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Space Telescope

Exoplanet Science with the Origins Space Telescope

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Exoplanet Science Working Group Co-Leads
and the OST Exoplanets Science Working Group

Sept 18, 2018

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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

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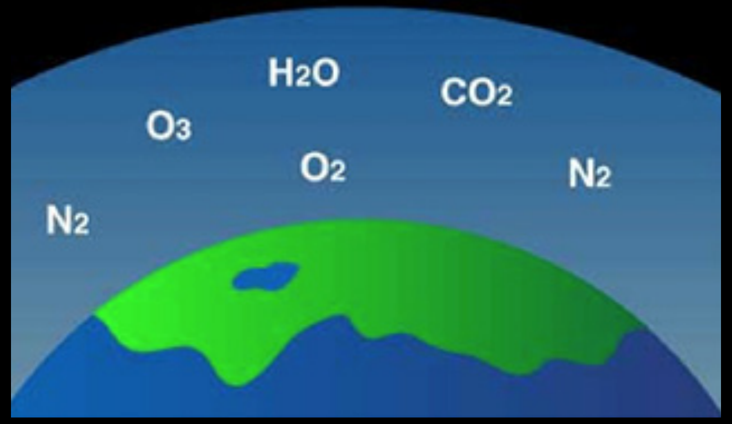
OST Science Programs



- *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 atmospheres of Earth-sized habitable exoplanets.

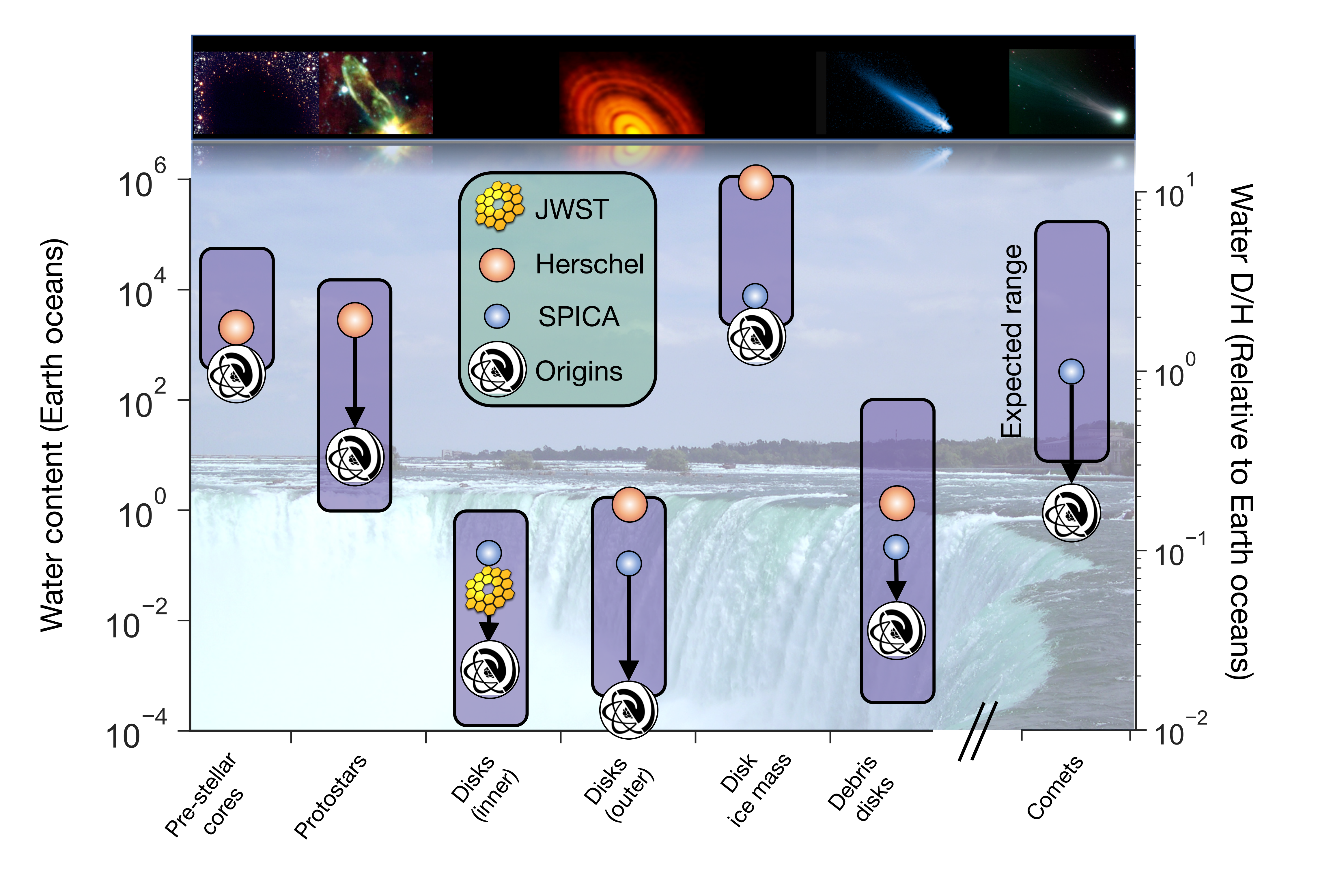
- *How did we get here?* **OST question: How do the conditions for habitability develop during the process of planet formation?** With the sensitive and high-resolution far-IR spectroscopy OST will map the water trail in our Galaxy.

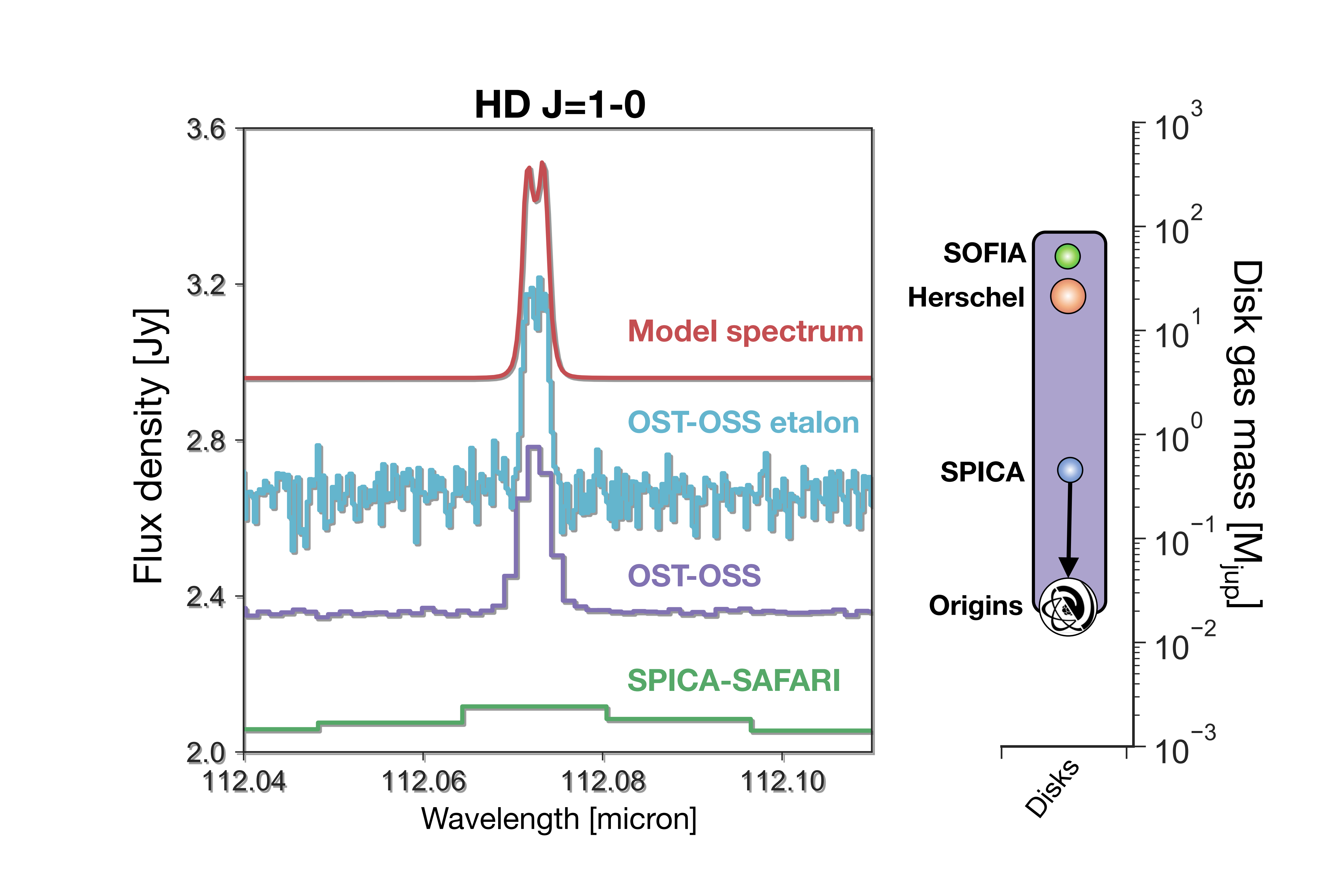
- *How does the Universe work?* **OST question: How do galaxies form stars, make metals, and grow their central supermassive blackholes from reionization to today?** OST will spectroscopically 3D map wide extragalactic fields to measure simultaneously properties of growing super-massive blackholes and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

Sensitivity of OST to water and disk masses

OST is designed to create a complete census of:

