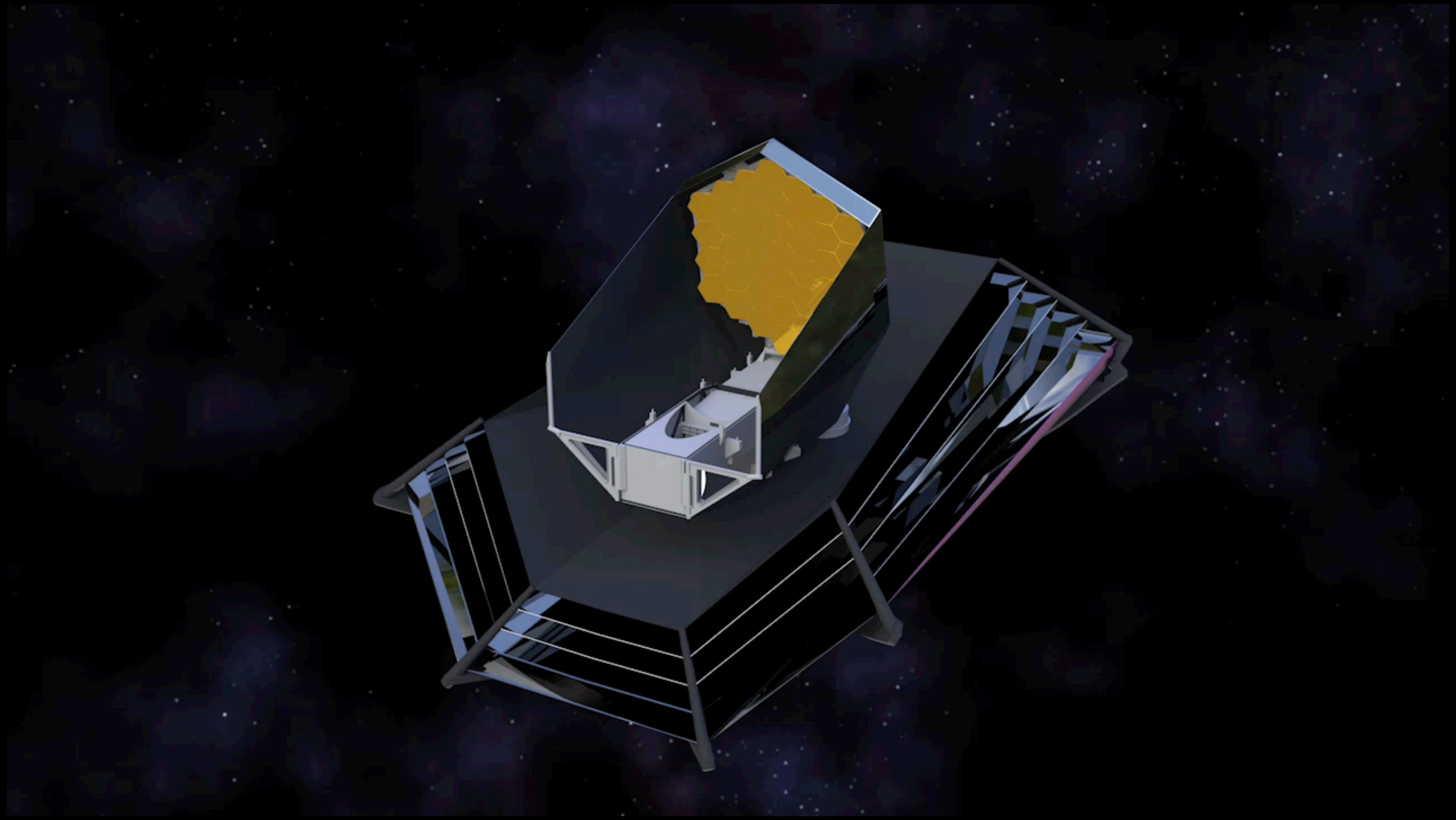
ORIGINS Space Telescope

A R Cooray for the OST STDT

@acooray



http://origins.ipac.caltech.edu

@NASAOriginsTele

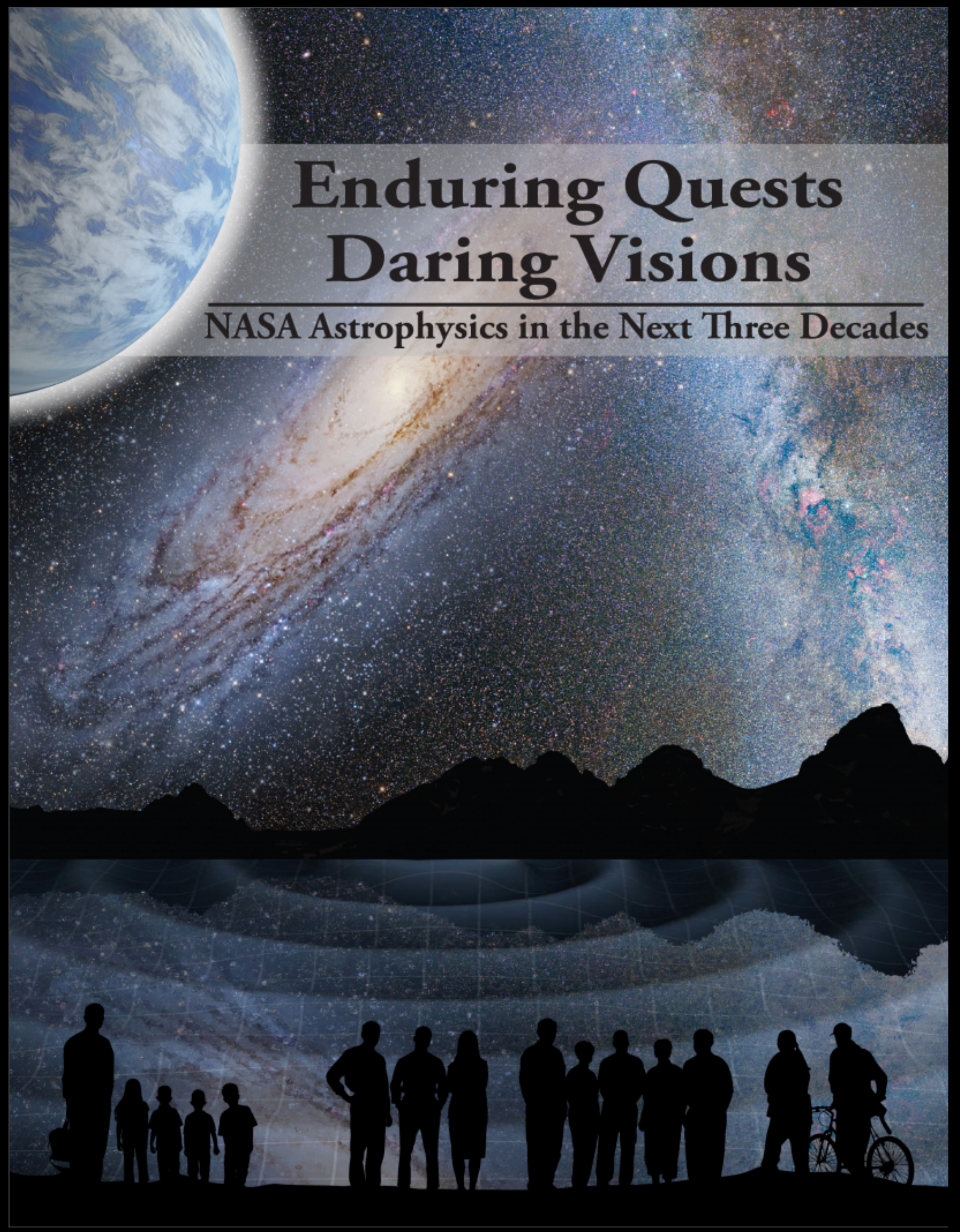
ORIGINS Space Telescope

From the first stars to life

NASA flagship class mission concept for the 2020 Decadal review.

Comes from the NASA Astrophysics Roadmap.

- <6 µm – 600 µm (diffraction limit around 20-40 µm)
- 4.5-5K actively-cooled 8-13m aperture operating at L2
- large gain in sensitivity => new spectroscopic capabilities
- exoplanet study capabilities via a mid-IR coronagraph
- modular instrument suite with robotic serviceability at L1
- Mission aimed at mid 2030s: post JWST, concurrent with WFIRST, Athena, LISA, and 25m-35m ground-based optical/IR facilities.
- Science goals and measurement requirements in 2030+



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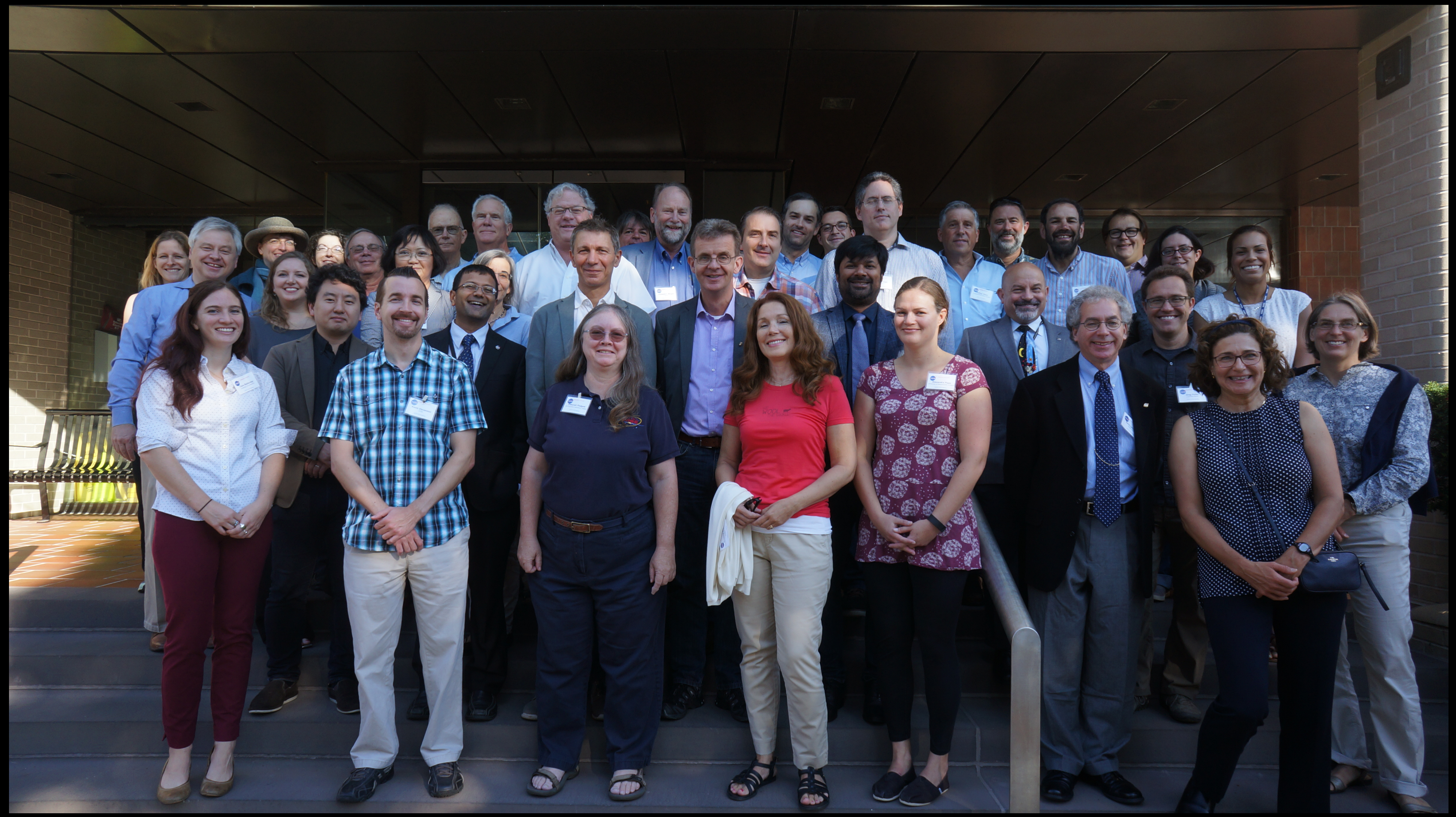

Study Team

- **Community Chairs: A. R. Cooray, UCI; M. Meixner, *STSCI/JHU***
- **Study Scientist:** D. Leisawitz, *GSFC*
- **Deputy Study Scientist:** J. Staguhn, *GSFC/JHU*
- **Study Manager:** R. Carter, *GSFC*
- **NASA HQ Program Scientists:** K. Sheth, D. Benford

- **NASA Appointed Members:** L. Armus, IPAC; C. Battersby, UConn; J. Bauer, UMD; E. Bergin, Michigan; M. Bradford JPL; K. Ennico-Smith, Ames; J. Fortney, UCSC; L. Kaltenegger, Cornell; G. Melnick, CfA; S. Milam, GSFC; D. Narayanan, UFlorida; D. Padgett, JPL; K. Pontopiddan, STSCI; A. Pope, UMass; T. Roellig, Ames; K. Sandstrom, UCSD; K. Stevenson, STScI; K. Y. L. Su, Arizona; J. Vieira, UIUC; E. Wright, UCLA; J. Zmuidzinas, Caltech
- **Ex-officio representatives:** S. Neff & E. Smith, NASA Cosmic Origins Program Office; S. Alato, SNSB; D. Burgarella, LAM, France; D. Scott, CAS; M. Gerin, CNES; I. Sakon, JAXA; F. Helmich, SRON; R. Vavrek, ESA; K. Menten, DLR; YS Song, KASI; S. Carey, IPAC
- **NASA Study Center (Goddard Space Flight Center) Team:** A. Flores (Mission Systems Engr), J. Kellogg (Instrument Systems Engr), M. DiPirro (Chief Technologist), L. Fantano (Thermal Systems Engr), A. Jones (Mechanical Systems Engr), J. Howard (Optical Systems Engr), J. Corsetti (Optical Engr), E. Canavan (Cryo Engr), J. Staguhn (Instrument Scientist)
- **Study Advisory Board:** J. Arenberg,Northrup Grumman; J. Carlstrom, Chicago, H. Ferguson, STScI, T. Greene, Ames; G. Helou, IPAC; C. Lawrence, JPL; S. Lipscy, Ball; J. Mather, GSFC; H. Moseley, GSFC; G. Rieke, Arizona; M. Rieke, Arizona; J. Turner, UCLA; M. Urry, Yale.

