble Space Telescope, but the IUE has remained a continuing source of new and exiting data in the ultraviolet for many fields of Astronomy. Together with the Astron satellite (USSR) no space facilities were available to Astronomy after the Challenger accident. The impact of the Astron satellite has been significantly less then that of the IUE, in part this is due to its limited sensitivity, but mainly because of its restricted availability to the general Community.

As a facility for observational Astronomy IUE has been successful without precedent and has set standards for the use of such highly efficient space observatories which will be difficult to surpass by future projects, both ground-based and space-borne. The efficiency of the IUE Observatory is clearly understood if one realizes that the IUE has already supplied, in its 9 years of operation, more observing time then most ground-based telescopes will supply in 30 years of operation. Compared with the modern good quality sites the available observing time per year on the IUE is more then 3 times as large. Of this time more then 50% is used for actual photon collection even in the present non-optimized mode of operations. Also the IUE Data Archive is a continuing source of data for many Astrophysical studies. The importance of the easily accessible data is clear from the fact that during the reporting period the number of spectra retrieved from the archive became larger then the number of spectra taken by the satellite (> 80000 spectra de-archived vs 60000 spectra taken).

It is not surprising that essentially no field of astronomy has been unaffected by such a rapid data and information flow. The distribution of the observations over the reporting period was:

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| Solar system | 1094 spectra | Variable stars | 1362 spectra |
| O-type and related | 2036 spectra | CV's | 2164 spectra |
| B stars | 3480 spectra | Nebulae | 490 spectra |
| A-K stars | 3526 spectra | Extragalactic | 1091 spectra |

Including calibrations this amounts to 15243 spectral images. The number of publications based on data of the IUE in the main refereed journals is by now well over 1200. The international nature of the IUE facility was reinforced by the merging of the various IUE conferences held under different sponsorship into one single conference cosponsored by NASA, ESA and SERC. The first such

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conference was held in London (Rolfe, 1986). Important reference atlases have been produced on the UV spectra of Supernovae (Benvenuti et al., 1982), Normal stars (Heck et al, 1984), O-type stars (Walborn et al., 1985) and Late Type stars (Wing et al., 1983) and extragalactic HII regions (Rosa et al., 1984). Also special mention can be made of the first reference book on UV astronomy "Exploring the Universe with the IUE satellite" (Kondo, 1987).

A quite important aspect of such long-lived relatively "simple" observatory-type satellite was high-lighted by the many UV observations made under the IHW with the IUE in support of the spacecraft encounters with Comet Halley. Of the many results I would like to mention the dramatic changes in the $CO2^+/OH$ ratio during outburst (Feldman et al., 1986) and very extensive (1 year) monitoring of the gas production rate. Similarly, the explosion of the first Supernova to reach naked eye brightness since Kepler's SN in 1604, has reinforced the importance of space borne facilities which are capable of rapid response and flexible scheduling. Although instrumentation and cost considerations drive at present the trend away from flexibility, as is also the case in many other sciences, it is worth while to remember than in Astronomy the schedule of many "cosmic experiments" is not under human control. The first results on UV observations of SN 1987A showed quite a few unexpected results. Early results are described by Wamsteker et al. (1987), Panagia et al. (1987), Cassatella et al. (1987), de Boer et al. (1987) and Fransson et al. (1987).

For a detailed and extensive overview of the many important results obtained with the IUE the reader is referred directly to Rolfe (1986) and Kondo (1987). However, it is considered to be justified to illustrate here with some examples the importance of the "workhorse" of UV astronomy: IUE. Although such a summary is unavoidably strongly biased it is a good indication of the width of the impact of the first general user space facility.

In the solar system area the detection of molecular sulfur in the cometary evaporates and the extensive series of observations of the IO Torus - the only region where HII region-like conditions have been studied both by classical means and through in situ observations, clearly stand out. Before IUE only 4 comets were observed in the UV, at this time an extensive data base is available with data for 26 comets.

In the area of stellar studies it is worth noting that before IUE only a single UV observation was available for classical novae, while at present a wealth of data, also at high resolution, has been obtained for 13 novae allowing detailed abundance analysis. From these results it has become obvious that the ejecta of all novae show abundance anomalies. We can also mention the considerable variations in the CIV lines' in Be stars; the discovery of absorption lines at the velocity plateau in the winds of WR stars; the first insights and consistent understanding of the symbiotic star phenomenon; the detailed studies of chromospheric activity in late type stars through Doppler imaging and the discovery of extended coronal regions around dwarf novae.

For the ISM we would like to mention the results on interstellar Zn depletion showing that although Zn and S contribute only a small mass fraction to the ISM,they play a crucial role in the surface chemistry of interstellar grains.

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In the extragalactic area the detection of the HeI line (584A) in a QSO at Z = 1.21 represents the first observation of this line in any astronomical object apart from the Sun. The accumulation of many spectra on the highly variable Seyfert I galaxies presents the prospect that we may begin to understand the processes driving Active Galactic Nuclei. The observations of CIV and Ly-α in absorption at redshifts lower then Z (emission) in QSO's do not indicate the presence of strong heavy element depletion, but may show some evidence of evolutionary effects in the intergalactic cloud number densities.

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