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ORIGINAL ARTICLE

# Summary of the First NUVA Conference Space Astronomy: the UV Window to the Universe

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**Abstract** In this summary of the conference Space Astronomy: the UV Window to the Universe, held in El Escorial, Spain, May 28 to June 1, 2007, I identify the important scientific questions posed by the speakers and the corresponding discoveries that future ultraviolet space instruments should enable. The science objectives described by the various speakers naturally fall into groups according to the needed instrumental requirements: wavelength coverage, spectral resolution, sensitivity, rapid access to targets, monitoring, and signal/noise. Although most of the science objectives presented during the conference require UV spectra in the 1,170–3,200 Å range, there are important science objectives that require spectra in the 912–1,170 Å range and at shorter wavelengths. I identify the limitations of present instruments for meeting these requirements. To avoid the upcoming UV dark age, important work must be done to properly build the World Space Observatory (WSO) and to plan future space missions.

**Keywords** Ultraviolet: spectra · Ultraviolet: ISM · Ultraviolet: stars · Techniques: spectroscopic

## 1 Objectives of this summary

I wish first to thank the conference organizers for inviting me to summarize the meeting and providing an opportunity to present some personal thoughts concerning what was said and plans for future instruments. I have been privileged to participate in the planning for and observations with ultraviolet space satellites over the course of nearly 40 years. These instruments include Copernicus, the International Ultraviolet Explorer (IUE), the Far-Ultraviolet Spectrograph Explorer (FUSE), and the Goddard High Resolution Spectrograph (GHRS), Space Telescope Imaging Spectrograph (STIS), and Cosmic Origins Spectrograph (COS) instruments on HST. I will share with you my perspectives and concerns pertaining to the present status and the future of research in astrophysics that requires ultraviolet observations.

Summary speakers usually try to identify the meeting highlights and the highest quality papers and posters. While that would be useful (if somewhat controversial), I will instead take a different approach. Since a major objective of this conference is to identify critical observations and future missions that are needed in the ultraviolet spectral region, I will summarize this meeting from the perspective of desired discovery space. To be specific, what are the instrumental capabilities of possible future ultraviolet satellites that will be needed to answer the scientific questions posed by the speakers at this meeting? While the speakers did not address the full range of questions, they did provide a first-order list of the needed observational capabilities. I will also highlight some clever ideas that need to be developed in the near future.

## 2 UV observational capabilities

First let's summarize the present and future data sets and observing capabilities:

**Existing facilities and data sets:** the Galaxy Evolution Explorer (GALEX), FUSE, and the Optical Monitor on XMM-Newton and UVOT instrument on the Soft Gamma-Ray

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Burst Mission (SWIFT) which both have three filters and a grism sensitive to UV radiation at $\lambda > 1{,}800$ Å. Also, the archives of previous instruments (e.g., IUE, HST/GHRS, HST/STIS, Extreme Ultraviolet Explorer (EUVE), Interstellar Medium Absorption Profile Spectrograph (IMAPS), Orbiting Retrievable Far and Extreme Ultraviolet Spectrometer (ORFEUS)) are incredibly valuable and accessible.

**Very near and likely future:** The COS and STIS instruments on Hubble beginning with Cycle 17. Servicing Mission 4 (SM4) to install COS and repair STIS is scheduled for August 2008. The Ultraviolet Imaging Telescope (UVIT) on the Indian satellite ASTROSAT to be launched in 2008 contains several UV filters for imaging in the 1,200–3,000 Å range. The Indian–Israeli small satellite TAUVEX, also planned for a 2008 launch, contains filters for UV imaging in the 1,400–3,200 Å range.

**Three- to five-year probable future:** The World Space Observatory (WSO) telescope is partially built and the focalplane instruments are in phase A studies.

**Modest instruments that could be proposed:** Enhanced versions of FUSE and EUVE could be proposed soon for prephase A studies.

