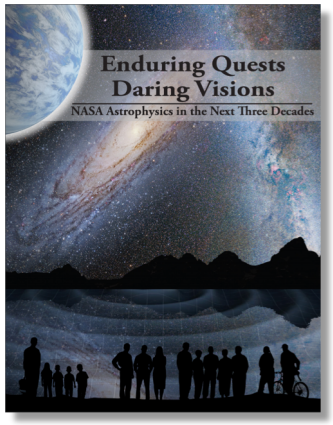
Origins Space Telescope:

Meixner: Science

Leisawitz: Mission

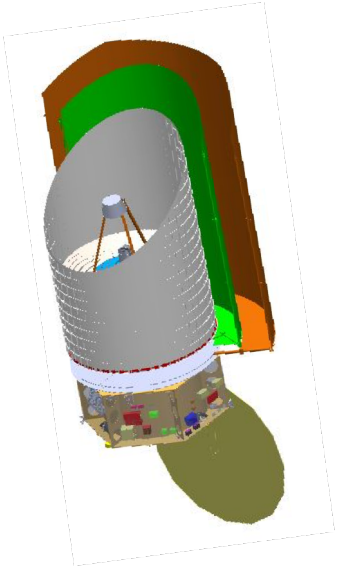
Dipirro: Cryo & Technology

From the community, by the community, and for the community



Through the Astrophysics Roadmap, the community expressed interest in a “Far-IR Surveyor” mission.

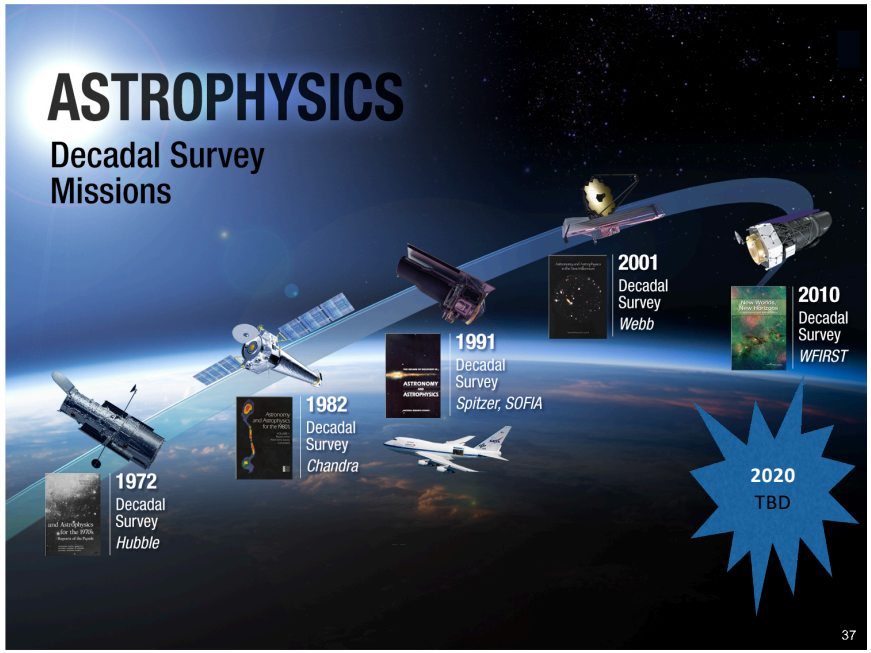
The OST Science and Technology Definition Team engages with and represents the community and directs the Decadal mission concept study.



Guest Observers will use OST to answer the mission-driving science questions and make unexpected, transformative discoveries.

Study goal

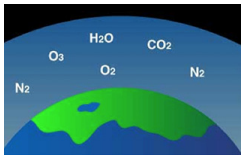
Deliver a scientifically compelling, executable mission concept to the 2020 Astrophysics Decadal Survey by June 2019.



NASA has a strong track record when it comes to implementing the large missions recommended in past Decadal Surveys.

OST is one of four large missions under study. The others are Lynx, HabEx, and LUVOIR.

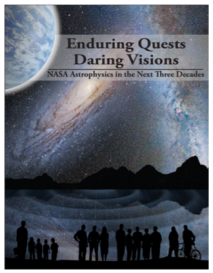
Top three themes



(I) Are we alone? OST goal: OST will assess the habitability of nearby exoplanets and search for signs of life.

(II) How did we get here? OST question: How do the conditions for habitability develop during the process of planet formation?

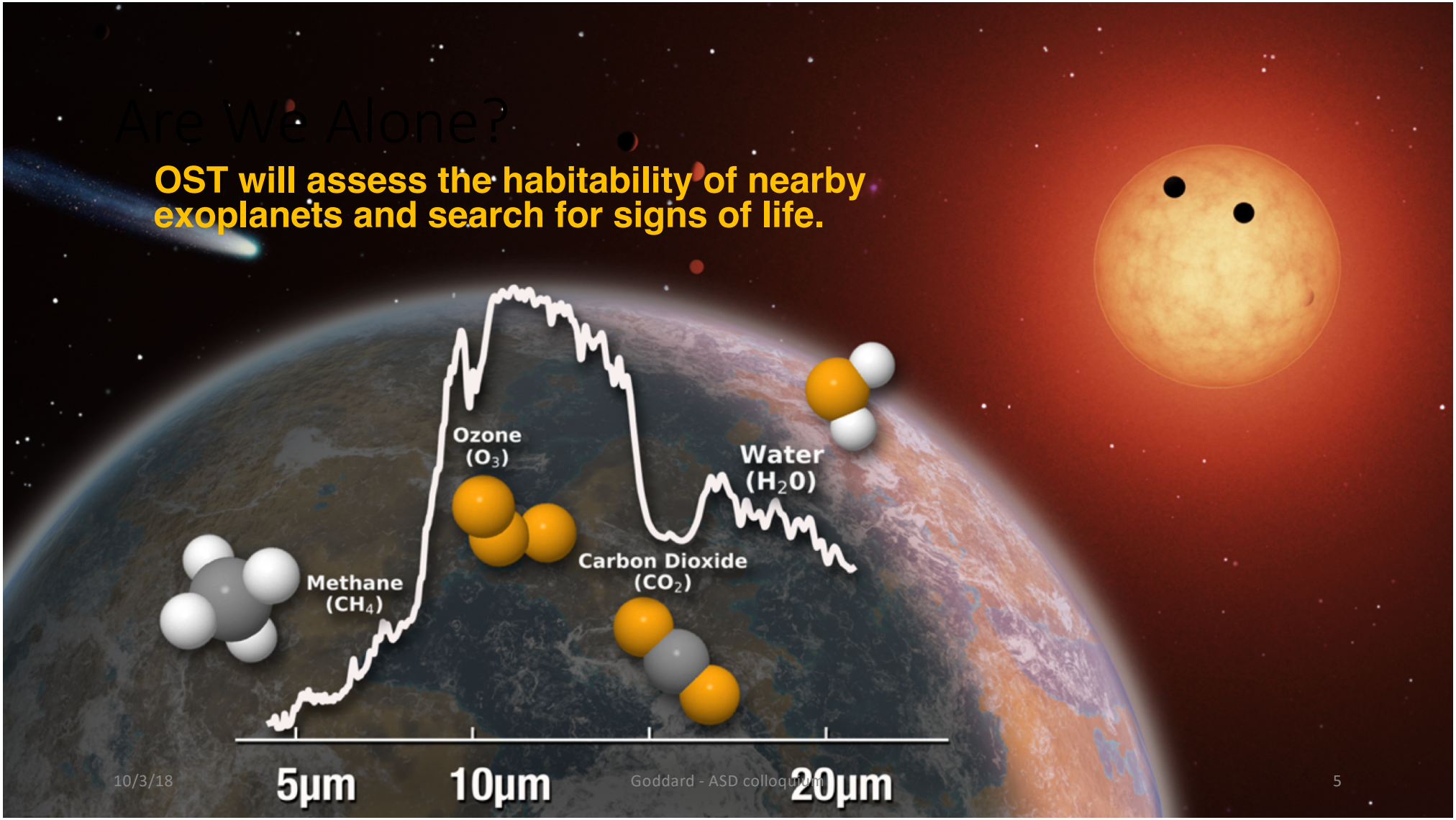
(III) How does the Universe work? OST question: How do galaxies form stars, make metals, and grow their central supermassive blackholes from reionization to today?



OST level-0 goals map to 2013 NASA Astrophysics Roadmap top-level goals (I): Exo-Planets; (II) Cosmic Origins; (III) Cosmic Origins+Physics of Cosmos

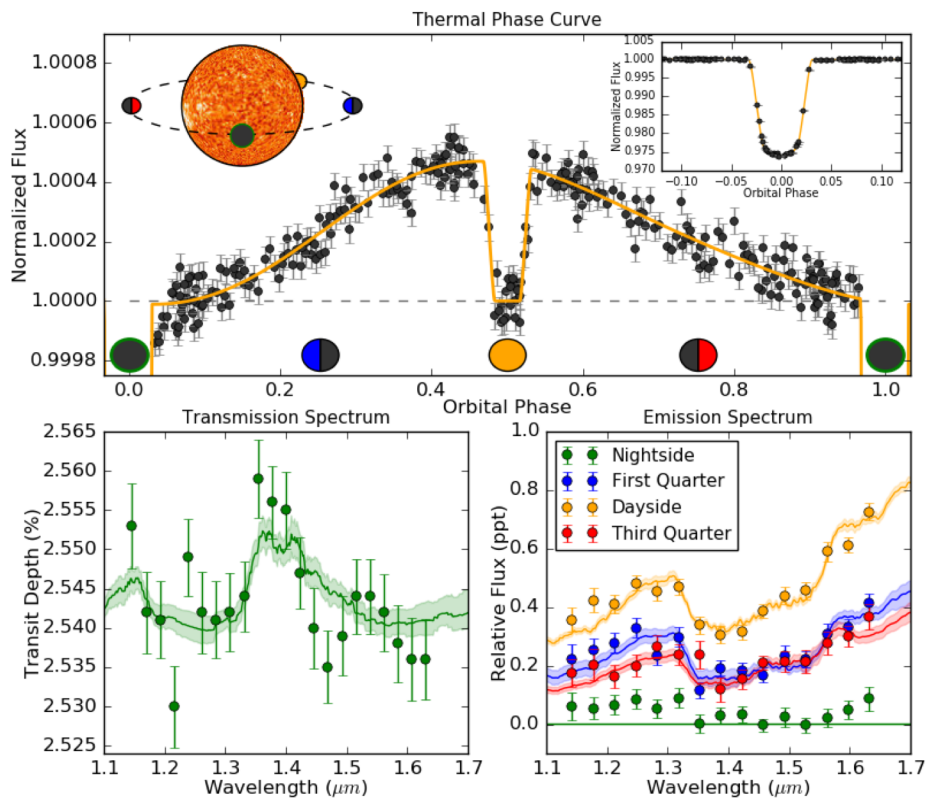
Are We Alone?

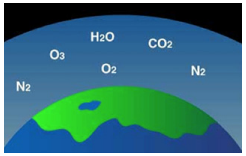
OST will assess the habitability of nearby exoplanets and search for signs of life.



Geometry of Transiting Exoplanets

- Primary Transits
  - Phase = 0 & 1
  - Transmission spectrum
- Secondary Eclipses
  - Phase = 0.5
  - Dayside emission spectrum
- Thermal Phase Curves
  - Phase = 0 to 1
  - Phase-resolved emission spectrum

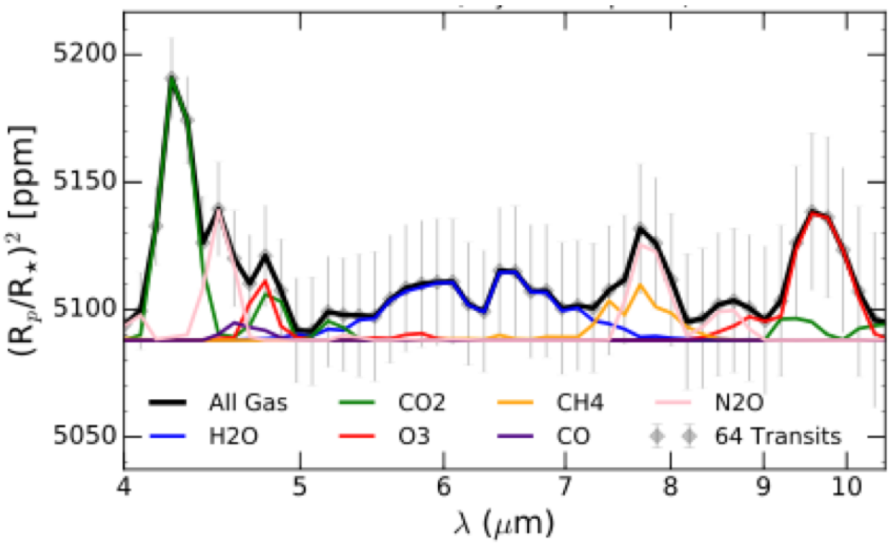




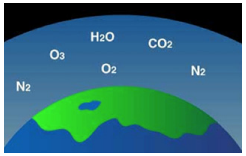
OST will assess the habitability of nearby exoplanets and search for signs of life.

Science Objective 1: Characterize the atmospheres (clear or cloudy) of 10 habitable-zone (Teq < 400 K), terrestrial (<1.6 REarth) exoplanets in spectral regions containing bio-indcators (CO2, H2O), enabling a culling of the sample down to 5 candidate life-bearing planets for followup.

