The WSO-UV space telescope science operations

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Abstract: The World Space Observatory-Ultraviolet (WSO-UV) is a space telescope built to guarantee access to the ultraviolet range (1150Å-3500Å) in the post Hubble Space Telescope (HST) epoch. WSO-UV is an international endeavor led by the Russian Federal Agency, ROSCOSMOS. WSO-UV is a medium size scientific mission with a telescope of 170 cm primary diameter. The telescope is equipped with instrumentation for astronomical imaging and spectroscopy. WSO-UV 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 September 2015. The WSO-UV Ground Segment 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. The Ground Segment is being developed by Spain in collaboration with Russia within a consortium that involves Academia (the Universidad Complutense de Madrid (UCM) and the Institute of Astronomy of the Russian Academy of Sciences (INASAN)) and industry (GMV and Lavochkin Association) in both countries. Industry is developing, for some components jointly with Academia, the ground segment components that are defined and will be used by the Academic partners. The Academia will have a major involvement in the mission infrastructure development and operations. The Academia partners will also handle the interaction with the international scientific community and the creation of the Scientific Archive. In this contribution, the characteristics of this Russian-Spanish collaboration to jointly operate the WSO-UV space telescope from the academic environment will be described, including the cooperation between Academia and Industry.

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I. Introduction

The World Space Observatory – Ultraviolet (WSO-UV) is an international space observatory for observation in UV spectral range (1050Å-3200Å). Several fundamental astrophysical processes occur at UV wavelengths, which unfortunately are beyond the reach of ground-based instruments. The main driver of the WSO-UV is the needs of scientists to have an UV facility in the horizon of the next decade; indeed, it will be the only two meters class mission for UV observations in the post- Hubble Space Telescope (HST) era. The WSO-UV project is managed by an international consortium led by the Federal Space Agency (Roscosmos, Russia). It consists of a 1.7 m aperture telescope with instrumentation designed to carry out high resolution spectroscopy (spectral resolution ~55,000), long-slit low resolution spectroscopy (spectral resolution ~1500) and direct imaging and slitless spectroscopy (R~500) . 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 is set to late 2015.

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. In principle, 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.

The science operations system and a fraction of the mission operations system are part of the Spanish contribution to the WSO-UV. They are being developed by the Spanish company GMV, under contract from Spanish Ministry of Industry, Energy and Tourism (MINETUR). 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 Support Team, hereafter 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. This contribution summarizes the high level definition documents, approved at mission level, for the development of the main science systems for WSO-UV GS. Sect. II describes the WSO-UV mission with its goals; in Sect. III the structure of the Ground Segment is shown, while Sect. IV depicts the Ground Segment and Science teams. Sects. V, VI and VII describe the main tasks of the Science Team. A brief summary is provided in Section VIII.

II. Mission description and goals

The resonance transitions of the most abundant species in the Universe are in the UV range that it is blocked by the Earth's atmosphere. The high scientific success of previous UV missions such as the International Ultraviolet Explorer (IUE), the HST or the Far UV Spectroscopic Explorer (FUSE) amply demonstrate the relevance of the UV range to modern astronomy[1]. The WSO-UV is an international space telescope that will be launched in late 2015, to guarantee observatory-type access in the UV range to astronomers after the end of the HST mission[2,3]. With a 2015 launch date, the WSO-UV comes timely for follow-up studies after the end of the ultraviolet all sky survey being run by the NASA UV mapper, GALEX.

Figure 1: The WSO-UV Space telescope

The WSO-UV is a multipurpose observatory in a geosynchronous orbit, which will provide observations of exceptional importance for investigating several astrophysical problems (see Figure 1). The WSO-UV is equipped with a 170 cm aperture telescope and with instrumentation capable of high-resolution spectroscopy, long slit low-resolution spectroscopy, and deep UV imaging and slitless spectroscopy:

- HIgh Resolution Double Echelle Spectrograph[4] (HIRDES), to carry out high resolution spectroscopy (R~55,000) of point sources in the range 1030Å–3100Å by means of two echelle set-ups.
- Long Slit Spectrograph4 (LSS) for long-slit low resolution spectroscopy (R~1500) in the 1020Å-3200Å
- Imaging Slitless Spectrograph Instrument for Surveys[5,6] (ISSIS) for imaging and slitless spectroscopy through two channels (R~500) : the FUV channel, operating in the 1150Å-1750Å range, and the NUV channel, operating in the 1850Å-3200Å range.

