Monte Carlo Radiation Transfer in Protoplanetary Disks

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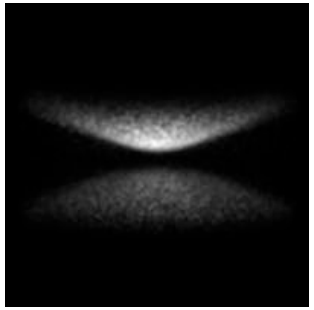
Radiation Transfer + Hydrodynamics

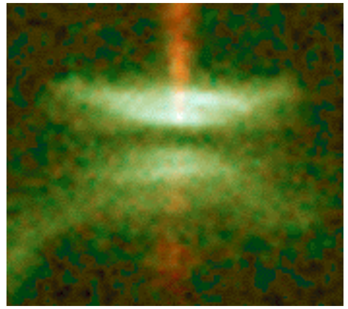
RT Models:	Barbara Whitney, Jon Bjorkman, Christina Walker, Mark O'Sullivan Tom Robitaille
Dust Theory:	Mike Wolff
SPH Models:	Ken Rice, Mike Truss, Ian Bonnell
Observations:	Rachel Akeson, Charlie Lada, Ed Churchwell, Glenn Schneider, Angela Cotera, Keivan Stassun

Monte Carlo Development History

- Scattered light disks & envelopes (1992)
- 3D geometry & illumination (1996)

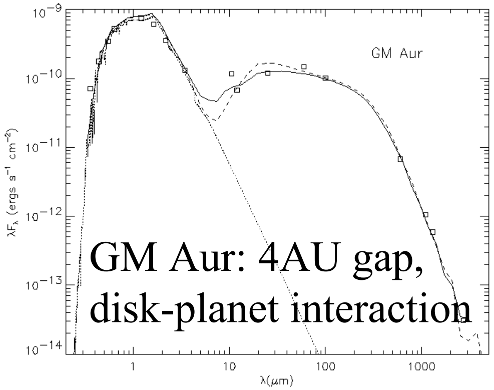


1992: Predictions



1996: HST data

- Dust radiative equilibrium (2001)
  SEDs disks + envelopes
- Monte Carlo for disk surface + diffusion for interior (2002)



- Density grids from SPH simulations (2003)
- Spatial variation of dust opacity (2003)
- Self consistent vertical hydrostatic equilibrium (2004)

Disk Structure Calculations

- Our models used parameterized disks:

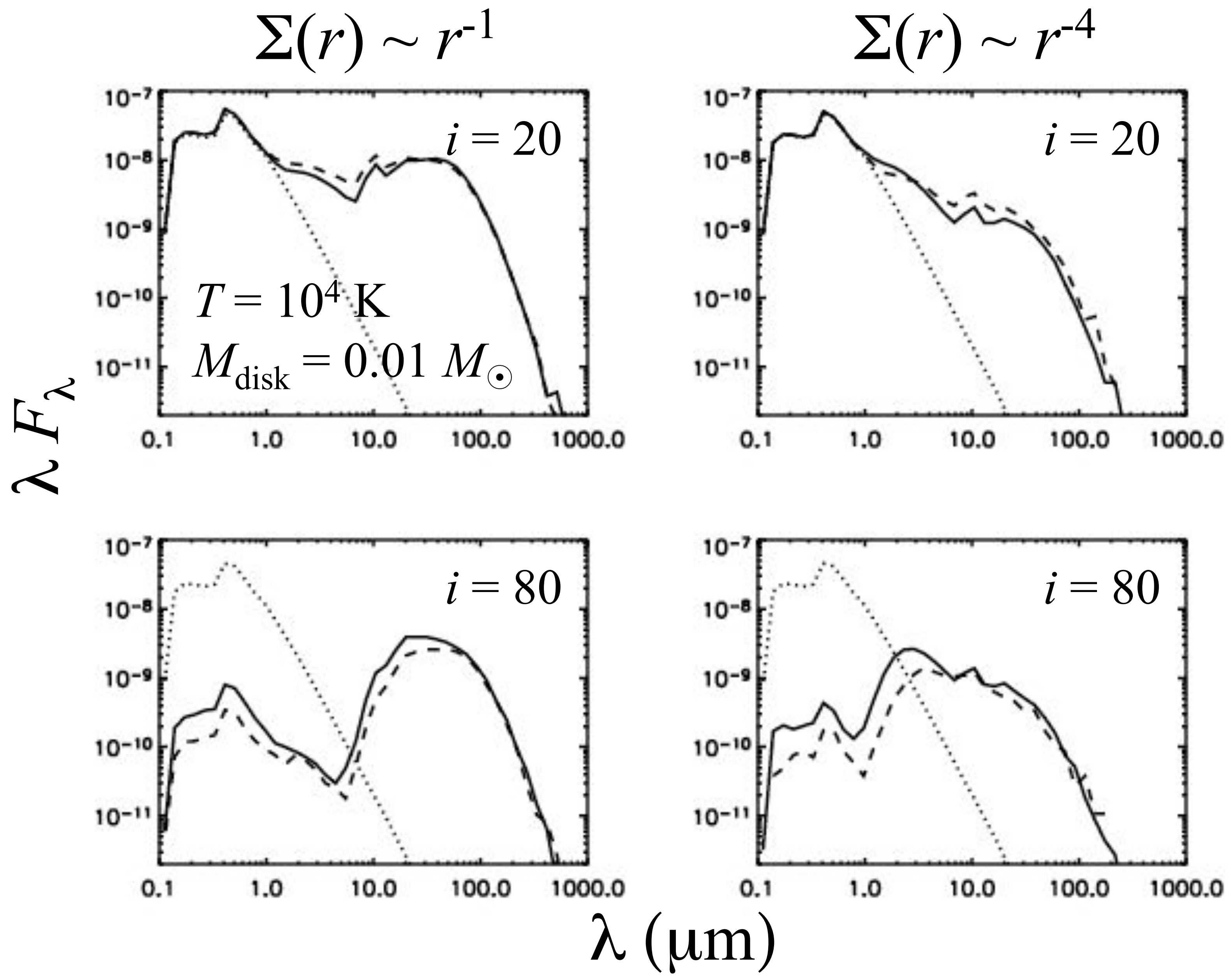
$$\Sigma(r) \sim r^{-p},\ h(r) \sim r^{\beta}$$

