ORIGINS
Space Telescope

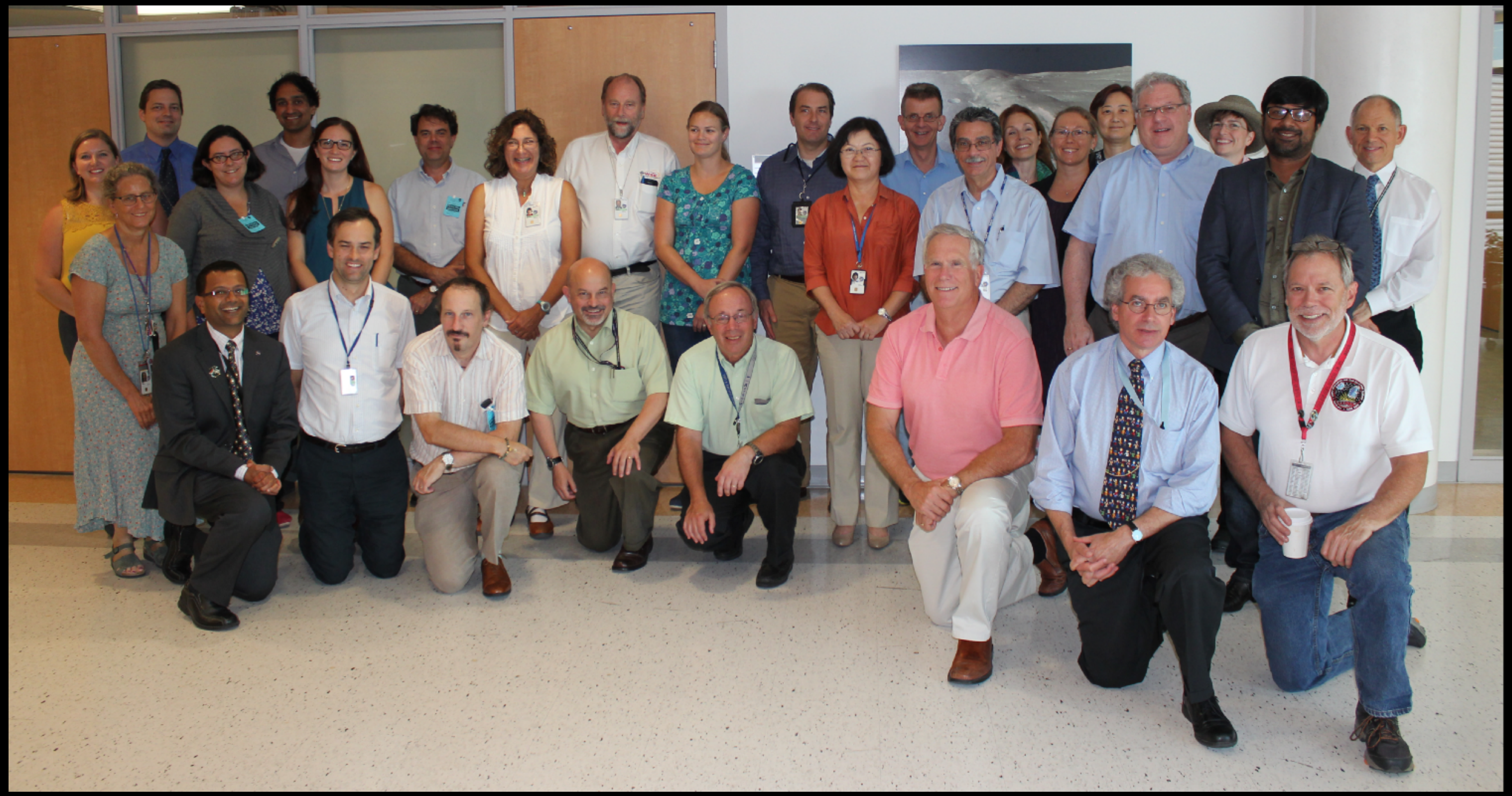
Asantha Cooray @acooray

http://origins.ipac.caltech.edu

Twitter: @NASAOriginsTele

ORIGINS Space Telescope

Tracing the rise of dust & metals in galaxies and the path of water across cosmic time to Earth and other habitable planets.



Study Team

- **Study Chairs: Asantha Cooray, *UC Irvine;* Margaret Meixner, *STSCI/JHU***
- **Study Scientist:** David Leisawitz, *GSFC*
- **Deputy Study Scientist:** Johannes Staguhn, *GSFC/JHU*
- **Study Manager:** Ruth Carter, *GSFC*
- **NASA HQ Program Scientists:** Kartik Sheth, Dominic Benford

- **NASA Appointed Members:** Lee Armus, IPAC; Cara Battersby, CfA; Edwin Bergin, Michigan; Matt Bradford, JPL; Kim Ennico-Smith, Ames; Lisa Kaltenegger, Cornell; Gary Melnick, CfA; Stefanie Milam, GSFC; Desika Narayanan, University of Florida; Klaus Pontopiddan, STSCI; Alexandra Pope, UMass; Thomas Roellig, Ames; Karin Sandstrom, UCSD; Kevin Stevenson, STScI; Kate Y. L. Su, Arizona; Joaquin Vieira, UIUC; Edward Wright, UCLA; Jonas Zmuidzinas, Caltech
- **Ex-officio representatives:** Susan Neff & Deborah Padgett, NASA Cosmic Origins Program Office; Susanne Alato, SNSB; Douglas Scott, CAS; Maryvonne Gerin, CNES; Itsuki Sakon, JAXA; Frank Helmich, SRON; Roland Vavrek, ESA; Karl Menten, DLR; Yong-Seon Song, KASI; Sean Carey, IPAC
- **NASA Study Center (Goddard Space Flight Center) Team:** Anel Flores (Mission Systems Engr), James Kellogg (Instrument Systems Engr), Michael DiPirro (Chief Technologist), Louis Fantano (Thermal Systems Engr), Andrew Jones (Mechanical Systems Engr), Joseph Howard (Optical Systems Engr), James Corsetti (Optical Engr), Ed Canavan (Cryo Engr), Johannes Staguhn (Instrument Scientist)
- **Study Advisory Board:** Jon Arenberg,Northrup Grumman; John Carlstrom, Chicago, Harry Ferguson, STScI, Tom Greene, Ames; George Helou, IPAC; Charles Lawrence, JPL; Sarah Lipscy, Ball Aerospace; John Mather, GSFC; Harvey Moseley, GSFC; George Rieke, Arizona; Marcia Rieke, Arizona; Jean Turner, UCLA; Meg Urry, Yale.

Origins Space Telescope

Tracing the rise of dust & metals in galaxies and the path of water across cosmic time to Earth and other habitable planets.

How did we decide on the Origins Space Telescope?

(1) Define Science

(consider 2018-2035 science developments; science goals for 2035)

(2) Prioritize science

(STDT internal voting process - completed August 2016 meeting)

(3) Derive mission and instrument requirements

(Completed Nov 2016 meeting)

Science process is through six science working groups (SWGs). Membership in SWGs is open to the community.

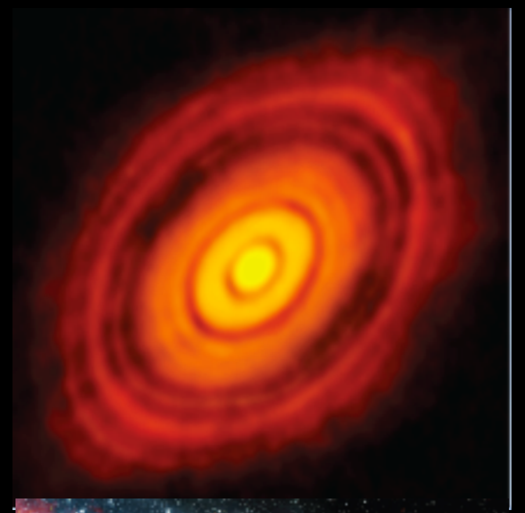
OST interest groups in Europe and Japan

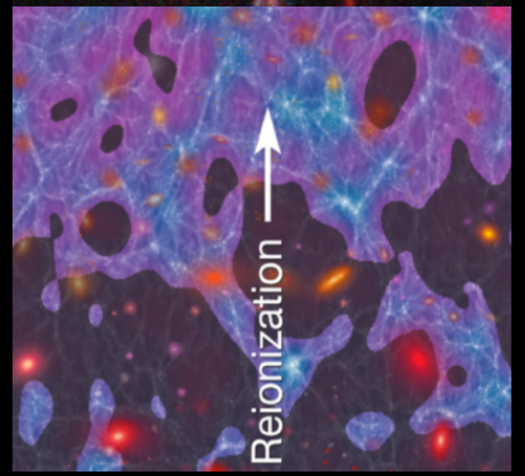
(about 250 community members active already! SWG listings on our website)

ORIGINS Space Telescope

Tracing the rise of dust & metals in galaxies and the path of water across cosmic time to Earth and other habitable planets.

Science Working Groups

- **Solar System**: Stefanie Milam
- **Exoplanets**: Lisa Kaltenegger and Kevin Stevenson
- **Disks and Protoplanets**: Klaus Pontoppidan and Kate Su
- **Milky Way, ISM and Nearby Galaxies**: Karin Sandstrom and Cara Battersby
- **Galaxy Evolution over Cosmic Time**: Lee Armus and Alex Pope
- **Early Universe and Cosmology**: Matt Bradford and Joaquin Vieira

ORIGINS Space Telescope

Tracing the rise of dust & metals in galaxies and the path of water across cosmic time to Earth and other habitable planets.