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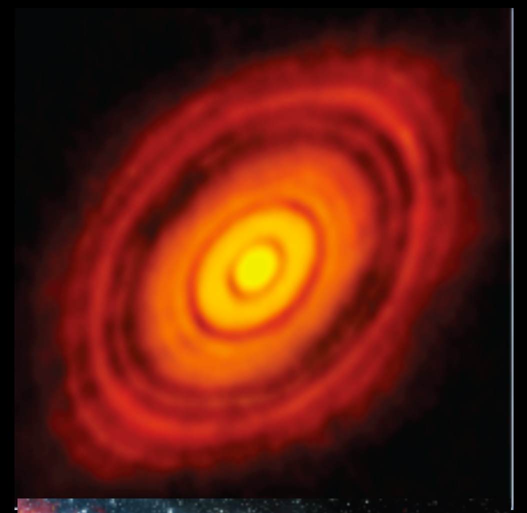
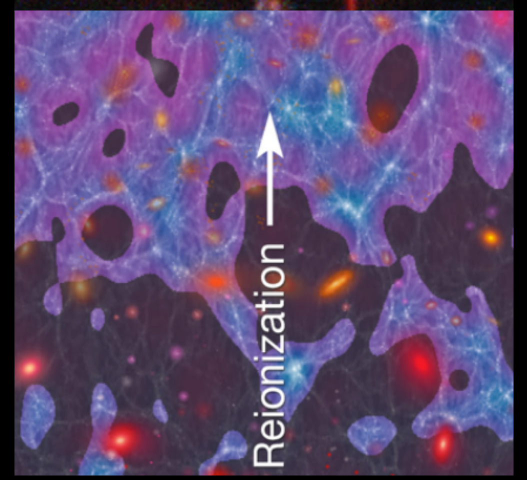
Science Working Groups





- **Solar System**: Stefanie Milam, James Bauer
- **Planet Formation**: Klaus Pontoppidan and Kate Su
- **Exoplanets:** Kevin Stevenson, Jonathan Fortney
- **Milky Way 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

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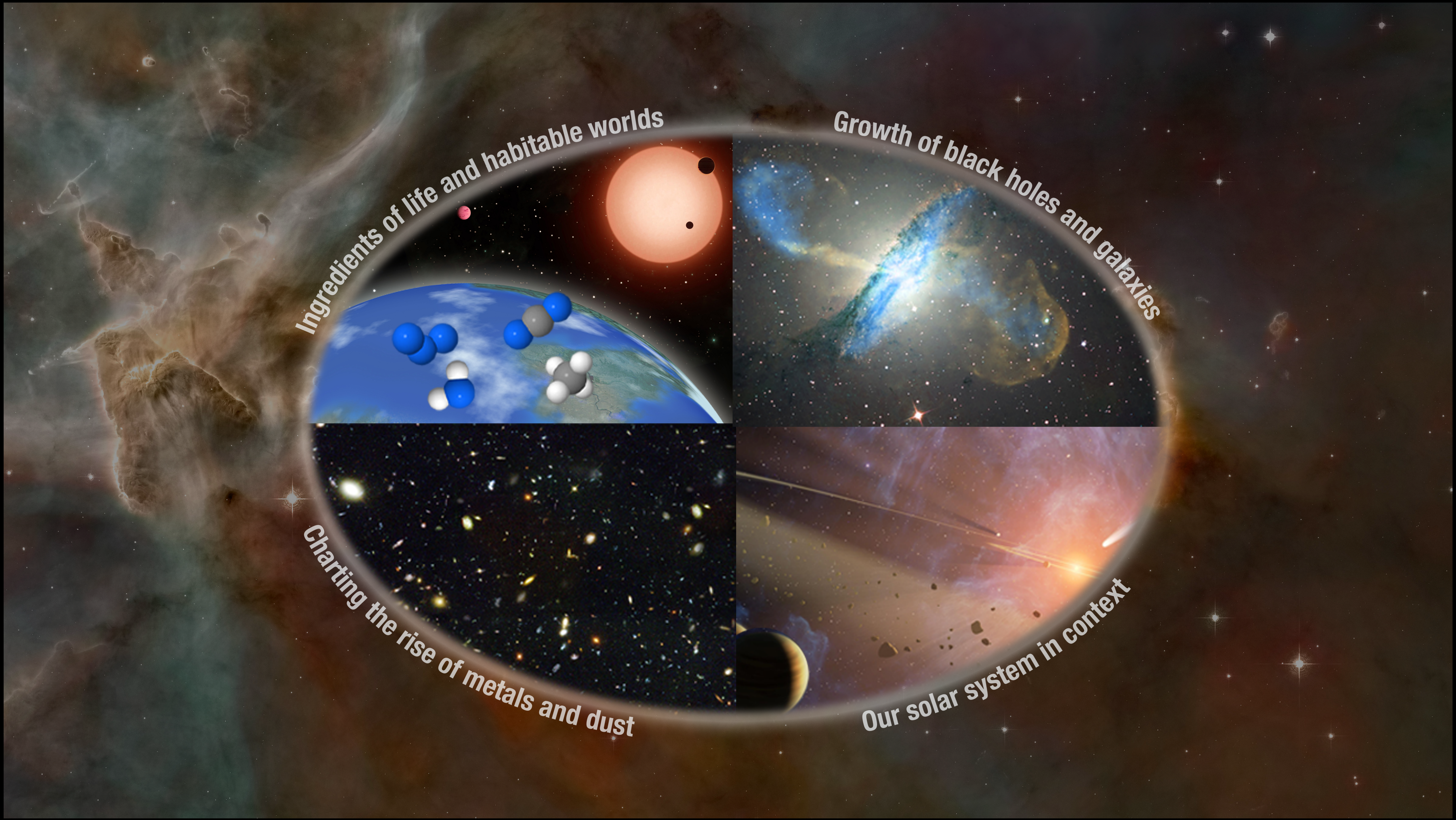

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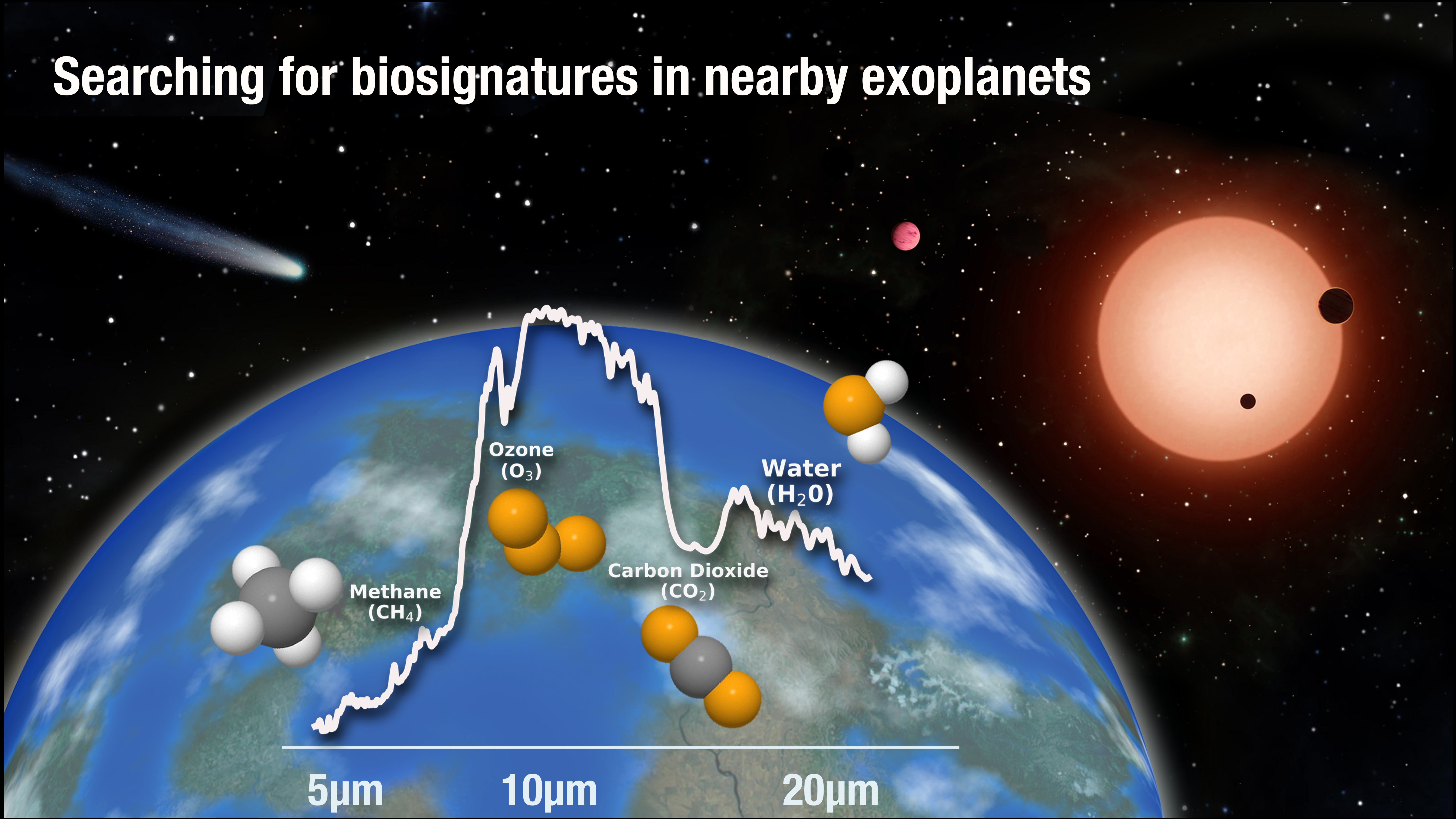

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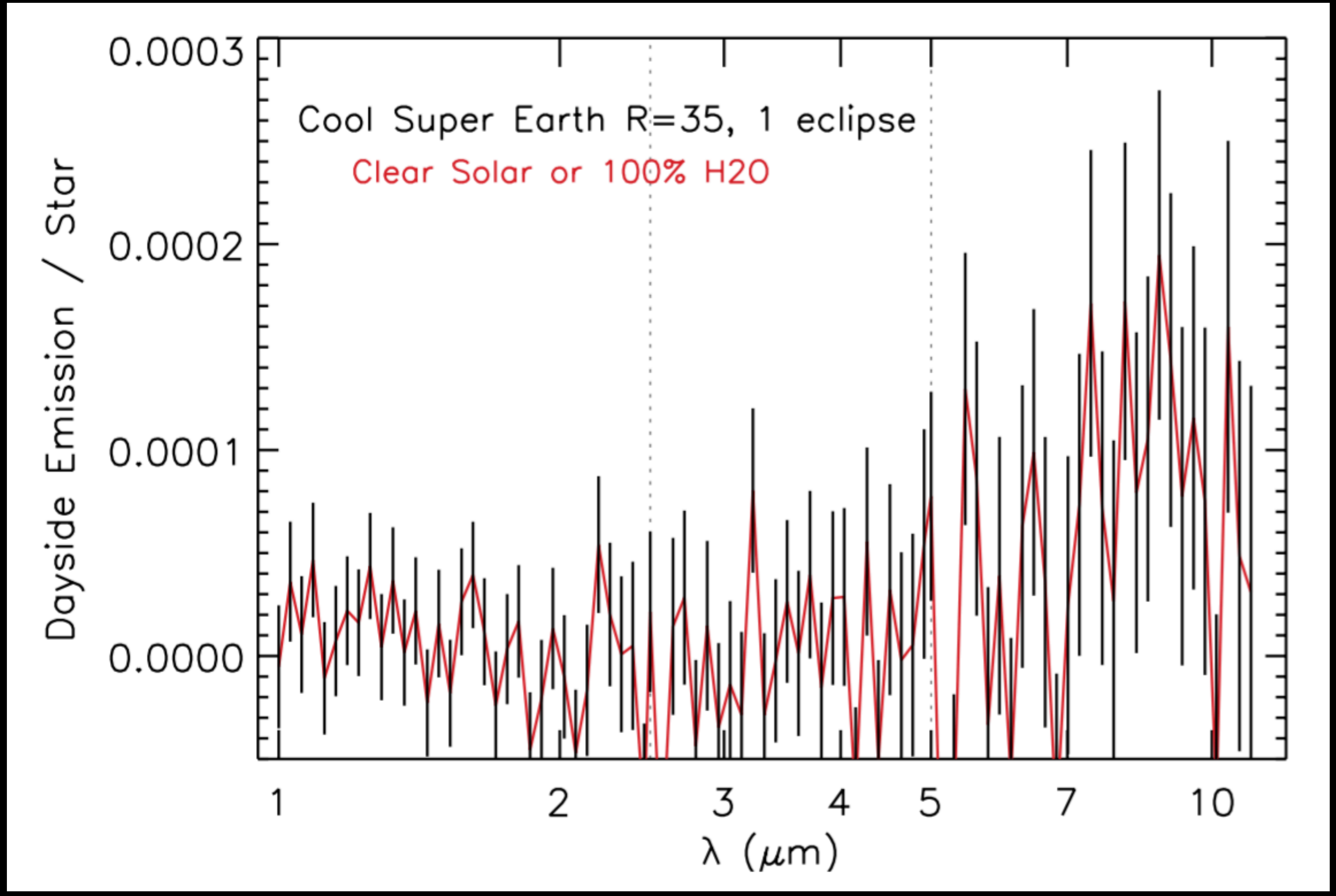
To detect biosignatures:

- 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 30ppm-50ppm JWST cannot study habitable zone worlds (Greene et al. 2016)

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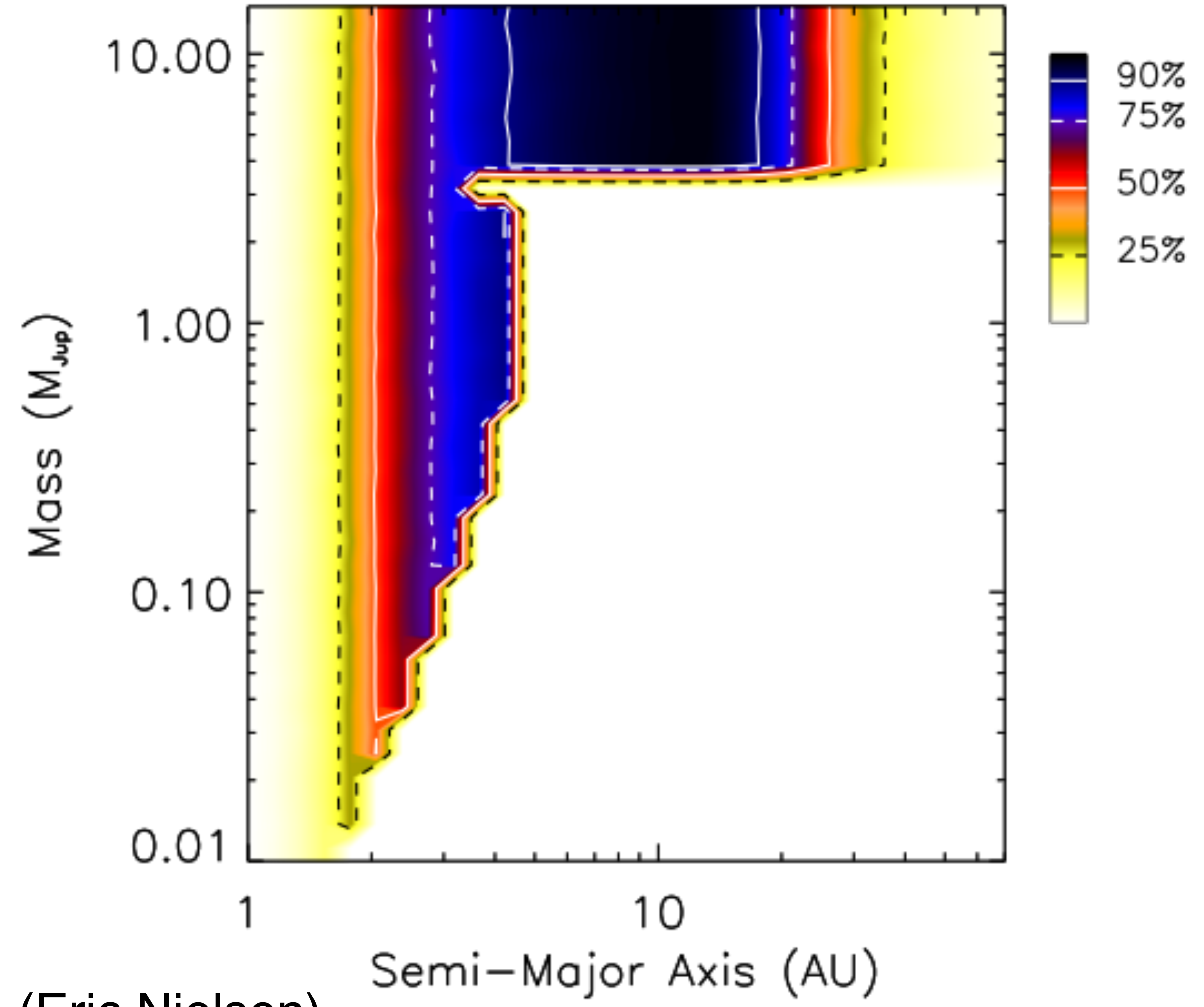
Directly image warm Neptunes and Jupiters around the nearest Sun-like Stars



(Eric Nielsen)

- Coronagraph will enable direct imaging of Jupiters at 5 – 14 AU and warm Neptunes into 2 AU

Kepler finds planets smaller than Neptune are ubiquitous close to their parent stars.