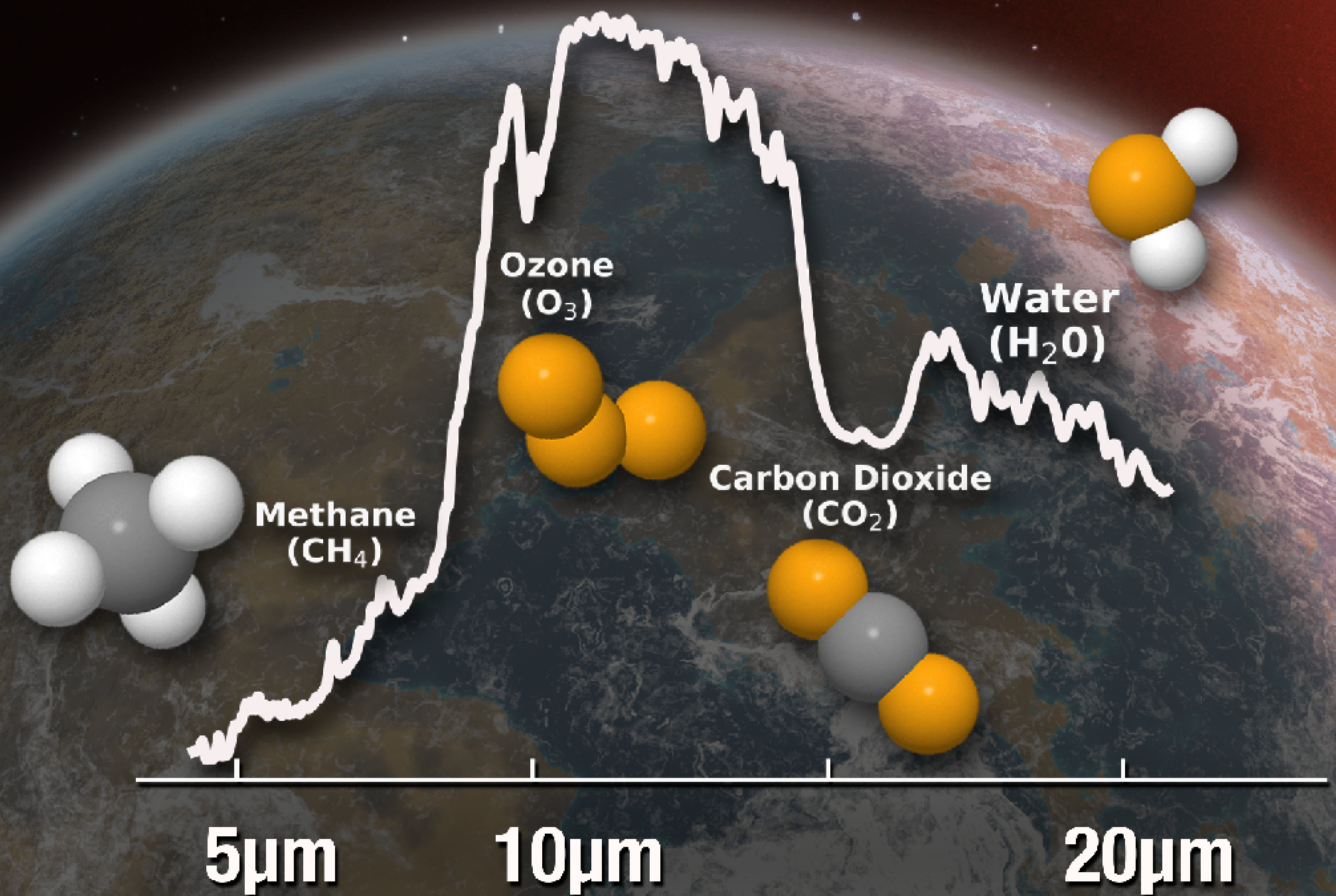
1. Volatiles (traced by water) from the ISM to exoplanetary atmospheres around all stellar types
2. Planet-forming gas mass in the Galaxy





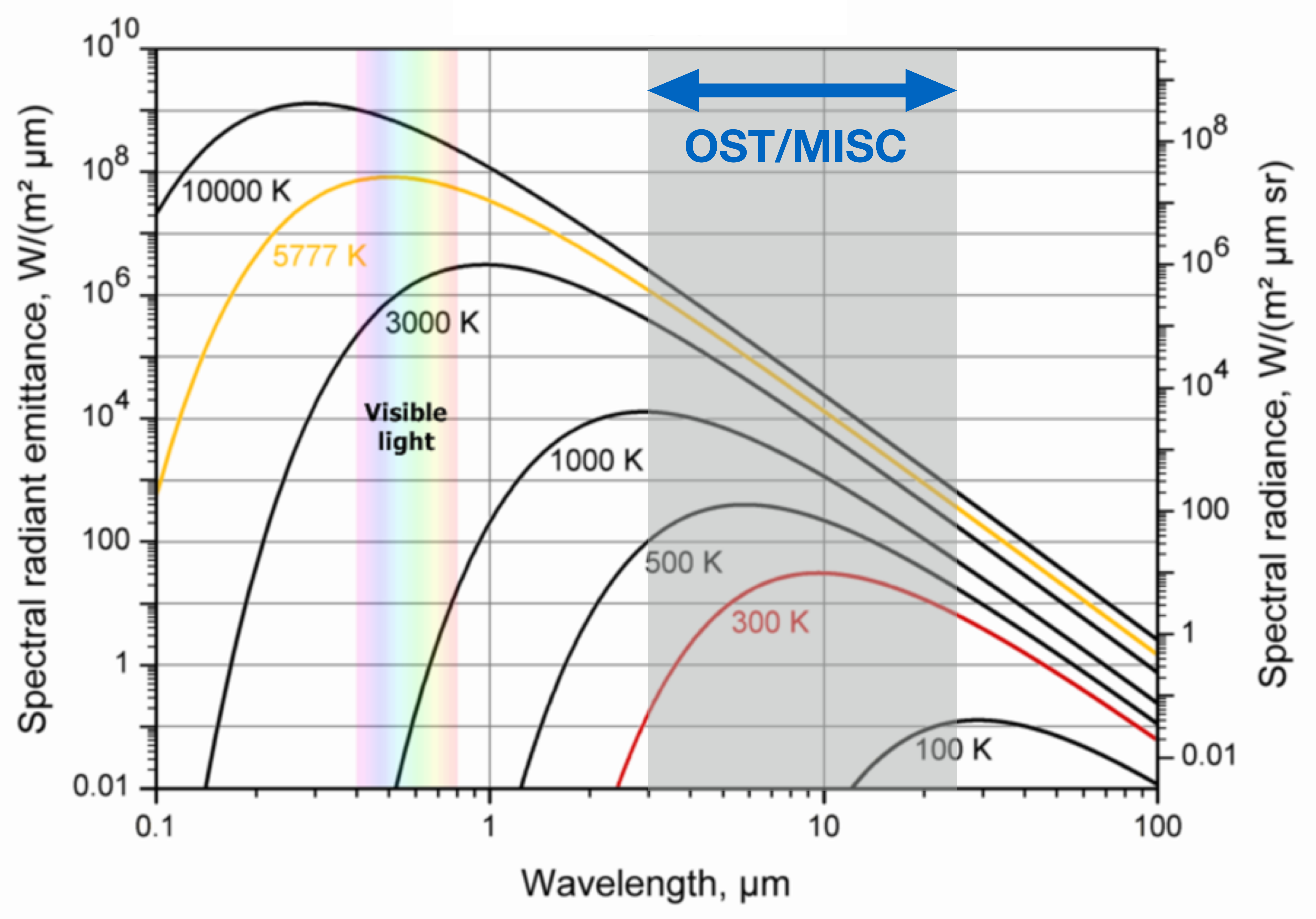
Are we alone?

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



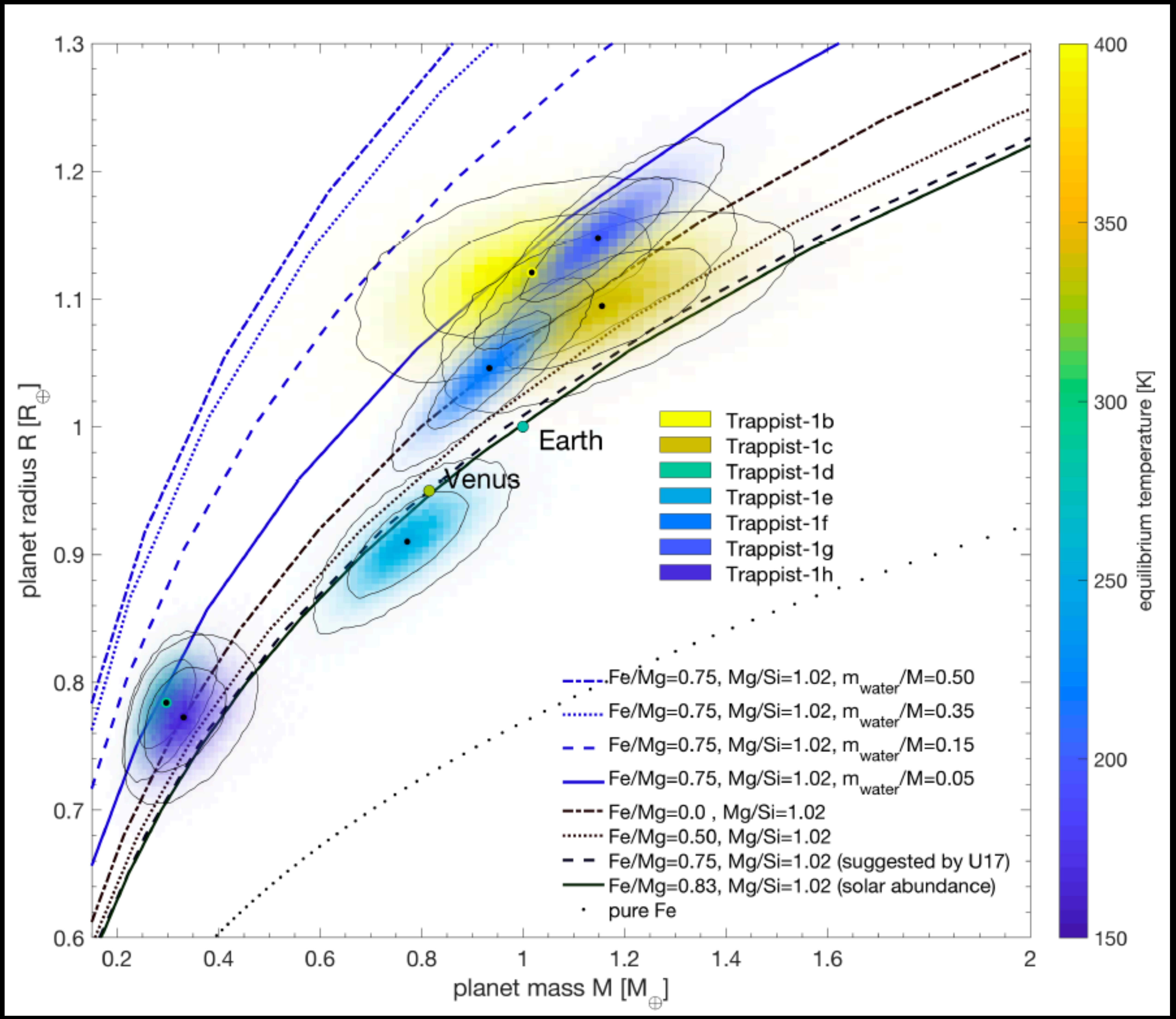
Why the mid-infrared?

