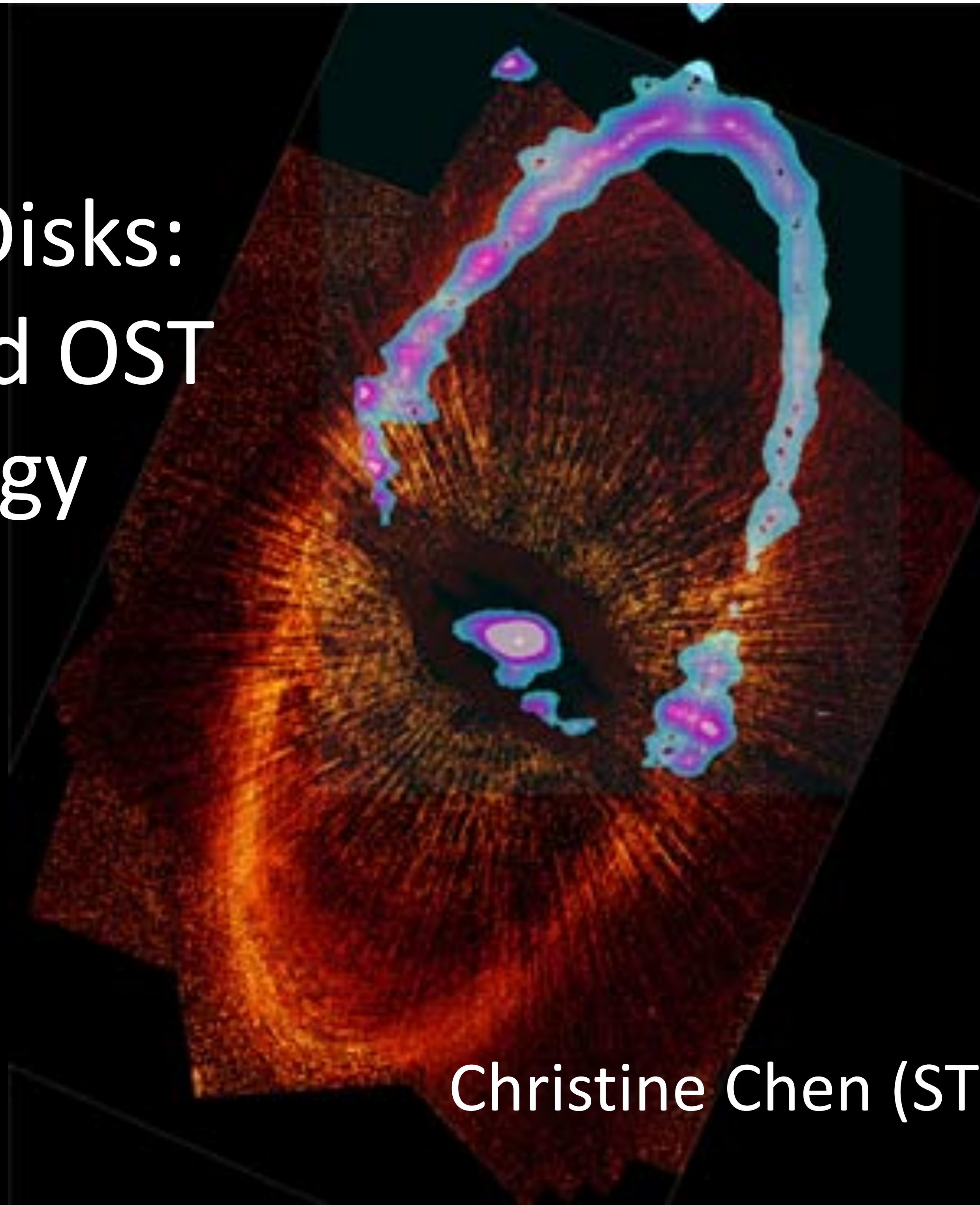
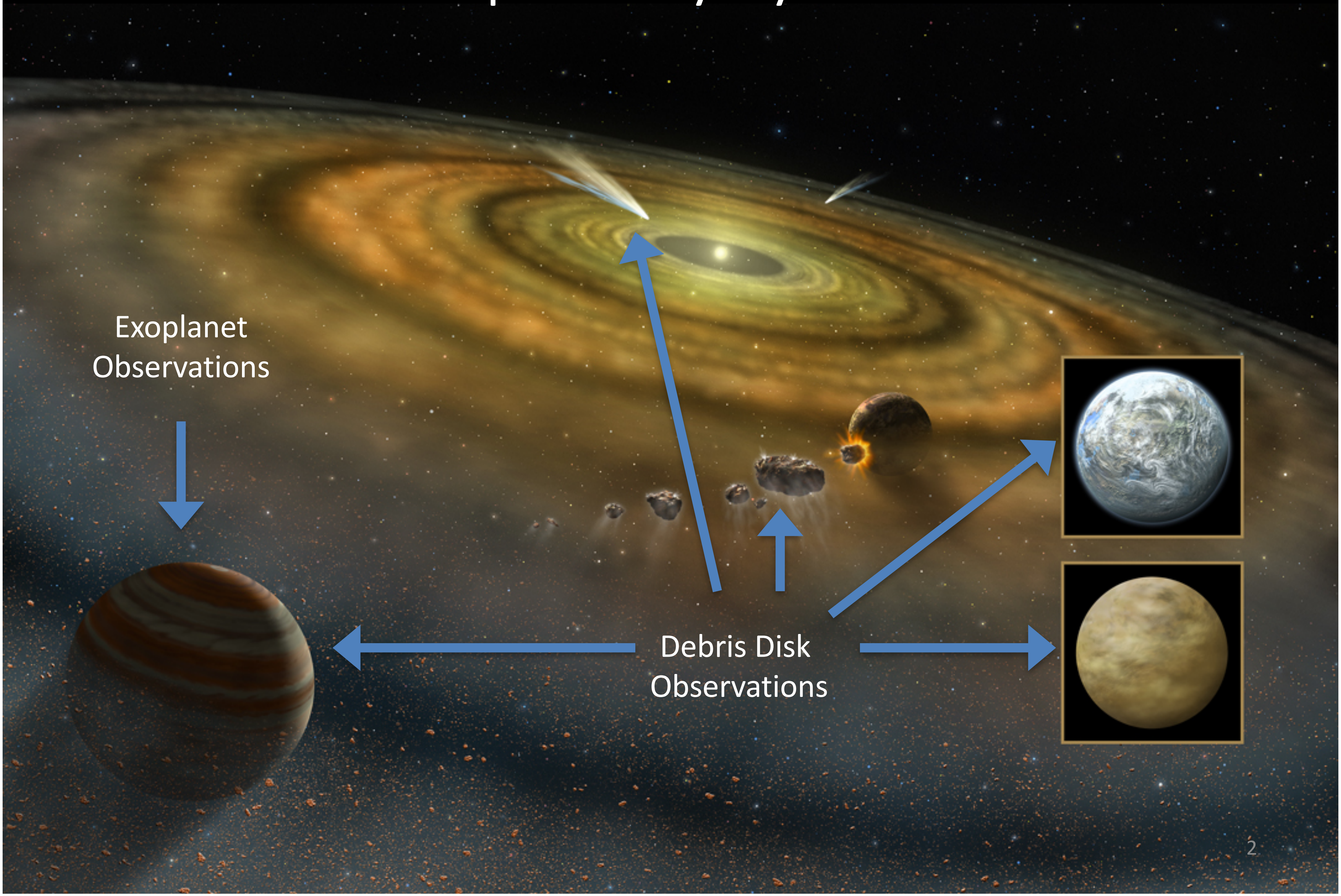
Debris Disks: JWST and OST Synergy



Christine Chen (STScI)

Exoplanetary Systems



Goals

- Understanding what a debris disk is
- Understanding what is known from thermal emission imaging of the dust and what can be learned using OST
- Understanding what is known about the composition of the dust and what can be learned using OST
- Understanding what is known about the gas and what can be learned using OST