Near the habitable zone of the closest stars, the thermal emission of these planets can be bright enough to be seen behind the glare of their parent stars.

OST spectroscopy will allow us to directly probe the atmosphere and composition of these “Neptunes".

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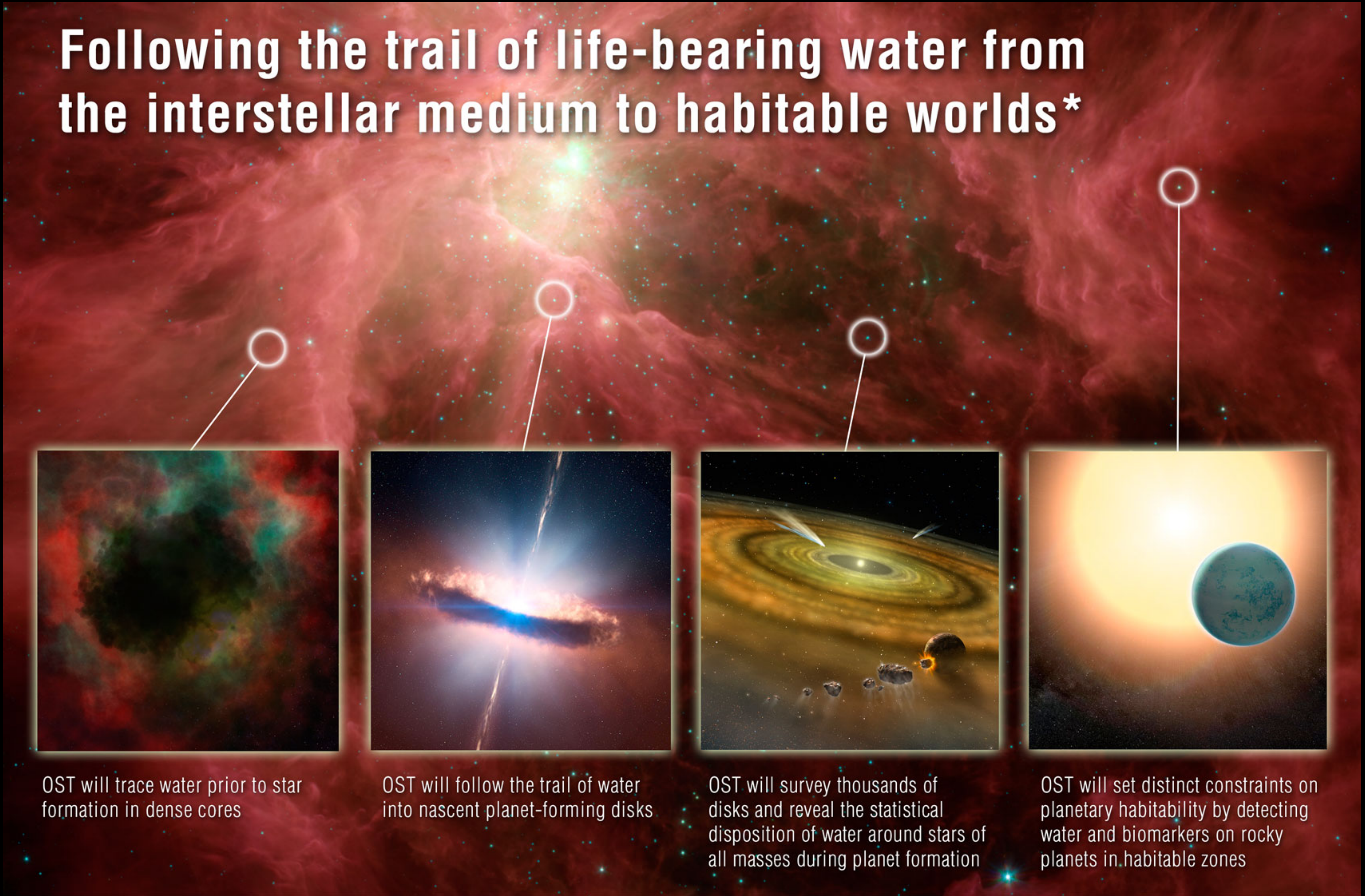

Probing the total gas content during the time of planet formation

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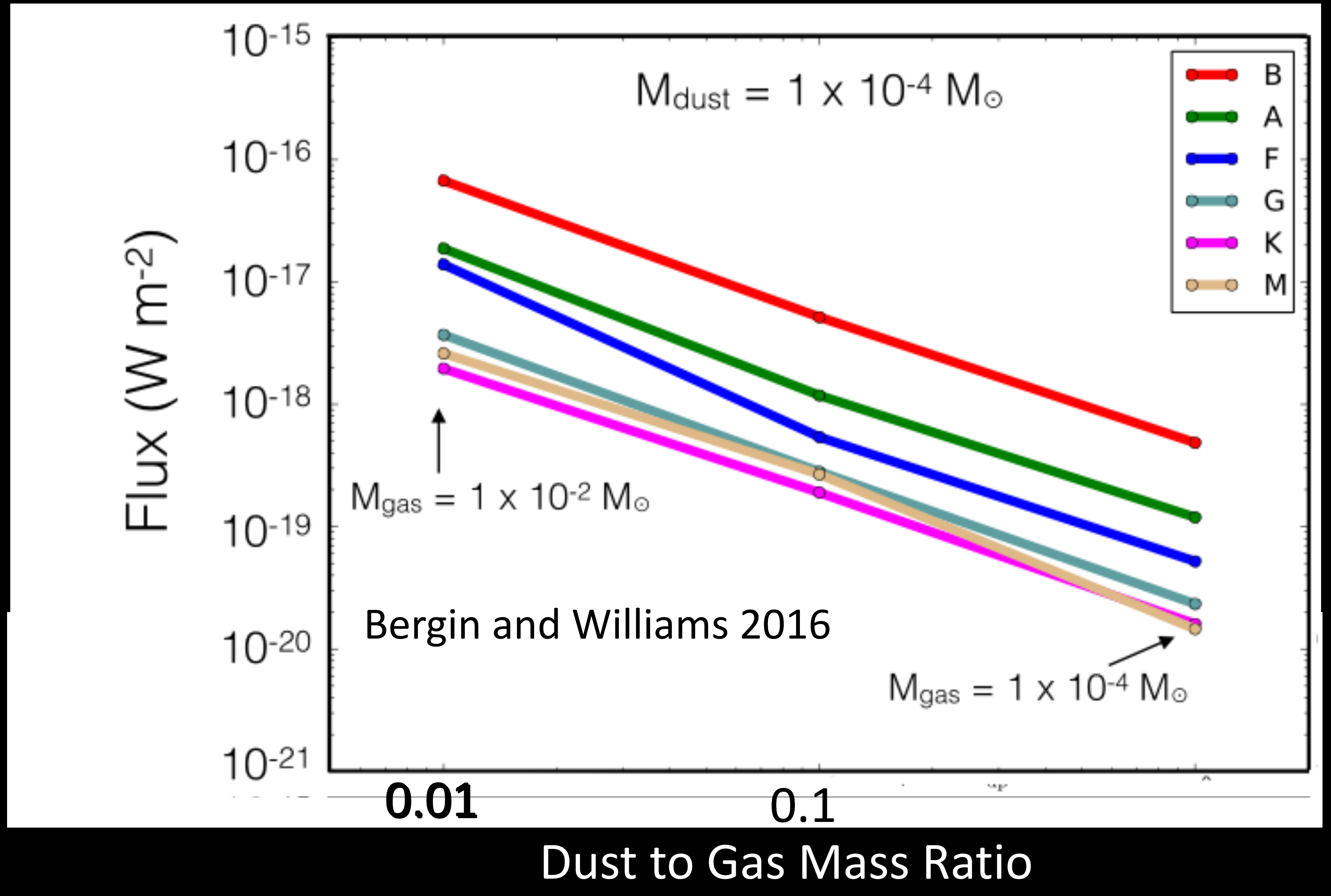
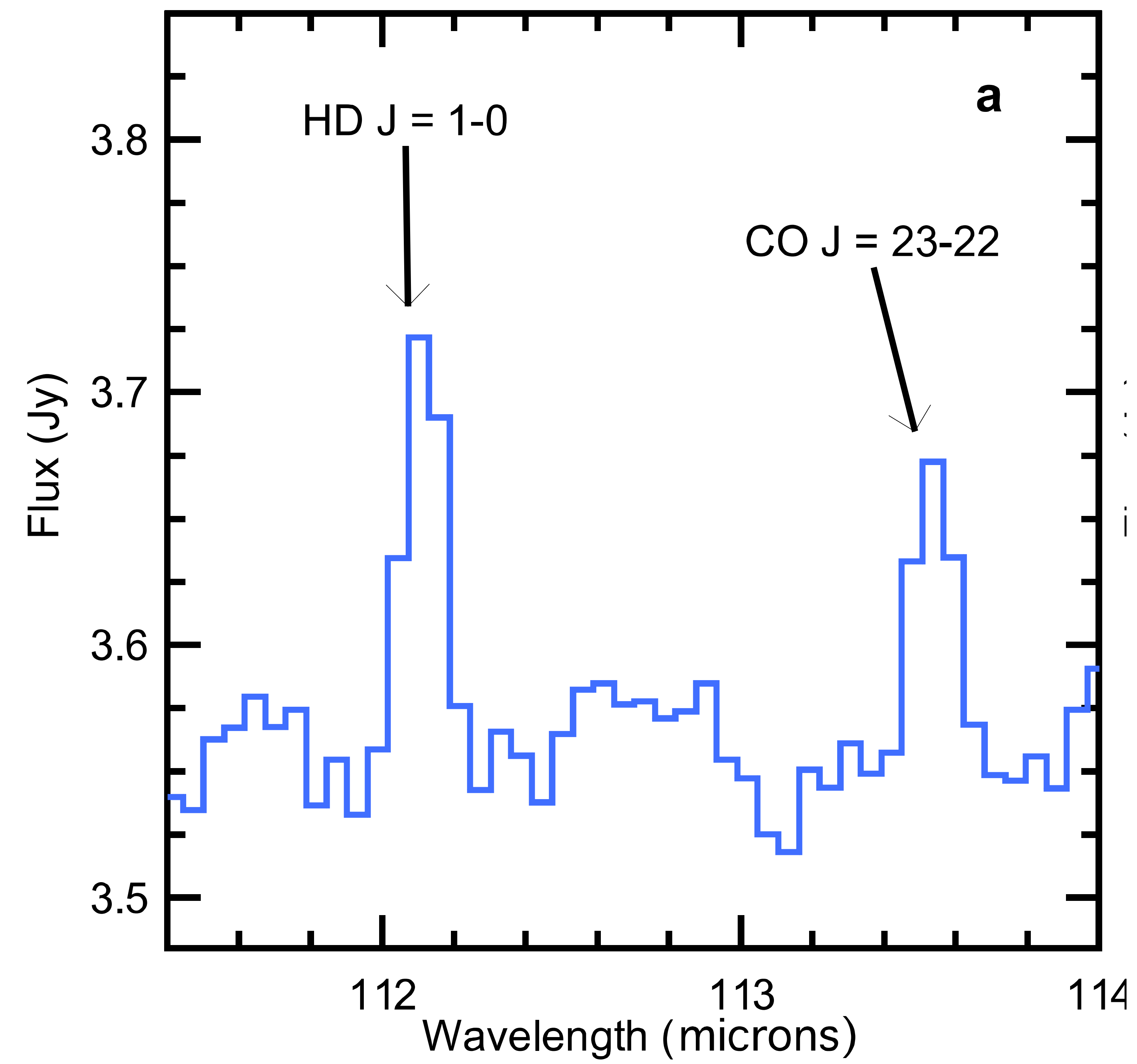
What are the timescales of gas/ice giant and super-Earth formation? What is the total gas content to unlock the ability to follow the implantation of C, H, O, N into pre-planetary materials?. **Use HD to measure the gas mass in disks down to cool stars with a gas/dust mass ratio of unity.**





Herschel Detection of HD J = 1-0 towards TW Hya providing the first (semi)direct contraints on the gas mass (Bergin et al. 2013)

