The High ORbit Ultraviolet-Visible Satellite, Horus Astrophysics and Planetary Science

Jet Propulsion Laboratory
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Overview:

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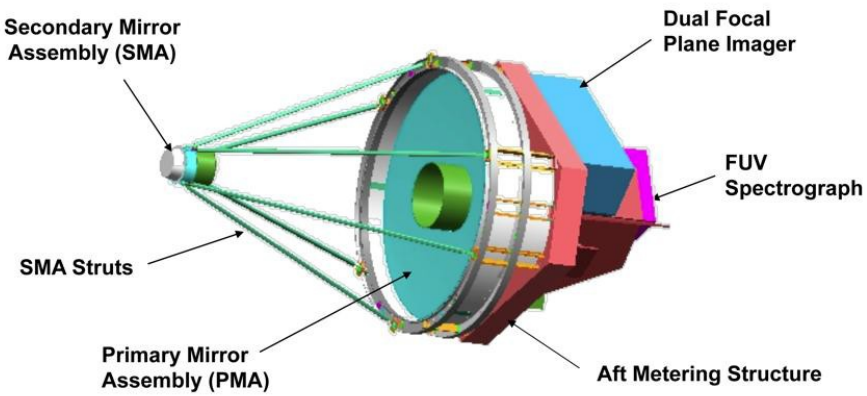
The *HORUS* mission will study planetary atmospheres, the solar system and beyond in the UV and visible, contributing vital information on how solar systems form and survive, and whether habitable planets should be common or rare. It also will investigate the structure, evolution, and destiny of galaxies and the Universe, relying on focused capabilities unique to space that no other planned mission will provide: a wide (14') FOV with 0.05 arcsecond angular resolu1on (0.04 arcsecond pixels) and UV 100-320nm spectroscopy at up to R=40,000.

Graphic:



Description:

HORUS will enjoy a stable environment for thermal and pointing control, and long-duration target visibility. We baseline using L2 for orbit, but will consider GEO with servicing capability as a trade. The UV/optical Imaging Cameras (200-1100nm) use two 21k x 21k Focal Plane Arrays (FPAs) consisting of tiled Si CCD elements. The FUV spectrometer (100-320nm) uses cross strip anode based MCPs improved from HST-COS technology. All utilized technology is TRL 6 or above.

The following observations (both imaging and spectroscopic) are planned:

- Determine atmospheric processes in Solar System planets to serve as analogs to extrasolar planets.
- Characterize the atmospheres of transiting exoplanets
- Determine the evolution of gas and ionizing radiation in the inner regions of young planetary systems in our Galaxy.
- Survey nearby galaxies to assess the role of starbursts in their evolution.
- Measure element production rate in the nearby Universe
- Characterize galaxy assembly at high redshift.

A General Observer Program is included in the mission lifetime. Currently, no utilization of human exploration capabilities is envisioned.

Value to NASA:

This proposed concept addresses key science themes in planetary atmospheres, origins of solar systems, star formation, element production, galaxy formation and evolution, and structure of the Universe outlined in the 2010 decadal survey of Astrophysics and is complementary to the goals of WFIRST.

HORUS represents a major step in our understanding of the structure and evolution of the Universe and how it ultimately led to the formation of our planet Earth. It utilizes advanced telescope, instrument and detector technology, in particular UV detector technology and UV coating technology (ALD Al/MgF_2).

This improved understanding of star, planet and element formation is complementary to the human exploration of solar system bodies.

HORUS' near-UV-visible dual-channel camera and FUV spectrograph provide a powerful general observing facility to a large community of Guest Observers.

While HORUS is an Astrophysics mission, it also addresses topics in both Planetary Science and Space Technology development.

THE HIGH ORBIT ULTRAVIOLET-VISIBLE SATELLITE, *HORUS*

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Primary Concept Goal Category:
Astrophysics

Abbreviated Concept Summary:

The High-ORbit Ultraviolet-visible Satellite (*HORUS*) is a 2.4-meter class space telescope that will conduct a comprehensive and systematic study of the astrophysical processes and environments relevant for the births and life cycles of stars and their planetary systems, to investigate and understand the range of environments, feedback mechanisms, and other factors that most affect the outcome of the star and planet formation process. *HORUS* will provide 100× greater imaging efficiency and combines the resolution of *STIS* with the throughput of *COS*. The *HORUS* mission will contribute vital information on how solar systems form and whether habitable planets should be common or rare. It also will investigate the structure, evolution, and destiny of galaxies and the universe.

This program relies on focused capabilities unique to space that no other planned NASA mission will provide: near-ultraviolet (UV)/visible (200-1100nm) wide-field (14' square), diffraction-limited imaging; and high-sensitivity, high-resolution FUV (100-320nm) spectroscopy. From its baseline orbit at L2 *HORUS* will enjoy a stable environment for thermal and pointing control, and long-duration target visibility. The core *HORUS* design will provide wide field of view imagery and high efficiency point source far-ultraviolet (FUV) spectroscopy using a novel combination of spectral selection and field sharing.

