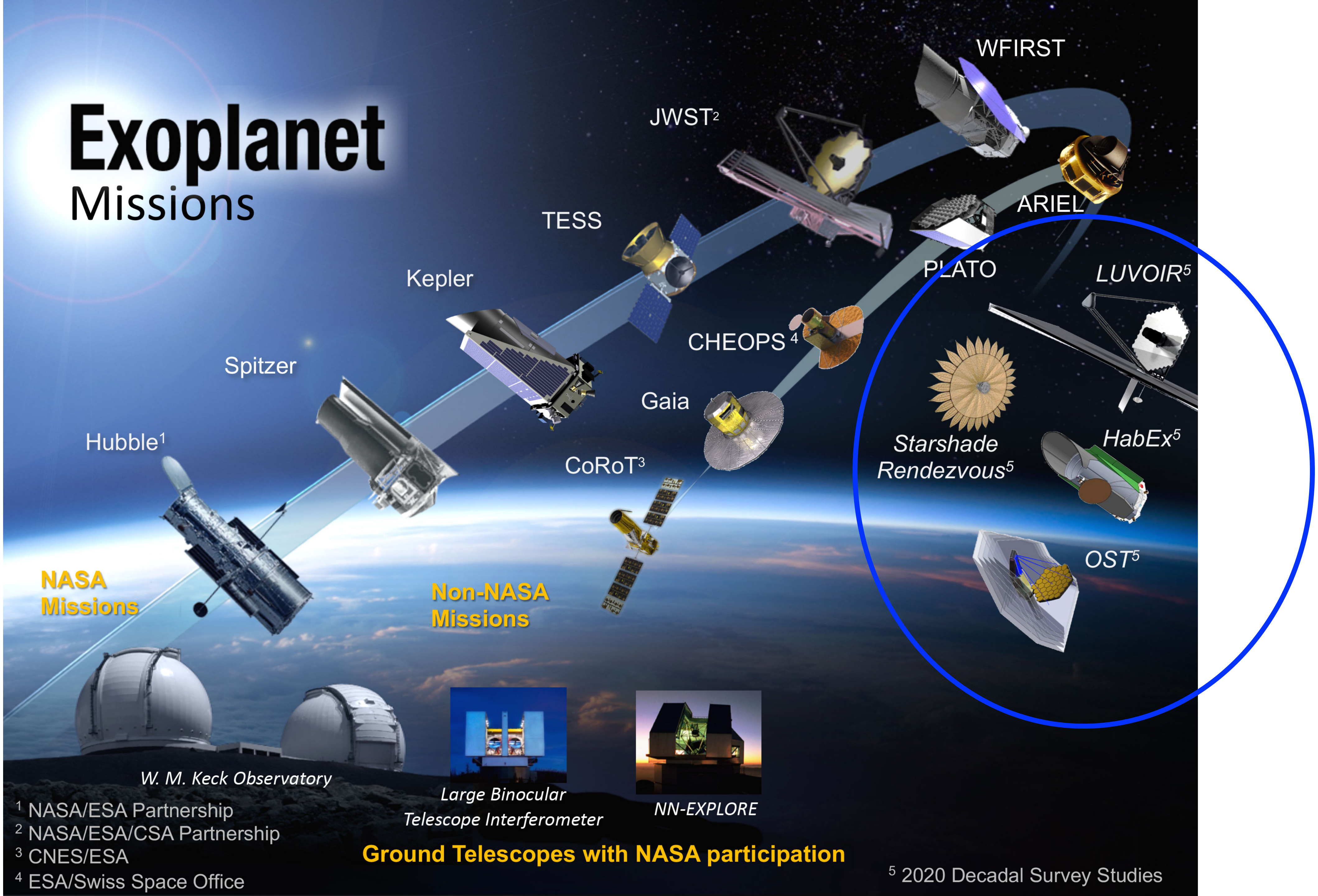
ORIGINS Space Telescope | From first stars to life

The search for life with the *Origins Space Telescope*

Tiffany Kataria (JPL) on behalf of co-leads Kevin B. Stevenson (STScI) and Jonathan J. Fortney (UCSC), Robert Zellem (JPL), Luke Tremblay (ASU), Michael Line (ASU), Caroline Morley (UT Austin), OST STDT members and the OST Exoplanets SWG

June 23, 2019

CL#19-5052


Exoplanet
Missions
WFIRST
JWST2
ARIEL
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PLATO
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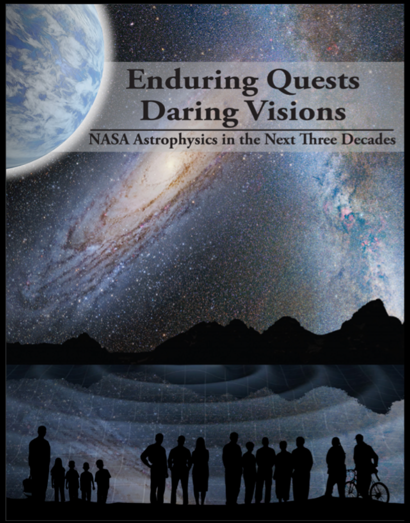
Kepler
CHEOPS 4
Spitzer
Gaia
Starshade
Rendezvous5
HabEx5
Hubble1
CoRoT3
OST5
NASA
Missions
Non-NASA
Missions
W. M. Keck Observatory
Large Binocular
Telescope Interferometer
NN-EXPLORE
1 NASA/ESA Partnership
2 NASA/ESA/CSA Partnership
3 CNES/ESA
4 ESA/Swiss Space Office
Ground Telescopes with NASA participation
5 2020 Decadal Survey Studies

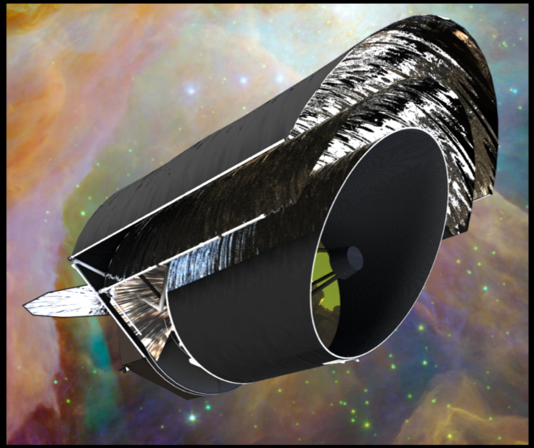
ORIGINS
Space Telescope

From the community, by the community, for the community.



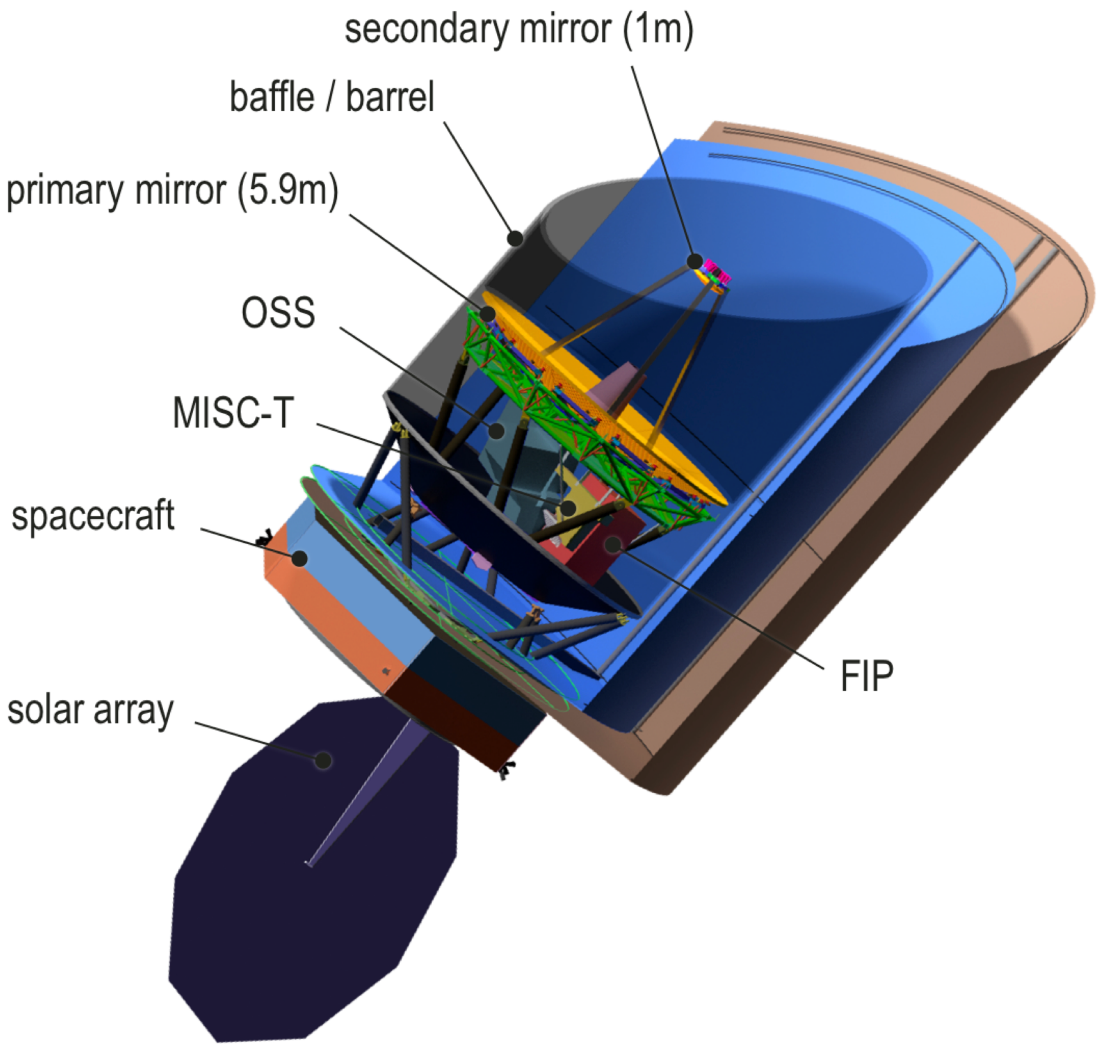
Through the Astrophysics Roadmap, the community expressed interest in a "Far-IR Surveyor" mission.

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



Guest Observers would use *Origins* to answer mission-driving science questions and make unexpected, transformative discoveries.

Origins: Spitzer-like minimal deployable design



Wavelength coverage: **2.8-588 μm**

Telescope:

- diameter: 5.9 m
- area: 25 m^2 (=JWST area)
- diffraction-limit: 30 μm
- temperature: 4.5 K

Cooling: long life cryo-coolers

Agile Observatory for surveys: 60” per second

Launch Vehicle:

Large, SLS Block 1, Space-X BFR

Mission: 10 year propellant, serviceable

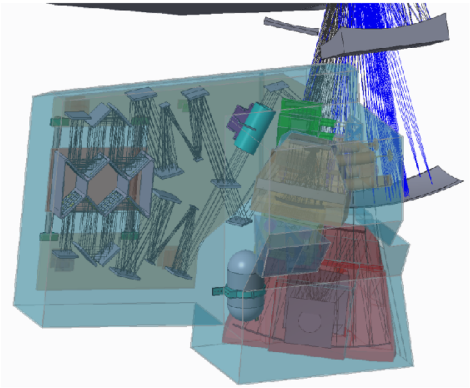
Orbit: Sun-Earth L2

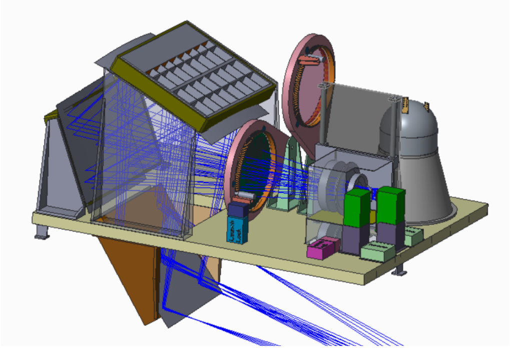
OSS: Origins Survey Spectrometer

-25-588 μm R~300, survey mapping

-25-588 μm R~43,000, spectral surveys

-100-200 μm R~325,000, kinematics





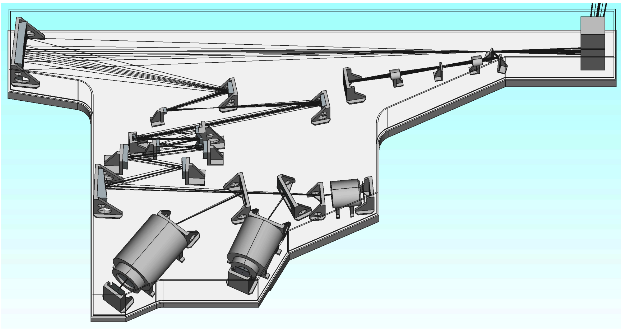
FIP: Far-infrared Imager Polarimeter

- 50 or 250 μm, Large area survey mapping
- 50 or 250 μm, polarimetry

MISC-T: Mid-Infrared Spectrometer Camera Transit

-Ultra-Stable Transit Spectroscopy

-2.8-20 μm R~50-295



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Enabling Technologies

Detectors:

