# Let’s discover our ORIGINS

*From First Light to Life*

**ORIGINS**
Space Telescope

## How does the universe work?

How do galaxies form stars, make metals and grow central supermassive black holes?

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

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## Discovery of new phenomena

Origins will open unprecedented discovery space in the Far-IR, what mysteries lay in wait?

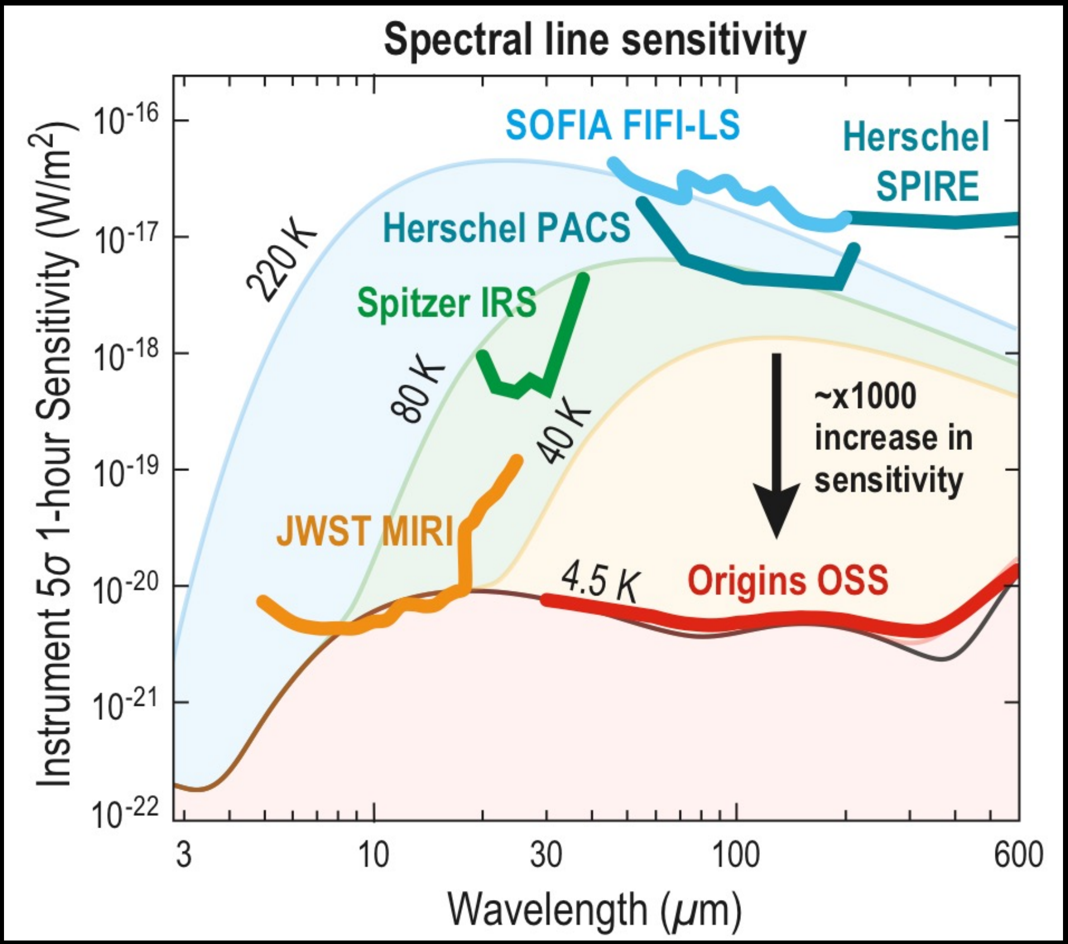
ORIGINS Space Telescope

★ ***1000x more sensitive*** than any previous far-IR mission

★ 5.9 m, ***non-deployed cold*** aperture (4.5K)

★ ***Low-risk*** development, testing, and deployment

★ ***Broad wavelength coverage***: 2.8 – 588 $\mu$m



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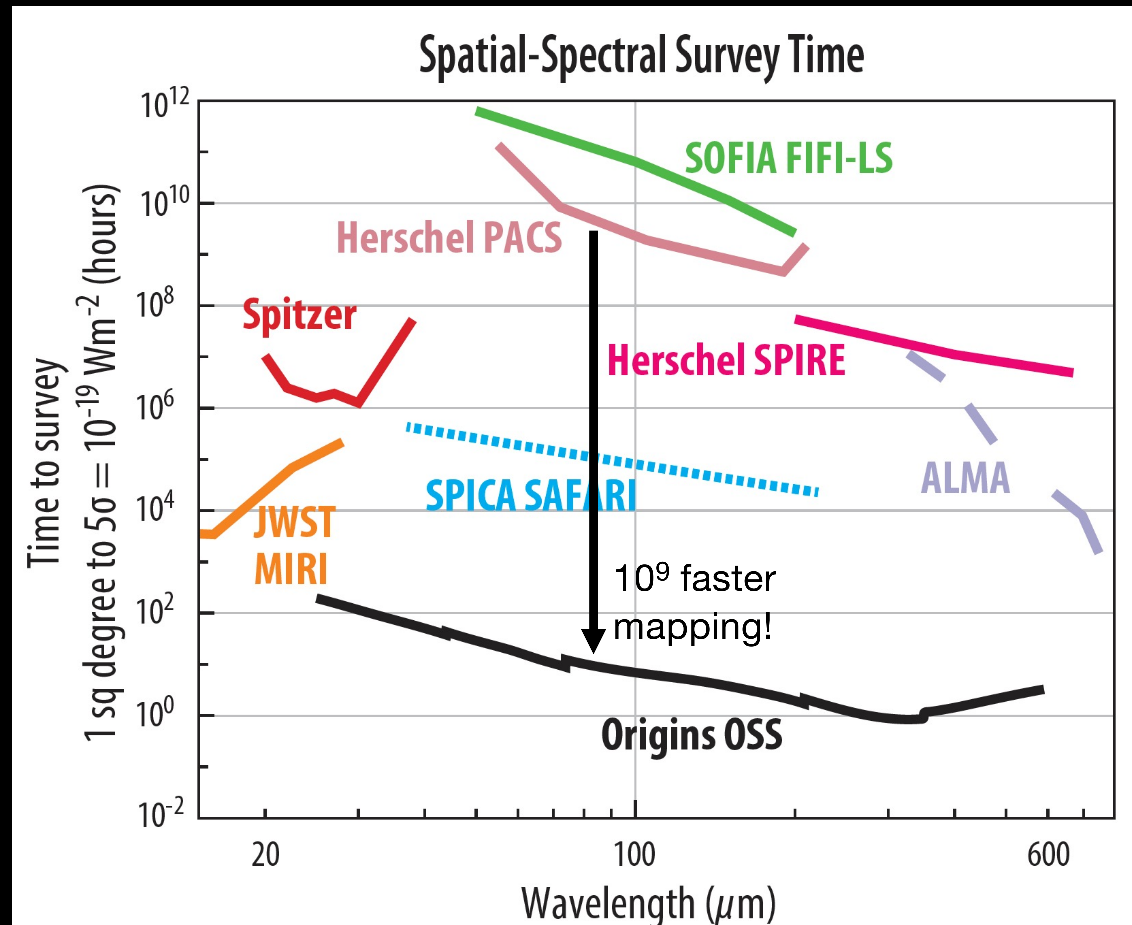

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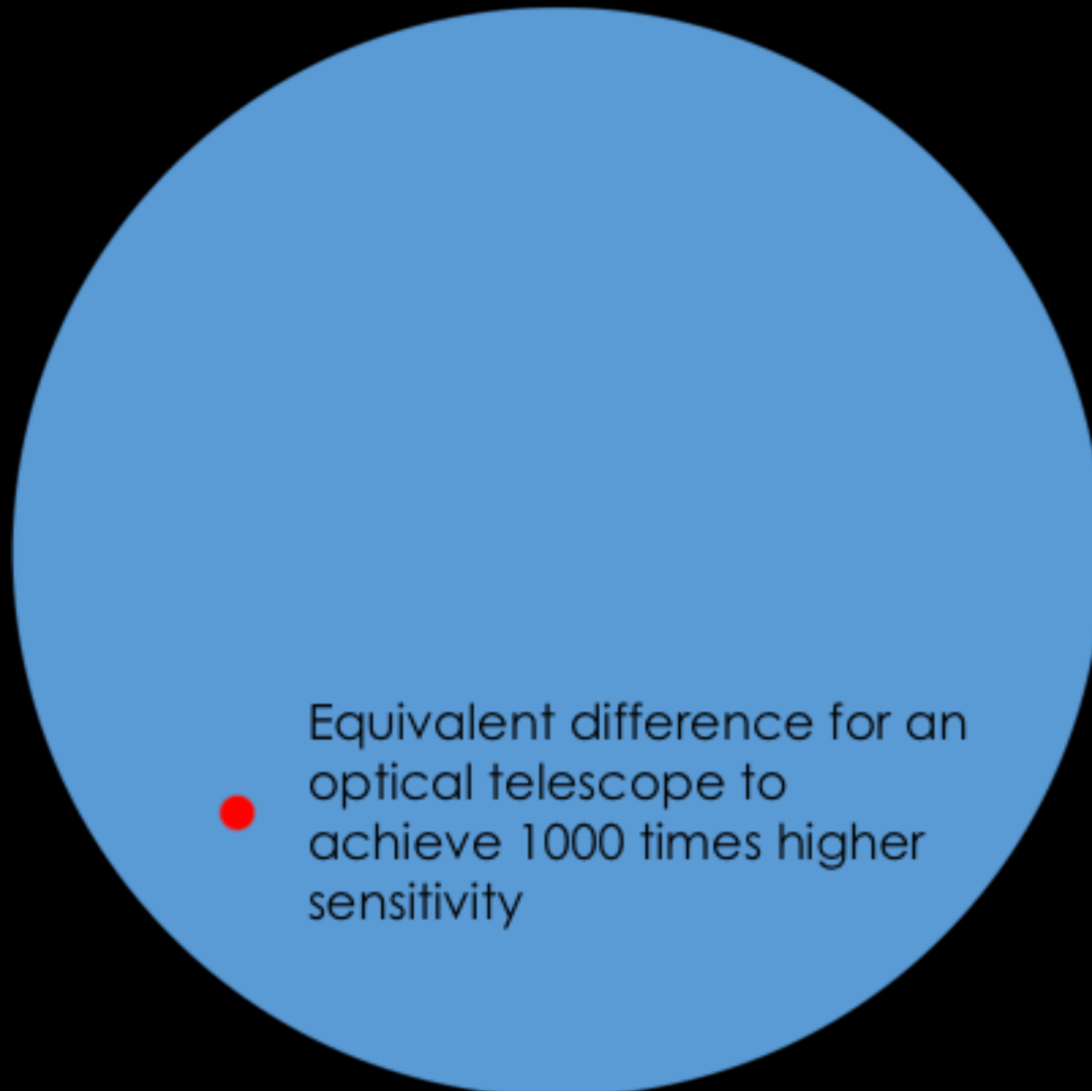

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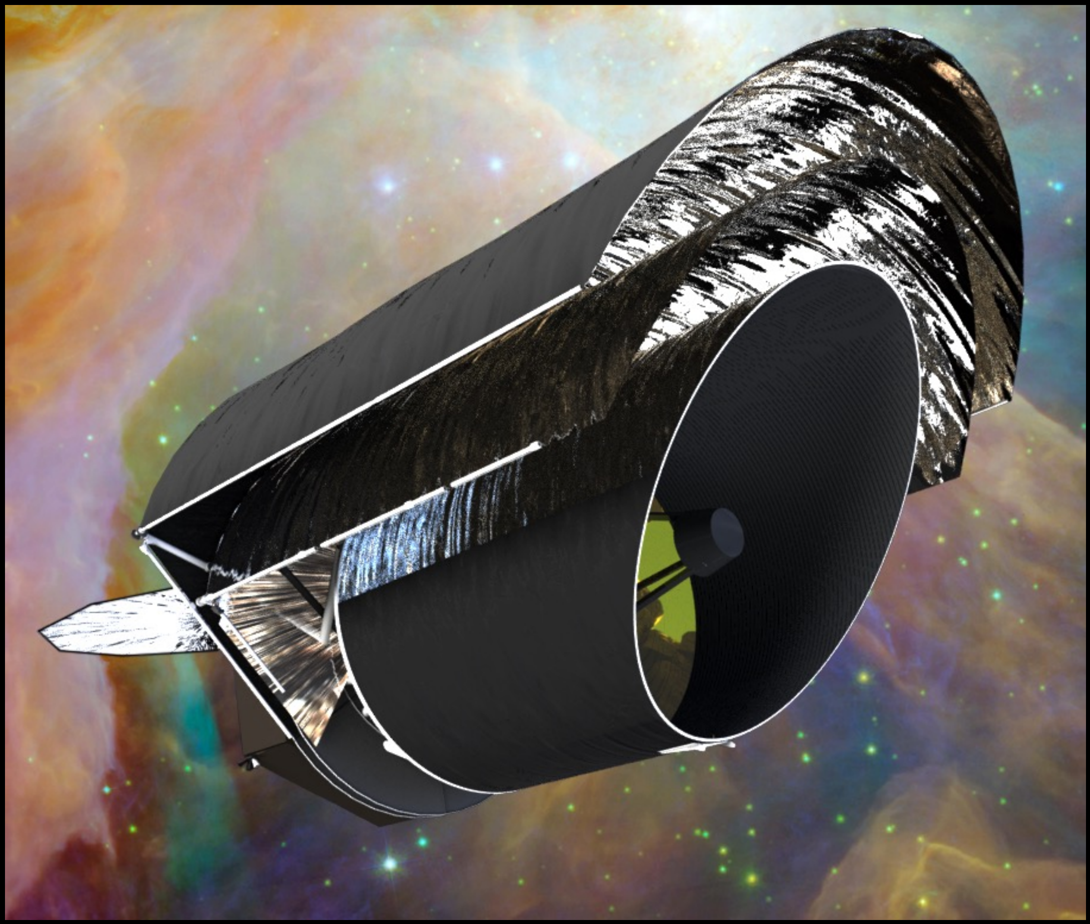

