

OVERVIEW OF THE *FAR ULTRAVIOLET SPECTROSCOPIC EXPLORER* MISSION

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ABSTRACT

The *Far Ultraviolet Spectroscopic Explorer* satellite observes light in the far-ultraviolet spectral region, 905 – 1187 Å with high spectral resolution. The instrument consists of four coaligned prime-focus telescopes and Rowland spectrographs with microchannel plate detectors. Two of the telescope channels use Al:LiF coatings for optimum reflectivity from approximately 1000 to 1187 Å and the other two use SiC coatings for optimized throughput between 905 and 1105 Å. The gratings are holographically ruled to largely correct for astigmatism and to minimize scattered light. The microchannel plate detectors have KBr photocathodes and use photon counting to achieve good quantum efficiency with low background signal. The sensitivity is sufficient to examine reddened lines of sight within the Milky Way as well as active galactic nuclei and QSOs for absorption line studies of both Milky Way and extra-galactic gas clouds. This spectral region contains a number of key scientific diagnostics, including O VI, H I, D I and the strong electronic transitions of H₂ and HD.

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1. INTRODUCTION

The *Far Ultraviolet Spectroscopic Explorer (FUSE)* is a NASA astronomy mission, developed in cooperation with the Canadian Space Agency and the Centre National d'Etudes Spatiales of France, that is exploring the far-ultraviolet (FUV) universe from 905 to 1187 Å with high spectral resolution. *FUSE* was launched 1999 June 24 on a Delta II rocket. Early Release Observations, which are the basis of the papers in this issue of the *Astrophysical Journal Letters*, began in 1999 October and regular science operations commenced in 1999 December.

After the decommissioning of the *Copernicus* Mission (Spitzer & Jenkins 1975) in 1981, it was clear that a follow-on mission with much higher sensitivity and a velocity resolution comparable to or better than that of *Copernicus* ($\sim 15 \text{ km s}^{-1}$ FWHM²⁴) was highly desirable. The utilization of modern detectors and mirror technology opens the spectral bandpass from the short-wavelength cutoff of the *Hubble Space Telescope (HST)* down to the H I photoionization limit at 912 Å for observations at distances far beyond the $\sim 1 \text{ kpc}$ limit for routine *Copernicus* measurements. *FUSE* received strong support from two decadal survey committees (Field et al. 1982; Bahcall et al. 1991). Although cost considerations restricted the telescope for such a mission to roughly the one meter class, modern detectors that simultaneously cover most of the bandpass made high spectral resolution measurements with excellent sensitivity possible. In addition, by using modern mirror technology, the bandpass could be extended below $\sim 1000 \text{ Å}$ where the *Copernicus* sensitivity was limited by the drop in reflectivity of mirrors overcoated with Al and a thin covering of LiF (Al:LiF). Finally, the installation of the Space Telescope Imaging Spectrograph (STIS) (Woodgate et al. 1998) on the *HST* with a lower limit of $\sim 1150 \text{ Å}$ meant that the *FUSE* mission could be designed primarily for the wavelengths below the STIS limit.

Exploration of this spectral region since the *Copernicus* mission has been limited. The Voyager ultraviolet spectrometers (Broadfoot et al. 1977) obtained low resolution ($\Delta\lambda \geq 18 \text{ Å}$) spectra of a number of sources, e.g. (Holberg et al. 1991). Several missions covering this wavelength range have been flown as space shuttle sortie missions with operational lifetimes of up to two weeks. These included the Hopkins Ultraviolet Telescope (HUT) (Davidsen et al. 1992; Kruk et al. 1995), the Orbiting and Retrievable Extreme Ultraviolet Spectrometers (ORFEUS) (Grewing et al. 1991; Hurwitz et al. 1998) and the Interstellar Medium Absorption Profile Spectrograph (IMAPS) (Jenkins et al. 1996). These missions performed a wide range of important studies. However, they were precluded from carrying out more detailed and comprehensive studies by the limited length of the missions as well as limits to the velocity resolution or sensitivity.