NASA

Science Case - Number and Title

19. The Rise of Metals
14: Biosignatures of Transiting Exoplanets **revamped**
27: The First Dust
9: Water Content of Planet-Forming Disks
21: Connection Between Black Hole Growth and Star Formation Over Cosmic Time
15: Direct Detection of Protoplanetary Disk Masses
26: Birth of Galaxies During Cosmic Dark Ages
18: Galaxy Feedback from SNe and AGN to z~3
30: Survey of Small Bodies in the Outer Solar System
16: Direct Imaging of Exoplanets **revamped**
22: Star Formation and Multiphase ISM at Peak of Cosmic Star Formation
29: Thermo-Chemical History of Comets and Water Delivery to Earth
5: Galaxy Feedback Mechanisms at z<1
4: Water Transport to Terrestrial Planetary Zone
13: Frequency of Kuiper Belt Analogues
24: Feedback on All Scales in the Cosmic Web
7: Magnetic Fields and Turbulence - Role in Star Formation
New#1 The EBL (extra-galactic background light) with OST
New#2: Determining the cosmic-ray flux in the Milky Way and nearby galaxies
17: Episodic Accretion in Protostellar Envelopes and Circumstellar Disks
8: Formation and History of Low-Mass Ice Giant Planets
32: Find Planet IX
New#3: Fundamental of dust formation around evolved stars
New#4: The dynamic interstellar medium as a tracer of galactic evolution
New#5: Probing magnetic fields with fine structure lines

Science white papers are publicly available from https://asd.gsfc.nasa.gov/firs/
STDT will revise these and also collect more papers from community in Summer 2017

ORIGINS Space Telescope

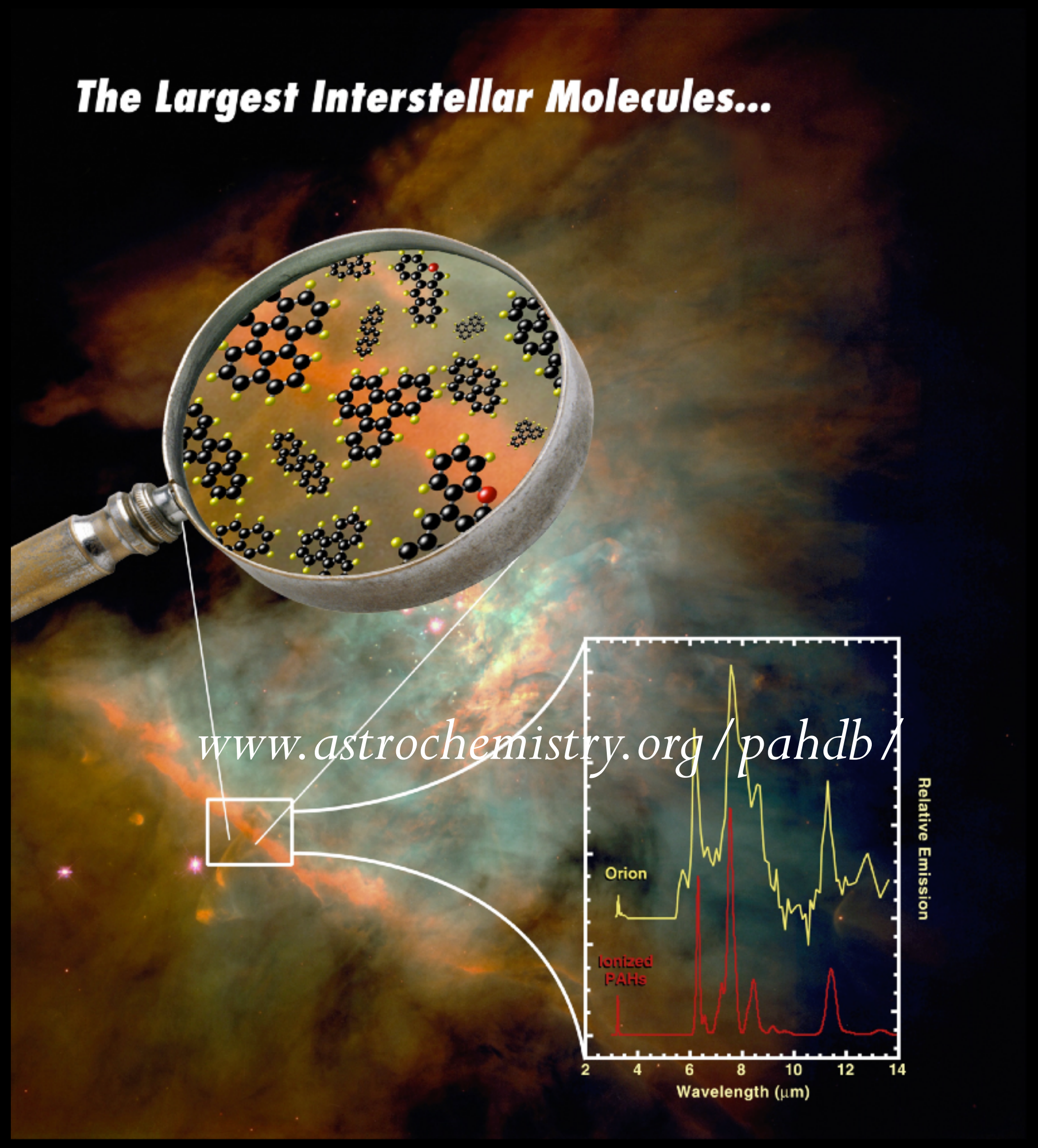
Tracing the rise of dust & metals in galaxies and the path of water across cosmic time to Earth and other habitable planets.

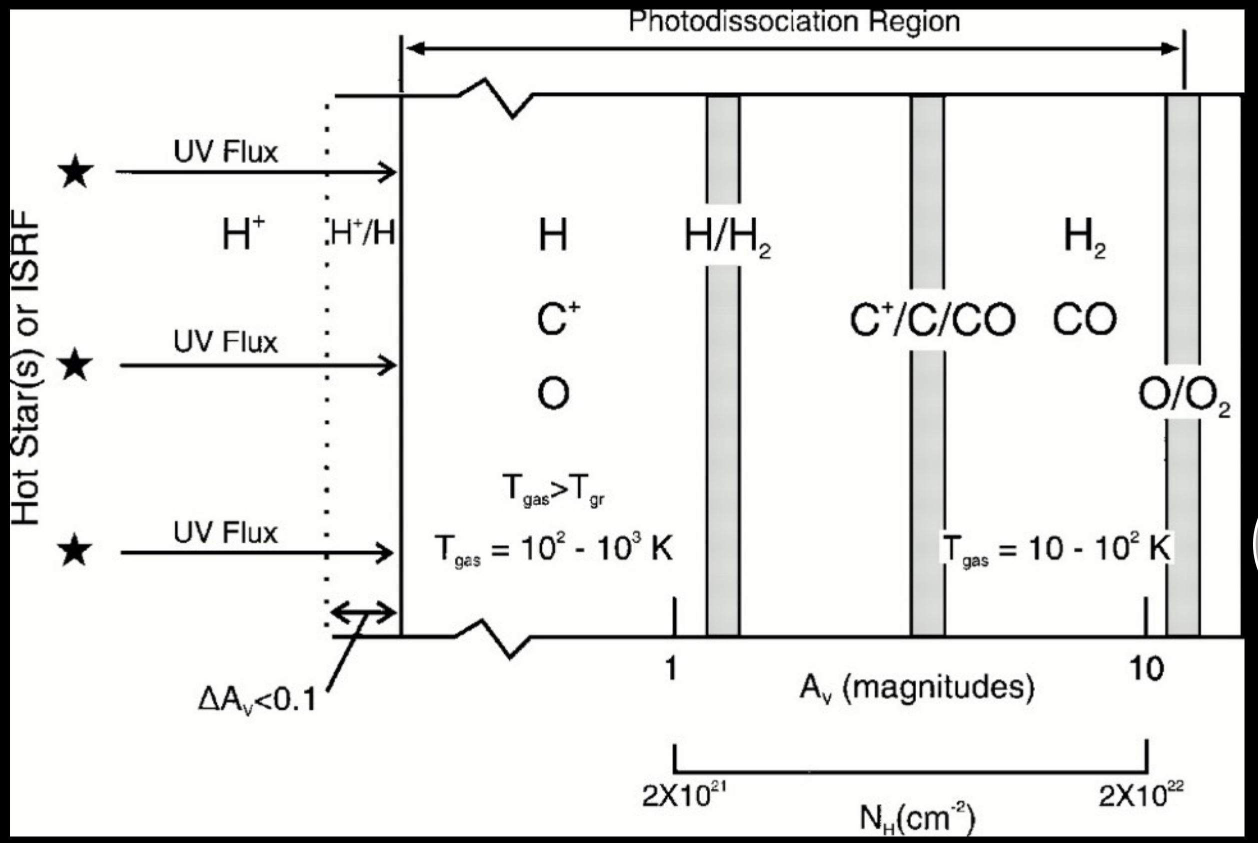
An Example Science Traceability Matrix

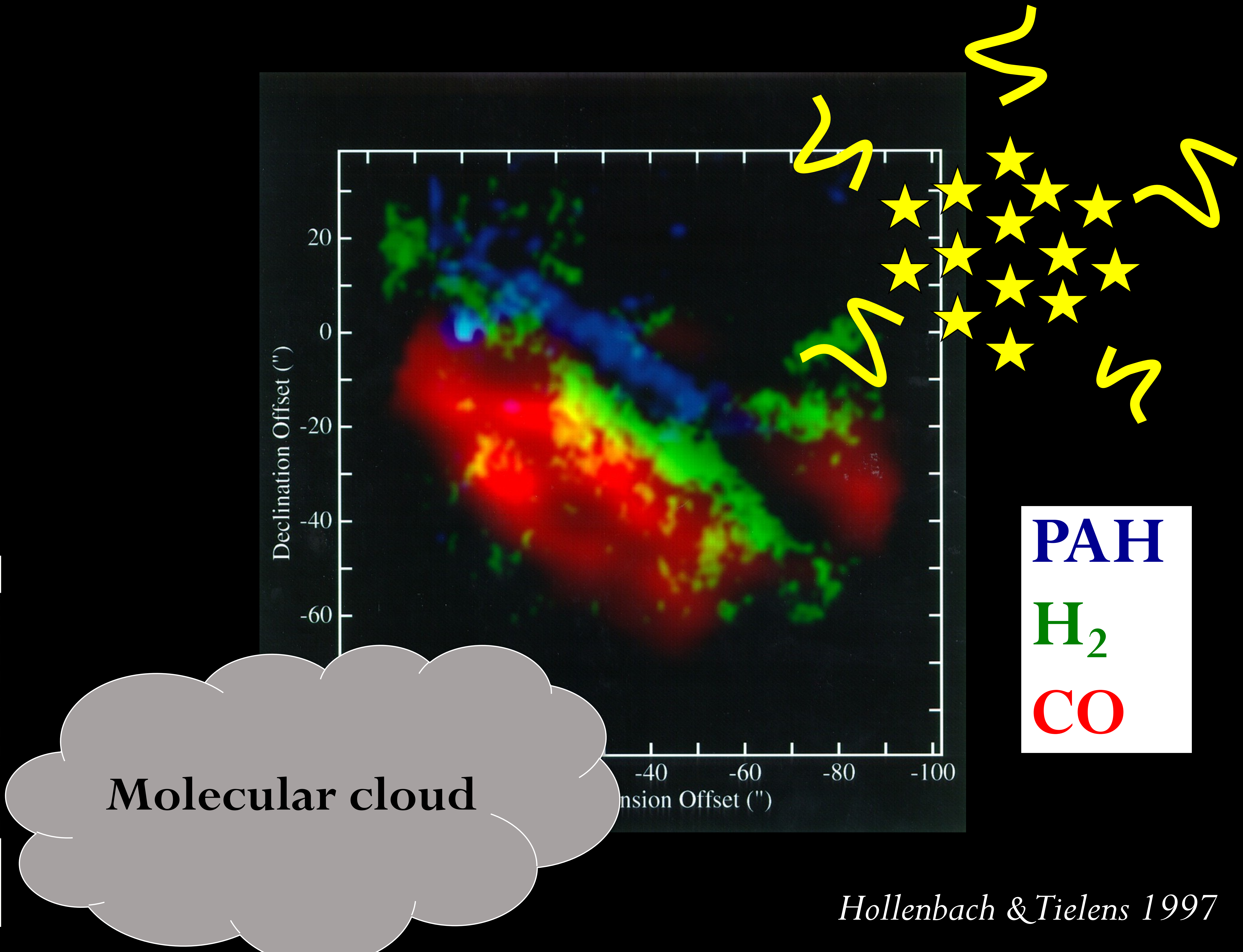
OST Science Case Number/Title Theme	OST Science Theme NASA Science Goal Decadal Science Goal	Science Objectives	Science Requirements		Instrument Requirements		
			Science Observable	Measurement Requirement	Technical Parameter	Technical Requirement	Instrument(s)
19, Rise of Metals, Dust, and the First Galaxies Trace the dust and metal enrichment history of the early Universe. Find the first cosmic sources of dust, and search for evidence of the very earliest stellar populations forming in pristine environments.	***OST-2:*** *(Charting the) Rise of Metals, Dust, and the First Galaxies* ***NASA-2:*** *How did we get here?* ***Decadal-1:*** *Cosmic Dawn*	Trace the rise of metals and (a) determine the evolution in metallicity from z=1 to z=3 to 0.1 dex down to $10^{11} L_{sun}$; (b) determine the cosmic metal abundance Ωmetals from z=0 to z=8 to 0.1 dex accuracy in 8 redshift bins; and (c) measure the multiple phases of the ISM to infer the physical phenomena that regulate SF efficiency at the peak of cosmic star formation at z=1-3.	z=1-3 relative metallicity tracer: [NeII]12.8, [NeIII]15.6, [SIII]18.7, [SIV]10.5; z=0-8 relative metallicity tracer: [OIII] 52+88 µm, [NIII] 57 µm ; cooling and heating of the ISM through [OI], [OIII], [NII], [CII]. A multi-tiered survey, with a wide tier of ~10 deg^2, with sensitivity down to $10^{11} L_{sun}$ galaxies at z=3 and $10^{12} L_{sun}$ galaxies at z=8. Aim is a sample with >10000 galaxies with IR luminosity $>10^{11} L_{sun}$ at z=1-3	Rest-frame mid and far-IR spectral mapping to select z=0 to 8 galaxies	Wavelength range	20-800 µm	incoherent spectrometer, low res mode
				Identify galaxies in a tiered spectral mapping survey	Spatial resolution	5 arcsec at 200 µm (min. 9 m Telescope)	
				Measure line flux densities of identified galaxies	Spectral line sensitivity	1e-21W m-2 (driven by the MIR lines)	
					Spectral Resolving power	λ/Δλ = 500	
					survey area, instan-taneous FOV, FoR	10 deg^2	
					Mapping Speed		

