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The World Space Observatory Project for Ultraviolet

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Abstract In this paper we report on the World Space Observatory for Ultraviolet (WSO/UV), a project to implement a 2m class space telescope dedicated to UV spectroscopy and imaging. We give some technical informations on the project and discuss its primary science objectives. A report on the status of its implementation is also given.

Key words: telescopes — instrumentation: spectrographs — instrumentation: high angular resolution — ultraviolet: general

1 INTRODUCTION

Most resonance transitions from ions, atoms, and molecules of astrophysical significance are in the ultraviolet wavelength domain. Hence, UV spectra provide the most sensitive tools to trace the distribution of (baryonic) matter in the Universe and to diagnose the chemical composition, the physical properties, and kinematics of astronomical objects of all types. UV astronomy, born in the 60's with pioneering rocket flights, started its mature age with the NASA's Orbiting Astronomical Observatory *Copernicus*, (*OAO–C*), launched in 1972. Then, the International Ultraviolet Explorer (*IUE*), a joint NASA, ESA and British SERC project, secured more than 18 years of very productive data from January 1978 to September 1996. Thanks to its broad spectral coverage (110–320 nm), high spectral resolution (up to $R = \lambda/\Delta\lambda = 10\,000$ in its echelle modes), and higher sensitivity than previous UV missions, *IUE* provided numerous key discoveries in many different areas of astrophysics: from the solar system, to stellar physics, physics of the interstellar medium, stellar populations, AGNs, and even cosmology. Detailed summaries of the achievements in each of these fields at the end of the *IUE* mission can be found in the Proceedings of the Conference "Ultraviolet Astrophysics beyond the IUE Final Archive" (Wamsteker & González-Riestra 1998).

After *IUE*, four missions have made further and substantial contributions to UV Astronomy, i.e. the Hubble Space Telescope (*HST*), the Extreme Ultraviolet Explorer (*EUVE*), the Far Ultraviolet Spectroscopic Explorer (*FUSE*), and the Galaxy Evolution Explorer (*GALEX*). The *HST* UV spectrographs – GHRS and STIS – covered the same range as *IUE*, but the much larger telescope aperture, higher spectral resolution in some of the observing modes, more sensitive digital cameras, and the ability to achieve high spatial resolution (in STIS long-slit modes) permitted the observation of targets many magnitudes fainter than accessible in the pre-*HST* era. *EUVE* was launched in 1992 and operated until January 2001. It covered the extreme ultraviolet wavelengths from 6 nm up to the Lyman continuum (LyC) edge at 91.2 nm, but only few stars were observable longward of ∼40 nm owing to interstellar extinction. Of the 734 sources

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cataloged in *EUVE*'s all-sky survey, 55% were identified as late-type stars. An account of the achievements of *EUVE* can be found in Bowyer et al. (2000). Finally, *FUSE*, launched in 1999, covers the 91.2–118.7 nm spectral range with four separate telescope/spectrograph channels (further subdivided by redundant detector segments), while GALEX is mainly devoted to carry out the first all-sky UV survey. Both *FUSE* and *GALEX* are presumed to operate for other 1–2 years from now. After the NASA decision in 2004 to cancel further servicing missions to *HST* and the failure of its prime UV spectrograph (STIS) in August 2004, no facilities to get UV spectra in the classical UV domain ($\sim$100–300 nm) are available. We present here the only space mission dedicated to UV currently approved by a space agency: the World Space Observatory for Ultraviolet (WSO/UV). It will fill in the gap in UV facilities after *HST* era and before the advent of future large UV telescopes, e.g. *SUVO*[1], presently under consideration in the United States.

2 THE WSO/UV SATELLITE

WSO/UV is an international collaboration to build a UV (100–310 nm) dedicated telescope capable of: *i*) high resolution spectroscopy by means of two echelle spectrographs covering the 100–310 nm range; *ii*) long slit low resolution (R $\sim$1 000–2 500) spectroscopy; *iii*) deep UV imaging. It will be operated like a ground-based telescope, i.e. capable to perform "real time" operations in an orbit free of visibility constraints (L2).

