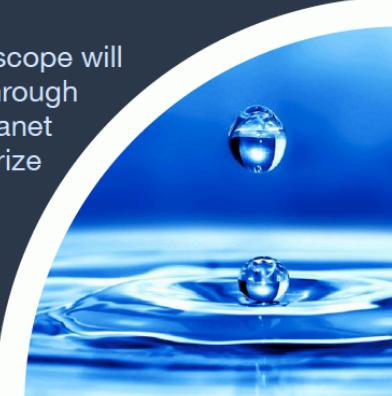


Tracing the Signatures of Life and the Ingredients of Habitable Worlds

The Origins Space Telescope will map the trail of water through all stages of star and planet formation and characterize the atmospheres of potentially habitable worlds.



Unveiling the Growth of Black Holes and Galaxies over Cosmic Time

The Origins Space Telescope will reveal powerful starbursts and buried black holes, energetic feedback, and the dynamic interstellar medium from which stars are born.



The Origins Space Telescope will trace the rise of metals in thousands of galaxies to $z \sim 10$, probe the first sources of cosmic dust and signatures of the earliest stars, and the birth of galaxies.

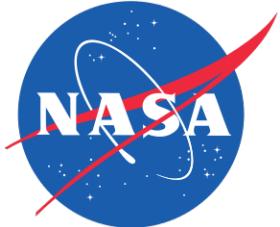


Charting the Rise of Metals, Dust, and the First Galaxies

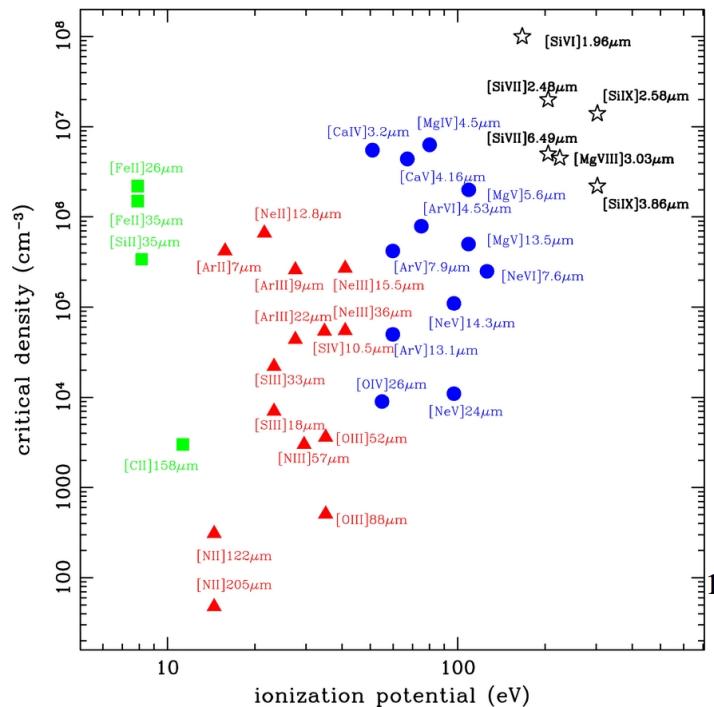
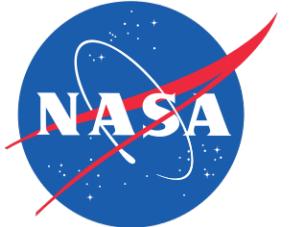
The Origins Space Telescope will chart the role of comets in delivering water to the early Earth, and survey thousands of ancient Trans-Neptunian Objects at distances greater than 100 AU and down to sizes of less than 10 km.



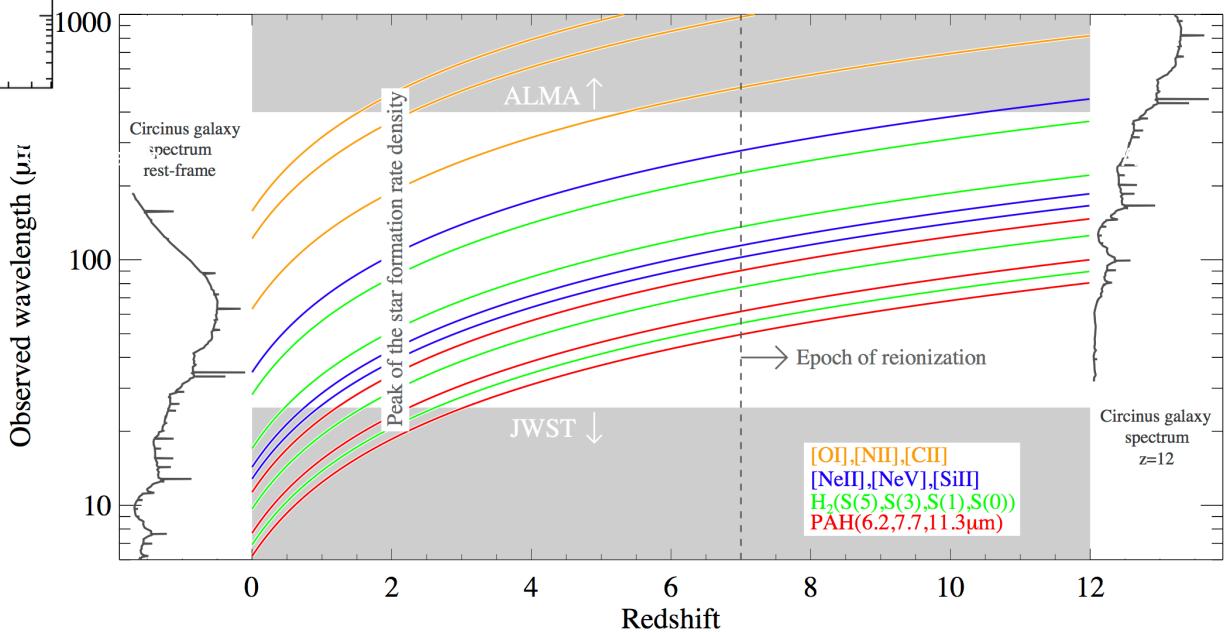
Characterizing Small Bodies in the Solar System



Major Science Goals

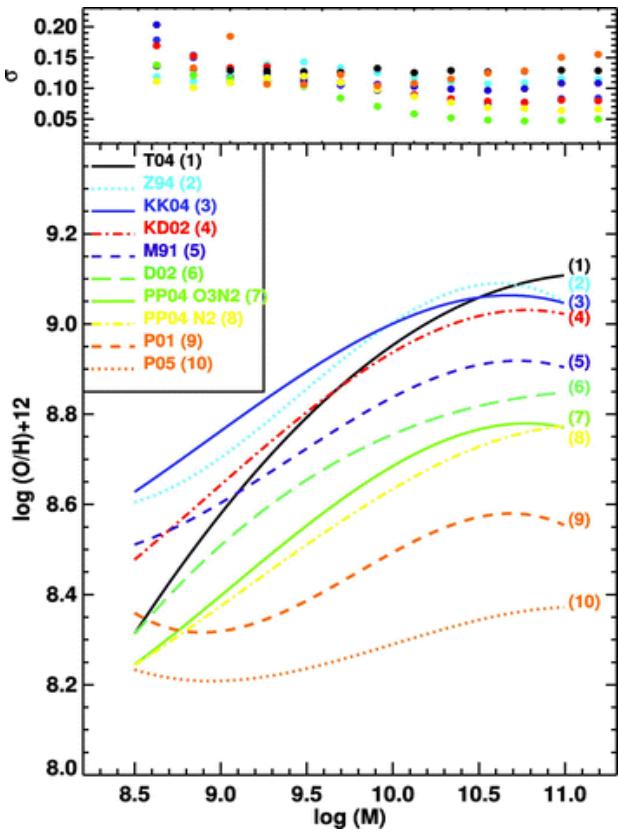


Diagnostic lines in the Infrared



The Rise of Metals

Tracing the metal enrichment history of the Universe

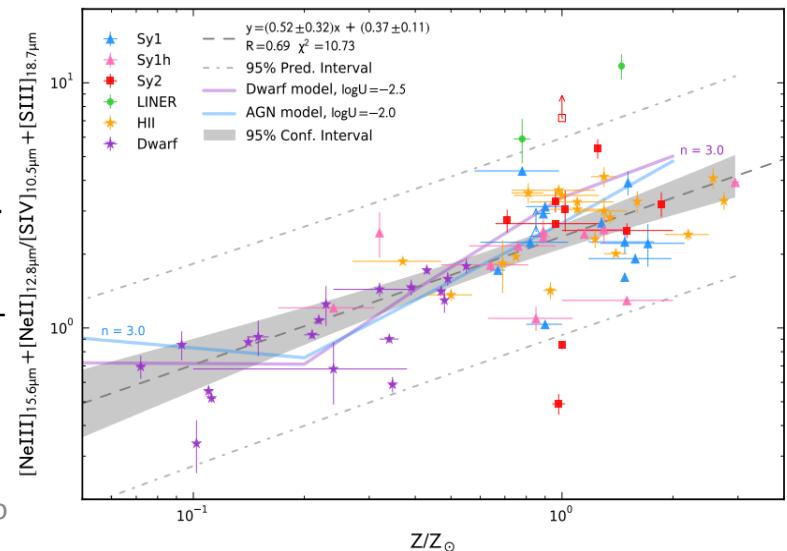


Mass-metallicity relation
(Kewley+08) for ten optical O/H
indicators.

At what rate was the Universe enriched with metals?
In what types of galaxies did the bulk of this enrichment
happen? When were galaxies suitably enriched to support
the development of life?

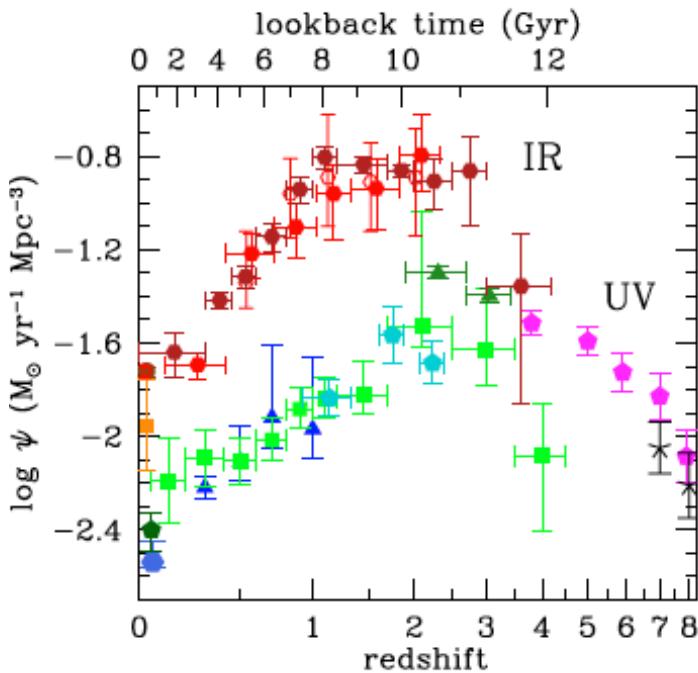
**The mid- and far-IR fine structure lines do not suffer from
dust extinction or the degeneracies of common optical
indicators.**

Mid-IR Ne and S
abundance indicator for
OST vs optical
metallicities (Fernández-
Ontiveros+16)





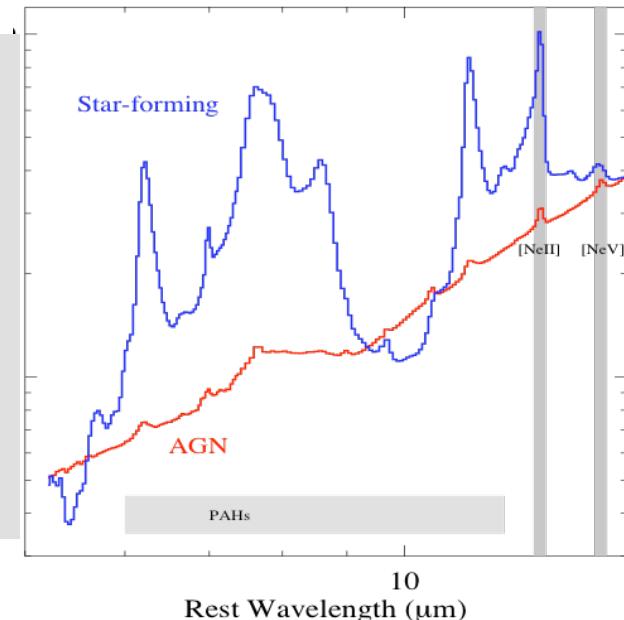
Understanding the co-evolution of galaxies and supermassive black holes over cosmic time



Star formation rate density traced by **obscured** (IR) and **unobscured** (UV) activity. Most of the power emerges in the IR to $z \sim 3$, but the landscape at earlier epochs is unknown. Figure from Madau & Dickinson (2014).

