ORIGINS Space Telescope

Asantha Cooray @acooray

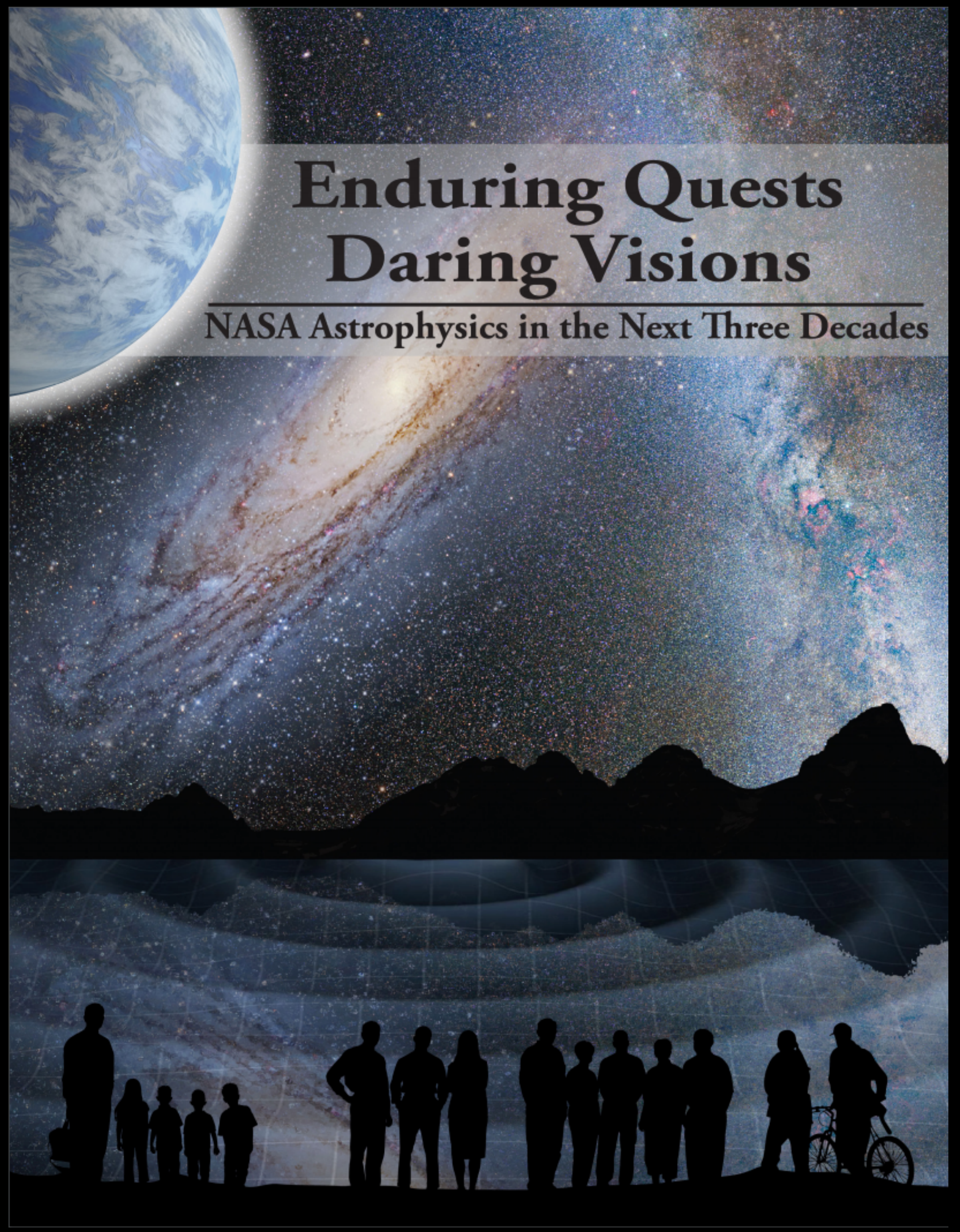
ORIGINS Space Telescope

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

NASA 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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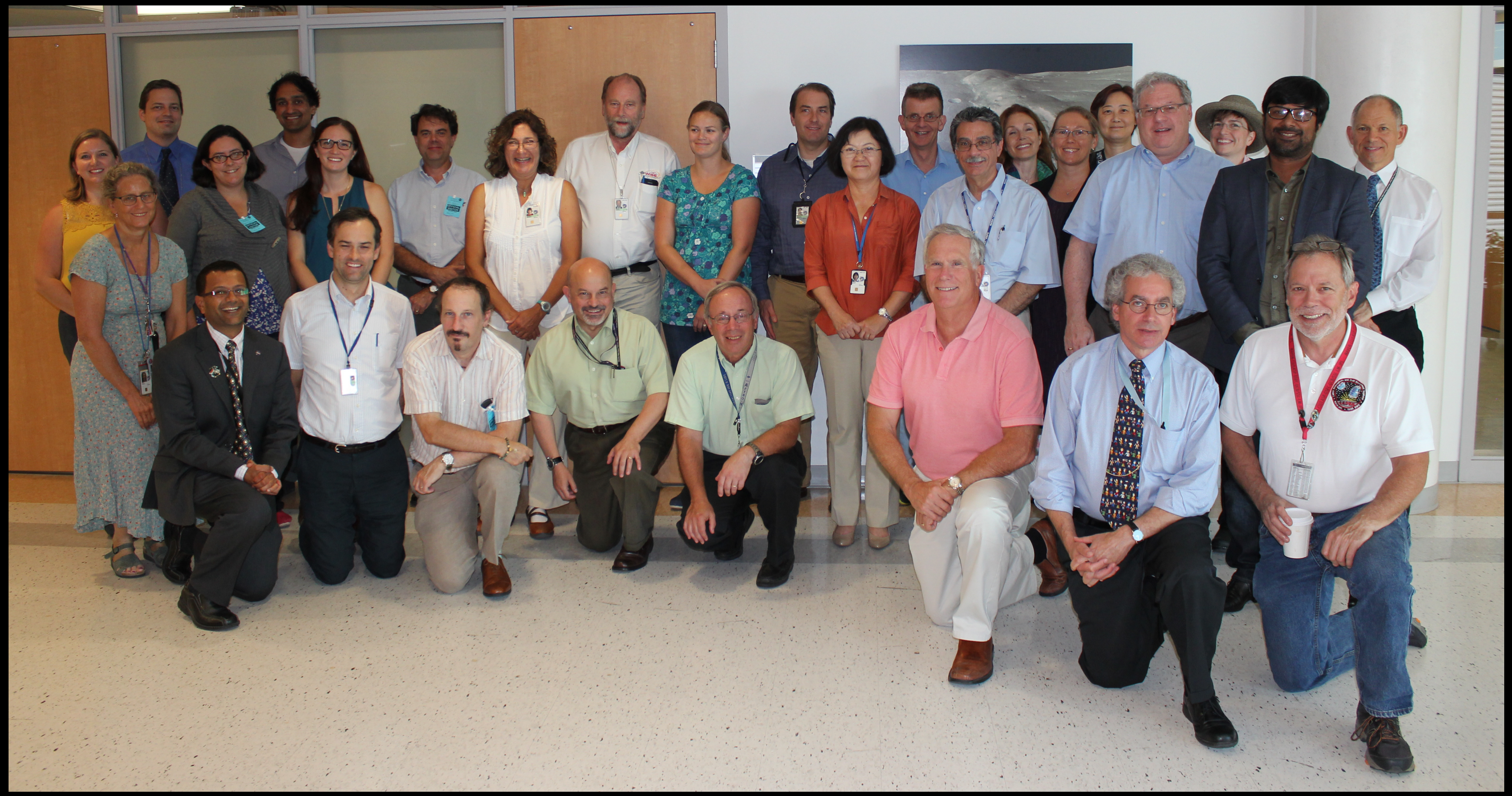

Study Team

- **Community Chairs: 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; Gary Melnick, CfA; Stefanie Milam, GSFC; Desika Narayanan, University of Florida; Klaus Pontopiddan, STSCI; Alexandra Pope, UMass; Thomas Roellig, Ames; Karin Sandstrom, UCSD; 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.

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 five science working groups (SWGs). Membership in SWGs is open to the community.

(about 150 community members active already! SWG listings on our website)

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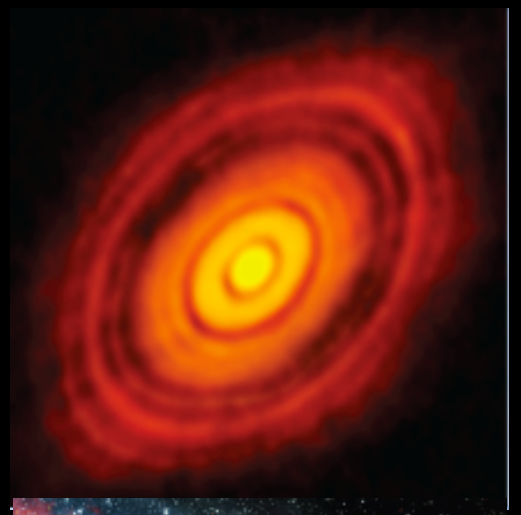
Science Working Groups

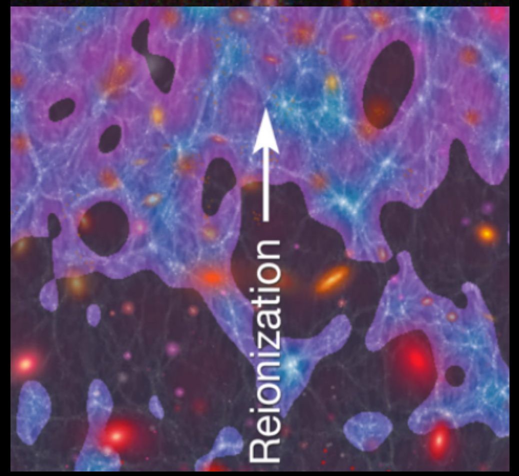
- **Solar System**: Stefanie Milam



- **Planet Formation and Exoplanets**: Klaus Pontoppidan and Kate Su
  (**Exoplanet** science study led by Eric Nielsen, Tyler Robinson)

- **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

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Science Case - Number and Title

19. The Rise of Metals
9: Water Content of Planet-Forming Disks
27. The First Dust
15: Direct Detection of Protoplanetary Disk Masses
14. Super Earth Biosignatures And Climates
4: Water Transport to Terrestrial Planetary Zone
21: Connection Between BH Growth and Star Formation Over Cosmic Time
26: Birth of Galaxies During Cosmic Dark Ages
18: Galaxy Feedback from SNe and AGN to z~3
29: Thermo-Chemical History of Comets and Water Delivery to Earth
22: Star Formation and Multiphase ISM at Peak of Cosmic Star Formation
7: Magnetic Fields and Turbulence - Role in Star Formation
5: Galaxy Feedback Mechanisms at z<1
30. Survey of Small Bodies in the Outer Solar System
10: Ice/Rock Ratio in Protoplanetary Disks
20: Role of Environment in Galaxy Evolution
13: Frequency of Kuiper Belt Analogues
23. Galaxies at Reionization
8: Formation and History of Low-Mass Ice Giant Planets
25: Large-Scale Structure - Crucial FIR Link
24. Feedback on All Scales in the Cosmic Web
6: Obscured AGN
2: Regulating the Multiphase ISM
16: Jupiter and Saturn Analogues
28: Planetary Origins and Evolution of the Solar System
17: Episodic Accretion in Protostellar Envelopes and Circumstellar Disks
12: Gas and Comets in Exoplanetary Systems
32. Find Planet IX
1: Stochastic vs secular accretion in forming star
11: Cooling Power of Molecular Gas in Star-Forming Regions
3: Star Formation Efficiency Outside the Milky Way
31. Comparative Climate and Thermal Evolution of Giant Planets

Initial 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 2017

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NASA

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		

Mission Study Design Implementation

- Through an active mission development working group (led by Tom Roellig).
- Identified five instruments and ranked their relative priorities.
- We are forming five instrument teams (ITs) - instrument leads identified.
- Membership in ITs will be open to the community. *An announcement for expressions of interest to join ITs will be out soon.*
- Industry partners or substantial industry interest in the concept development.
- Study Center (GSFC) will be issuing a Cooperative Agreement Notice (CAN) for FY2017 this month to formalize industry contributions.

ORIGINS Space Telescope

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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**
Mid-Infrared coronagraph/ imager/IFU	<6 (~2?) to 40 μm	imager: R~10; IFU: R>3000	~10^7	photometric: 1 μJy @10 μm	coronagraph 10^{-7}-10^{-8} IWA=2λ/D
Imager + Polarimeter	35 to 600 μm (5-10 channels)	R~10	~500,000	1 μJy - 10 mJy (confusion limit)	polarimetry, spectral line filters
Low-Res Spectrometer	35 to 600 μm	low-res~500 high-res~10^4	100 per channel	10^{-21} W/m^2 (spectral line)	4-5 channels
High-Res Heterodyne Spectrometer	150 to 600 μm	~10^7	10 - 100	2 mK in 0.2 km/s @ 1 THz	polarized, background limited
Mid-Res Spectrometer	50 to 600 μm	low-res ~ 8x10^4 high-res~5x10^5	100	10^{-21} W/m^2 5 σ (spectral line)	photo-counting

Instrument Study Teams

- **Mid-IR imager/coronagraph/IFU** *(lead institution TBD; possibly one of industry/JAXA/Ames)*: Tom Roellig/Itsuki Sakon (Leads), Kim Ennico-Smith (Instrument Scientist)

- **Imager/polarimeter (*GSFC led*):** Johannes Staguhn (Lead), Margaret Meixner (Instrument Scientist)

- **Low-Res Spectrometer** *(JPL contributed)*: Matt Bradford (Lead), Lee Armus (Instrument Scientist)

- **High-Res - heterodyne - Spectrometer** *(Europe contribution with CNES/France as lead)*: Martina Weidner (CNES; Lead), Gary Melnick/Maryvonne Gerin (Instrument Scientists)

- **Mid-Res Spectrometer** *(GSFC led)*: Dave Leisawitz (lead), Ed Bergin (Instrument Scientist)

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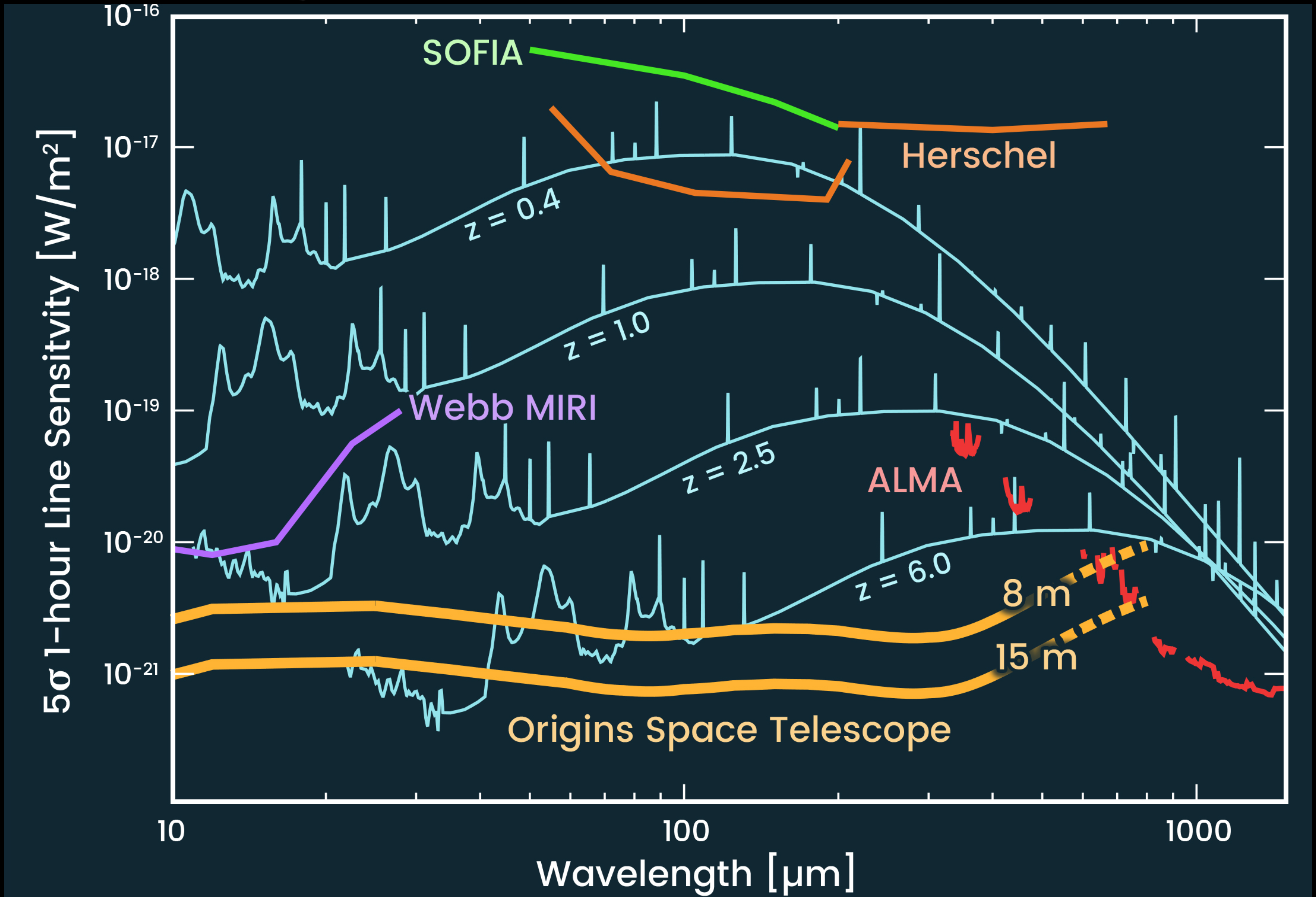
Two Orders of Magnitude!