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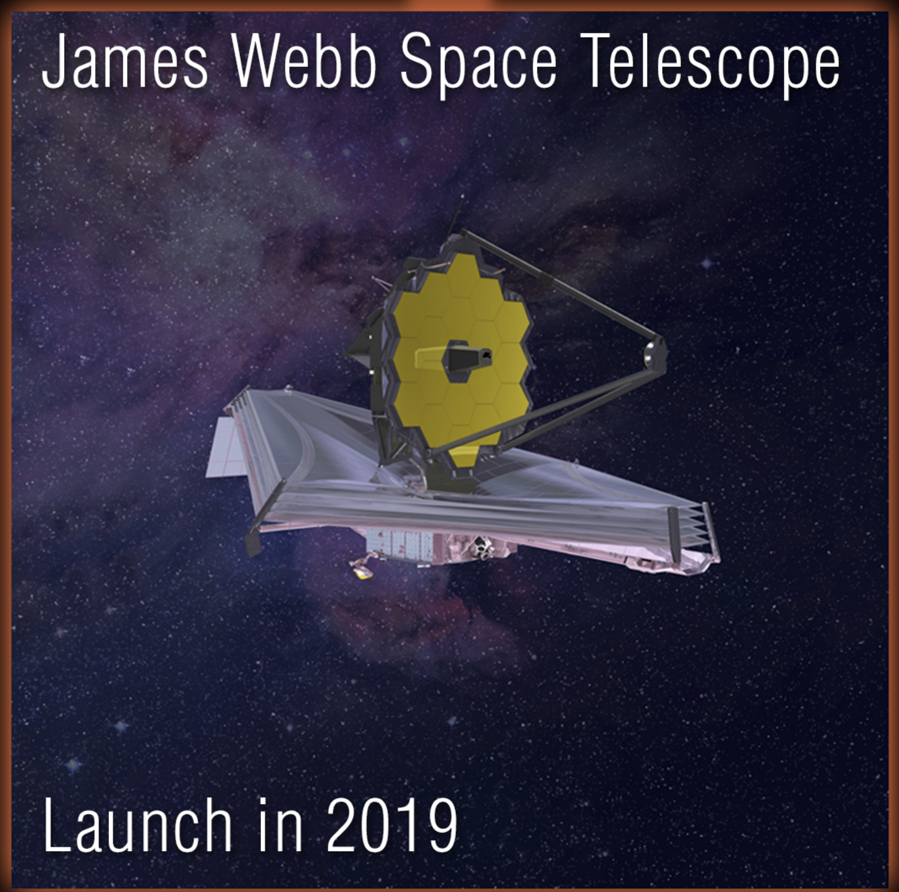
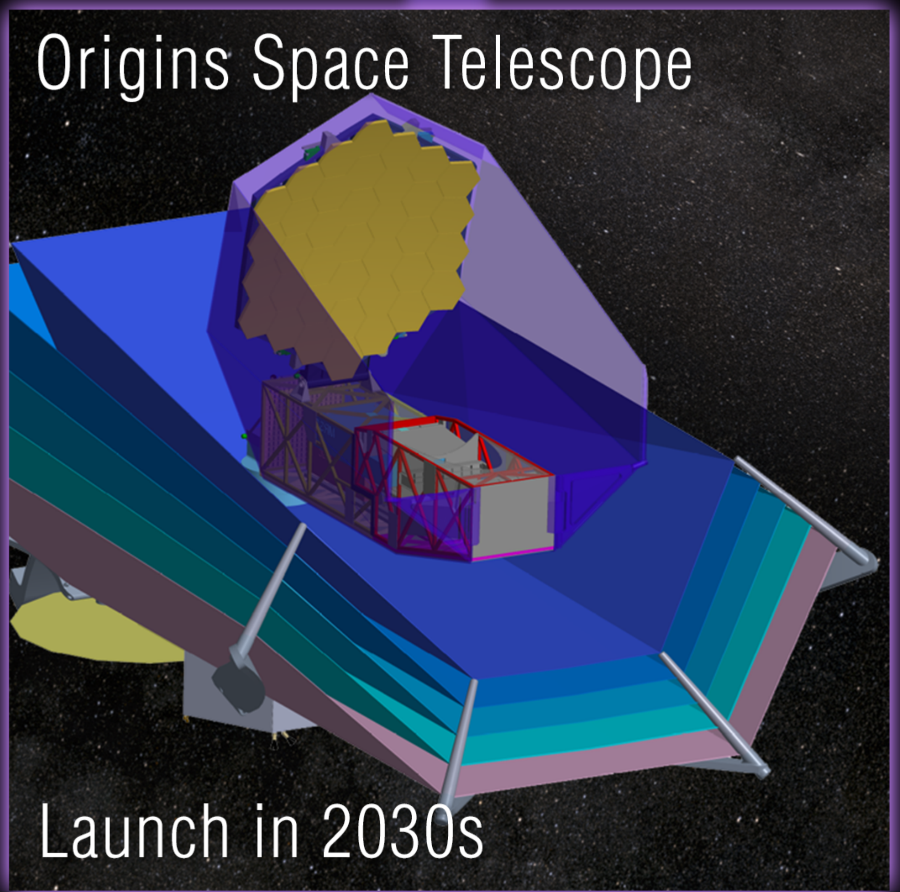
REDSHIFT	1	6	8	12	16	1100
BILLIONS of YEARS AGO		12.6	13.1	13.4	13.5	13.8





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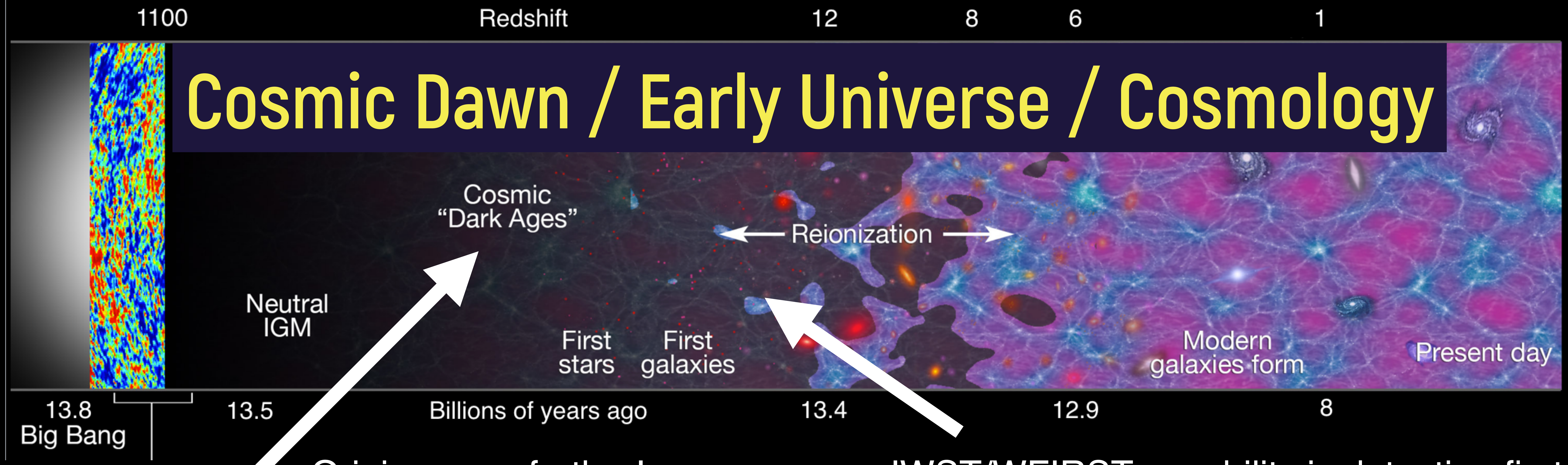
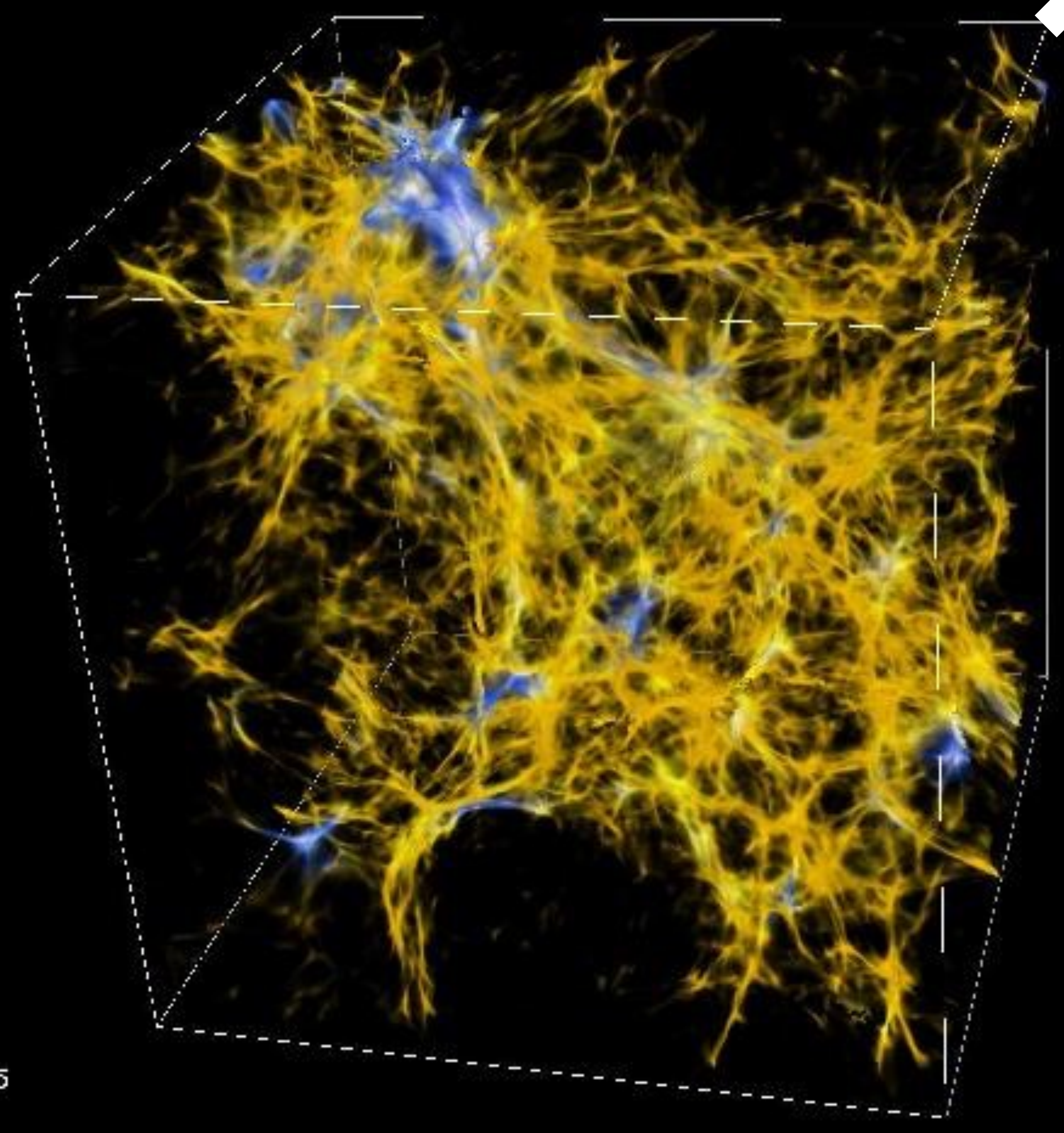


Origins goes further!

JWST/WFIRST capability is detecting first stellar emission



z = 12.5

- 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)