**Vision concepts under study:** The Stellar Imager (possible launch in 2024) and the Fresnel Interferometer Imager.

**Very uncertain and distant future:** A major UV/optical mission (the focus of this meeting).

## 3 What UV instruments will likely exist in 2025?

I select this time frame as it would be difficult to build and launch any major instrument by 2025 that has not already been studied in detail. For reference, the gestation period from conception to launch for the relatively unsophisticated FUSE satellite was nearly 20 years.

- In the 912–1,175 Å range, FUSE may provide data for a limited time,[1] but no replacement is now planned that will likely be available in the 2025 time frame.
- If all goes as planned, the COS instrument will be installed on HST, and the STIS instrument on HST will be repaired in August 2008. These instruments and the Hubble spacecraft could operate for the next 10 years but will unlikely operate beyond about 2020 as there is no servicing mission planned after SM4. I encourage everyone to propose for observing time in Cycle 17.
- If there are no major problems (and there always are), the WSO could be operating in the 2012–2020 time frame.
- GALEX is now operating well and could continue operating until perhaps 2017, depending on the recommendation of NASA's senior review committees.
- Stellar Imager is unlikely to be built before 2024, and the Fresnel Interferometric Imager concept is not yet in prephase A study.
- There are ideas for a four- to six-meter class UV/optical telescope for imaging and spectroscopy, but there are no detailed studies underway. The long gestation period for large missions suggests a launch date no earlier than 2027. I know of two previous conferences devoted to this mission (Morse et al. 1999; Sembach et al. 2003) and this conference is the third. The Space Telescope Science Institute is just beginning to plan for such a mission in the post-JWST era.

The hard conclusion from this summary of future instruments is that **astronomy will be entering a UV dark age unless we act soon**.

## 4 Advantages and disadvantages of the STIS instrument on HST

When thinking about possible future UV spectroscopic/imaging instruments, it is useful to list the strengths and weaknesses of the STIS instrument as an example of a multipurpose instrument. Among its strengths are spectroscopy covering the full 1,175–3,200 Å range in a few grating settings with a variety of spectral resolutions (1.5, 3, 15–30, and 150 $\mathrm{km\,s^{-1}}$) with broad wavelength coverage at one time and a range of aperture sizes. STIS has long slit-imaging spectroscopy capability and can obtain solar-blind UV images with an occulting slit for coronographic studies. The STIS instrument has very accurate photometric and wavelength calibrations (with on-orbit Doppler compensation) that permit high signal/noise observations. Like other Hubble instruments, it benefits from very stable pointing, all-sky coverage (but not at any one time), and a well-calibrated archive.

On the other hand, STIS has a number of disadvantages, not the least of which is that it is not currently operating. Assuming that STIS is rejuvenated in August 2008, its throughput will be modest for the 2.4 m aperture telescope because of the many internal reflections required to support its many observing modes and the need to share observing time with the other focal plane instruments. STIS has no sensitivity below about 1,170 Å and, except for the long slit mode, it can obtain spectra of only one object at a time. Operation in low Earth orbit means interrupted observations and difficulty in scheduling coordinated observing with other observatories. While a future multipurpose instrument could be designed to minimize some of these problems, one can assume that the more complex the instrument, the more likely that some observing capabilities will be compromised.

[1] FUSE ended scientific operations on July 12, 2007.

## 5 Advantages and disadvantages of the COS instrument on HST

As described by Cynthia Froning, COS was designed with a more focused set of goals than STIS. To achieve the highest feasible throughput at a spectral resolution of about 15 $\mathrm{km\,s^{-1}}$ in the 1,170–1,800 Å spectral range, COS has a large entrance aperture and uses one optical element to disperse and collimate the light and to correct for aberrations of the HST primary mirror. As a result, COS has only limited observing modes with no long slit or imaging capability. COS does have low-resolution modes for the 1,170–1,800 Å range and both low and medium resolution modes for longer wavelengths. Thus, the extremely high throughput comes at the price of a limited set of observing modes.