Four Orders of Magnitude!

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

What blank-field extragalactic sky images will look like (100 microns*)

(*Not a wavelength observable by James Webb Space Telescope).

Previous opportunities: IRAS (1983), 60cm, 2K
Spitzer (2003-), 85cm, 5K
Herschel Space Observatory (ESA-led, NASA contributions) 2009-2013, 3.5m, 70K

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.

Tracing the signatures of life and the ingredients of habitable worlds

Origins will trace the trail of water from interstellar clouds, to proto-planetary disks, to Earth itself facilitating understanding of the abundance and availability of water for habitable planets.

Unveiling the Growth of Black Holes and Galaxies over Cosmic Time

Origins will reveal the co-evolution of super-massive black holes and galaxies, energetic feedback, and the dynamic interstellar medium from which stars are born.

Origins will trace the metal enrichment history of the Universe, probe the first cosmic sources of dust, the earliest star formation, and the birth of galaxies.

Charting the Rise of Metals, Dust, and the First Galaxies

Origins will chart the role of comets in delivering water to the early Earth, and conduct a survey of thousands of ancient Trans Neptunian Objects (TNOs) in the outer reaches of the Solar System.

Characterizing Small Bodies in the Solar System

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

What is the cosmic history of the growth of metals and dust?

What is the chemical trail and path of water from molecular clouds to proto-planetary disks?

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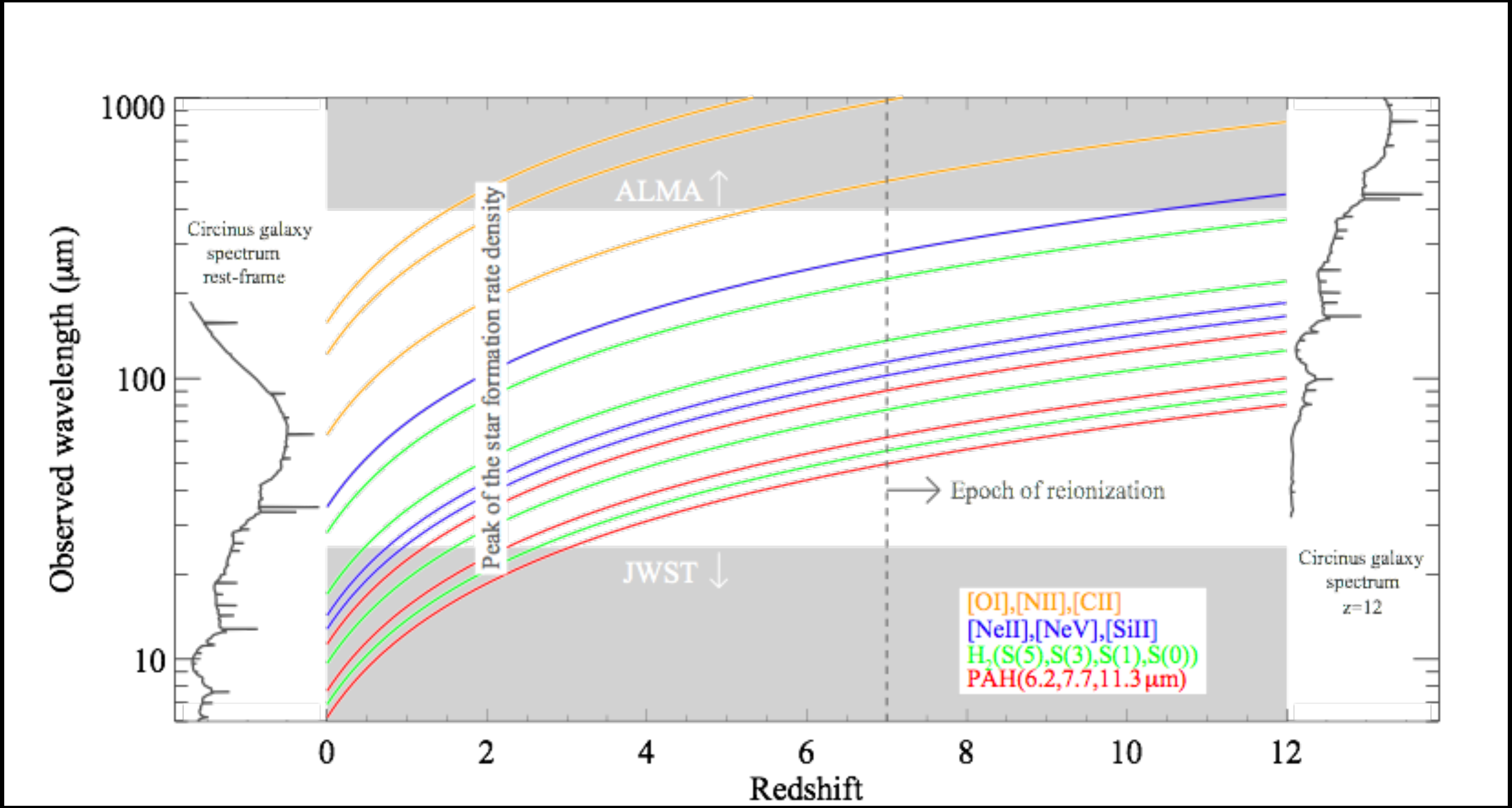
NASA

Infrared is rich in key spectral lines!



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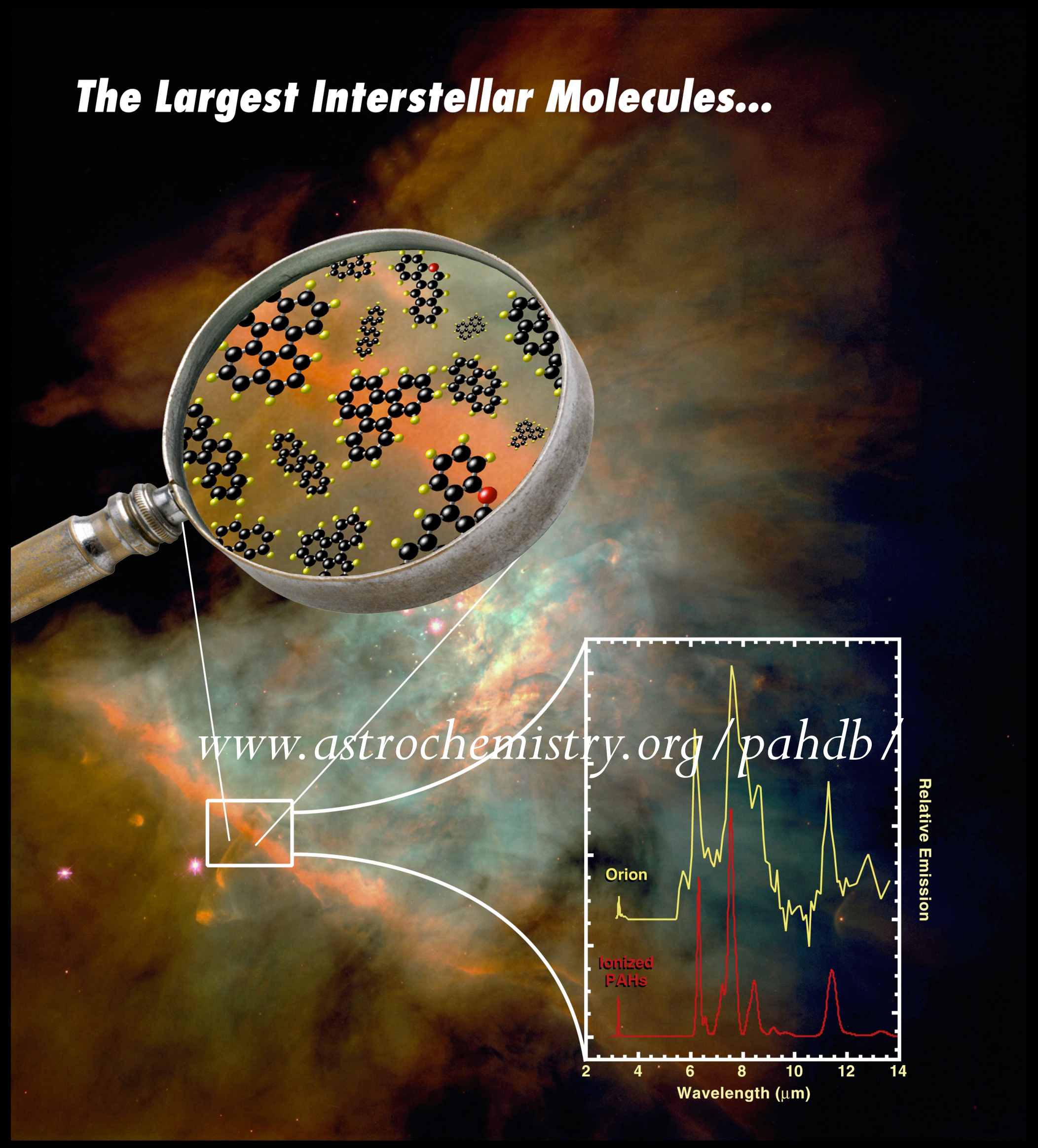
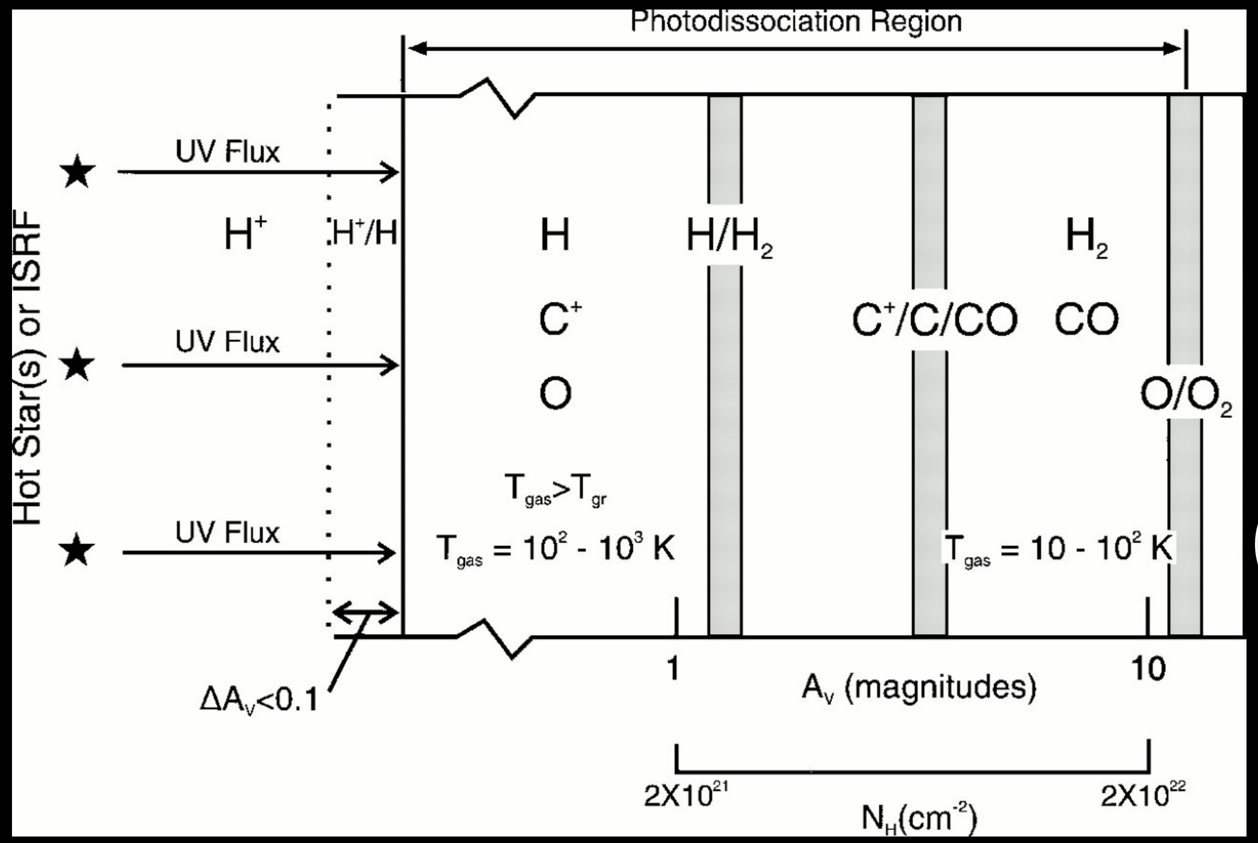
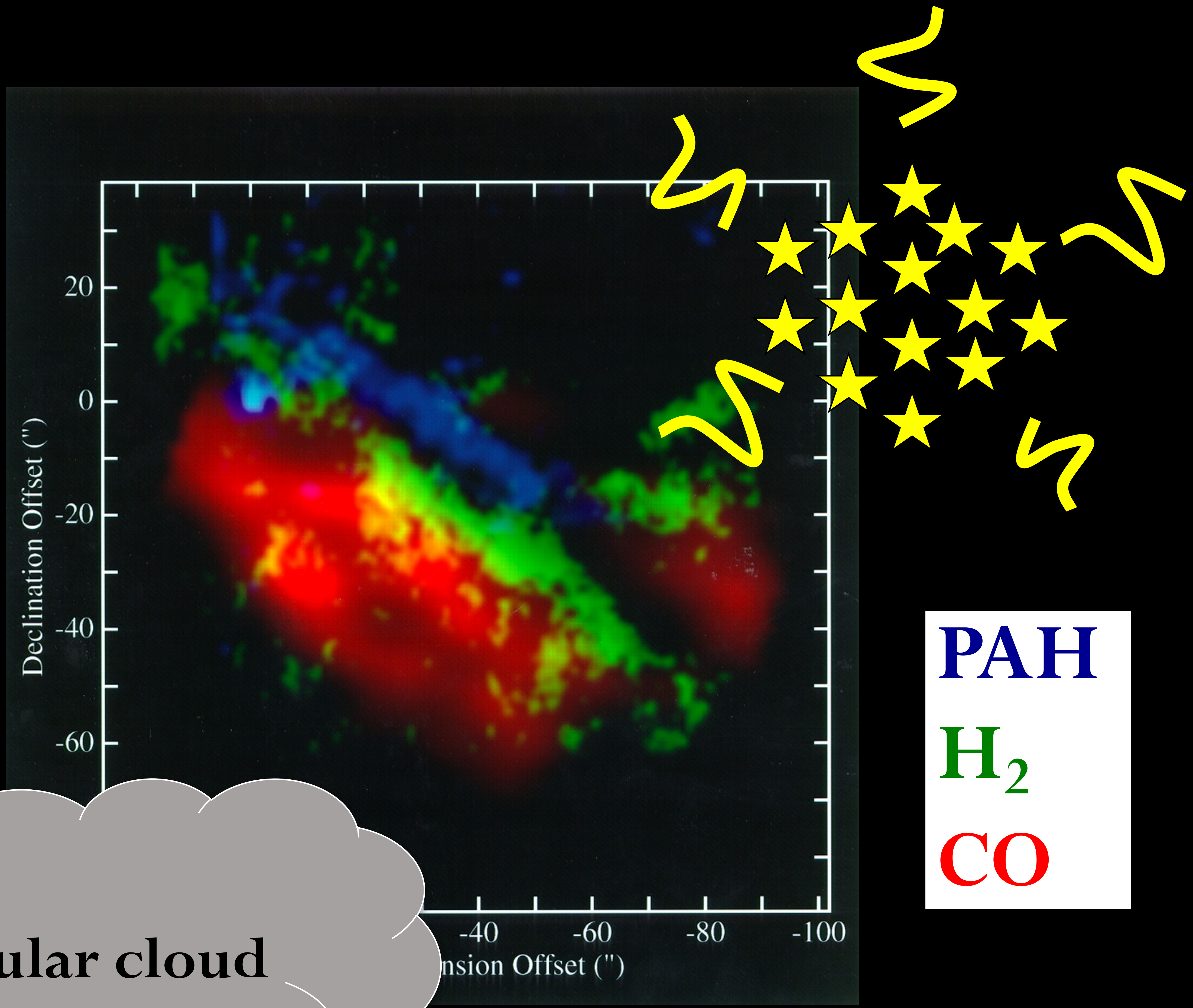
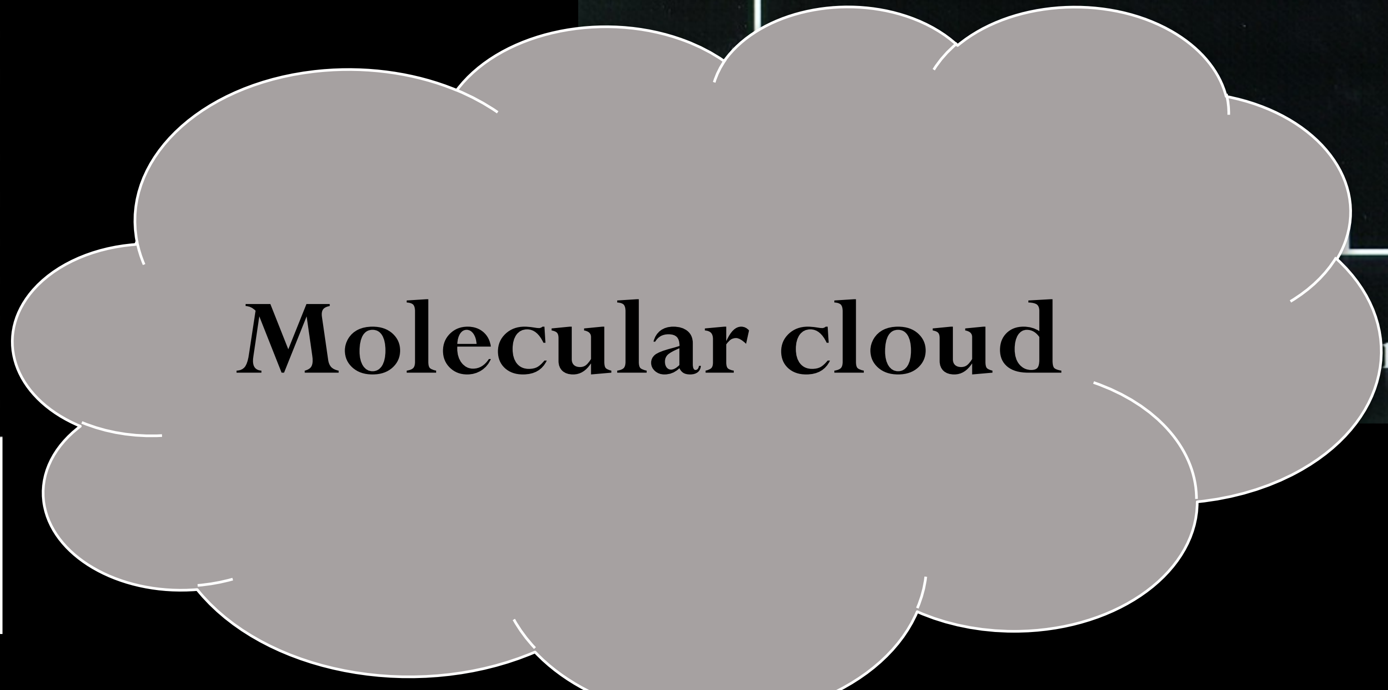
NASA

