Gas in the Inner Disk:
The Inner Disk Edge
in T Tauri Stars

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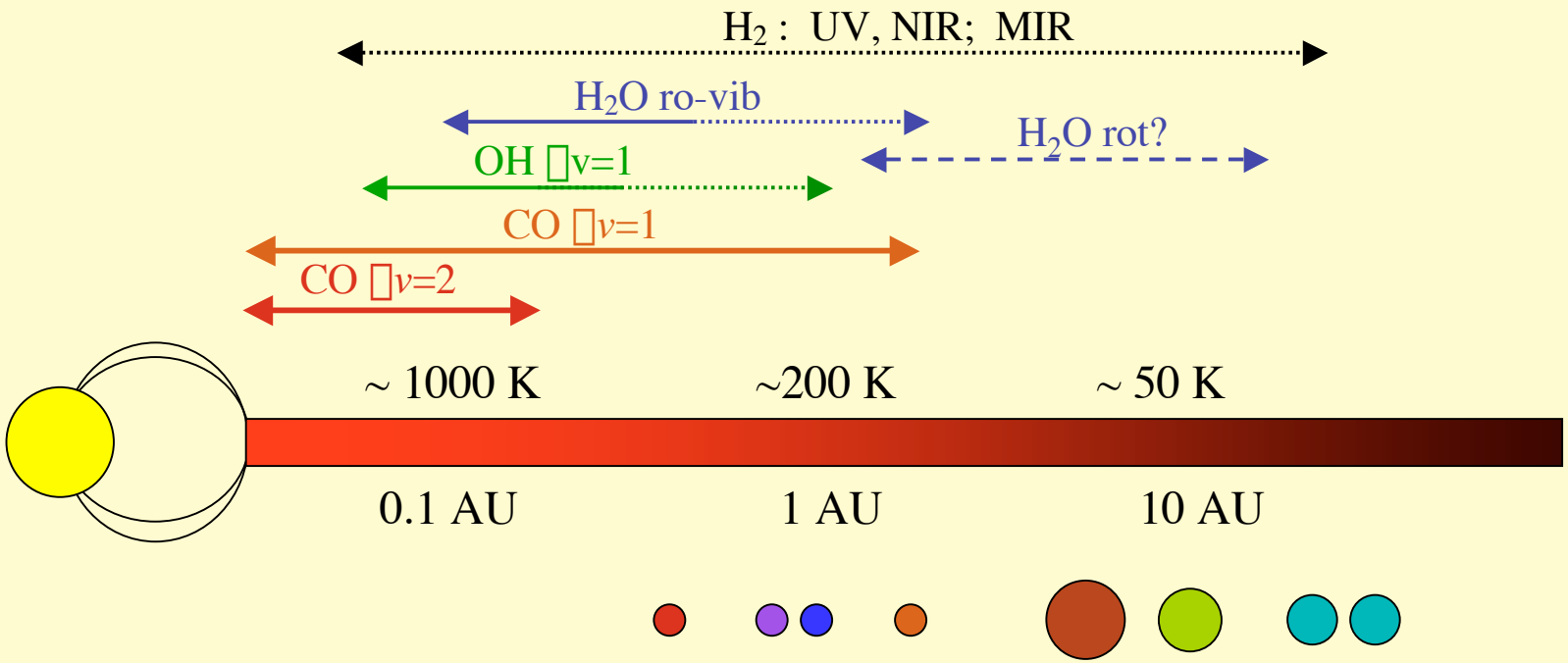
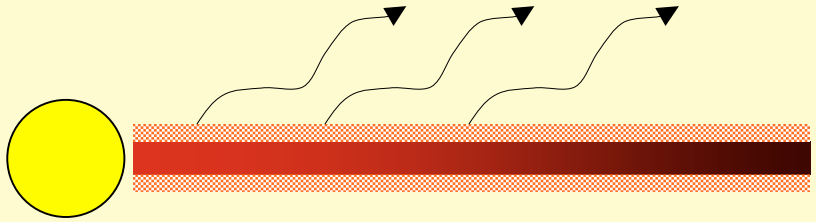
Probes of Inner Disk Gas in CTTS

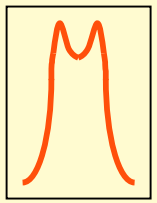


Temperatures 100 - few 1000K, high densities

- Molecules abundant in gas phase
- Excitation of rotational, ro-vibrational levels
- Transitions in near- and mid-infrared

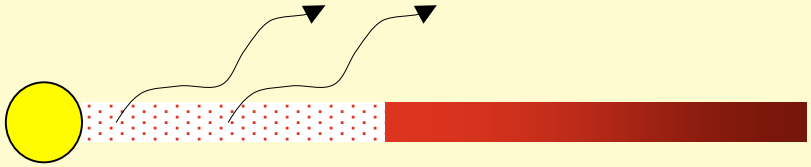
Emission Lines from Inner Disks





- Optically Thick Disk
- Temperature Inversion
  (e.g., externally irradiated)

Only observe atmosphere!