- Disk theory: reduce model parameter space
- Irradiated accretion disks in vertical hydrostatic equilibrium (HSEQ): (D'Alessio, Calvet, et al.)

$$\Sigma \sim r^{-1},\ h \sim r^{1.25}$$

- New Monte Carlo: iterate for self consistent disk structure (Walker et al. 2004, 2005)
- ***How well can power law disks reproduce structure, SEDs and images of HSEQ disks?***

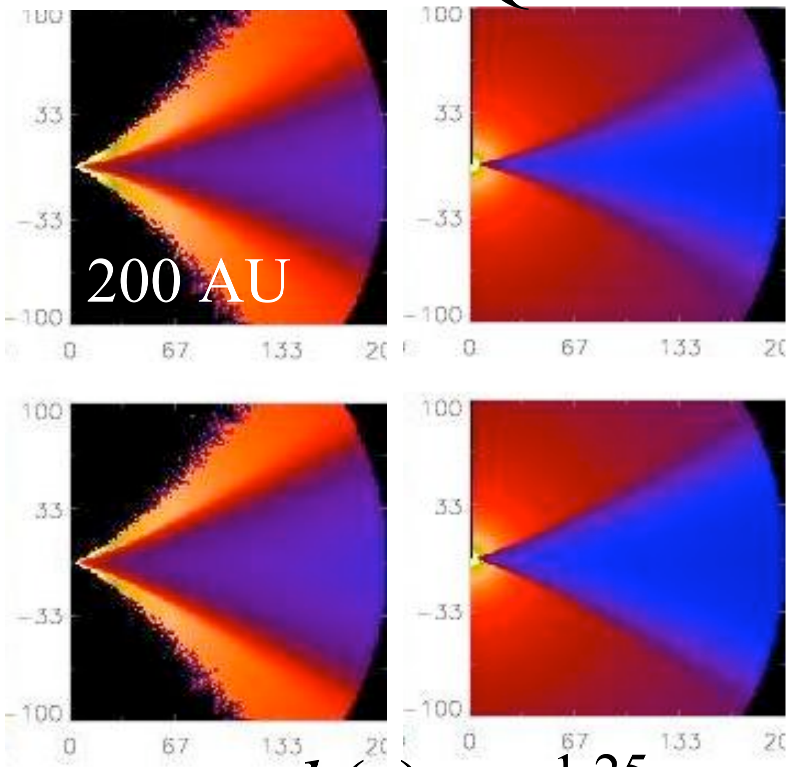
HSEQ vs Power Law Disks



Temperature Structures

$\Sigma(r) \sim r^{-1}$

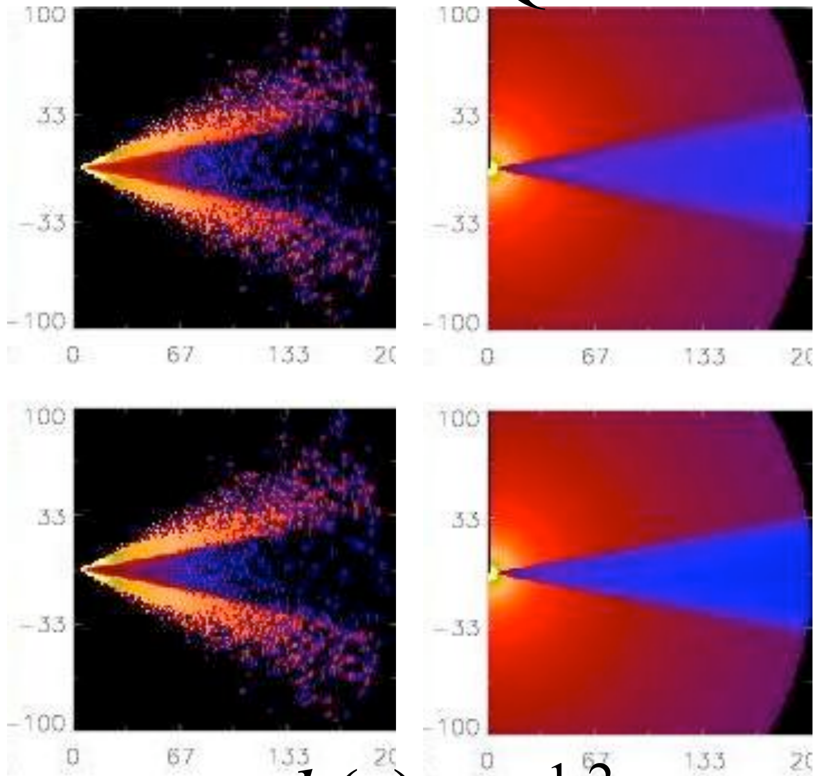
HSEQ



$h(r) \sim r^{1.25}$

$\Sigma(r) \sim r^{-4}$

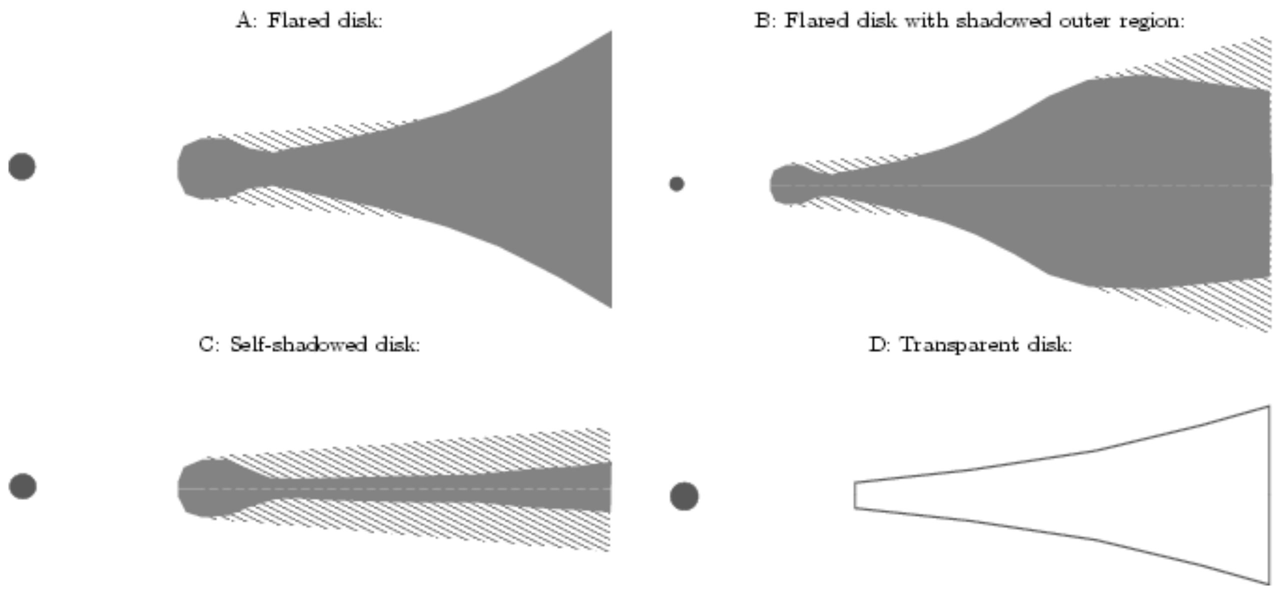
HSEQ



$h(r) \sim r^{1.2}$

Inner Edge of Disk