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









PAH

H_2

CO

Hollenbach & Tielens 1997

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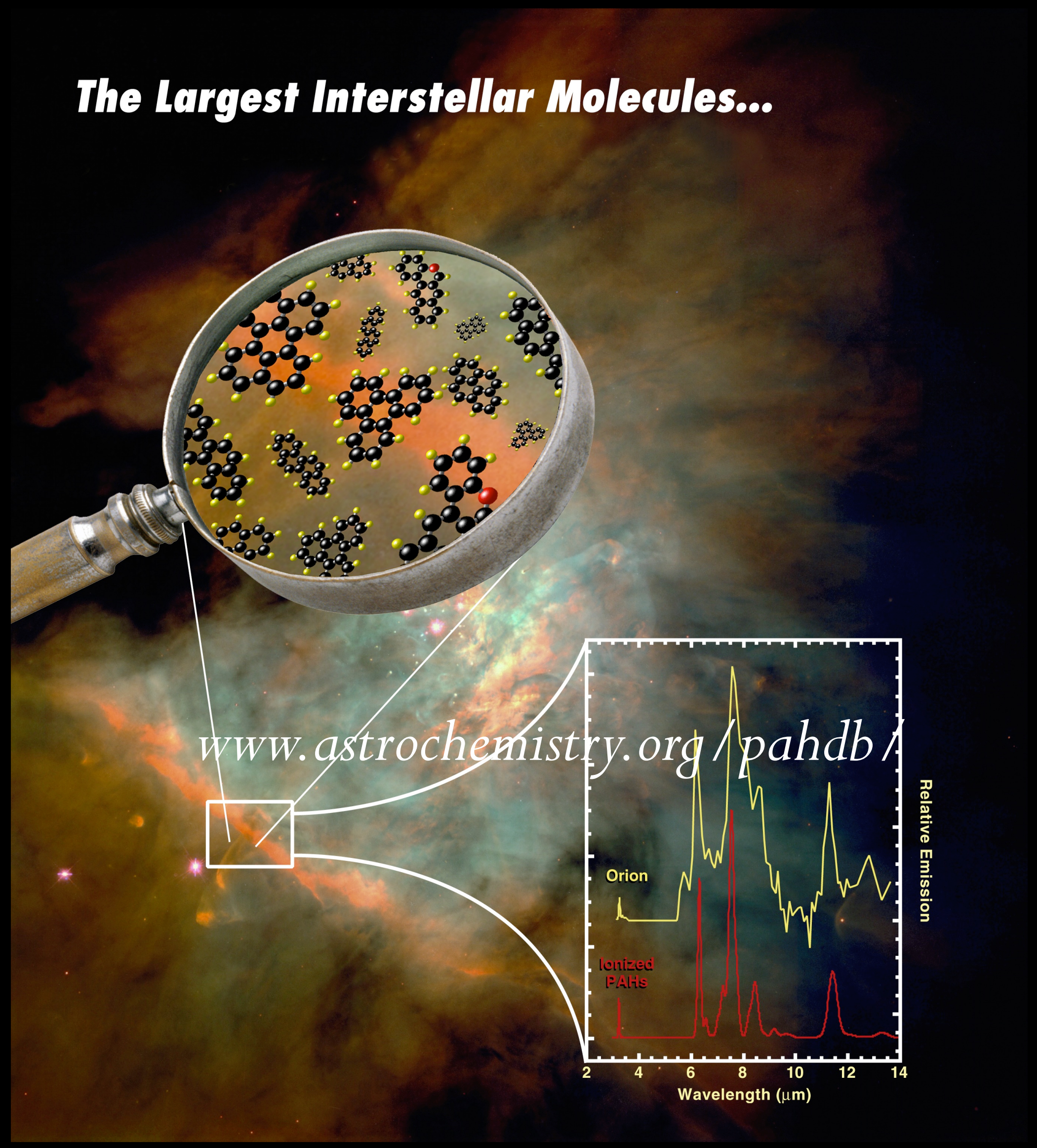

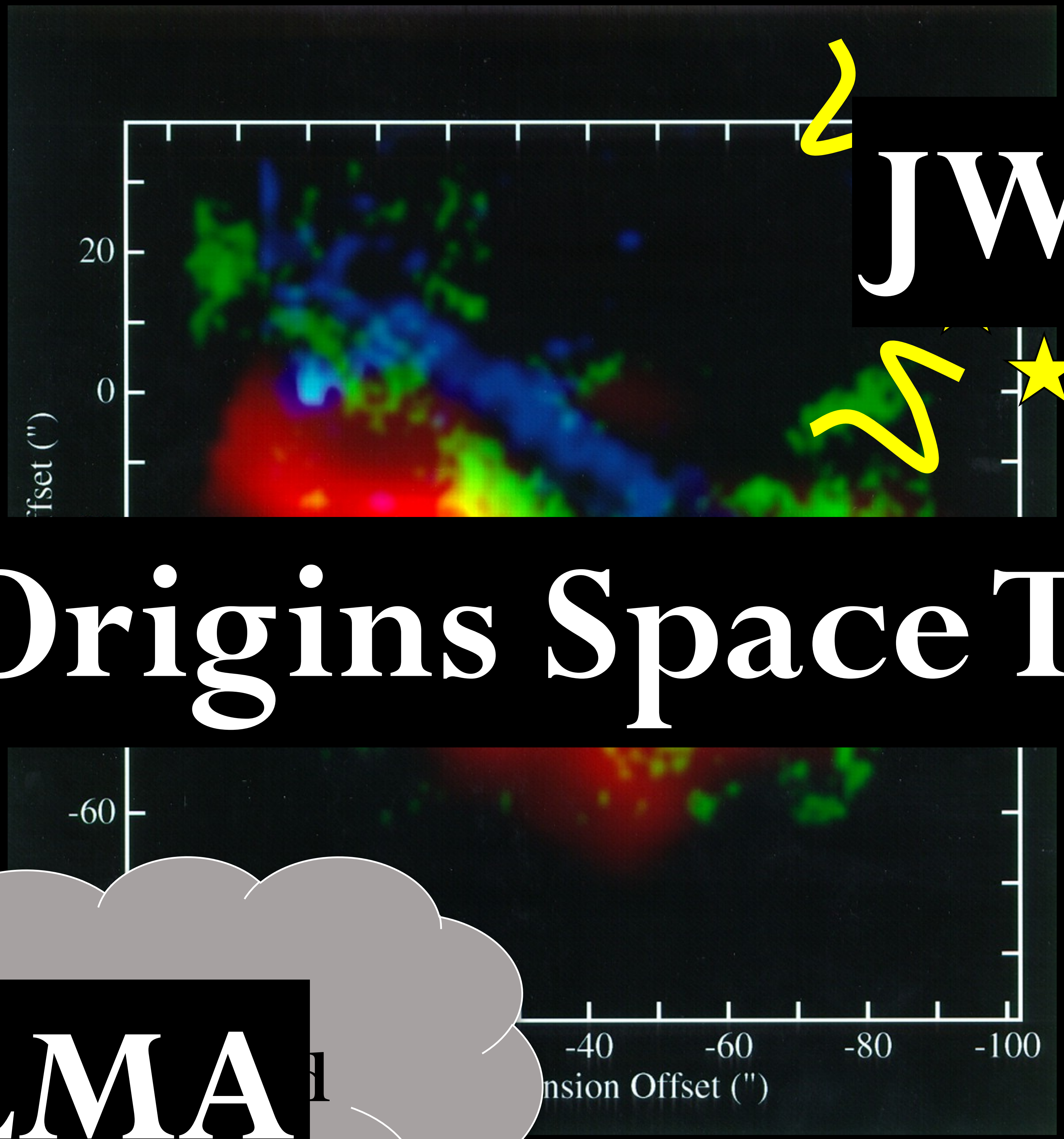

JWST

Origins Space Telescope

H_2

CO

ALMA

Hollenbach & Tielens 1997

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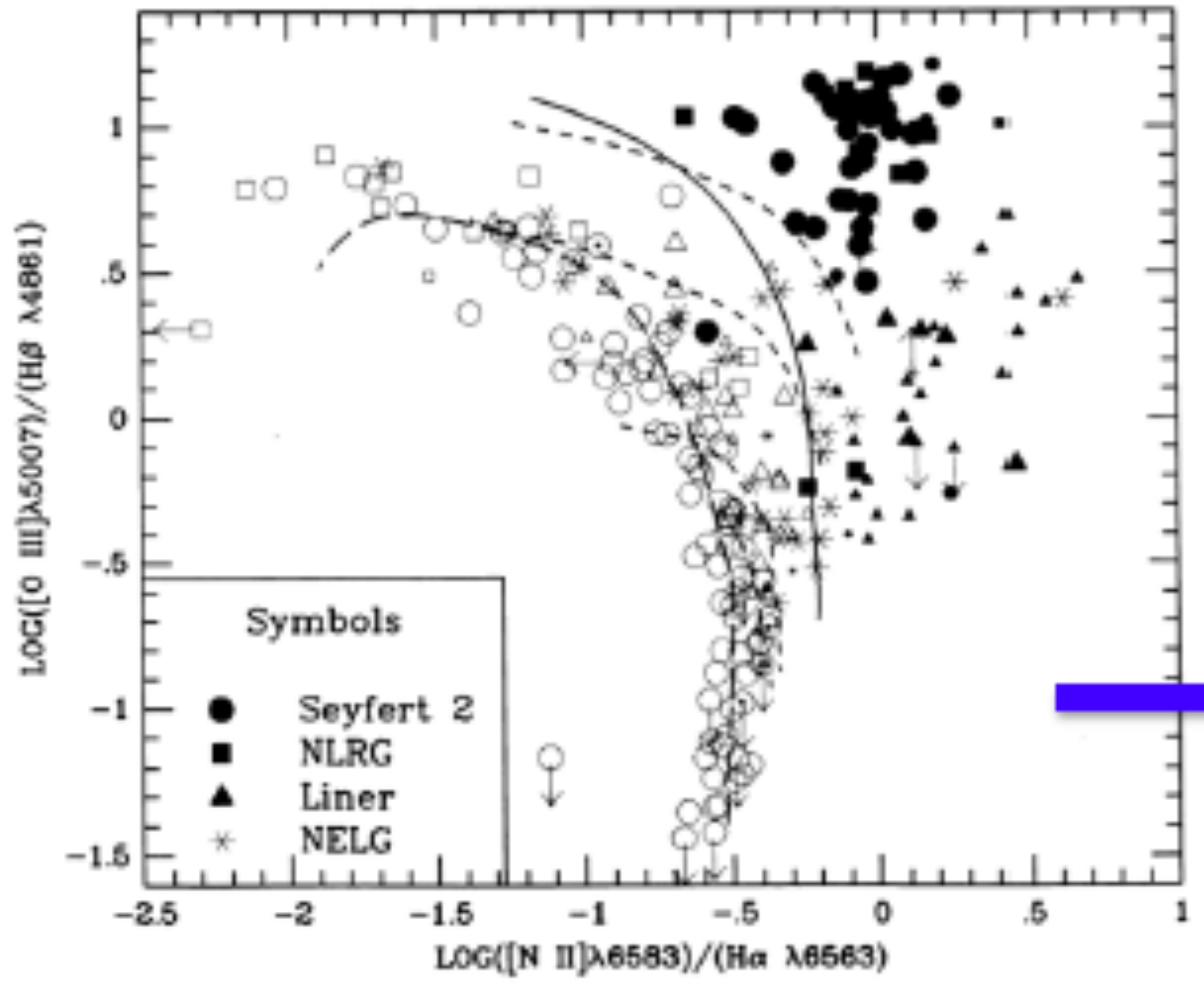
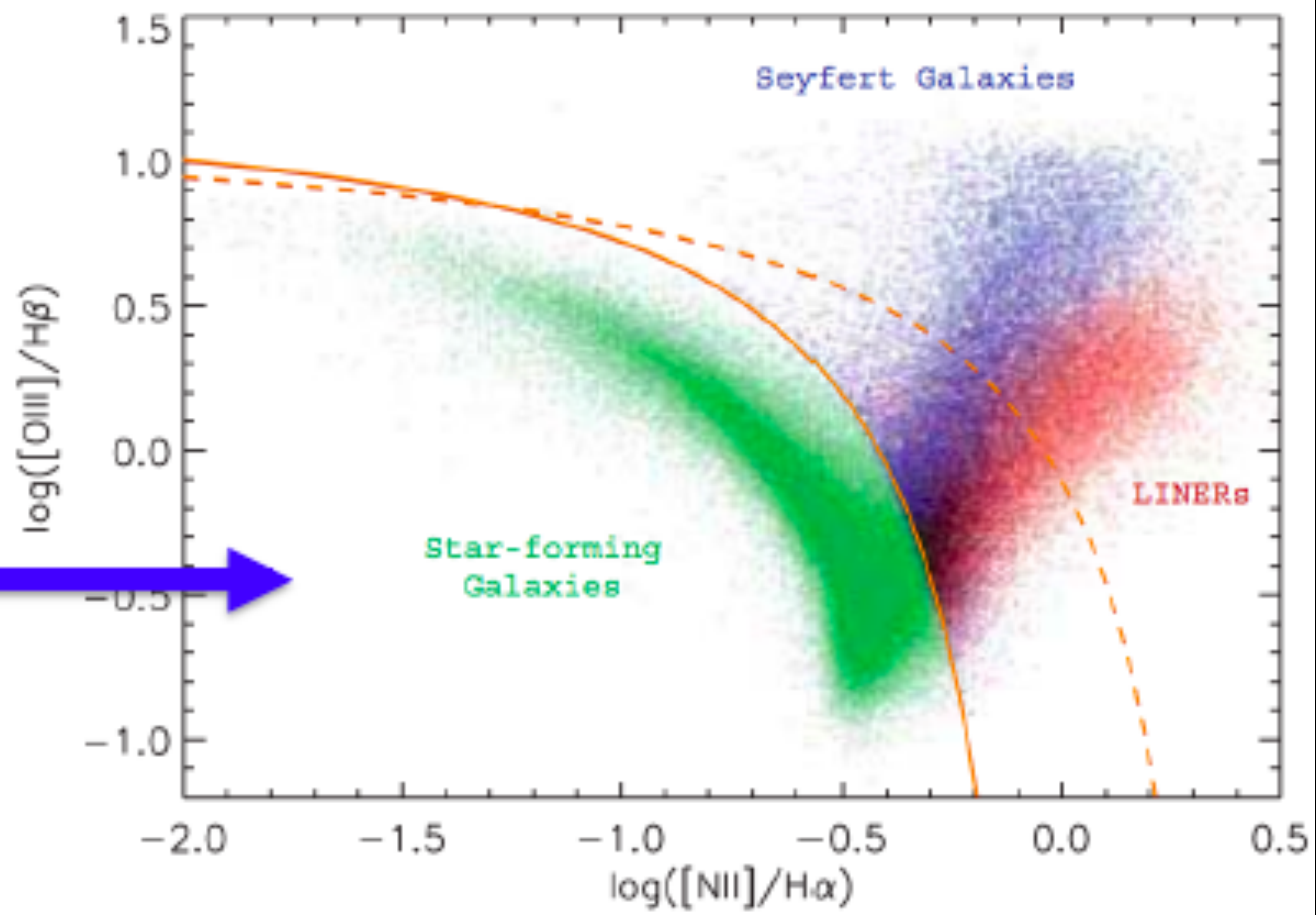
OPTICAL SPECTROSCOPY