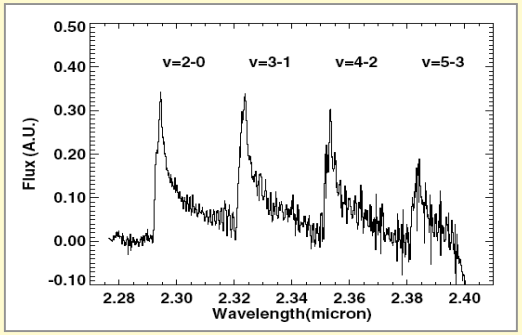
- Optically Thin Disk, Hole or Gap
  (e.g., grain growth)

Studying Gas at the Inner Edge of T Tauri Star Disks

- CO molecule: abundant to T ≥ 4000 K
- CO likely to trace gas to the inner disk edge in Classical T Tauri stars (unlike in HAeBe stars)
- Gas will be warm (> 1000 K) and dense
- The near-infrared ro-vibrational transitions of CO probe these conditions

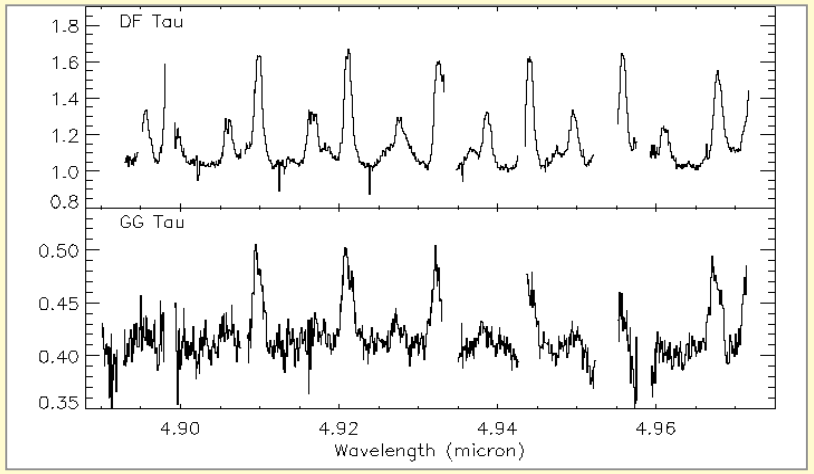
CO Emission in T Tauri Stars

- CO Overtone: $\Delta v=2$, 2.3 μm
  - T = 2000 – 4000 K
  - traces disk gas, but ...
  - *only* observed in most active CTTSs



Thi et al. 2005

- CO fundamental: $\Delta v=1$, 4.6 μm
  - probes lower T, N(CO) than the overtone
  - observed in *nearly all* CTTs
  - v=1-0, 2-1, 3-2 and ^{13}CO, depending on T and Δ
  - general tracer of inner gas



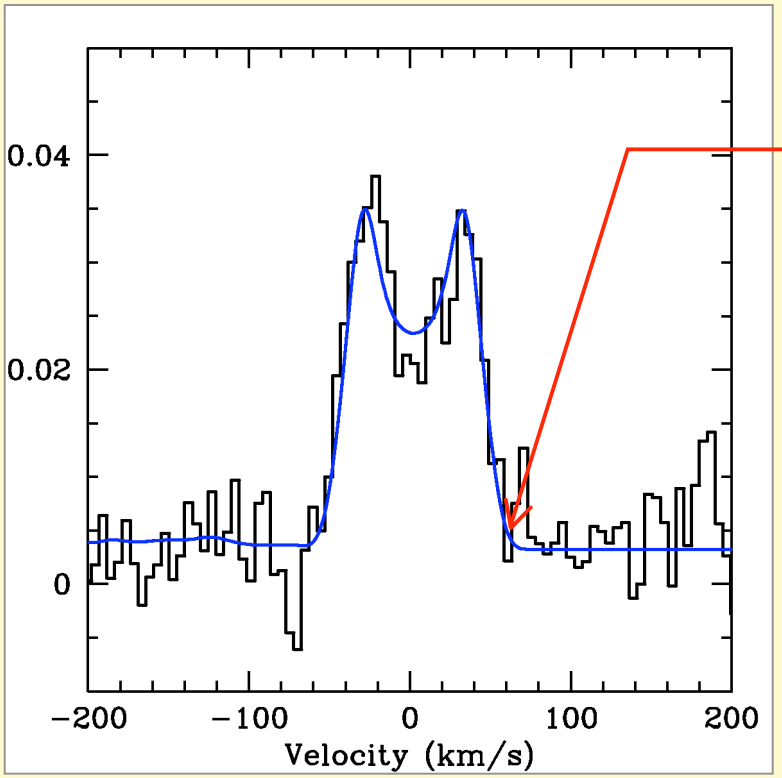
Najita et al. 2003

see poster by Barsony

Studying Gas at the Inner Edge of T Tauri Star Disks

- Gas not spatially resolved: region < 1 mas
  ideally, desire spectro-interferometry
- Use velocity-resolved line profiles to determine radial variation of gas emission, gas temperature and column density

