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Status update of the WSO-UV project in 2012: The Spanish participation in WSO-UV

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Abstract

The World Space Observatory-Ultraviolet (WSO-UV) is a space telescope developed to guarantee access to the ultraviolet range (1150-3200 Å) in the post Hubble Space Telescope (HST) epoch. WSO-UV is a medium size scientific mission with a telescope of 170 cm primary diameter, equipped with instrumentation for astronomical imaging and spectroscopy. It will be in a geosynchronous orbit ideally suited for monitoring programs and the observation of weak UV sources. Its expected lifetime is 5+5 years with foreseen launch date at the beginning of 2016. The project has entered into phase C. WSO-UV is a Russian led program. Spain contributes to it with the imaging and slitless spectroscopy instrument (ISSIS) as well as a fraction of the ground segment development and operation. This article summarizes the current status of the project as presented in the Scientific Meeting of the Spanish Astronomical Society.

1 Introduction

The ultraviolet (UV) range is fundamental for astrophysical investigations, since the resonance transitions of the most abundant species in the Universe occur at these wavelengths / energies. The radiation cut-off at wavelengths shorter than 2800 Å by the Earth's atmosphere makes UV astronomy only accessible from space. Thus UV astronomy began with Space exploration. After the Copernicus mission, the International Ultraviolet Explorer (IUE) was launched in 1978, becoming the first UV space observatory operated in real time; the IUE

Figure 1: The WSO-UV Space Observatory.

allowed to carry out spectroscopic observations from 1150 Å to 3200 Å. Later on, the Far Ultraviolet Spectroscopic Explorer (FUSE) mission (1999-2007) opened the 900 Å−1000 Å spectral range for spectroscopic studies. The Galaxy Evolution EXplorer (GALEX, 2003-2011) has mapped, for the first time, the UV sky. As today, the Hubble Space Telescope (HST) is the only operational mission in the UV range. HST is expected to last for a few more years. All these missions have amply demonstrated the feasibility and the relevance of UV studies [1, 2].

The World Space Observatory-Ultraviolet (WSO-UV) is an international space mission born as a response to the growing up demand for UV facilities by the astronomical community. In the horizon of the next decade, the WSO-UV will be the only two-meters class mission in the post-HST epoch which will guarantee access to UV wavelenghts. 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 the Spanish contribution is described in Sect. 3; it includes the final design of the ISSIS instrument as well as an update on WSO-UV ground segment and the procurements being made for the next call for the WSO-UV key programs. Finally, a brief summary is provided in Sect. 4.

2 The WSO-UV mission

The WSO-UV is a multipurpose observatory on a geosynchronous orbit, which will provide data of large importance to investigate several open problems in astrophysics. The science drivers of the project 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 starburts, 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 cathegory includes stars, black holes, and all those objects dominated by accretion flow 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 the the extrasolar planetary atmospheres and astrochemistry in presence of strong UV radiation fields – chemical properties of the atmospheres of T Tauri stars to study the environment where protoplanets grow.

The WSO-UV telescope has an F/10 Ritchey-Chretien mounting with a primary diameter of 170 cm. WSO-UV has been thought as a multipurpose, observatory-type mission henceforth carrying instrumentation for UV imaging and spectroscopy [5, 6].

The WSO-UV imaging and slitless spectroscopy instrument (ISSIS) is a multipurpose instrument with a mode selector wheel that permits to carry out imaging and slitless spectroscopy in the 1150-3200 Å spectral range. The instrument is equipped with two MCP detectors, with CsI and CsTe photocathods for FUV and NUV observations, respectively. The resolution in the slitless spectroscopy mode is $R = 500$ and the spatial resolution is < 0.1 arcsec.

The WSO-UV spectrographs (WUVES) consists of a set of three instruments:

- The far UV high resolution spectrograph (VUVES) that will permit to carry out echelle spectroscopy with resolution $R \sim 55,000$ in the 1020-1800 Å range. It will be equipped with a photon-counting, Micro Channel Plate (MCP) detector

- The near UV high resolution spectrograph (UVES) to carry out echelle spectroscopy with resolution $R \sim 55,000$ in the 1740-3100 Å range. It will be equipped with a CCD detector to observe in the near UV.

