The Origins Space Telescope Mission Study

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The *Origins Space Telescope* is an evolving concept for the *Far-Infrared Surveyor* mission, and the subject of one of the four science and technology definition studies supported by NASA Headquarters to prepare for the *2020 Astronomy and Astrophysics Decadal Survey*. The *Origins Space Telescope* will discover or characterize exoplanets, the most distant galaxies, nearby galaxies and the Milky Way, and the outer reaches of our solar system (**Figure 1**). In this article, we expand on some key science drivers identified by the team, describe the status of our study, and solicit your science and technology ideas and input to our process.

Figure 1: *Origins Space Telescope* science themes range from the cosmic origin of dust and metals to the formation of habitable planets (credit: Hurt/IPAC).

[1] See http://origins.ipac.caltech.edu or http://asd.gsfc.nasa.gov/firs/team for a list of study team members.

Science Drivers

Formation and Characterization of Exoplanets and Exoplanetary Systems

The *Origins Space Telescope* will open a vast discovery space in the study of cool exoplanets in habitable zones and in following the trail of ingredients needed to foster life in exoplanetary systems.

Targeting exoplanet observations in the 6–40 micron wavelength range, it will measure the temperatures and search for basic chemical ingredients for life in the atmospheres of small, warm planets. The *Origins Space Telescope* will be able to detect the thermal emission peak of cool exoplanets at habitable temperatures (~300 K) at wavelengths where the planet-to-host star contrast is most favorable, and measure their atmospheric composition. This may be accomplished by a combination of transit spectroscopy and direct coronagraphic imaging. Important atmospheric diagnostics include spectral bands due to ammonia (a unique tracer of nitrogen), the 9 micron O_3 line (ozone; a key bio-signature), the 15 micron CO_2 band (carbon dioxide; an important greenhouse gas), and many water bands.

Leveraging orders of magnitude of improvements in sensitivity over past missions in the mid- to far-infrared range, the *Origins Space Telescope* will also trace the path of water as both ice and gas from the interstellar medium (ISM) to the inner regions of planet-forming disks, and definitively measure the total masses of disks around stars across the stellar-mass range out to distances of 500 pc.

The *Origins Space Telescope* will also address fundamental questions on how planetary systems evolve after they initially form by determining the true frequency of Kuiper-belt analogs and measuring the mineral and volatile composition of a large sample of debris disks. Finally, it will determine the frequency of wide-orbit ice giants (Uranus and Neptune analogs) by imaging gravitationally sculpted debris-disk structure.

Evolution of Galaxies over Cosmic Time

By exploiting sensitive spectral diagnostics of both ongoing star formation and galactic nuclear activity, the *Origins Space Telescope* can trace the co-evolution of stars and supermassive black holes in galaxies over more than 95% of the age of the universe — penetrating even the most heavily dust-obscured galaxies.

Specifically, the *Origins Space Telescope* will directly measure the star formation and black hole accretion rate densities from $z \sim 3$ to the Epoch of Reionization, and quantify the effects of feedback from supernovae and active galactic nuclei on the decline in the cosmic star-formation rate density. With access to a rich set of infrared diagnostic lines, and the ability to map large areas of the sky, the *Origins Space Telescope* will measure multiple phases of the ISM in a very large sample of galaxies to infer the physical conditions that regulate star formation as a function of redshift, age, nuclear activity, and galactic environment.

Using extinction-free tracers, the *Origins Space Telescope* will chart the rise of metals and the dust enrichment in galaxies and will also provide a unique astrophysical probe of the conditions of the intergalactic medium at $z > 6$ and the galaxies that dominated the epoch of reionization.

Finally, because the infrared contains unique signatures of dust and warm molecular hydrogen, the *Origins Space Telescope* will be able to study the properties of the first stars via the fingerprints they leave in the ISM, and detect some of the earliest forming structures as they collapse and cool via H_2 emission out of the cosmic web.

Nearby Galaxies, Milky Way

Origins Space Telescope studies of the ISM in the Milky Way and nearby galaxies will provide fresh insights to link our understanding of the formation of stars and planetary systems with the evolution of galaxies over cosmic time.

Most of the fundamental diagnostic tools for such studies are found in the far-IR: the peak and long-wavelength tail of the dust spectral energy distribution, and the dominant cooling lines for most ISM phases. In addition to pushing into new regimes of sensitivity and angular resolution with these fundamental tracers of ISM energetics and physical state, the *Origins Space Telescope* will provide an array of powerful new tools for studying star formation and the energetics and physical state of the ISM.

