Current and Future Observations of Gas Disks

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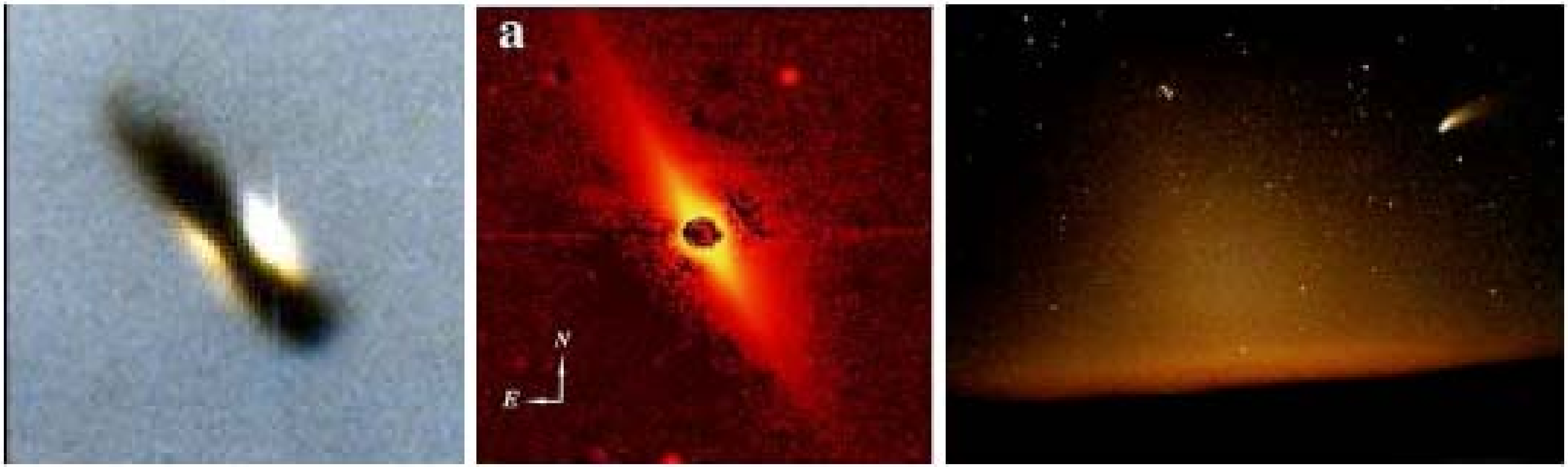
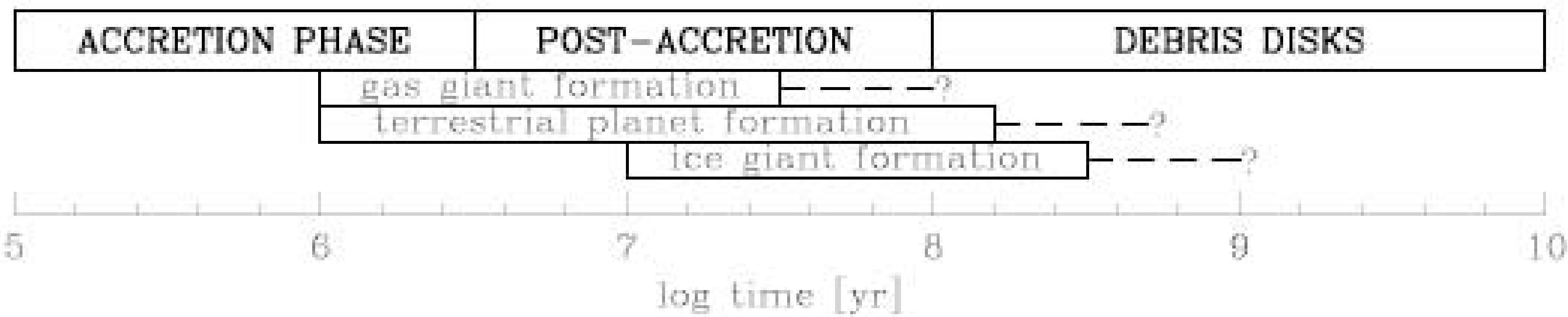
A very broad area for a very short talk…
apologies if I miss your favorite result!

Circumstellar disks are…

- Ubiquitous (at least for cool stars)
- Necessary to conserve angular momentum and allow a star to grow
- Sites of planet formation
- Short-lived and evolve rapidly
- Small, low mass, chemically complex, and mostly cold

Dusty disk evolution



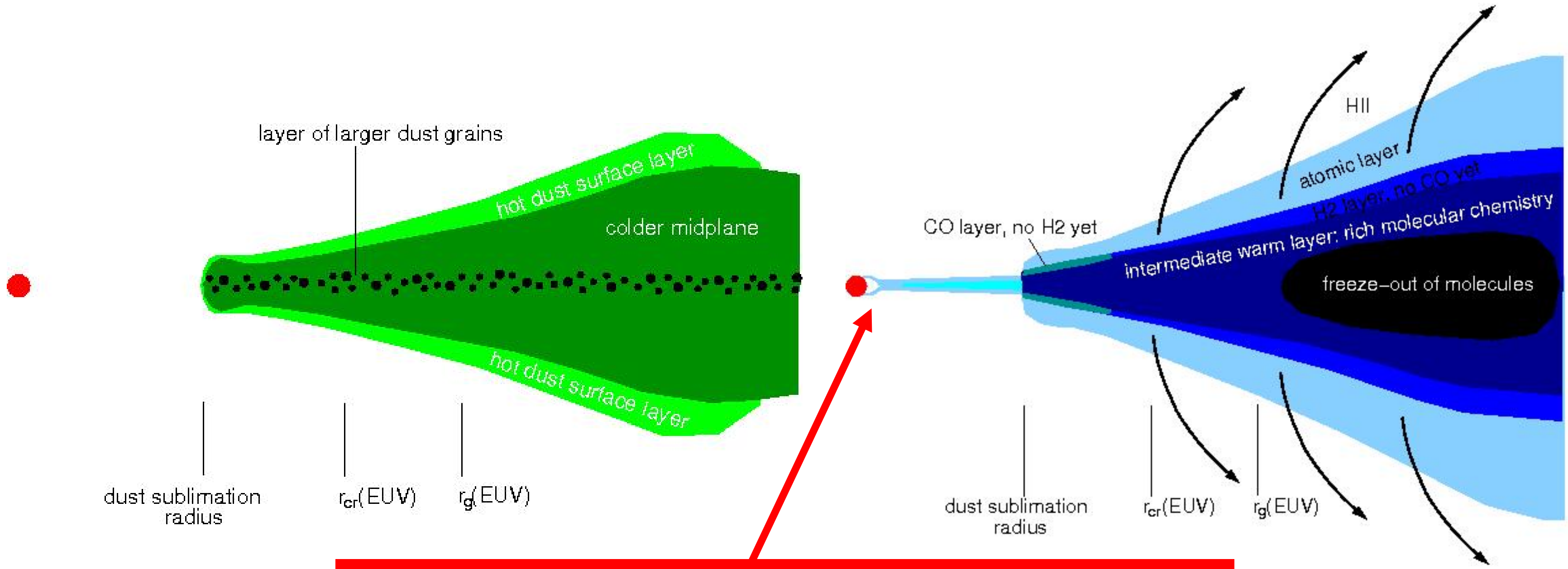


Hillenbrand 2005

Dust is not enough!

- Gas provides 99% of the initial disk mass and most of the SS planetary mass
  - disk stability and mode of planet formation
  - timescale for planet formation
  - planet migration
- Gas largely dictates disk heating, cooling, chemistry
- Gas drag affects dust dynamics

