Exoplanet Science with the Origins Space Telescope

Tiffany Kataria (NASA JPL/Calfornia Institute of Technology) on behalf of Kevin B. Stevenson (STScI) and Jonathan J. Fortney (UCSC), STDT members and Exoplanet Science Working Group Co-Leads and the OST Exoplanets Science Working Group

Sept 18, 2018

The OST NASA Decadal Study

• NASA Astrophysics Roadmap "Enduring Quests-Daring Visions", formerly known as Far-Infrared Surveyor • Goal: large general astronomy mission with exciting science that is technologically executable in 2030s • OST study has two concepts: Mission Concept 1, completed, described in interim report - Mission Concept 2, design reviews underway, will be described in final report due early next year

From first stars to life

- *Are we alone?* OST question: How common are life bearing planets around **dwarf stars?** With sensitive mid-infrared transit spectroscopy, OST will measure biosignatures, including ozone, carbon-dioxide, water, and methane in the

How did we get here? **OST question: How do the conditions for habitability develop during the process of planet formation?** With the sensitive and highresolution far-IR spectroscopy OST will map the water trail in our Galaxy.

- How does the Universe work? OST question: How do galaxies form stars, make **metals, and grow their central supermassive blackholes from reionization to today?** OST will spectroscopically 3D map wide extragalactic fields to measure simultaneously properties of growing super-massive blackholes and their galaxy

- zones. This determines how many target stars we have to observe to fnd a certain number of exoEarths. As described in Section 2.2, this percentage will be securely determined with data from Kepler, TESS, and $\mathcal{F}(\mathcal{F})=\mathcal{F}(\mathcal{F})$ the habitable $\mathcal{F}(\mathcal{F})$ the habitable $\mathcal{F}(\mathcal{F})$ target stars are. Dust in the habitable zones (exozodiacal dust) comes *years ago, contained large amounts of gases released from volcanoes. Right: Earth's present-day atmosphere, containing abundant free oxygen coming from life. Credit: NASA*
	- around nearby stars will likely be limited by light from this dust. The astronomical community has recognized the importance of \mathcal{C} p assess that the assess typical exozodiac dust levels to assess that $\mathcal{P}(\mathcal{P})$ (Astro2010 Decadal Survey). NASA has funded construction and operation of a ground-based instrument to perform this $\mathcal{L}_{\mathcal{B}}$ on the Large Binocular Telescope at $\mathcal{L}_{\mathcal{B}}$ \mathcal{A} arizona, which is now being commissioned. LBTI science \mathcal{A} they become incorporated into asteroids and comets. We need to directly detect water in protoplanetary disks and map its locations. Although some by-products of water, such as deuterated species, are visible at millimetersubmillimeter wavelengths, the chemical processes creating them may have multiple pathways leading to inconclusive results about the distribution and evolution of water in other star systems. In the next 0 years, the Far-IR Surveyor will directly measure water emission lines from young stellar systems identifed by ALMA and JWST. It would also provide the resolution needed to distinguish whether water is present everywhere in a star system or only in its outskirts. Moreover, by studying star systems at different evolutionary stages, we should be able to determine how the distribution of water evolves with time. *Debris Disks* DeBrIs disks are the evolutionary link between gas-rich protoplanetary disks and mature planetary systems, representing the late stages of planetary system formation (**Figure 3.3**). These low-mass dusty disks around main-sequence stars are produced by colliding and evaporating asteroids and comets, the building blocks of planets. <ounger debris disks (0±00 million years) are the likely sites of ongoing rocky planet formation. In older systems (0.± billion years), impacts by water-rich asteroids from the outer stellar system may be delivering water and other volatiles to young rocky planets. Probing the composition of debris disks will reveal the makeup of planetary building blocks. In this area have been made with HST, which have been made but to survey more than Must a few systems, the LUVOIR Surveyor's much greater sensitivity is needed.
- atmospheres of Earth-sized habitable exoplanets.
-
- hosts across cosmic time.

ORIGINS
Space Telescope OST SC **OST Science Program**

Sensitivity of OST to water and disk masses

OST is designed to create a complete census of: 1. Volatiles (traced by water) from the ISM to exoplanetary atmospheres around all

- stellar types
- 2. Planet-forming gas mass in the Galaxy

OST will assess the habitability of nearby exoplanets and search for signs of life. **Are we alone?**

Ozone

 (O_3)

10µm

Methane
(CH₄)

 $5 \mu m$

Carbon Dioxide
(CO₂)

$20 \mu m$

Wavelength, um

Why the mid-infrared?

