WORLD SPACE OBSERVATORY – ULTRAVIOLET

USER'S HAND BOOK

This document is written in support to the first call for proposals for the WSO-UV core program. This first call is **only** for projects requiring preparatory observations with other facilities. The call is issued 4 years prior to the launch of the observatory to enhance the scientific efficiency of WSO-UV. It will guarantee astronomers core program observing time while running, in advance, preparatory observations for target selection or characterization. At this time, WSO-UV is not fully built, tested or calibrated. Applicants should be aware of this fact.

1. World Space Observatory – Ultraviolet overview

The World Space Observatory – Ultraviolet (WSO-UV) is part of ROSCOSMOS scientific program and has been developed in collaboration with Spain. WSO-UV is the third mission of the Spektr (spectrum) series of the Russian Federal Space Program after Spektr-R (in orbit since 2011) and Spectr-RG (with Russian ART- and e-Rosita payloads). All missions of the Spektr series use the NAVIGATOR platform.

The scientific payload consists of a 170cm primary space telescope, equipped with instrumentation for imaging and ultraviolet spectroscopy in the 115 to 315nm range, from Lyman-α to the atmospheric cut-off. The WSO-UV will be placed in geosynchronous orbit in 2023 by a Proton launcher becoming the first 2-m class ultraviolet observatory flown into High Earth Orbit (HEO).

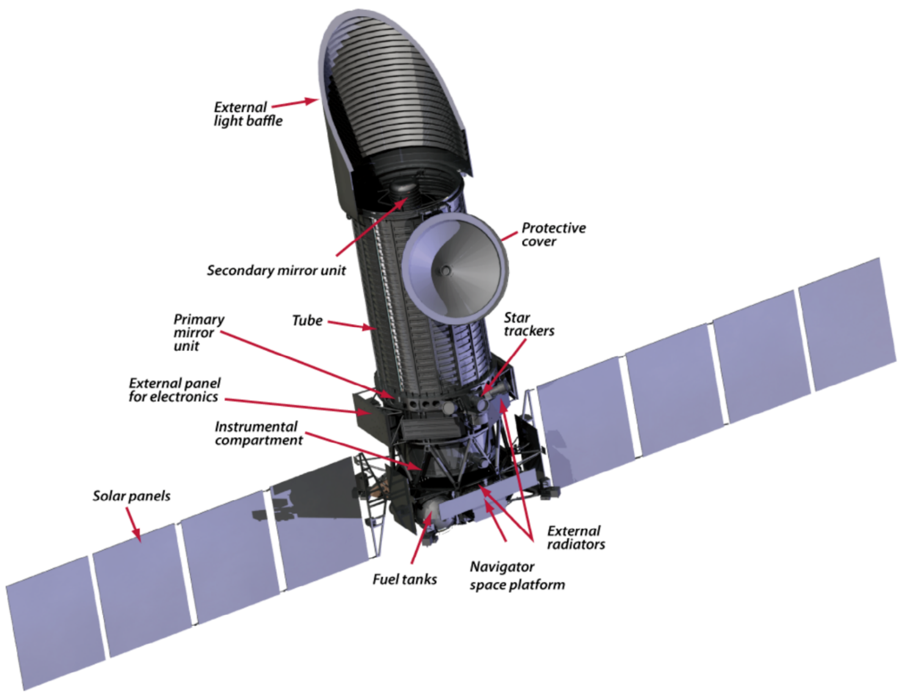

Figure 1: The WSO-UV spacecraft

2. Payload

WSO–UV consists of a Ritchey– Chrétien T170 telescope. The telescope is composed by the optical system, the structural module and the service complex. The primary mirror unit (PMU) is the main structural element of the telescope. The telescope feeds two main instruments: the WSO-UV Spectrographs (WUVS) and the Focal Camera Unit (FCU) for imaging and slitless spectroscopy.

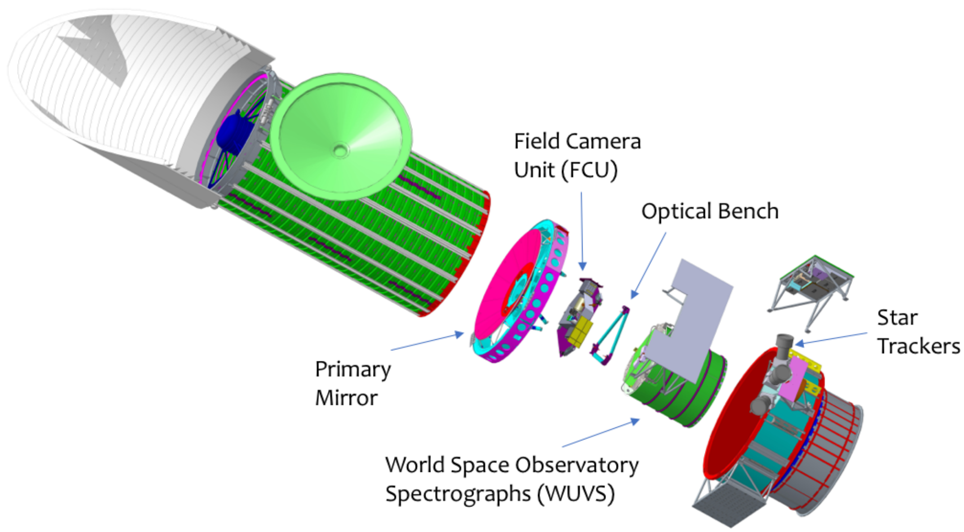

Figure 2: WSO-UV Instruments Compartment

The most important characteristics of the WSO-UV are compiled here:

- **Long continuous target visibility.**
- Small Pollution from Earth atmosphere. The FCU will be the first UV imager flown in a geosynchronous orbit, above the Earth geocorona.
- **Simultaneous** operation of WUVS and FCU is feasible.
- High sensitivity, with a total mirror geometric effective area of $2.27 m^2$.
- Guiding stability of 0.1 arcsec at 3σ.
- Spectral dispersion as high as D=50,000 in the full 115-315 nm range with the WUVS instrument.

Table 1: T170M main characteristics

Optical System	Ritchey-Chrétien
Aperture diameter	1.7 m
Focal length	17 m (primary mirror)
f/#	10.0
Field of View (FoV)	30 arcmin (150 mm in diameter)
Wavelength range	115-600 nm
Primary Wavelength	200 nm
Optical quality	Diffraction limited at FoV center
Angular resolution on focal plane	12.13 arcsec/mm
Mass	1570 kg (1600 kg with adapter truss)
Size	5.67 2.30 m (transport) 8.43 x 2.3 m (operational)

3. The telescope T-170M

The T-170M telescope provides an accessible **field of view of 30 arcmin** on the telescope focal plane and the optics is **diffraction limited at 200 nm**. The main characteristics of the T-170M are summarized in Table 1. The optical system is close orthoscopic; the maximum image distortion is only about 0.06%.

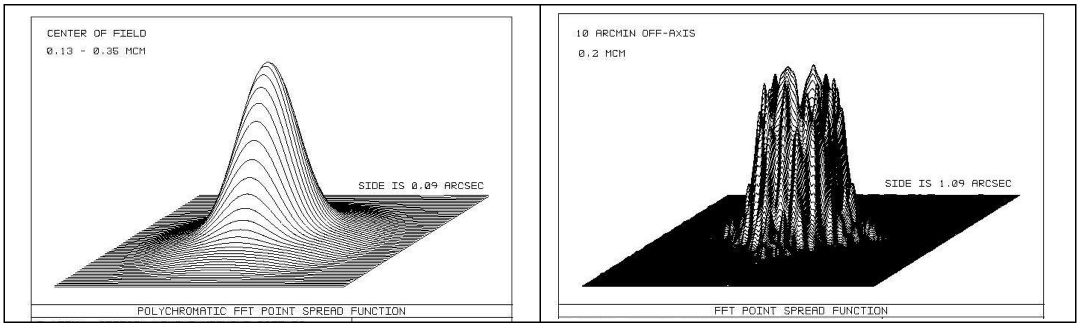

Figure 2: T170M PSF at center of Field and Off Axis at 200nm

In the instruments compartment, the optical bench – used as reference plane for all the onboard instrumentation – is aligned and maintained in the correct position with respect to the primary mirror using a three rods system. The FCU is mounted on the upper basis of the optical bench, in the space available between the primary mirror and the optical bench itself, while WUVS is mounted to the optical bench bottom basis. The Fine Guiding Sensors (FGS) are also mounted on the focal plane. The sensors are placed at the vertex of an equilateral triangle in the focal plane close to the spectrograph entrance slits, **ensures a pointing stability 0.1 arcsec**. Each of the focal plane instruments has its own power supply and data handling unit in a service box mounted on the external side of the instrument compartment.

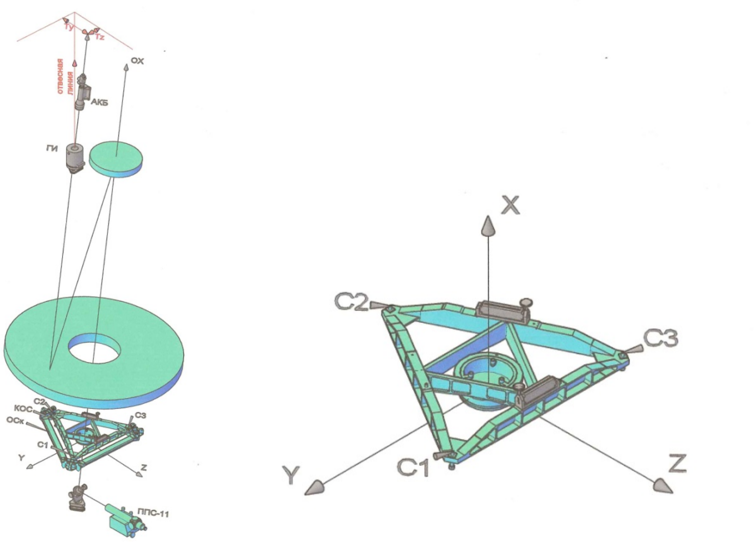

Figure 3: Assembling and pointing of the optical system.