## 6 Choices for future UV instruments

There are many possibilities for a future UV mission(s) in the era after HST, FUSE, GALEX, and WSO. I can imagine the following, albeit incomplete, list:

- A more modern, multipurpose STIS-like instrument with a larger aperture telescope and/or better orbit.
- A wide-field multiband UV-imaging instrument with slitless spectroscopy more capable than GALEX.
- An instrument that strengthens some of the capabilities of STIS while deleting other capabilities (e.g., COS).
- An instrument that covers a different wavelength range than STIS (e.g., the FUSE and/or EUVE ranges).
- Totally new instruments (e.g., ultrahigh angular resolution imaging or narrow-band full-field-imaging spectroscopy).

All of these choices involve tradeoffs driven by science, technology, costs, politics, and **vision**. What do the science drivers described at this meeting say that will help us make the right choices for future instruments? **Where is the discovery space?**

### 6.1 What science objectives require 912–1,170 Å (FUSE range) spectra?

While Copernicus with its LiF-overcoated optics pioneered spectroscopy in the 912–1,170 Å wavelength range, its modest sensitivity and single-channel detectors limited its targets to only the brightest hot stars. With LiF- and SiC-overcoated optics and modern detectors, FUSE now studies a broader range of stars, solar system objects, and the brighter galaxies and AGN. Several speakers identified important scientific reasons for a new instrument operating in the 912–1,170 Å spectral range.

Luciana Bianchi argued that broadband imaging at $\lambda <$ 1,350 Å on a future GALEX-like instrument is needed to measure the metallicity of galaxies and star-forming regions. Unfortunately, GALEX lacks an observing band in this spectral range, which compromises its scientific return. Kathy Cooksey showed that a spectrograph more sensitive than FUSE is needed to study the metallicity, temperature, and ionization processes in the warm–hot IGM at low redshift. The C III/O VI column density ratio is a useful test of whether collisional ionization or photoionization is important in the IGM. The study of these lines in the 912–1,170 Å range, together with the resonance lines of C IV, Si IV, and N V observable with STIS or COS, is needed to search for missing baryons in the warm–hot IGM, which may be a two-phase medium.

To learn more about disk-halo interactions, including Galactic fountain flows and nonequilibrium ionization processes, Miguel de Avillez and Boris Shustov pointed to the need for high-resolution spectra both in the FUSE (C III and O VI) and STIS (C IV, Si IV, and N V) spectral ranges. It is important to understand that the scales of the different components of the interstellar medium and the flow of energy are often dominated by ram pressure. Once these processes are understood, one has a better physical basis for understanding the dynamics of gas flows in other galaxies and the IGM.

The presence or absence of O VI in the Local Bubble is a critical test of the presence of hot gas, but the separation of interstellar from white dwarf photosphere O VI absorption is very difficult with available FUSE spectra. Martin Barstow argued that a new spectrograph with higher spectral resolution, sensitivity, and signal/noise than FUSE is needed. This instrument would also be very useful, as described by David Boyce, in separating stellar from IS absorption in WD spectra.

Klaus Werner showed that a sensitive high-resolution spectrograph operating in the 912–1,170 Å range, where a plethora of lines from highly ionized species is present, is needed to study the chemical abundances in dredged-up intershell material of post-AGB stars. Mass loss from evolved giants in accreting binary systems also provides a means for testing the chemical composition of the interior of the mass-losing star where nuclear processing has occurred. Emission lines of ionized C, N, O, and Si present in this spectral range can provide tests of nonstandard evolutionary paths of accreting binaries (Domitilla de Martino).

### 6.2 What science objectives require EUV (100–600 Å) spectra or broadband data?

The Wide Field Camera on ROSAT and the EUVE satellite provided the first all-sky surveys in the extreme ultraviolet. Also, EUVE obtained low-resolution EUV spectra of many sources. Domitilla de Martino pointed out that there are many physical questions concerning accretion flows and the evolution of cataclysmic variables and other binary systems during quiescent and outburst phases which are best studied in the EUV. In particular, time-resolved spectroscopy and eclipse mapping in the EUV and 912–1,170 Å spectral ranges are needed to infer the temperature, accretion rates, and physical processes occurring in the disks of these systems. EUVE and FUSE lack sensitivity for such high time resolution studies.

