Protoplanetary Disk Structure with the SMA

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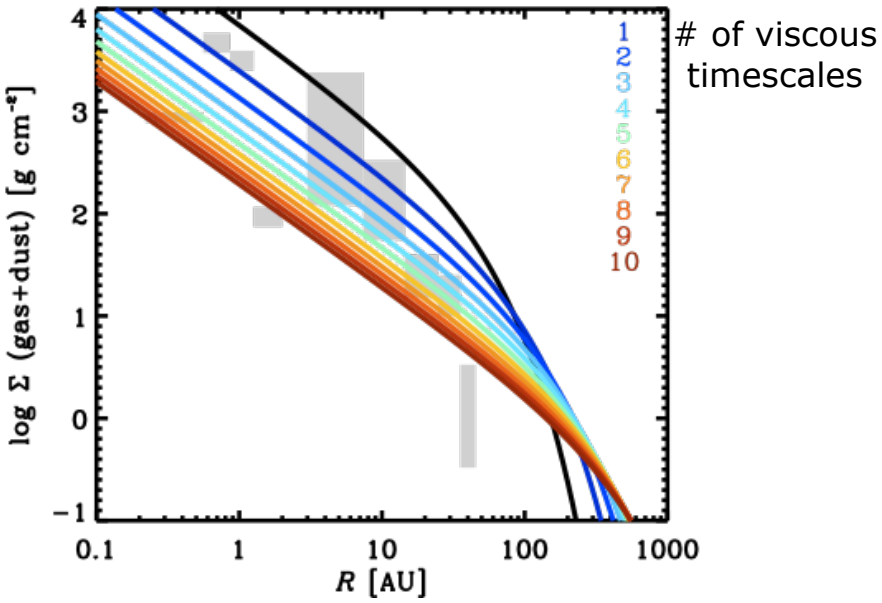
+ David Wilner, Meredith Hughes, Charlie Qi +

protoplanetary disk structure

mass inventory

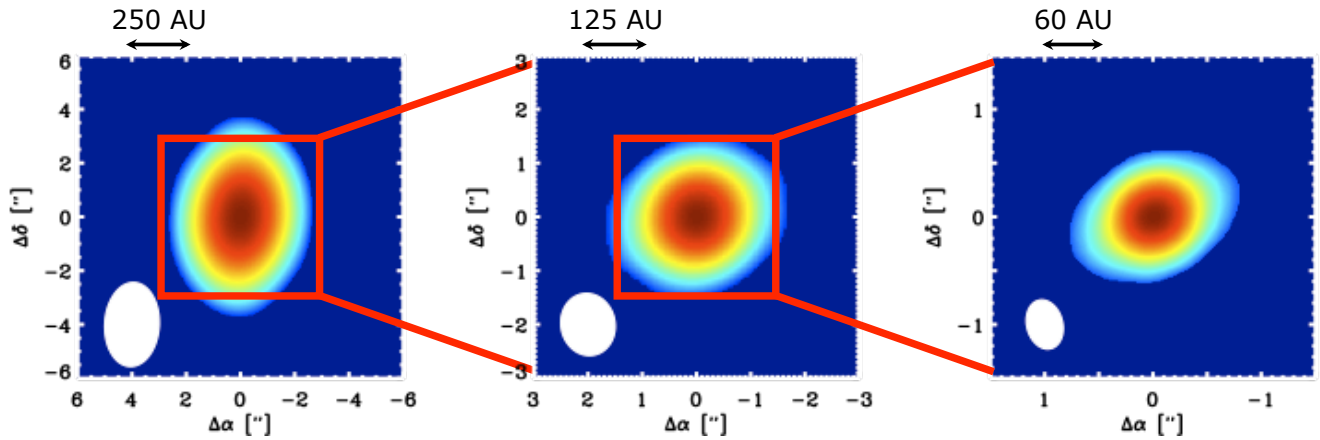
density evolution of a viscous accretion disk



1. Is there enough material to make planets? *in the right places*?
2. How does the disk structure change with time?

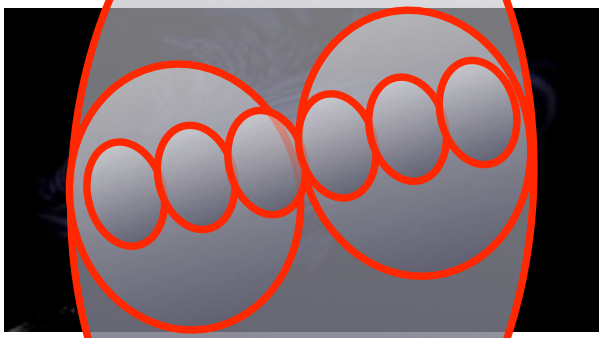
goal: measure density structure with resolved submillimeter data

resolution matters



>2" resolution ~1" resolution ~0.3" resolution

....outer disk only....