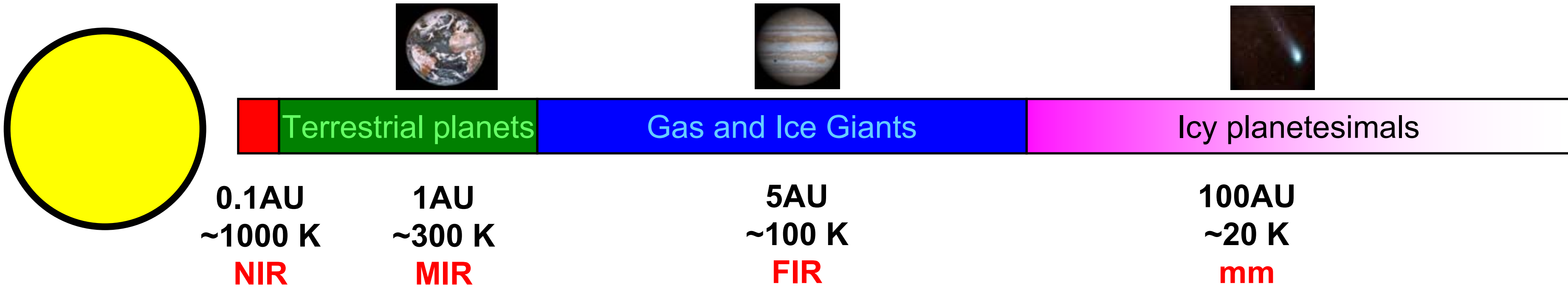
Dust and Gas Structures

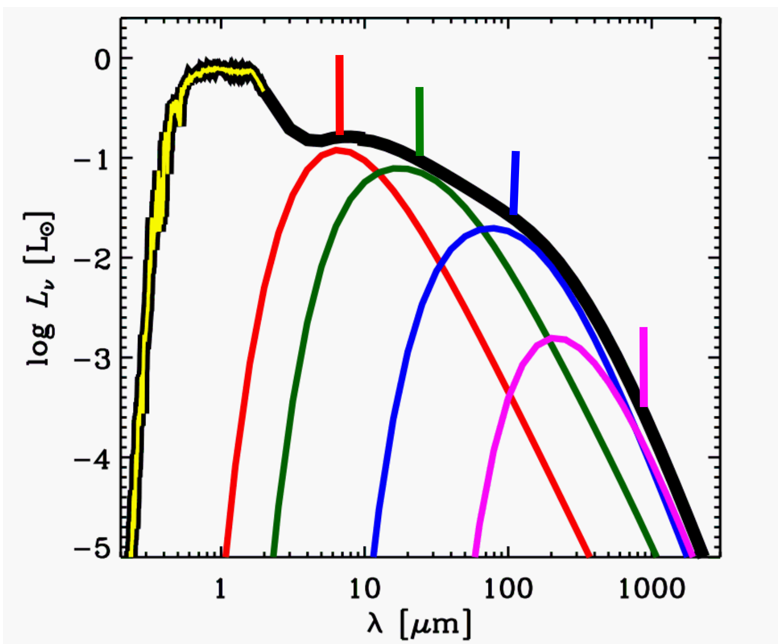


See Sicilia-Aguilar talk

Dullemond et al. 2005
(image courtesy of Inga Kamp)

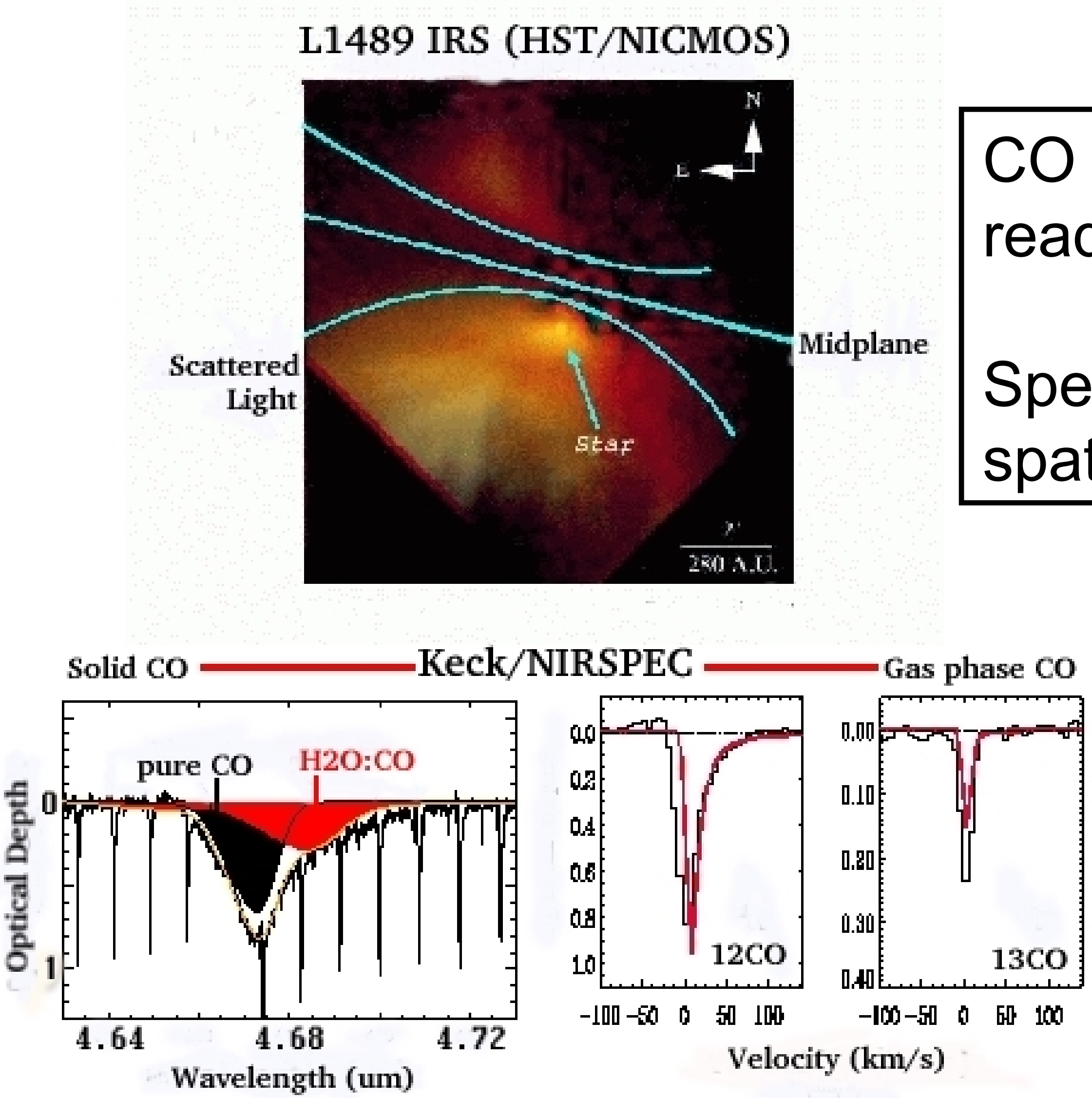
Temperature structure





Spectral lines show the gas at the same *approximate* radius

The inner disk: CO ro-vibrational lines



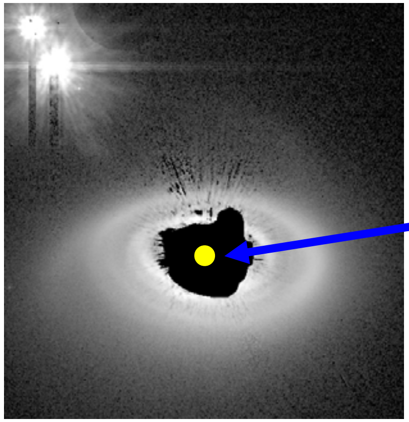
CO fundamental emission readily detectable in CTTs

Spectral profiles provide spatial information.