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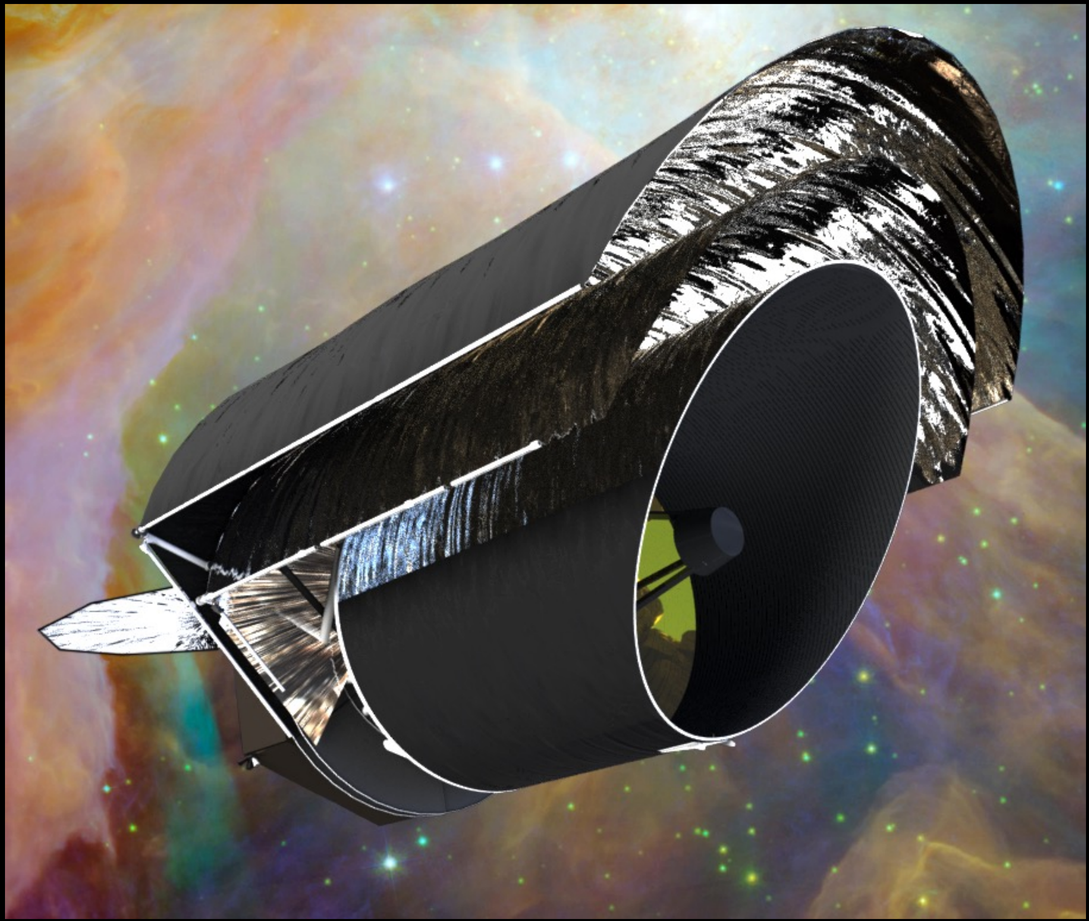

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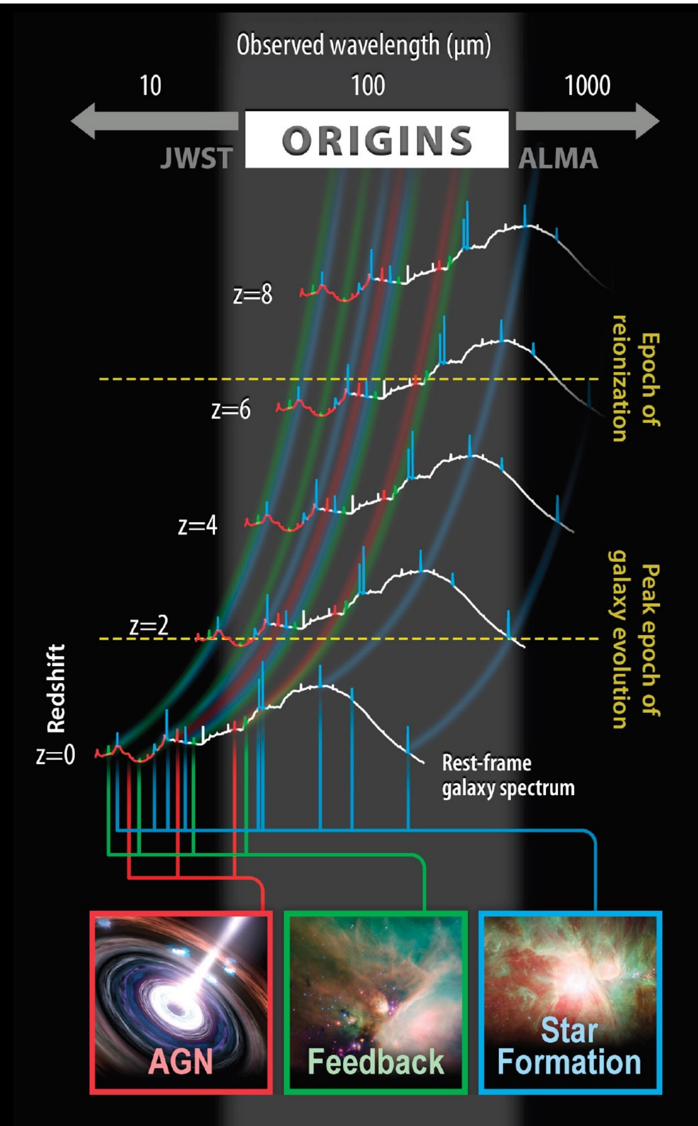

# **Now** is the time for a Far-IR revolution

- ★ Advances in technology are opening up ***unprecedented discovery space***
- ★ ***Key wavelength coverage*** between JWST and ALMA
- ★ ***Cannot be done from the ground***
- ★ ***Simple architecture*** with a ***robust technology*** development plan

*arXiv:1912.06213*
[https://origins.ipac.caltech.edu/](https://origins.ipac.caltech.edu/)

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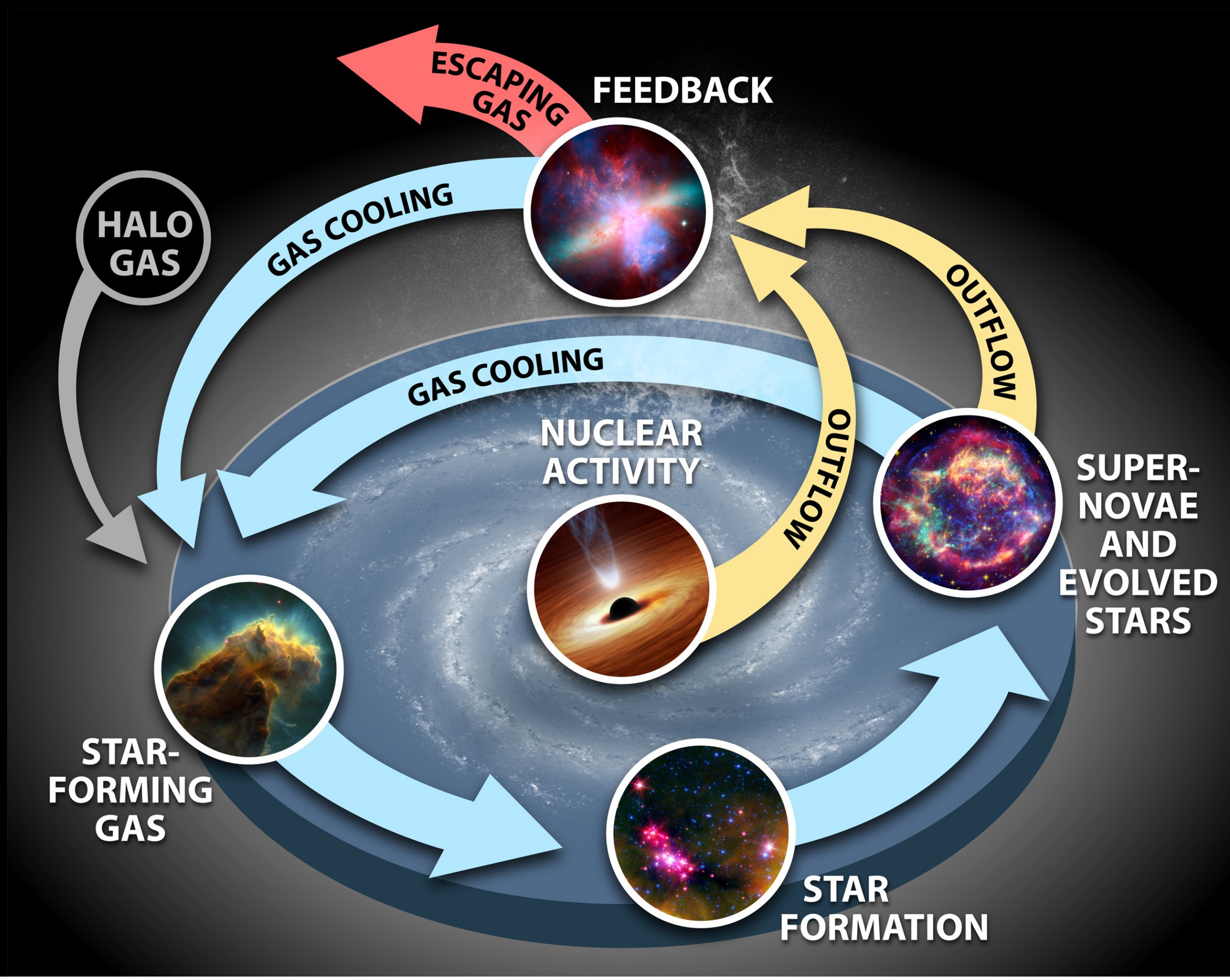
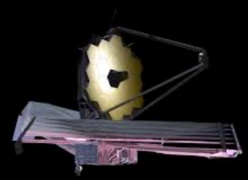
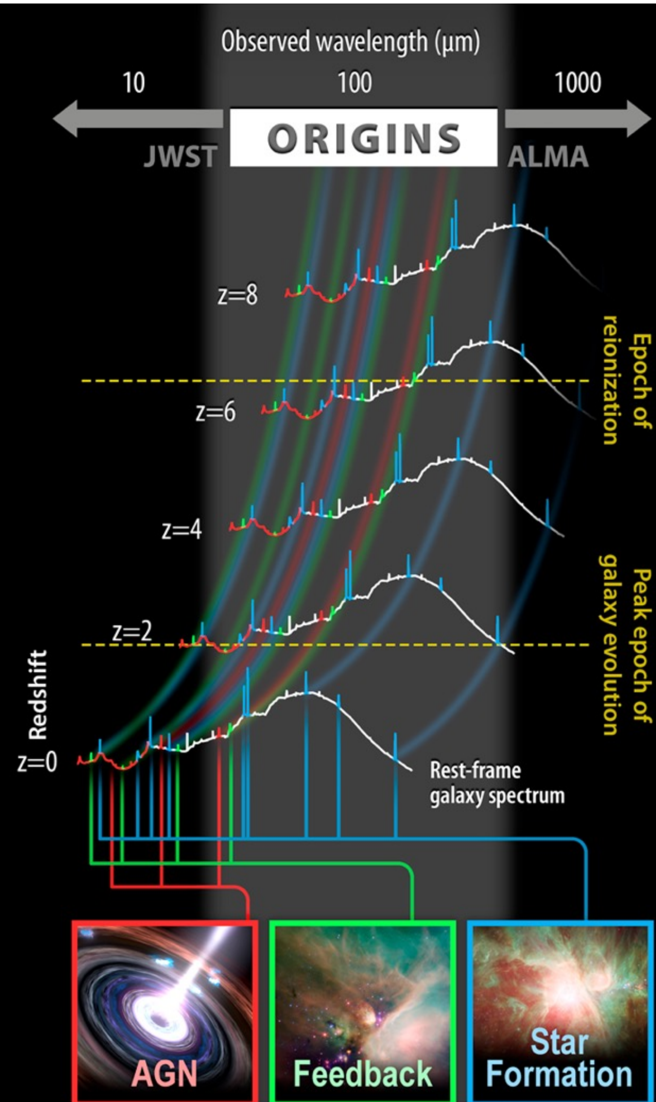
# Origins probes galaxy ecosystems








- ★ Origins **simultaneously traces** AGN, Star Formation, and Feedback
- ★ **Covers the gap** from JWST to ALMA
- ★ Key diagnostics from the **local universe to the epoch of reionization**

# Origins: 3D unbiased surveys of galaxies

- ★ **Spectra for millions of galaxies** over a few sq. degrees out to z = 8 in a 2000 hr blind survey

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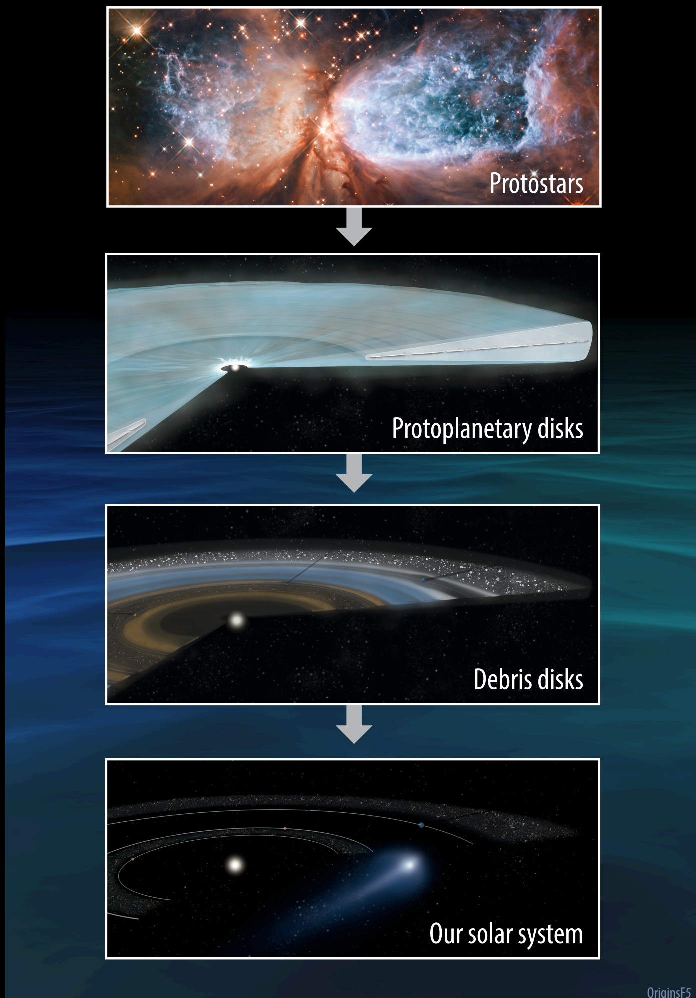
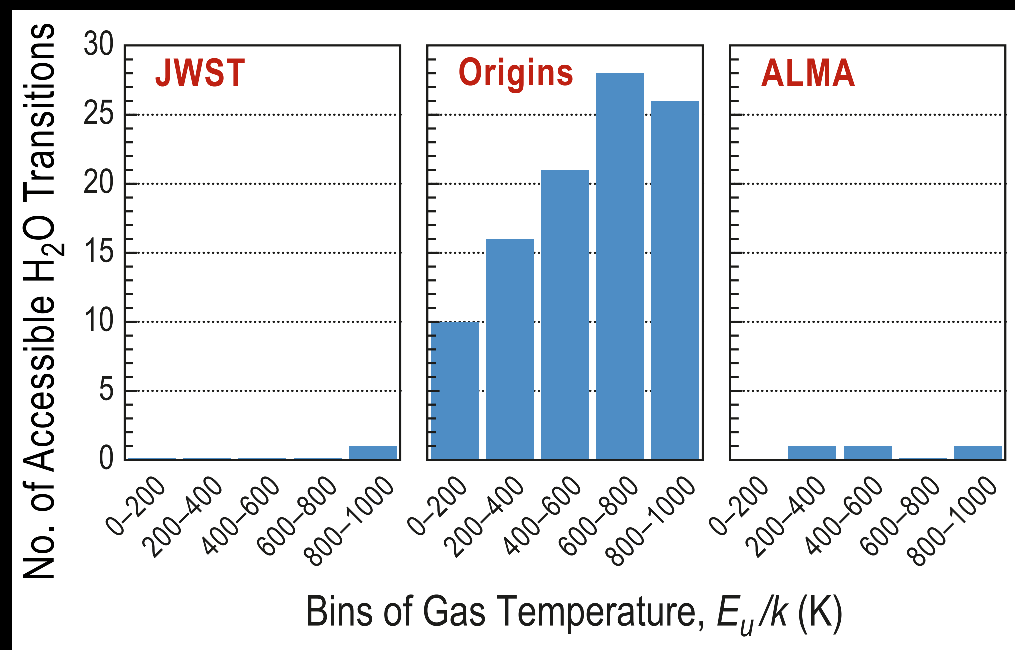
# The Trail of Water




★ **Origins uniquely follows the trail of water,** from protostars, through disks, to objects in our own solar system.