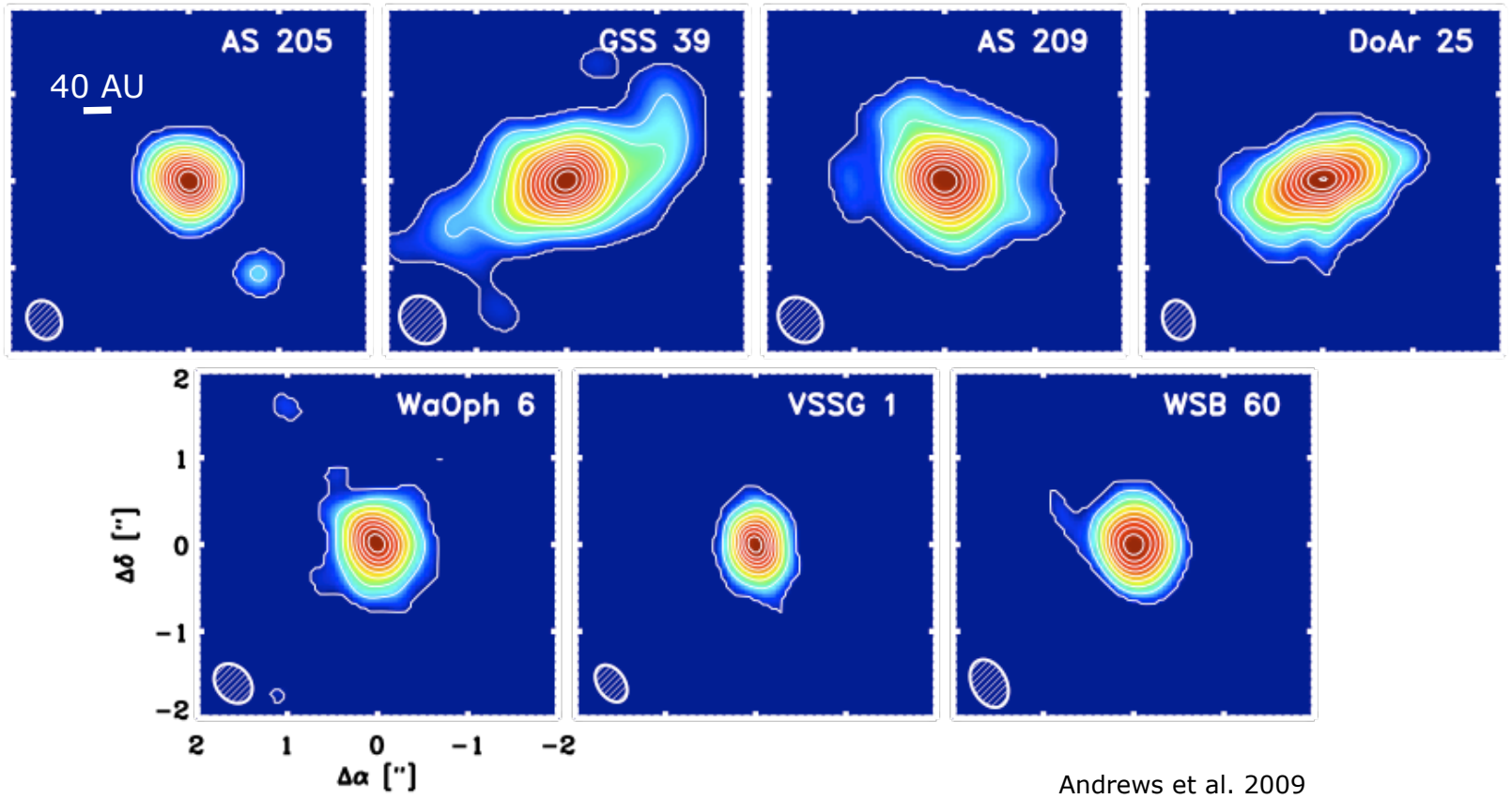


~150 AU

- better leverage on brightness (i.e., density) distribution
- directly probing regions more relevant to planet formation

SMA survey of Oph disks

- 0.3" resolution (*R*~20 AU), 850 microns
- 9 of the brightest Class II disks



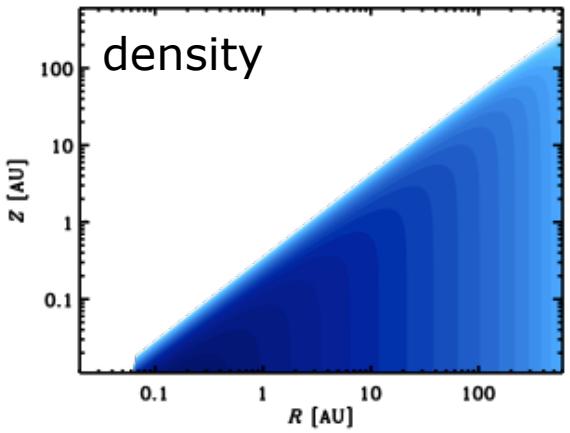
Andrews et al. 2009

modeling disk structure

2-D axisymmetric Monte Carlo radiative transfer code (RADMC)