4. Science Instruments

The WSO-UV telescope feeds two main instruments: the spectrographs unit (WUVS) and field camera unit (FCU), as well as the Fine Guidance System (FGS). WSO-UV instrumentation is designed to provide:

- Spectroscopic observations in the 115-315 nm range with dispersion 50,000.
- Long slit spectroscopy with spectral dispersion 1,000.
- Imagery of space objects with high resolution (up to 0.1 arcseconds in the 115-176 nm range) and wide field imaging in the 200-600 nm range.

The focal plane layout is shown in Figure 4. The Fine Guiding Sensors are located in a circle of radius 24.25 arcmin around the T-170M optical axis. WUVS entrace slits are intercalated between them, to guarantee accurate guiding during the foreseen long spectroscopic observations. The FCU picks off the beam from the telescope axis but requires an independent refocussing mechanism.

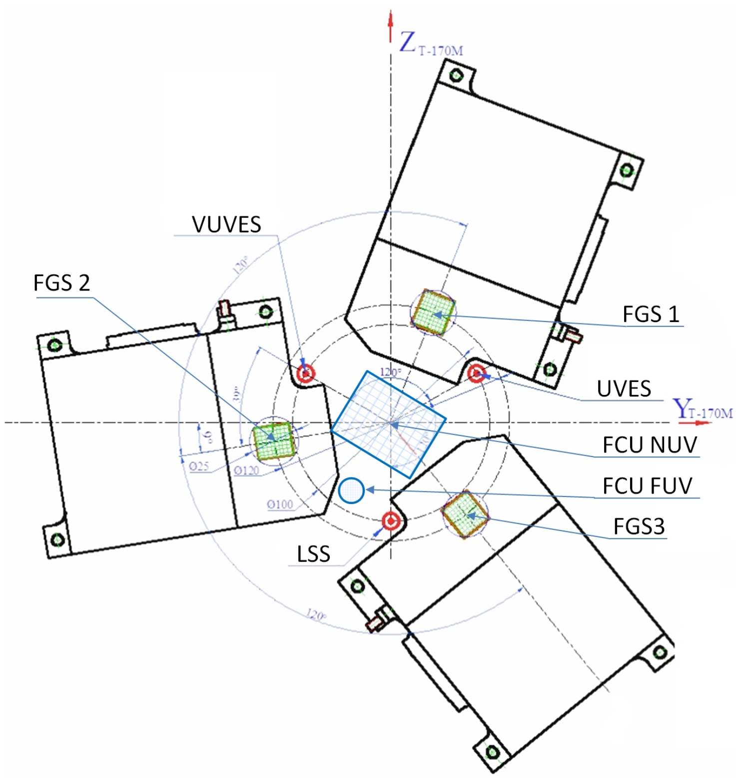

Figure 4: Focal plane layout. Entrance slits to WUVS and fine guiding sensors are marked. The location of FCU pick-off mirrors is also indicated.

4.1 WSO-UV Spectrographs Unit (WUVS)

The WUVS spectrographs assembly consists of three channels:

- Vacuum Ultraviolet Echelle Spectrograph, VUVES
- Ultraviolet Echelle Spectrograph, UVES
- Long-Slit Spectrograph, LSS

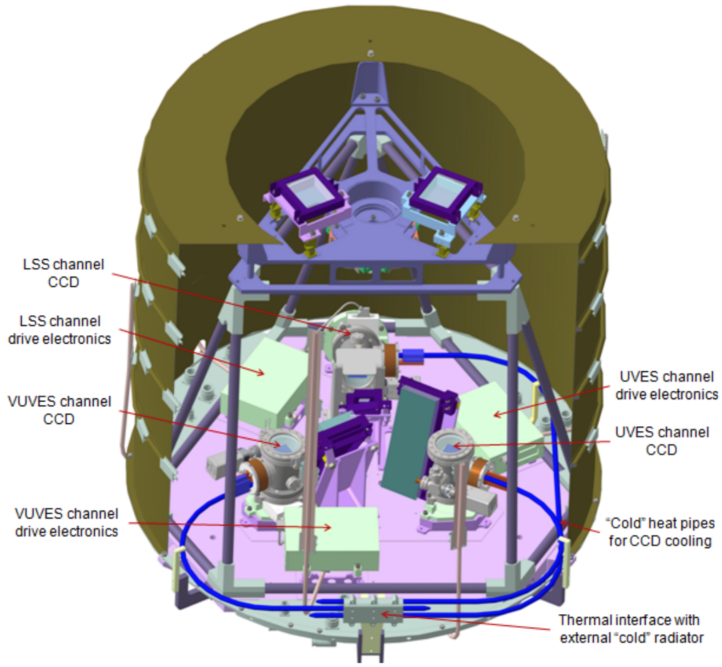

Figure 5: The WSO-UV Spectrographs (WUVS)