- Inner edge is important for setting near IR excess (Natta, Dullemond, Dominik, & collaborators)
- Recent HSEQ models suggest a new class of disk where inner edge shadow dominates structure and SED (e.g., Dullemond & Dominik 2004)



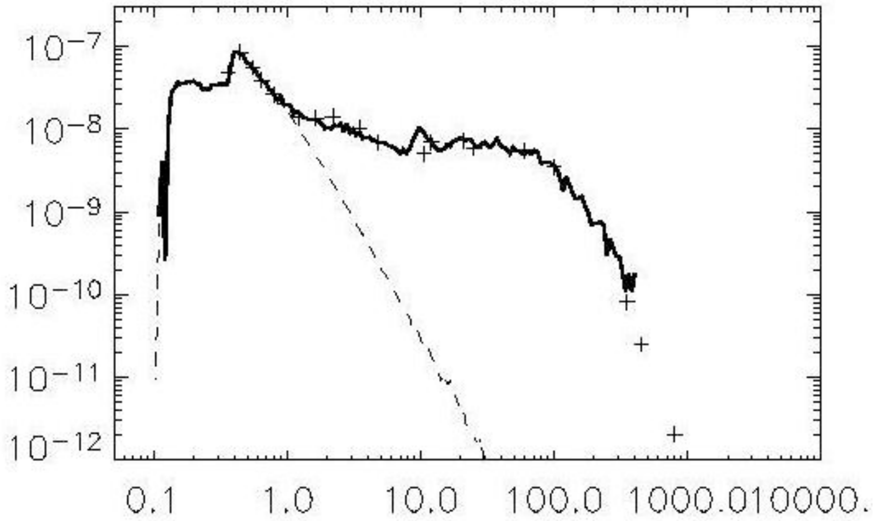
Inner Edge of Disk

- Can reproduce HSEQ disk temperature structure, SEDs, and images with power law disks with monotonically increasing scaleheight $h = h_0\ (r/R_0)^{\beta}$
- General recipe: scale $h(r)$ from hydrostatic value at dust destruction radius, $\beta = 1.2$ to 1.3
- ***HSEQ disks: dust settling and disk surface density dominate over inner edge effects***
- ***Inner edge can shadow if outer disk not in HSEQ***

