The Ultraviolet Solar System Observatory (USSO)

Advancing Solar System Science, Space Technology, Astrophysics, and Human Spaceflight

Overview:

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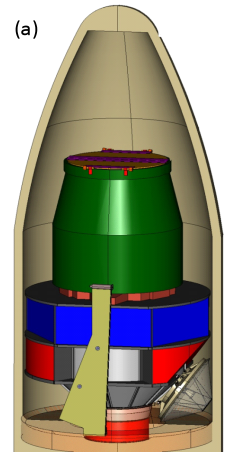
Key collaborator: Lockheed Martin Space Systems Company, Denver.

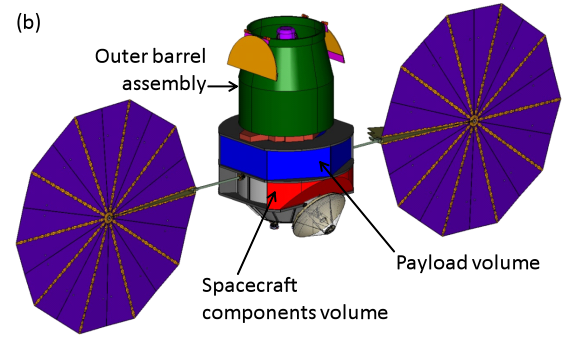
Goals:

1. Follow the movement of mass, momentum, and energy from the Sun to small bodies, planets, satellites, and the heliosphere.
2. Measure the organization, photo/ion chemical state, loss rates, and temporal evolution of planetary upper atmospheres.
3. Probe the cosmogonic significance of the elemental, molecular, and isotopic composition of sublimating material from pristine small bodies.
4. Observe the atmospheric composition of transiting extra solar planets.
5. Complementary Astrophysics research into high energy process in shocks regions, nebulae, galactic nuclei, and hot stars.

Advantage: Ultraviolet observations target ion and neutral resonance lines to follow energetic processes and track composition for targets in and beyond the solar system with minimal solar continuum.

Payload:





The USSO operation configuration for launch (a) and operation (b). USSO carries 3 primary instruments primary and with a 4th bay to support expansion and novel UV interferometric instruments. A deployable sun-shield to allow observations to within 25° of the Sun is not shown.

Spacecraft and Instrumentation Description:

- A high-heritage spacecraft design operating in a S-E L2 halo orbit.
- 2000 kg payload mass with ≤ 3000 W for science instruments.
- Dual coated mirror (r = 0.4-0.7m Al/MgF_2/B_4C, r = 0.7-1.2 m Al/LiF)
- Photon counting detectors with KBr, CsI, and CsTe photocathodes.
- High data rate for science via high power Ka and/or optical com.

Primary Science Instruments:

Broadband Flexible Field Imager:

- 30-300 nm spectral range. All reflective narrowband filters.
- Selectable reimaging optics for narrow (1.5' x 1.5' 0.04" pixels), medium (15' x 15', 0.4" pixels), and wide (30' x 30', 0.9" pixels) fields of view.

FUV-NUV Spectrograph:

- 90-300 nm bandpass.
- Selectable echelle option for high resolution.

EUV Long Slit Imaging Spectrograph:

- 30-90 nm bandpass. Single reflection Rowland circle design.

Stretch Technologies: Advanced mirror coatings. EUV interferometry.

Technology readiness: high-TRL detectors and spacecraft.

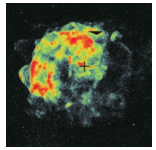
External collaborations: TBD

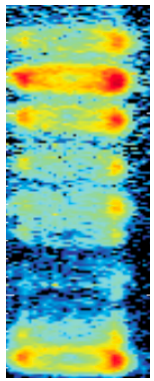
Human exploration capabilities: Robotic or Human Serviceable payload.

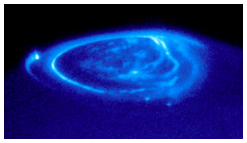
Broad Value of USSO to NASA:

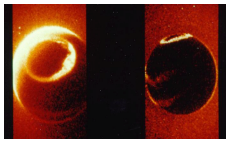
USSO will contribute to multiple NASA goals:

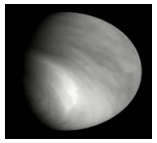
- Time domain studies of various planetary and small body near space regions will improve our understanding of *how the Sun and planets interact* over the solar cycle.
- UV transit studies will *characterize extra solar planets* with minimal parent star contamination.
- Small body observations will examine their *composition, heterogeneity, and formation history* in the early solar system.
- Heliospheric measurements will *probe ISM boundary*.
- High ionization state plasma measurements (astrophysical and solar system) reveal magnetic and shock properties of energetic systems like the Io torus, hot stars, and supernova remnants.
- Builds on the legacies of HST, FUSE, HUT, and EUVE.
- Provide test beds for new game changing technologies.
- Provide opportunities for remote human servicing.