Tracing the rise of dust & metals in galaxies and the path of water across cosmic time to Earth and other habitable planets.

How do we probe the interstellar medium in high redshift galaxies?







PAH
H_2
CO

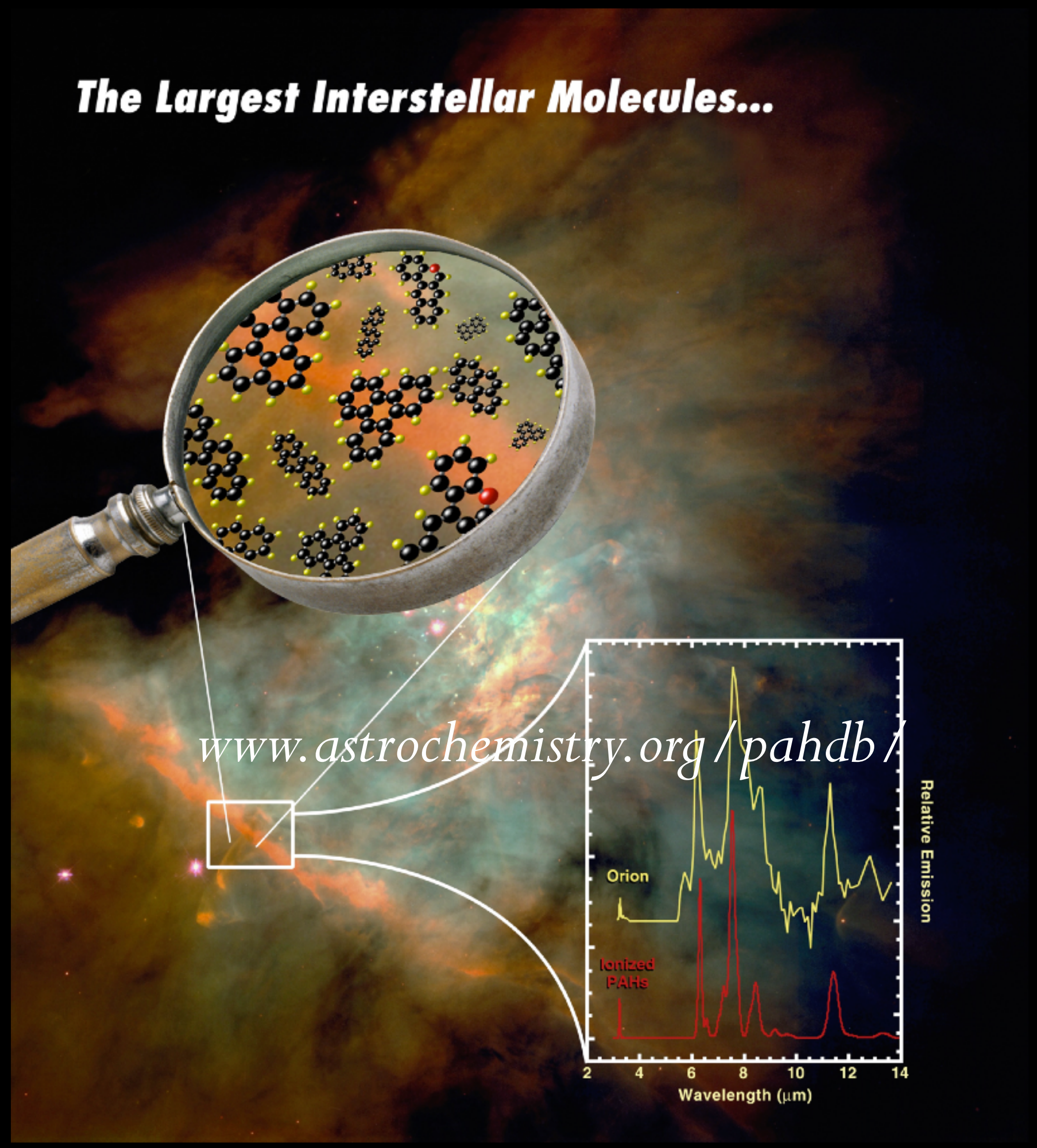
Hollenbach & Tielens 1997

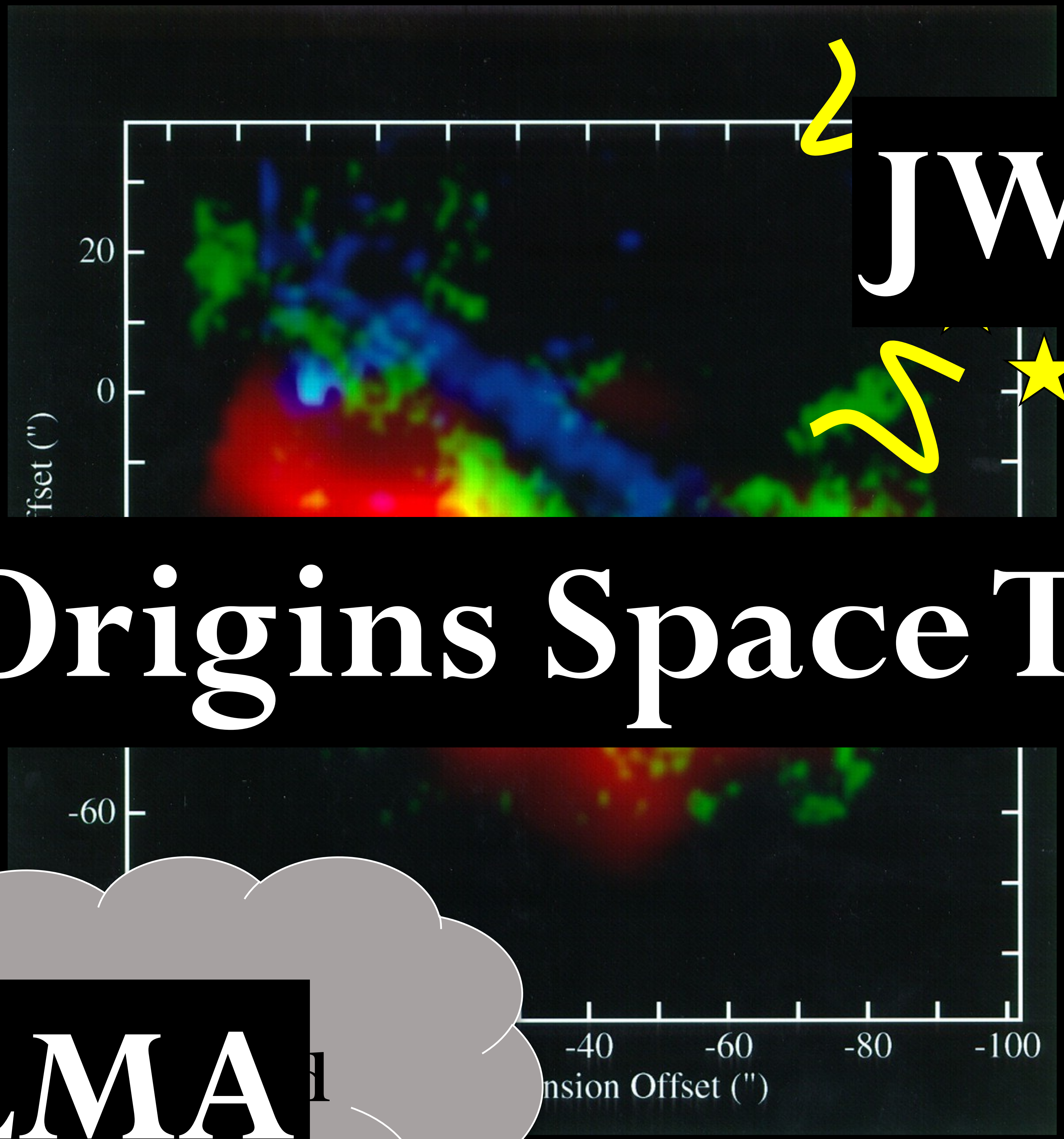
ORIGINS Space Telescope

Tracing the rise of dust & metals in galaxies and the path of water across cosmic time to Earth and other habitable planets.

NASA

How do we probe the interstellar medium in high redshift galaxies?