C. P. Dullemond

- temperature structure computed, not imposed
- fit SMA visibilities and full SED simultaneously



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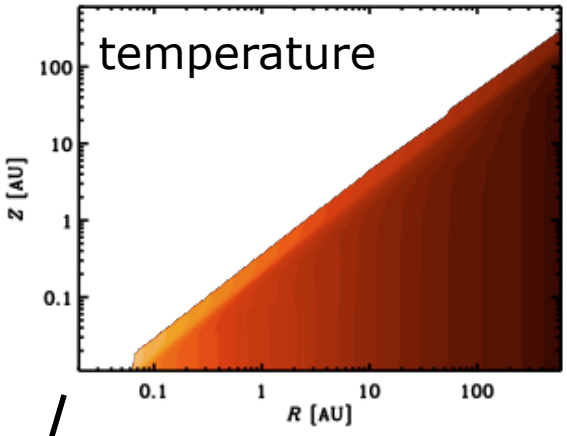
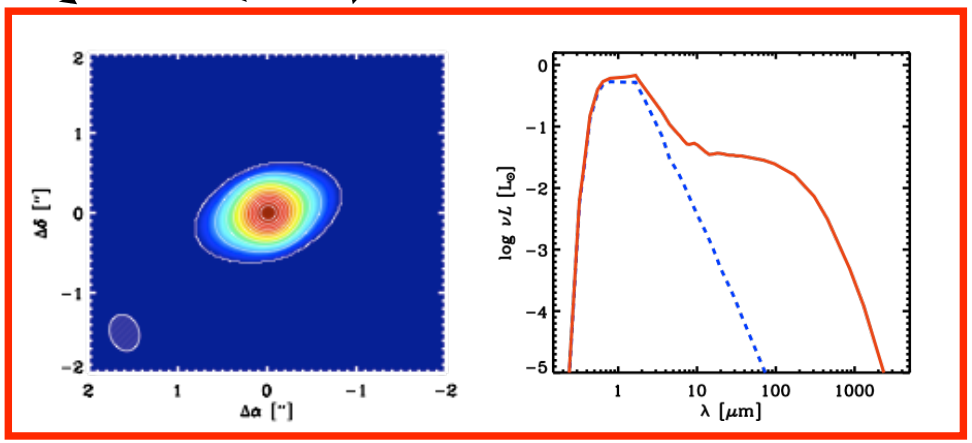


$$\rho(R,Z) = \frac{\Sigma}{\sqrt{2\pi}H}\exp\left[-\frac{1}{2}\left(\frac{Z}{H}\right)^2\right]$$

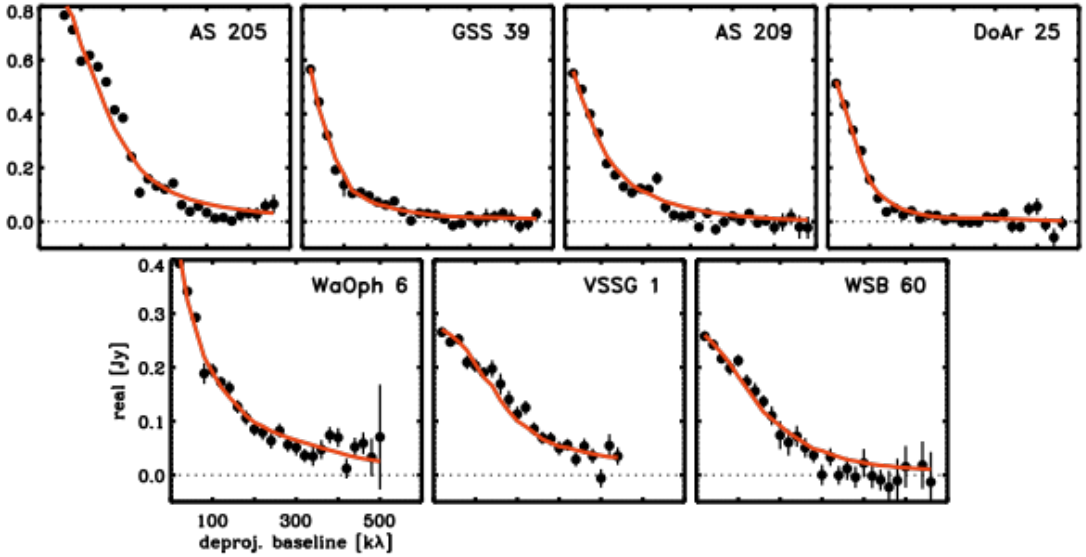
$$\Sigma = \Sigma_0\left(\frac{R}{R_d}\right)^{-p}\exp\left[-\left(\frac{R}{R_d}\right)^{2-p}\right]$$