Far-IR:

improved sensitivity: 3×10^{-20} W/Hz$^{1/2}$

state-of-the-art: 10^{-19} W/Hz$^{1/2}$

increase array size: 104 pixels

state-of-the-art: 3000 pixels

Kinetic Inductance Detectors (KIDs),

Transition Edge Sensor (TES) bolometers

Mid-IR:

improved relative spectral stability, 5 ppm

state-of-the-art: 20-50 ppm

HgCdTe, Si:As, TES

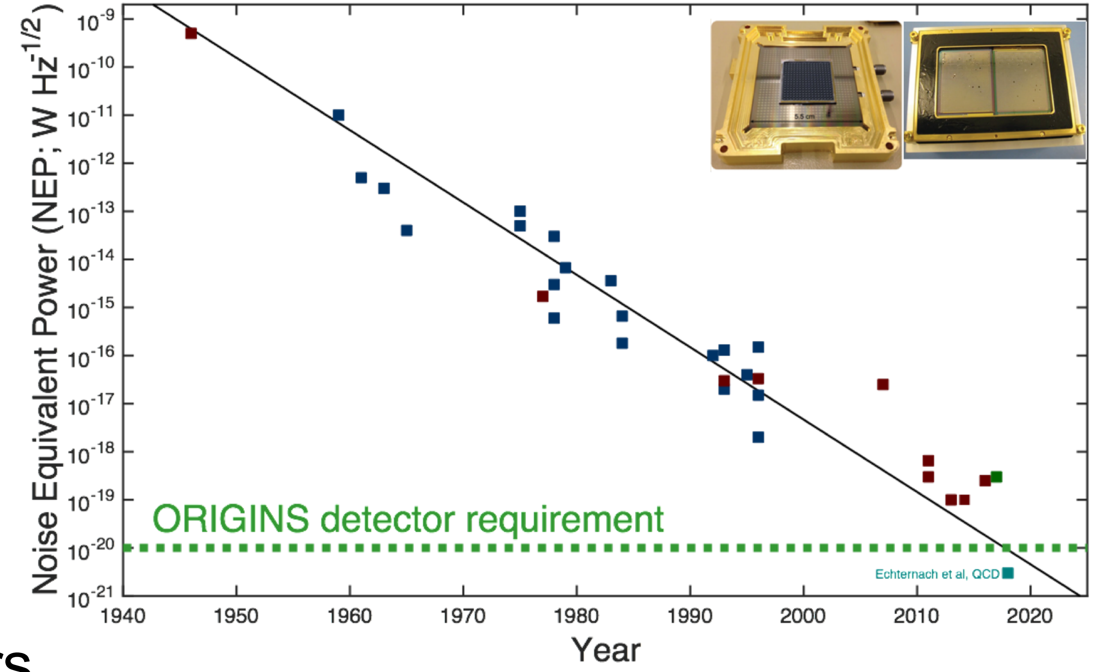
Cryocoolers: are in hand

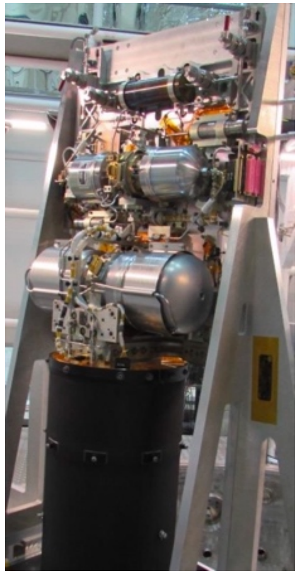
-4.5 K: Have already flown on Hitomi (2016),

JWST/MIRI (TRL 7, 6 K)

-50 mK: NASA development

Far-IR: KIDs or TES





NGAS JWST/MIRI

SHI Hitomi

SCIENCE DRIVERS FOR MISSION DESIGN

HOW DOES THE UNIVERSE WORK?

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

Using sensitive spectroscopic capabilities of a cold telescope in the infrared, Origins will measure properties of star-formation and growing black holes in galaxies across all epochs in the Universe.

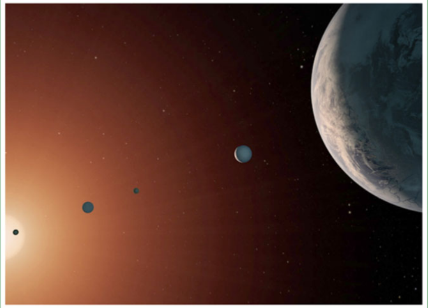
HOW DID WE GET HERE?

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

With sensitive and high-resolution far-IR spectroscopy Origins will illuminate the path of water and its abundance to determine the availability of water for habitable planets.

ARE WE ALONE?

Do planets orbiting M-dwarf stars support life?



By obtaining precise mid-infrared transmission and emission spectra, Origins will assess the habitability of nearby exoplanets and search for signs of life.

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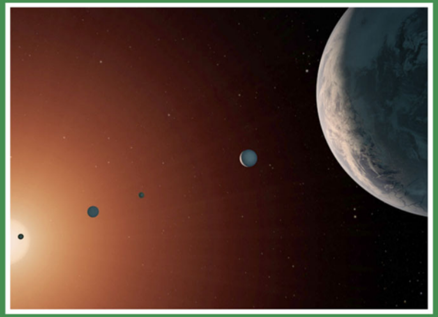

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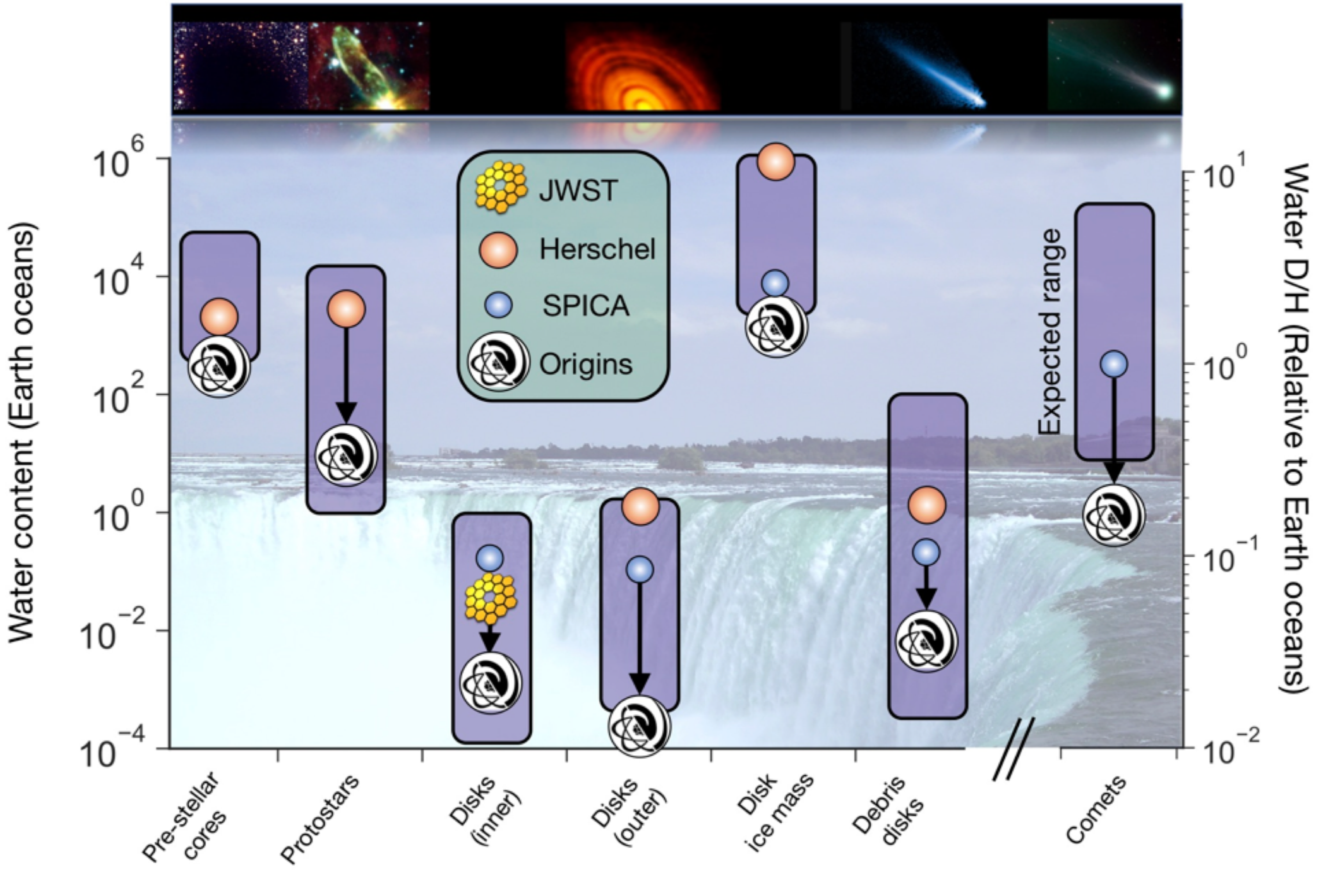
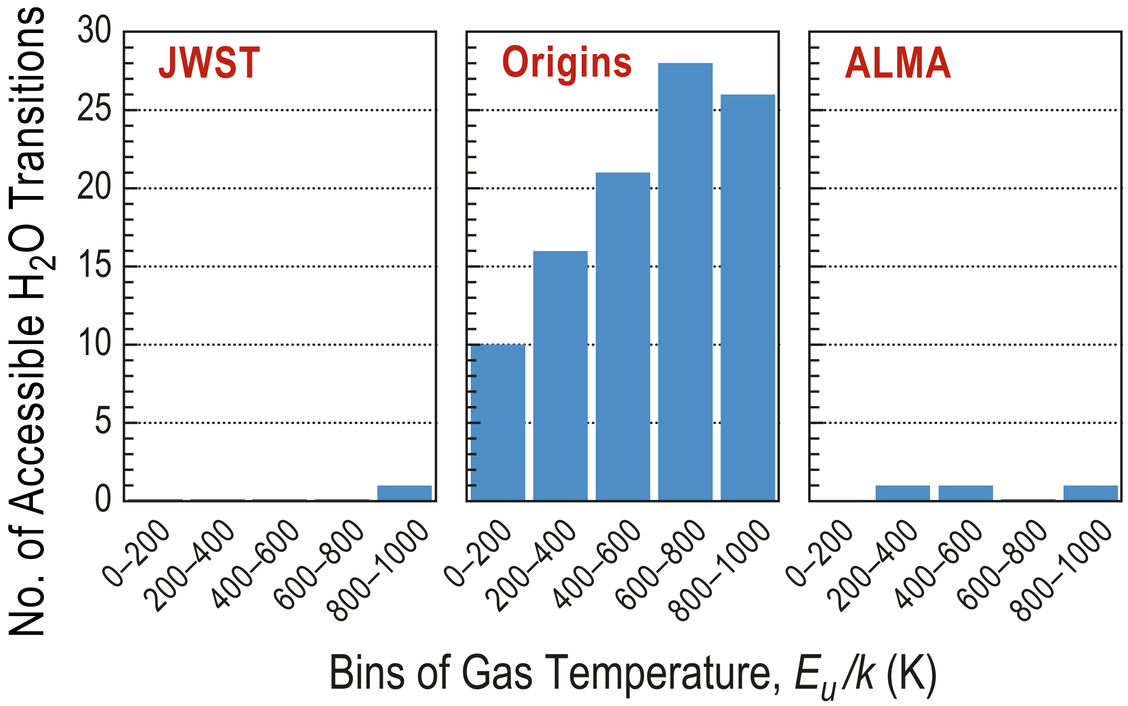
Origins follows the water trail to much fainter limits