JWST

Origins Space Telescope

H_2

CO

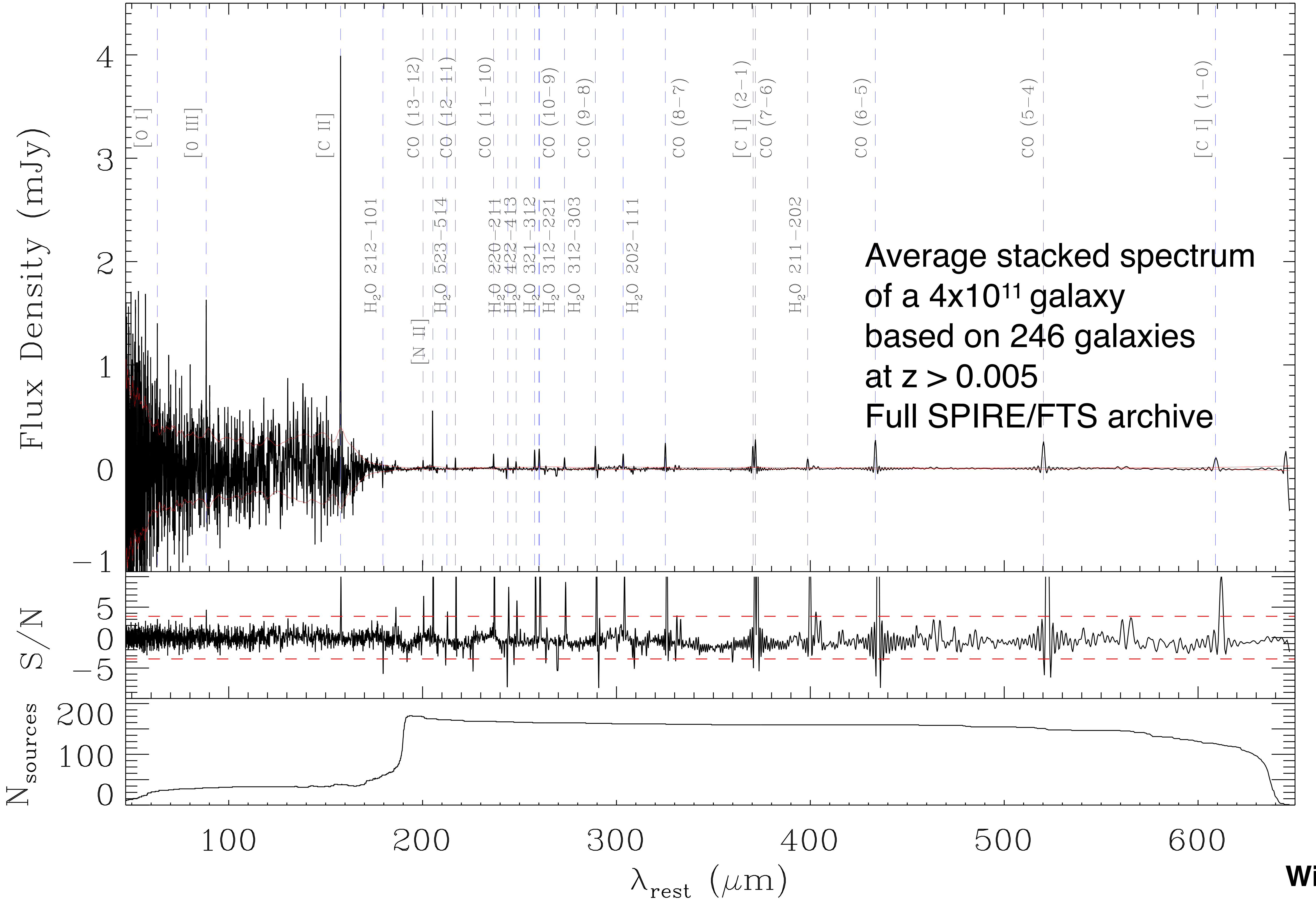
ALMA

Hollenbach & Tielens 1997

ORIGINS Space Telescope

Tracing the rise of dust & metals in galaxies and the path of water across cosmic time to Earth and other habitable planets.

Infrared is rich in key spectral lines!



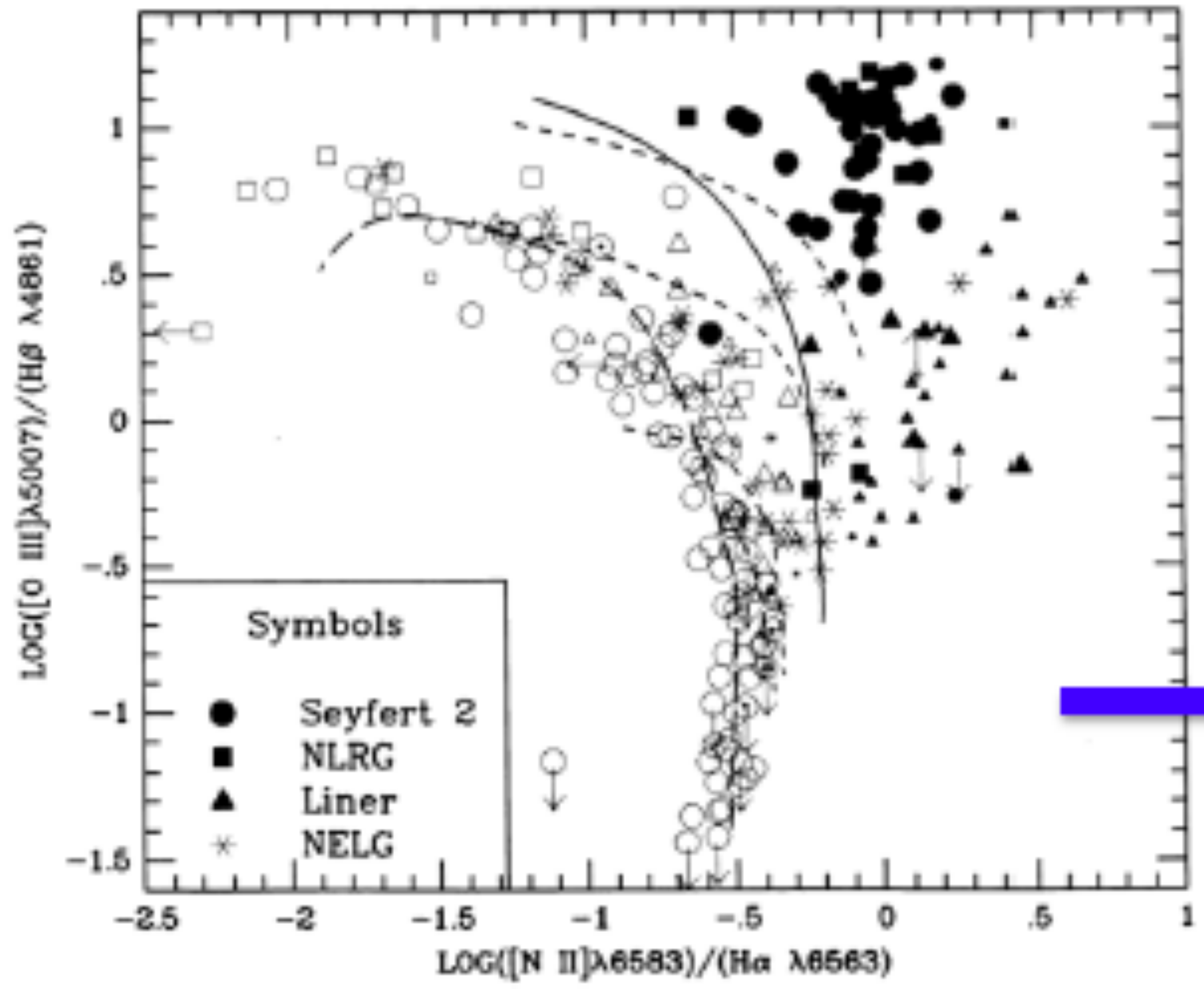
Wilson et al. 2017

ORIGINS Space Telescope

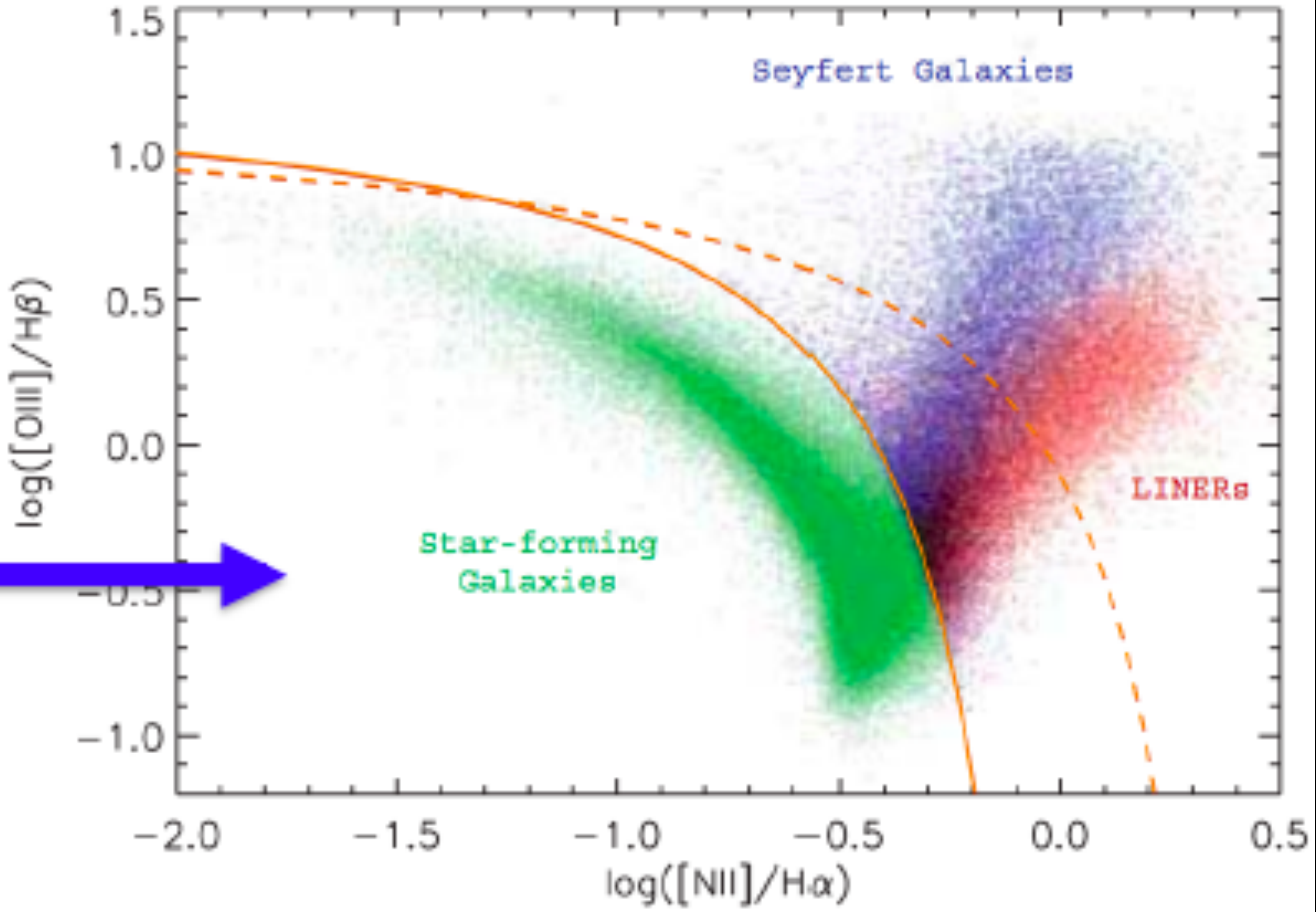
Tracing the rise of dust & metals in galaxies and the path of water across cosmic time to Earth and other habitable planets.