The *Origins Space Telescope* will enable a comprehensive view of magnetic fields, turbulence, and the multi-phase ISM, connecting physics at all scales, from galaxies to protostellar cores. With unprecedented sensitivity, the *Origins Space Telescope* will measure and characterize the mechanisms of feedback from star formation and active galactic nuclei over cosmic time and trace the trail of water from interstellar clouds, to protoplanetary disks, to Earth itself — in order to understand the abundance and availability of water for habitable planets.

Solar system

Studies of our own solar system with the *Origins Space Telescope* will contribute to our understanding of the connection between star-formation processes and the development of habitable environments. Current models of the solar system formation are not well constrained and still await detailed measurements of the outer solar system objects.

The *Origins Space Telescope* will chart the role of comets in delivering water to the early Earth. It will trace the molecular heredity and probe the distribution of small bodies in the outer solar system, significantly advancing our understanding. A survey to measure the deuterium-to-hydrogen ratio in comets will provide a statistical sample to constrain the cometary contribution of water and other organics to Earth and other terrestrial bodies.

Additionally, the *Origins Space Telescope* will survey thousands of ancient trans-Neptunian objects in the outer solar system (>100 AU). The telescope's unprecedented sensitivity will allow for a thorough investigation of the size distribution of these small bodies down to sizes of less than 10 km. A large survey will provide tests of the formation scales of planetesimals and evolutionary models of the early solar system, contributing to our understanding of planetary system formation by bridging traditional discipline boundaries.

The mission study status

Over the summer of 2016, the *Origins Space Telescope* Science and Technology Definition Team (STDT) engaged the community to develop breakthrough science proposals for our mission study. More than 32 community-driven science proposals were developed by five science working groups covering: (1) Solar System; (2) Planet Formation and Exoplanets; (3) Milky Way, Interstellar Medium, and Nearby Galaxies; (4) Galaxy and Black Hole Evolution over Cosmic Time; and (5) Early Universe and Cosmology.

Potential relevance of the science to the *2020 Decadal Survey in Astrophysics* was assessed by the STDT, with due consideration given to the likely persistence of the science question into the late 2020s. The measurement requirements of the 14 top-ranked proposals were used to select a baseline architecture. The *Origins Space Telescope* will be an actively cooled, filled-aperture telescope with an effective diameter likely between 8 and 15 meters (**Figure 2**).

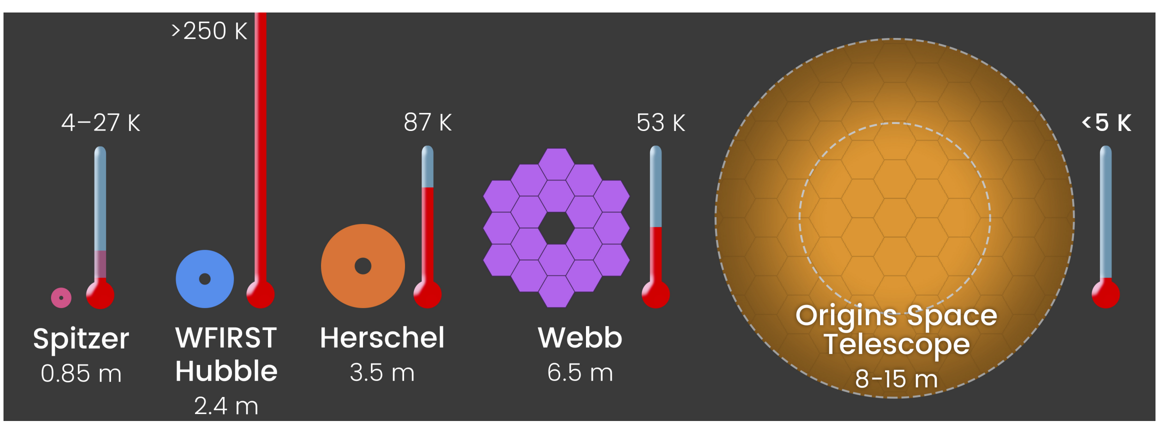

Figure 2: With a large, actively cooled telescope, the *Origins Space Telescope* will attain sensitivities 100–1000 times greater than any previous far-infrared telescope (credit: Hurt/IPAC).

During the November 2–3, 2016 (Boulder, CO) face-to-face meeting, the *Origins Space Telescope* STDT defined the requirements for the instrument suite. Five instrument studies have been identified: a far-infrared imaging polarimeter; a mid-infrared instrument with imaging, low resolution spectroscopy and coronagraphy; a wide field low resolution spectrometer, a high resolution far-infrared photon detection spectrometer and a high resolution heterodyne spectrometer. The combined instrument and telescope will offer a tremendous sensitivity increase over prior missions (**Figure 3**) enabling spectacular progress across astrophysics.