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

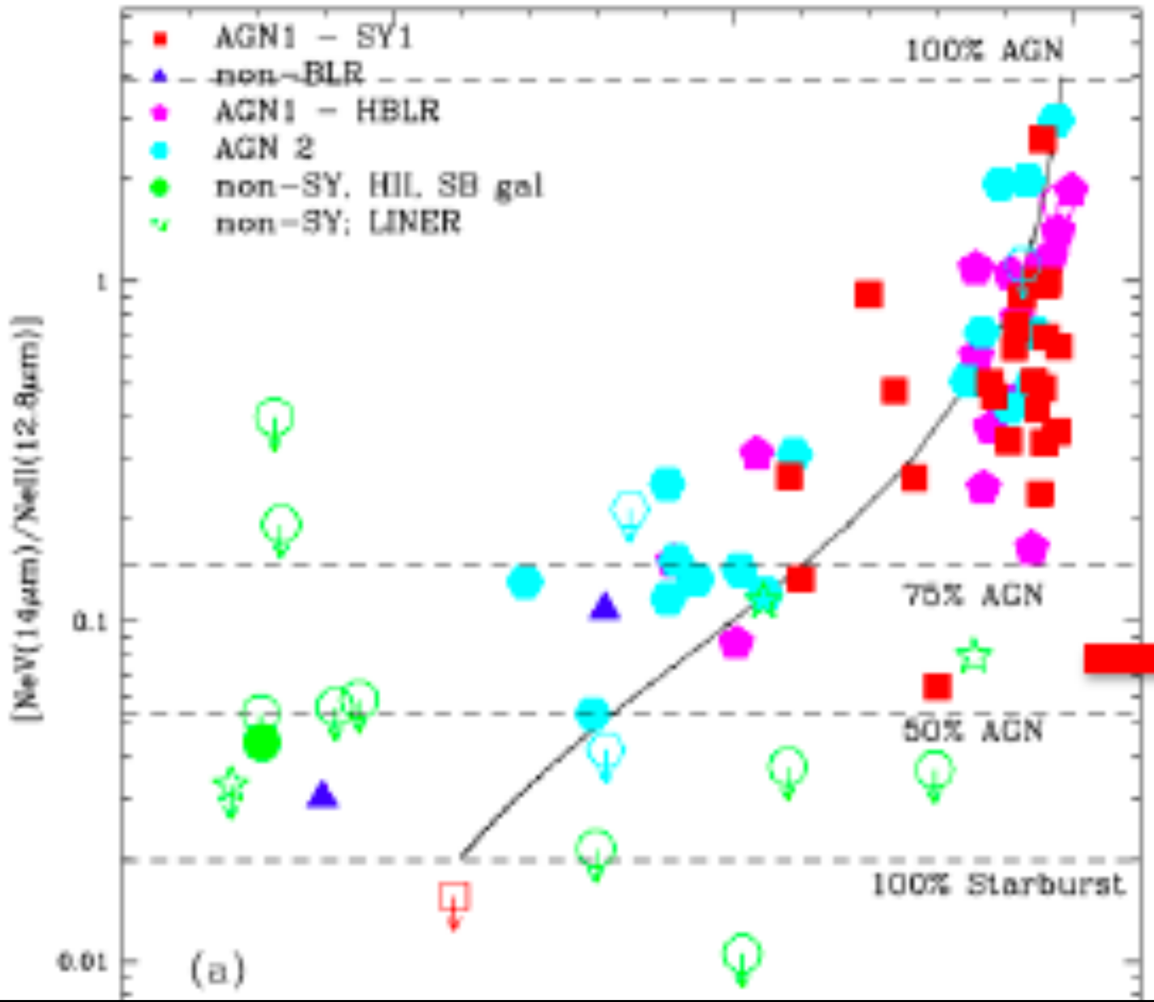


Groves+ **2006** (>10^5 galaxies)



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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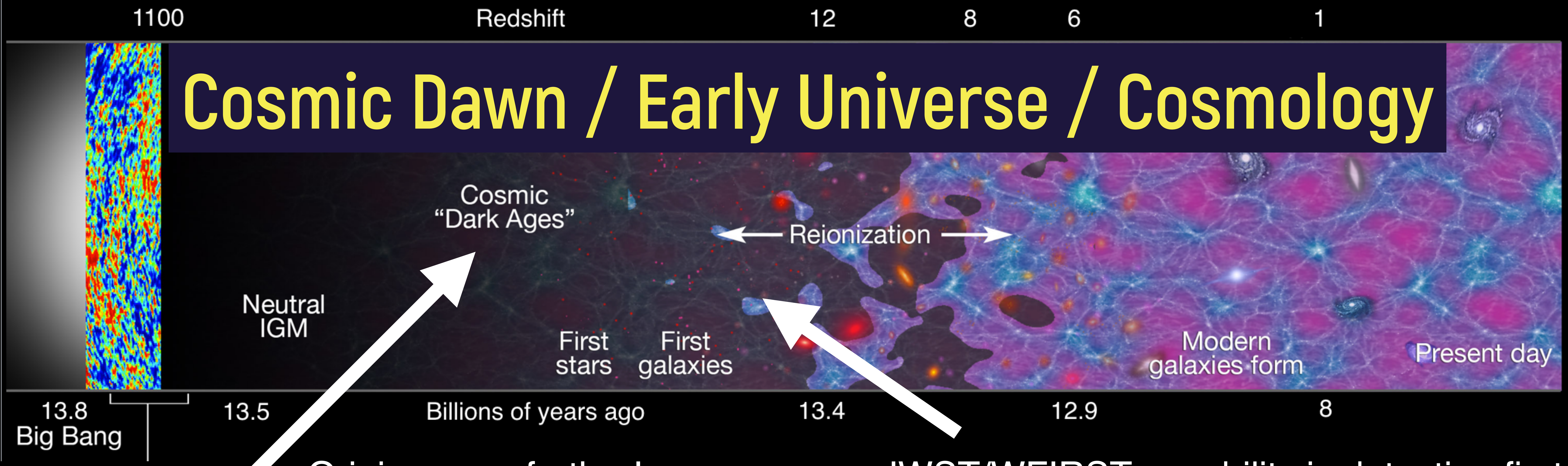
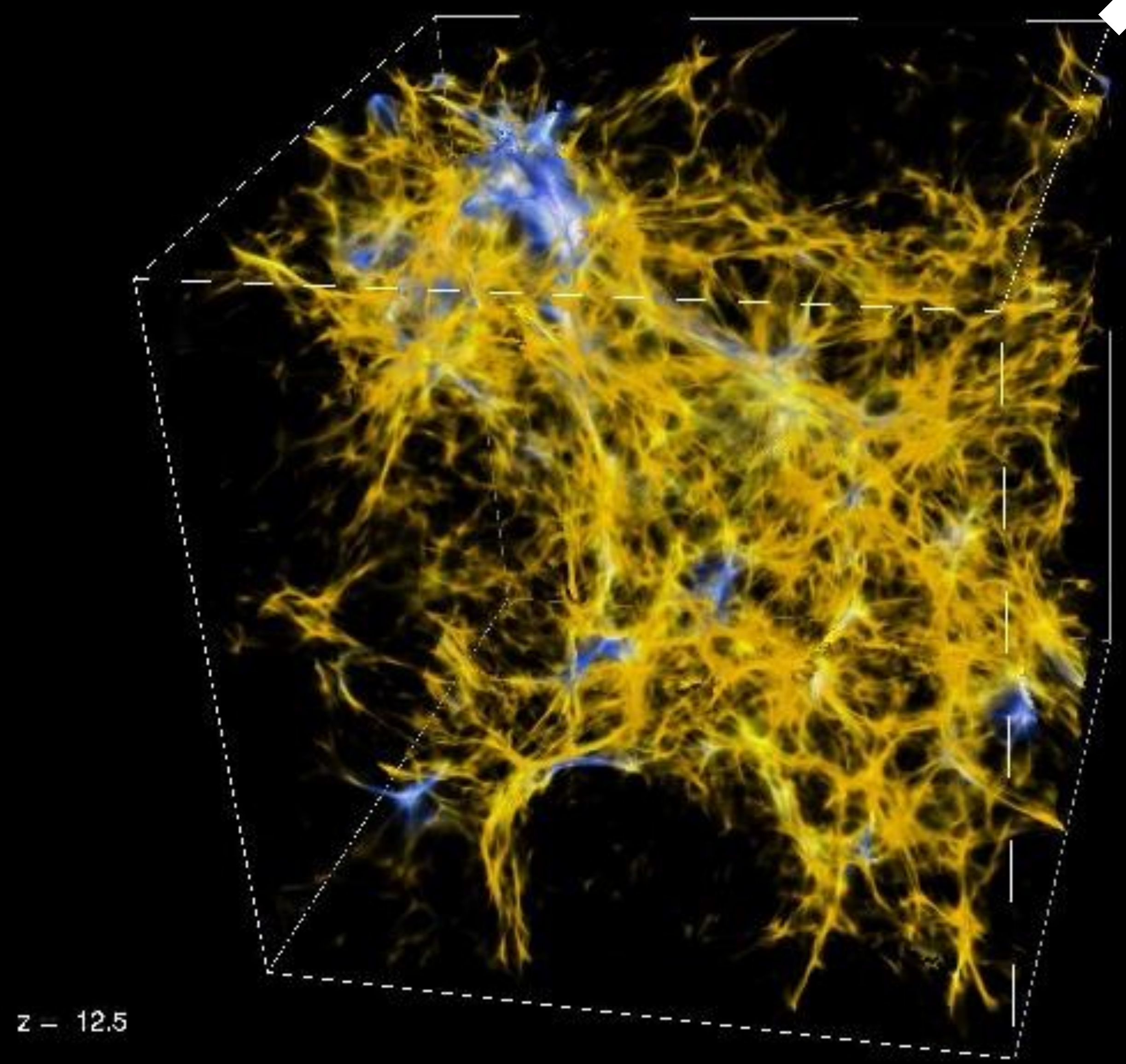


Origins goes further!

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)