VUVES and UVES optical design is based on a Rowland circle[1]; as a result, if the slit is placed anywhere on the circumference of the circle, the spectral orders are exactly focussed in the circumference around the circle. The LSS optical design is shown in Figure 6; it makes use of two toroidal gratings to produce the 102-300 nm spectrum in the reduced space left for the third WUVS channel. The main optical characteristics of WUVES optical elements are summarized in Table 2.

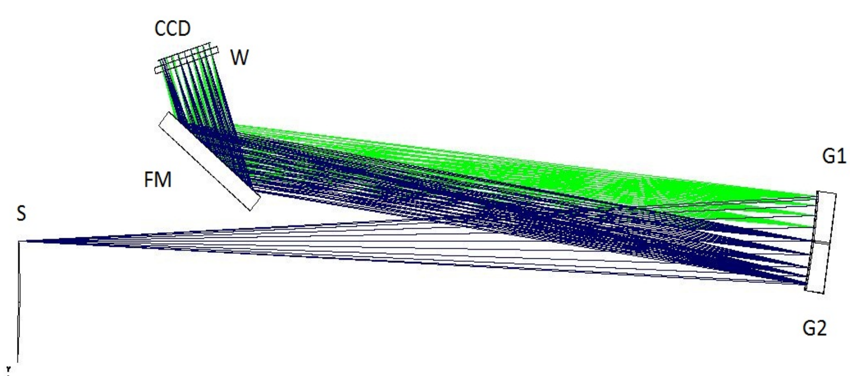

Figure 6: Optical design of WUVS/LSS. The letters in the figure stand for: **S**: entrance slit, **G1,G2**: gratings 1 and 2, respectively; **FM**: folding mirror, **W**: window of the CCD detector.

[1] A Rowland circle has as diameter the radius of curvature of a concave diffraction grating.

Table 2: Main characteristics of WUVES optical elements

	Size (mm)	Curvature Radius (mm)	Grooves density (mm^{-1})
VUVES			
Echellé	260x90	∞	100
Cross-disperser	100x130	1600	600
UVES			
Echellé	260x90	∞	60
Cross-disperser	100x130	1600	300
LSS			
G1, λλ=184-305	40x85	R_m=687.0, R_s=680.0	600
G2, λλ=115-187	40x85	R_m=687.0, R_s=680.0	1000

The effective area of WUVS compared with the performance of similar instruments on board the Hubble Space Telescope (HST) is shown in Figure 6a,b. WSO-UV collecting surface is a factor of 2 smaller than Hubble however, the high efficiency of WUVS new generation detectors raises significantly its sensitivity, especially above 200 nm. WUVS main features are summarized in Table 3.

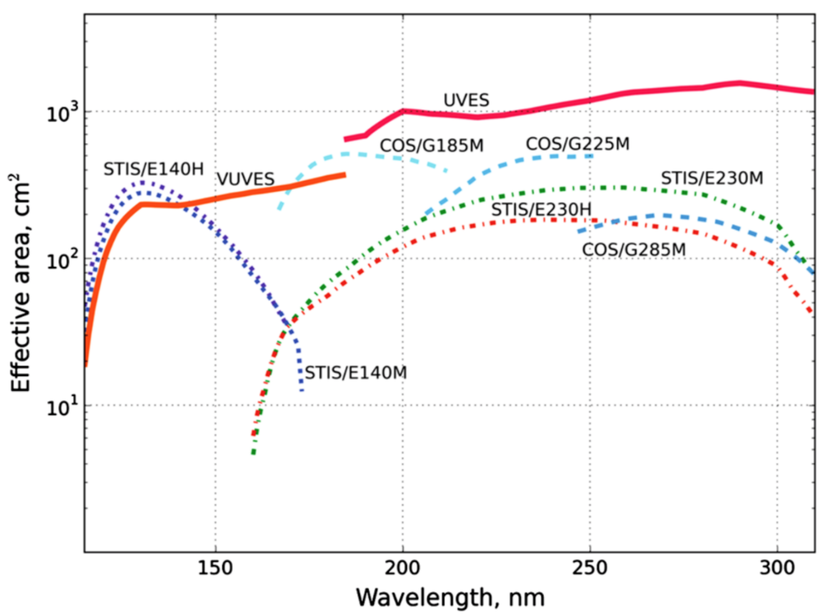

Figure 6a: Effective area of the UVES and VUVES channels of the WUVS, compared with the COS/HST and STIS/HST instruments.