Origins is designed to create a complete census of volatiles (traced by water) from the ISM to exoplanetary atmospheres around all stellar types

TRACING WATER EMISSION IN DISKS

Movie Credit: Klaus Pontoppidan

SCIENCE DRIVERS FOR MISSION DESIGN

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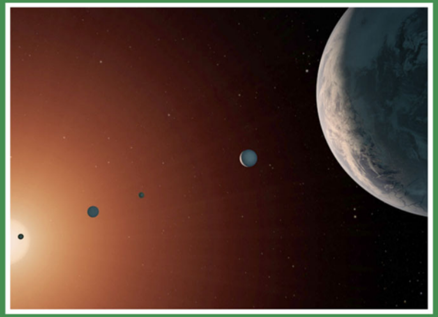
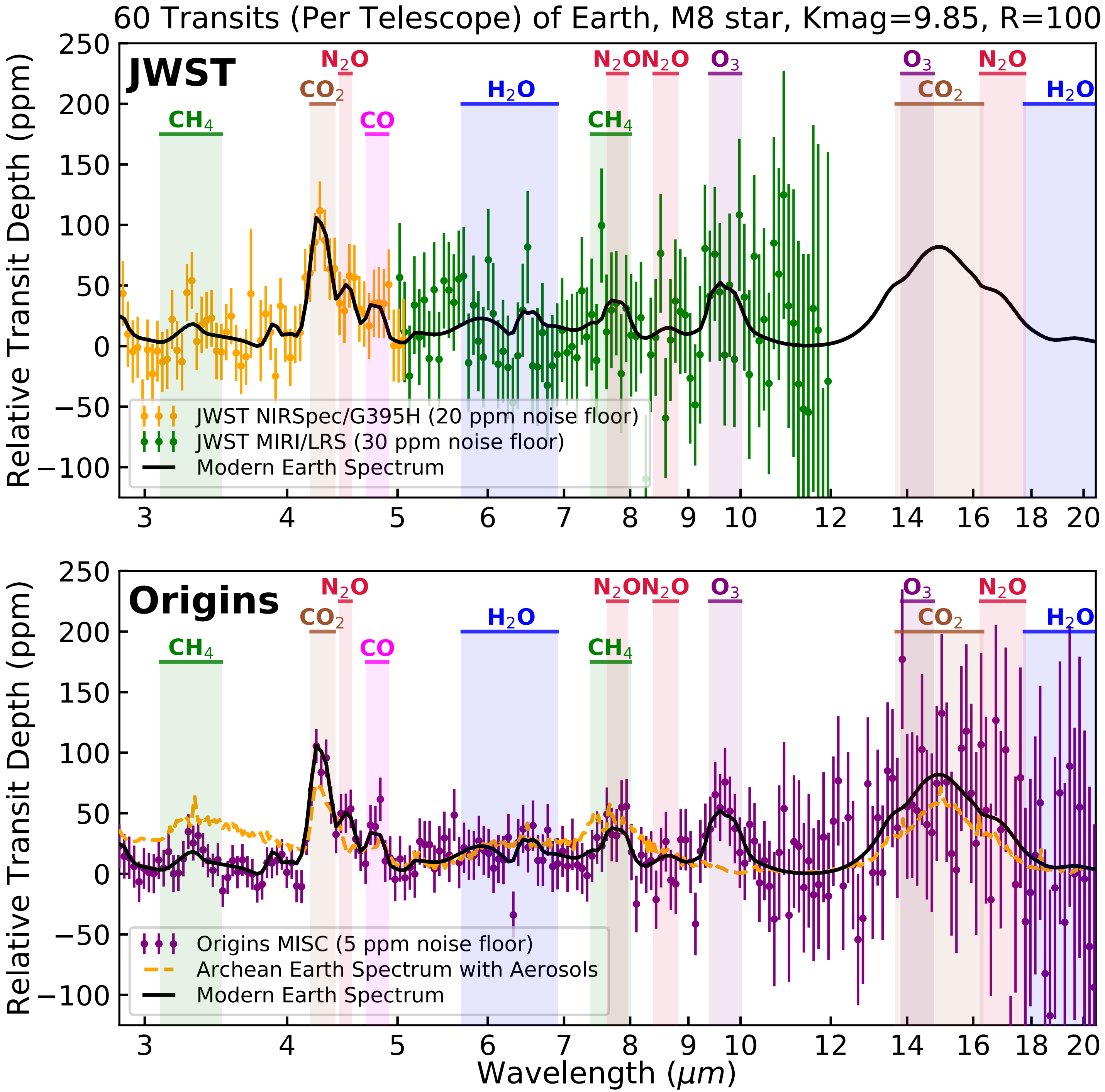


By obtaining precise mid-infrared transmission and emission spectra, Origins will assess the habitability of nearby exoplanets and search for signs of life.

Origins will leverage the transit technique to characterize the atmospheres of terrestrial exoplanets

Origins MISC-T

- **Simultaneous** wavelength coverage from 3-22 microns
- Spectral resolving power (**λ/Δλ**) of R=50-300
- 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
- Broad wavelength coverage = **context**
  - Detection of the unexpected



Origins will use a multi-tiered observing strategy to search for life

Tier 3
Search for biosignatures (O_3+N_2O, O_3+CH_4) with additional transits of temperate worlds

Tier 2
Eclipse observations of clear **M-dwarf planets** to determine if they are temperate

Tier 1
Transit observations of **M- and K-dwarf planets** to determine which planets have tenuous, clear or cloudy atmospheres

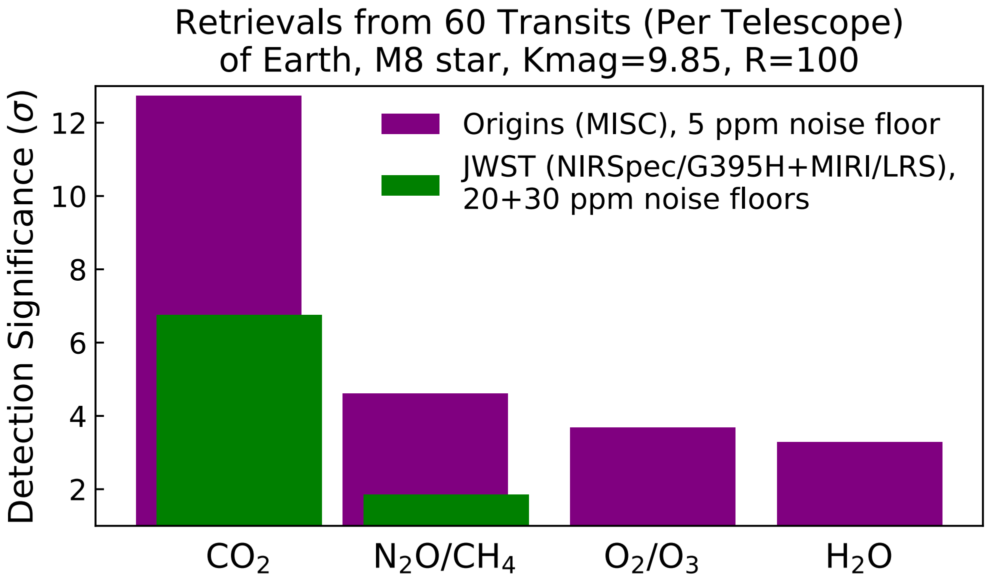
Pre-select terrestrial M-dwarf planets based on M_p, R_p and T_{eq}, relatively rank based on suitability for detailed atmospheric characterization (e.g., Cowan et al. 2015; Zellem et al. 2017; Goyal et al. 2018; Kempton et al. 2018; Morgan et al. 2018).

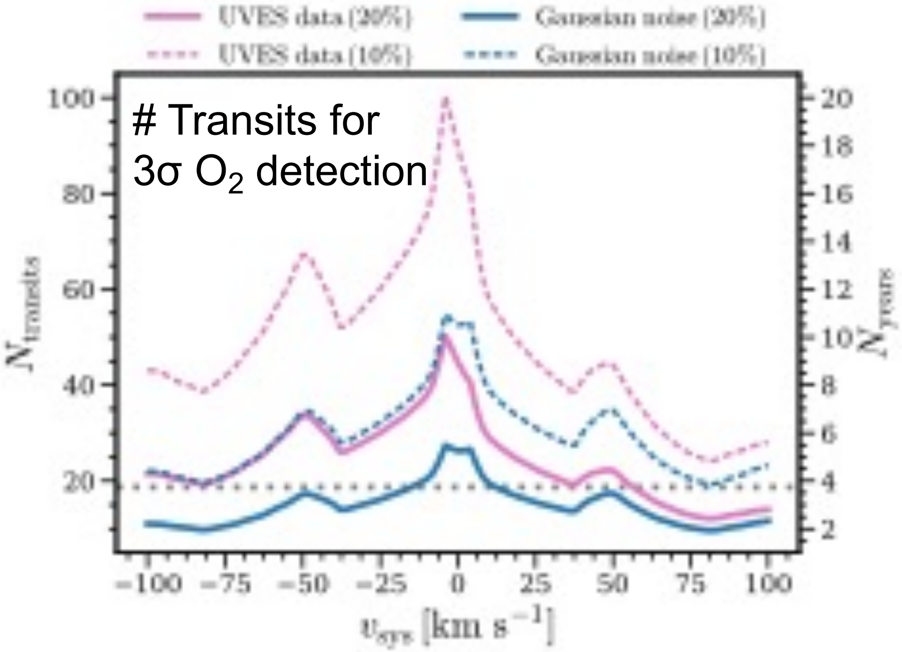
Number of planets in a 4000-hr program with *Origins*

Tier	# of Planets	Median observation	Total hrs
1	28	8 transits	896
2	17	15 eclipses	1020
3	10	52 transits	2080

Synergies between Origins, JWST, ELTs

- **JWST** can determine presence of an atmosphere and constrain abundances of some molecules (e.g., H_2O, CO_2, CH_4, depending on the atmospheric composition)
- **ELTs** could use very high-resolution spectroscopy (R~100,000+) in optical to search for O_2 in transit (Snellen et al. 2013, Rodler & Lopez-Morales 2014, Serindag & Snellen, 2019)
  - Technique could be extended to detections of CH_4 and H_2O
  - However, thermal background noise limits this ground-based approach to bluer than 5 microns (Snellen et al. 2015)
- HRS observations to date have provided only molecular detections, not abundance determinations, due to loss of continuum information (Brogi & Line 2018)
- Emission from M-star HZ planets within reach for a handful of systems at N-band (10 mm) (Quanz et al., 2014) but will likely come via photometry, rather than spectroscopy
- Therefore, visible or thermal IR observations with JWST, ELTs would be entirely complementary to *Origins* transit and emission spectra