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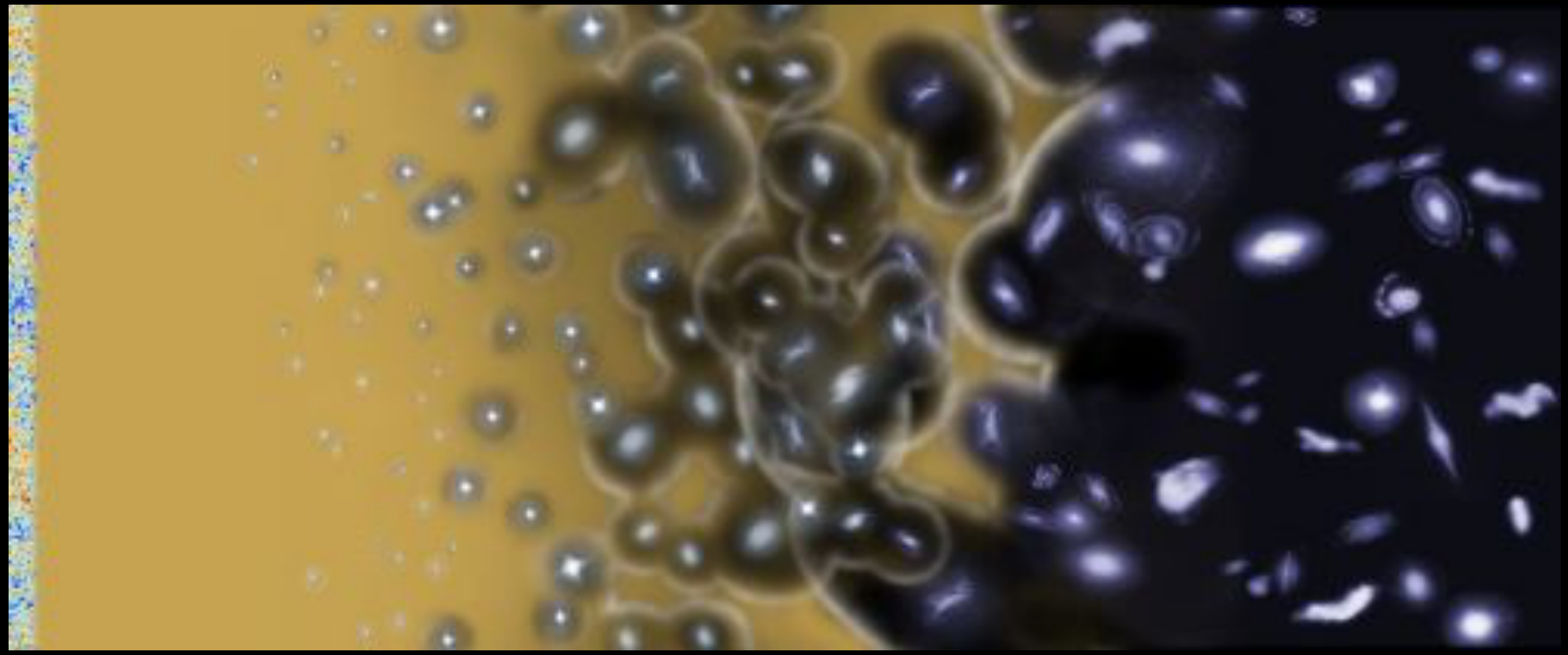
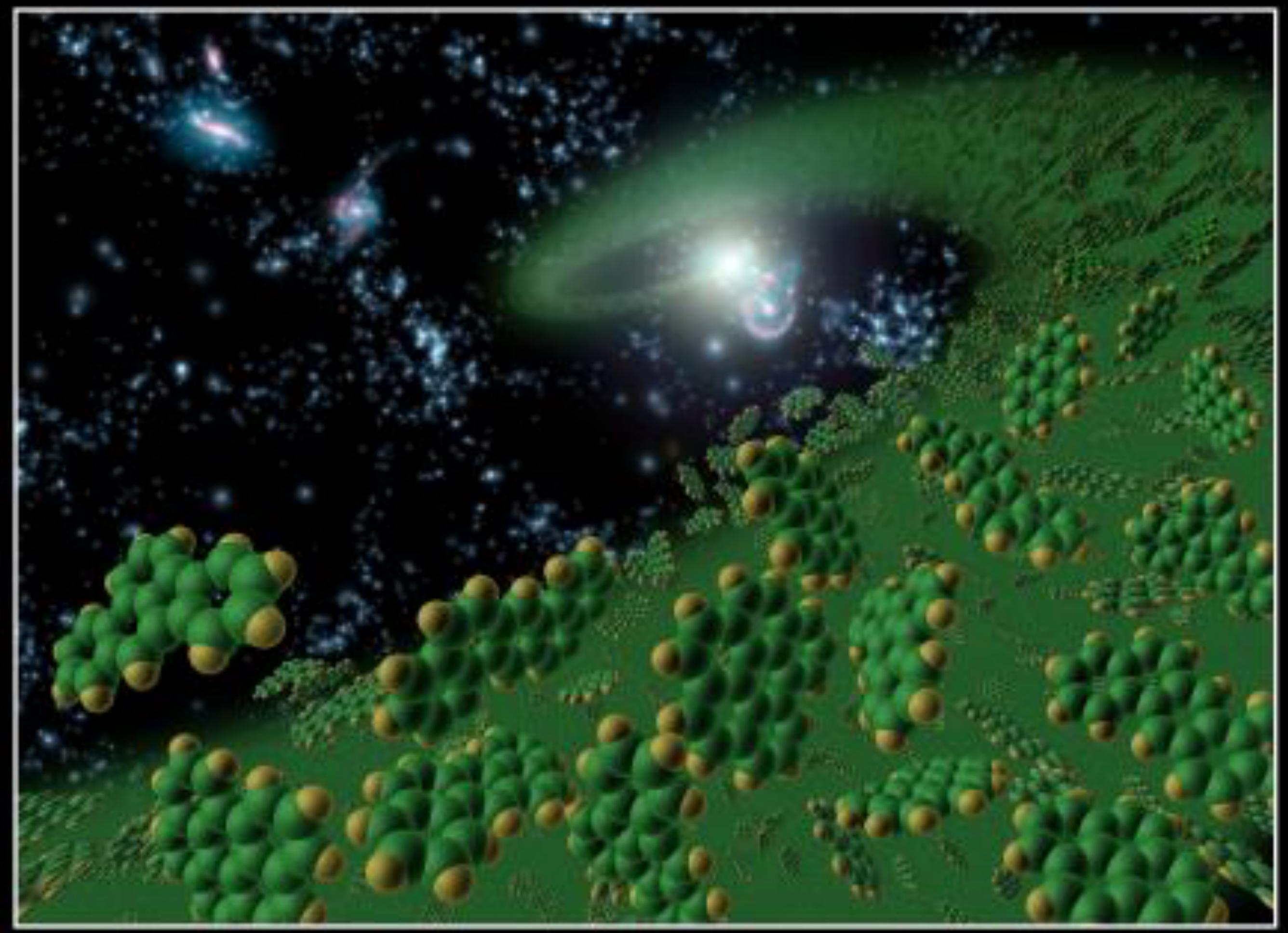
Tracing the signatures of life and the ingredients of habitable worlds

From cosmic origins and birth of galaxies

To habitable worlds in our Galaxy





200 Myr after Big Bang

Water in planets and Solar system

Trace the trail of water from interstellar clouds, to protoplanetary disks, to Earth

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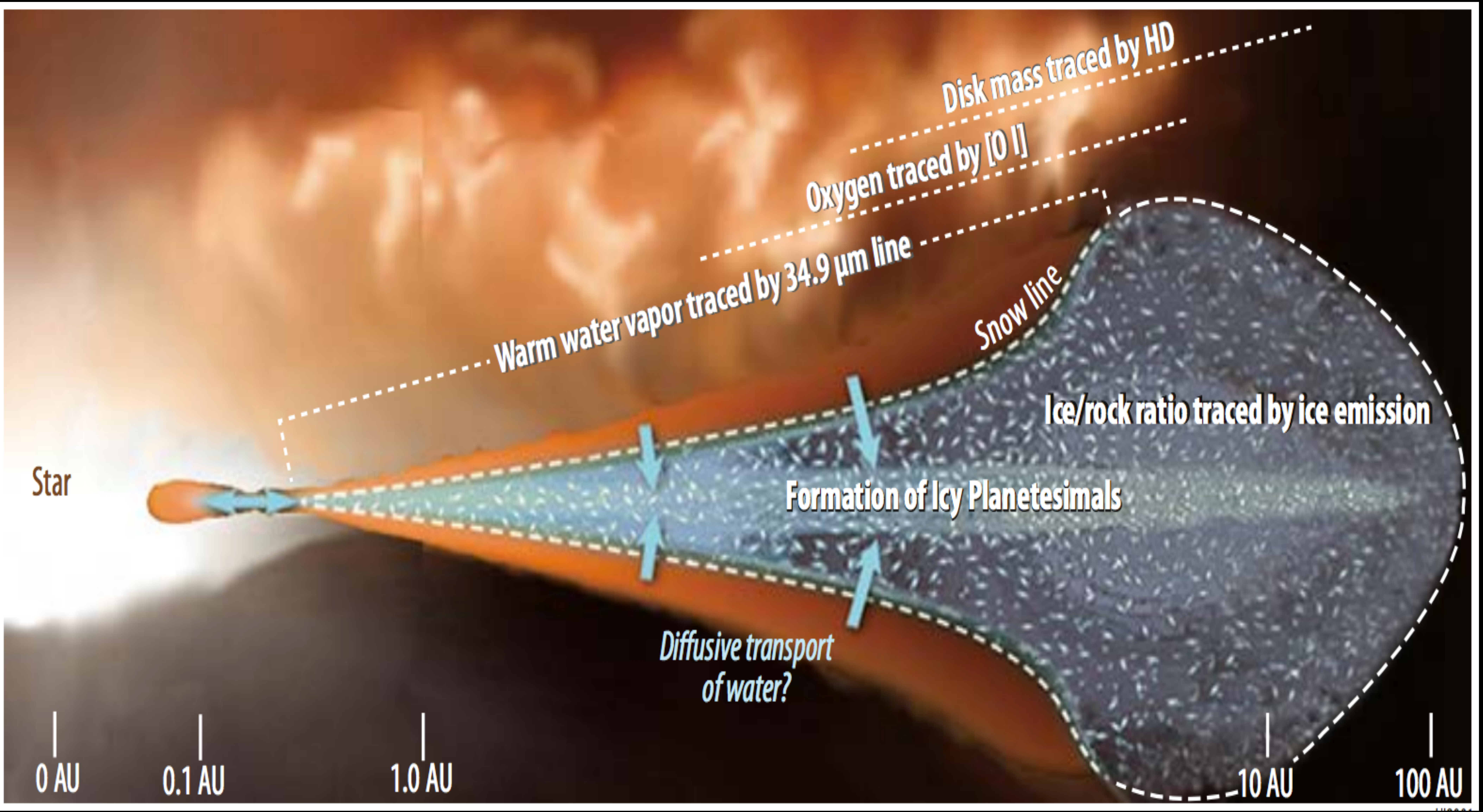

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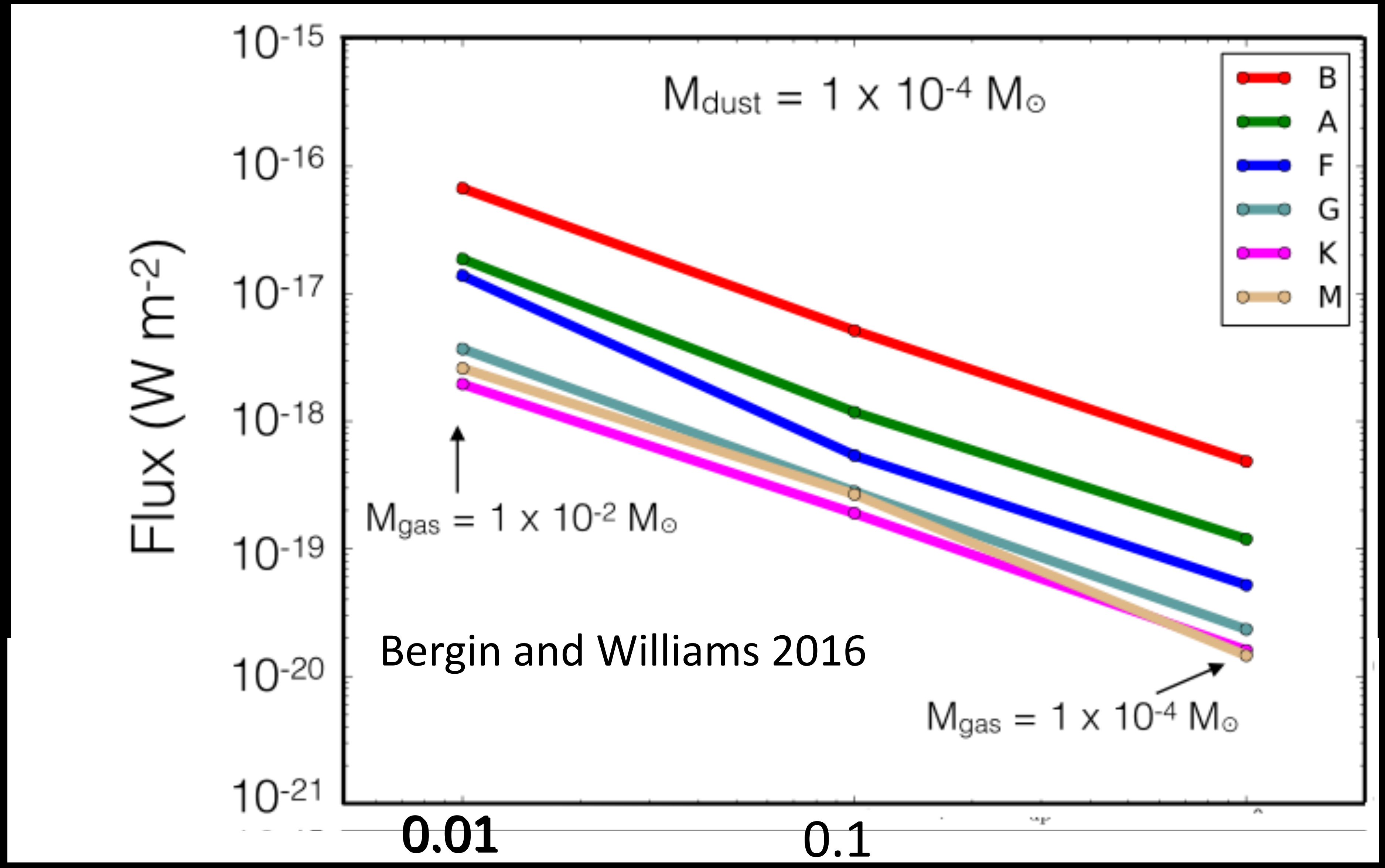
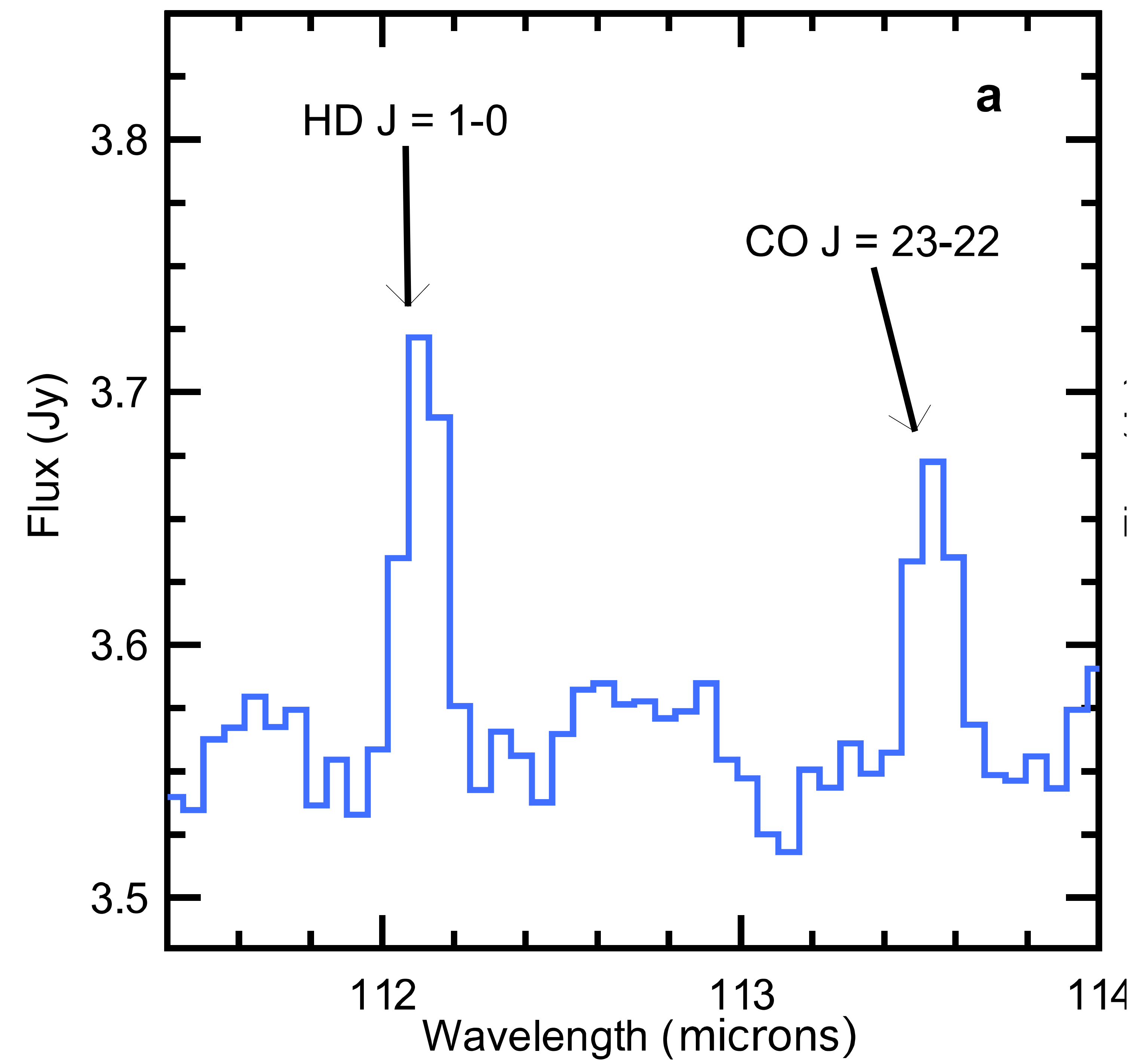
Probing the total gas content during the time of planet formation

