



1: Comparison of the GALEX (left) and visible light (right) images of M31, showing how UV emission highlights star-formation regions ([www.galex.caltech.edu](http://www.galex.caltech.edu)).

# Does ultraviolet astronomy have a future?

Martin Barstow sees a bleak future ahead for UV astronomy, unless HST replacement plans receive widespread support – and soon.

## Abstract

Recent news of the cancellation of further servicing missions for HST and the recent failure of its prime UV spectrograph has brought into focus the limited future for UV astronomy, without rapid action. If this situation does not change, the routine access to the far-UV that we have enjoyed for more than 25 years, since the launch of IUE, will end by around 2008. Although the James Webb Space Telescope is planned to replace HST in the next decade, it is infrared-optimized and has no UV capability. Indeed, not one future UV/optical mission is currently approved by any space agency. This article reviews the status and likely future of the current UV missions, addresses the scientific importance of UV observations and presents a way forward that could fill the “UV-gap” in the decade beyond HST.

The success of the International Ultraviolet Explorer (IUE) observatory and successor instruments such as the GHRS and STIS spectrographs on-board the Hubble Space Telescope (HST) demonstrate the major impact that observations in the far ultraviolet wavelength range, from ~100 to 300 nm, have had on modern astronomy. Of particular importance has been access to high-resolution  $R \sim 40,000$ – $100,000$  échelle spectra providing an ability to study the dynamics of hot plasma and separate multiple galactic, stellar or interstellar spectral lines. Since 1978 astronomers have enjoyed continuous access to the far-UV. Observing time on HST remains heavily oversubscribed in total (a factor ~6 in 2004), with far-UV observations taking a large share. However, in August this year, the Space Telescope Imaging Spectrograph (STIS) failed, leaving HST without its UV spectroscopic capacity. At the moment, there are two other UV-capable observatories in orbit. The Far Ultraviolet Spectroscopic Explorer (FUSE) operates in a waveband complementary to HST, covering the waveband 90–120 nm, while the Galaxy Evolution Explorer (GALEX) is a survey mission providing broadband imaging and low resolution grism spectroscopy between ~130 and 280 nm.

However, there are serious emerging problems with this provision. Even before the recent news,

HST operations were scheduled to end in 2010. Subsequently, NASA has announced a programme to develop a robotic servicing mission. However, with several years needed to bring this to fruition and a potential price-tag of around \$1 billion, it is hard to see the situation changing significantly. Furthermore, FUSE has just celebrated its fifth year in orbit and will have only a further one or two years of useful life at best. GALEX provides spectacular images (such as figure 1) but does not deliver either the high-resolution imaging or spectroscopic capability that we need. Therefore, by around 2008, the continued access to the UV/FUV that we have enjoyed for more than a quarter of a century, since the launch of IUE, will end. This fate has already befallen astronomy in the important and closely related EUV band, since the Extreme Ultraviolet Explorer (EUVE) ended its mission in January 2001.

Unfortunately, the James Webb Space Telescope, the planned replacement for HST, is infrared-optimized and has no UV capability. Indeed, not one future UV/optical mission is currently approved by any space agency. The UV is an integral part of the astronomical coverage of the electromagnetic spectrum, just as are  $\gamma$ -rays, X-rays, optical, IR and radio. Its amazing diagnostic richness, including almost *all* the

resonance lines of *all* elements in *all* ionization stages, and covering plasmas from the coolest regimes (10–1000 K) up to the hottest ( $10^7$  K), addresses the widest possible range of science (e.g. figure 2). Losing these capabilities will weaken astronomical research in its entirety.

### Essential future UV science

Nevertheless, the continued stiff competition for UV observations with HST (~20–25% of HST time was devoted to the UV until the STIS failure) and the results of several NASA-sponsored UV workshops show that continued access to the far-UV waveband will be essential for a substantial amount of fundamental science in the foreseeable future. Indeed, a large volume of important science can be carried out only in the far-UV or a complementary EUV waveband. The topics that can be addressed cover all aspects of astrophysics in fields from planetary science to cosmology:

- **Planetary science.** UV/FUV/EUV observations reveal auroral variability in the major planets, the dynamics of planetary upper atmospheres and cometary evaporation and gas production.