Tier-1: Observations of 10 candidates, 4 transists

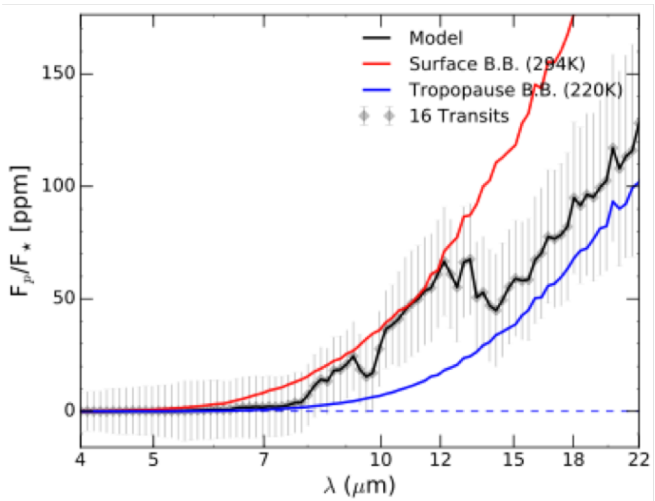


Model transmission spectra for a TRAPPIST-1e like planet with an Earth-like atmospheric composition with a dry stratosphere orbiting a Kmag=8 star. The uncertainties assume 4 transits using OST MC2 and a noise floor of 5 ppm.

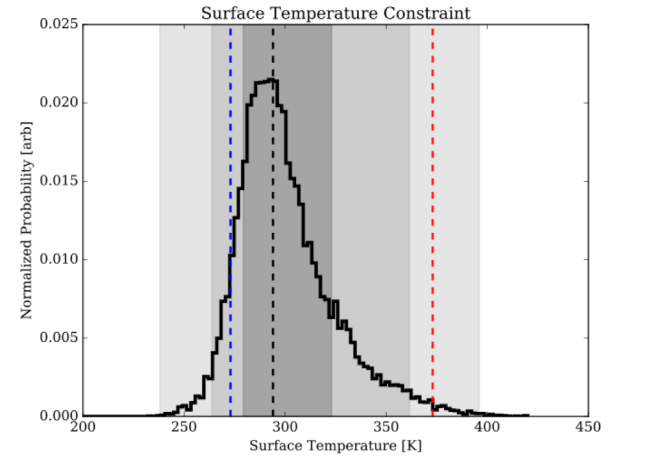


OST will assess the habitability of nearby exoplanets and search for signs of life.

Science Objective 2: **Constrain the temperature, Tsurf, at the apparent surface of 5 habitable zone exoplanets with detected bioindicators, to be consistent (at >95% confidence) with liquid water.**



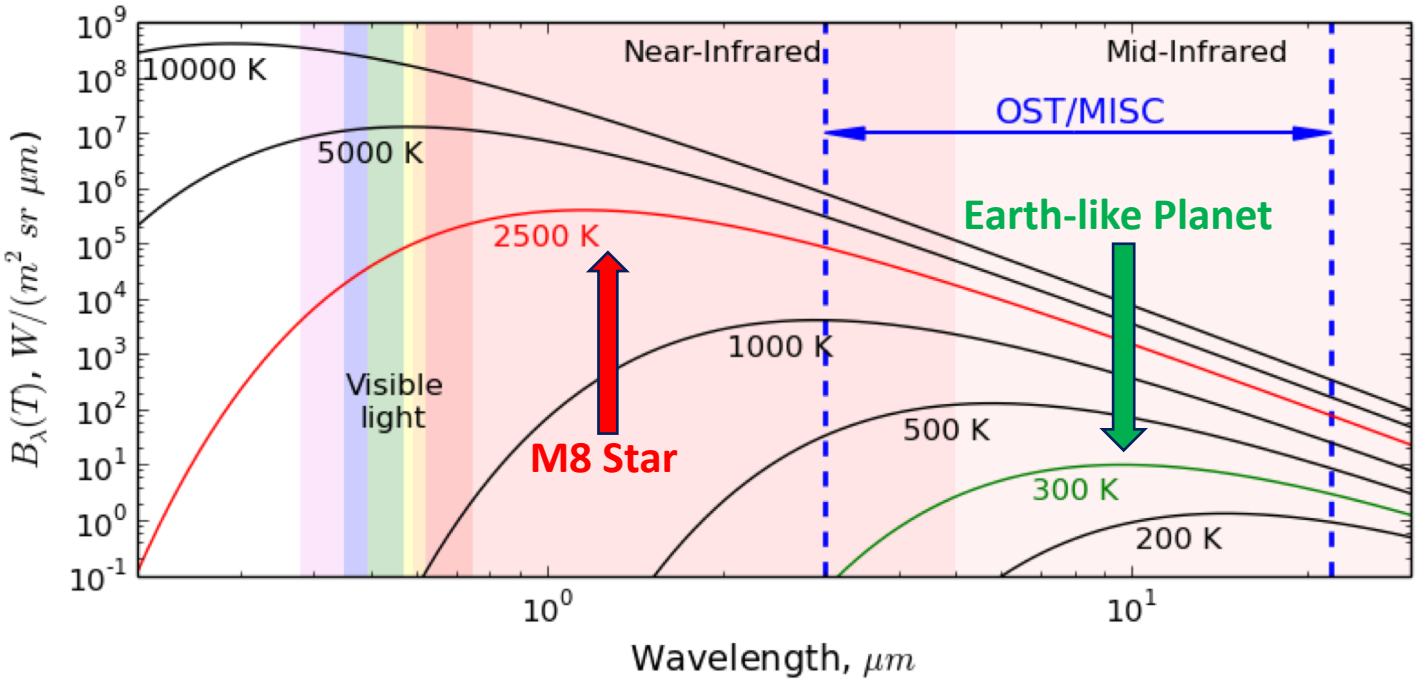
Model emission spectrum for a TRAPPIST-1e like planet with an Earth-like atmospheric composition and temperature profile orbiting a Kmag=8 star. The uncertainties assume 16 eclipses using OST MC2 and a noise floor of 5 ppm.



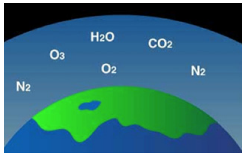
Surface temperature constraint for the above scenario. The red and blue vertical dashed lines indicate boiling and freezing, respectively, and the black the input value. The shading shows the 68, 95, and 99.7% confidence intervals

Tier-2: Observations of 5 candidates, 16 eclipses

Thermal-IR Advantage



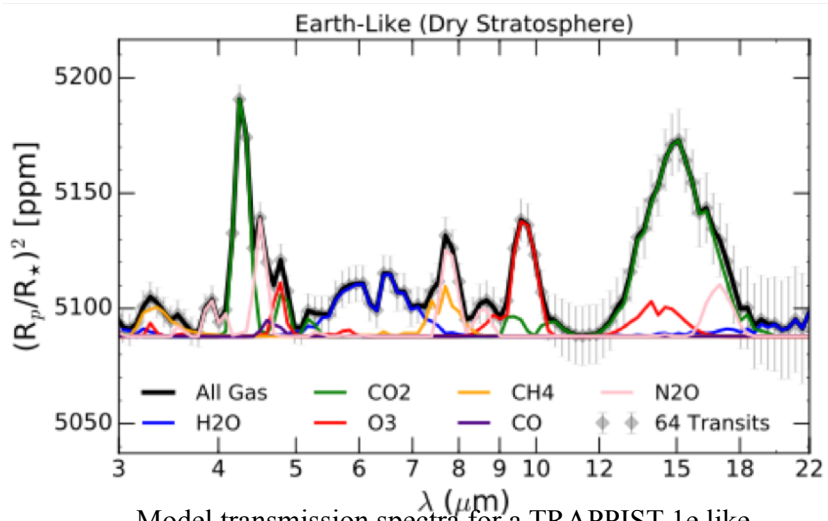
- Planet-star contrast ratio always improves at longer wavelengths
- Overall SNR falls off at >22 µm
- HZ SNR sweet spot is 8 – 10 µm



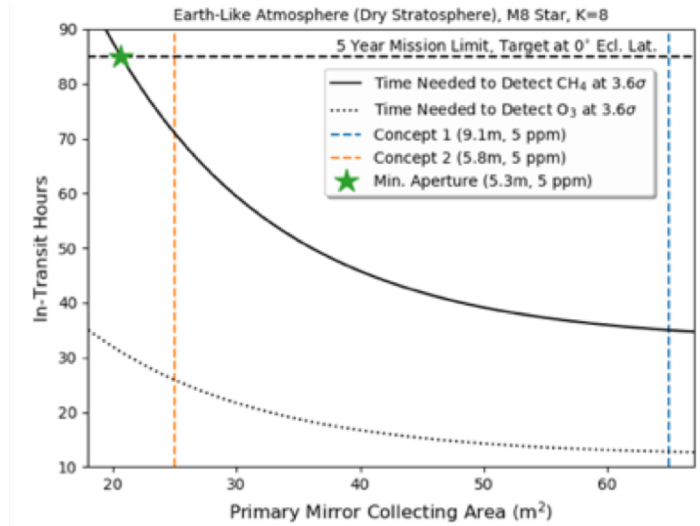
OST will assess the habitability of nearby exoplanets and search for signs of life.

Science Objective 3: Confirm the presence of biosignatures at 3.6s (assuming an Earth-like atmosphere), if they exist, in the atmospheres of the 4 highest-ranked temperate Earth-like exoplanets.

Tier-3: Observations of 4 candidates, 64 transists

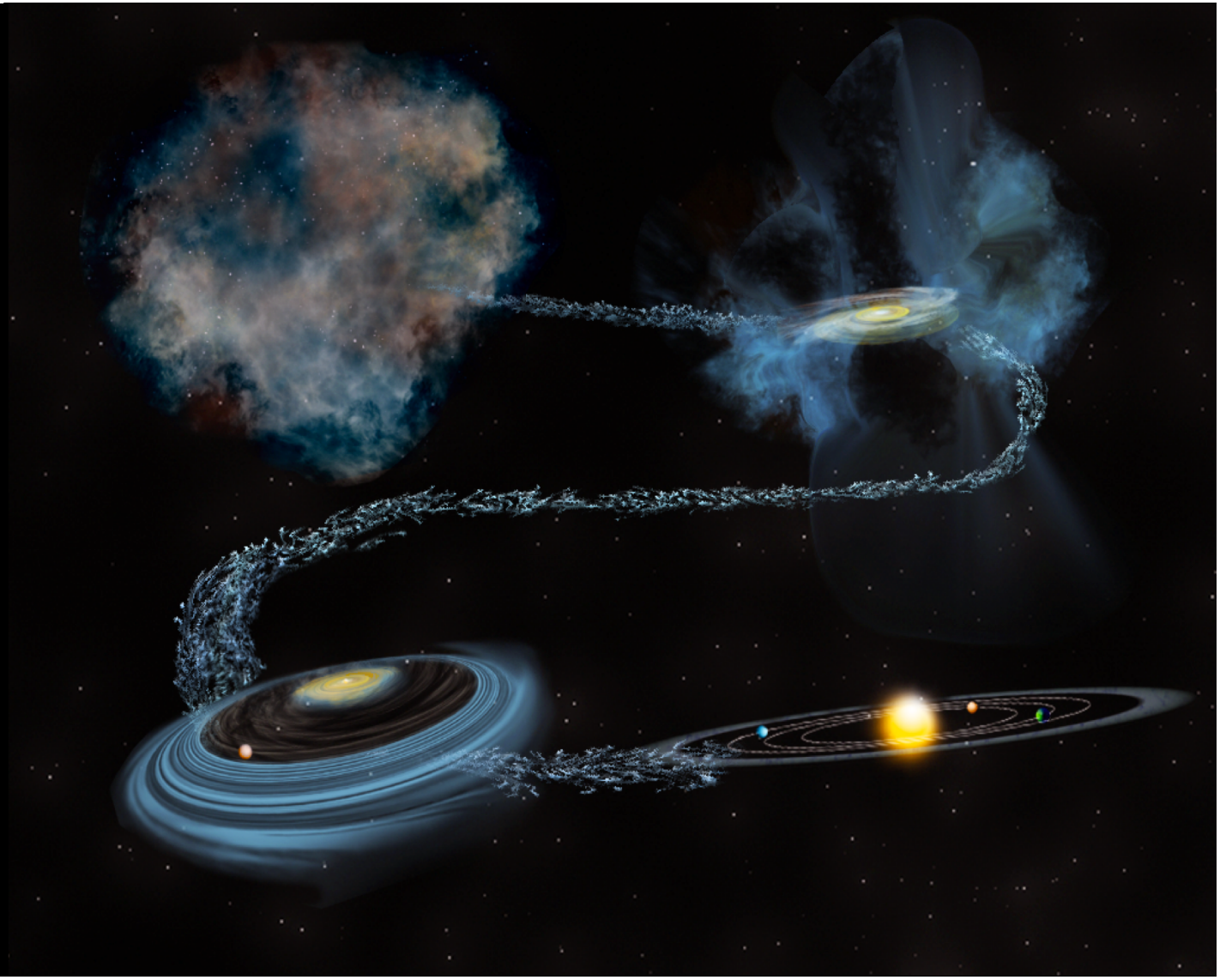


Model transmission spectra for a TRAPPIST-1e like planet with an Earth-like stratospheric composition orbiting a Kmag=8 star. The uncertainties assume 64 transits using OST MC2 and a noise floor of 5 ppm



Number of in-transit hours needed to detect methane (solid curve) and ozone (dotted curve) at 3.6 sigma confidence as a function of telescope primary mirror size.

How do the conditions for habitability develop during the process of planet formation?