This article presents an overview of the *FUSE* mission. A discussion of the scientific background is followed by a description of the mission. The following article (Sahnow et al. 2000) discusses the on-orbit performance of the *FUSE* satellite in more detail.

2. SCIENTIFIC BACKGROUND

The density of strong spectral absorption lines per wavelength interval rises sharply in the FUV because a large number of astrophysically important species have strong transitions in this region. This is not surprising for neutral species, since the photon energy at these wavelengths approaches one rydberg (13.6 eV). For some species, the access is unique. These include all of the resonance lines of H and D except for Ly α , the strong resonance lines of C III, O VI and S VI, as well as the electronic ground-state absorption bands of H₂ and HD, including the Lyman and the Werner bands. With modest redshifts, extreme ultraviolet (EUV) transitions become observable including O V $\lambda 629.73$, Ne VIII $\lambda\lambda 770.4, 780.32$ and Mg X $\lambda\lambda 609.85, 625.28$, which provide access to the hot intergalactic medium (Verner et al. 1994).

As an example of the rich variety of spectral features found in the *FUSE* bandpass, Figure 1 displays a spectrum of the central star of the planetary nebula (CSPN) K1-16 (V=15) covering 912–992 Å obtained while mapping the large spectrograph entrance aperture during on-orbit checkout. The spectra were corrected for the wavelength shifts induced by the target motion in the aperture and coadded to give a total integration time of 27 ks. A large number of transitions are apparent within this relatively narrow spectral region. Identified transitions due to the intervening gas (including nebular gas) are marked below the spectrum and include those of H₂, H I, O I, N I, Si II, P II, C III and S VI. Above the spectrum, stellar lines due to transitions between excited states of He II, C IV and O VI are marked with identifications based on those in representative PG 1159 stars (Kruk & Werner 1998).

A number of the papers in this issue demonstrate the unique capabilities of the *FUSE* mission for studies of the interstellar and intergalactic gas. For example, the O VI $\lambda\lambda 1032, 1038$ transitions are extremely sensitive tracers of hot gas in the Galactic halo shock-heated by supernova explosions in the disk (Savage et al. 2000). Several other papers (Murphy et al. 2000; Oegerle et al. 2000b; Sembach et al. 2000) use these transitions to study the properties of hot gas both in and outside of the Milky Way. At the other temperature extreme, the strong Lyman and Werner transitions provide exceptional sensitivity to cold molecular hydrogen (Shull et al. 2000a; Snow et al. 2000; Ferlet et al. 2000). Additional interstellar medium studies include the ionization balance of the local interstellar medium (Jenkins et al. 2000) and a line of sight through the Milky Way to the LMC (Friedman et al. 2000). Studies of the abundance ratios of deuterium to hydrogen are a major objective of the *FUSE* mission (Moos et al. 1998). These studies will provide a much better understanding of the astration cycle whereby deuterium is destroyed by stellar processes concurrent with metal production. Lines of sight providing a wide variety of astrophysical environments are planned, including the local interstellar medium, the Milky Way disk and halo, high velocity clouds, and the local intergalactic medium. Observations for the deuterium program began in the early spring 2000 and deuterium measurements will be reported at a later date.

Studies of winds from massive stars in the LMC and the SMC (Bianchi et al. 2000; Crowther et al. 2000; Fullerton et al. 2000; Massa et al. 2000) use the O VI transitions to

²⁴Full-width-half-maximum of a spectral profile. All resolution widths are FWHM unless specifically stated otherwise.

probe the highest temperature gas and show that it exists throughout the wind. These studies confirm significant differences between the properties of the winds of otherwise similar stars in LMC and SMC, which may indicate significant differences in stellar evolution and fueling of the interstellar medium. Even at this early stage of the mission, *FUSE* has been used for a wide variety of studies. Note the articles on the active cool star AB Dor (Ake et al. 2000), the discovery of P and Fe in a hot white dwarf (Chayer et al. 2000), the SNR N49 in the LMC (Blair et al. 2000), intergalactic Ly β absorbers (Shull et al. 2000b), the lack of molecular H $_2$ in I Zw 18 (Vidal-Madjar et al. 2000), and the Seyfert 1 galaxy Mkr 509 (Kriss et al. 2000). The articles in this issue provide a snapshot of the *FUSE* mission a half-year after launch and show the potential for future studies. It is expected that both the Principal Investigator Team and Guest Investigators will use the satellite for an even wider variety of investigations.

