The Emergence of the Modern Universe:
Tracing the Cosmic Web with SUVO
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We provide a focussed summary of the direct connections of the proposed SUVO (Space Ultraviolet/Optical Observatory) mission to the NASA/OSS and SEU strategic plans. The full scientific and technological aspects are contained in the report of the Ultraviolet-Optical Working Group (UVOWG) – see http://origins.Colorado.EDU/uvconf/UVOWG.html. The UVOWG was commissioned by NASA to study the scientific rationale for new missions in ultraviolet/optical space astronomy. A large-aperture UV/O telescope in space will provide a major facility in the 21st century for solving scientific problems in the NASA/OSS Strategic Plan and SEU roadmap:

- Map dark baryons, metals, large-scale structure, & dark-energy eq. of state
- Detect unseen matter through weak gravitational lensing
- Study the feedback from star formation
- Determine the evolution of stars, planets, and the elements

Some of these science goals are complementary to those in the IR and X-ray. However, some can only be achieved using the images and sensitive spectral diagnostics of UV/O bands. In particular, images of weak gravitational lensing and large-scale surveys of Lyα and metal absorption lines (O VI, C IV) may be the only way to find the dominant components of the "invisible universe". SUVO will allow astronomers to map out the large-scale distribution of dark matter and the nearly invisible warm photoionized and hot shocked components of the "Cosmic Web" of matter that may dominate the missing baryons.

SUVO will extend the scientific heritage of HST and NGST. No space astrophysics mission has demonstrated wider public appeal than the *Hubble Space Telescope*. Discoveries from the *Hubble* program provide an effective combination of captivating images and compelling scientific questions. SUVO will continue this tradition, through its wide-field images of galaxies, nebulae, clusters, stars, and planets. Its spectroscopic studies will produce answers to fundamental astrophysical and cosmological questions about the origin and evolution of matter in the Universe. To inform and engage the public, these answers must be cast in a framework of large questions about galaxy formation, the evolution of large-scale structure, and transport of heavy elements.

The UVOWG studied the science of both 4m and 8m UV/O telescopes; AURA is currently studying a large NHST (Next-Generation Hubble Space Telescope) to be launched in the decade after ~ 2010. This mission would focus on UV spectroscopy, wide-field imaging, and planet-finding (coronagraphy). However, no high-throughput UV/O mission will be possible without significant investments in technology, including UV detectors, gratings, mirrors, spectrographs and imagers.

1. Key Science Goals of SUVO

The NASA strategic plan goals are directly related to key science identified for SUVO, focussed on three themes: (1) Measuring the dark matter and baryons; (2) Understanding the chemical evolution of the elements; (3) Observing the major construction phase of galaxies and quasars. Our overall theme is entitled *"The Emergence of the Modern Universe"*, defined as the period from redshifts $z \approx 3 - 4$ down to the present epoch. This period occupies over 80% of cosmological time, and captures the evolution of nearly every major astronomical structure, from galaxies and clusters to quasars and the IGM. During this time (8–10 Gyr), large-scale structure developed in both dark matter and baryons. Much of the intergalactic gas collapsed onto galaxies, over 90% of the heavy elements were formed, and the energy sources of radiation, hot gas, and dynamic outflows acted back on the surrounding galaxies and gas clouds. This "feedback" of galaxy formation is the least understood aspect of galaxy evolution and assembly. The proposed SUVO mission will provide definitive measurements, with unprecedented accuracy, to fill in the evolutionary gap of galaxies, the IGM, and large-scale structures from infancy to maturity. This mission will also provide accurate (nearby, low-confusion) low-z templates required to understand the high-z phenomena. To complement the distant frontiers, SUVO will be able to thoroughly characterize nearby bright objects, with exquisite imaging and spectra.

SUVO will connect the high-redshift universe observable by NGST to the low-redshift universe, which SUVO can study in detail by wide-field imaging and quantitative spectroscopy. SUVO will also relate infrared and sub-mm observations of distant galaxies (NGST, FAIR/SAFIR) to optical and ultraviolet observations of the local universe. NGST observes the rest-frame ultraviolet light of the first stars, galaxies, and quasars, redshifted to 1–5 μm by cosmological expansion. For cosmological studies of the distant universe, space astronomy must adopt a multi-spectral view, in which NGST and SUVO complement one another, both in wavelength and across cosmological time.

Major Scientific Questions for SUVO:

Where is the rest of the unseen universe?

What is the interplay of the dark and luminous universe?

How did the IGM collapse to form the galaxies and clusters?

What is the role of star-formation "feedback" in radiation and energy on galaxies?

When were galaxies, clusters, and stellar populations assembled into their current form?

Are massive black holes a natural part of most galaxies?

What is the history of star formation and galactic chemical evolution?

How do extra-solar planetary systems evolve, and what do they look like?