$$H = H_0\left(\frac{R}{R_d}\right)^{\psi}$$

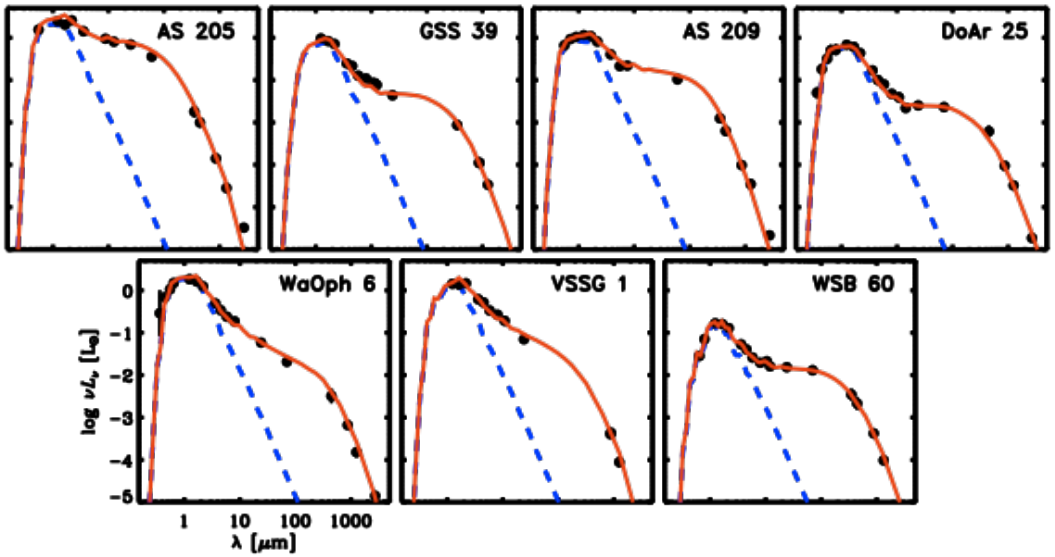


modeling results

visibilities

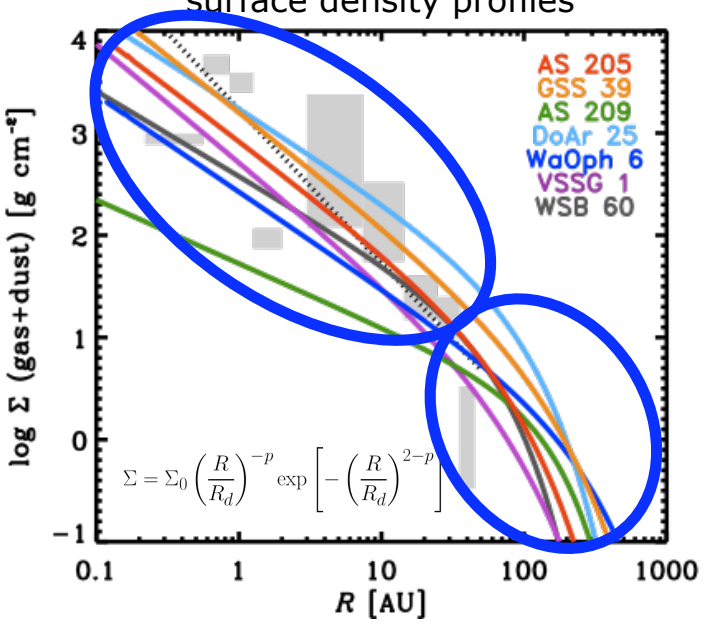


SEDs

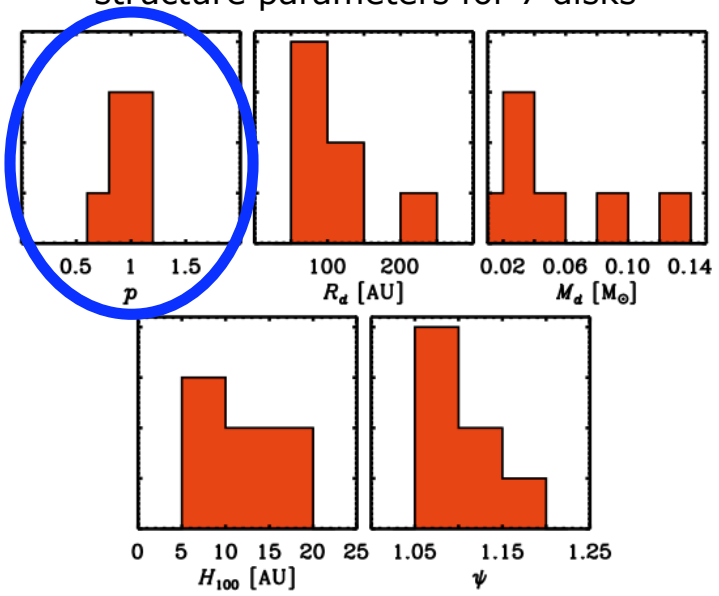


modeling results

surface density profiles



structure parameters for 7 disks



grey panels = Solar System

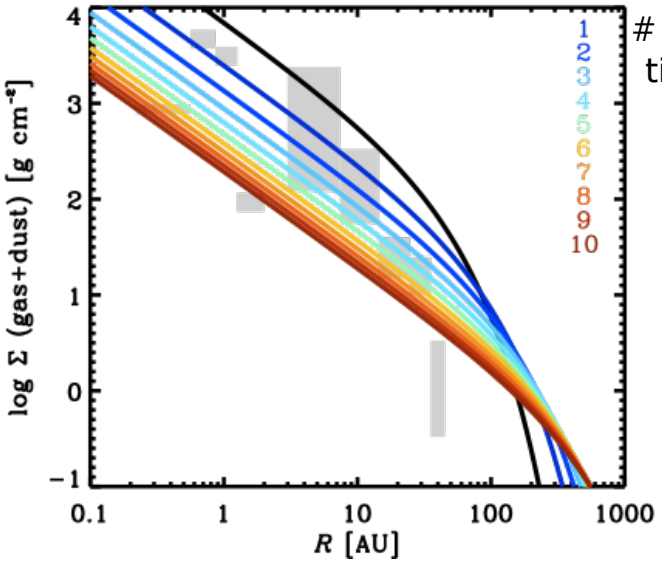
Weidenschilling 1977; Kenyon 2002

1. densities comparable to MMSN + significant mass reservoir
   - good potential for planet formation e.g., Inaba et al. 2003; Hubickyj et al. 2005

2. density gradients clustered near $p = 1$
   - tells us about evolution of disk structure Hartmann et al. 1998

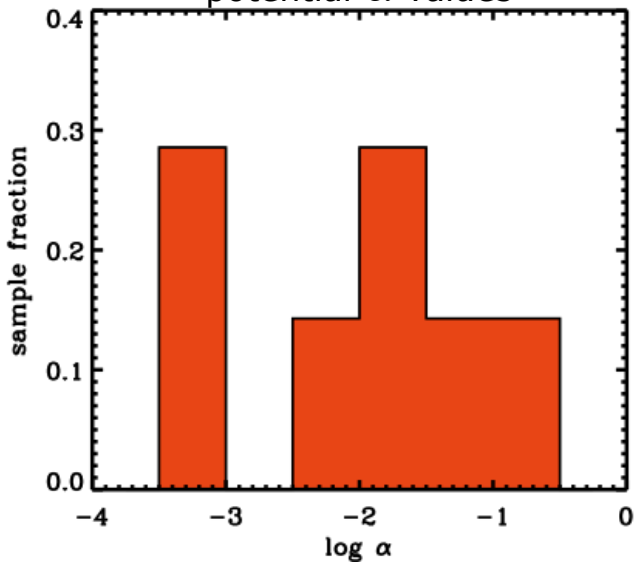