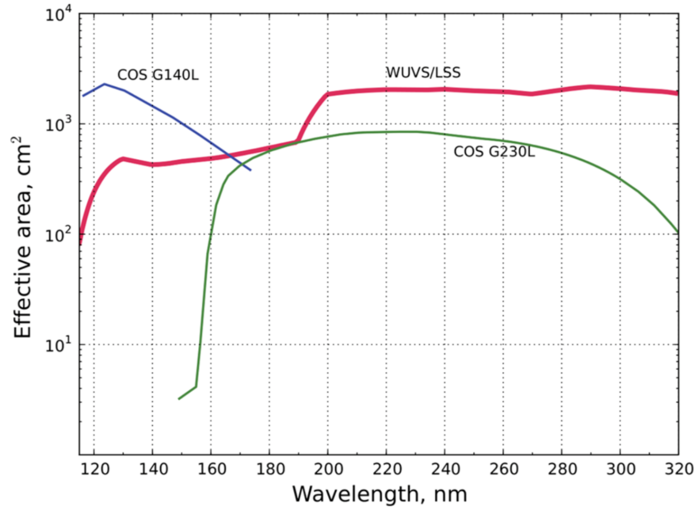

Figure 6b: Effective area of the LSS channel of the WUVS, compared with the COS/HST channels

Table 3: WUVS Main features

Parameters	UVES	VUVES	LSS
Wavelength Rage (nm)	174-310	102-176	102-300
Spectral Dispersion	>50,000	>50,000	>1000 @ 150nm
Entrance Slit Dimension (arcsec)	0.97	0.97	1x72.82
Detector Pixel Pitch (µm)	12	12	12
SNR (after 10hrs)	10 (18mag)	10 (16mag)	10
Angular Resolution	NA	NA	0.5 arcsec
Operation Temperature (K)	293	293	293
Throughput[2]	24%	13%	26%

4.1.1. WUVS Operational Modes

FUV echellé Spectroscopy.
The FUV high-resolution spectrograph (VUVES) provides echellé spectroscopy capabilities with high resolution (R ~ 50 000) in the 115–176 nm range.

NUV echellé Spectroscopy.
The NUV high-resolution spectrograph (UVES) provides echellé spectroscopy capabilities with R ~ 50 000 in the 174– 310 nm range.

Long Slit Spectroscopy.
The Long-Slit Spectrograph (LSS) provides low resolution (R ~ 1000), long slit spectroscopy in the 115– 305 nm range. The spatial resolution is better than 0.5 arcsec.

[2] Excluded telescope and detector, at the center of the band

4.2 WSO-UV Field Camera Unit: FCU

The FCU is mounted on top of the optical bench, below the primary mirror of the T-170M. The FCU has two channels, each fed by an independent pick off mirror. The far UV (FUV) channel has capabilities for high resolution imaging. Also, some low dispersion spectroscopic capabilities around Lyman-alpha (121.5 nm) and the C IV resonance transition at 155.0 nm are available. The UV-optical (UVO) channel is designed for wide field imaging from 200 to 600nm. The main features of the FCU are summarized in Table 4.

Table 4: Main features of the WSO-UV FCU

Parameters	FUV channel	UVO channel
Detector	MCP	CCD
Spectral Range (nm)	115-176	174-310 (ext. to 600)
Effective Area (m^2)	0.068	0.270
Field of View (arcsec)	121x121	597x451
Scale (arcsec/pixel)	0.08 (tentative)	0.146
Detector Size (nm)	30	49 x 37
Detector Format	2k x 2k	4k x 3k
Number of Filters	Up to 10 + 2prisms	Up to 15

The effective area of the FCU is shown in Figure 7 and the preliminary filter list in Table 5. FCU PDR will be at the end of 2018. There may be slight changes in the quoted performances.

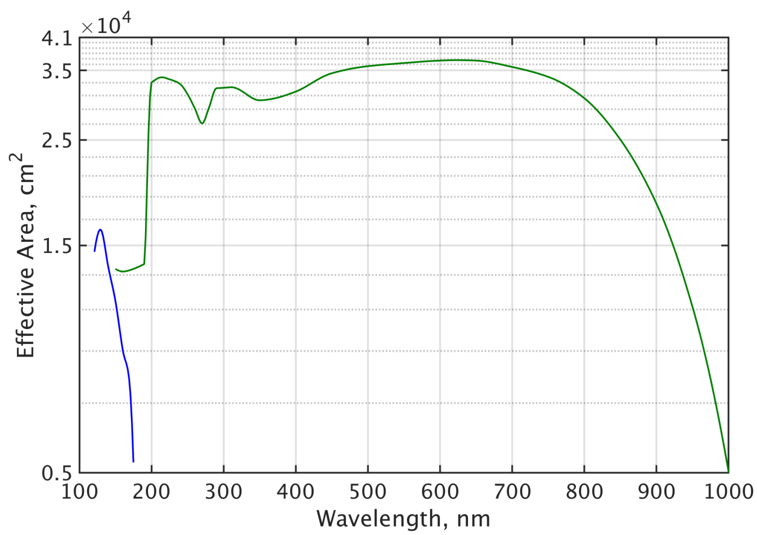

Figure 7: Effective area of the FCU

4.2.1 FCU Operational Modes

Imaging:
The beam is focused on the selected channel (FUV or UVO).