With large statistical samples of galaxies, OST will uniquely separate the star formation and active galactic nuclei from the peak through Reionization ($z \sim 2-7$)

Rest-frame mid-IR spectra comparing a **star forming** galaxy and **strong AGN** (Stierwalt +13), normalized at 15 microns. The $[\text{NeV}]/[\text{NeII}]$ ratio and the PAH bands can be used to separate AGN and star formation activity in even the most heavily obscured galaxies.



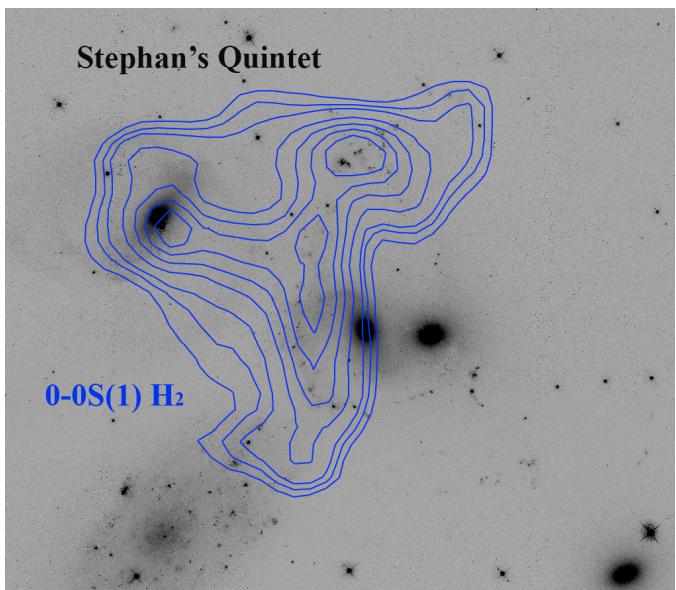


Probing the Birth of Galaxies in the Cosmic Dark Ages

How and when did the first gas clouds collapse to form galaxies?

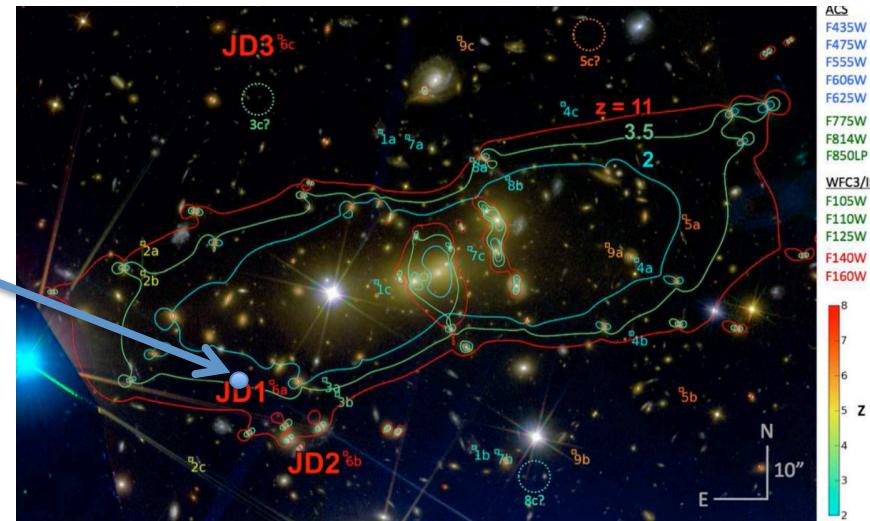
Faint spectral signatures in primordial molecular hydrogen will radiate faintly in the far-IR at high redshift ($z = 8-12$) and may be amplified by large-scale shocks-as seen in local analogs

We will use deep surveys of gravitational lensing systems to further amplify the primordial gas signals as warm H_2 collapses and shocks in rapidly-merging dark matter halos

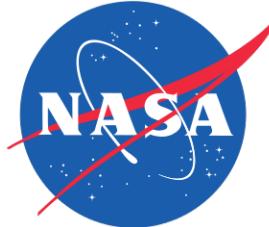


(Cluver +10, Appleton+16)

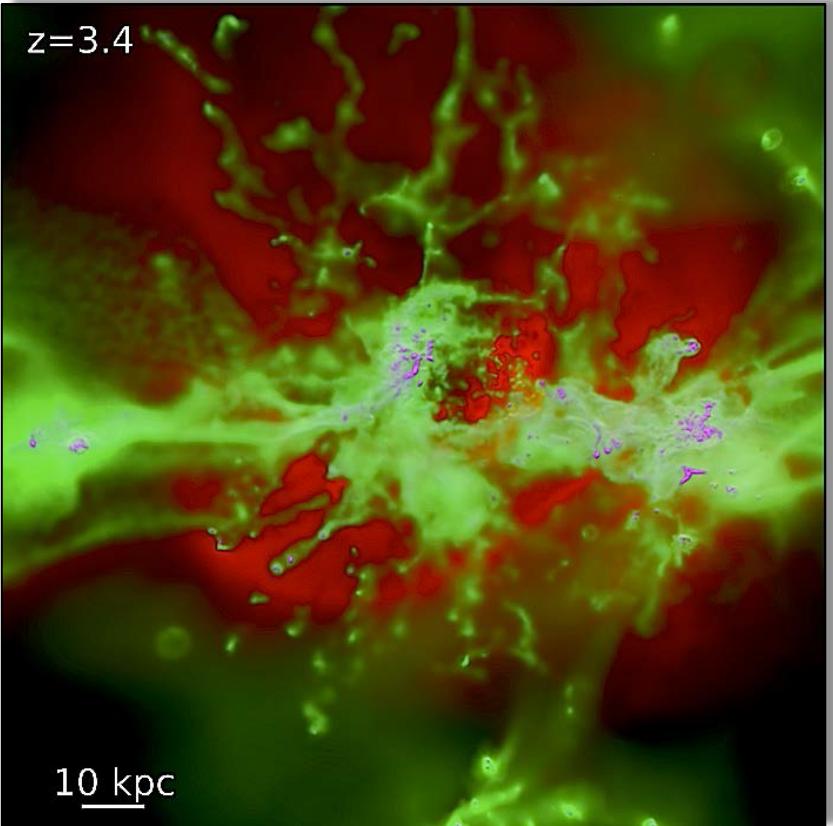
10-m telescope
beam @200 μ m



Search strategy: Map along critical lensing caustics like those in foreground cluster MACSJ0647.7+7015 (Coe et al. 2013).

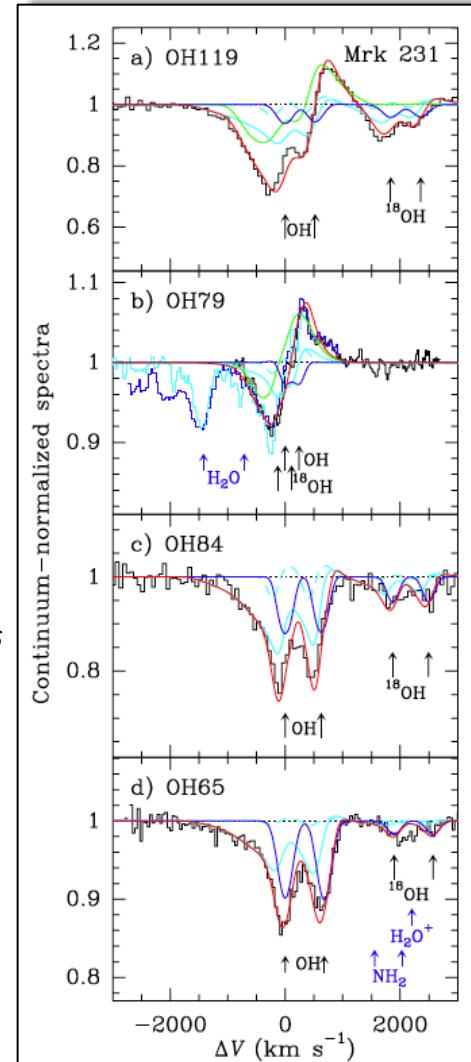


Tracing the baryon cycle with OST



Simulation of a MW-type galaxy at $z=3.4$ showing feedback-driven structure in the cold ($<1000K$ magenta), warm (10^4K green) and hot (10^6K red) gas (Hopkins +14).

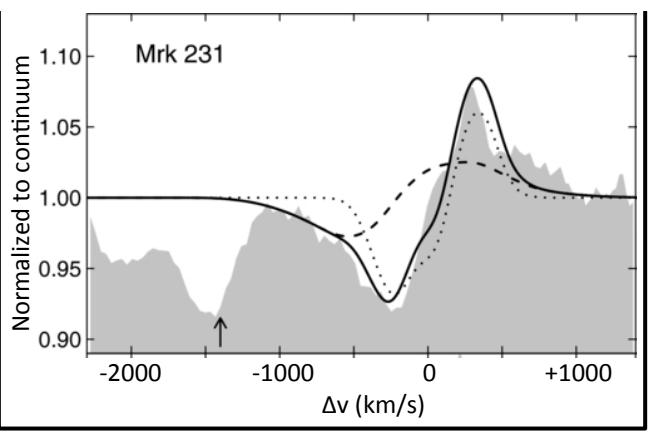
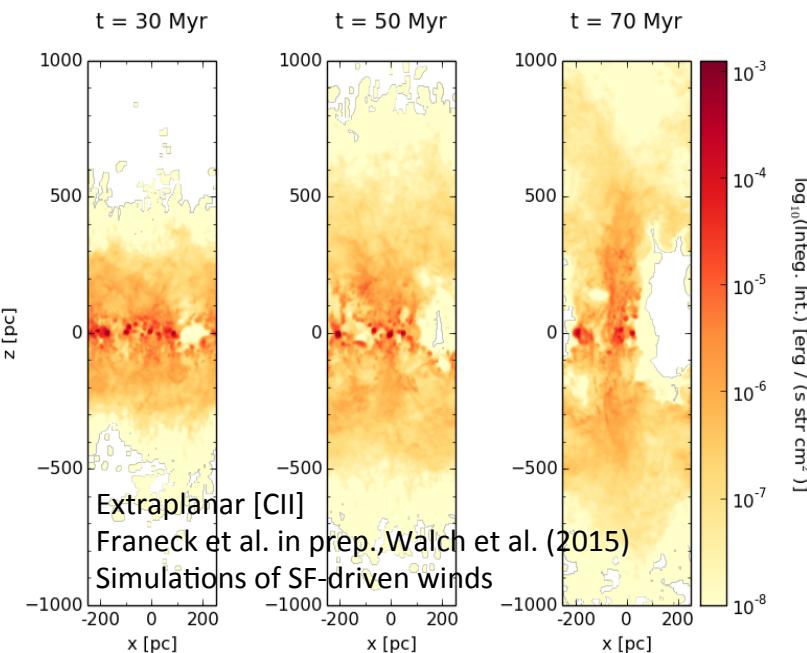
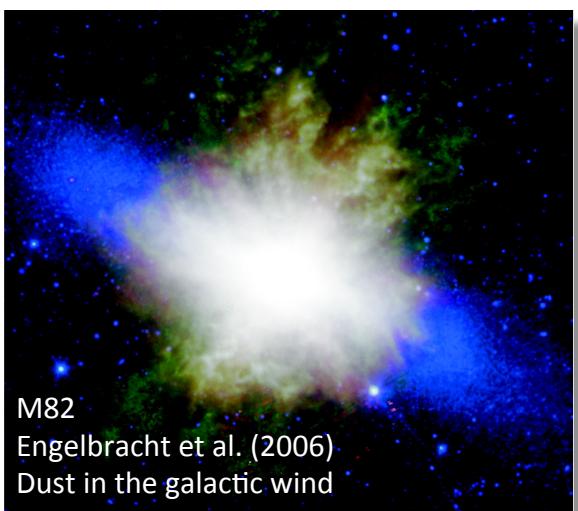
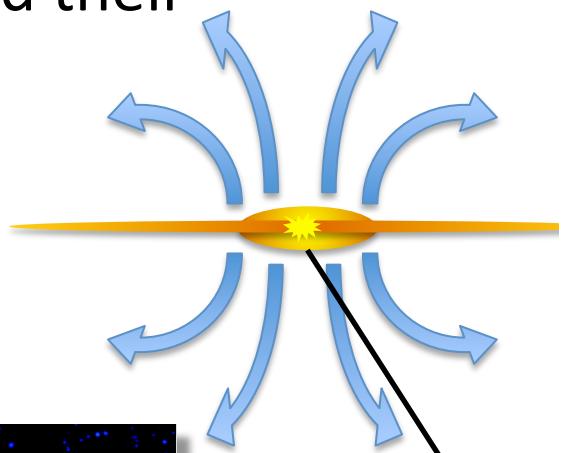
Mid and far-IR emission and absorption lines trace feedback on the atomic and molecular ISM, responsible for quenching, galactic outflows, and the flow of metals from galactic disks to halos.