- The Long Slit Spectrograph (LSS) that will provide low resolution ($R \sim 1500$), long slit spectroscopy. The spatial resolution will be 0.5 arcsec also, the width of the slit is 0.5 arcsec. The detector is a CCD cooled to -120^o C to be sensitive to the Far UV.

Prior to final tests, after the end of the construction phase, WSO-UV instrumentation is expected to provide sensitivities similar to those of the HST instrumentation. The factor of 2 difference in the collecting surface between HST and WSO-UV is compensated by the, much more effcient, high Earth orbit of the WSO-UV, a geosynchronous orbit with inclination 51^o. This will also allow to carry out efficient monitoring programs.

WSO-UV expected launch date is 2016 and will be operational for five years with a possible extension to five years more. The space telescope is planned to be operated from two sites at Madrid (UCM) and Moscow (INASAN) that will also host also the Science and Mission Archives. The ground segment is being designed under a shared operations scheme.

The WSO-UV will run three major science programs:

- *The core program* includes the key scientific programs that will carry over the scientific objectives of the mission. The core program will be run for the first two years of the mission and international teams involving members of the consortium are expected to apply for observing time. The call for the core program is intended to be in 2013.
- *National programs:* each country or founding body contributing to the project is entitled to receive a fraction of the observing time proportional to its contribution. After the third year of the project, 60% of the observing time will be awarded to these programs. National calls are expected to be issued for the national programs though they will be synchronized with the general project calls. Guaranteed time for the instruments teams should be included in the national contributions.
- *Open Program* to the world wide scientific community. This program will handle a 40% of the observing time after the 3rd year of the mission.

Targets of opportunity observations will be managed within these programs.

3 The Spanish contribution to the WSO-UV

3.1 The Imaging and Slitless Spectroscopy Instrument for Surveys - ISSIS

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 dimishing significantly the UV background. The Fine Guiding System of the WSO-UV telescope will guarantee a very high pointing stability (better than 0.1 arcsec at 3σ). ISSIS will directly receive the central part of the beam, after reflection from the secondary mirror. The instrument is planned to provide high spatial resolution and UV sensitivity for imaging with an optimal wavelength coverage. Slitless spectroscopy has been implemented as the most efficient tool for classification and analysis of the observed objects [7, 8].

ISSIS is located below the primary mirror and above the optical bench. This fact imposes additional constraints to its design being the most conspicuous the weight (a maximum of 61.5 kg on the optical bench is allowed) and size (the full instrument has to be fit within a flat cylinder of height 17.3 cm). This forces ISSIS to have small, MCP type detectors and to fold the on-axis radiation beam from the telescope adding 1 reflection. Thus, the final design is a compromise between the scientific requirements and the telescope/platform constraints.

Scientific requirements [7] can be summarized as:

- High resolution mapping of weak and nebulous sources such as microjets or gravitational lenses;

- The mapping of UV emission lines in extended emission nebulae (H II regions, supernovae remnants, planetary nebulae) and jets (from protostars or compact objects);
- Efficient spectroscopy of weak sources, such as transiting planets, Active Galactic Nuclei and star forming galaxies at low redshift ($0.5 < z < 1.5$);
- Resolution of at least $R \sim 500$ to study the absorption of stellar radiation by transiting planets, or to derive the terminal velocity of winds from O stars in the Local Group;
- Enhancement of the dynamic range with coronographs or masks in order to map the faint emission close to bright sources: e.g. disks, jets, binary components;
- Short time resolution to track the evolution of instbilities in disks surrounding compact sources.

3.1.1 ISSIS optical design

The current design was approved in the Preliminary Design Review (PDR) in June 2012 (see for more details [9]), and includes two acquisition channels for imaging and slitless spectroscopy:

- The Far Ultraviolet (FUV) channel, working in the range 1150-1750 Å;
- The Near Ultraviolet (NUV) channel, covering wavelegnths in the 1750-3200 Å interval.

Slitless spectroscopy is a fast mean to analyze multi-objects fields, and at the same time it acts as a narrow-band imaging technique. This is a very good alternative to the use of narrow band filters in the UV, whose transmittance is typically $\sim$3 % .