As far as the scientific goals are concerned, the WSO-UV will provide observations of exceptional importance for the study of several astrophysical problems. The mission has four key objectives:

- Determination of the diffuse baryonic content in the Universe and its chemical evolution
- The formation and evolution of the Milky Way
- The physics of accretion and outflows: the astronomical engines
- Extrasolar planetary atmospheres and astrochemistry in presence of strong UV radiation fields

III. Ground Segment description

The Ground Segment[6] 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 structure is shown in Figure 2.

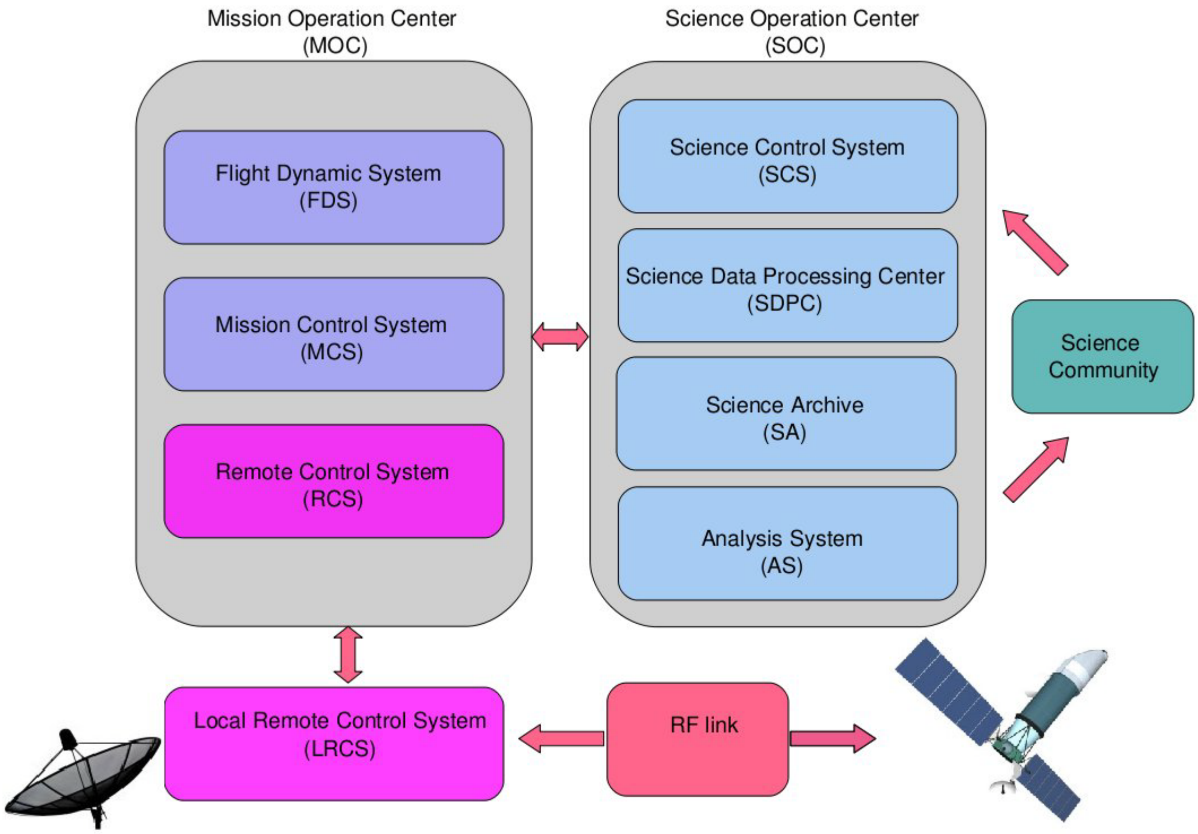

Figure 2: Layout of the WSO-UV Ground Segment

The Mission Control System (MCS) is in charge of providing operations such as monitoring, commanding, mission planning, on-board management and maintenance, and so on. The Flight Dynamic System (FDS) is linked to the spacecraft orbit and attitude maintenance; some of the tasks performed by the Flight Dynamics (FD) are, for example, the orbit and attitude maintenance or manoeuvre monitoring

The purpose of the Remote Control System (RCS) is to allow operation of all the WSO-UV ground stations from a single operator position located in the MOC, even if local operation is still possible. The main aim of the RCS is to continuously monitor the status of the GS equipment, record all important events during operations and support the station engineers in analysing problems.

