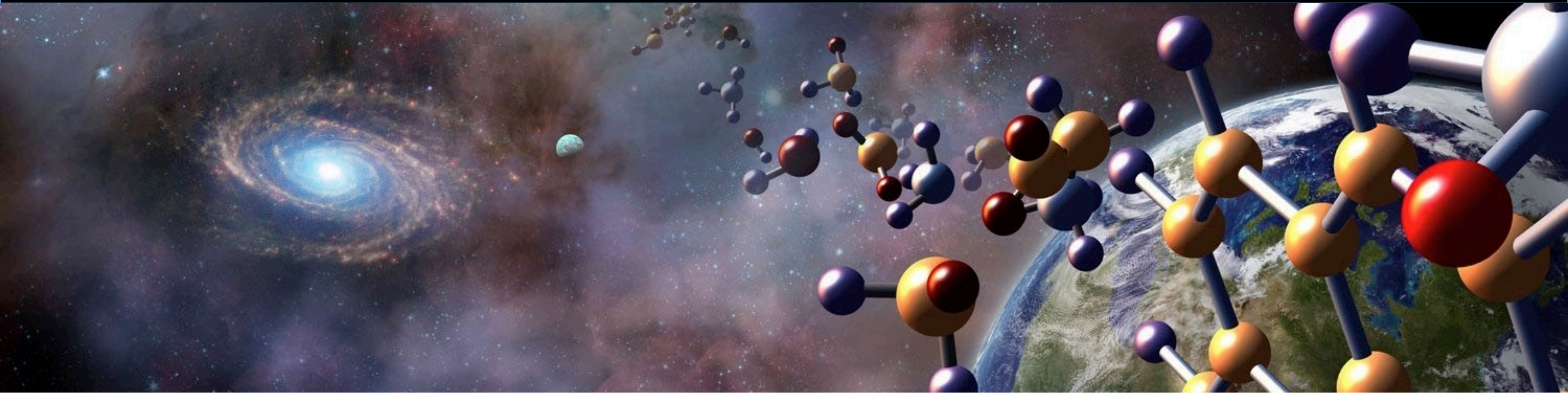
ORIGINS Space Telescope

From the Rise of Metals to Water for Habitable Worlds



Margaret Meixner

Space Telescope Science Institute,

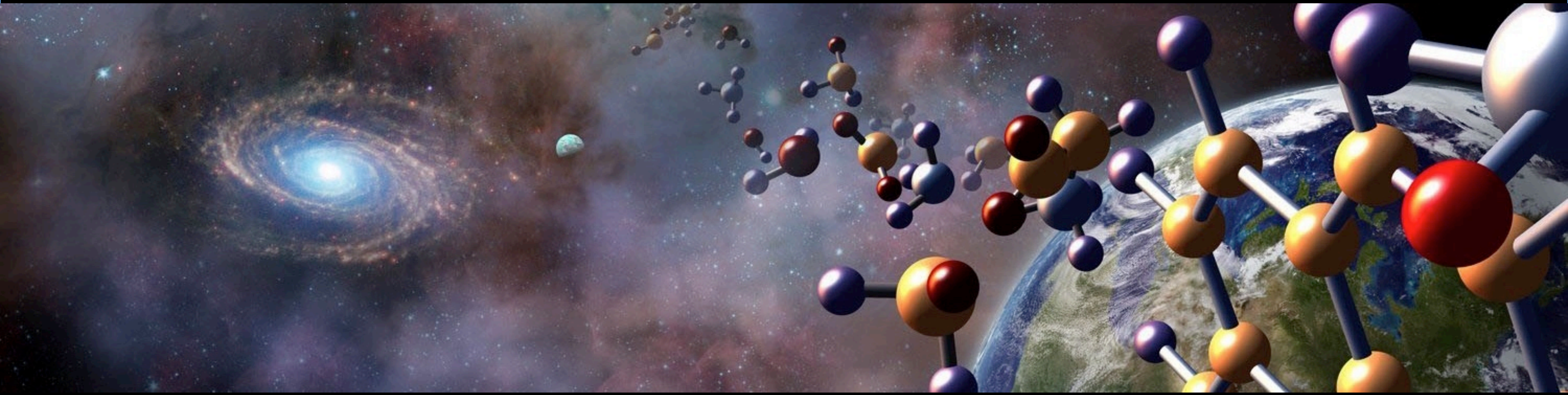
Johns Hopkins University

on behalf of the FIRS Science Technology Definition Team

asd.gsfc.nasa.gov/firs

ORIGINS Space Telescope

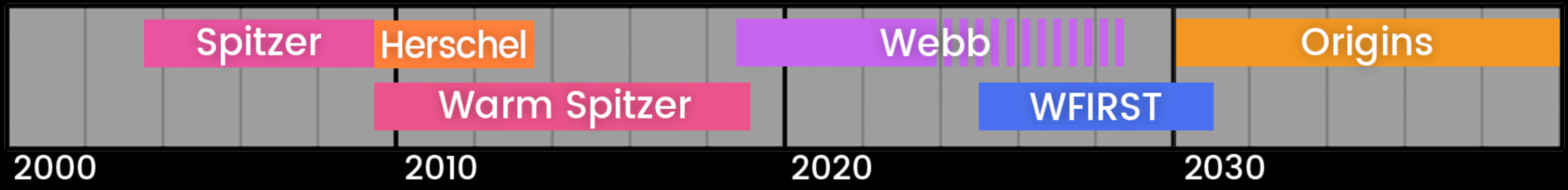
From the Rise of Metals to Water for Habitable Worlds



NASA Mission concept for 2020 Decadal review; launch 2030ish

6 µm – 1000 µm (ish), Large aperture 8-15 m

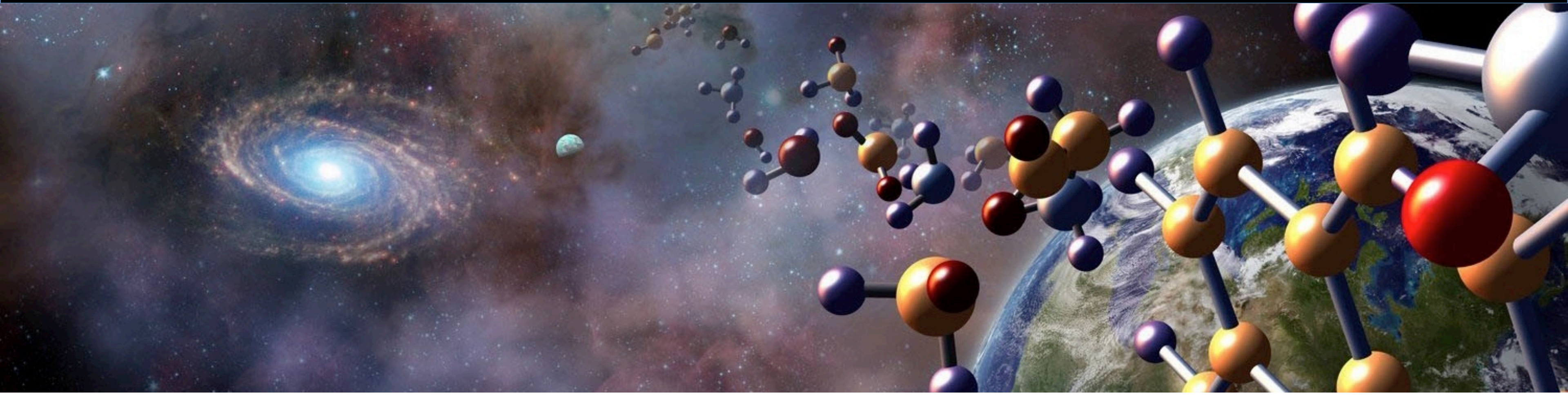
Study Chairs: Margaret Meixner & Asantha Cooray



ORIGINS Space Telescope

From the Rise of Metals to Water for Habitable Worlds

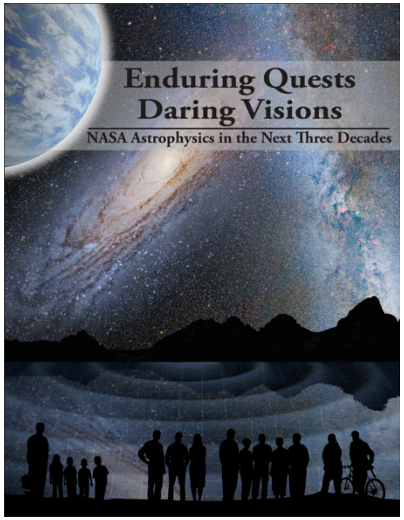
NASA



NASA Mission concept for 2020 Decadal review; launch 2030ish

10 µm – 1000 µm (ish), Large aperture 8-15 m

Study Chairs: Margaret Meixner & Asantha Cooray



Comes from the NASA Astrophysics Roadmap, Enduring Quests, Daring Visions

ORIGINS Space Telescope

From the Rise of Metals to Water for Habitable Worlds

NASA

Community Chairs:

Margaret **Meixner,** STSCI, Asantha **Cooray**, UC Irvine

NASA Study Center:

Goddard Space Flight Center (GSFC): Ruth **Carter,** David **Leisawitz,** Johannes **Staguhn,** Michael **Dipirro**, Anel **Flores,** Joseph **Howard**, James **Corsetti**, Andrew **Jones**, James **Kellog**, Louis **Fantano**

NASA Head Quarters (HQ) Program Scientists (non-voting):

Kartik **Sheth** and Dominic **Benford**

Ex officio non-voting 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; Sean **Carey**, IPAC

Members appointed by NASA (> 90 applications):

Lee **Armus**, NASA IPAC; Cara **Battersby**, Harvard-Smithsonian CfA; Edwin **Bergin**, University of Michigan; Matt **Bradford**, NASA JPL; Kim **Ennico-Smith**, NASA Ames; Gary **Melnick**, Harvard-Smithsonian CfA; Stefanie **Milam**, NASA GSFC; Desika **Narayanan**, University of Florida; Klaus **Pontopiddan**, STSCI; Alexandra **Pope**, University of Massachusetts; Thomas **Roellig,** NASA Ames; Karin **Sandstrom**, UC, San Diego; Kate Y. L. **Su**, University of Arizona; Joaquin **Vieira,** University of Illinois, Urbana Champaign; Edward **Wright,** UC Los Angeles; Jonas **Zmuidzinas**, Caltech

ORIGINS Space Telescope

From the Rise of Metals to Water for Habitable Worlds

NASA

Community Chairs:

Margaret **Meixner,** STSCI, Asantha **Cooray**, UC Irvine

NASA Study Center:

Goddard Space Flight Center (GSFC): Ruth **Carter,** David **Leisawitz,** Johannes **Staguhn,** Michael **Dipirro**, Anel **Flores,** Joseph **Howard**, James **Corsetti**, Andrew **Jones**, James **Kellog**, Louis **Fantano**

NASA Head Quarters (HQ) Program Scientists (non-voting):

Kartik **Sheth** and Dominic **Benford**

ORIGINS Space Telescope

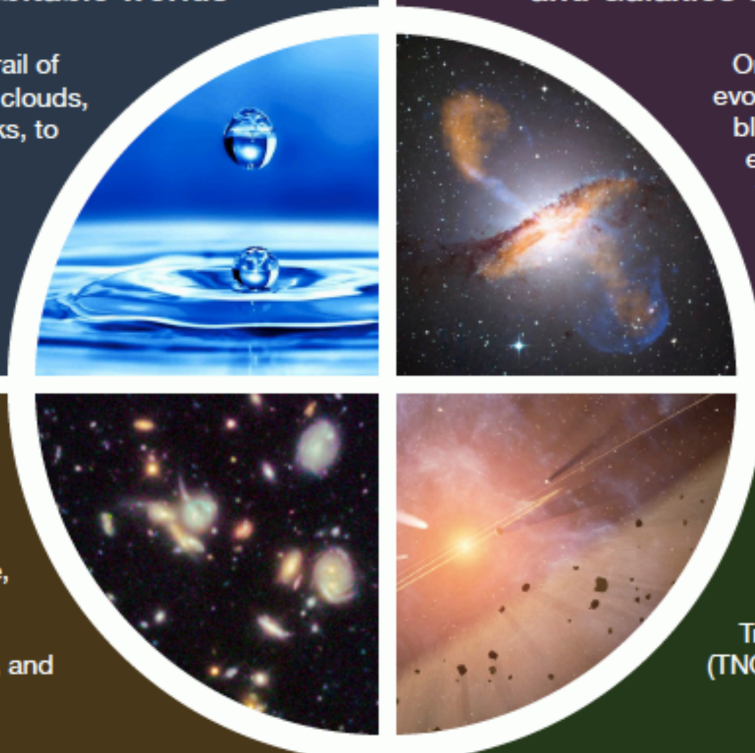
From the Rise of Metals to Water for Habitable Worlds

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.