USSO: The Ultraviolet Solar System Observatory:

Background: Observations in ultraviolet spectral range from 300-3000 Å are a proven tool for studies of a wide variety of energetic and compositional signatures in and beyond the solar system that range in scale from comet atmospheres to the interstellar medium. Most of the deeper UV spectral range is free from background contamination from stellar continua except for very hot stars. Within the solar system, this allows high signal to noise observation of emission line sources (both internally generated and from the scattering of solar resonance line emission) that can be used to study energy deposition, ionization & recombination processes, atmospheric escape, isotopic signatures, airglow, magnetized plasmas & drift, the heliopause crossing neutral ISM (H I and He I), and the high ionization state solar wind (e.g. O II, He II, Ne VII). Similar advantages exist for astrophysical studies in the UV, which enables measurement features such as background interstellar ionization (e.g. C IV, N V), shock features in supernova remnants (e.g. O VI), and stellar remnants. Reduced background also provides comparable opportunities for the study of UV line absorption during stellar transits of thin atmospheres, from line of sight ISM attenuation toward nearby stars, and absorption by the exospheric constituents of transiting extra solar planets. The treasure trove of information available to UV observers has increased our understanding of planetary near space, atmospheric composition & evolution, the origin of small bodies, the ISM energetic state, and the ISM interaction with stars and nebulae.

The terrestrial atmosphere prevents ground based UV observations. To get around this, over the past 40+ years, a series of space-based NASA observatories have been used to open the UV universe to study, including, mission such as the IUE, FUSE, EUVE, GALEX, and HST. This era of exploration produced an initial survey of the phenomena described above and has identified several avenues for more detailed study. Unfortunately, the last remaining of these great observatories (HST) is nearing the end of its mission with no planned replacement. Without a new resource for observations below 3000 Å, we will soon lose our window into this important spectral range.

New Opportunities: Here we describe the opportunity for a new era of ultraviolet astronomy built around a 2.4 m wide-field telescope. This facility, the *Ultraviolet Solar System Observatory* (USSO) will build on the legacy of previous missions with broad spectral coverage over an expansive range of UV wavelengths (300-3000 Å) sensed by a mix of high heritage state-of-the-art imaging & spectroscopic instruments and new, potentially game-changing technologies, all of which will be housed in a human or robotically serviceable payload bay. Though primarily directed toward solar system exploration, USSO will provide improved capabilities for the study of astrophysical targets, particularly wide-field features such as SNRs and the interstellar background.

Grand Questions: Building on the legacy of previous UV observational campaigns, USSO is designed to pursue 6 primary scientific questions that are responsive the NASA strategic plan for solar system exploration.

Scientific Question 1: How does the solar interaction affect the movement of mass, momentum and energy within a planetary environment? How does it affect the composition, organization, and energy balance of planetary upper atmospheres? *Approach: Temporally resolved imaging of*

the Corona, regions of atmospheric energy deposition, in situ plasma dynamics, auroras, airglow, and escaping neutrals (energetic and thermal). Spectroscopic study of particle deposition velocities, molecular line rations, and line broadening from radiative transfer or thermal effects.

Scientific Question 2: What is the nature of incoming neutral ISM and how is it modified by its transition across the heliopause? *Approach: Wide field all-sky imaging of the background of resonantly scattered solar emission from interplanetary H I and He I. combined with high-resolution spectroscopic measurements of their bulk velocity and velocity distributions. Search for changes during the solar cycle.*

Scientific Question 3: How and where did planets, comets, and asteroids form? What happened to the original water and other volatiles? Does pristine material remain locked in small bodies and are they uniform? *Approach: Measure the isotopic ratios in planet and comet atmospheres (e.g. from H_2, H, C^{12}/C^{13}, O^{16}/O^{18}. N^{14}/N^{15} etc). Spectroscopic search for Noble gasses (e.g. Ar/Ne/He) and compositionally significant molecular species (e.g. N_2, NH_4, S_2), Monitoring for chemical heterogeneity in small bodies from measurement of volatile outgassing rates on time scales from diurnal to heliocentric distance (seasons).*

Scientific Question 4: What are the compositions and physical distributions (e.g. loss lobes) of extra solar planetary atmospheres? *Approach: Spectroscopic measurement of atomic and molecular absorption and possible emission features (e.g. aurora). Temporal measurement of transit light curves.*