3. MISSION OVERVIEW

The *FUSE* satellite, with a length of ~ 5.5 m and a mass of ~ 1300 kg, was launched from Cape Canaveral Air Force Station into a 768 km near-circular orbit with 25° inclination to the equator. The *FUSE* satellite consists of a single instrument and the spacecraft bus built by Orbital Sciences Corporation. Located below the instrument section, it provides power, attitude control, and communications. The primary ground station in Puerto Rico and a secondary station in Hawaii provide about eight contacts of approximately 10 minutes duration each day. Thus, real time operations are limited. All scientific observations are pre-planned in detail and performed under autonomous satellite control. The resulting data sets are then stored on the spacecraft recorder until contact is made with a ground station. The ground contacts are adequate for transmitting the data to the ground during nominal operations, although high data rates require special planning to prevent recorder overflow. A Fine Error Sensor (FES) camera with a 20' field of view views one of the telescope Focal Plane Aperture assemblies (FPA). FES images are used for autonomous target field identification. When the error signals from the FES are combined with those from the spacecraft inertial reference unit, pointing with a stability of 0.3'' is routinely achieved. The positional uncertainty is somewhat larger due to thermal effects on the structure (Sahnou et al. 2000) and uncertainties between target coordinates and positions of guide stars selected from the *HST* Guide Star Catalog (Lasker et al. 1990).

Instrument designs for this spectral region are challenged by the low reflectivity of optical coatings: the number of reflections must be as small as possible. For HUT, this led to an optically economical design: a prime focus telescope and single focusing grating in a Rowland configuration (Davidsen et al. 1992) with a resolution of ~ 300 km s $^{-1}$. For high resolution spectroscopy, the focal ratio must be > 5 in order to restrict optical aberrations. This leads to very long instruments with extremely large gratings that are beyond the scope of most missions. This was solved for the Berkeley spectrograph on the ORFEUS-SPAS missions by sharing the beam between three gratings to achieve a velocity resolution of ~ 95 km s $^{-1}$ (Hurwitz et al. 1998).

For designs with higher resolution, obscuration by the

gratings becomes a serious consideration. To solve this, it is necessary to divide the single primary mirror into several physically separated optical elements. Thus, the *FUSE* instrument consists of four coaligned prime focus telescopes (off axis parabolas, each with 352 mm by 387 mm clear aperture and a focal length of 2245 mm) feeding light to four Rowland spectrographs (Green et al. 1994; Sahnou et al. 1996; Friedman et al. 1999). Figure 2 shows the *FUSE* optical system. In addition to making the mission practicable, this approach allowed optimization of the optical coatings for different telescope/grating channels. Two use Al:LiF coatings for optimum reflectivity from ~ 1000 to 1187 Å and the remaining two channels utilize SiC coatings for optimized throughput between 905 and 1105 Å.

The FPA in each telescope focal plane can be moved in the z -direction to adjust the spectrograph focus or moved in x (the dispersion direction) to coalign the channels. The x motion can also be used to shift the spectrum ≤ 0.36 Å for the SiC channels and ≤ 0.39 Å for the LiF channels. Each FPA contains three entrance apertures for each spectrograph, corresponding to projected angles on the sky of 30'' \times 30'' (used for most observations), 4'' \times 20'' and 1.25'' \times 20''. The entire satellite pointing is changed in order to place a target in a particular aperture for all four channels. The grating surfaces are spherical with a radius-of-curvature of 1652 mm and are holographically ruled at a line density ~ 5767 mm $^{-1}$ for the SiC coated gratings and ~ 5350 mm $^{-1}$ for the Al:LiF coated gratings (Green et al. 1994). In addition to providing very high ruling density, the holographic ruling process corrects for most of the astigmatism (Grange 1992), decreasing the contribution from the detector background signal significantly. The use of holographic ruling also minimizes the scattered FUV light.

