# Childhood to Adolescence: Dust and Gas Clearing in Disks

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MPE

Cool Stars 15

21 July, 2008

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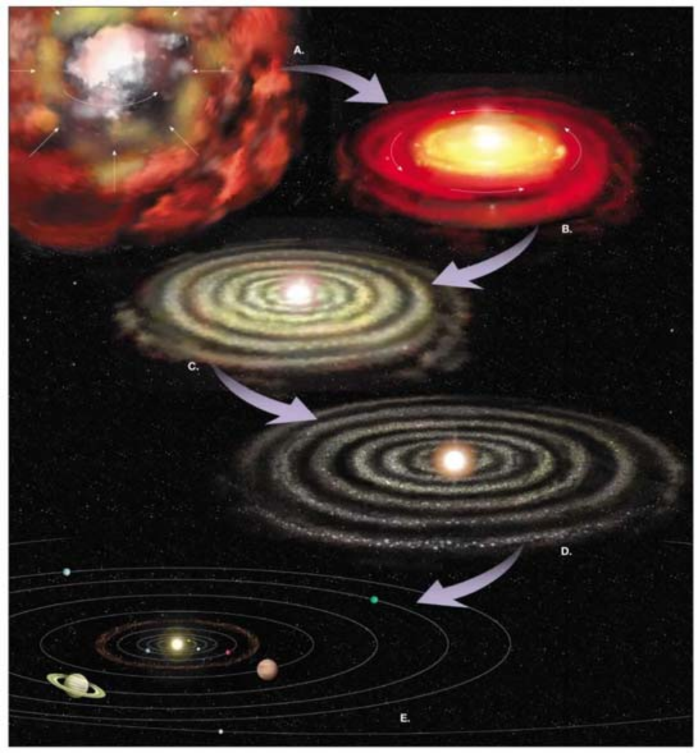
# Transitional disks




WHAT?

- Disks where dust clearing has begun
- Rare, presumably short-lived, phase between dusty protoplanetary disk and star with planetary system
- Identifiable through mid-IR photometry (Spitzer)

WHY?

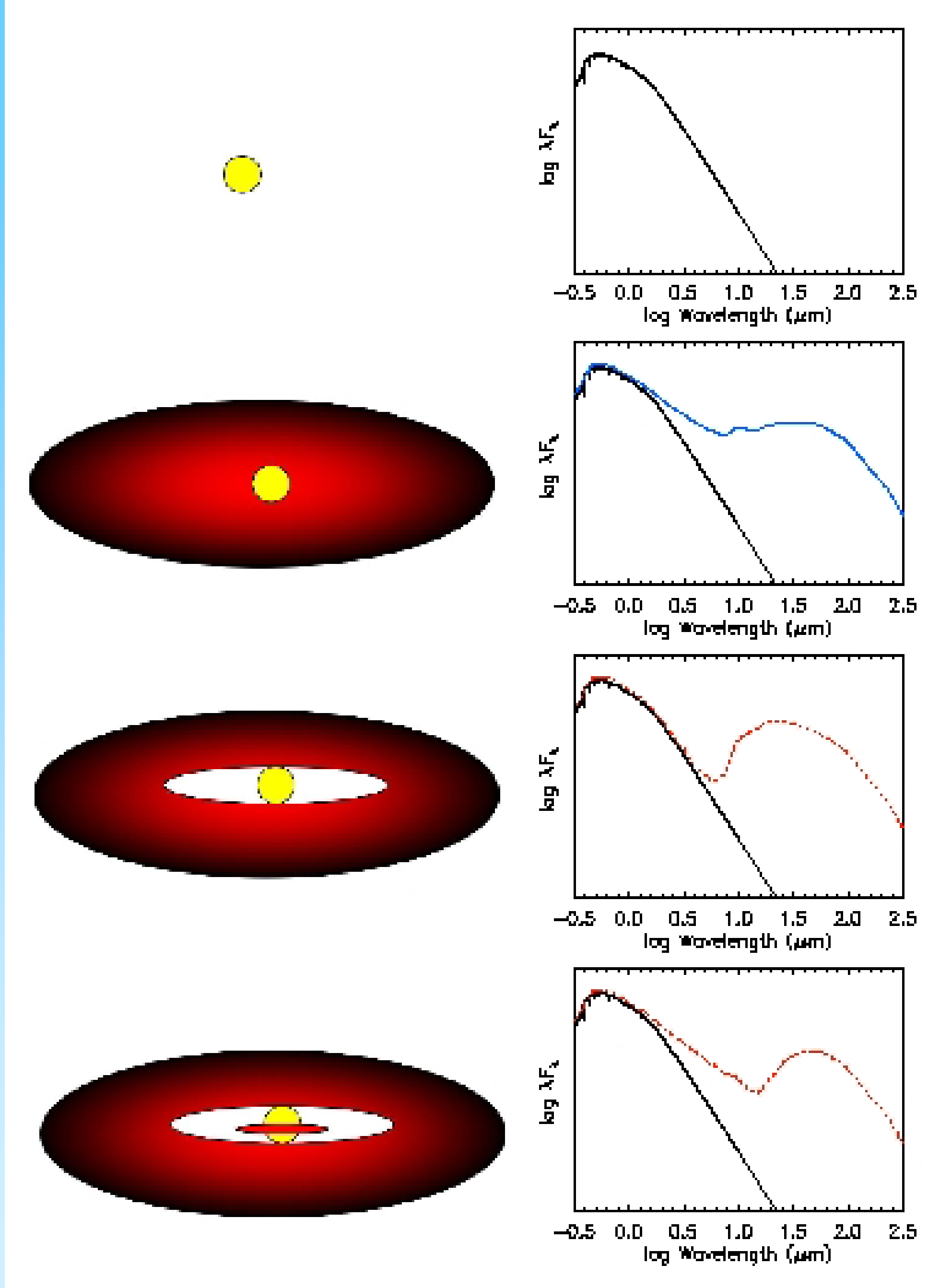
- Stage where planets are forming/young
- Look at how disks disperse