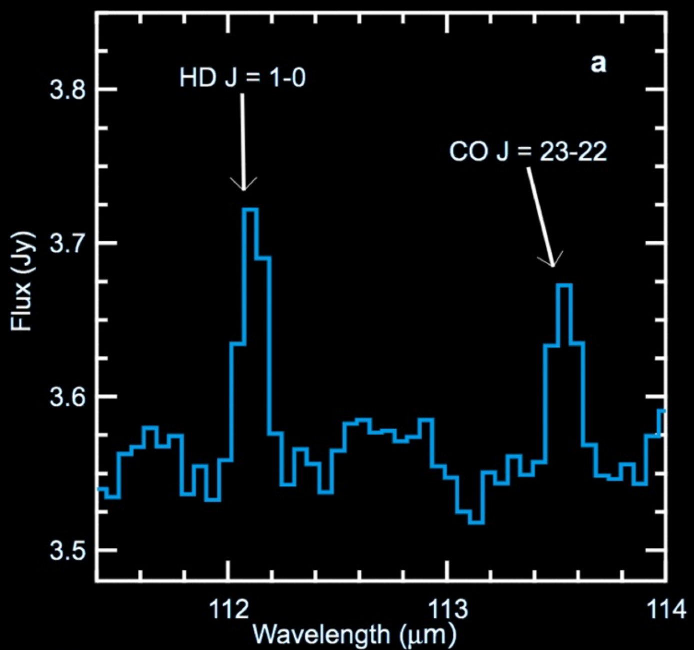


# TRACING WATER EMISSION IN DISKS

Movie Credit: Klaus Pontoppidan

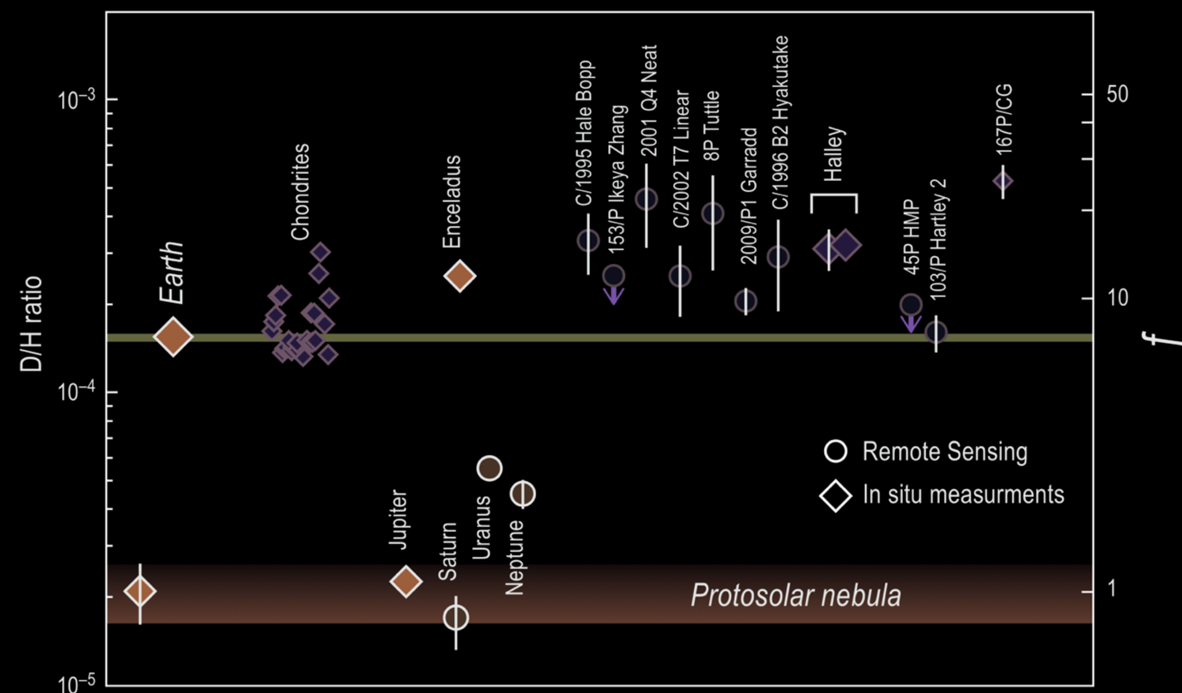
# The Trail of Water

★ Using HD, **Origins** can unambiguously trace 1000s of disks around **stars of all masses**




Bergin et al. 2013

★ And study solar system objects to unveil **the origin of Earth's oceans.**



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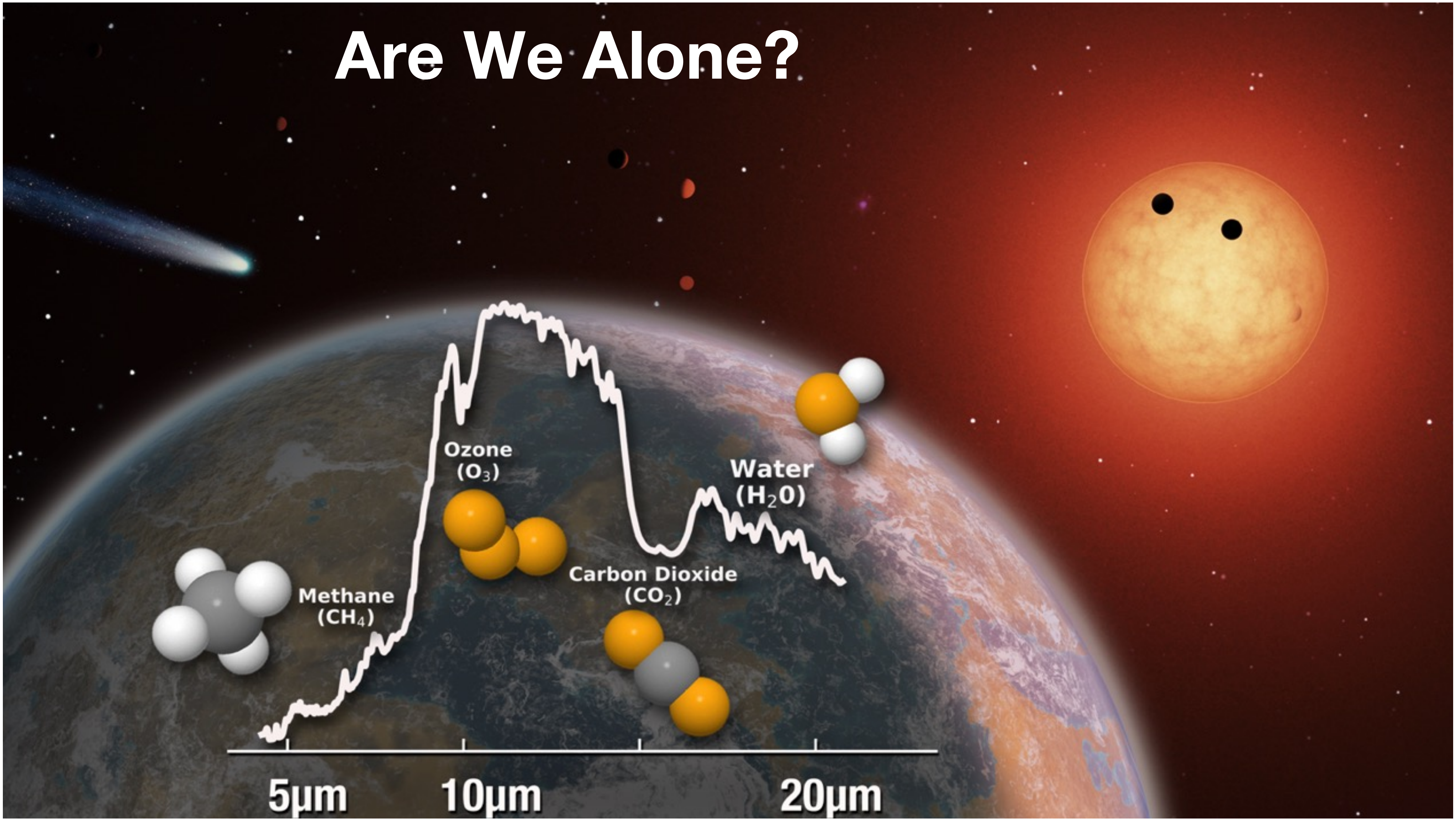

Are We Alone?
Ozone
($O_3$)
Water
($H_2O$)
Methane
($CH_4$)
Carbon Dioxide
($CO_2$)
5µm
10µm
20µm

# Why M and K Dwarfs?

**M and K dwarfs are common**

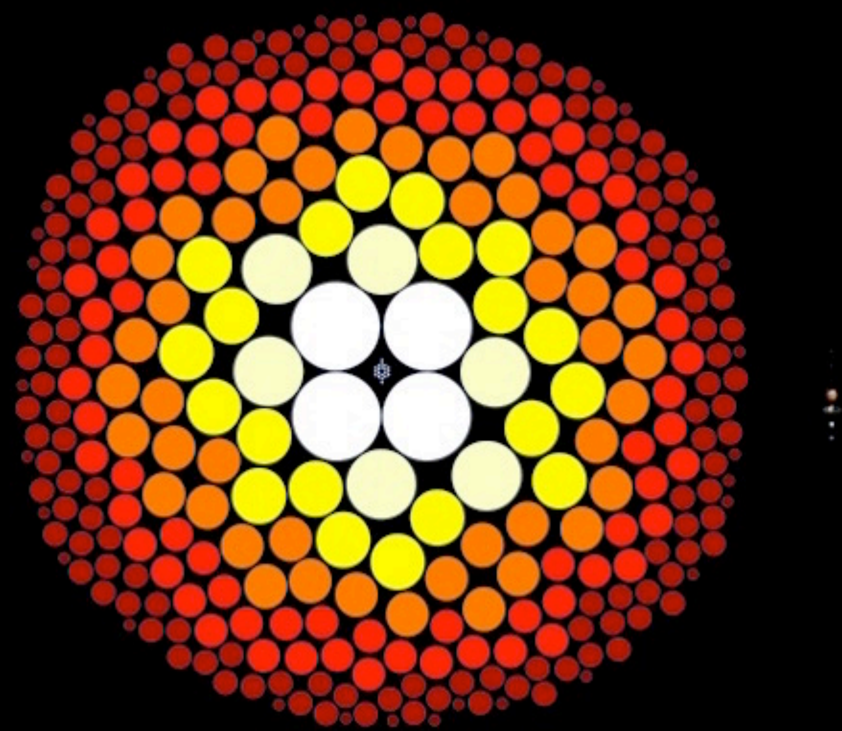
- 75% of stars within 15 pc are M dwarfs

**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



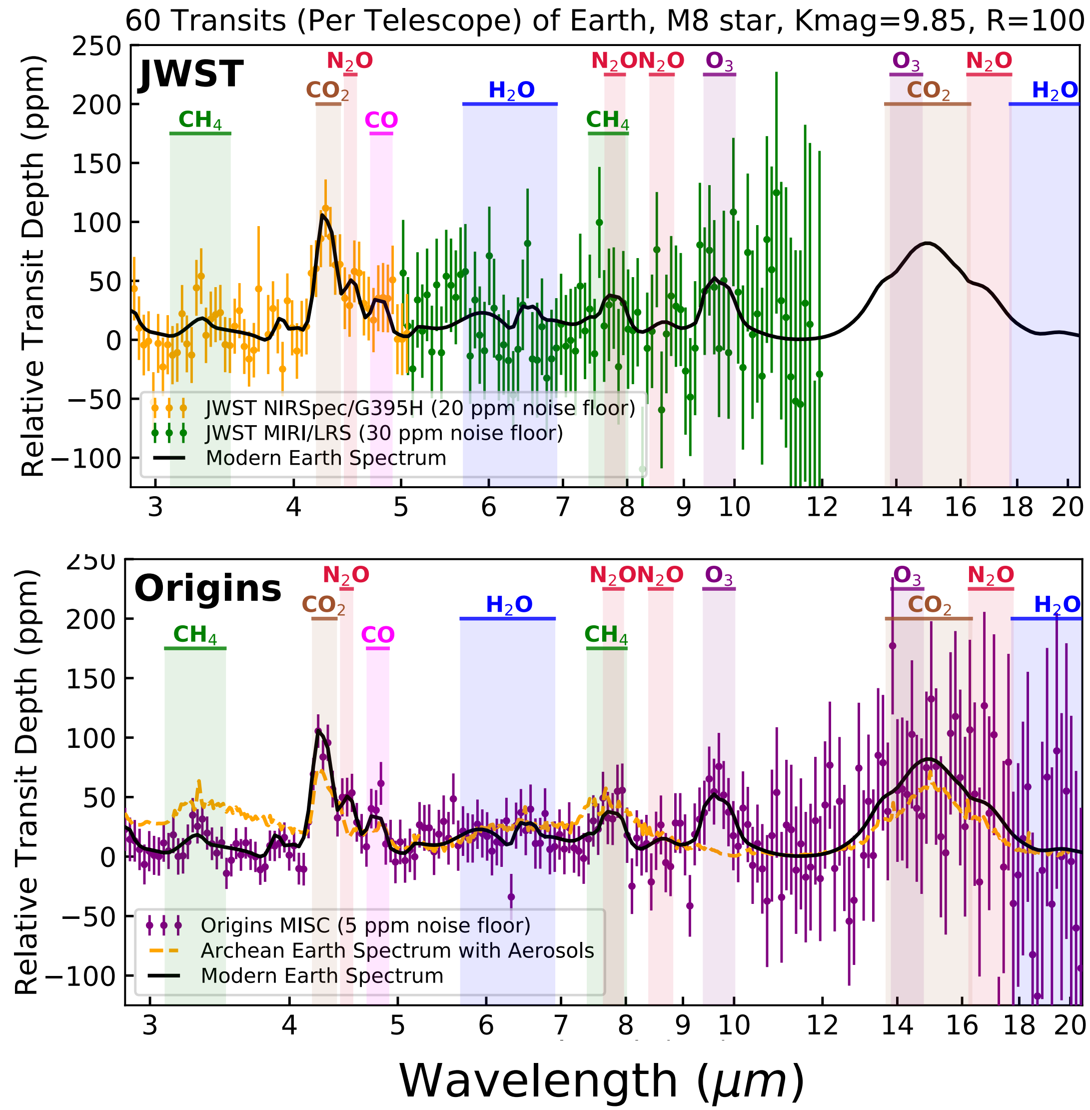
T. Henry, RECONS Survey

# Searching for life in Transiting Exoplanets

★ **Origins** will measure **key habitability indicators**
(may suggest presence of life, but can also be produced without life: e.g. $H_2O$, $CO_2$, $O_3$, $CH_4$, $N_2O$ alone)