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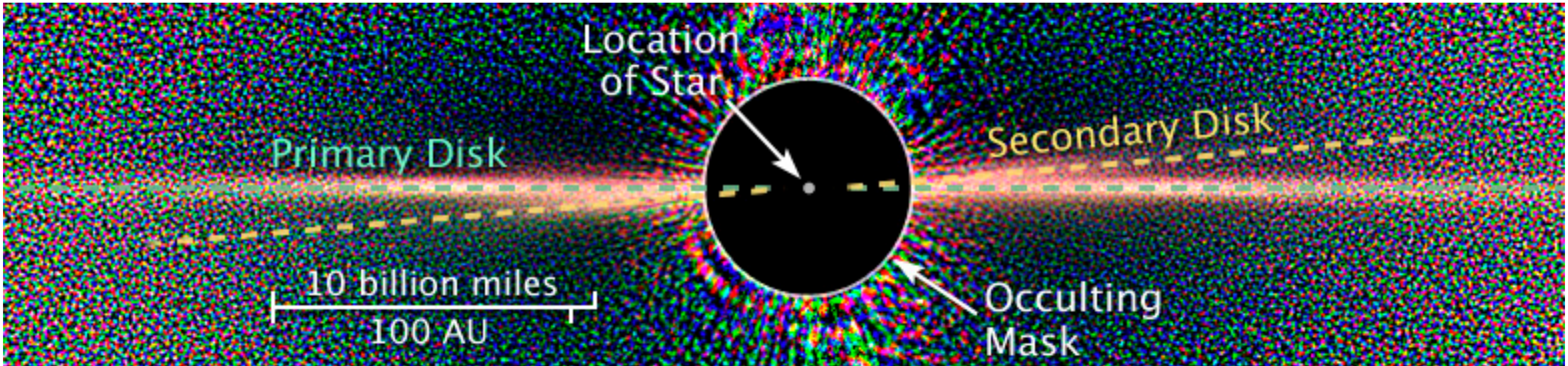
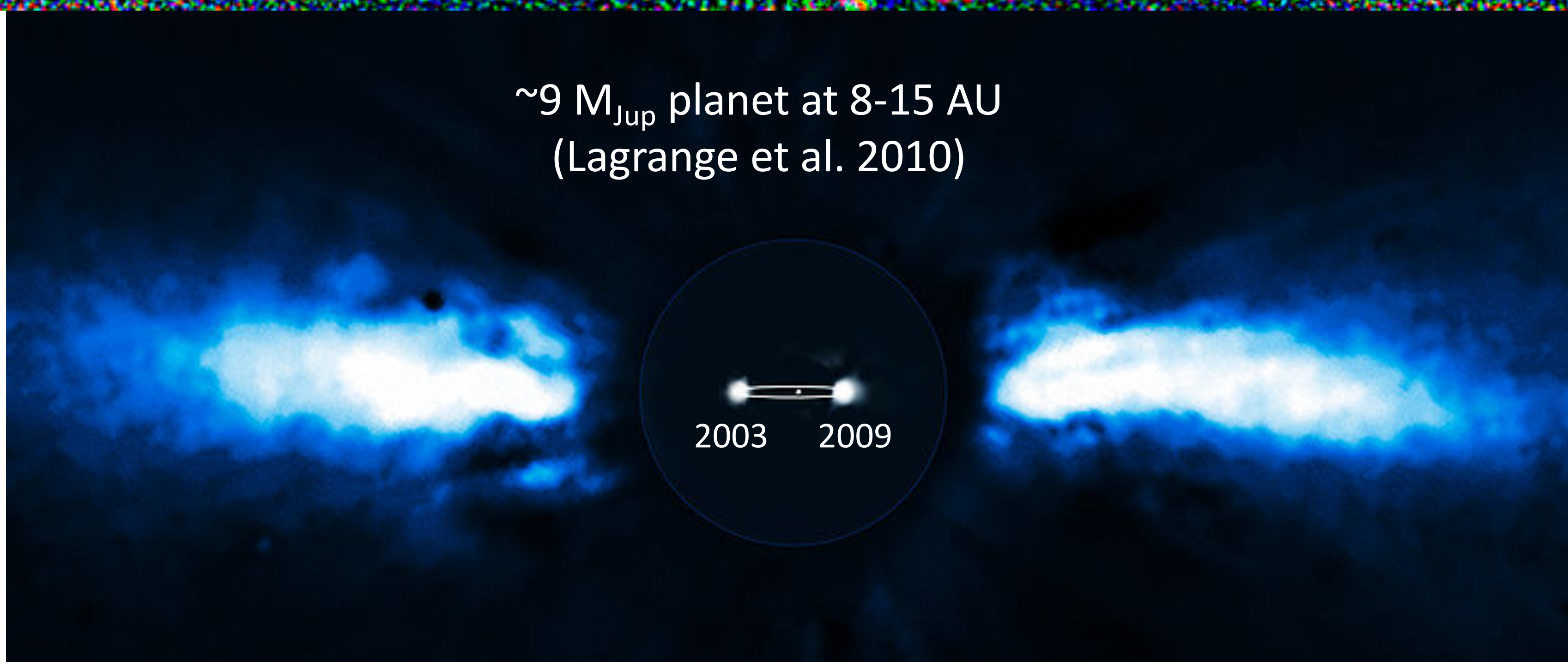
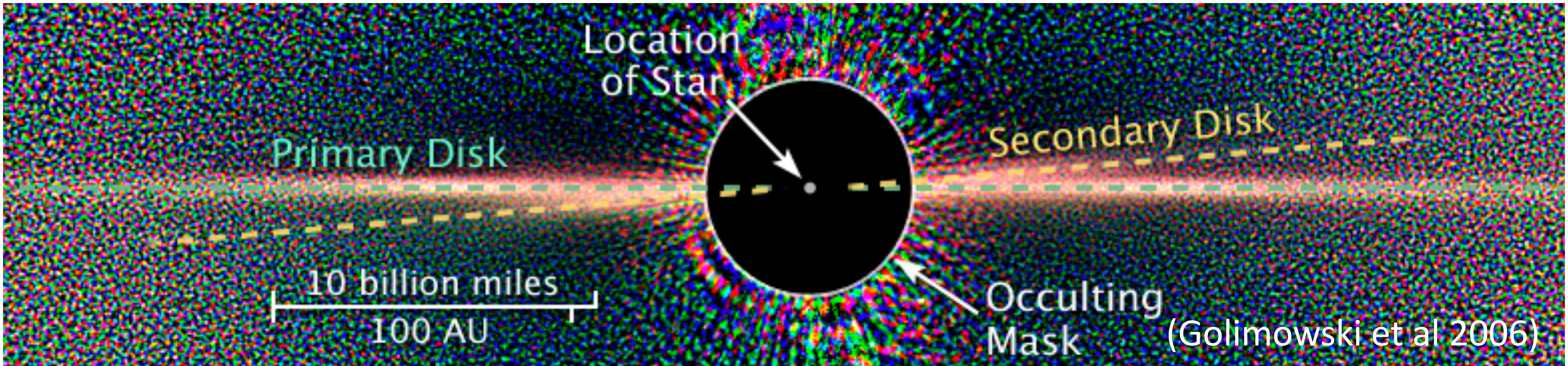
Reconstructing the β Pictoris Planetary System

Extended disk of small grains up to ~1400 AU from the star (Golimowski et al. 2006)



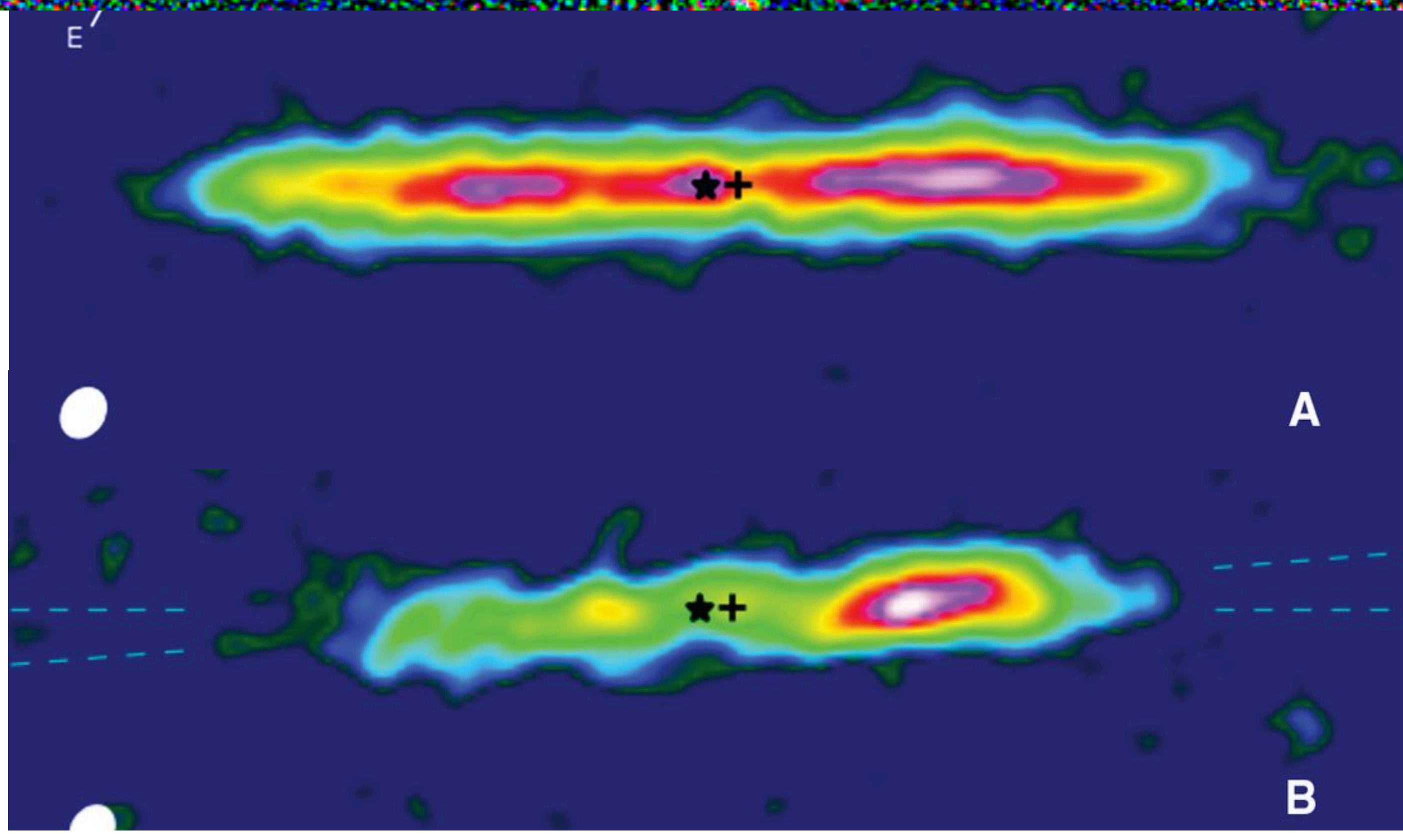


Reconstructing the β Pictoris Planetary System



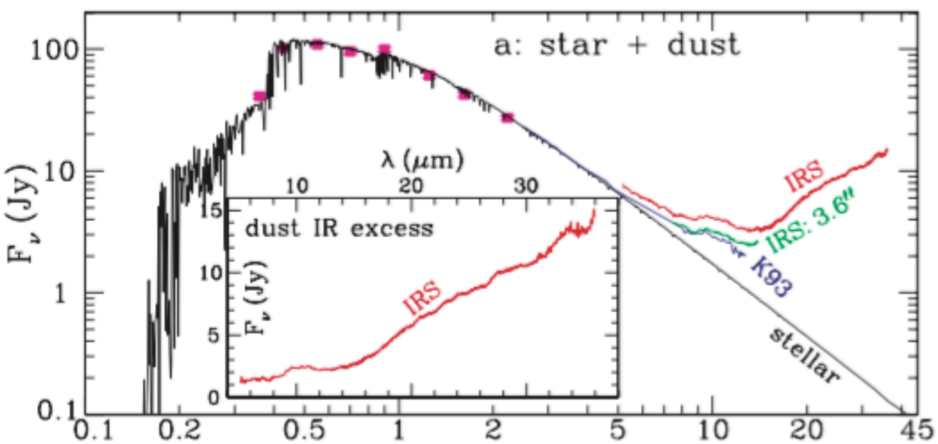
Ring of large grains at 95 AU (Dent et al. 2014)

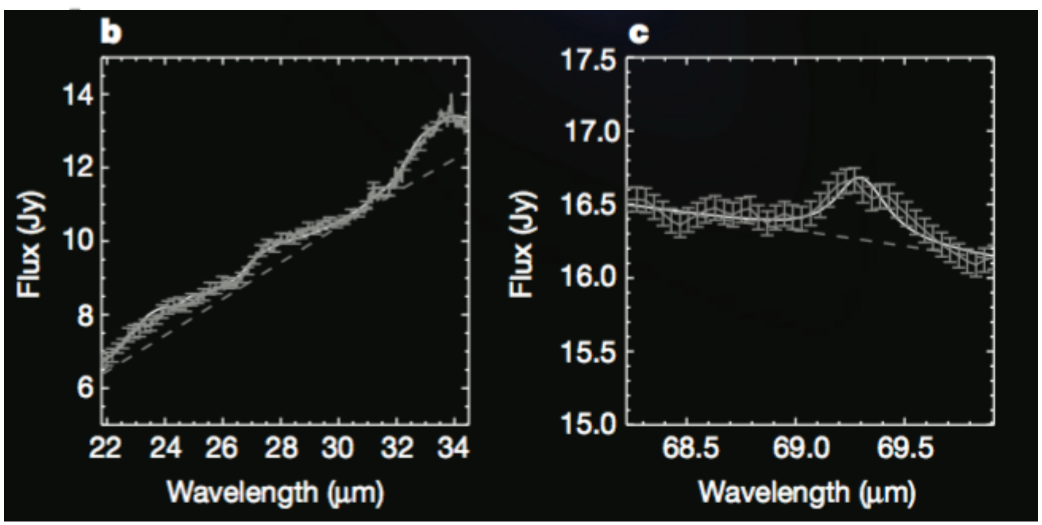
Clump of comets at 50 -60 AU (Dent et al. 2014)