Martin Barstow described the proposed Stellar and Galactic Environment Survey (SAGE) instrument that will use multilayer normal-incidence mirrors and gratings to obtain EUV spectra with a resolution of about 30 $\mathrm{km\,s^{-1}}$. The science objectives of this instrument include the study of the dynamics of hot gas in stellar coronae, white dwarfs, accreting binary systems, and interstellar gas.

### 6.3 What science objectives require very high spectral resolution ($\leq 3\ \mathrm{km\,s^{-1}}$)?

Both the GHRS and STIS instruments on HST could obtain spectra in the 1,175–3,200 Å region with about 3 $\mathrm{km\,s^{-1}}$ resolution. STIS also has a rarely used slit that supports spectra with 1.5 $\mathrm{km\,s^{-1}}$ resolution. COS has lower resolution (15 $\mathrm{km\,s^{-1}}$) in this spectral region, and the UVES and VUVES spectrometers on WSO will have resolutions up to 5 $\mathrm{km\,s^{-1}}$, as described by Boris Shustov and Norbert Kappelmann. Are there important science goals that require higher spectral resolution than STIS and WSO?

In the low-z universe, the missing baryons could be located in the hot IGM where the O VI lines would be useful tracers. At higher redshifts, metal absorption lines are hard to detect in the highly contaminated spectra of damped Lyman-$\alpha$ systems. Andrew Fox proposed that both problems could be addressed with high-resolution, high-sensitivity spectra of low-z systems that are too faint for study by STIS or WSO. Since warm gas line widths are about 10 $\mathrm{km\,s^{-1}}$, COS spectra will likely be unresolved.

Isabella Pagano showed the beautiful STIS echelle spectrum of $\alpha$ Cen A ($m_{\mathrm{V}} = 0.0$), containing 671 emission lines from 37 species which is a useful prototype of the rich spectra of much fainter stars that could be studied in detail with a high-resolution spectrometer more sensitive than STIS. At a resolution of 3 $\mathrm{km\,s^{-1}}$, one can study stellar winds, plasma flows, chemical abundances, atmospheric structures, flares, heating processes, disks, fluorescent excitation processes, and other phenomena. Even several weak coronal emission lines are present in the FUSE and STIS spectral ranges. For late-type active stars, high cadence monitoring and Doppler imaging can identify regions on a stellar surface where starspots and active regions are located. Colliding winds and accretion phenomena in symbiotic stars like Z And are best studied with high-resolution UV spectra. Elena Kilpio argued that even small changes in wind velocity can lead to major changes in the accretion rate and thermonuclear burning rates at the base of an accretion flow. Massive outflows are typical for hot supergiants and are best studied by analyzing the P Cygni-type profiles of the ultraviolet lines of C IV, Si IV, and N V.

Since UV spectra of starburst galaxies are dominated by emission from their hot supergiants, the analysis of starburst spectra provides information on the chemical abundances of more distant galaxies. While the FLAMES survey of O star spectra in the Milky Way and Magellanic Clouds with STIS has been useful in testing the predictions of radiatively driven wind theory (in particular the effects of line blanketing and clumping), Artemio Herrero would like to see a more sensitive high-resolution UV spectrograph to study the more distant low-metallicity starburst galaxies.

High-resolution UV spectroscopy is needed not just for stellar studies. Jeffrey Linsky showed that the structure and physical properties of the local ISM are best studied with high-resolution UV spectra because the resonance lines of a wide variety of atoms and ions are located in the UV, the metal absorption lines formed in cold and warm gas are narrow, and the velocity separation of individual clouds along a given line of sight is often only a few $\mathrm{km\,s^{-1}}$. Once the physical processes and structure of nearby interstellar gas are understood, then we are positioned to study the more distant ISM. This will require a high-resolution UV spectrograph more sensitive than STIS with the ability to obtain high signal/noise spectra with very accurate velocity scales.