Both channels are equipped with MCP detectors, with a CsI photocathod for the FUV channel and a CsTe detector for the NUV channel. Space and weight limitations forced to discard the use of a Charge Coupled Devicd (CCD) detector in the NUV channel. The use of MCPs imposes strong constraints to the instrument capabilities, in particular on the field of view, barely 60 arcsec, and on the dynamical range. There are ongoing studies to increase the dynamical range by using masks. Also a set of neutral filters has been included to satisfy the sensitivity requirements and also to be able to observe some brighter sources and nebulae.

Figure 2 shows the ISSIS optical bench assembly. The layout is arranged as a telephoto system (positive elements are followed by negative elements), to enlarge the overall focal length. A refocusing mechanism (RM), located at the coupling stage between the telescope and ISSIS, changes the distance between the intermediate image from the telescope and the first mirror of ISSIS. The different operation modes for the two channels (imaging, spectroscopy, or calibration) are selected trhough the mode selection mechanism (MSM, see Fig.3):

- Imaging: the MSM uses flat mirrors aligned to direct the light into the selected channel (FUV or NUV). The optical filters are accomodated on two wheels for each channel;

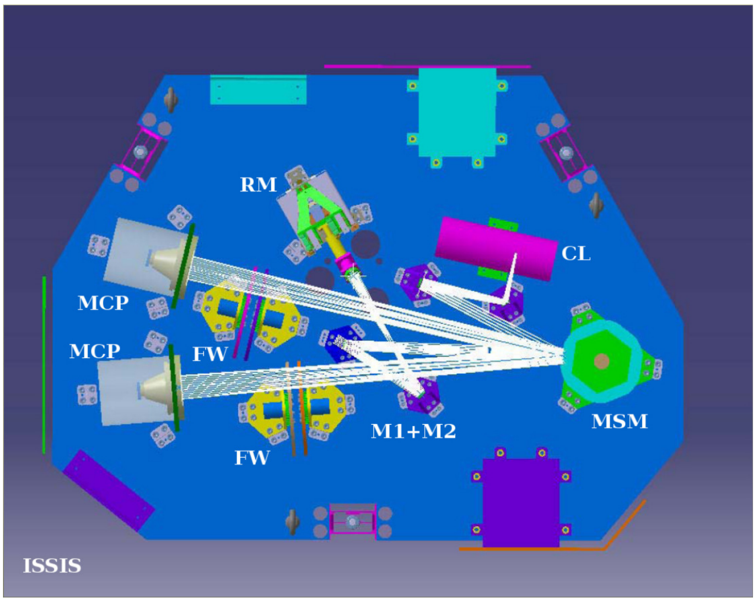

Figure 2: The optical bench assembly (without cover) for ISSIS.

there are long-pass filters and narrow band filters for specific investigations, as well as two neutral filters for each channel, to increase the dynamical range.

- Spectroscopy: the beam is directed to the dispersive elements, which are reflection gratings located at the MSM; in the nominal spectroscopy mode, the filter wheels are positioned into a hole configuration (no filter). The FUV diffraction grating has peak efficiency at 1400 Å and groove density of 450 lines/mm, while the NUV one has the peak at 2300 Å and 250 lines/mm.

- Calibration: a shutter is used to block the light from the telescope, and the beam is directed to the calibration subsystem in order to take flat field images on a pixel-to-pixel basis. The calibration unit inludes the lamp, optics and shutter.

3.1.2 ISSIS performance

Figure 4 shows the estimated throughput for the whole system in the whole wavelength range. The throughput estimates includes the T-170M telescope and ISSIS mirrors. Also the difraction grating reflectivity and the MCP detectors efficiency curves are included. The total throughput for the imaging mode is estimated to be about 1% at 1300 Å (FUV) and 7% at 2500 Å (NUV), while for slitless spectroscopy the peaks are 0.03% at 1300 Å and 3.2 % at 2500 Å (FUV and NUV, respectively). The expected radiometric sensitivity of ISSIS can be best evaluated using the Exposure Time Calculator available in the project web page (http://www.wso-uv.es) where also the transmittance functions for the filters are included.