Star

Disk

Hole

Gap




Infrared excess from thermal dust emission

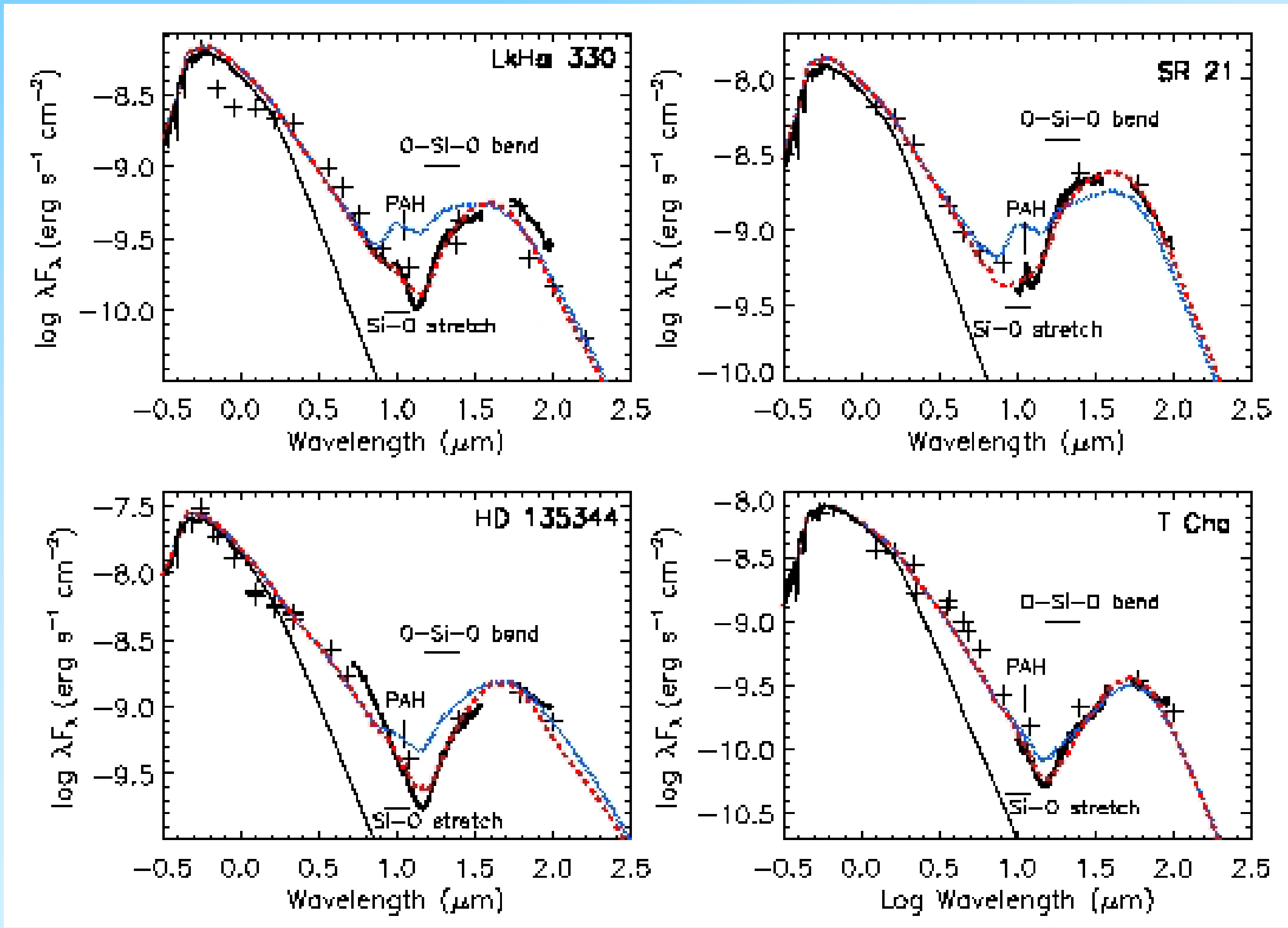
Hot dust emits at shorter wavelengths, cold dust at longer

So wavelength ~ radius and missing emission = missing dust

Does not trace gas

# Spitzer disks with gaps

CoKu Tau 4 (Sargent et al. 2004, D'Alessio et al. 2005), DM Tau, GM Aur (Calvet et al. 2005), CS Cha, UX Tau, LkCa 15 (Espaillat et al. 2007)