### 6.4 What science objectives require higher sensitivity than COS (at moderate or low spectral resolution)?

Whether high-velocity clouds are galactic waste or represent material being accreted into galaxies and responsible for their observed substructure is an important question concerning galactic chemical evolution posed by Brad Gibson. He noted that 10 $\mathrm{km\,s^{-1}}$ resolution spectra with higher sensitivity than possible with COS are needed to measure the metallicity and velocity structure of high-velocity clouds without line saturation. Artemio Herrero pointed out that to study the mass–loss rates for low-metallicity O supergiants in distant galaxies will require spectral resolution somewhat lower than COS but higher sensitivity.

With higher sensitivity comes the possibility of observing phenomena with very high time resolution. One example would be UV spectroscopy of cataclysmic variables with a time resolution of a fraction of a second and UV photometry with a time resolution of tens of milliseconds to study accretion variability during outbursts. Domitilla de Martino stated that high temporal resolution spectroscopy of eclipsing binary systems containing a white dwarf can lead to eclipse maps with a resolution of one white dwarf radius.

### 6.5 What science objectives require very high signal/noise spectra?

Although many science objectives would benefit from higher signal/noise spectra than is feasible with instruments on HST, one important science objective would benefit enormously. Roger Ferlet showed STIS observations of stars with transiting planets. The atmospheres of these planets can be studied during transits using the depth and shape of absorption in the Lyman-$\alpha$ and other lines. The chemical composition and outflow rates are important questions, especially for planets with masses only a few times that of the Earth located in the star's habitable zone. Since the line absorption is generally weak, high signal/noise spectra are essential for this work. Improved detectors with minimal fixed pattern noise and excellent photometric calibration will greatly benefit this program, but a telescope with a larger aperture than the 2.4 m HST is clearly needed for a major advance in this area.

### 6.6 What science objectives require narrow-band UV-imaging?

The star formation rate as a function of look-back time can be studied using the ultraviolet narrow-band all-sky survey of GALEX because young stars are bright in the UV, whereas most old stars are not. Such surveys are also useful in determining the density and galactic location of hot white dwarfs and the identification of hot or accreting companions of normal stars. Domitilla de Martino argued that high angular resolution 912–1,170 Å images of globular clusters and nearby galaxies are needed to identify interacting binary systems in these very crowded fields. Luciana Bianchi made the case for a GALEX follow-on mission that would include a sensitive 1,200–1,350 Å channel to measure metallicity in star-forming regions. Alessandro Bressan added that the combination of UV and mid-IR images will provide information on the chemical composition of dust and young stars and break the age-metallicity degeneracy. Excellent angular resolution is needed to separate starbursts from galactic nuclei. This is also important, as stated by Rosa Gonzalez Delgado, for the study of Seyfert galaxy nuclei.

The UV background is likely dominated by dust-scattered starlight, which Jayant Murthy said can be studied in an all-sky survey with sensitive narrow-band or low spectral resolution UV imaging. Jose Cernicharo described how the UV radiation field incident on molecular clouds from the background and nearby stars can lead to the formation of complex carbon molecules including polyenes, carbon clusters, and polycyclic aromatic hydrocarbons.

### 6.7 What science objectives require high-resolution imaging spectroscopy?

Long-slit imaging spectroscopy with high angular and spectroscopic resolution is a powerful observing tool for studying physical processes that change rapidly with position near a target. One important example is the study of accretion from circumstellar disks onto the magnetic surfaces of young stars. Ana Gómez de Castro described how high-resolution imaging spectroscopy of premain sequence stars with an angular resolution of 7 milliarcseconds would be very useful in studying where accretion occurs on these stars, the physical properties of gas flows in and near disks, the acceleration of bipolar outflows with distance from the star, and the interaction of these outflows with interstellar gas clouds. Imaging spectroscopy could also help identify the location of $H_2$ and UV continuum emission relative to these stars. Imaging spectroscopy of the Lyman-$\alpha$ line provides information on strong outflows of galaxies, which apparently depend on metallicity. Miguel Mas-Hesse predicted that about 10% of the luminosity of some galaxies may be in the resonantly scattered Lyman-$\alpha$ line.