★ And uniquely probe **biosignatures**
(a combination of molecules that can only be produced by life: e.g. $O_3 + CH_4$ or $O_3 + N_2O$)

***toward Habitable Zone** planets with **Earth-like atmospheres** transiting mid-to-late **M dwarfs***



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

**Tier 3**
Search for bio-signatures ($O_3$+$N_2O$, $O_3$+$CH_4$) with additional transits of temperate worlds ($N_p > 10$)

**Tier 2**
**Eclipse** observations of clear planets to determine if they are temperate ($N_p > 14$)

**Tier 1**
**Transit** observations to determine which planets have tenuous, clear or cloudy atmospheres ($N_p > 28$)

**Pre-select terrestrial M-dwarf planets** based on: (i) Planet radius and equilibrium temperature.
(ii) Relative rank based on suitability for detailed atmospheric characterization.
(iii) Pre-*Origins* observations with JWST, ELTs etc.

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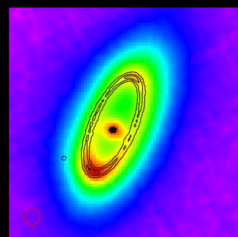
# Infrared: Unanticipated Discoveries with every new facility

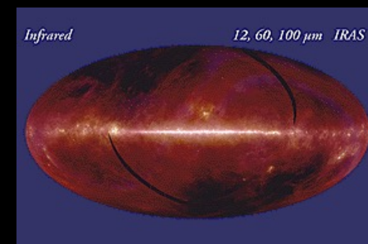
Significant gain in sensitivity has resulted in unanticipated discoveries!

1980s

*debris disks*

*IR-bright galaxies*




*cirrus, dust bands, Earth trailing dust*

2000s

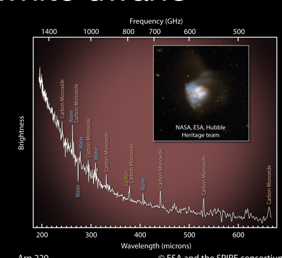


*multi-planet systems*

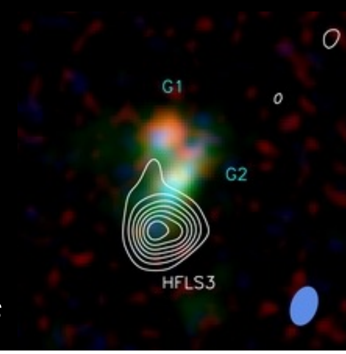
*asteroidal dust rain on white dwarfs*

*In-falling gas in galaxy groups cool via $H_2$*


*Water vapor around Ceres*



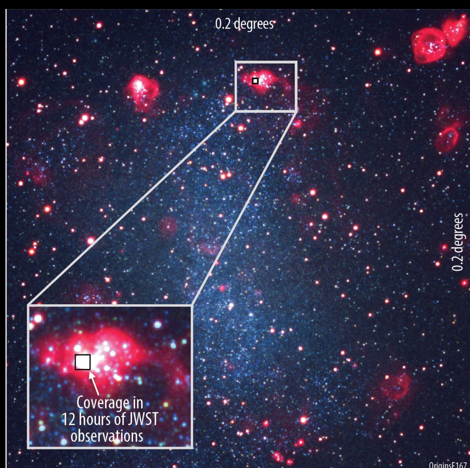

*Water line cooling in galaxies*



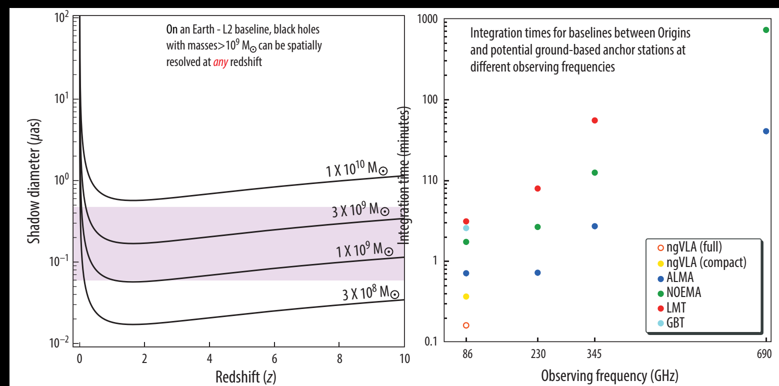

*Extraordinarily massive, starbursting galaxies ~800 Myr after Big Bang*

# Discovery Space of Origins

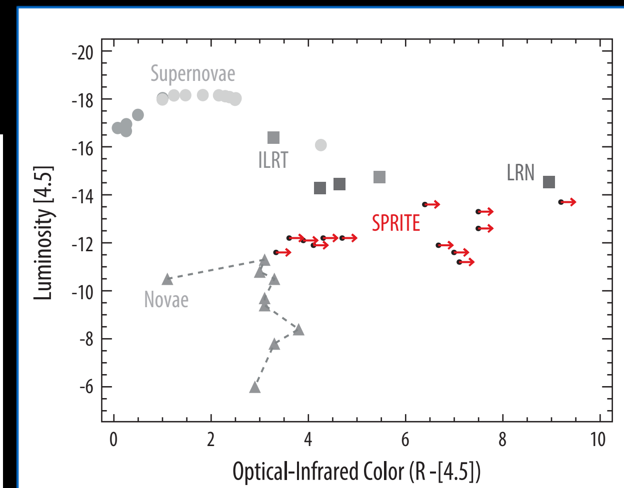
## Expectations from modern astrophysics

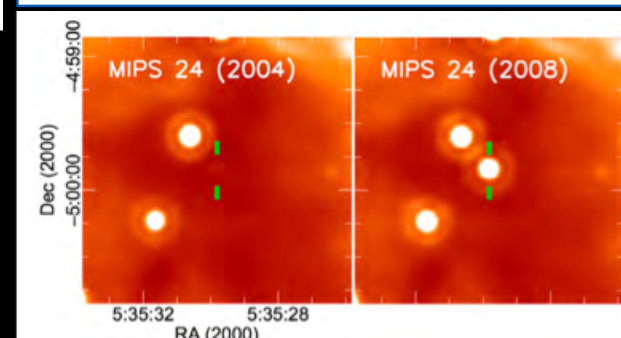



Origins provides a ~100x field of view for ***$H_2$ mapping in near-by galaxies*** *(vs JWST)*



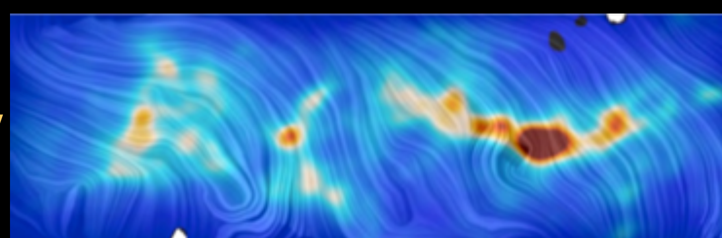

***Origins can be used as a uniquely valuable baseline in the Event Horizon Telescope.***
*An Origins upscope can resolve blackholes above $10^9$ Msun throughout the full cosmic history*




***Time domain:*** *Top (mid-IR): SPRITES, GW Counterparts. Bottom (far-IR): proto-stellar accretion*

*2" & 9" scale maps* ***of ISM dust polarization*** *to bridge Planck (2') & ground (1")*

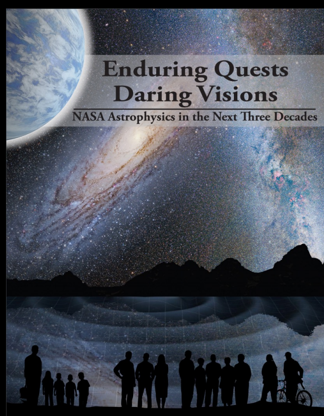


**And lots and lots more!**

ORIGINS
Space Telescope

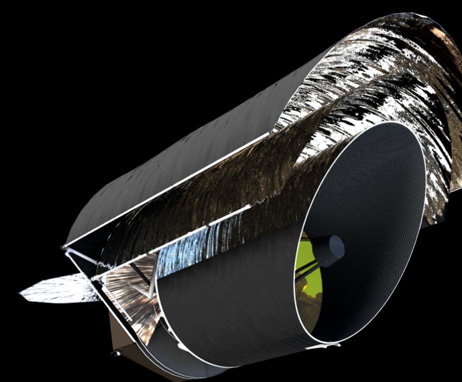
**... is for everyone!**

# **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 engaged 100s of members of **the international scientific community and guided the development** of the mission concept



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

# Now is the time to discover our ORIGINS

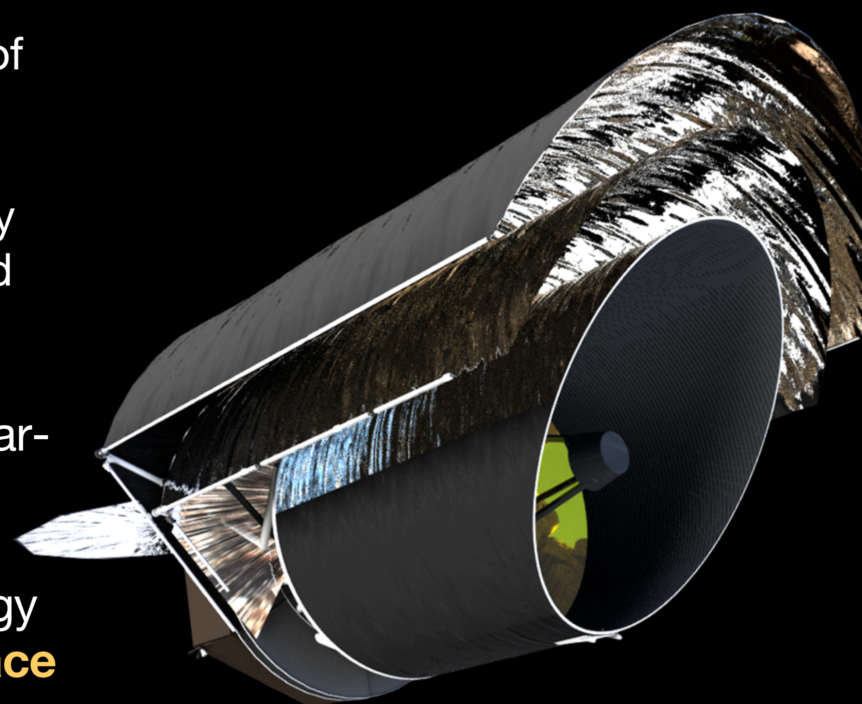
★**Broad range of scientific studies,** from Solar system to primordial gas cooling prior to the era of reionization.

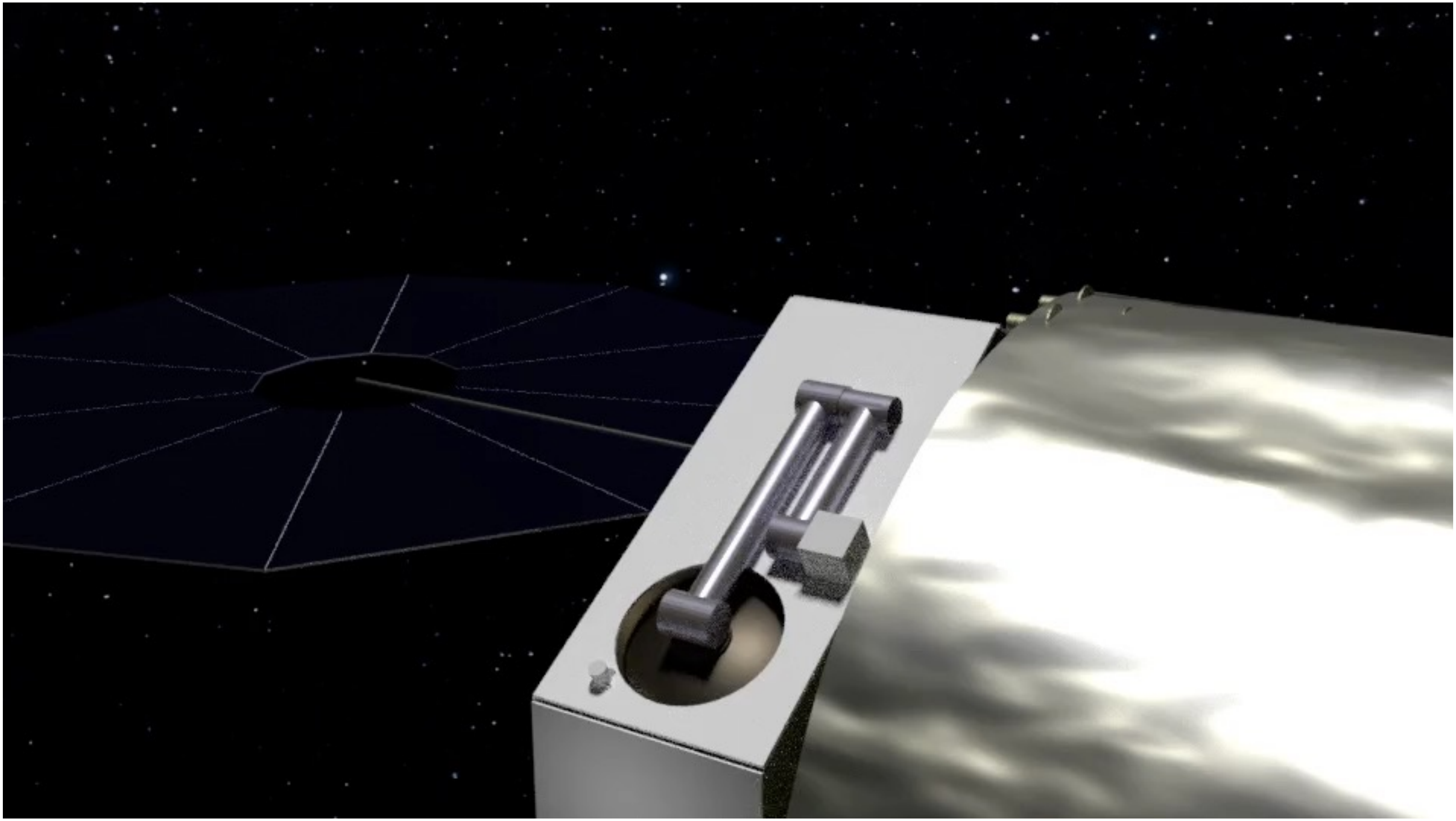
★**Efficient 3D spectroscopic mapping** enabled by wide area field of view (e.g., WFIRST vs. HST) and fast scan speed (e.g., Herschel/Planck)

★Enabled by a **1000x gain in sensitivity** in the far-IR relative to anything before.