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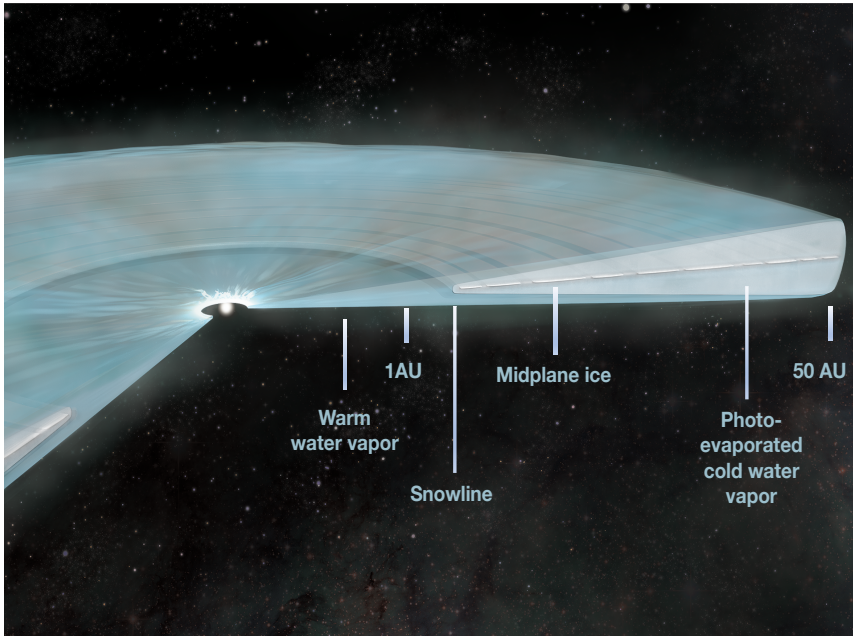
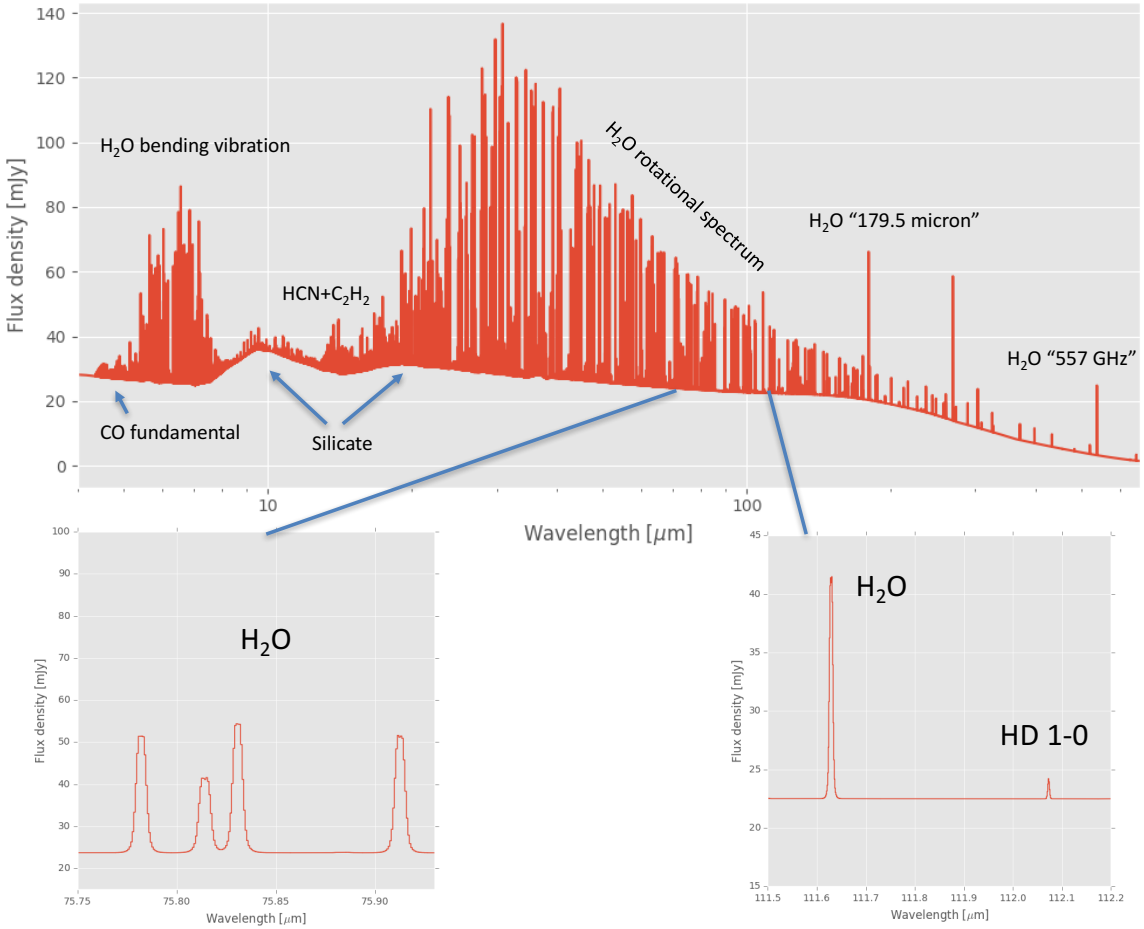
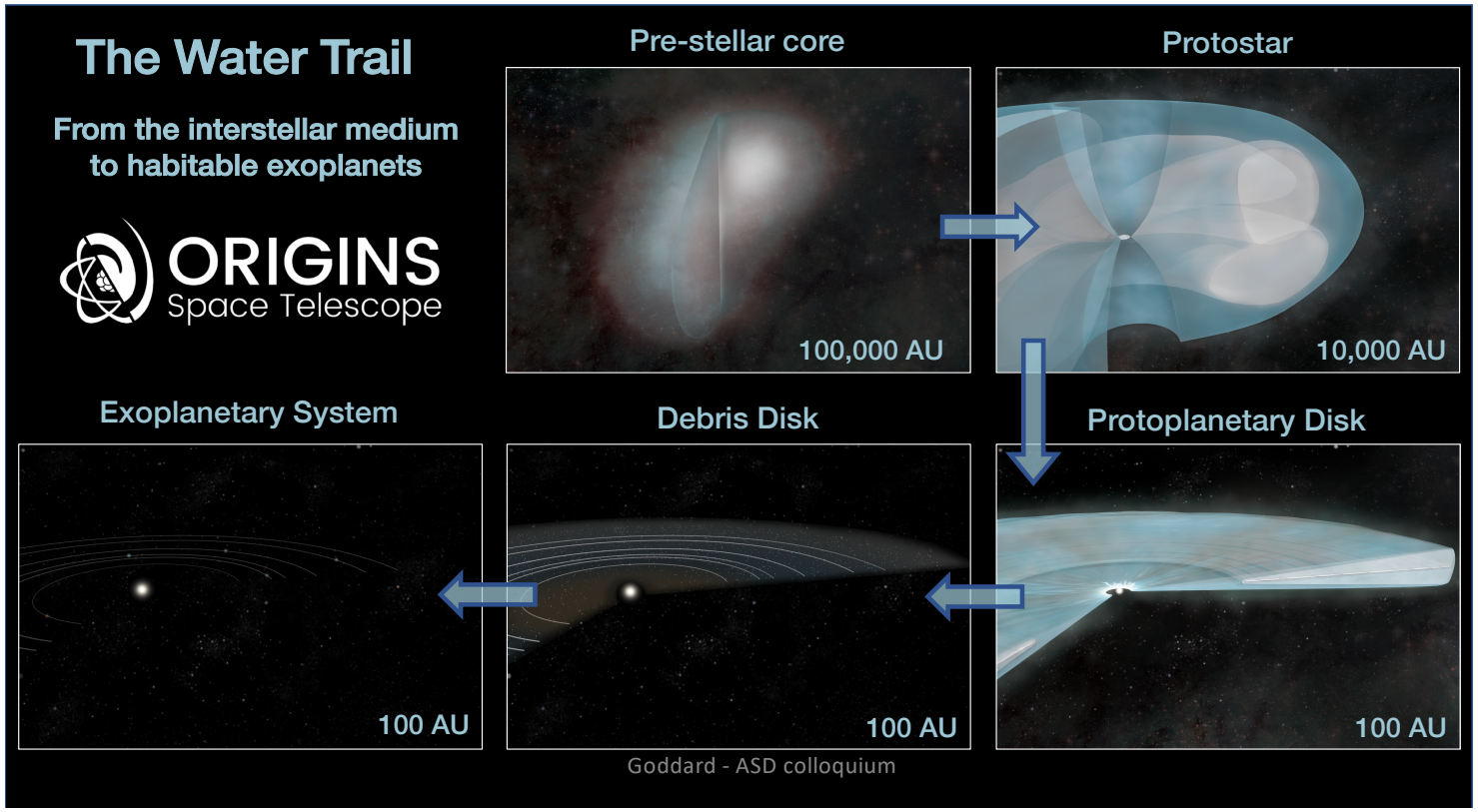




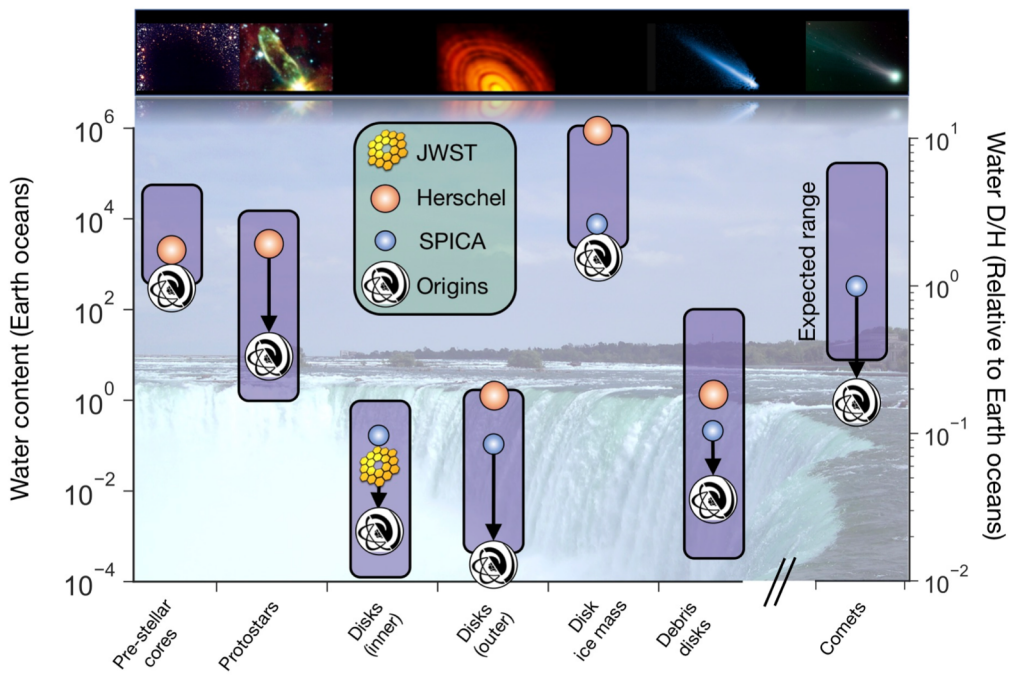
How do the conditions for habitability develop during the process of planet formation?

Science Objective 1: Measure the water mass at all evolutionary stages and across the range of stellar mass tracing water vapor and ice at all temperatures between 10 and 10,000 K.



How do the conditions for habitability develop during the process of planet formation?

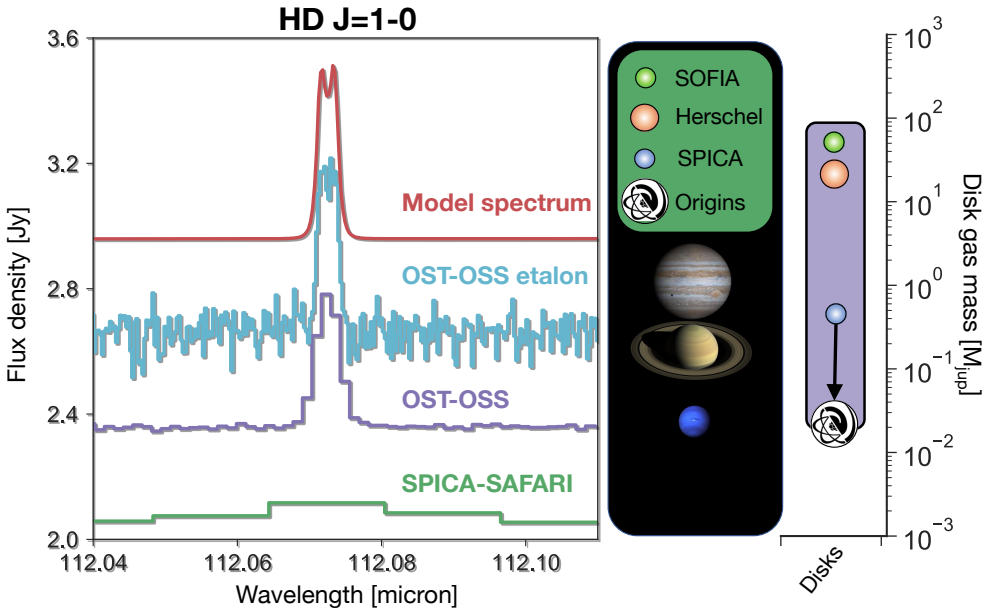
Science Objective 1: Measure the water content in all evolutionary stages and across the stellar mass range tracing water vapor and ice at all temperatures between 10 and 10,000 K down to fundamental chemical limits.



OST will make the definitive statement on the disposition of water as stars and planets are assembled.

How do the conditions for habitability develop during the process of planet formation?

Science Objective 2: Determine the planet-forming disks gas mass from the mass of Neptune to 300 Jupiter masses in over > 500 disk systems via HD J=1-0.