Measuring the Inner Gas Radius

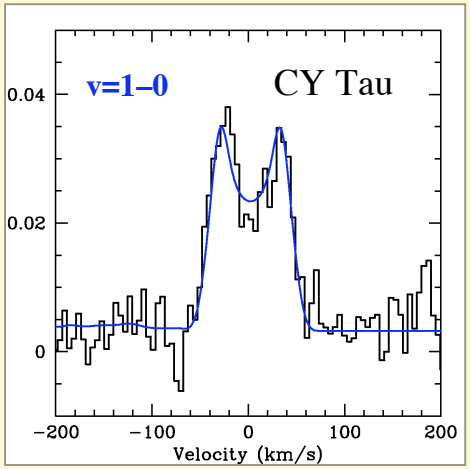


V_max

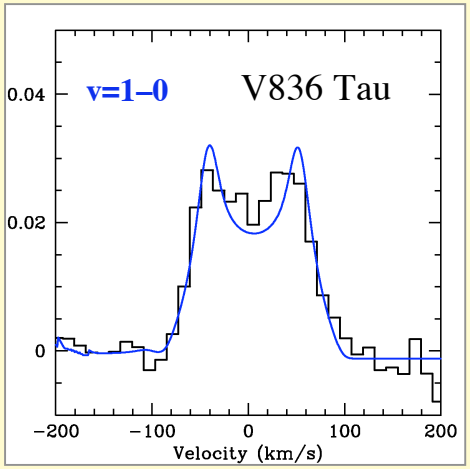
- Maximum CO velocity
- Keplerian rotation
- Stellar mass
- sin i

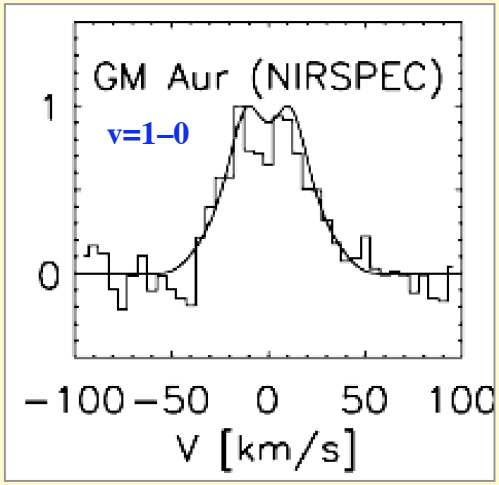
→ Inner gas radius

CO Fundamental Line Profiles



Disk profiles are observed in the v=1-0 lines in a small number of T Tauri stars, but ...

