HIRDES – The High-Resolution Double-Echelle Spectrograph for the World Space Observatory Ultraviolet (WSO/UV)

K. Werner [a], J. Barnstedt [a], W. Gringel [a], N. Kappelmann [a], H. Becker-Roß [b], S. Florek [b], R. Graue [c], D. Kampf [c], A. Reutlinger [c], C. Neumann [c], B. Shustov [d], A. Moisheev [e], E. Skripunov [e]

[a] *Institut für Astronomie und Astrophysik, Universität Tübingen, Sand 1, 72076 Tübingen, Germany*

[b] *Institute for Analytical Sciences, Albert-Einstein-Str. 9, 12484 Berlin, Germany*

[c] *Kayser-Threde GmbH, Wolfratshauser Str. 48, 81379 München, Germany*

[d] *Institute of Astronomy RAS, Pyatnitskaya st. 48, 119017, Moscow, Russia*

[e] *Lavochkin Association, Leningradskoye Shosse, Khimki, 141400, Moscow, Russia*

Abstract

The World Space Observatory Ultraviolet (WSO/UV) is a multi-national project grown out of the needs of the astronomical community to have future access to the UV range. WSO/UV consists of a single UV telescope with a primary mirror of 1.7 m diameter feeding the UV spectrometer and UV imagers. The spectrometer comprises three different spectrographs, two high-resolution echelle spectrographs (the High-Resolution Double-Echelle Spectrograph, HIRDES) and a low-dispersion long-slit instrument. Within HIRDES the 102–310 nm spectral band is split to feed two echelle spectrographs covering the UV range 174–310 nm and the vacuum-UV range 102–176 nm with high spectral resolution ($R > 50\,000$). The technical concept is based on the heritage of two previous ORFEUS SPAS missions. The phase-B1 development activities are described in this paper considering performance aspects, design drivers, related trade-offs (mechanical concepts, material selection etc.) and a critical functional and environmental test verification approach. The current state of other WSO/UV scientific instruments (imagers) is also described.

Key words: Visible and ultraviolet spectrometers, Space-based ultraviolet, optical, and infrared telescopes, Astronomical and space-research instrumentation
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1 Introduction

The World Space Observatory (WSO/UV) will provide future access to high-resolution far-UV spectroscopy. WSO/UV is an international collaboration led by Russia (Roscosmos) to build a UV (102–310 nm) mission with capabilities which are presently and in the near and long-term future unavailable to the world-wide astronomical community. The mission is scheduled for launch in 2010. The planned instrument sensitivity will exceed that of HST/STIS by a factor of 5–10 and all observing time will be available for UV astronomy. The present mission design comprises a 1.7 m telescope. The focal-plane (FP) instruments consist of two high-resolution spectrographs ($R \sim 55\,000$) covering the 102–310 nm range and a long-slit (1" × 75") low-resolution ($R \sim 500-5000$) spectrograph. Although the primary science of the WSO/UV mission is spectroscopy, high spatial-resolution UV imaging instruments are foreseen. Additionally, a direct imager which samples the best diffraction-limited resolution of the optical system is implemented. WSO/UV will be operated like a ground-based telescope, i.e., it will perform "real-time" operations in an orbit with reduced visibility constraints (high-Earth orbit). Overviews of the WSO/UV mission and its science case were given by Barstow et al. (2003) and Gómez de Castro et al. (2006), respectively.

2 The WSO/UV telescope

The heritage for the WSO telescope design is the Russian-led international space observatory Spectrum-UV – a Russian, Ukrainean, German and Italian project – that was canceled due to funding problems. The WSO/UV telescope (T-170M) is a new version of the T-170 telescope designed by Lavochkin Association, Moscow. Modifications have been made to reduce the weight of the telescope below 1600 kg. The T-170M telescope and its structure are shown in Fig. 1 with the principal structural elements: the primary and secondary mirrors, and the instrument compartment. The primary mirror unit (PMU) is the telescope's main structural element. There are three attachment points of the telescope to the spacecraft's (S/C) service module (S/M). The optical bench with the scientific instrumentation devices and the primary mirror's baffles are mounted on the PMU frame. The optical design is a Ritchey-Chrétien type with a 1.7 m hyperbolic mirror. The mirror has an equivalent focal length of 17.0 m, and a field of view (FOV) of 30' (Ø=150 mm). The optical quality of the main and secondary mirrors is $\lambda/30$ rms at 633 nm and the angular resolution at the focal plane is 12.05"/mm. The characteristics of the T-170M telescope are given in Tab. 1. The platform for WSO/UV is the same as that developed by Roscosmos for Spectrum-X-Gamma, the NAVIGATOR bus, but it will be tailored to the WSO/UV requirements (Tab. 2). A Russian Zenith 2

Table 1
Characteristics of the T-170M telescope.

