Grain Growth and Substructure in Protoplanetary Disks

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From Dust to Planets

T Tauri & HAe stars
age 1-10 Myr
100’s at ~140 pc

Planetesimal formation

Collisional agglomoration

???
(collective effects)

Gravity-assisted growth

Gas capture

Planet formation

1 μm 1mm 1m 1km 1000km

NASA/JPL T. Pyle
Protoplanetary Disk Dust Emission

- mm/cm wavelengths
  - avoid high opacities mass tracer
  - sensitive to cold dust including mid-plane
  - sensitive to large dust grain growth
  - contrast with star planet-forming region
  - subarcsec imaging with high sensitivity EVLA!
  - sometimes ionized gas
Spectral Signatures of Growth

- mm/cm emissivity $\kappa \sim \lambda^{-\beta}$
- $\beta$ diagnostic of max size
- if optically thin, R-J
  $F \sim \kappa \Sigma T \sim \lambda^{-(\beta + 2)}$
EVLA Observations

• photometry survey
  – D/DnC/C arrays, ongoing
  – 60+ nearby disks at 7/9/13/50 mm
  – spectral indices for grain growth
  – statistics, e.g. star properties, environment

• image subsets at higher resolution, to 50 mas = few AU
  – C/CnB/B/BnA/A arrays, coming soon
  – locate large grains
  – surface density structure
  – evidence for disk-planet interactions
Example Taurus Images (Preliminary)

\[ \lambda = 9 \text{ mm (30.5 and 37.5 GHz)} \]
\[ \theta \sim 0.7 \text{ arcsec} = 100 \text{ AU} \]
spectral indices
Some Early Analysis

• compare with Birnstiel et al. 2010 models
  – self-consistent calculation of grain size distribution,
    coagulation/fragmentation and irradiated disk structure
  – predict mm/cm fluxes and spectral index $\beta$

$\alpha_{1-7\text{mm}} = 2 + \beta$

Table 1. Parameters of the model grid.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M_{\text{disk}}$</td>
<td>$5 \times 10^{-3}$, $1 \times 10^{-2}$, $5 \times 10^{-2}$, $1 \times 10^{-1}$</td>
</tr>
<tr>
<td>$\alpha_t$</td>
<td>$5 \times 10^{-4}$, $1 \times 10^{-3}$, $5 \times 10^{-3}$, $-$</td>
</tr>
<tr>
<td>$u_t$</td>
<td>$1$, $3$, $10$, $-$</td>
</tr>
<tr>
<td>$f_{\text{vac}}$</td>
<td>$10$, $30$, $50$, $-$</td>
</tr>
<tr>
<td>$\xi$</td>
<td>$1.0$, $1.5$, $1.8$, $-$</td>
</tr>
</tbody>
</table>

Notes. $M_{\text{disk}}$ is the total disk mass, $\alpha_t$ is the turbulence parameter, $u_t$ is the critical collision velocity, $f_{\text{vac}}$ is the grain volume fraction of vacuum, and $\xi$ is the index of the distribution of fragments. The parameters of the fiducial model are highlighted in bold face.
Resolved Disk Colors and Structure

efficient grain growth at highest densities?

disk-planet interactions?

surface densities and initial conditions?

Kokubo and Ida 2002

Hughes et al. 2007

217th AAS Meeting, Seattle, January 2011
Disks@EVLA: Summary

- grain growth and substructure in protoplanetary disks
- last observable link in chain from ISM to planets

- photometry of 60+ disks at 7/9/13/50 mm
  - spectral indices reveal large grains
  - reduction and modeling underway

- imaging of subsets, to 50 mas = few AU
  - expect resolved mm/cm colors
  - surface densities, disk-planet features

- thanks to EVLA commissioning team!