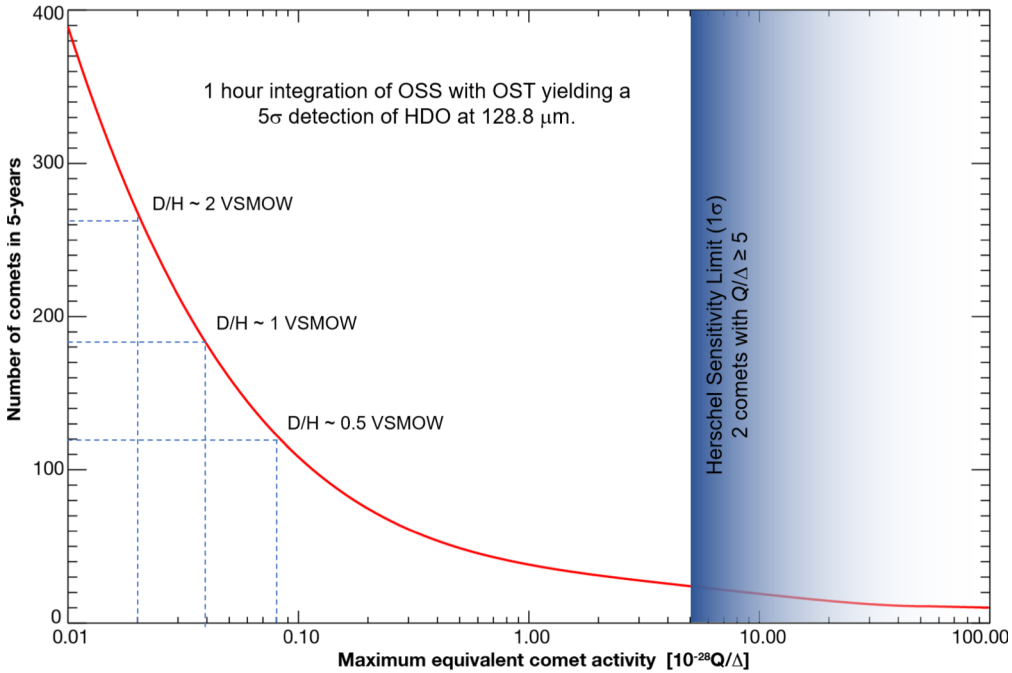


OST will be the only observatory capable of spectrally resolving the HD line with sensitivity - enabling exploration of total mass and its distribution in disks out to 500 pc.

How do the conditions for habitability develop during the process of planet formation?

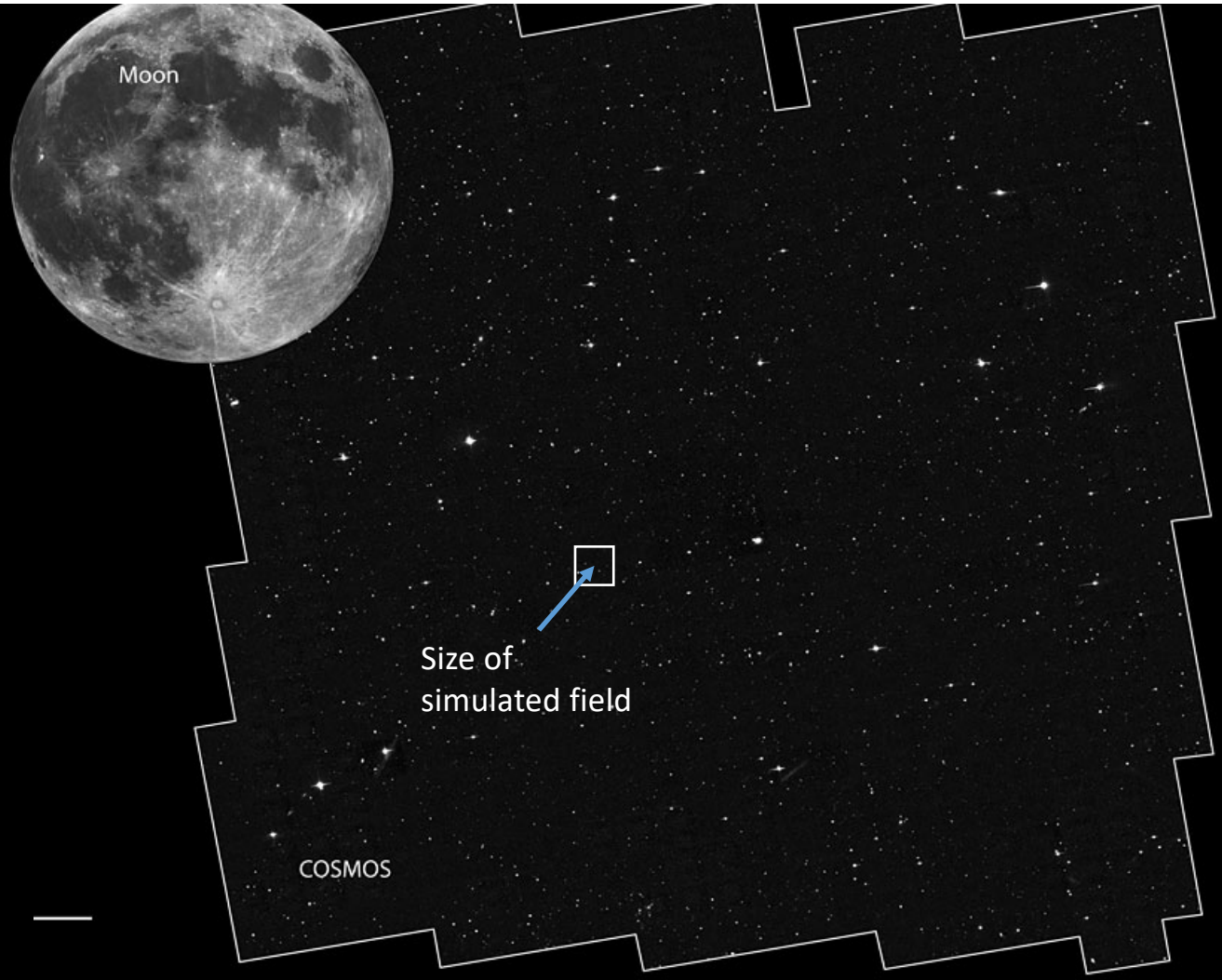
Science Objective 3: Definitively determine the cometary contribution to Earth's water by measuring the D/H ratio with high precision (< 0.1 VSMOW*) in over 200 comets in 5 years.

*Vienna Standard Mean Ocean Water – standard definition of isotropic composition of ocean water

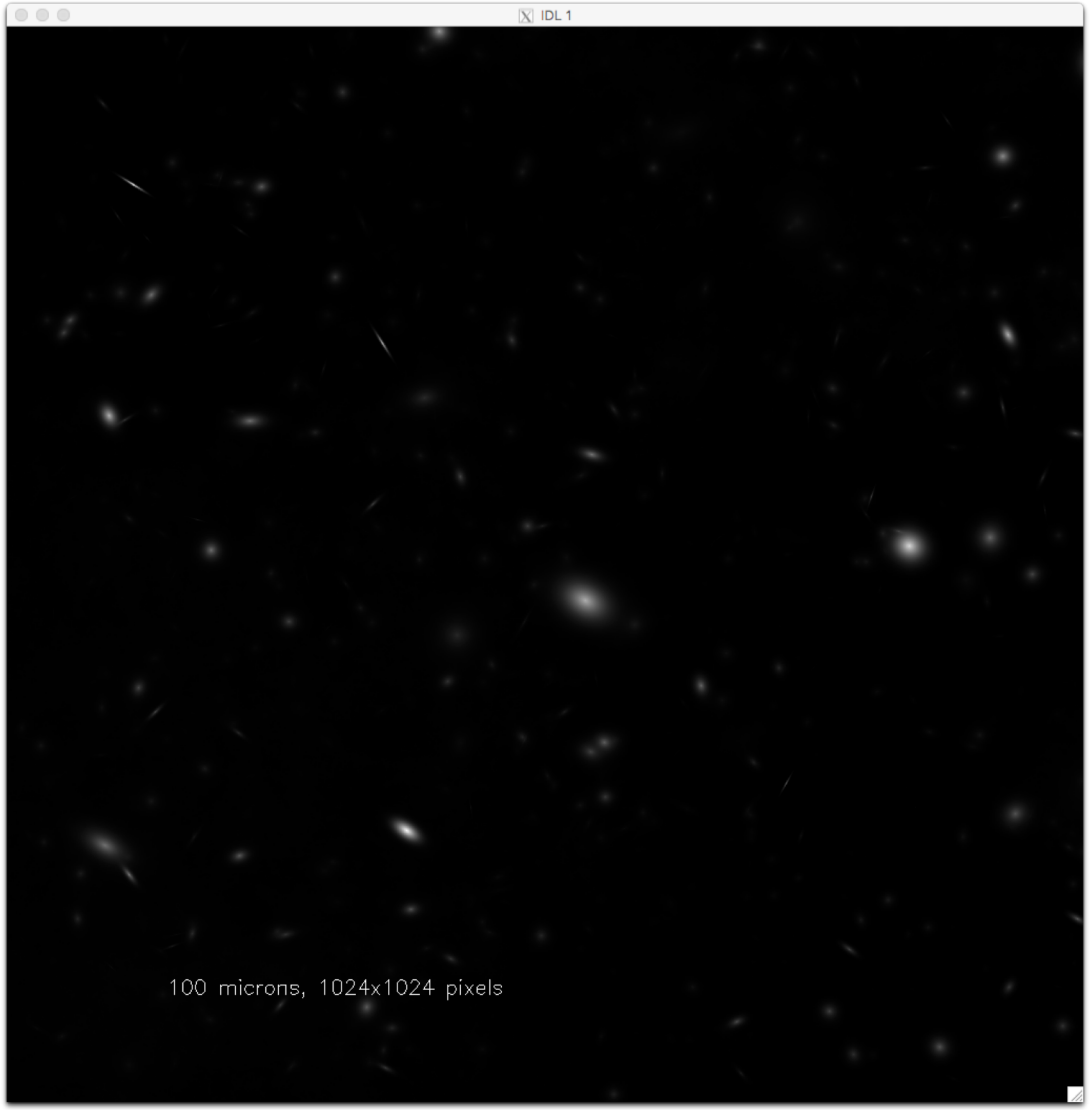


OST will detect and measure the D/H ratio in water in over 200 comets with enough precision to delineate the diversity in the population for the first time.

How do galaxies form stars, make metals, and grow their supermassive black holes from reionization to today?



OST beam



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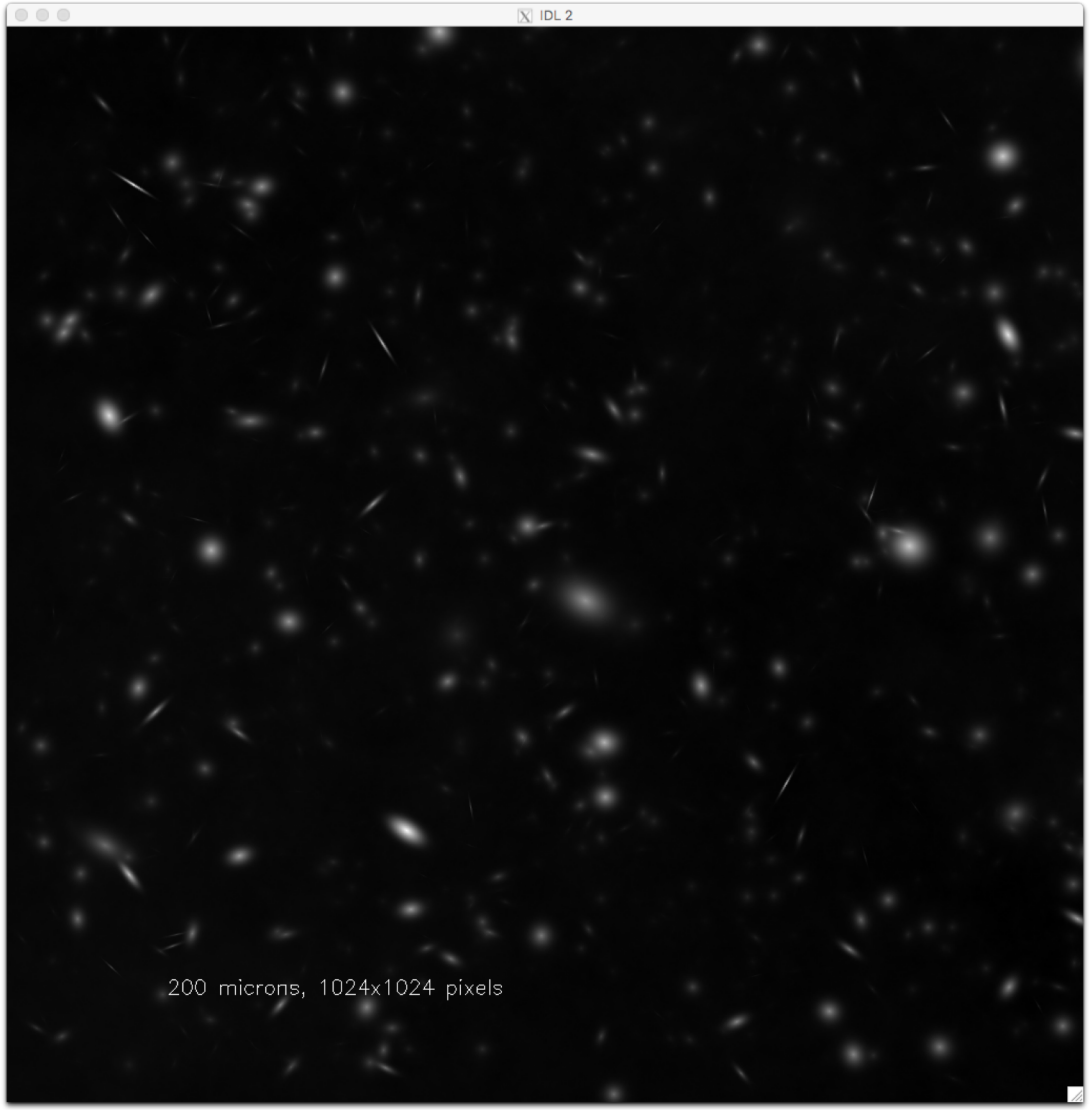