Imaging Time-tag:
Photon counting image mode on 10x10 pixels on the detector. Photons will be count at a pace of at most 40 ms/read-out over 5 minutes. It may require to include a previous acquisition image to set the target in a pre-defined area of fast read-out.

Spectroscopy:
The beam is directed to the prisms. It may require refocusing the camera.

Spectroscopy Time-Tag:
Photon counting slitless spectroscopy mode on 20x300 pixels on the detector. Photons will be count at a pace of at most 40 ms/read-out over 5 minutes. It may be require including a previous acquisition image to set the target in a pre-defined area of fast read-out.

Parallel-UVO:
FCU/UVO Channel is used in parallel mode while using any other instrument.

Table 5: Filters and dispersive elements in the WSO-UV/FCU (transmission curves available online)

FILTER NAME	DESCRIPTION
FILTERS FOR THE FCU/FUV CHANNEL	
F125LP	Step filter: Transmittance 0 for wavelengths below 1250Å and Transmittance 1 for wavelengths above 1250Å
F140LP	Step filter: Transmittance 0 for wavelengths below 1400Å and Transmittance 1 for wavelengths above 1400Å
F150LP	Step filter: Transmittance 0 for wavelengths below 1500Å and Transmittance 1 for wavelengths above 1500Å
F165LP	Step filter: Transmittance 0 for wavelengths below1650Å and Transmittance 1 for wavelengths above 1650Å
DISPERSIVE ELEMENTS FOR THE FCU/FUV CHANNEL	
P122	Prism with peak dispersion D=600 at 1215 Å, decreasing to D=200 at 1400 Å
P155	Prism with peak dispersion D=1400 at 1400 Å, decreasing to D=600 at 1550 Å
FILTERS FOR THE FCU/UVO CHANNEL	
G_{BP}	GAIA BP filter
F255W	As F255W in HST/WFPC2
F336W	As F336W in HST/WFPC2
F555W	As F555W in HST/WFPC2
F233N	A 50Å passband(FWHM) Gaussian filter centred at λ2 323Å with transmittance 1at this wavelength

F280N	A 50Å passband(FWHM) Gaussian filter centred at λ2800Å with transmittance 1at this wavelength
F308N	A 50Å passband(FWHM) Gaussian filter centred a λ3080Å with transmittance 1at this wavelength
F656N	A 50Å passband(FWHM) Gaussian filter centred a λ6563Å with transmittance 1at this wavelength
F673N	A 100Å passband(FWHM) Gaussian filter centred at λ6730Å with transmittance 1at this wavelength
F250SP	A red-leak filter with transmittance 0 for wavelengths above 2500Å and Transmittance 1 for wavelengths below 2500Å

5. Observing with WSO-UV

An observation is a combination of a target and specific observing parameters, and this section describes those aspects related to the spacecraft operation.

WSO-UV will observe in a **parallel-instrument sequences. The FCU/UVO channel will be operated simultaneously with the rest of instruments. During the long spectroscopic observations, the FCU will obtain deep images of nearby fields.**

The onboard memory size for temporal storage of scientific data is 4 MByte (flash memory).

5.1 WSO-UV Orbit

A Proton launcher will launch the WSO-UV, aiming for a final geosynchronous orbit (GSO). The ground track will have the shape of a more or less distorted figure-eight, returning to the same places once per sidereal day. This keep the satellite in view of its assigned ground stations and receivers, appearing to oscillate in the sky from the viewpoint of a ground station, tracing an analemma in the sky.

Table 6: WSO-UV Orbit main characteristics

Semimajor axis	42.164 Km (as in any GSO)
Eccentricity	0.003
Inclination	40 deg
R.A. Ascending node	140.38 deg
Argument of Perigee	0.0 deg
Period	23 hrs 56min 4 secs (one sidereal day)
Epoch	TBD