Optical system	Ritchey-Chrétien aplanat
Aperture diameter	1700 mm
Telescope f-number	10.0
FOV	30' (Ø=150 mm)
Wavelength range	100–310 nm (+visible)
Primary wavelength	200 nm
Optical quality	Diffraction optics at the FOV center
Mass	1570 kg (1600 kg with adapter truss)
Size	$5.67\,\mathrm{m} \times 2.30\,\mathrm{m}$ (transport); $8.43\,\mathrm{m} \times 2.3\,\mathrm{m}$ (operational)

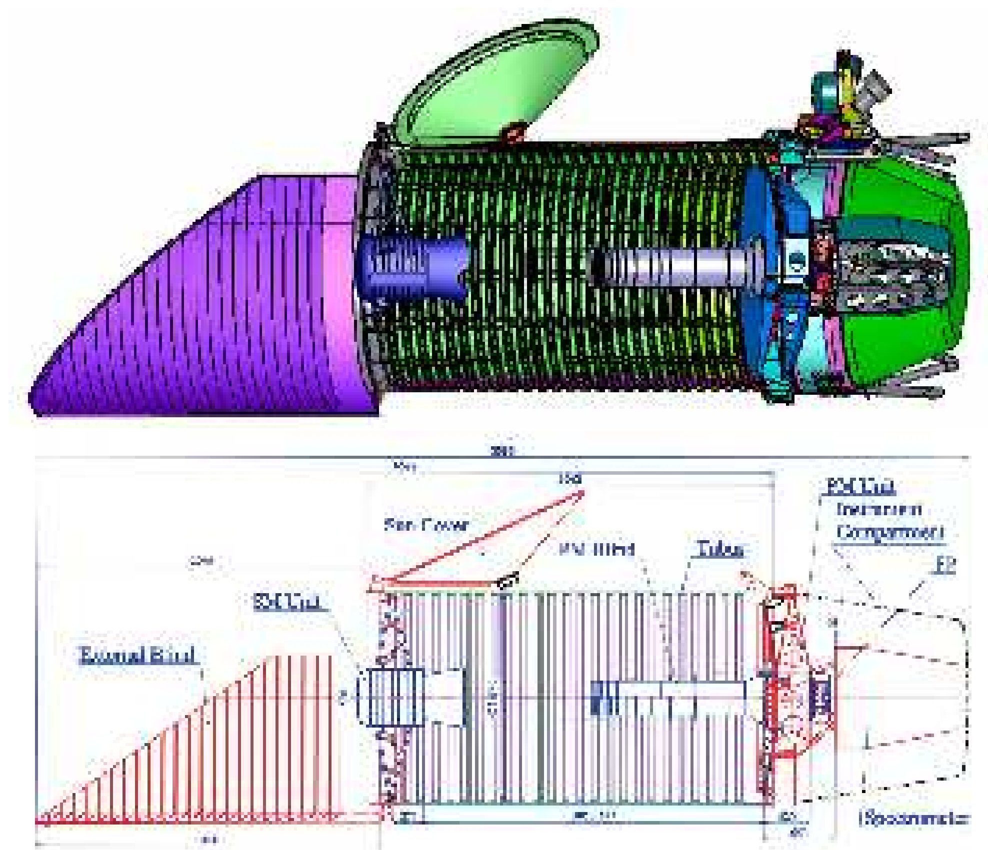

Fig. 1. The T-170M telescope of WSO/UV.

is the likely launch vehicle.

3 The high-resolution double-echelle spectrograph

The UV spectrometer comprises three different single spectrographs, two high-resolution echelle spectrographs – the High-Resolution Double-Echelle Spectrograph (HIRDES) – and a low-dispersion long-slit instrument. The HIRDES

Table 2
Characteristics of the NAVIGATOR bus.

