PLANET FORMATION AND EXOPLANETS SUBGROUP

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SCIENCE THEMES

Planet formation and protoplanetary disks

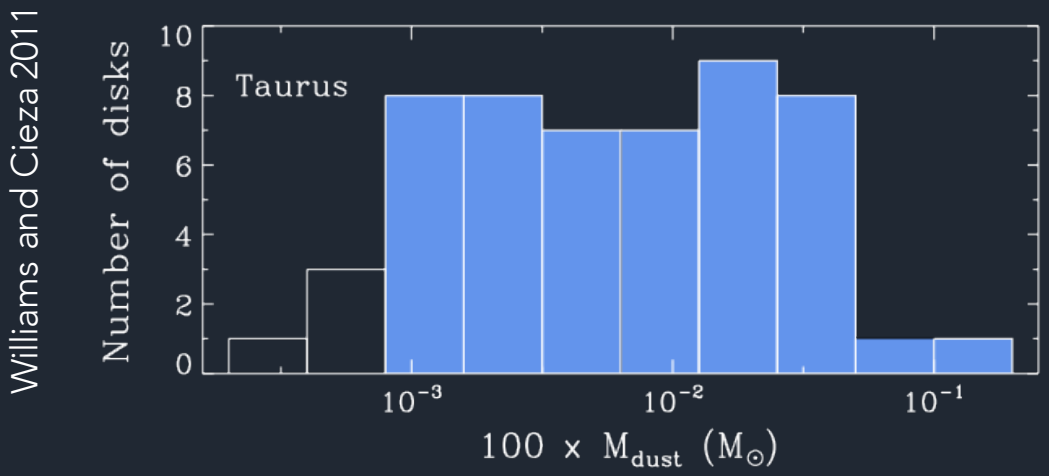
Planet evolution and debris disks

Exoplanet atmospheres and composition

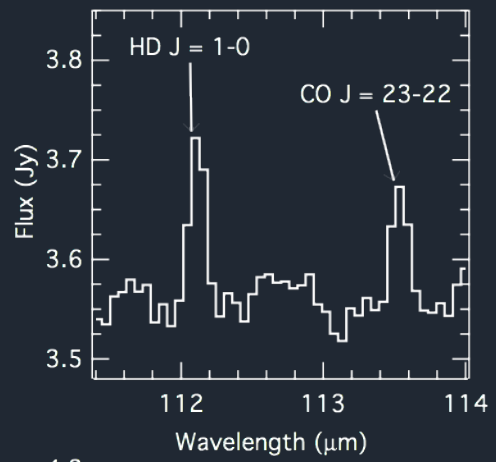
WHAT ARE PP DISK GAS MASSES?

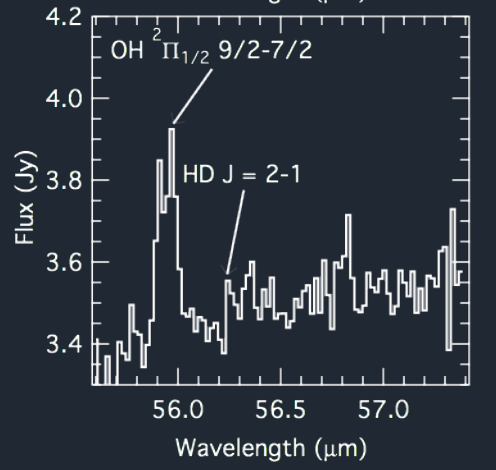
- ➡ HD is a million times more emissive than H_2 at T ~ 20 K.
- ➡ Atomic D/H ratio inside the local bubble is well characterized (~ 1.5×10^{-5})
- ➡ HD will follow H_2 in the gas

- ➡ TW Hya disk mass M_{disk} ~ 0.05 $M_\odot$



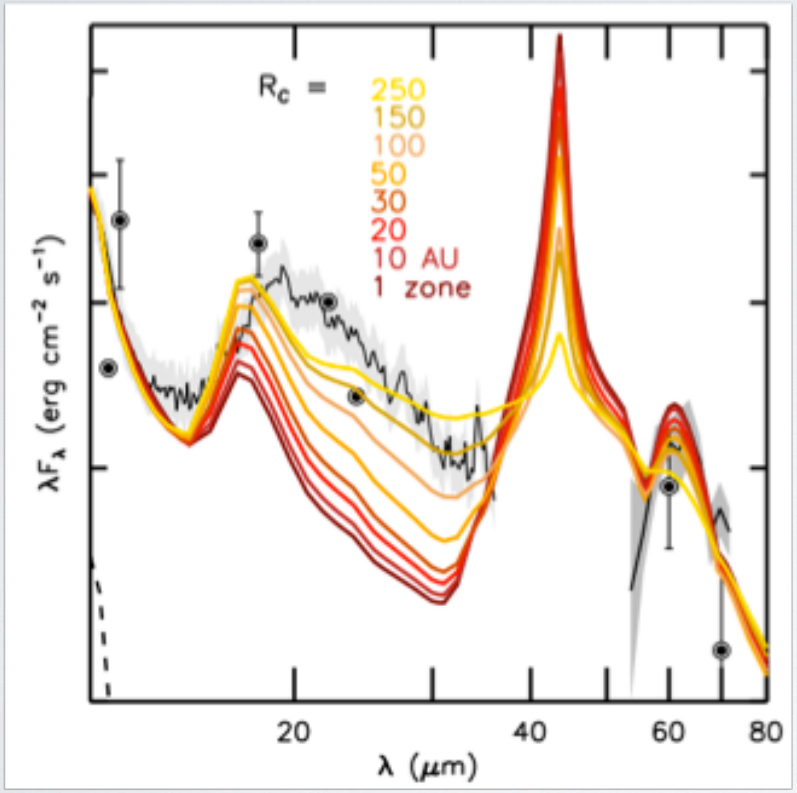
Williams and Cieza 2011



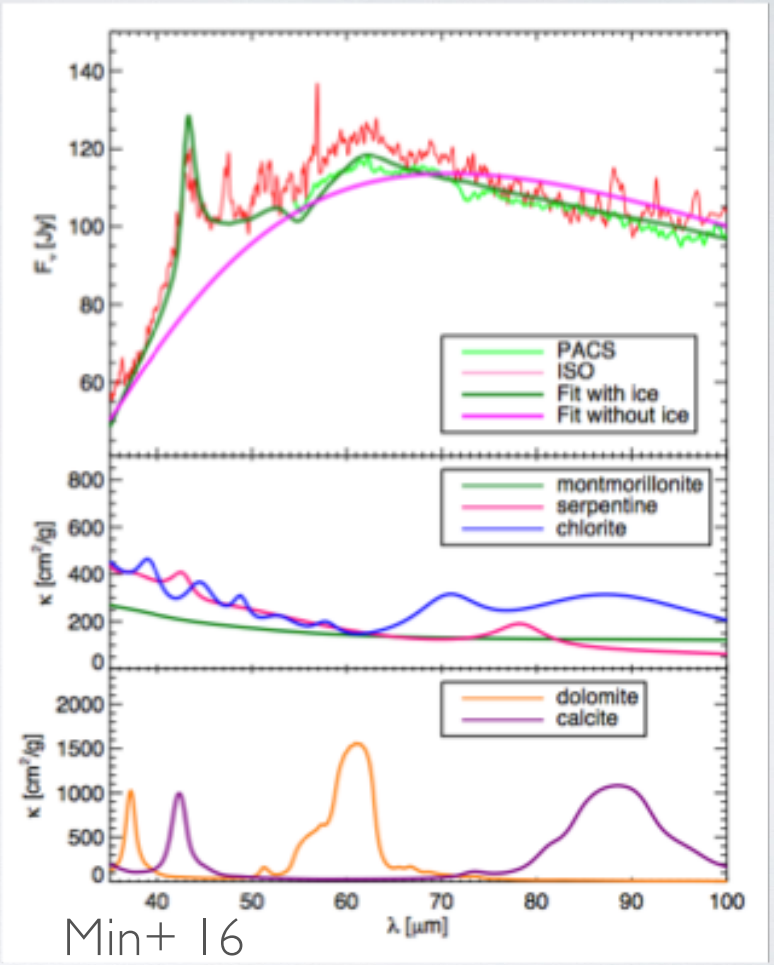


Bergin+ 2013

WHAT ARE PP DISK ICE MASSES?