Key enabling technologies for the *Origins Space Telescope* are under development or approaching maturity. The greatest technology need is for large arrays of detectors with sufficient sensitivity to attain astrophysical-light photon background performance (Figure 3). All components need to be cold, with detectors at ~50 mK and the telescope optics at ~4 K. These temperatures can be obtained with existing or incrementally improved cryocooler systems, sub-Kelvin coolers, and careful observatory thermal design. Instrument technologies such as compact direct-detection spectrometers are also needed to enable fast, multiplexed spectroscopy.

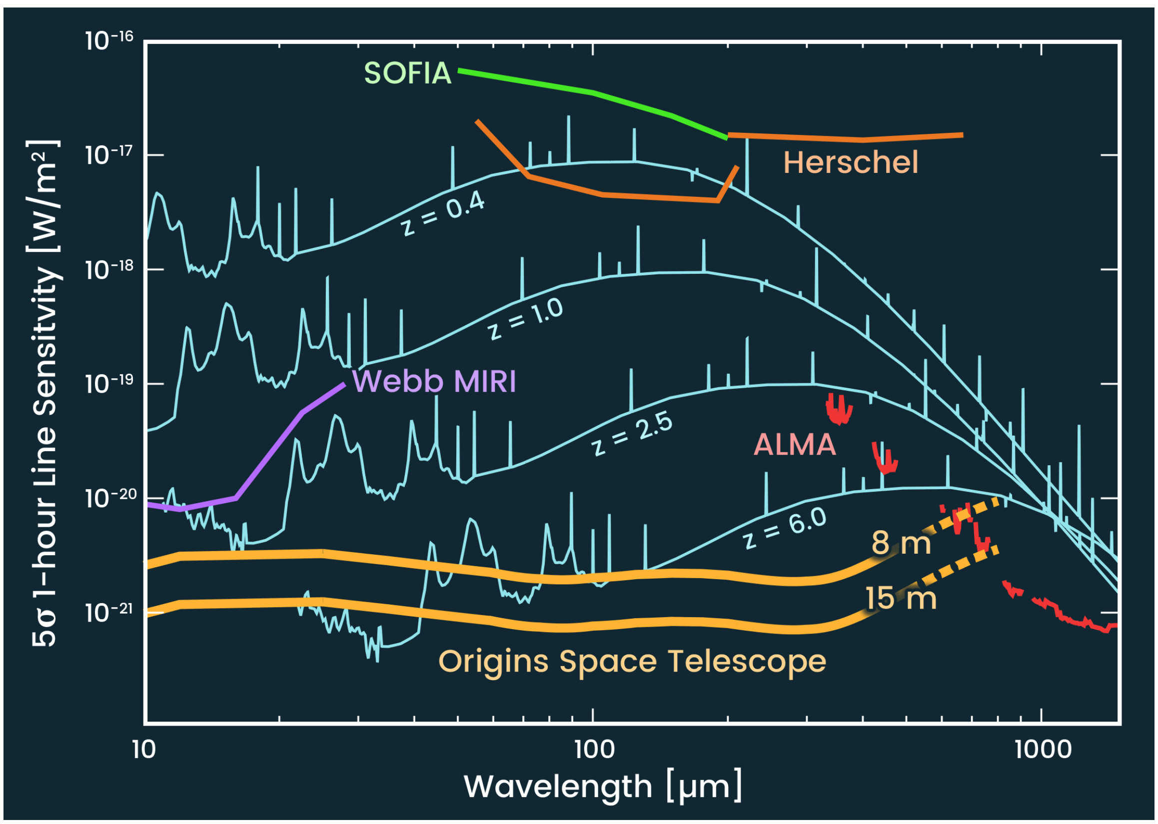

Figure 3: Unprecedented sensitivity — Fast mapping speed with hundreds or thousands of independent beams will enable 3D surveys of large areas of sky, pushing to unprecedented depths to discover and characterize the most distant galaxies (spectra shown above for redshift values up to $z = 6$), and measure low surface-brightness circumstellar disks and faint objects in the outer solar system (credit: Bradford/JPL).

Contribute your ideas!

We will continue to develop the scientific requirements for and detailed design of the *Origins Space Telescope* and instruments. All members of the scientific community are encouraged to participate in future discussions. There will be a discussion of the study at the Far-IR Science Interest Group meeting (January 6) at the upcoming January 2017 AAS meeting in Grapevine, Texas, where there will also be a special session on Decadal Missions (January 7). In addition to talks and presentations on the *Origins Space Telescope*, representatives of the *Origins Space Telescope* study team will be present at the NASA Cosmic Origins exhibit booth throughout the AAS meeting. Members of the community interested in contributing to the science case for the *Origins Space Telescope* should contact any member of the STDT (http://origins.ipac.caltech.edu or http://asd.gsfc.nasa.gov/firs/) or email us at ost_info@lists.ipac.caltech.edu.