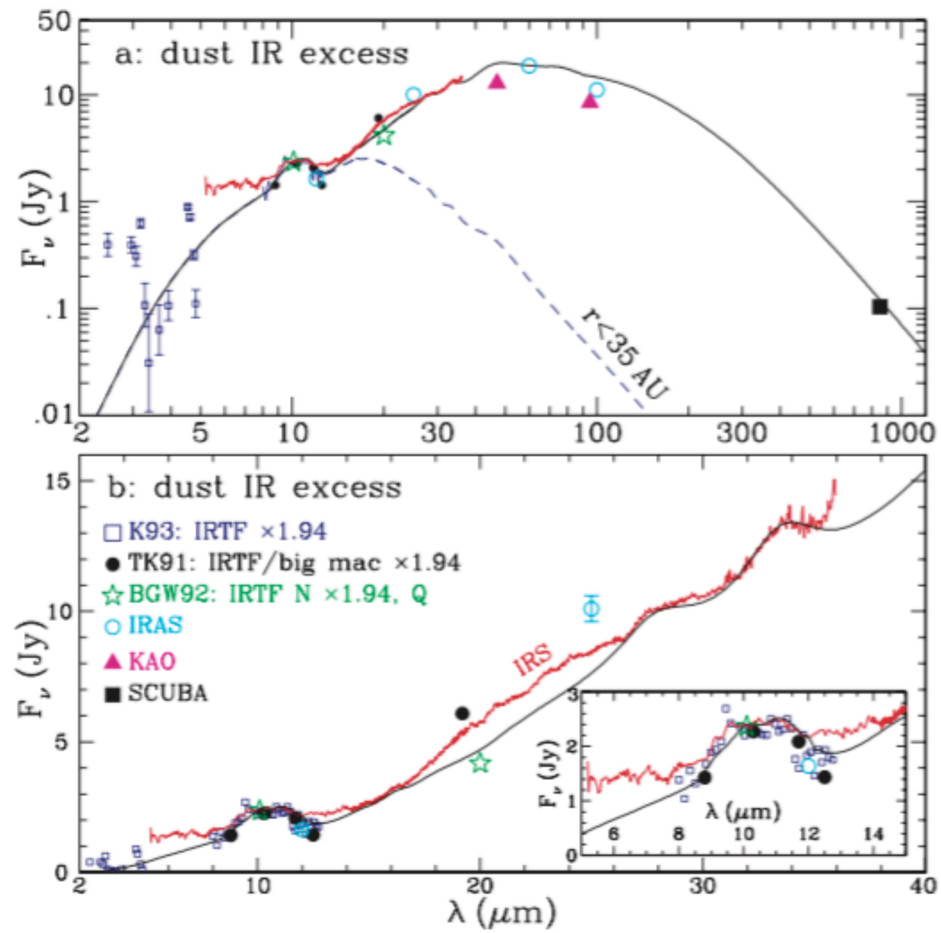
Reconstructing the β Pictoris Planetary System

- The majority of debris disks were unresolved or poorly resolved by Spitzer and/or Herschel; therefore, many analyses rely entirely on SED modeling



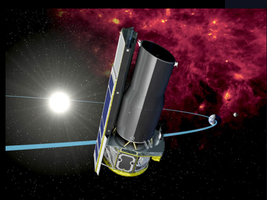


De Vries et al. (2011)



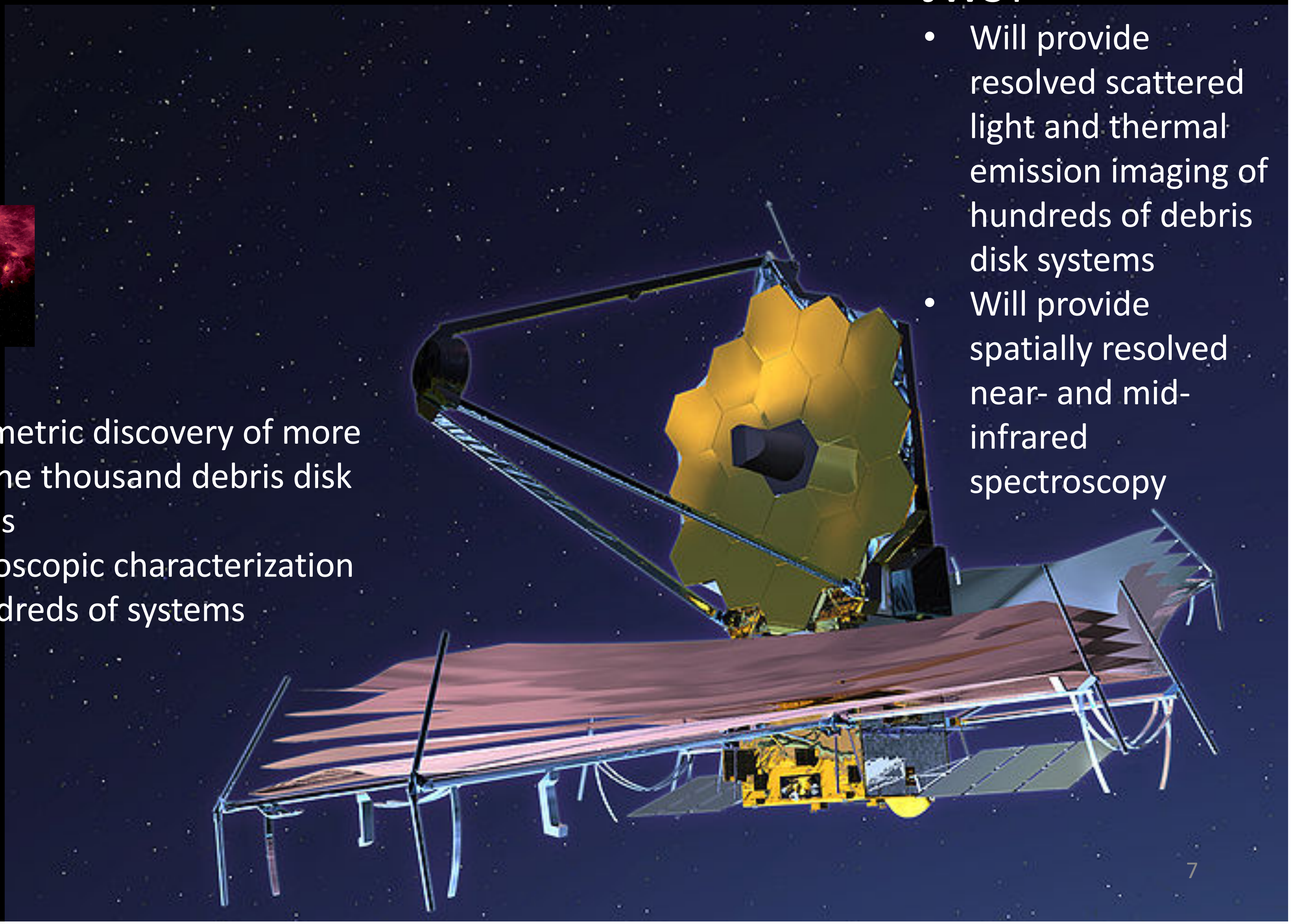
Chen et al. (2007)

Tracing the Dust and Gas…



Spitzer

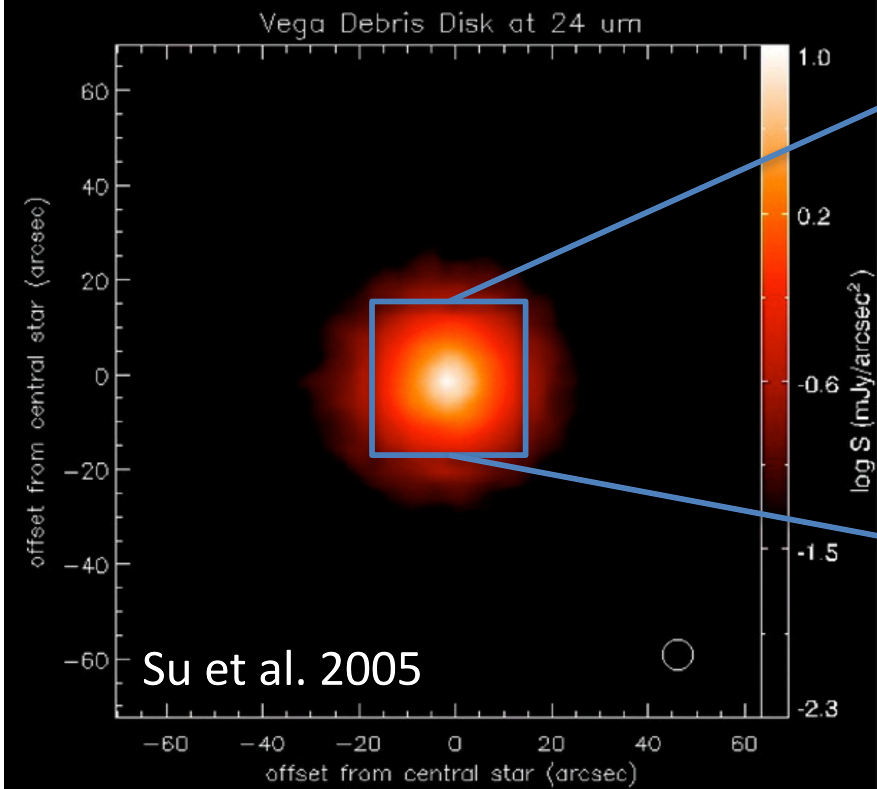
- Photometric discovery of more than one thousand debris disk systems
- Spectroscopic characterization of hundreds of systems