- 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?

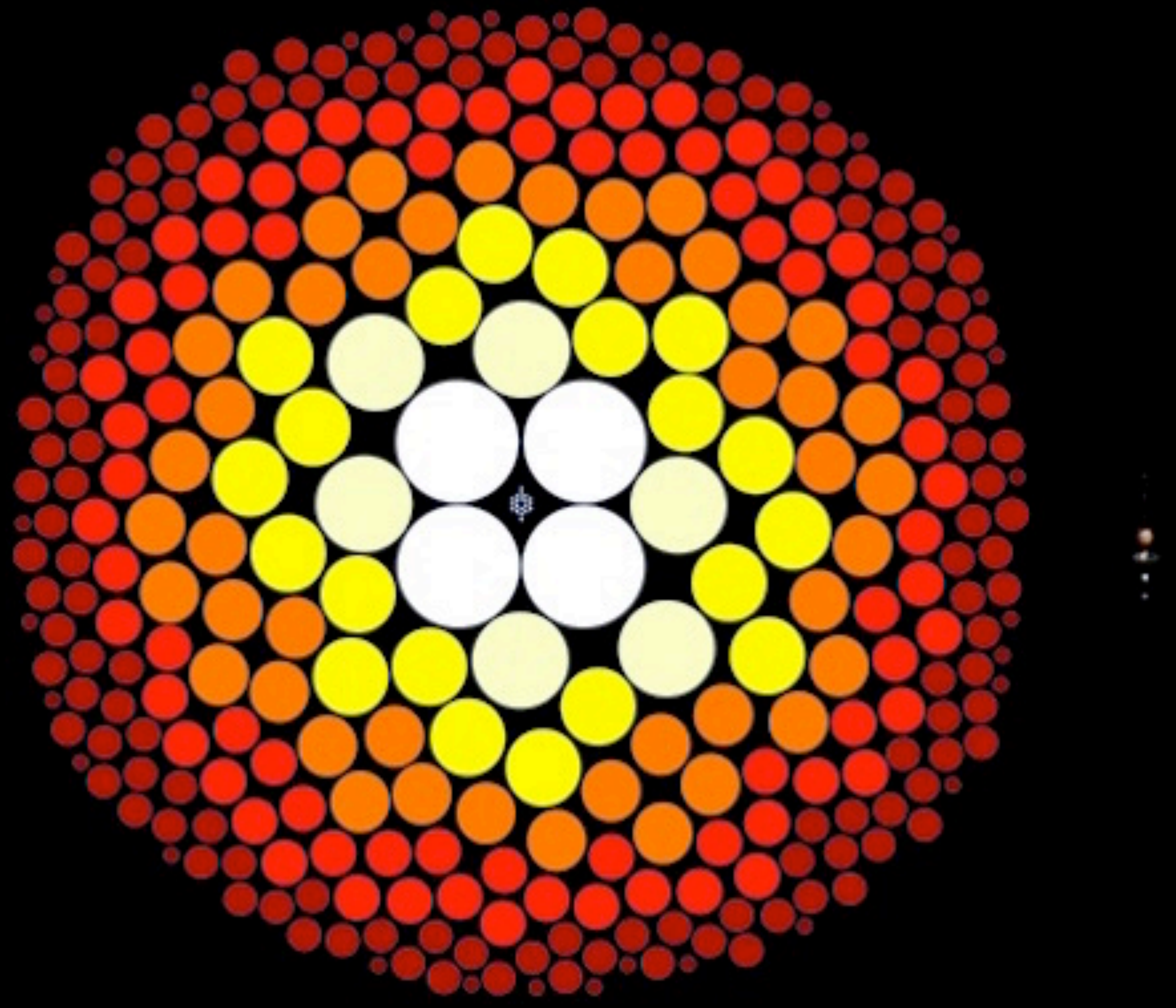
- Precisely determined masses and radii
- Stellar (and planetary) radii to ~5% with GAIA
- Bulk densities for planetary classification before atmospheric characterization
- We can target planets known to be predominantly rocky



Why M dwarfs?

- 75% of stars within 15 pc are M dwarfs
- Expect to detect about a dozen HZ 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)

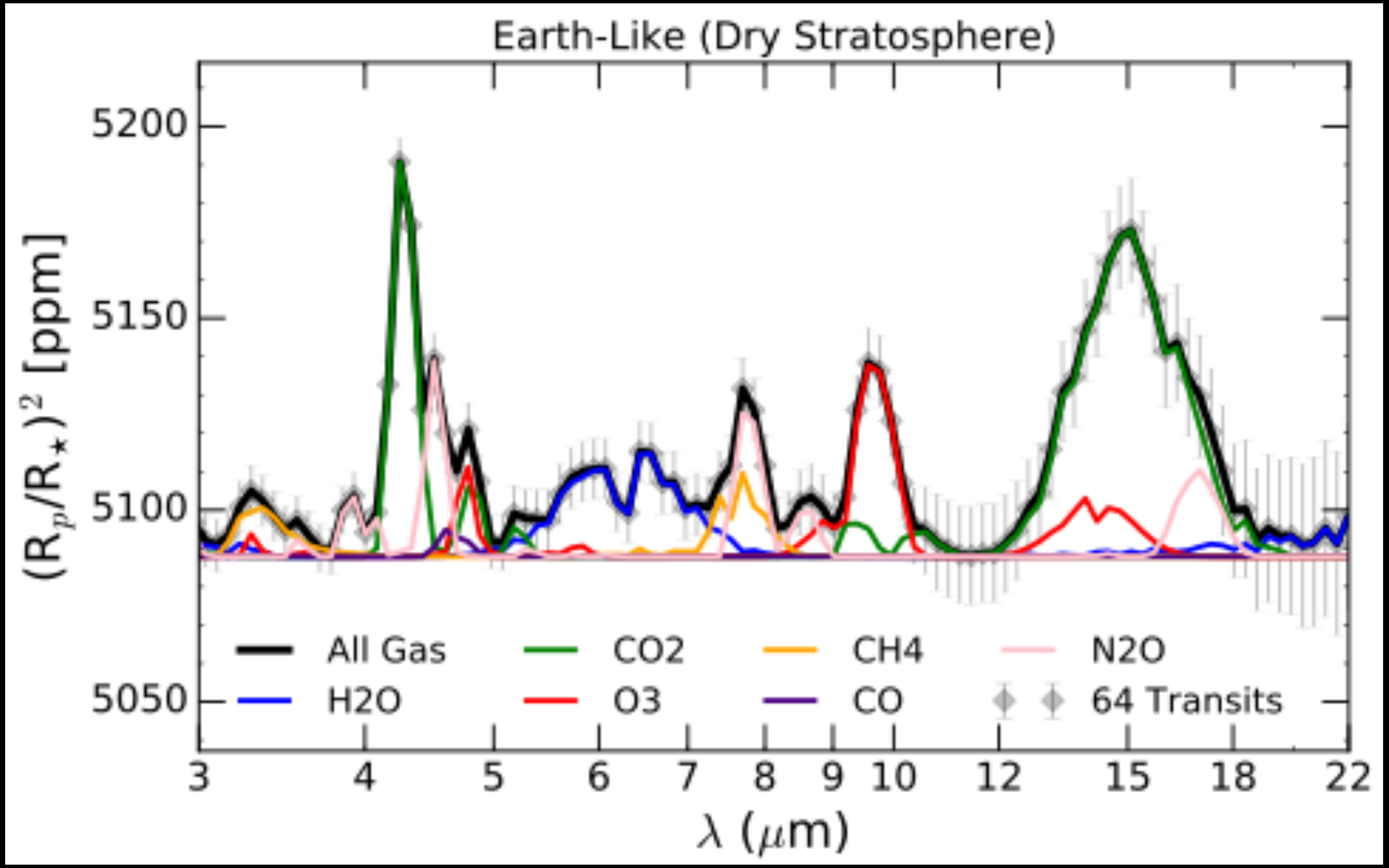
- Advantages of small planets transiting smaller stars
  - Larger transit depths
  - Closer habitable zones (5 – 100 days)
  - Increased transit probability in HZ