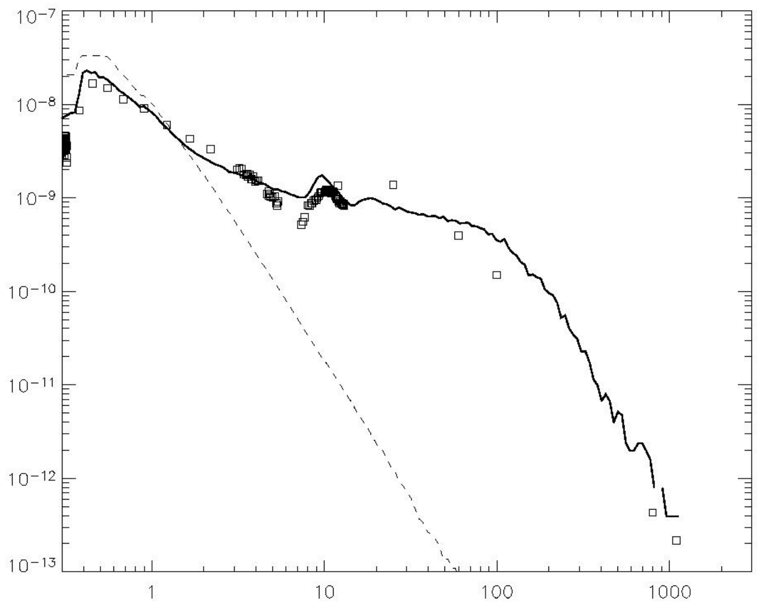
Group I & II Herbig Ae Disks

- Similar mm fluxes
- Group II: lower mid to far-IR fluxes
- ***Mid to far IR SED: dust settling, disk viscosity?***

AB Aur I



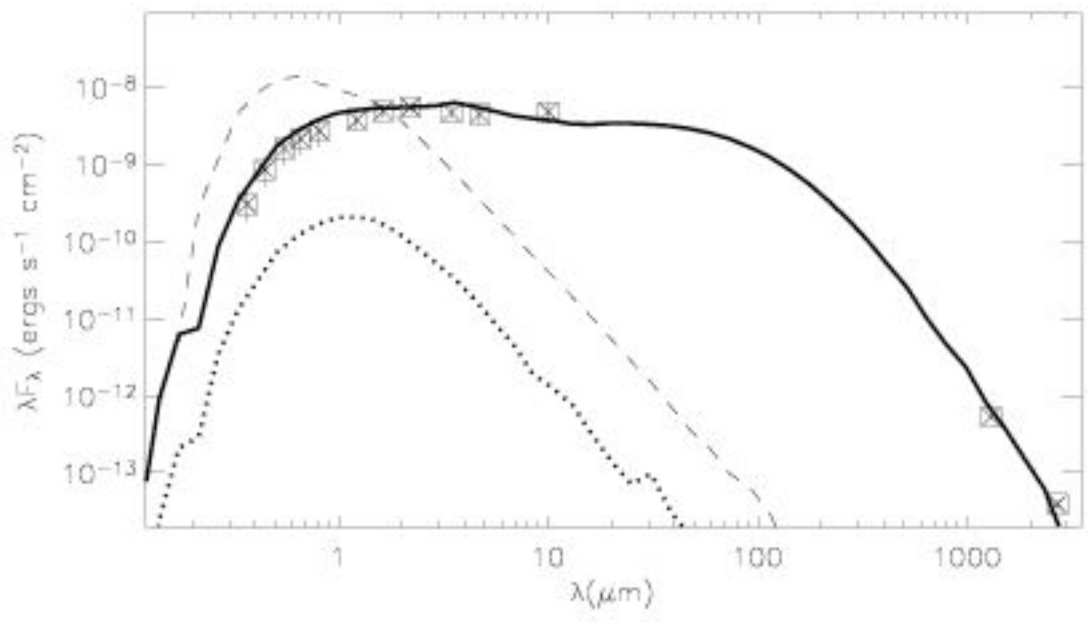
HD 35187 II

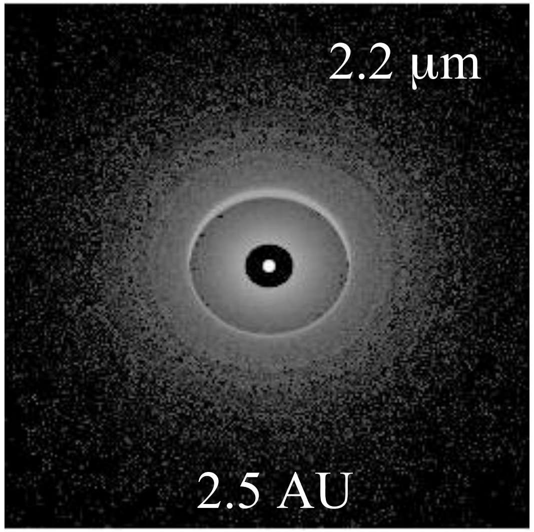


SED data compiled by Mike Sitko

T Tauri Disks: SED + Interferometry

- RY Tau: $M_d = 0.015 M_\odot$, $M_{acc} = 2.5 \times 10^{-7} M_\odot$ /yr
- Inner disk: $R_{dust} = 0.27$ AU, $R_{gas} = 5\ R_*$
- Gas opacity, inner edge, disk locking models
- ***Gas emission inside dust fits PTI 2.2μm data***