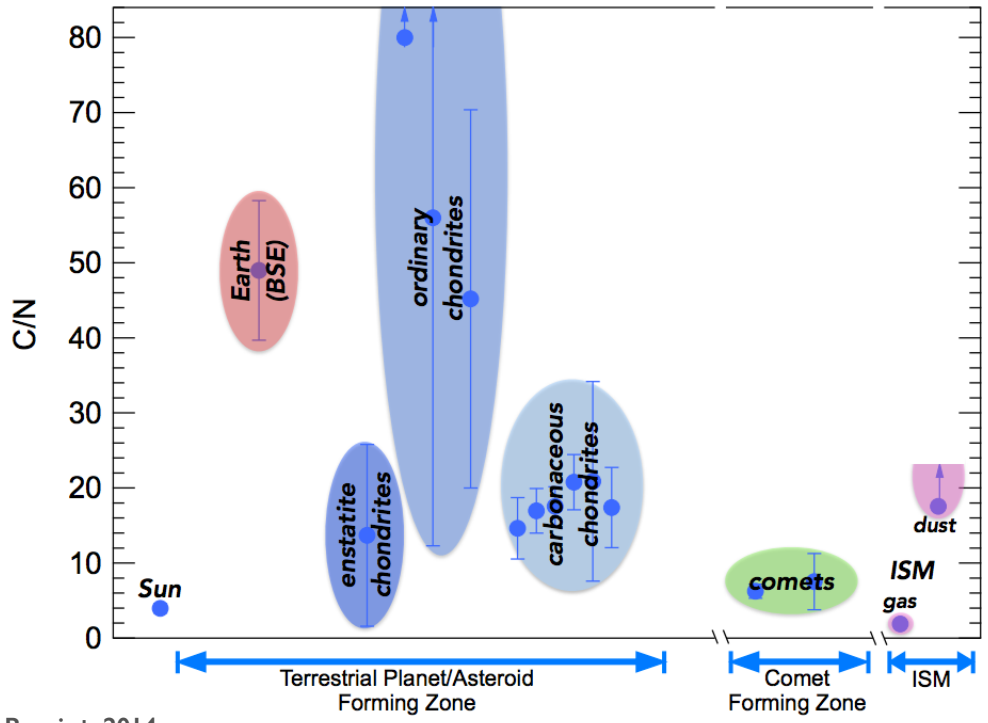


McClure+ 15

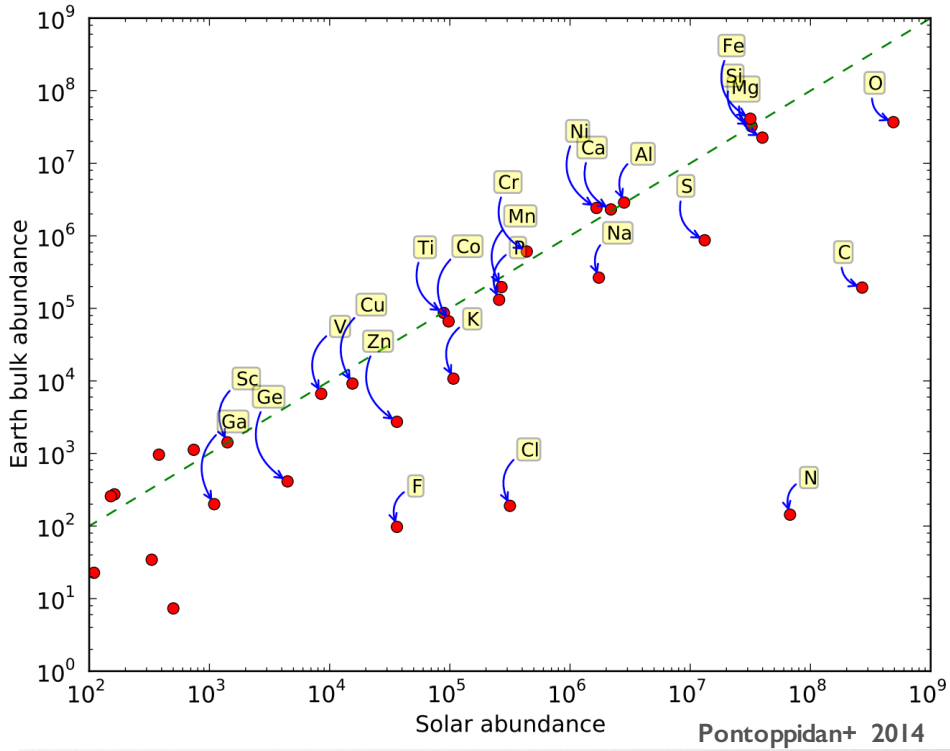


Min+ 16

WHAT ARE THE VOLATILE RESERVOIRS OF PP DISKS? WHERE IS THE OXYGEN, CARBON, NITROGEN, FLUORINE, SULFUR, …?

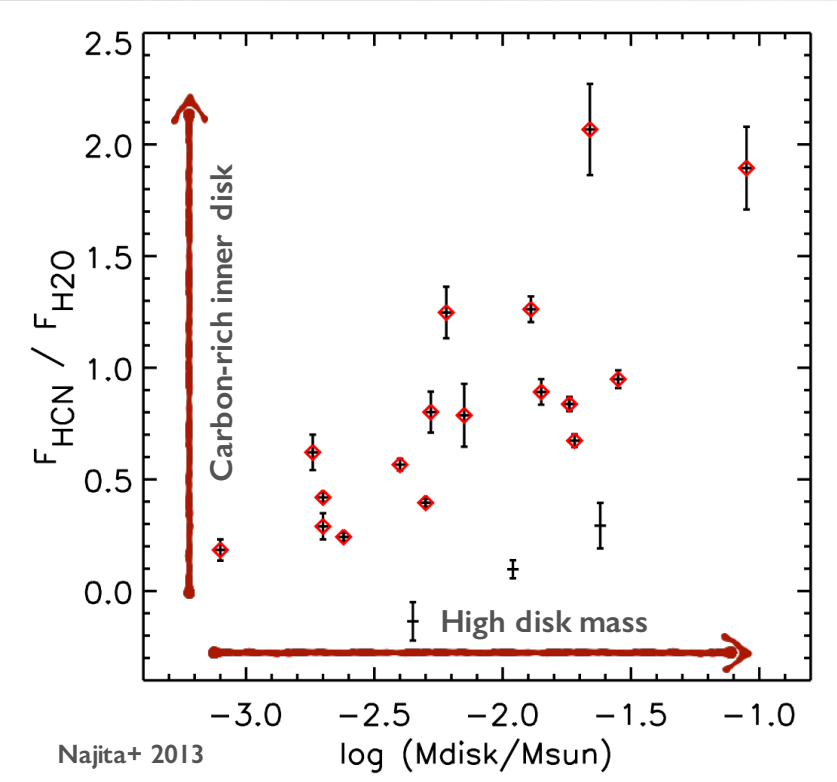


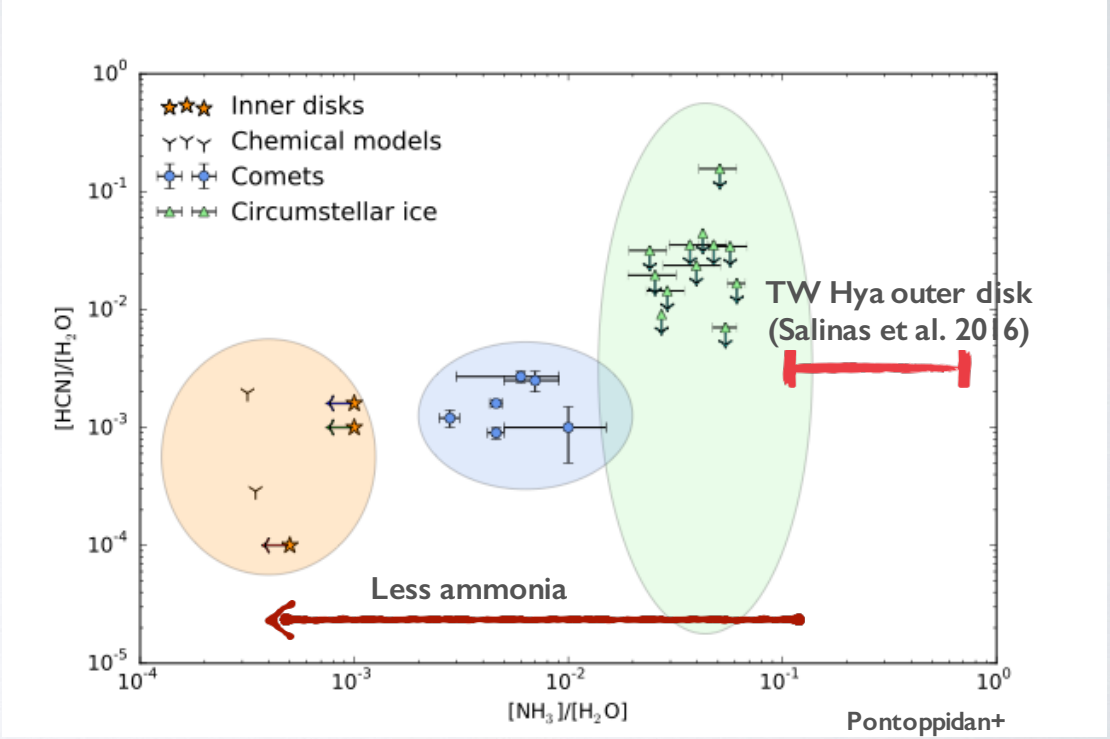
Bergin+ 2014



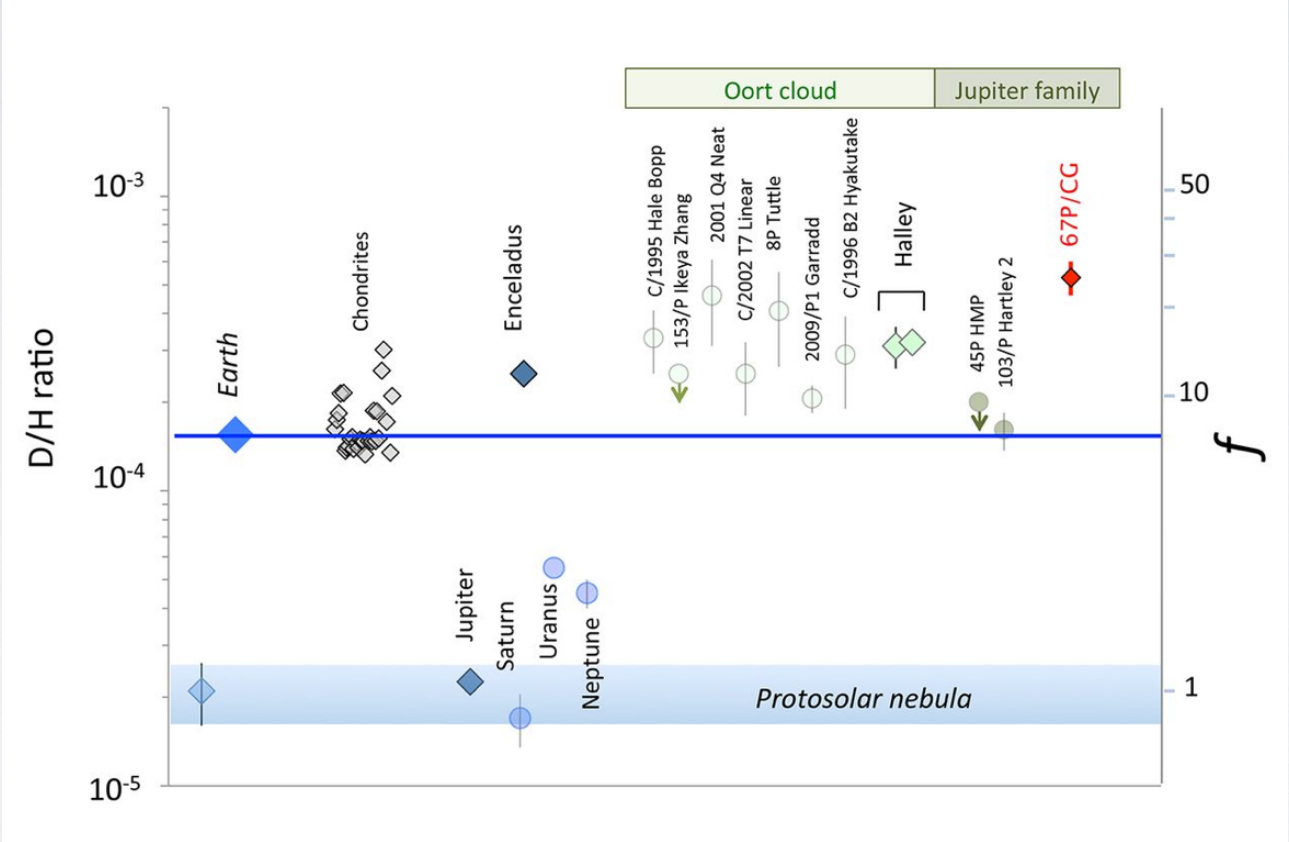
Pontoppidan+ 2014

IS PLANET-FORMING CHEMISTRY INHERITED FROM THE ISM OR CREATED IN THE DISK?