The WSO concept was discussed for the first time in the conclusions and recommendations of the 8th UN/ESA Workshop for Basic Space Science in the Developing Countries. In order to assess the mission feasibility and to provide the conceptual design of the WSO/UV space/ground system, an ESA internal study was conducted under the ESA General Studies Programme[2] followed by an assessment study at JPL/NASA[3]. The basic ideas under the WSO project are to use application innovation, but avoid technical development innovation, use heritage as much as possible, apply new engineering methods (concurrent design), keep the mission simple, and allow science operations centers at national level. Making use of existing technology reduces the development time (a few years) and cost (about 300 million USD).

According to current plans, WSO/UV launch is foreseen for 2010 by means of the chinese Long-March launcher. It will be placed in a orbit around the Lagrangian point L2 for 5 years (+5 years possible extention). The ground segment will consist of a Mission Operation Center and a Science Operation Center that jointly coordinate a distributed net of ground stations/control centers located in Argentina, China, Russia, South Africa, and Spain.

2.1 The Telescope

The heritage for the WSO telescope design is the Russian-led international space observatory ASTRON, launched in 1983. It functioned for six years and was the first UV telescope placed into a highly eccentric orbit. This led to the proposed development of the Spectrum UV mission – a Russia, Ukraine, Germany and Italy project – that was eventually cancelled because of the reduced funding of the Russian space programme after the restructuring and political changes that took place in the former Soviet Union countries. The WSO/UV telescope is a new version of the T-170 telescope designed in Russia by Lavochkin Association for Spectrum-UV mission (see the series of reviews in Belvedere and Rodonò, 1993). It is a Ritchey-Chretien with 1.7m aperture, equivalent focal length of 17.0 m, FOV of 40 arcmin ($\oslash$200 mm), optical quality of the two mirrors of l/30 rms at 633 nm, capable of 12.05 arcsec mm^{-1} angular resolution on the focal plane.

2.2 The Spectrographs

WSO/UV has three spectrographs in its focal plane, as well as a set of optical and UV cameras. An industrial Phase A study for all spectroscopic capabilities in a single box, namely the HIRDES instrument – designed using the heritage of the ORFEUS missions successfully flown on two space shuttle flights in 1993 and 1996 (Barnstedt et al. 1999, Richter et al. 2000) – has been completed in 2001 by Jena-Optronik funded by the German DLR. HIRDES comprises two echelle instruments, UVES (178–320 nm) and VUVES (103–180 nm), that were designed to deliver high spectral resolution (R $\sim$50 000), and a low dispersion long

[1] See the *SUVO status* report on $http://origins.colorado.edu/uvconf/UVOWG.html$

[2] ESA/CDF-05(A), http://wso.vilspa.esa.es-/docs/WCC/DOC/Attachments/GEN-TN-0002-1-0.pdf

[3] ADP Report: CL#01-1168 http://wso.vilspa.esa.es/docs/WCC/DOC/Attachments/GEN-TN-0001-Draft-0.pdf