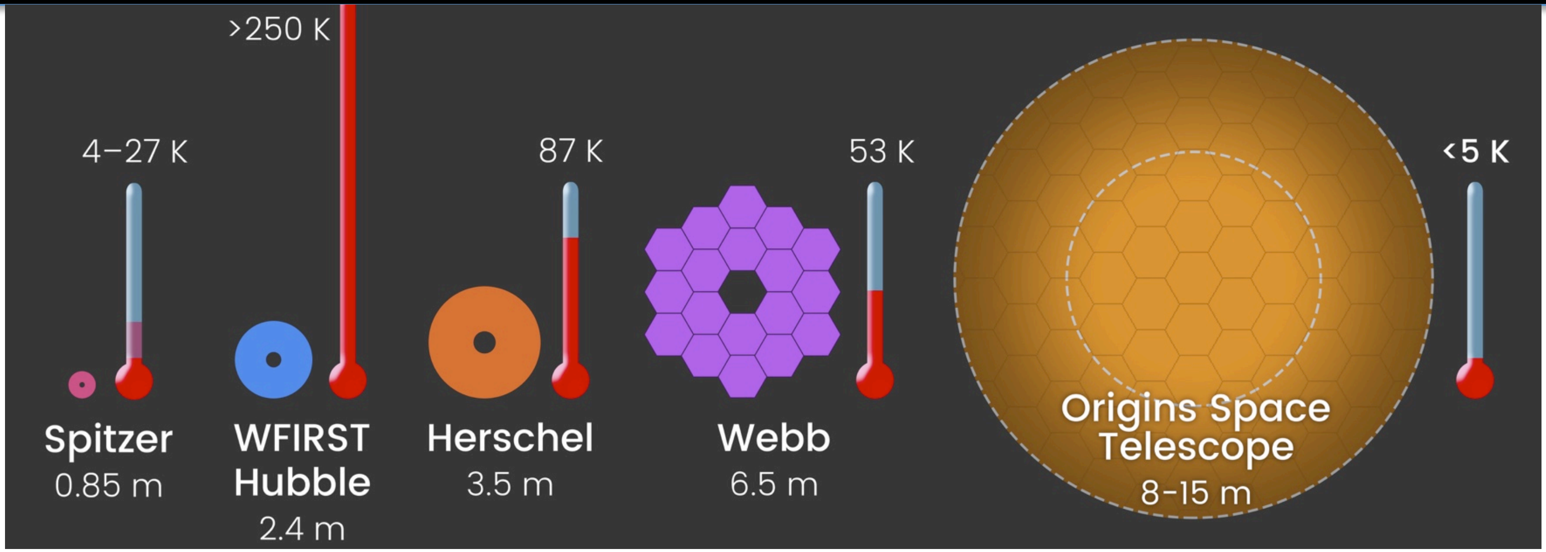


Origins will trace the metal enrichment history of the Universe, probe the first cosmic sources of dust, the earliest star formation, and the birth of galaxies.

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



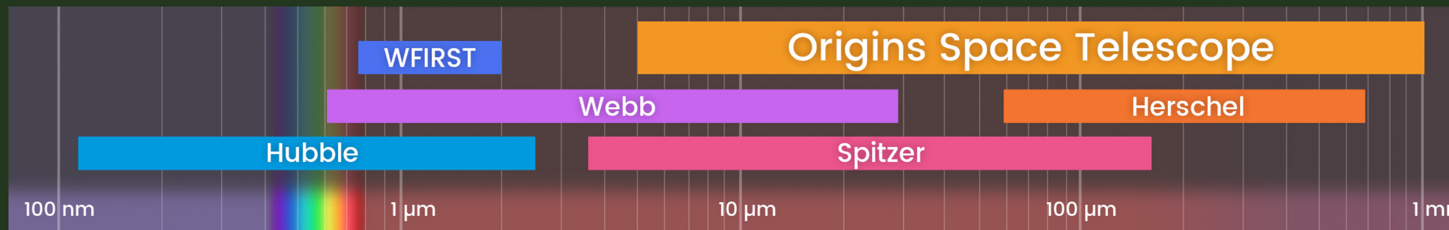
Telescope Parameters

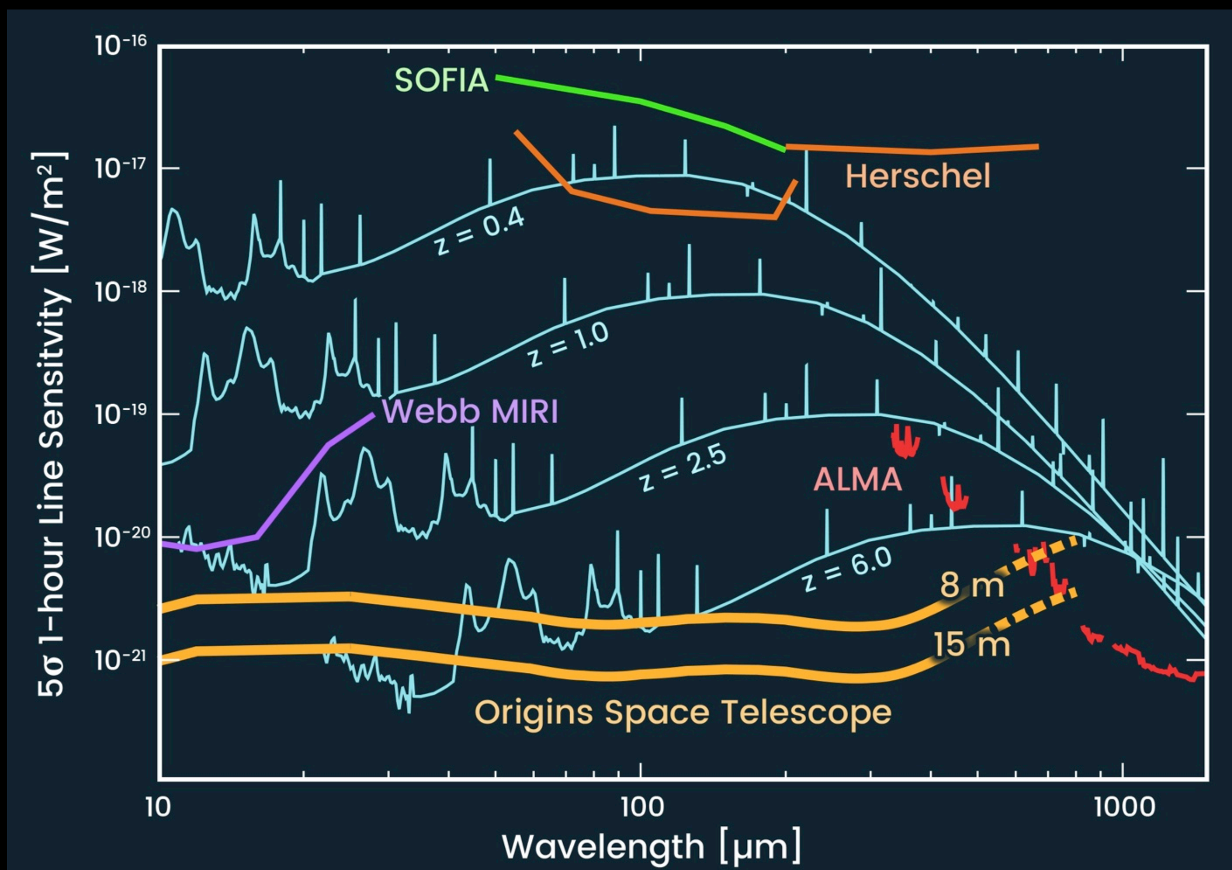
Aperture Diameter	FOV	Diffraction Limited at	Temperature
8-15 m	0.5-1 square degree	40 µm	~4 K

ORIGINS Space Telescope

Technical Definition

Potential Wavelength Coverage from 5 μm–1 mm





Instrument Specifications					
Instrument	Wavelength Coverage µm	Spectral Resolution (λ/Δλ)	Field of view #spatial pixels	Typical Required Sensitivity:	Other

Instrument Specifications					
Instrument	**Wavelength Coverage µm**	**Spectral Resolution (λ/Δλ)**	**Field of view #spatial pixels**	**Typical Required Sensitivity:**	**Other**
Low-Res Spectrometer	35 to 500	low-res~500 high-res~10^4	100 per channel	10^{-21} W/m^2 (spectral line)	multi-channel

Instrument Specifications					
Instrument	Wavelength Coverage µm	Spectral Resolution (λ/Δλ)	Field of view #spatial pixels	Typical Required Sensitivity:	Other
Low-Res Spectrometer	35 to 500	low-res~500 high-res~10^4	100 per channel	10^{-21} W/m^2 (spectral line)	multi-channel
High-Res Spectrometer	50 to 500	low-res ~ 8x10^4 high-res~5x10^5	100	10^{-21} W/m^2 5 σ (spectral line)	photo-counting

Instrument Specifications					
Instrument	**Wavelength Coverage µm**	**Spectral Resolution (λ/Δλ)**	**Field of view #spatial pixels**	**Typical Required Sensitivity:**	**Other**
Low-Res Spectrometer	35 to 500	low-res~500 high-res~10^4	100 per channel	10^{-21} W/m^2 (spectral line)	multi-channel
High-Res Spectrometer	50 to 500	low-res ~ $8x10^4$ high-res~$5x10^5$	100	10^{-21} W/m^2 5 σ (spectral line)	photo-counting
Heterodyne Spectrometer	150 to 500	~10^7	10 - 100	2 mK in 0.2 km/s @ 1 THz	polarized, background limited

Instrument Specifications					
Instrument	**Wavelength Coverage μm**	**Spectral Resolution (λ/Δλ)**	**Field of view #spatial pixels**	**Typical Required Sensitivity:**	**Other**
Low-Res Spectrometer	35 to 500	low-res~500 high-res~10^4	100 per channel	10^{-21} W/m^2 (spectral line)	multi-channel
High-Res Spectrometer	50 to 500	low-res ~ $8x10^4$ high-res~$5x10^5$	100	10^{-21} W/m^2 5 σ (spectral line)	photo-counting
Heterodyne Spectrometer	150 to 500	~10^7	10 - 100	2 mK in 0.2 km/s @ 1 THz	polarized, background limited
Far-infrared imager	35 to 500	R~15	100,000	1 μJy - 10 mJy (confusion limit)	5 to 10 channels, polarimetry, spectral line filters

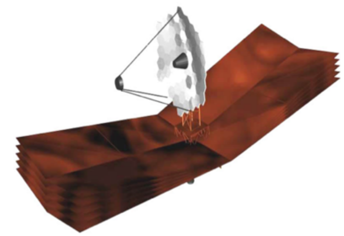
Technical Definition

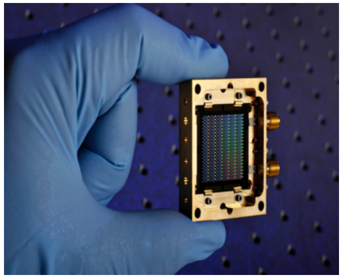
Instrument Specifications					
Instrument	Wavelength Coverage µm	Spectral Resolution (λ/Δλ)	Field of view #spatial pixels	Typical Required Sensitivity:	Other
Low-Res Spectrometer	35 to 500	low-res~500 high-res~10^4	100 per channel	10^{-21} W/m^2 (spectral line)	multi-channel
High-Res Spectrometer	50 to 500	low-res ~ $8x10^4$ high-res~$5x10^5$	100	10^{-21} W/m^2 5 σ (spectral line)	photo-counting
Heterodyne Spectrometer	150 to 500	~10^7	10 - 100	2 mK in 0.2 km/s @ 1 THz	polarized, background limited
Far-infrared imager	35 to 500	R~15	100,000	1 µJy - 10 mJy (confusion limit)	5 to 10 channels, polarimetry, spectral line filters
Mid-Infrared Instrument	6 to 40	imager: R~15, spectrometer: R>500	10^6	photometric: 1 µJy @10 µm	coronagraph~ 10^-6 @ 0.5" @ 10 µm

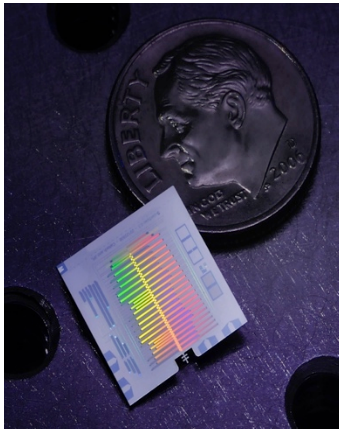
ORIGINS Space Telescope

New Science Requires New Technologies

New Technology	New Capability
Space	Wavelength coverage JWST<—>ALMA
Cold Mirror	Spectroscopic line sensitivity
Large Telescope	Spatial resolution and sensitivity
Large Detector Arrays	Wide field imaging
Compact Gratings & Integrated Spectrometers	3D mapping
Mid-IR Coronagraph	Exoplanet+Disk Characterization