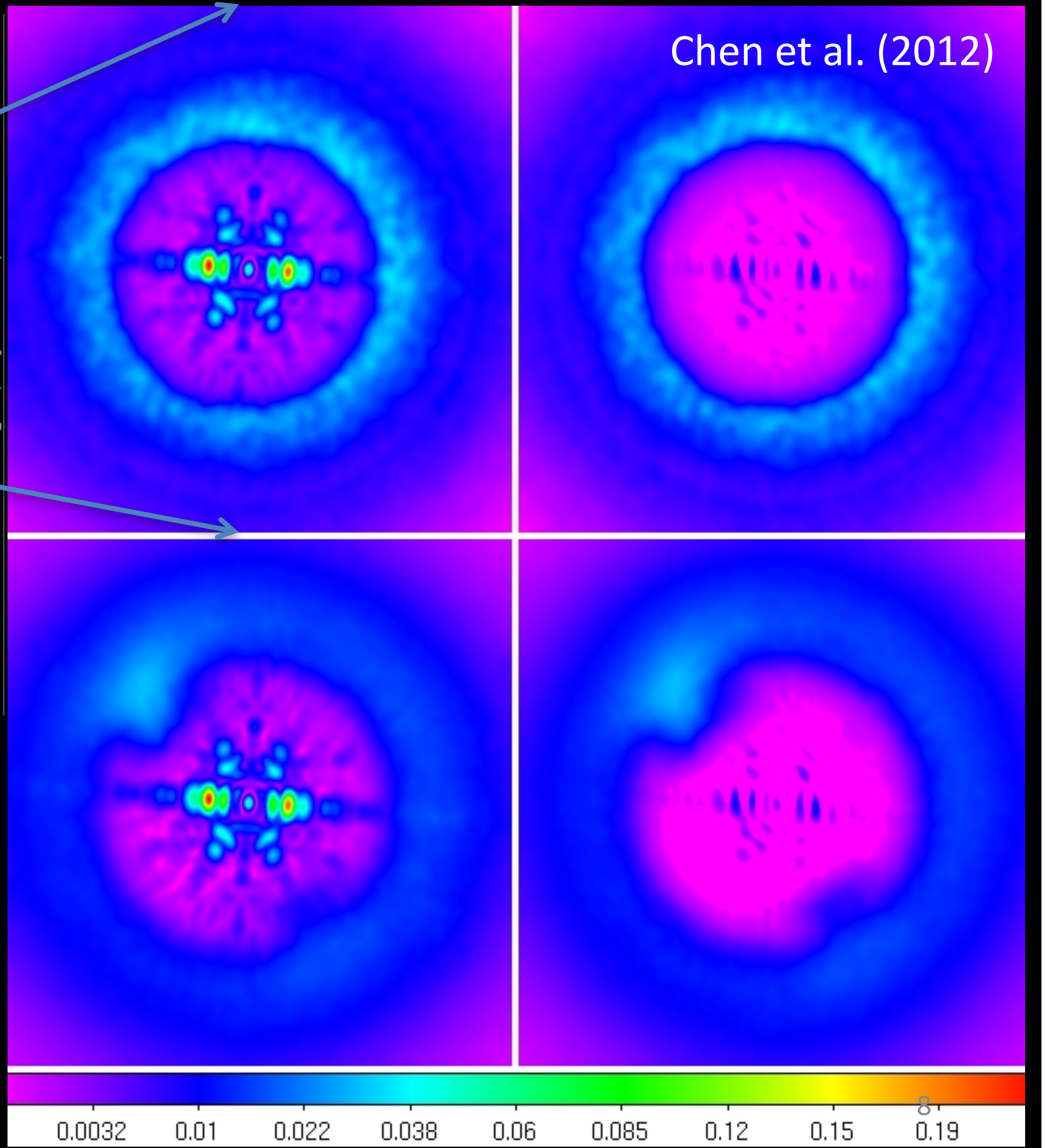


JWST

- Will provide resolved scattered light and thermal emission imaging of hundreds of debris disk systems
- Will provide spatially resolved near- and mid-infrared spectroscopy

JWST: Structure Imposed by Companions

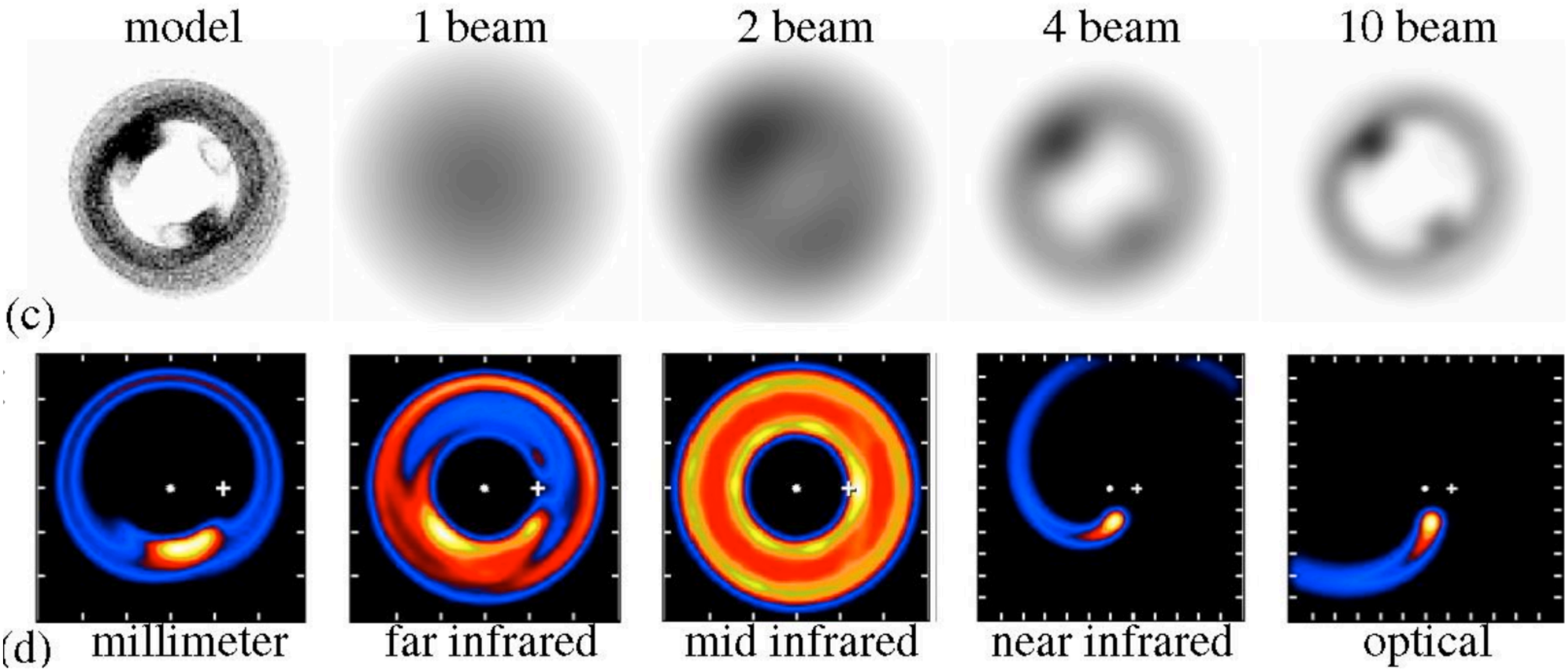




JWST MIRI Imaging GTO Programs

- (PI G Rieke) Archival Debris Disk program to map the thermal emission for Vega, Fomalhaut and ε Eridani debris disks
- Is there a hot, asteroidal component?
- Are parent bodies trapped into mean motion resonances with an unseen companion?

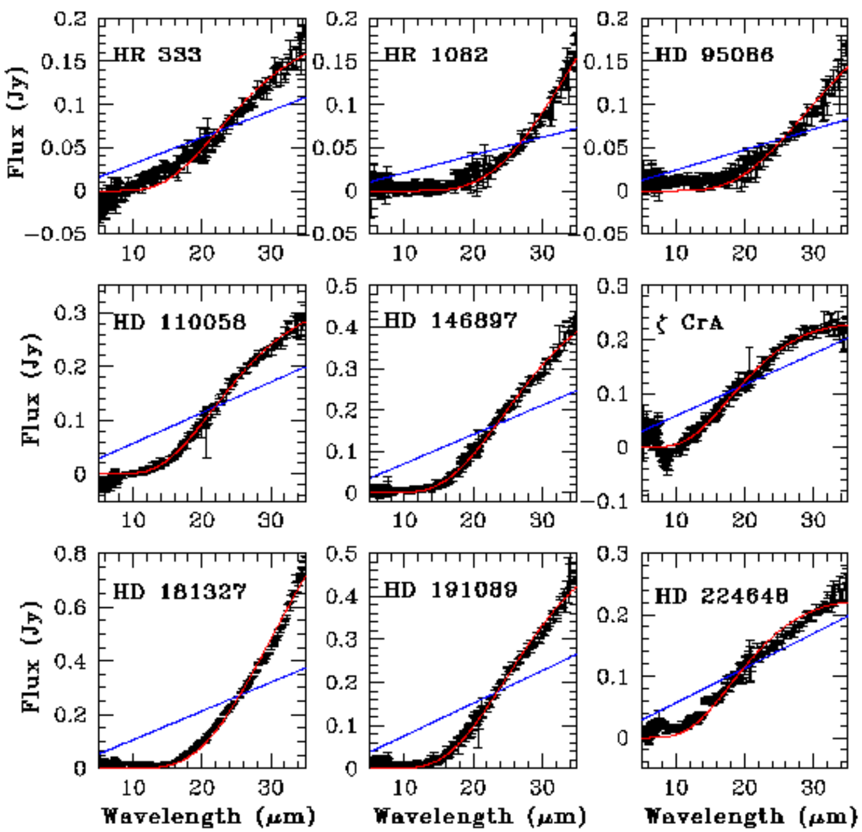
Grain Dynamics Revealed via Multi-wavelength Thermal Emission Mapping



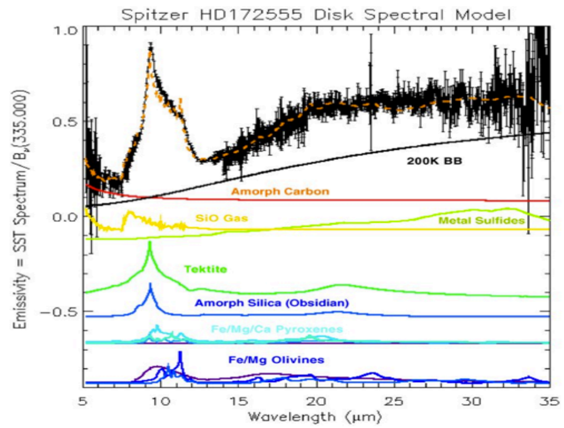
From Kate Su's "Tracing the Formation and Evolution of Low-Mass Ice-Giant Planets with Debris Disk Structures", including dynamical modeling by Wyatt (2006)