implications for structure evolution

viscous evolution of densities



# of viscous timescales

potential α values



estimated density structures *now*, but how do they evolve?

structure + accretion rates
&
similarity solutions for evolving viscous accretion disks

$$\nu = \alpha c_s H$$

- range of α from ~0.001-0.1 (consistent with MRI...)

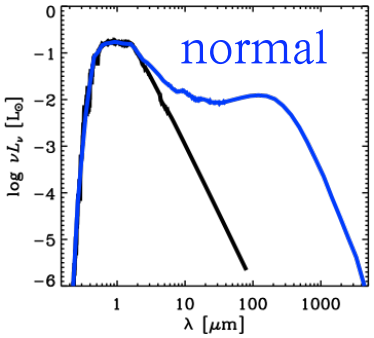
(when do we start the clock?)

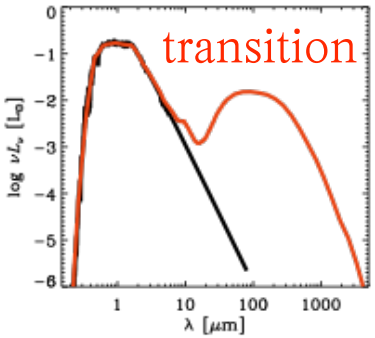
- initial conditions estimates
sizes: R_1 ~ 40-100 AU
masses: $M_{d,0}$ ~ 2-10 $M_{d,now}$

evidence for central cavities

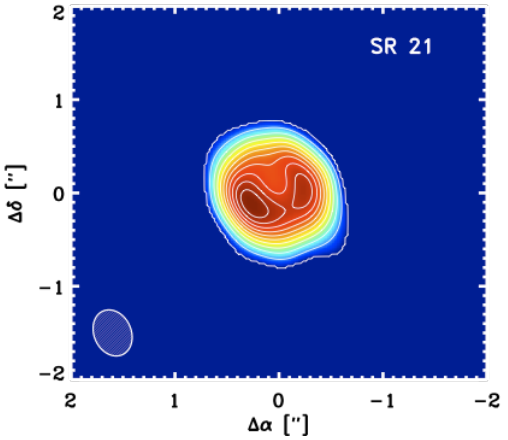
the other 2 Oph disks I haven't mentioned yet...