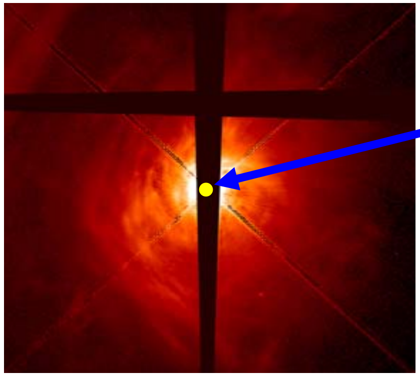
Boogert, Hogerheijde, & Blake 2002

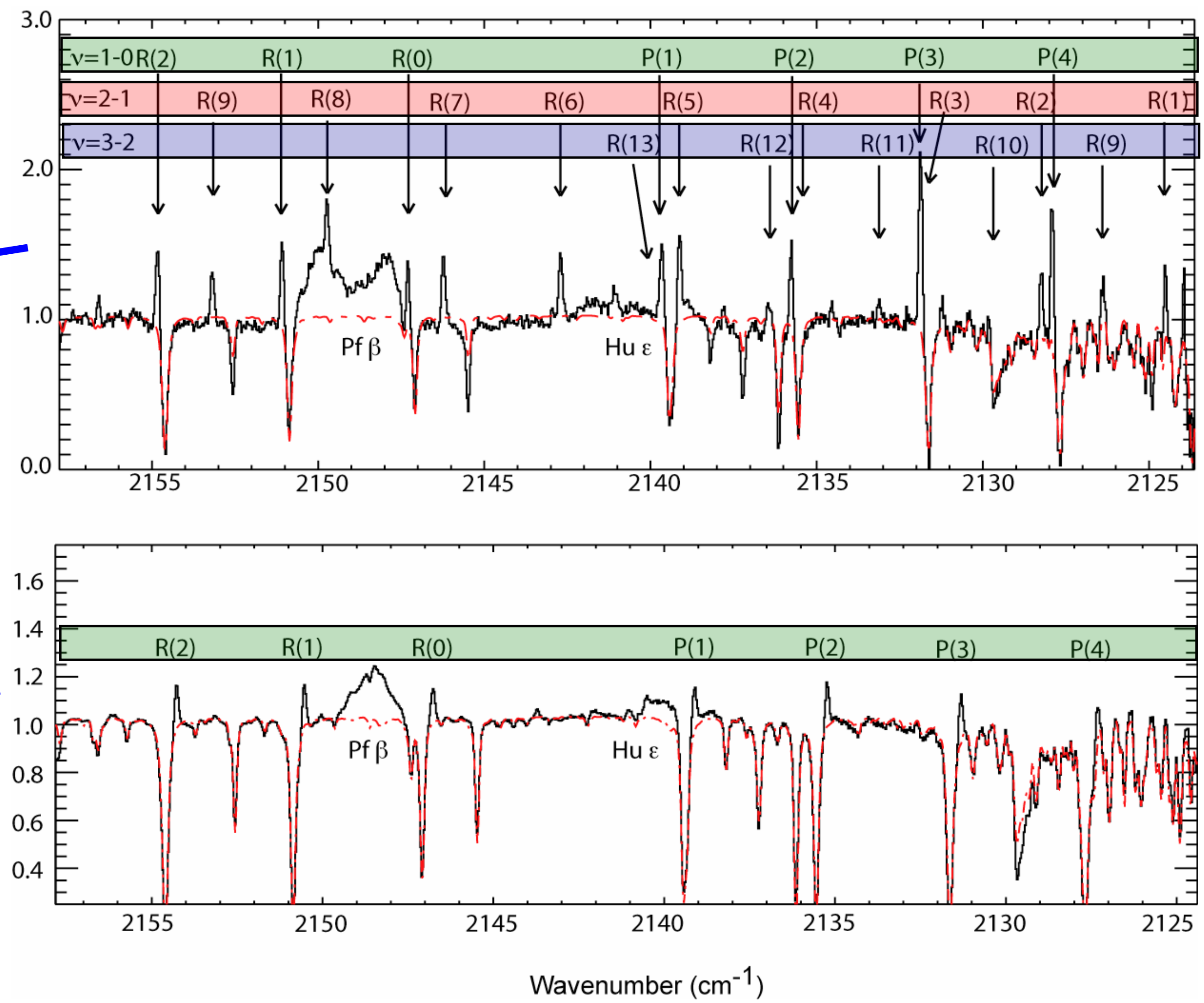
The inner disk: UV excited lines

HD 141569



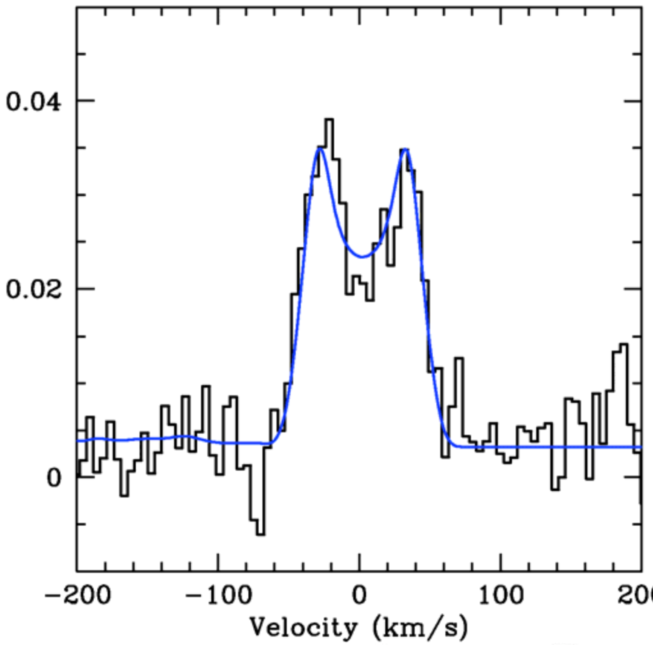
AB Aur

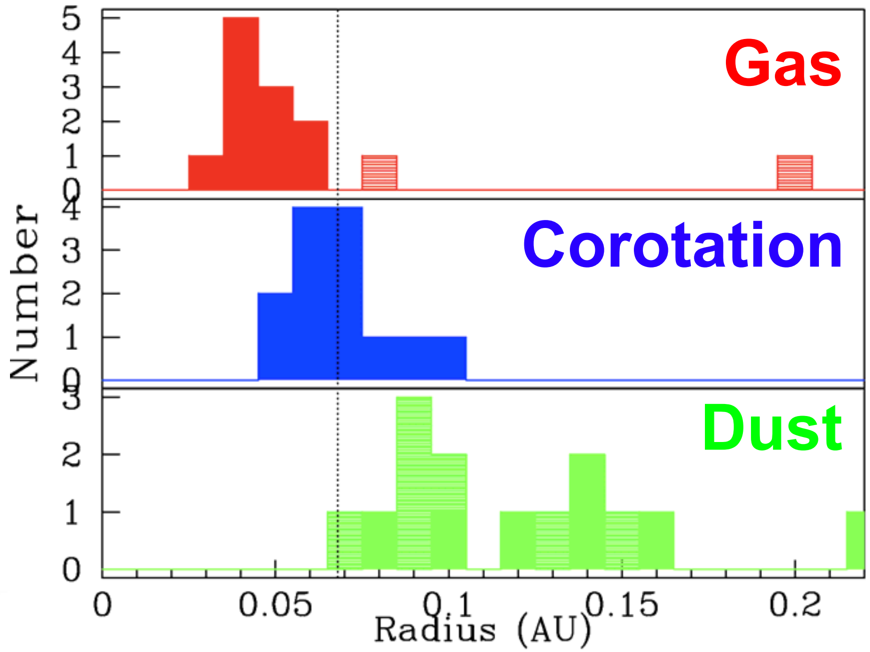


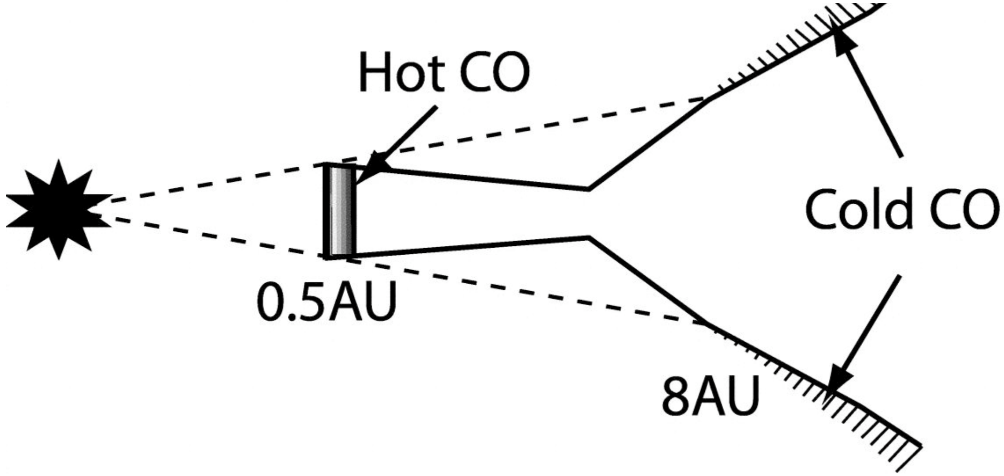


Brittain et al.

Inner gas radius

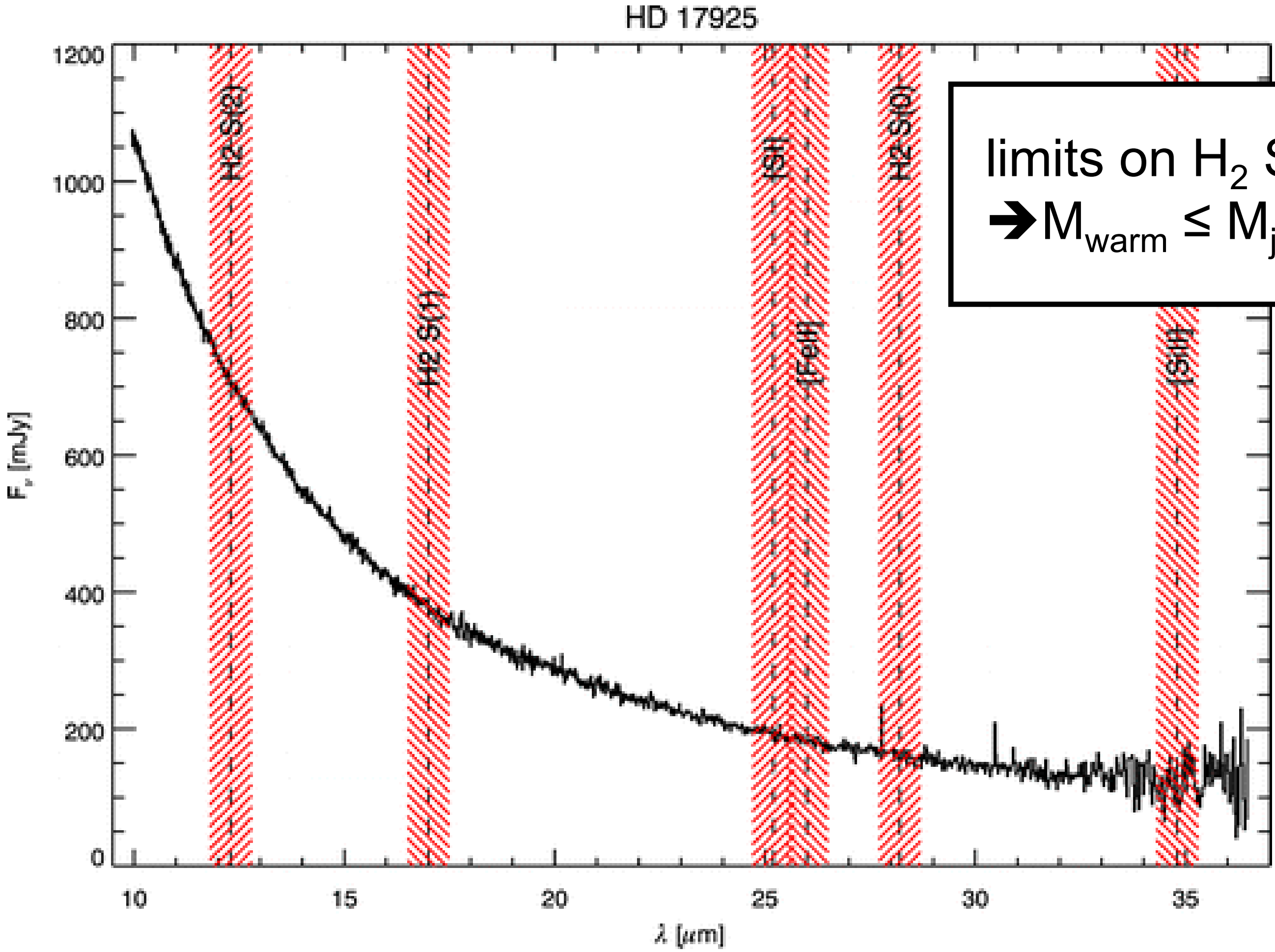






Carr IAU talk

The terrestrial zone: mid-infrared observations with Spitzer



limits on H_2 S(0), S(1)