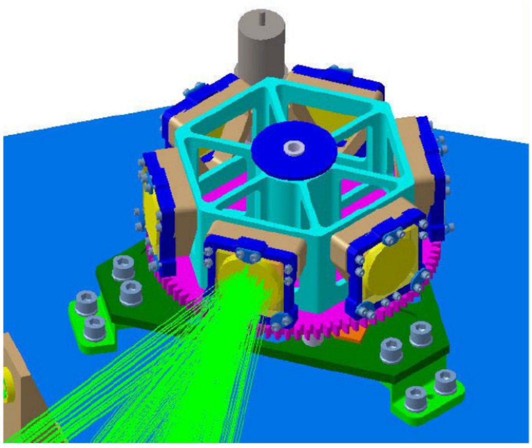

Figure 3: The mode selection mechanism (MSM) employed in ISSIS.

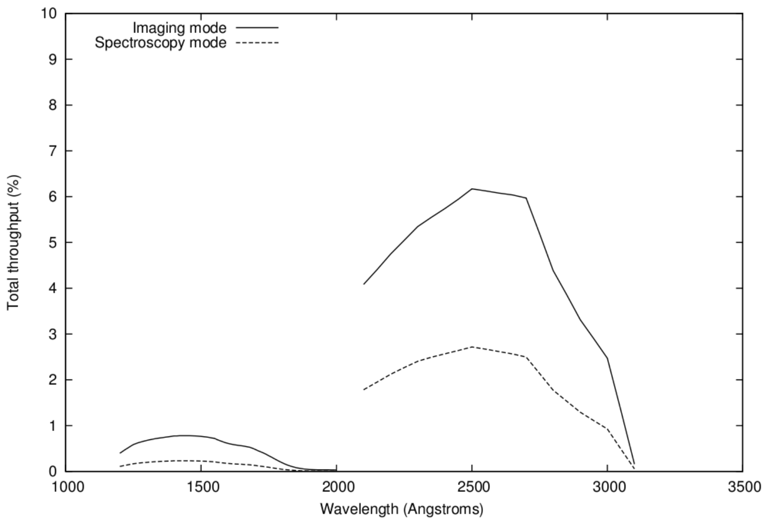

Figure 4: Throughput curves for the whole system in the two ISSIS channels. The estimate includes the two telescope mirrors, the ISSIS mirrors, the detector, and the grating (the latter one only in spectroscpy mode); filters are not considered.

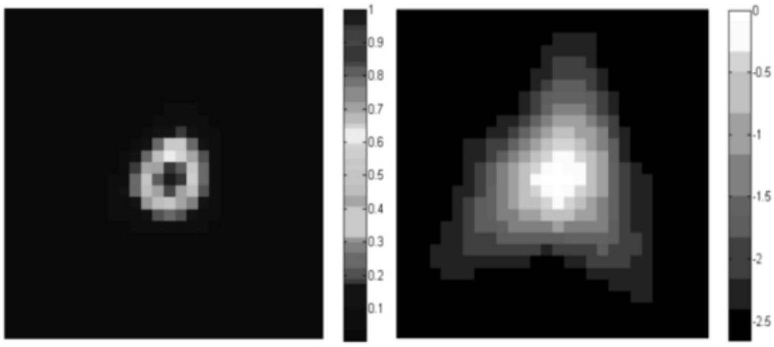

Figure 5: Simulation of the expected PSF for a point source (left) and in logarithmic scale (right).

ISSIS has been designed to map extended sources. For this purpose the point spread function (PSF) needs to be properly sampled. The Fine Guiding Sensors (FGSs) in the WSO-UV have been designed to provide a spatial resolution of 0.1 arcsec at 3σ. Thus ISSIS optical system modifies the T170M focal length to have this PSF sampled by 2-3 pixels. According to optical simulations, an asymmetrical Point Spread Function (PSF) is expected: this effect cannot be avoided at UV wavelengths, since the optical quality is dominated by geometrical, non-symmetric aberrations. The asymmetry in the PSF is close to 17 % and to 8 % in the FUV and NUV channels, respectively. Fig. 5 displays an example of PSF simulation for the FUV channel.