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 (H_2O, CO_2, O_3, CH_4, N_2O) 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

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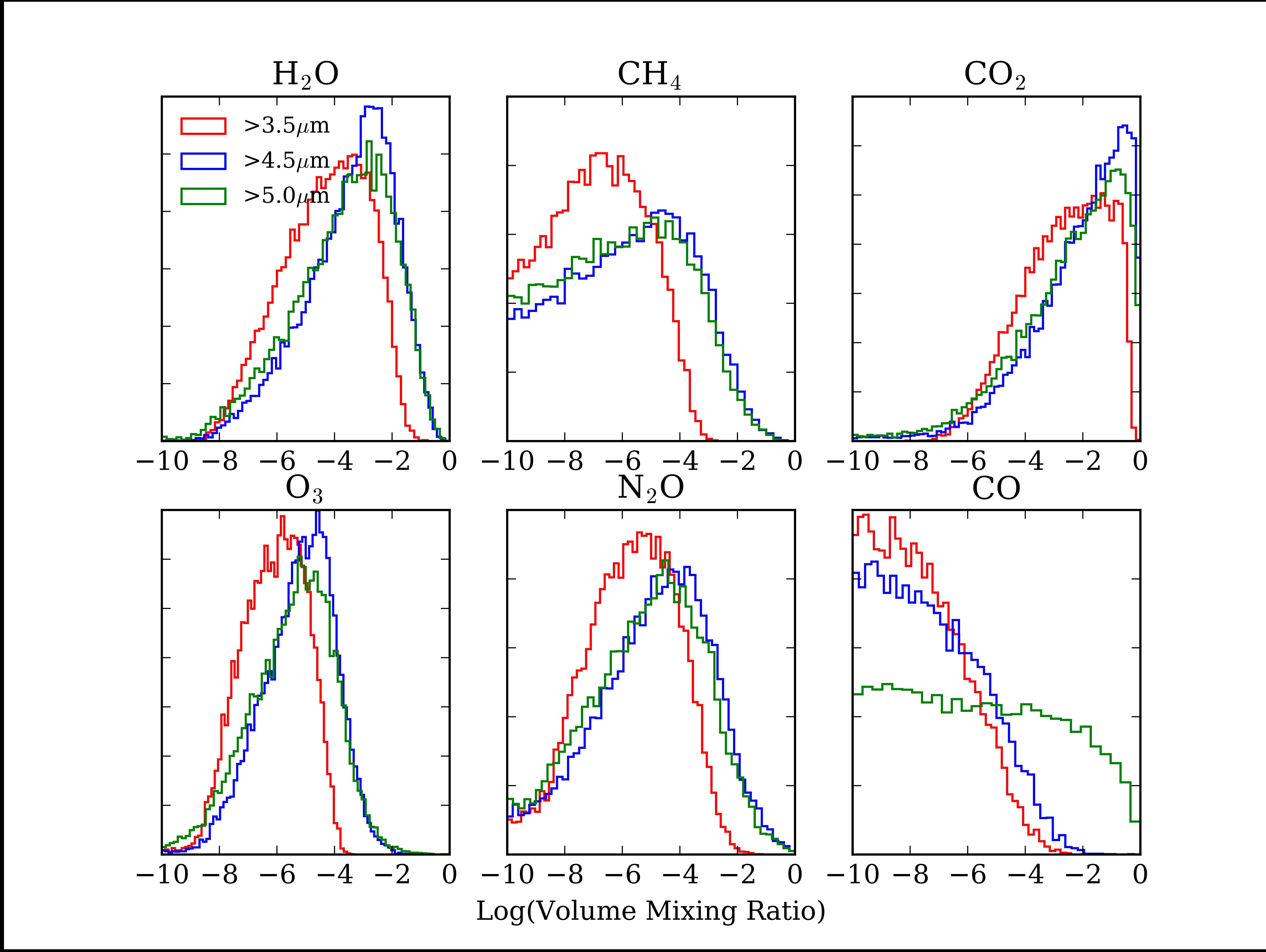
OST Exoplanet Papers

- **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?

