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WSO-UV project for high-resolution spectroscopy and imaging

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During the last three decades, astronomers have had practically continuous access to the 100–300 nm spectral range that is unreachable with ground-based instruments but where astrophysical processes can be efficiently studied with unprecedented capability since the resonance lines of the most abundant atoms and ions at temperatures between 3 000 and 300 000 K are in the UV. The successful International Ultraviolet Explorer (IUE) observatory, Russian ASTRON mission and successor instruments such as the COS and STIS spectrographs on-board the Hubble Space Telescope (HST) demonstrate the major impact that observations in the UV wavelength range have had on modern astronomy. The access to space-based observatories is very limited. For the next decade, for the post-HST era, the World Space Observatory UltraViolet (WSO-UV) will be the only large telescope class mission for UV observations, both spectroscopic and imaging. By its potential, the WSO-UV mission is similar to the HST, though it exceeds the HST/STIS in sensitivity by a factor 5–10, but all the observing time will be available for UV astronomy. In this paper, we briefly outline the WSO-UV mission model, instrumentation description, science management plan as well as some of the key science issues that WSO–UV will address during its lifetime.

1 Introduction

The World Space Observatory-Ultraviolet (WSO-UV) is an international space mission born as a response to the growing demand for UV facilities by the astronomical community. In the horizon of the next 10 years, the WSO-UV will be the only 2-meters class mission in the after-HST epoch that will guarantee access to the UV wavelength domain. The project is managed by an international consortium led by the Federal Space Agency (ROSCOSMOS, Russia). In this article, we describe the WSO-UV project with its general objectives and main features (Sect. 2); the details and status of instrumentation is described in Sect. 3; it includes WUVS (spectrographs) and the ISSIS instrument (Field Camera Unit); WSO-UV ground segment (Sect. 4); science management plan (Sect. 5), the WSO-UV key science issues (Sect. 6), and finally details of high-resolution spectroscopy (Sect. 7). A brief summary is provided in Sect. 8.

2 WSO-UV mission model

The WSO-UV consists of a 1.7 m aperture telescope (under responsibility of Russia) with instrumentation designed to carry out high resolution spectroscopy (spectral resolution about 55 000), long-slit low resolution spectroscopy (spectral resolution about 1000) and direct sky imaging. The WSO–UV Ground Segment (GS) is under development by Spain and Russia and both countries will coordinate the mission and scientific operations and will provide the satellite tracking stations for the project. The nominal lifetime is 5 years with a planned extension to 10 years. The project launch date set in late 2017. Aiming to maximize the scientific return along such a long lifetime, the ground segment architecture is to be based in a modular approach, relying in a common framework able to run together different subsystems developed from different agencies and institutes, which may be fully upgraded and even replaced along the years (Sachkov et al. 2007).

2.1 The T170M telescope

The T-170M telescope (see Fig. 1) is designed as a powerful concentrator of radiation for spectroscopy and direct images at 115–310 nm (Sachkov et al. 2009). The T-170M telescope is a Ritchey-Chrétien on reflection optics with a focal length of 17 m. The primary mirror diameter is 1.7 m. The telescope provides an accessible field of view of 30 arcmin on the telescope focal surface (see Shustov et al. 2009, 2011). At the moment of paper writing the telescope passed its vibration-vacuum tests (Fig. 2). The T-170M telescope has inherited the successful experience gained during the Soviet ASTRON project.

2.2 Space satellite bus

WSO-UV will use the Russian NAVIGATOR platform which was designed in Lavochkin Science & Technology Association (Russia) as a unified unit for several missions

