THE CONNECTION BETWEEN INNER AND OUTER DEBRIS DISKS PROBED BY INFRARED INTERFEROMETRY

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From Atoms to Pebbles – Herschel’s view of Star and Planet Formation
Grenoble, 22 March 2012
**Inner vs. outer debris disk**

- **T ~ 40 K**
  - Prominent far-IR excess
  - Easy to resolve (>1")

- **T > 300 K**
  - Small near/mid-IR excess
  - Difficult to resolve (< 0.1")

Lisse et al. 2012
Infrared interferometry may help

- Disk larger than angular resolution ($\lambda/B$) \(\rightarrow\) incoherent flux
  - Induces a visibility drop at all baselines
- Best detected at short baselines (~10-30m)

\[ \nu^2 \approx (1 - 2 \frac{2 J_1(\pi b \theta / \lambda)}{\pi b \theta / \lambda})^2 \]

Flux ratio

Requires very good accuracy (<1%)

Resolved at 200m

~2 mas

~40 mas \(\rightarrow\) resolved at 10m
HIGH PRECISION INTERFEROMETERS

FLUOR at CHARA

(IONIC at IOTA)

(VINCI) PIONIER at VLTI
Vega viewed by CHARA/FLUOR

Mean $\theta_{LD}$: $3.32 \pm 0.005 \pm 0.013$ mas

Disc/star: $1.26 \pm 0.27 \pm 0.068 \pm 2.92$

$\chi^2_r = 1.18$
Radiative transfer modeling

- H- and K-band interferometry (CHARA/FLUOR, IOTA/IONIC)
- N-band nulling interferometry (MMT/BLINC)
- Archival near- to mid-IR spectro-photometry
MOST PROBABLE DUST PROPERTIES

- Bayesian $\chi^2$ analysis of large parameter space
  - Grains < blowout size
  - Hot grains (> 1000 K)
  - Presence of carbons ≥ 10%
  - Distance: ~ 0.1 – 0.5 AU
  - Steep density power law: $\alpha < -3 \rightarrow$ ring?

- Mass: $\sim 2 \times 10^{-9} M_{\text{Earth}}$

- Luminosity: $\sim 5 \times 10^{-4} L_{\text{star}}$

(same approach as in Lebreton et al.)
**Next step: low-resolution spectra**

- Dispersed fringes with PIONIER (soon FLUOR)
  - Flux ratio measurements across H and/or K band
  - Direct constraint on dust temperature

![Graph showing flux vs. wavelength](image)

Defrère et al. (in prep)
**Origin of hot dust: steady state?**

- Local production?
- Connection to outer disk?
  - Poynting-Robertson drag?
  - Multiple scattering of comets?
STEADY STATE MULTIPLE SCATTERING

- Requires 3+ planets and $10^3 M_E$ in cold reservoir
**Origin of hot dust: transient?**

- **Isolated event?**
  - Large collision (e.g. Earth-Moon)
  - Break-up of giant comet

- **Dynamical perturbations?**
  - Falling Evaporating Bodies
    - Asteroid belt disturbed by MMR with massive planet
  - Late Heavy Bombardment
    - Global rearrangement

- **Statistical study may help**
Debris disk survey at CHARA/FLUOR

- Magnitude-limited sample ($K < 4$)
  - 25 cold disk host stars (dec > -15°)
  - “Unbiased” control sample: 25 stars w/o cold dust
- Observed most stars, ~42 of sufficient quality
- One surprise: companion to epsilon Cephei

![Graph](image)

Mawet et al. 2011

330 mas separation, 2% flux ratio
Many more K-band excesses than anticipated!
- Still need confirmation that this is (only) dust

A-type stars more prone to hot dust
- Same trend as in cold disks, frequency compatible
- Suggests that they could be related (scattering?)

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**Hot dust (Absil et al., in prep)**

<table>
<thead>
<tr>
<th>Spectral Type</th>
<th>Exozodi Detection Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>38%</td>
</tr>
<tr>
<td>F</td>
<td>21%</td>
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<tr>
<td>GK</td>
<td>27%</td>
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</tbody>
</table>

**Cold dust (Spitzer/MIPS24+70)**

<table>
<thead>
<tr>
<th>Spectral Type</th>
<th>DEBRIS</th>
<th>DUNES</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>30%</td>
<td>37%</td>
</tr>
<tr>
<td>A</td>
<td>26%</td>
<td>20%</td>
</tr>
<tr>
<td>F</td>
<td>33%</td>
<td>25%</td>
</tr>
<tr>
<td>G</td>
<td>16%</td>
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<tr>
<td>FG</td>
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<td></td>
</tr>
<tr>
<td>K</td>
<td>16%</td>
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</tbody>
</table>
**Preliminary Statistics vs. Cold Dust**

- No correlation with cold dust reservoirs
  - Suggests transient event rather than steady state

![Graph showing exozodi detection frequency with and without cold dust](image-url)

- Exozodi detection frequency
  - Cold dust: 32%
  - No cold dust: 25%

*Hot dust (Absil et al., in prep)*
EXOZODI project (French ANR, 2011-2015)

- Extend survey to confirm statistics (goal: 200 stars)
  - North: refurbished FLUOR at CHARA
  - South: PIONIER at VLTI (Le Bouquin et al.)
- Investigate age dependence
- Follow up detections
  - Discriminate with potential binaries
  - Multi-color information for SED modeling
- Search for variability
- Improve models (RT, dynamics, collisions)