The *HORUS* Optical Telescope Assembly (OTA) design makes optimal use of the SALSO capabilities using a three-mirror anastigmatic configuration to provide excellent imagery over a large FOV. The UV/optical Imaging Cameras use two 21k x 21k Focal Plane Arrays (FPAs) consisting of multiple tiled Si CCD elements. The FUV spectrometer uses cross strip anode based microchannel plates (MCPs) improved from *HST-COS* technology. Fine guidance sensing is accomplished via Si arrays mounted at the Cassegrain focus.

Goal of the Proposed Application:

The *HORUS* science program employs a multi-step approach in which both imaging and spectroscopy contribute essential information to our investigation and can be completed inside a 3-year mission.

Goal 1 — In order to understand the formation and evolution of circumstellar protoplanetary disks and other detailed aspects of star and planet formation in a wide variety of different environments, we shall conduct an imaging census of all high-mass star formation sites within 2.5 kpc of the Sun down to physical resolutions of 50's of AUs to determine how frequently solar systems form and survive, and develop observational criteria from our data that connects the properties of ionized gas to the underlying stellar population and distribution of protoplanetary disks.

HORUS' FUV spectroscopy provides a unique tool for observing the inner molecular disk of protoplanetary systems. High-resolution, high-throughput spectroscopy will allow measurement of the radial gas profiles in rotating disks and determine gas disk lifetimes. FUV observations of photoexcited CO and H_2 emission will be used to measure the Lyα radiation field to understand protoplanetary disk chemistry during planet formation.

Observations of exoplanet atmospheres via FUV spectroscopy will reveal the temperature and pressure profiles of low-mass exoplanets, and sensitive NUV spectroscopy may reveal the presence of biomarker molecules (e.g. O_2 and O_3) on Earth-like exoplanets.

Goal 2 — In order to understand the influence of star formation on the evolution of galaxies we plan to survey all major star forming regions in the Magellanic Clouds, where we can still resolve relevant physical scales and structures, access starburst analogs, and sample star formation at low metallicity applicable to high-redshift galaxies. The

HORUS Magellanic Clouds Survey consists of three components: I) A complete-area, broadband survey in 8 UV-optical filters; II) A narrowband survey in 7 nebular filters to cover 21 HII regions and a large-area, contiguous survey of the diffuse, warm ISM; and III) a comprehensive FUV spectroscopic survey of 1300 early-type stars. The science areas to be investigated include: A) Massive star feedback in both HII regions and the diffuse, warm interstellar medium (ISM); B) A comprehensive study of the 30 Doradus giant extragalactic HII region; C) Quantitative parameterization of stellar clustering properties; D) FUV studies of early-type stellar atmospheres and energy distributions; E) FUV absorption-line studies of molecular cloud structure and ISM extinction properties.

Goal 3 — We intend to learn how galaxies evolve through studies of their stars. To this end we will extend the *Goal 2* star formation survey to galaxies in the nearby universe in order to increase the range of galaxy interaction and metallicity environments probed. *HORUS* can observe entire galaxies surveyed by *GALEX* and *Spitzer* with more than 100× better spatial resolution. We shall employ a full set of analysis options extending from color-magnitude diagram fitting for resolved stars to modeling of multi-band colors through population synthesis to derive physical properties of target galaxies. This program relies on *HORUS'* powerful combination of a substantial field of view, wavelength agility, sensitivity, and angular resolution that will allow the first full survey of galaxies to be undertaken with a 2.4m telescope at diffraction-limited resolution. The resulting 21st century digital 'Hubble Atlas' of ~100 representative nearby galaxies will provide a standard for testing our understanding of how galaxies came to have their present forms and how their stellar components are likely to evolve.

Goal 4 — In order to determine how galaxies assemble and how the elements critical to life such as C and O are generated and distributed through cosmic time, we plan to measure star formation and metal production rates in the distant universe.

• Measure the luminosity function (LF) of dwarf galaxies from $z \approx 9$ to $z \approx 5$. Stars at the high-mass end of the Pop II initial mass function (IMF) in these objects likely completed the reionization of the universe by $z \approx 6$.

• Measure galaxy assembly in the redshift range $5 \geq z \geq 1$. With ≥ 8 UV-optical filters, exquisite photometric redshifts will be available for 6×10^5 objects to AB ≤ 27 mag.

• Using specific galaxy classes that are rare locally but abundant at high redshifts (e.g. "tadpole" galaxies), we will directly measure the strongly epoch-dependent merger rate, and hence constrain how the Cosmological Constant, Λ, has affected galaxy assembly.