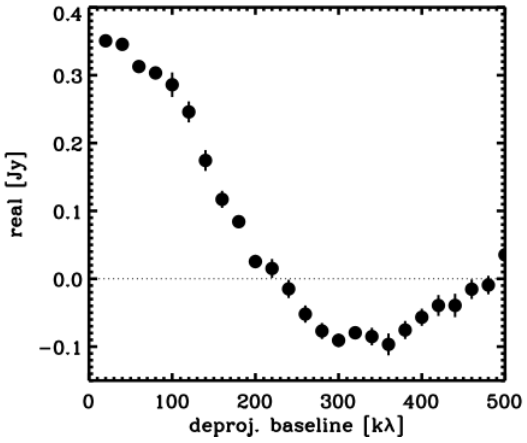
diminished 850 micron emission inside R~20-50 AU



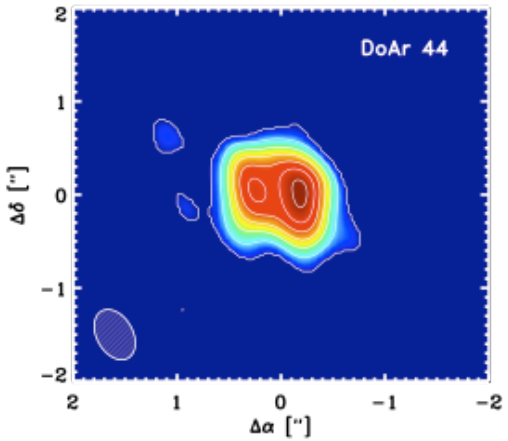


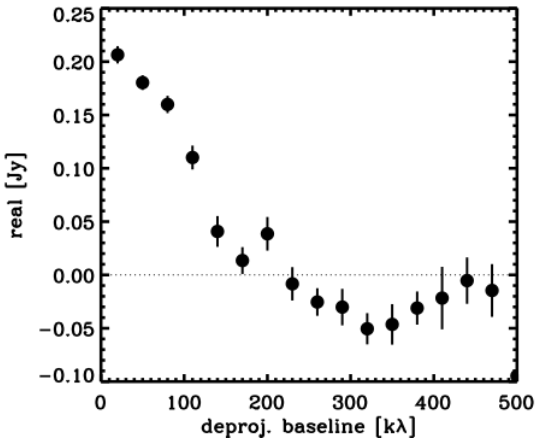
why do ~2/9* of the brightest Oph disks have large inner holes?