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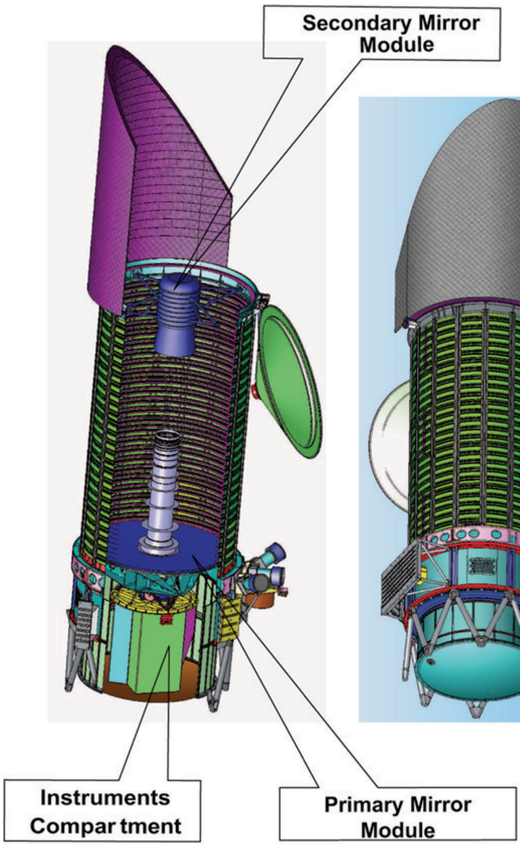

Fig. 1 The T-170M telescope scheme.

including the Spektrum series of the Russian space program: Radioastron (successfully launched 2011), Spektrum-Roentgen-Gamma (launch scheduled 2014) and WSO-UV. The platform is also used for commercial satellites, which successfully proofed the concept. WSO-UV will be launched from Baikonur (Kazakhstan) with a Proton rocket. The platform weighs 1300 kg and has a payload mass of 1600 kg. With assistance through the fine guidance system the pointing stabilization is about 0.03 arcseconds. The bus provides 300 W power for all instruments and a data download up to 4 Mbit s^{-1}.

2.3 Orbit

The factor of 2 difference in the collecting surface between HST and WSO–UV is compensated by the much more efficient geosynchronous orbit with inclination of $51\overset{\circ}{.}6$. Earth occultation will be small and the orbital period will allow to time-track targets and to have rapid access to targets of opportunity. A geosynchronous (not geostationary) orbit was chosen based mainly on the following criteria: (a) launcher capabilities, (b) time of stay in the Earth radiation belts, (c) continuous visibility zones, (d) minimum stay in the Earth shadow, (e) stability of the orbit, and (f) available technical equipment of the space and ground segments for radio communication.

Fig. 2 The T-170M telescope at the Lavochkin Science & Technology Association after vibration-vacuum tests.

3 Instruments

WSO-UV has been thought as a multipurpose, observatory-type mission henceforth carrying instrumentation for UV imaging and spectroscopy (Fig. 3).

3.1 WSO-UV spectrographs

The WSO–UV spectrographs (WUVS) consists of a set of three instruments (Fig. 4):

- the far UV high resolution spectrograph (VUVES) that will permit to carry out échelle spectroscopy with resolution about 50 000 in the 115–176 nm range;
- the near UV high resolution spectrograph (UVES) to carry out échelle spectroscopy with resolution of about 50 000 in the 174–310 nm range;
- the Long Slit Spectrograph (LSS) that will provide low resolution ($R = 1000$), long slit spectroscopy in the 115–305 nm range. The spatial resolution will be 0.5 arcsec.

All spectrographs will be equipped with a CCD cooled to minus 100 °C.

Since 2012 WUVS instrument is under the full responsibility of Russia.