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.**



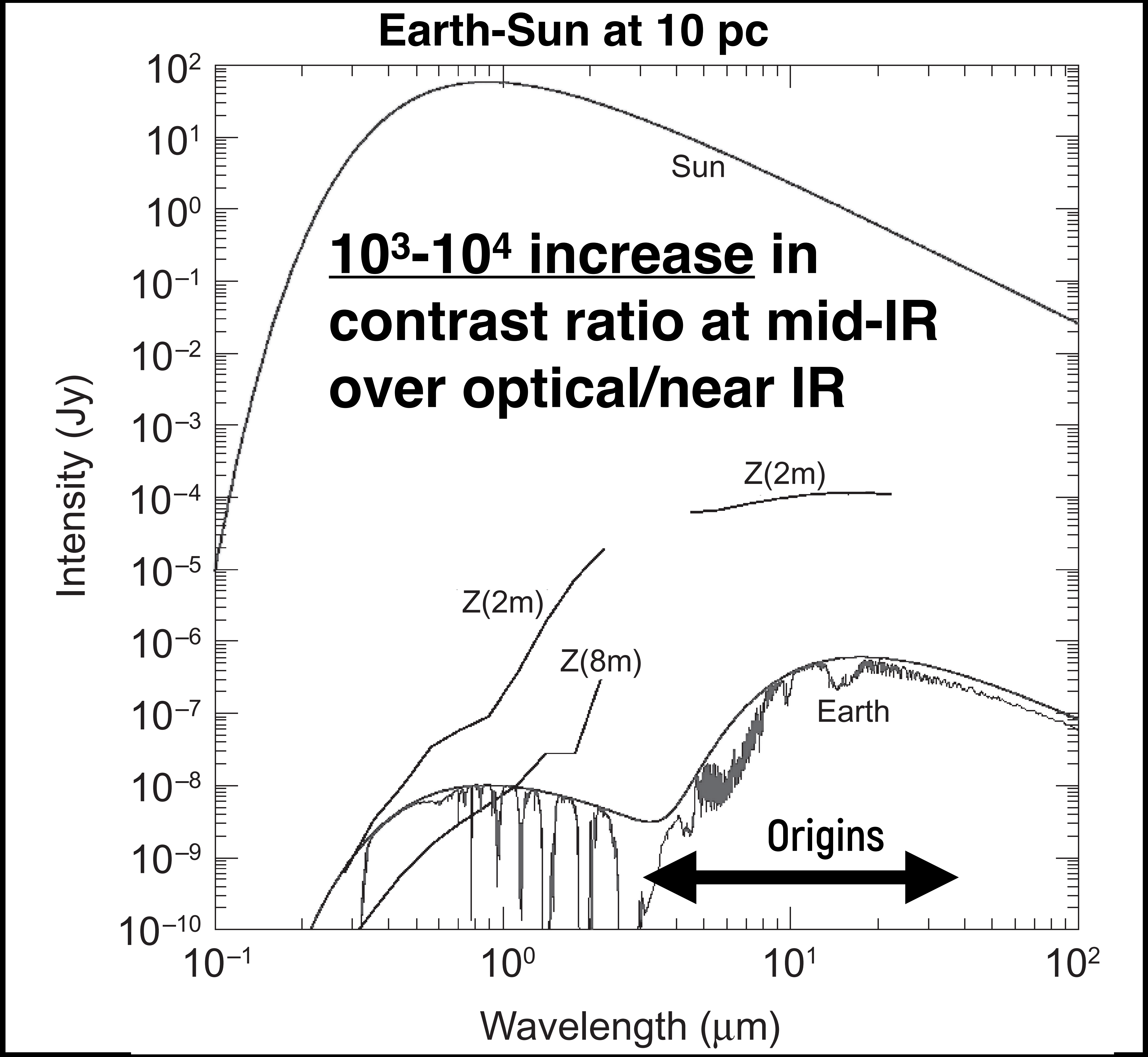
Dust to Gas Mass Ratio

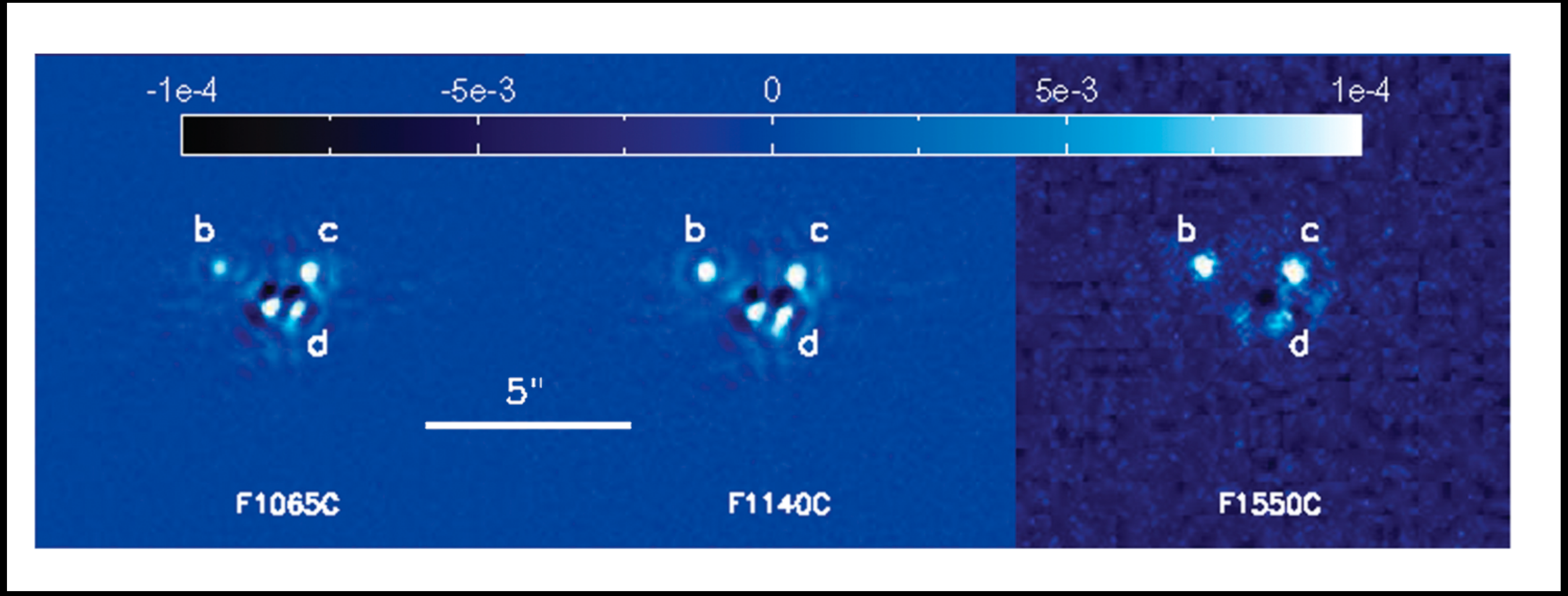


Herschel Detection of HD J = 1-0 towards TW Hya providing the first (semi)direct contraints on the gas mass (Bergin et al. 2013)

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

Direct imaging via a mid-IR coronagraph

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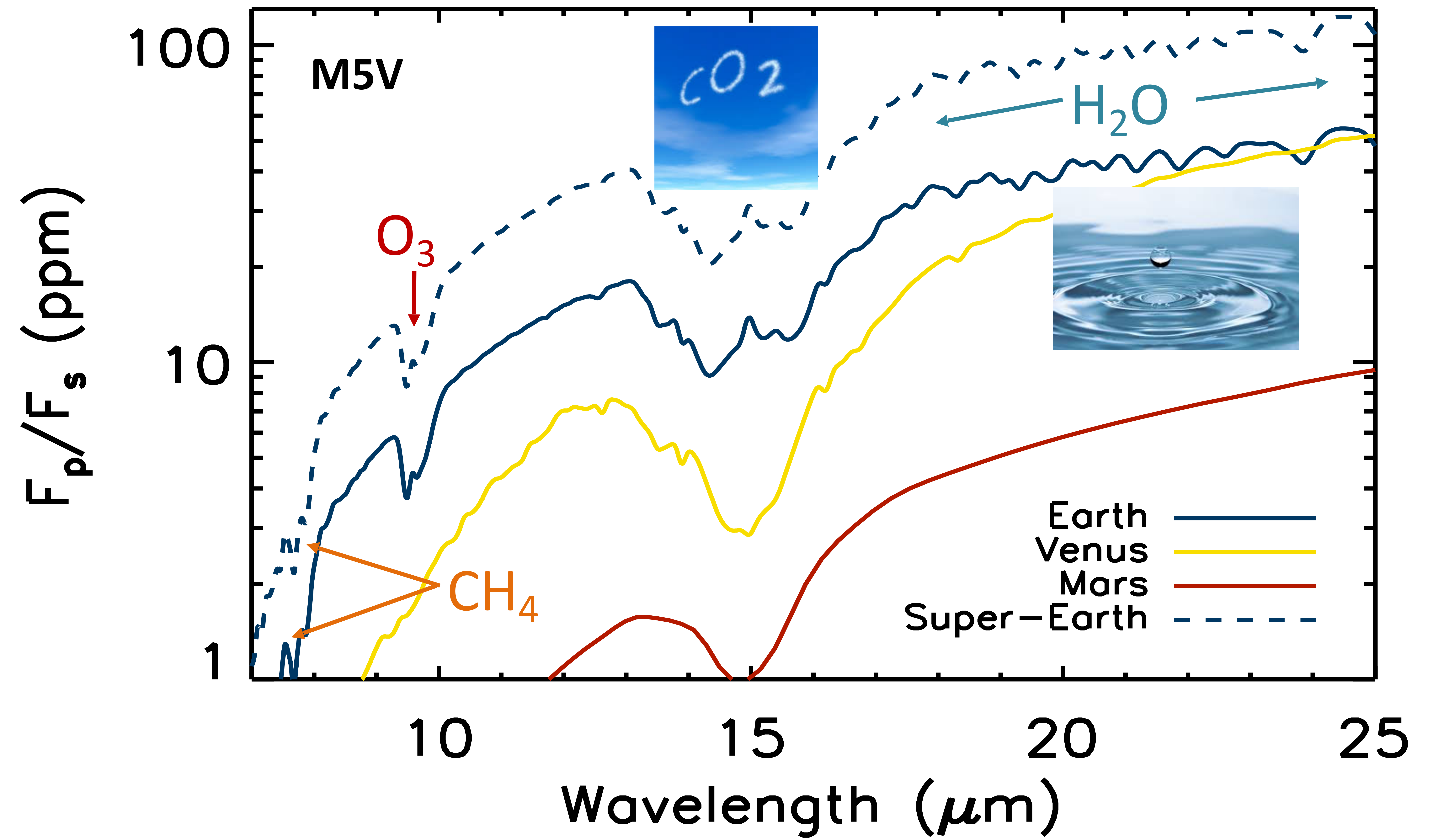
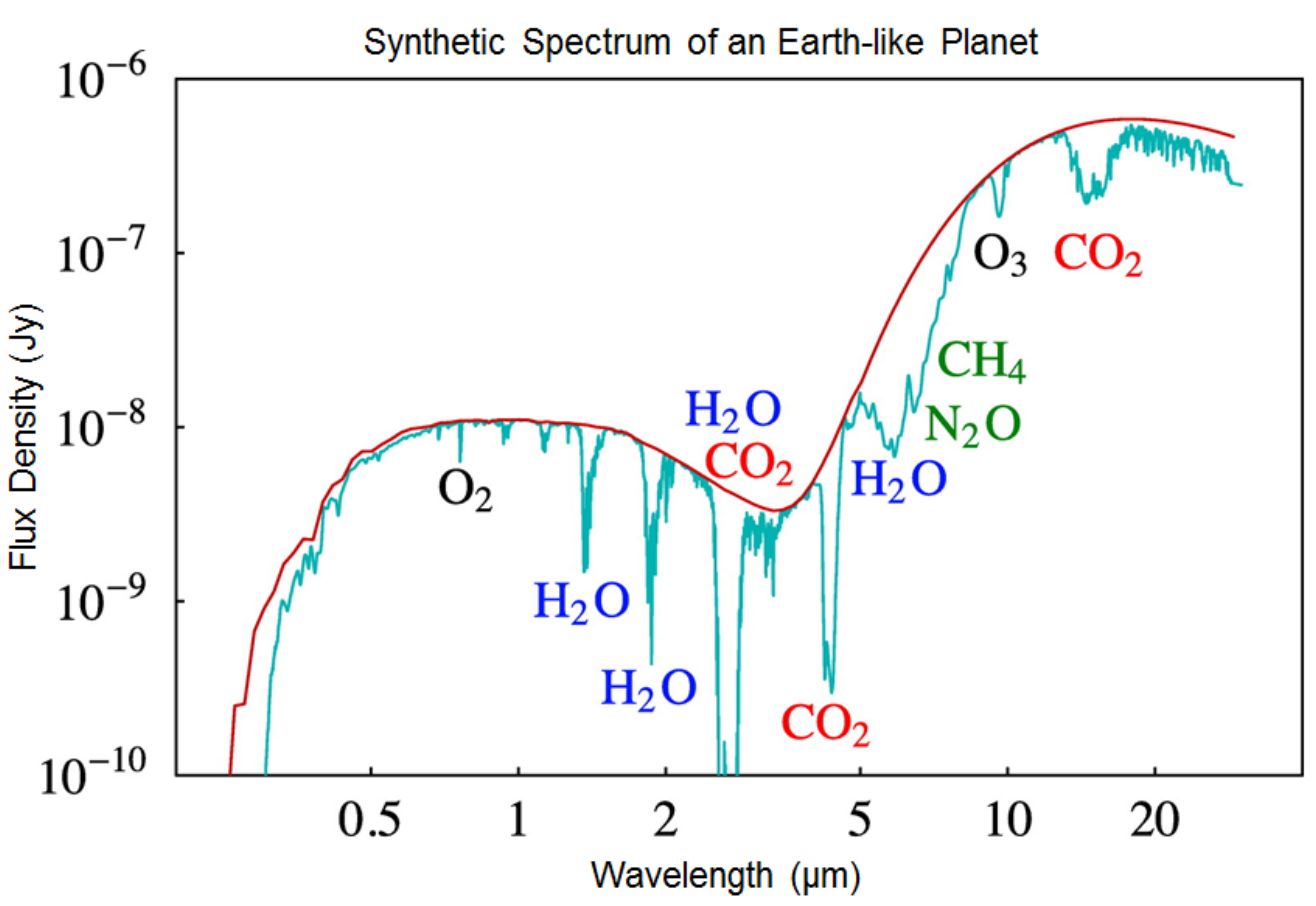
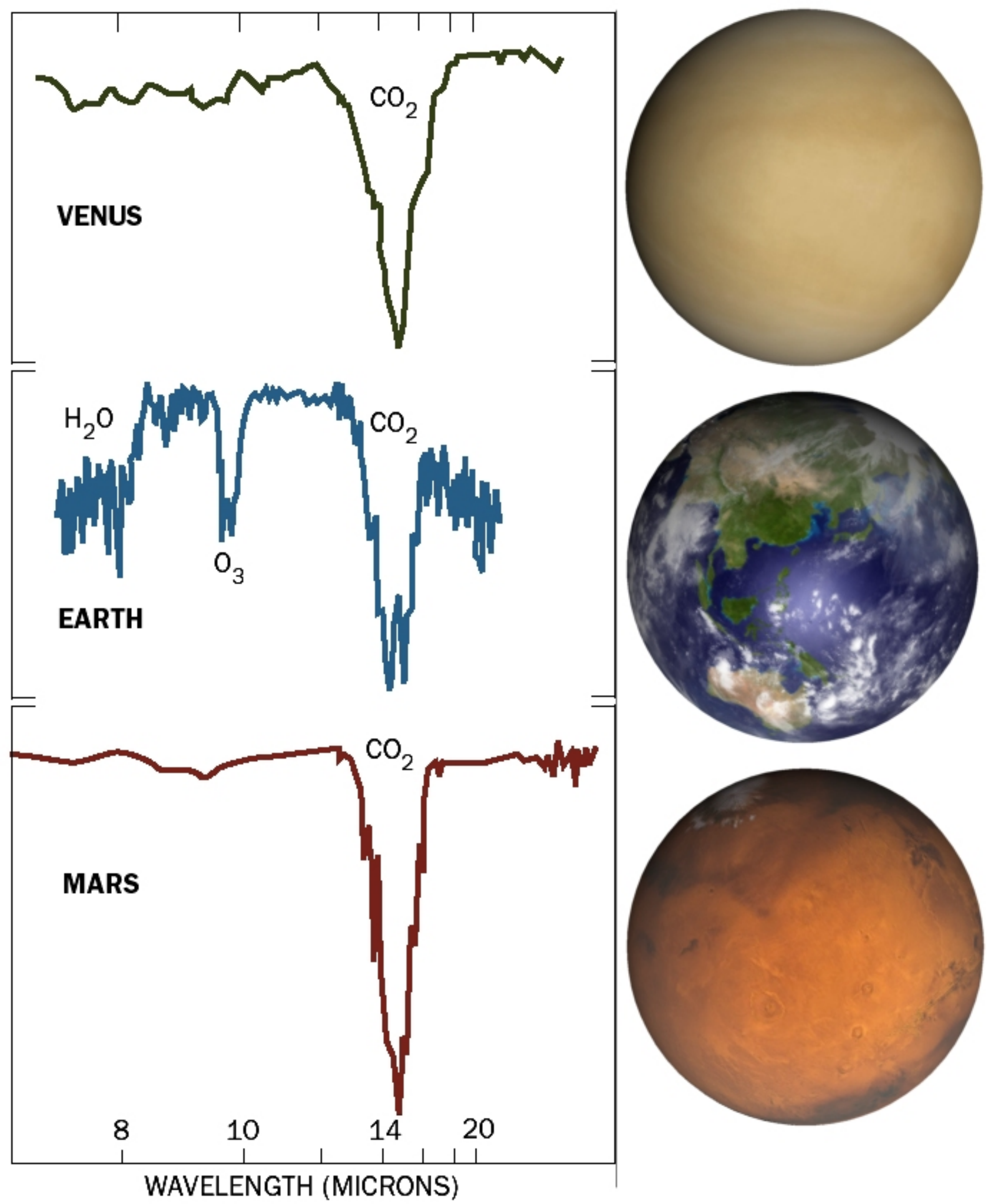
Signal Size for Habitable Zone for M Dwarf Planets