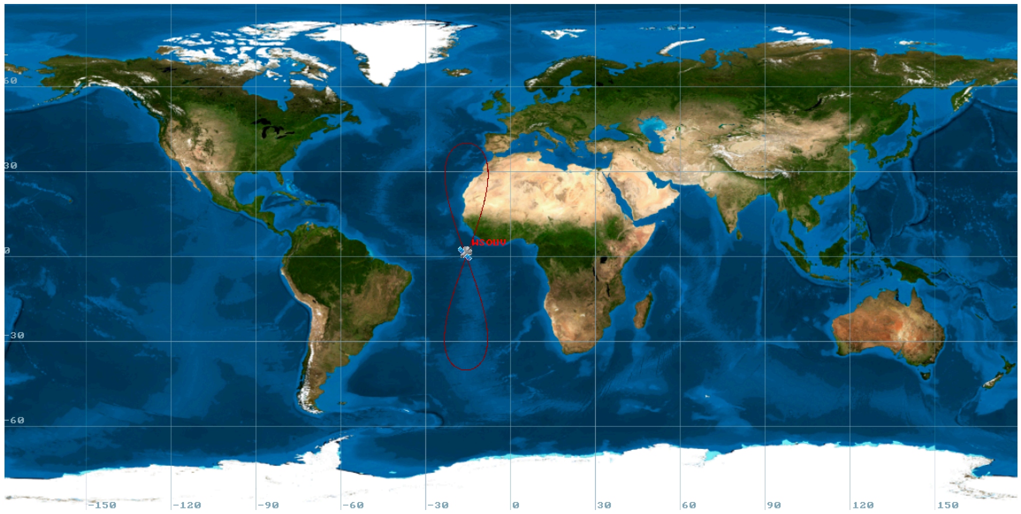

Figure 8: Ground track for WSO-UV orbit

5.2 Viewing Constraints

The visibility of the sources in the sky depends on several constraints:

- Solar avoidance because of WSO-UV design.
- Earth limb avoidance, to prevent the penetration of Earth scattered solar radiation into the telescope tube.

Table 7: WSO-UV Viewing Constraints

Solar Avoidance	40 deg
Earth Avoidance	15 deg
Data Transmission Rate	4 Mbits/s

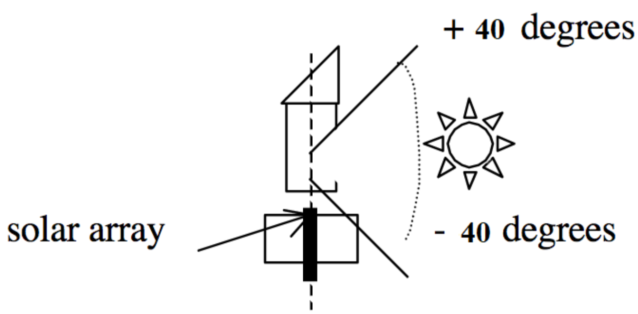

Figure 9: Solar Avoidance WSO-UV Constraint

5.3 Pointing Performance and Fine Guidance Sensors (FGS)

Pointing and tracking will be performed on guide stars using the dedicated FGS (see Figure 5). In normal operation, a combination of any two sensors is used, which makes it possible to measure the deviation of the axis from the direction of sight with the required accuracy.

- The distance of each detector to the optical axis is 60 mm.
- The operating wavelength range is from 400nm - 800nm.
- Each CCD detector size is 1024x1024 pixel with a pixel size of 16um with a quantization depth of 12bit.
- The FoV is 3x3 arcmin and the IFoV of one pixel is 0.19x0.19 arcsec.

The standard WSO-UV observing mode is a 3-axis stabilized pointing at the selected target. This enables observations for a period of up to several hours.

The spacecraft will be able to rotate around every axis, allowing to orientate the instruments arbitrarily on the sky and to align scans and maps with respect to celestial coordinates**.**

The pointing accuracy is 0.1 arcsec and the stabilization accuracy 0.1 arcsec at 3σ level.
The performance of the Guiding System (SGD) is shown in Table 6 and Figure 12.

Table 8: Accuracy in determining the orientation of the SDG

Stellar Magnitude	Errors in determining the absolute orientation
16	0,0567"
17 (Max. recorded)	0,0570"

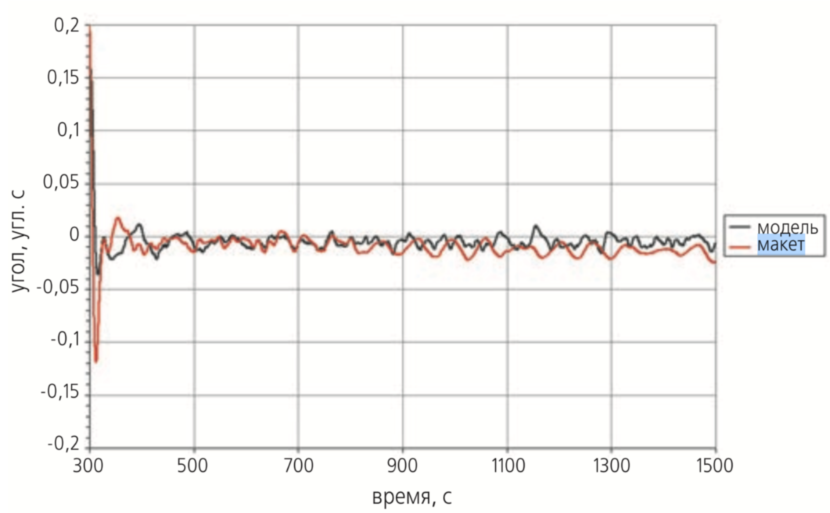

Figure 10: Angular deviation (arc sec) against time (sec)

Therefore, for each observing target must be at least one valid guide star in the FoV of the FGS with R magnitude smaller than 16 mag.