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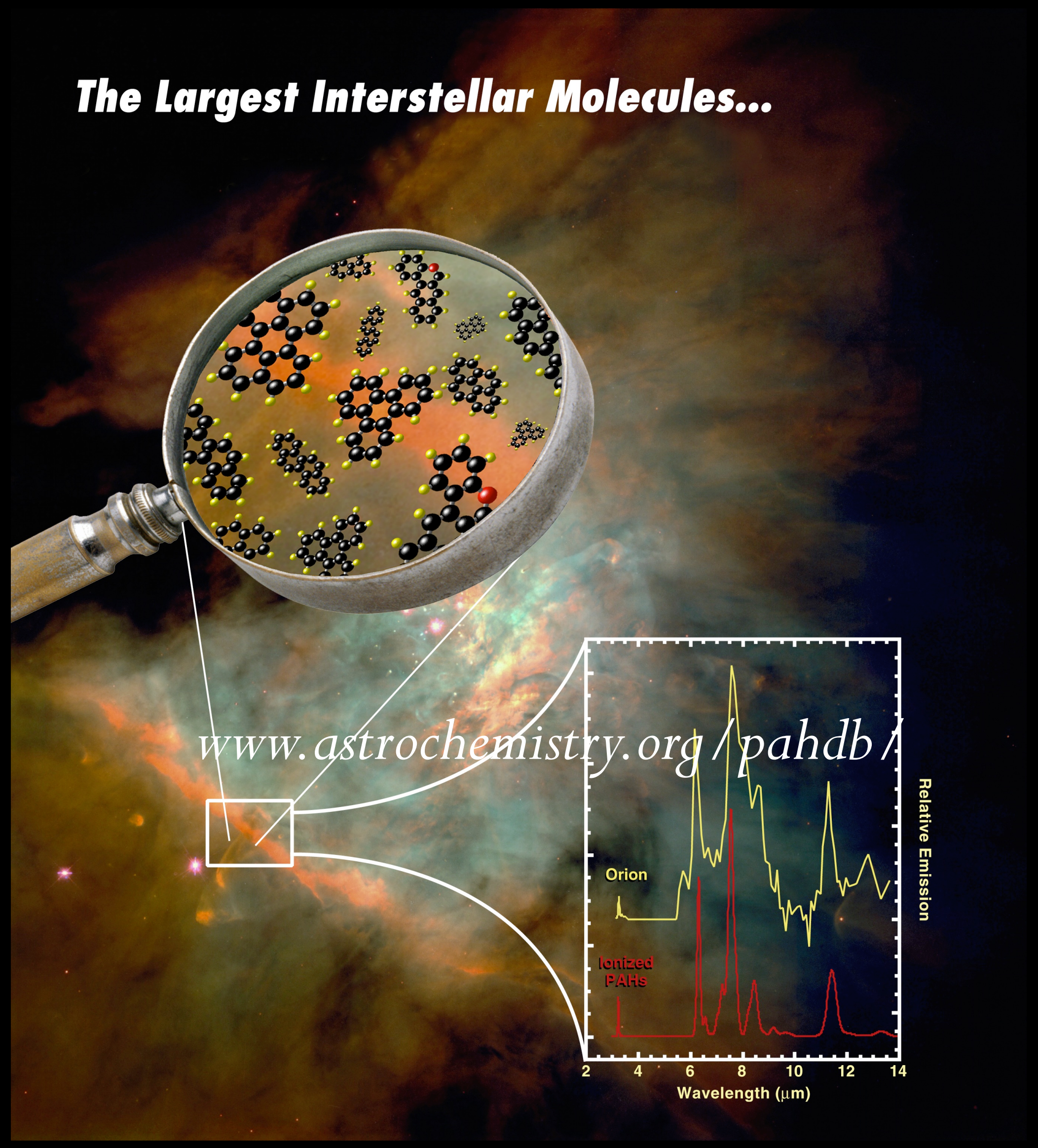
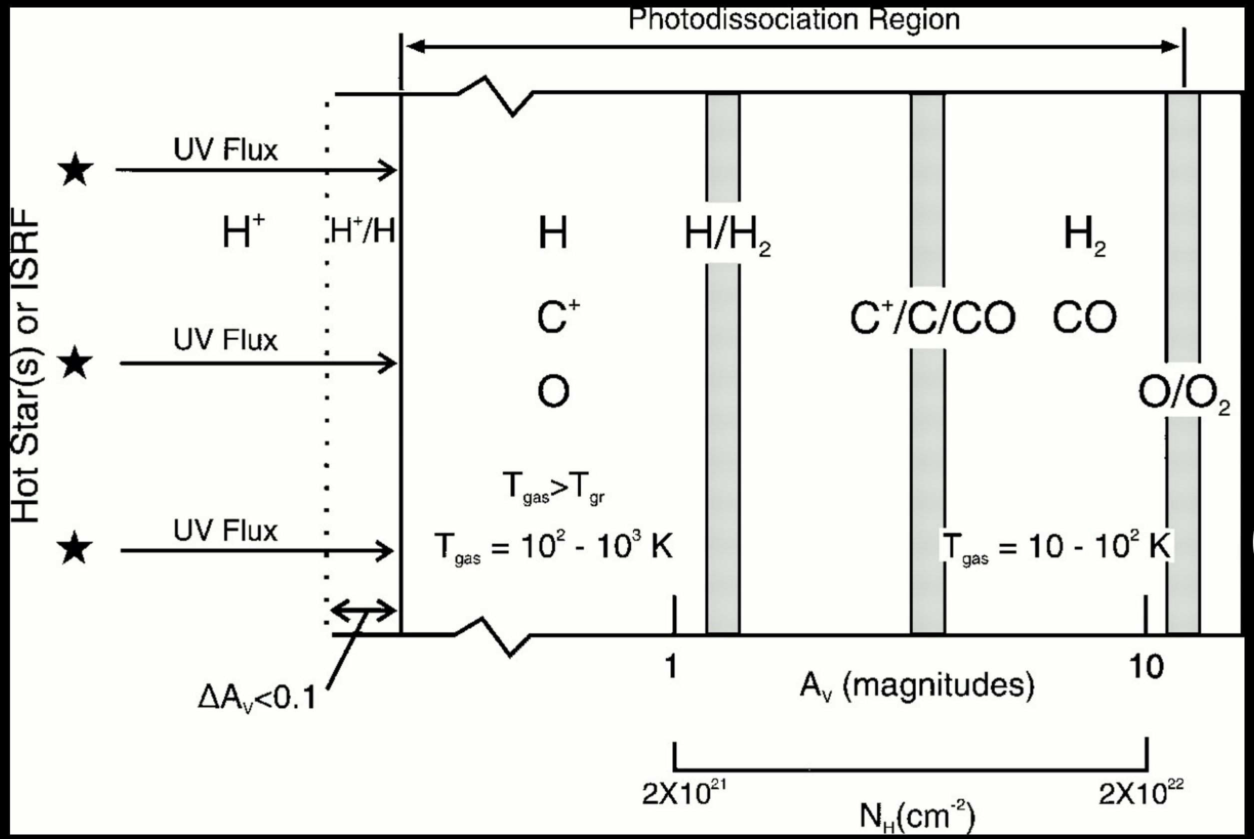
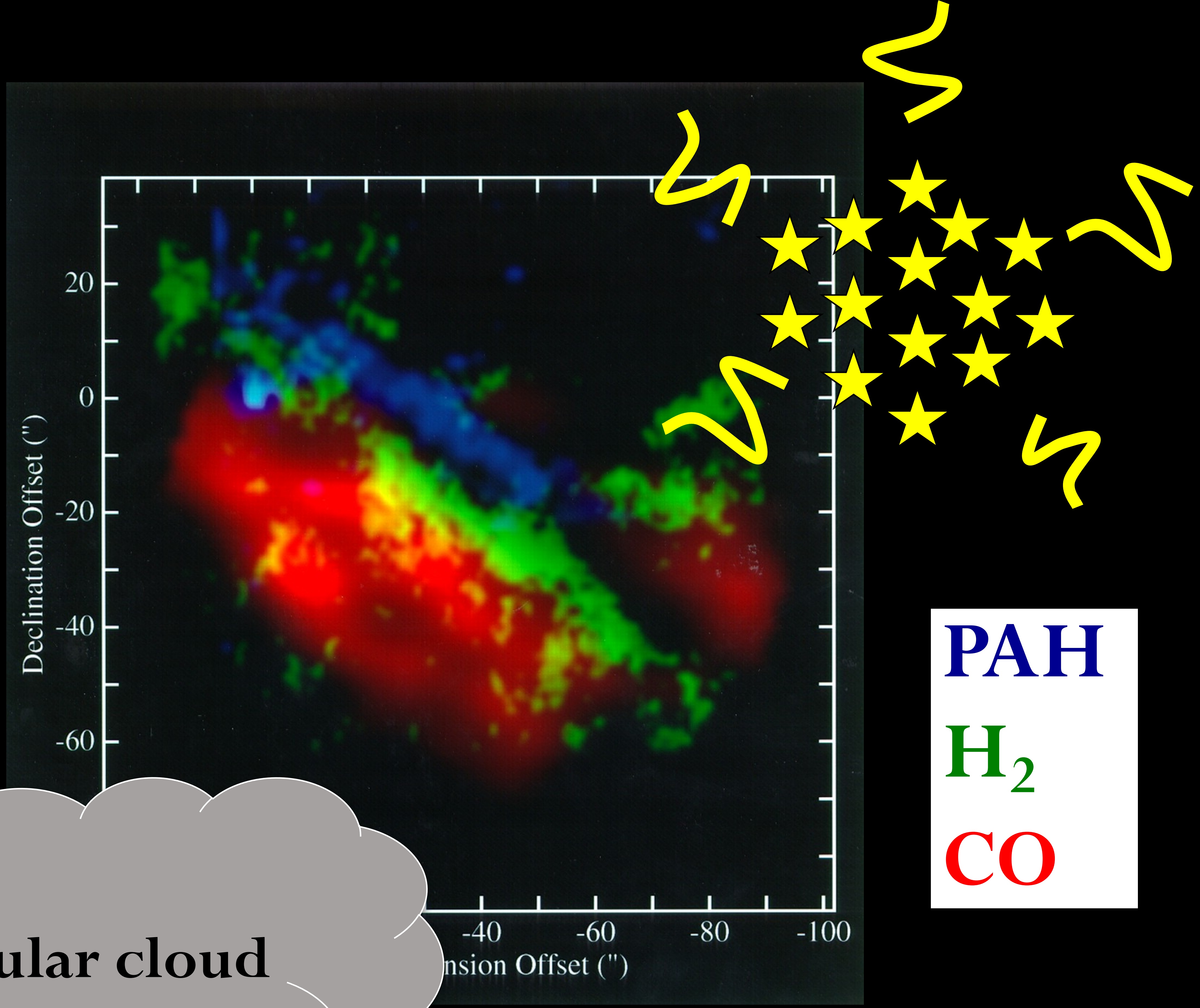
How do we probe the interstellar medium in high redshift galaxies?







Molecular cloud

PAH
H_2
CO

Hollenbach & Tielens 1997

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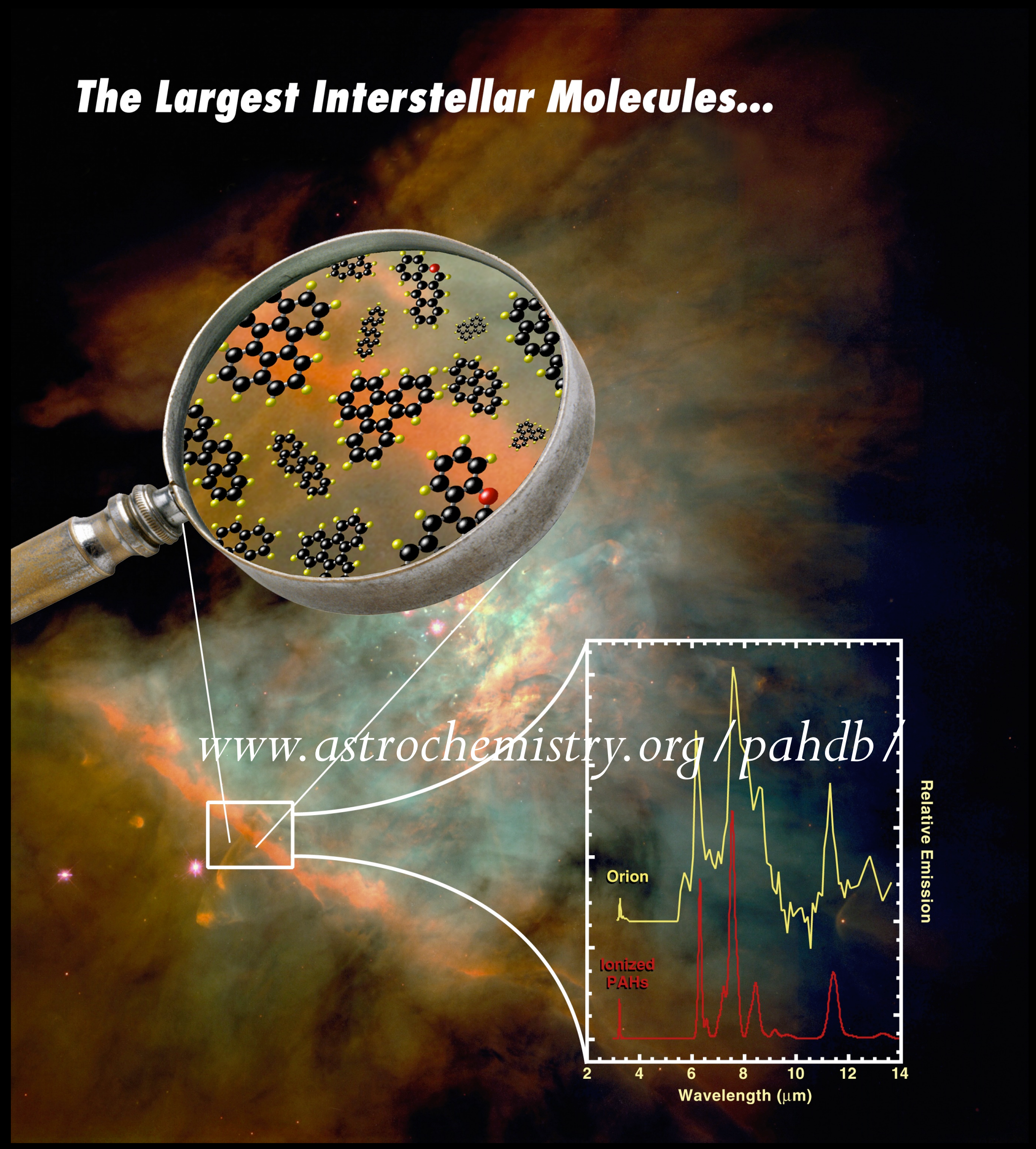
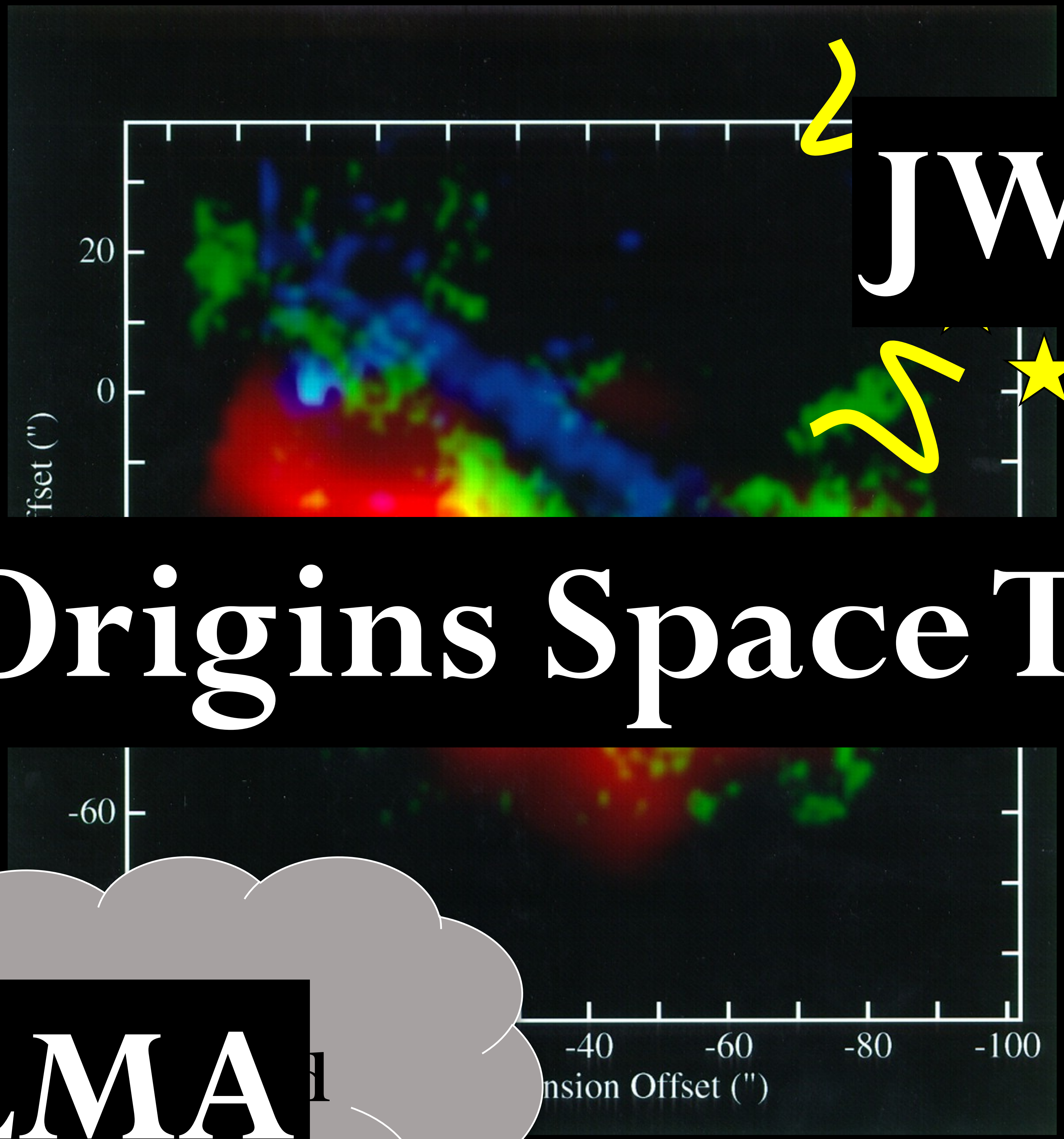
How do we probe the interstellar medium in high redshift galaxies?