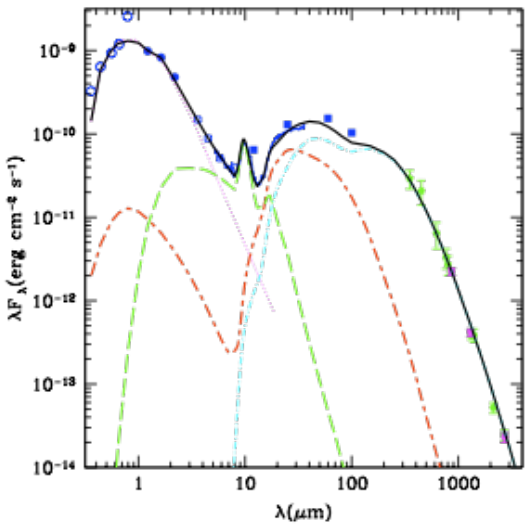
J. Brown, Ph.D. thesis





Andrews et al. 2009

cavity in the GM Aurigae disk

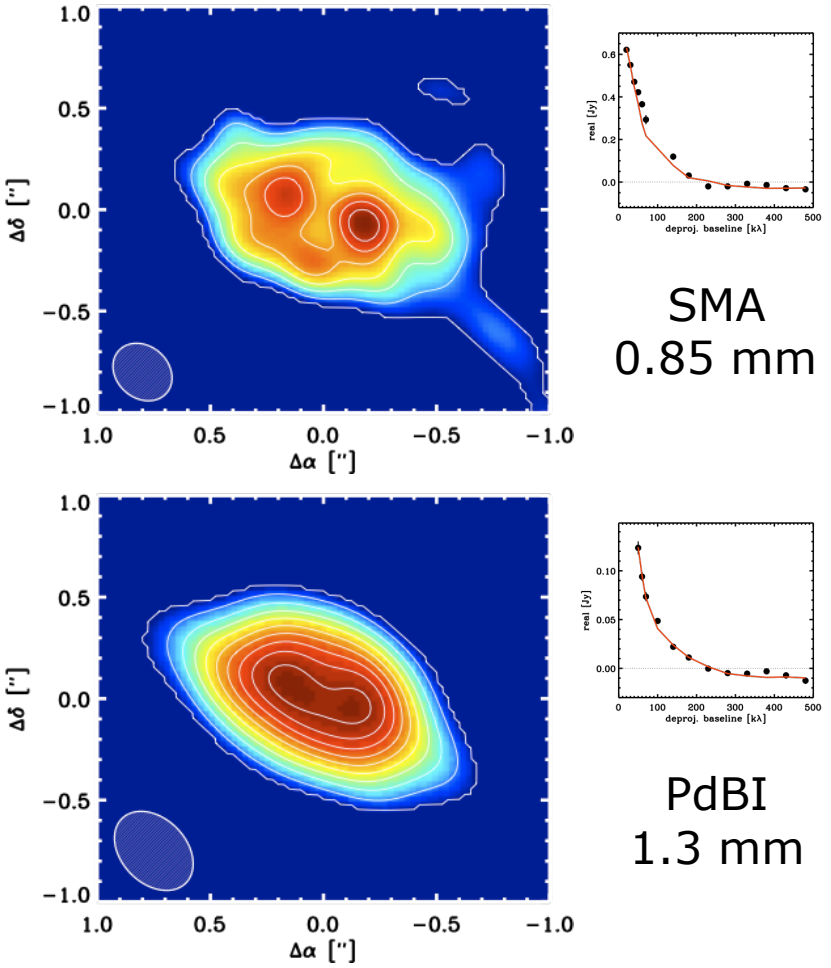


Calvet et al. (2005):
diminished optical depth
for R<24 AU

resolved mm image
predictions based solely
on unresolved SED

see also D'Alessio et al. 1998; 2001
and Furlan et al. 2006

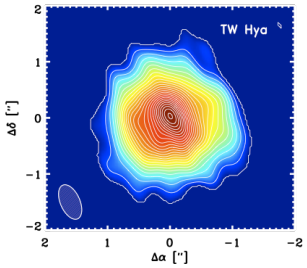
real data

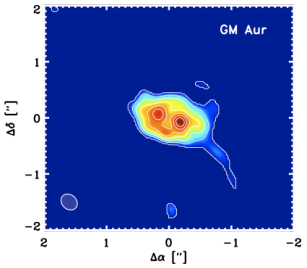


SMA
0.85 mm

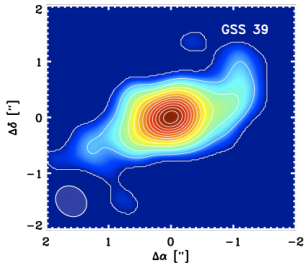
PdBI
1.3 mm

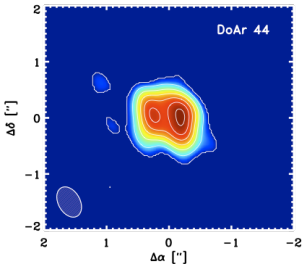
Hughes, Andrews, Espaillat et al. 2009

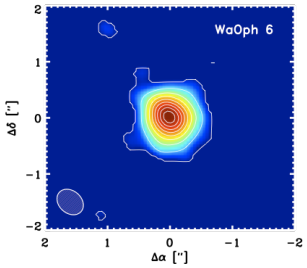




summary

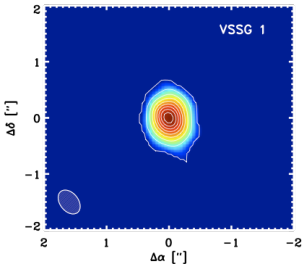






high resolution (0.3": R ~ 20 AU) 850 micron SMA survey of Class II disks in Ophiuchus

leverage on brightness profile at most relevant radii



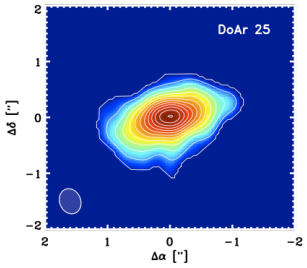
constrain parametric models of disk structure

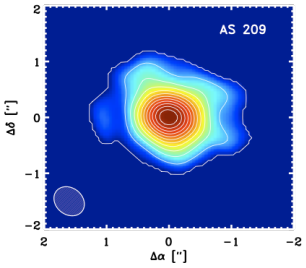
simultaneously fit SED and SMA visibilities using 2-D RT code

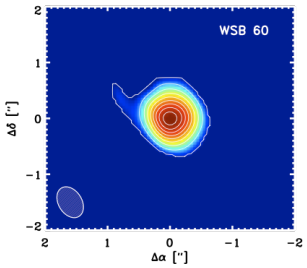
radial density gradient p ~ 1 with exponential edge