Mid- to Far-Infrared Spectroscopy

Dust Spatial Distribution

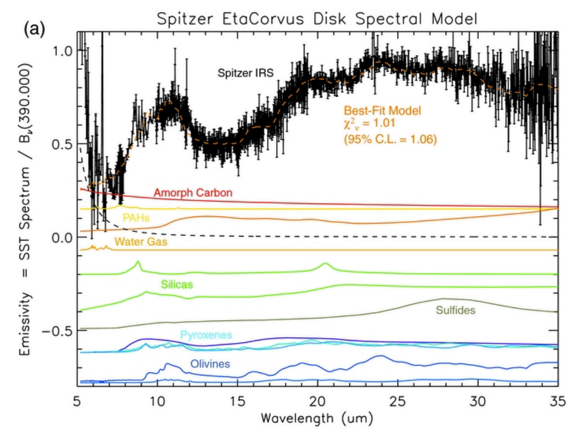


Dust Composition



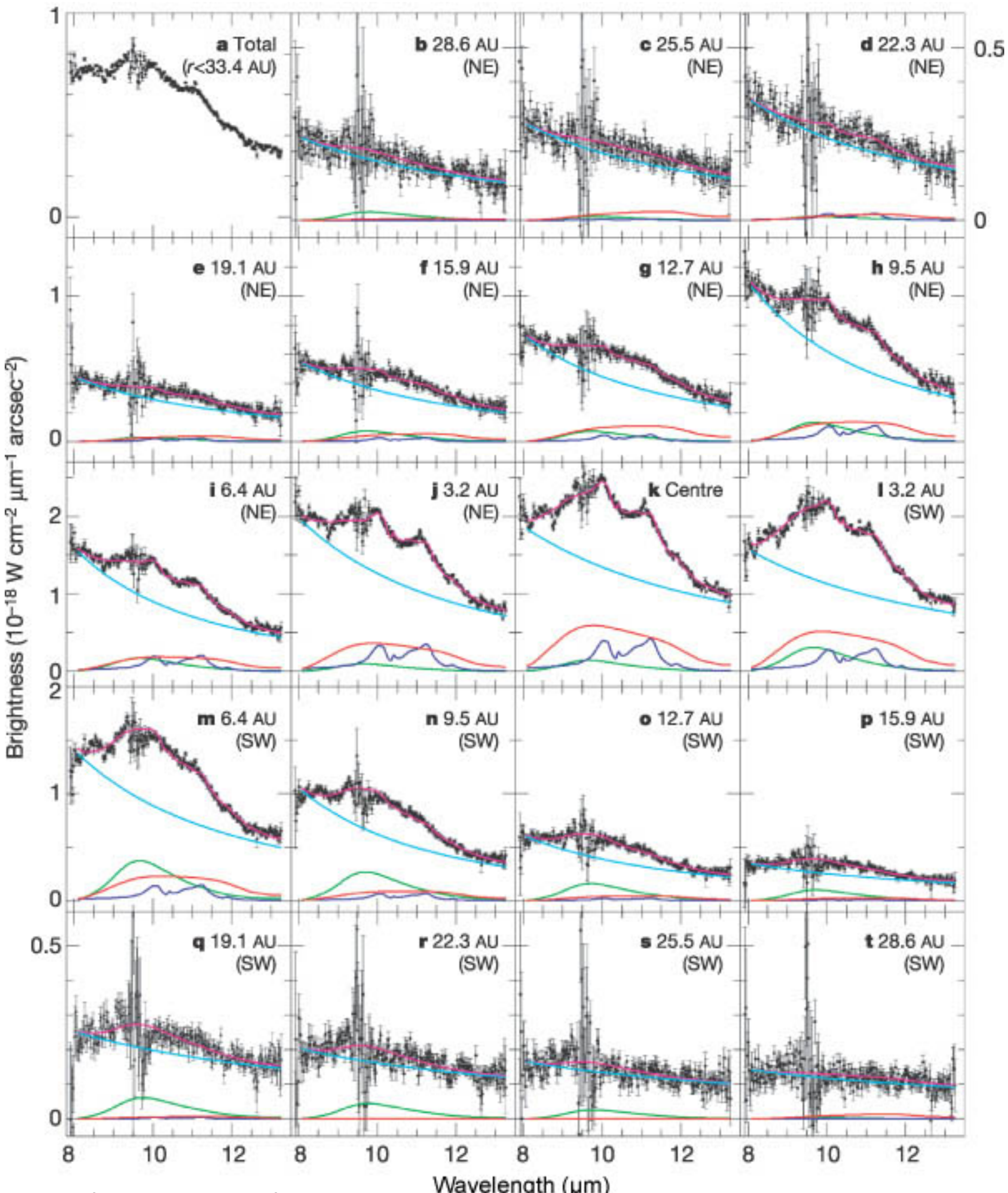
HD 172555: glassy silicas (Obsidian and Tektite), steep grain size distribution with large quantities of fine dust and possible fundamental and first overtone emission from SiO -> Hypervelocity Collision (Lisse, Chen et al. 2009)

Eta Crv: warm, water- and carbon-rich dust in the terrestrial habitable zone -> Period of Late Heavy Bombardment (Lisse, Wyatt, Chen et al. 2012)

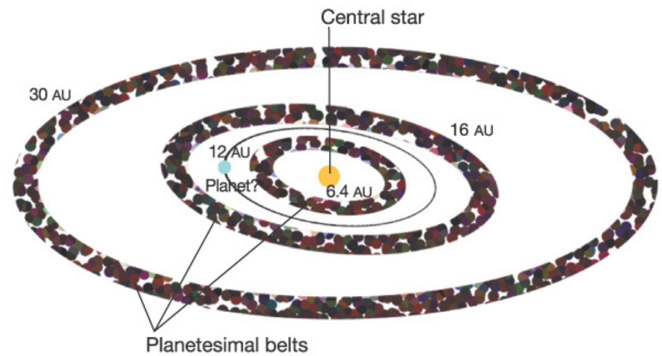


- Spitzer demonstrated that the mid-infrared spectra were typically featureless and well-fit using black bodies; although some objects had silicate emission features indicating to what degree parent bodies were processed and therefore their origin (Chen et al. 2006)

JWST: Mapping Spectral Features



Okamoto et al. 2004

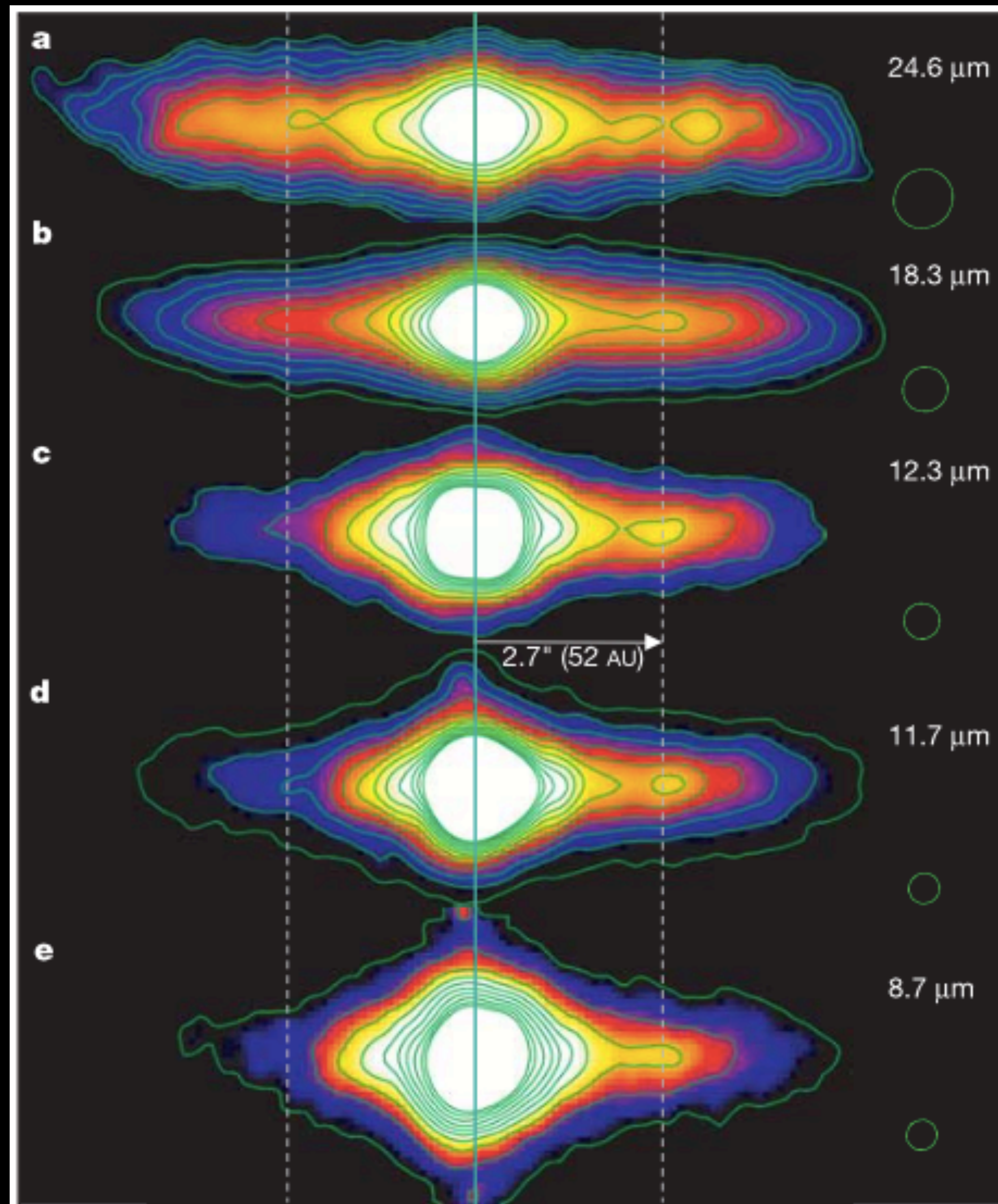


MIRI Spectroscopic GTO Programs

- (PI Chen) Program to map the 10 and 20 μm silicate emission features in the β Pic debris disk
- (PI Henning) Program to observe debris disks with CO emission
- (PI G. Rieke) Program to observe extreme debris disks with very bright 10 silicate emission features
- Subaru/COMICS observations of β Pic show small grains generated by collisional grinding in specific belts and crystalline silicates concentrated at the disk center (consistent with thermal annealing)