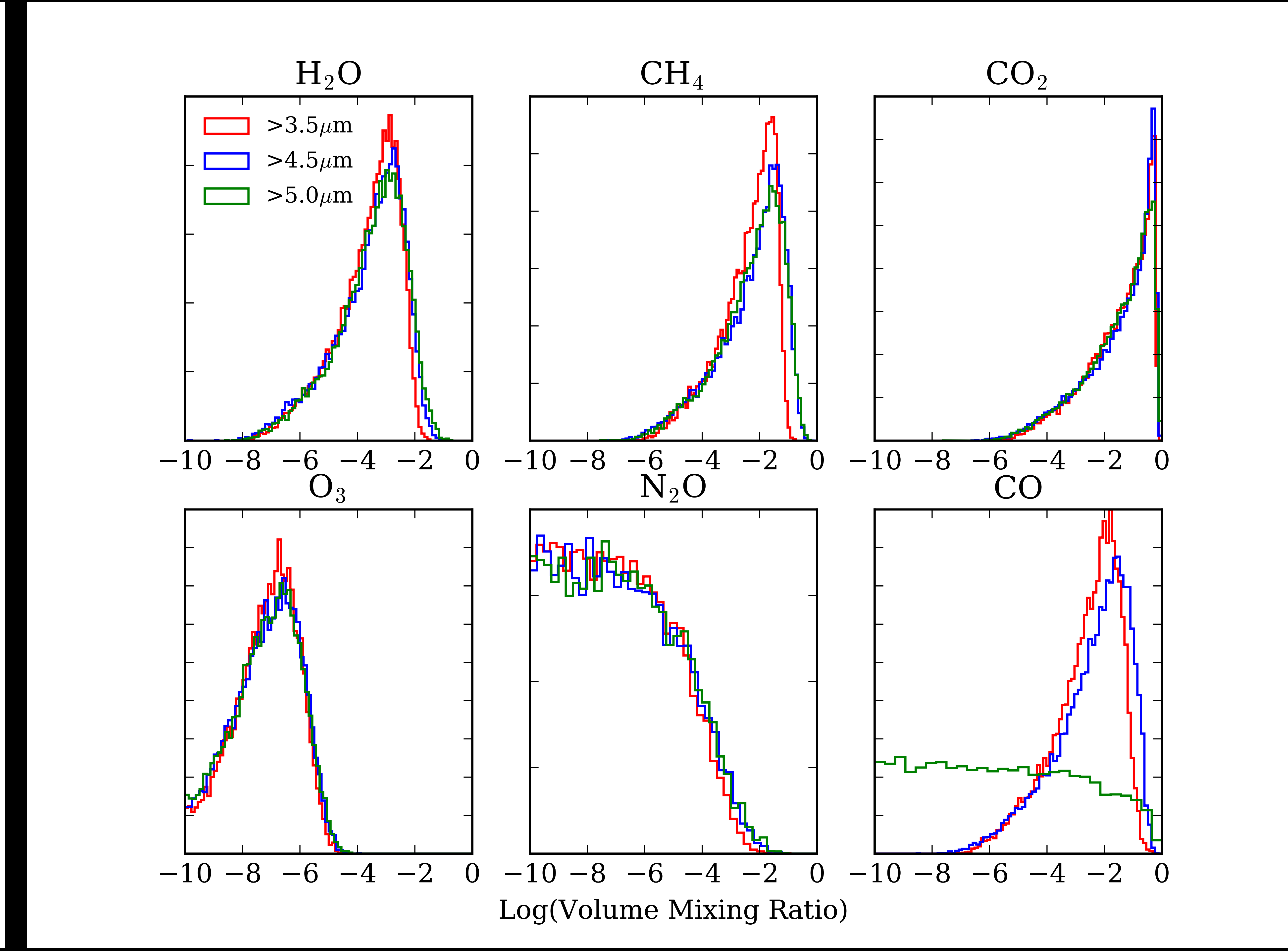
Transmission Spectroscopy

Wavelength coverage

Earth-Like

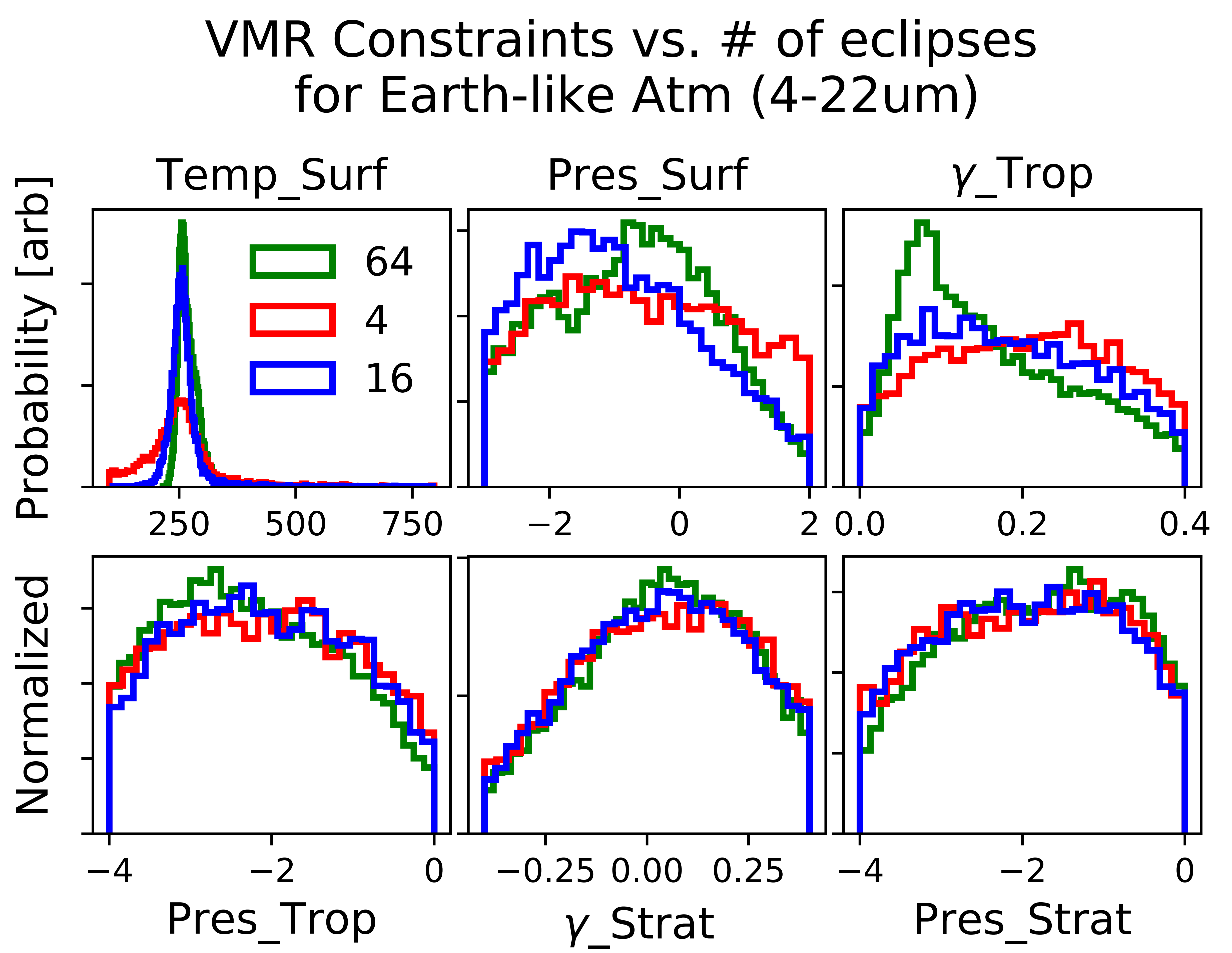


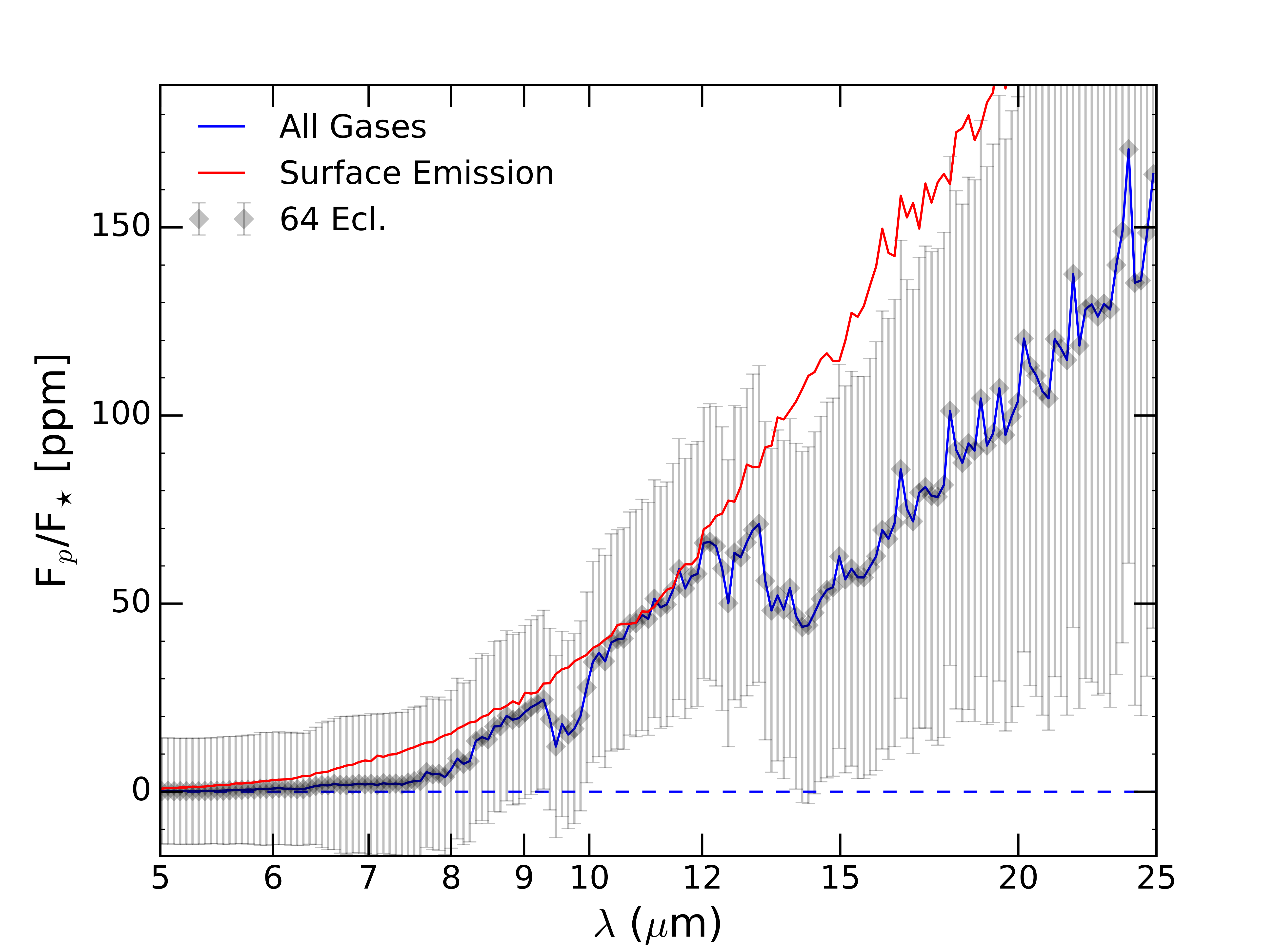
Enhanced methane



Emission Spectroscopy

Thermal constraints



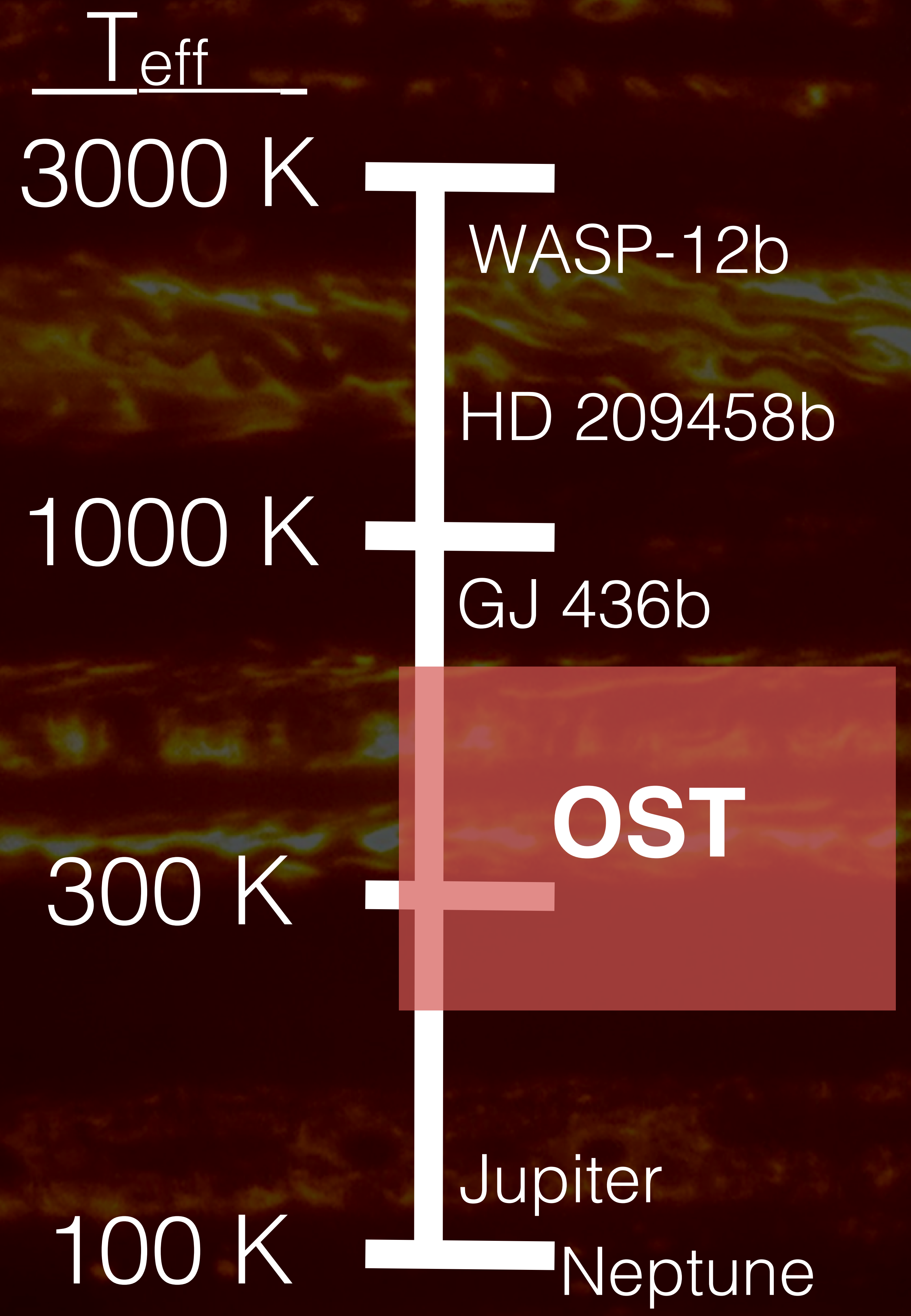


Layer-Cake Observing Strategy

Tier	Objectives	# of Planets	# of Transits/ Eclipses Per Planet	Total # of Transits/ Eclipses	Total time (hrs)
1	Spectral modulation	12-16	4 transits	48-64	192-256
2	Temp to support liquid H2O	6-8	12 eclipses	72-96	288-384
3	Search for biosignatures (CH4, O3, N2O)	best 4	67 transits	268	1072