Major contributions to the PSF are the rugosity of the optical coatings and the swinging of the secondary. The use of photoncounting MCP detectors and the angular sampling (0.035 arcsec x 0.038 arcsec) will permit to follow and correct for some of the PSF distortions. Yet, the major broadening effect is associated with the quality of the mirrors coating.

The field of view is limited by the photocathods sensitive area in the MCP detectors and the required spatial resolution to $\sim$1.2 arcmin. This field of view will permit direct imaging as well as obtaining images of extended nebular objects in the most prominent spectral lines in the slitless spectrospy mode. The geometric distortion is expected to be $< 2\%$ in the field view on the detector plane. The main characteristics of ISSIS are summarized in Table 1.

3.2 The WSO-UV ground segment

The WSO-UV 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 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.

Table 1: The main characteristics and performances of the ISSIS instrument.

	FUV channel	NUV channel
Spectral range	1150-1750 Å	1850-3200 Å
FoV imaging	70 arcsec x 75 arcsec	70 arcsec x 75 arcsec
FoV spectroscopy	36 arcsec x 65 arcsec	31 arcsec x 61 arcsec
Pixel scale	0.036 arcsec	0.036 arcsec
Scale ratio	$< 7\%$	$< 7\%$
Number of reflections	4	4
Temporal resolution	40 ms	40 ms
Detector type	CsI MCP	CsTe MCP
Detector diameter	40 mm	40 mm
Peak throughput	~1300 Å	~2500 Å
Slitless spectrosocpy resolution	$R = 500$	$R = 500$
Spatial resolution	0.11 arcsec	0.11 arcsec
Detector format (equivalent)	>2048 x 2048 pixels	>2048 x 2048 pixels

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 (RPS), the Science Data Processing System (SDPS), the Science Archive (SA) 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 Russian Science 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 ST constitutes the core of the future WSO-UV international observatory.

The Ground Segment includes the Mission Operation Center (MOC), and the Science Operation Center (SOC). The MOC is in charge of the Mission Control System (MCS), the Flight Dynamic System (FDS), and the Remote Control System (RCS); the SOC controls and develops the Science Control System (SCS), the Science Data Processing Center (SDPC), the Science Archive (SA) and the Analysis System (AS).

The GS Team is responsible for the implementation of the operational concept of the mission and of conducting the WSO-UV operations. It is lead by the GS Manager, and split into MOC and SOC Teams. Each team is divided into areas corresponding to the sub-activities of the MOC and SOC. Therefore, the MOC team includes the MCS (spacecraft controllers, timeline planner, telescope and platform engineers), the FDS (FD operator, FD engineer, FD administrator), and RCS (communication controller); the SOC team is composed by SCS, AS, SDPC and SA areas. As the operational approach for the mission should be simple and transparent for the end users, the operational duties of the Science Team will be mainly, the development and supervision of tools for the scientific use of the telescope and its products. The Science Team is the human interface between the end-users and the TAC. The science users can have a data retrieval role (from the archive, using web-based tools),