Characterizing Dust in the Terrestrial Planet Zone

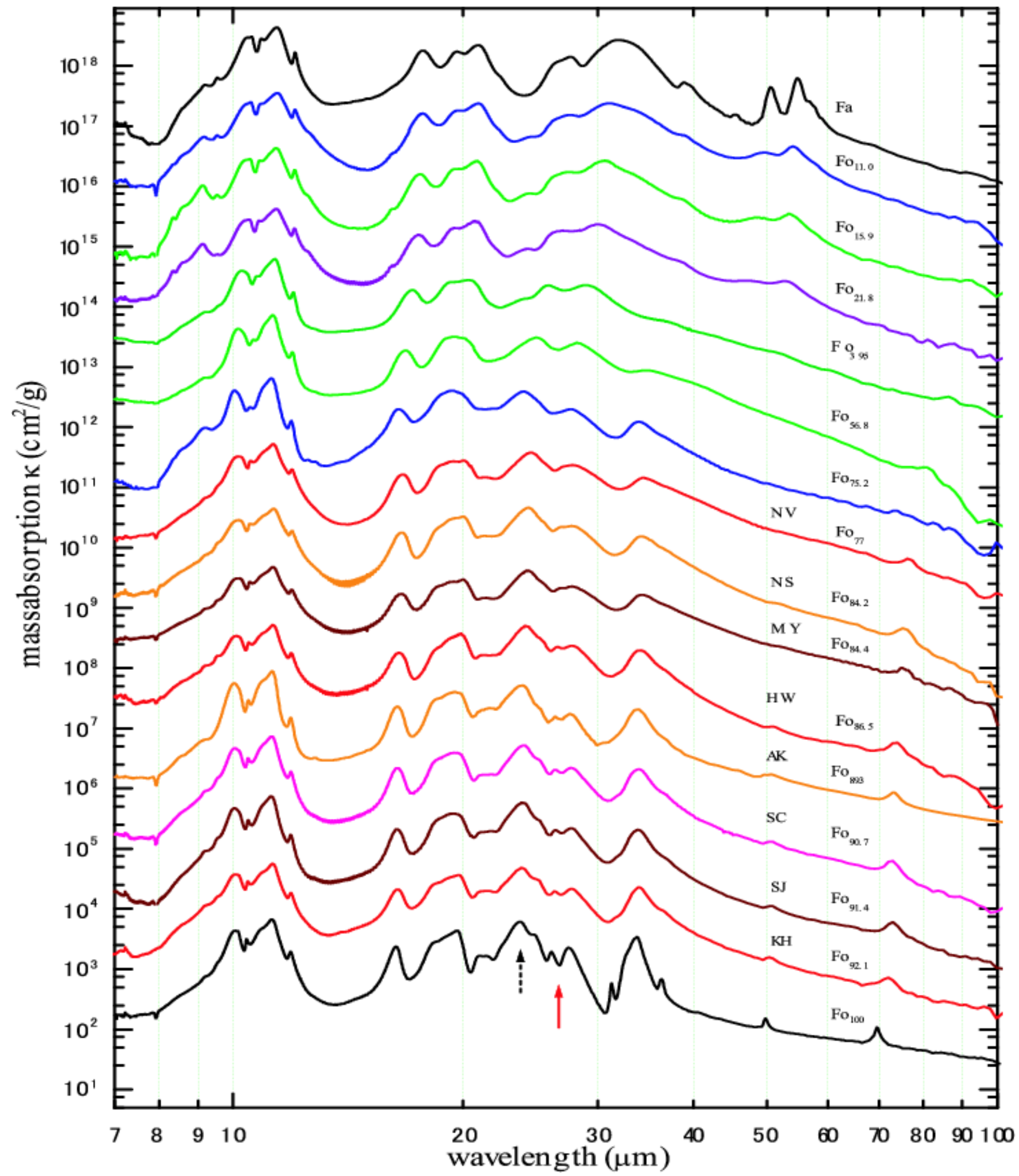
- Spitzer provided high SNR 10 μm silicate emission features for ~two dozen "extreme" systems and discovered evidence for features toward an additional ~100 sources
- JWST is expected to characterize the Spitzer faint silicate sources and provide insight into oligarchic growth
- Origins/MISC could spatially resolve the terrestrial temperature dust and take high SNR spectra for mature planetary systems



Telesco et al. 2005

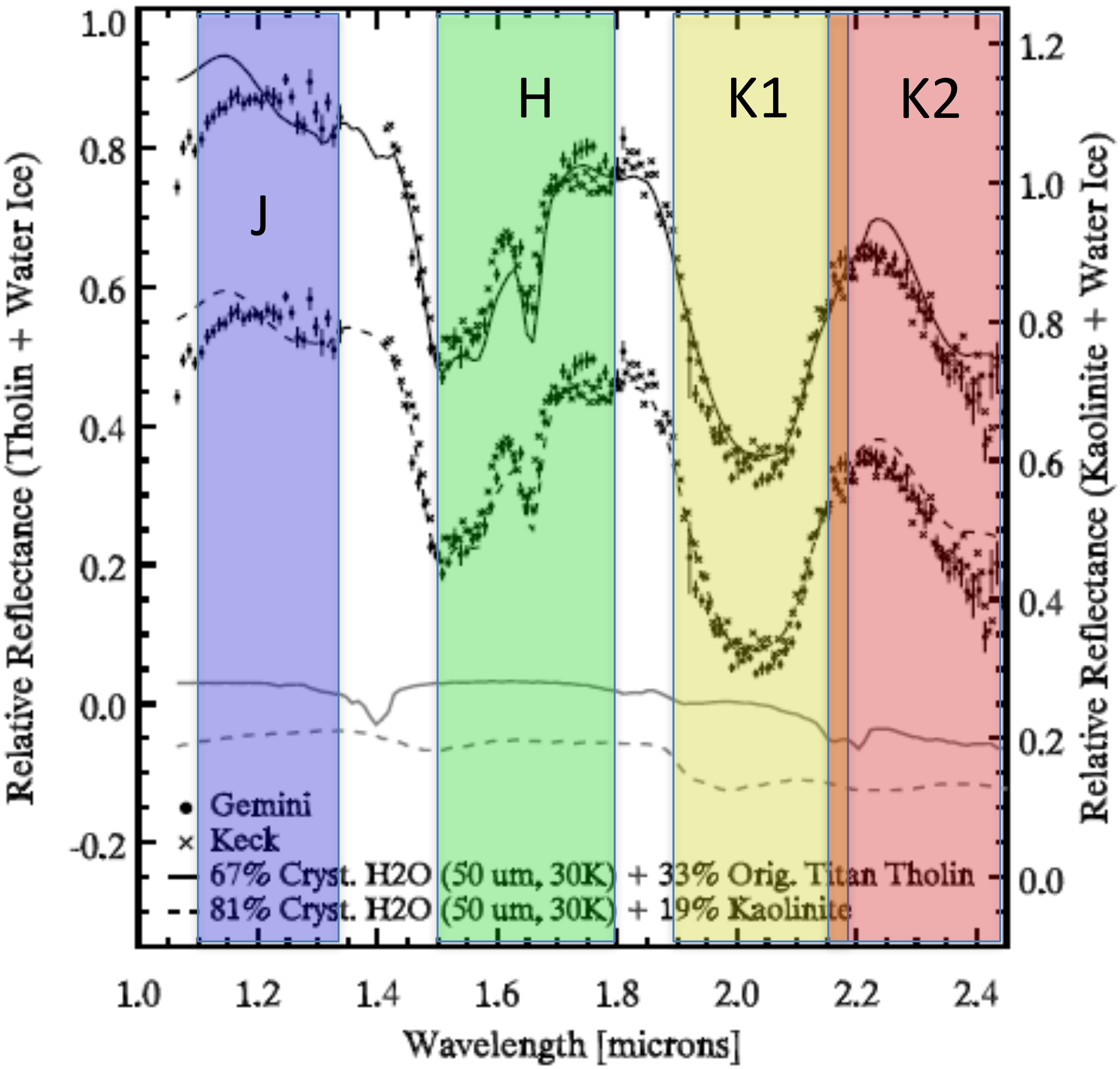
Characterizing Cold Silicate Dust

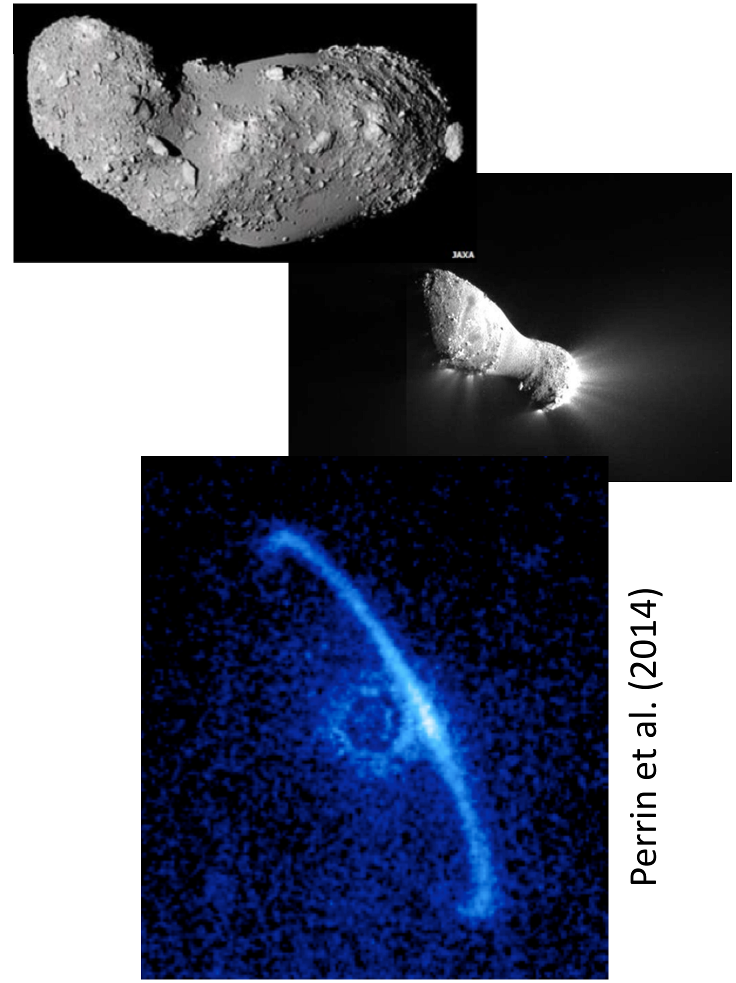
- Requires spectral resolution (R≥1000)
- Mg:Fe ratio is inferred from peak position
- Grain crystallization and size are inferred from the shape of the emission features
- If dust is co-spatial, then grain temperature is inferred from relative intensities of emission features



(Koike et al. 2003)