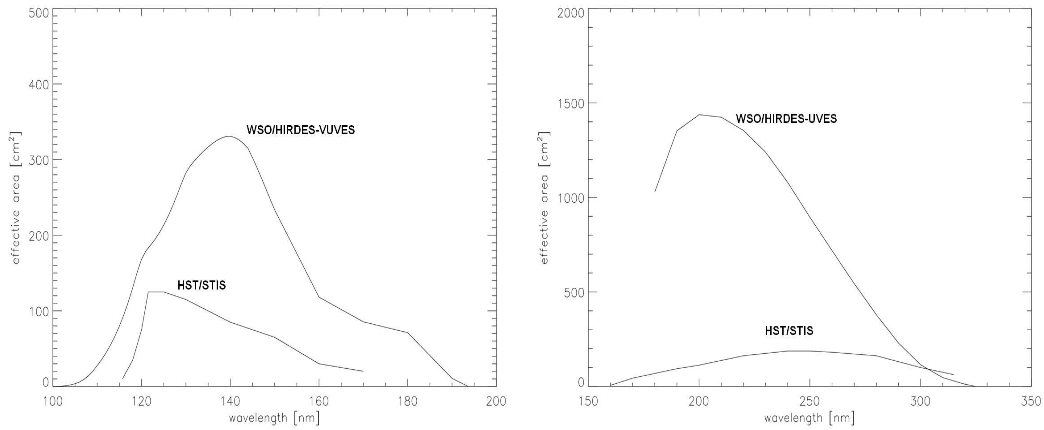

Fig. 1 A comparison of the effective area of the WSO/UV instruments with that of the UV spectrographs STIS on HST at comparable resolution.

slit instrumen: LSS (R ~1000). Each of the three spectrometers has its own entrance slit lying in the focal plane of the T-170 M telescope on a circle with diameter 100 mm. The three optical trains can be operated in sequential mode. This is managed by satellite motion with a pointing stability requirement of 0.1 arcsec to be monitored by three Fine Guidance Sensors (FGS). The latter are part of the payload and their provision by Italy is under negotiation.

A comparison of the Effective Area of the WSO/UV instruments with the UV spectrographs STIS on HST at comparable resolution is given in Figure 1. The spectral resolution provided by HIRDES is similar to that provided by HST-STIS, but higher than that provided by HST-COS, the instrument designed to replace STIS. As far as sensitivity is concerned, WSO/UV-HIRDES is comparable to HST-COS and definitely better than HST-STIS. Accounting also for the fact that WSO/UV will be a dedicated UV telescope and will have a high efficiency of observations at L2, WSO/UV will provide a net increase in UV productivity of a factor about 40–50 compared to HST/STIS at the same spectral resolution. A modified industrial Phase B1 study for VUVES and UVES spectrograph has been recently started in Germany in collaboration with Russia, while an assessment study for a modified LSS with better spatial and spectral resolution is ongoing in Russia and Ukraine.

2.3 The UV and Optical Cameras

WSO/UV will be capable to perform high spatial resolution UV and optical imaging of the sky. The imagers on WSO/UV are: a F/50 UV and a F/50 optical cameras, with resolution of 0.03 arcsec pixel^{-1} and 1 arcmin FoV, plus a F/10 UV camera with 0.15 arcsec pixel^{-1} resolution and 5 arcmin FoV. The UV and optical imagers view adjacent fields to those sampled by the spectrometers, hence other than dedicate imaging observations, also serendipitous science during spectroscopic observations will be contemplated. The imaging performance compares well with that of HST/ACS. The broad band sensitivity at 150 nm is $\sim 2.5\times10^{-18}$ erg s^{-1} cm^{-2} Å^{-1} for a A1 V star at $V = 23$ mag, and $\sim 6\times10^{-18}$ erg s^{-1} cm^{-2} Å^{-1} for a S0 galaxy at $V = 21$ mag.

3 SCIENCE CASE FOR WSO/UV

The UV is an essential part of the electromagnetic spectrum to be covered for astrophysical studies. Indeed, a large volume of relevant science can only be carried out in the far-UV, or complementary EUV waveband. The principal reason is the diagnostic richness of the UV/FUV/EUV wavebands that contain almost all the resonance lines of relevant elements in all ionization stages and cover gas/plasma emissions from the coolest regimes (10–1000 K) up to the hottest (10^7 K), thus addressing a wide range of science. In fact, the topics that can be addressed concern numerous astrophysical aspects, from planetary science to cosmology:

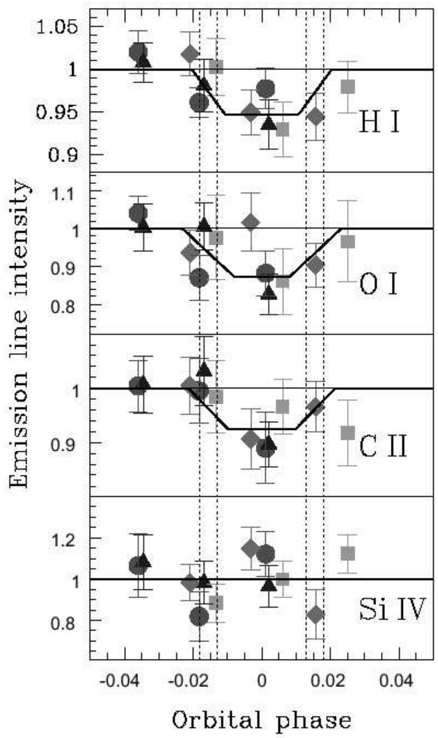

Fig. 2 Line fluxes vs. orbital phase from HST/STIS spectra of the G0 V star HD 209458 which hosts a giant planet ($M = 0.69\ M_J$) in an orbit of radius 0.045 AU. Circles, squares, triangles and diamonds are for the 1st up to the 4th observed transits, respectively. The vertical dotted lines corresponds to the position of the 1st to the 4th contacts of the planetary disk transit. The thick line represents the best fi t to the data. Absorptions are detected in H I, O I, and C I, during the transits; no signifi cant absorptions are detected in the other lines, i.e. Si IV (fi gure adapted from Vidal-Majar et al. 2004).

– **Planetary Science**. UV/FUV observations are essential to study the auroral variability in the major planets, the dynamics of planetary upper atmospheres, cometary evaporation and gas production. Also atmospheres of extrasolar planets can be characterized in UV: HST/STIS observations of the star HD209458 show a 15% change in the Lyα depth during the transit of HR209458b (cf. Figure 2), a Jovian-like planet orbiting close to the star, that was interpreted by Vidal-Majar et al. (2003) as due to a planetary extended atmosphere suffering a mass loss rate $\geq 10^{10}$ g s^{-1}. Moreover, UV data show the presence of C and O in the HD 209458b atmosphere (Vidal-Majar et al. 2004).
– **Stars**. UV/FUV spectroscopy are the best tools for the study of hot star atmospheres, winds and evolution (inc. young neutron stars, white dwarfs, OB stars, WR stars), accretion and outflow physics in star formation, and CVs. Also the study of cool late-type stars greatly benefits from UV/FUV photometry and spectroscopy that allow us to investigate their hot chromospheres, transition regions and coronae (cf. Figure 3) in full details (see Catalano et al. 1999), in particular their active structures that are shaped by the magnetic field, and their dynamics. This work can also be extended to the formation of massive stars and supernovae in external galaxies. UV imaging is essential for astrometry of white dwarf + MS binaries (IMF, white dwarf mass-radius relation), and accurate astrometry of cluster stars. Moreover, UV photometry of hot peculiar stars (anomalously hot HB stars, blue stragglers, CVs, etc.) in stellar clusters is of paramount importance because these peculiar objects strongly contribute to the UV upturn in elliptical galaxies, and therefore are relevant in any population synthesis model.

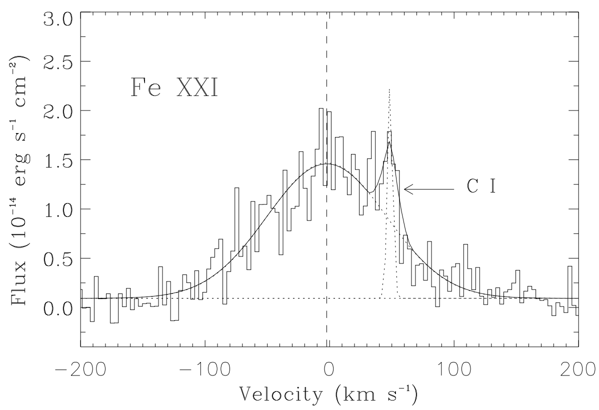

Fig. 3 The coronal Fe XXI 135.4 nm line profile in the spectrum of the dM1e star AU Mic, as observed by HST/STIS. The absence of line shift with respect to the rest frame given by photospheric lines suggests a stationary corona. The non-thermal width is less than the sound speed hence no supersonic motions contributes to coronal heating. High resolution spectroscopy of coronal lines with this quality ($R \sim$50 000) is not feasible in X-ray with current or next generation X-ray telescopes (figure adapted from Pagano et al. 2000).