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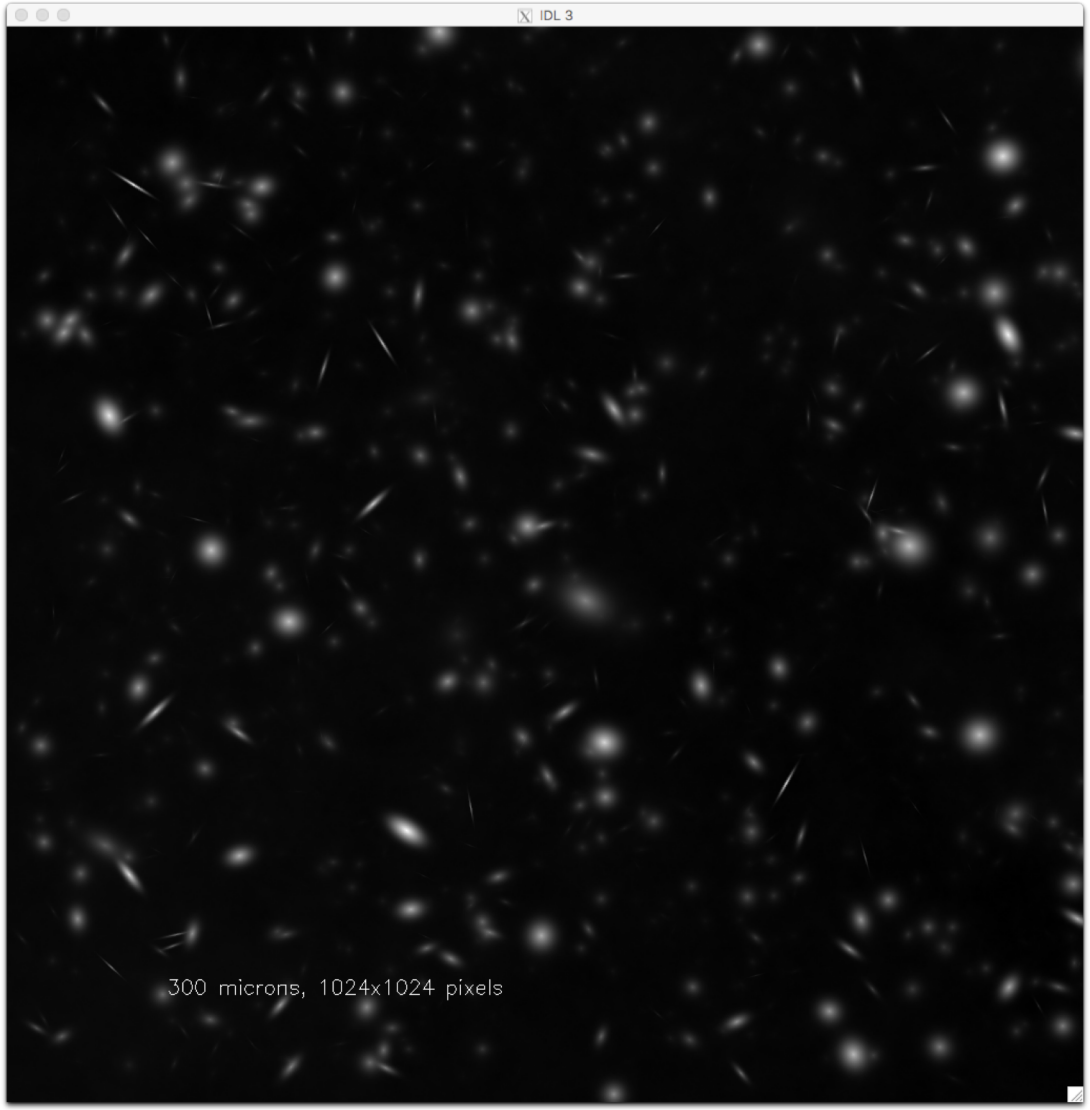

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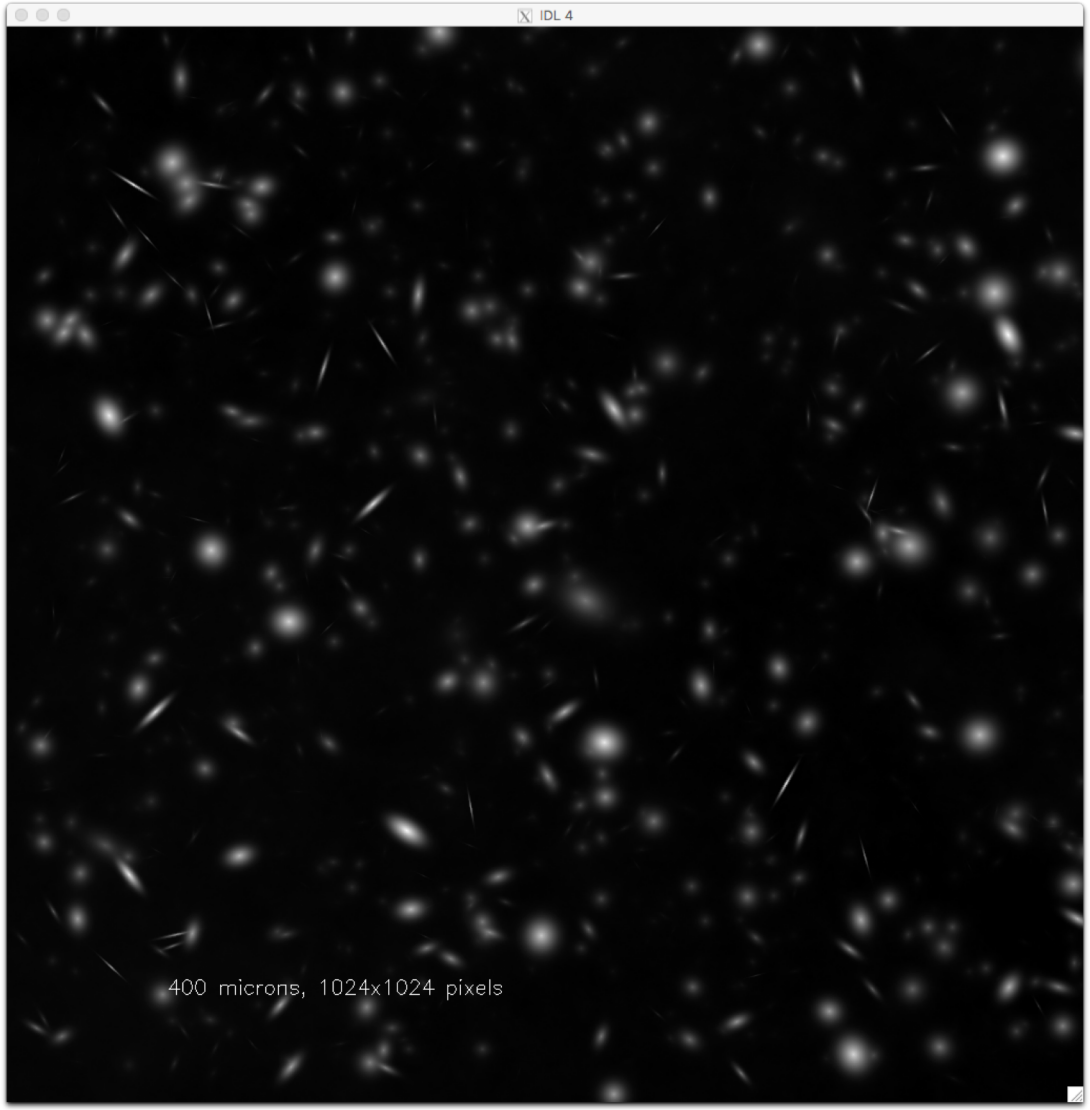

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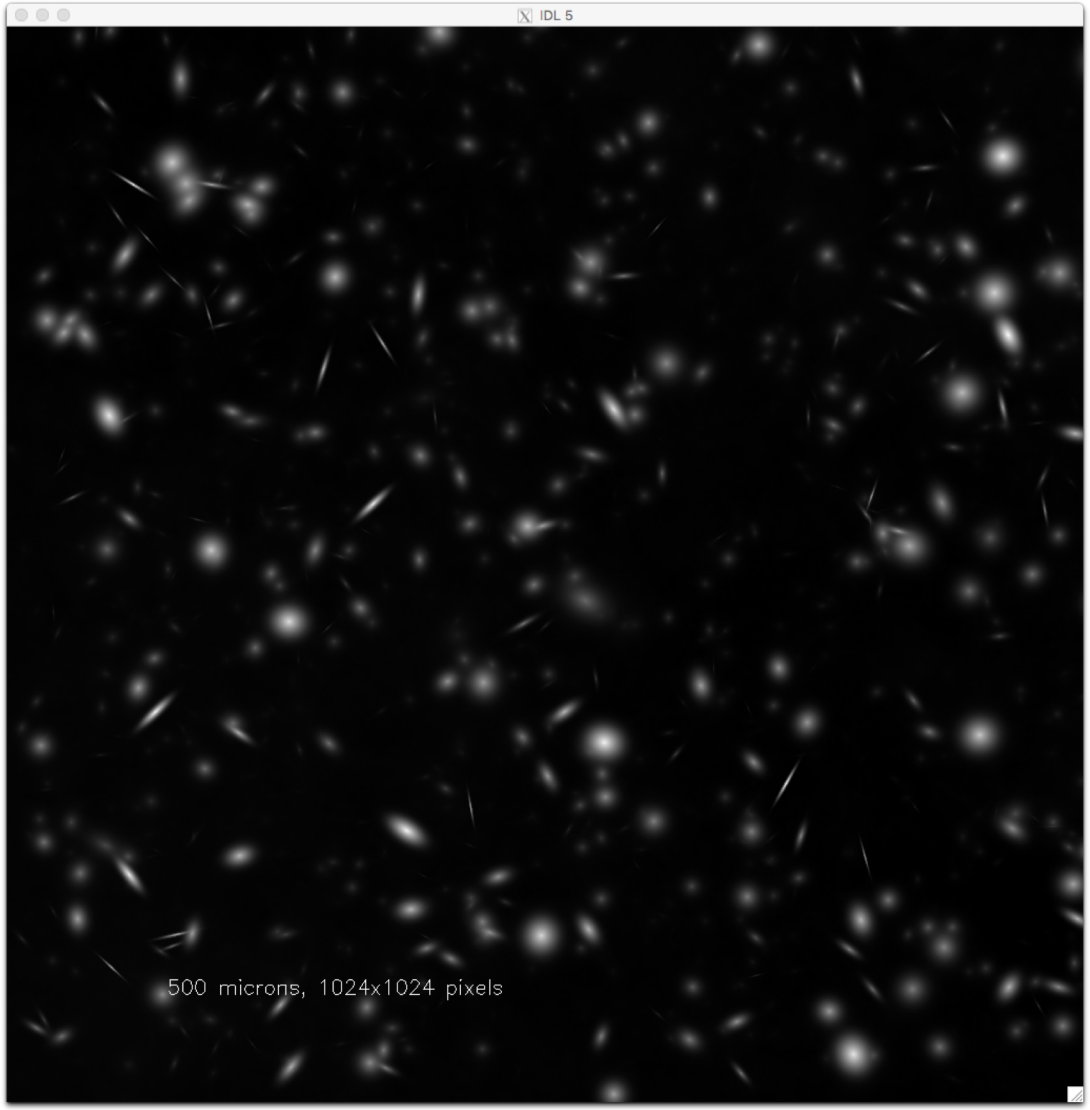