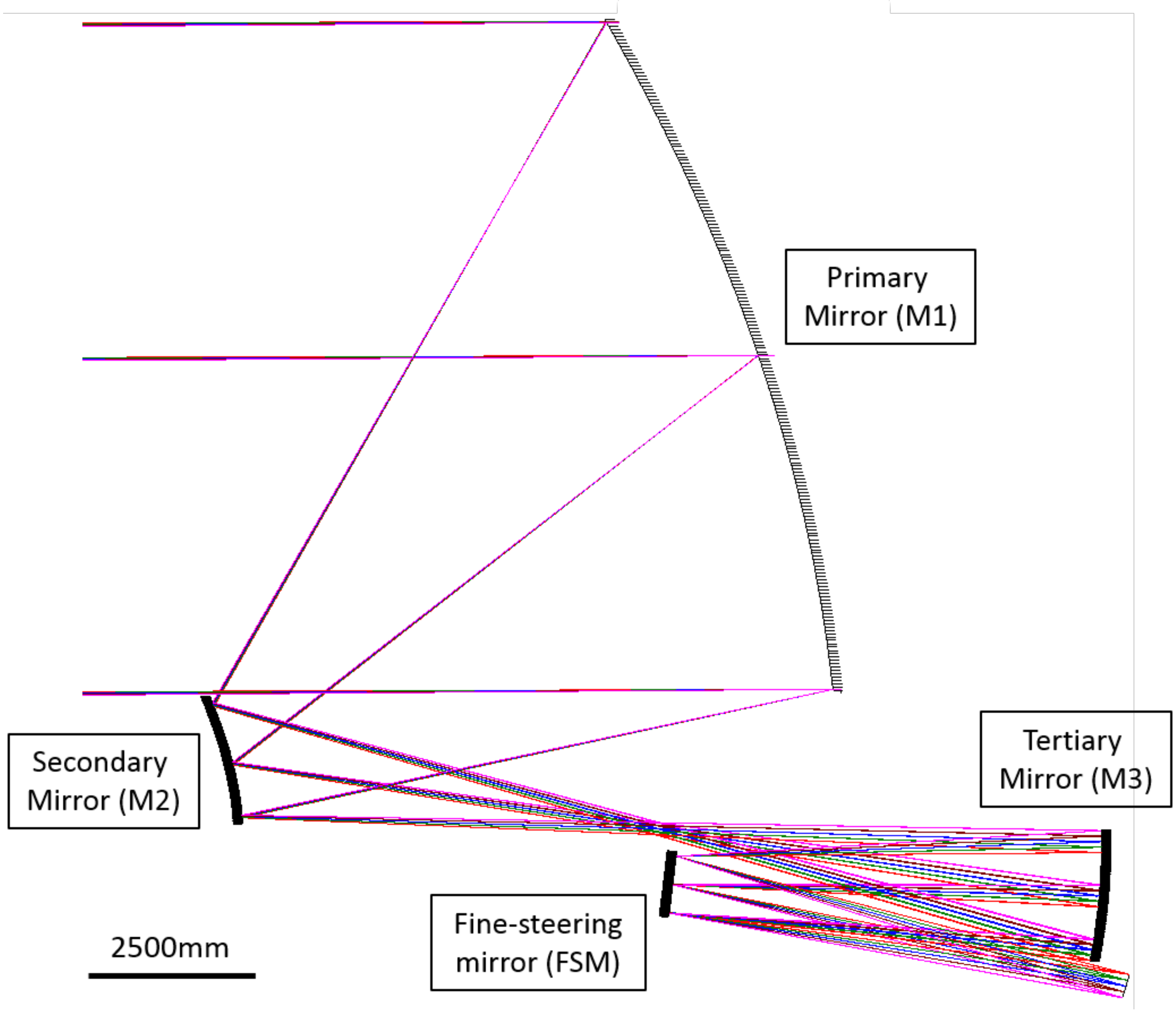






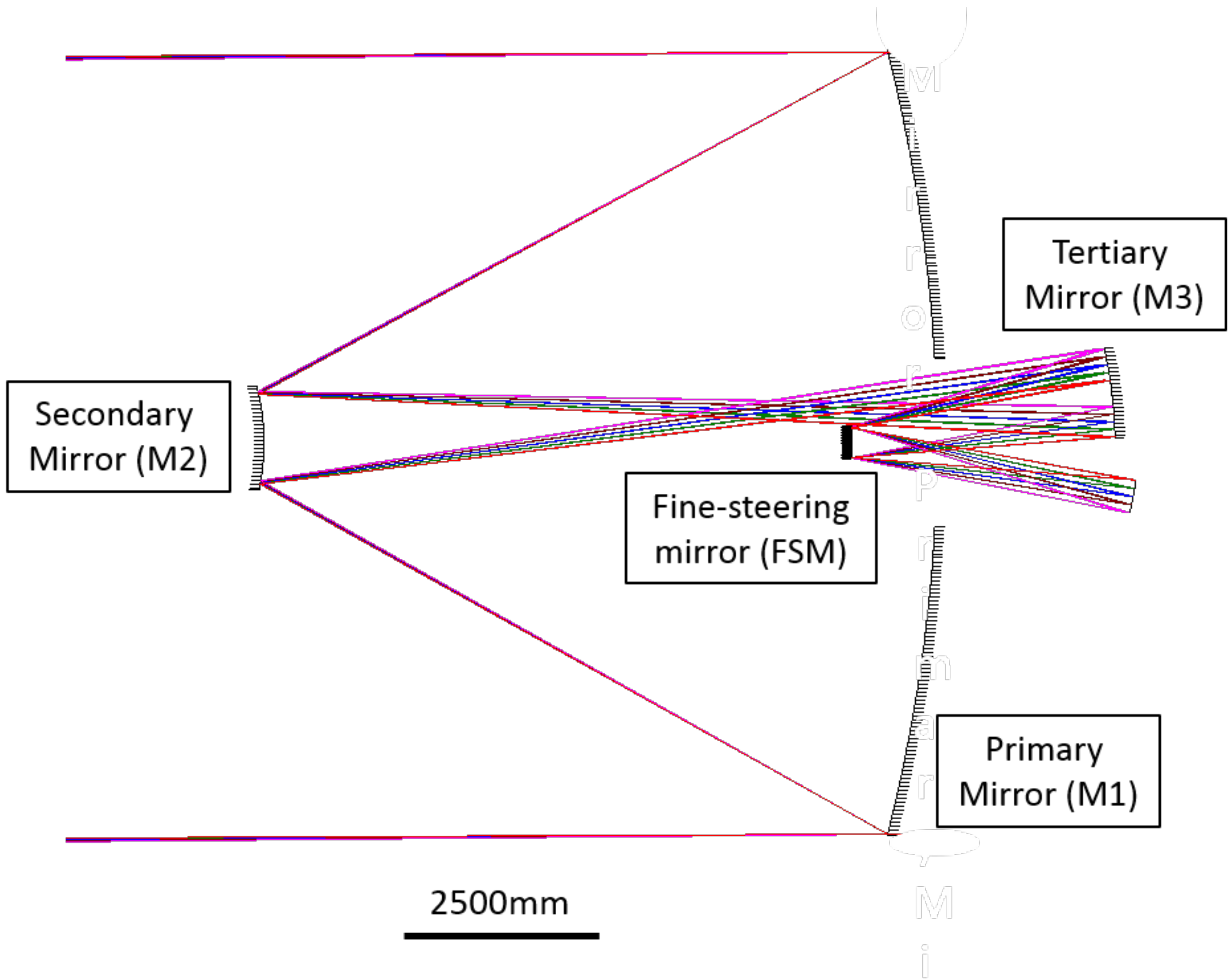
Bradford

Technical Definition: Telescope Design



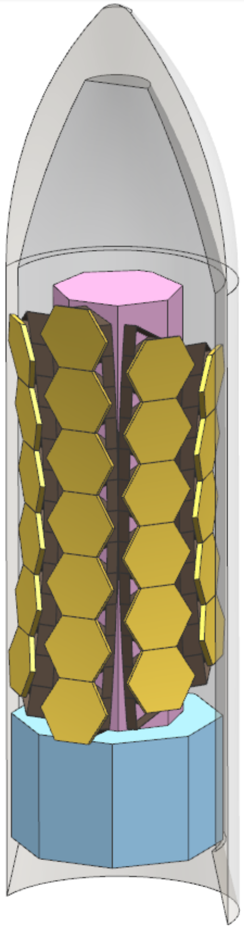
ORIGINS Space Telescope

Technical Definition: Telescope Design

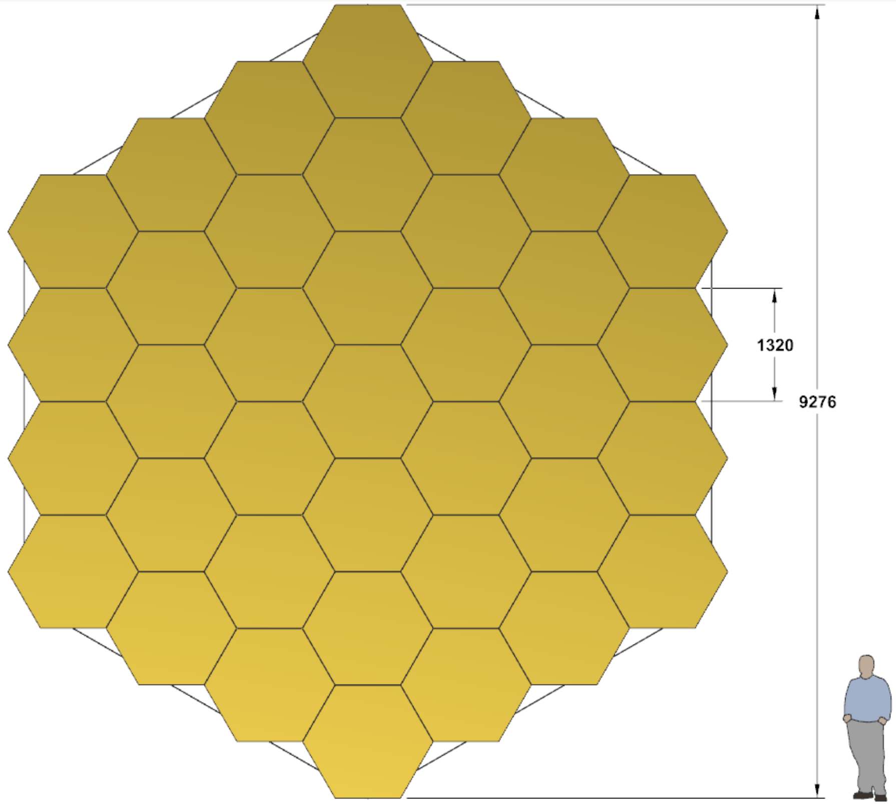


ORIGINS Space Telescope

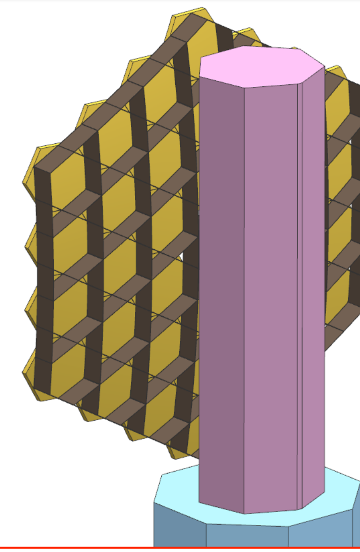
Technical Definition: JWST Segment 56 m² Area