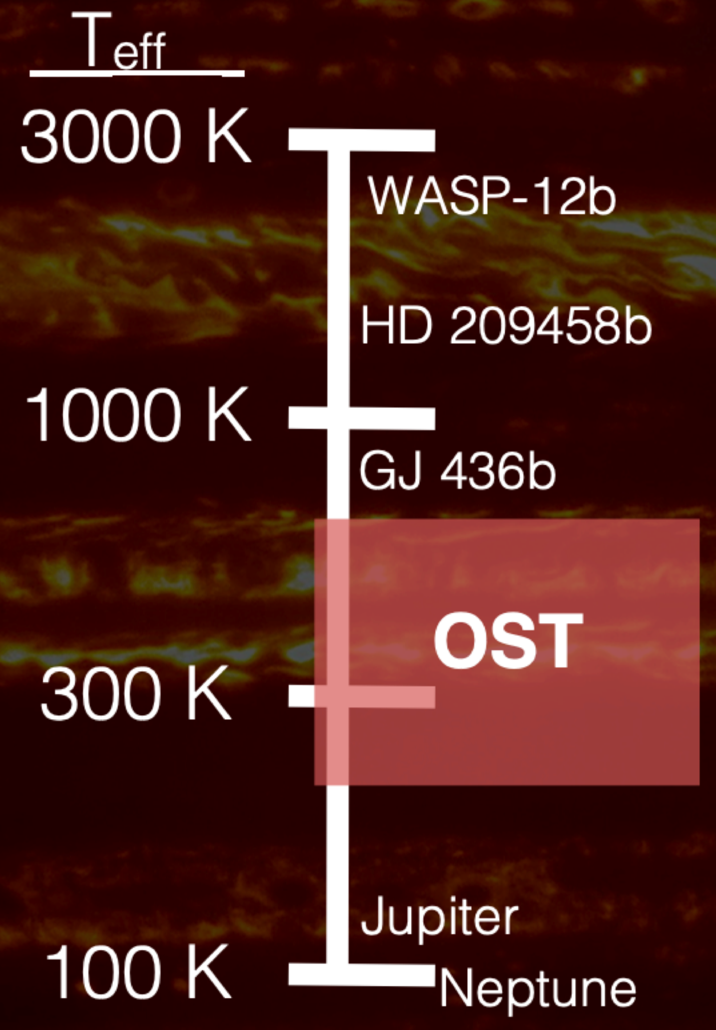




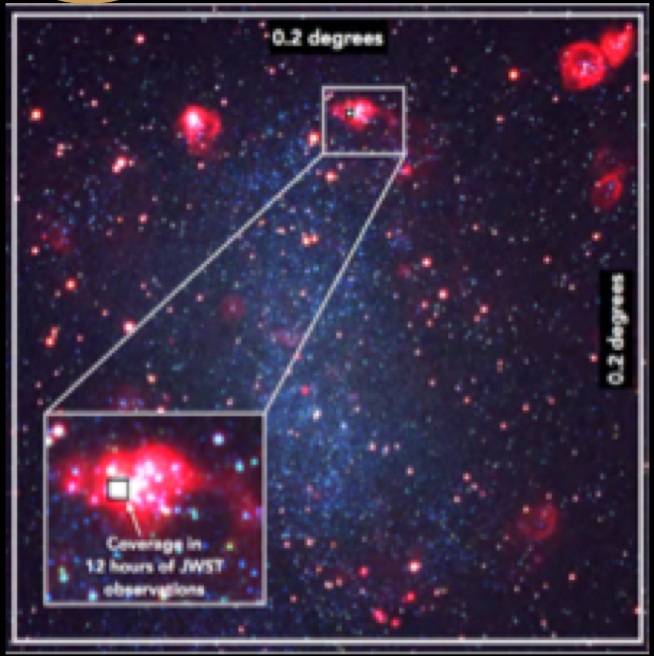
Serindag & Snellen 2019

Ancillary Exoplanet Science with Origins

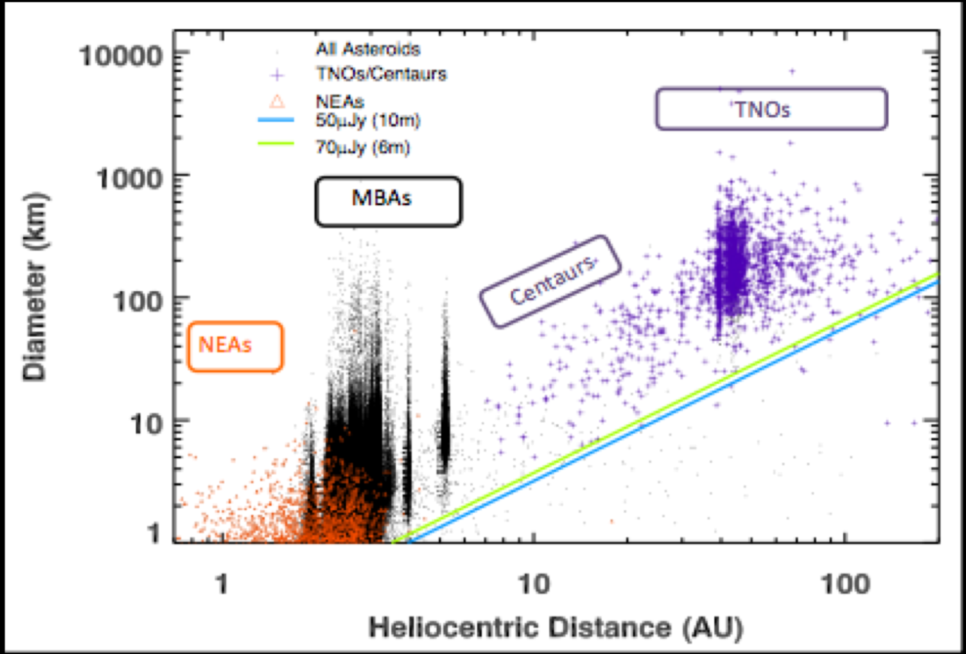
- Characterizing Jupiter- and Neptune-class atmospheres at closer to solar system temperatures, beyond the reach of JWST
- Jupiter and Saturn analogs through time via coronography (an upscope)
- Thermal phase curves and eclipse mapping of terrestrial HZ planets



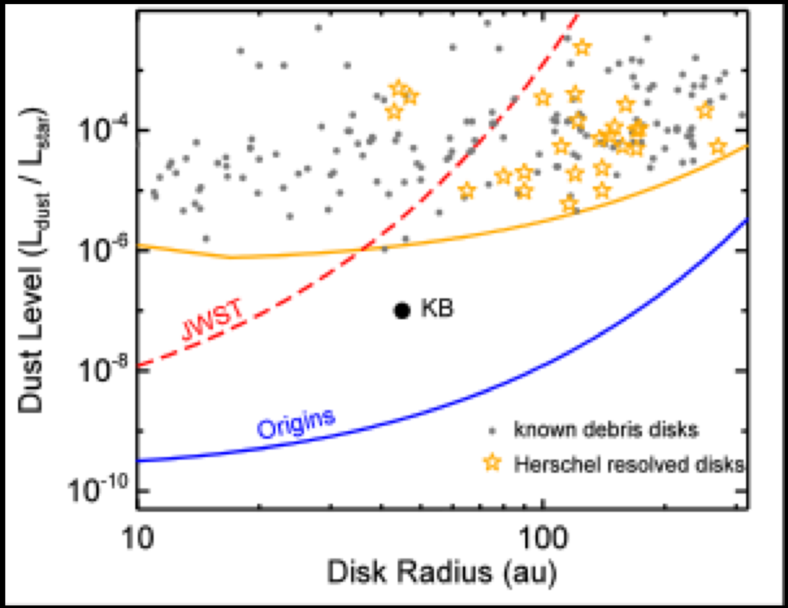
Discovery Space of Origins



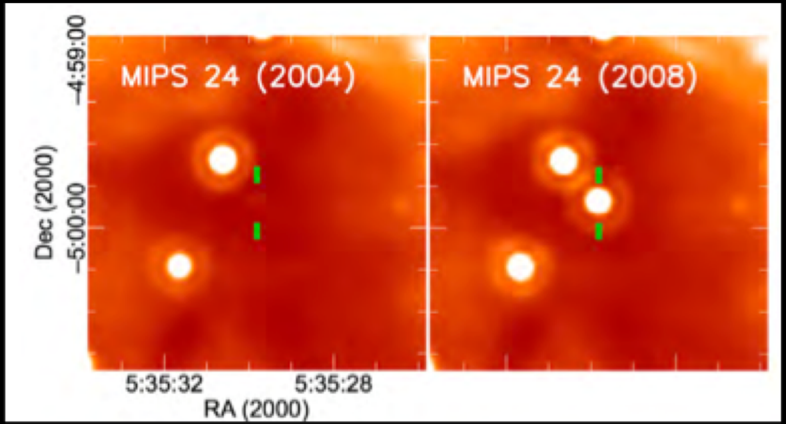
H2 mapping with Origins vs JWST in near-by galaxies (in 12 hours)



Measure sizes to all KBOs > 10 km in a few hundred hour survey

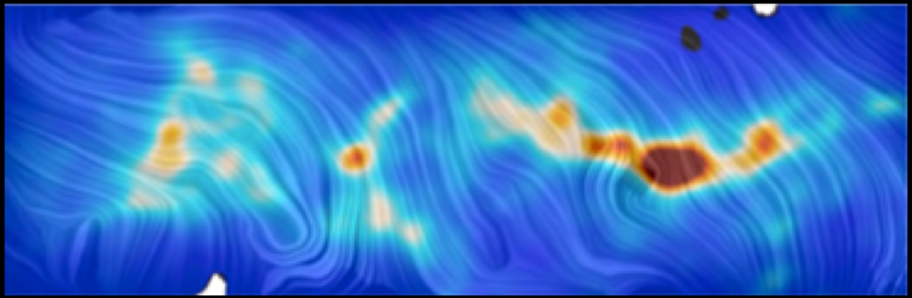


Dust in debris disks



Time variability in protostellar accretion (*Time-domain panel*)

15" scale maps of dust polarization to bridge Planck (2') & ground (1")



And much more…

Conclusions

ORIGINS Space Telescope | From first stars to life

- M dwarfs are important targets in the search for life
- *Origins* will target terrestrial planets in the habitable zone of M dwarfs to detect biosignatures and constrain habitability
- *Origins* will enable technical advances with detector technology
- *Origins* will characterize the atmospheres of planets that will have already been discovered by ground- and space-based surveys
- *Origins* will leverage previous heritage of characterizing transiting exoplanets, extending high-fidelity measurements to the mid-IR