Scientific Question 5: How are sublimation driven planetary atmospheres organized? What are the seasonal effects on composition/pressure? What are the loss rates and trapping rates with location on a surface? How does energy deposition (UV radiation/charged particles) modify the chemistry/evolution/production of a thin atmosphere? *Approach: Spectroscopic measurements of volatile frost distributions (e.g. SO_2 on Io), outgassing from volatile rich regolith (Lunar polar craters) and surface sputtering by solar wind ions. Monitoring of comet activity profiles and the eclipse/egress behavior of vapor pressure equilibrium atmosphere. Occultation measurements of atmospheric attenuation. Temporal studies of seasonal and diurnal changes in atmospheric density, composition, and loss rates.*

The USSO Science Payload:

Target Bandpass: 300-3000A

Telescope Mirrors: Dual coating optical design on primary and secondary mirrors

- EUV optimized coating over a radius from 0.4-0.7 m (e.g. $Al/MgF_2/B_4C$).
- FUV-NUV coating over a radius form 0.7 to 1.2 m (e.g. Al/LiF-85%).

Expected Image Quality and Stability: Focal plane imaging PSF = 0.1". Spacecraft targeting *stability* < 0.25". Spacecraft pointing *knowledge* = 0.05". (Use active photon position correction.)

Pointing Limits: Solar Exclusion: 25° (Sunshield-deployable) Mercury targeting.

Orbit: Halo orbit at L2.

Duration: ½ to a full solar cycle

Primary Instrumentation:

Imaging: The primary imaging system will have selectable reimaging optics to provide 3 fields of different size onto detectors optimized for the NUV-EUV. The three channels will include a narrow field (1.5' by 1.5') option with ~0.04" pixels, an intermediate field (15' by 15') option with

~0.4" pixels, and a wide field (30' by 30') option with ~0.8" pixels. A filter wheel with all reflective narrow band filters will isolate important diagnostic emission lines.

Spectroscopy: USSO supports two spectroscopic channels.

- A 900-3000 Å spectral range spectrometer with multiple apertures for imaging spectroscopy and velocity resolution. Multiple grating options will select bandpass within the full range and an echelle mode (with selectable cross disperser) will provide high resolution.
- A 300-900 Å single grating (e.g. Rowland circle) long slit spectrometer will provide low to intermediate resolution in the EUV.

Technical Innovations: USSO will explore the addition of two emerging capabilities.

- New coating technologies for the FUV (heat treatment/molecular beam) with up to 90-95% reflectivity above 900Å.
- All-reflective wide field of view broadband heterodyne spectrometers with km/sec velocity resolution.

The USSO Spacecraft Design:

The Lockheed Martin spacecraft design utilizes established hardware, software, technology, and processes from Earth sensing, planetary spacecraft, and powerful space-based astronomical observatories built by LM in the last 40 years.

The bus is a combination of flight proven heritage components and subsystems configured for the Large Optical Payload. The spacecraft supports a 2000 kg payload/instrument mass and provides up to 3000 W of total power to the science instruments. The bus uses a compact, stiff structure that has been tailored to an optical payload and designed for compatibility with Atlas V, Delta IV, and Falcon launch vehicles. Its simple design is highly centralized, enabling straightforward integration of the telescope payload, high pointing stability, low disturbances for long stare times, and thermal stability. A human or robotically serviceable payload midsection accommodates at least three instruments via an isolated optical bench, provides all instrument interfaces needs, and offers the ability for each instrument to be readily exchanged. The high-heritage approach also relies on LM's proven ability to integrate large optical systems (Hubble, SIRTF, GeoEye-2) and related planetary flight systems.

The baseline telecom system provides high data rates for science by virtue of the large power budget available for data transmission, and the stable pointing. The avionics and power distribution systems provide common interfaces and functionality for instruments assuring low risk, and uses proven flight software. A capable GN&C system provides precision pointing and control that meets the requirements of the focal plane imager.

Operation: The spacecraft operates in a halo orbit at the Sun-Earth L2 to minimize Earth coronal contamination and permit direct observations the lunar exosphere and terrestrial space environment with the wide field imager. Once in the final science orbit, the spacecraft has six basic operational modes: (1) UV/EUV observations of the major planet systems, (2) Small body UV/EUV observations for high value targets of opportunity, (3) UV/EUV observations of fixed astrophysical targets, (4) Time critical planetary transit observations, (5) contextual observations of the lunar and terrestrial near space, and (5) Data downlink with Earth. It is expected that science observations are competed in line with utilization of other ground- and space-based high-capability assets.