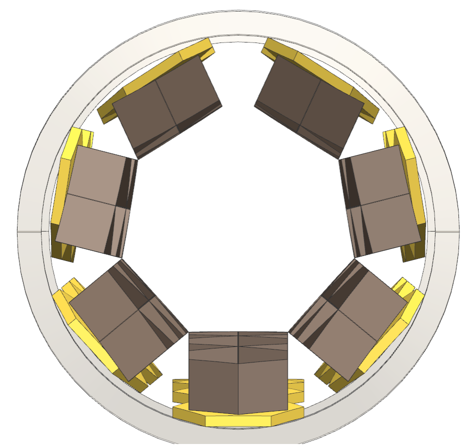
5m x 19.8m Fairing
Inst: 48m³
Bus: 38m³



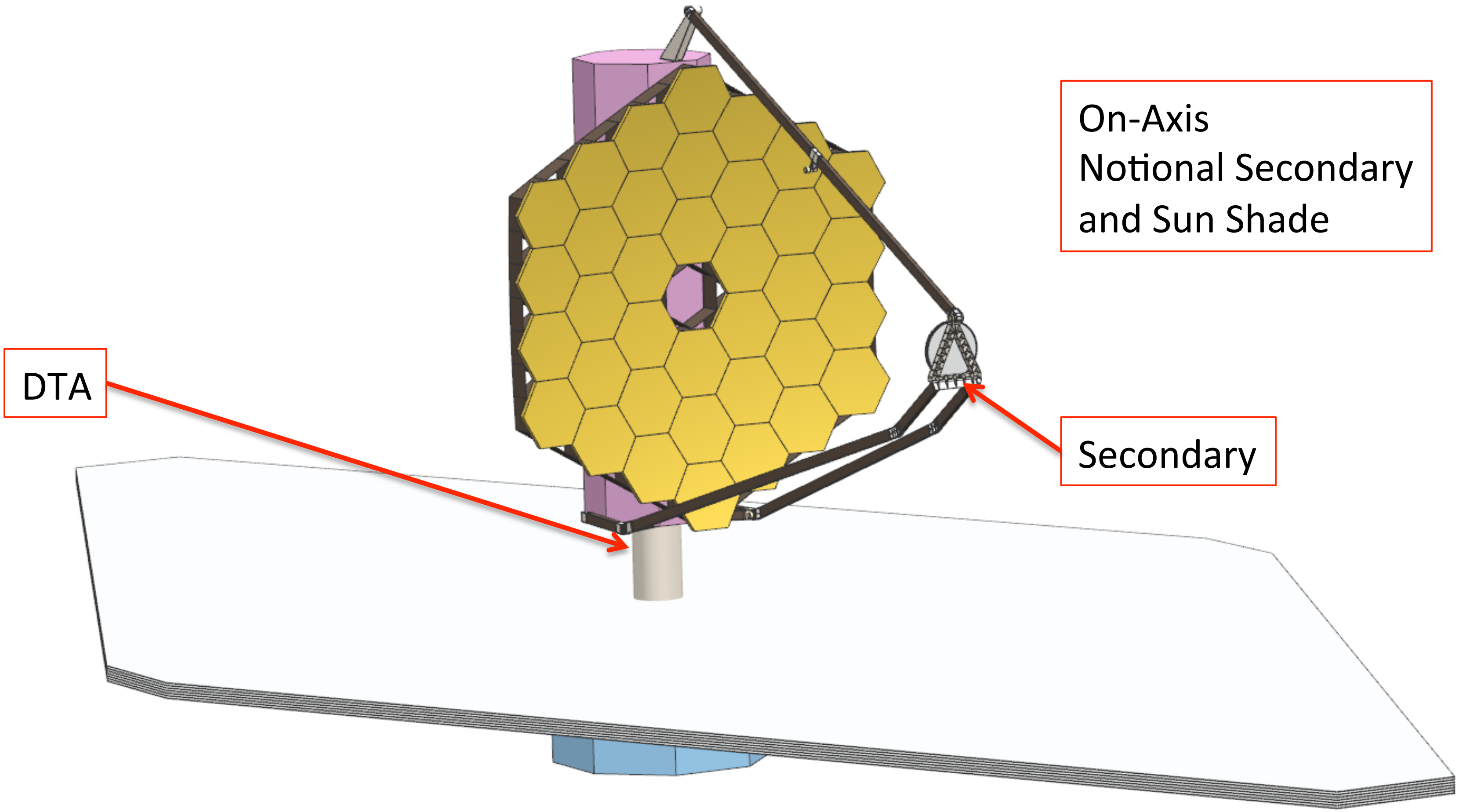
Off-Axis 9.3m Diameter
Projected Area: ~56m²
37 Segments
Segment Flat to Flat: 1320mm
Mass Rough Estimate: 3462 kg



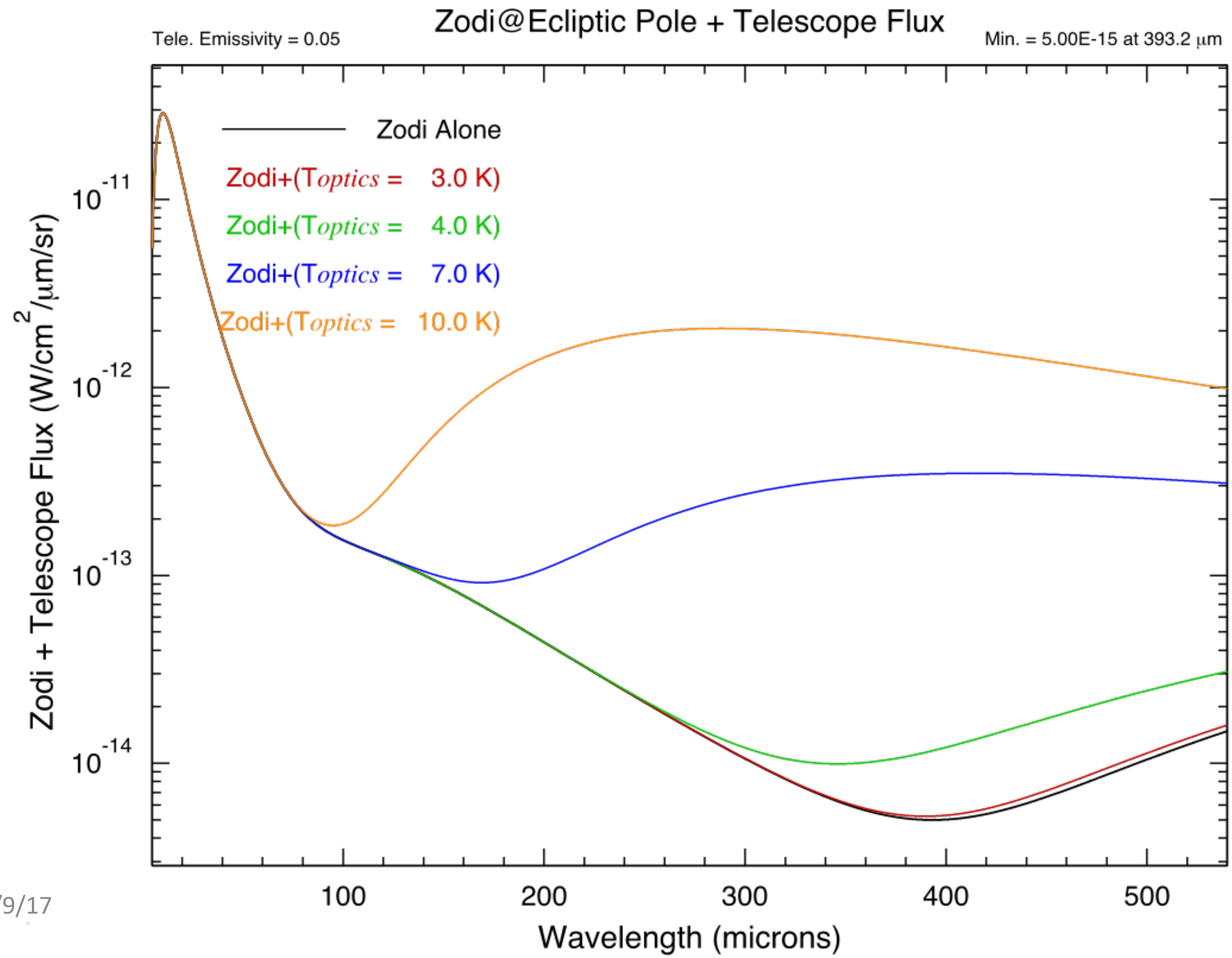
Backplane Depth: ~495mm



Technical Definition: Secondary & Shade



Technical Definition: Telescope Temperature

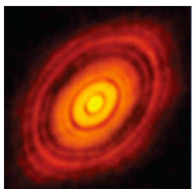


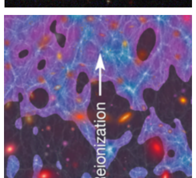
Science & Technology Definition Team Schedule

- **January to July 2017:**
  - Complete preliminary designs for telescope and instruments
  - Secure instrument design contributions
  - Identify technology drivers
- **August to September 2017**
  - Define required technologies
  - Complete preliminary mission design
- **January to March 2018:**
  - Finalize Telescope and Instrument Designs
  - Finalize mission design including spacecraft bus
- **April to August 2018:**
  - Identify de-scope options
  - End-to-end Mission cost estimations
- **January 2019:**
  - Submit the final study report to NASA HQ
- **March 2019:**
  - Far-IR Study Results presentation to Decadal Committee

ORIGINS Space Telescope

How do I get involved?



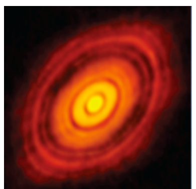


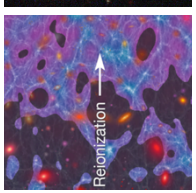
What's happening now:

- Five science working groups: membership is open to the community (US and foreign)
- Deciding on science questions in the post-JWST, 15 years of ALMA operations in an era of Extremely Large Telescope (ELT) and guiding instrument and telescope design.

Solar System: Stefanie Milam
Planet Formation and Exoplanets: Klaus Pontoppidan and Kate Su
Milky-Way, ISM and Local Volume of Galaxies: Cara Battersby and Karin Sandstrom
Galaxy and Blackhole Evolution Over Cosmic Time: Lee Armus and Alexandra Pope
First Billion Years: Joaquin Vieira, Matt Bradford

How do I get involved?

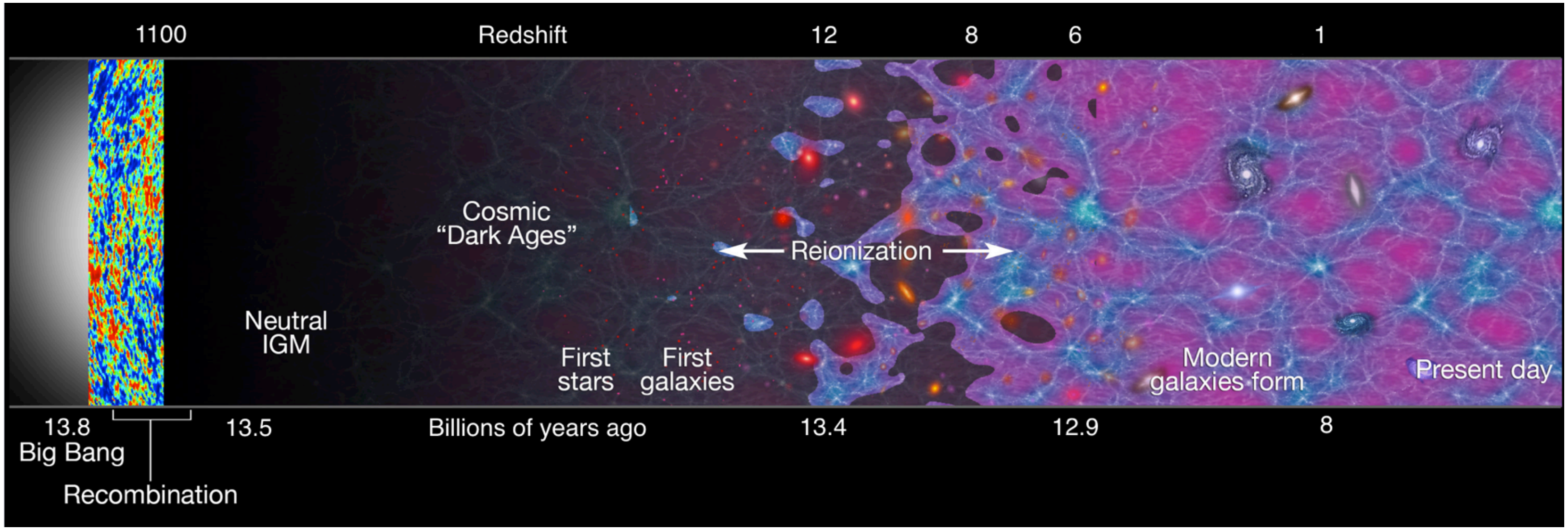
Send email to:

ost_info@lists.ipac.caltech.edu

Science coverage will be broad: highlight some of the goals

- First Billion Years:
  - Protogalaxies
  - Galaxy evolution
- Galaxy and Blackhole Evolution
  - ISM probes for galaxies
  - Rise of metals
- Nearby Galaxies & Milky Way:
  - Polarization
  - Feedback in galaxies
  - Water transport
- Planetary systems: Formation & Exoplanets
  - Dust disks
  - Gas disks
  - Exoplanet atmospheres
- Solar system
  - Small body census
  - Planet IX
  - Isotopes and origin of Earth water

COSMIC DAWN - EARLY UNIVERSE - COSMOLOGY



Big Picture topics already identified:

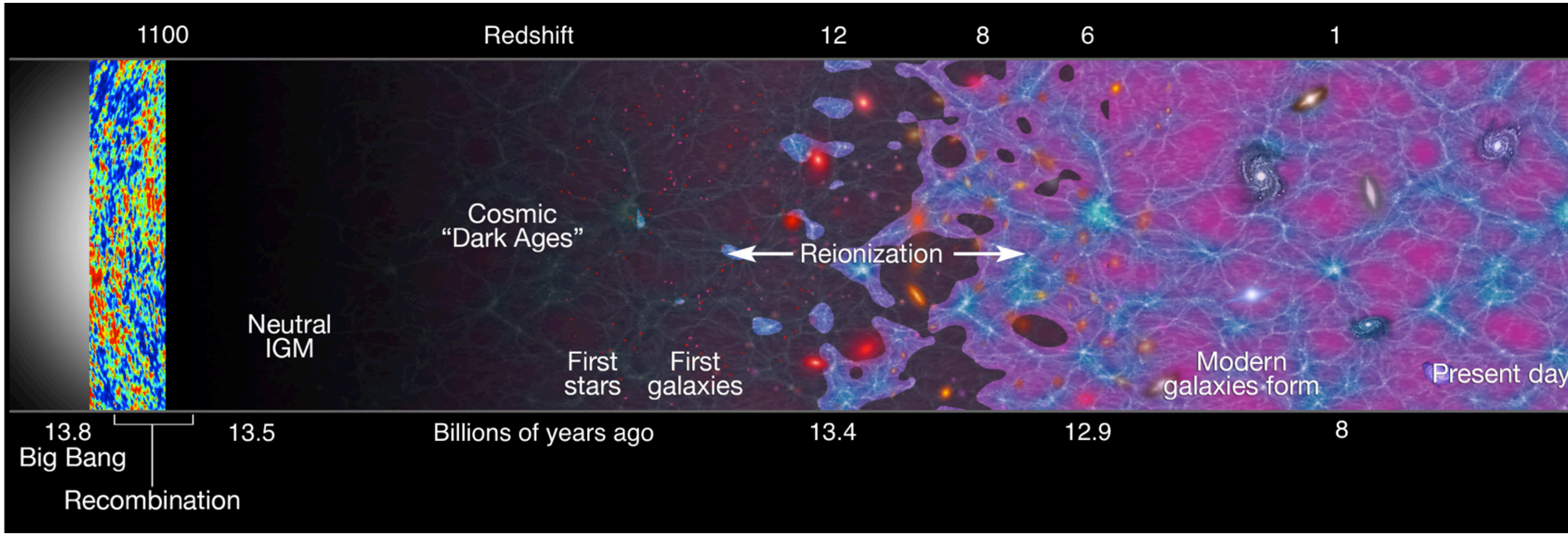
- Collapse to form first stars and proto-galaxies
  - Primordial cooling via H_2 rotational lines
  - seeds of super massive black holes
- Cosmic chemical evolution of the Universe
  - First dust, rise of heavy elements and building blocks of life
- Properties of reionizing galaxies
  - 3-D maps of the Universe
  - 3-D clustering revealing fine-structure line intensities -> metallicity, UV fields

Vieira

ORIGINS Space Telescope

Science Topics
First Billion Years

COSMIC DAWN - EARLY UNIVERSE - COSMOLOGY



Big Picture topics already identified:

Scavenger Hunt Secret Word: Universe

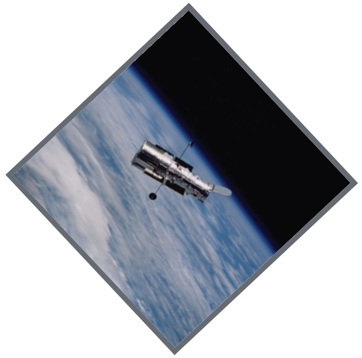
tinyurl.com/OSTScavengerHunt

- Collapse to form first stars and proto-galaxies
  - Primordial cooling via H_2 rotational lines
  - seeds of super massive black holes
- Cosmic chemical evolution of the Universe
  - First dust, rise of heavy elements and building blocks of life
- Properties of reionizing galaxies
  - 3-D maps of the Universe
  - 3-D clustering revealing fine-structure line intensities -> metallicity, UV fields

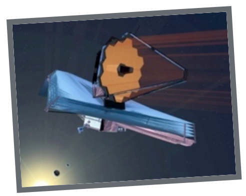
Vieira

Science Topics
First Billion Years:

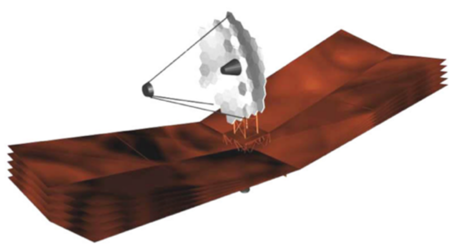
Hubble Space Telescope
1990—2025+
2.4 meter
0.1—2.4 μm
260 K

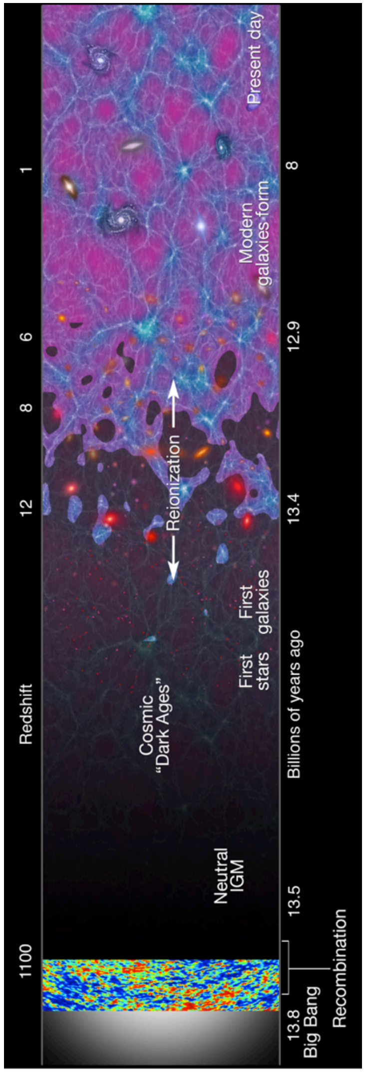


James Webb Space Telescope
2018—2028
6.5 meter
0.7—28.3 μm
50 K



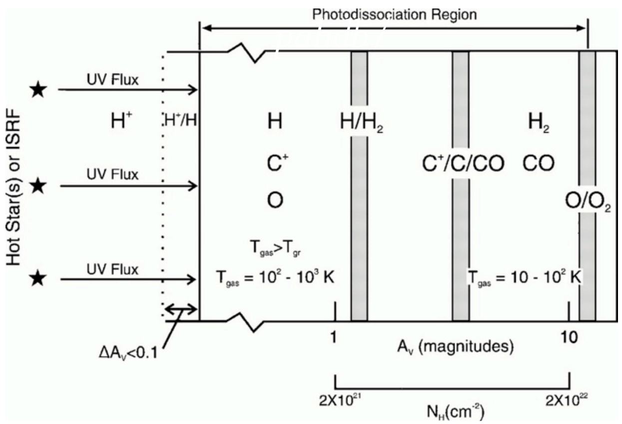
Origins Space Telescope
2020 Decadal
8-15 m single aperture
6—1000 μm (TBD)
4.5 K





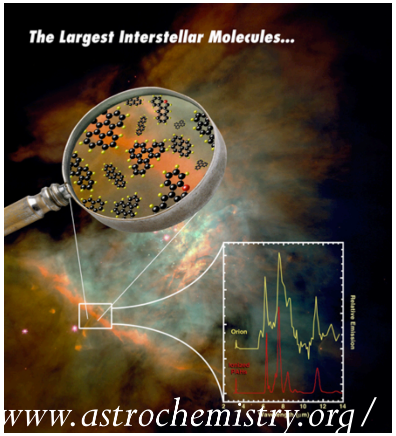
Vieira

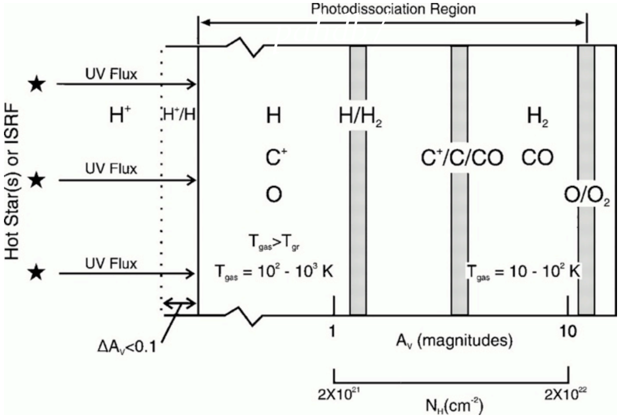
How do we probe the interstellar medium (gas and dust where stars are forming) in high redshift galaxies?



Pope

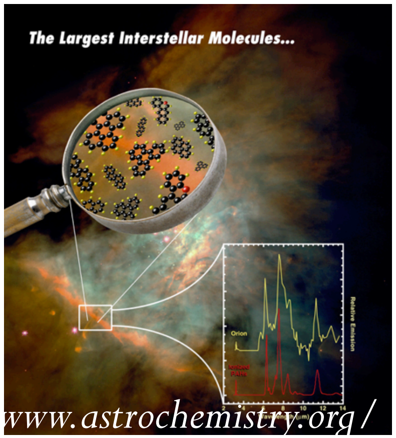
How do we probe the interstellar medium (gas and dust where stars are forming) in high redshift galaxies?

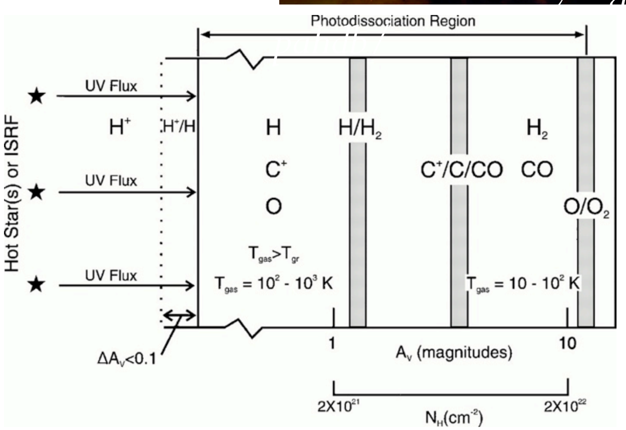


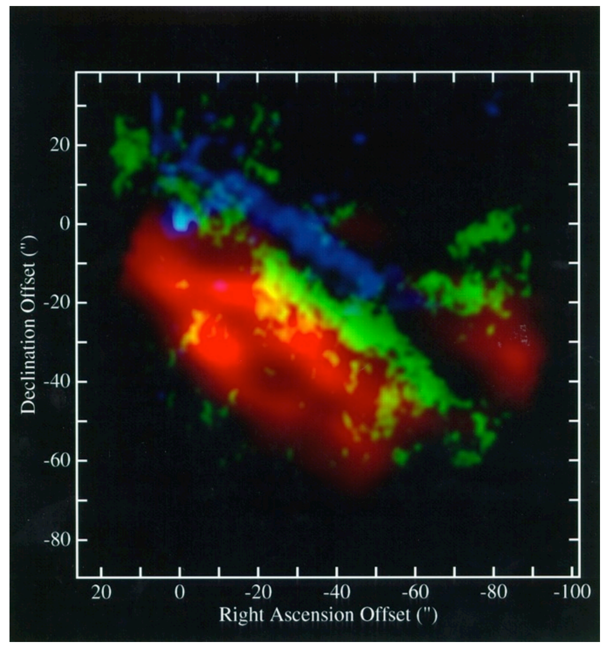


Pope

How do we probe the interstellar medium (gas and dust where stars are forming) in high redshift galaxies?







PAH

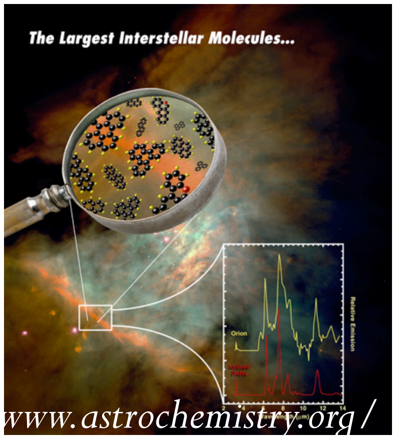
H_2

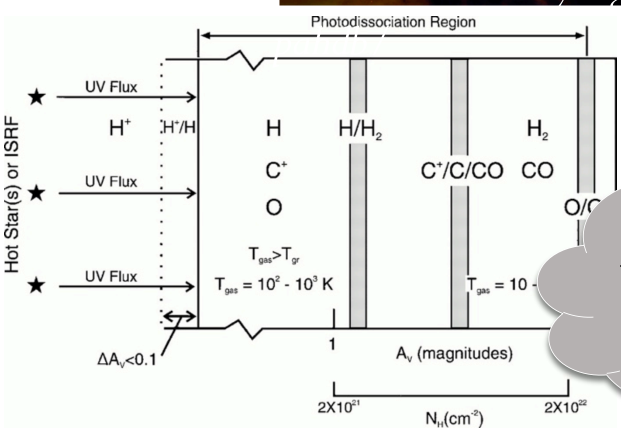
CO

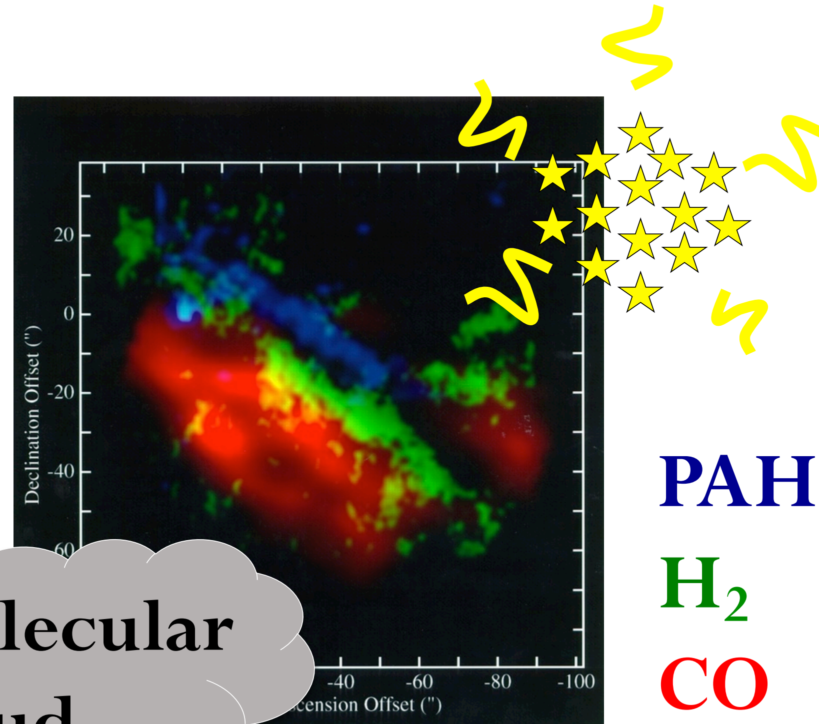
Hollenbach & Tielens 1997

Pope

How do we probe the interstellar medium (gas and dust where stars are forming) in high redshift galaxies?