The requirement for resolution ≤ 15 km s $^{-1}$ leads to a dispersion of 1.03 Å mm $^{-1}$ for the SiC coated channels and 1.12 Å mm $^{-1}$ for the Al:LiF coated channels. This in turn leads to large-format detectors. The two *FUSE* detectors are multi-segment, two dimensional microchannel plate (MCP) detectors with helical double delay line anodes (Siegmond et al. 1997). By placing one LiF spectrum and one SiC spectrum in parallel along a single detector, we reduced the number of detector systems to two. Each detector consists of two segments, each with an active area of 88 \times 10 mm curved to approximately match the Rowland Circle; each pair of segments is separated by a gap of ~ 10 mm, producing a corresponding wavelength gap. The front surface of each MCP is coated with a KBr photocathode to maximize the FUV response with a low background count and low sensitivity to out-of-band longer wavelength scattered light. Behind each plate are two additional plates that amplify the charge associated with each photon event to the equivalent of $\sim 2 \times 10^7$ electrons for counting and geometric location of each photon event. The detector pixels are ~ 6 μ m in the dispersion direction and 9-16 μ m (depending on the detector segment) in the cross dispersion direction, for a full extent of roughly 16384 by 1024 pixels. The intrinsic detector resolution, however, is determined by the MCP pore size and spacing (10-15 μ m), and by the design of the readout electronics; it was shown by ground measurements to be ~ 20 μ m in the dispersion direction and ~ 80 μ m in the

cross-dispersion direction.

In addition to increasing the effective area, the multiple channel design introduces redundancy over most of the spectrum. The optical design is identical for the two Al:LiF coated channels and for the two SiC coated channels; the wavelength coverage differs only because the two detectors are offset at slightly different locations along the Rowland circles. SiC1 covers 905–1090 Å with a gap between the two detector plates at 993–1003 Å. SiC2 covers 917–1104 Å with a gap at 1006–1016 Å. LiF1 covers 988–1187 Å with a gap at 1083–1094 Å and LiF2, 979–1179 Å with a gap at 1075–1086 Å. (The transmission of both LiF1 and LiF2 fall sharply below the Al:LiF reflectivity cutoff at ~ 1000 Å.) Thus, the majority of the wavelength range is covered by two detectors and the central third by all four channels, making the system extremely robust against a partial failure of an optical channel or even one of the detectors. In addition, this design aids in distinguishing between real features in the data and instrumental artifacts.

The data are recorded in two modes. For low data rates the x - y address of each detected photon is listed in order of detection. A time stamp with an accuracy of 8 ms is inserted in the list once a second. At count rates above ~ 2500 s $^{-1}$, this mode would require an excessive allocation of on-board memory and the spectral image mode is used instead. In this mode, images corresponding to the portions of the detectors on which the spectra appear are integrated over an exposure. To further reduce the required memory, we bin the data by 8 pixels in the cross-dispersion direction. In this case, there is no photon timing information and on-ground Doppler corrections can only be made on the image as a whole; therefore, each orbit of the observation is divided into multiple (typically four) exposures.

Once the data are transferred from the satellite to the Spacecraft Control Center at the Johns Hopkins University, they are passed through level zero processing, which sorts the data packets and checks for duplicate or missing packets. The data are then passed to the OPUS pipeline (Rose et al. 1998), which controls the processing of data from ingest until archiving. OPUS also converts the data into FITS format and populates a number of keywords in the header with entries from the mission planning database. OPUS passes the data to the calibration pipeline which is a software package specifically designed for *FUSE* data. This software takes raw photon address data or spectral image data and creates a calibrated, extracted one-dimensional spectrum. Even though the gratings are holographically corrected, a small amount of astigmatism and line curvature remain. This and other effects (Sahnou et al. 2000) must be removed for measurements with the most demanding velocity-resolution requirements. Although not implemented at present, the calibration pipeline has been designed to include these corrections in future calibrations of the data. Finally, OPUS collects all the raw and calibrated data files from an observation and generates ancillary files needed for ingestion

of the data into the Multi-Mission Archive at the Space Telescope Science Institute (MAST). The individual steps in the calibration pipeline are described in the *FUSE* Data Handbook²⁵ (Oegerle et al. 2000a).