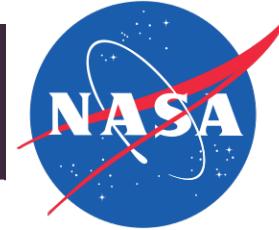
Galaxy Feedback to $z < 1$:

How do galaxies shape themselves and their environment?



The Origins Space Telescope.
Alberto Bolatto

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

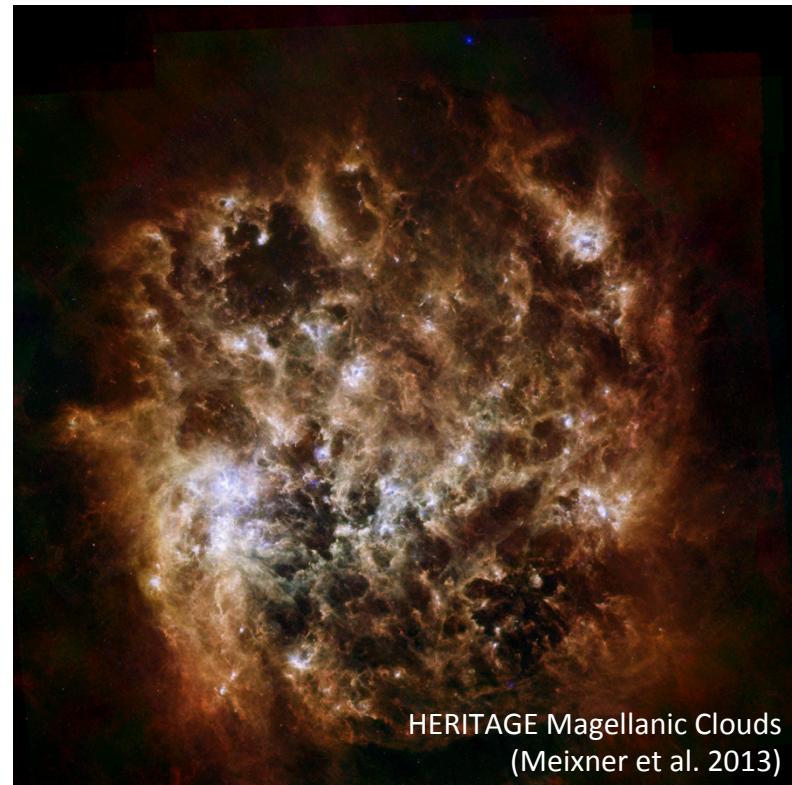


The Multiphase ISM:

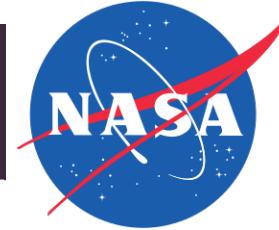
what sets the balance of ISM phases? What is the origin and lifetimes of molecular clouds?



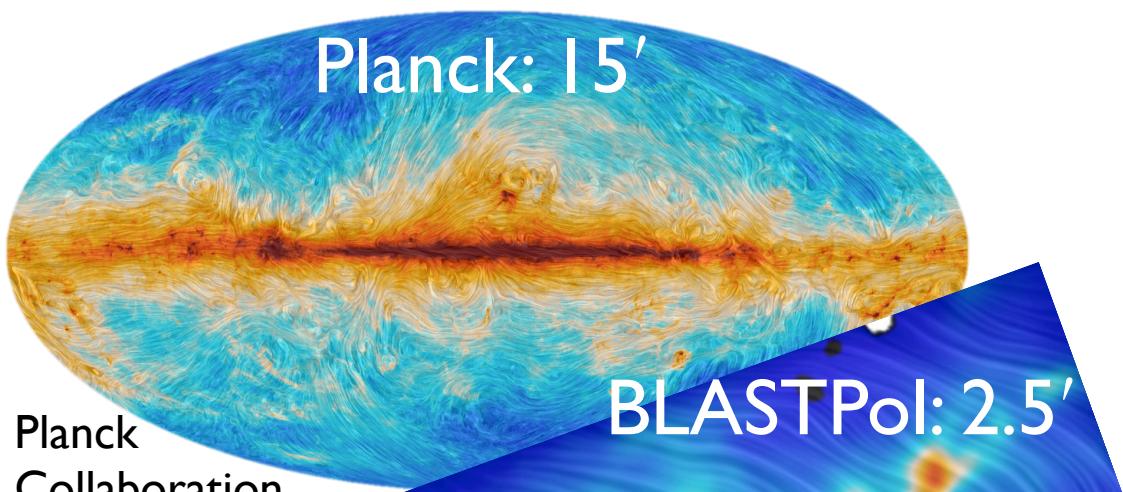
Credit: PAWS team/IRAM/NASA HST/T. A. Rector (University of Alaska Anchorage), E. Schinnerer. H_2 , H



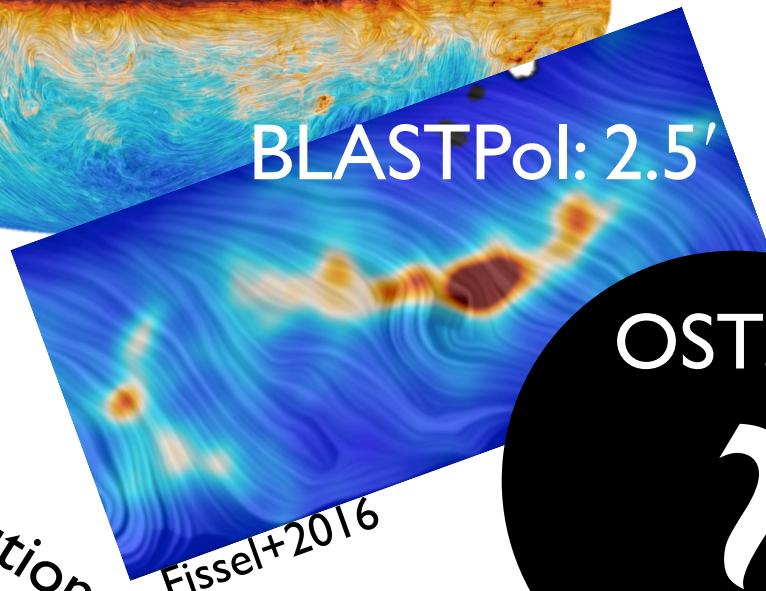
HERITAGE Magellanic Clouds
(Meixner et al. 2013)



Magnetic fields and turbulence



Planck
Collaboration

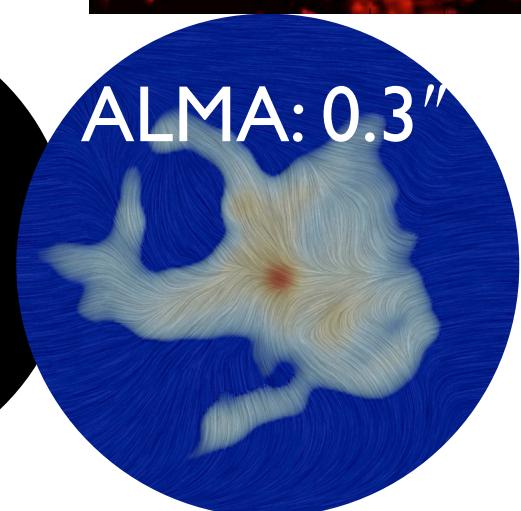
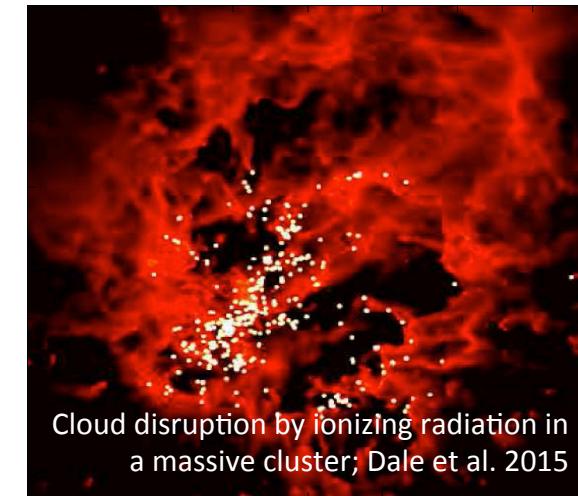


Higher resolution

Fissel+2016



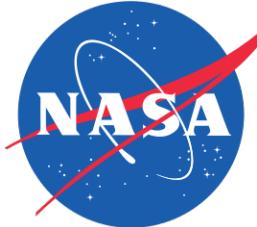
The Origins Space Telescope:
Chat Hull, Erik Rosolowsky



Hull+ 2016; Image courtesy of Phil Mocz



Tracing the signatures of life and the ingredients of habitable worlds
Origins will trace the trail of water from interstellar clouds, to protoplanetary disks, to Earth itself facilitating an understanding of the abundance and availability of water for habitable planets.

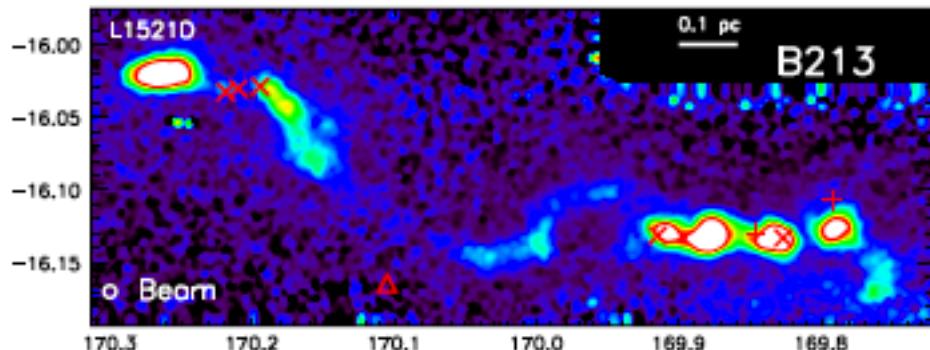


The Path of Water:

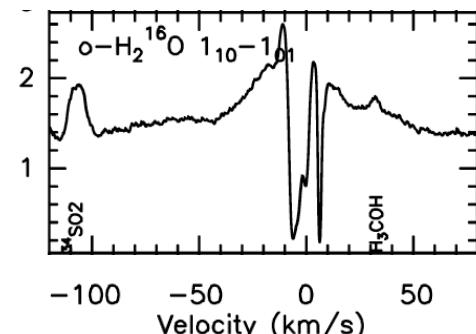
Trace the path of water from the ISM to molecular clouds to cores, disks, and the terrestrial planet zone.

What is the velocity field in collapsing dense cores that are on the verge of forming new stars?