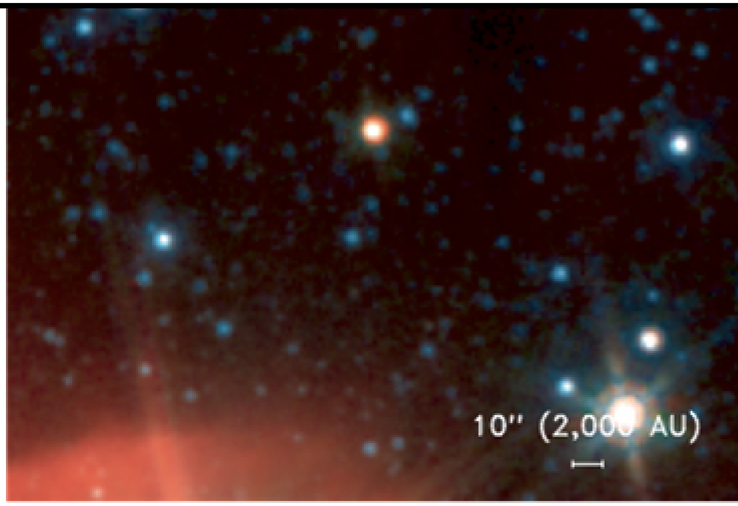
➔ $M_{warm} \leq M_{jup}$ for t > few Myr

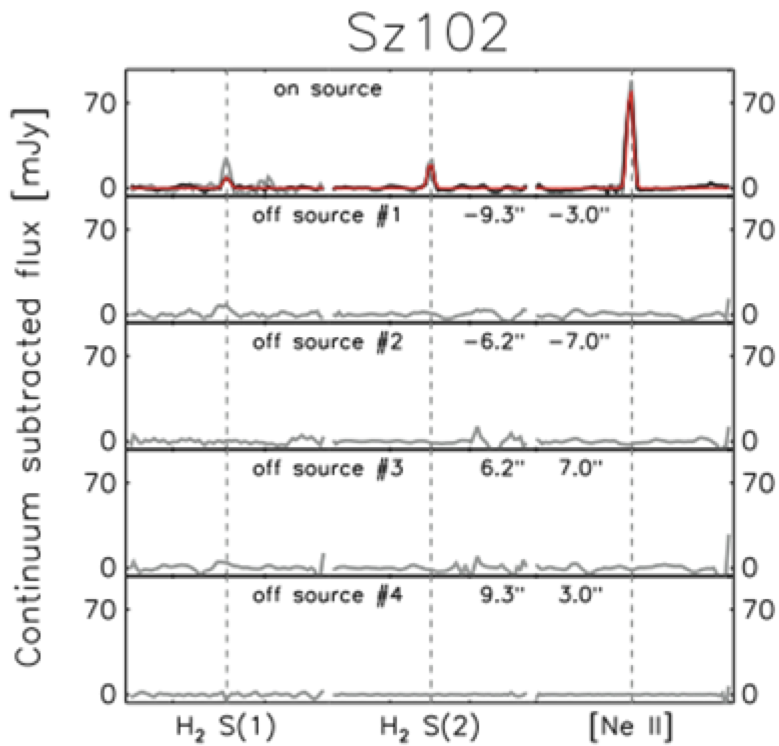
Gorti & Hollenbach 2004; Pascucci et al. 2006, 2007

The terrestrial zone: mid-infrared observations with Spitzer

Fe[I] ➔ M_{warm} ~0.1 M_{jup}

Ne[II] ➔ X-ray ionization of surface



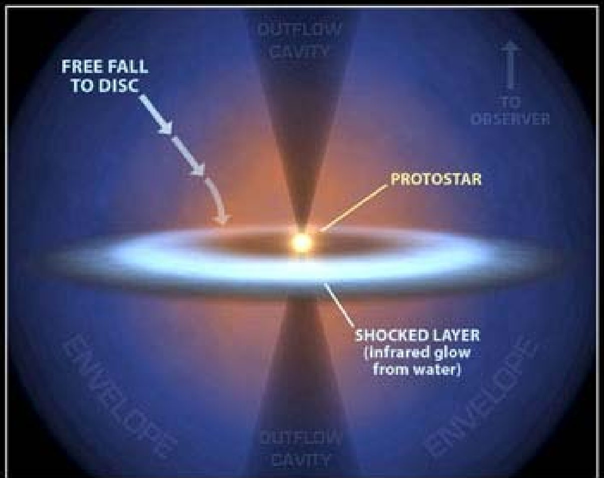


17.0 12.3 12.8µm

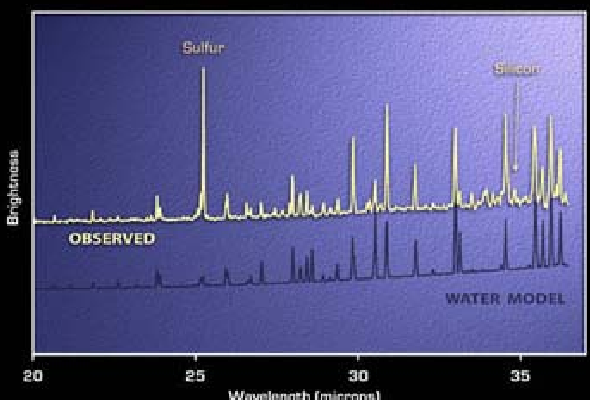
Lahuis et al. 2007

See Pascucci talk

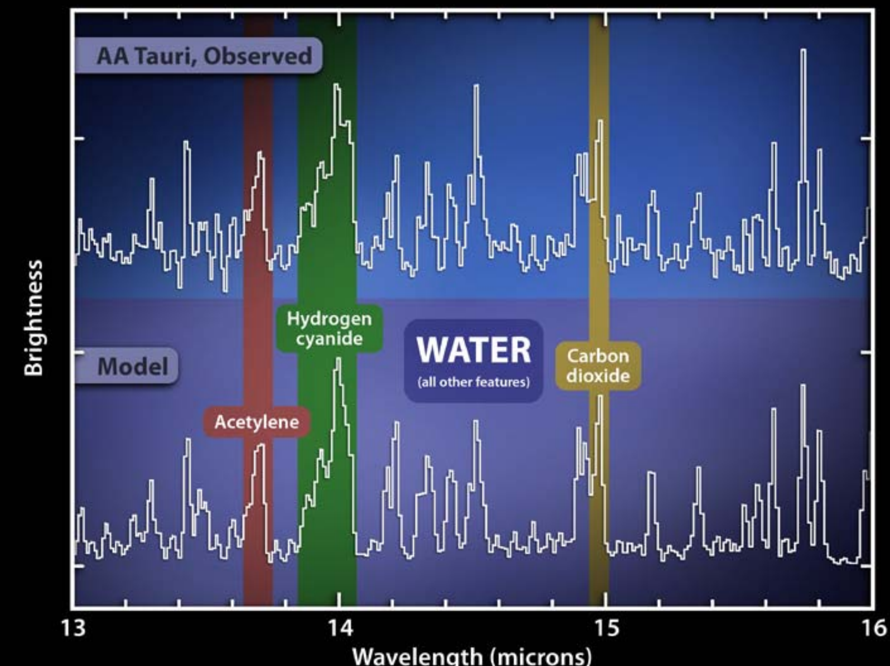
Water and organic molecules



Infrared Water Emission From Protoplanetary Disk Spitzer Space Telescope • IRS
NASA / JPL-Caltech / D. Watson (Univ. of Rochester) ssc2007-XX



NGC 1333 IRAS4B Spectrum Spitzer Space Telescope • IRS
NASA / JPL-Caltech / D. Watson (Univ. of Rochester) ssc2007-14a



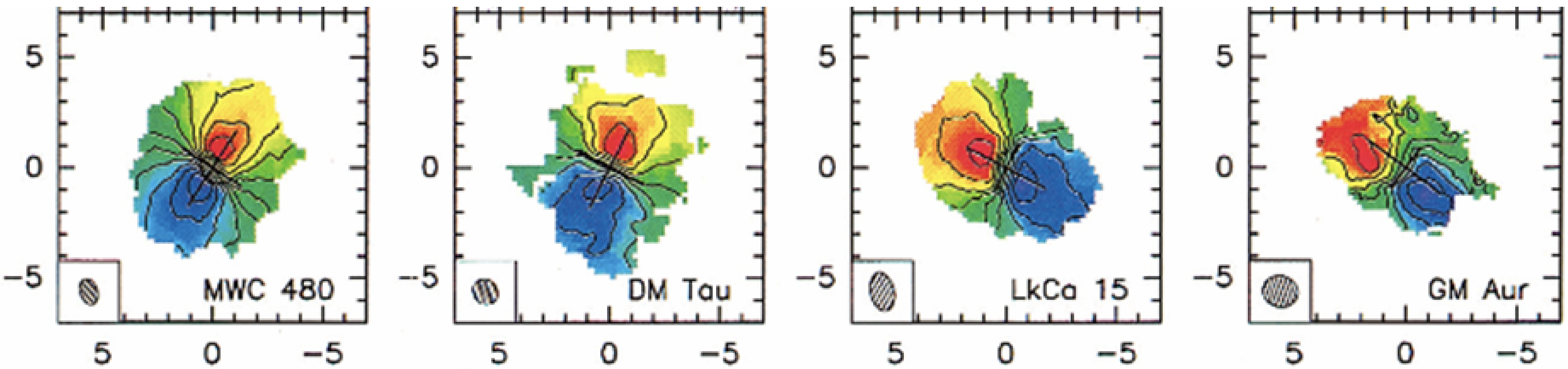
Organic Molecules and Water in a Protoplanetary Disk Spitzer Space Telescope • IRS
NASA / JPL-Caltech / J. Carr (Naval Research Laboratory) ssc2008-06a