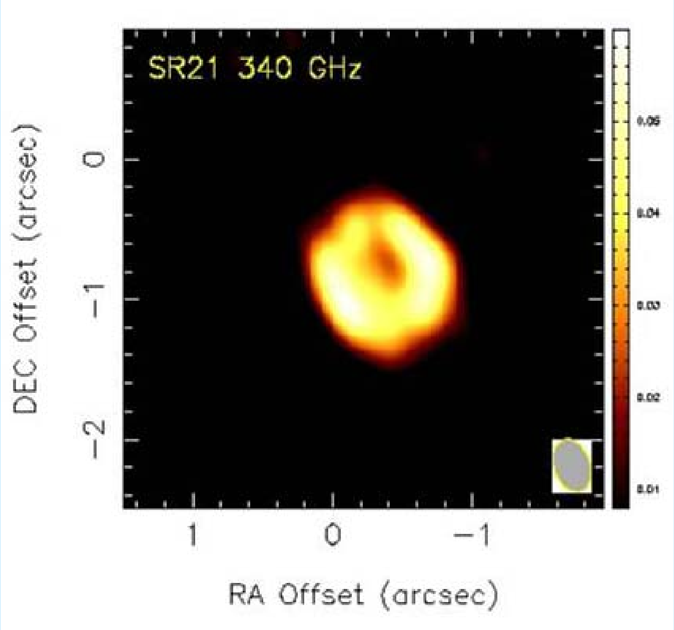


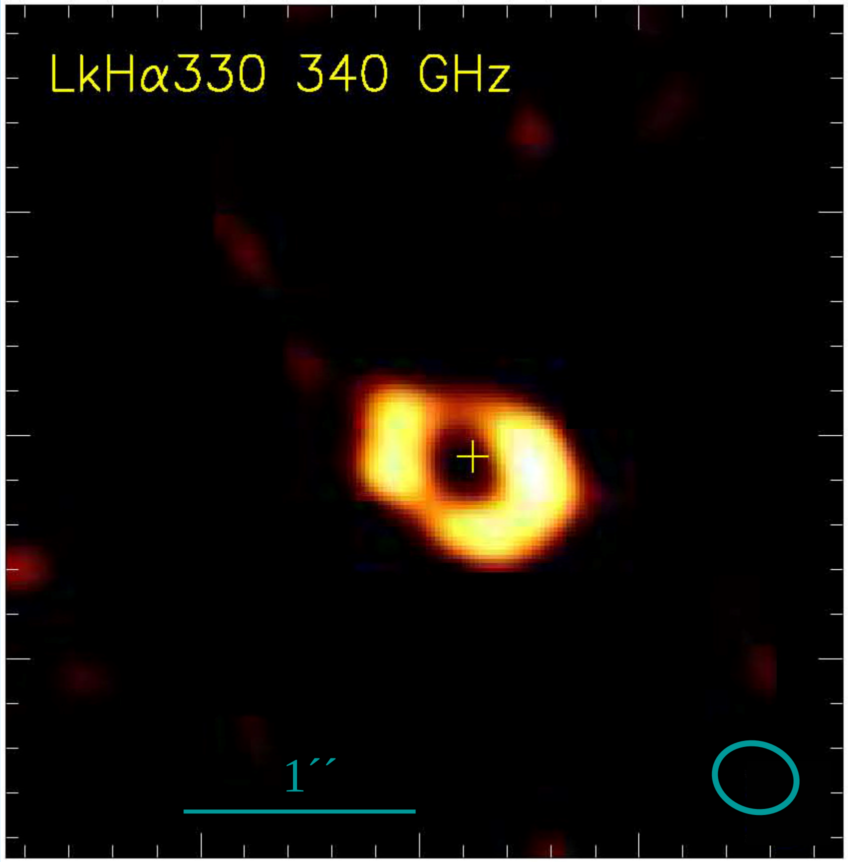

Brown et al. 2007

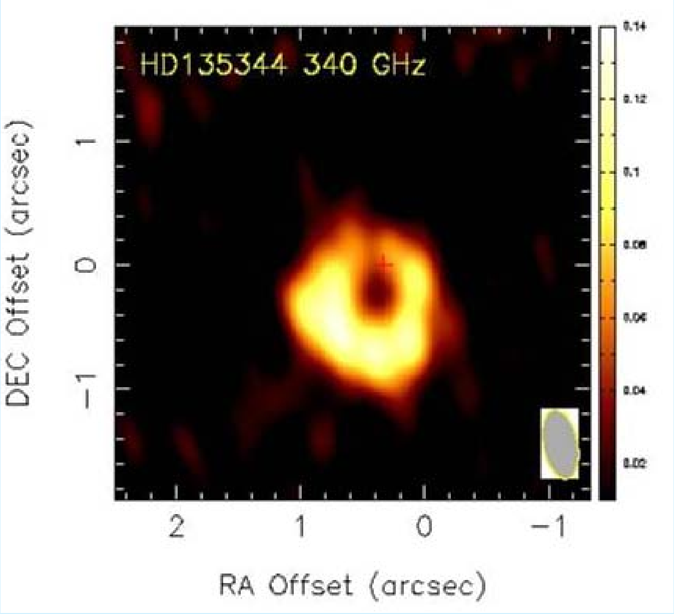
- •IRS spectra show sharp rise
- •Large gap radius implied, with sharp boundary
- •Little silicate emission limiting small grains
- •Strong near-IR excess w/T~1500K

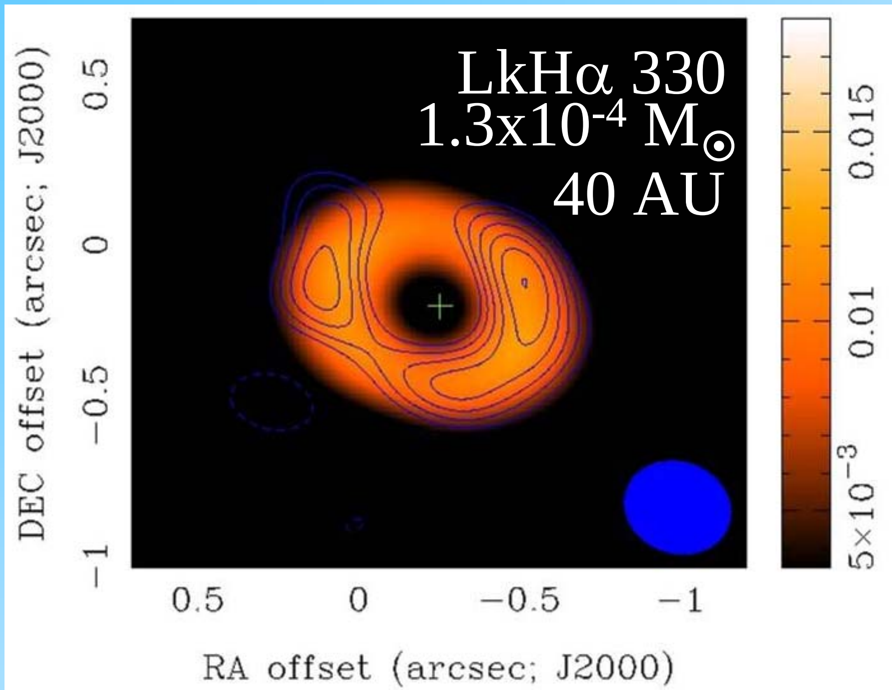
# Is it a hole?