4. PERFORMANCE

The on-orbit performance properties of the *FUSE* satellite are discussed in detail by Sahnou et al. (2000). We discuss here the steps taken to maintain an effective area sufficient for absorption-line studies of the Milky Way halo and extragalactic gas clouds. We note that the low scattered light leads to accurate values of the flux levels in the cores of strongly saturated interstellar absorption lines. Also, the background signals (Sahnou et al. 2000) due to the detector dark count and scattered airglow are sufficiently low that very faint objects can be studied to a limited extent.

In the FUV spectral region reflecting optics are very sensitive to contamination by organic materials and considerable care in the material selection and assembly procedures are necessary. Also, mirrors and gratings that are overcoated with Al and a thin layer of LiF are easily degraded by exposure to air. The LiF overcoat absorbs water easily and even modest exposures to normal laboratory conditions with a relative humidity of 50% will lead to decreases in reflectivity (Oliveira et al. 1999). Thus, it was necessary to perform most of the instrument assembly and testing with the mirrors and gratings in a dry nitrogen environment. The total exposure to cleanroom air with relative humidity 30–50% was limited to an equivalent total of less than 5 days. The launch vehicle was also maintained at a low humidity in order to prevent condensation on ascent (Choueiri et al. 1994; Friedman 1997). The high effective area, and particularly the good reflectivity down to ~ 1000 Å (Sahnou et al. 2000), are due to both very conservative procedures and the extreme vigilance of the engineers and scientists assembling the instrument.

The *Copernicus* mission showed on-orbit degradation of the Al:LiF overcoated optics with time (Kalil et al. 1981). HUT also showed a slight degradation of its SiC coated optics during its second flight (Kruk et al. 1999), which was attributed to hydrocarbon contamination in the shuttle environment. For the first three months of the mission, as the *FUSE* instrument outgassed, it was pointed at the continuous viewing zone in order to prevent polymerization of outgassed hydrocarbons onto the telescope mirrors by ultraviolet light reflected from the Earth. A conservative ram avoidance angle of $> 20^\circ$ for the line of sight is used to prevent degradation by the small but non-negligible abundance of terrestrial atomic oxygen at this altitude. Although these steps slowed observational activity, particularly during the first three months, the high effective area and its stability certainly justify the investment; measurements of the sensitivity made over a four month period show degradation of the effective area to be $\leq 5\%$.

The profiles of highly absorbed lines are essentially black in the center.²⁶ Figure 3 shows a highly absorbed line due primarily to interstellar C II $\lambda 1036.3$, C II* $\lambda 1037.0$.

²⁵The *FUSE* Data Handbook (Oegerle et al. 2000a) is available at <http://fuse.pha.jhu.edu>

²⁶Although the K1-16 data in Figure 1 dip almost to zero, they are not representative. The data were obtained as part of an on-orbit scan to map the large aperture. The absorption lines are contaminated by both terrestrial airglow and relatively strong nebular emission lines. Also, when individual spectra were corrected for wavelength shifts, small artifacts due to the adjoining continuum may have been introduced.

The data have been binned over 4 pixels in the dispersion direction (0.027 Å) and 67 pixels perpendicular to the dispersion direction so that the area on the detector associated with a data point is $1.6 \times 10^{-4} \text{ cm}^2$. No corrections have been made in the figure for the contribution of dark count, scattered airglow or scattered stellar light. The continuum is sloped due to a O VI $\lambda\lambda 1031.9, 1037.6$ P Cygni profile and rises from ~ 1400 counts at pixel 8150 to about ~ 3500 counts near pixel 8700. The dashed line in the lower panel is drawn at 4.5 counts. The detector dark background (Sahnow et al. 2000) is $\sim 0.8 \text{ counts s}^{-1} \text{ cm}^{-2}$ and hence the contribution to the line center is 0.9 counts. If the remainder is due solely to scattered stellar light, it is $< 0.2\%$ of the average nearby continuum.