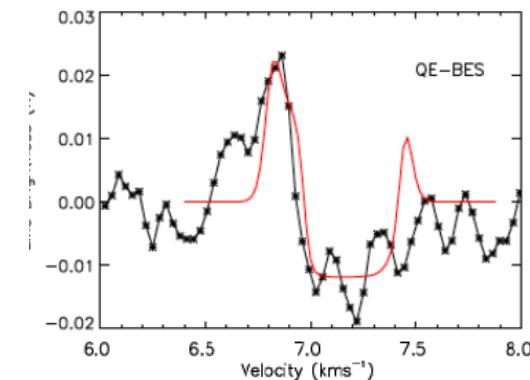
Cores in Taurus mapped using ammonia together with young stellar objects (YSOs) (Seo et al. 2015)



The Origins Space Telescope:
Paul Goldsmith



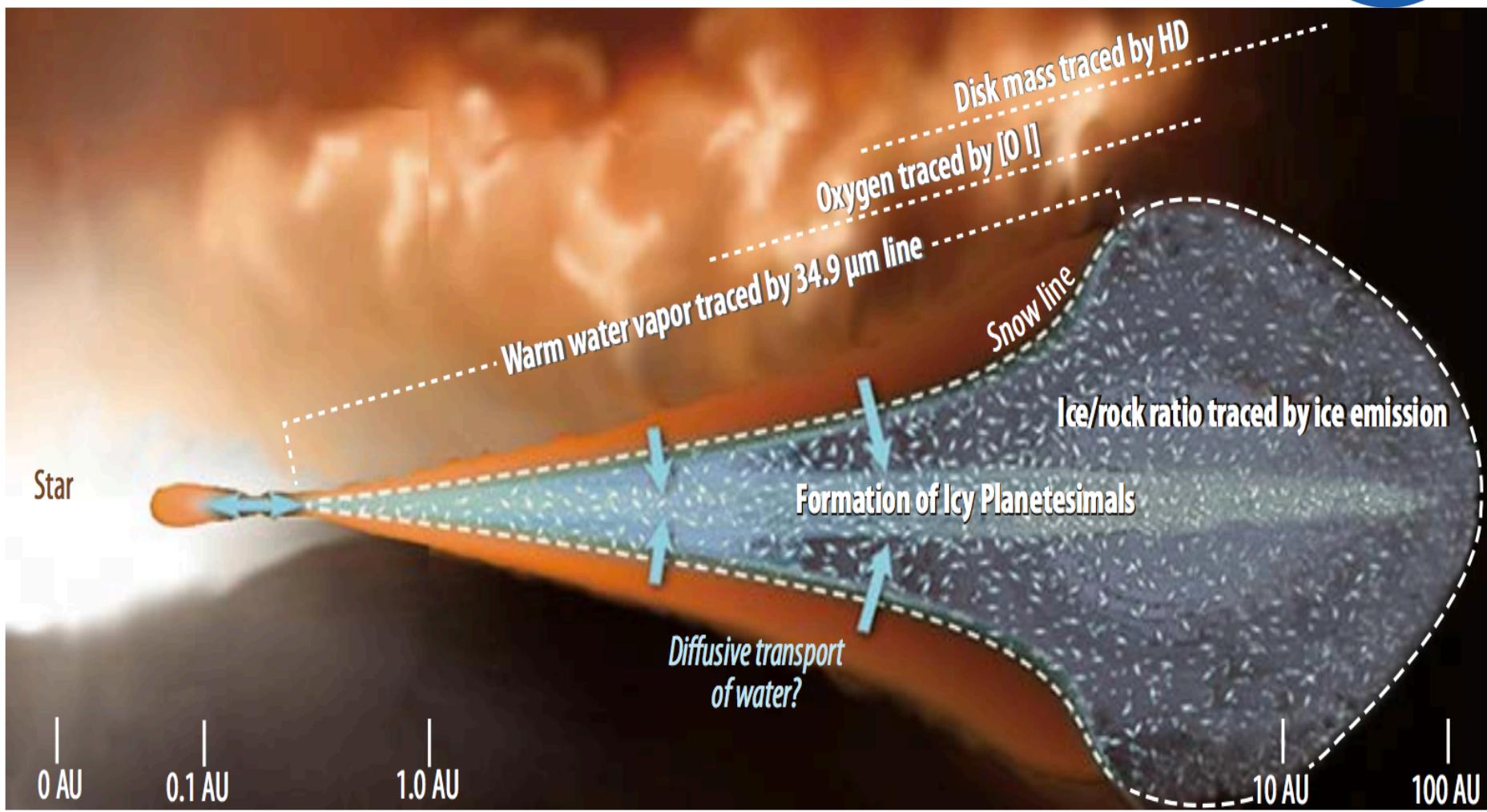
Complex H₂O emission & absorptiion profile in NGC6334 (Emprechtinger et al. 2010)

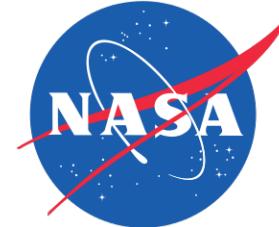


L1544 Observed and best-fit theoretical collapsing core model (Keto et al. 2015)



Grounding Knowledge of Planet Formation

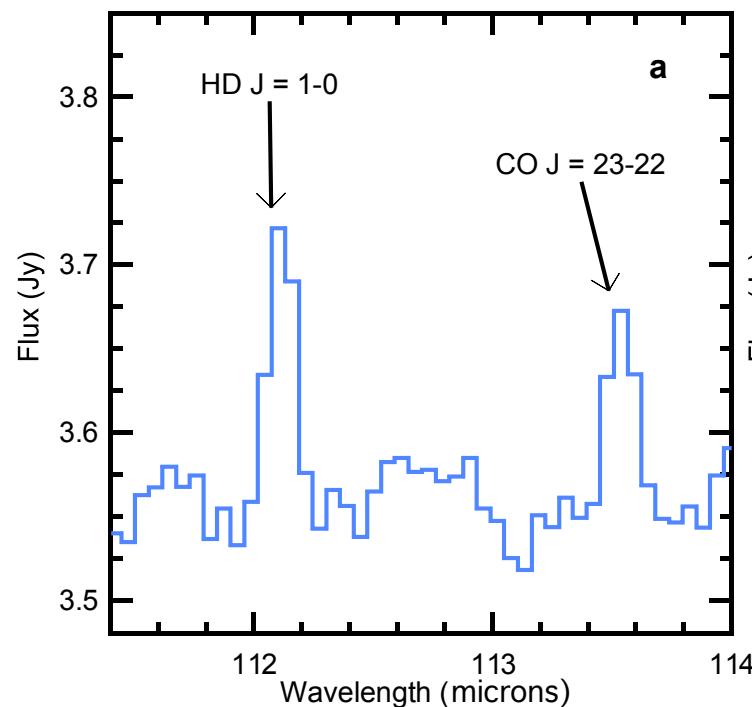
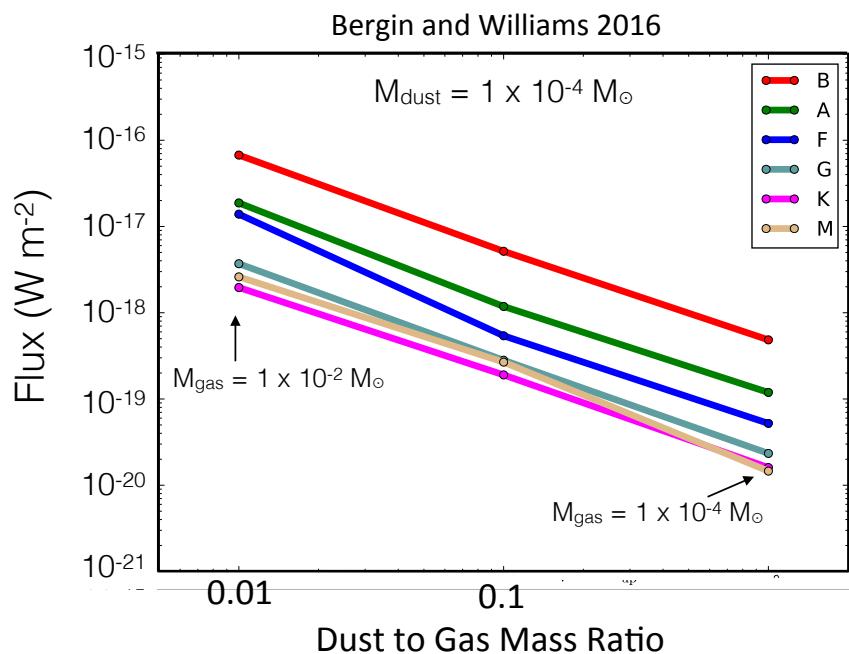




Probing the total gas content during the time of planet formation

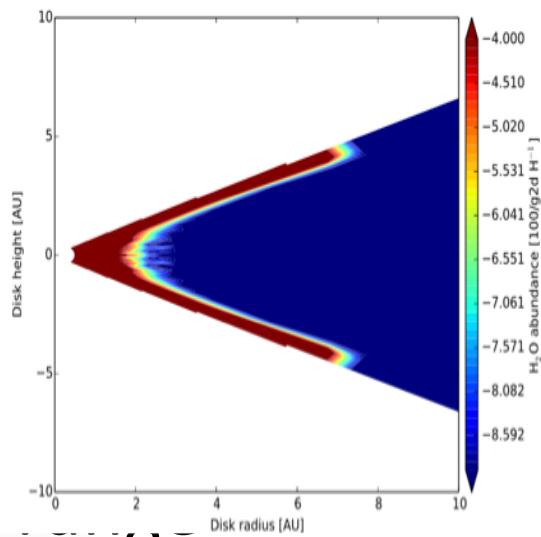
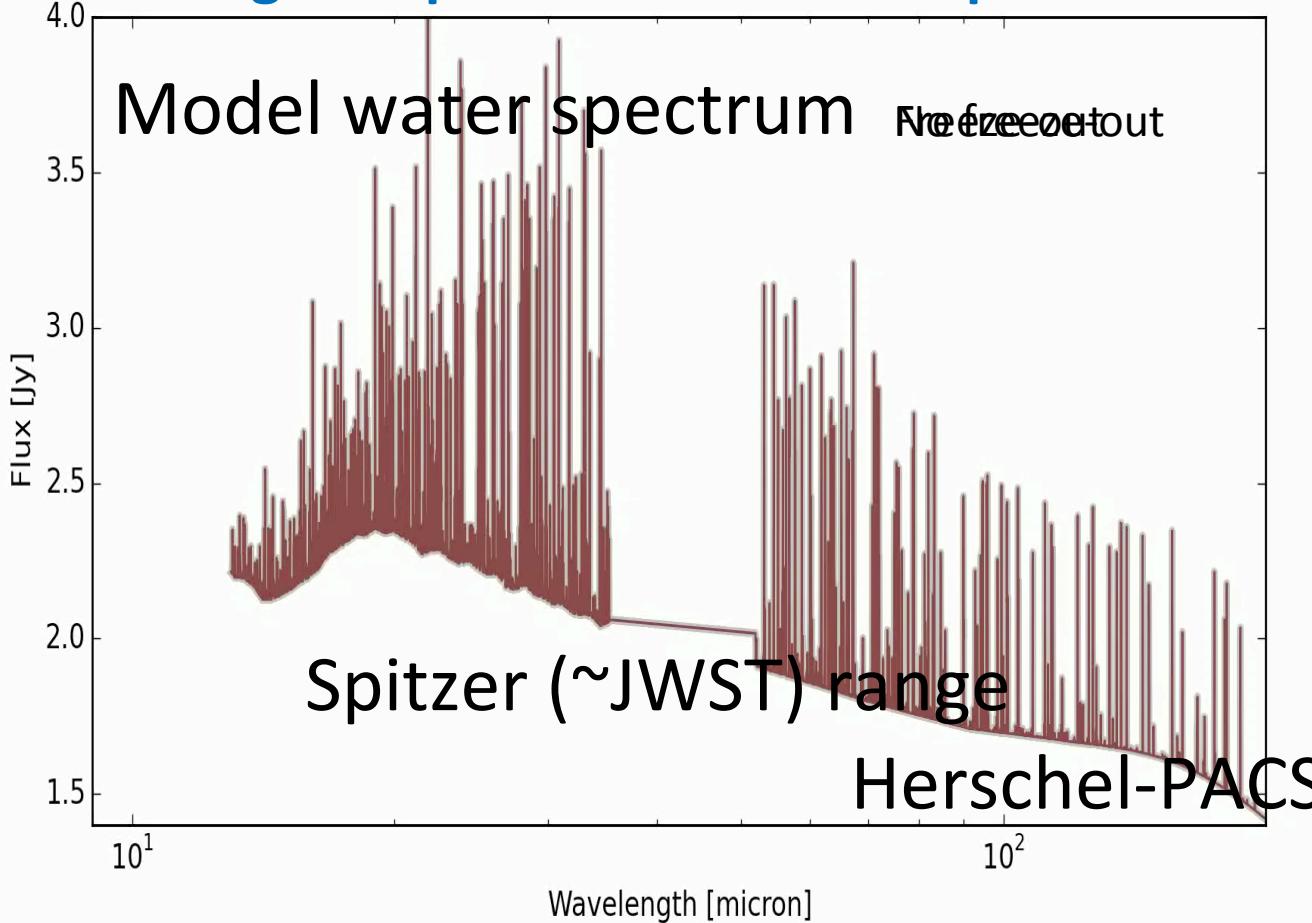
- timescales of gas/ice giant and super-Earth formation
- total gas content and chemical composition

Use HD to measure the gas mass in disks down to cool stars with a gas/dust mass ratio of unity.