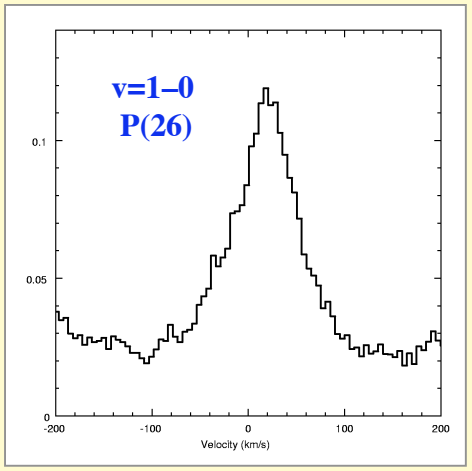




Keck data: Carr, Najita, Mathieu

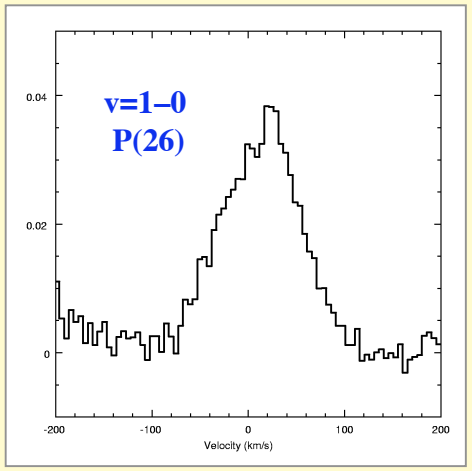
Salyk et al 2007

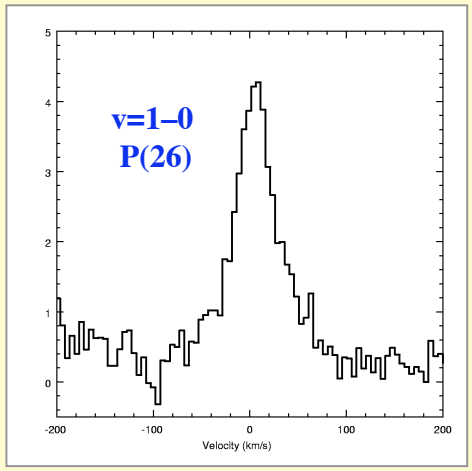
CO Fundamental Line Profiles



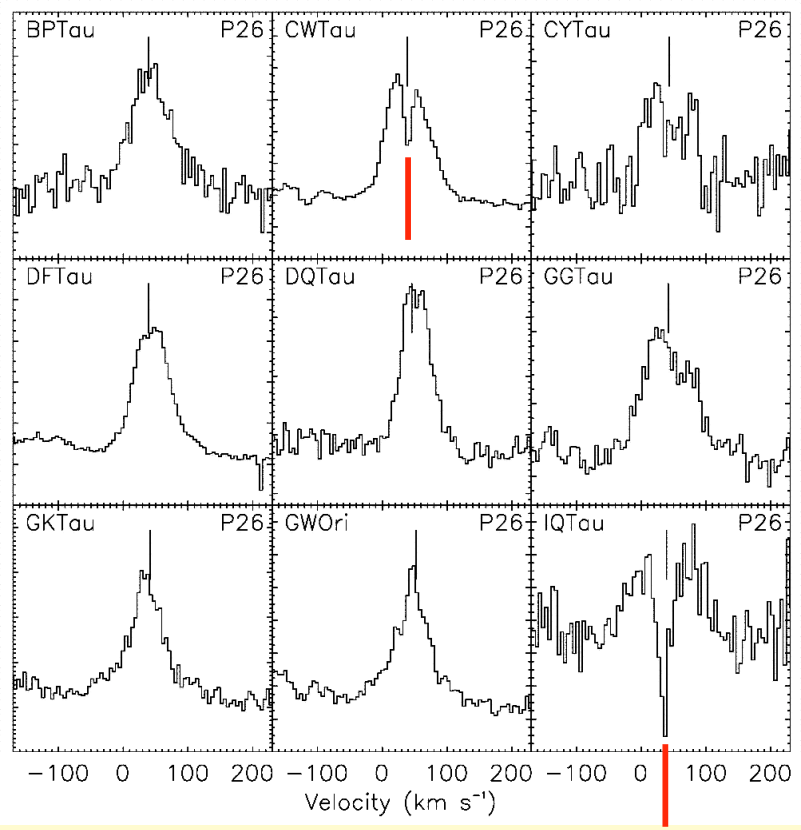
... most often, the v=1-0 profiles

- are centrally peaked
- show asymmetries





CO Fundamental Line Profiles



A few CTTS show narrow, optically thick absorption, due to cooler intervening gas

1) Cool gas, T ~ 100 K

Brittain et al. 2005;

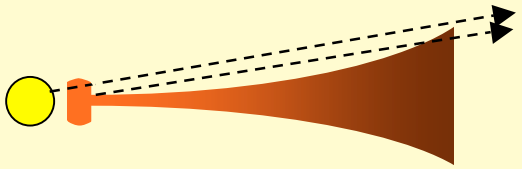
Retting et al. 2006; e.g., HL Tau

Absorption in extended disk

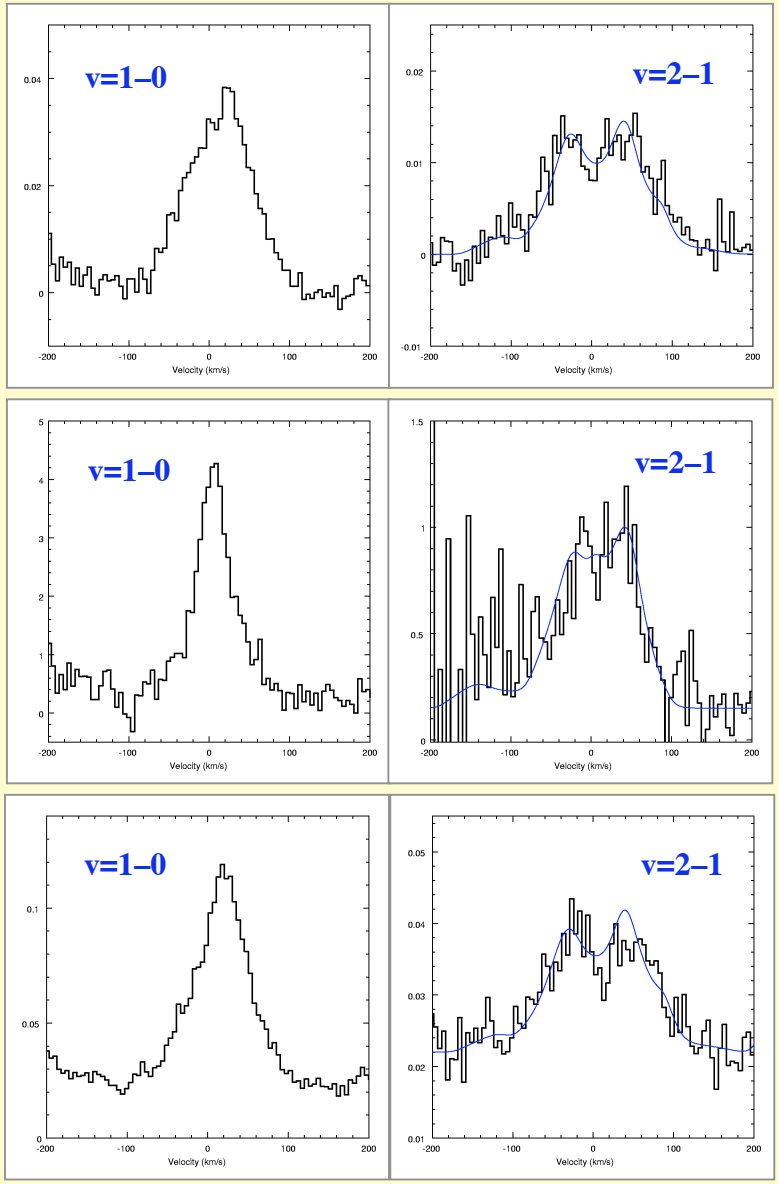
2) Hot gas, T ~ 1000 K

e.g., AA Tau, CW Tau

Absorption in puffed-up dust rim or warped inner disk?