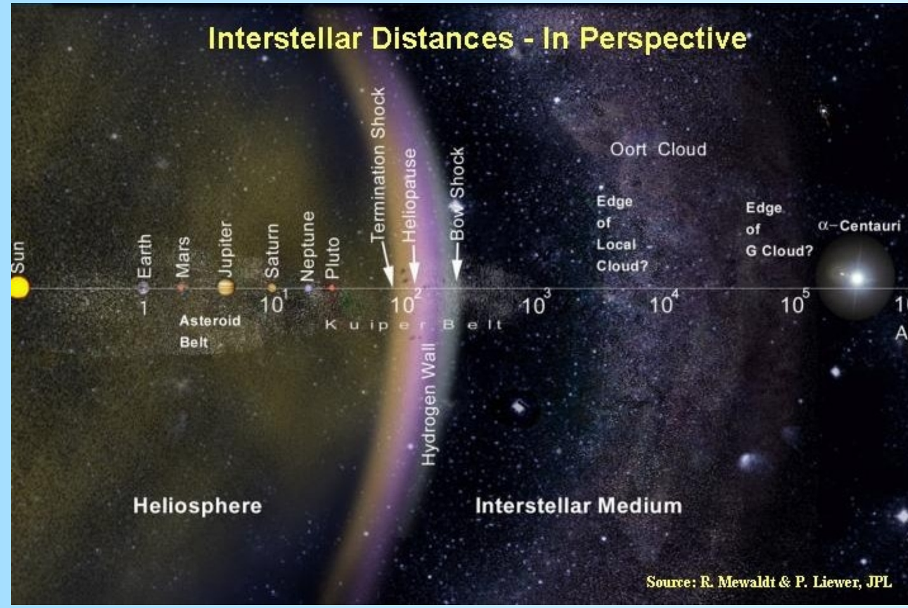
SMA very extended configuration

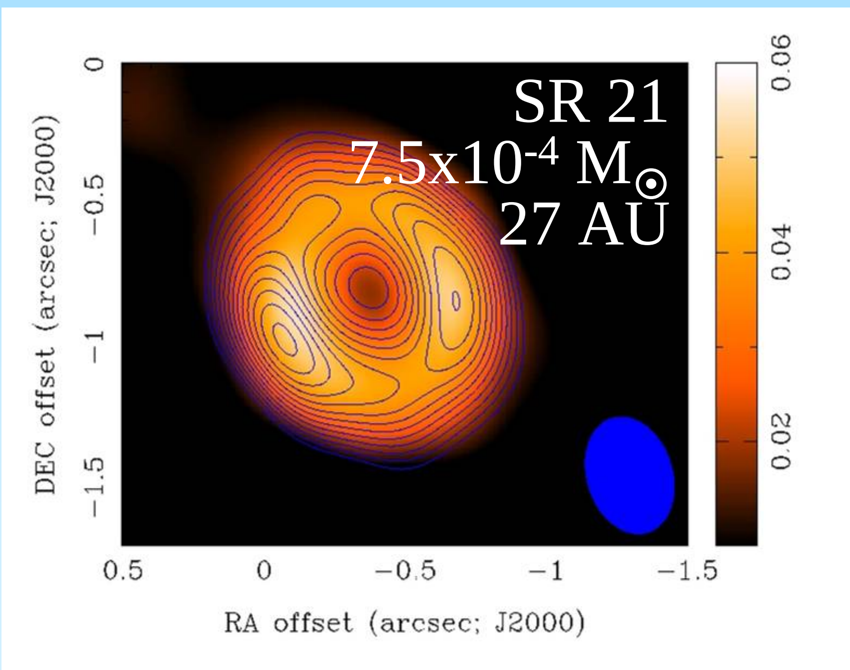


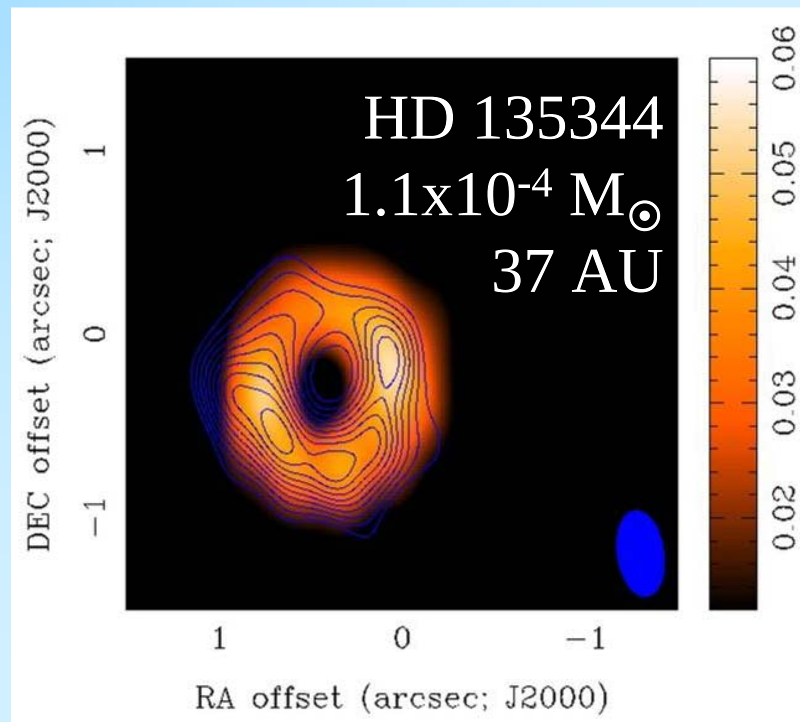



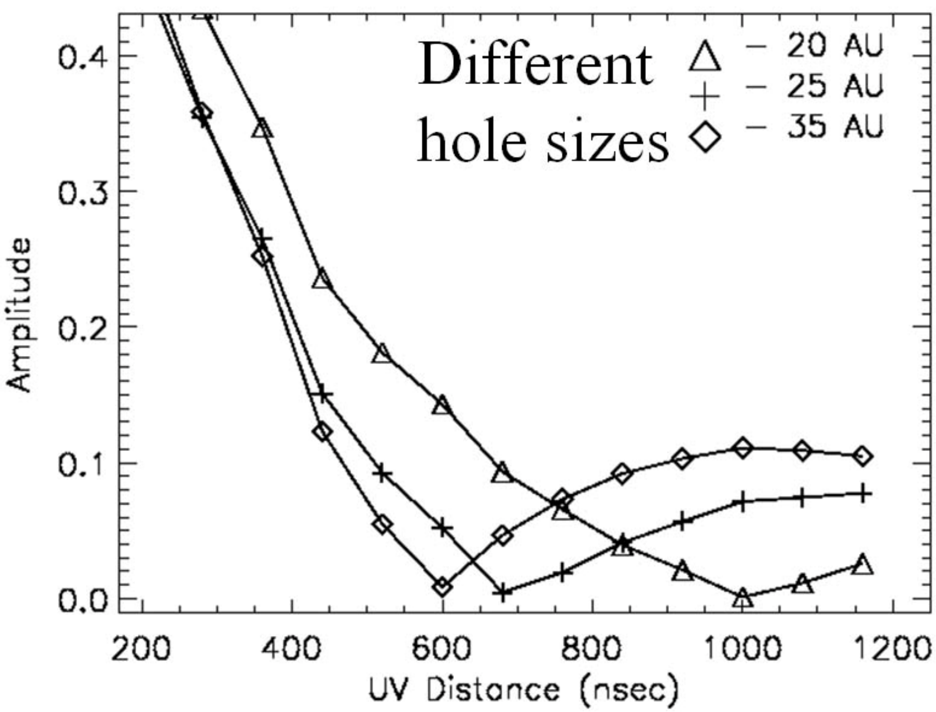




LkHα 330
1.3x10-4 M⊙
40 AU
DEC offset (arcsec; J2000)
RA offset (arcsec; J2000)
0.5
0
−0.5
−1
0.015
0.01
5×10−3