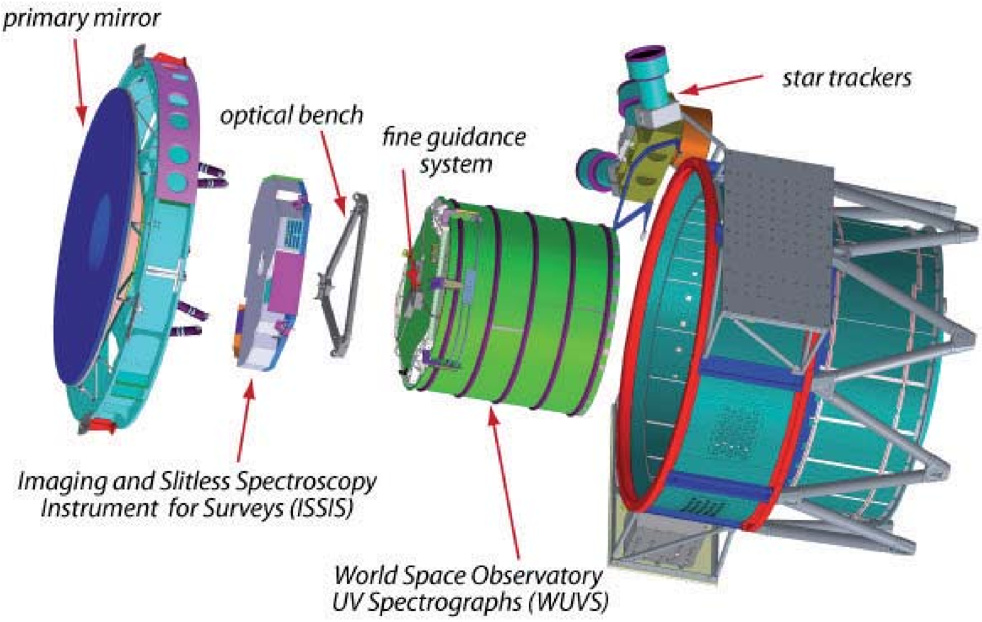

Fig. 3 WSO-UV Instrument Compartment.

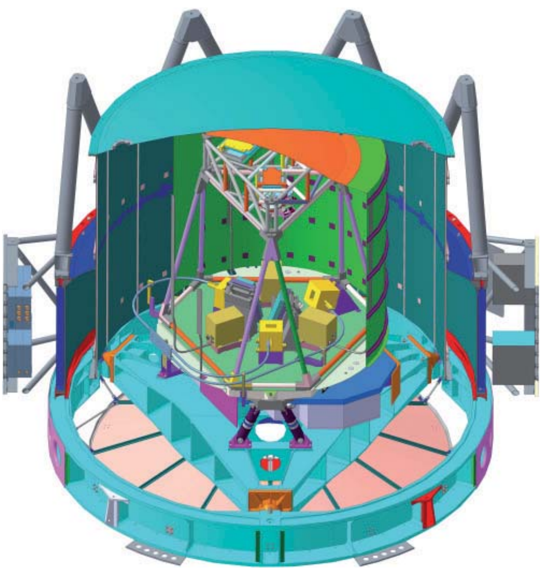

Fig. 4 WSO-UV Spectrographs (WUVS).

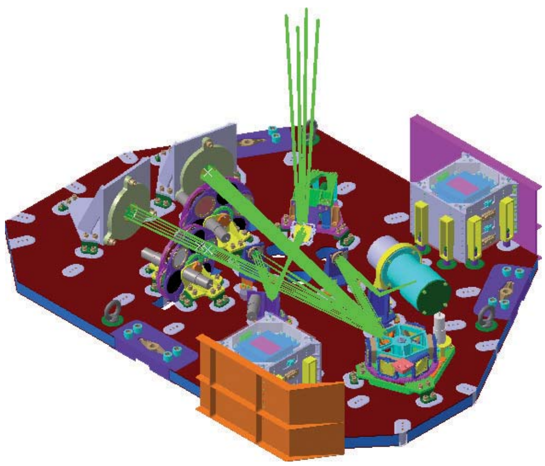

Fig. 5 WSO-UV Imagers (ISSIS).

3.2 WSO-UV imagers

The WSO-UV Imaging and Slitless Spectroscopy Instrument (ISSIS) is a multi-purpose instrument with a mode selector wheel that permits to carry out imaging and slitless spectroscopy in the 115–320 nm spectral range. The instrument is equipped with two MCP detectors, with CsI and CsTe photocathodes for FUV and NUV observations, respectively. The resolution in the slitless spectroscopy mode is about 500 and the spatial resolution is less than 0.1 arcsec. ISSIS will be the first UV imager located on such a high altitude orbit. This has the advantage of being above the geocoronal emission and thus diminishing significantly the UV background. The current design was approved in the Preliminary Design Review (PDR) in June 2012 (Fig. 5). The ISSIS Instrument is under responsibility of Spain (Gómez de Castro et al. 2011, 2013).