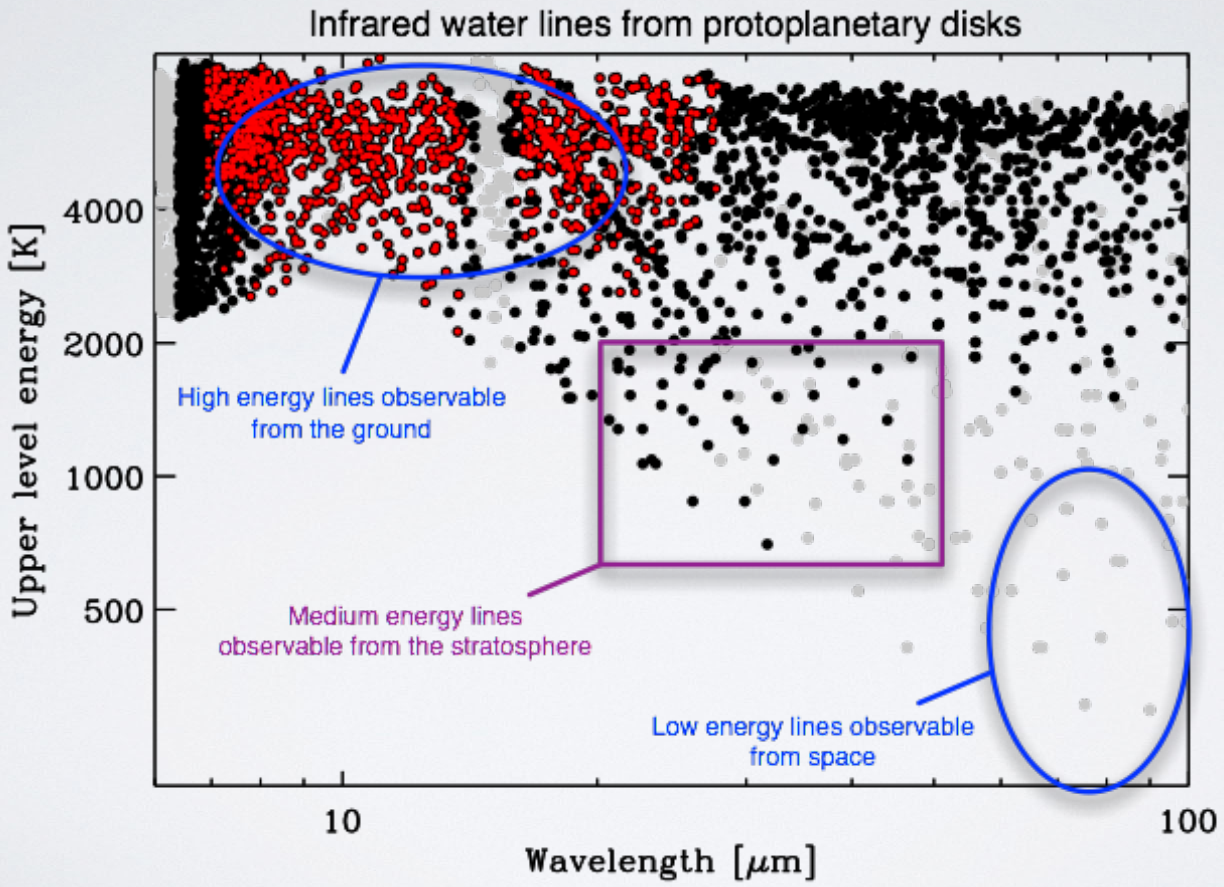


INHERITANCE OR RESET 2: D/H RATIOS IN DISKS

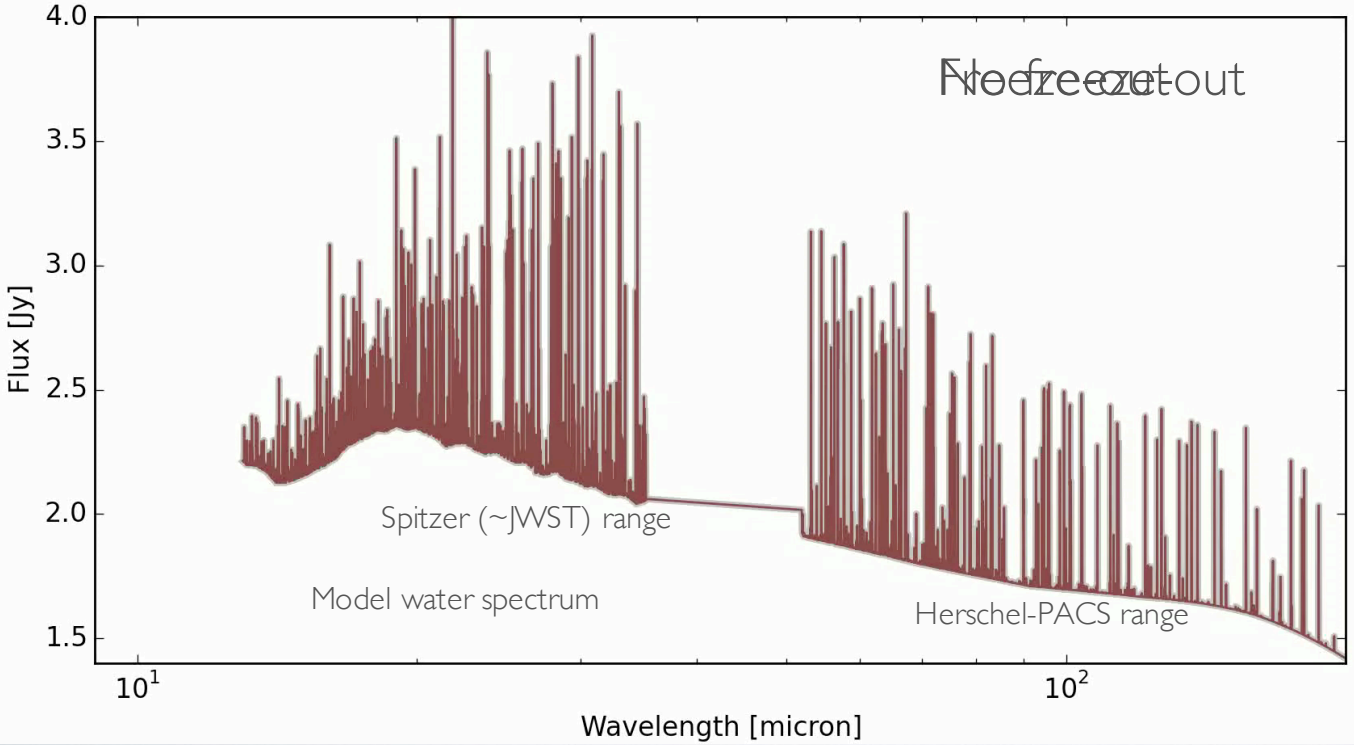


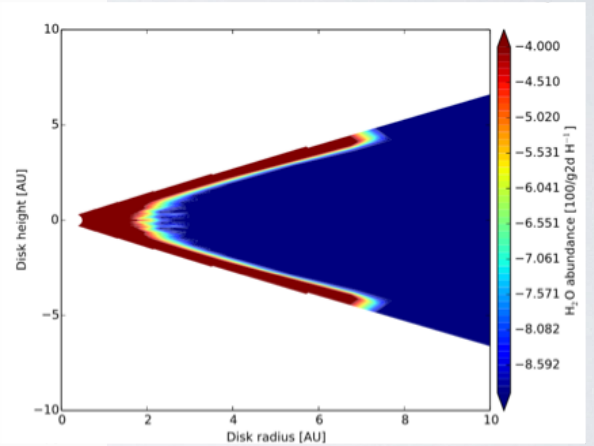
Altwegg+ 2014

OBSERVABILITY OF WATER

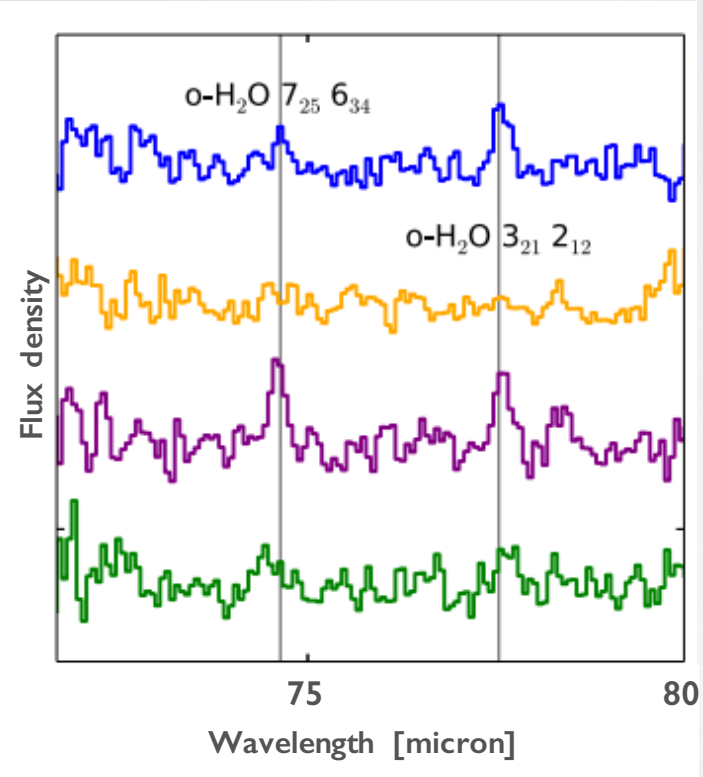


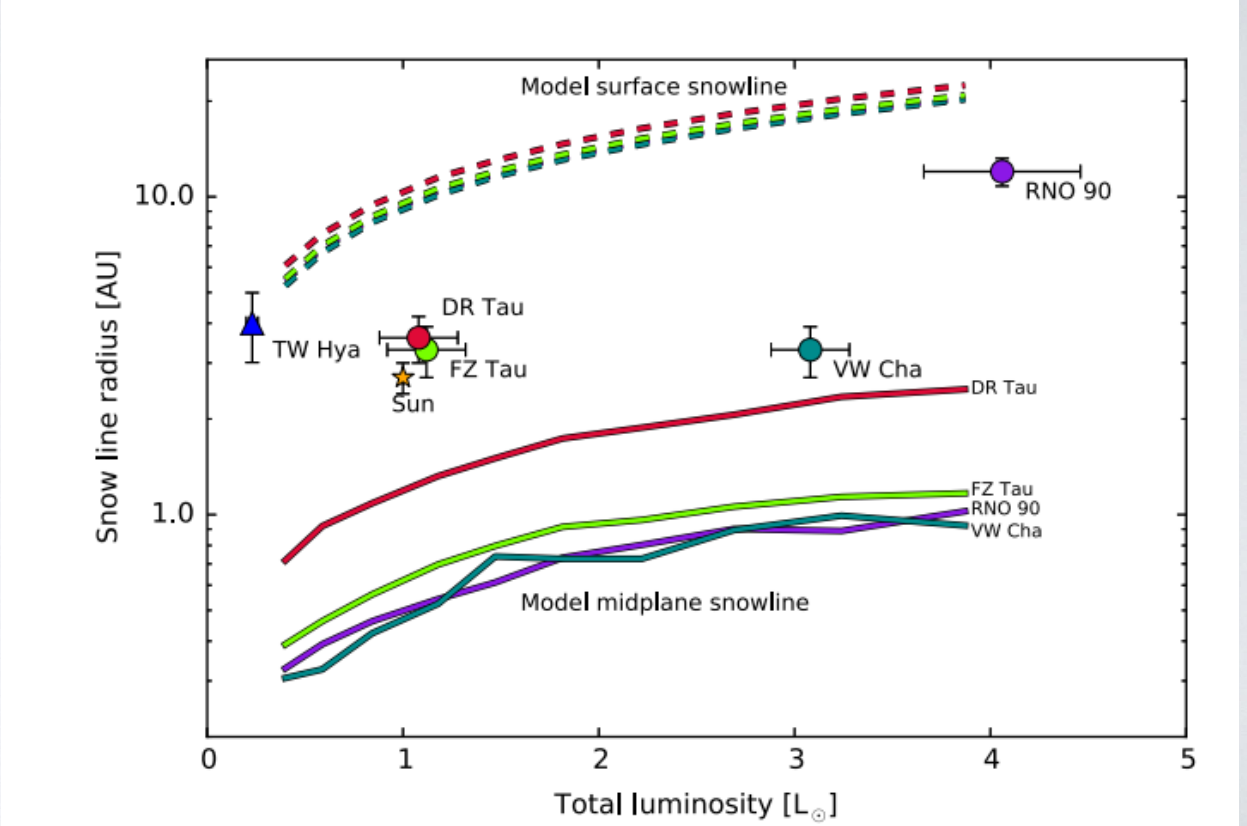
SPECTROSCOPIC EFFECTS OF A SNOW LINE





WHERE IS THE WATER SNOW LINE?