Interstellar Distances - In Perspective
Sun
Earth
Mars
Jupiter
Saturn
Neptune
Pluto
Termination Shock
Heliopause
Bow Shock
Hydrogen Wall
Asteroid Belt
Kuiper Belt
Oort Cloud
Edge of Local Cloud?
Edge of G Cloud?
α−Centauri
AU
Heliosphere
Interstellar Medium
Source: R. Mewaldt & P. Liewer, JPL


SR 21
7.5x10-4 M⊙
27 AU
DEC offset (arcsec; J2000)
RA offset (arcsec; J2000)
0.5
0
−0.5
−1
−1.5
0.06
0.04
0.02


HD 135344
1.1x10-4 M⊙
37 AU
DEC offset (arcsec; J2000)
RA offset (arcsec; J2000)
1
0
−1
0.06
0.05
0.04
0.03
0.02




Visibility plane before Fourier transform

Average flux in annuli

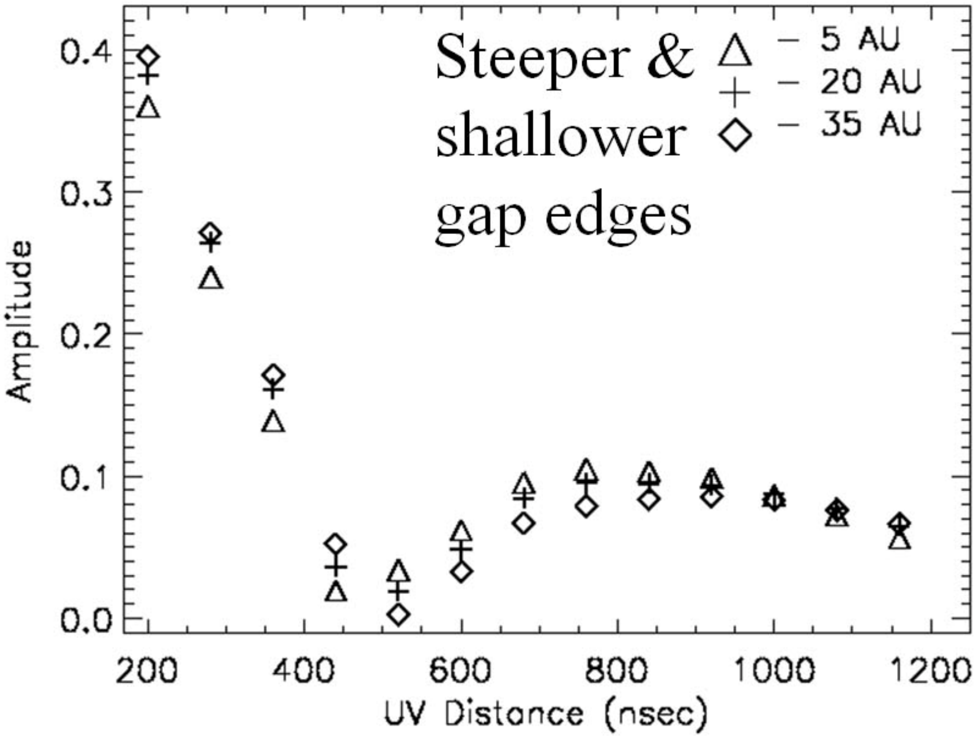
Hole visible as null

Simple step function gap edge

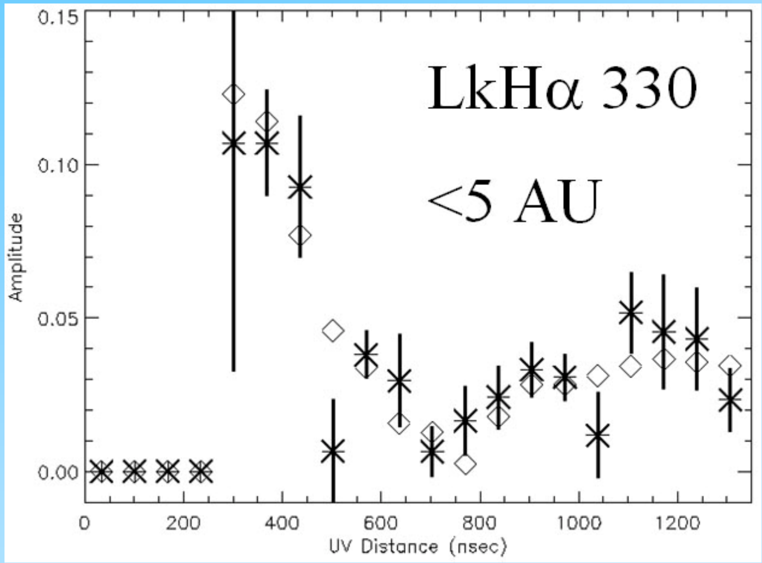