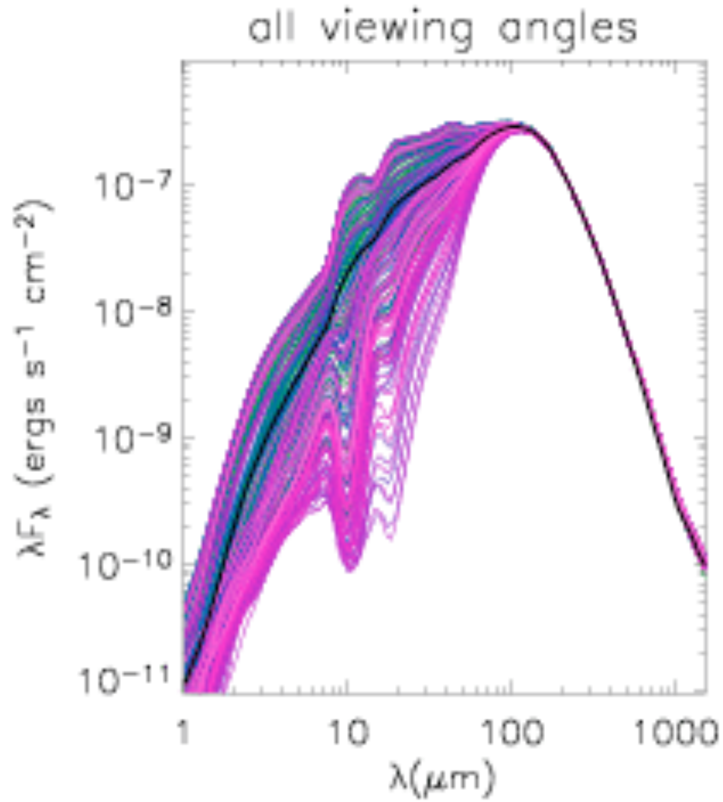


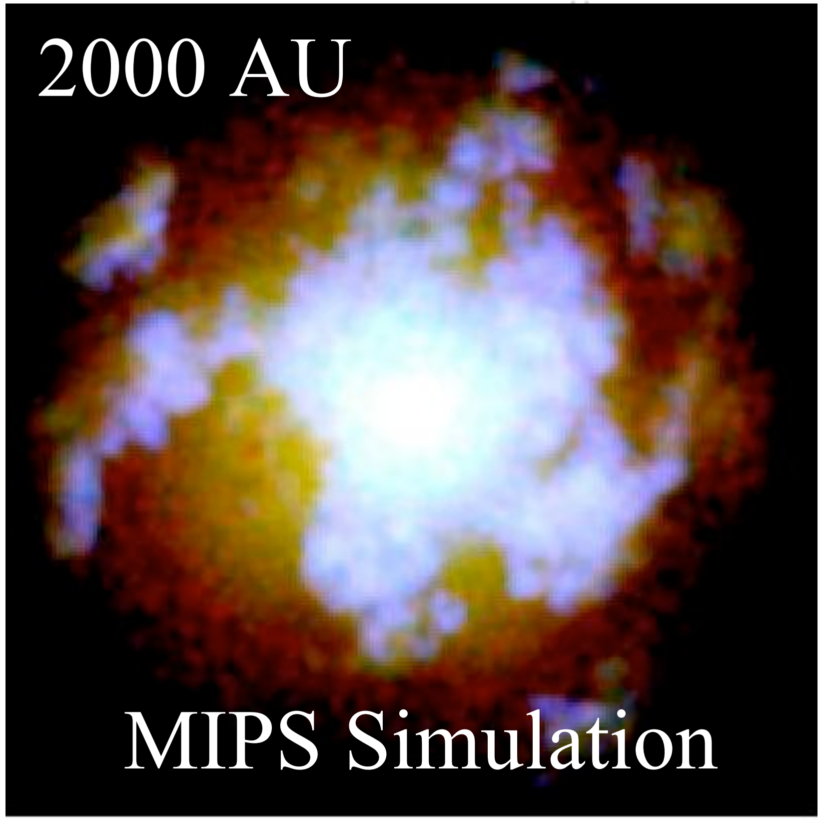


Akeson et al. (2005)