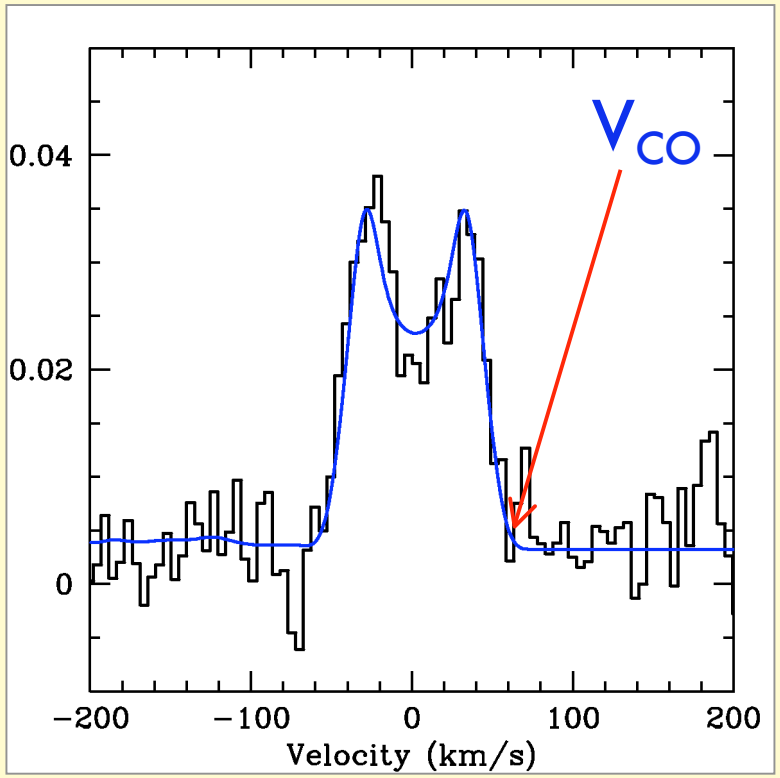
CO Fundamental Line Profiles



However, when the v=2-1 profiles can be measured, they tend to show a double-peaked or flat-topped profile consistent with a disk

- FWHM v=2-1 > FWHM v=1-0
  -> v=2-1 flux from smaller radii, on average
- FWZI velocity about same
  -> same inner radius

Measuring the Inner Gas Radius



Stellar mass and sin i:

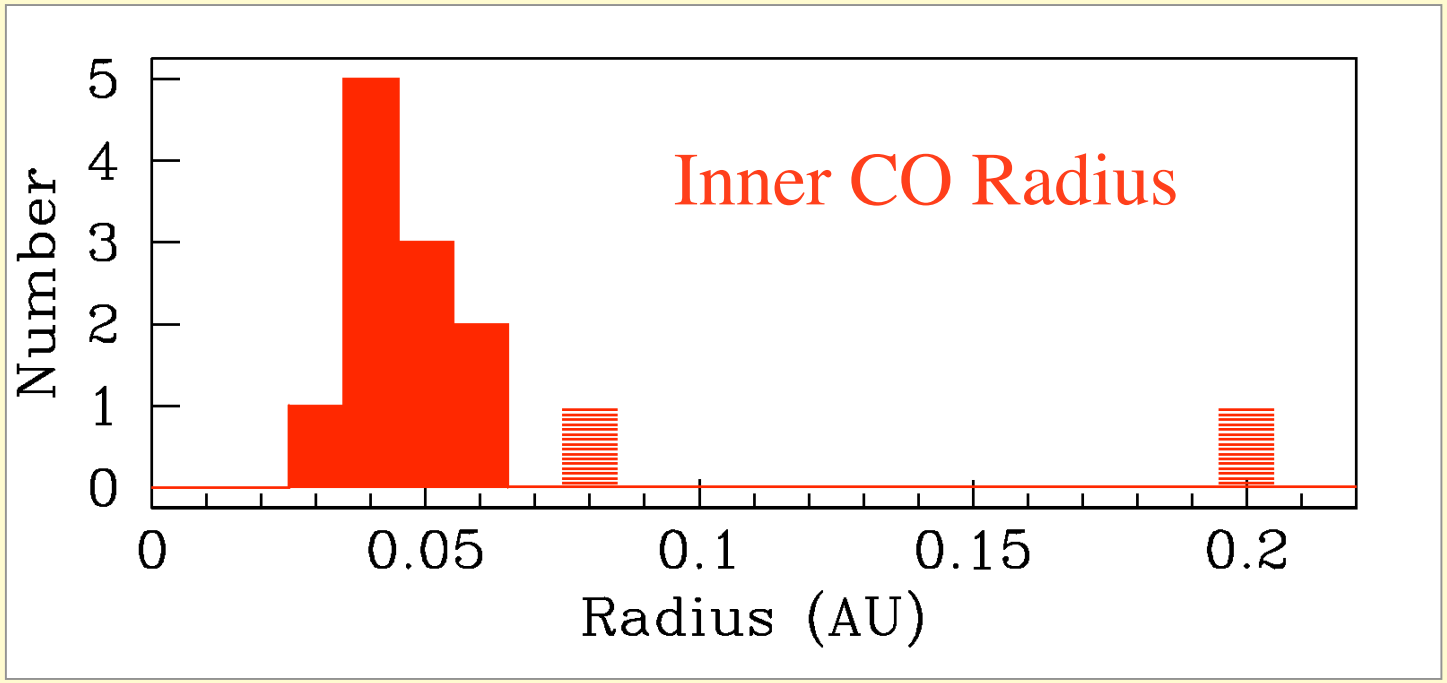
1) mm line interferometry of extended Keplerian disk (i.e. Simon et al. 2000)
2) mass from tracks (M_*,T_*)
   sin i from P_{rot}, vsini, R_*