OPTICAL SPECTROSCOPY

Veilleux & Osterbrock **1987** (~100 galaxies)

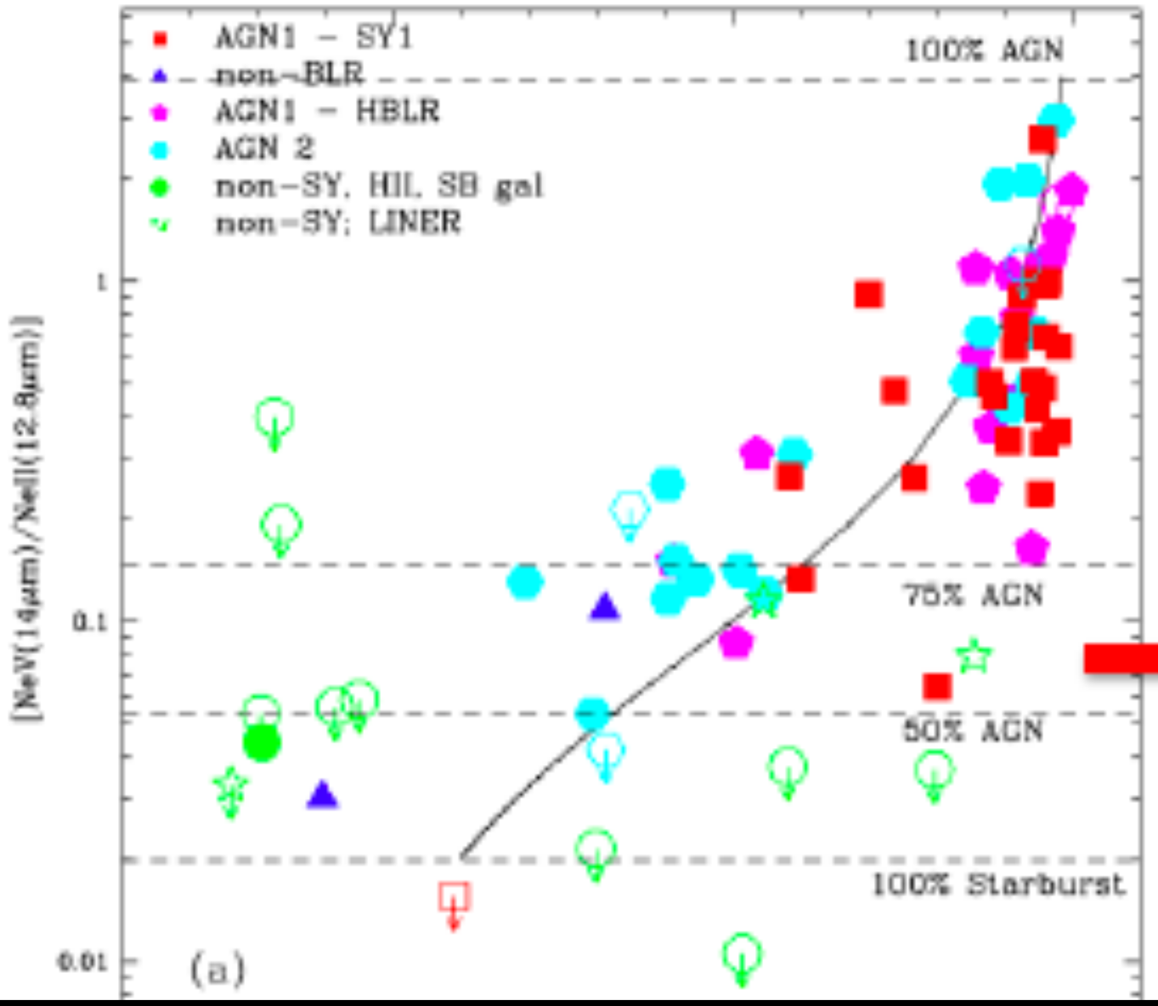


Groves+ **2006** (>10^5 galaxies)



MIR-FIR SPECTROSCOPY

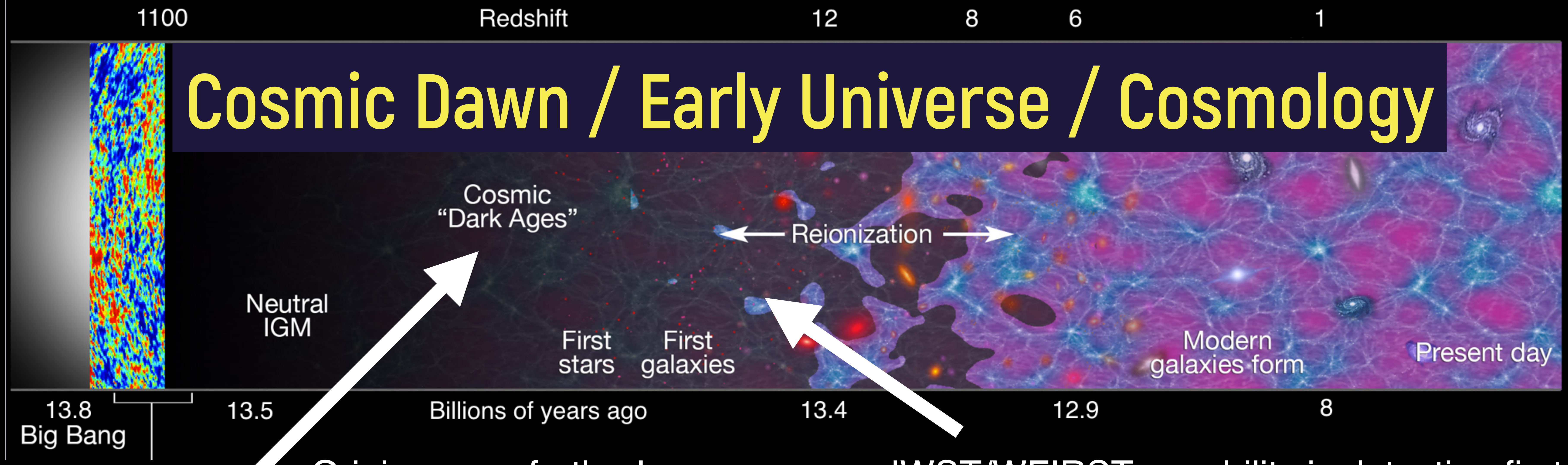
Tommasin+ **2010** (~60 galaxies)



Origins Space Telescope:
~ mid and far-IR spectra for 10^6 galaxies, from starbursts to Milky Way-like galaxies
(2030+ -> 20 year development consistent with optical technology development to get million optical spectra)

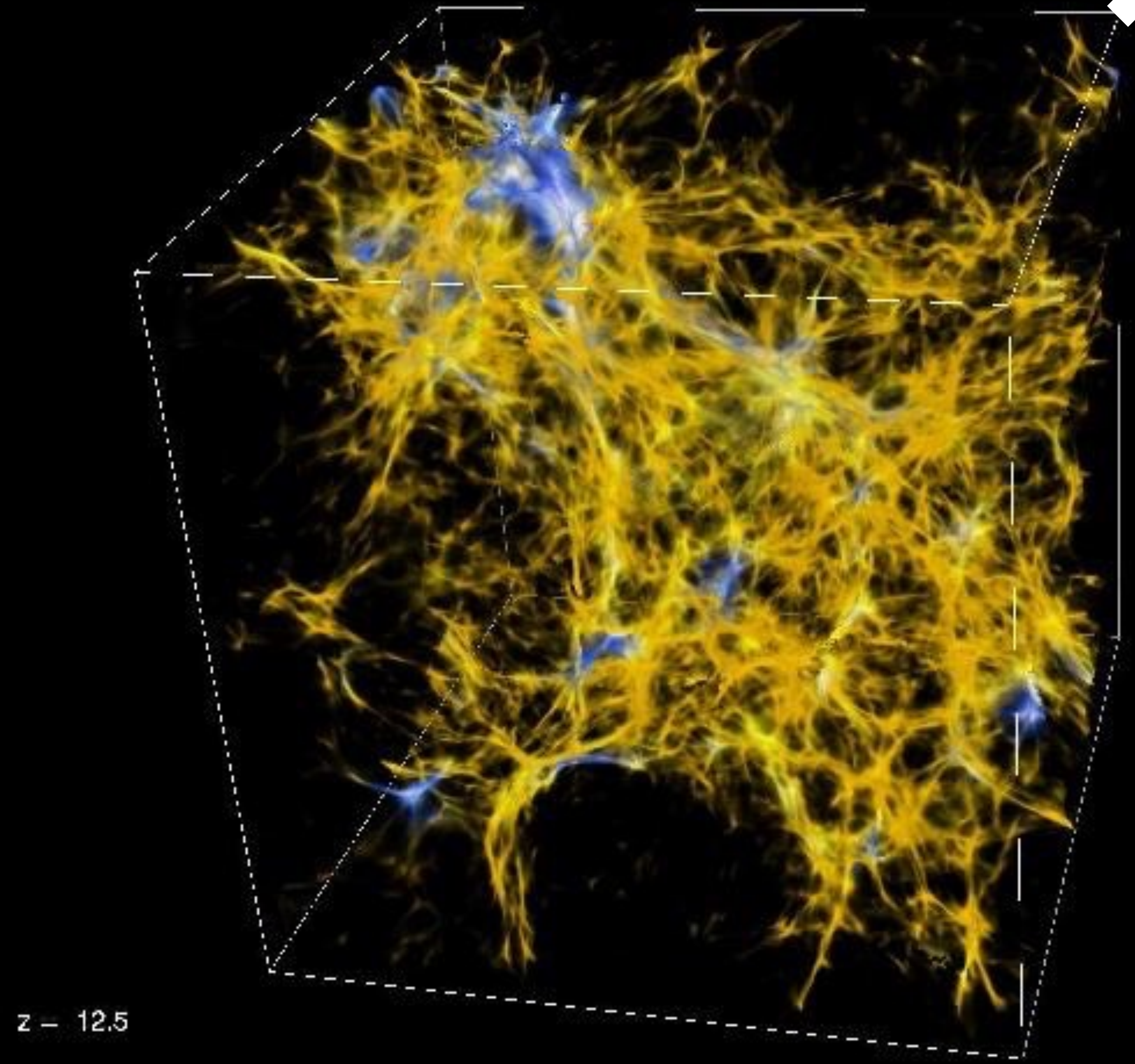
ORIGINS Space Telescope

Tracing the rise of dust & metals in galaxies and the path of water across cosmic time to Earth and other habitable planets.



