FAR AND EXTREME ULTRAVIOLET ASTRONOMY WITH ORFEUS

G. KRÄMER, J. BARNSTEDT, N. EBERHARD, M. GREWING, W. GRINGEL, C. HAAS, A. KAELBLE, N. KAPPELMANN, J. PETRIK
Astronomisches Institut, Waldhäuserstr. 64, 7400 Tübingen, F.R.G.
I. APPENZELLER, J. KRAUTTER, H. MANDEL, R. ÖSTREICHER
Landessternwarte Heidelberg, Königstuhl, 6900 Heidelberg, F.R.G.
and
S. BOWYER, M. HURWITZ
Space Sciences Laboratory, University of California, Berkeley, CA, 94720, U.S.A.

Abstract. ORFEUS (Orbiting and Retrievable Far and Extreme Ultraviolet Spectrometer) is a 1 m normal incidence telescope for spectroscopic investigations of cosmic sources in the far and extreme ultraviolet spectral range. The instrument will be integrated into the freeflyer platform ASTRO-SPAS. ORFEUS-SPAS is scheduled with STS ENDEAVOUR in September 1992. We describe the telescope with its two spectrometers and their capabilities i.e. spectral range, resolution and overall sensitivity. The main classes of objects to be observed with the instrument are discussed and two examples of simulated spectra for the white dwarf HZ43 and an O9-star in the LMC are shown.

1. Introduction

ORFEUS is a collaborative project between the Federal Republic of Germany represented by the BMFT and the United States of America represented by NASA. The scientific institutes participating in the development of the instruments and the scientific preparation of the mission are the Astronomical Institute of the University of Tübingen (AIT), the Landessternwarte Heidelberg (LSW) and the Space Sciences Laboratory of the University of California at Berkeley (SSL).

The ORFEUS telescope will be the first scientific payload (out of four) which will fly on the ASTRO-SPAS satellite. The platform will be launched and retrieved by the Shuttle. The mission duration will be several days.

2. The Space Platform ASTRO-SPAS

Fig. 1 shows the ASTRO-SPAS platform (Shuttle Pallet Satellite) with the 1 m ORFEUS telescope integrated into its modular structure. The satellite is designed to operate autonomously in low earth orbit in the vicinity of the Space Shuttle for a limited period of 7 to 10 days. The ASTRO-SPAS has its own power supply (batteries), its own attitude measurement and control system and facilities for data handling and storage. A telemetry/telecommand link through the Space Shuttle provides for short periods the possibility to dump specific quick-look data to the ground station and to send commands for online control of the SPAS and the