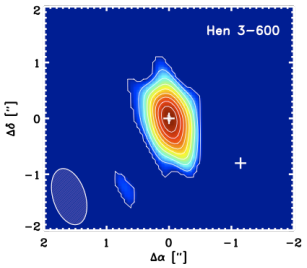
densities consistent w/ MMSN & accretion disk models

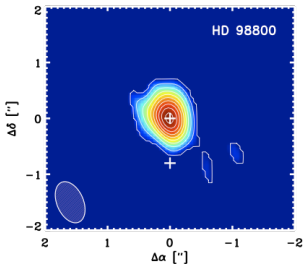
resolved cavities in a number of bright disks

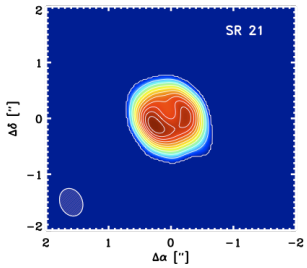


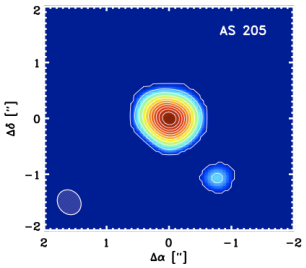




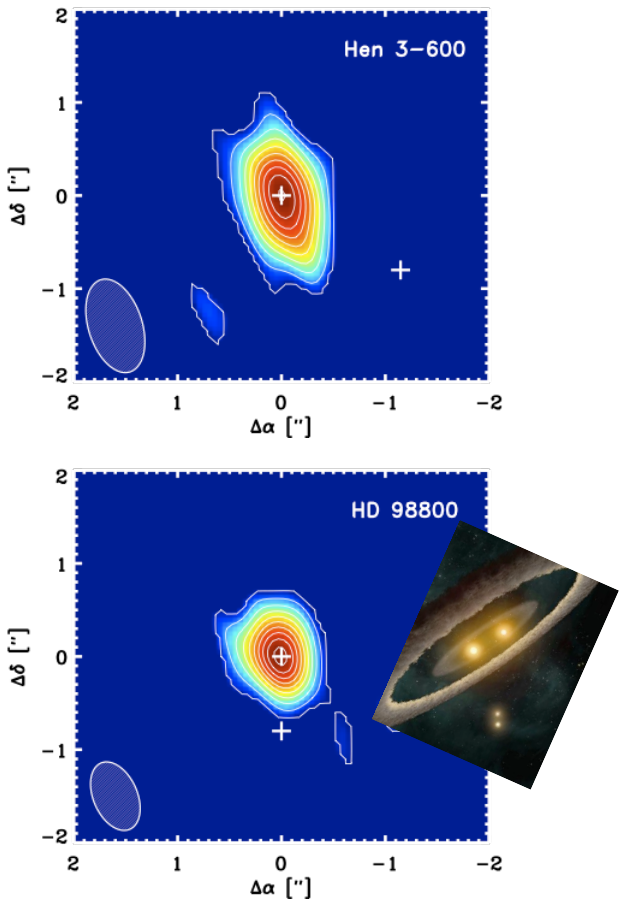


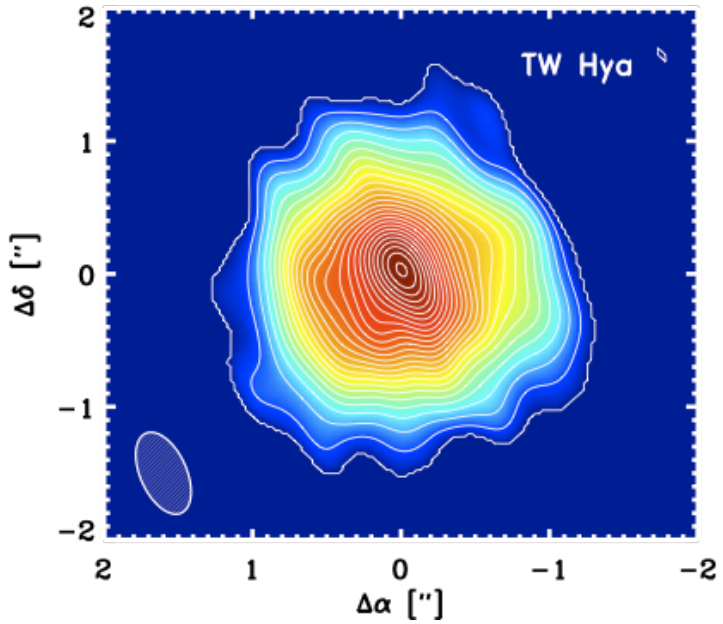






SMA sample of TWA disks





~3x closer; sampling *R*~7 AU scales