Origins goes further!

JWST/WFIRST capability is detecting first stellar emission



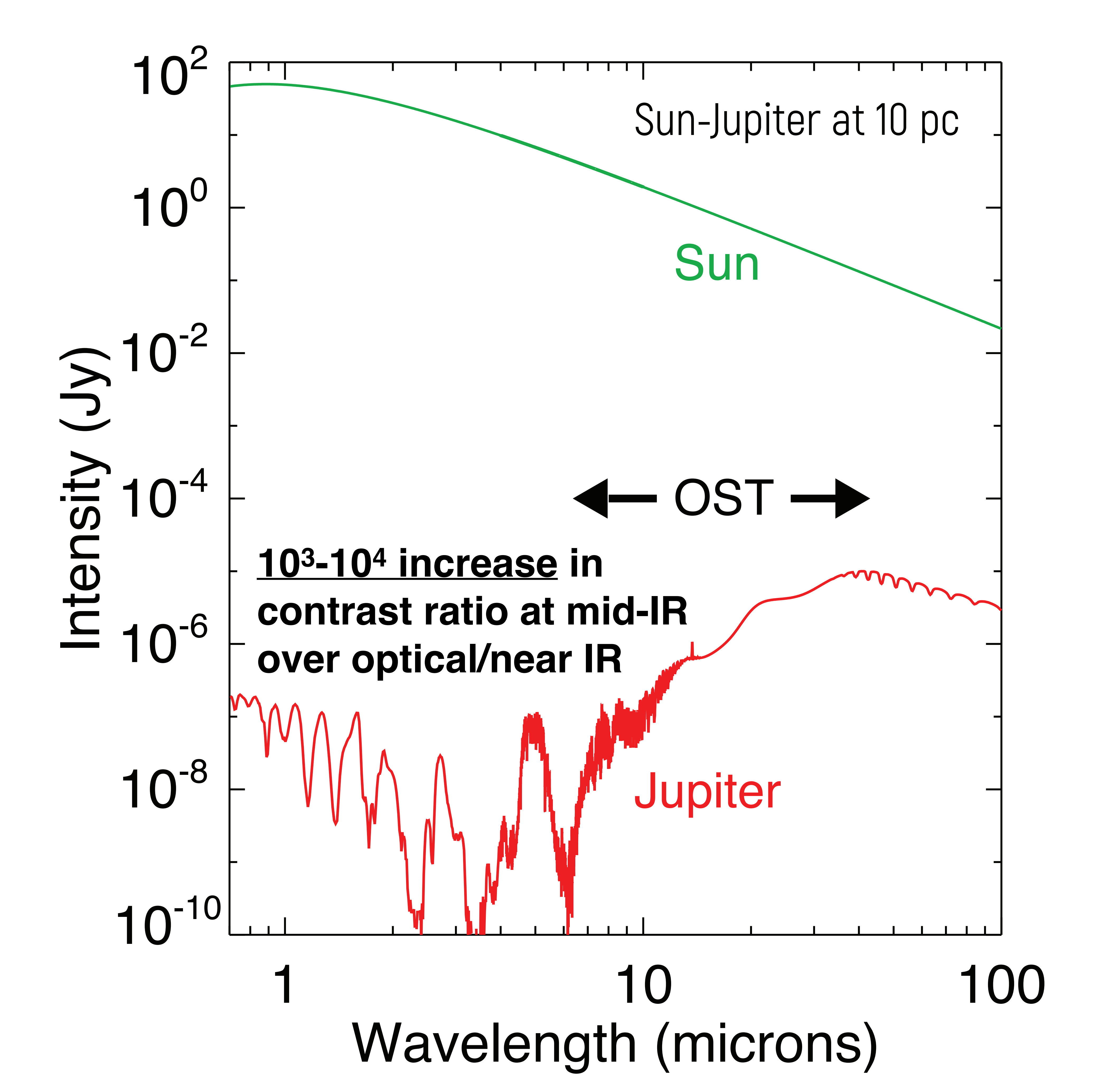
- Origins Space Telescope will venture beyond JWST and image gas collapsing to form first stars!
  - Primordial cooling via H2 rotational lines
  - Seeds of super massive black holes

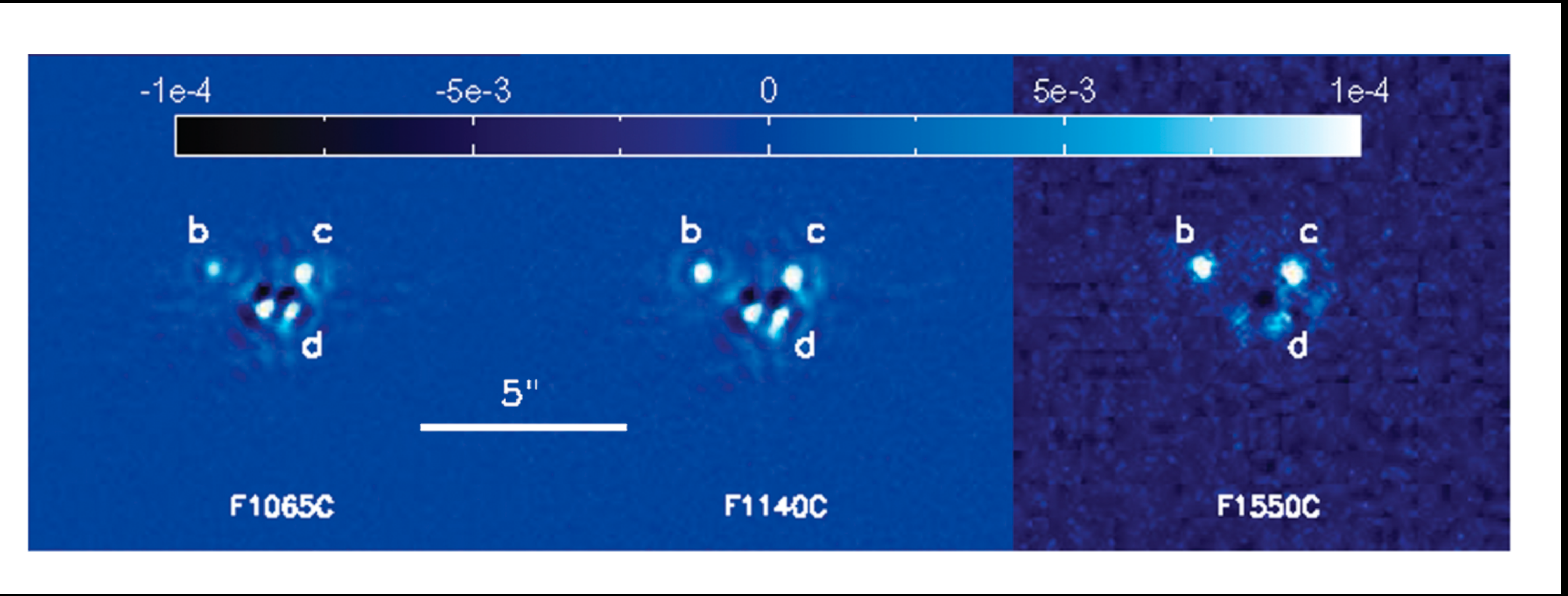
To detect primordial H_2 line cooling at formation sites of first stars and galaxies at z ~10-15 *Origins Space Telescope* sensitivity will need to be down to 10^{-23} Wm^{-2} in a deep field integration in rotational lines (rest-frame 12.3,17, 28 μm)

ORIGINS Space Telescope

Tracing the rise of dust & metals in galaxies and the path of water across cosmic time to Earth and other habitable planets.

Weather and climate on exoplanets: Super Earths to Jupiters



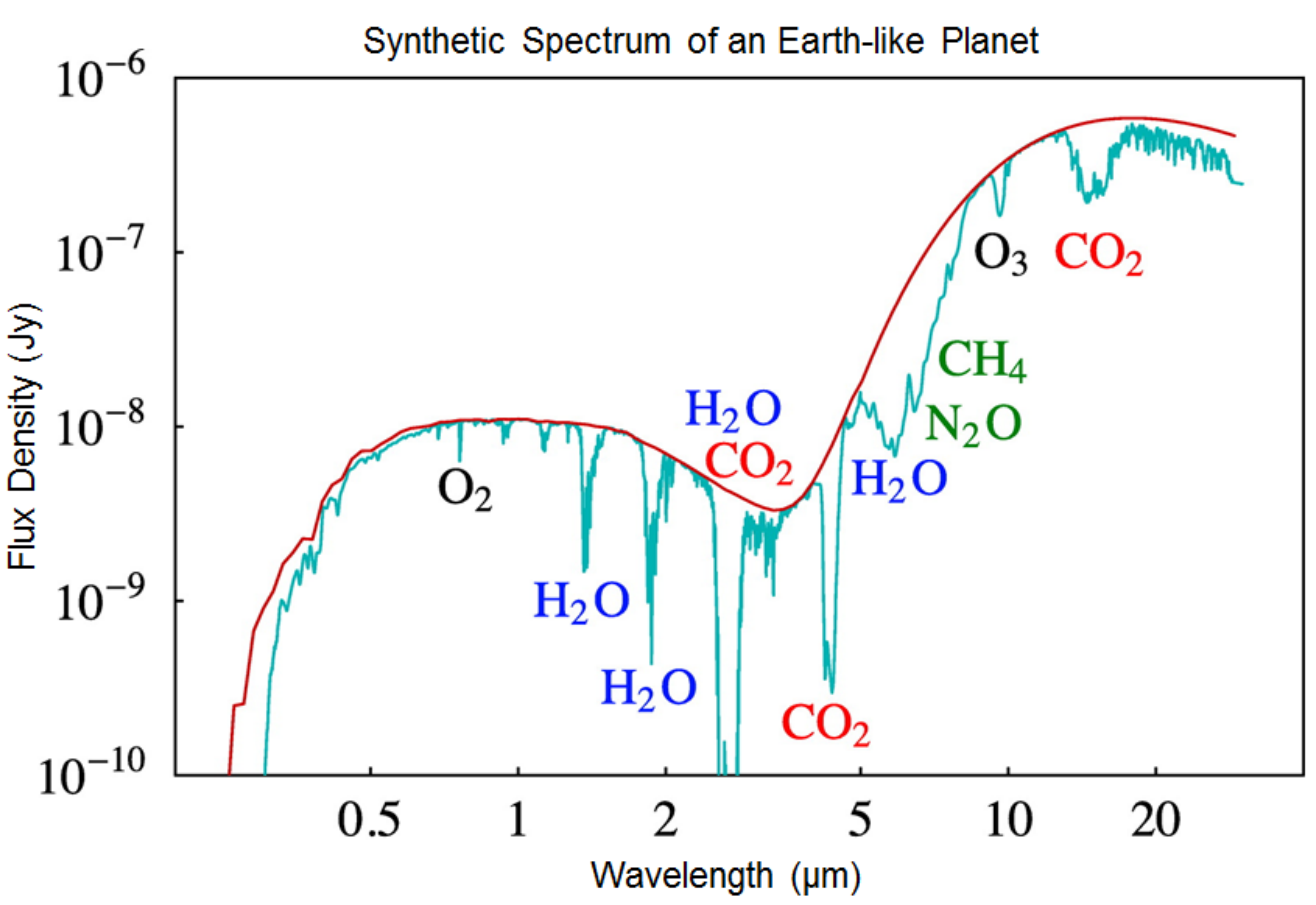


Simulated MIRI coronagraphy of HR 8799

Transit/secondary eclipse spectroscopy (Earths/super-Earths around MK-dwarfs)