- **Stellar Populations in external galaxies**. The access to UV bands allows observers to easily recognize and date young, massive stars, an issue strictly related to the study of starburst galaxies, i.e. systems whose energetic output is dominated by a major event of star formation. In addition the UV region is essential also to characterize hot, low-mass stars belonging to the evolved populations of elliptical galaxies and spiral bulges.
- **Interstellar and Intergalactic Media**. These are mainly studied through their absorption lines, superimposed on strong background sources, which appear exclusively in the UV/FUV and (in the case of helium) EUV. WSO can probe hot gas and deuterium in local group galaxies (inc. the Milky Way), ionized helium in our own galaxy and observe the hot IGM and galactic halos, studying galactic enrichment out to $z = 2$.
- **Galaxies and Active Galactic Nuclei**. Any attempt to resolve structure and dynamics of the AGN broad line emitting region passes through high-and low ionization emission line profile intercomparison and through reverberation mapping, for which UV data of HST-like quality and better are strictly necessary.
- **Cosmology**. Rest frame studies of local counterparts to cosmological objects (galaxies, clusters, SNe etc.). Access to UV/FUV spectroscopy is essential for a variety of cosmological observations including: the Gunn-Peterson effect for ionized helium $z > 3$, the cut off energy in QSOs, chemical evolution in AGN and normal galaxies, high velocity clouds in AGN, accretion rates and flows in massive central black holes, interaction between the radiation field and gas near central black holes and the physics of star bursts from the Lyman continuum.

A book review on the “Fundamental questions in UltraViolet Astrophysics” has recently published as a special issue of Astrophysics and Space Science (Gómez de Castro and Wamsteker, 2005). Among the themes discussed above, three topics are proposed to constitute the core program of WSO/UV spectroscopy, namely:

- probing the structure and atmosphere of extrasolar planets;
- tracing the history of cosmic reionization and large scale structure formation using H I, He I, and He II Gunn-Peterson effects;
- outflow and accretion physics.

4 WSO/UV PROJECT ORGANIZATION

WSO/UV is a completely new approach to space science, drawing on contributions from a larger number of countries than usual, sharing the costs more widely. WSO/UV project is lead by the Russian Federal Space Agency (FSA). Participation in the project is organized through a network of National WSO Working Groups (NWWGs), the chair of each of these acting as a national project representative on the WSO Implementation Committee (WIC). 14 NWWGs representing scientists from 17 countries (about 200 scientists & 10 industries) are involved in the implementation of the project: Russia (chair), Argentina, China, Israel, Mexico, South Africa, Ukraine, and the european countries: France, Germany, Italy, the Netherlands, Spain, UK, Sweden, and Belgium.

The WSO project is acting as a stimulus for a wide international cooperation and, within Europe, this has led to the constitution of the Network for Ultraviolet Astrophysics (NUVA), which has been established as a subgroup of the EU Framework 6 funded OPTICON (Optical Infrared Coordination Network). The objectives of NUVA are to formulate and operate a UV astronomy network and to plan and execute a road-mapping exercise for UV astronomy. As part of the latter, NUVA and its members have contributed to the recent ESA *Cosmic Visions 2015–2020* consultation exercise. The reader interested to the future of ultraviolet astronomy is invited to contact the NUVA people at the website http://www.ucm.es/info/nuva/.

Acknowledgements We want to recall here Dr. Willem Wamsteker, prematurely passwed away on Nov 24th 2005. Dr. Wamsteker, ESA Director of IUE for about 14 years, was a great astrophysicist and a generous colleague. His enthusiastic pushing ahead the WSO/UV project was fundamental for the first steps in its implementation.

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