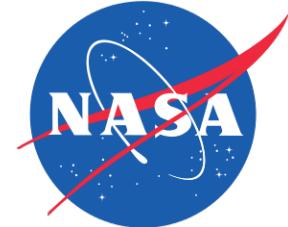


Herschel Detection of HD J = 1-0 towards TW Hya providing the first (semi)direct constraints on the gas mass (Bergin et al. 2013)

Detecting the spectrum of water vapor from low to high energy

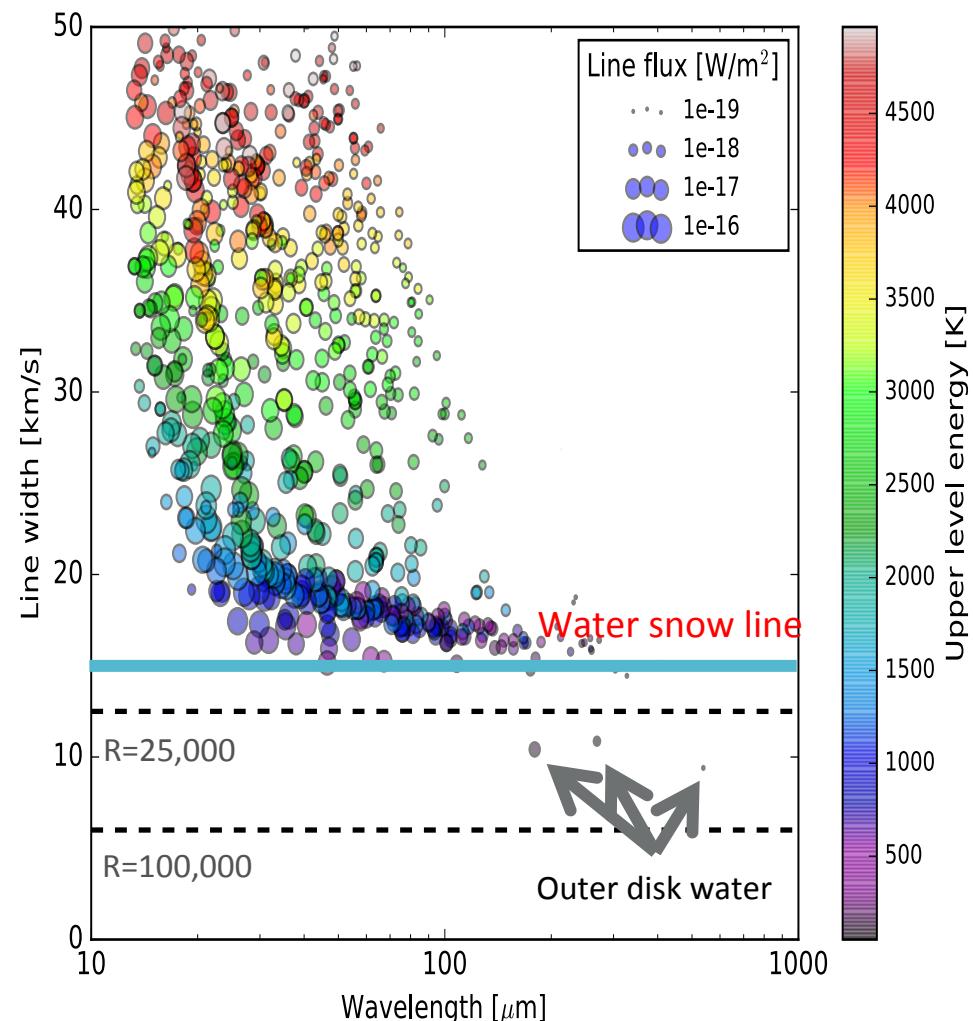


← →
OST range



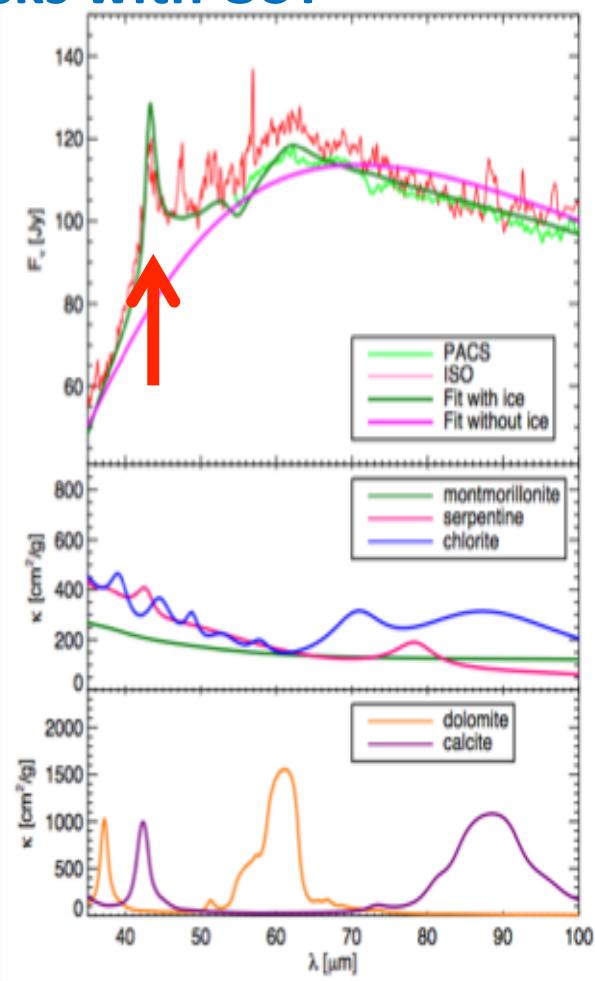
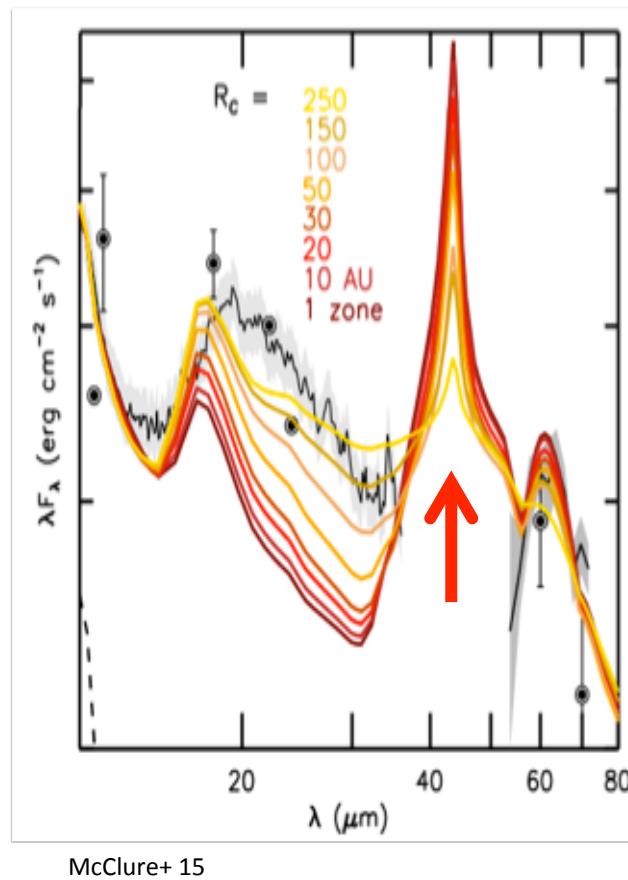
Measuring water snow lines with resolved FIR spectroscopy

- Fluxes and widths of water lines from a typical protoplanetary disk
- Lines at 20-100 micron needed to trace region near snow line.
- Lines at 179-600 micron needed to trace water outside of snow line.
- OST can detect the water spectrum and constrain the snow line in over 1000 disks

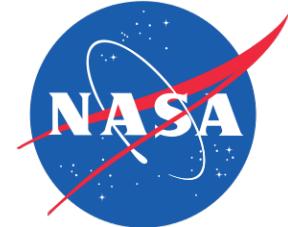


Measuring the ice mass in protoplanetary disks with OST

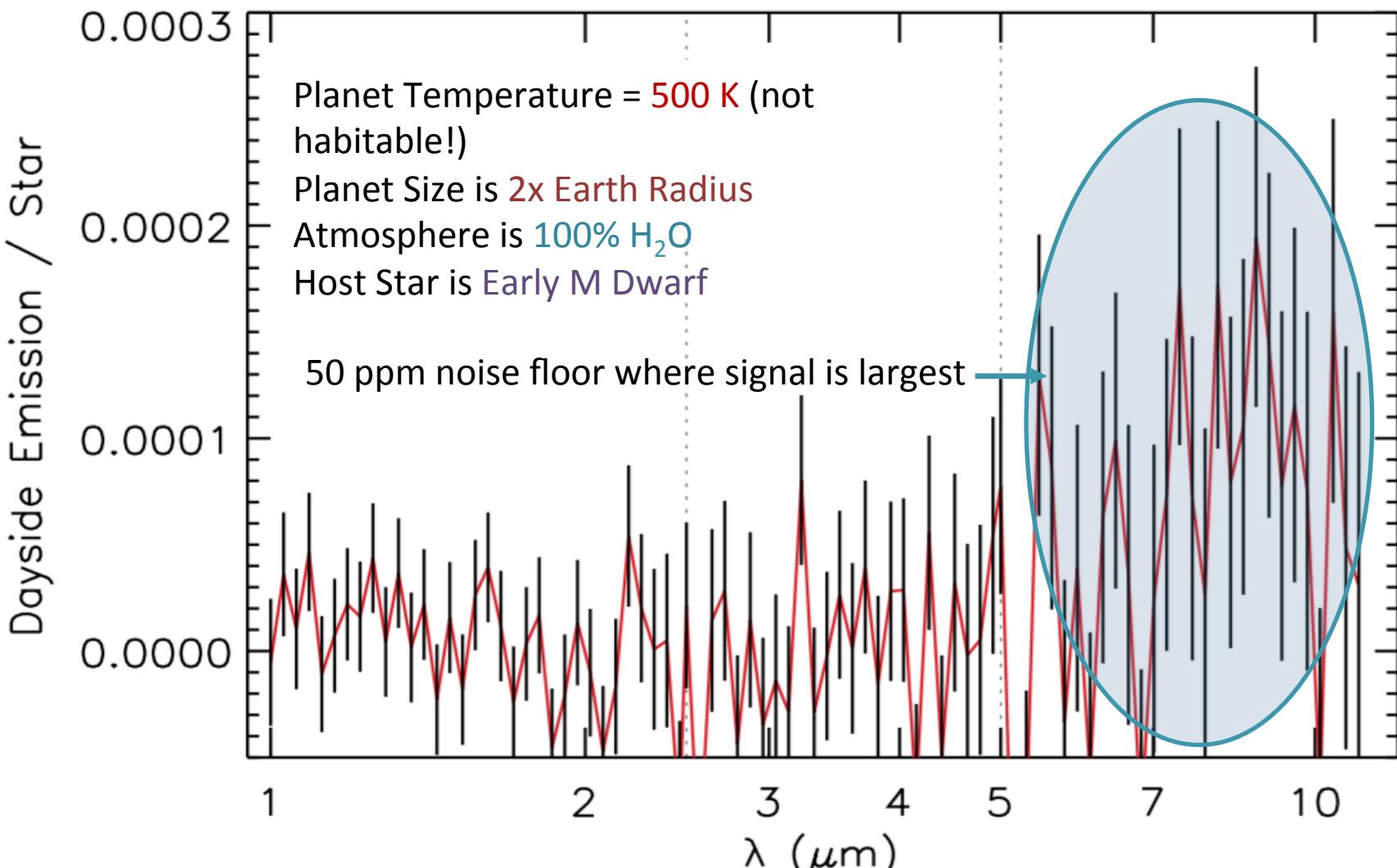
- The 43 micron emission band is the most sensitive tracer of bulk water ice in disks.
- OST will be sensitive enough to measure it across the stellar mass range, and from debris disks to protoplanetary disks out to several kpc.
- OST will measure the water gas/ice ratio in hundreds of systems.