Disks are full of water!
Organic molecule abundances in AA Tau > star forming cores

Watson et al. 2007; Carr & Najita 2008; Salyk et al. 2008

Millimeter lines: the cold outer reservoir

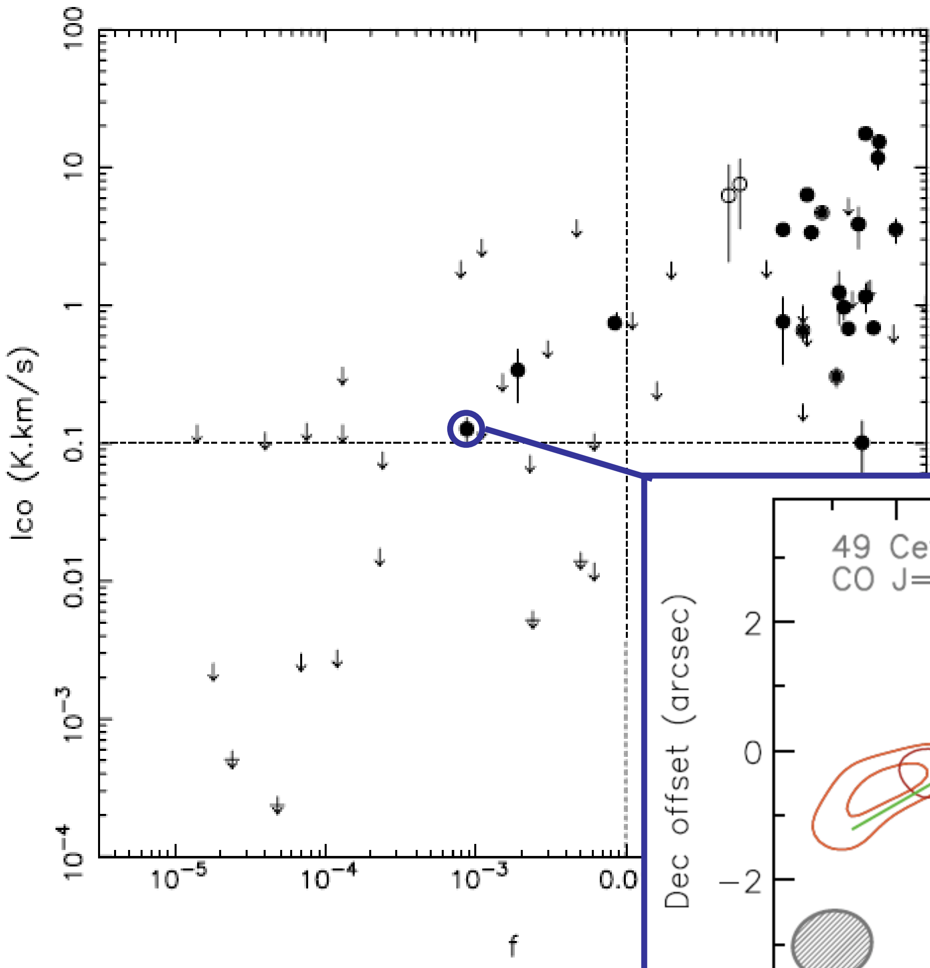
Young disks



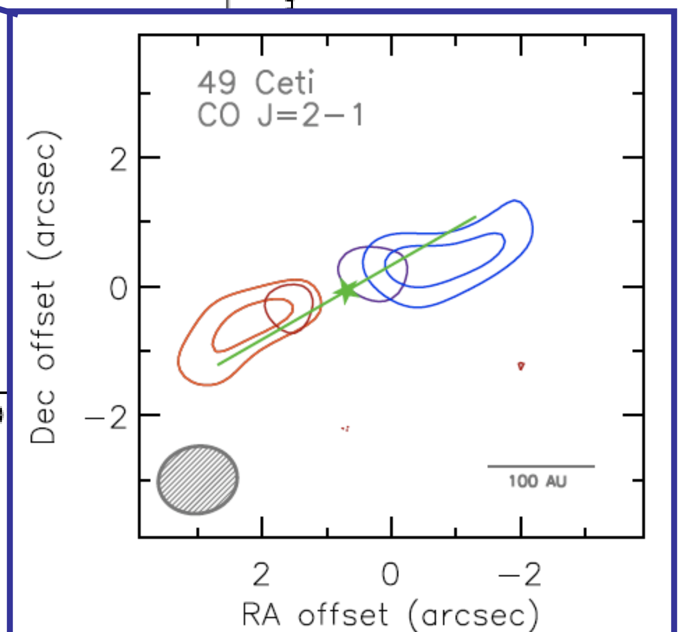
- H_2 has no dipole moment and is undetectable in cold gas
- CO rotational lines detected in ~100 disks
- High spatial and spectral resolution allow PMS stellar masses to be measured
- Photodissociation and depletion greatly affect abundances (and make it difficult to measure gas mass accurately)

Simon et al. (2000)