Y. Kondo (ed.), Observatories in Earth Orbit and Beyond, 177–184.

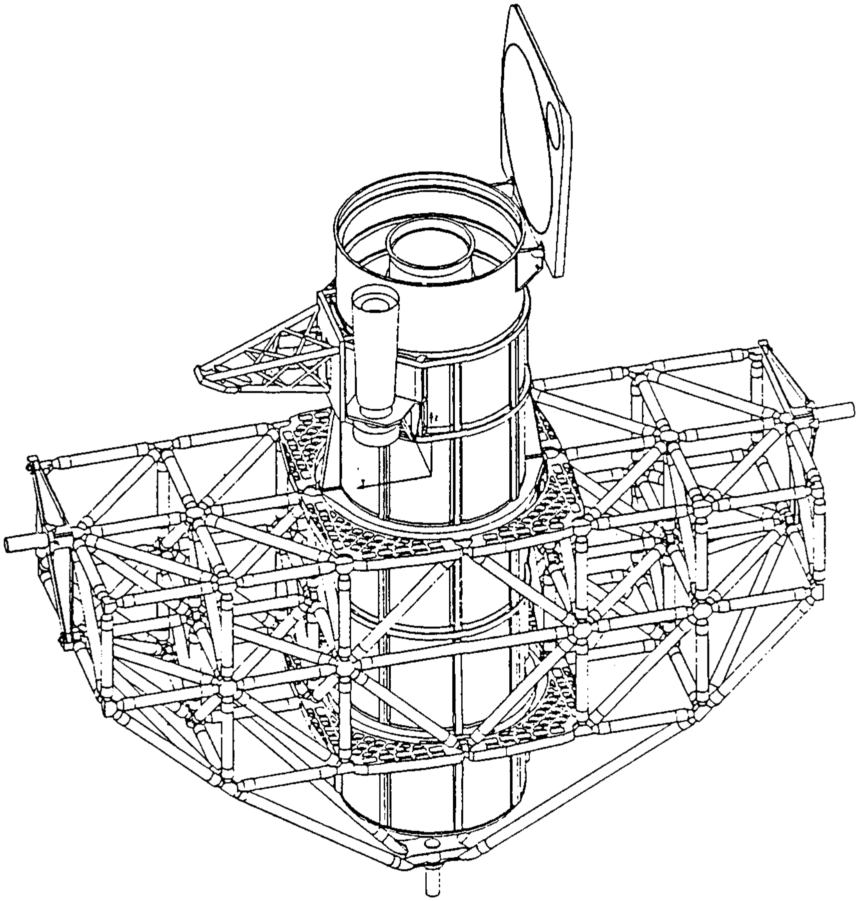

Fig. 1. The Space platform ASTRO-SPAS with the ORFEUS telescope.

experiments. Furthermore a preprogrammed target list for the next autonomous phase will be loaded into the satellite data processing unit during these contact times.

The pointing capability of the ASTRO-SPAS is of particular importance for ORFEUS since high resolution spectroscopy requires a pointing stability in the range of arcseconds or better. The ASTRO-SPAS offers an absolute pointing accuracy of ±7 arcsecs and a pointing stability of ±5 arcsecs continuously for more than 25 mins.

Manoeuvering capability is achieved through a cold gas system which allows the aquisition of a target in less than 20 minutes and a total number of more than 100 major slews (typically 180 degrees).

3. The ORFEUS Instrumentation

The ORFEUS payload comprises a 1 m normal incidence telescope feeding light into two spectrographs which can be operated alternatively (Grewing et al. 1990; Krämer et al. 1988). The overall payload configuration is shown in Fig. 2. In the following sections we briefly describe the main characteristics of the telescope and the two spectrometers.

3.1. The Telescope

The telescope is built around a 1000 mm clear aperture f/2.4 light weight (90 kg) Zerodur primary mirror. The optical bench, a graphite-epoxy cylinder, supports the primary focus instrumentation including the Rowland spectrograph. The total weight of the ORFEUS telescope will be about 800 kg.

A wheel mechanism with 3 diaphragms of angular diameters 10 arcsecs, 20 arcsecs and 10 arcmins is located in the focal plane. The 10 arcmin hole will be used for in orbit alignment of the optical axes of the telescope and the star tracker which is part of the attitude control system of the ASTRO-SPAS. The relative position of the optical axis of the telescope is controlled by means of an image system which is integrated into the Berkeley spectrometer. This system, which is illuminated by a small part of the telescope aperture, re-images the target within the entrance aperture onto a sealed MCP detector.

The undeflected light beam from the primary mirror will enter the modified Rowland spectrometer designed and constructed by the SSL. Alternatively, a pick off mirror can be moved into the beam to feed the light into the Echelle spectrometer developed and designed by LSW and AIT.

3.2. The Echelle Spectrometer

This spectrometer covers the wavelength range from 90 nm to 125 nm and offers a spectral resolution of approximatly 10,000 (Appenzeller et al. 1988). The Echelle is equipped with a parabolic off axis collimator which collimates the light and reflects it towards the Echelle grating which is used in the diffraction orders 45 to 62. The different orders are subsequently separated by a cross disperser which also acts as a correctorless Schmidt camera. This camera images the twodimensional spectrum onto a microchannelplate detector with a wedge and strip readout system. The image format is 1024×512 pixels.

With conventional coatings for the optical elements like iridium, gold and ARC 1000 the overall effective area of the instrument ranges between 1 cm^2 and 12 cm^2 for the 90 to 125 nm wavelength region. Especially close to 90 nm the sensitivity might be improved substantially if the collimator and the gratings could be coated successfully with SiC. With this Echelle spectrometer ORFEUS essentially extends the IUE capabilities into the FUV range, i.e. we will be able to observe unreddened early type stars in high resolution down to 10^{th} magnitude. As the instrument will be photon noise limited, rebinning photon events offers the possibility to reach even much fainter objects.