• Access to **thermal emission** and the temperature structure of atmospheres • Absorption features for a range of interesting gases • Broad wavelength coverage for context and the detection of the unexpected

Why transiting exoplanets?

- Precisely determined masses and radii
- Stellar (and planetary) radii to \sim 5% with GAIA
- Bulk densities for planetary classification before atmospheric characterization
- We can target planets known to be predominantly rocky

Why M dwarfs?

- 75% of stars within 15 pc are M dwarfs
• Expect to detect about a dozen HZ • Expect to detect about a dozen HZ exoplanets transiting mid-to-late M dwarfs within 15 pc (later slides) • Four such planets are already known (TRAPPIST-1d,e,f and LHS-1140b)
- Advantages of small planets transiting smaller stars
	- Larger transit depths
	- Closer habitable zones (5 100 days)
	- Increased transit probability in HZ
-

T. Henry, RECONS survey

Mid-Infrared Spectrometer and Camera (MISC) Instrument

-
- Simultaneous wavelength coverage from 3-22 microns
	- Spectral resolving power ($\lambda/\Delta\lambda$) of R=50-300
- HgCdTe detectors will be developed to meet science requirements (noise floor goal of $<$ 5 ppm over 3-10.6 µm)
- MISC design is insensitive to telescope jitter (Matsuo et al, 2016) • MISC will be sensitive to key spectral signatures (H2O, CO2, O3, CH4, N2O) for HZ planets with Earth-like atmospheres transiting mid-to-late M dwarfs

TRAPPIST-1e-like planet (0.91 Earth radii), TRAPPIST-1-like star (2560 K, Kmag = 8), Earth-like atmospheric composition, 64 visits, R=100, 5ppm noise floor for MISC

ORIGINS

Space Telescope

OST Exoplanet Papers

- **Tremblay** et al., NAS ESS White paper • **Tremblay** et al., in prep
	- Question: How well can we can constrain the presence of biosignatures in the atmospheres of terrestrial HZ planets orbiting M stars? – Trades explored: Aperture size, wavelength coverage, atmospheric
	- type
- **Zellem** et al., in prep
	- Question: What are the estimated yields of terrestrial HZ M dwarf planets? What metrics will we use to select targets?
- **Morley** et al., in prep
	- Question: What planetary types will we characterize with OST?

ORIGINS Transmission Spectroscopy Wavelength coverage

Earth-Like Enhanced methane

Emission Spectroscopy Thermal constraints

for Earth-like Atm (4-22um)

Layer-Cake Observing Strategy

Ancillary Exoplanet Science with OST

100 K Jupiter Neptune

- Characterizing Jupiter- and Neptune-class atmospheres at closer to solar system temperatures, beyond the reach of JWST • Jupiter and Saturn analogs through time via coronography (an upscope) • Thermal phase curves and eclipse mapping of terrestrial HZ planets
- 1000 K

3000 K

Teff

- 300 K
- HD 209458b GJ 436b WASP-12b

Conclusions

- M dwarfs are important targets in the search for life
- OST will target terrestrial planets in the habitable zone of M dwarfs to detect biosignatures and constrain habitability
- OST will enable technical advances with detector technology
- Ultimately, OST will leverage previous heritage of characterizing transiting exoplanets, extending high-fidelity measurements to the mid-IR which are best studied via transit spectroscopy

Earth-like case

TRAPPIST-1e-like emission/transmission spectra, 64 visits each, R = 50, Kmag = 8 Optimistic 30 ppm noise floor for MIRI/LRS, 5ppm for OST

Enhanced methane case

TRAPPIST-1e-like emission/transmission spectra, 64 visits each, R = 50, Kmag = 8 Optimistic 30 ppm noise floor for MIRI/LRS, 5ppm for OST

Planet/star occurrence

Transiting Exoplanets within 15pc

How many M dwarf planets? Figure 12 shows that SPECULOOS will be well sensitive to Earth-sized planets, its most likely detected planet being an Earth-sized world on a ⇠2d orbit around a ⇠0.09 *M* star with a *K*-mag around 12. This harvest has of course to be taken with a pinch of salt, as the planetary population of UCDs is still poorly explored. Nevertheless, the planetary population of UCDs is still poorly explored. Nevertheless, the planetary population of UCDs there are only 81 objects with *K*-mag 10.5 in the SPECULOOS target list, including TRAPPIST-1 (*K*-mag =

planets - including 0-2 temperate ones - within ⇠1-3 systems. The detection of TRAPPIST-1 is thus consistent

with a high frequency (a few dozens of %) of compact systems of Earth-sized planets around UCD stars. But we

simulations, and resulting harvest (*bottom*). SPECULOOS estimated yields, Delrez+2018

Atmosphere types