Ancillary Exoplanet Science with OST

- 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



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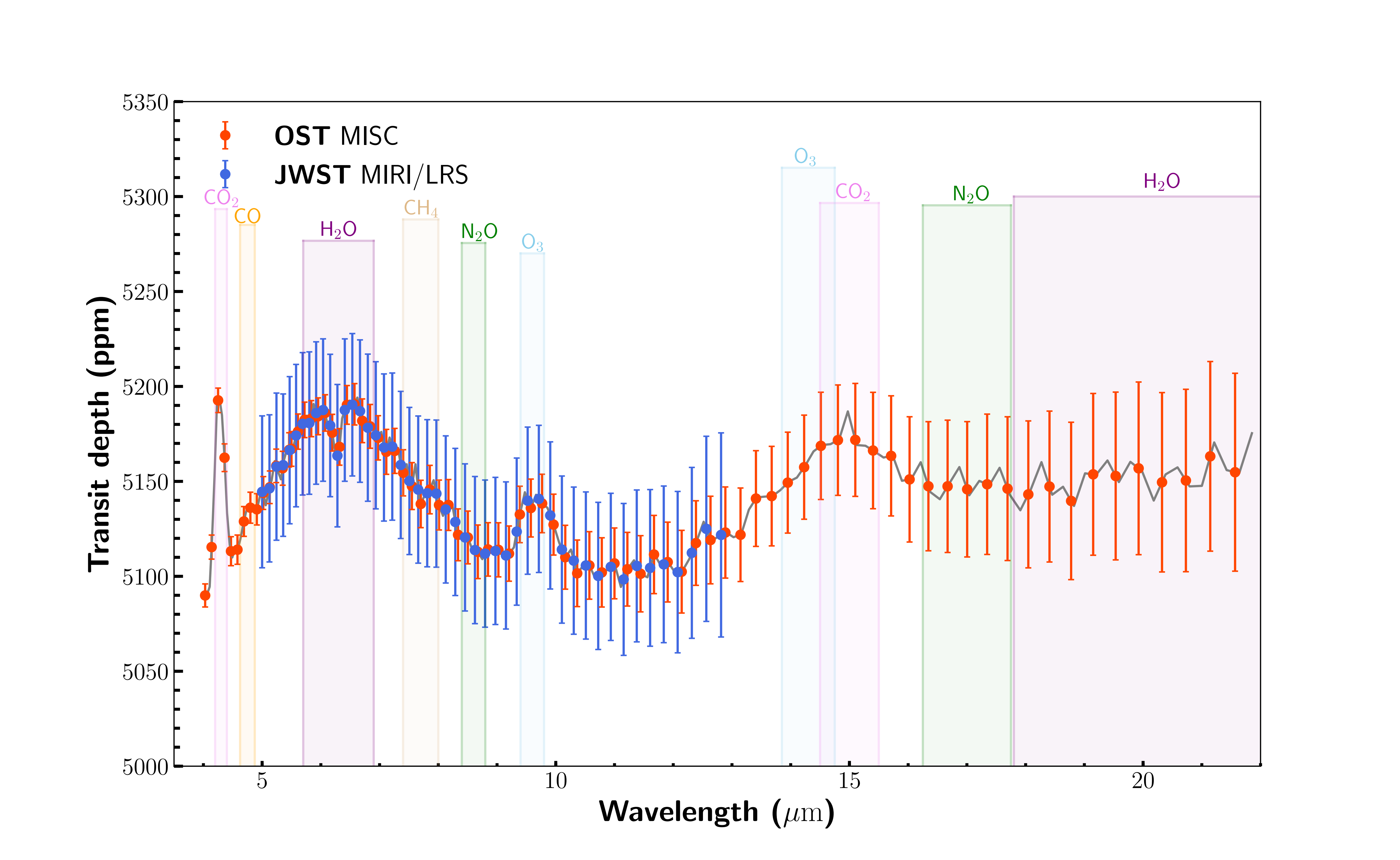
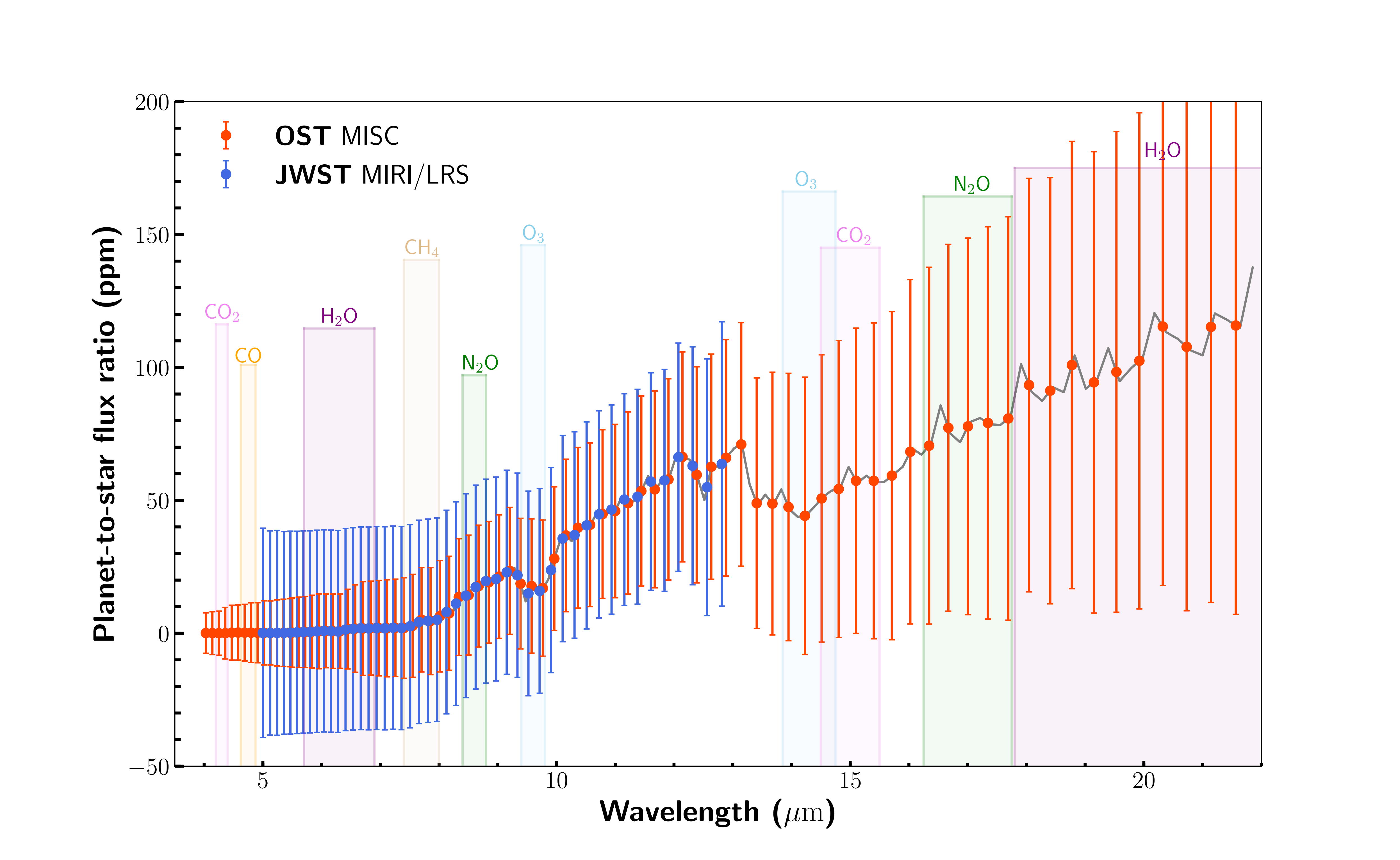
Conclusions