4 WSO-UV Ground Segment

The WSO-UV Ground Segment (GS) is comprised of all the infrastructure and facilities involved in the preparation and execution of the WSO-UV mission operations, which typically encompass real-time monitoring and control of the spacecraft, telescope and instruments as well as reception, processing and storage of the scientific data. There will be two complete GS systems: the Russian one will be located in Moscow (Lavochkin Science & Technology Association and Institute of Astronomy of the RAS), and the Spanish one will be sited at Madrid. The satellite operations will be shared between both Ground Control Centers, transferring the mission control from one center to the other on a regular basis.

The science operations system and a fraction of the mission operations system are part of the Spanish contribution to the WSO-UV. The Remote Proposal System, the Science Data Processing System, the Science Archive and the Scheduling systems are defined by the international science team composed by Spanish and Russian Science Support Teams based at the Universidad Complutense de Madrid (UCM) and Institute of Astronomy of the Russian Academy of Science (INASAN). The Science Team is part of the man power of the GS, and is responsible of laying the foundation of and supervising all the operations related to the mission primary users: the scientists. At mission level, the Science Team constitutes the core of the future WSO–UV international observatory. The satellite operations will be shared between both Ground Control Centers transferring the mission control from one center to the other on a regular basis. One of the main challenges on GS development is the management of shared information between both centers and the alignment of all the operational data (telemetry, telecommand and planning) according to the operational shifts (see Lozano et al. 2010; Gómez de Castro et al. 2013).

5 WSO-UV science management plan

WSO-UV will work as a space targeted observatory with a core program, an open program for scientific projects from the world-wide community and national (funding bodies) programs for the project partners (Malkov et al. 2011). A Core Program (CP) of scientific observations with the WSO-UV is defined to allow the conduction of high impact or legacy scientific projects that deserve large amounts of observing time. The projects are selected on the basis of their scientific excellence. The Open Program (OP) consists of astronomical observations obtained with the WSO-UV by astronomers who may or may not belong to the WSO-UV international consortium. Funding Bodies Program (FBP) is the guaranteed time granted to each one of the national bodies funding the WSO–UV project. Time Allocation Committee (TAC), appointed by the agencies funding the project, will select the scientific programs for the CP and the OP. OP TAC has to be renovated every two years. CP TAC will be the same as the OP TAC selected for the first two years of the WSO–UV mission. The National Time Allocation Committees will select the scientific programs for the FBP.

The time for astronomical observations will be distributed according to the following scheme:

- During the first and second years: 50 % of the total time will be granted to the CP, 48 % to the FBP, and 2 % to the Director Discretionary Time (DDT). The CP shall be completed within the first 2 years of the mission.
- For the following years: 58 % for the FBP, 40 % OT, 2 % DDT.

6 WSO-UV key science issues

The science drivers of the project (that are included into the Core Program) are:

- The determination of the diffuse baryonic content in the Universe and its chemical evolution – the main topics will be the investigation of baryonic content in warm and hot IGM, of damped Lyman-α systems, the role of starbursts, the formation of galaxies, and so on.
- The study of the formation and evolution of the Milky Way – the UV plays a particularly important role in the determination of energy inputs of the gas interacting with stars, and in the investigation of magnetic fields on star formation. The Milky Way history could be tracked through observations complementary to those obtained by the GAIA mission.
- The physics of accretion and outflows: the astronomical engines – this category includes stars, black holes, and all those objects dominated by accretion mechanisms. The efficiency and time scales of the phenomena will be studied, together with the role of the radiation pressure and the disk instabilities.
- The investigation of extrasolar planetary atmospheres and the astrochemistry in presence of strong UV radiation fields – chemical properties of the atmospheres of T Tauri stars to study the environment where protoplanets grow.

See the paper by Gómez de Castro et al. (2009) for more details.