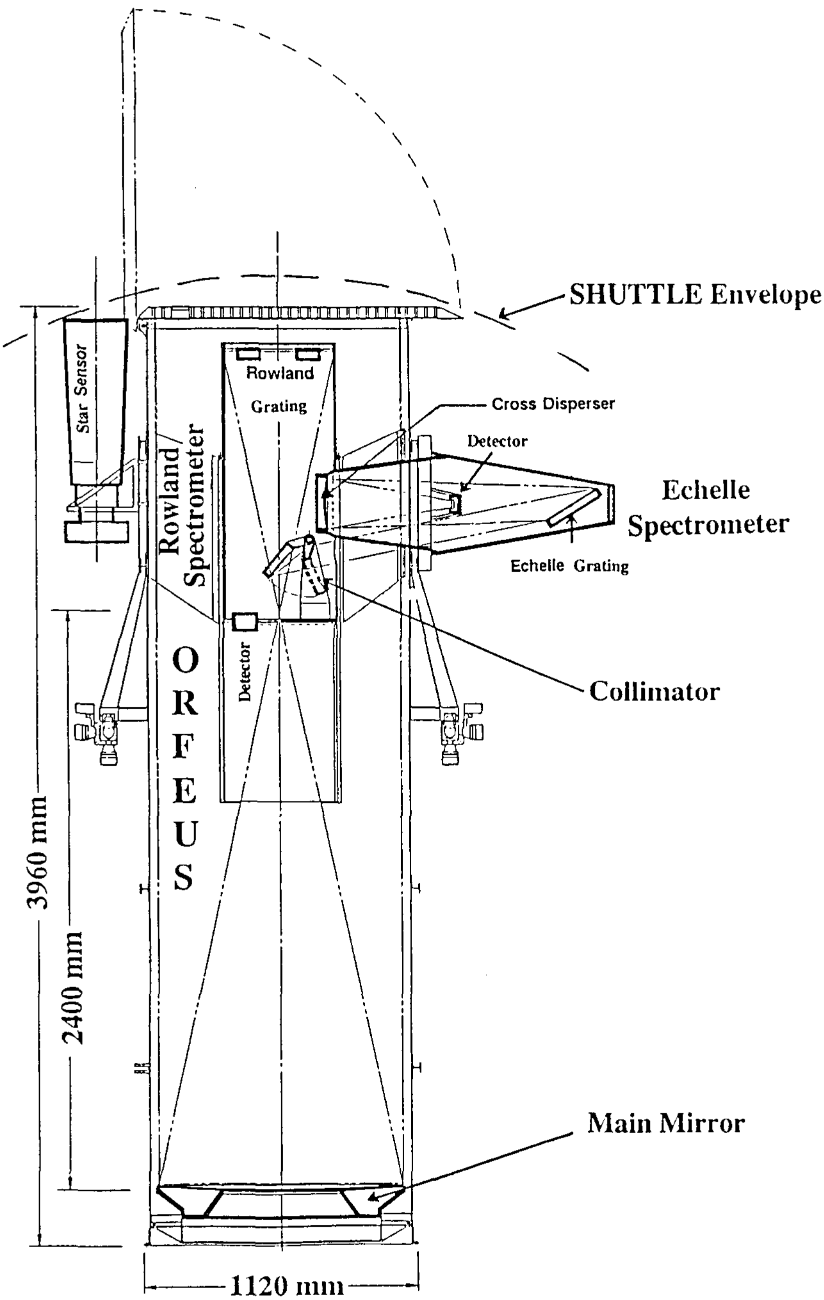

Fig. 2. Cross Section of the ORFEUS telescope system.

For brighter targets the spectral resolution may be improved above 10,000 by post flight correction of the telescope jitter: The star tracker has an intrinsic pointing accuracy of 2 arcsecs. With these data available in 1 sec intervals and the time tagged individually recorded photon events the movement of the spectrum on the detector induced by the jitter may be corrected.

3.3. The Berkeley Spectrometer

The Berkeley spectrometer covers the wavelength range from 39 to 120 nm. Its spectral resolution will be about 5000. It consists of four concave diffraction gratings, each of which is illuminated by approximately 20% of the telescope aperture. Each grating has a unique central line density, so that each disperses a sub-bandpass across a spectral detector. The line density on each grating is not constant, but is instead a fourth order function of position on the optic. This reduces astigmatism and improves spectral resolution substantially over what could be obtained with conventional uniform line-space gratings. The two short-wavelength and the two long-wavelength gratings respectively share a common detector. These two spectral detectors contain curved microchannel plates coupled to a delay line/charge division readout system, which yields very high pixel resolution in the dispersion direction and moderate resolution in the perpendicular direction.