Min+ 16

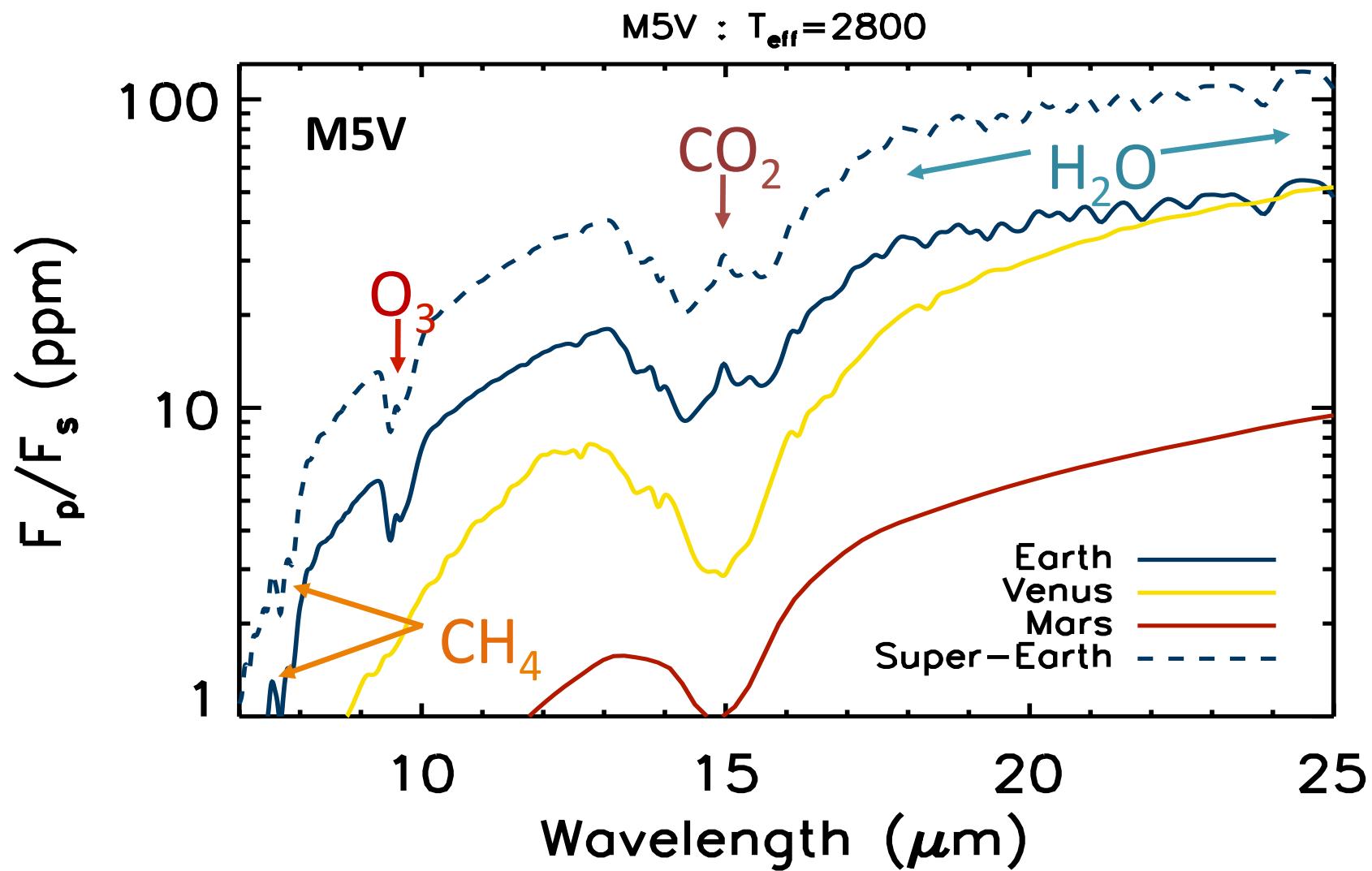


JWST is Unlikely to Study Habitable Zone Worlds





Signal Size for Habitable Zone for M Dwarf Planets





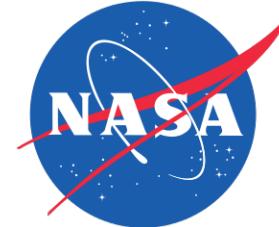
OST and Habitable Worlds



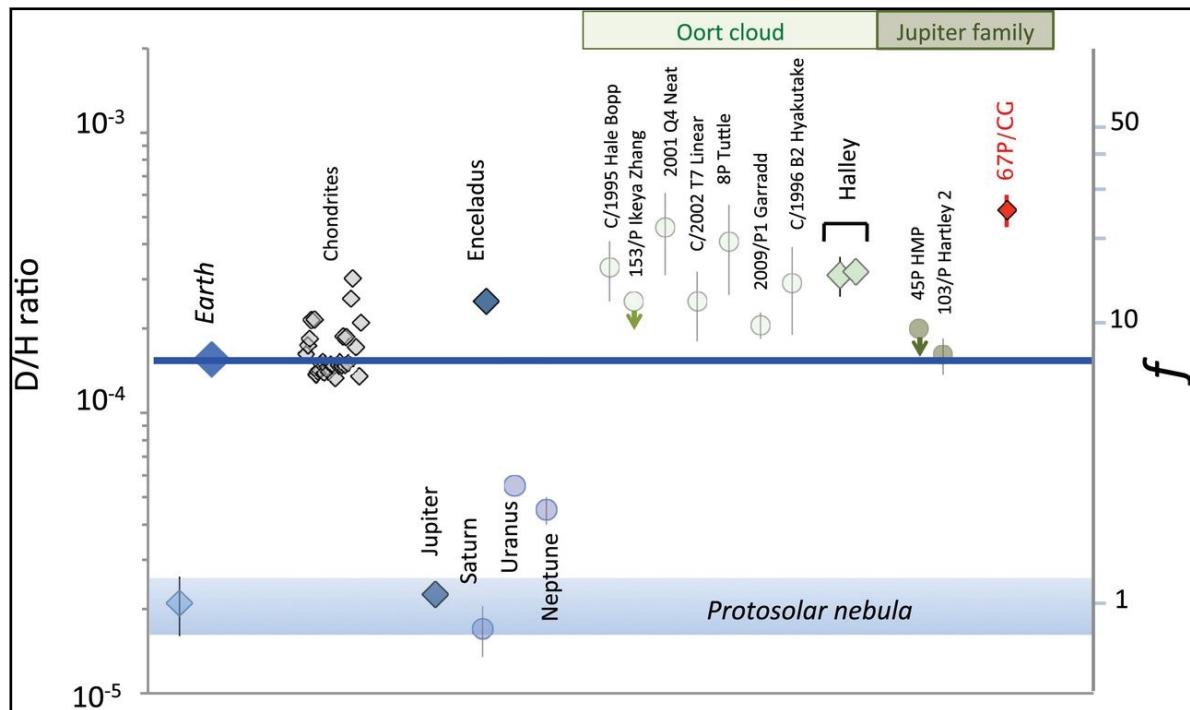
To detect biosignatures:

- Noise floors < 10 ppm
 - (M3V@20 pc – 2 hr at 7 μm)
- Short wavelength cutoffs of:
 - 9 μm for ozone (biosignature)
 - 7 μm for methane (life detection)
- Exploring coronagraph enabling direct detection of giant planets at 5 – 14 AU and warm Neptunes into 2 AU

Thermo-Chemical History of Comets and Water Delivery to Earth

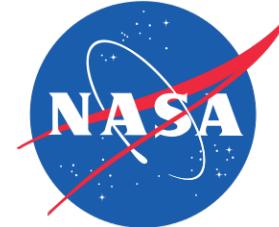


Studies of Isotopes Across the Solar System

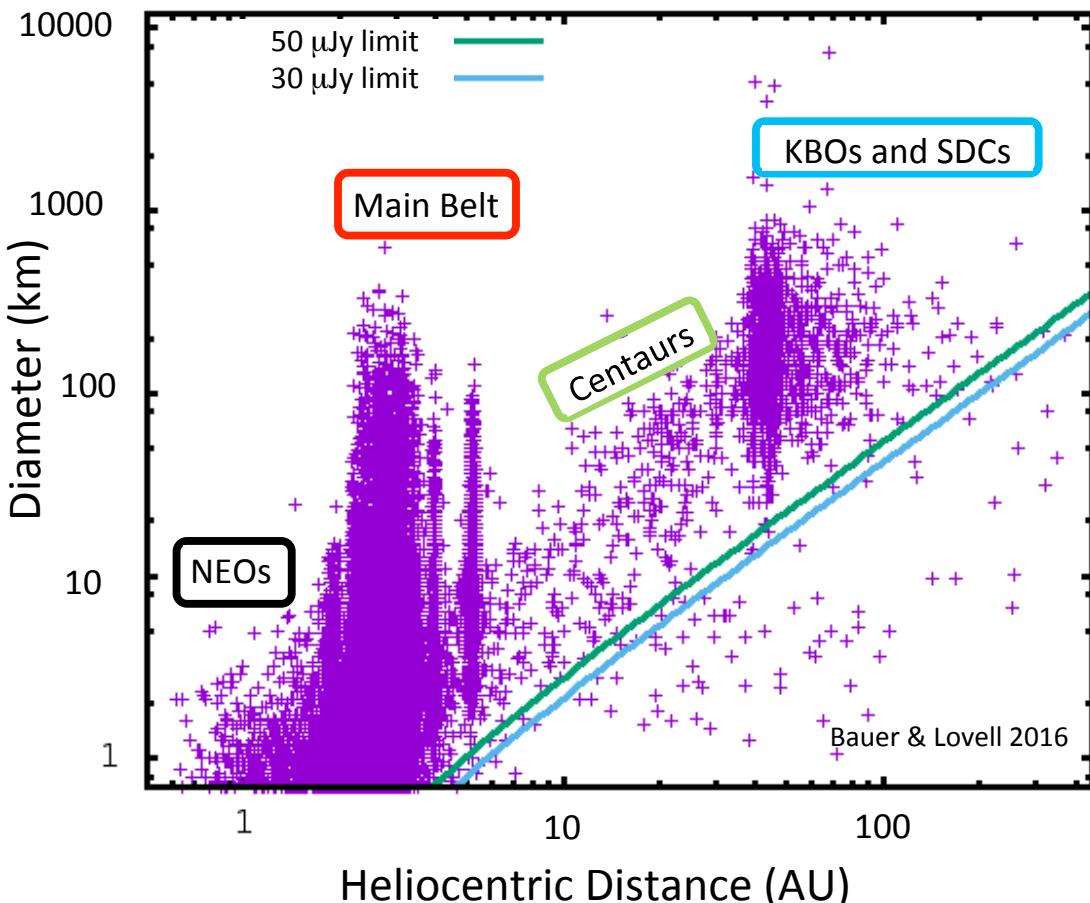


D/H measurements in comets, from Altwegg, K. et al. 2015. A larger statistical sample of targets are needed to determine the origin of Earth's ocean and measure the dispersion of this ratio in both dynamic families.