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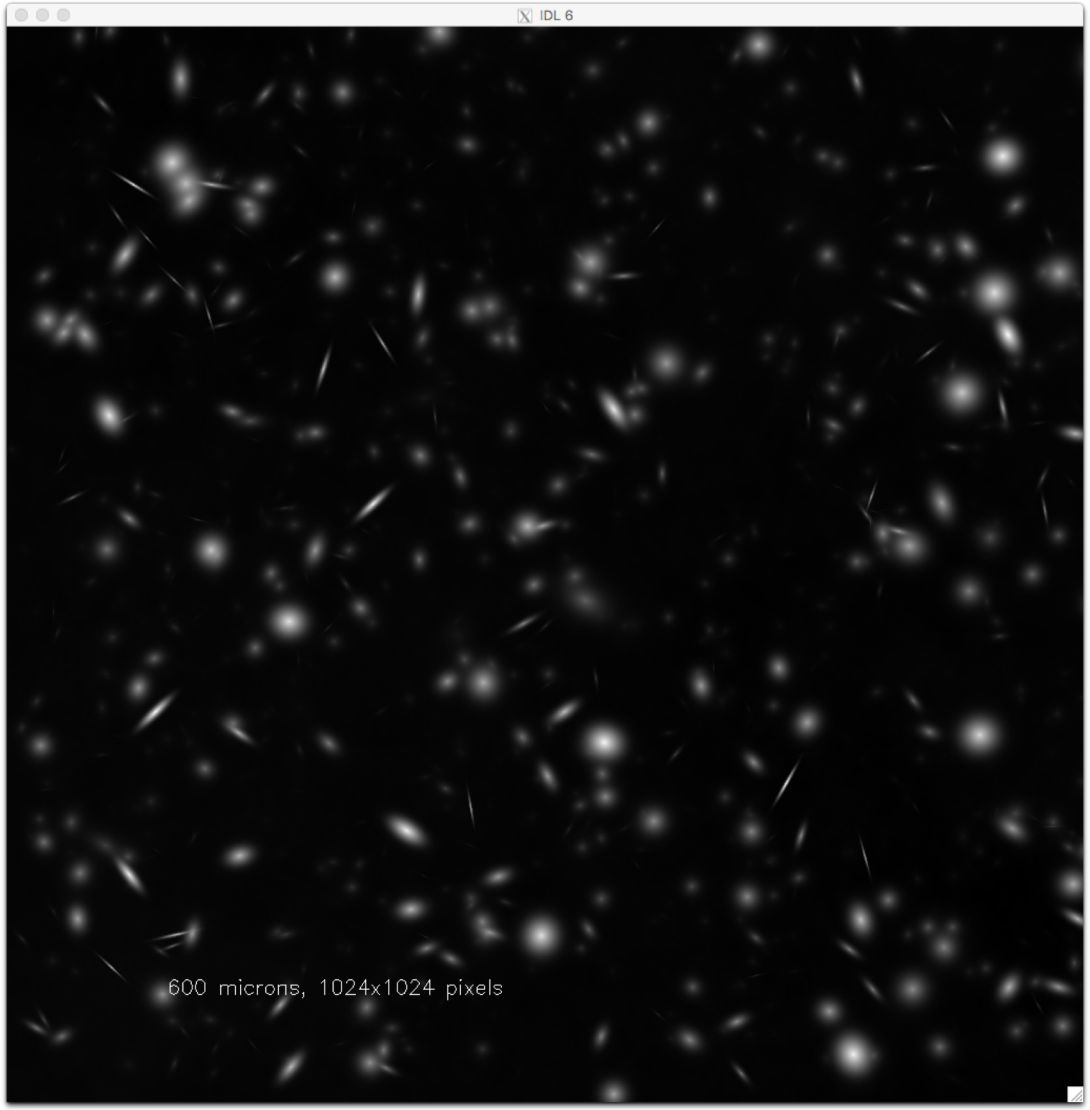
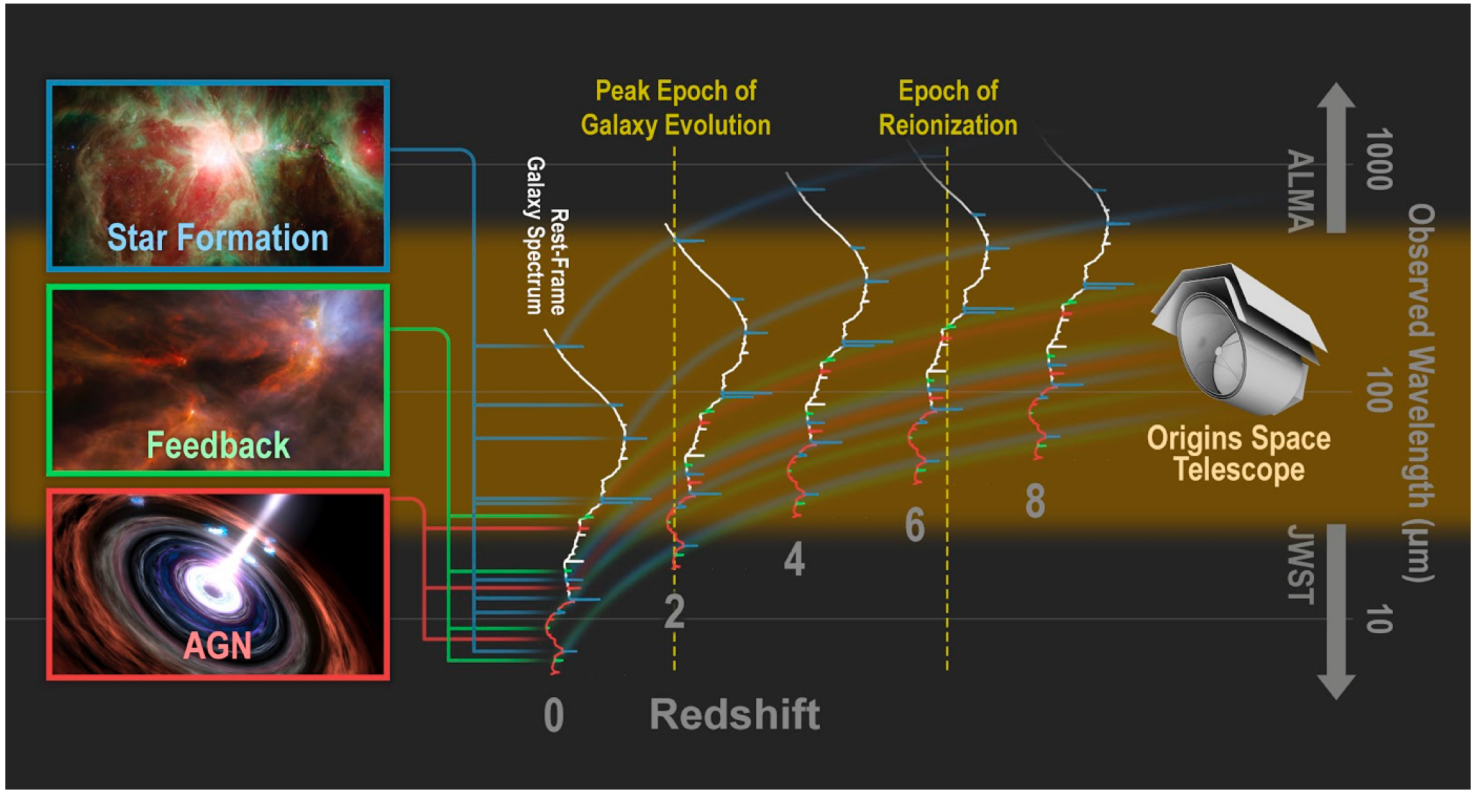


OST beam

How do galaxies form stars, make metals, and grow their central supermassive blackholes from reionization to today?



How do galaxies form stars, make metals, and grow their central supermassive blackholes from reionization to today?

Science Objective 1: **Measure the star formation and black hole accretion rates in galaxies since the epoch of reionization, performing the first unbiased survey of the co-evolution of stars and supermassive black holes over cosmic time.**

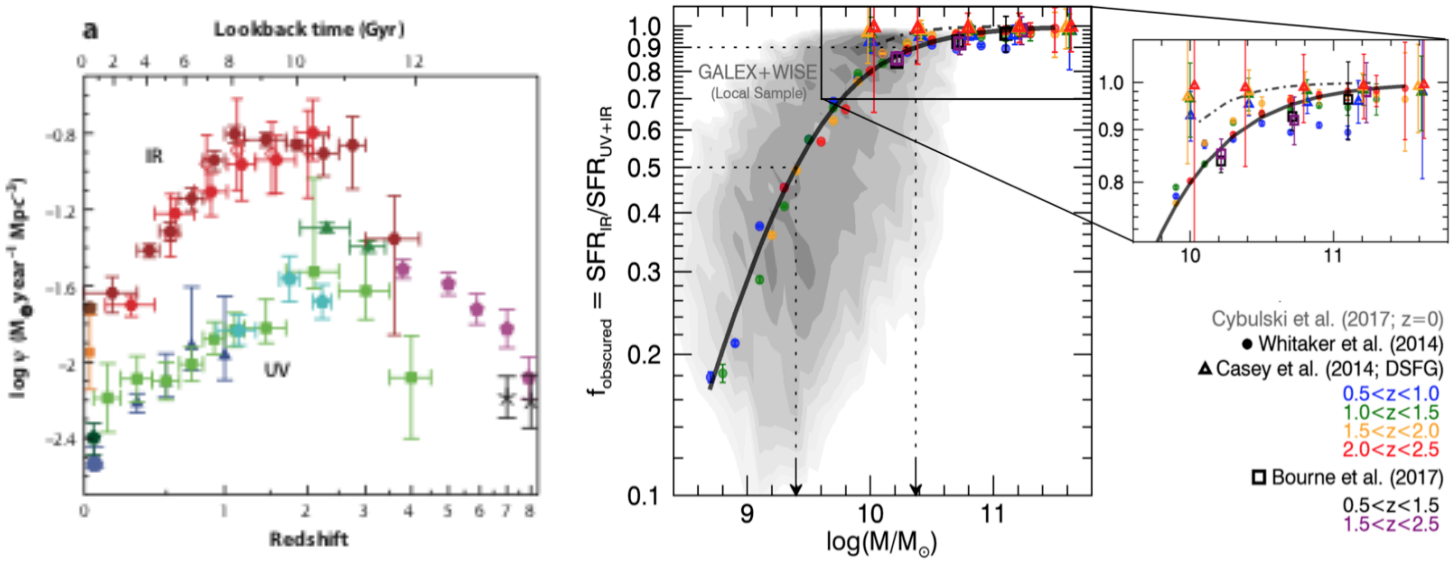


Figure caption: Dust-obscured star formation dominates over cosmic time (left, Madau & Dickinson 2014), and even down to relatively low stellar masses (right, Whitaker et al. 2017).

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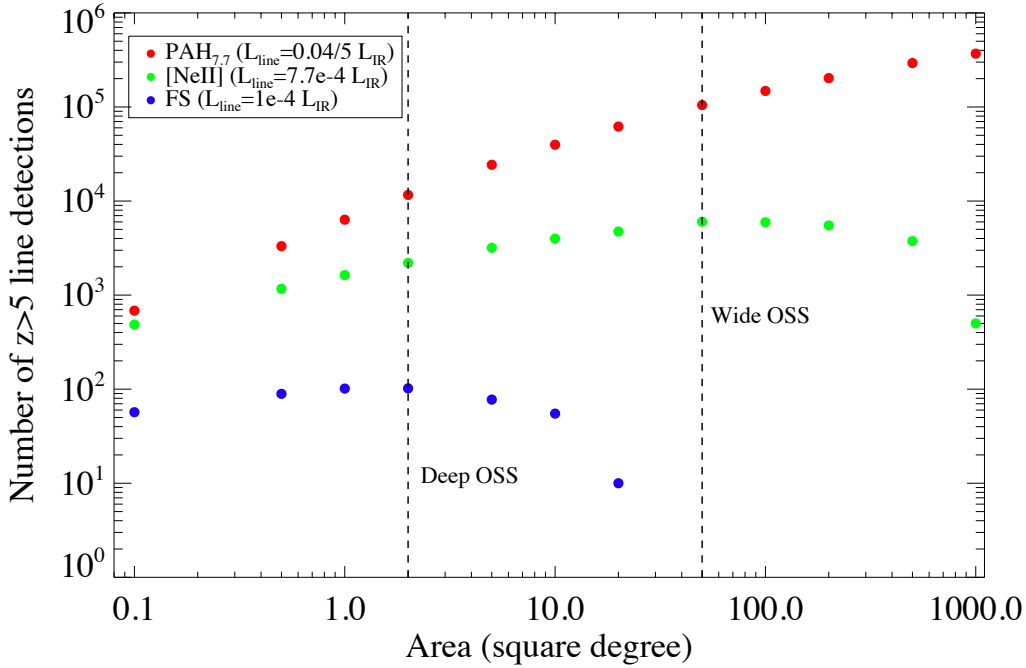

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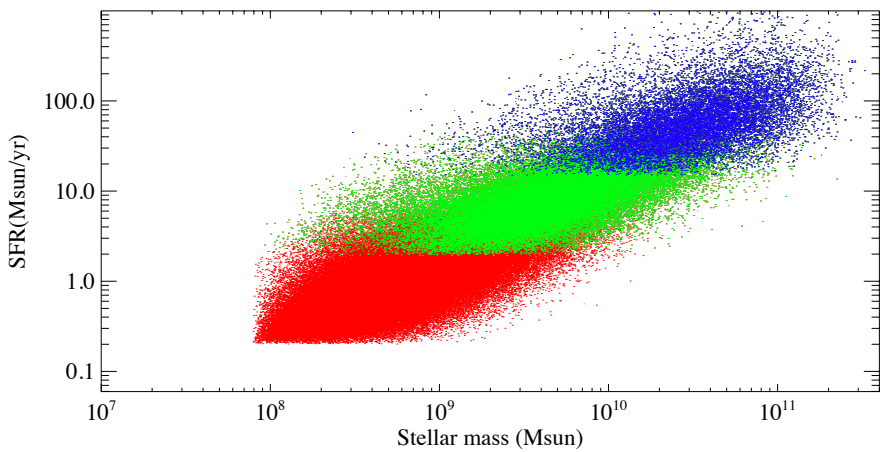
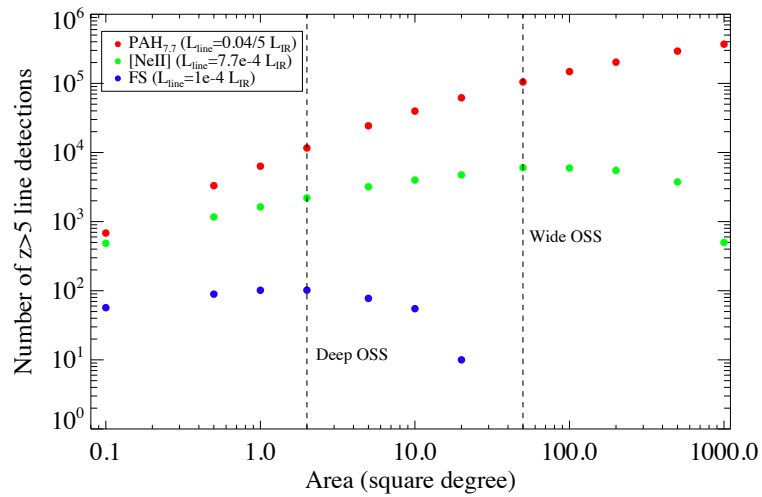


Galaxy main sequence at z=1.5-2 from the OSS deep survey. Colors denote which galaxies will be detected in PAHs (red), bright FS lines (green), and fainter FS lines (blue). OST will measure SFRs for all galaxies in this plot, metallicities for galaxies above 10^9Msun and black hole accretion rates for every galaxy above 10^10 Msun!