The Science Control System (SCS) has both monitoring and science capabilities. Indeed it will acquire both housekeeping telemetry on the platform and the instruments, and also all science data generated on-board; on the other hand, the SCS will allow the pre-processing of science telemetry.

The Science Data Processing Center (SDPC) will provide the end users of the mission with all the data and products required. It may be centralized in one single physical location or distributed along several locations; in particular, it will run the Pipeline processing system (see Sect. VII).

The Science Archive (SA) is responsible of providing secure and persistent storage for data belonging to the WSO-UV mission, and of allowing authorized users to access to these data in a fast and reliable way. Most importantly, it guarantees the usability of the mission products in the future, for research, education, and engineering analyses. The SA is not just a repository of processed images. It must provide, apart from secure storage for image and calibration files and auxiliary data, a reliable retrieval service, data transfer and cross-correlation tools, documentation and user support services.

The Analysis System (AS) is the set of facilities and tasks required for offline WSO-UV data processing; in particular, it is intended for the annual and/or preliminary SCS products processing.

IV. Ground Segment Team and Science Team

The man power for GS is represented by the Ground Segment Team and the Science Team.

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.

The need for a Science Team supporting the GS comes from the fact that the primary users of WSO-UV are scientists; therefore, the operational approach for the mission should be simple and transparent for the end users. The operational duties of the Science Team concern mainly the development and supervision of tools for the scientific use of the telescope and its products. The WSO-UV Science Team will issue three main tasks, that is: (i) the management of proposals for observations with the telescope instruments, and the associated documentation handling; (ii) the scheduling of the scientific proposals approved by the Time Allocation Committee (TAC); (iii) the processing of the scientific data and archiving. All these aspects are described in detail in the following sections. 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), 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.

V. Science proposals and documentation handling

Proposals are applications made by scientists to get an amount of a telescope observing time, in order to carry out a well defined scientific project. The applications are examined by a scientific committee that evaluates their scientific impact. The main mission programs, defined in the Time Sharing Policy Agreement signed by the parties funding the project[7] are:

- Core Program (CP) – The WSO-UV will provide observations of exceptional importance for the study of several astrophysical problems. Around these science drivers, the WSO-UV science community will build a set of well defined, large proposals that will also constitute the main legacy of WSO-UV to science. The CP is an international program led by Principal Investigators (PIs) who carry out their research in the countries funding the project. Strong collaboration among the WSO-UV partners is expected. There will be special calls for applications for this program during the first three years of the project.
- National Programs (NP) – Or Funding Bodies Program (FBP); they are the result of the observing time granted to the national agencies co-funding the development of the WSO-UV: the Russian Federation, Spain, and other participants. A Guaranteed Time program for the teams developing the instruments will be included within the National Programs.
- Open Program to the International Community (OP) – This program is open to researchers worldwide and will be open every year since the mission second year.

In addition there will be a Director Discretionary Time Program (DDTP) representing a small fraction of the observatory time and it is left to be used by the WSO-UV observatory to allow a rapid response to unexpected important astronomical events or for other scientific purposes. The use of this program is directly handled by the Board of Directors, led by PI of the WSO-UV, Dr. Boris Shustov. There will not be open calls for this program but scientist applying to the Board of Directors to make use of it. Also for specific observations and measurements to calibrate and ensure the optimal performance of the WSO-UV, there will be a Calibration program run by the WSO-UV team and the instrument teams.
The scientific proposals will have a life cycle[8], 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. The proposal life cycle may extend over several years for long term proposals. A proposal is concluded at the time when all the approved observations are completed. The basic cycle can be summarized in Figure 3.