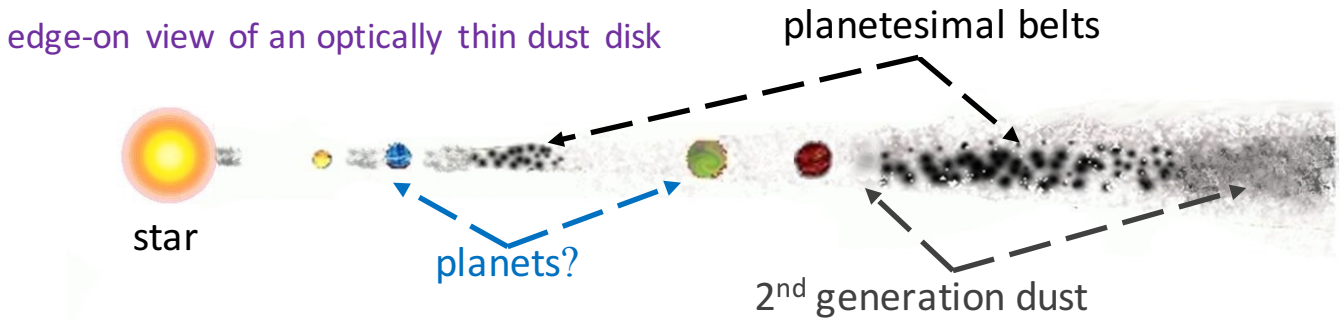
Blevins, Pontoppidan+ 2016

Debris Disk Science Theme

- Planetary Architecture – Is our Solar System an Outlier?
  - Use debris disk structures to find and characterize the masses and orbits of exoplanets not found by ~2030 with other measurement technique
  - Use debris disk structures to constrain planet formation and migration history
  - Demographic studies of debris disks (disk brightness vs. other parameters: spectral type, metallicity, presence of known planets, stirring mechanisms)
- Composition in Debris Disks -
  - Gas in debris disks – where does it come from? Composition?
  - Dust mineralogy – silicates, ices, and calcites…etc, hydro-material?

    formation and transportation history, link to protoplanetary disks
- Planetary Systems beyond Main Sequence
  - Detecting the reservoir of surviving asteroids and KBOs

Definition of Debris Disks



- dust replenished by collisions or cometary activity
- leftover ~km-size planetesimals that failed to form planets
- The large surface area of a dusty disk makes it readily observable in Infrared, and optical scattered light in favored conditions.
- The gravity of giant planets determines where leftover planetesimal belts can exist, stirs up collisions in the belts, and sculpts the dust distribution through resonant and secular interactions.

Solar System's Debris Disk

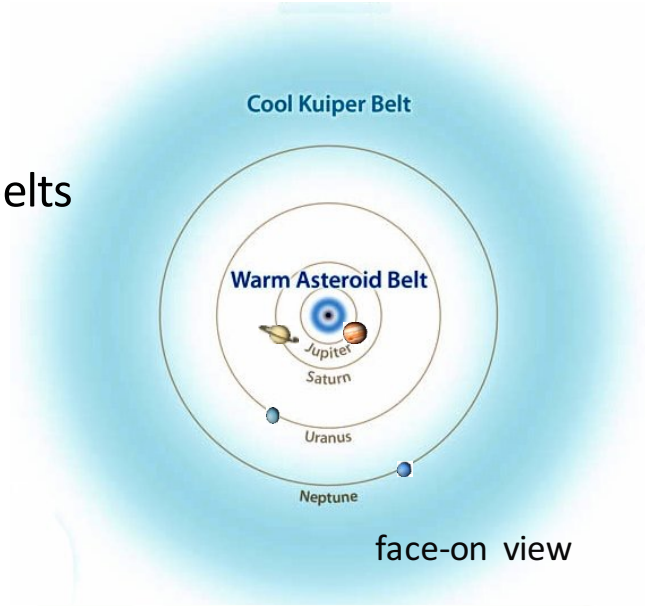
Two leftover planetesimal (parent-body) belts

Asteroid Belt (2-4 AU): km-size bodies

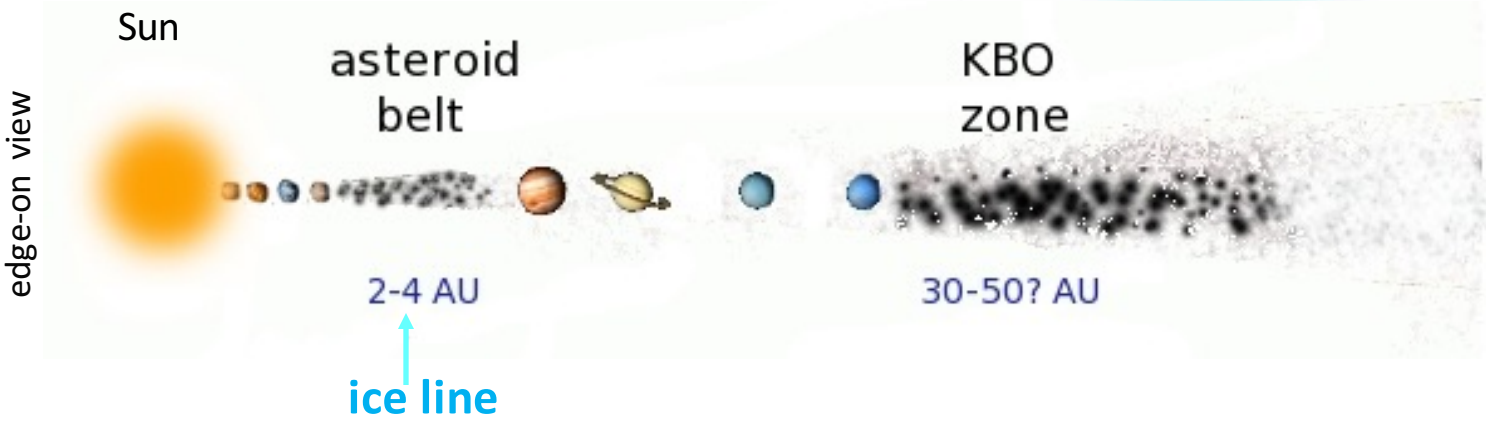
its structure greatly influenced by Jupiter