Weather and climate on exoplanets: Super Earths to Jupiters



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



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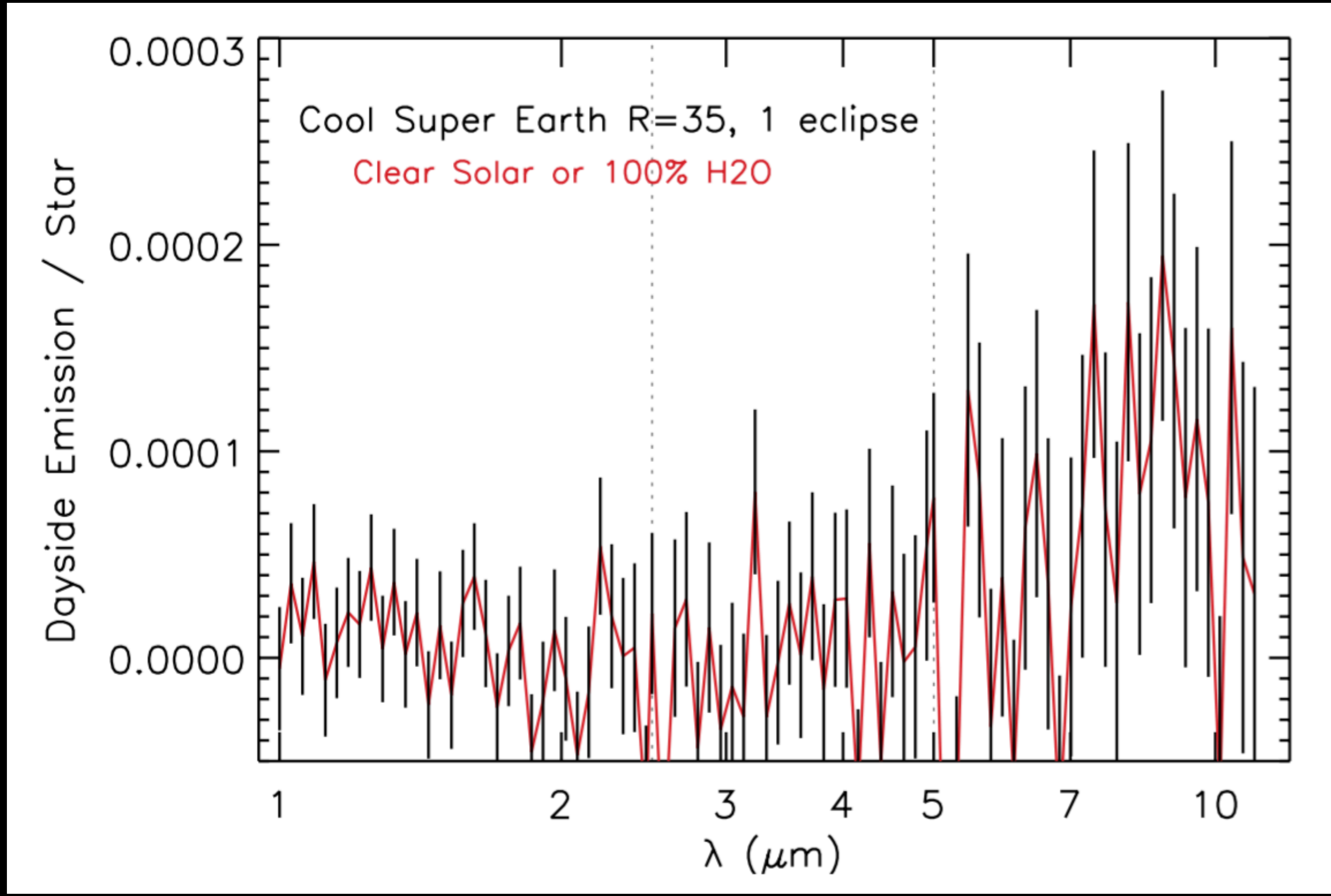
To detect biosignatures:

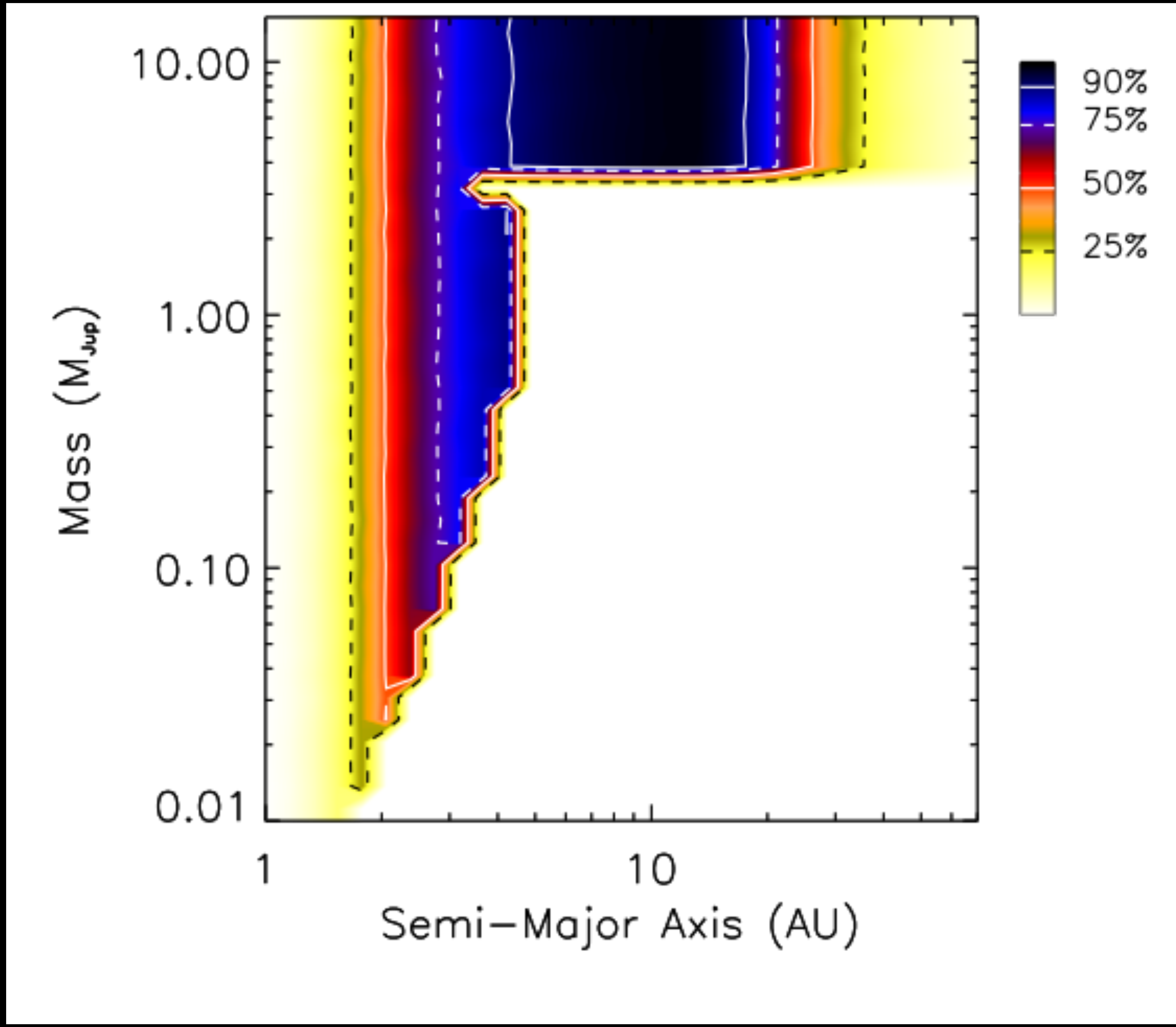
- Spectral resolving power (λ/Δλ) of 30-50
- Noise floors < 10 ppm
  - (M3V@20 pc – 2 hr at 7 µm)
- Key spectral signatures of Super-Earths that Origins will detect:
  - 9 µm for ozone (biosignature)
  - 7 µm for methane (life detection)

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



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

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

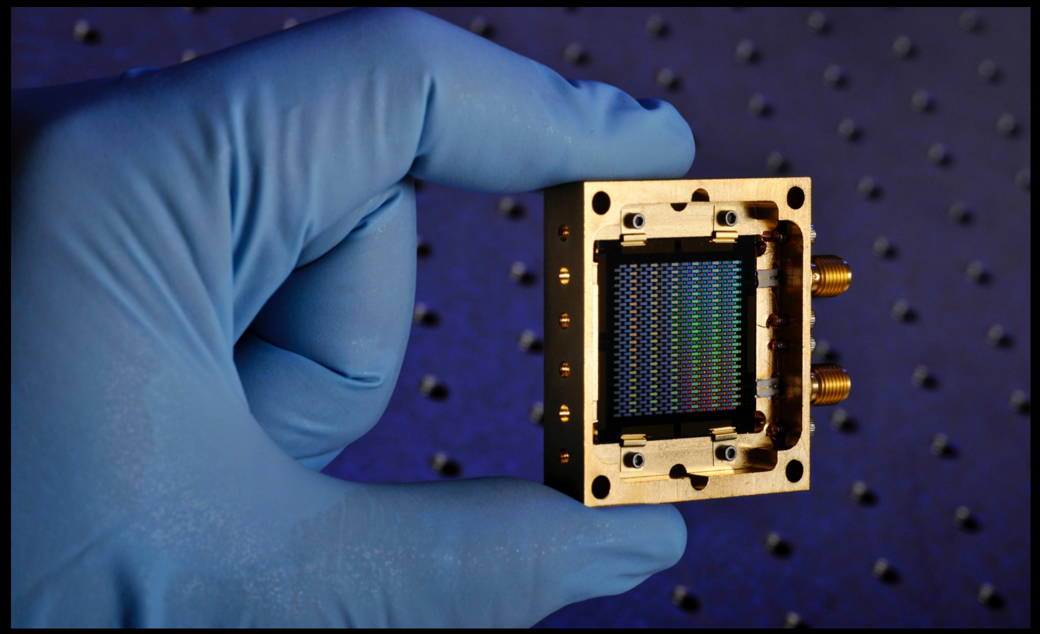
Kepler finds planets smaller than Neptune are ubiquitous close to their parent stars.

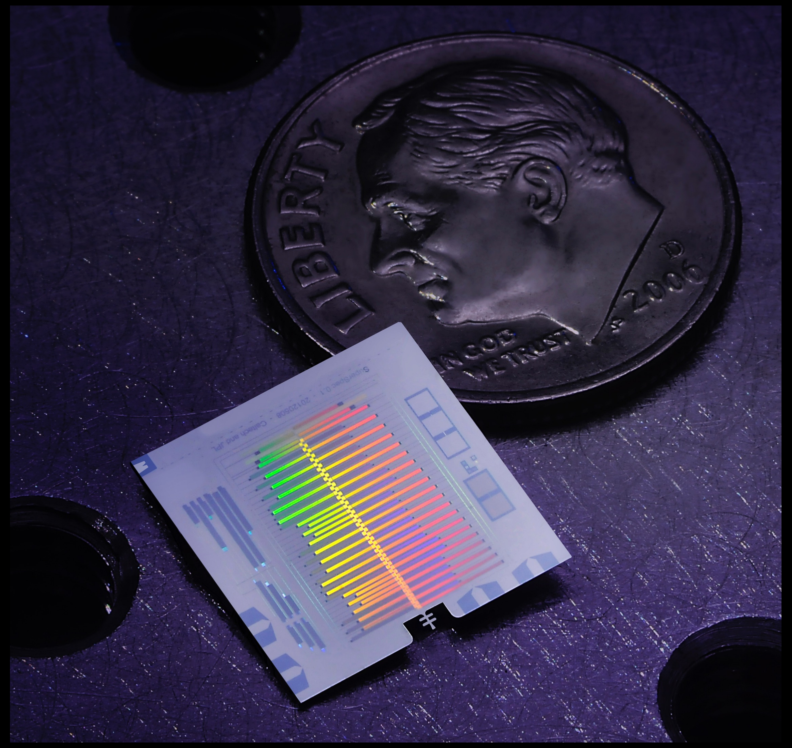
Near the habitable zone of the closest stars, the thermal emission of these planets can be bright enough to be seen behind the glare of their parent stars.

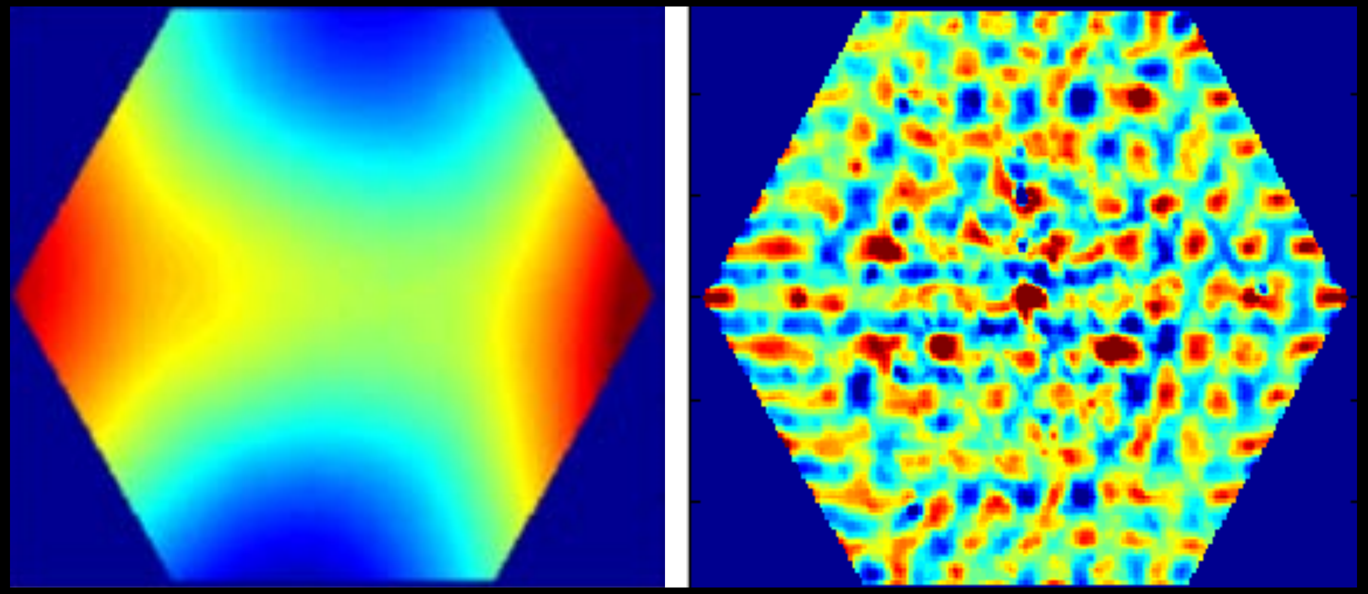
OST spectroscopy will allow us to directly probe the atmosphere and composition of these “Neptunes".