OST/OSS survey areas are driven by the need to maximize the number of redshifts and SFR measurements at z > 5 (wide survey) and the number of sources with accurate SFR and BH accretion rate measurements at z=3 (deep survey)

How do galaxies form stars, make metals, and grow their central supermassive blackholes from reionization to today?

Science Objective 2: **Measure the metal content of galaxies as a function of cosmic time, tracing the rise of heavy elements, dust and organic molecules across redshift, morphology and environment.**

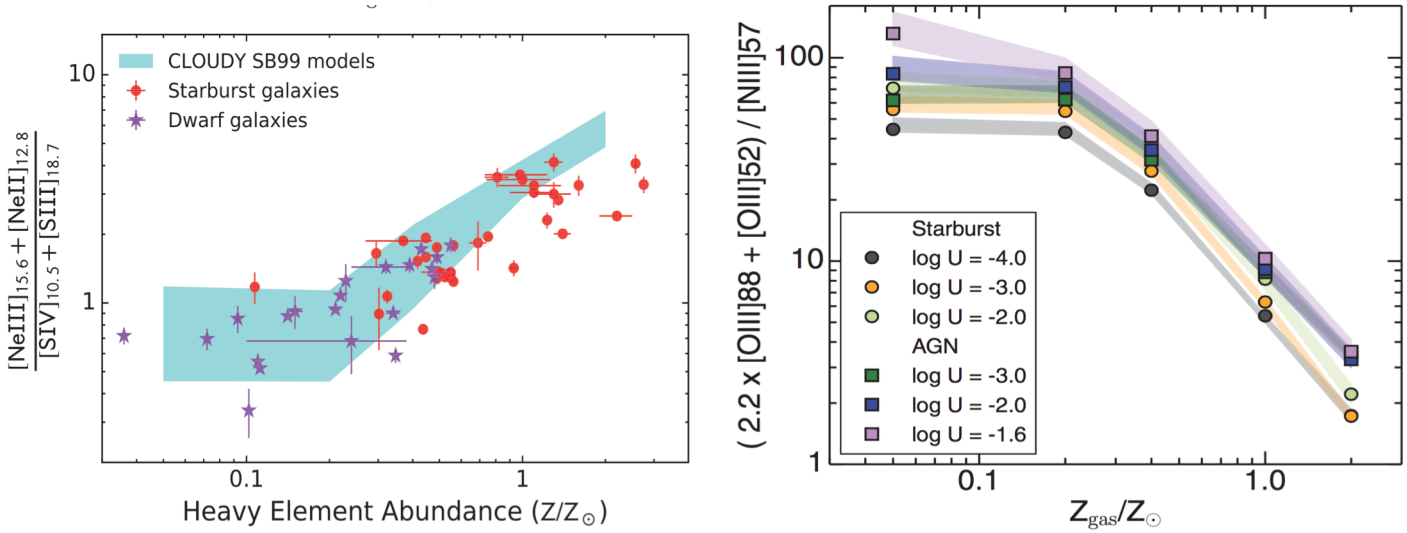


***Fig. 3**: Infrared metallicity line diagnostic diagrams for the bright MIR (left) and FIR(right) emission lines (Fernández-Ontiveros et al. 2016; Pereira-Santaella et al. 2017).*

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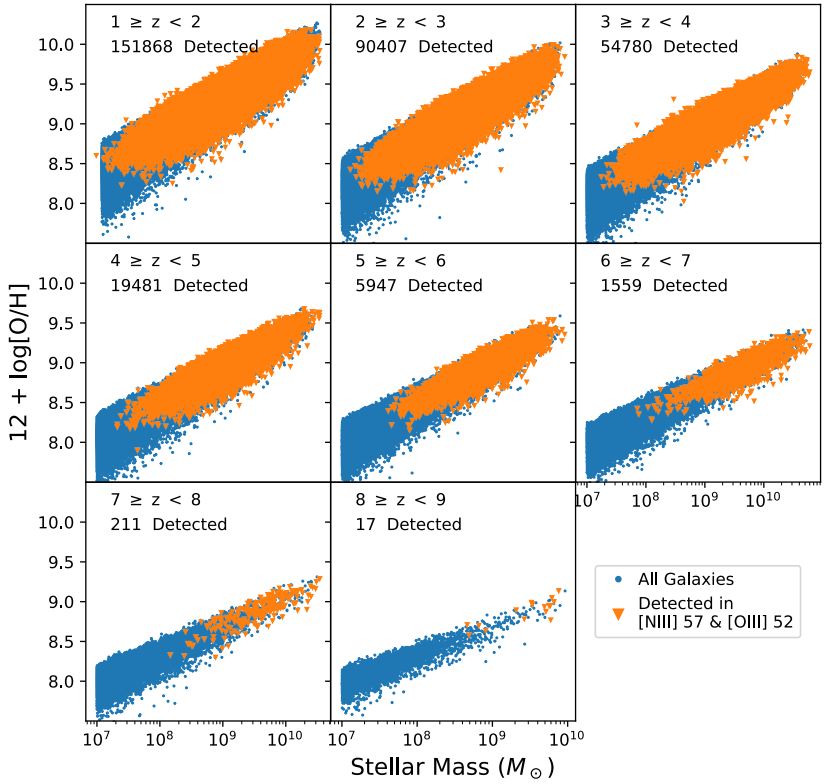

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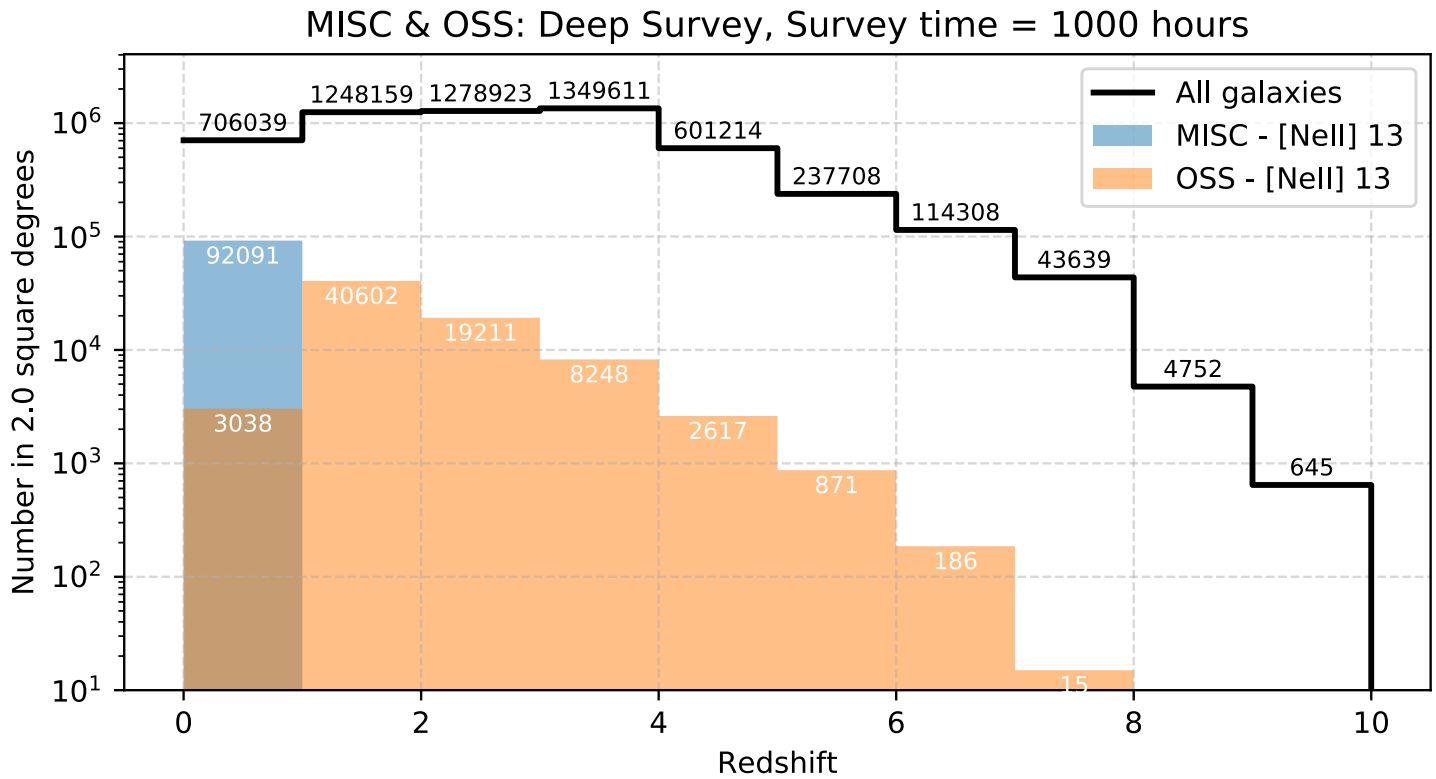
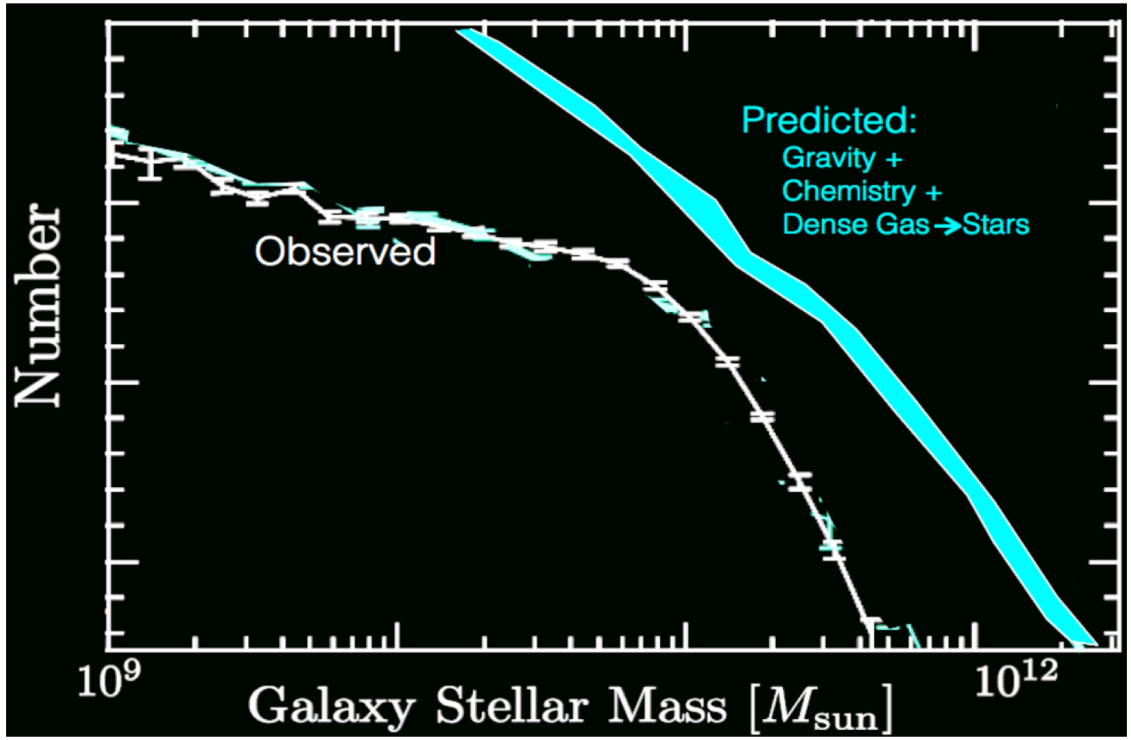


How do galaxies form stars, make metals, and grow their central supermassive blackholes from reionization to today?