Steepness of gap edge also seen

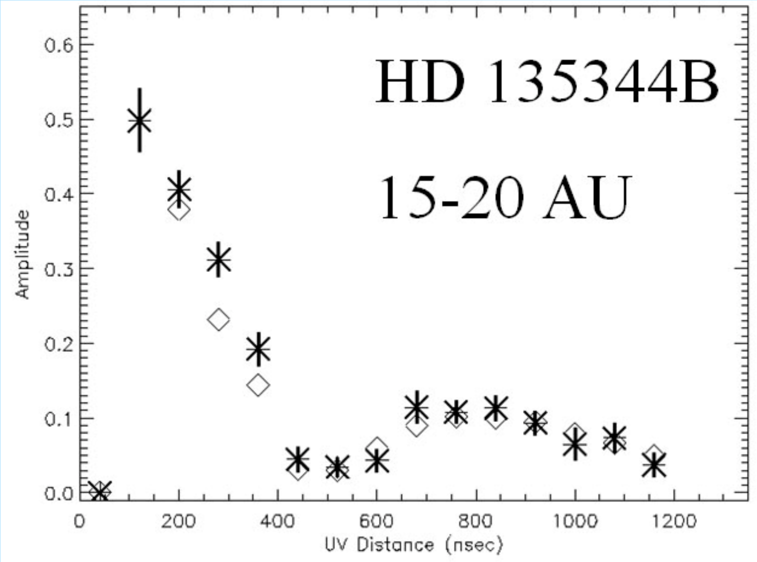
Model with 37 AU hole

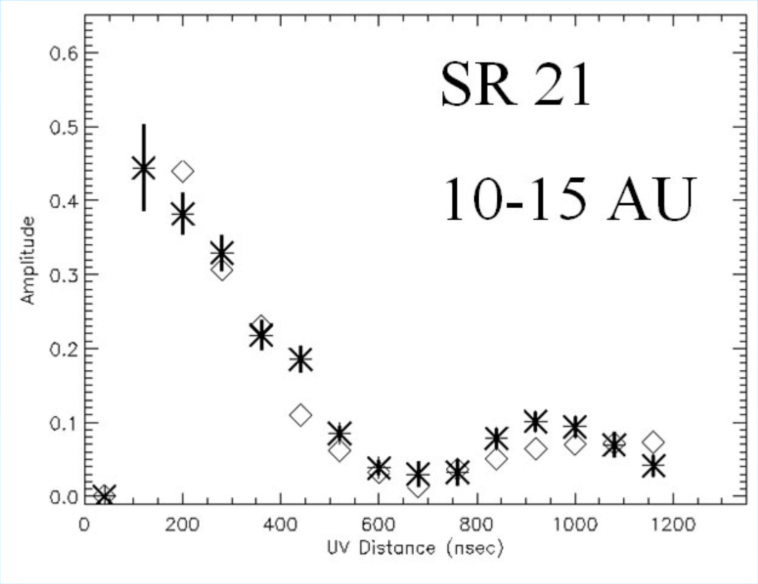
Most differences in null where amplitude lowest



# Amplitude vs. (u,v) distance



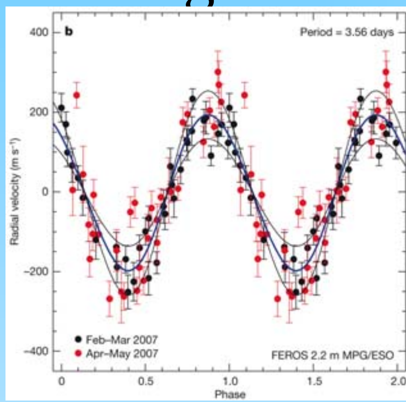

Models fit well in (u,v) plane also

Steepness of gap edges vary

# Causes of holes

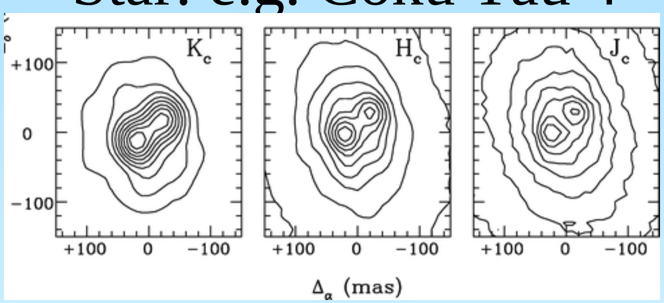
## Companion

Planet: e.g. TW Hya



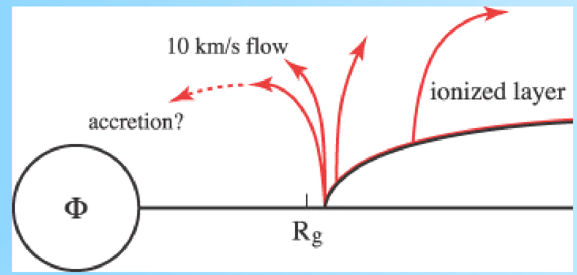

Setiawan et al. 2008

Star: e.g. Coku Tau 4




Ireland et al. 2008

## Photoevaporation



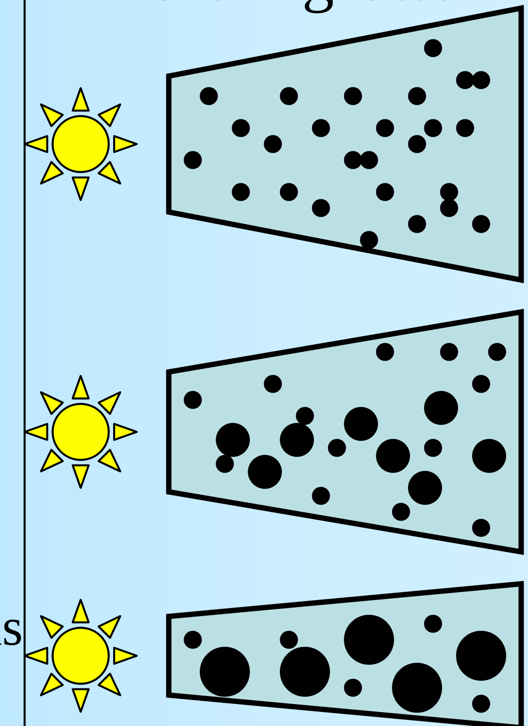

Alexander et al. 2006

Radiation creates ionized surface layer

Ionized gas is unbound outside gravitational radius and flows away at sound speed