4. Scientific Objects

a. *Chromospheres and coronae of cool stars* with photospheric temperatures like the sun show strong emissions at FUV and EUV wavelengths. Since ions from different ionization stages probe the temperature and density at different heights within the atmospheres, ions like CIII having all its resonance lines at these short wavelengths will add important information on the structure of the outer atmospheric layers of cool stars.

b. For *hot stars* it is, by contrast, mainly the understanding of the photospheric processes that will be enhanced by measurements at FUV and EUV wavelengths. Observations of continua and absorption edges will allow detailed tests of the theoretical predictions from atmosphere calculations. Studies of FUV spectra will enhance our knowledge about the ionization in stellar winds and improve our knowledge about stellar mass loss rates.

c. Obvious targets for observations at FUV and EUV wavelengths are *highly evolved* stars such as the subdwarfs, the nuclei of planetary nebulae, and hot white dwarfs because they have surface temperatures well in excess of 10^4K. Both the slope of their continua and their line spectrum will be of interest for very much the same reason as in the case of young early type stars, i.e. to study their atmospheric properties, especially the chemical composition of their atmospheres.

d. As shown by the COPERNICUS satellite the FUV range offers unique information about *the interstellar medium*. For example OVI absorption being seen

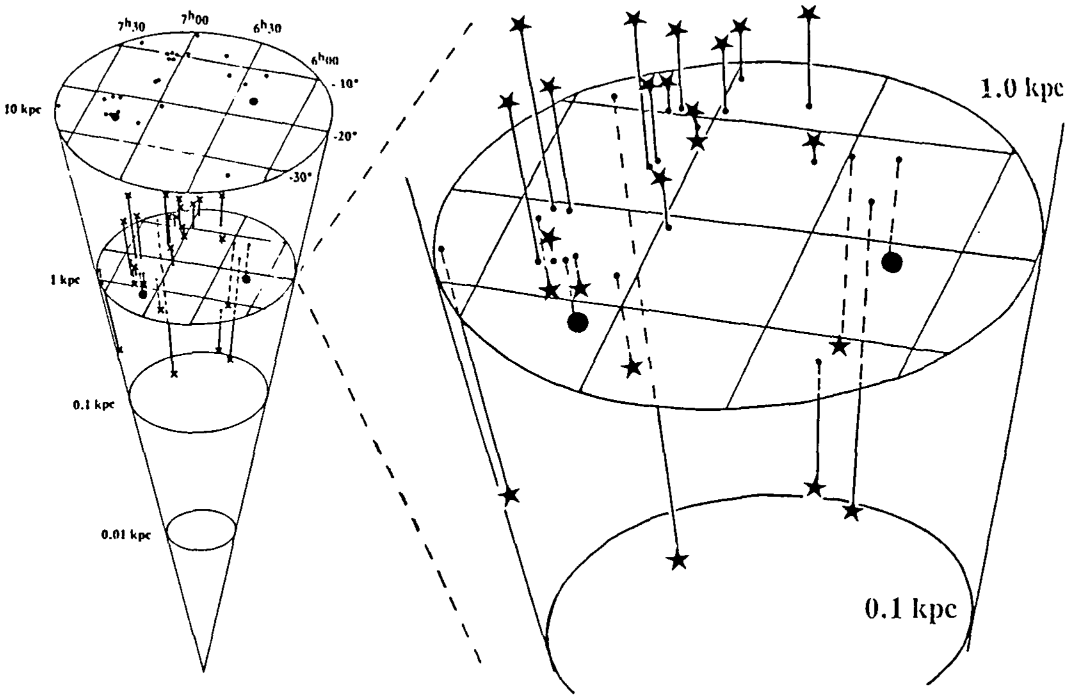

Fig. 3. Selected Field of Stars of Spectral Type O6 to B1.

along many lines of sight was a totally unexpected discovery. The large amounts of molecular hydrogen that were discovered through the FUV band spectrum totally changed the picture about the molecules in the interstellar mass budget and stimulated a large number of theoretical studies on their origin. ORFEUS, more sensitive by a factor of 100 will allow to expand these studies for a number of lines of sight by using far more distant background targets. Fig. 3 shows a field of stars of spectral type O6 to B1. Two of them could be observed with COPERNICUS, whereas ORFEUS can observe all of them with full spectral resolution. Consequently the ISM can be traced in a much narrower network at least in a selected area of special interest.

e. Last but not least gas streams and accretion discs in *close binary systems* (cataclysmic variables, X-ray binaries etc.) are to be mentioned as further classes of highly interesting objects which have never been observed in the FUV/EUV-region.

5. Model Spectra

In order to demonstrate the power of ORFEUS a model spectrum of an O9 star with $M_v = -6.95^m$ in the LMC was simulated. The spectrum in Fig. 4 is based on the COPERNICUS spectrum of μCol and an adopted integration time of 1000