### 6.8 What science objectives require rapid access to targets of opportunity?

Rapid access to newly discovered supernovae will enable studies of the interaction of supernova blast waves with the circumstellar material ejected by the star prior to its explosion. The metal content of the circumstellar material, which Milena Bufano said is best studied in the ultraviolet, contains nuclear-processed material from the outer regions of the pre-SN star that provide a test of the late stages of stellar evolution. Pilar Ruiz Lapuente added that UV spectra of supernovae at high redshift as a function of time after the explosion are needed to study dust extinction and to determine whether the intrinsic colors of distant supernovae are similar to those of previously studied nearby supernovae. This is important for testing the cosmic distance scale. Domitilla de Martino pointed out that rapid access to dwarf novae during outbursts and UV spectroscopy with a time resolution of a few minutes are needed to study the propagation of heating fronts that result from unstable accretion.

### 6.9 What science objectives require dedicated long-term monitoring?

An excellent example of the need for dedicated long-term monitoring is the study of the shape of the emission line region in AGN through the reverberation mapping technique. Using as examples data sets from IUE, Brad Peterson showed that the UV emission lines show the same time behavior as the continuum formed in AGN nuclei but with a time delay indicative of the light travel time between the nucleus and structures (e.g., rings and disks) in the emission line region. Such data can be used to measure black hole masses. For reverberation-mapping programs, uninterrupted sequences of observations obtained every few days for several months are needed. WSO is an ideal instrument for this work. Isabella Pagano showed that regular sequences of observations of rapidly rotating cool stars with a cadence of hours and spectral resolution of $\leq$10 km s$^{-1}$ are needed to construct Doppler images of active regions on the surfaces of these stars to study magnetic activity. Jorge Sánchez-Almeida described magnetic activity on the surface of a low-activity star—the Sun. Studies of stellar flares require the same spectral resolution but with a cadence of minutes. Also, eclipse mapping and time-resolved spectra of low-mass X-ray binary systems with a cadence of minutes is needed to model the accretion disks of these systems. Domitilla de Martino described the physical processes that can be studied with moderate resolution UV spectroscopy. WSO is well suited for these studies as well.

John Hawley and Ana Gómez de Castro described the range of important physical questions concerning the winds, disks, magnetic structures, accretion flows, and jets of pre-main sequence stars, including T Tauri stars and the more massive Herbig Ae/Be stars. These questions can be addressed by high spectral resolution observations of UV emission lines, which have shapes that change on daily or hourly timescales. Ana Gómez de Castro said that WSO can monitor the brightest of these stars, but a more sensitive 6 m class telescope is needed to study these stars which are typically $\geq$140 pc away.

### 6.10 Instrumental capabilities not identified at this conference

Before the conference, I had listed three more instrumental capabilities that I thought would be identified by speakers as needed for important science objectives. Those instrumental capabilities that were not requested by the speakers are:

- multiobject UV spectroscopy,
- UV coronographic imaging, and
- onboard optical, IR, or X-ray instruments.

Whether the absence of requests for these capabilities is due to oversights, my not understanding what was said, or they are truly not needed is unclear.

## 7 Important instrument/technology developments

The scientific questions that can be addressed by future instruments often depend on the development of new technology or improvements in existing technology. Several speakers discussed ongoing technology developments and needs. John Vallerga showed that new MCP-based detectors have reduced fixed pattern noise, higher count rates, longer lifetimes, higher spatial resolution, and the ability to count multiple events. Such detectors on future instruments will enable higher signal/noise spectra and higher time resolution of variable bright sources, even if the telescope aperture is moderate in size. The development of detectors with good energy resolution would be a major breakthrough, permitting imaging spectroscopy over wide fields. Ken Carpenter said that precision formation flying and control concepts are becoming feasible for missions like Stellar Imager. Dennis Serre showed that new apodization techniques could enable the science program for the Fresnel Interferometric Imager. Finally, Mónica Fernández Perea described recent advances in multilayer coatings for UV filters and mirrors that could be used in future missions like WSO.