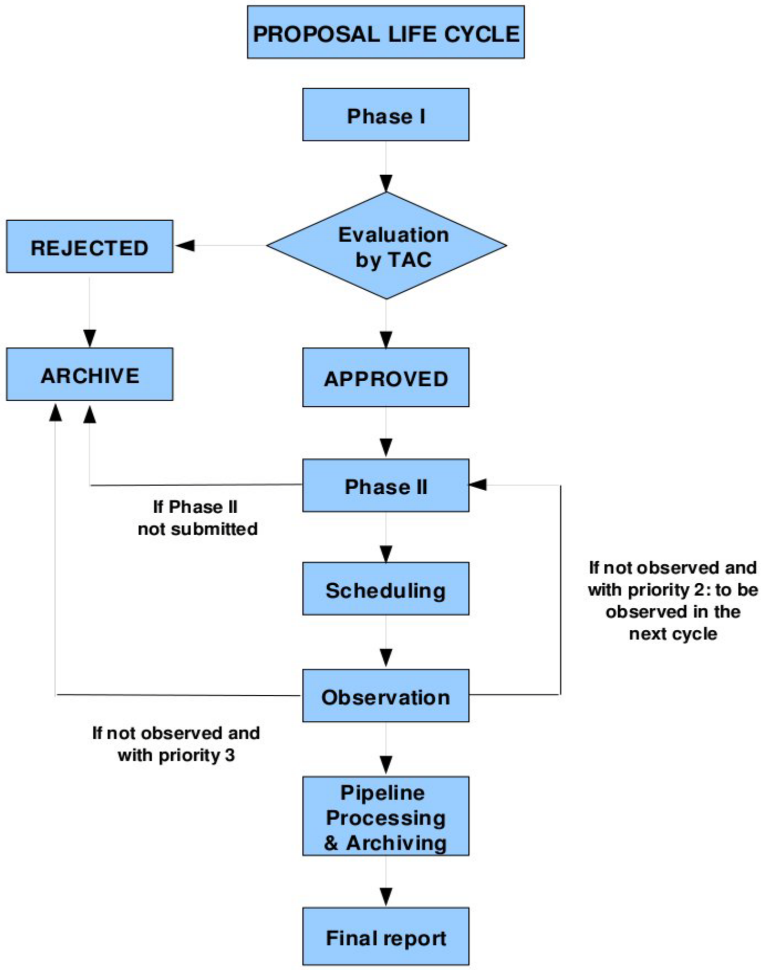

Figure 3: Sketch with the proposal life cycle

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. At this step, the PI must provide the best possible information to carry out his scientific project, under his responsibility. Failures in providing this information on time result on cancellation of the observing program.

After Phase II, the observations are scheduled and the PI is informed about it. Observations will be carried out under the supervision of the WSO-UV observatory science operations team. The PIs will be informed on the details of the observations. Finally, data are processed by the pipeline and archived into the WSO-UV Archive. The PI is informed when the data are available in the archive for their retrieval. Observations in the archive have a 6-12 months proprietary period. The information for the PI to re-process the data, including the calibration files, system and algorithms must be also made available at the time the observations are released. The astronomers will be invited to submit to the observatory a final report with the list of publications derived from the research project and suggestions of improvements to the Observatory services (reporting tools, pipeline processing, etc).

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 Figure 4.

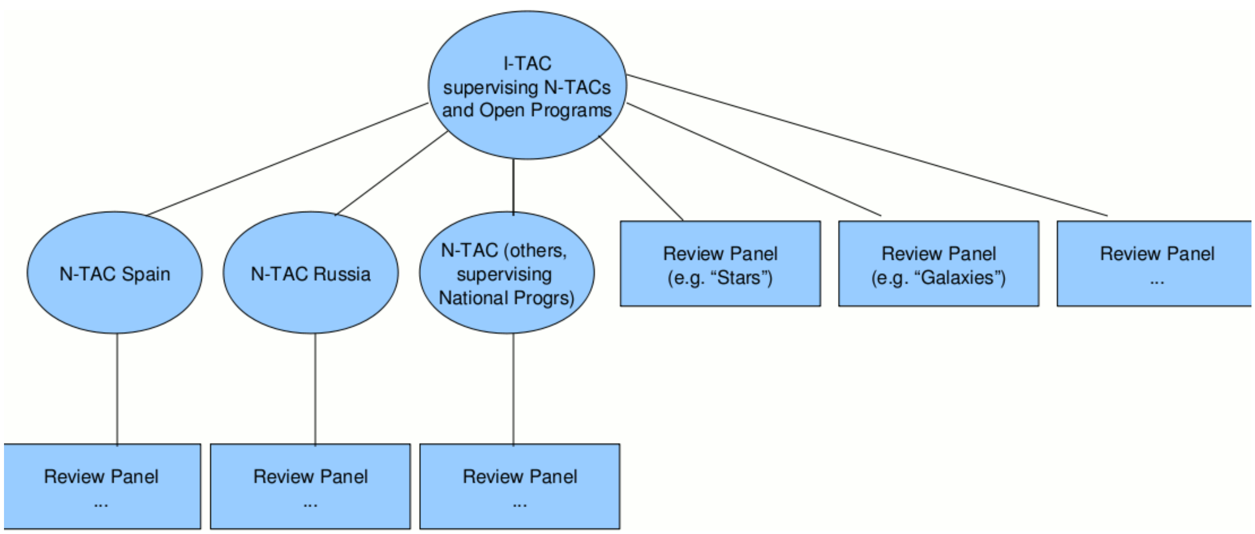

Figure 4: Sketch describing the WSO-UV Time Allocation Committees and their foreseen interaction.