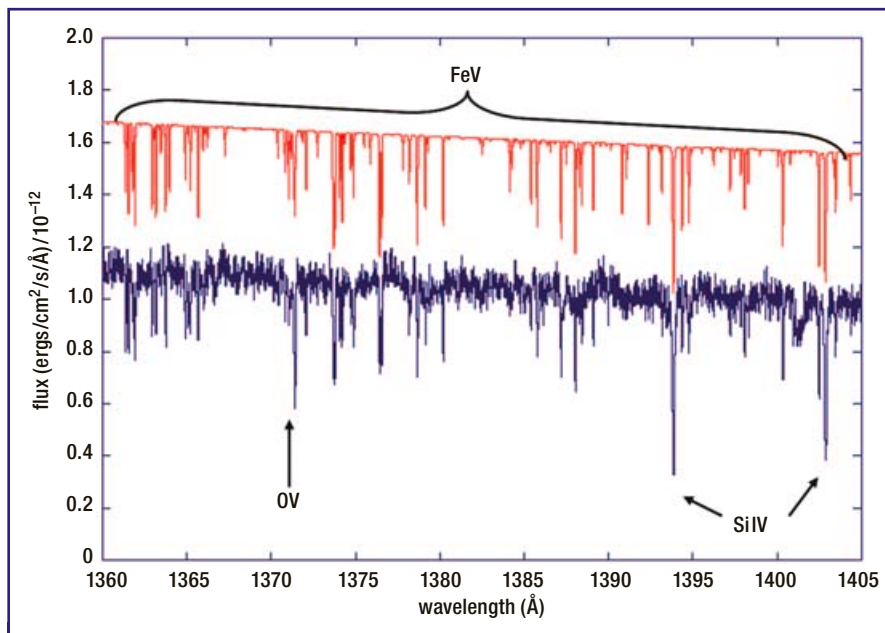
- **Interstellar and intergalactic media.** These are mainly studied through their absorption lines, superimposed on strong background sources, which appear exclusively in the UV/FUV and (in the case of helium) EUV. We can probe hot gas and deuterium in local group galaxies (including the Milky Way), ionized helium in our own galaxy and observe the hot IGM and galactic halos, studying galactic enrichment out to  $z=2$ .

- **Stars.** UV/FUV/EUV spectroscopy is essential for the study of hot star atmospheres, winds and evolution (including young neutron stars, white dwarfs, OB stars and WR stars); cool star chromospheres, transition regions, coronae and winds; accretion and outflow physics in star formation and interacting binaries. 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).

- **Cosmology.** Access to UV/FUV spectroscopy is essential for various cosmological observations including: the Gunn-Peterson effect for ionized helium at  $z > 3$ , the cut-off energy in quasi-stellar objects, chemical evolution in active galactic nuclei 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.

### WSO: the future of UV astronomy?

Some of us have seen the UV astronomy problem emerging for a while and have been attempting to plan for the future. However, development of facilities on the scale of HST and



2: High-resolution spectrum of a hot white dwarf, recorded using the STIS instrument on HST. The data in blue are compared with a theoretical model in red, revealing strong absorption lines from highly ionized oxygen and silicon plus a large number of lines from iron V.



3: An artist's impression of the World Space Observatory.