- 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

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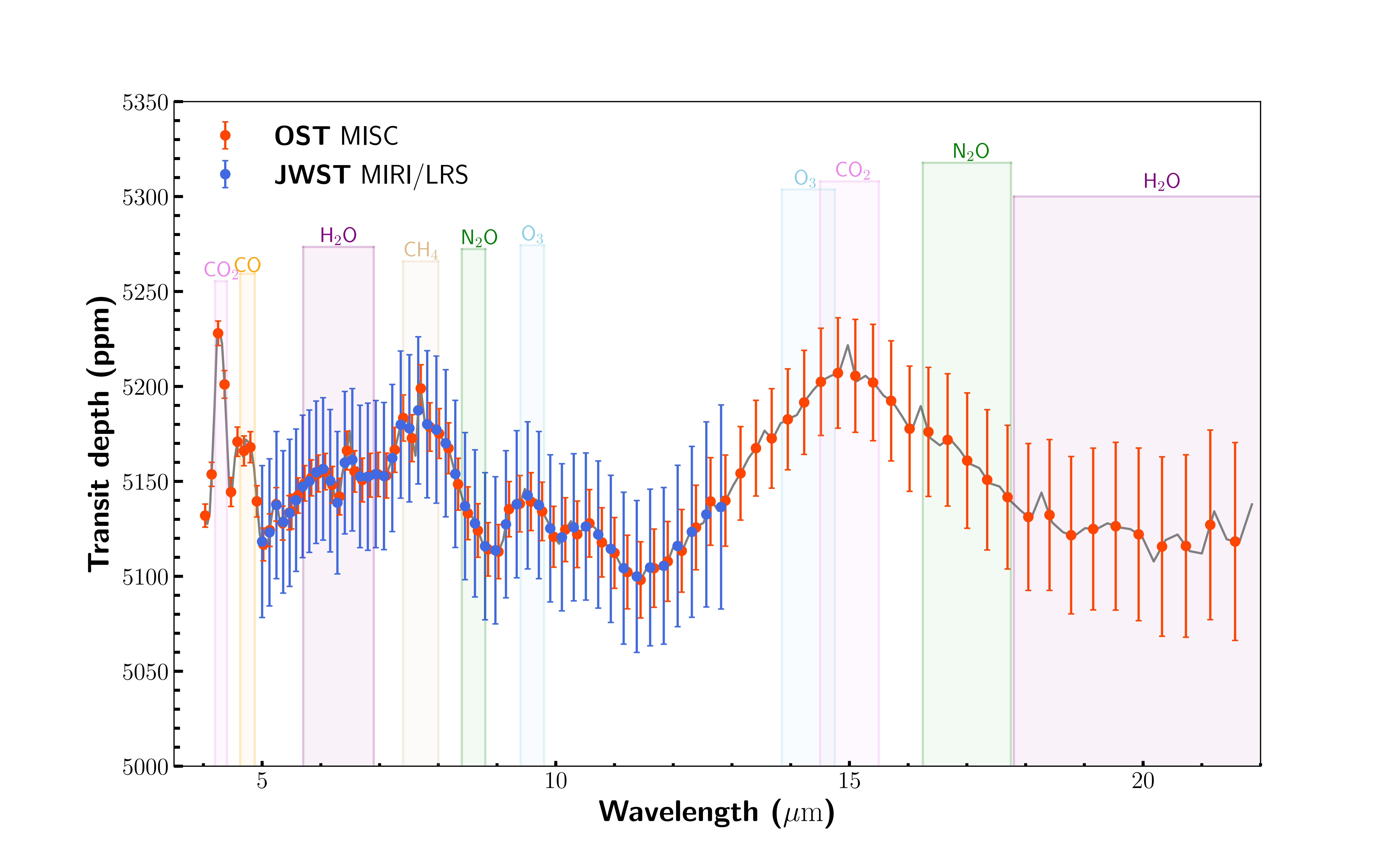
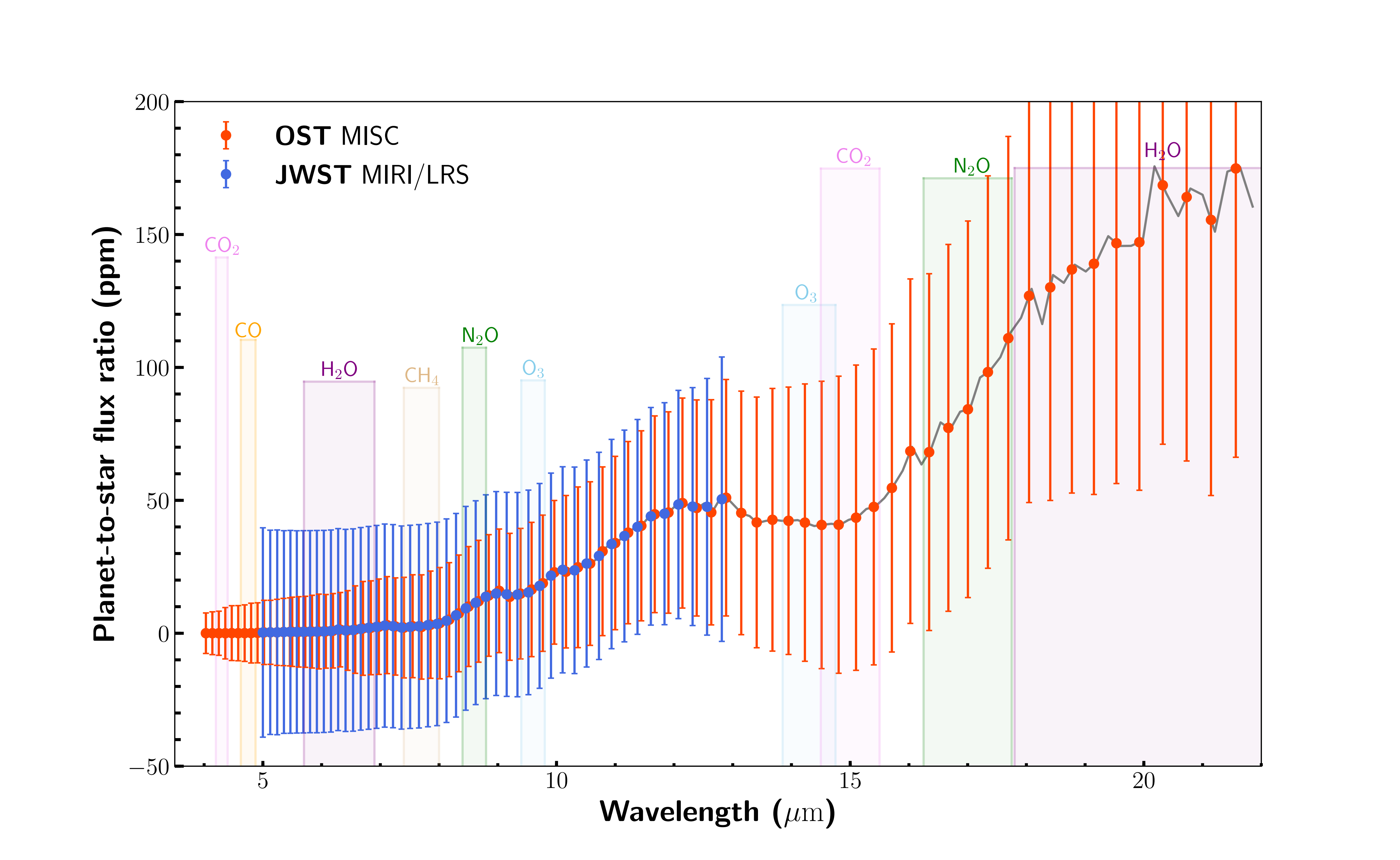
Enhanced methane case