Platform (S/M)	Navigator
Mass of S/C with propellant	2900 kg
S/M mass	1300 kg
S/M propellant mass	150 kg
S/M propellant	Hydrazine
Payload (P/L) mass	1600 kg
Pointing accuracy with star sensors	4 (2)'
Accuracy of pointing and stabilization with the FGS	0.1"
Slewing rate	Up to 0.1°/sec
Maximum exposure time	30 hours
Download of scientific data	Up to 1 Mbit/sec
H/K data transmission rate	Up to 32 Kbit/sec
Electric power (EP) available for P/L	750 W
EP for science instrument for the FP compartment	300 W
Voltage of electric power supply	27±1.35 V

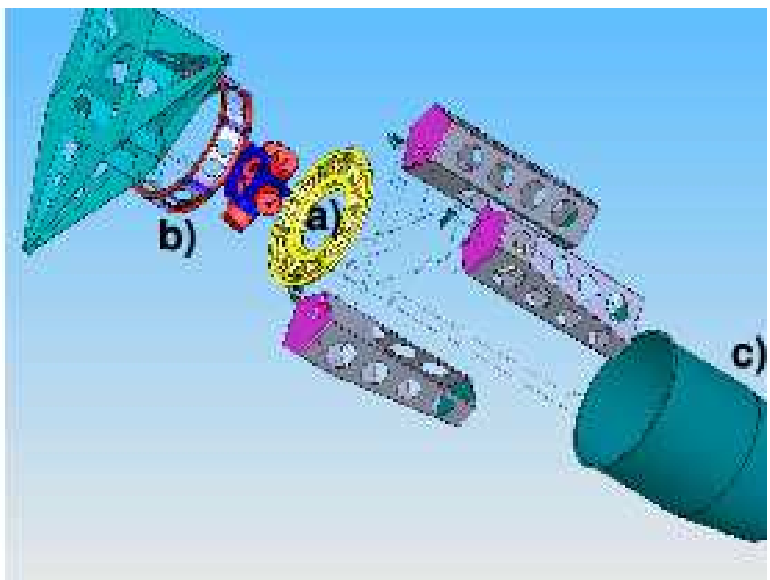

Fig. 2. The WSO/UV spacecraft interfaces, i.e., a) optical bench plate, b) external instrument plate, and c) protective case.

spectral band (102–310 nm) is split and fed into two echelle spectrographs covering the UV range 174–310 nm (UVES channel) and vacuum-UV range 102–176 nm (VUVES channel) with a high spectral resolution of $R > 50\,000$. Each spectrograph encompasses a standalone optical bench structure with a fully redundant high-speed MCP detector system, the optomechanics and a network of mechanisms with different functionalities. After a HIRDES assessment study for the Spectrum-UV mission a phase-A study was performed by Jena-Optronik, Jena, in 2001. The main goal of this study was the rearrangement of the echelle spectrographs and the long-slit spectrograph due to

Table 3
General requirements for UV and VUV echelle spectrographs (UVES and VUVES).

Parameter	Baseline requirements
Wavelength coverage VUVES	102–176 nm
Wavelength coverage UVES	174–310 nm
Spectral resolution	$R > 50\,000$
Minimum sensitivity SNR=10 in 10 h	$m_{VUV} = 16$; $m_{UV} = 18$
Minimum sensitivity SNR=100 in 10 h	$m_{VUV} = 11$; $m_{UV} = 13$
Limit loads in all axes w/o SF	15 g (tbc)
Stiffness (1st fundamental eigenfrequency)	> 40 Hz
Envelope	Protective case
Mass	155 kg
Power	150 W
Data rate (downlink)	1.6 Mbit/sec

the fact that HIRDES was considered the only focal-plane spectrograph in the instrumental bay of WSO/UV. HIRDES is located in the S/C instrument compartment with mounting interfaces to the main S/C structure (optical bench) and it is covered by a protective case (Fig. 2). The associated electronic boxes are located separately at the protective case and the electronic-box panels are provided by the S/C.

4 Phase-B1 study of the spectrographs

A phase-B1 study was performed by Kayser-Threde GmbH, Munich, in close cooperation with Lavochkin Association, Moscow. It was started in 2005 and finished in April 2006. The Institute of Analytical Sciences in Berlin was responsible for the optical layout of the spectrographs. The optical layout of the long-slit spectrograph (LSS) was not part of this study. A phase-A study for the LSS is currently being performed in China. The main spectrometer requirements are given in Tab. 3 and the optical design of HIRDES is shown in Fig. 3.