★Advances in detector and cryocooler technology are opening up **unprecedented discovery space** in a **simple and robust technology**

★**Key wavelength coverage** between JWST and ALMA and **cannot be done from the ground**





# Backup

ORIGINS Space Telescope

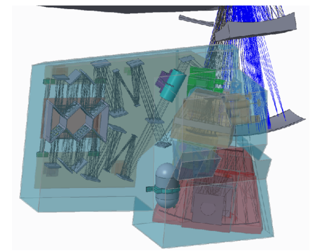
# **Origins:** Three Instruments

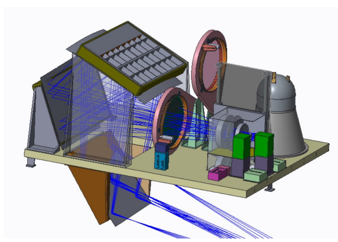
**OSS:** Origins Survey Spectrometer

-25-588 μm R~300, ***survey mapping***

-25-588 μm R~43,000***, spectral surveys***

-100-200 μm R~325,000, ***kinematics***





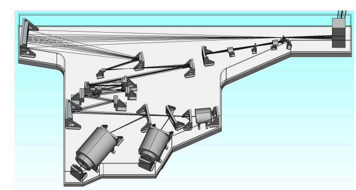
**FIP:** Far-infrared Imager Polarimeter

- 50 or 250 μm, ***Large area survey mapping***
- 1.75” @ 50  8.75” @ 200 PSF/FWHM
- 50 or 250 μm, ***polarimetry***

**MISC-T:** Mid-Infrared Spectrometer Camera Transit

- ***Ultra-Stable Transit Spectroscopy***

-2.8-20 μm R~50-295



ORIGINS
Space Telescope

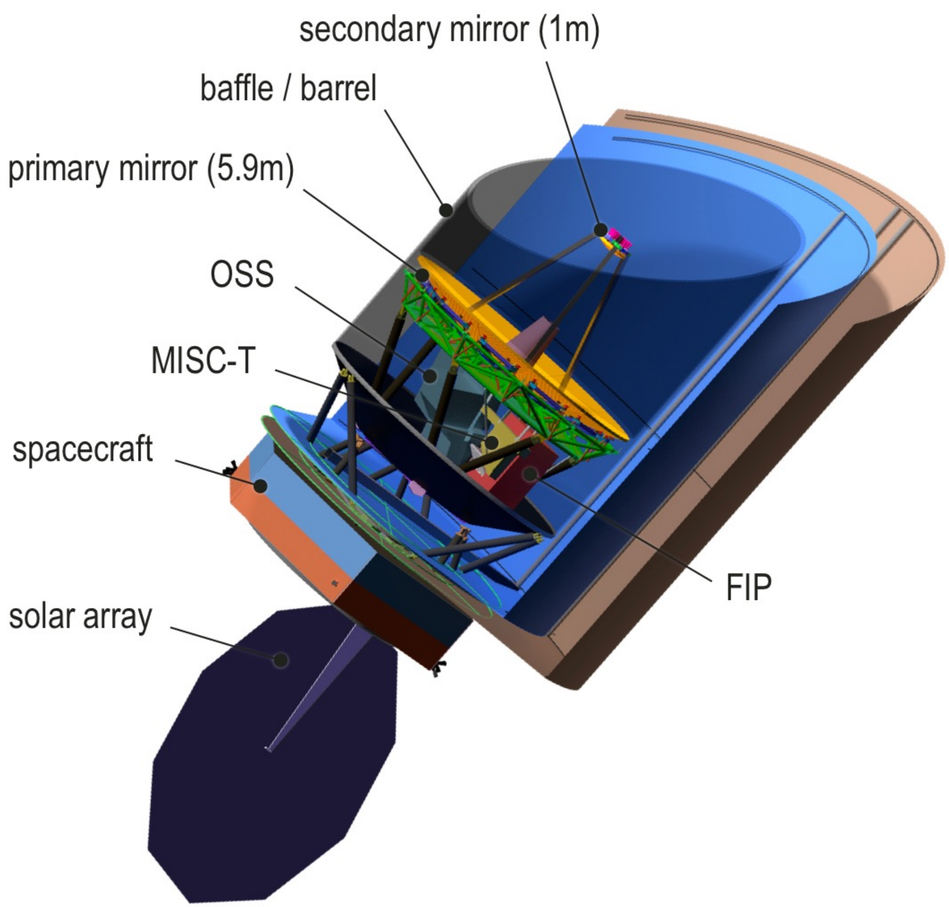
# Three instruments

**Table 4: Instrument Capabilities Summary**

| Instrument/ Observing Mode | Wavelength Coverage (μm) | Field of View (FOV) | Spectral Resolving Power (R=λ/Δλ) | Saturation Limits | Representative Sensitivity 5σ in 1 hr |
|---|---|---|---|---|---|
| ***Origins* Survey Spectrometer (OSS)** | | | | | |
| Grating | 25¾588 μm simultaneously | 6 slits for 6 bands: 2.7´ x 1.4″ to 14′ x 20″ | 300 | 5 Jy @ 128 μm | $3.7 \times 10^{-21}$ W m$^{-2}$ @ 200 μm |
| High Resolution | 25¾ 588 μm with FTS | Slit: 20″ x [2.7″ to 20″] | 43,000 ´[112 μm/λ] | 5 Jy @ 128 μm | $7.4 \times 10^{-21}$ W m$^{-2}$ @ 200 μm |
| Ultra-High Resolution | 100¾ 200 μm | One beam: 6.7″ | 325,000 ´[112 μm/λ] | 100 Jy @ 180 μm | $\sim 2.8 \times 10^{-19}$ W m$^{-2}$ @ 200 μm |
| **Far-IR Imager Polarimeter (FIP)** | | | | | |
| Pointed | 50 or 250 μm (selectable) | 50 μm: 3.6′ x 2.5′<br>250 μm: 13.5′ x 9′<br>(109 x 73 pixels) | 3.3 | 50 μm: 1 Jy<br>250 μm: 5 Jy | 50/250 μm: 0.9/2.5 μJy Confusion limit<br>50/250 μm: 120 nJy/1.1 mJy |
| Survey mapping | 50 or 250 μm (selectable) | 60″ per second scan rate, with above FOVs | 3.3 | 50 μm: 1 Jy<br>250 μm: 5 Jy | Same as above, confusion limit reached in 50/250 μm: 1.9 hours/2 msec |
| Polarimetry | 50 or 250 μm (selectable) | 50 μm: 3.6′ x 2.5′<br>250 μm: 13.5′ x 9′ | 3.3 | 50 μm: 2 Jy<br>250 μm: 10 Jy | 0.1% in linear and circular polarization, ±1° in pol. Angle |
| **Mid-Infrared Spectrometer Camera Transit Spectrometer (MISC-TRA)** | | | | | |
| Ultra-Stable Transit Spectroscopy | 2.8¾20 μm in 3 simultaneous bands | 2.8–10.5 μm: 2.5″ radius<br>10.5–20 μm: 1.7″ radius | 2.8-10.5 μm: 50–100<br>10.5-20 μm: 165–295 | K~3.0 mag<br>30 Jy @ 3.3μm | Assume K~9.85 mag M-type star, R=50 SNR/sqrt(hr)>12,900 @ 3.3 μm in 60 transits with stability ~5 ppm < 10.5 μm, ~20 ppm > 10.5 μm |

