The **SMA** Perspective on Planet-forming Disks around Young Stars

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**goal:**

a planet formation model grounded in observations

**requirements:**

- enough stuff + enough time
- evolution of mass distribution
- viscous + material evolution
- dissipation/metamorphosis

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**SMA 880 μm**

50 AU cavity

[Andrews et al., in prep]

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[NASA/JPL/SSC/T. Pyle]
measuring the mass content of a protoplanetary disk

we assume most of the mass is cold, molecular gas (H₂)

problem: “dark matter”

rely on dust as a tracer

(it dominates the opacity)
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- radio: mass in the midplane

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\text{emission} \propto \kappa \nu \Sigma T
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an appropriate model for the density structure?

a density puzzle:

if $\Sigma$ is a power law+edge,
dust sizes $<<$ gas sizes (!)

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the solution:

$\Sigma$ has a large-$R$ taper; expected for accretion disks

no sharp (outer) edges!

[Hughes et al. 2008]
disk density structures from radio interferometry data

parametric model:

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

+ starlight, dust population

+ radiative transfer calculations

resolved radio emission \( \propto \kappa \nu \Sigma T \)

IR spectrum/scat. light/CO \( \sim T \)

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new results: SMA disk survey
0.85 mm, 0.3”=20 AU resolution
2-D Monte Carlo RT (RADMC)

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residuals

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can these disks make planets?

**mass distributions:**

- $\Sigma \sim$ solar nebula (10-40 AU)
- $\Sigma \sim 1/R$ ($\sim$20-100 AU)
- $1/\exp(R)$ (larger $R$)
- $mass \sim 0.01 \, M_\odot$ (40-50%)
- $0.1 \, M_\odot$ (<1%)

**disk structure “snapshots”:**

- viscosity $\sim$ linear in $R$
- $+ \, \dot{M} = \alpha \sim 0.001$-0.01
- massive disks are larger
the evolution of disk structure: slow, then fast

.timeline

- formation
- viscous evolution (particle growth?)
- dissipation
- accretion + diffusion
- inside-out clearing (?)
- sedimentation + growth

1/2-life ~3 Myr
dust < few AU

[L-B & P 1974]
[Mamajek 2009]
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formation viscous evolution (particle growth?) dissipation

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[![Graph showing disk structure evolution](image)]
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the evolution of disk structure: slow, then fast

formation \rightarrow \text{viscous evolution (particle growth?)} \rightarrow \text{dissipation}

accretion + diffusion \rightarrow \text{inside-out clearing (?)}

sedimentation + growth

\[ \log \Sigma [g/cm^2] \]

\[ \text{radius [AU]} \]

\[ 0.100 \text{ Myr} \]

\[ \text{IR excess fraction [%]} \]

\[ \text{cluster age [Myr]} \]

\[ \text{dust < few AU} \]

\[ 1/2\text{-life } \sim 3 \text{ Myr} \]

\[ \lambda F_{\lambda} [\text{erg s}^{-1} \text{cm}^{-2} \text{Å}^{-1}] \]

\[ \lambda [\mu\text{m}] \]

\[ \text{[Furlan et al. 2009]} \]

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formation → viscous evolution (particle growth?) → dissipation

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[Sean Andrews
October 12, 2010 - SMA Advisory Committee Meeting]

dissipation

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transition disks: rapid clearing of the inner disk

missing warm dust near the star

resolving the disk cavity:

• size of cleared region
• properties of remnant disk
• contents of inner disk
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• ~1% (1 Myr); ~10% (3 Myr)  
  [Strom+ 1989; Muzerolle+ 2010]

• >100x less emission in cavity
• cavity sizes: $R \sim 20-40$ AU
• massive outer disks (>0.01 $M_\odot$)  
  [Pietu; Brown; Hughes; Isella; Andrews]

• lower accretion rates (~10%)  
• some material in cavity (gaps?)  
  [Espaillat+ 2007, 10]
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summary: disk structure, evolution, planet formation

SMA: dust sensitivity + angular resolution

“new” field of observational planet formation

1. disk densities
   - resolved radio emission $\rightarrow \Sigma$
   - $\Sigma$ varies like $1/R$ near star, tapered $1/e^R$ at large $R$

2. viscous evolution
   - viscosity ($\alpha$) $\sim$ MRI
   - mass correlated with size

3. rapid “transitions”
   - large, resolved cleared regions
   - very young (1 Myr) exoplanets?

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