7 High-resolution spectroscopy with WSO-UV

7.1 WUVS Optical Scheme

The first design of high-resolution spectrographs was developed by Kappelmann et al. (2006) and was based on the heritage of ORFEUS mission having flown aboard the Space Shuttle in 1993 and 1996. The spectra separated by a cross disperser were focused on a MCP detector. Design of the LSS provided high sensitivity for observations of faint objects. In order to maximize sensitivity the LSS was equipped with holographic gratings to reduce the number of reflecting surfaces in the optical path and to increase overall spatial resolution along the slit. In this instrument was used MCP detector as well. CeSiC material was selected for the spectrograph construction (Reutlinger et al. 2011).

The current design was approved in April 2013 during the Preliminary Design Review (PDR) . CCD detectors are being to use in all 3 channels. The new optical design was performed by optical team from Special Astrophysical Observatory of RAS. In this design basic schemes of the VUV and UV spectrographs are quite similar. The new design of UV channel is based on the cross disperser combined with UV camera mirror (identical to the VUV spectrograph). Segmented toroidal gratings are used in the LSS design. The

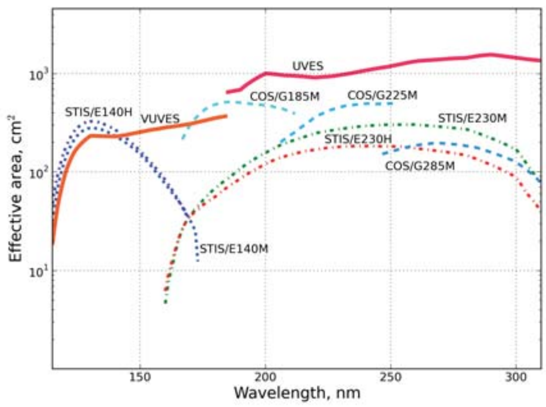

Fig. 6 Expected efficiency of WSO-UV high-resolution spectrographs UVES and VUVES in comparison with COS/HST and STIS/HST.

geometrical stability of spectrograph provided by titanium heap pipes, all heat sources inside spectrographs connected to outer wall by additional heat pipes. Detector's cooling system consists of large external radiator and isolated heat pipe, that is connected to detectors cold fingers.

7.2 WUVS efficiency

Possible prospects of WSO-UV capabilities for stellar spectroscopic studies are discussed in a paper by Sachkov (2010). Such characteristics will make it possible to perform detailed spectral observations and analysis of objects up to $V = 17^{\rm m}$ (Klochkova et al. 2009).

The spectral resolution provided by VUV and UV channels of WUVS is similar to that offered by STIS (HST) at medium resolution with its échelle gratings, but higher than the maximum resolution provided by HST COS ($R \sim 20\,000$). The effective area of WUVS is presented in the Fig. 6 in comparison with COS/HST and STIS/HST.

7.3 Prospects of the WSO-UV mission for high-resolution spectral observations

Using the technical characteristics of the instruments of the WSO-UV mission and data from previous UV spectroscopic studies one can estimates the limiting apparent magnitudes for stars that can be observed with the signal-to-noise ratio required in fine spectroscopic analysis. If we look at the sections of near- and far-UV spectrum of the star PG 1219+534 ($T_{\rm eff} = 33\,500$ K, $\log g = 5.87$, $V = 13.2^{\rm m}$; see O'Toole & Heber 2006), flux at the wavelength 2270 Å is about $3.5{\times}10^{-13}$ erg s^{-1} cm^{-2} Å^{-1} and about $1.2{\times}10^{-12}$ erg s^{-1} cm^{-2} Å^{-1} near 1540 Å. Observations with the UVES and VUVES at the same wavelengths will allows to reach S/N = 85 and 50, respectively, during 3100 s exposures. The high resolution spectra ($R = 50\,000$) of this star with S/N = 10 can be observed during about 2 min exposures.

8 Conclusions

The World Space Observatory-Ultraviolet is the solution to the problem of future access to UV spectroscopy. WSO-UV is ideally placed in time, and essential, to provide follow-up studies of the large number of UV sources observed by the GALEX sky survey. The WSO-UV is a Russian-led mission with an important Spanish participation both in instrumentation (ISSIS) and in the ground segment. The project has entered in Phase C with a foreseen launch in 2016. The AO call for the key programs will be released in 2014. The current information on the WSO-UV project can be found at the official web site: http://wso-uv.org.

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