5.4 Sky visibility

The percentage of time a given point of the sky is free of any of the mentioned constraints during a whole year is shown in the figure. This is a first-order approximation of the sky visibility during the one year.

The maximum 100% percentage value means the sky bin is visible for the whole year. The minimum 0% value means is only visible for a few hours. This figure just serve for illustrative purposes, aiming to assess which areas of the sky will have better coverage.

For reference, the Galactic Center appears as a blue star, the Galactic North Pole and South Poles appear as yellow stars.

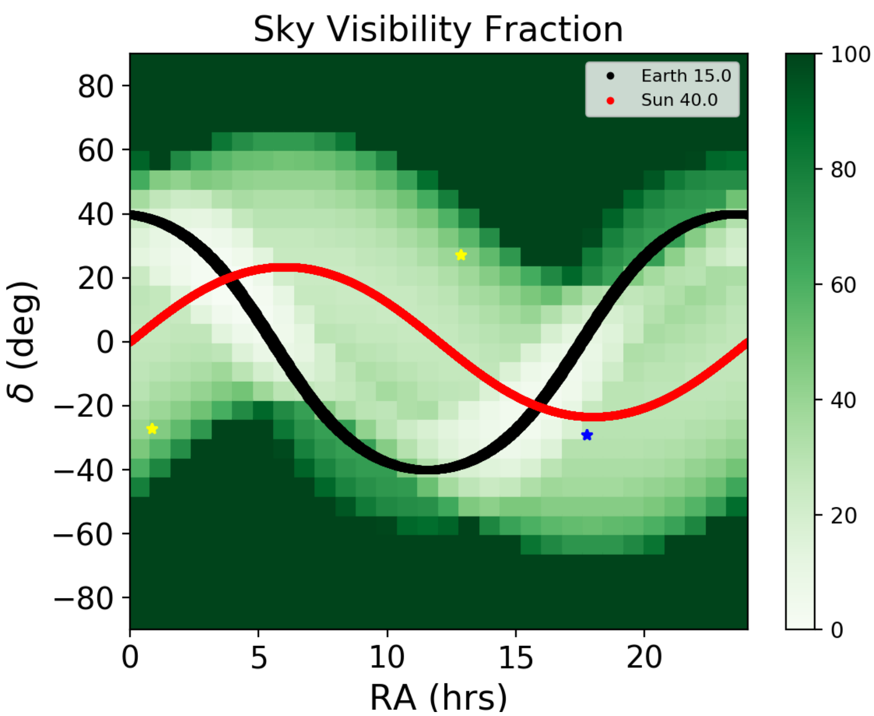

Figure 11: Sky visibility fraction (all time visible=100%) during a year for the orbit shown in Figure 8.

5.5 Operational overheads

An overhead is the time to prepare the satellite and the instrument for a new observation or measurement before the photons can be collected form the source.

The Operational Overheads relates to the slew time to move to target coordinates and the star tracker acquisition time to actual target position after slew.

These overheads **do not need to be taken into account for this call**.

5.6 Spacecraft Observing Modes

The following are the foreseen observing modes:

5.6. 1 Single Pointing
An observation at a single sky position with a single instrument.

5.6.2 Raster Map
A series of pointings where the observer specifies the number of points in a scan line (or scan map), and the size of every step defining the scan line (or map).
The scan line (or map) will be considered as a single observation, and will be scheduled as a whole or not.

5.6.3 Concatenated Observations
A sequence of observations from the same proposal which have to be performed contiguously in time. All target must lie in an area of 1 degree diameter.
For scheduling, concatenated observations are treated as a single unit.

5.6.4 Linked Observations
An observation that depends on the results of a previous observation is defined as 'linked'.

5.6.5 Fixed and Periodic Time Observations
Regular observations are carried out when they can be scheduled conveniently in order to maximize the whole scientific return of the mission. Therefore, the exact time of execution is not known in advance when the observation is proposed.

Fixed Time observations are those that must be executed at user provided exact times. When periodic observations are requested, the input parameters are the initial time and delta time.

These observations reduce the flexibility of the WSO-UV scheduling. Therefore, a strong justification is necessary at proposal time.

5.6.6 Targets of Opportunity and Anticipated Targets of Opportunity
The Director Discretionary Time Program is managed by the director of the WSO–UV observatory to allow a rapid response to unexpected important astronomical events. However, some observations may be requested, but only triggered and performed when certain known conditions are met. These Anticipated ToOs observations are evaluated like regular observations, but only scheduled when those conditions are met.