Kuiper Belt (30-50 AU): large icy bodies

the inner edge maintained by Neptune

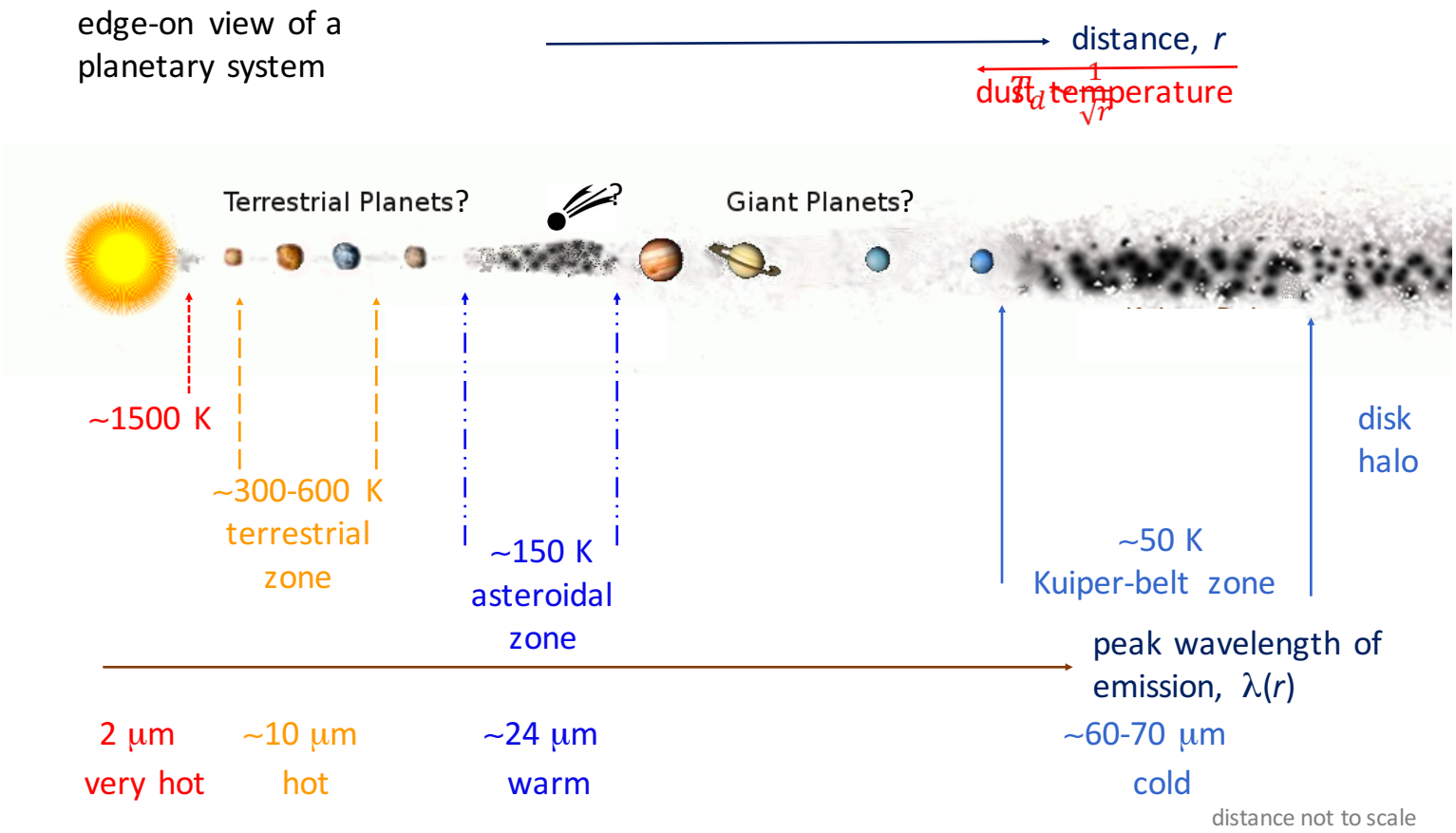


face-on view



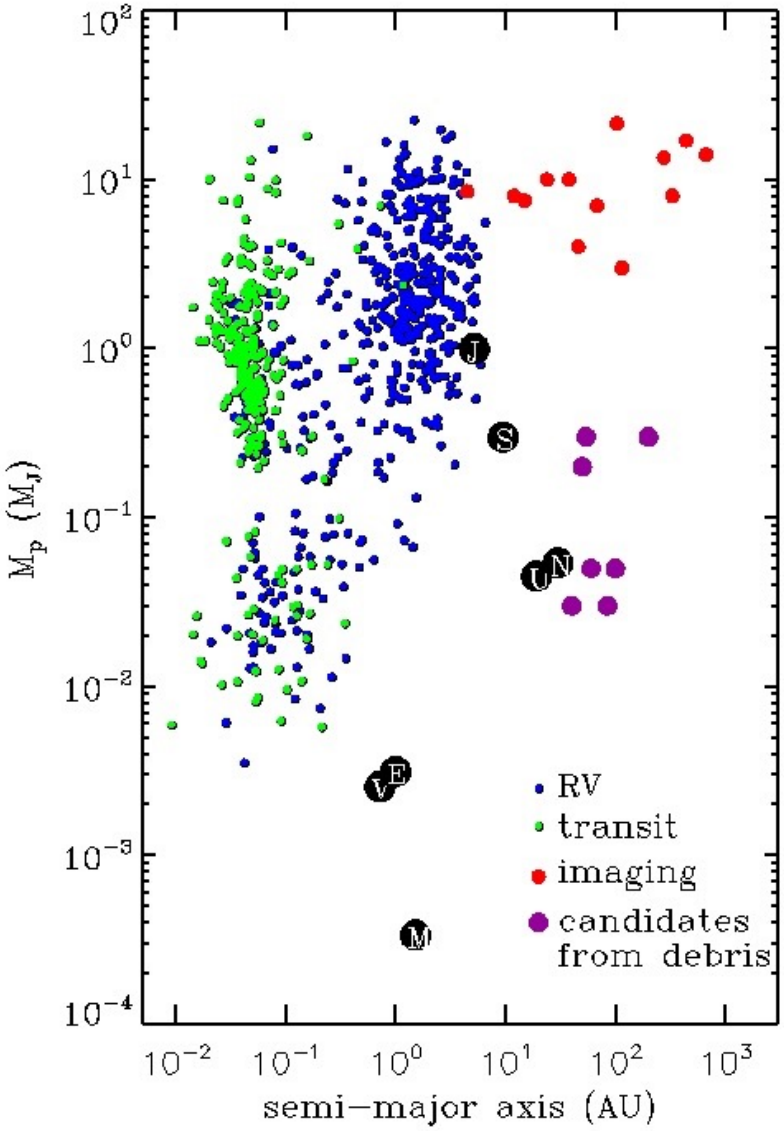
edge-on view

Five Zones of Debris Dust



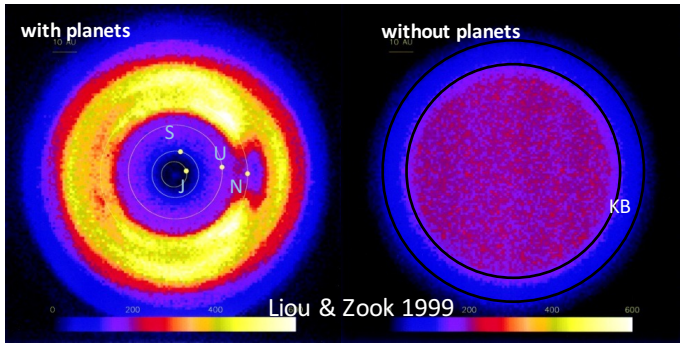
Signpost of Exoplanets

- Current search methods are strongly biased.
- Look for solar analogs that have giant planet at large radial distance. The existence of habitable terrestrial planets relies on gas giants remaining at large orbital radii.
- Planets inferred by debris disk structures are good analogs.

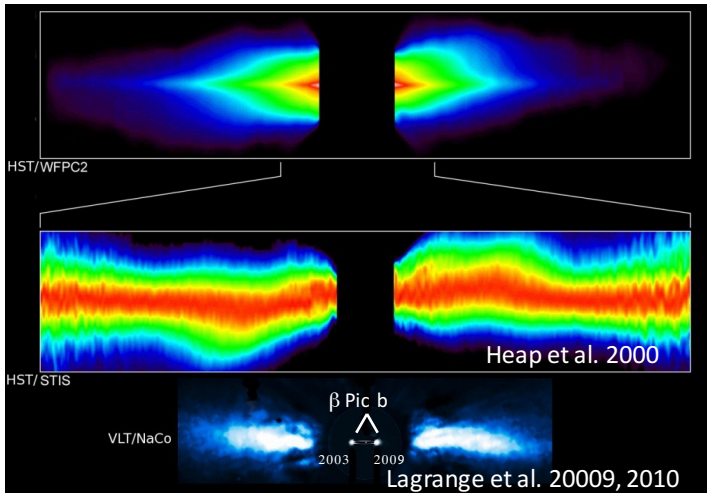


Planet-Disk Interaction - structures created by planet(s)

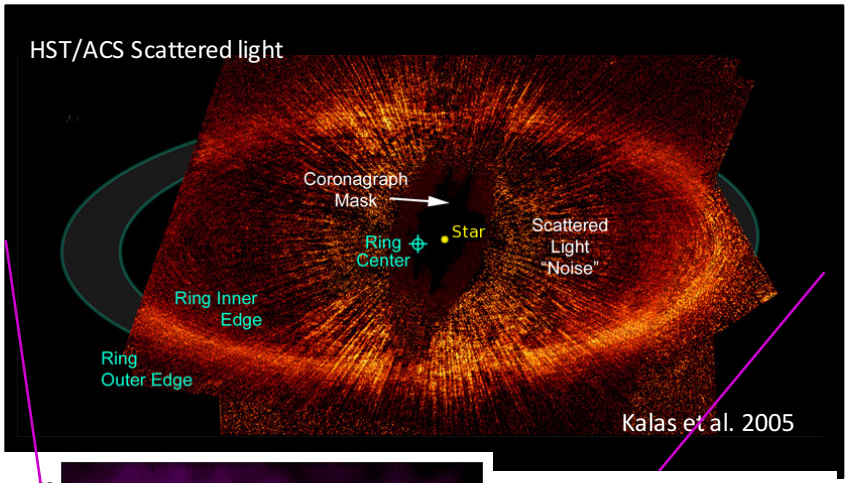
- Particle Distribution for Solar System