JWST

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H_2

CO

ALMA

Hollenbach & Tielens 1997

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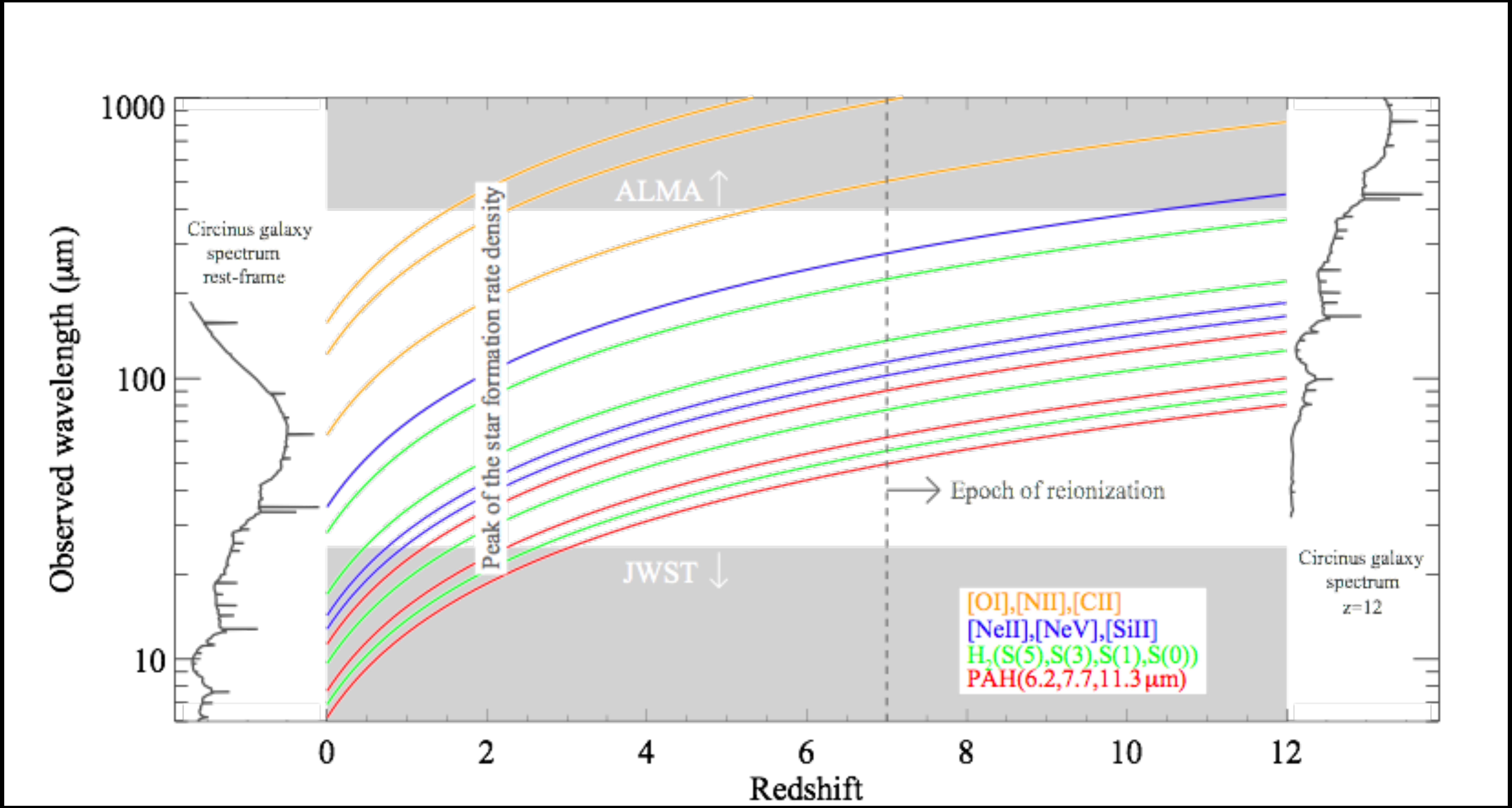
Infrared is rich in key spectral lines!



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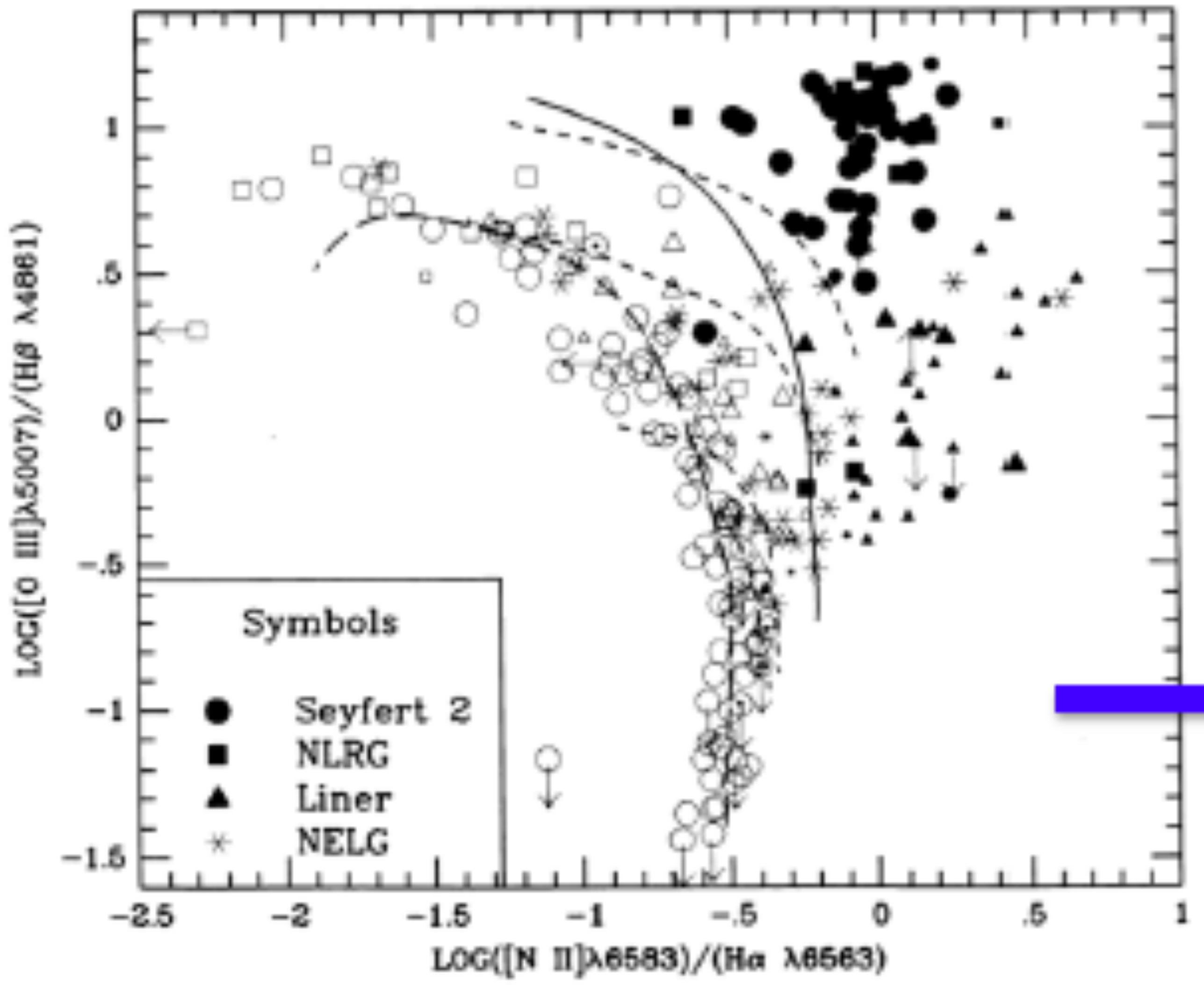
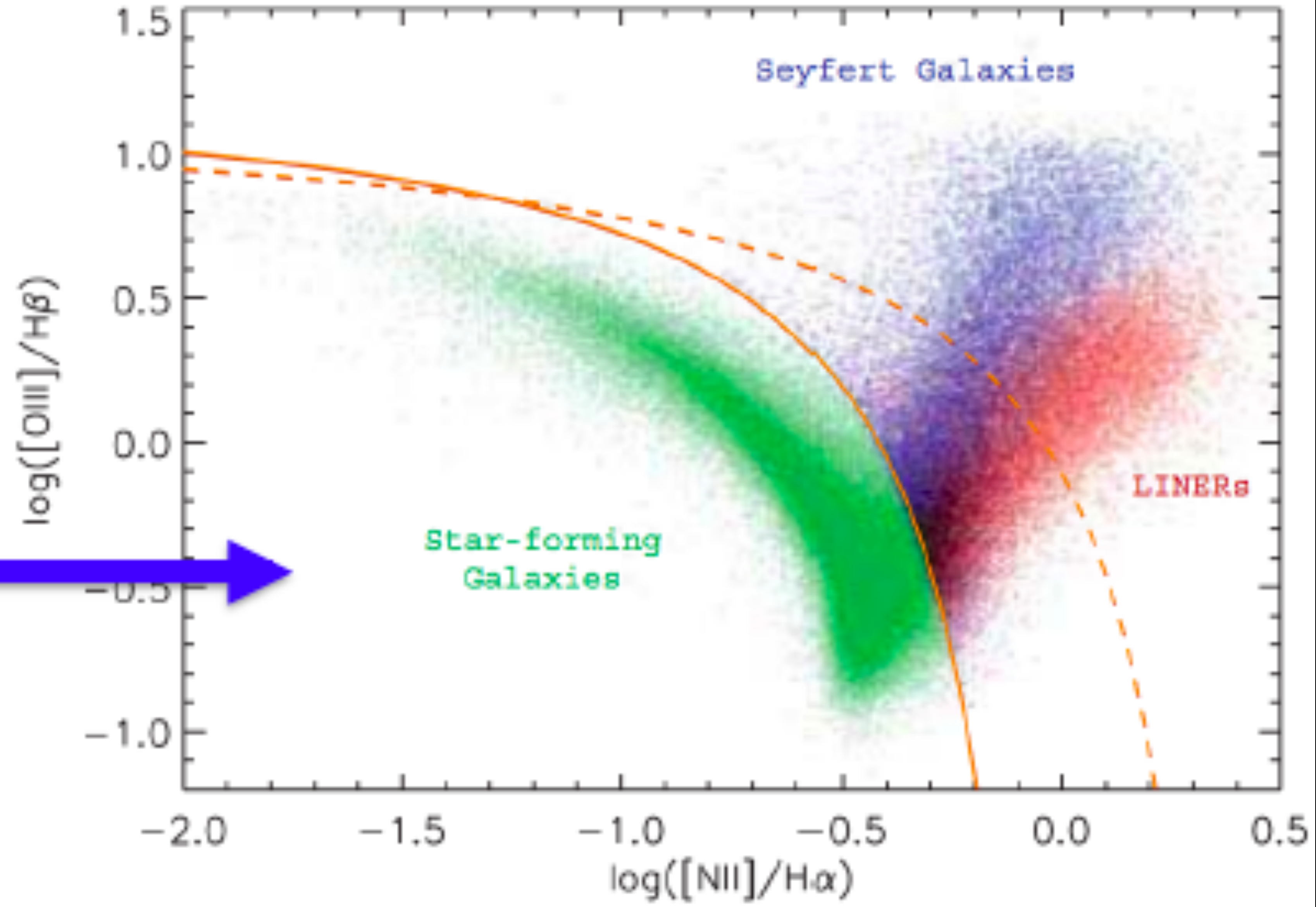
OPTICAL SPECTROSCOPY

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

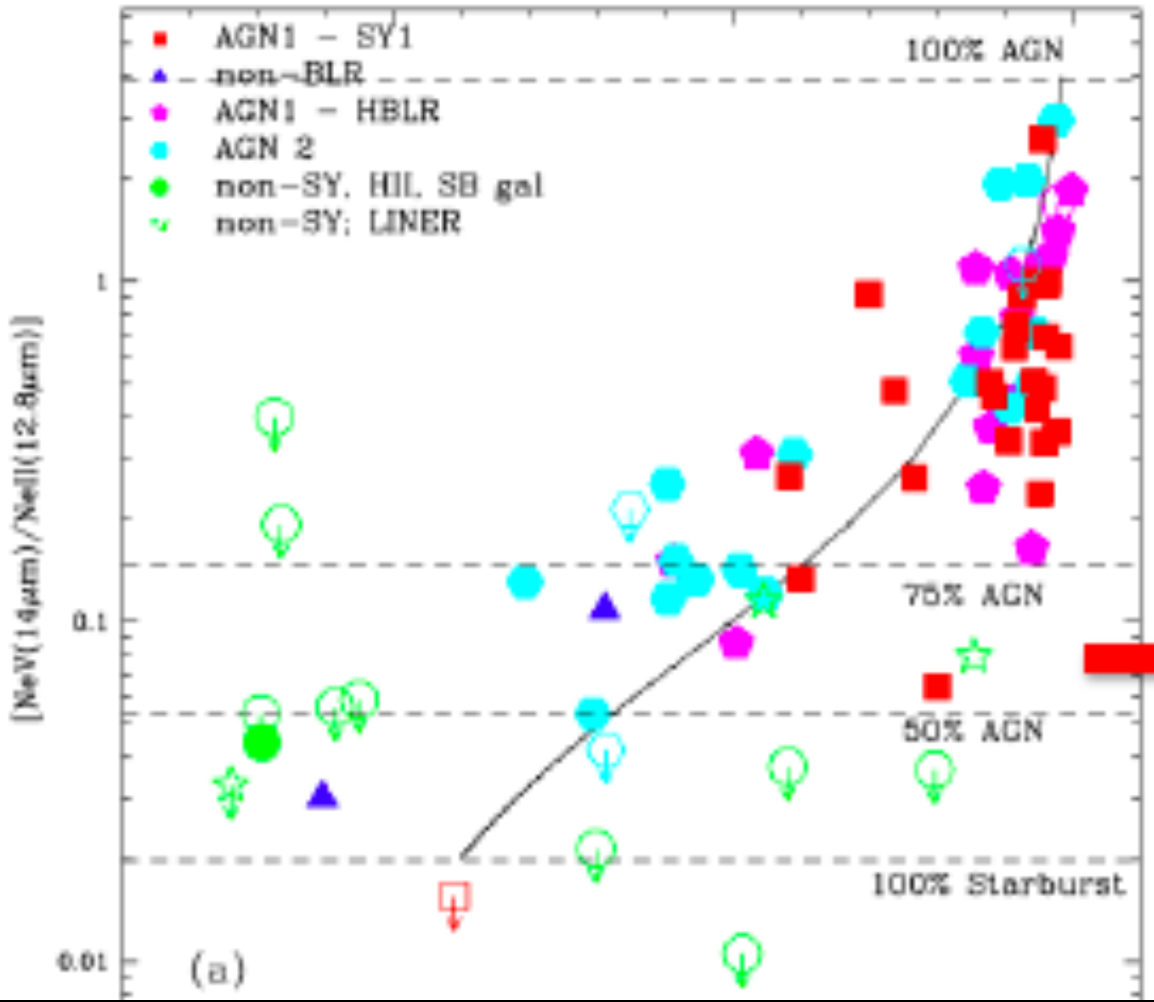


Groves+ **2006** (>10^5 galaxies)



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)

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An Example Science Traceability Matrix

OST Science Case Number/Title Theme	OST Science Theme NASA Science Goal Decadal Science Goal	Science Objectives	Science Requirements: Science Observable	Science Requirements: Measurement Requirement	Instrument Requirements: Technical Parameter	Instrument Requirements: Technical Requirement	Instrument Requirements: 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		

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Identify visionary, robust, and compelling science questions

↓

Derive from those questions a set of high-priority measurement requirements for the mission

↓

Choose a mission architecture

↓

Determine technology needs

↓

Evaluate trades and iterate engineering design with STDT

Estimate cost

Present to Decadal Survey

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Concept 1 Highlights

- **Telescope type**: three mirror anastigmat; unobstructed primary mirror
- **Primary mirror**: 9.1 meters in diameter; 37 hexagonal segments
- **Five instruments housed in an Instrument Accommodation Module (IAM)**
  - –Medium Resolution Survey Spectrometer (MRSS) – JPL
  - –Hi Res (Far-IR) Spectrometer (HRS) – GSFC
  - –Heterodyne Instrument (HERO) – CNES
  - –FIR Imager/ Polarimeter (FIP) – GSFC
  - –MID-IR Imager Spectrometer/ Coronagraph (MISC) – JAXA
- **Instrument Wavelength Coverage:** 5 to 660 μm
- **MISC serves as guider for the spacecraft attitude control system**
- **Telescope and instrument operating temperature:** 4 to 4.5 K
- **Cryocoolers (current SOA) used for cooling,** not expendable cryogen
- **Instrument warm electronics housed in the spacecraft bus (270 K)**