Sample:

14 T Tauri stars with 5μm echelle spectra from Keck

(Najita, Carr & Mathieu 2003; Carr, Najita & Mathieu, in prep; Salyk et al. 2007)

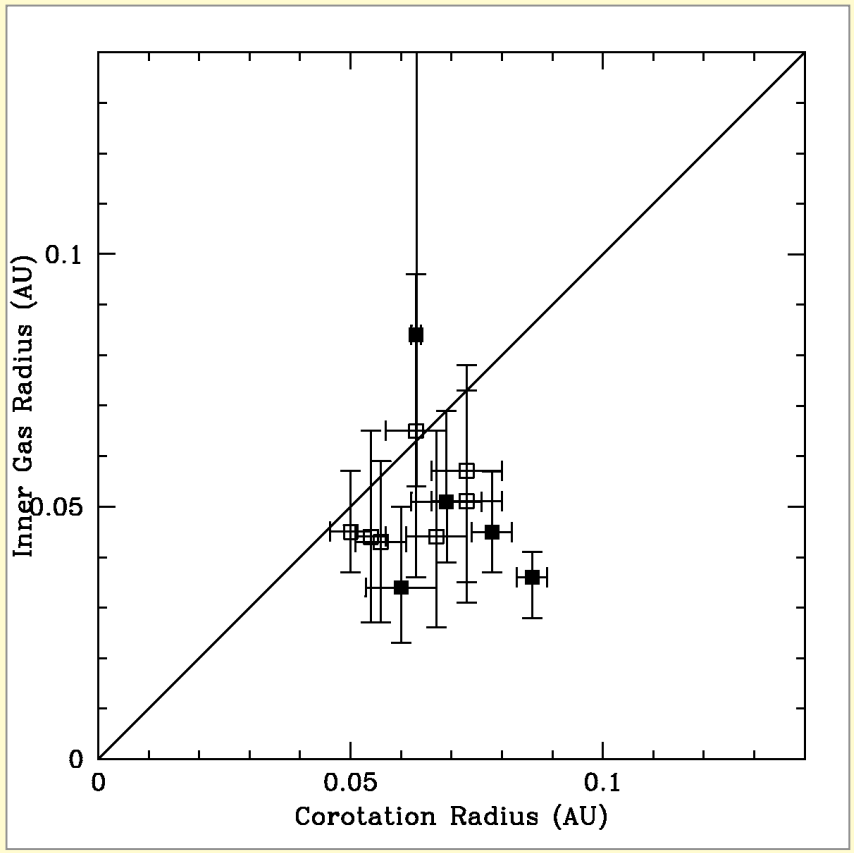
Inner Gas Radii in T Tauri Stars



The inner gas radius distribution, as measured by CO, shows a peak at ~ 0.04 AU

Inner Gas Radii in T Tauri Stars

Inner gas radius vs. Corotation radius

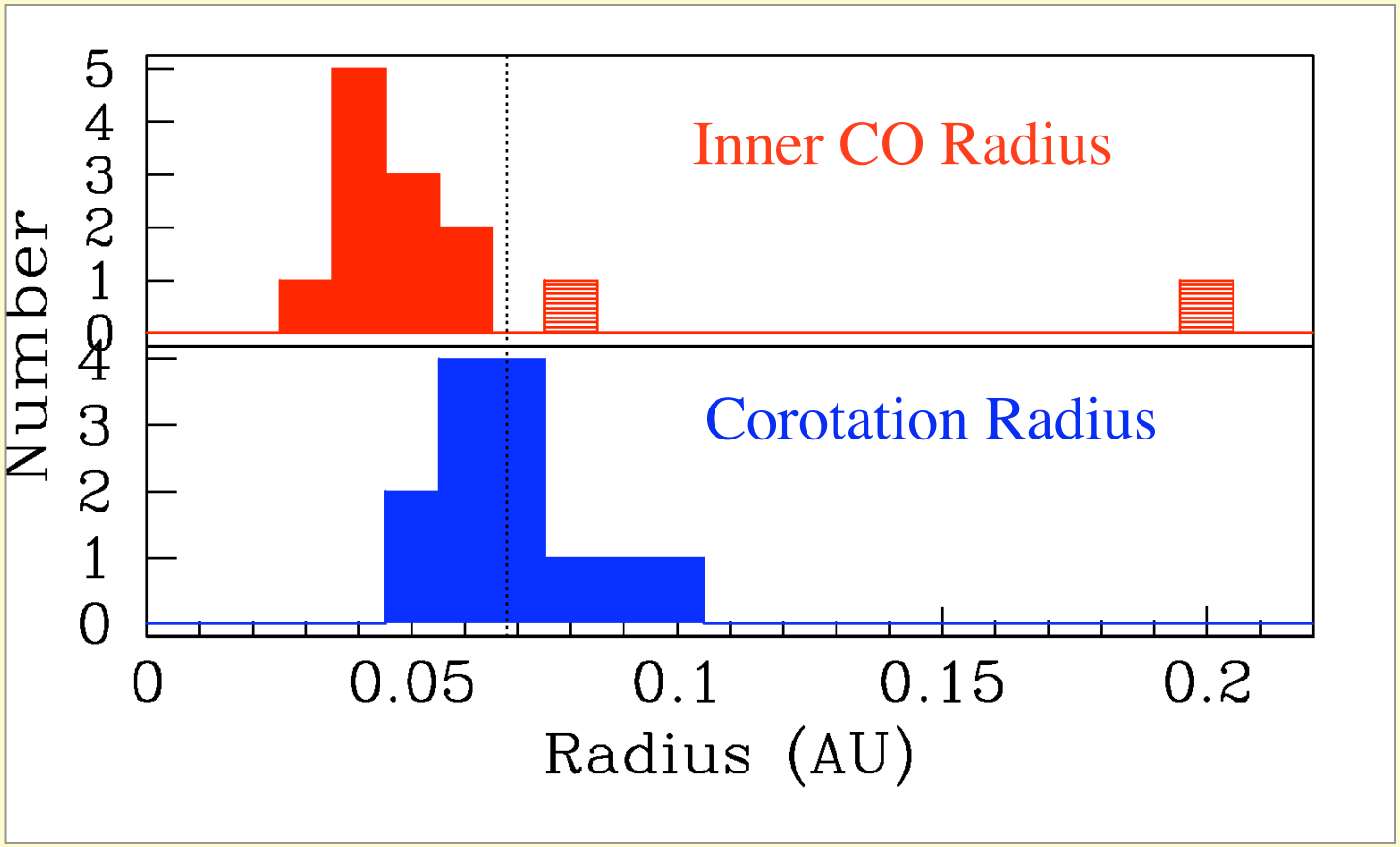


$R_{gas} \leq R_{corot}$

Inner Gas Radii in T Tauri Stars