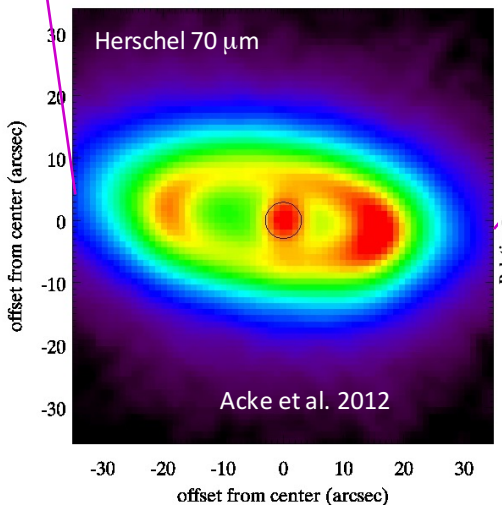


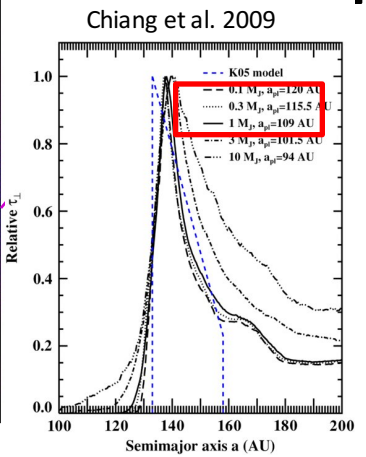
- Warp Disk – β Pictoris



- Offset Narrow Ring – Fomalhaut

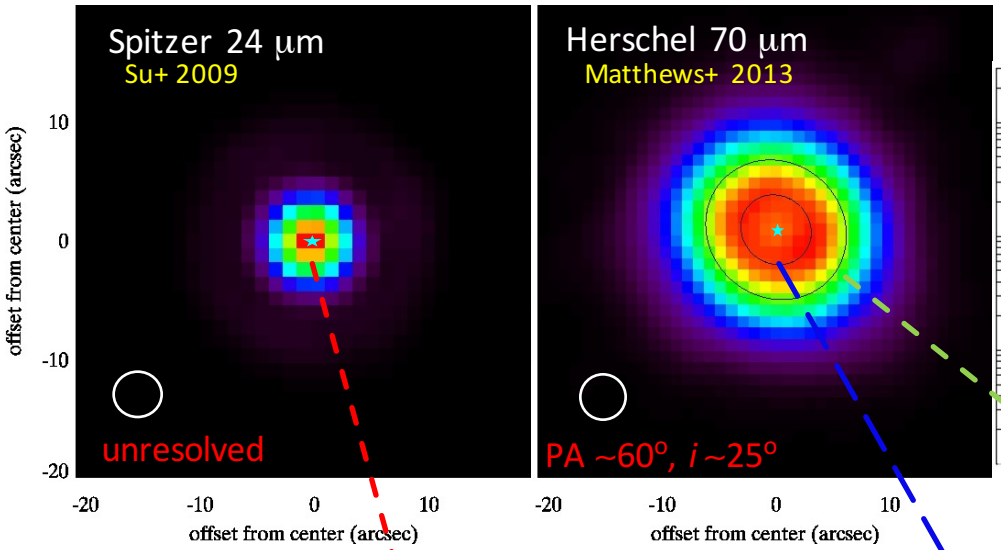


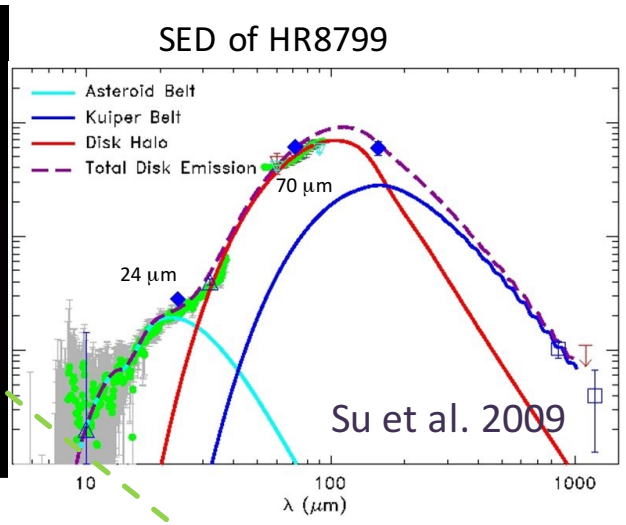


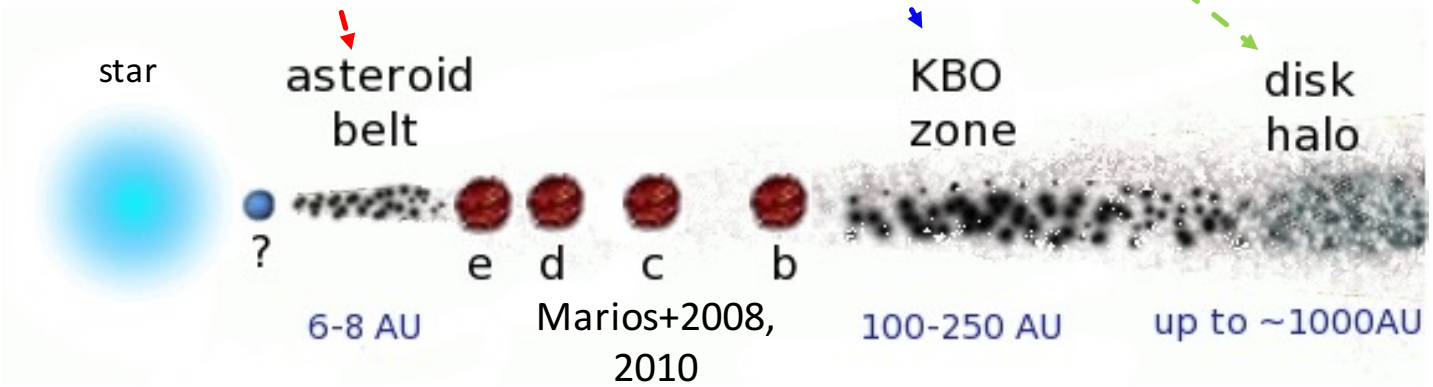


also see Boley et al. 2012

HR 8799 Debris Disk and Four Giant Planets

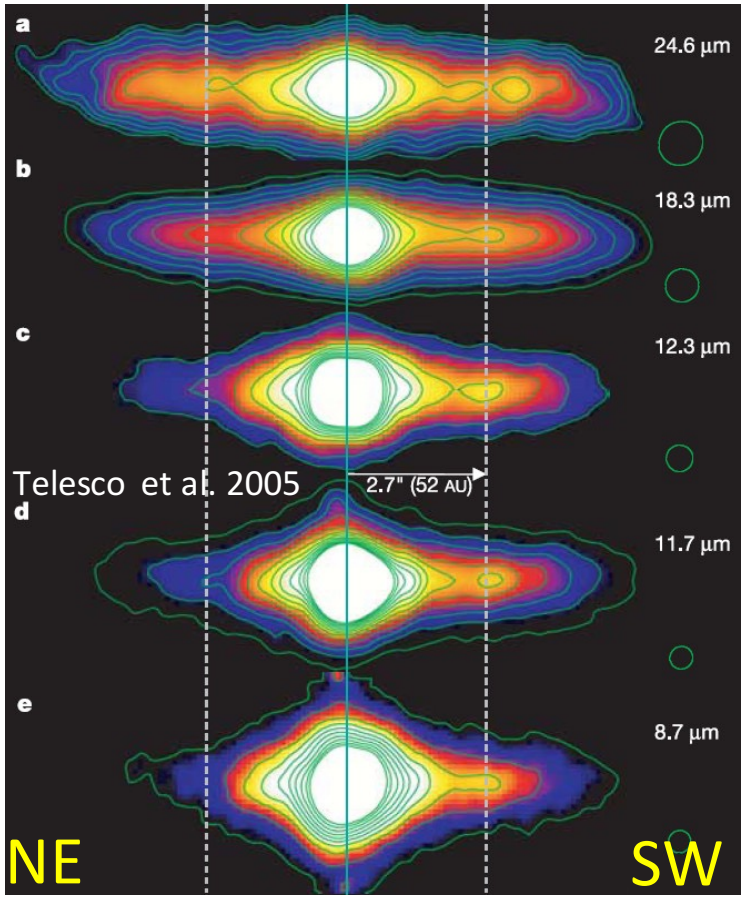


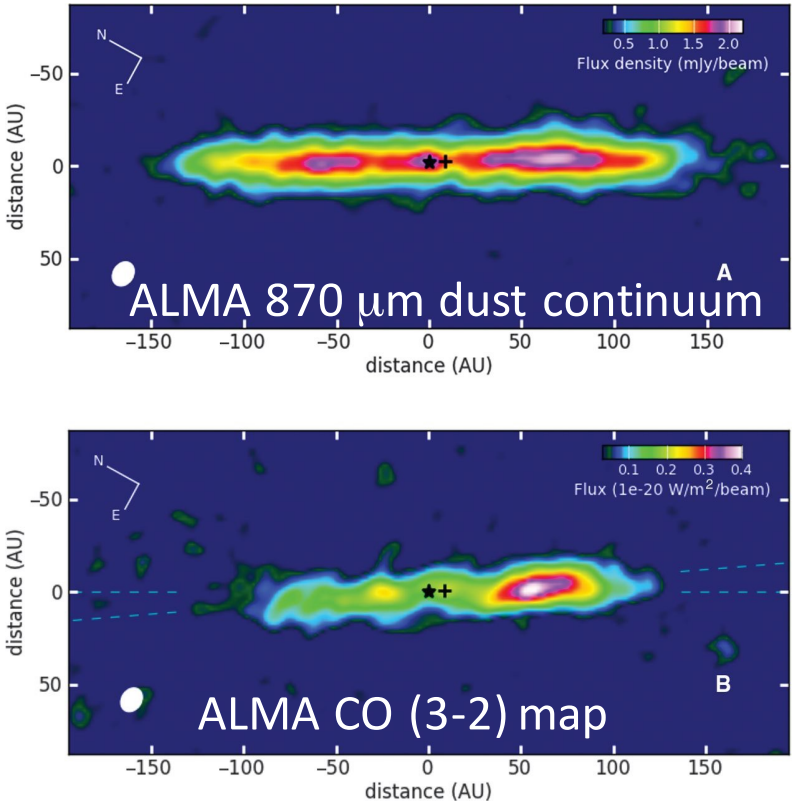




Marios+2008, 2010

The β Pic Disk – clump

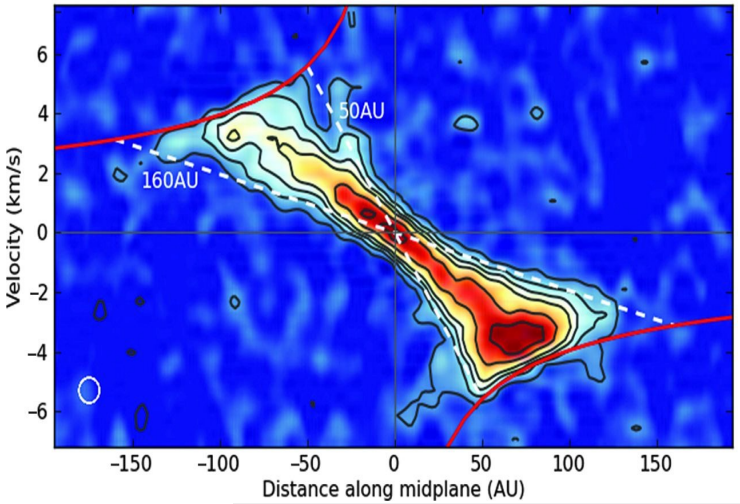




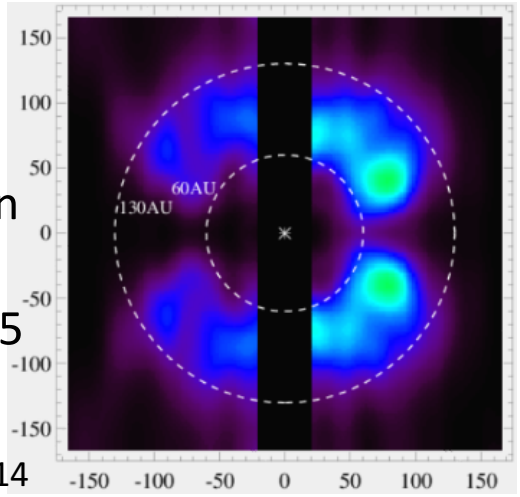
Dent et al. 2014

dust clump at 52 AU with T_d~ 190 K,
M_d ~4x10^{20} g

The β Pic Disk – clump



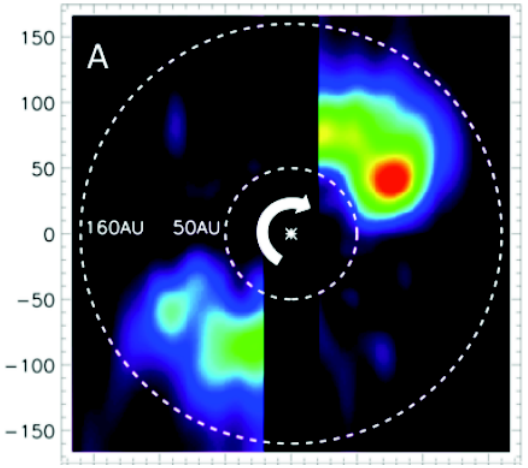
ALMA CO velocity information puts the clump at 85 AU