3D Models: Fractal Clouds

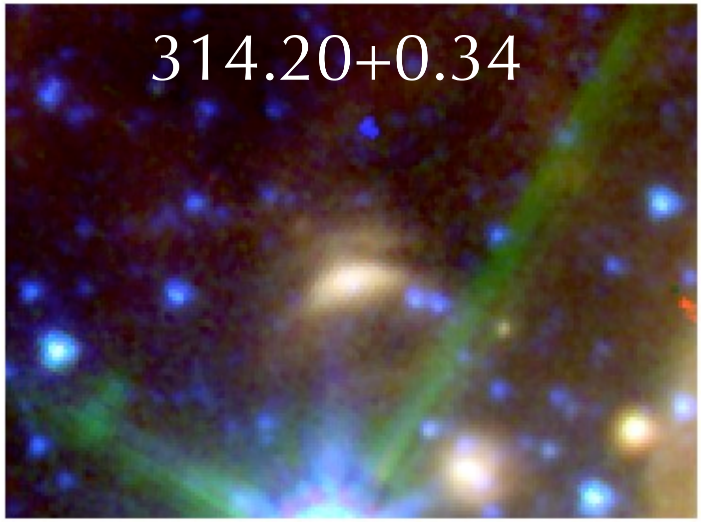
- ***Big variations with viewing angle in optical to IR SED and silicate features***



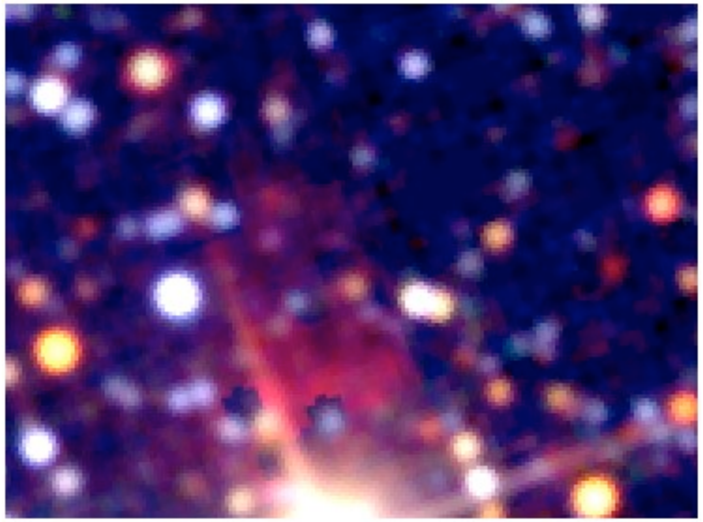


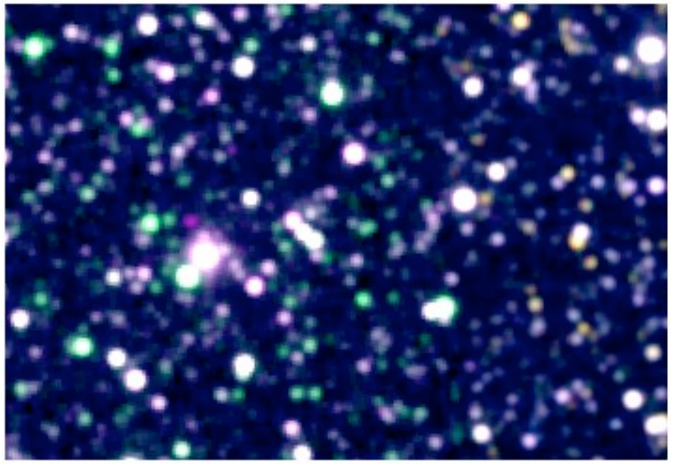
Whitney et al. (2005)

Disk Candidates from GLIMPSE?