The origins of modern galaxies lie in their accretion of gas from the intergalactic medium (IGM), their return of matter, metals, and energy to the IGM, and in galaxy/galaxy mergers and interactions. *HORUS* will address three important issues in conclusive fashion: (1) the bimodal accretion of baryons into galaxies, via "hot", "cold", or "multiphase" accretion, (2) the return of the products of star formation to the IGM, and subsequent feedback effects, by supernova-driven winds, and (3) the "missing baryons" in the IGM, both directly seen and as indicated by their interactions with cooler gas in IGM/galaxy interface regions.

Benefits of the Application:

This proposed concept addresses several key science themes in origins of solar systems, star formation, element production, galaxy formation and evolution, and structure of the Universe outlined in the 2010 decadal survey of Astrophysics and is complementary to the goals of *WFIRST*.

HORUS represents a major step in our understanding of the structure and evolution of the Universe and how it ultimately led to the formation of our planet Earth. This improved understanding of star, planet and element formation is complementary to the human exploration of solar system bodies.

Top-level Description of the Design, Operation, and Results:

The *HORUS* OTA design effectively utilizes the 2.4m SALSO telescope with minor changes to its two mirrors limited to recoating with *HST*-like UV Al+MgF_2 to establish FUV sensitivity. We add our instrumentation in the region behind the current OTA structure. We are compatible with the current opto-mechanical interfaces. Component alignment tolerances are small, but reasonable. LOS jitter will be controlled at a fractional pixel level (10 mas - 3σ) to maintain our specified 50 mas spatial resolution. Based on our error budgeting diffraction-limited imagery can be achieved at 500 nm with *HST*-like mirror tolerances.

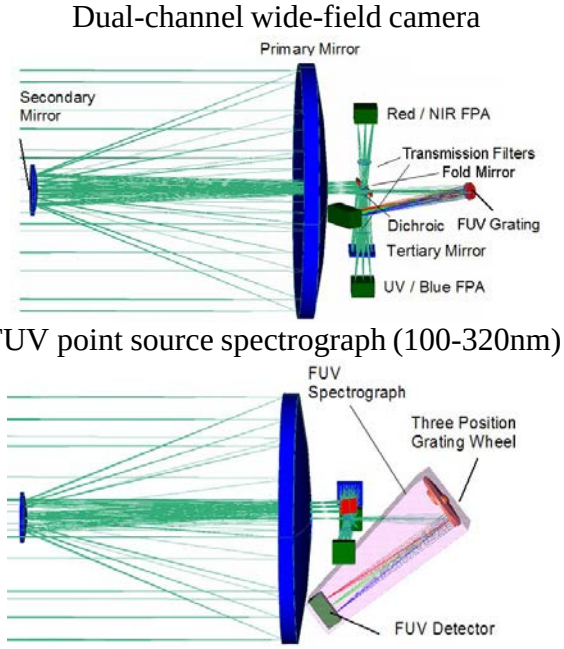

Figure 1 – *HORUS* baseline instruments.

The design, packaging, costing, risk assessment and mitigation have already been through two design sessions at JPL and two assessments with their Team-X facility. It is a mature solution for the 2.4m OTAs.

We use a novel approach to package both imaging instrumentation and the FUV spectrograph channel. The entrance slits of the UV channels are positioned at the Cassegrain focus of the OTA, while the imaging instruments are at the TMA focal plane. The image quality on-axis is adequate for the small FOV spectrometers, so this design ensures maximum FUV throughput with only two mirror reflections and one grating using the *COS-HST* approach.

HORUS uses a dichroic beamsplitter to image UV-blue, red wavelengths onto separate 21k×21k mosaics providing the 14' field, behind a large suite of broad and narrow-band imaging filters. Our baseline detector system uses mosaics of large format CCD detectors optimized for each passband by the JPL Delta-Doping technique combined with appropriate anti-reflection coatings. The FOV is simultaneously imaged in the blue and red channels, increasing the observing efficiency by a factor of two. The detector and optical performance are optimized for the bandpass of each channel.

To address the manufacturing of a large number of science grade large format detector arrays, JPL has recently scaled up its UV/Vis/NIR back-illuminated detector fabrication processes and facility infrastructure to meet large FPA mission deliverables. This infrastructure includes JPL's acquisition of a state-of-the-art Si-MBE system that enables up to 8-inch wafer level processing of detectors, as well as batch processing of multiple wafers to the point where a lot run of wafers can be processed quickly. This capability increases the throughput and reproducibility over equivalent die-level processes.

UV performance is increased by the combination of high-reflectivity UV-coatings on the gratings (R=100 through 40,000; 3× improvement per optic at λ <1100Å) and low-noise borosilicate glass photon-counting detectors (10× lower-noise than *COS*).

We originally baselined launching *HORUS* into a semi-stable orbit at Earth-Sun L2, where it would enjoy a stable environment for thermal and pointing control, long-duration target visibility, and the absence of geocoronal Ly-α. However, we intend to trade this baseline against a GEO orbit to provide a servicing capability. The spacecraft bus is derived from the *SIRTF* bus. We envision a three-year primary mission followed by many years of addition observation capability.