Cannot resupply inside $R_g$ -> Hole

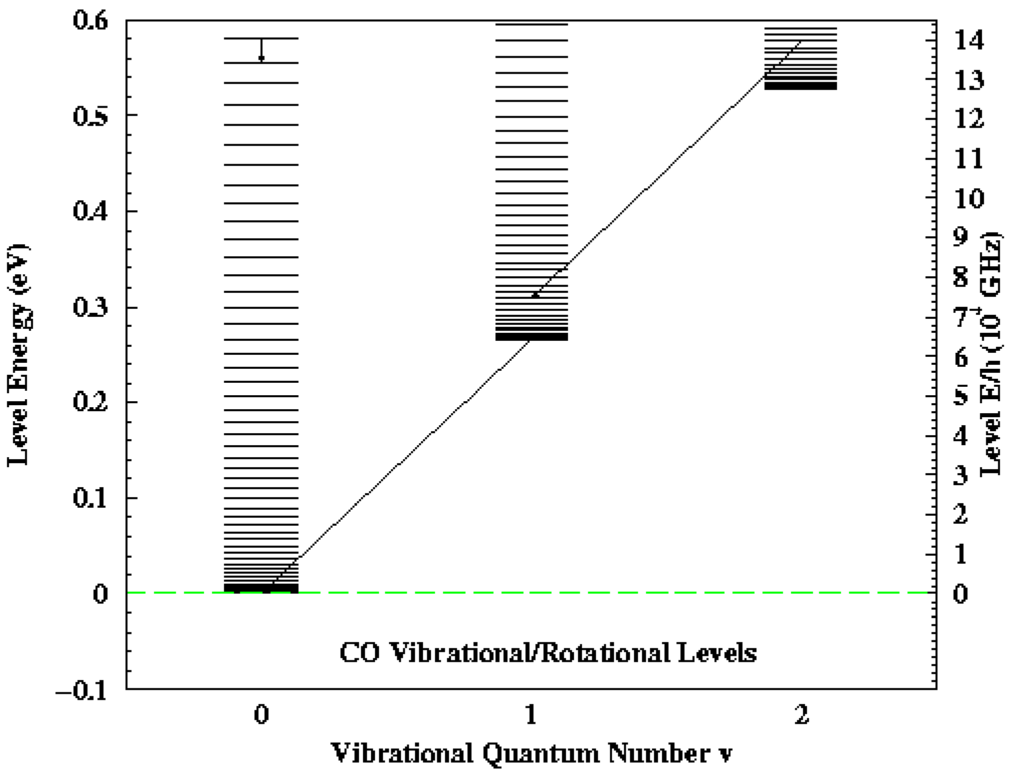
## Grain growth



e.g. Dullemond& Dominik 2005

**Should be distinguishable by gas signatures**

# How to look for gas in the holes?

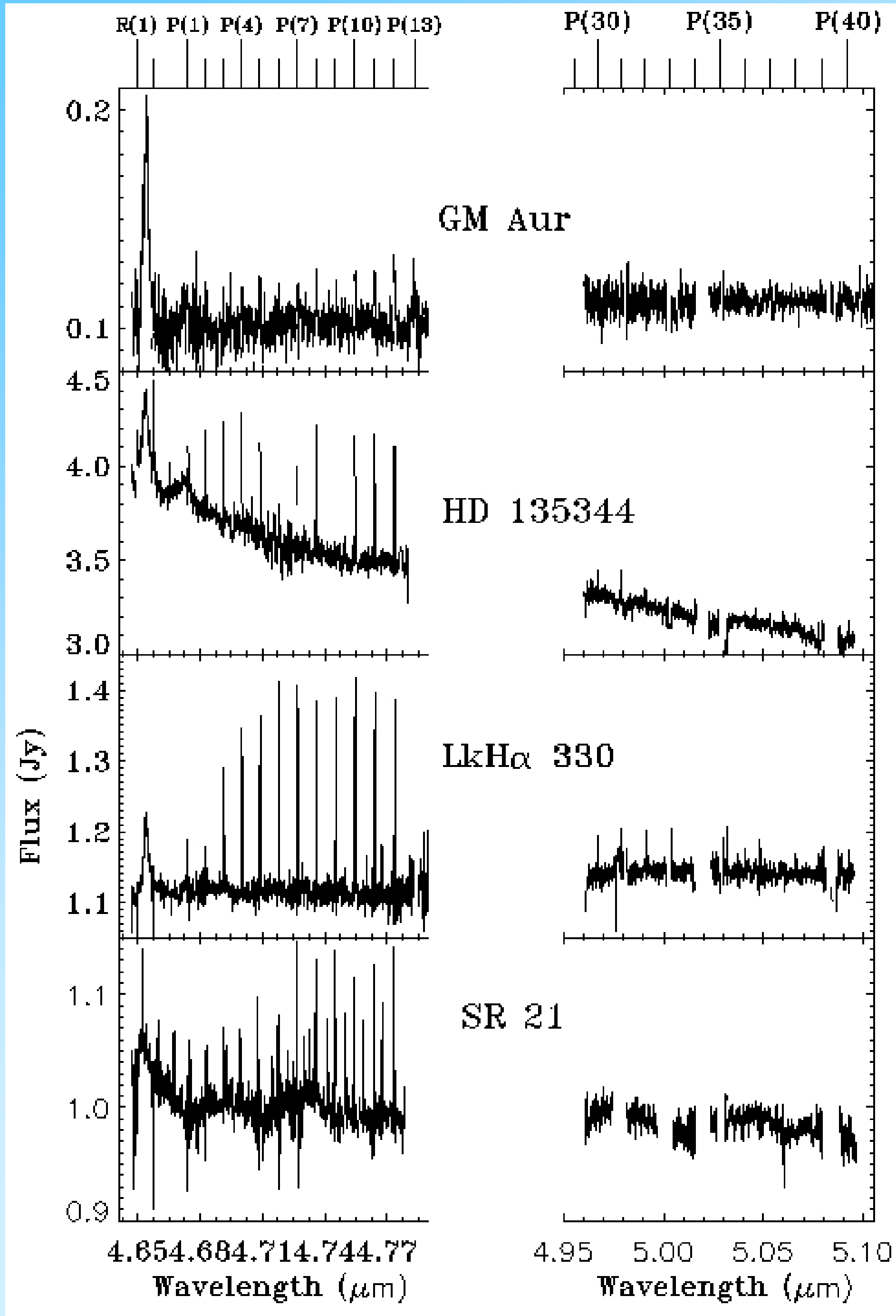



Molecular hydrogen abundant but hard to see

Carbon monoxide (CO) - abundant in young disks

Rovibrational (v=1-0) band at 4.7 μm

Probes gas ~1000K and rovibrational nature means traces a range of energies



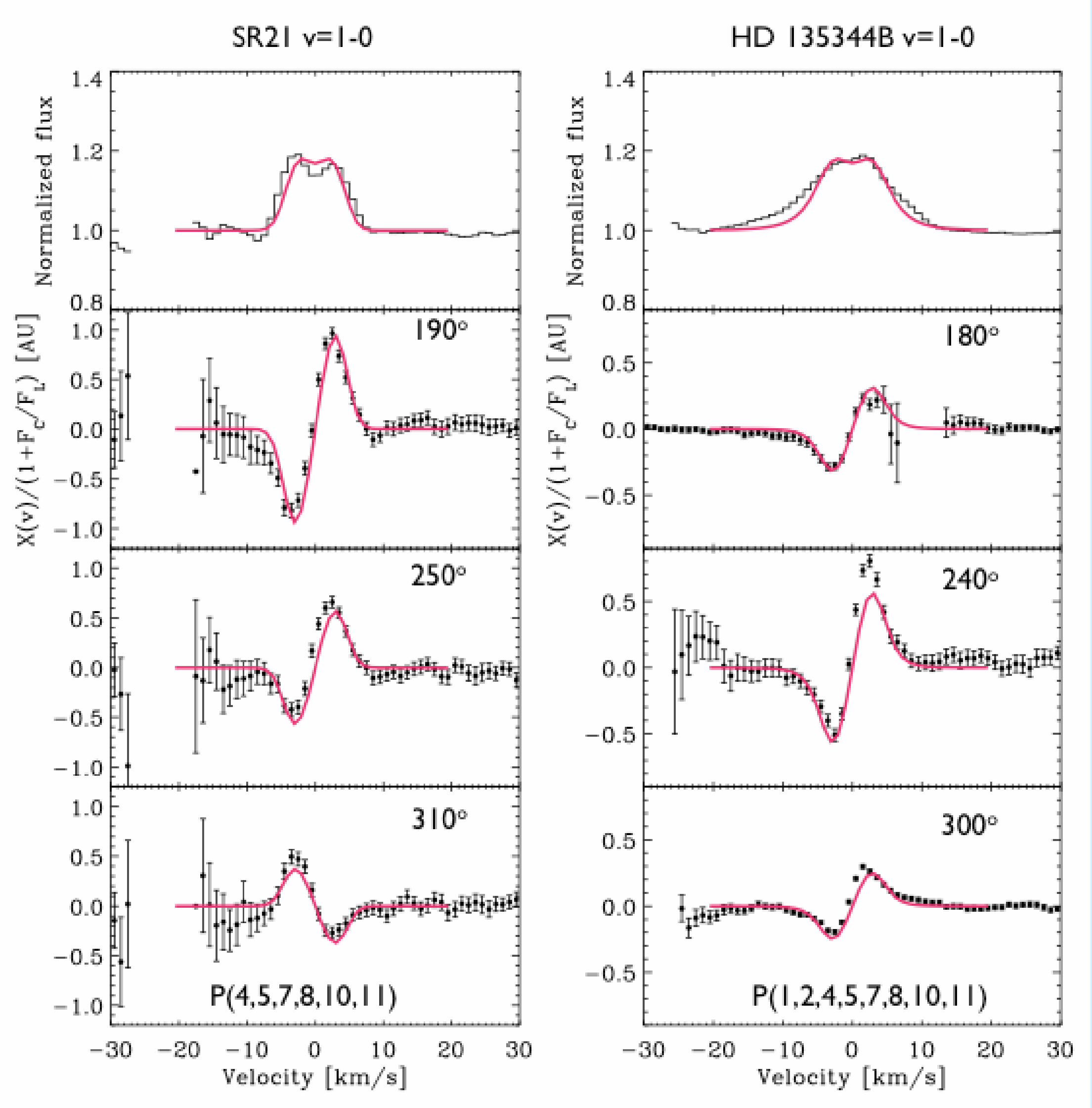

# High Resolution IR Spectroscopy & Disks

R=10,000-100,000 (30-3 km/s) echelles (NIRSPEC, PHOENIX,TEXES, CRIRES) on 8-10 m telescopes can now probe "typical" T Tauri/Herbig Ae stars