GPI Reflectance Spectroscopy



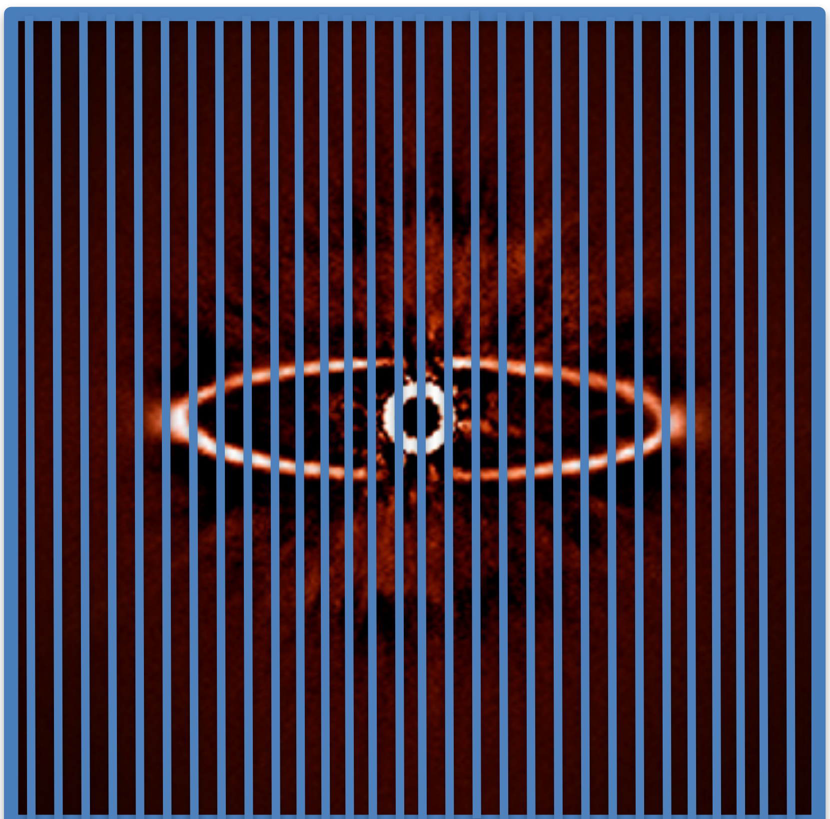


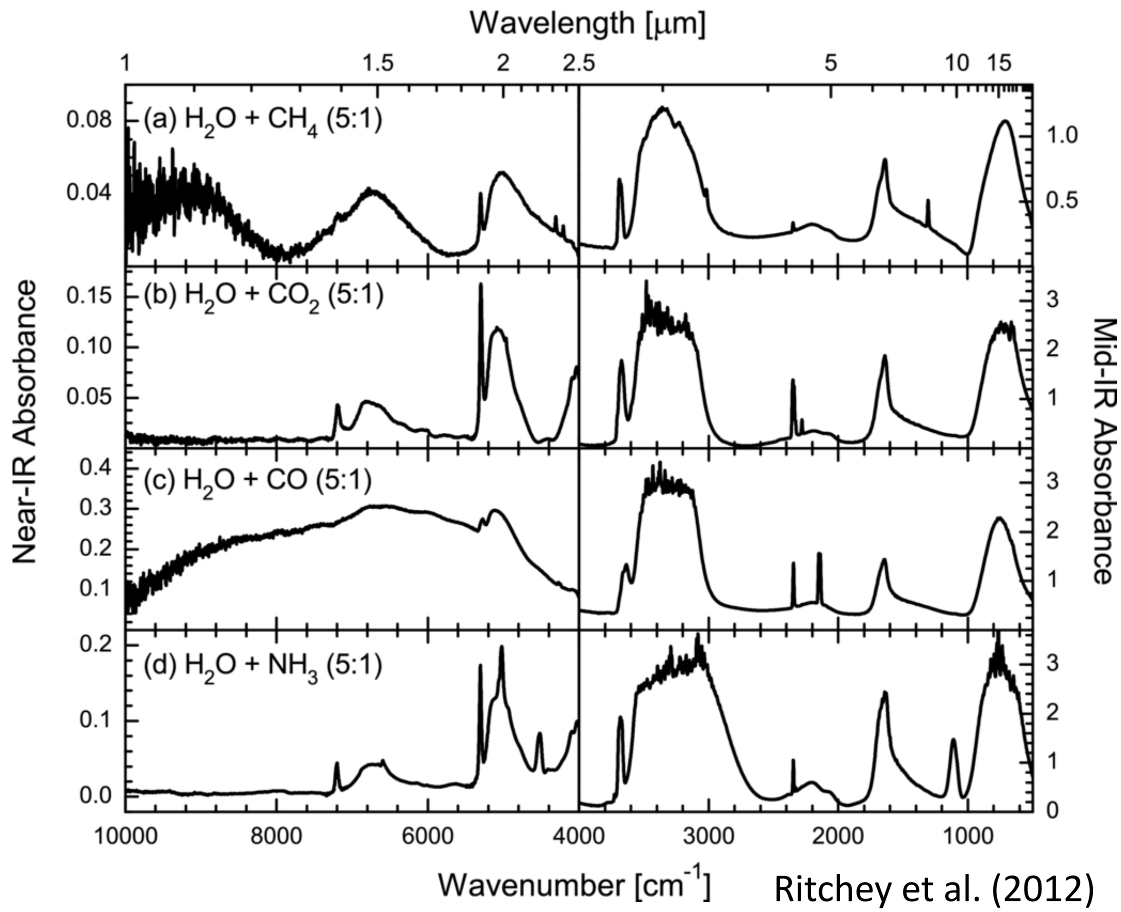
Perrin et al. (2014)

Gemini 2015B Large and Long Program "Characterizing Dusty Debris in Exoplanetary Systems" (PI Chen)

Searching for Water Ice Signatures using JWST

The JWST NIRSpec IFU will provide thirty 0.1” (dispersion) x 3” (spatial) slices providing spectra at 0.6 – 5 µm with spectral resolutions of R ~ 100, 1000, and 2700

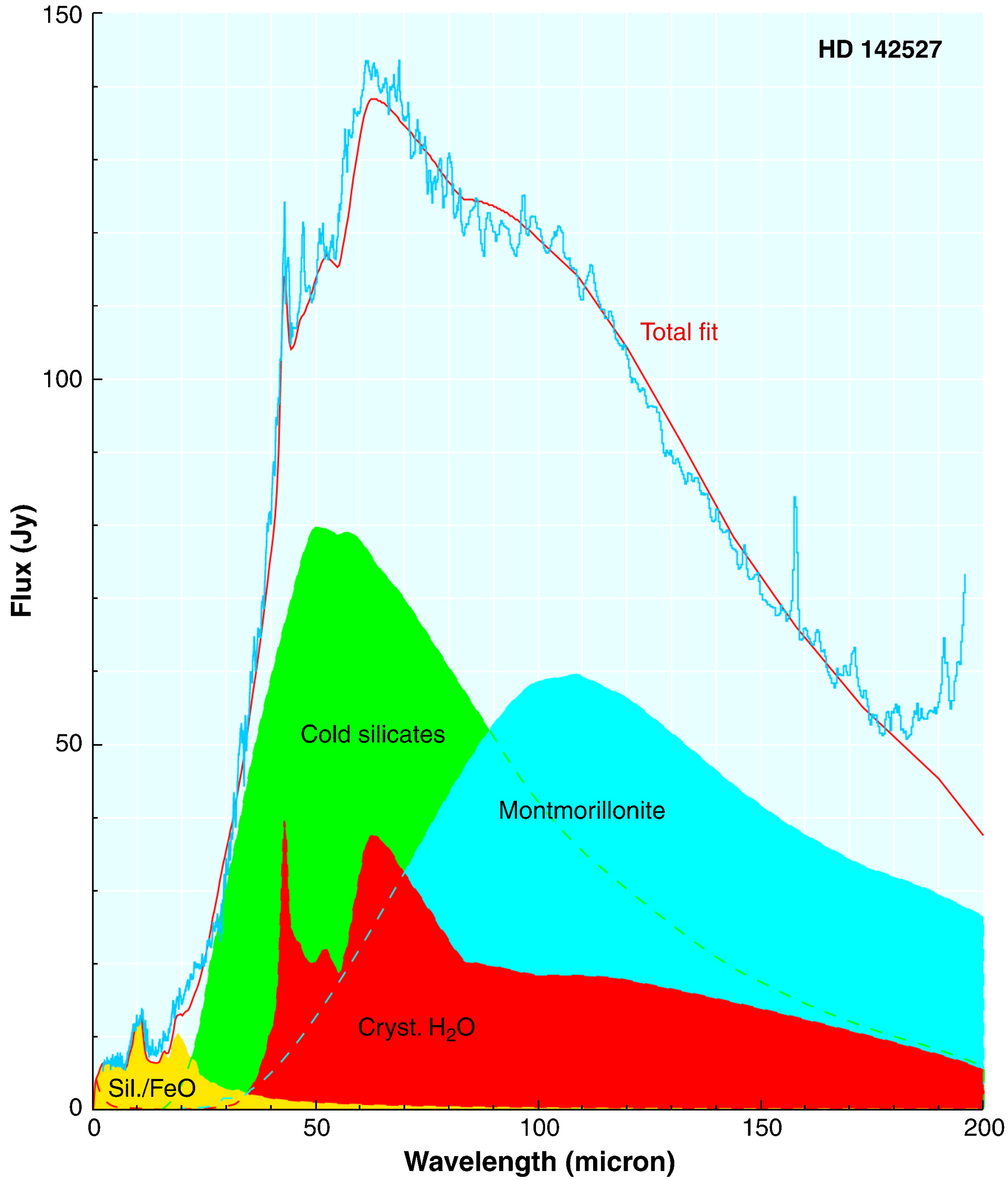




Ritchey et al. (2012)

This wavelength coverage will provide access to the primary water ice feature at 3 µm, detailed characterization of could constrain the presence of minority constituents and the grain size

Water Ice and Phyllosilicates

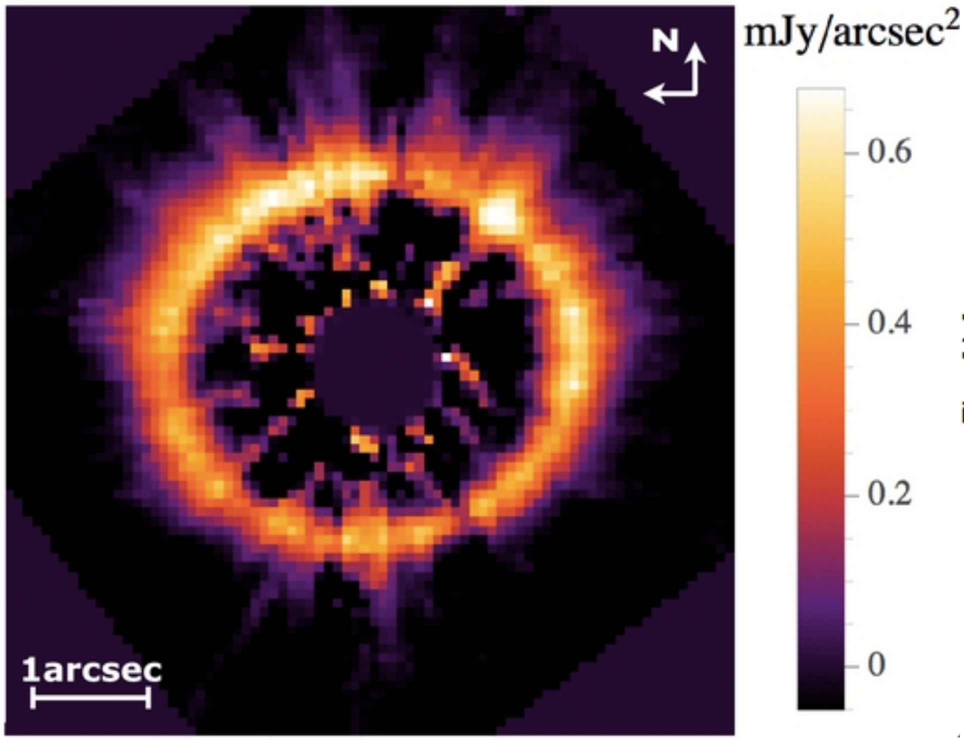


- ISO far-infrared spectroscopy of a pre-main sequence star
- Warm dust component (500-1500 K), dominated by silicate emission with some C-rich dust (Graphite and [CII])
- Cool dust component (30 - 60 K), dominated by O-rich dust. Crystalline water ice and hydrous silicates are present in the cold environment