The UV and VUV spectrographs are equipped with an in-field fine guidance system (IFGS). The IFGS is used for a multi-step pointing system to stabilize the spectral image of the spectrometers. The IFGS sensors are placed near the entrance slits. For the focal-plane array detectors of the IFGS a selection between two detector concepts (CCD, CMOS) was performed. CMOS detectors were selected because they are less environment sensitive (radiation, EMC) and easier to operate. The design envelope of the spectrometers and external electronic boxes is mainly determined by the S/C interfaces (protective case and optical bench). An overview of the HIRDES is given in Fig. 4.

The flexural mounts are made from Invar and shall be bonded into the mirror

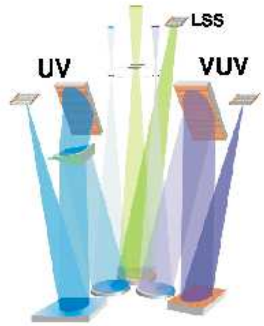

Fig. 3. Optical layout for the UV spectrograph with an echelle grating (40 lines/mm, 70° blaze angle) and prism (fused silica, 12°); and optical layout for the VUV spectrograph: dispersion by echelle grating (65 lines/mm, 71°) and order separation by cross disperser (on-focus mirror, 625 lines/mm). A preliminary optical layout of the long-slit spectrograph (LSS) is added.

Fig. 4. Schematic overview of the UV and VUV spectrometers and electronic boxes.

substrates as given in Fig. 5. This technique was successfully qualified for the ORFEUS telescope. The HIRDES suspension is configured to establish the isostatic mounting of the three spectrometers at the S/C optical bench. Considering the limited envelope and the high mechanical loads Invar pads with stainless steel flexurable links with high strength offers the best performance in terms of stiffness, strength and minimized thermal conductivity (ORFEUS heritage), see Fig. 6.

The following mechanisms are foreseen for both UVES and VUVES: vacuum shutter mechanism for the detectors, servo-mirror mechanism to switch between normal operating and redundant detector heads, and a mechanism for

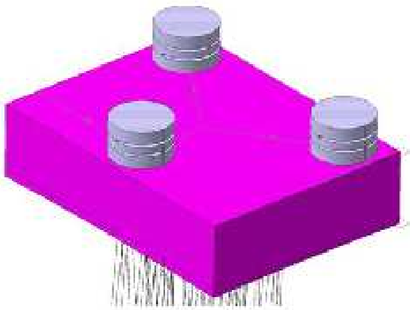

Fig. 5. Isostatic mirror suspension.

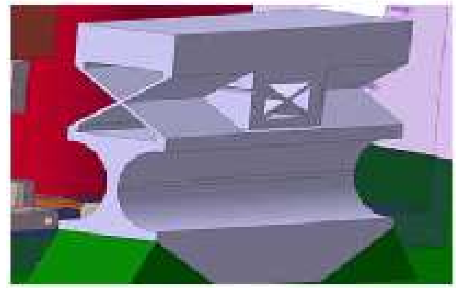

Fig. 6. Invar suspension with stainless steel flexural blades.

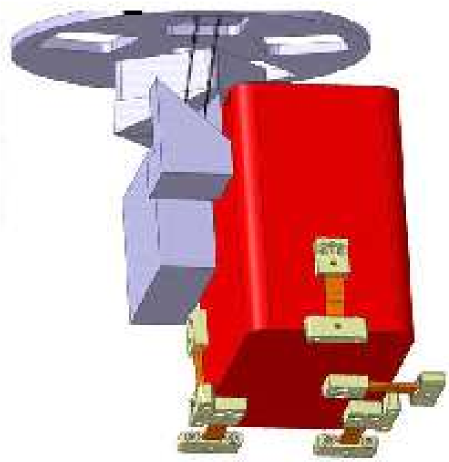

Fig. 7. MCP detector box with isostatic suspension made from carbon fibre, and with a filter wheel for grey filters.

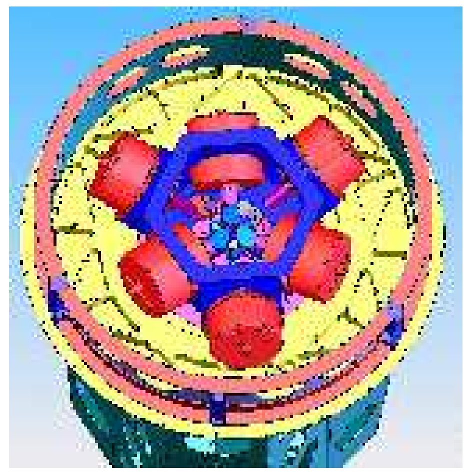

Fig. 8. Preliminary arrangement of the focal camera unit.

grey filters (Fig. 7) which will be used to observe bright targets.