Dent et al. 2014

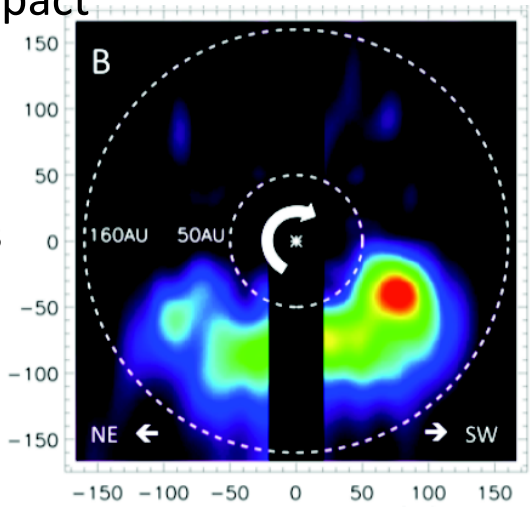
A: Resonance due to unseen planet

>10 $M_\oplus$ planet at 54 AU

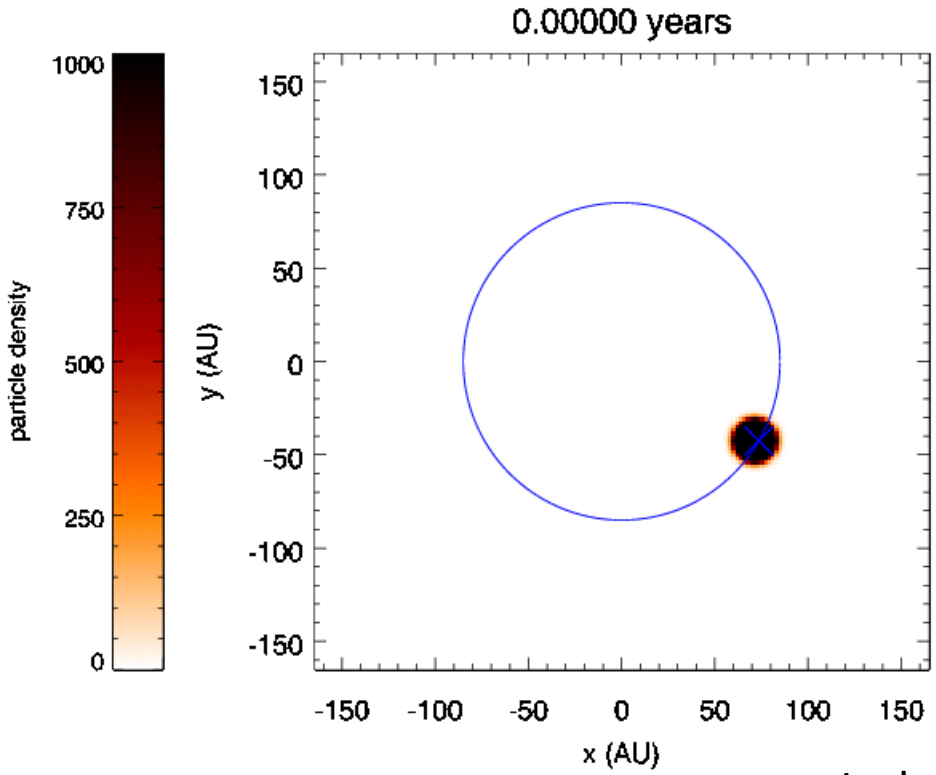


B: Giant impact

A planet with a few Mars mass



Debris Evolution due to Giant Impact



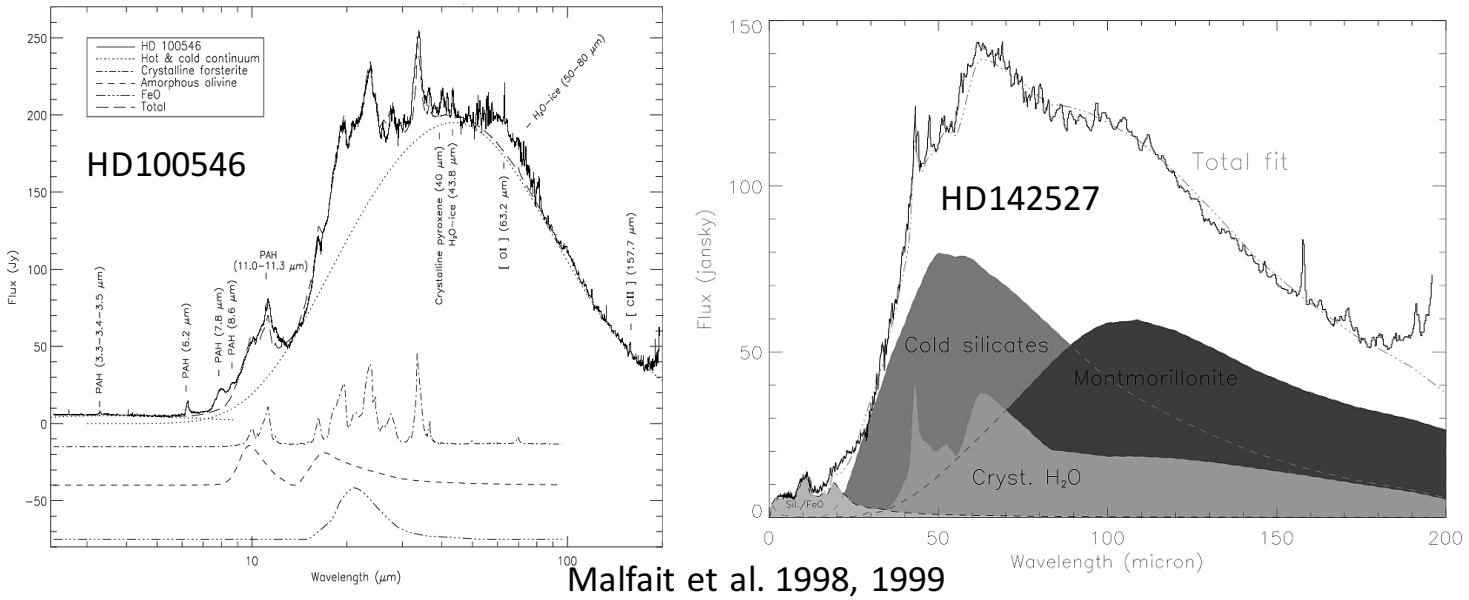
Jackson et al. 2014

Far-Infrared Spectroscopy – Trace Material in the cold Zone

ISO – Long Wavelength Spectrometer (LWS)

Herbig Ae/Be Stars: crystalline silicates, crystalline water ice, phyllosilicates

No debris disks (~ 2 orders of mag. fainter)

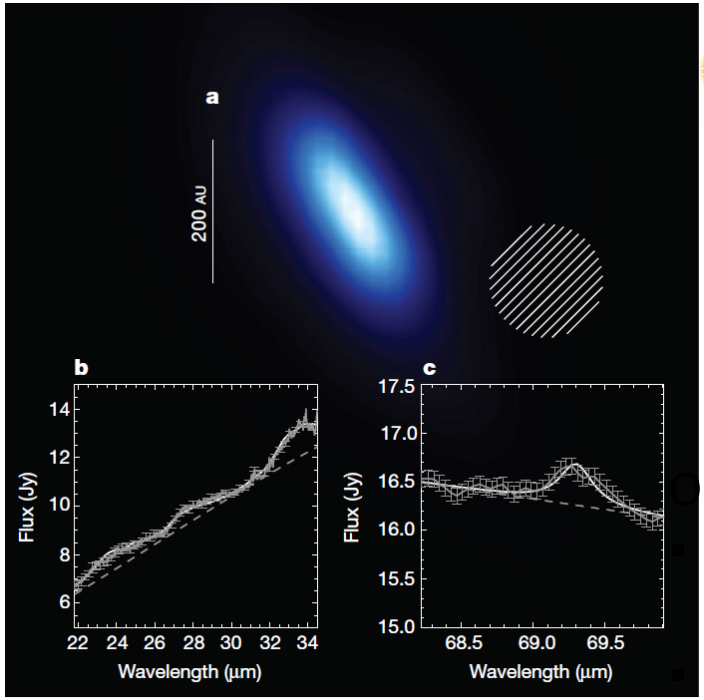


Malfait et al. 1998, 1999

Far-Infrared Spectroscopy – Trace Material in the cold Zone

Herschel – PACS spectroscopic mode

- 69 μm low-iron Olivine feature (one debris disk: β Pic)



De Vries et al. 2012

- ~20-30% Iron asteroidal, warm, equilibrated
- ~1% Iron cometary, cold, un-equilibrated

Other solid-state features:

- Olivine, Pyroxene: high temperature formation/alteration
- Calcite, Dolomite: low temperature, link to water (life)

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    formation and transportation history, link to protoplanetary disks
- Planetary Systems beyond Main Sequence
  - Detecting the reservoir of surviving asteroids and KBOs

IS THERE WEATHER AND CLIMATE ON EXOPLANETS?

POTENTIAL FOR TRANSITING HABITABLE PLANETS AROUND M DWARFS?

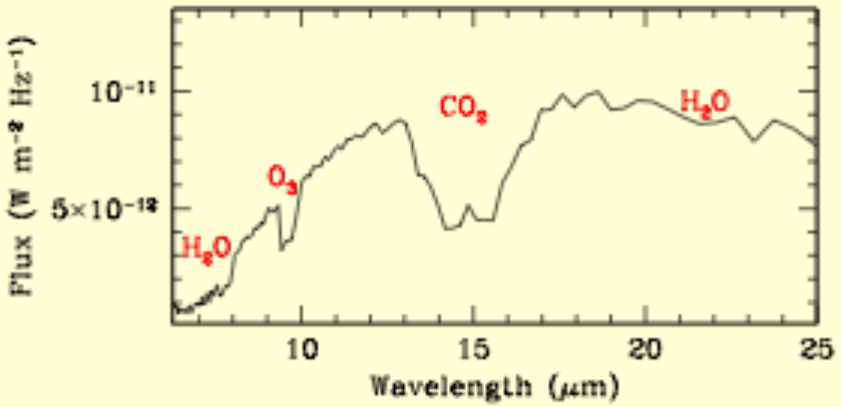
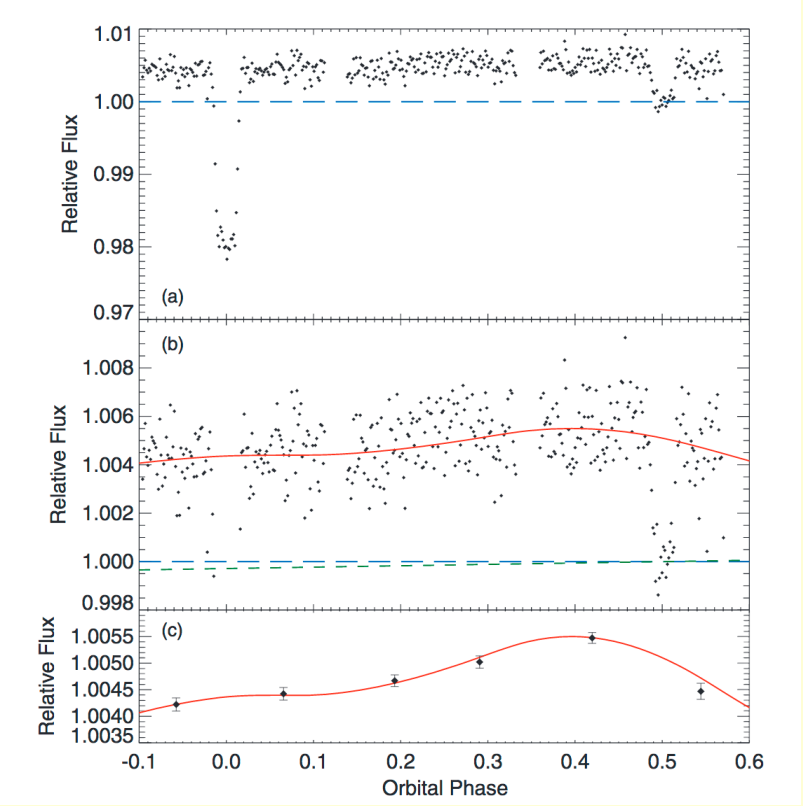