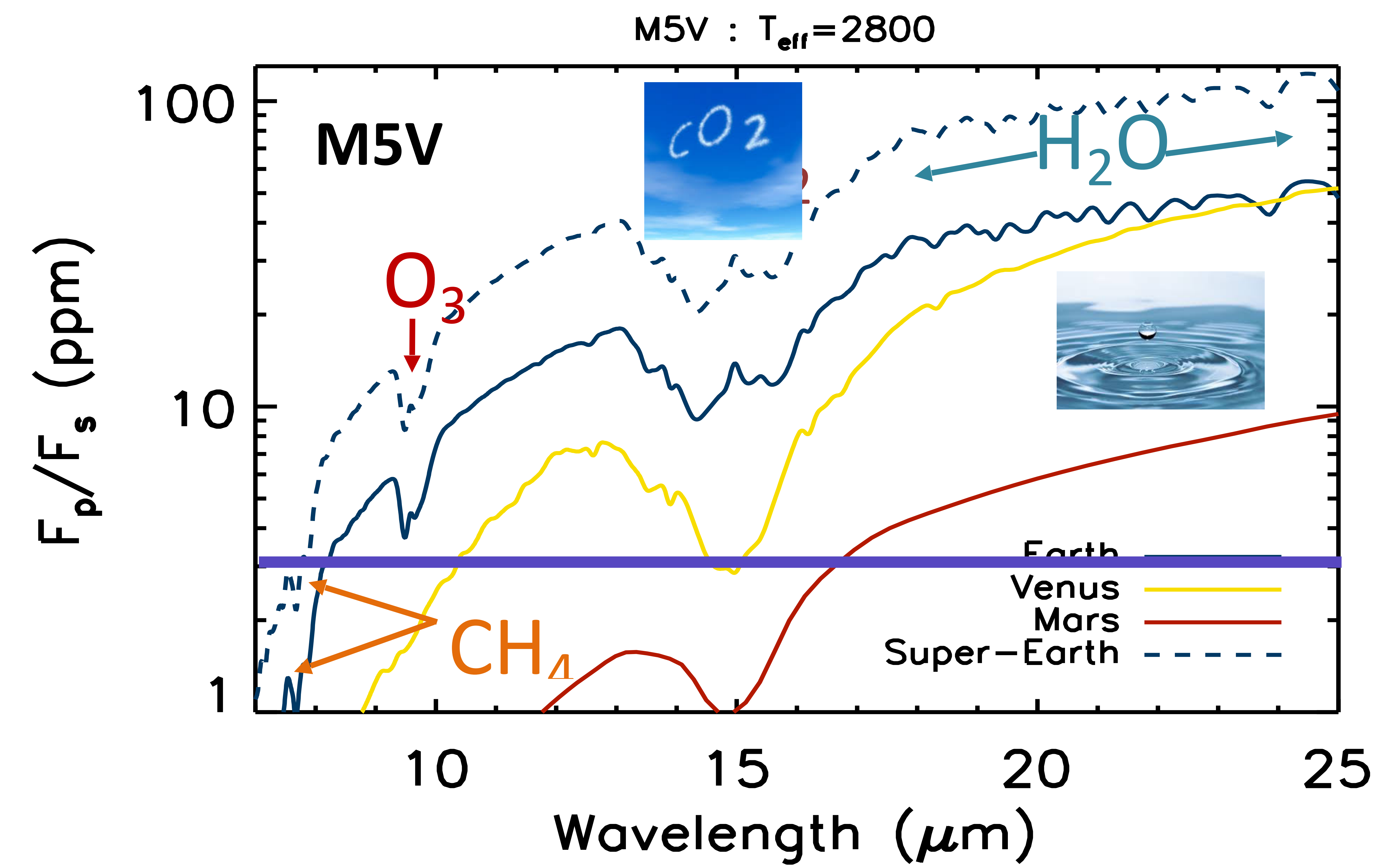
Direct imaging via a mid-IR coronagraph (Jupiters/Saturns/Neptunes)

Weather and climate on exoplanets: Super Earths to Jupiters



Rauer et al. 2011 Potential Bio-Signatures in Super-Earth Atmospheres, A&A

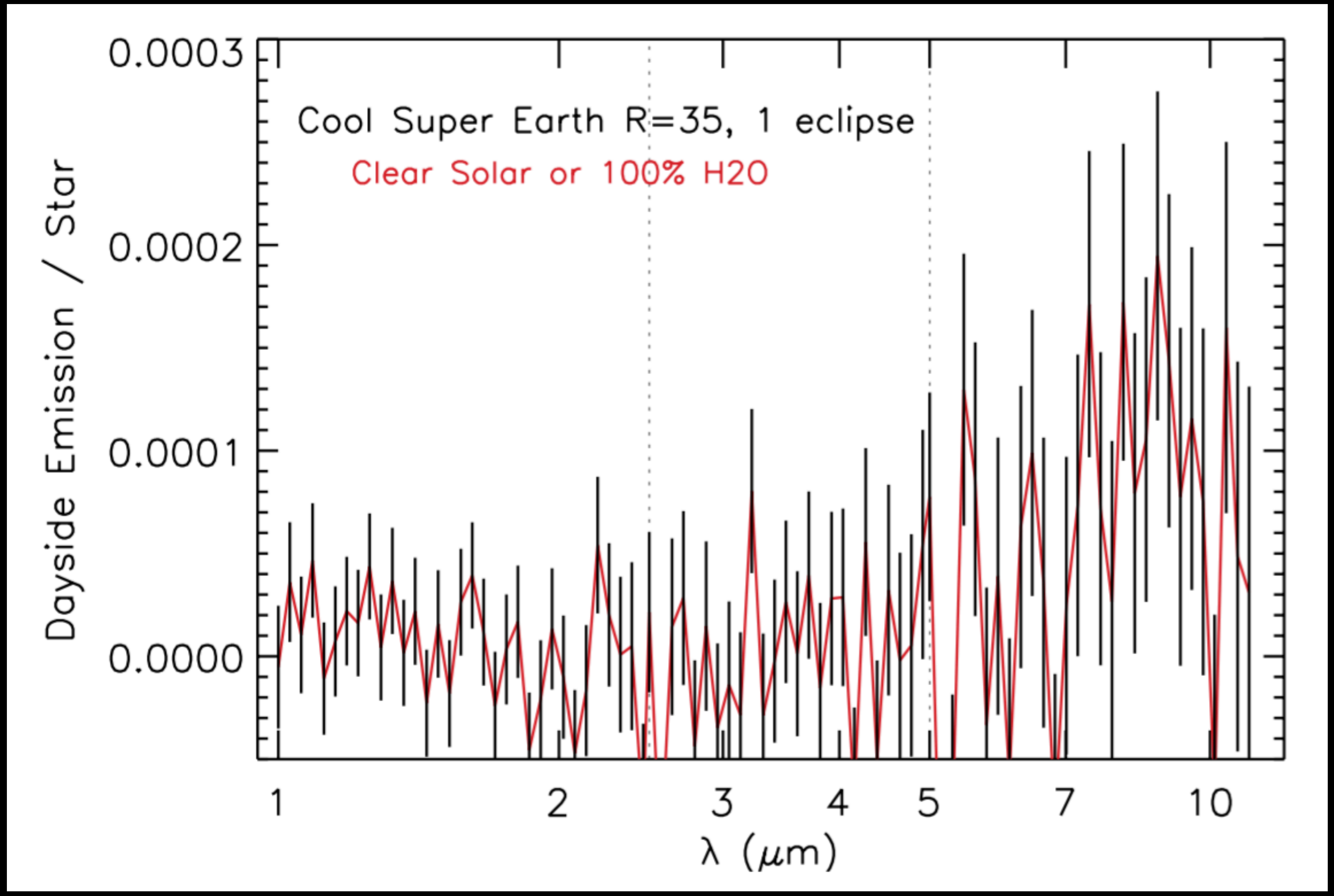
Signal Size for Habitable Zone for M Dwarf Planets



To detect biosignatures:

- Spectral resolving power (λ/Δλ) of 30-50
- Noise floors < 10 ppm
  - (M3V@20 pc – 2 hr at 7 μm)
- Key spectral signatures of Super-Earths that Origins will detect:
  - 9 μm for ozone (biosignature)
  - 7 μm for methane (life detection)

Origins Space Telescope will have mid-IR capability down to 6 μm; noise floor will be due to mid-IR detector stability.



At 50ppm JWST cannot study habitable zone worlds (Greene et al. 2016)

ORIGINS Space Telescope

Tracing the rise of dust & metals in galaxies and the path of water across cosmic time to Earth and other habitable planets.

NASA

Mission Study Design Implementation

- Led at GSFC, coordinated through STDT via the Mission Development Working Group (led by Tom Roellig).
- We have formed five instrument teams (ITs), two foreign contributions (Europe through CNES and Japan/JAXA)
- Formal industry partnership through a Cooperative Agreement Notice (CAN) with **Ball Aerospace as the lead, Northrop Grumman, Harris, and Lockheed Martin** as contributorsor. Industry is studying items put forward by the STDT and Study Center (thermal, deployment, Sun shield/Solar panels).

Ball HARRIS NORTHROP GRUMMAN LOCKHEED MARTIN

ORIGINS Space Telescope

Tracing the rise of dust & metals in galaxies and the path of water across cosmic time to Earth and other habitable planets.