- How does presolar deuterium chemistry inform our understanding of D/H in the solar system and the development of Earth's oceans?
- Measure HDO in 100s of comets for an un-biased survey.
- Measure accurate isotopic ratios (H, C, N, O) and abundances of trace gases, to constrain models and inform understanding of solar system origin and evolution.



History and Evolution of the Solar System (SS)



Measure the thermal emission (via Far-IR imaging) of small bodies in outer SS – several 1000's of targets out to >100 AU and sizes down to <10 km.

Volatile isotope measurements (HCNO) across the SS

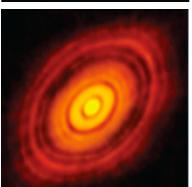
Constrain the Thermal History/Evolution of the Solar System – He/H₂ measurements.

Not limited by confusion.



Get Involved (open to community):

- Science working groups
- Instrument teams are forming (ost_info@lists.ipac.caltech.edu)



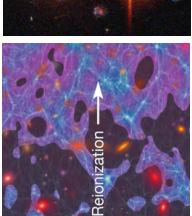
Solar system: Stefanie Milam



Planet formation and exoplanets: Klaus Pontoppidan and Kate Su

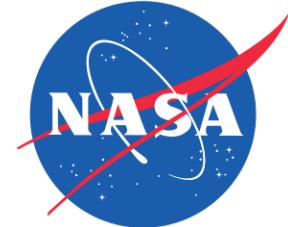


Milky-Way, ISM and local volume of galaxies: Cara Battersby and Karin Sandstorm



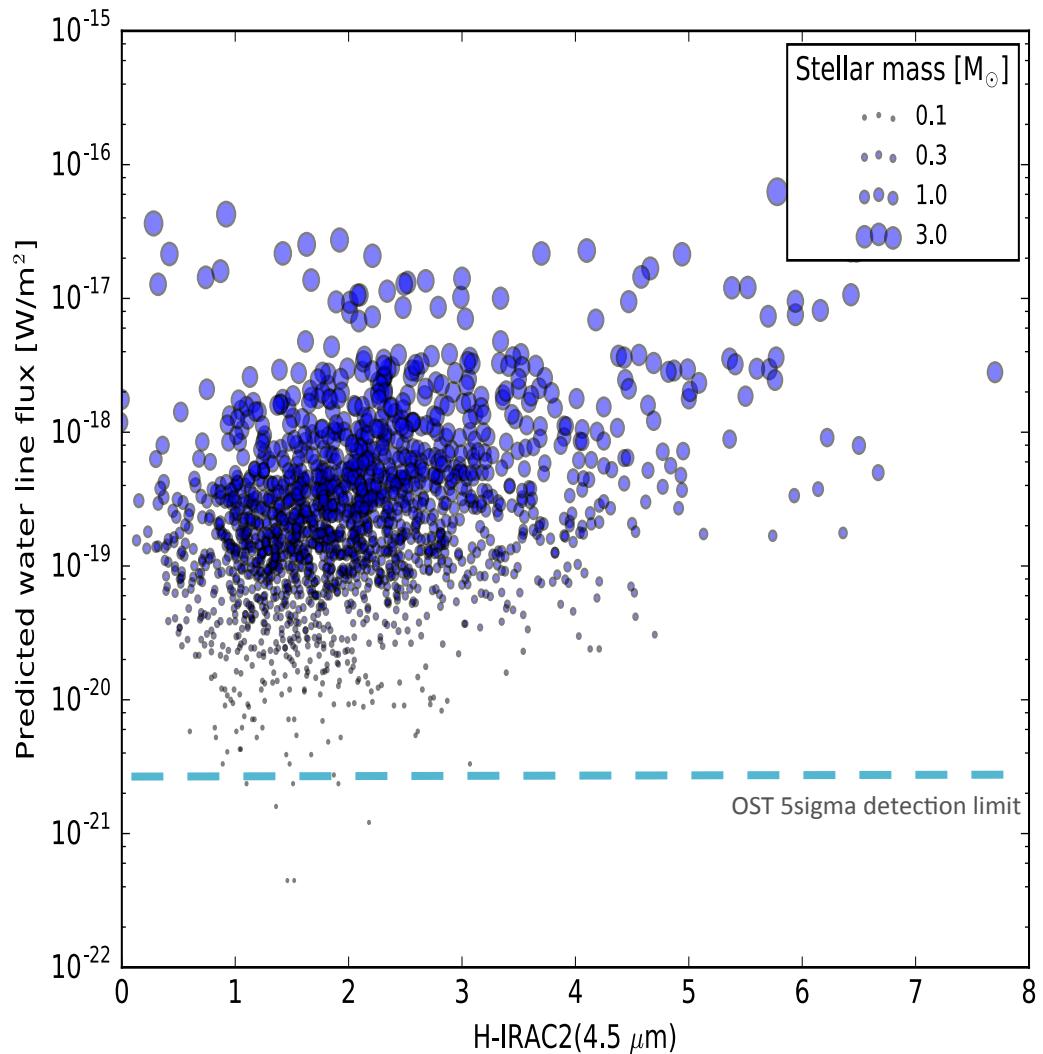
Galaxy and blackhole evolution over cosmic time: Lee Armus and Alexandra Pope

First Billion years: Joaquin Vieira, Matt Bradford



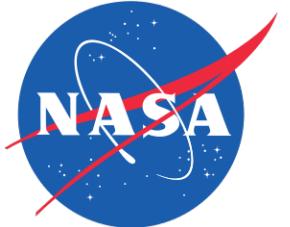
Water in 1000 solar-nebula analogs

- Predicted fluxes of a typical 20-100 micron rotational water line tracing the snow line, for disks in the Orion cluster (Megeath+ 2010).
- OST will have the sensitivity to efficiently survey water vapor emission from large samples of protoplanetary disks out to at least 500 pc.