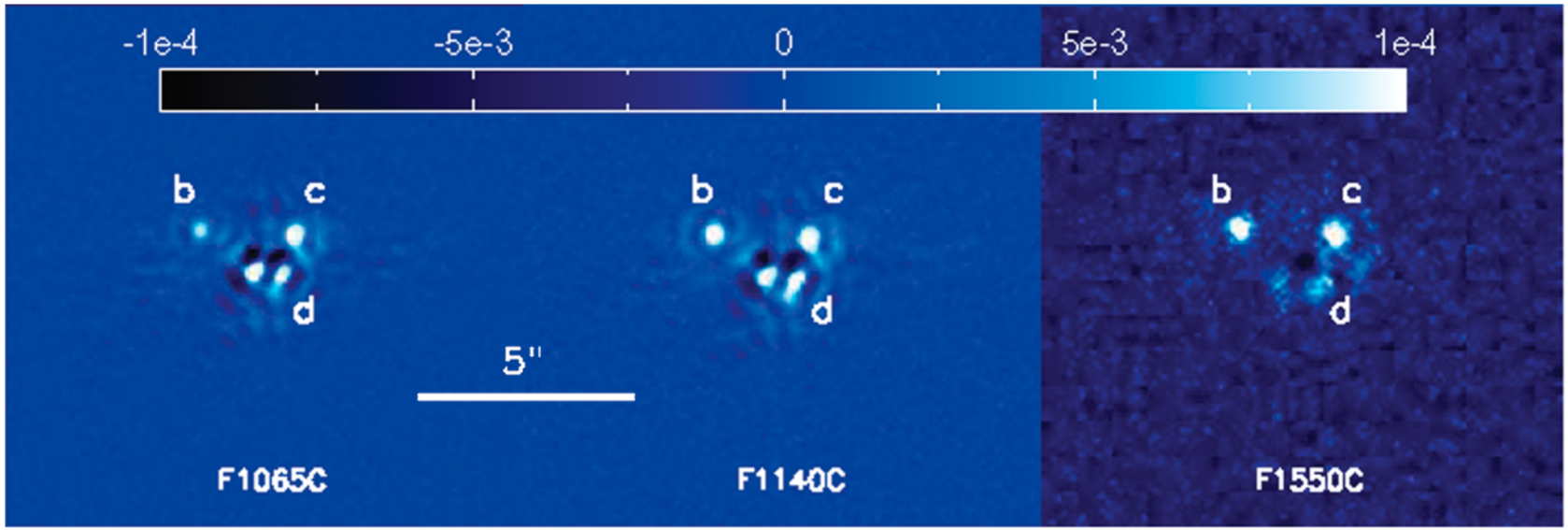
Fig. 9 Earth's mid-infrared spectrum as observed by Mars Global Surveyor enroute to Mars [59]. Major molecular absorption features are noted.

Spitzer 24 micron phase curve of HD 189733b



Knutson+ 2009

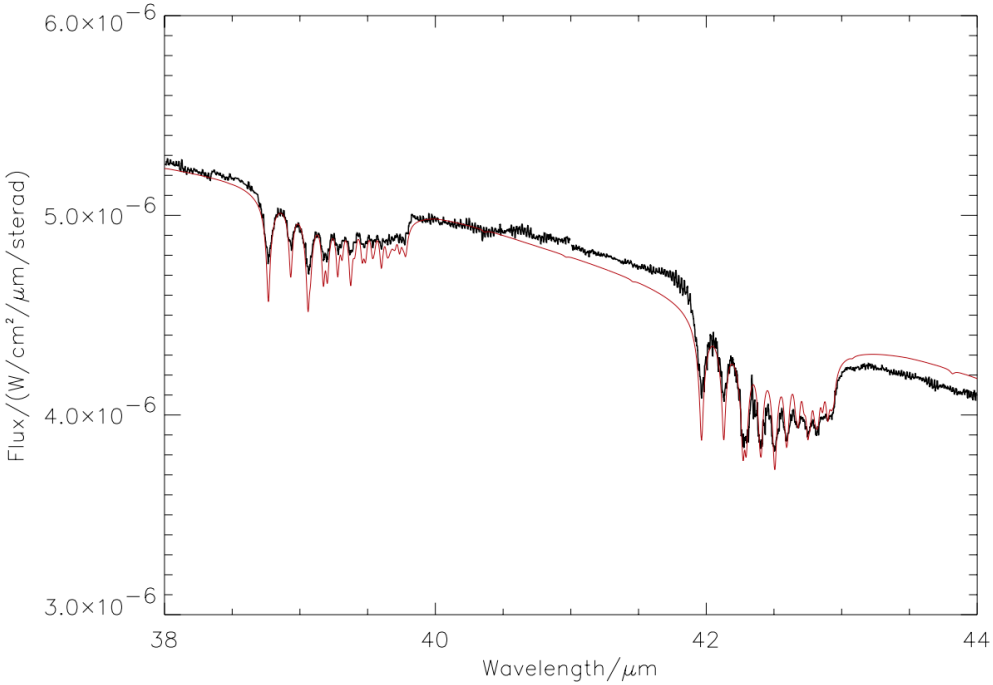
WHAT IS THE ATMOSPHERIC COMPOSITION OF COOL PLANETS?

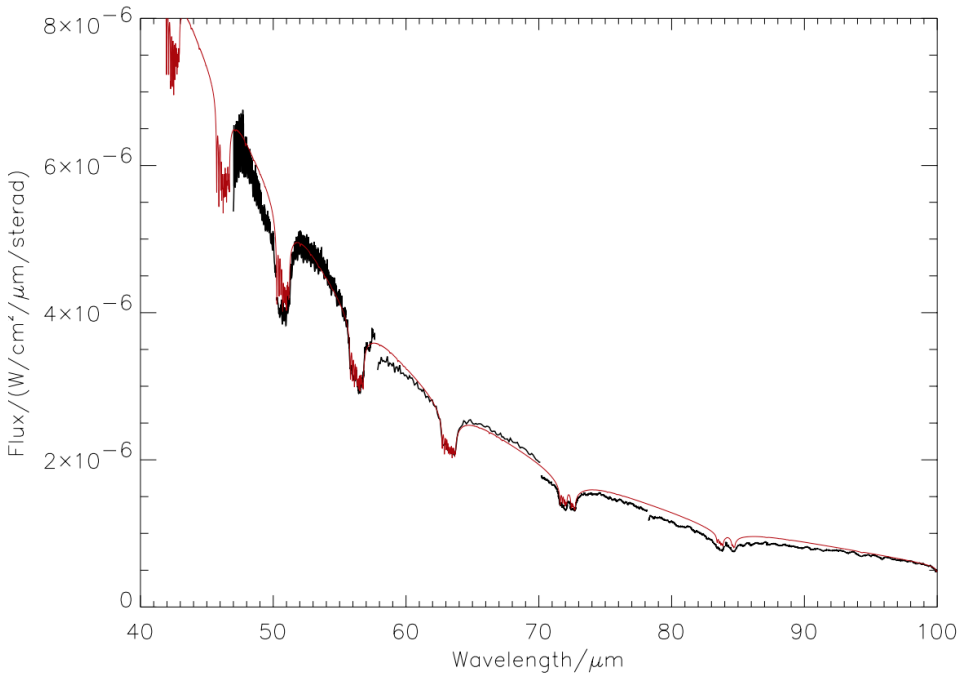


Boccaletti+ 2014

Simulated MIRI coronagraphy of HR 8799

WHAT IS THE ABUNDANCE OF NH3/PH3 IN EXOPLANETS? COMMONALITY WITH SOLAR SYSTEM JOVIANS?

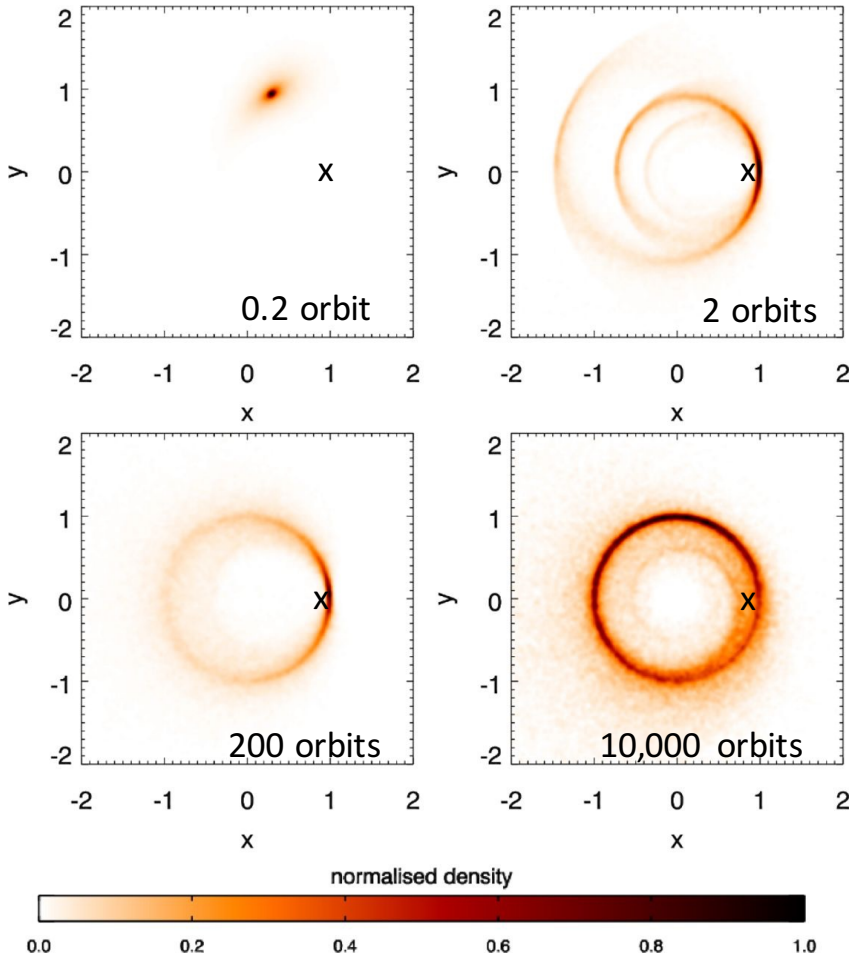




Burgdorf+ 2002

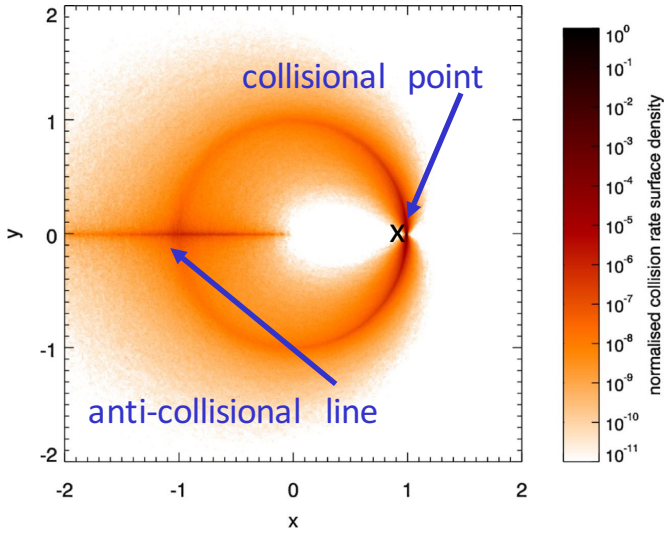
EXTRAS/TECHNICAL

Debris/Fragments Evolution



Jackson et al. (2014)

- 1st orbit – clump
- ~2-10 orbits – spiral
- After ~10 orbits – smooth asymmetric disk lasting for ~1000 orbits



- Two special locations that all fragments must go through.

SPATIAL REGIONS TRACED