Additional slides

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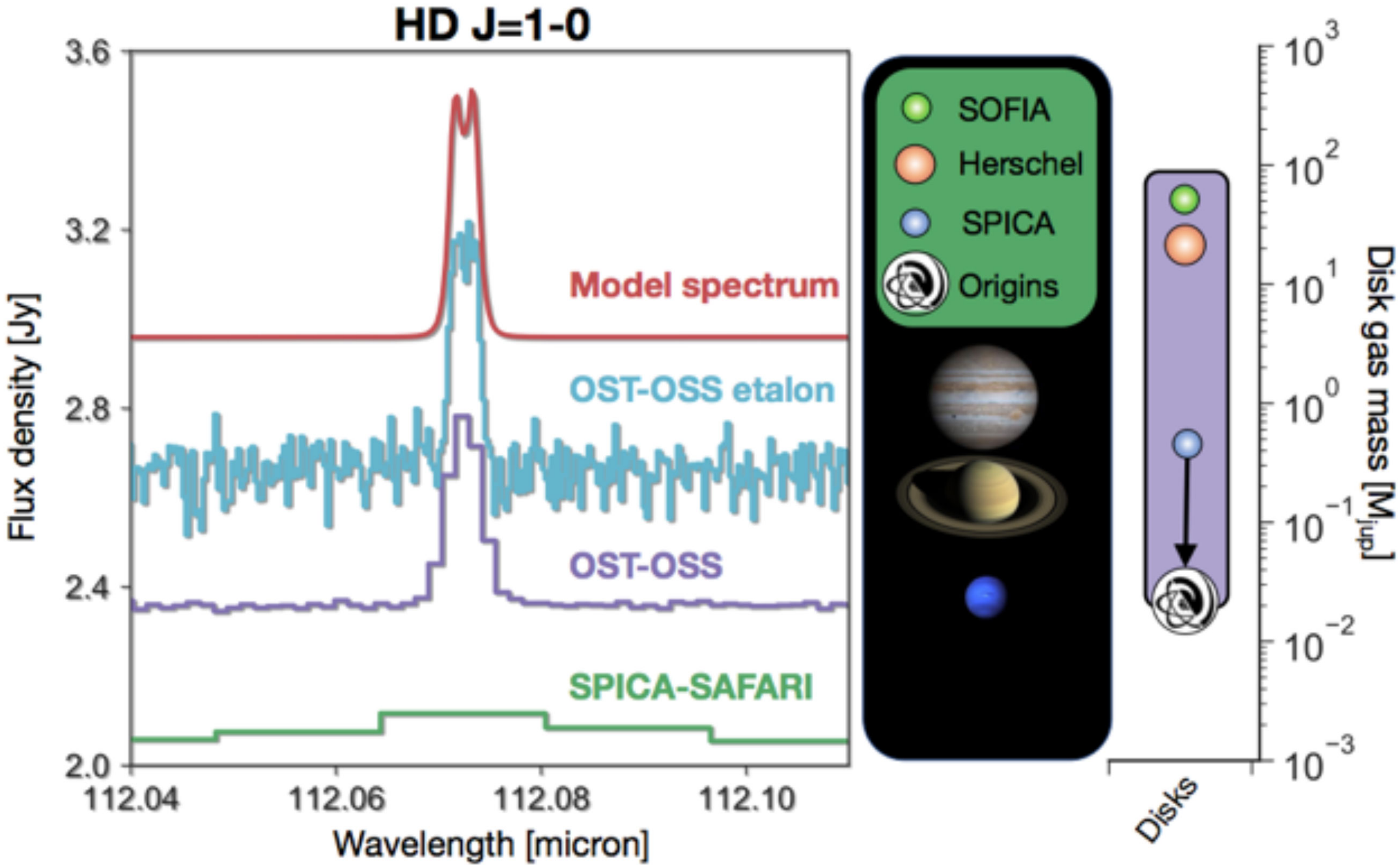
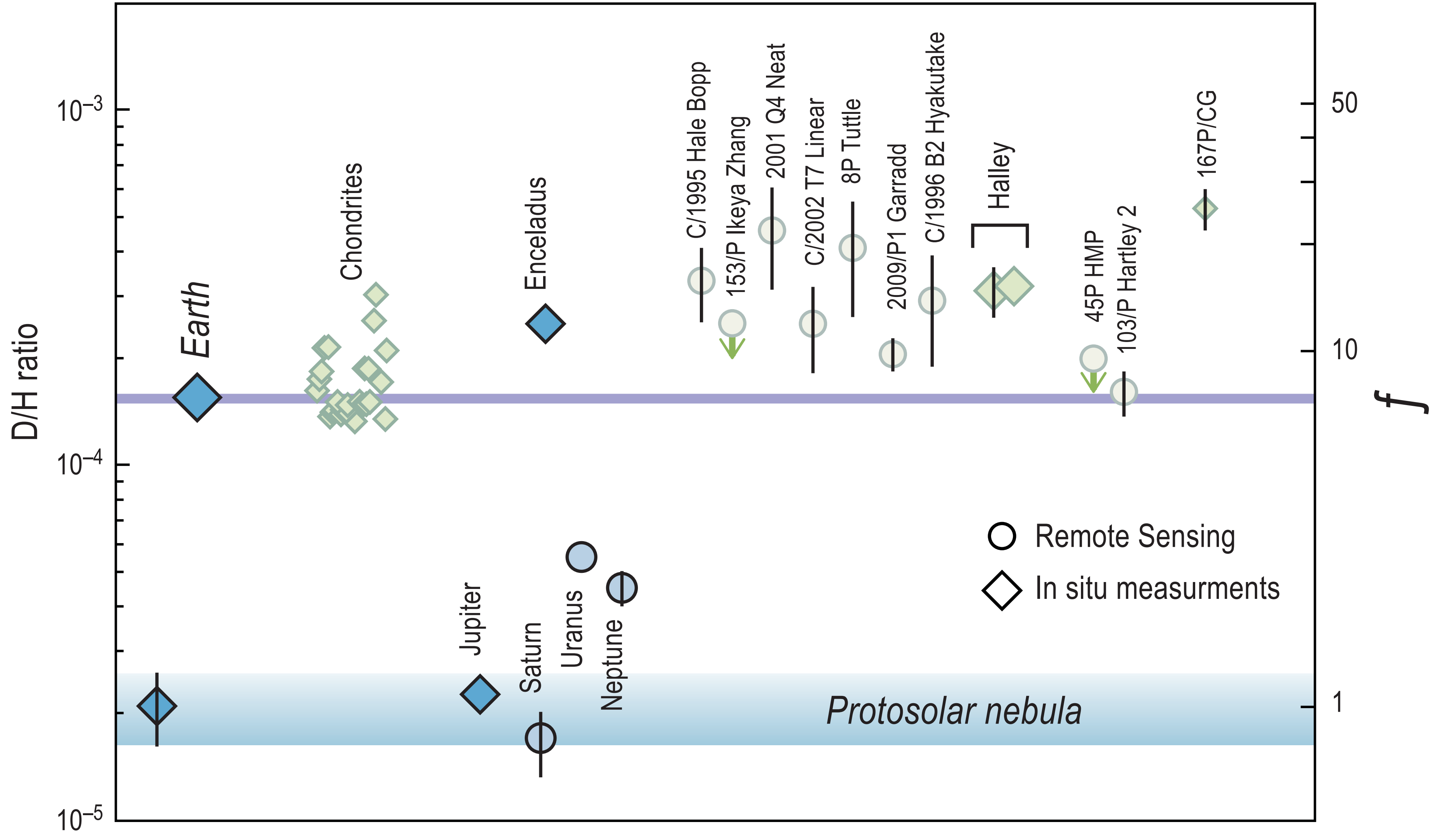
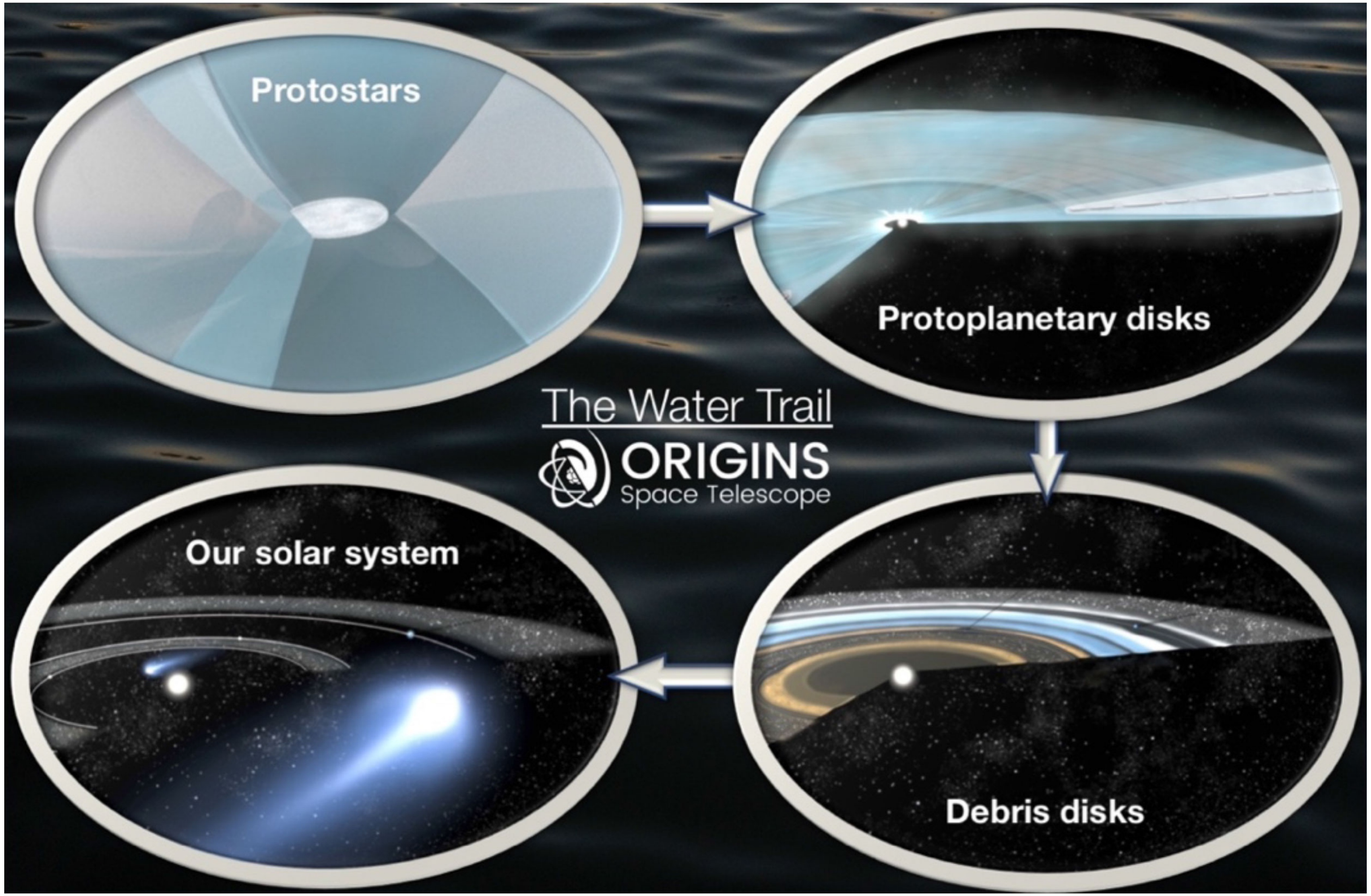
Origins definitively measures gas mass of planet forming disks



Origins definitively measures D/H (HDO/H_2O) in >200 comets & asteroids

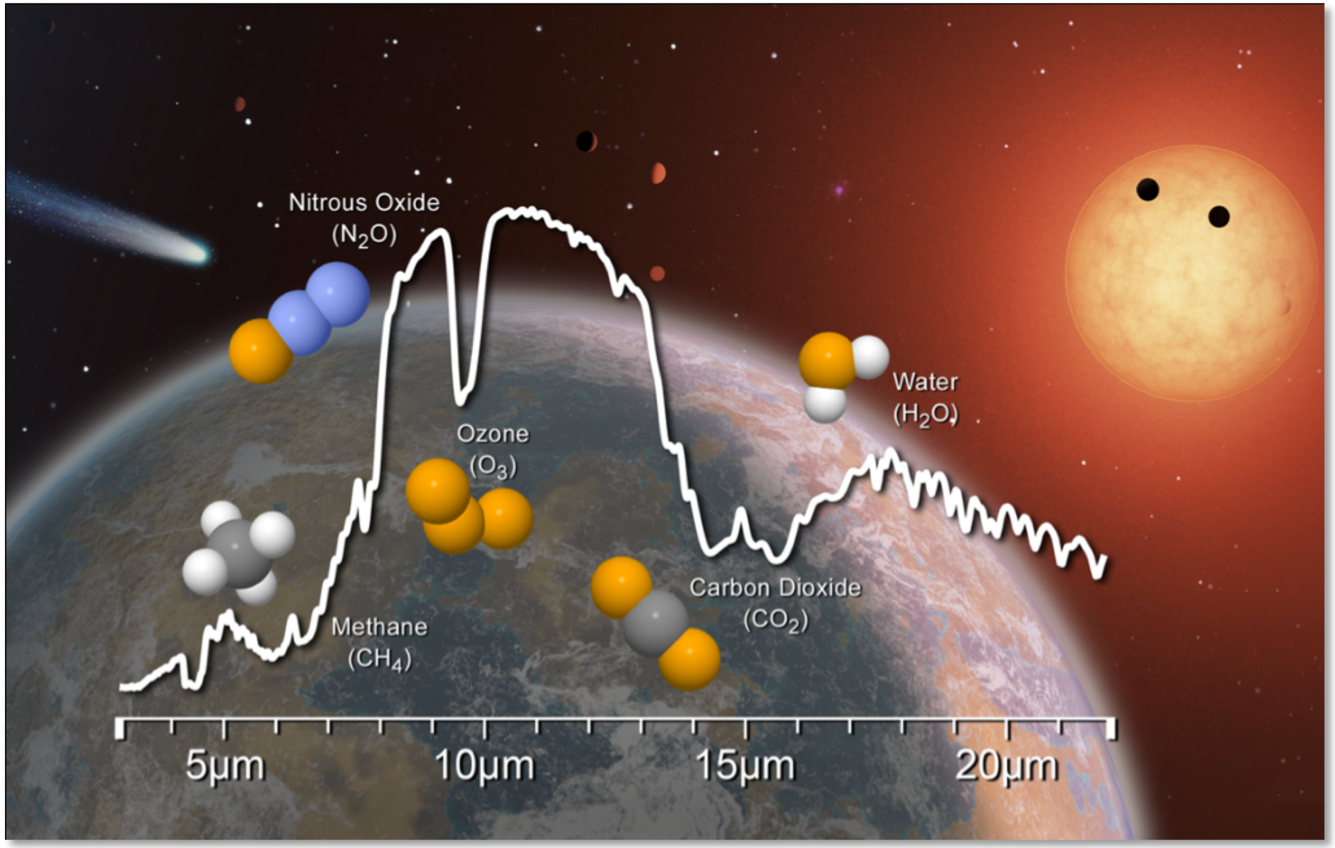


- Water vapor emission tracing gas at temperatures 10K to 1000K in 30-600 microns. *10K-300K gas cannot be studied with SOFIA.* HD line emission is a tracer of gas mass in young proto-planetary disks around stars of all masses.
- High spectral resolution R for water and moderate R for deeper sensitive observations for HD in disks.