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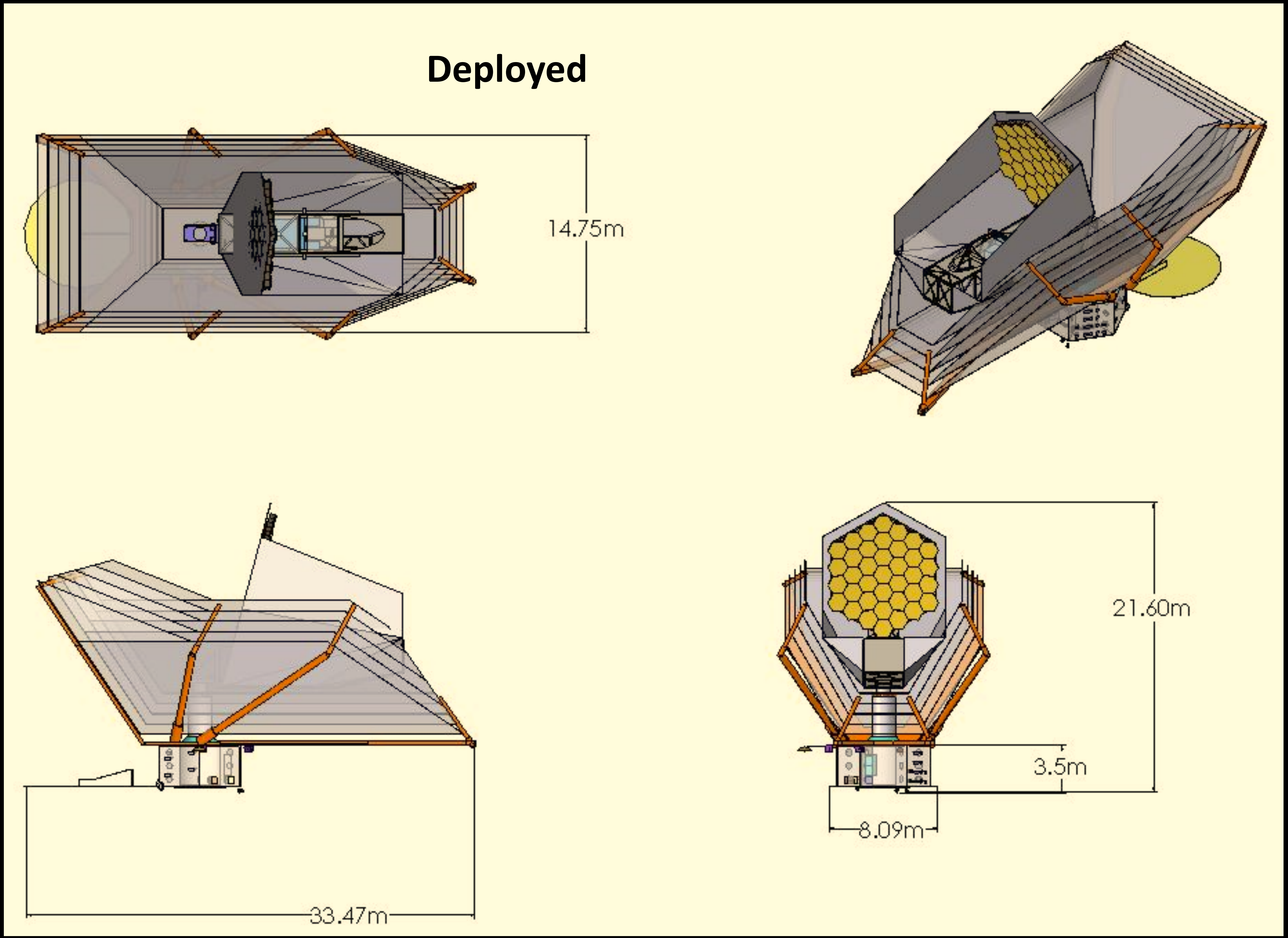
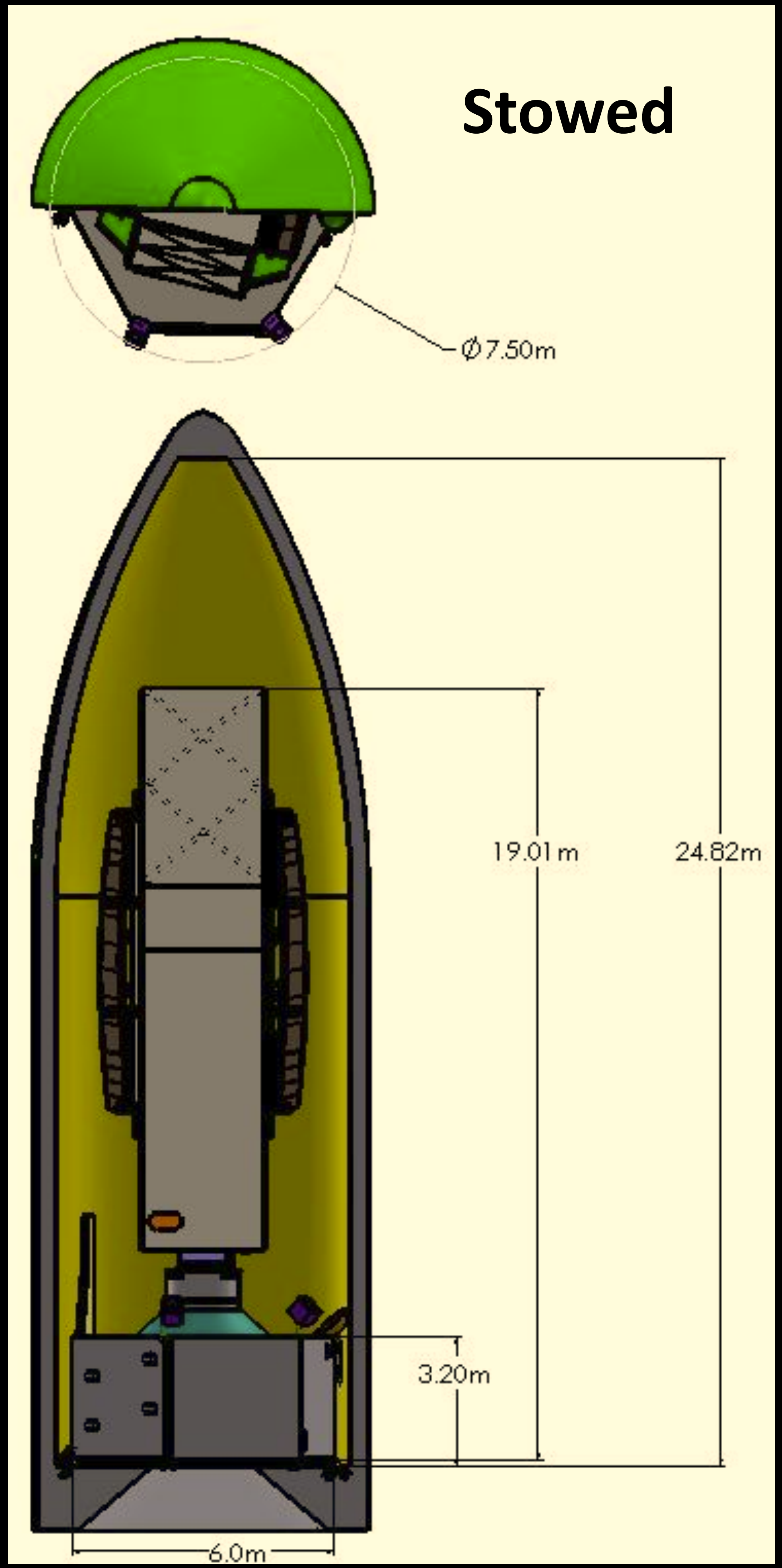
Concept 1 configuration





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Concept 1 Requirements

- **Mission Life**: 5 Years with 10-year consumables
- **Launch Vehicle**: SLS Block 2, 8.4m x 27.4m fairing
- **LRR**: September 1, 2035
- **OST Observatory Size**:
  - 14.75 x 21.6 x 33.5 m (deployed), 19L x 7.5D m (stowed)
- **Mission Orbit**: Sun-Earth L2 (Sun, Earth, Moon avoidance, No eclipses)
- **Pointing Control** – 44 mas; **Pointing Knowledge** – 30 mas; **Jitter** – 22 mas
- **Folded/scooped sunshade to minimize size** (size fixed for this study)
- **IAM** is to be on-orbit serviceable (underside)
- **Science Observation**: > 70%
- **Field-of-Regard** (FOR): -5˚- +45˚ Pitch off Sun Line, 360˚ Yaw about Sun Line, ±5˚ Roll about Line of Sight (LOS) off max power roll angle
- **Communication**: 2 optical terminals, 1 S-band OMNI Pair, 1 S-band HGA
- **Observatory Mass**: ~30000 kg (CBE)
- **Observatory Power**: ~7500 W (CBE)
- **Peak Data Rate**: ~350 Mbit/sec

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Instrument Specifications					
Instrument	**Wavelength Coverage**	**Spectral Resolving Power (λ/Δλ)**	**Number of spatial pixels or sky beams**	**Typical Required Sensitivity:**	**Other**
MISC	<6 (~2?) to 40 μm	imager: R~15; spectrometers, R=300 to 25000	$\sim 10^{7}$	photometric: 1 μJy @10 μm	coronagraph 10^{-7}-10^{-8} IWA=λ/D
FIP	40, 80, 120, 240 μm	R~15	~500,000	1 μJy - 10 mJy (confusion limit)	polarimetry, spectral line filters
MRSS	30 to 660 μm	low-res~500 high-res$\sim 4\times10^{4}$	100 per channel	2.6×10^{-21} W/m^{2} (spectral line)	4-5 channels
HERO	150 to 600 μm	$\sim 10^{7}$	10 - 100	2 mK in 0.2 km/s @ 1 THz	polarized, background limited
HRS	50 to 500 μm	low-res ~ 5×10^{4} high-res$\sim 5\times10^{5}$	1	2.6×10^{-21} W/m^{2} 5 σ (spectral line)	photo-counting

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Operational modes

- Large scale survey mapping: FIP, MRSS, MISC

(100 arcsec/second scan speed allowing 1000 sq. degree+ survey maps with FIP etc)