# Origins:

## Spitzer-like low-risk 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" / second

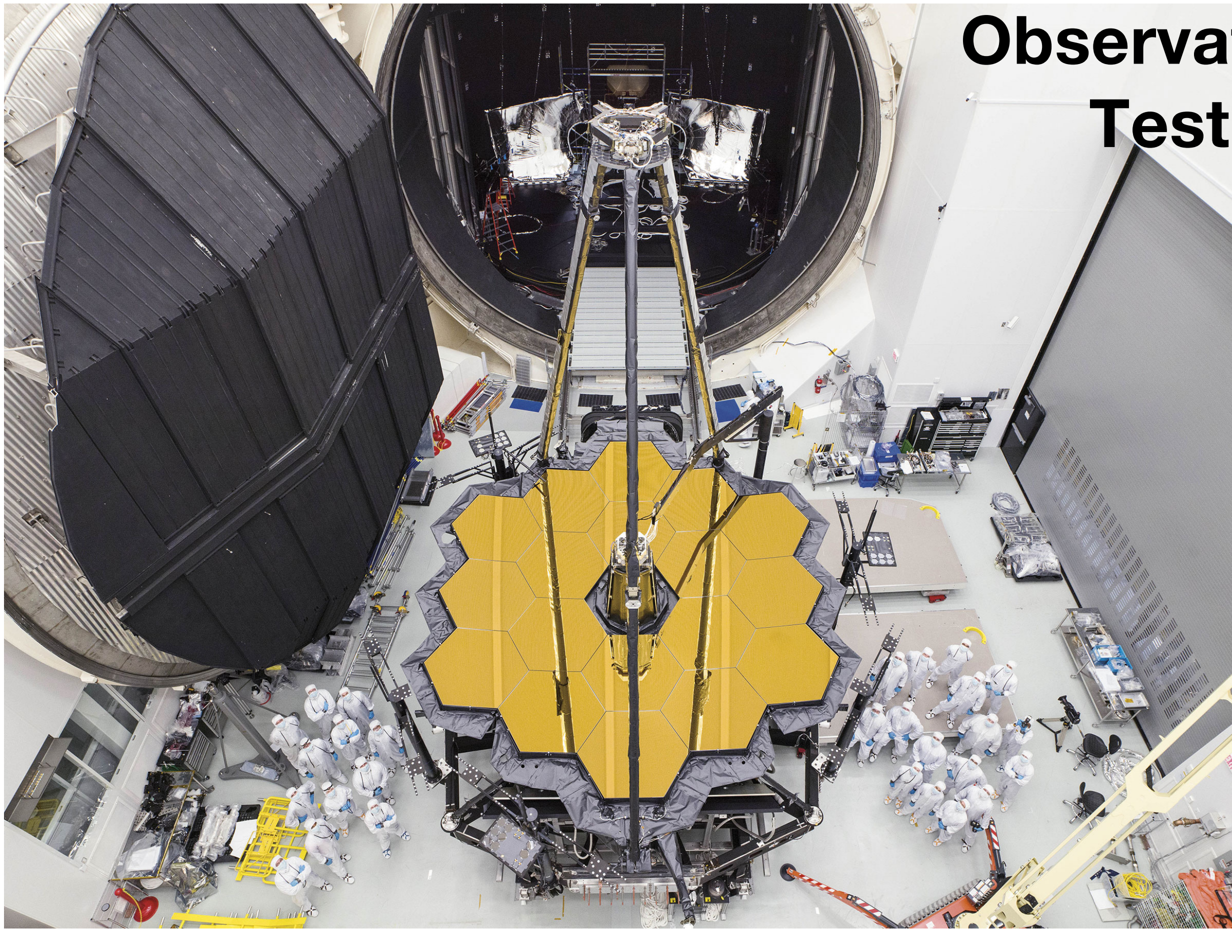
**Launch Vehicle:**

Large, SLS Block 1, Space-X BFR

**Mission:** 10 year propellant, serviceable

**Orbit:** Sun-Earth L2

# Origins:
## Observatory Integration and Testing is Simplified



Compared to JWST :
- **fewer deployments**
- modular design

**Uses existing test facilities:**
-re-uses Johnson Space flight Center Chamber A: end-to-end, “test as you fly”

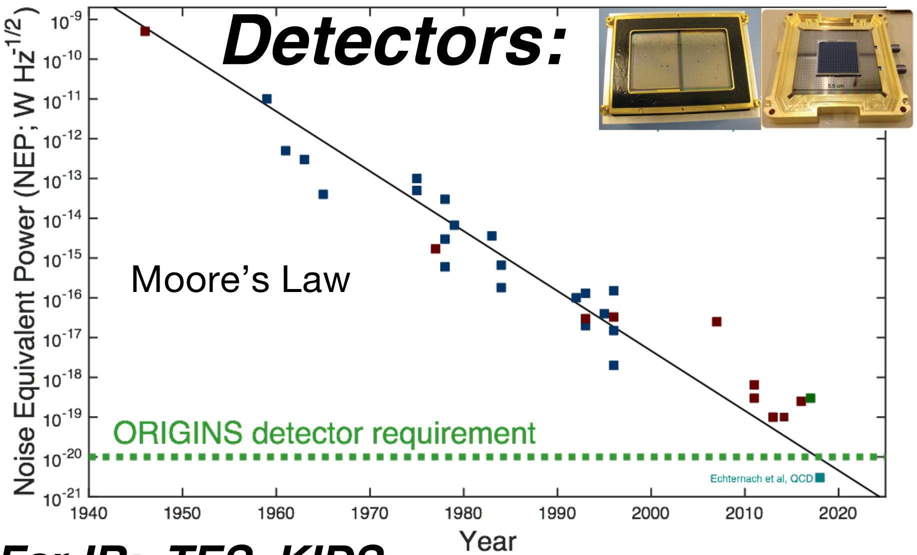
ORIGINS Space Telescope

# Origins:

## Key Technologies are on track

### *Detectors:*

Far-IR: TES or KIDS




***Far-IR: TES, KIDS***

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

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

increase array size: $10^4$ pixels

state of the art: 3000 pixels

***Mid-IR: HgCdTe, Si:As, TES***

improved relative spectral stability, 5 ppm

state of art: 20-50 ppm

NGAS JWST/MIRI

SHI Hitomi/SXS

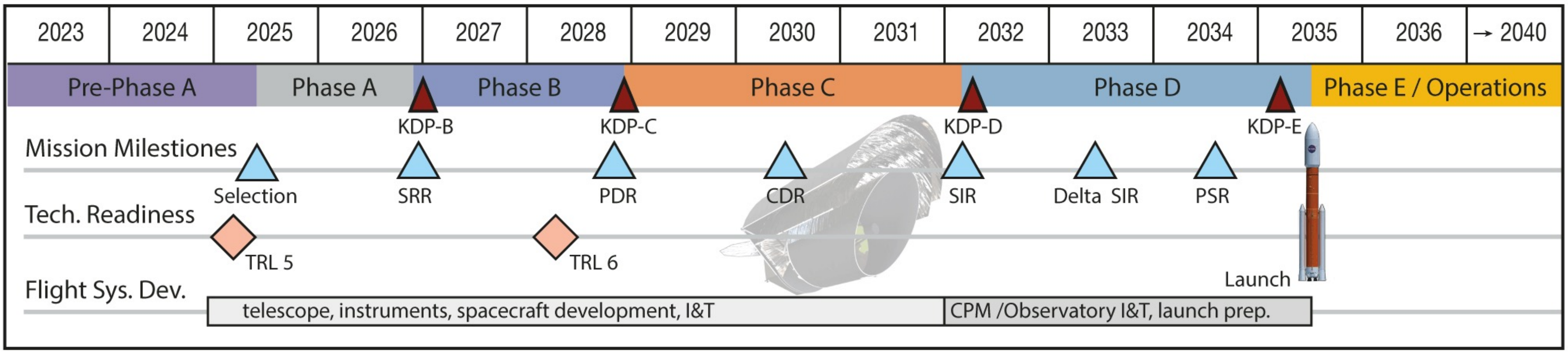
### *Cryocoolers:*

-4.5 K: Thanks MIRI/JWST + Hitomi!

-50 mK: NASA Dev.

# Origins:

## Simpler Design = Shorter Timeline



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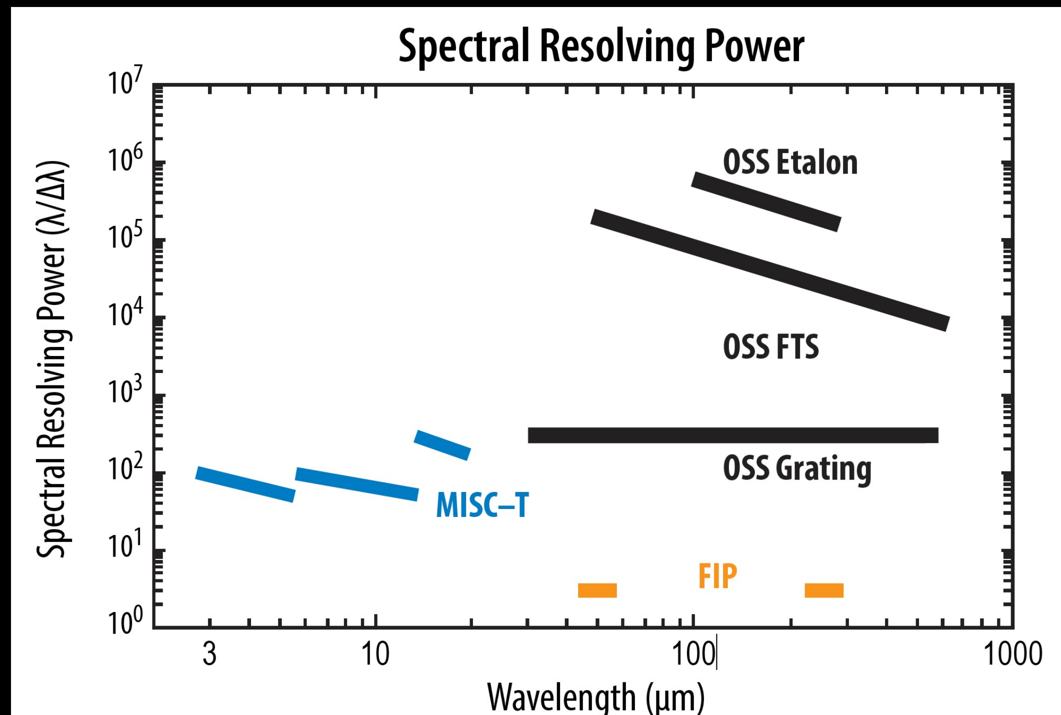
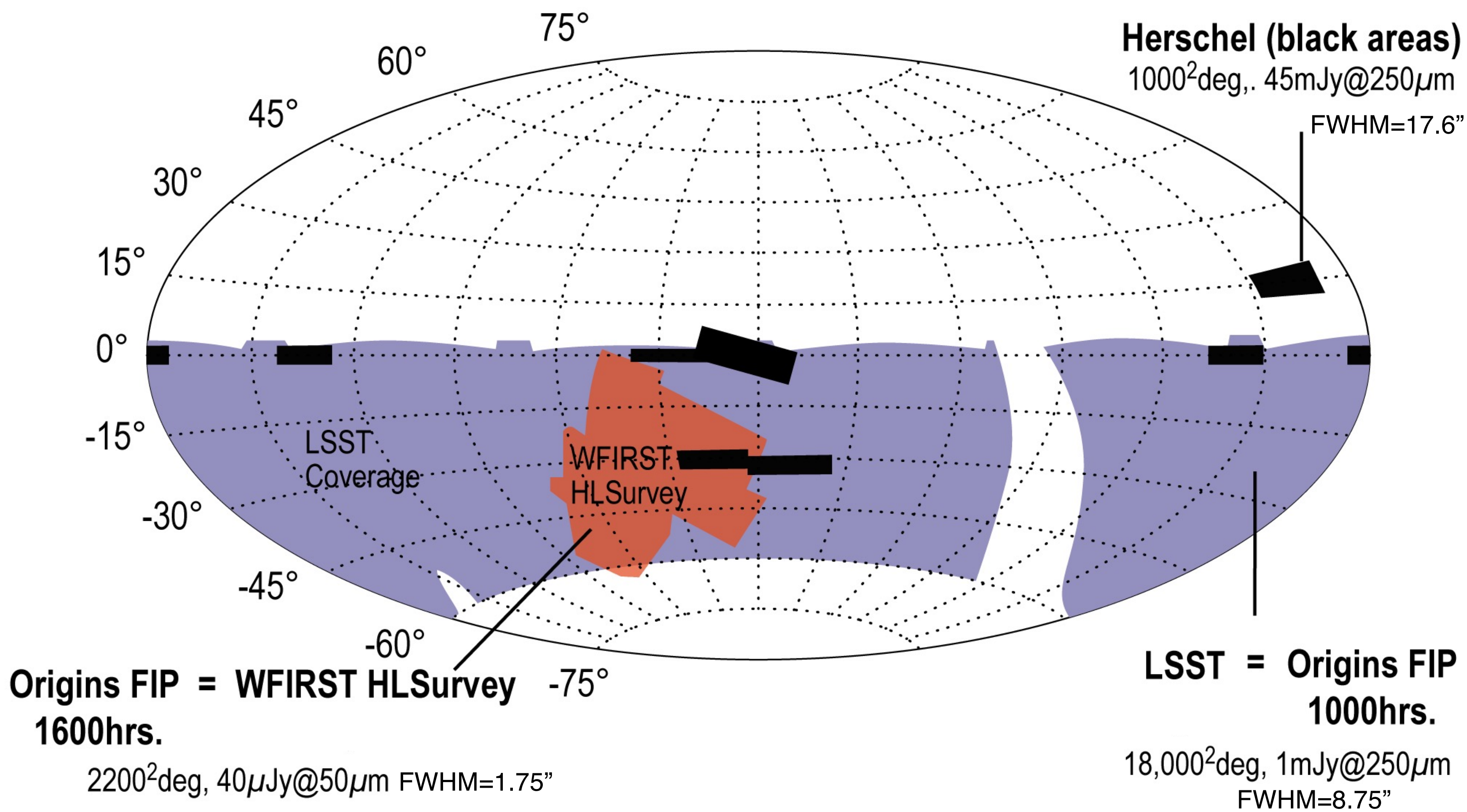
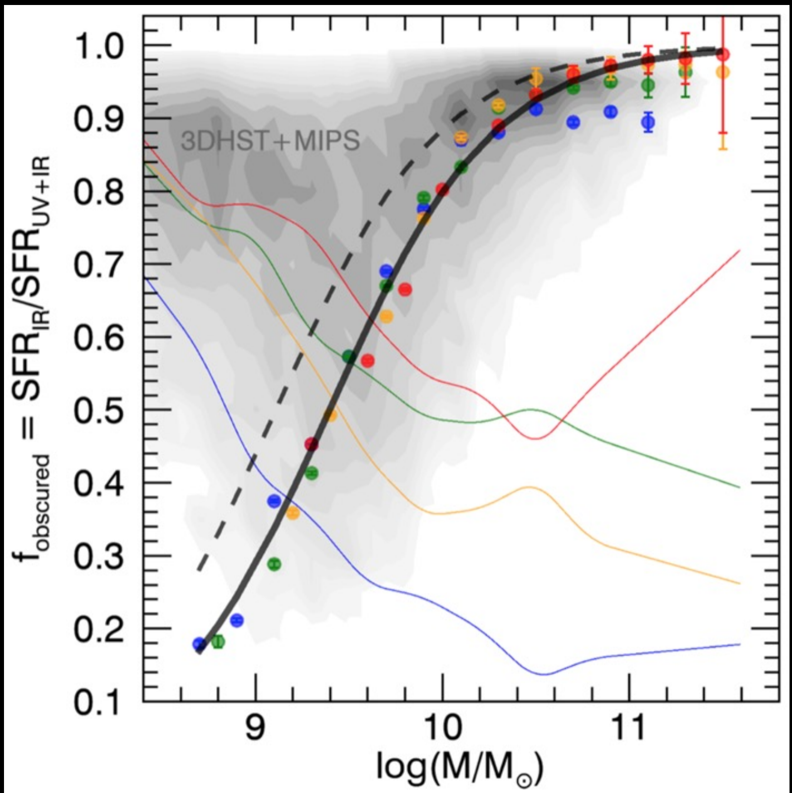
- ★ 5.9 m, ***non-deployed cold*** aperture (4.5K)
- ★ ***Low-risk*** development, testing, and deployment
- ★ ***Broad wavelength coverage***: 2.8 – 588 $\mu$m



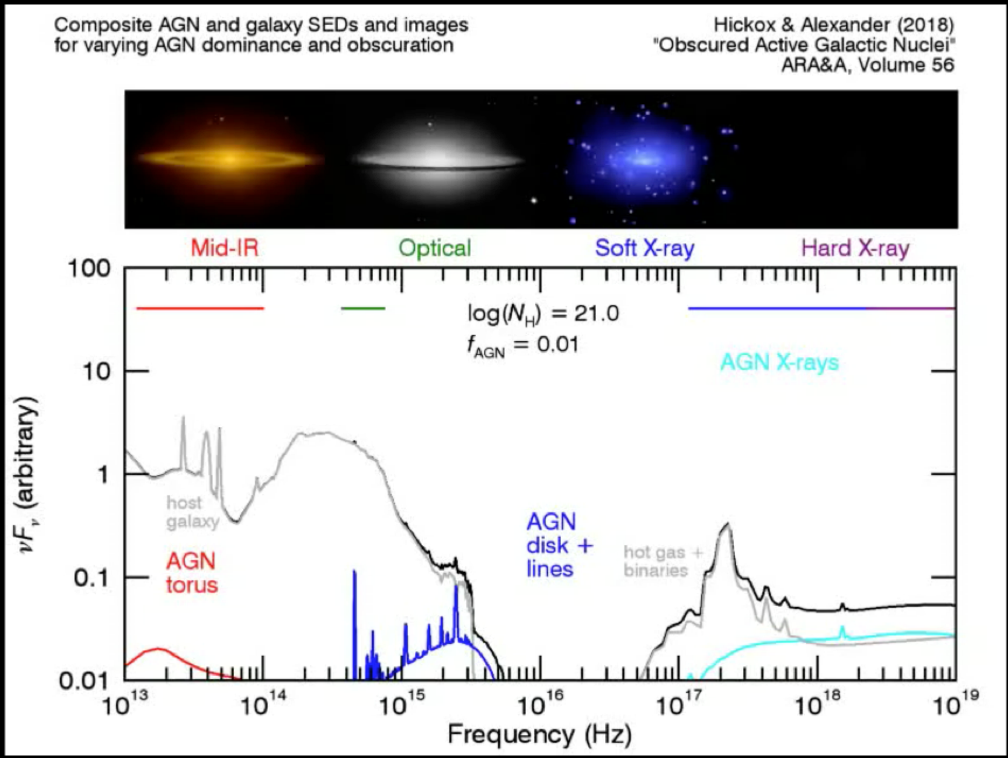
# Origins/FIP Surveys LSST and WFIRST Areas