Although *FUSE* was designed to observe relatively bright AGNs and QSOs with fluxes of $1\text{--}2 \times 10^{-14} \text{ ergs cm}^{-2} \text{ s}^{-1} \text{ \AA}^{-1}$ as sources for absorption spectroscopy, the sensitivity is such that it can detect much fainter objects. However wavelength binning with an accompanying reduction in velocity resolution may be necessary to reduce observation times. Figure 4 compares the spectrum of the QSO HS1700 + 64 obtained by the *FUSE* LiF2 channel with that from HUT (Davidsen et al. 1996). The HUT instrument was designed for spectroscopy of faint objects with a low dispersion that kept the detector dark signal to a minimum. The HUT data were taken at night which reduced the effects of both scattered airglow and airglow features. The *FUSE* spectra shown contain

both day and night data. Features detected in a ~ 50 ks blank sky exposure, probably terrestrial airglow, have been removed at the positions marked in the figure. The background due to dark count was equivalent to roughly twice the signal from the QSO at $\lambda > 1140 \text{ \AA}$. A second similar spectrum was obtained with the LiF1 channel. The *FUSE* results demonstrate that flux levels of order $\leq 5 \times 10^{-16} \text{ ergs cm}^{-2} \text{ s}^{-1} \text{ \AA}^{-1}$ can be detected, although careful studies of background effects and detector artifacts will be necessary before using the data for detailed quantitative work.