Molecular cloud

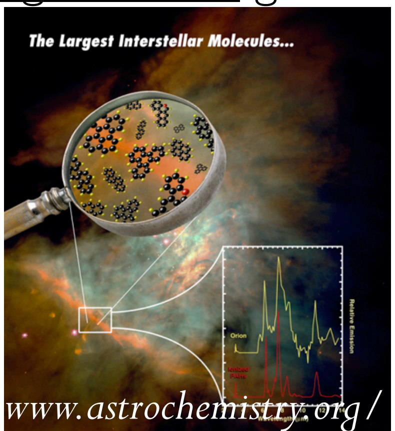
PAH
H_2
CO

Hollenbach & Tielens 1997

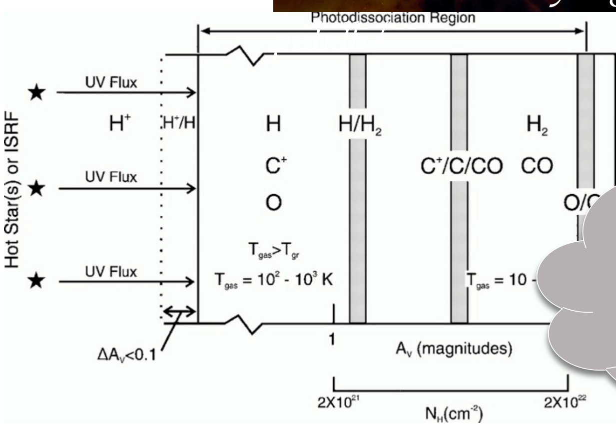
Pope

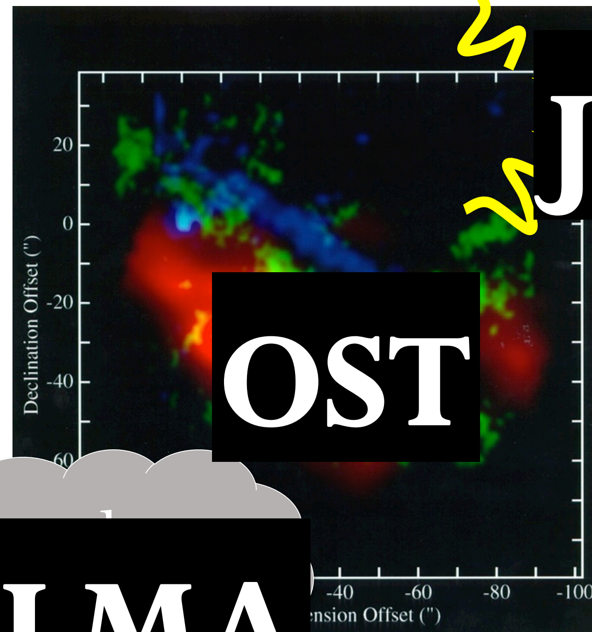
Science Topics
Galaxy and Blackhole Evolution

How do we probe the interstellar medium (gas and dust where stars are forming) in high redshift galaxies?



www.astrochemistry.org/





JWST

OST

ALMA

PAH

H_2

CO

Hollenbach & Tielens 1997

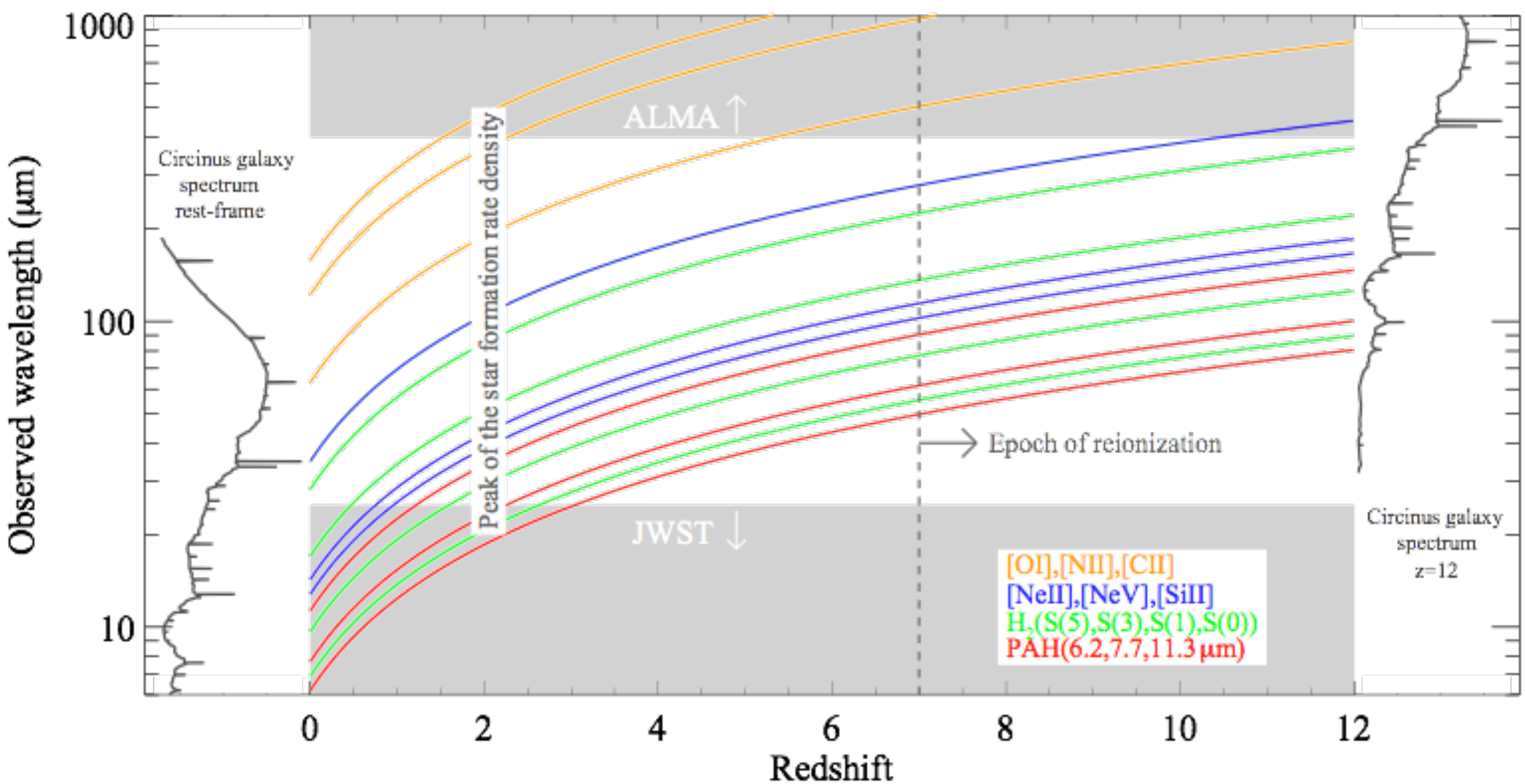
Pope

Spectral probes from 10 – 500 μm

Species	Wavelength [μm]	f (M82)	f (Arp220)	Diagnostic Utility
Ionized Gas Fine Structure Lines				
Ne V	24.3			Unambiguously AGN
O IV	25.9, 54.9			Primarily AGN
S IV	10.5	2.1 (-5)		
Ne II	12.3	1.2 (-3)	7.5 (-5)	Probes gas density and
Ne III	15.6, 36.0	2.05 (-4)		UV field hardness in
S III	18.7, 33.5	1.0 (-3)	7.3 (-5)	star formation HII
Ar III	21.83	9.1 (-6)		regions.
O III	51.8, 88.4	1.3 (-3)		
N III	57.3	4.2 (-4)		
N II	122, 205	2.1 (-4)		Diffuse HII regions
Neutral Gas Fine Structure Lines				
Fe II	26.0			Density and temperature probes
Si II	34.8	1.1 (-3)	7.7 (-5)	of photodissociated-neutral
O I	63.1, 145	2.2 (-3)	6.8 (-5) (abs)	gas interface between HII
C II	158	1.6 (-3)	1.3 (-4)	regions and molecular clouds.
Molecular Lines				
H_2	9.66, 12.3, 17.0, 28.2	2 (-5)	3 (-5)	Coolants of first collapse
CH	149		4 (-5)	Ground state absorbtion:
OH	34.6, 53.3, 79.1, 119	2 (-6)	2 (-4) (abs)	gives column and abundance.
OH	98.7, 163		5 (-5)	Emission: gas coolants, constrain
H_2O	73.5, 90, 101, 107, 180		5 (-5)	temperature, density of warm
CO	325, 372, 434, 520	3 (-6)	1 (-5)	(50K < T < 500 K) mol. gas

Vieira

OST provides the crucial link in wavelength coverage between JWST and ALMA to complete our view of the evolution of the universe.