# Star Formation and AGN growth are heavily obscured by dust in galaxies

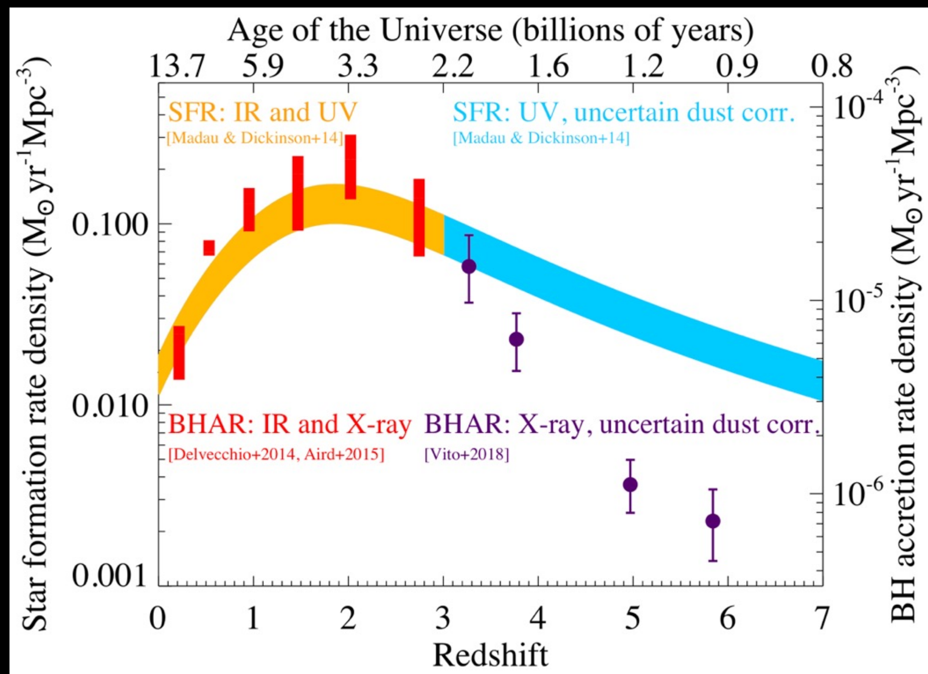


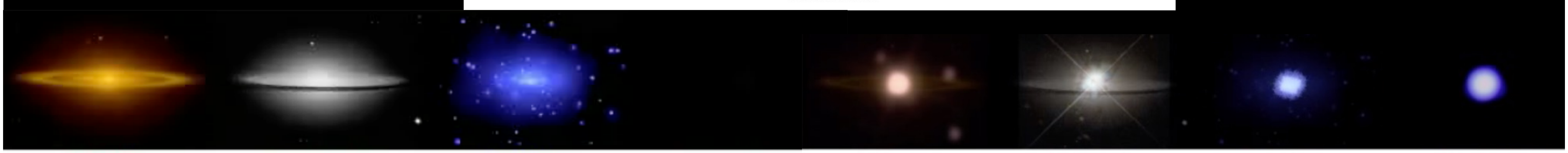

Whitaker et al. 2017




Hickox & Alexander 2018

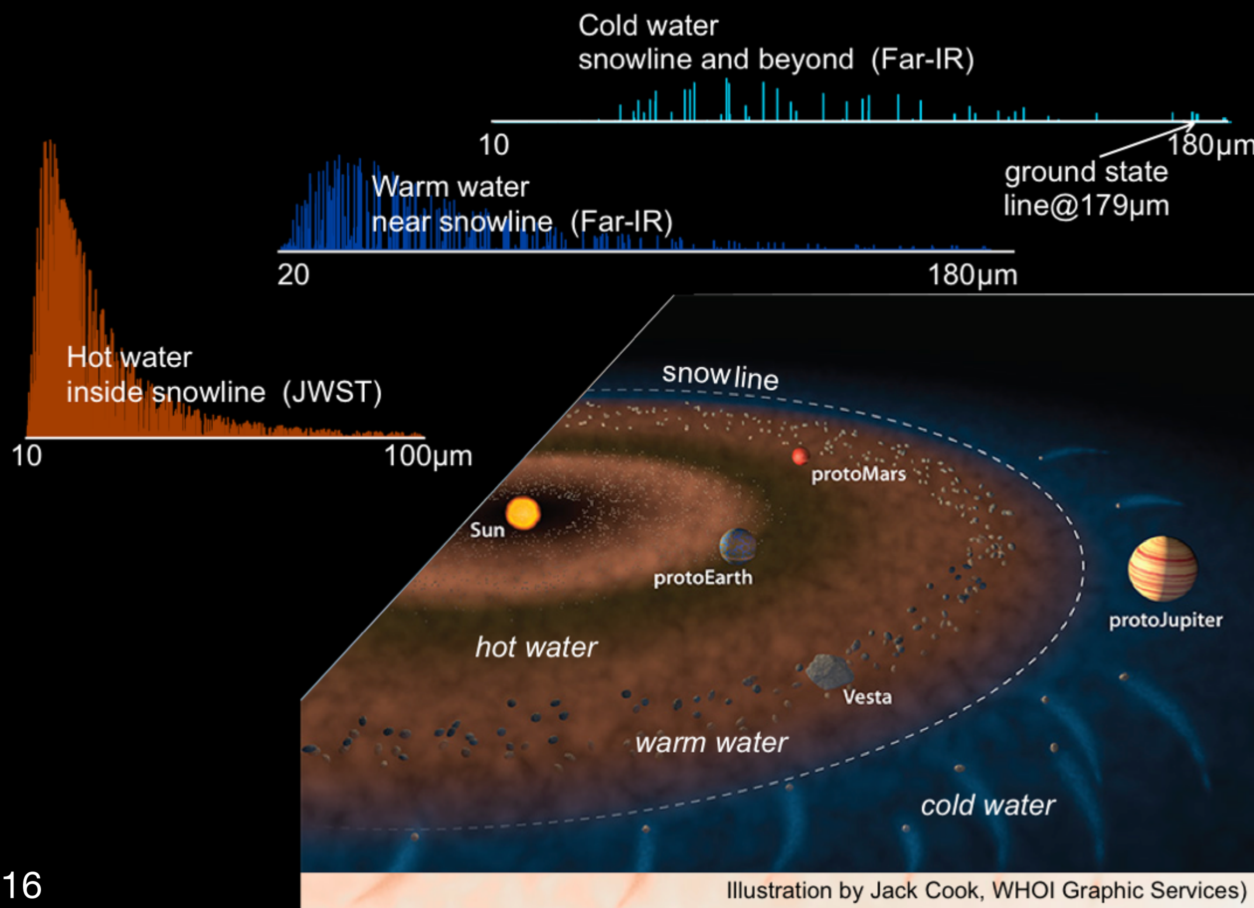
# Relative growth of stars and supermassive black holes in galaxies is relatively uncertain over cosmic time



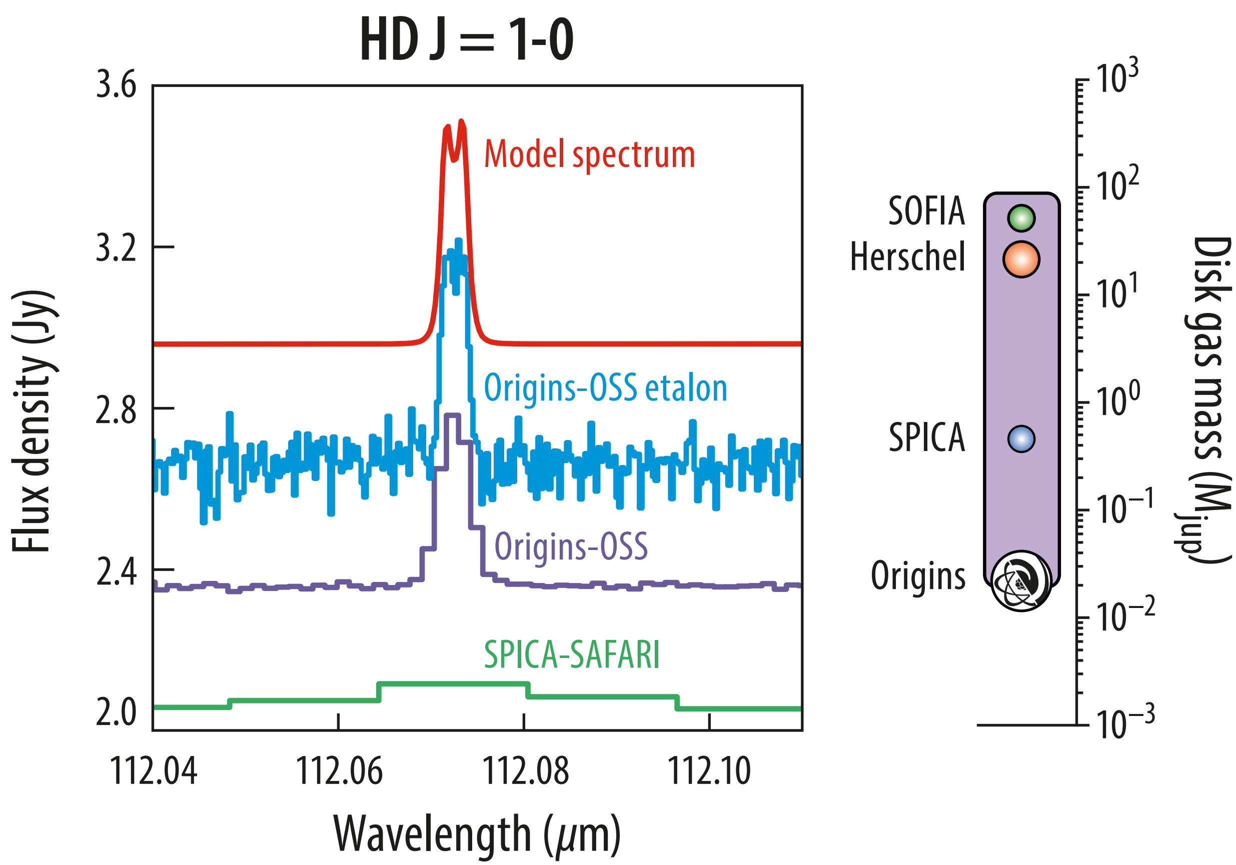

Hickox & Alexander 2018

# The Water Spectrum is a Temperature Distribution

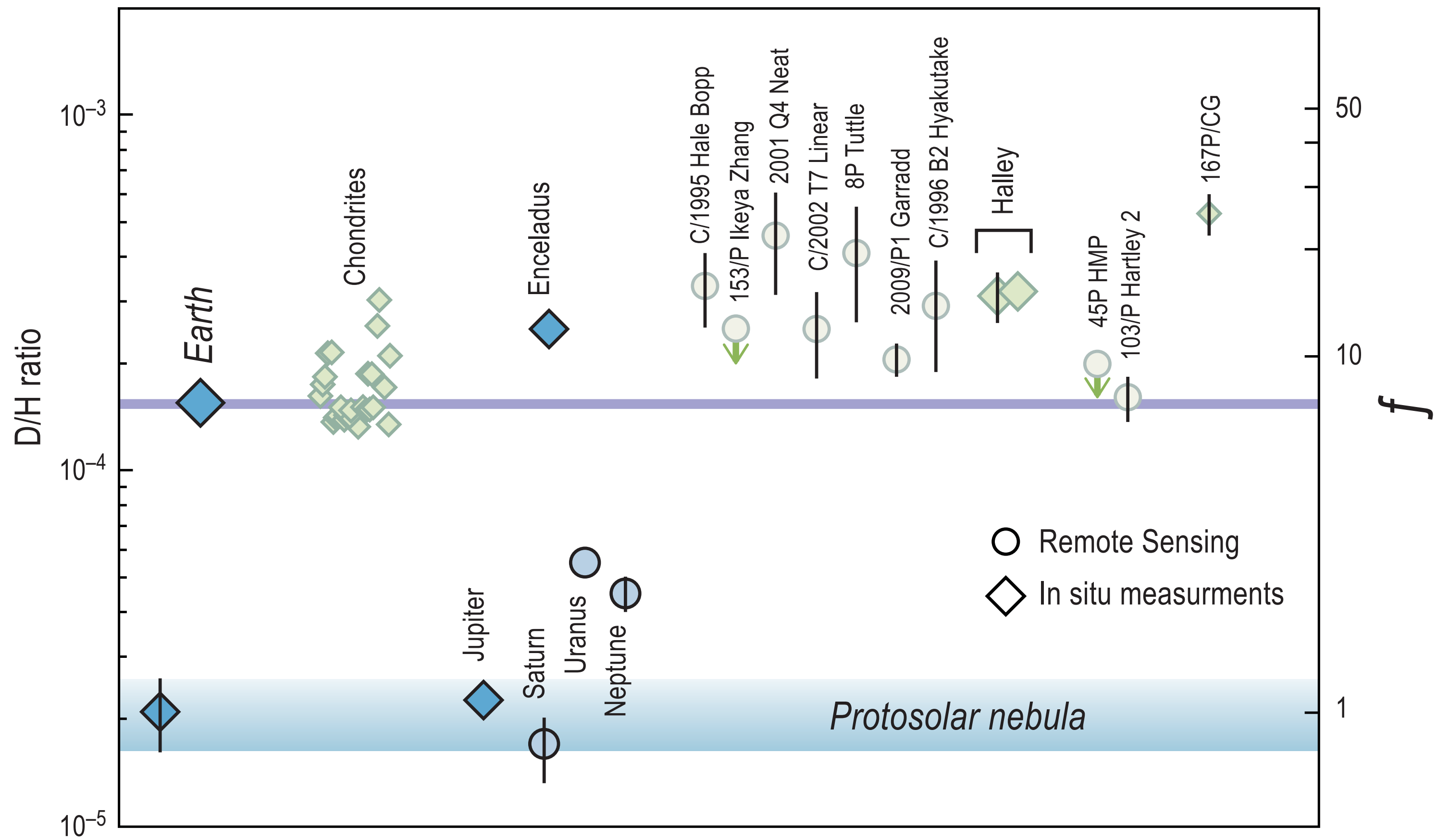



Blevins et al. 2016

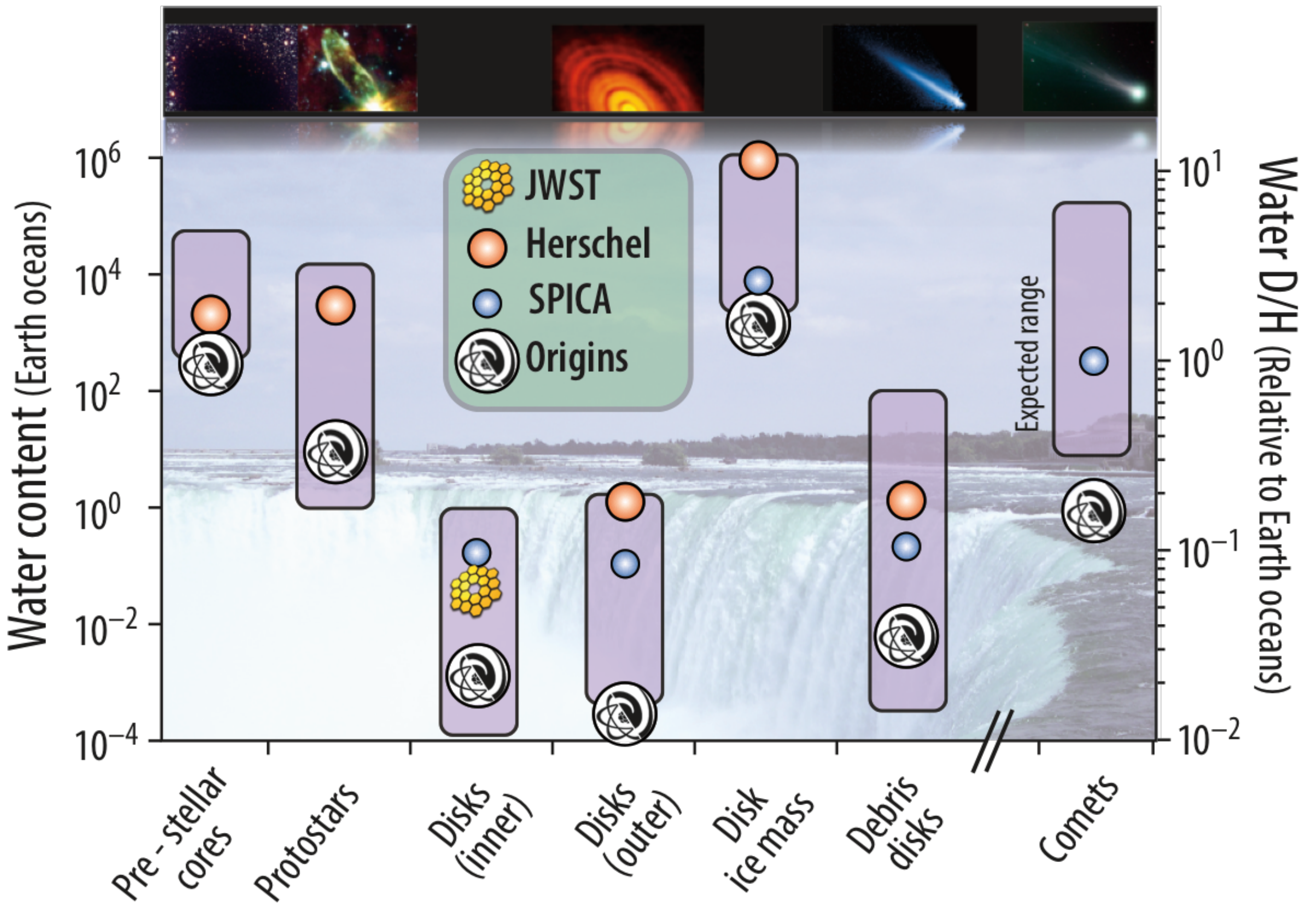
# Origins measures gas mass of planet forming disks