NASA

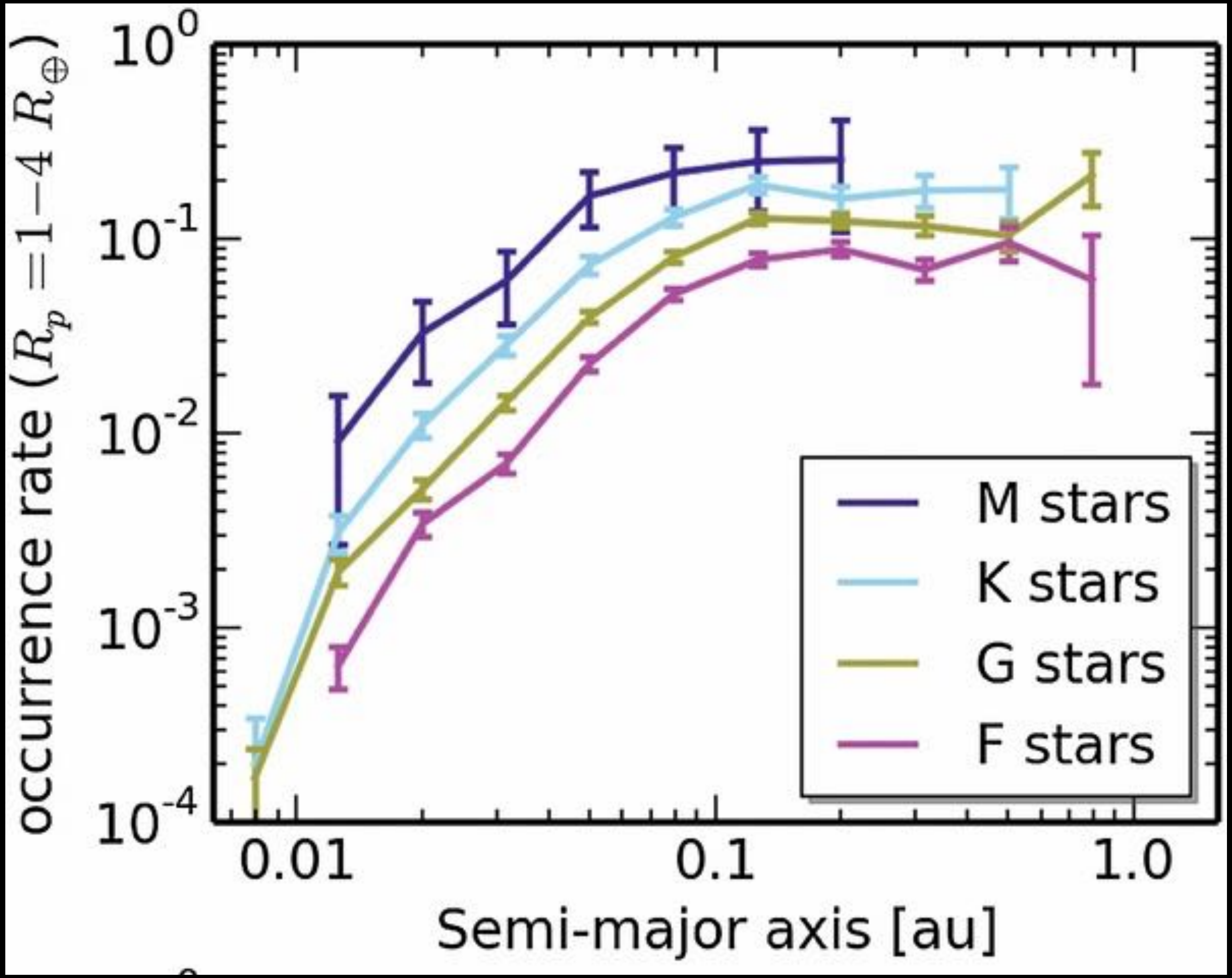




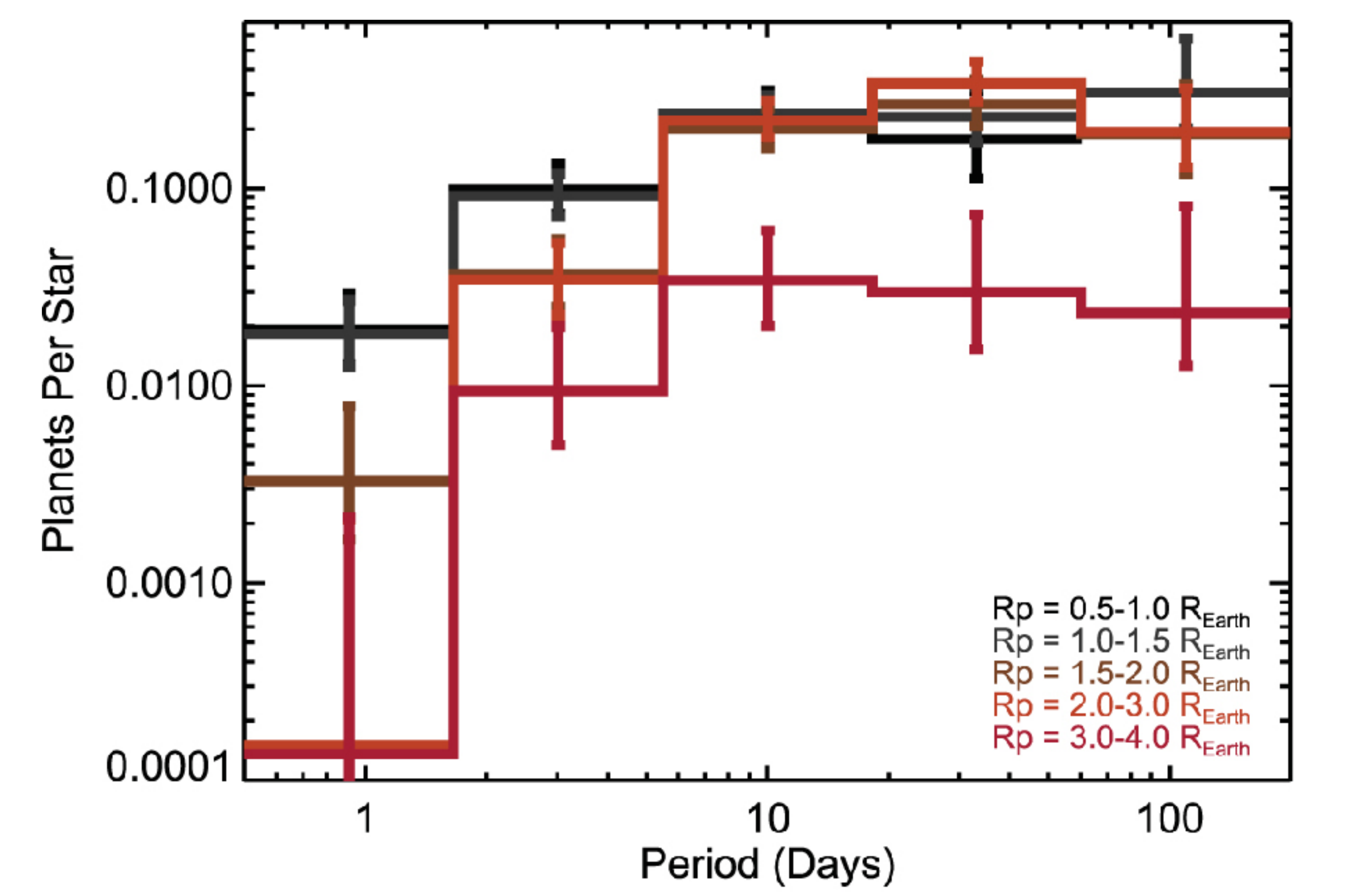
TRAPPIST-1e-like emission/transmission spectra, 64 visits each, R = 50, Kmag = 8

Optimistic 30 ppm noise floor for MIRI/LRS, 5ppm for OST

Planet/star occurrence

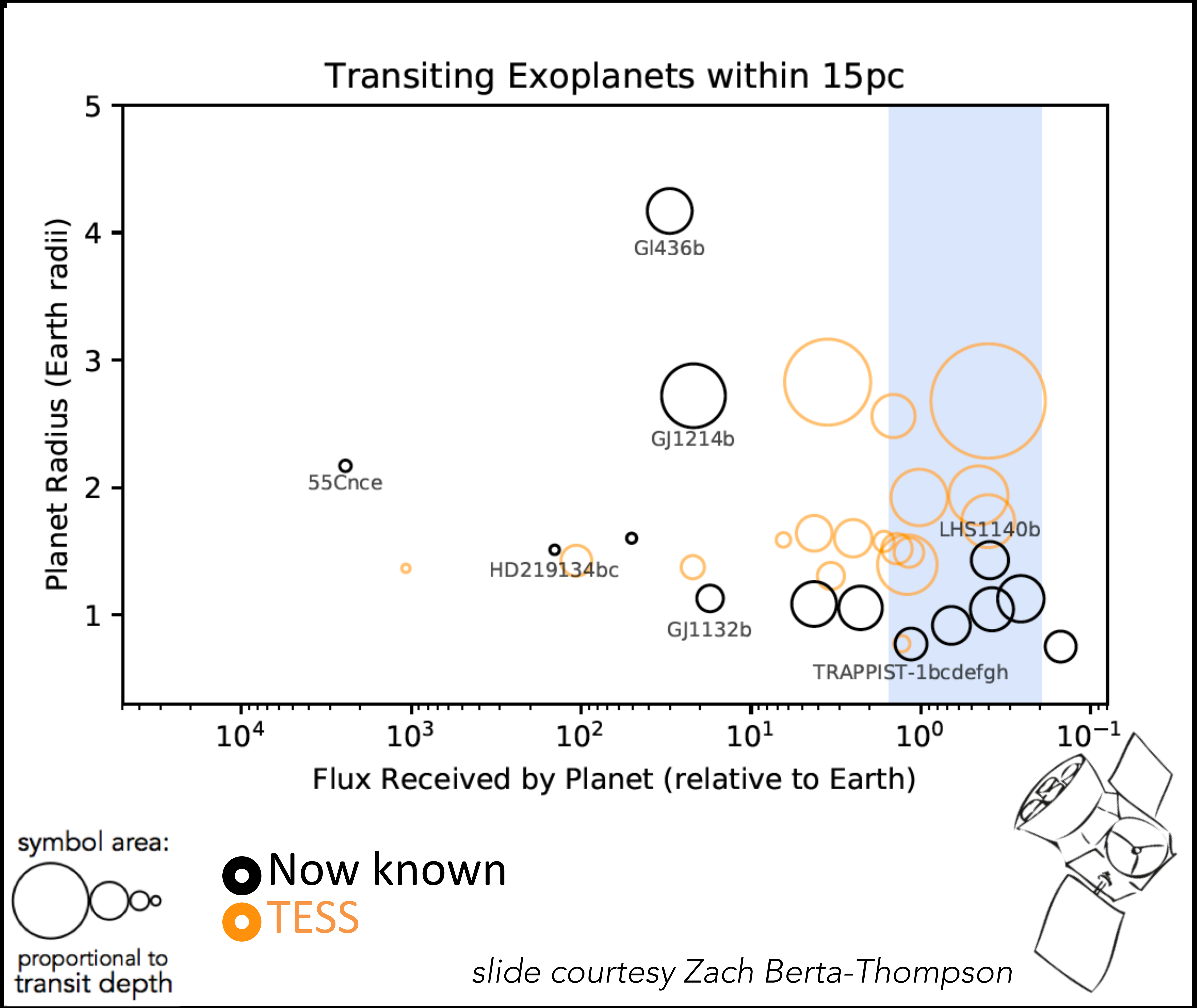


Mulders et al. (2015)



Dressing and Charbonneau (2015)

How many M dwarf planets?



Spectral type	Mass ($M_\odot$)	Radius ($R_\odot$)	$T_{\rm eff}$ (K)
M7-M7.5	$N(0.1, 0.01^2)$	$N(0.12, 0.01^2)$	$N(2700, 200^2)$
M8-M8.5	$N(0.09, 0.01^2)$	$N(0.11, 0.01^2)$	$N(2500, 200^2)$
M9-M9.5	$N(0.08, 0.01^2)$	$N(0.1, 0.01^2)$	$N(2300, 200^2)$
L	$N(0.07, 0.01^2)$	$N(0.09, 0.01^2)$	$N(2100, 200^2)$
	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	

SPECULOOS estimated yields, Delrez+2018

Atmosphere types