Millimeter lines: the cold outer reservoir
Old disks



Dent, Greaves, & Coulson 2005

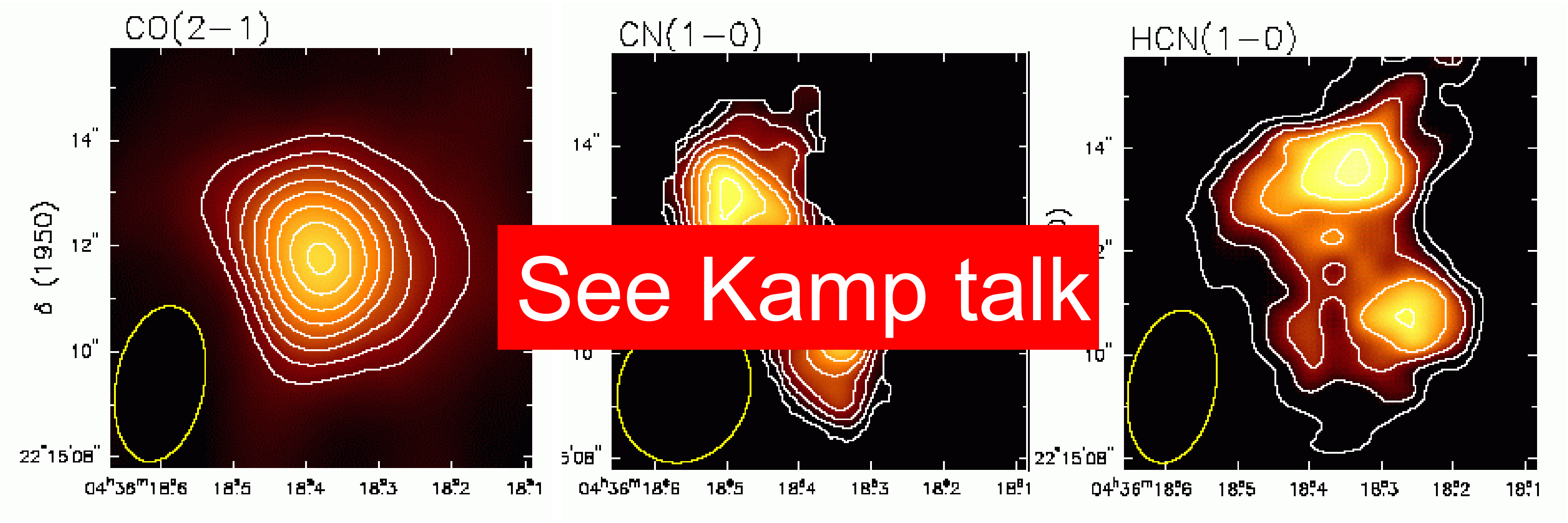


Hughes et al. 2008

CO rarely detectable around debris disks for $L_{disk}< 0.1\ L_{star}$

And appears to dissipate from inside-out

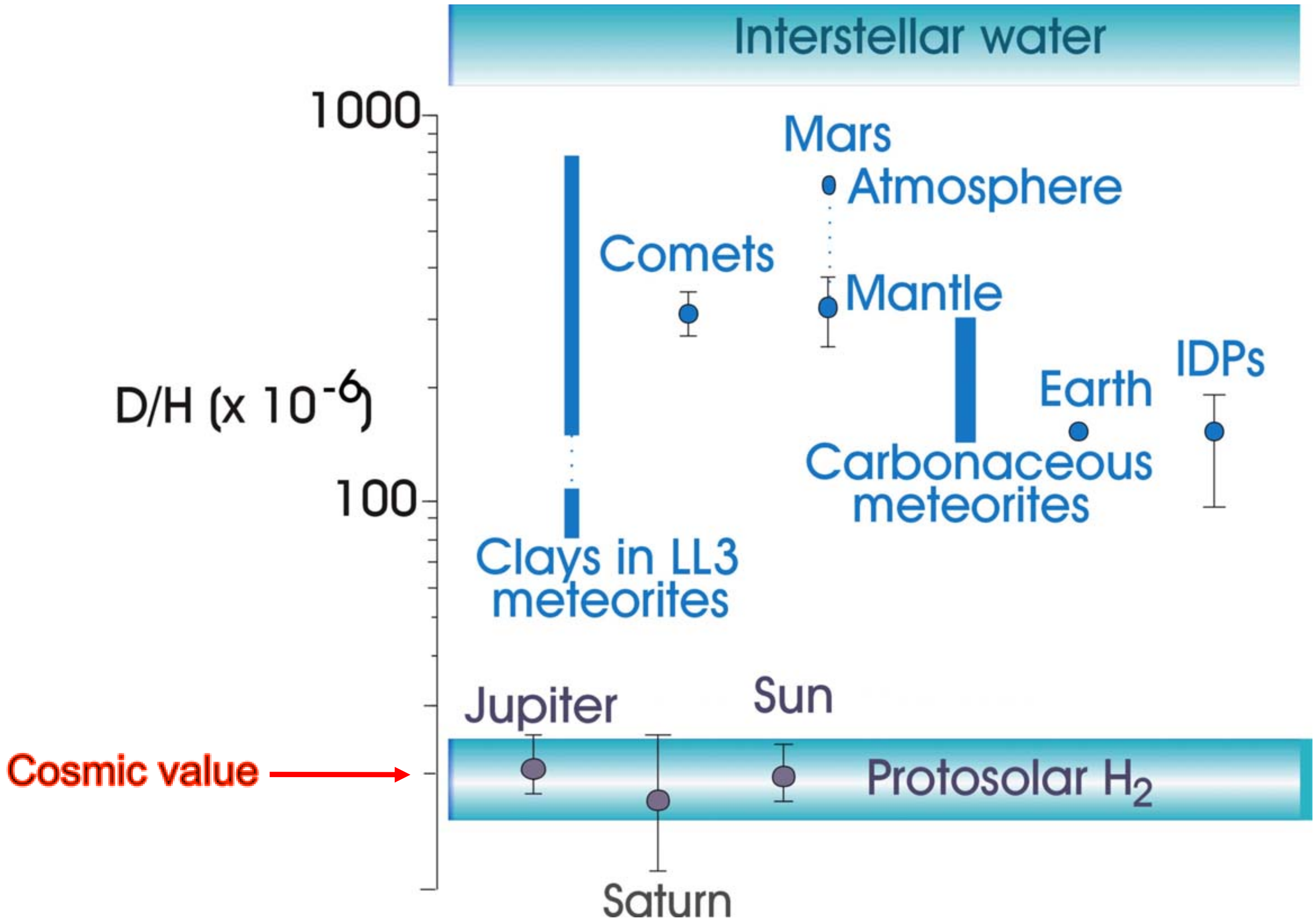
Disk chemistry



Detection of the CO “frost line”?

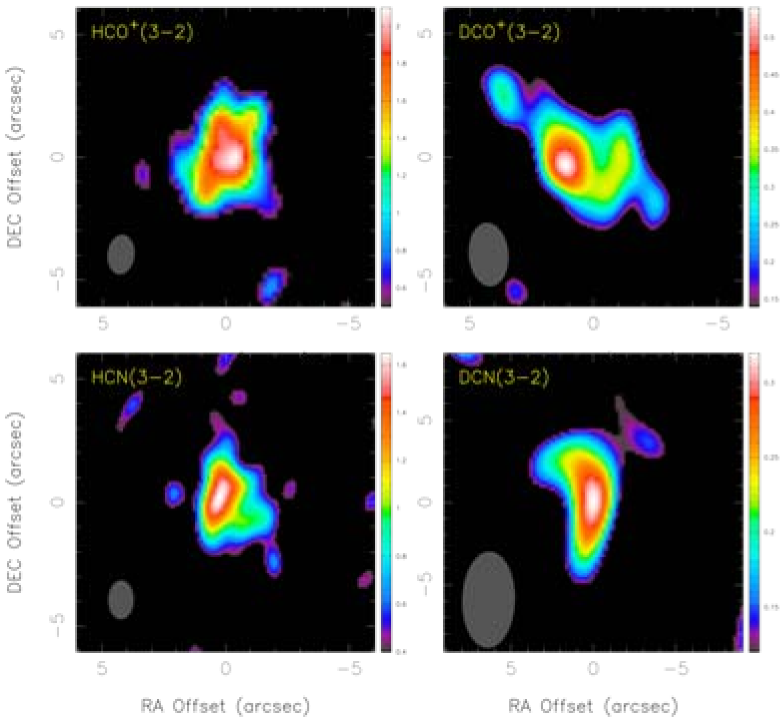
Qi PhD thesis 2000

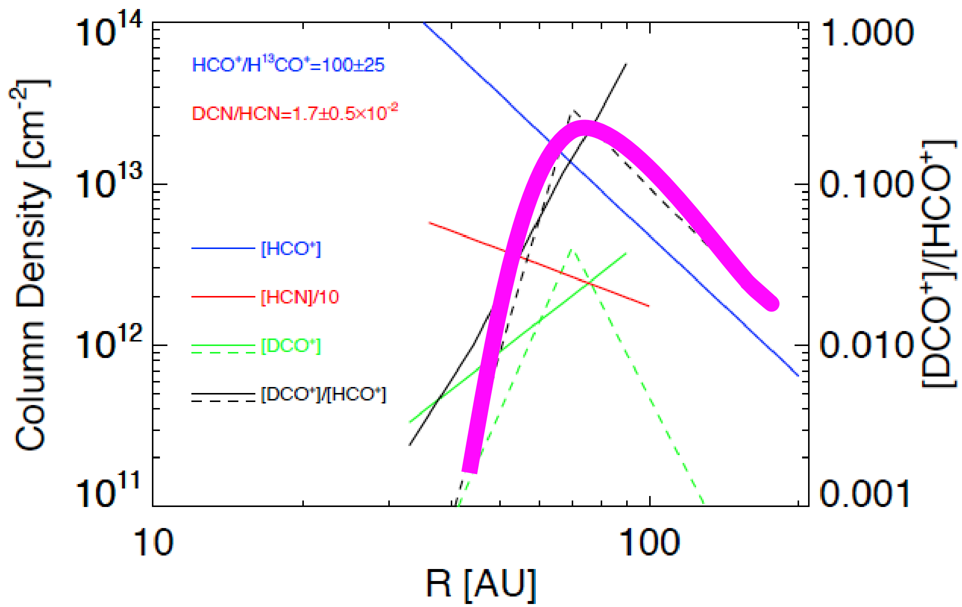
Disk chemistry: D/H ratio



Disk chemistry: D/H ratio

First resolved D/H abundance profile across a disk!