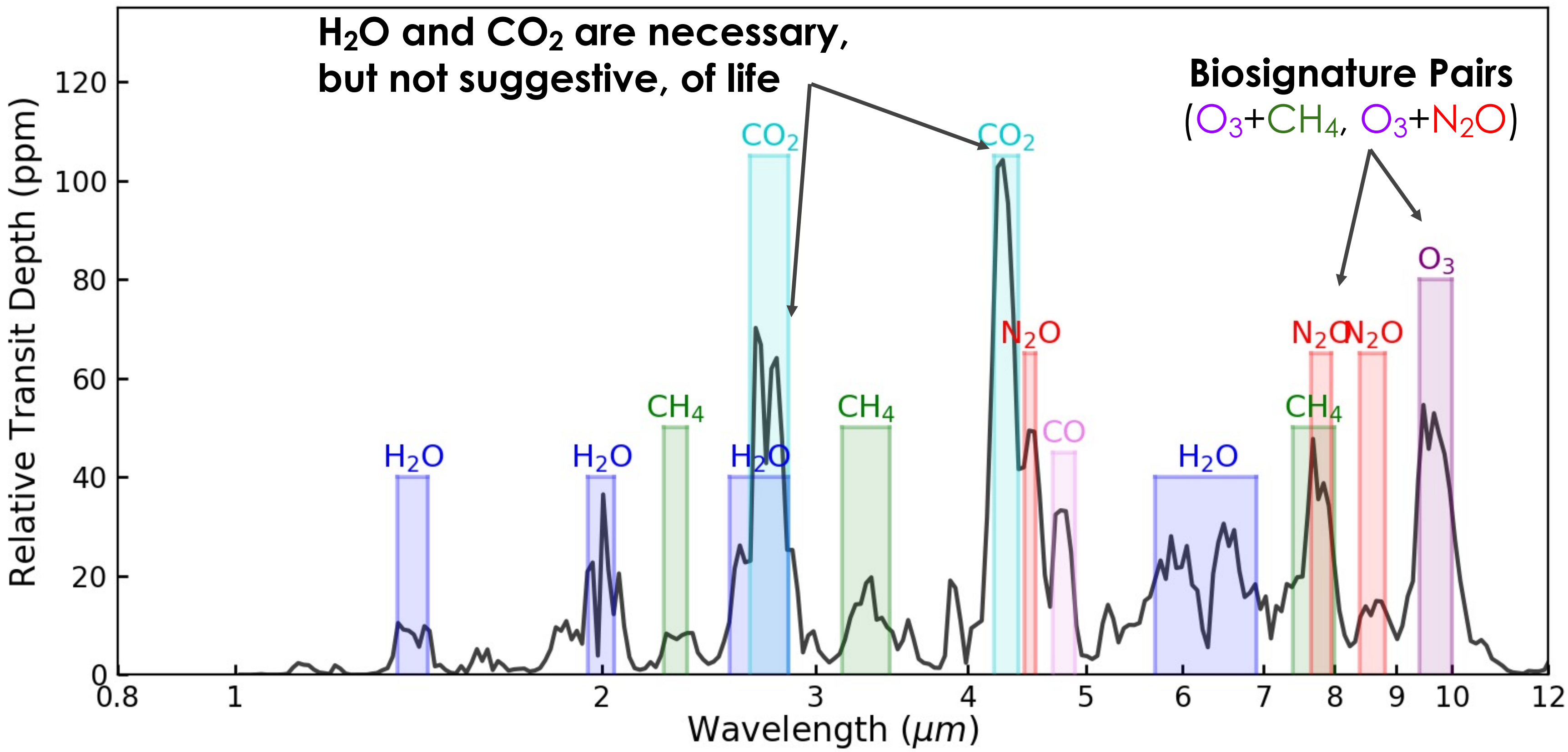
# How did Earth get its water?



# Origins definitive measurements of water trail



# Origins: IR wavelengths rich in biologically interesting molecules



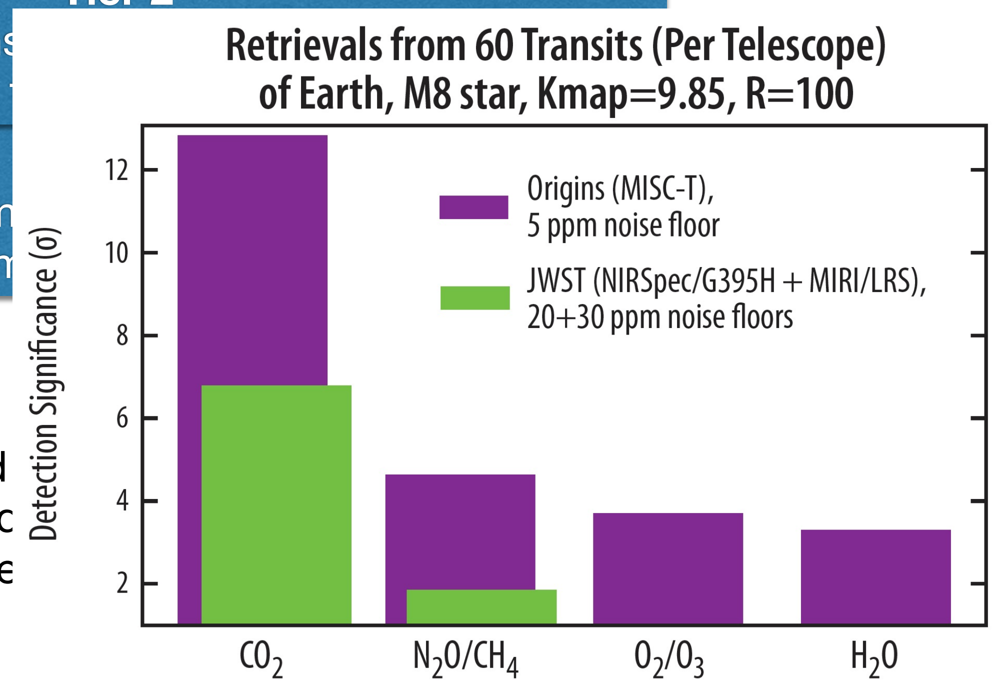
# Origins will use a multi-tiered strategy to **search for life**

**Tier 3**
Search for bio-signatures ($O_3$+$N_2O$, $O_3$+$CH_4$) with additional transits of temperate worlds (Np > 10)

**Tier 2**
**Eclipse** observations
they are

**Transit** observations to determ
cloudy atm

**Pre-select terrestrial M-dwarf planets** based
(ii) Relative rank based on suitability for detailec
(iii) Pre-*Origins* observations with JWST, ELTs e



# Are We Alone?

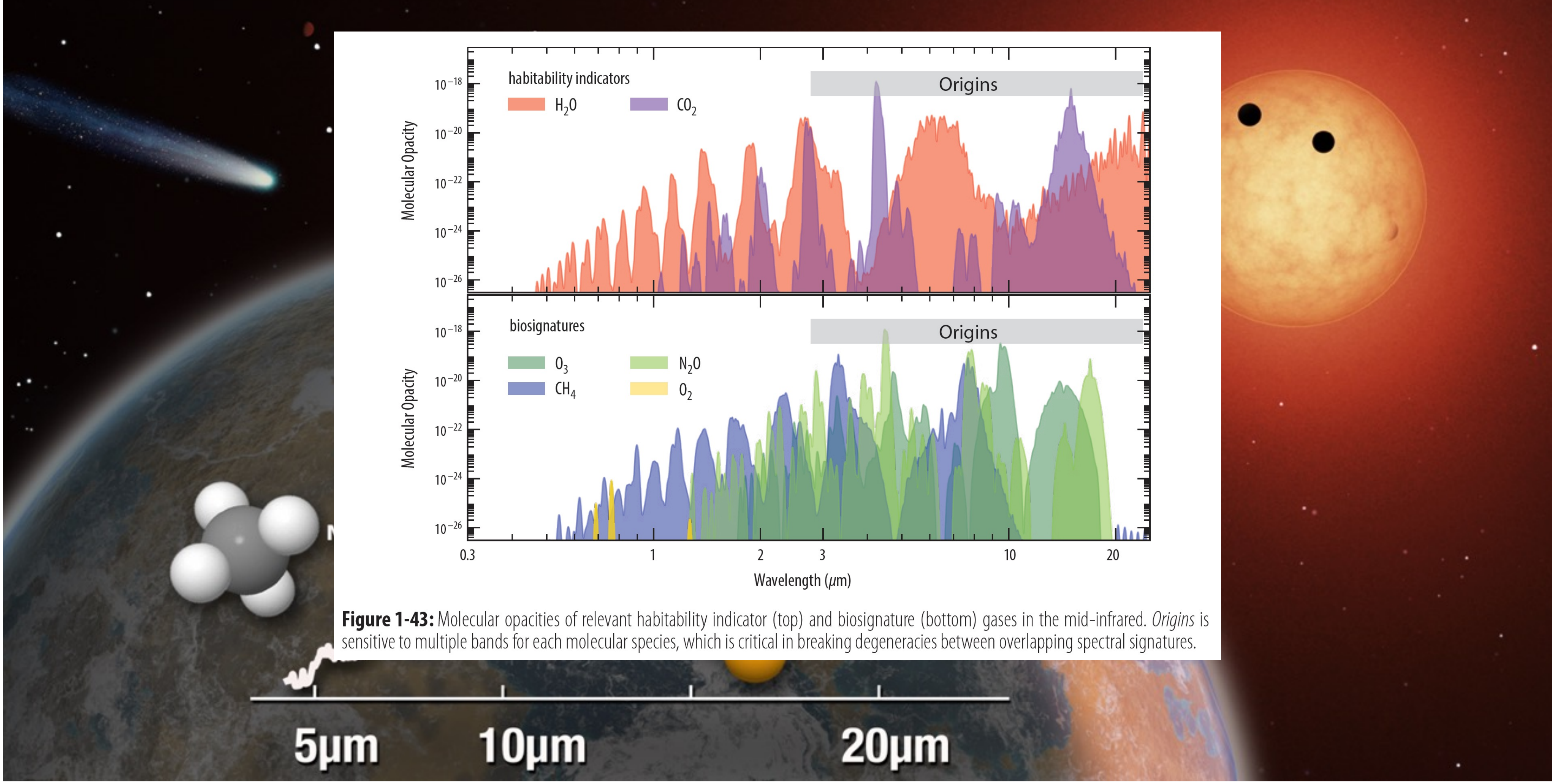



**Figure 1-43:** Molecular opacities of relevant habitability indicator (top) and biosignature (bottom) gases in the mid-infrared. *Origins* is sensitive to multiple bands for each molecular species, which is critical in breaking degeneracies between overlapping spectral signatures.

# Exoplanet Science Strategy Report supports *Origins*

- A cooled near-to-far infrared (IR) mission such as the Origins Space Telescope (*Origins*) would advance exoplanet science both by providing inputs to the study of planet formation through investigations of protoplanetary disks and by allowing planetary atmospheric characterization via the transit method.
- For the study of protoplanetary disks, the committee considers such a mission to be potentially ***transformative given its far-IR coverage***. High spectral resolution investigation of water lines would allow study of the spatial distribution of water across disks. Measurements of hydrogen deuteride (HD) lines would allow direct measurement of hydrogen masses of disks. Both would provide important information about the conditions under which planets form.
- Finding: The combination of transiting planet detection with TESS, mass measurements with radial velocities, and atmospheric characterization with JWST will be transformative for understanding the nature and origins of close-in planets. Future space missions with broader wavelength coverage, a larger collecting area, or reduced instrumental noise compared to JWST would have greater reach to potentially habitable planets.

# Exoplanet Science Strategy Report

- For the direct study of exoplanets, *Origins*' primary strength is in atmospheric characterization through transit spectroscopy in both primary and secondary eclipse. Like JWST, *Origins*' mid-IR wavelength coverage allows secondary eclipse measurements to probe thermal emission from temperate atmospheres and detect a variety of key molecules using transmission and emission spectroscopy. Given sensitivity constraints, *Origins* would be able to characterize terrestrial-size planets in the liquid water habitable zone around mid- to late M-dwarfs but not around earlier-type stars, including Sun-like stars.
- The currently proposed aperture, spectral resolution, and wavelength coverage of *Origins* do not differ substantially from JWST, and thus improvements over JWST in *Origins*' ability to characterize atmospheres are primarily predicated on an improved instrumental noise floor. Since detector stability for transit spectroscopy was not a technology driver for JWST's design, such an improvement is plausible, but not guaranteed.
- The committee is excited about exploring the atmospheres of terrestrial planets in the habitable zones of M dwarfs. These planets may host life and, given the large of abundance of M dwarfs, may even be the most common habitable environments……the habitable zone of M dwarfs might not in fact be a habitable environment given its extreme exposure to high-energy stellar irradiation.