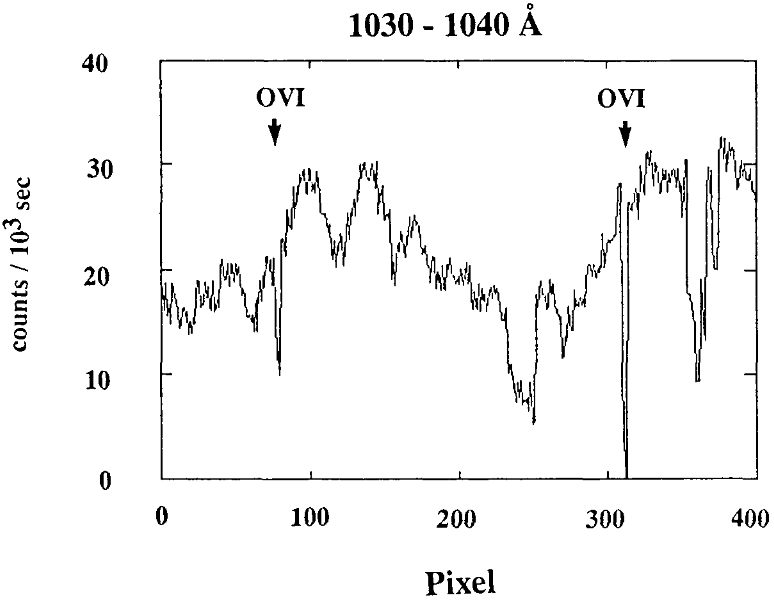

Fig. 4. Section of a Simulated ORFEUS Echelle Spectrum of an O9 Star in the LMC.

secs. It shows the details in the spectral range of the OVI doublet at 103.19 and 103.76 nm. The spectral resolution achieved corresponds to a pointing jitter of the telescope of 10 arcsecs peak to peak. As discussed before the spectral resolution may be improved by almost a factor of two by post flight restauration.

Fig. 5 shows model spectra of the hot white dwarf HZ43 calculated for both spectrometers: The Echelle spectrum is simulated for different coating combinations for the optical elements of the instrument. The coatings are itemized as follows: Primary mirror, collimator, Echelle grating, cross disperser. The abbreviations mean Ir (iridium), SiC (silicon carbide), ARC 1000 and 1200 are special coatings developed by Acton Research. No line spectra are included in this model. The Berkeley model spectrum includes the first few resonance lines of hydrogen and helium. Both spectra are based on calculations for the active area of the instruments including reflectivities and diffraction efficiencies of mirrors and gratings and the quantum yield of the MCP detectors.

Acknowledgements

This research was funded by BMFT Grant 01 OS 8501 8 and NASA Grants NASA/NGR-05-003-805 and NGT-50185.

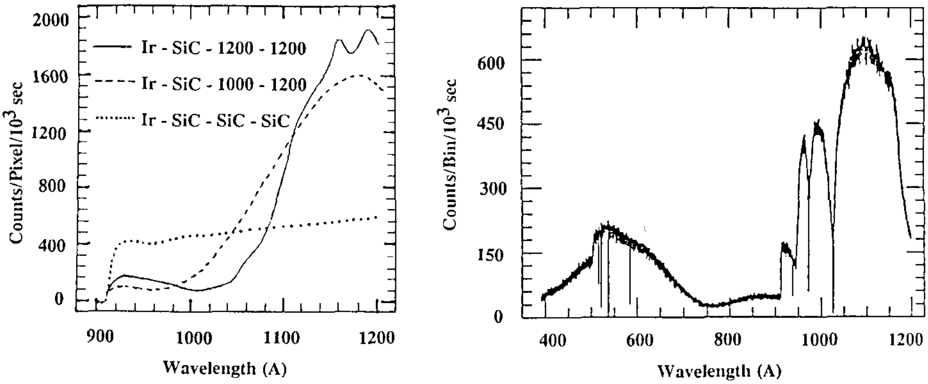

Fig. 5. Model Spectra of HZ43 calculated (A) for the Echelle and (B) the Berkeley spectrometer with an adopted integration time of 1,000 secs. For details see text.

References

Grewing M., Krämer G. et al.: 1990, in R.F. Malina and S. Bowyer, ed(s)., *Extreme Ultraviolet Astronomy*, Pergamon Press, New York,

Hurwitz M., Bowyer S.: 1990, in R.F. Malina and S. Bowyer, ed(s)., *Extreme Ultraviolet Astronomy*, Pergamon Press N.Y.,

Krämer, G. *et al.*, 1988, ORFEUS: A 1 m EUV/FUV Telescope on the Space Platform ASTRO-SPAS, in *A Decade of UV Astronomy with IUE* ESA SP 281, Vol. 2, p. 333

Hurwitz, M., Bowyer, S.: 1988, in , ed(s)., *A Decade of UV Astronomy with IUE*, ESA SP 281, Vol. 2, 329

Appenzeller I. et al.: 1988, *A Decade of UV Astronomy with IUE*, ESA-SP-281, Vol. 2, 337