The observational proposals will be submitted through a web-based interface including links to internal and external tools, for example: the Astronomer’s Proposal Tool (a software package specific for each call or Cycle), the handbook for proposal preparation (updated for each Cycle), the instruments handbook(s), the Exposure Time Calculators (ETC) of the instruments , and the e-mail system to inform the user about the proposal status. The user interface will also include links to useful external interfaces and software facilities, for example to derive target coordinates (or other information) and build sky maps, to consult astronomical databases and sky catalogs, or to visualize images. Reporting tools will also be defined for the PIs tracking of the observational program status and the interaction among the three actors in the proposal generation, evaluation and execution, namely, the PI, the scientific committees (TACs and Review Panels), and the Science Support Group for the call (constituted by designated members of the WSO-UV Observatory Science Team) supported by the instruments technical teams. The system should also guarantee the information flow between the WSO-UV Science Operations sites at Moscow and Madrid. Altogether, these tools constitute the core of the Remote Proposal System (RPS). A first version of this system is now under development since the first call for the core program is expected to be released in 2013.

VI. Science scheduling

Accepted research projects will be transformed and then ingested into the scheduler[9]. The scheduling process will be run in the following steps:

- The list of accepted applications will be transformed within the RPS into a list of observations and science constraints at the completion of the proposal Phase II submission.
- This information will be transferred from the RPS to the Scheduling system to be processed taking into account the scientific constraints.
- Target visibility will be determined from FD inputs.
- Additional, platform dependent or instrument dependent constraints will be introduced in the system.
- A Long Term Planning (LTP) will be produced. This is a single queue of observations that extends over the whole cycle and contains the whole list of observations intermingled with the WSO-UV maintenance activities.
- A Short Term Planning (STP) will be produced to define the sequence of observations to be uploaded in the space telescope.
- Scientific contingencies will be examined (Targets of Opportunity (ToO) such as supernovae, special calibrations, etc) to modify if required the STP.
- The STP is transformed in a sequence of instructions to be uploaded into the telescope Science Data Management Unit (SDMU).

The Schedule Generator Subsystem (SGS) is a functionality of the Science Control Center (SCS) included in the SOC of the WSO-UV mission. The Scheduling process, which basically is defined by two-steps: the LTP, and the STP, which also includes the scheduling of triggered observations (ToO).

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 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). The WSO-UV mission will strongly benefit of having a unique observing queue implemented in the LTP, where observations of the various programs are integrated together instead of having several program- associated queues that are later integrated, more or less rigidly, into the LTP.

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[10], the UCM Scheduler Prototype (USP). The scheduling algorithms have as input the approved proposals, divided into three priority categories: "must do" proposals (priority 1), good proposals (priority 2), and back up proposals (priority 3). For engineering and technical purposes, some time must be spent in maintenance, including the calibration programs, which are time fixed and define the Scheduling Skeleton File (SSF). The scheduling process proceeds according to the following steps:

- Step 1: calibration and maintenance tasks are booked in the different days of the semester according to the SSF.
- Step 2: the astronomical observations included in the priority 1 proposals will be assigned to the different days of the semester taking into account the observability constraints from FD calculations.
- Step 3: USP insert a parameter named the Available Time Ratio (μ) to add flexibility in the LTP. This parameter is the rate between the time required to carry out priority 1 proposals and the total time available science observations. This parameter is a tunable parameter that has been set to 0.6 for the tests.
- Step 4: the astronomical observations included in the priority 2 proposals will be assigned to the different days of the semester building completed the LTP and building the STP.

The inputs to the USP are: the different mission programs, the cycle durations, the observable bins, the SSF, the candidate observation file, and μ. The two steps of the scheduling process, the LTP and the STP, are governed by procedures whose objective is the maximization of the scientific return of the satellite.

A greedy approach has been applied in both of them, and they have been included in the prototype. They have been tested for some randomly generated examples, with up to 2000 astronomical observations. Their performance results very good in terms of program efficiency and computational time.