Qi et al. 2008

Future observations

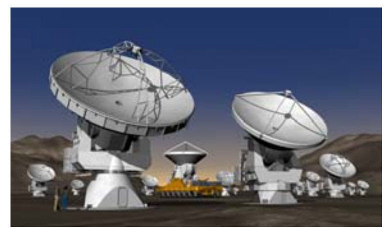
Herschel
λ=60-670μm
3.5m, space

2009

SOFIA
λ=1-600μm
2.7m, airborne

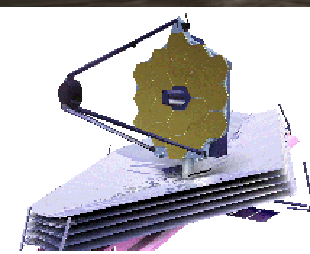
2009

ALMA
λ=300-3000μm
54x12m + 12x7m



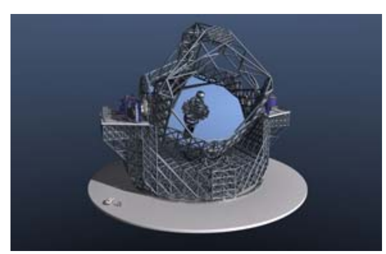
2012

JWST
λ=0.6-28μm
6.5m, space



2013

Super-Kecks
λ=0.5-20μm
30+m



2015+

Future observations

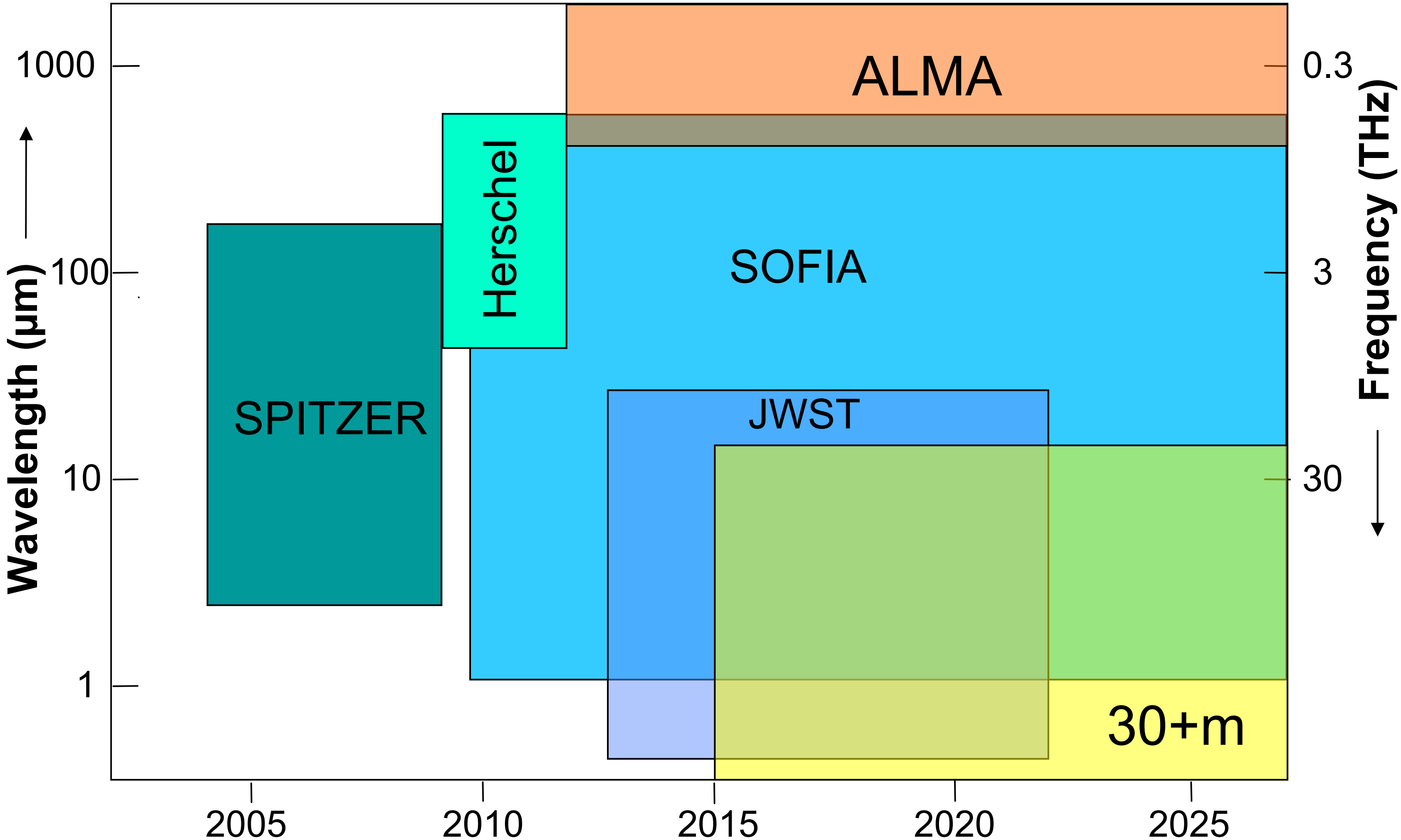
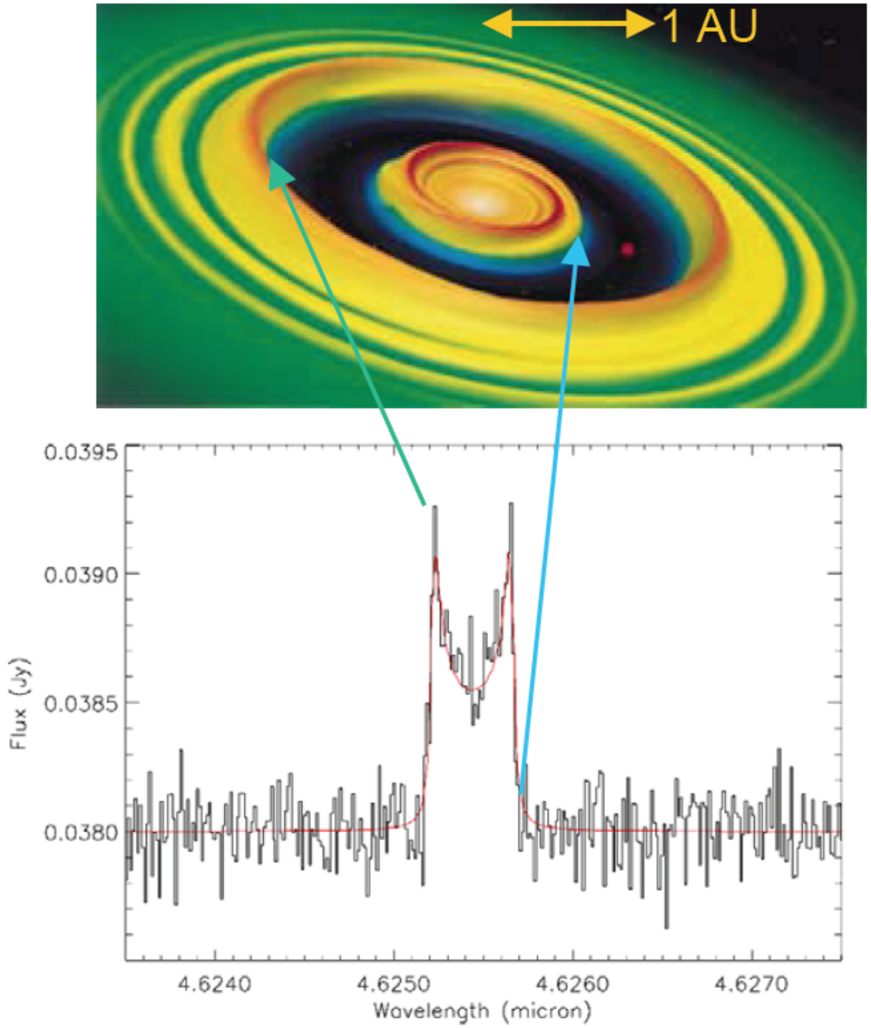