Accessing Biosignatures and Thermal Properties with *Origins*

- ***Origins* will assess the habitability of nearby exoplanets and search for signs of life.**
  - Transmission and emission (dayside and phase-resolved) exoplanet spectroscopy from 3-22 μm
- *Origins* Objectives
  - **Search for bioindicator gases**
  - **Measure the temperatures** of planet surfaces
  - For the most promising targets, **search for biosignature gases**, allowing for a unique assessment of a planet's ability to harbor life



Origins will leverage the transit technique to characterize the atmospheres of terrestrial exoplanets

- Precisely determined masses and radii
- Bulk densities for planetary classification before atmospheric characterization
- We can target planets known to be predominantly rocky

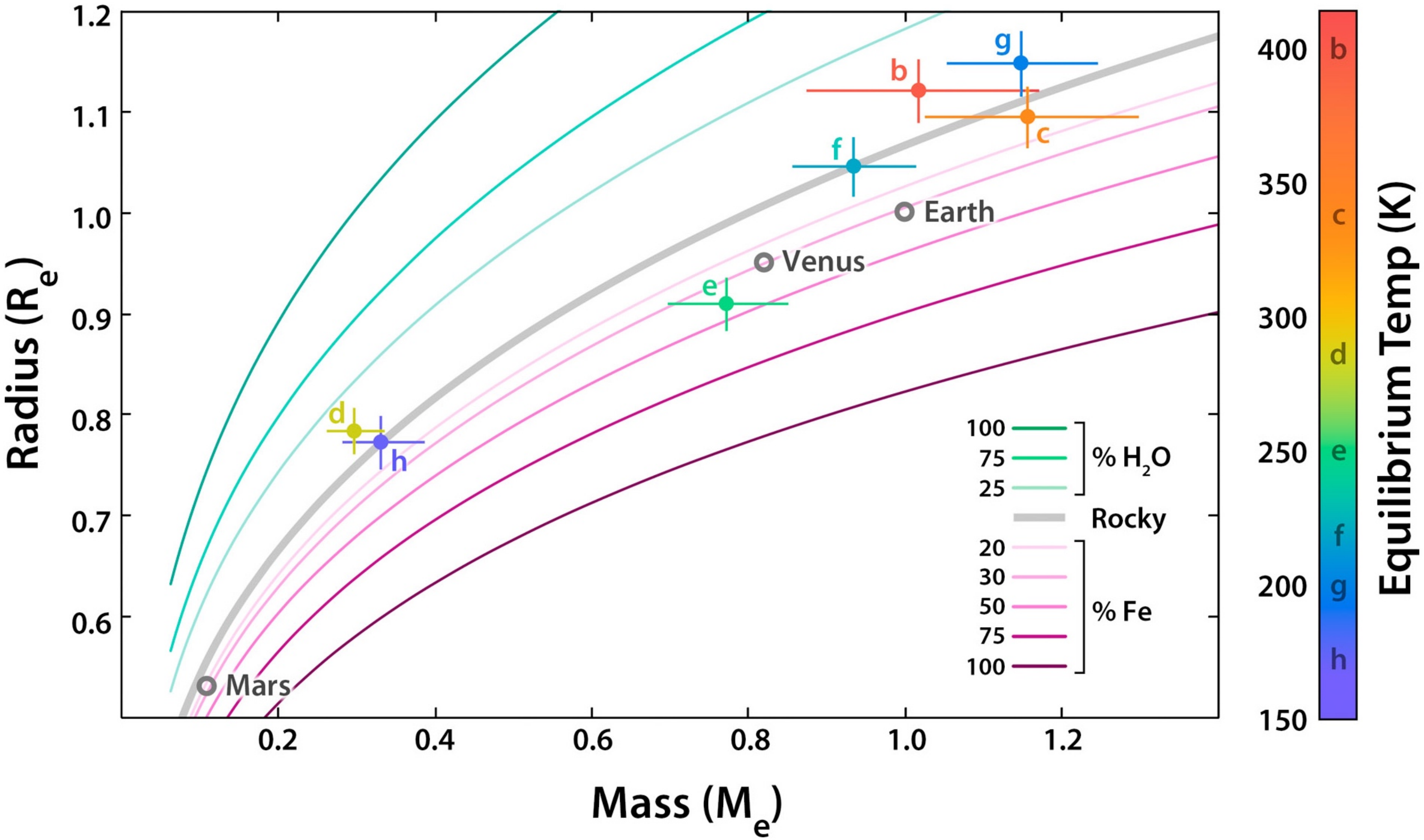
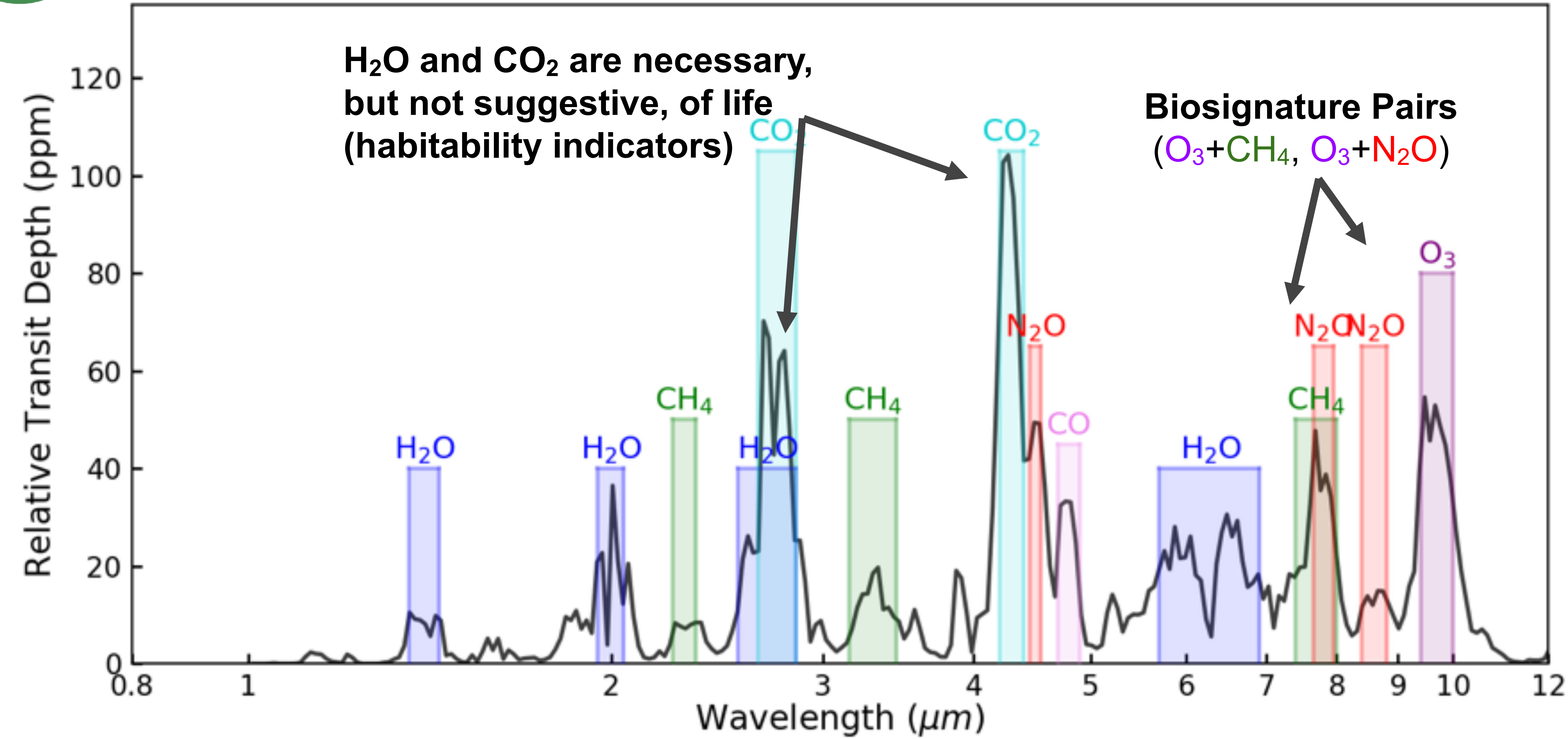


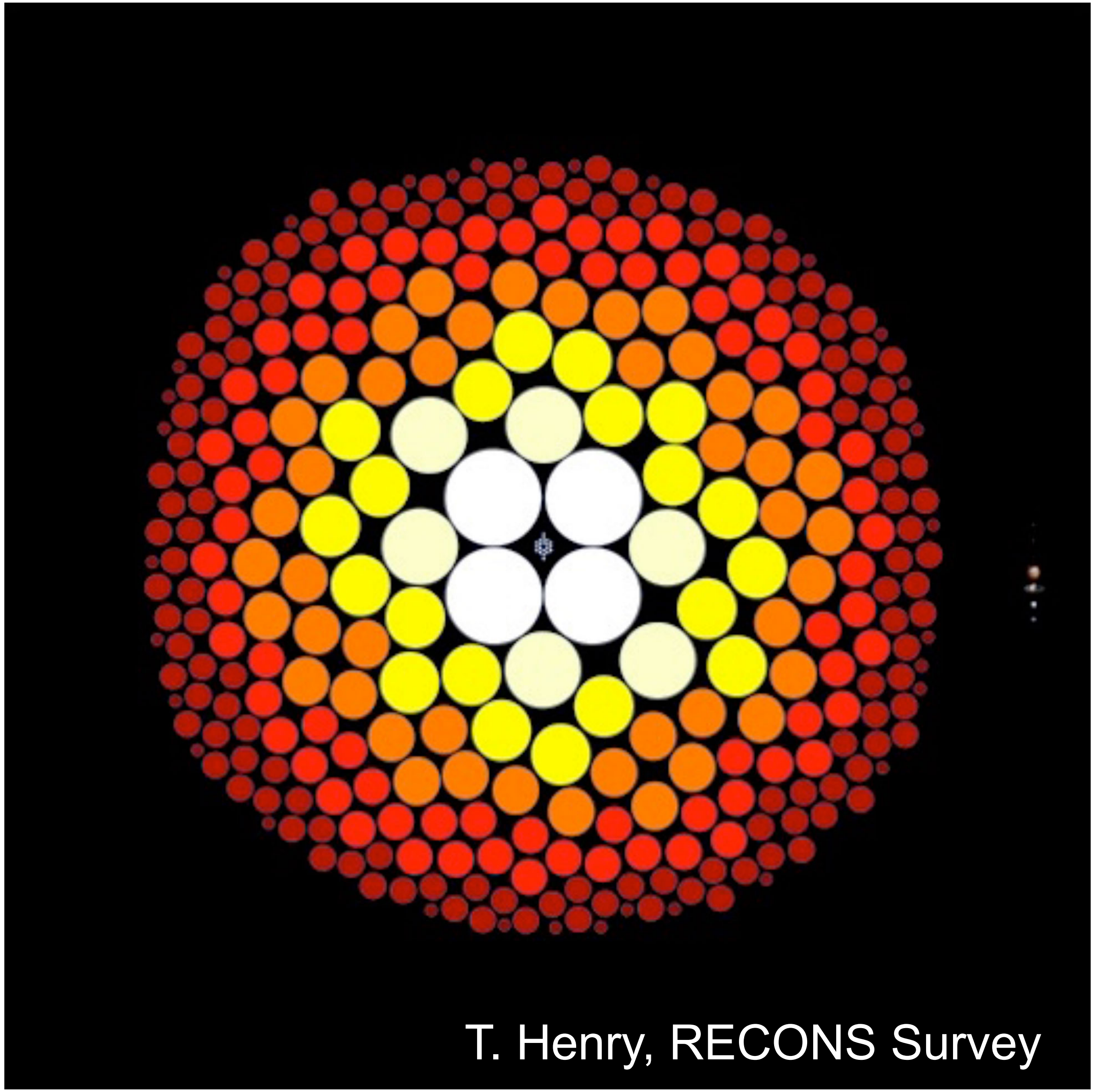
Fig. courtesy IPAC, adapted from Grimm et al. 2018