JWST takes a considerable time. Even if a large 6 m class optical/UV telescope were approved today to take up the mantle of HST, it would require around 15 years development time and would not make it into orbit much before 2020. One possible solution to fill the yawning time-gap in UV astronomy is the World Space Observatory (WSO, figure 3). The WSO is a novel approach to space science, drawing on contributions from a larger number of countries (~20) than usual, sharing the costs more widely. Current plans for WSO envision a 1.7 m aperture UV-only telescope carrying a suite of imagers, two high-resolution échelle spectrographs (together covering the 100–300 nm range) and a low-dispersion ( $R \sim 1000$ ) long-slit spectrograph. Despite having a smaller aperture than HST (which has 2 m), better instrument efficiency yields an effective area ~5–10 times that of the HST/STIS instrument. Making use of existing technology reduces the development time and cost for WSO to around \$300 million,

and it could be launched within five to six years if approved now.

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 with Russian, Ukrainian, German and Italian partnership. However, the changes taking place in the former Soviet Union countries reduced funding of the Russian space programme and limited progress in all space projects. As Russia emerges from its economic difficulties, the experience gained in the development of the Spectrum UV telescope is now being applied to a modified version for the much broader international scope of the WSO (figure 4). The UV spectrometer comprises three different single spectrometers (figure 5). Two of these are échelle instruments, designed to deliver high spectral resolution, and the third is a low-dispersion

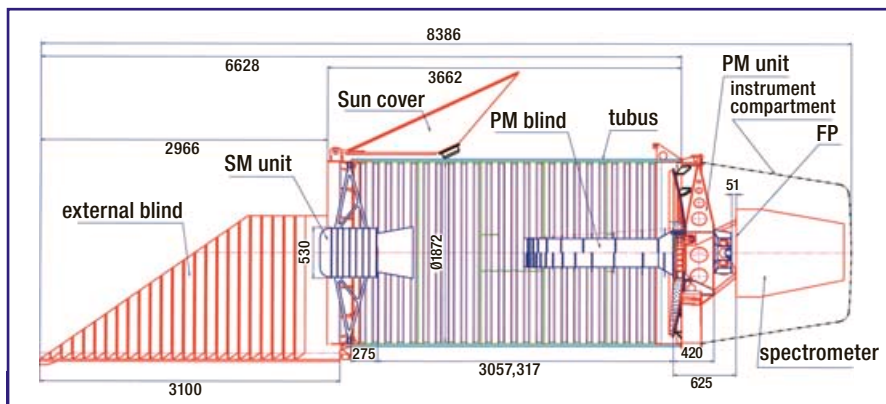
long-slit instrument (LSS). At high dispersion, the 110–320 nm waveband of the WSO will be divided into two, the UV (UVES, 178–320 nm) and VUV (VUVES, 103–180 nm). The fundamental concept of HIRDES is based on the design heritage of the ORFEUS missions (Orbiting and Retrievable Far and Extreme Ultraviolet Spectrometer, mounted on the ASTRO-SPAS free flyer), successfully flown on two Space Shuttle flights in 1993 and 1996. Although the primary science of the WSO mission is spectroscopic, there is an important role for high spatial resolution UV-imaging of the sky. Therefore it is planned to include a complement of UV imaging detectors in the focal plane, to provide serendipitous science during spectroscopic observations as well as planned studies of specific target areas.