The HIRDES and IFGS detector suspensions are configured to establish the isostatic mounting of the boxes and additionally a thermal decoupling of these boxes from the spectrometer structure. By separating the directions a strut solution was found, where every strut supports one degree of freedom and is flexible for the others (Fig. 7). The struts are made of CFRP (Herschel-PACS heritage).

The material of mirrors to be used must be very homogeneous. Several different types of materials were traded with respect to environmental and performance requirements. Fused silica mirrors with Invar flexible mounts (ORFEUS heritage) were selected due to superior performance in terms of light-weighting, bonding techniques, surface quality and manufacturing costs.

Very low mechanical tolerances are required due to high optical stability requirements, namely translation: 10–50 μm, and rotation: 2–5". The trade-off of the following candidate materials has given the technical and related costs features: composite materials, aluminum and ceramics. The candidate materials were investigated. Aluminum seems to be very critical with respect to the thermal stability requirements. Due to quasi-ambient temperatures, high accuracy, cost efficiency and specific experience the selected baseline for the primary structure of the spectrometers was the concept based on CeSiC. The thermostable CeSiC structure is not sensitive to thermal gradients. No mechanisms with high functional, technical and operational complexity and dedicated system costs are necessary. Therefore the required spectral resolution is achieved without active control of optical elements, and the complex collimator and echelle-grating mechanisms for focusing (introduced in the assessment and phase-A studies) are no longer necessary.

The architecture of the structural design of UVES and VUVES spectrometer structures provides the following features: standalone structure, independent assembly and alignment S/C accommodation, independent functional performance testing. The envelope of the UVES and VUVES spectrometers covers 240°, the envelope of the LSS covers 120° of the instrument compartment around the optical axis. The following features can be highlighted with respect to the structural design:

- Monolithic structure made from CeSiC
- Cost-effective light-weight approach; fabrication technology available
- Reduced manufacturing tolerances (procurement costs) due to standardized adjustment devices for each optical component
- Isostatic suspension for the HIRDES spectrometers to the S/C interface
- Isostatic suspensions, i.e., thermo-mechanical decoupling for the detectors from the main spectrometer housings

5 The focal plane imagers

Although the primary aim of WSO/UV is spectroscopy, there is an important role for high-resolution imaging. The focal camera unit (FCU) will include:

- An optical camera (OC), working at the best diffraction-limited resolution with the largest FOV which is possible to accommodate; this camera is intended to perform astrometry in crowded fields.
- Two UV imagers: one f/50 camera with a resolution of $\sim$ 0.03"/px and $\sim$ 1.2' FOV (long focus, LF), and one f/10 camera with $\sim$ 0.15"/px resolution and $\sim$ 6' FOV (short focus, SF). Each of these cameras is equipped with one or two filter wheels in order to accommodate passband filters.

The possibility to accommodate redundant UV and optical cameras in the FCU has to be evaluated during the phase-A/B1 study (Fig. 8 shows a possible

Table 4
Specifications for the focal cameras.

Camera	Range	Focal ratio	FOV	PSF sampling	Resolution
SF	UV	f/10	6.0'	0.15"/px	0.3"
LF	UV	f/50	1.2'	0.03"/px	0.1"
OC	visible	tbd	tbd	≤0.03"/px	≤0.1"

design and Tab. 4 summarizes the specifications), which shall be completed in Italy in 2007. The final choice of detectors – MCP and/or CCD – will be a task of this study. However, from a preliminary assessment study the baseline choice is MCP for the UV cameras and CCD for the optical camera.

6 Conclusion

The WSO/UV mission will provide high-resolution UV spectroscopy and imaging. We have presented parts of the phase-B1 study of the main instrument of the WSO/UV mission, the High-Resolution Double-Echelle Spectrograph HIRDES. With the choice of a ceramic material (CeSiC) for the structure of the optical benches of the individual standalone spectrographs, the high spectral resolution can be achieved without active control of optical elements. Furthermore it is not necessary to install complex focusing mechanisms. The introduced mirror, detector and spectrometer suspensions are already successfully qualified by other space missions.

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