Origins MISC-T: IR wavelengths rich in biologically interesting molecules



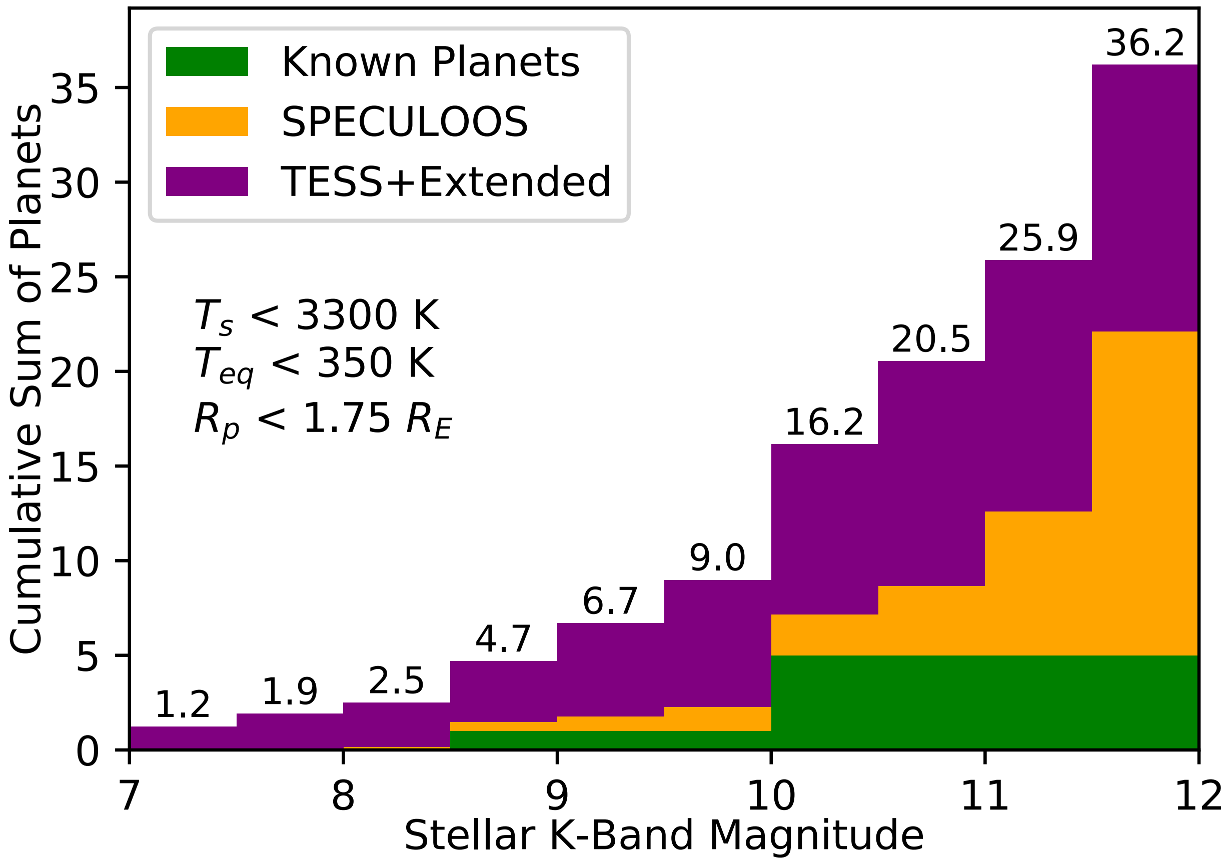
M Dwarfs are Compelling Planet-Hosting Stars

- M dwarfs are common
  - 75% of stars within 15 pc are M dwarfs
- 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



Expected Yields of Temperate M-Dwarf Planets

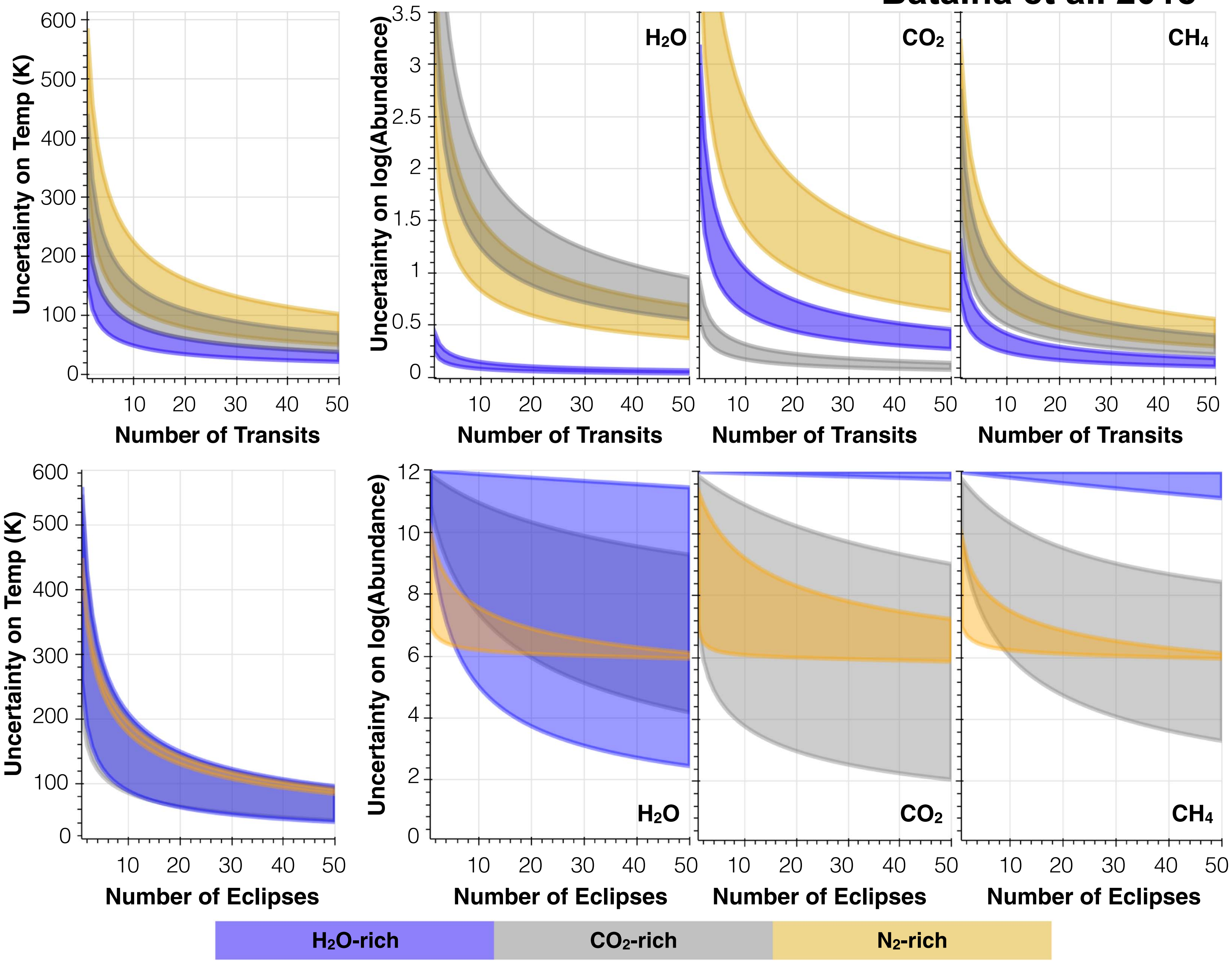
- ***Origins* will characterize the atmospheres of terrestrial M-dwarf planets that will have already been discovered by ground- and space-based transit surveys.**
- TESS is expected to discover **43±7** temperate, terrestrial exoplanets (Barclay et al. 2018),
- SPECULOOS is expected to identify **14±5** temperate, terrestrial planets orbiting late M to early L dwarfs (Delrez et al., 2018)
- Target stars as faint as K=11.5



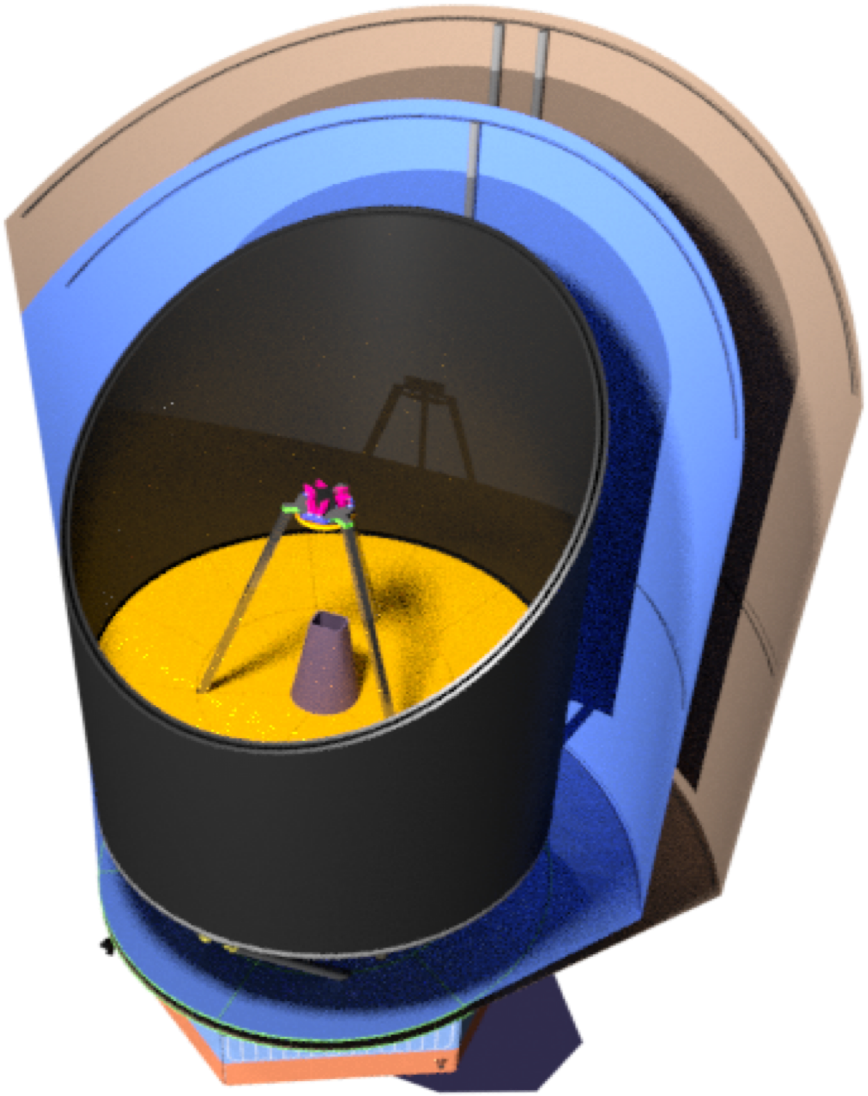
Comparing Comparing *Origins* and JWST

- JWST can determine presence of an atmosphere and constrain abundances of some molecules (e.g., H_2O, CO_2, CH_4, depending on the atmospheric composition)
- Need assessment of noise sources for JWST, a la Krick et al. (2016) for *Spitzer*
- *Origins* will be purpose-built with optimal noise-floor and wavelength coverage to spectrally measure the abundances of key molecular gases and detect signs of life

Batalha et al. 2018



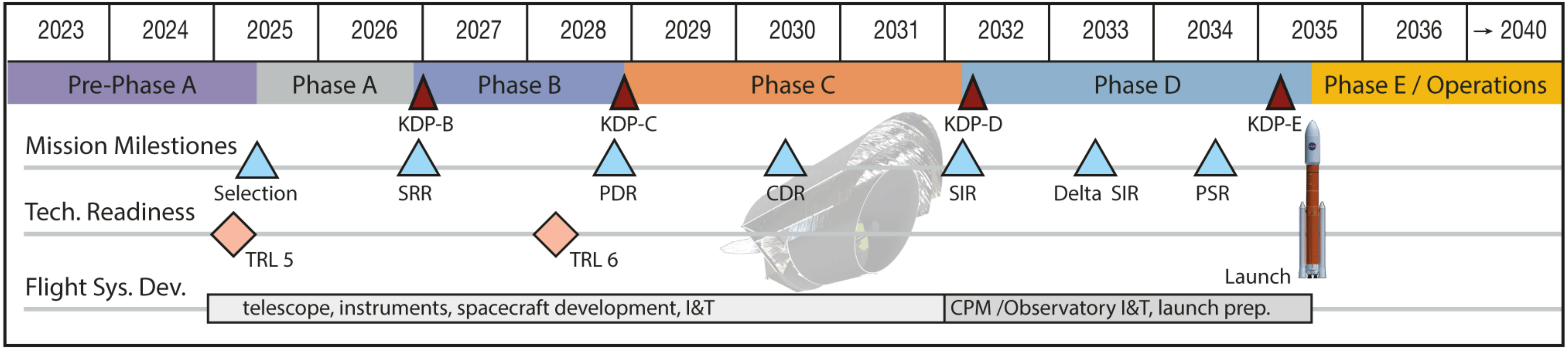
Origins Baseline Concept



- **Spitzer-like architecture** with minimal deployments
- JWST sized telescope (~25 m^2, 5.9 m), diffraction limited @ 30 μm
- **Wavelength Coverage 2.8-590 μm**
- **Cold** (~4.5 K) telescope and three cold (<=4.5 K) instruments, cooled with long-life cryo-coolers
- Launch 2035 on large rocket (SLS or BF3)
- Detector Technology development on track to reach TRL 5 by 2025
- Mission operations at Sun-Earth L2 orbit
- 5 year lifetime, with consumables for 10 years
- **Community selected science programs**