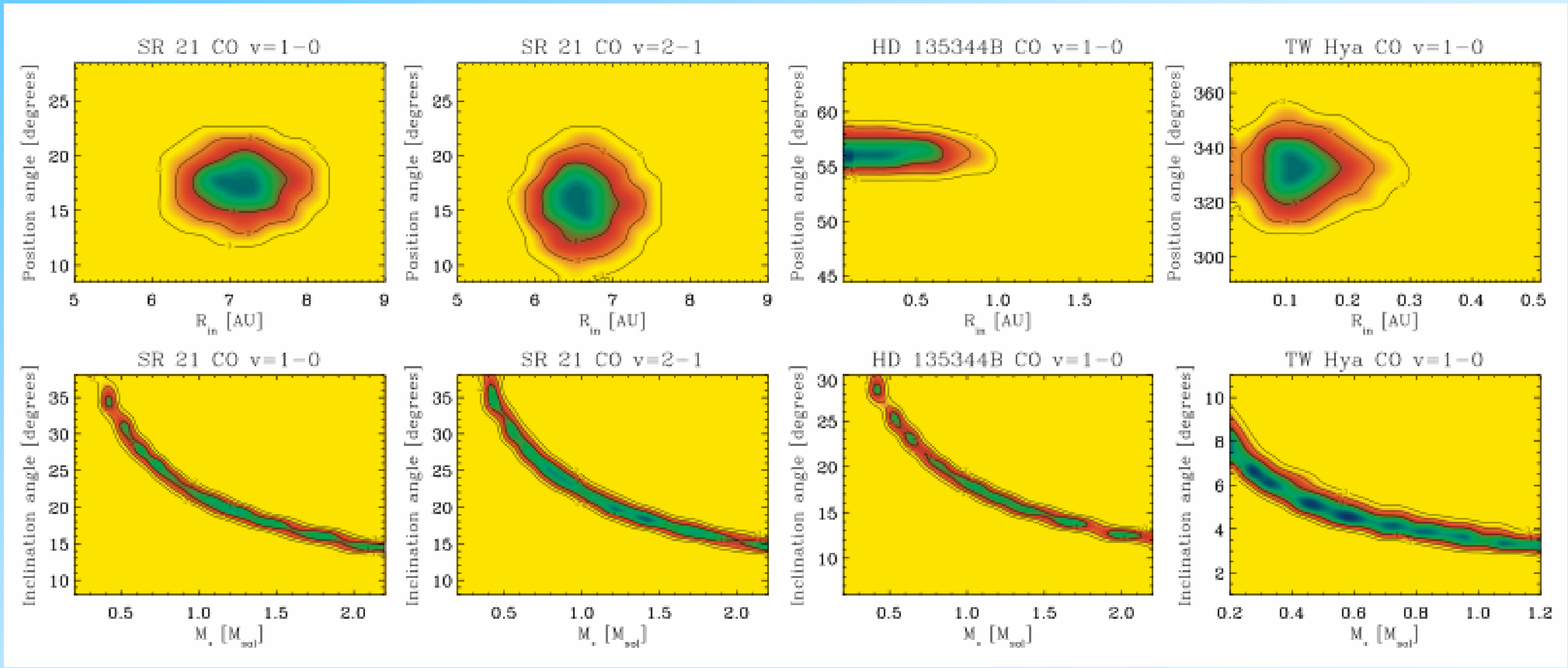
# Gas location via spectroastrometry

CRIRES high spectral resolution echelle (R=100,000) behind AO on the VLT

Can determine gaussian centroid more accurately than width




Pontoppidan et al 2008




Gas is present within dust gaps

Gas distribution is different in different disks

# Conclusions

- Spitzer photometry and IRS spectra can reliably isolate disks with unusual dust/gas properties over the 1-40 AU region.
- Initial follow-up (sub)mm wave imaging with the SMA has confirmed that these disks do in fact have gaps with low dust content.
- CO M-band spectroastrometry reveals that gas is present within the gaps limiting formation mechanisms.