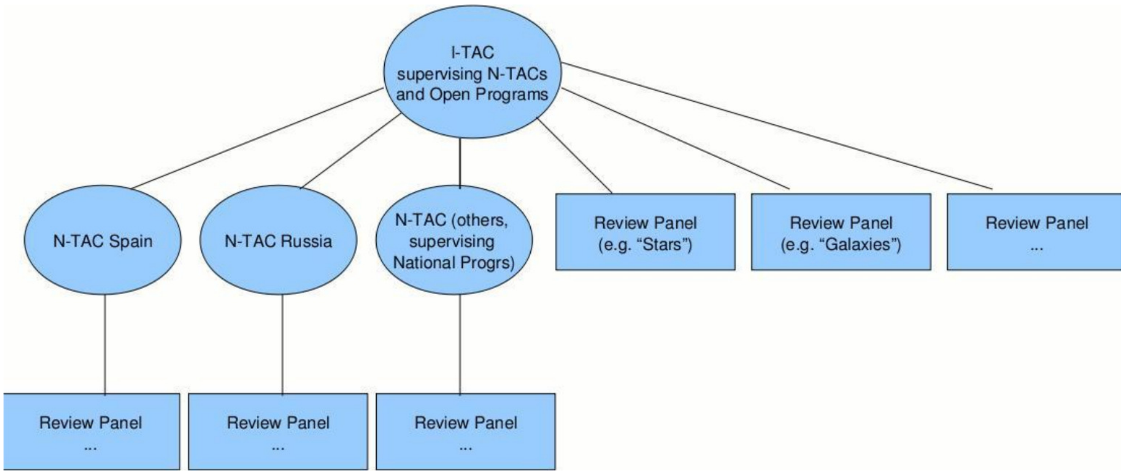

Figure 6: Sketch describing the WSO-UV Time Allocation Committees and their foreseen interaction.

or a science collaborator role (providing documents and algorithms to be used in the data processing). The TAC will be in charge of the scientific assessment and ranking of observing proposals for the WSO-UV and will regulate the access to the scientific results.

Three main system will control the interface between the WSO-UV operational team and the scientific community:

- The Science proposals and documentation handling system. The scientific proposals will have a life cycle, that is the period lasting from the application for observing time, after the announcement of opportunity by the WSO-UV observatory, to the final release of the data to the proposal PI. This life cycle is similar to those implemented in other space telescopes: Phase I application: to insert into the system the information needed to evaluate the scientific quality and the technical viability of the proposal. Phase II application: to provide technical details (acquisition mode, observing instrument and mode, exposure times and observing sequence for each target and observation) on the performance of the observational program once the proposal is accepted by the TAC and approved by the Board of Directors.

  After Phase II, the observations are scheduled and will be carried out under the supervision of the WSO-UV observatory science operations team. Finally, data are processed by the pipeline and archived into the WSO-UV Archive.

  The peer review of the proposals is carried out by 6-10 Review Panels that report to the TAC. Review Panels are mission dependent. The following panels are expected to work for the WSO-UV project: National Review Panels for Russia and Spain and the International Review Panel. There will be as many sub-panels as proposal categories. At least five sub-panels/categories are foreseen to be issued : Solar System, Stars, The Galaxy, Extragalactic Astrophysics and Cosmology. Members of the WSO-UV science and instrument teams are expected to assist the technical evaluation of the panels.

The International Time Allocation Committee (I-TAC) is constituted by the chairs of the Review panels that will report to the I-TAC on the decisions of their panels. The I-TAC will be chaired by the WSO-UV PI in Russia. All the PIs of the National teams are also natural members of the I-TAC. The role of the I-TAC is to generate the final list of approved research projects and to select those of the highest scientific quality for this purpose. The I-TAC acts also as a conflict solver in case of duplications between programs according to the project regulations . The hierarchical structure of the TACs and Review Panels is outlined in Fig. 6.

- Scheduling and science planning.

  The complexity of the WSO-UV science planning resides in the fact that it includes several programs, containing proposals with different scientific priority, that have to be scheduled in a single WSO-UV Long Term Planning (LTP), satisfying the WSO-UV time sharing policy. The generation of the LTP is expected to be done by an unsupervised scheduling computer program that takes into account all the constraints (science drivers, mission drivers and technical constraints associated with the telescope and instruments).

  To evaluate the impact on having an unsupervised scheduling computer program working on a single queue on the completion of the National Programs on cycles associated with the Call for proposals, the Science Team at the UCM, has developed a simple prototype of the scheduling computer program, the UCM Scheduler Prototype (USP) [10].

- Science data processing and archiving.

  The pipeline will be created by the GS and Science and Instrument teams. Four generic types of data products are foreseen to be produced by the pipeline: uncalibrated science data, uncalibrated support data, intermediate data and calibrated data. The mission and science information will be stored into the Scientific Archive (SA). The science contents are all the relevant scientific information obtained by the WSO-UV. The archive must warrant the traceability of the scientific data and it is the main guaranty of the scientific results of the mission.

4 Summary

The World Space Observatory-Ultraviolet (WSO-UV) is the forthcoming space mission which will guarantee the access to the UV range for the investigation of several fundamental astrophysical topics, in the post-HST epoch. 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 2013.

Acknowledgments

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