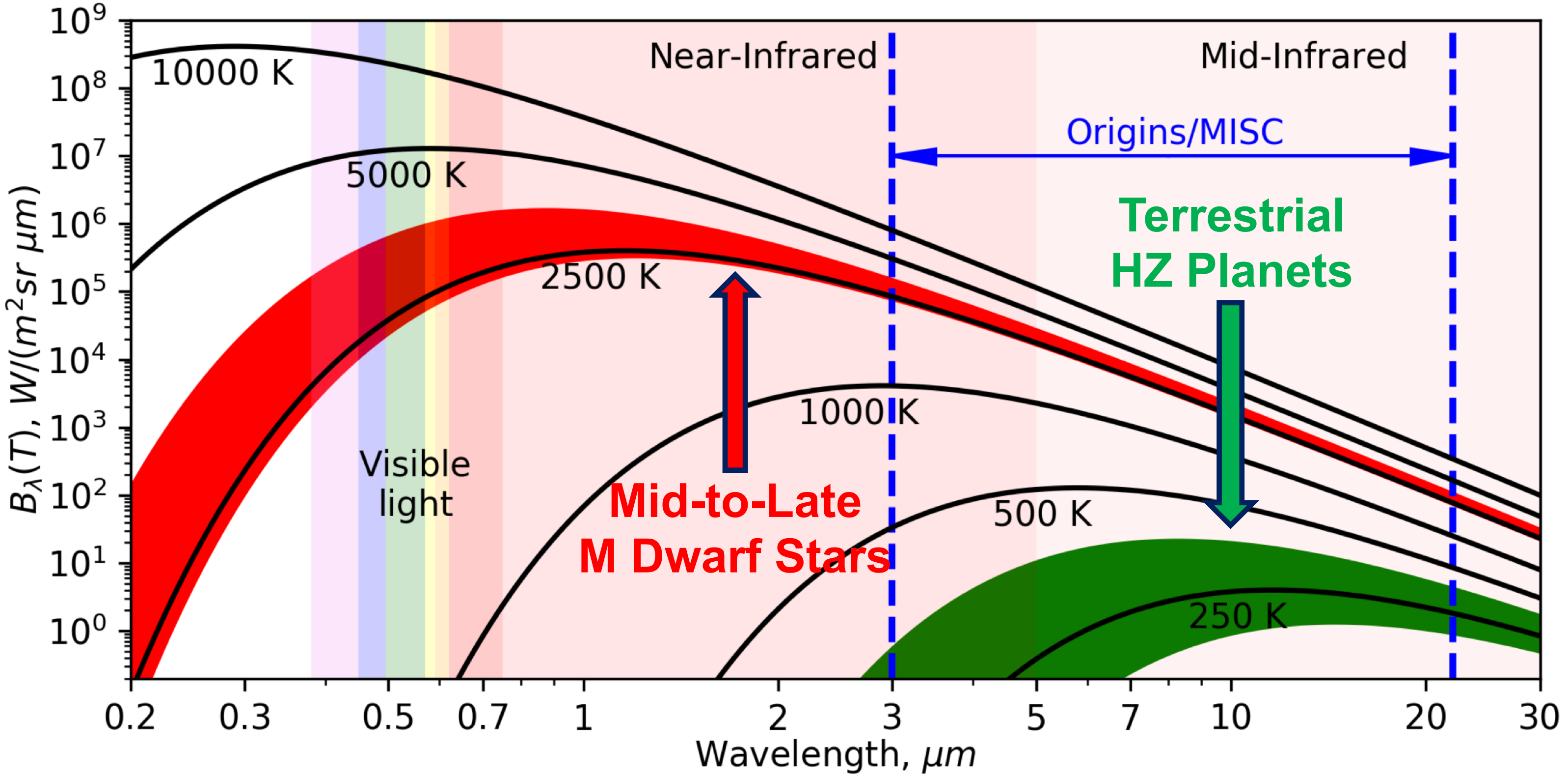
ORIGINS Space Telescope

Origins Mission Development Timeline

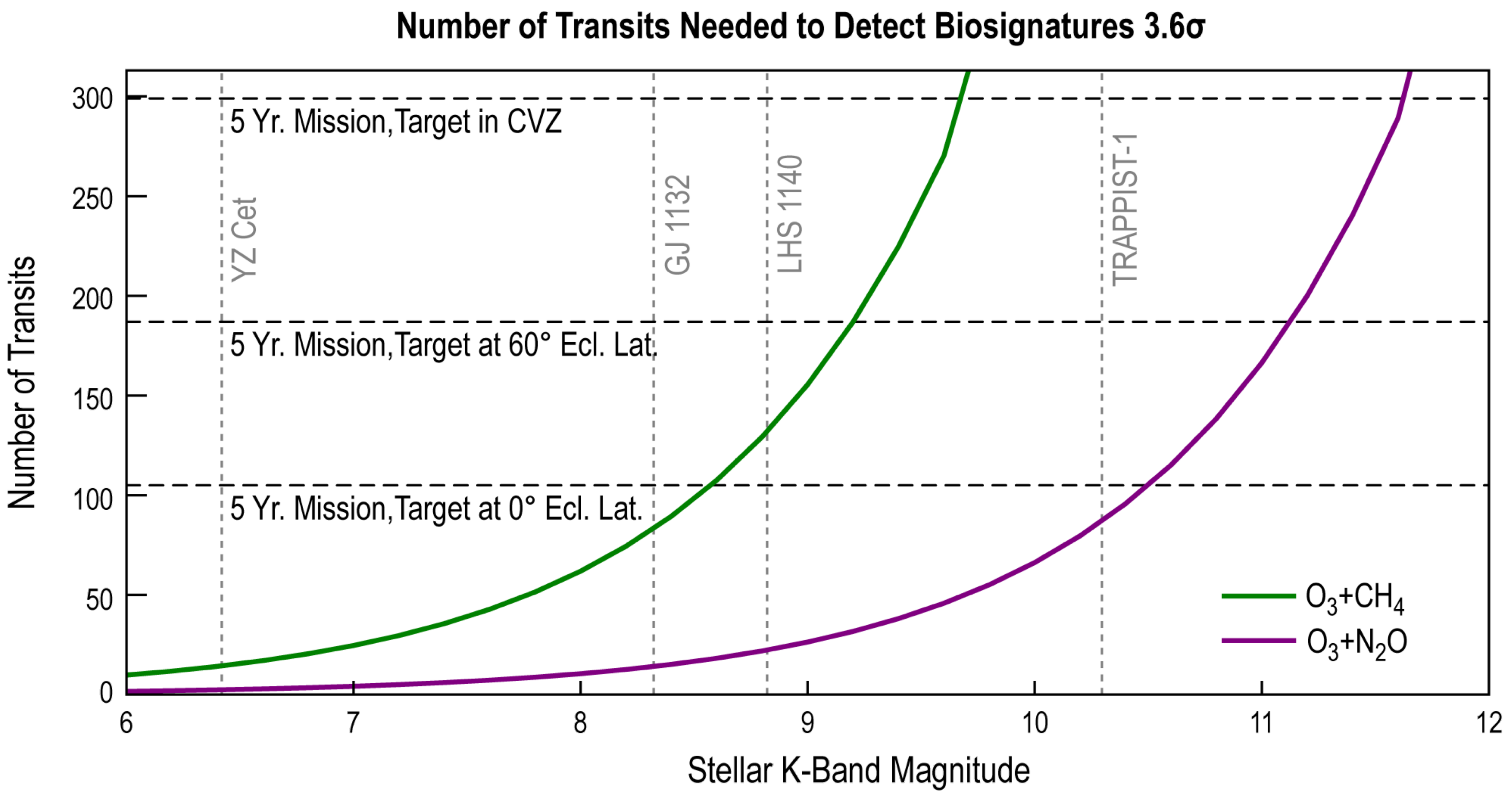


The Power of the Mid-IR

- 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



Detecting Biosignatures



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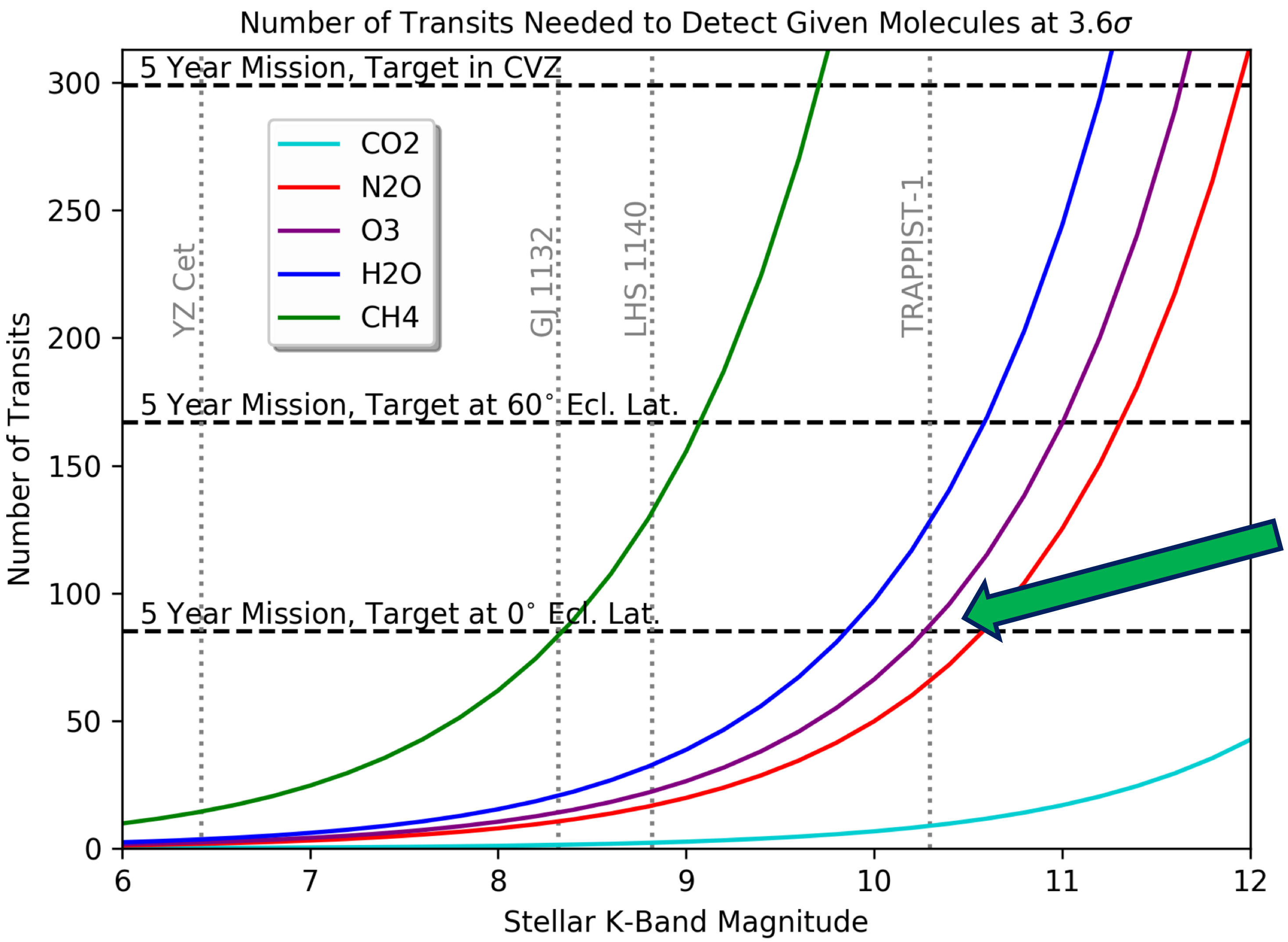

Origins will be sensitive to detecting biosignatures (O_3+N_2O) in TRAPPIST-1e's atmosphere with 15 eclipses + 85 transits (~400 hours over 5 years)