VII. Science data processing and archiving

The set of processes by which raw science and support data are treated in order to obtain output files that can be used directly for scientific analysis is known as a pipeline; this 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[11]: uncalibrated science data, uncalibrated support data, intermediate data and calibrated data**.** Uncalibrated science data and support data are processed through the pipeline in order to produce final calibrated data that can be used by the scientific community. During the process some intermediate files are produced and stored. After the initial process tasks (to initialize error and data quality arrays, to calculate noise and so on), the main steps are: geometric distortion corrections, cosmic ray removal, flat fielding, flux calibration, astrometric calibration, spectral extraction, addition of calibrated dithered observations, image statistics.

The pipeline relies on various related tools such as correlators, the mission source catalog, visualization tools and reporting tools. Cross-correlation service has to be provided in order to compare properties (astrometry, photometry) of detected sources with data from external catalogs; the mission source catalog will contain detailed information on all the observations carried out with the WSO-UV; as far as visualization is concerned, the User Interface (UI) of the pipeline will be designed to allow users viewing data stored in the WSO-UV catalogs, and to do cross and view catalog queries involving data available from external archives.

Users should be able to view raw data files, calibration data files, meta-data such as the observing log and observing programs associated with datasets, processed data, with the type of processing done selected by the user. UI should provide preview display for datasets in the WSO-UV archive, and also provide links to documentation of the telescope and instruments; appropriate reporting tools are necessary to inform on the observations being processed, and to keep internal communication between the various actors.

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. Most of the scientific users of the WSO-UV data products will be archive users and their activity will last many years after the end of the mission. Science data from the WSO-UV become available to the astronomical community at the end of the proprietary period. Catalog information is searched through a web-based interface that allows simple queries or large and complex quests that can be uploaded as a file including SQL-like queries. In principle, searches should be possible over all the data headers contents. In practice, the headers contain much internal information on the intermediate processing or instrument dependent data that are only expected to be queried for by the mission astronomers and the instrument teams for special tests and quality control processes.

File format for data files will be FITS (Flexible Image Transport System). FITS is the standard format for exchanging astronomical data which is independent of the hardware platform and software environment. A data file in FITS format consists of a series of Header Data Units (HDUs), each containing two components: an ASCII text header and the binary data. The header contains a series of header keywords that describe the data in a particular HDU, while the data component immediately follows the header. Header keywords will be implemented following the experience of previous space observatories and especially growing on the HST heritage. Eventually, all of the fully-reduced data will be converted and stored in Virtual Observatory format files (http://www.ivoa.net).

VIII Summary

The high level structure and scientific requirements to operate the science systems in the WSO-UV have been described. The basic layout implies the industry involvement in the software development and mission operations and a fraction of the science operations including real-time. The role of the science team in the academia has been to define the high level requirements for the science operations software. In the future, the academia will be operating the main science systems and subsystems, from the Remote Proposal System to the Analysis System and the

Archive that will be located in the Academic sites and kept synchronized between both sites. It will also provide the support to the scientific community making use of the WSO-UV.

Appendix A

Acronym List

AS	Analysis System
ETC	Exposure Time Calculator
CP	Core Program
DDTP	Director'd Discretionary Time Program
FD	Flight Dynamics
FDS	Flight Dynamic System
FITS	Flexible Image Transoprt System
GALEX	Galaxy Evolution Explorer
GS	Ground Segment
HDU	Header Data Unit
HIRDES	HIgh Resolution Double Echelle Spectrograph
HST	Hubble Space Telescope
ISSIS	Imaging and Slitless Spectrograph Instrument for Surveys
I-TAC	International Time Allocation Committee
LSS	Long Slit Spectrograph
LTP	Long Term Planning
MCS	Mission Control System
MOC	Mission Operation Center
NASA	National Aeronautics and Space Administration
NP	National Program
OP	Open Program
PI	Principal Investigator
RAS	Russian institute of Astronomy
RCS	Remote Control System
SA	Science Archive
SCS	Science Control System
SDMU	Science Data Management Unit
SDPC	Science Data Processing Center
SGS	Schedule Generator Subsystem
SOC	Science Operation Center
SQL	Structured Query Language
SSF	Scheduling Skeleton File
STP	Short Term Planning
TAC	Time Allocation Committee
ToO	Target of Opportunity
UCM	Universidad Complutense de Madrid
UI	User Interface
USP	UCM Scheduler Prototype
UV	Ultraviolet
WSO-UV	World Space Observatory-Ultraviolet

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