Inner gas radius ≤ Corotation radius

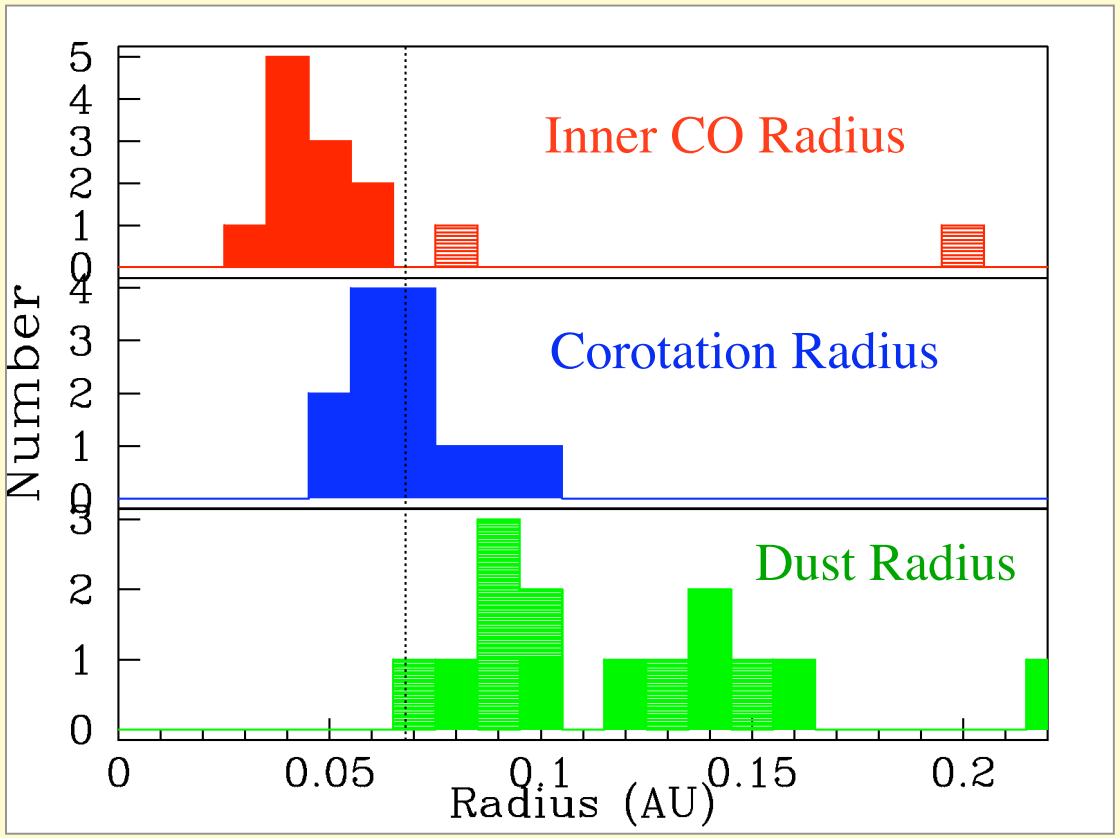
$R_{gas} = 0.7\ R_{corot}$, on average

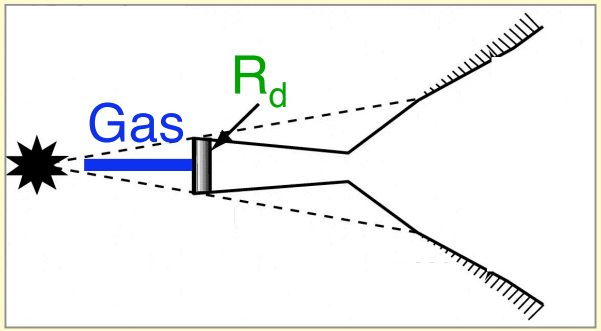


Inner Gas and Dust Radii

$R_{gas} \leq R_{corot} \leq R_{dust}$

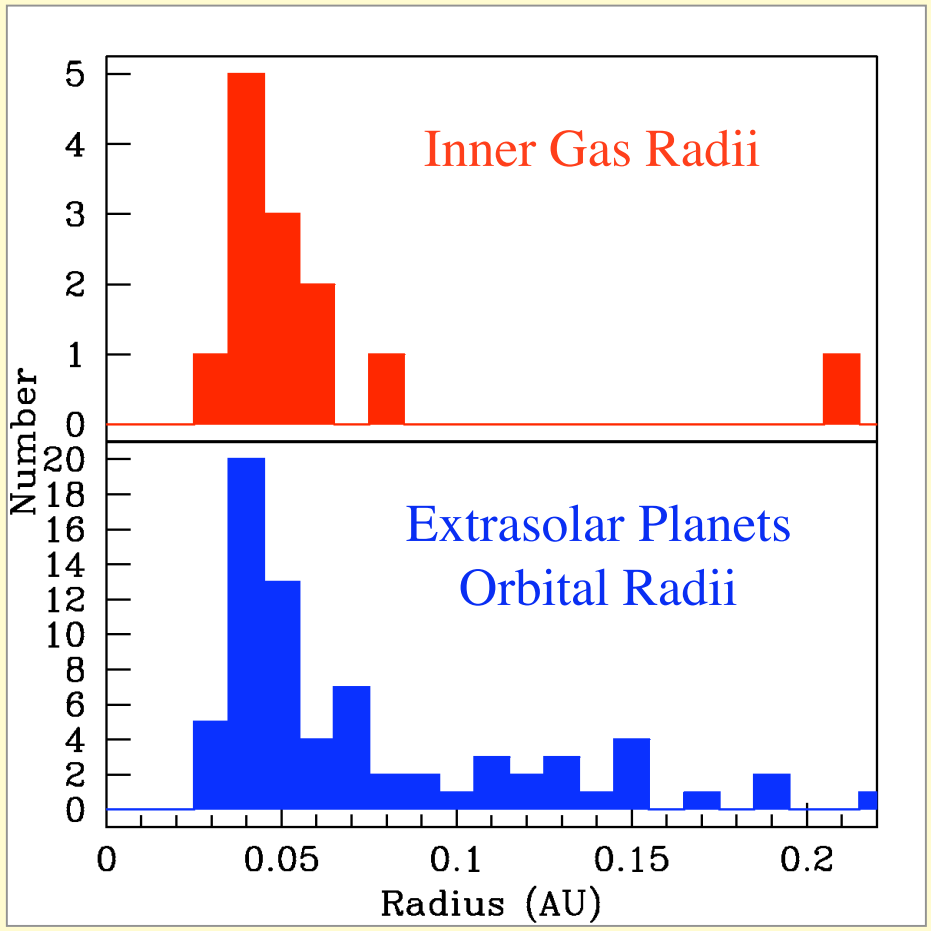
Gas extends inside Dust edge





Eisner et al. 2005
Akeson et al. 2005
Muzerolle et al. 2003

Inner Gas Radii and Extra-solar Planets



The peak of the inner gas radii distribution coincides with the peak in orbital radii of short-period extra-solar planets.

- Role of disk truncation in limiting inward orbital migration of giant planets

(Lin et al. 1996; Kuchner&Lecar 2002; Romanova&Lovelace 2006)

Summary

- For classical T Tauri star disks, CO should be a good probe of the inner gas radius
- The typical inner gas radius is ~ 0.04 AU
- The gaseous disk extends inside of the inner dust radius
- $R_{gas} = 0.7\ R_{corot}$
- The peak in orbital radii for short-period planets coincides with the peak for the inner gas radius