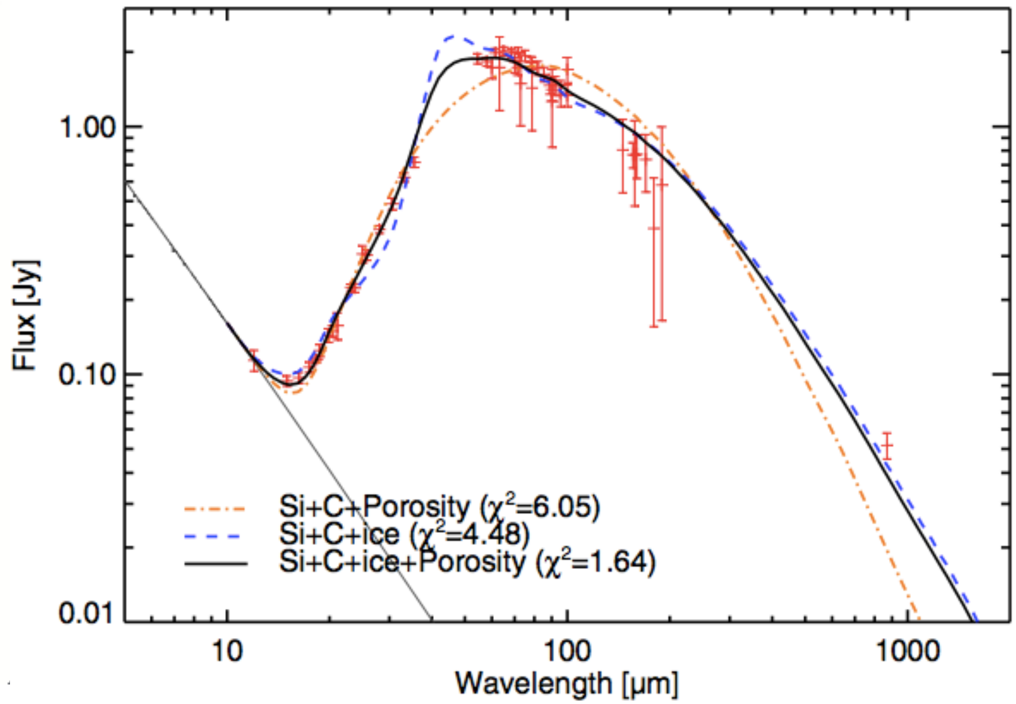
(Malfait et al. 1999)

Water Ice Detection Challenges

Multi-wavelength modeling of the disk around the Pic Moving Group member, HD 181327, suggests that the dust in this system is water-ice rich (Lebreton et al. 2012, Chen et al 2008)



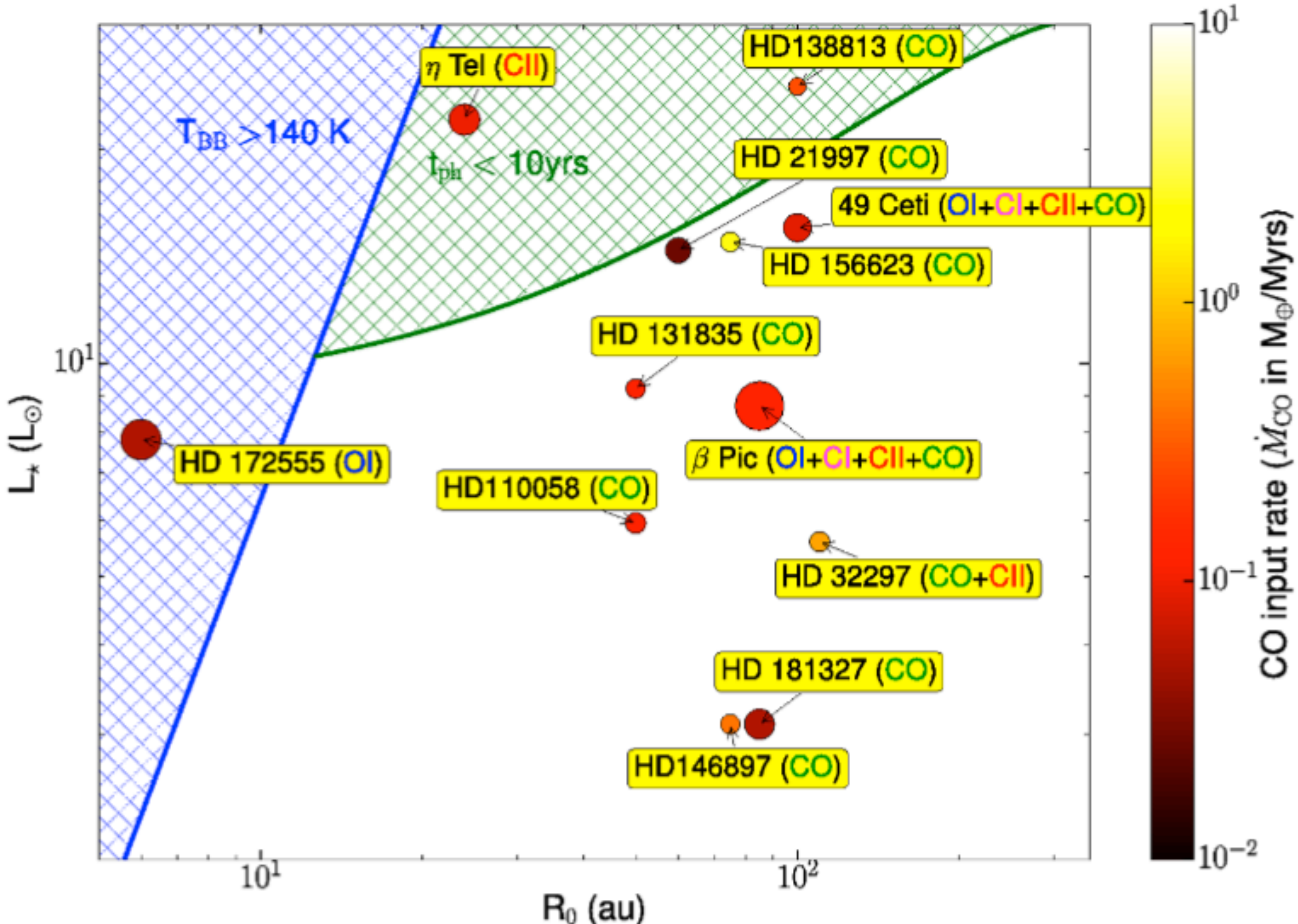
NICMOS 1.6 µm image (Soummer et al. 2014)



Spitzer and Herschel SED (Lebreton et al. 2012)

Since there are no strong crystalline features, it is particularly important to accurately correct the Spectral Response Function over a very large wavelength range.

Origin of Gas in Debris Disks



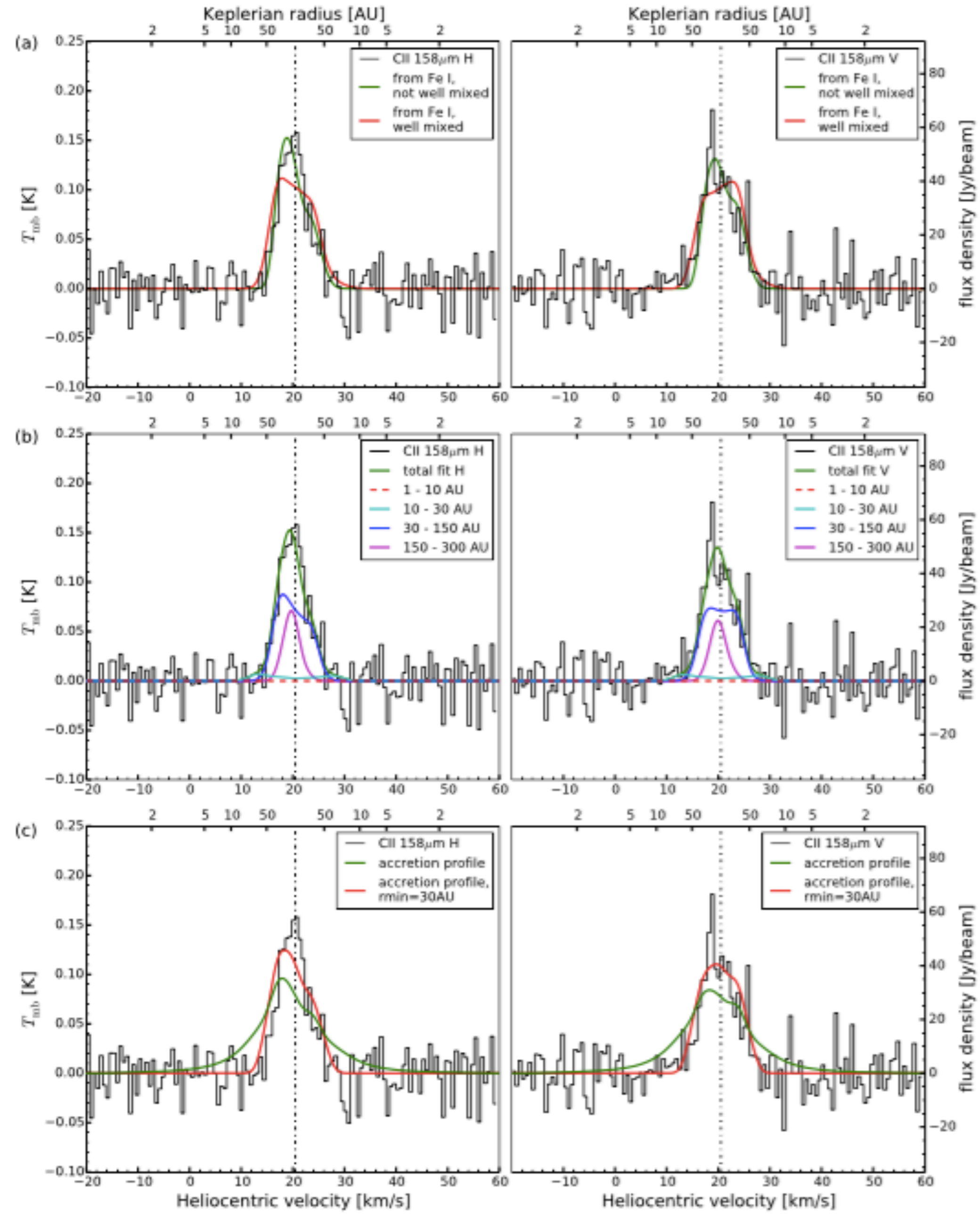
Kral et al. (2017)

- CO is sequestered in cool (T_{BB} < 140 K) parent bodies
- CO can be detected if the photodissociation lifetime is long (t_{ph} > 10 years)
- Parent bodies release CO during collisional grinding and gas viscously spreads spreads to form an accretion disk inside and an excretion disk outside the parent body ring
- Model predicts that C II and O I can be detected for all disks with CO detections and additional disks for which CO has not yet been detected

For more information, see Quentin Kral's "Gas in Debris Discs"

Inferring the Spatial Distribution of the Atomic Gas

- Herschel HIFI spectroscopy of β Pic
- CII Emission line is spatially resolved, providing an opportunity to better estimate the location of the emitting gas
- Modeling indicates that the majority of the emission originates from distances >100 AU consistent with a collision or photo-desorption origin



Cataldi et al. 2014

OST has the potential to greatly advance our understanding of the evolution of exoplanetary systems and to place the history of our Solar System into context