Figure adapted from Becklin

JWST and Super-Kecks



Diagnosing terrestrial planet forming radii

➔ inner disk CO, H_2O, organics

➔ spectrally resolved profiles and potential characterization of dynamical gaps

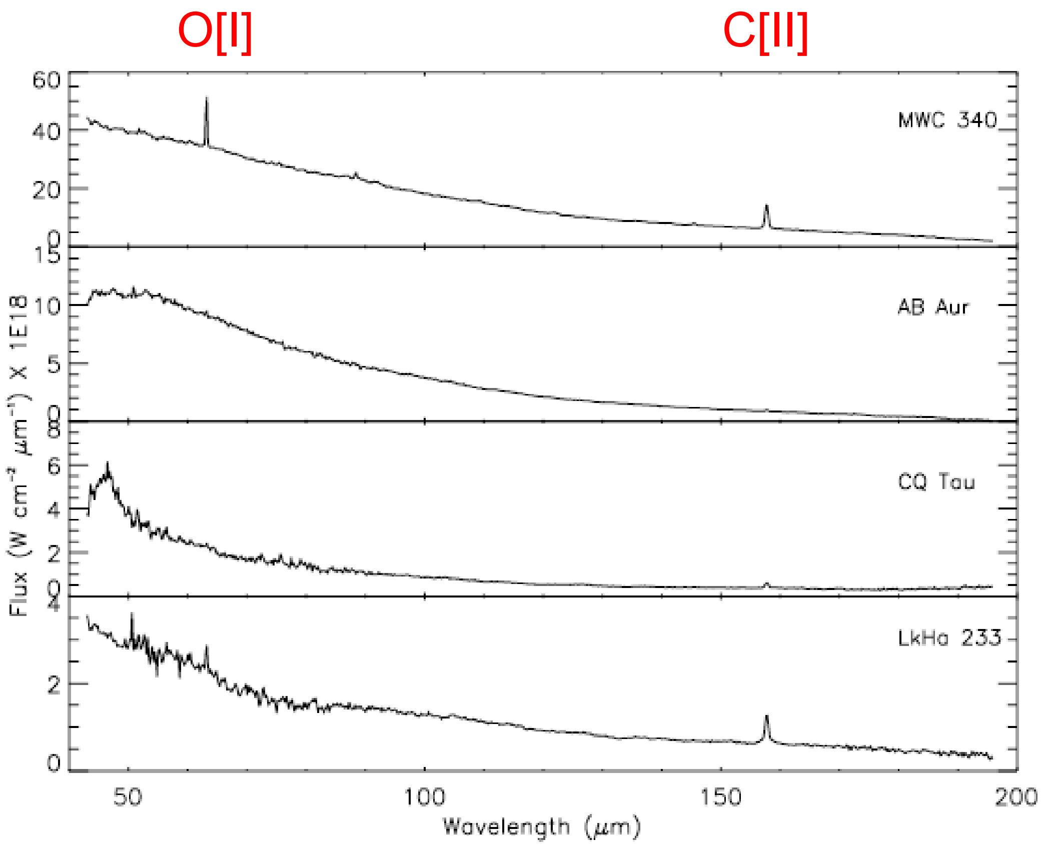
Figure adapted from Najita

Opening up the far-infrared with Herschel and SOFIA

Diagnosing giant planet formation radii

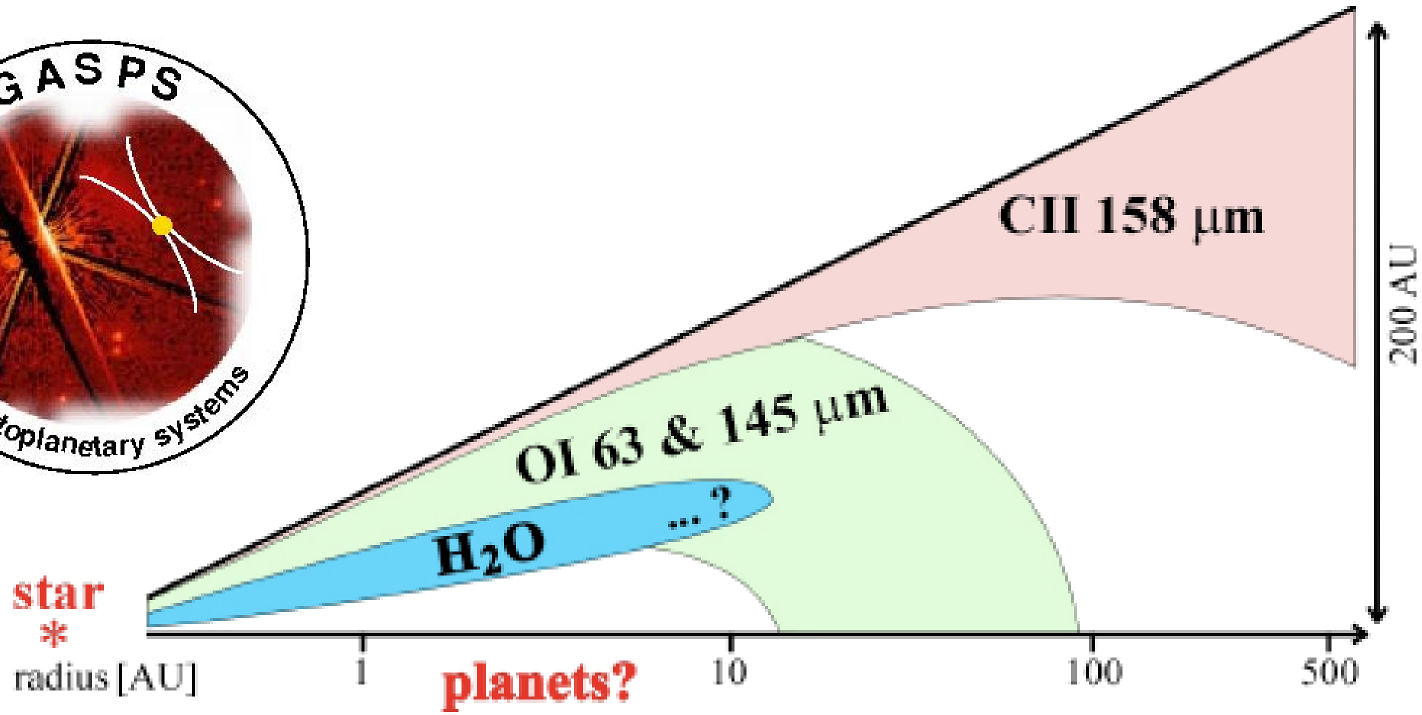
Herschel key project gas disk programs:
−Olofsson
−van Dishoeck *(WISH)*
−Evans *(DIGIT)*
−Dent *(GASPS)*

SOFIA has higher spectral resolution and longer lifetime than Spitzer & Herschel



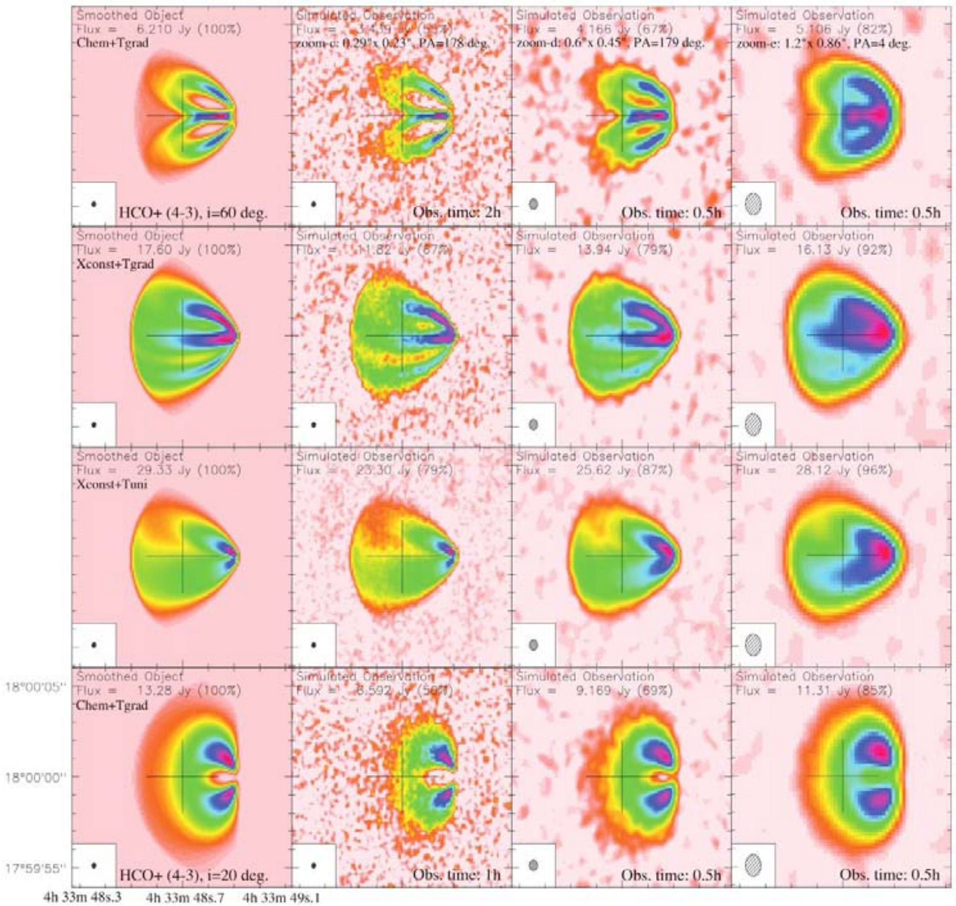
Creech-Eakman et al. 2002

GASPS - a Herschel key project



- First large scale survey of gas with mass sensitivity comparable to dust observations
- 400 hours to observe 250 disks with ages 1-30 Myr

Atacama Large Millimeter Array



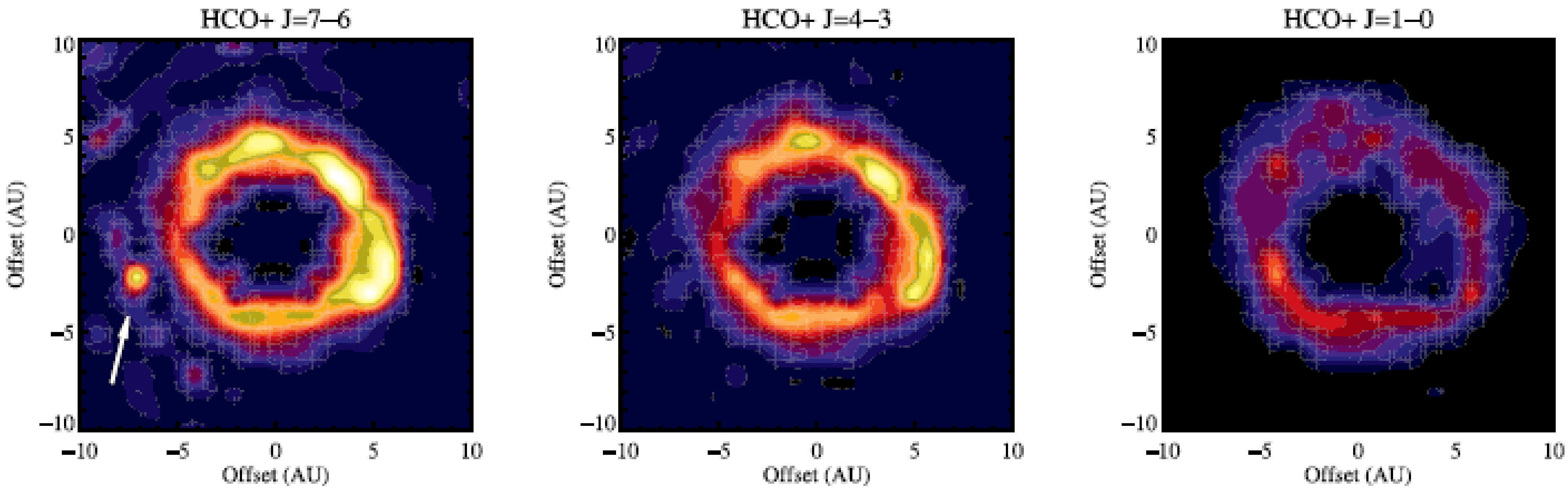
Diagnosing the cold disk (outer radii + midplane)

- ~AU, km/s resolution
- Very high sensitivity over wide wavelength range: can select different T,ρ, chemical properties
- Zoomable

Semenov et al. 2008

Atacama Large Millimeter Array

Direct imaging of giant proto-planets!



Narayanan et al. 2006

Under construction and on schedule for early science in fall 2010 with full operations (66 antennas) starting late 2012

What might we expect?

- The gas depletion timescale
- Improved understanding of
  - structure (radial and vertical)
  - dynamics (turbulence, transport)
  - chemistry (origin of the Earth's H_2O)
  - **evolution**
- Signatures of planets
  - instabilities, tidal gaps, gaseous debris*, direct detection of proto-planets
- The unexpected…

* See Roberge talk