Science Objective 3: **Determine how energetic feedback from AGN and supernovae regulate galaxy growth, quench star formation, and drive galactic ecosystems, by measuring galactic outflows as a function of SFR, AGN luminosity and redshift over the past 10 Gyr.**



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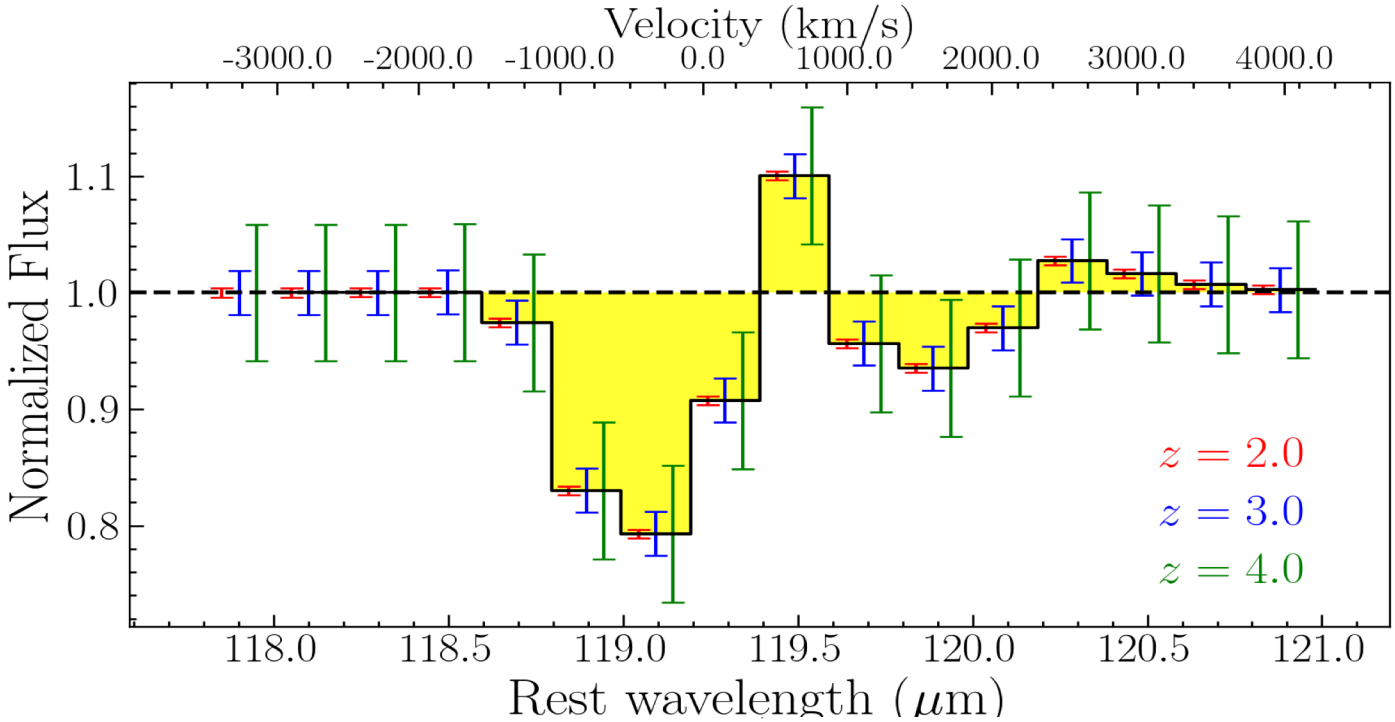
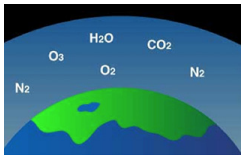


Science Summary



(I) Are we alone? OST goal: OST will assess the habitability of nearby exoplanets and search for signs of life.

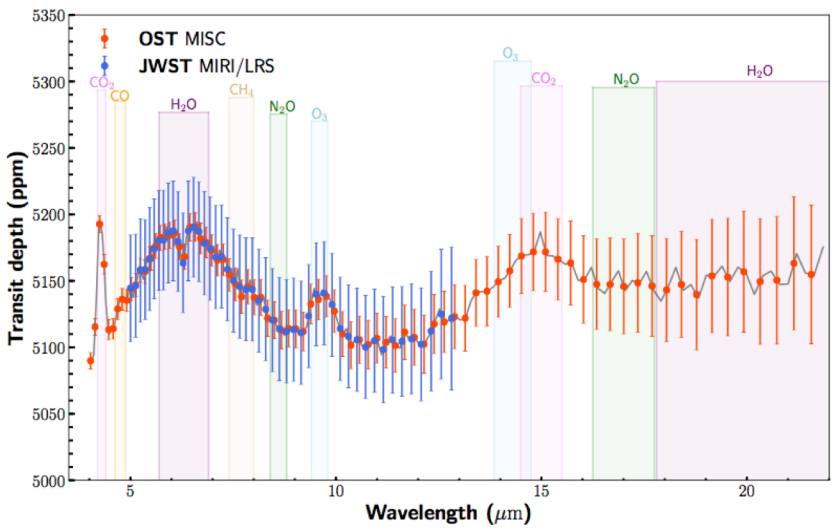
(II) How did we get here? OST question: How do the conditions for habitability develop during the process of planet formation?

(III) How does the Universe work? OST question: How do galaxies form stars, make metals, and grow their central supermassive blackholes from reionization to today?

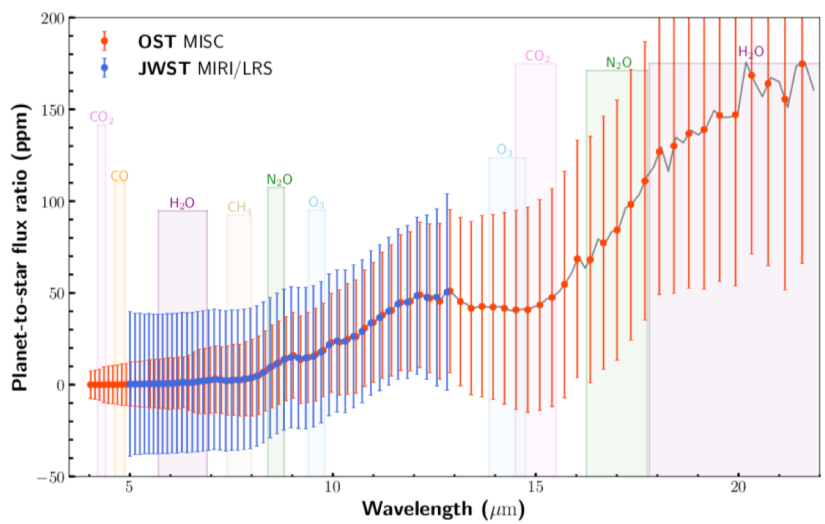
Backup

Science Overlap: OST vs JWST

Transmission Spectrum

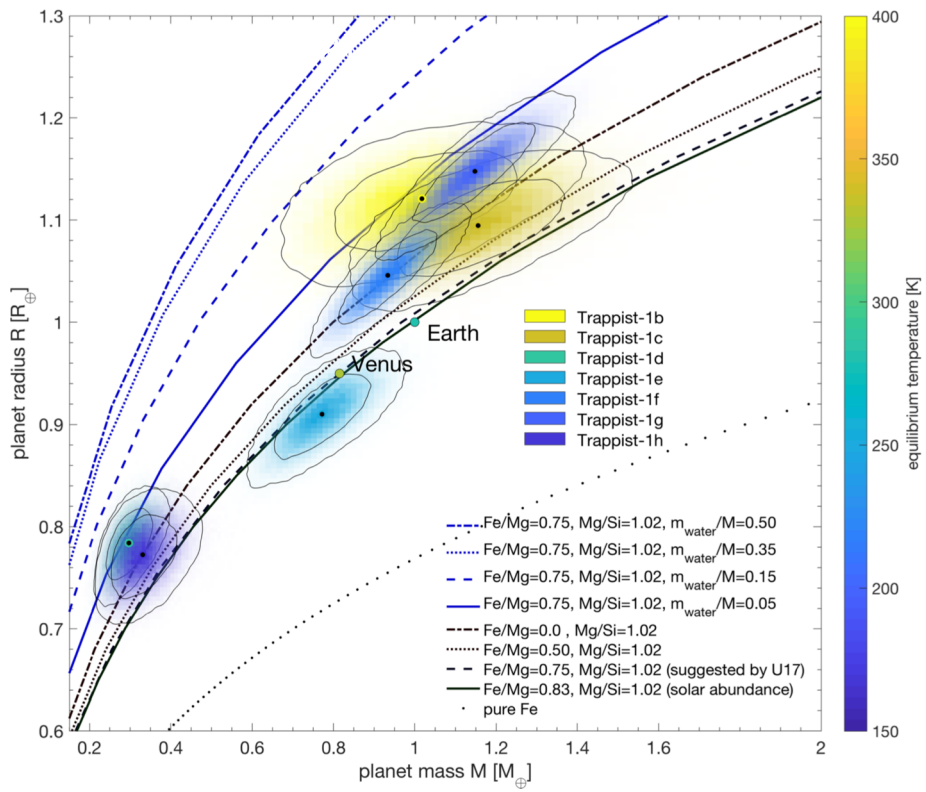


Emission Spectrum



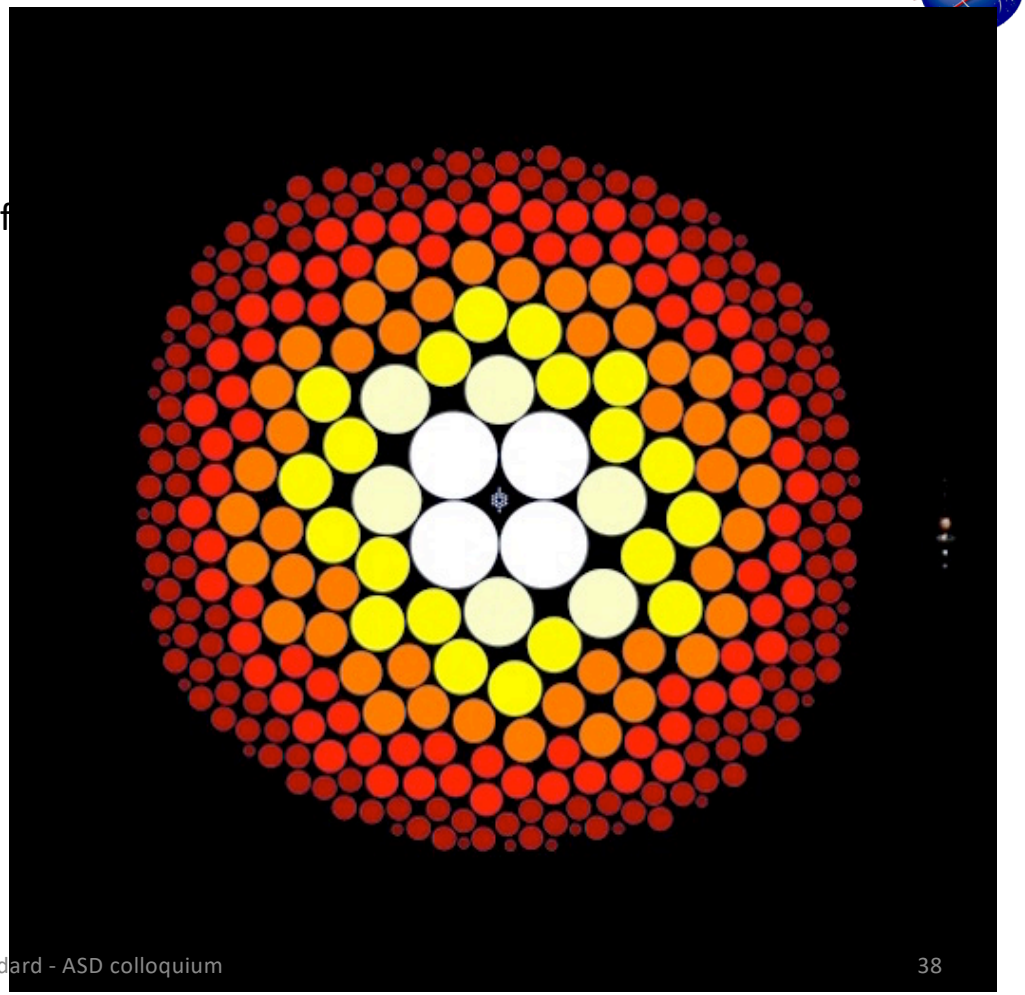
Why Transiting Exoplanets?

- Precisely determined masses and radii
  - Masses from RV instruments (more later)
  - Stellar (and planetary) radii to ~5% with GAIA
- Bulk densities for planetary classification before atmospheric characterization
- Target rocky planets known to have volatile-rich atmospheres



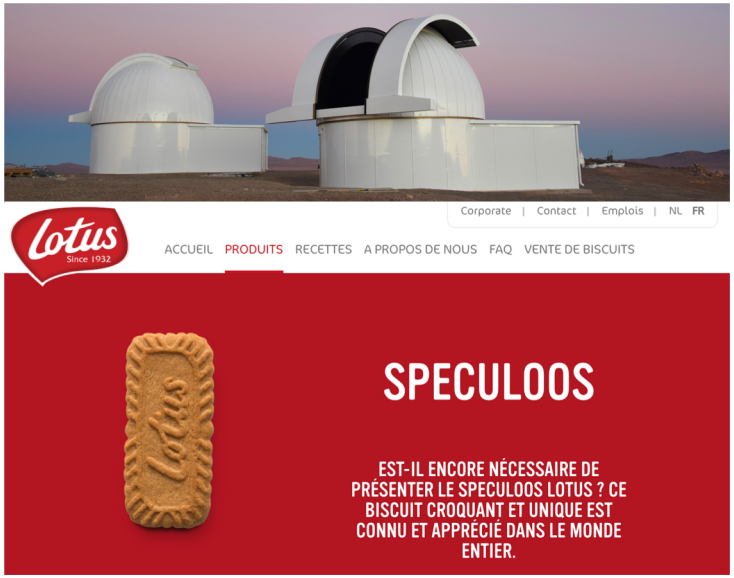
Why M Dwarfs?

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



Predicted Yields

- TESS is not ideal for late M dwarfs
- SPECULOOS will observe ~1200 M7-L3
- Delrez+ (2018) estimate 14±5 HZ planets
  - 1-3 systems within 10 pc (brighter than TRAPPIST-1)
- MEarth+TESS+SPECULOOS+Others will yield ≳dozen temperate terrestrial planets around mid/late M dwarfs within 15 pc



Planet mass ($M_\oplus$)	$N(0.81, 0.34^2)$
Planet density ($\rho_\oplus$)	$N(0.79, 0.12^2)$
Planets	42 ± 10
Systems	22 ± 5
Temperate planets	14 ± 5

Science Objectives

- Tier 3: OST shall detect biosign ing an Earth-like atmosphere, for t exhibit indicators of habitabilit

- Tier 2: OST shall obtain emissio planets that exhibit spectral m temperature at the apparent s confidence) with liquid water.

- Tier 1: OST shall obtain transm -16 terrestrial (R<1.6 R_{Earth}), habita transiting nearby M dwarf star atmosphere, detect spectral m