2. Specific Connections to NASA/OSS Strategic Plan

Many scientific programs can be accomplished with wide-field imaging and high-throughput spectroscopy on a 4–8m telescope in space (SUVO or NHST). Among these, several projects are unique to SUVO and worth special emphasis as they pertain to OSS:

1. Mapping Dark Baryons and Large-Scale Structure

From recent galaxy redshift surveys, astronomers have detected the existence of an organized large-scale structure in the galaxy distribution, which takes the form of large filamentary walls and "empty" voids. With H I, He II, and O VI absorption, we are starting to detect the variety of warm photoionized and hot shocked baryons and test the predictions of Λ-CDM simulations of structure formation and feedback of galaxy formation. By 2010, galaxy surveys will have outlined the distribution of luminous matter in fine detail, but the dark, gaseous universe (the IGM) will remain largely unexplored at $z < 1.6$. SUVO will measure the distribution of dark baryonic matter and heavy elements in these filaments and voids, "tracing the cosmic web" using UV spectra of H I, C IV, O VI, etc. toward QSOs. The goal is to conduct an IGM baryon and metal survey on sub-degree angular scales, comparable to that of the MAP explorer and to the structure seen in galaxy surveys. In doing so, we will connect the high-redshift seeds of galaxies and clusters with the distributions of galaxies and metals in the modern epoch, at $z < 1$. This project is impossible without improvements in UV detectors, gratings, and spectrographs. To achieve a frequency of one QSO every $10' - 20'$ on the sky requires using QSOs at $m_B = 18 - 20$ as background targets. In the next several years, the GALEX mission is expected to identify 10^5 QSOs with $18 < m_B < 20$, and the Sloan survey will provide redshifts for $\sim 10^5$ QSOs brighter than $i = 19$.

2. Detecting Unseen Matter in the Modern Universe.

SUVO can use large-scale weak gravitational lensing to probe the underlying matter in galaxy clusters and superclusters, extending over $5 - 20h^{-1}$ Mpc. A $10' - 15'$ field of view (much larger than HST or NGST instruments) provides a good match to expected correlation lengths of cosmological structures at $z < 1$. Through its wide-field imaging, SUVO will use weak gravitational lensing to map out the distribution of dark matter in clusters of galaxies and perhaps on the supercluster scale. The inversion of the lensed arclets is best done in space, with the stable point spread function over a wide field in the optical band. One can also characterize dark-energy equations of state.

3. Studying the Feedback from Star Formation.

SUVO will follow the evolution of the universe from the "dark ages" down to the "renaissance" of star formation, supermassive black holes (quasars) and metal production. Measuring the evolution of the Lyα baryon content is vital if we are to understand the mass evolution of galaxies, the rate at which gas in the IGM is incorporated into galaxies, and the rise of metallicity over cosmic time. We can study the interplay between the formation of galaxy structures and the IGM and study mass eXchange: the depletion of the reservoir of intergalactic gas into galaxies, and the flow of mass from galaxies back to the IGM through galactic winds and tidal stripping.

4. Studying Galactic Star formation.

With its wide-field imagers, SUVO will be able to map, in a single pointing, entire Galactic H II regions in diagnostic emission lines and broad-band colors. Within the Milky Way, but also in nearby external galaxies, SUVO will study global star formation and the interactions between young hot clusters and the interstellar medium at scale lengths necessary to measure important physical processes (winds, shock waves, ablation of disks). The dynamic range of these images will allow studies of the stellar initial mass function from the most massive stars down to brown dwarfs.

3. Required Key Technologies

As discussed in great depth in the UVOWG White Paper, the SUVO Mission Concept will require significant NASA technology investments. Throughput is the single most important technology driver for the future of UV/O space astronomy, both for spectroscopy and for wide-field imaging. The key areas are: detectors, large light-weight precision mirrors, optical materials and coatings, and precise optical elements (gratings and micro-mirrors). The following short list highlights the most critical needs identified by the UVOWG:

- Develop more sensitive UV detectors, with low background noise (including cosmic-ray exclusion), high quantum efficiency (QE), large dynamic range, and large formats. Increasing detector QE in the UV can be as important as building larger mirrors.
- Space-qualify large mosaics of low-noise, high-QE CCD detectors (at least $16K \times 16K$) for wide-field imaging cameras in the optical and near-UV.
- Develop micro-mirror arrays for use in multi-object and integral-field spectrographs in the UV and visible.
- Develop large, lightweight precision mirrors for use in the UV/Visible. Although SUVO could be done with a 4m monolith, the extension to an 8m aperture will likely require segmented deployable optics.
- On a very long time scale, develop "3D" energy-resolving detectors such as photon-counting superconducting tunnel junction (STJ) or transition-edge sensor (TES) devices. These cryogenic detectors have the potential to revolutionize UV/O astrophysics. This cryogenic technology would be shared with other missions (e.g., far-IR and sub-mm).