- Small maps: HERO, MISC, FIP, MRSS, HRS

- Pointed Observations: HERO, MISC, FIP, MRSS, HRS

- Coronagraphy: MISC

- Transit spectrometer: MISC

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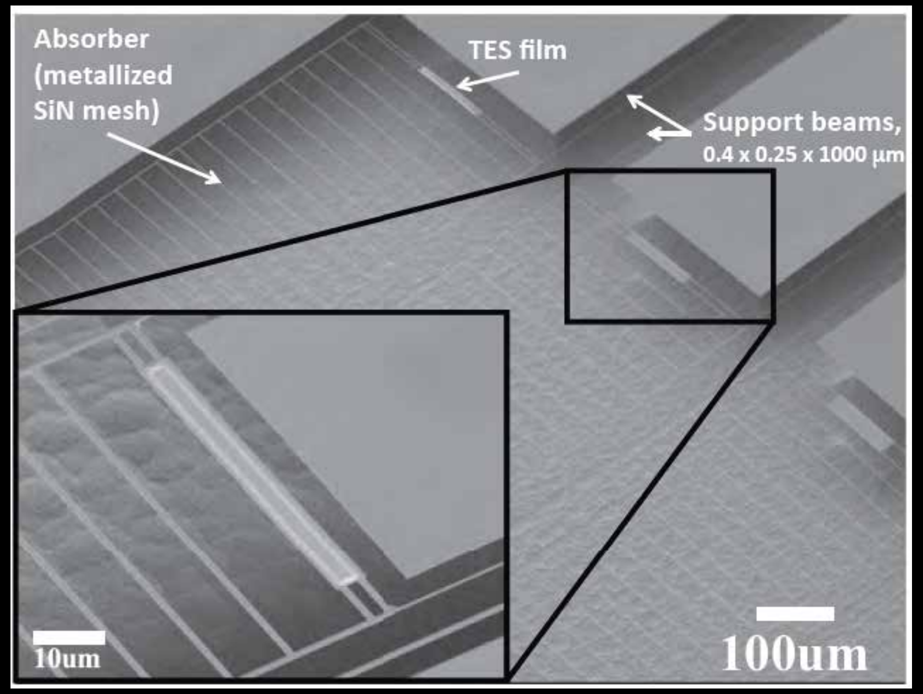
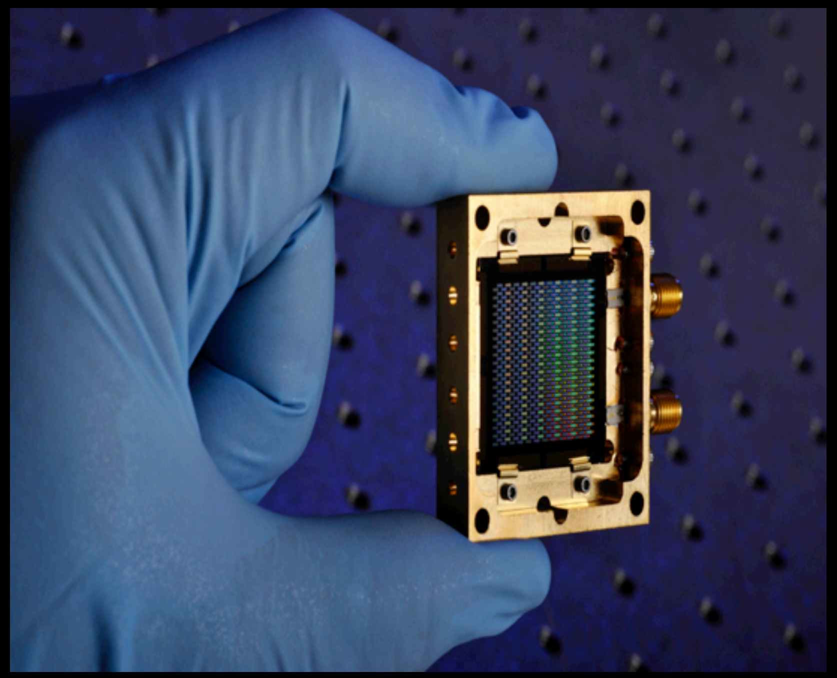
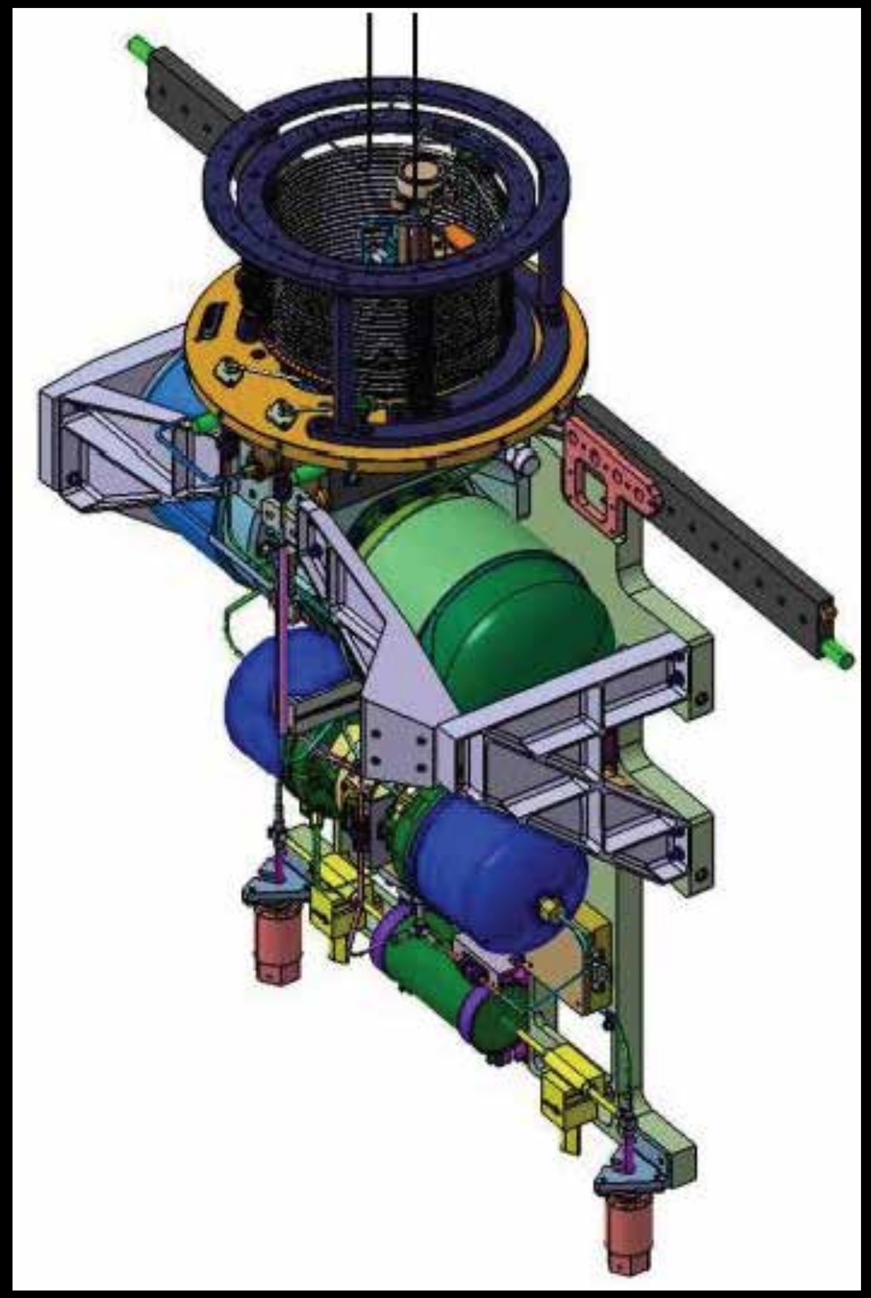
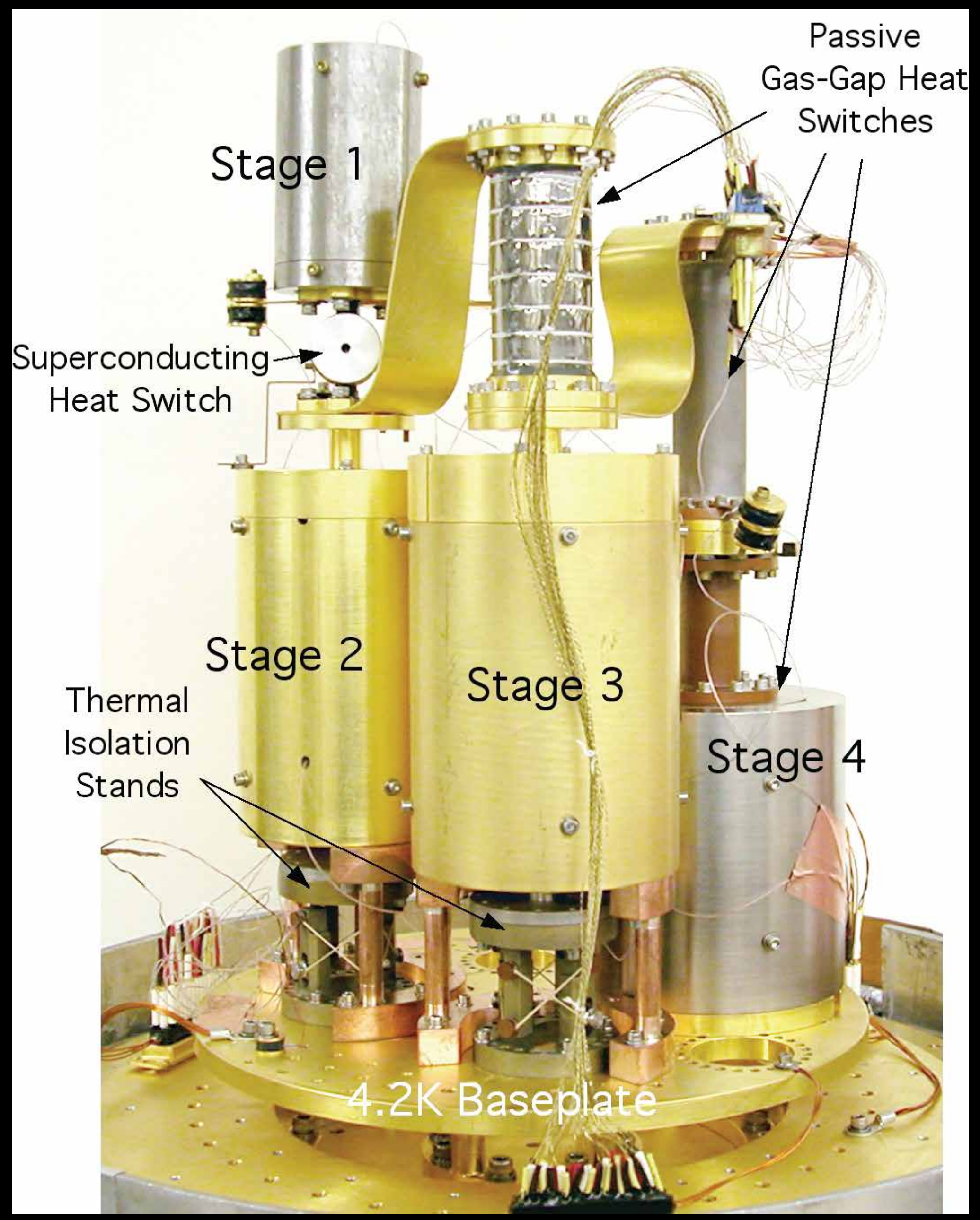
Technology Gaps

- Large-format, high-sensitivity **far-IR direct detectors, multiplexers, and readout electronics**
- Compact Far-IR spectrometers
- Heterodyne detectors
- Sub-Kelvin cooling
- Large cryogenic optics and actuators
- 4.5 K cryocoolers
- Mid-IR detectors and coronagraphy









What's coming up in 2018+

- **Concept 1 complete - STDT will deliver a report to NASA this Spring**
- **Concept 2 definition exercise started.**
  - Define Concept 2 and assess engineering feasibility
    - Aperture size
    - Instrument suite and priority
  - Inform/communicate feasibility assessments to the STDT
  - Iteration with the STDT
- **Select Concept 2 criteria**: STDT has agreed to consider a JWST-like size design that will fit into a maximum of a 7m-class fairing

Concept 2 will be less ambitious than Concept 1, esp instrument capabilities. Likely will be limited to 3 de-scoped instruments developed for Concept 1.

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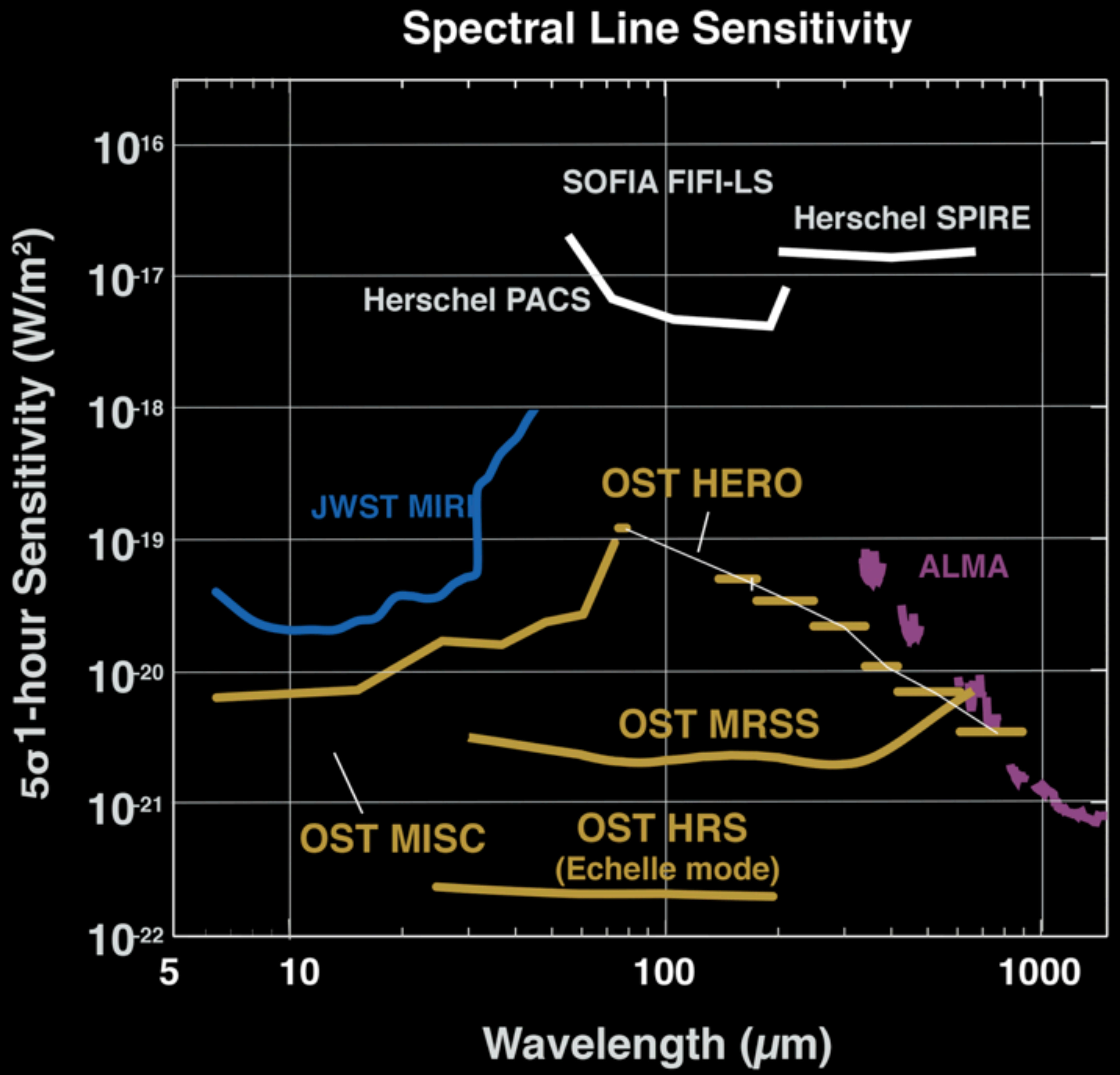

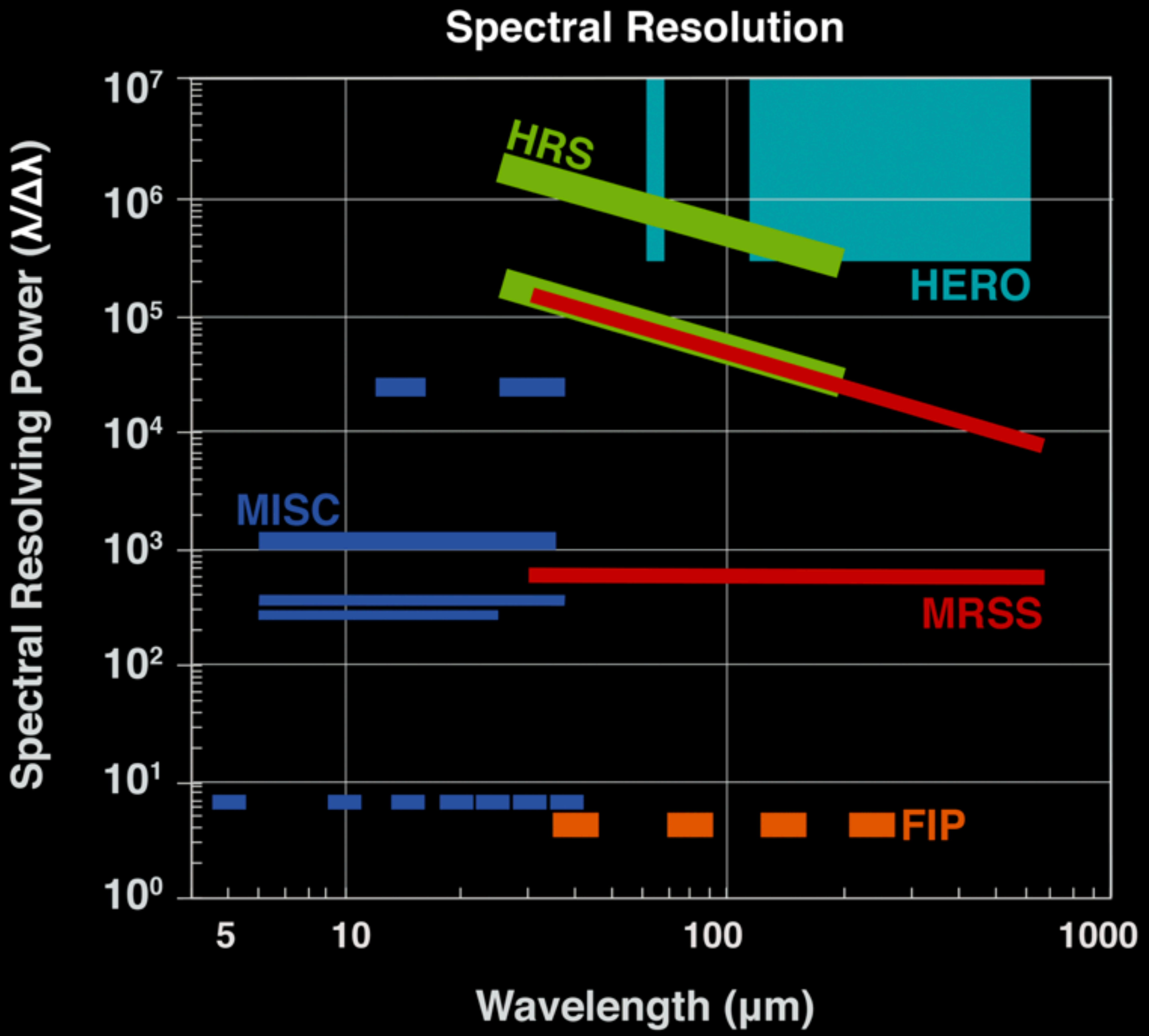

What Origins Space Telescope will do

- 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.

What Origins Space Telescope will be

- A flagship general observatory - community driven sciences and instruments.
- We want to hear about your:
  - Scientific questions that would define and use such an observatory
  - Your technical innovations that would help make *Origins* a reality.