NEW TECHNOLOGIES ENABLE NEW CAPABILITIES TO EXPLORE OUR COSMIC ORIGINS

New Technology	New Capability
4.5-5K large optics/cryo actuation	Spectroscopic line sensitivity
Large Detector Arrays	Wide field imaging
Integrated Spectrometers	3D spectro-mapping
High-contrast mid-IR Coronagraph/stability-improved mid-IR detectors	Exoplanet Characterization

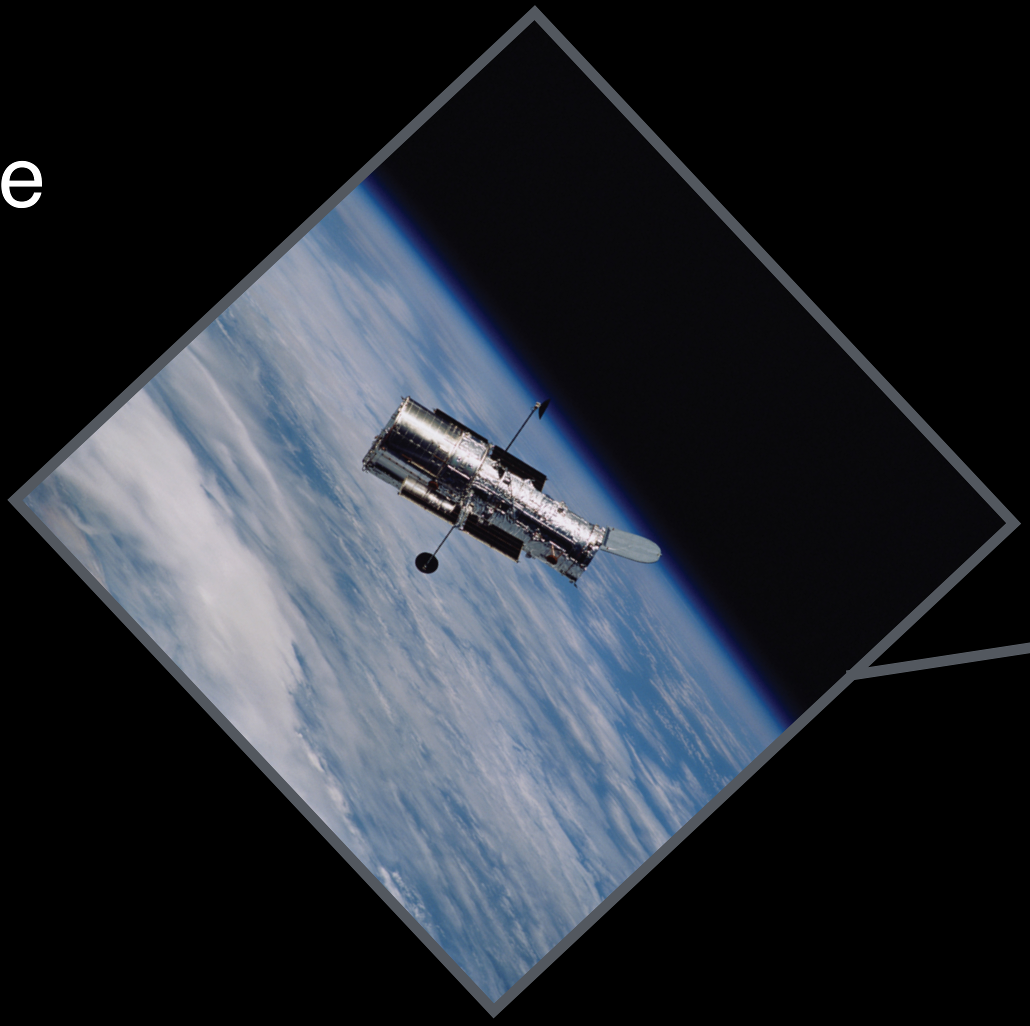




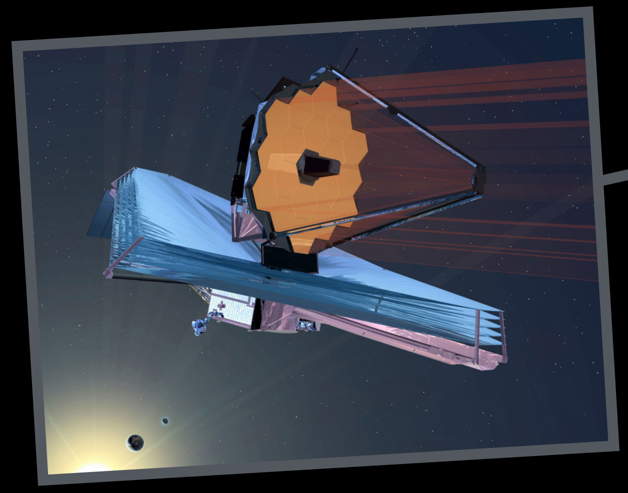


Study team is eager to partner with industry on key enabling technologies early on the mission design process.

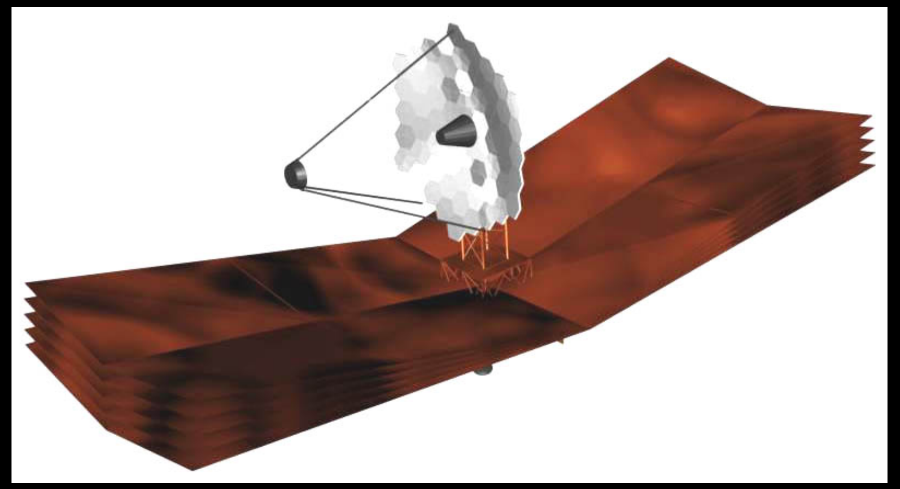
Hubble Space Telescope
1990—2025+
2.4 meter
0.1—2.4 µm
260 K



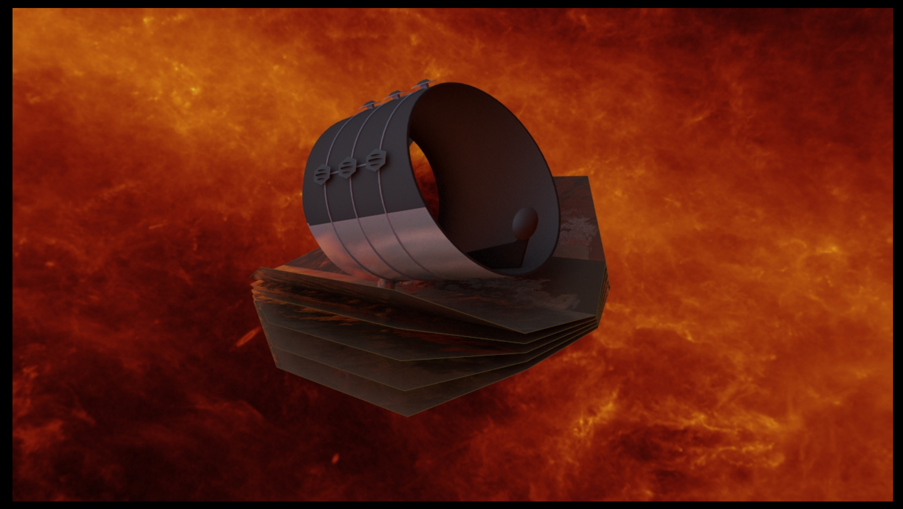
James Webb Space Telescope
2018—2028+
6.5 meter
0.6—27 µm
50 K



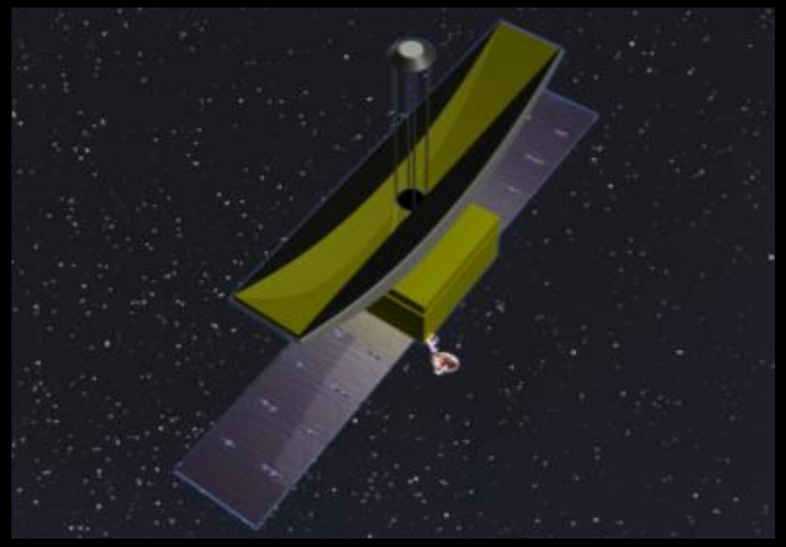
Origins Space Telescope
2020 Decadal
8-13m single aperture
5 —600+ µm
4.5 K active-cooled



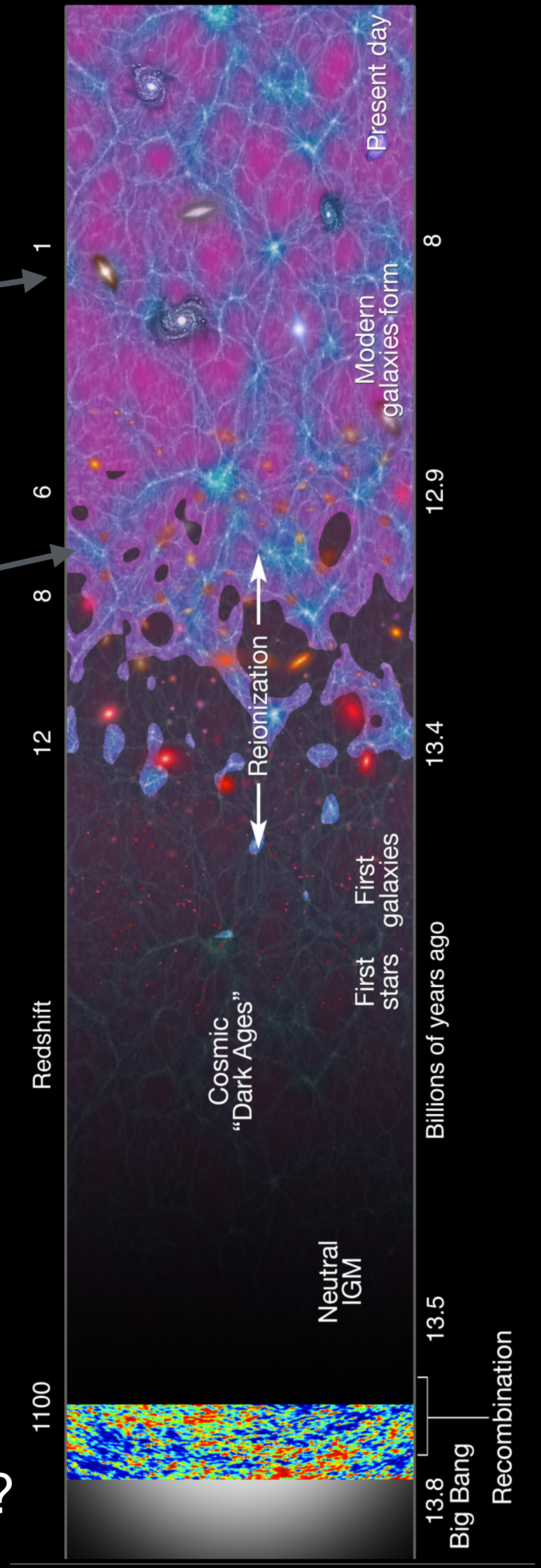
JWST-like?



Spitzer-like?



Rotating aperture?



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.

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

Join us, Follow us @NASAOriginsTelescope

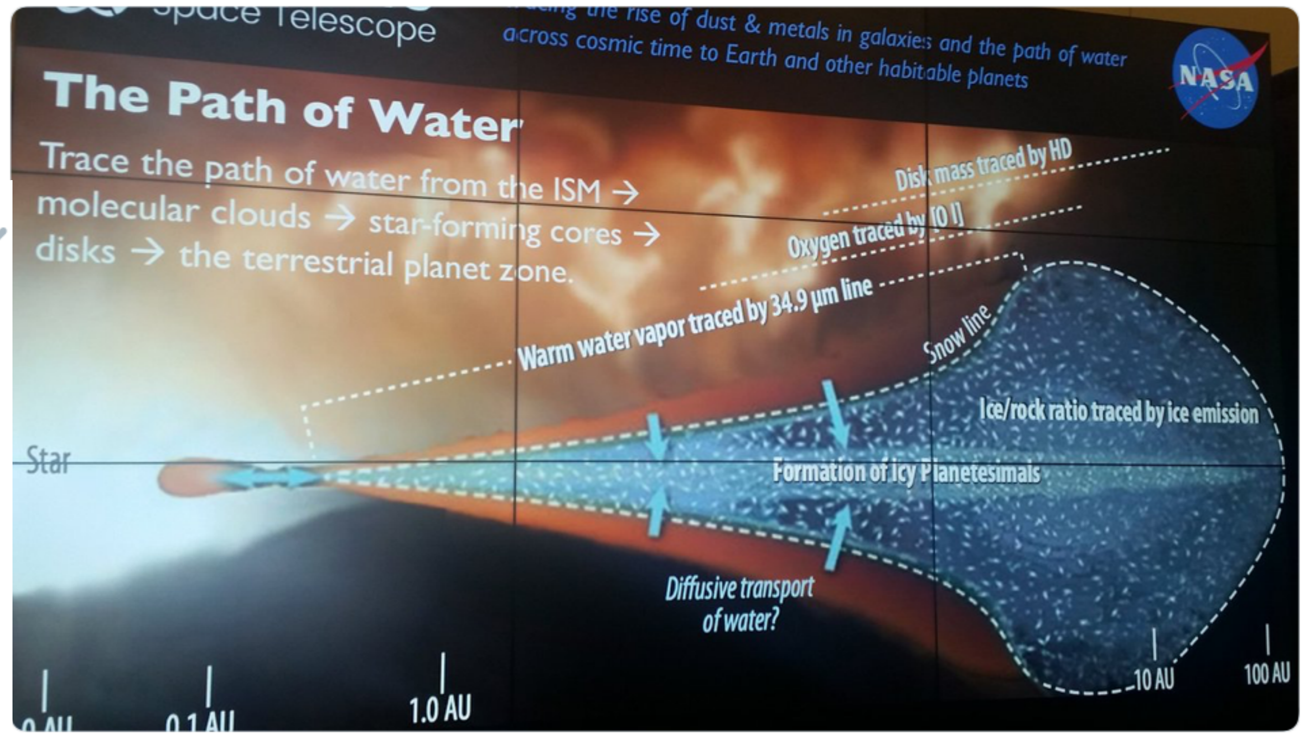
- Our science working groups and instrument teams are open to the community.

NASAOriginsTelescope @NA... ·6h
Grand prize for the #OST scavenger hunt has been awarded to @aussiastronomer! Four prizes remain, find words on our feed to win! #AAS229

NASAOriginsTelescope @NA... ·9h
McKee: "The major discoveries are often things you weren't even looking for - OST has amazing discovery potential"

NASAOriginsTelescope @NA... ·9h
Community panel on Far-IR Science now in San Antonio 1 #AAS229 right now, featuring McKee, Bradford, Fissel, Pontoppidan, Mather, Oberg

importance of the snow line with #OST @chathull @NASAHyperwall #AAS229



1 1

NASAOriginsTelescope @NA... ·9h
#OST will uniquely be able to simultaneously measure star formation, black hole accretion, and galactic feedback over cosmic time #AAS229