IRAC
1,3,4





2MASS
JHK

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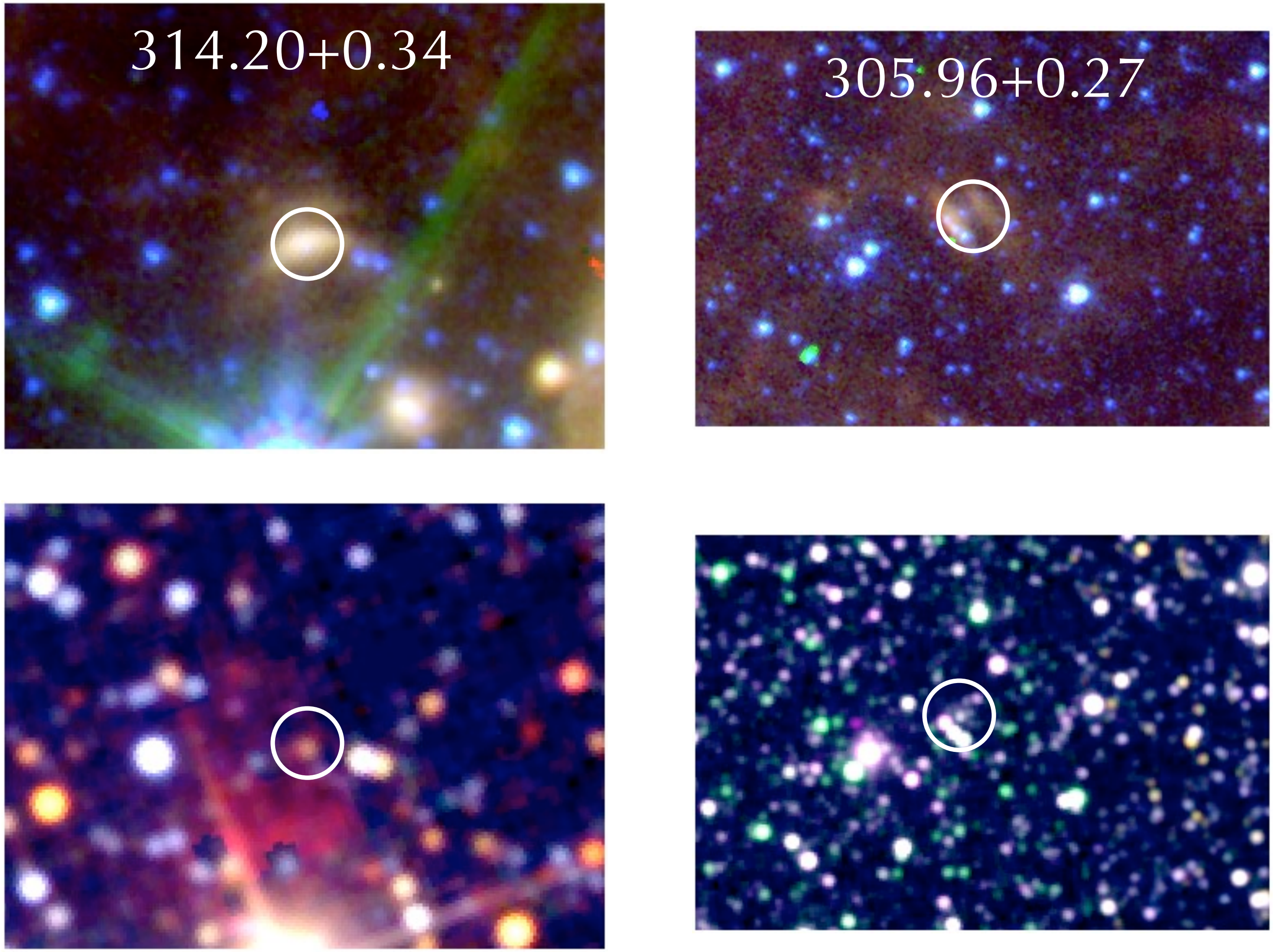
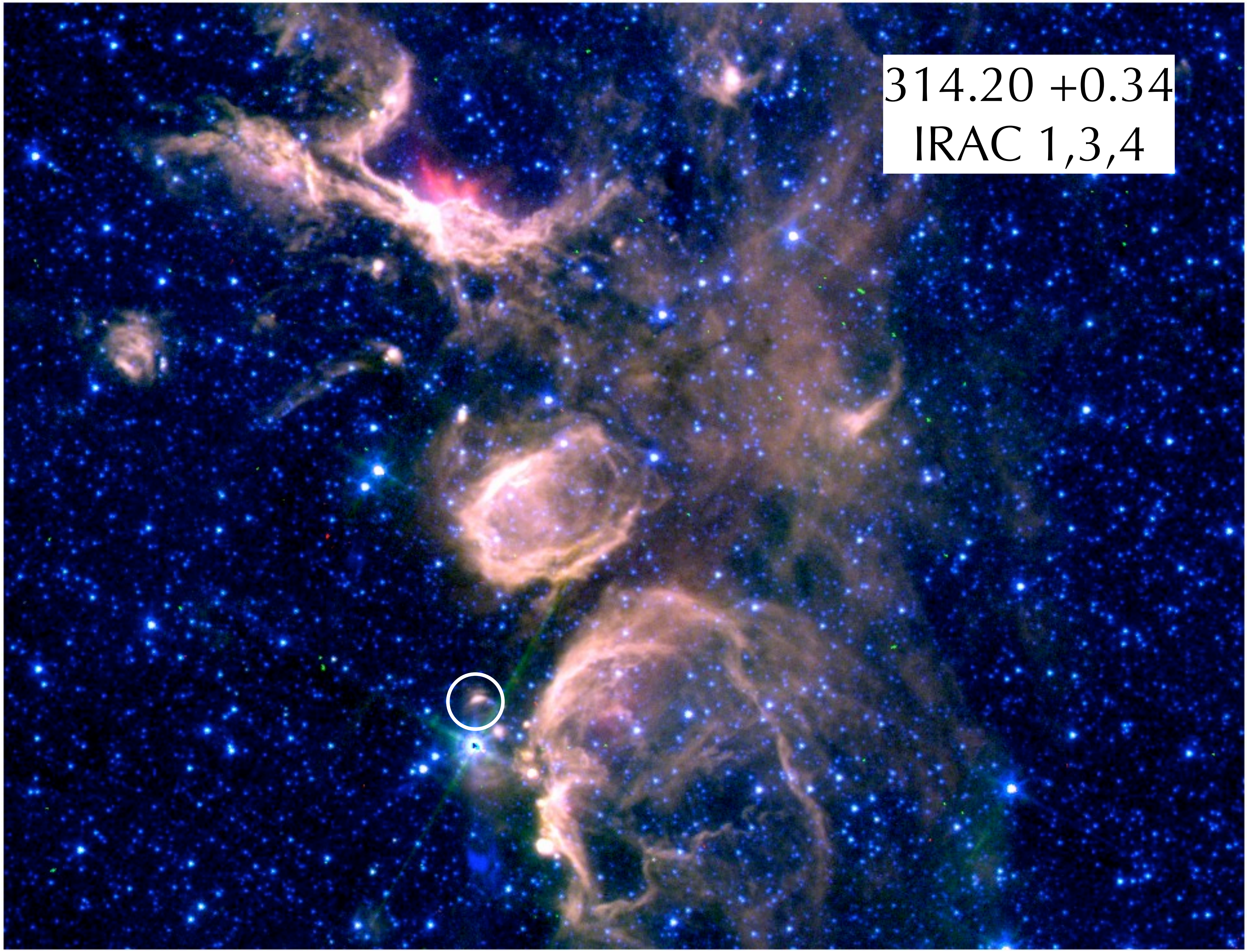