Origins Space Telescope Study Plan

- June 2017 f2f meeting STDT agreed to study/design three mission concepts
- **Concept 1 (science driven):** Off-axis 9m aperture with five instruments, SLS as the launch vehicle due to mass limits to L2 - not telescope size limits.
- **Concept 2 (science-per-dollar maximized):** smaller aperture size from the Concept A, based on a number of items, still TBD. Launchable in current 5m fairing sizes. STDT will discuss what these are at the September f2f.
- **Concept 3 (led at JPL; cost-max constrained)**: Maximum mission that can be designed for a total cost of $3B, keeping mid-IR and far-IR *(request from STDT to JPL to carry out this study at the June f2f).*

(Study Center has proposed to merge Concept 2 and Concept 3 in a joint GSFC/JPL study; TBD at September f2f)

ORIGINS Space Telescope

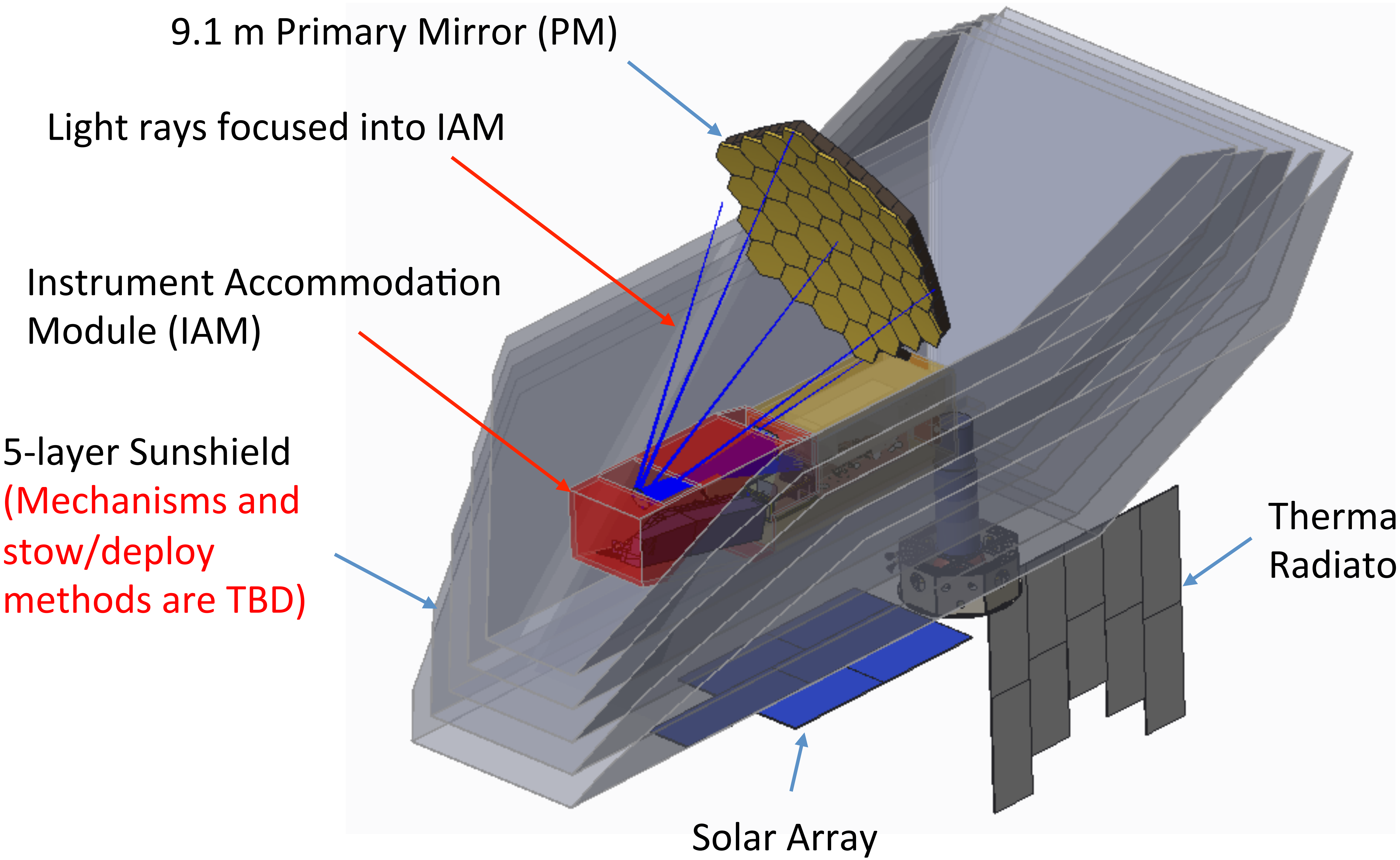
OST Concept 1

Top-Level Mission Parameters

- Mission Duration: 5 years nominal with up to 10 years extended
- Mission Classification: Class A, fully redundant and cross strapped
- Launch Vehicle (LV): Vulcan Aces, Falcon Heavy or similar LV capability
- LV Fairing Size: 5-m Atlas V fairing or similar
- Optical Telescope Element (OTE) Temperature: 4 K *Actively cooled using cryocoolers*
- 9.1-m Aperture Primary Telescope Diameter
- Wavelength Coverage: 6 to 600 microns
- Number of instruments: five (5)
    - Medium Resolution Survey Spectrometer (MRRS) – JPL
    - Hi Res (Far-IR) Spectrometer (HRS) - GSFC
    - Heterodyne Instrument (HI) – Europe
    - FIR Imager/ Polarimeter (FIP) – GSFC
    - MID-IR Imager Spectrometer/ Coronagraph (MISC) – JAXA

OST Concept 1

Deployed Configuration



OST Concept 1 Instrument Specifications

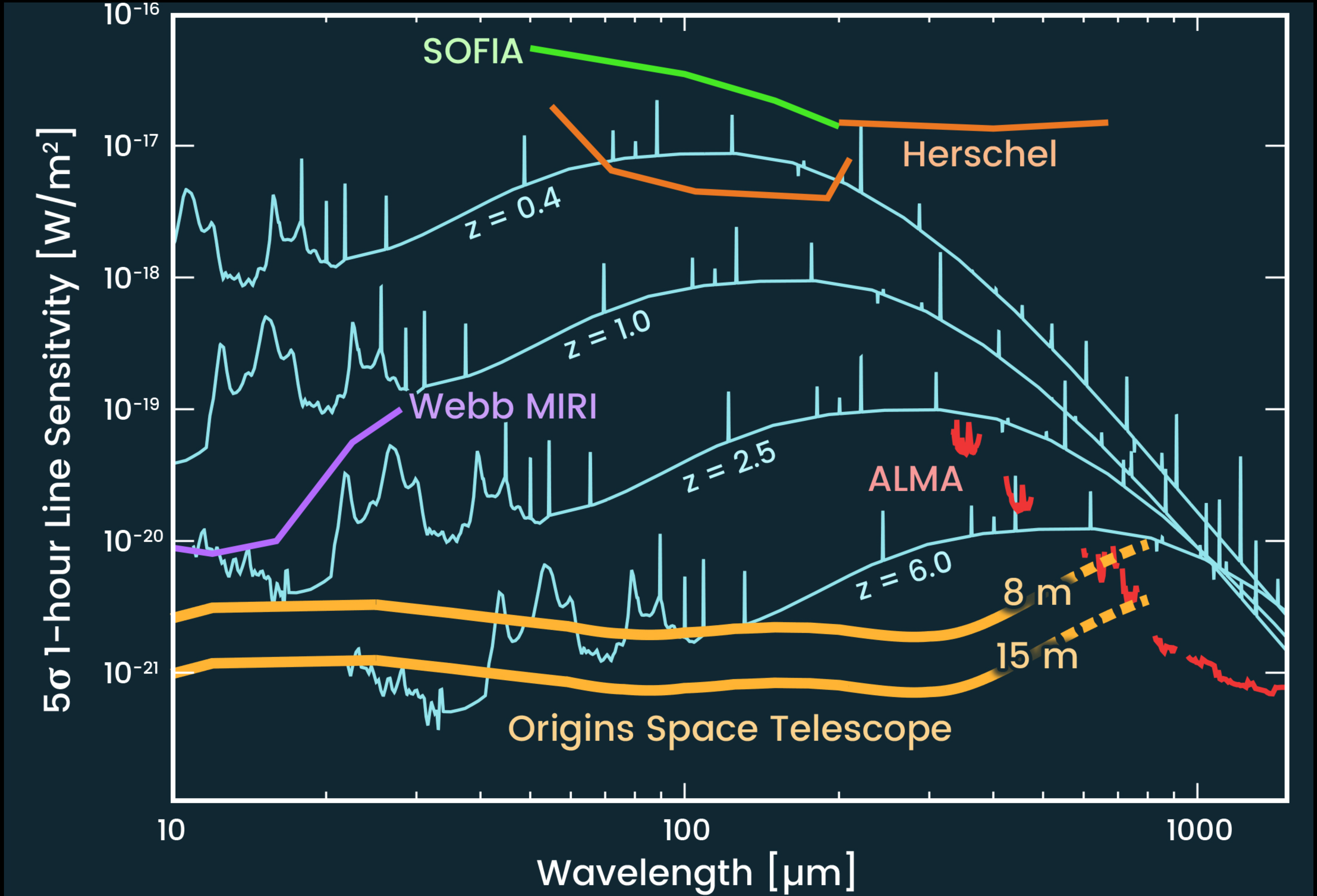
Instrument	Wavelength Coverage	Spectral Resolving Power (λ/Δλ)	Number of spatial pixels or sky beams	Typical Required Sensitivity:	Other	Lead institution
Mid-Infrared imager/ spectrograph/ coronagraph (MISC)	6 to 38 μm	imager: R~5-10; IFU: R>1500	3'x3' FoV; ~10^7	photometric: 1 μJy @10 μm	coronagraph 10^{-6}-10^{-7} IWA=1λ/D	JAXA/Japan
Far-Infrared Imager + Polarimeter (FIP)	35 to 240 μm (4 channels)	R~3.3	~500,000	1 μJy - 10 mJy (confusion limit)	polarimetry, spectral line filters	GSFC
MId-Res Survey Spectrometer (MRSS)	30 to 660 μm	low-res~500 high-res~10^4	100 per channel	10^{-21} W/m^2 (spectral line)	6 channels simultaneous	JPL
Heterodyne Receiver (HERO)	66 to 610 μm (7 discrete channels)	~10^7	1 - 15	2 mK in 0.2 km/s @ 1 THz	background limited	ESA/CNES
High-Res Spectrometer (HRS)	25 to 200 μm	low-res ~ 8x10^4 high-res~5x10^5	18"x3.6" grating FoV at 160 μm	10^{-21} W/m^2 5 σ (spectral line)	photo-counting	GSFC

ORIGINS Space Telescope

Tracing the rise of dust & metals in galaxies and the path of water across cosmic time to Earth and other habitable planets.

NASA

Two Orders of Magnitude!



Four Orders of Magnitude!

ORIGINS Space Telescope

Tracing the rise of dust & metals in galaxies and the path of water across cosmic time to Earth and other habitable planets.

What Origins Space Telescope will be

- A flagship general observatory - community driven sciences and instruments.
- Study gas cloud cooling at cosmic dark ages, to ozone and methane biosignatures of exoplanets, to pathway of water to habitable exoplanets and our Solar system.
- Provides a factor of 10,000 (!) improvement in sensitivity. An immense discovery potential.
- Origins Space Telescope will not be extending what we know already. It will be a true revolution in astronomy.

@NASAOriginsTelescope   origins.ipac.caltech.edu