### Community involvement

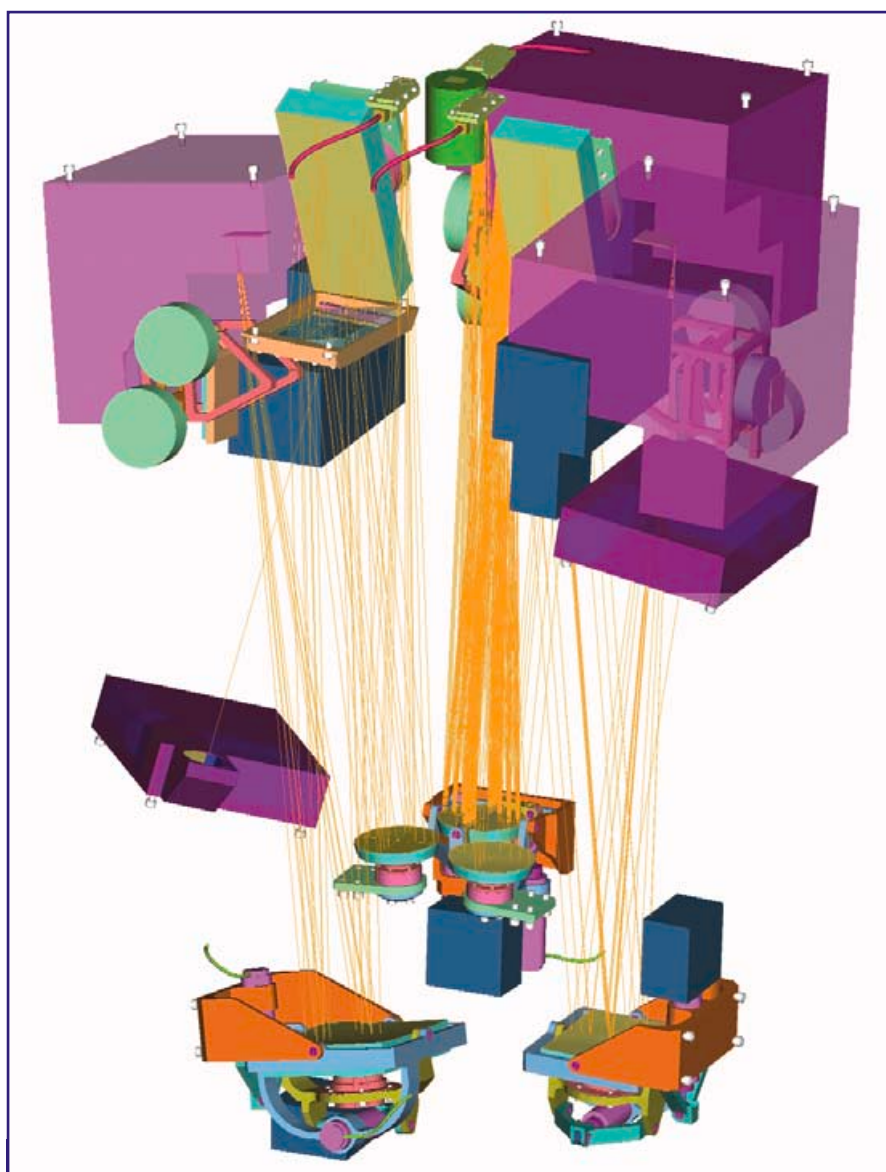
The WSO project is not led by a single agency but is being implemented as a distributed project with participation and contributions from several countries. However, it is essential to have space-agency contributions to deal with quality control and management issues that may be crucial to mission success. The Russian Federal Space Agency is taking a leading role in this area. Participation in the project is organized through a network of National WSO Working Groups, the chair of each of these acting as a national project representative on the WSO Implementation Committee (WIC). In the UK, the National Working Group is chaired by the author of this article; anyone can join.

Turning an idea like the WSO into a real space mission and ensuring a longer-term future for UV astronomy is not straightforward. It is necessary to obtain national support for any instrumental or scientific contributions from UK scientists. In this respect we all have a role to play in responding to the various science and technology reviews to make sure that UV astronomy takes its place (among other important areas of science) in the agenda. PPARC has recently carried out a review of future science priorities and contributions have been submitted to that.

In the wider context, a major space mission like the WSO or a future 6 m class facility requires multinational participation and the involvement of one or more major space agencies. The WSO has acted as a stimulus for international cooperation and, within Europe, this is seeing more general expression in 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. It is through



4: Engineering diagram of the WSO telescope.



5: Drawing of the HIRDES spectrograph showing both VUV and UV échelle arms (foreground) and the lower-resolution long-slit spectrometer (background).

these activities, carried out at both national and international level, that we can provide UV astronomy with a future. ●

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Implementation Committee, Chair of the UK WSO National Working Group, Member of NUVA board. The author is grateful to all those UK and European astronomers who have contributed to the ESA Cosmic Visions response, which formed part of this article.