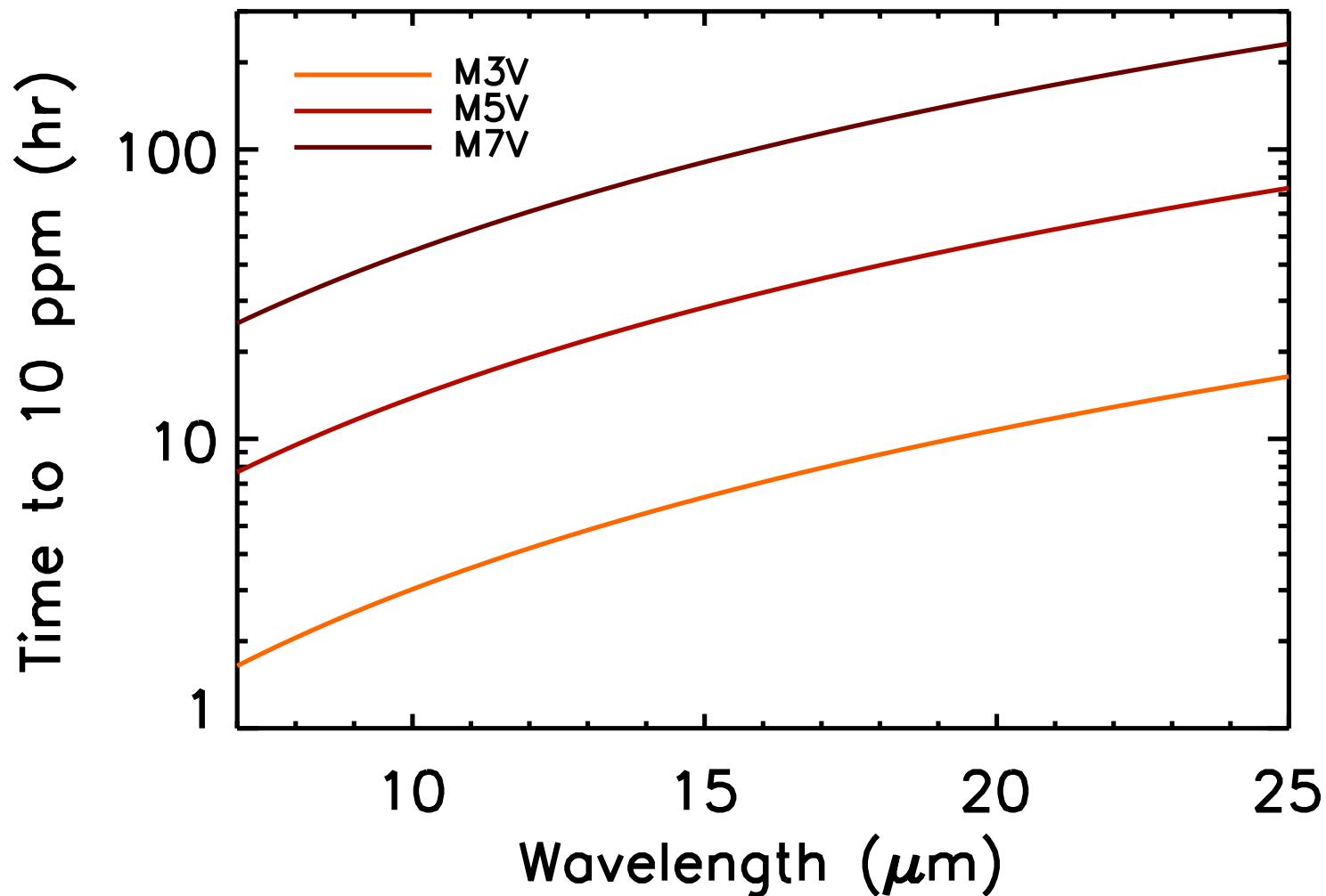


OST and Habitable Worlds



Time limits for baseline OST Concept to 10 ppm

D=15 m : 20 pc

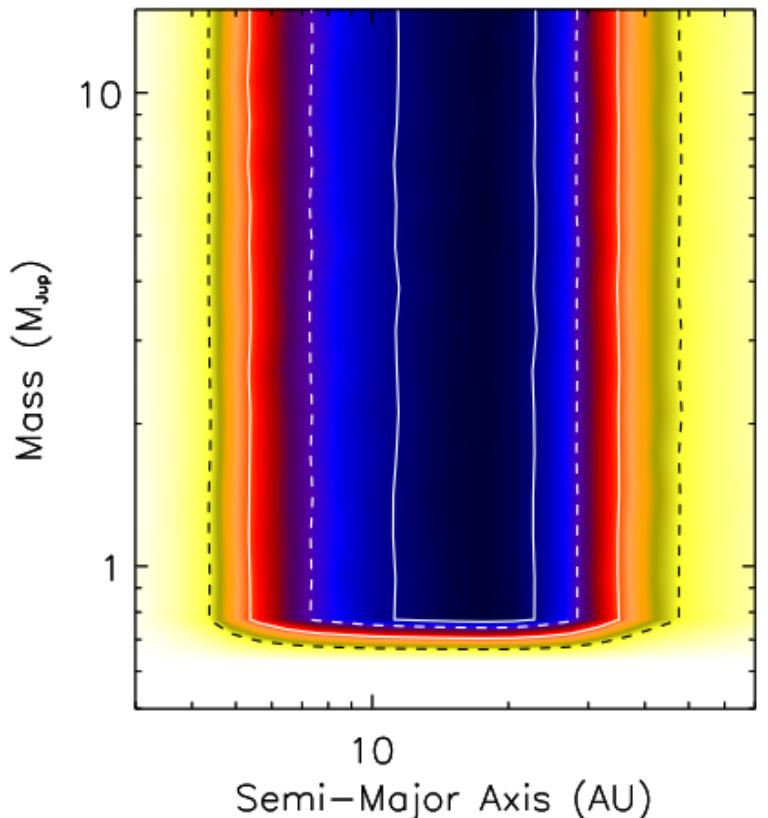


Q&A

Imaging Solar System Analogs among the Nearest Stars



Imaging Giant Planets with a 10 micron Coronagraph



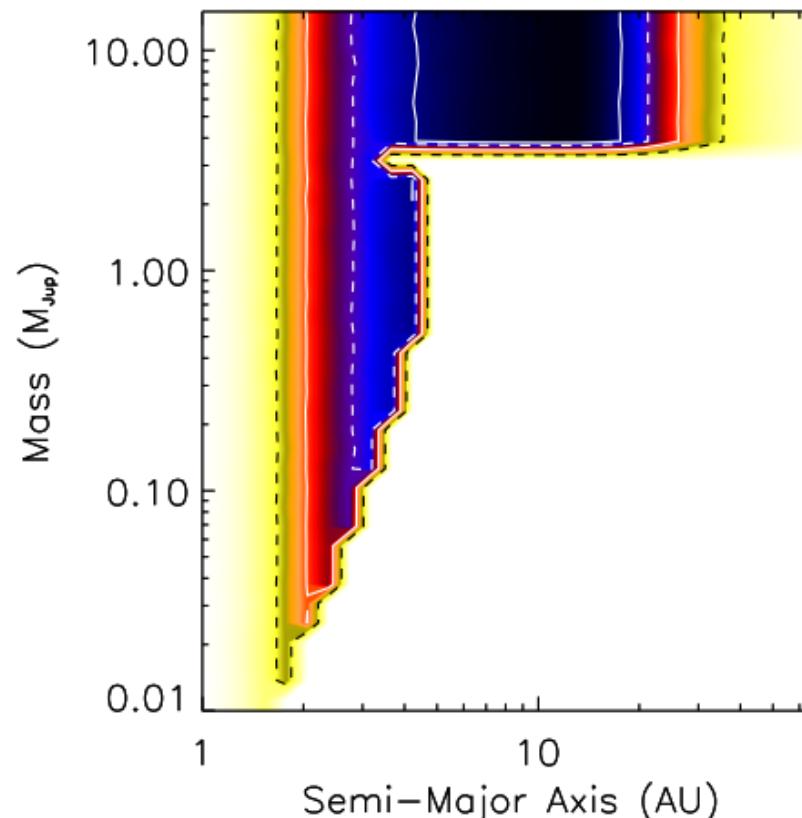
Are the giant planets in our Solar System an example of a typical mode of giant planet formation? Direct Imaging and Radial Velocity still struggle to find planets at the same mass and radius as Jupiter and Saturn.

True analogs to Jupiter and Saturn can be reached in the thermal IR with OST's large aperture, low wavefront error, and an advanced coronagraph.

Completeness to giant planets around a 1 Gyr M-star
at 10 pc.

Imaging Solar System Analogs among the Nearest Stars

Warm Neptunes around the nearest Sun-like Stars



90% Kepler has told us that planets smaller than Neptune are ubiquitous close to their parent stars, but are much too faint to image with current technology.

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 this new class of planets.

Completeness to Jupiters, Neptunes, and Super-Earths orbiting a G0 at 7.5 pc.

FAQ

1. Why do we need another IR telescope after Spitzer, Herschel, JWST and WFIRST? – answer: it is not the wavelength that matters – it is where are the unknown science frontiers. OST will provide access to the formation of galaxies from the end of the dark ages to today in a manner that will not be possible even with the above great telescopes, OST will probe the history of water and trace the formation of pre-planetary materials with unique contributions – even in the age of ALMA, finally OST will be able to detect biosignatures around habitable planets with the current baseline mission. These are all ground breaking goals that just cannot be accomplished by the other missions and they can be done with one general purpose platform.
2. How much will your mission cost?



Community Chairs:

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

NASA Study Center:

Goddard Space Flight Center (GSFC): Ruth **Carter**, David **Leisawitz**, Mike **Dipirro**, Anel **Flores**

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

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

Ex officio non-voting representatives:

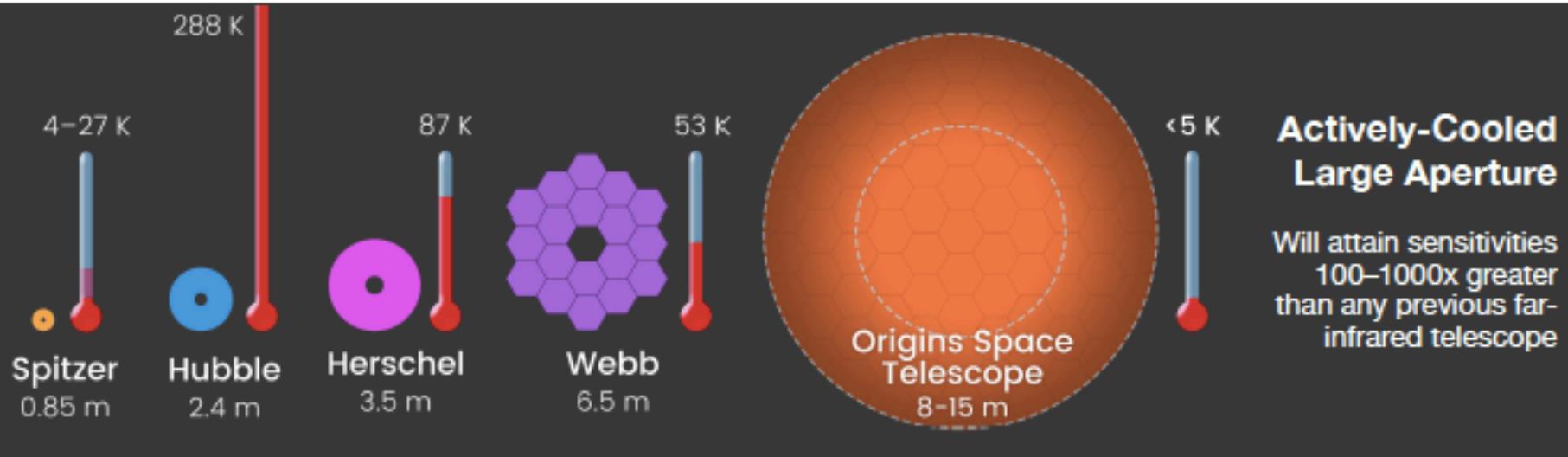
Susan **Neff** & Deborah **Padgett**, NASA Cosmic Origins Program Office; Susanne **Alato**, SNSB;
Douglas **Scott**, CAS; Maryvonne **Gerin**, CNES; Itsuki **Sakon**, JAXA; Frank **Helmich**, SRON; Roland
Vavrek, ESA; Karl **Menten**, DLR; Sean **Carey**, IPAC

Members appointed by NASA:

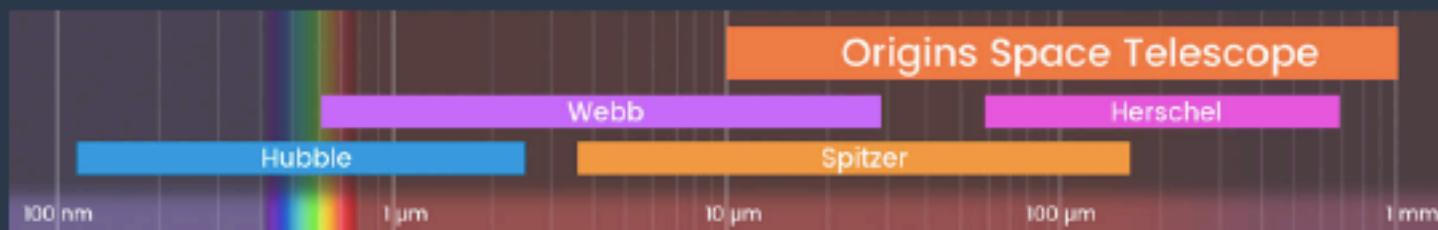
Lee **Armus**, NASA IPAC; Cara **Battersby**, Harvard-Smithsonian CfA; Edwin **Bergin**, University of Michigan; Matt **Bradford**, NASA JPL; Kim **Ennico-Smith**, NASA Ames; Gary **Melnick**, Harvard-Smithsonian CfA; Stefanie **Milam**, NASA GSFC; Desika **Narayanan**, University of Florida; Klaus **Pontoppidan**, 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



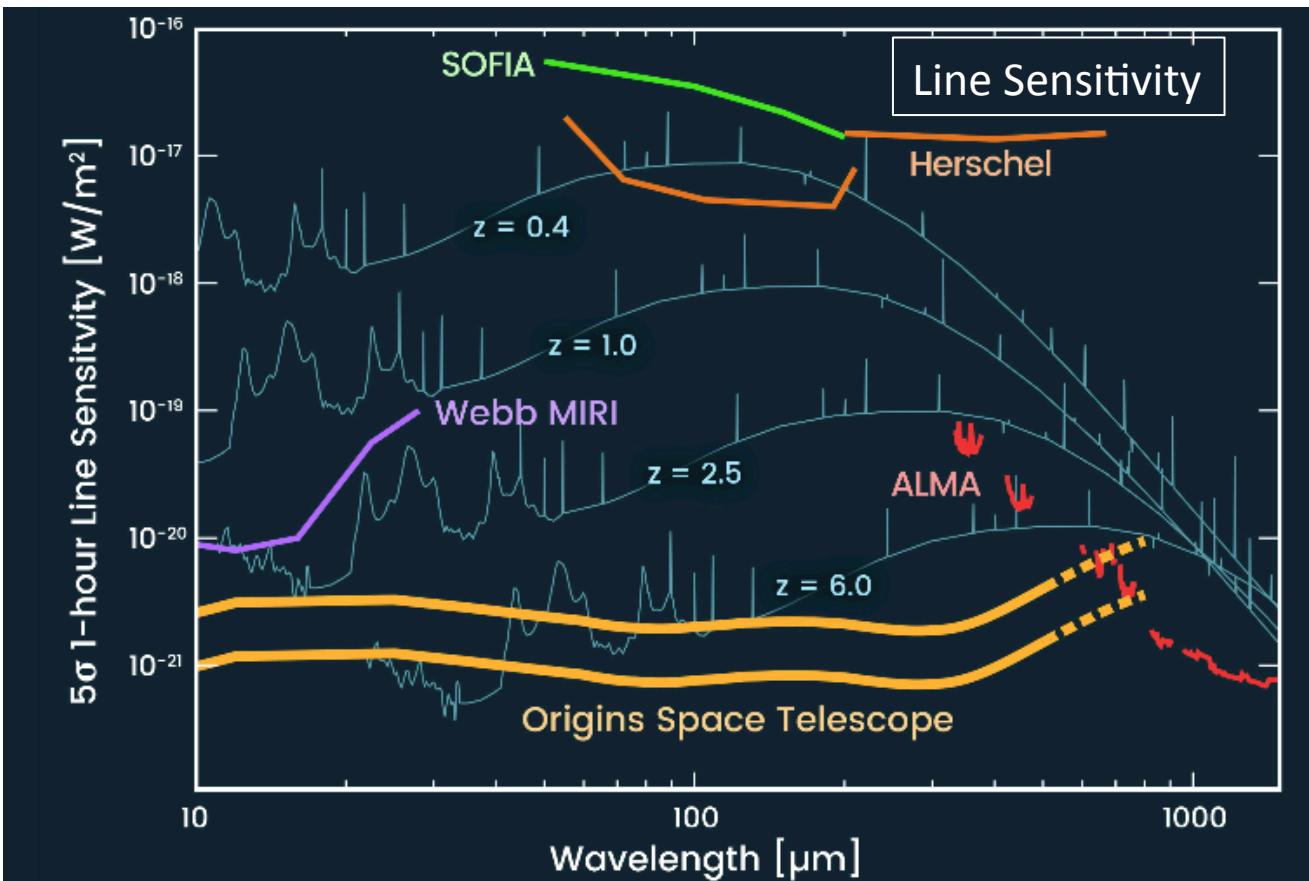
Technical Specifications



Wavelength Coverage from 10 μm -1 mm



Enables observations of biosignatures in the atmospheres of transiting Earth-like planets, mid- and far-infrared diagnostic lines in galaxies out to redshifts of 10, and characterization of water from the Solar System to the ISM.



Spectral instruments will capture full wavelength coverage over many pixels of sky coverage.

Continuum cameras will be wide field encompassing $\sim 15'$ square arc-min.

We are also exploring a Mid IR coronograph