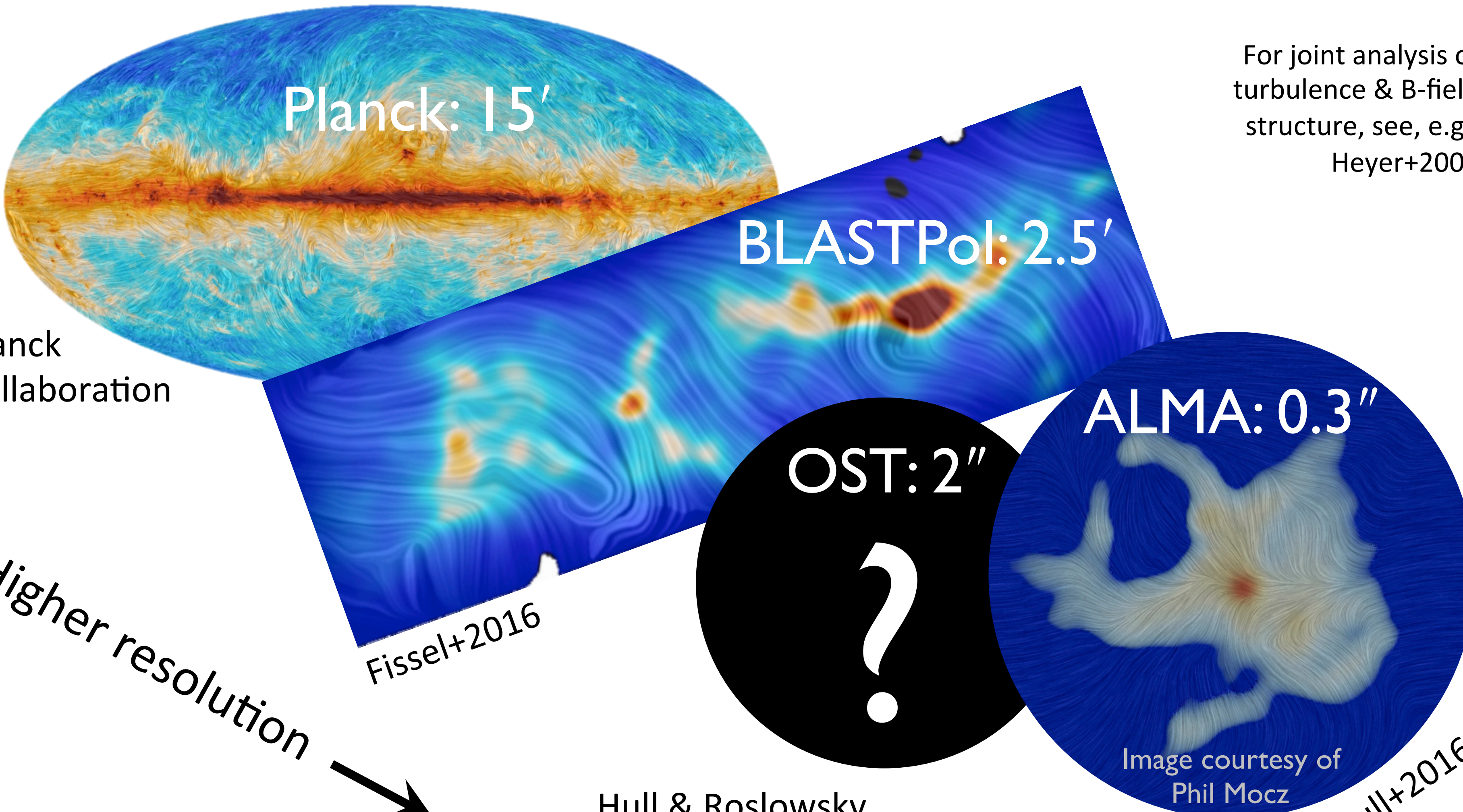
ALMA

JWST

Pope

Magnetic fields and turbulence

For joint analysis of turbulence & B-field structure, see, e.g., Heyer+2008



Planck Collaboration

Fissel+2016

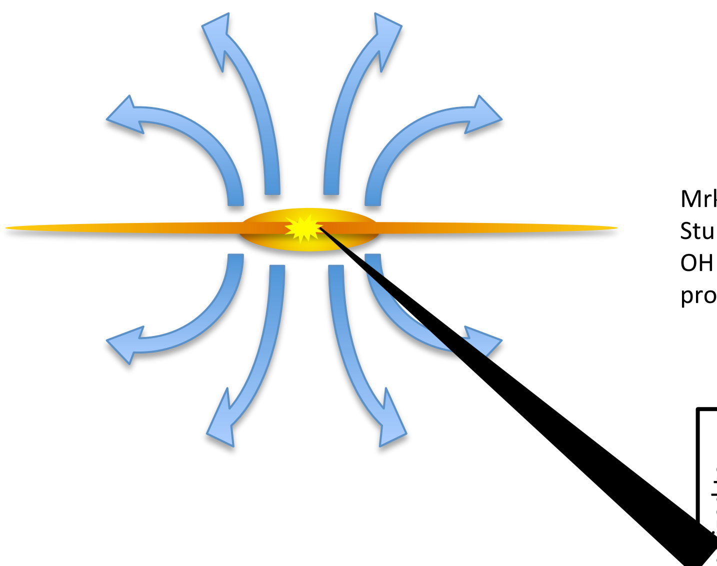
Hull+2016

Higher resolution

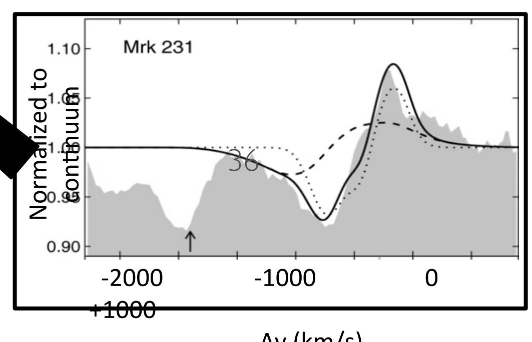
Hull & Roslowsky

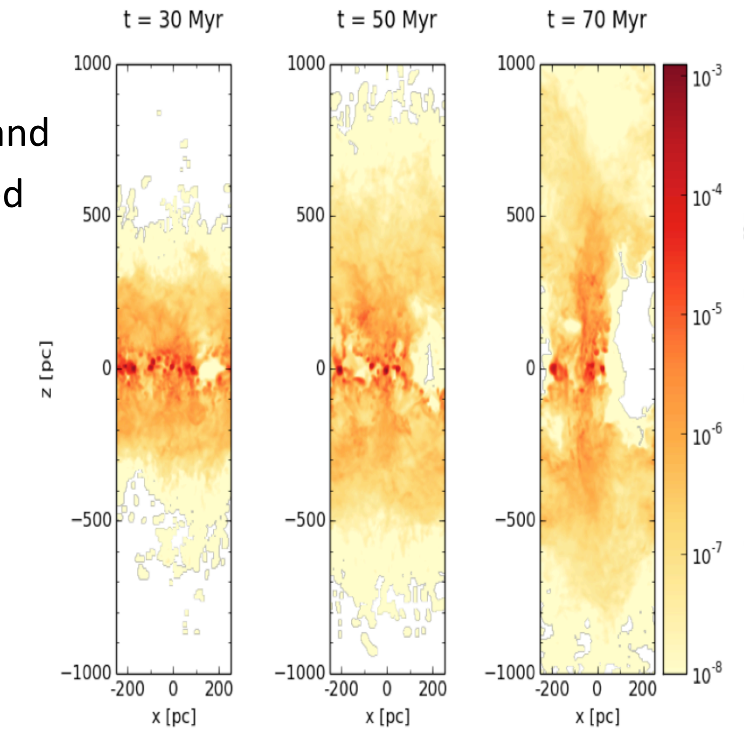
Galaxy Feedback Mechanisms at z<1

Science Goal: Characterize the mechanisms of feedback from AGN/star formation across the spectrum of galaxy masses and types and quantify the amount of material recycled/expelled from galaxies at z<1.



Mrk 231
Sturm et al. (2011)
OH P-Cygni
profiles



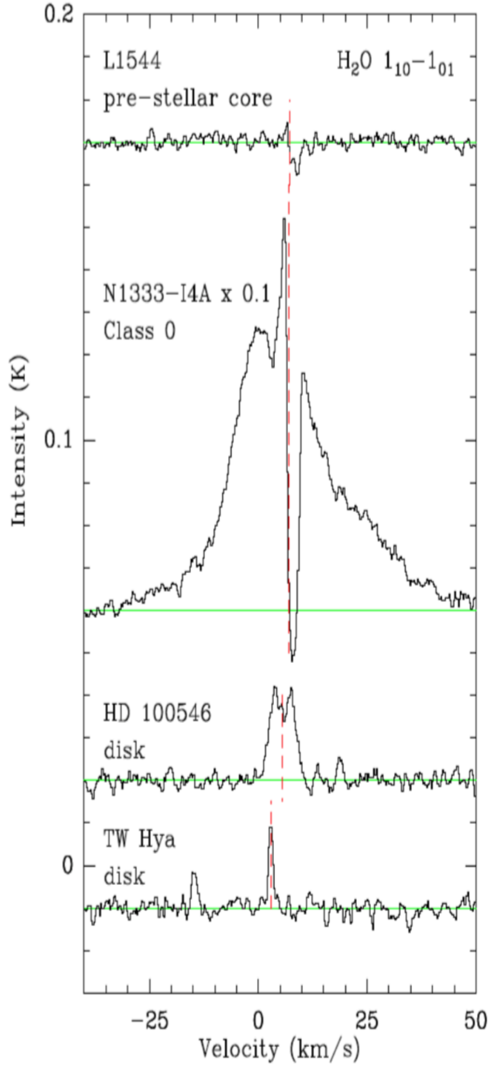


Extraplanar [CII]
Franeck et al. in prep.,Walch et al. (2015)
Simulations of SF-driven winds

Bolatto

Water Transport to Terrestrial Planetary Zone

Science Goal: Observe gas-phase water in interstellar clouds and dense star-forming cores to probe critical processes related to formation and transport of water to the terrestrial planet zone, as a key input to habitability.



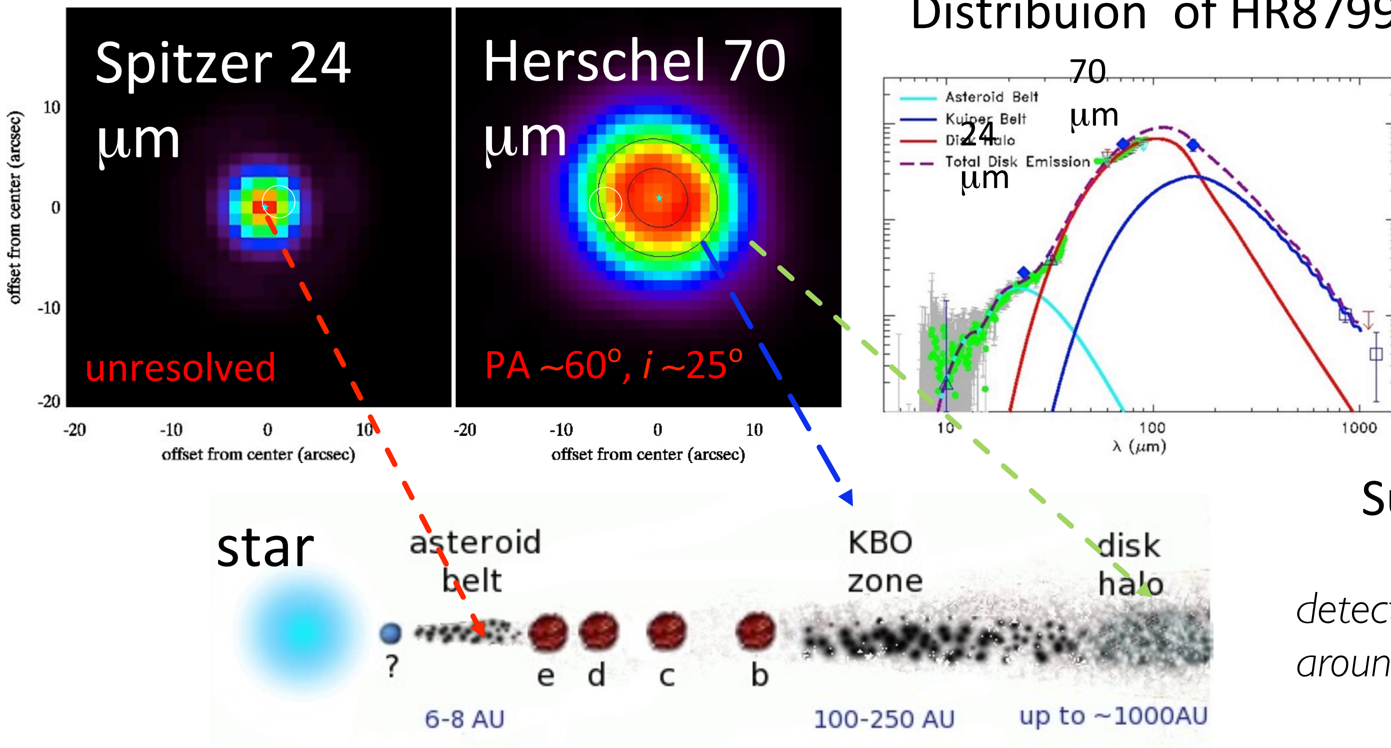
P. Goldsmith

Debris Disks and Giant Planets

Su+ 2009

Matthews+ 2013

Spectral Energy Distribuion of HR8799



Su et al. 2009

detect Oort clouds around nearby stars

Marios+2008, 2010

Pontoppidan

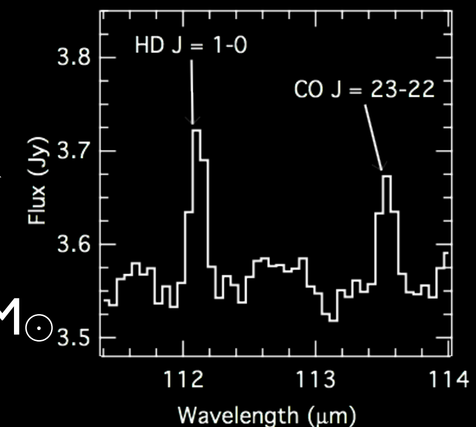
Science Topics
Planetary systems: Formation & Exoplanets

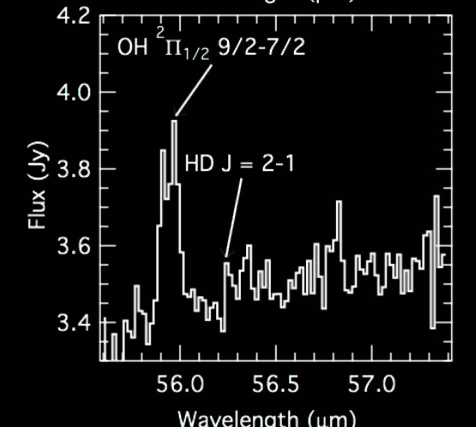
WHAT ARE PROTOPLANETARY DISK GAS MASSES?