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REFERENCES

- Ake, T. B., et al. 2000, ApJ, this issue
Bahcall, J. N., et al. 1991, *The Decade of Discovery in Astronomy and Astrophysics* (Washington, D.C.: National Academy Press)
Bianchi, L., et al. 2000, ApJ, this issue
Blair, W. P., et al. 2000, ApJ, this issue
Broadfoot, A. L., et al. 1977, *Space Sci. Rev.*, 21, 183
Chayez, P., et al. 2000, ApJ, this issue
Choueiri, E., Diamant, K., Jenkins, E. B., Reale, M., & Zucchino, P. M. 1994, unpublished memorandum, Investigations of the Damage on the Photocathode of the Interstellar Medium Absorption Profile Spectrometer (IMAPS)
Crowther, P. A., et al. 2000, ApJ, this issue
Davidsen, A. F., et al. 1992, ApJ, 392, L264
Davidsen, A. F., Kriss, G. A., & Zheng, W. 1996, *Nature*, 380, 47
Field, G. B., et al. 1982, *Astronomy and Astrophysics for the 1980's* (Washington, D.C.: National Academy Press)
Ferlet, R., et al. 2000, ApJ, this issue
Friedman, S. D. 1997, unpublished memorandum, Summary of Experiments to Determine Degradation in LiF Optical Coatings Due to Ascent Depressurization
Friedman, S. D., et al. 1999, *Proc. SPIE*, 3765, 1999
Friedman, S. D., et al. 2000, ApJ, this issue
Fullerton, A. W., et al. 2000, ApJ, this issue
Grange, R. 1992, *Appl. Opt.*, 31, 3744
Green, J. C., Wilkinson, E., & Friedman, S. D. 1994, *Proc. SPIE*, 2283, 12
Gunn, J. E., & Peterson, B. A. 1965, ApJ, 142, 1633
Grewing, M., et al. 1991, in *Extreme Ultraviolet Astronomy*, ed. R. F. Malina & S. Bowyer (Elmsford: Pergamon), 437
Holberg, J. B., Ali, B., Carone, T. E., & Polidan, R. S. 1991, ApJ, 375, 716
Hurwitz, M., et al. 1998, ApJ, 500, L1
Jenkins, E. B., Reale, M. A., Zucchino, P. M., & Sofia, U. J. 1996, *AP&SS*, 239, 315
Jenkins, E., B., et al. 2000, ApJ, this issue
Kalil, F., et al. 1981, OAO-3 End of Mission Tests Report, NASA Technical Memorandum 83824
Kriss, G. A., et al. 2000, ApJ, this issue
Kruk, J. W., Durrance, S. T., Kriss, G. A., Davidsen, A. F., Blair, W. P., Espey, B. R., & Finley, D. S. 1995, ApJ, 454, L1
Kruk, J. W., & Werner, K. 1998, ApJ, 502, 858
Kruk, J. W., Brown, T. M., Davidsen, A. F., Espey, B. R., Finley, D. S., & Kriss, G. A. 1998 ApJS, 122, 299
Lasker, B. M., Sturch, C. R., McLean, B. J., Russell, J. L., Jenkner, H., & Shara, M. M. 1990, AJ, 99, 2019.
Massa, M., et al. 2000, ApJ, this issue
Moos, H. W., Sembach, K. R., & Bianchi, L. 1998, *Origins*, eds C. E. Woodward, J. M. Shull & H. A. Thronson, ASP Conf. Ser., 148, 304
Murphy, E. M., et al. 2000, ApJ, this issue
Oliveira, C., Retherford, K. D., Conard, S. J., Barkhouser, R. H., & Friedman, S. D. 1999, *Proc. SPIE* 3765, 52
Oegerle, W. R., Murphy, E. M., & Kriss, G. A. 2000, *The FUSE Data Handbook*
Oegerle, W. R., et al. 2000b, ApJ, this issue
Rose, J. F., Heller-Bowyer, C., Rose, M. A., Swam, M., Miller, W., Kriss, G. A., & Oegerle, W. R. 1998, *Proc. SPIE*, 3349, 410
Sahnow, D. J., Friedman, S. D., Oegerle, W. R., Moos, H. W., Green, J. C. & Siegmund, O. H. W. 1996, *Proc. SPIE*, 2807, 2
Sahnow, D. J., et al. 2000, ApJ, this issue
Savage, B. D., et al. 2000, ApJ, this issue
Sembach, K. R., et al. 2000a, ApJ, this issue
Shull, J. M., Tumlinson, J., et al. 2000, ApJ, this issue
Shull, J. M., Giroux, M. L., et al. 2000, ApJ, this issue
Siegmund, O. H. W., et al. 1997, *Proc. SPIE* 3114, 283
Snow, T. P., et al. 2000, ApJ, this issue
Spitzer, L., Jr., & Jenkins, E. B. 1975, *ARA&A*, 13, 133
Verner, D. A., Tytler, D., & Barthel, P., D. 1994, ApJ, 430, 186
Vidal-Madjar, A., et al. 2000, ApJ, this issue
Woodgate, B.E., et al. 1998, *PASP*, 110, 1183

FIG. 1.— *FUSE* spectrum of the CSPN K1-16, 912–992 Å. Data are from the SiC channel on the detector 1 side. Transitions in the intervening gas are marked below the spectrum. Transitions intrinsic to the central star are marked above the spectrum.

FIG. 2.— Schematic of the *FUSE* instrument optical system. The telescope focal lengths are 2245 mm and the Rowland Circle diameters are 1652 mm.

FIG. 3.— Spectrum of HD93129A in the wavelength interval, 1034.9–1037.6 Å showing the low scattered signal near the center of the interstellar C II absorption line. Raw count data integrated over 7371 s from LiF1 are plotted as a function of pixel number in the dispersion direction. No corrections have been made for the contribution of dark count, air glow or scattered stellar light.

FIG. 4.— Comparison of *FUSE* spectrum of the QSO HS1700 + 64 ($z = 2.743$, $V = 16.1$) obtained in the LiF2 channel with that obtained by HUT. The vertical arrow indicates the onset of the Gunn-Peterson effect (Gunn & Peterson 1965) due to He II $\lambda 303.78$. Symbols indicate wavelengths where background features have been removed from the data. Data are binned over 2.5 Å.