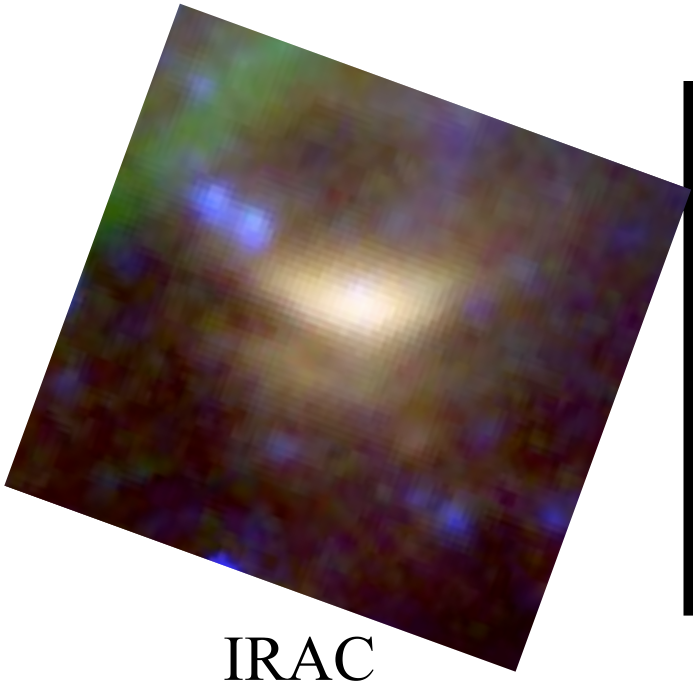
IRAC
1,3,4

2MASS
JHK

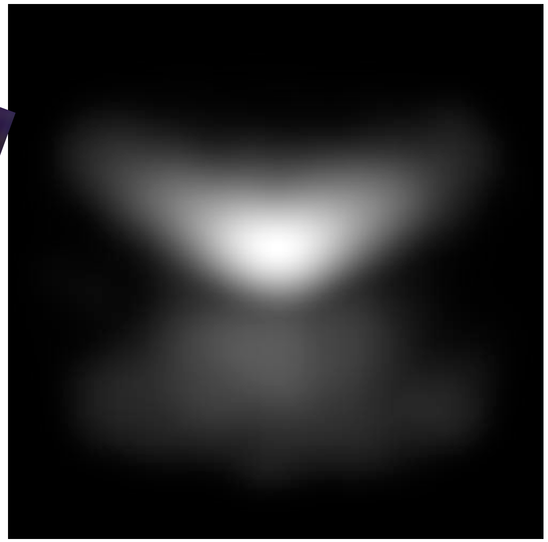

314.20 +0.34
2MASS


314.20 +0.34
IRAC 1,3,4

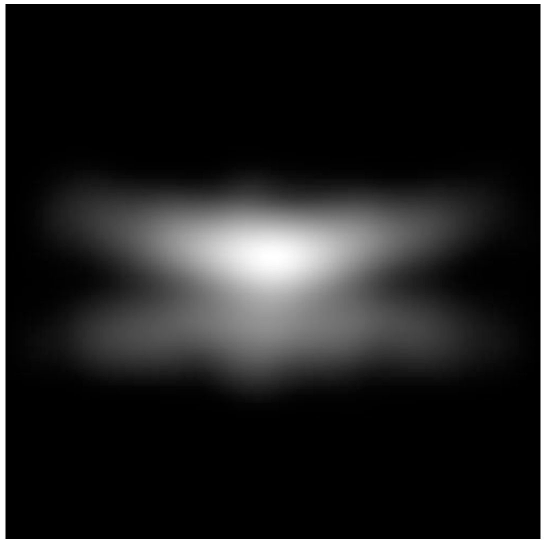
- Are these images of:
  - Very large, distant disks: $R_d \sim 10^4$ AU?
  - Smaller, nearby disks: $R_d \sim 1000$ AU?
  - Junk?



IRAC



$R_d = 1\,000$ AU
$d = 58$ pc



$R_d = 15\,000$AU
$d = 1$ kpc

Summary

- Monte Carlo: self-consistent disk structure calculations
- Dust settling and $\Sigma(r)$ dominate mid & far-IR SED
- Interferometry: emission from inner gas disks
- Huge disks from GLIMPSE?

Codes now available at:

http://gemelli.spacescience.org/~bwhitney/codes