- ➡HD is a million times more emissive than H_2 at $T \sim 20$ K.
- ➡Atomic D/H ratio inside the local bubble is well characterized ($\sim 1.5 \times 10^{-5}$)
- ➡HD will follow H_2 in the gas

➡TW Hya disk mass

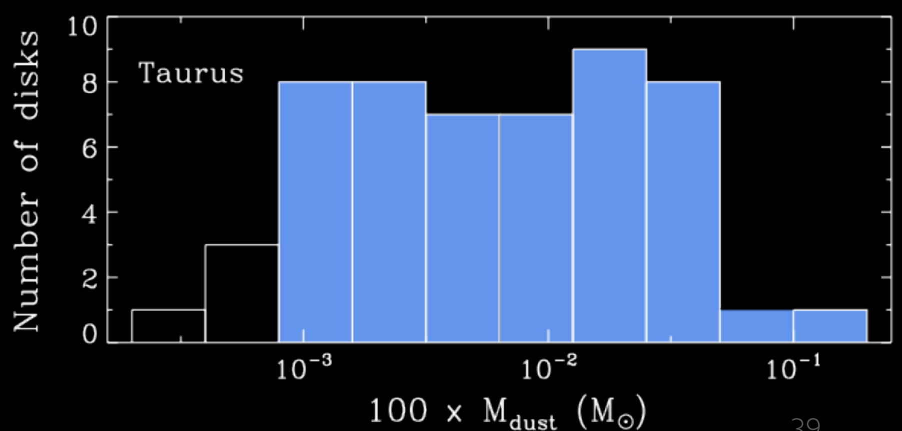
$M_{disk} \sim 0.05\ M_{\odot}$





Bergin+ 2013

Williams and Cieza 2011

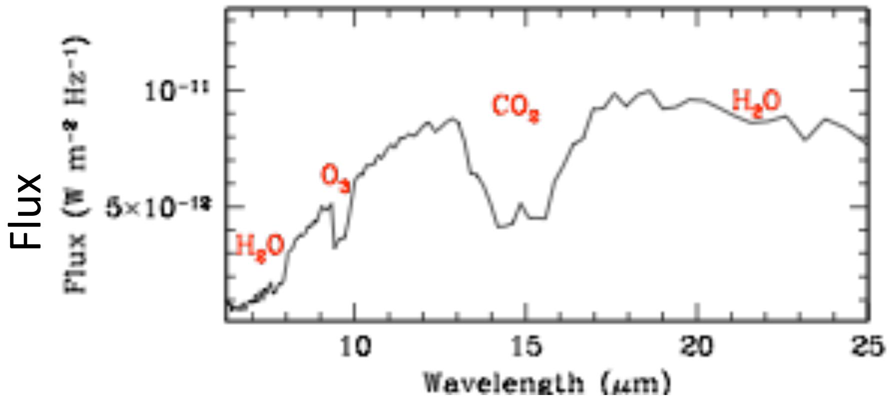


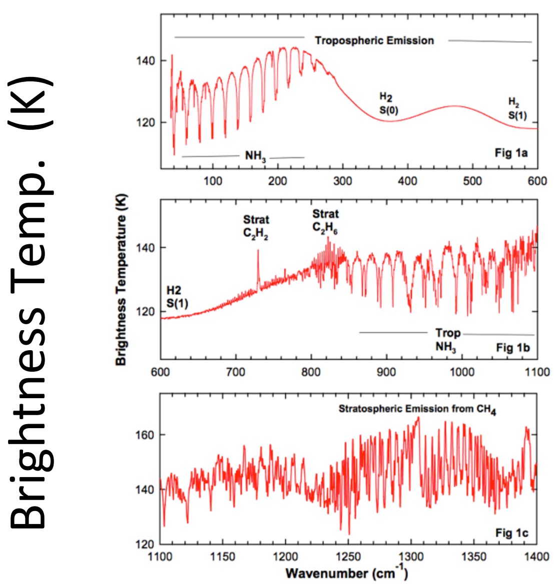
Pontoppidan

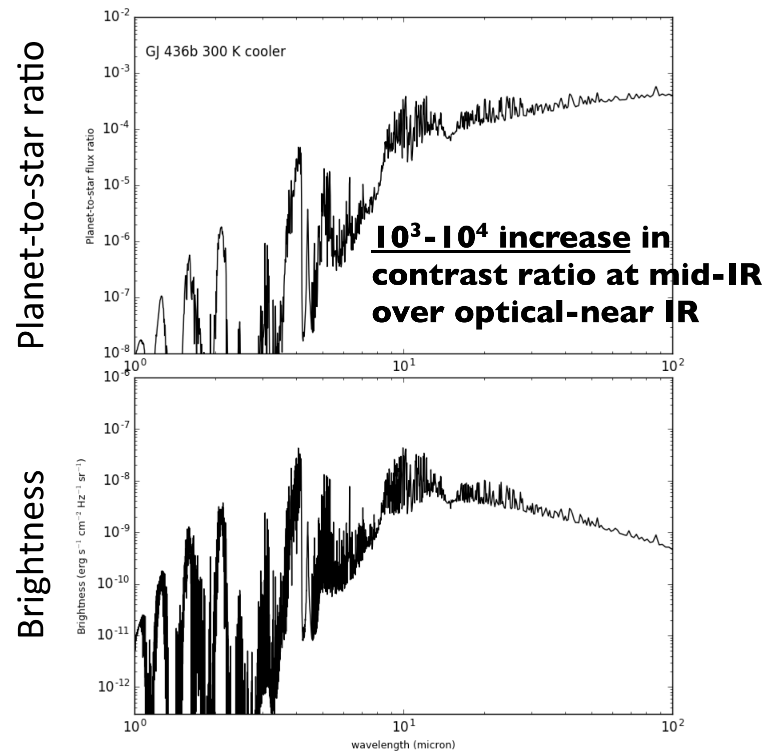
ORIGINS Space Telescope

Science Topics
Planetary systems: Formation & Exoplanets

POTENTIAL FOR TRANSITING HABITABLE PLANETS AROUND M DWARFS?





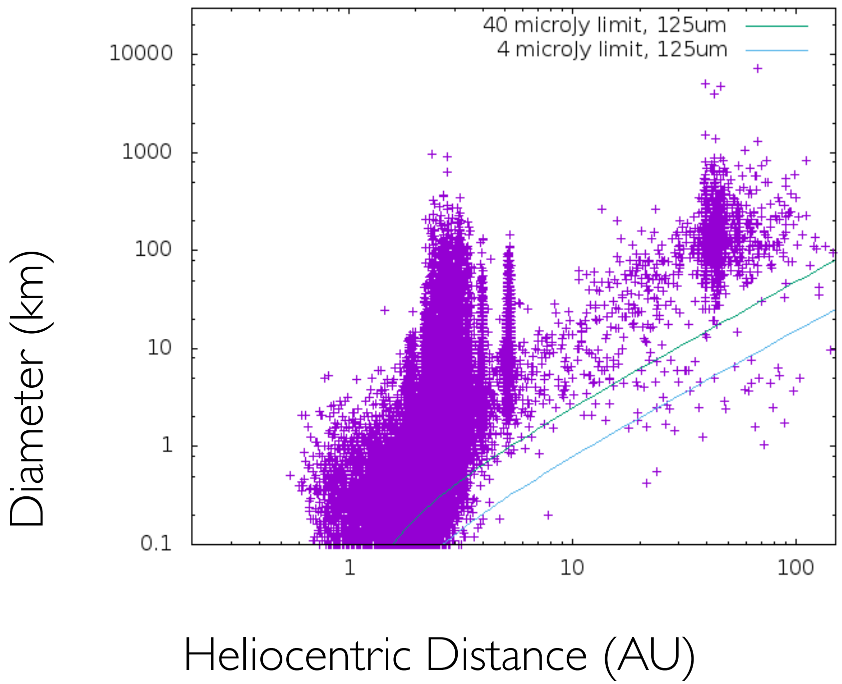


Jupiters around M-dwarf stars via transits.
Direct imaging of Jupiters at Jupiter distances with a coronagraph.

Pontoppidan

REVEALING THE SOLAR SYSTEM IN THE FAR-IR

History and Evolution of the Solar System (SS):



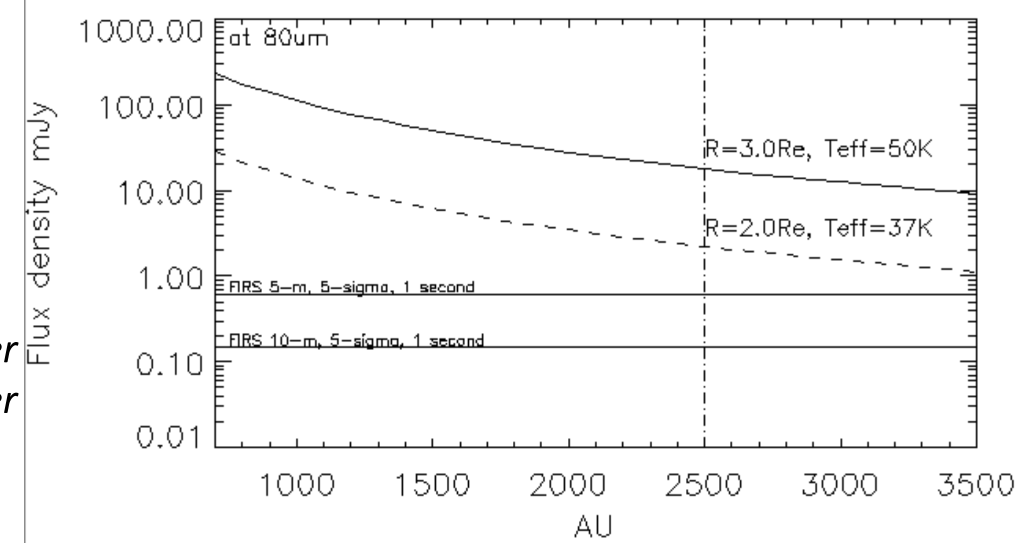
From Bauer and Lovell

- Measure the thermal emission (via Far-IR imaging) of small bodies in outer SS – 1000's of targets
- Moving Targets Not limited by confusion.

Milam

Find Planet IX

- **Goal:** *Do we really understand our outer backyard?: Find Planet Nine (from Outer Space!)*



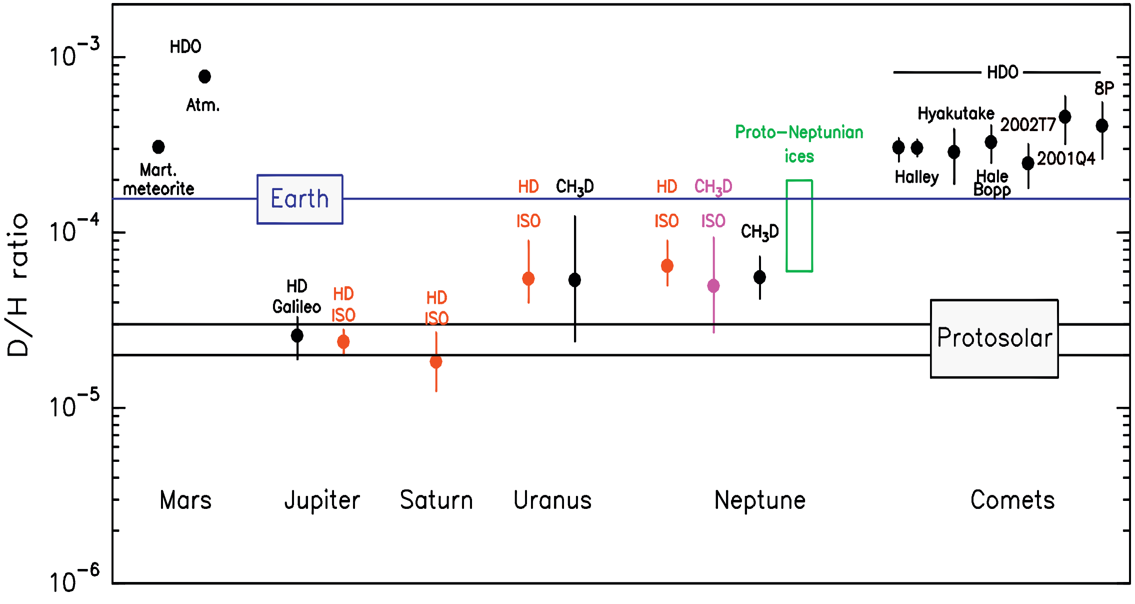
Even a 2 Earth Radius Planet 9, with Teff=37K has ~4 mJy flux at 80um is detectable with a 5 meter OST architecture. OST 5 meter (10 meter), 5-sigma, 1second sensitivity at 80um as 0.6 (0.15) mJy.

Wright/Milam

Planetary Origins a'nd Evolution of the Solar System

- **Goal:** *To measure accurate isotopic ratios and abundances of trace gases, to constrain models and inform understanding of solar system origin and evolution.*

Milam



ORIGINS Space Telescope

How do I get involved?

Send email to:

ost_info@lists.ipac.caltech.edu

Visit our website:

asd.gsfc.nasa.gov/firs

OST scavenger Hunt:

tinyurl.com/OSTScavengerHunt

Scavenger Secret word:

Universe