## 8 Recommendations for future missions

COS is now built, tested, and ready for insertion into Hubble during SM4 which is now planned for August 2008. While the launch and successful scientific observations appear to be very likely, we should be prepared to defend COS if/when there are problems in the SM4 program. This has happened before. I encourage people to write excellent proposals for Cycle 17 observations with COS. The call for proposals is planned for December 2007.

The repair of STIS is also on the manifest for SM4, but is lower in priority and may be more complicated than the installation of new instruments. We should also be prepared to defend STIS should there be any glitches in the SM4 program and write excellent proposals for Cycle 17 observations. As previously mentioned, STIS has many observing modes which are not feasible with COS.

Next in line is the WSO for which Russia will have a lead role in supplying the satellite bus, launch facilities, ground equipment, and 1.7 m aperture telescope. As described by Boris Shustov, Norman Kappelmann, Emanuele Pace, and Maohai Huang, the focal plane instruments, space flight control, and scientific operations centers will be supplied by the space agencies of at least four countries (Germany, Italy, Spain, and China). Given this diverse supply chain, excellent **systems engineering** is required to ensure that the different instruments and spacecraft components on WSO will work together. Interface requirements alone are not sufficient for this to occur. Project management must verify that the spacecraft components being built in different countries are actually built as required. **Robust testing** of the spacecraft and instruments together is needed to verify that all systems (optical, electrical, thermal, mechanical, etc.) work together and meet specifications. Internal refocusing in the instruments is needed to compensate for possible optical/thermal errors. Finally, **end-to-end optical testing** is needed to detect possible major problems. This was not done for Hubble, and the improperly built primary mirror was not known until after launch. During the WSO testing period, engineers should look for light leaks and excess scattered light in the instruments. HST-style calibration, data archive, and access is highly desirable. Pete Roming pointed out that UV flight hardware **must be clean** at all times. It is important to check for outgassing from hydrocarbon-containing materials (e.g., optical bench material, glues, shipping environment, etc.). Since space-qualified detectors often delay instrument delivery and compromise throughput (e.g., WFC3), the WSO project should identify and properly fund the **long-lead items**.

Looking beyond HST and WSO, there is a clear need for world-class leadership to guide the development of future missions. The experience of HST, FUSE, and many other missions is that at least 20 years is needed to develop a mission from conception to launch. In planning future missions, it is important to narrow the top scientific goals to a few that will not be accomplished with HST or WSO. New technology in the areas of detectors, optics, coatings, and gratings will increase the capabilities of missions and make them more interesting for space agencies to fund. In particular, energy-sensitive detectors which are needed for large area imaging spectroscopy could make future UV missions more powerful.

Excellence in space technology and the desire of space agencies and governments to support successful programs in space are now widely distributed in the world. Astronomers have a long successful history of international collaboration, and previous space missions have demonstrated that the contributions of individual space agencies to international missions are valuable and often necessary for the successful execution of the missions. It is important to extend this tradition when planning for future missions, especially as space missions become more expensive and technically challenging. It is essential, therefore, to identify and minimize the practical barriers to future collaborations. While there are many barriers both large and small associated with international collaborations, a major problem today is ITAR (International Traffic in Arms Regulations), a law in the United States that has the effect of restricting the sharing of technology between the U.S. and foreign entities. While modification of the ITAR regulations will be difficult and take time, careful long-term planning may smooth the implementation of international collaborations involving NASA participation. Other problems associated with international collaborations may be minimized with patience, recognition of different national cultures, and better communication.

What is the best approach in planning for a future mission? This conference highlighted the broad range of observational capabilities required to answer important scientific questions, but it is not feasible to include all of these capabilities in one instrument or on one mission with several instruments. Several missions more narrow in scope are easier to realize technically and will permit many optimizations. Most of the scientific questions presented at this conference require measurements of metal abundances and gas flows. UV spectroscopy is the best tool for these studies. The major questions for the design of future UV instruments are, therefore, what spectral region to optimize for, what spectral resolution, what sensitivity and signal/noise, and what angular resolution and field of view? Critical thinking concerning these questions is needed now.

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