The CHARA/FLUOR survey of debris disk stars: results and statistics

Zodiacal dust in the Solar system

• Within ~1 AU, the inner solar system is filled with dust near the ecliptic plane

• Origin:
  • Comets (90%, Nesvorny et al. 2010)
  • Asteroid collisions

• It’s not a smooth cloud:
  • Dust bands: asteroids families?
  • Resonant ring caused by the Earth
Why we care about exozodiacal dust?

**Exozodiacal dust** = dust clouds in and around the habitable zone of stars

1. Understand exoplanetary systems
   - Planetary system formation and evolution theories
   - Dust-planet interaction

2. Prepare future exo-Earth imaging missions
   - Solar zodiacal cloud ~300 times brighter than Earth (IR and Visible)
   - Asymmetric features can mimic the planetary signal
What do we know? …not much

• Single-dish photometry
  ✓ Spitzer: ~1% of 152 main-sequence stars (Lawler et al., 2009)
  ✓ WISE: ~1% of 350 main-sequence stars (Morales et al. 2012)
  ✓ Sensitivity threshold ~1000 zodis

• Infrared interferometry
  ✓ KIN: ~10 detections out of 41 main-sequence stars (Millan-Gabet et al., 2011, Mennesson et al. in prep).
  ✓ VLTI/MIDI: HD 69830 and η Crv (Smith et al., 2009), HD 113766 and HD 172555 (Smith et al. 2012), β Pic (di Folco et al., in prep).
The observing challenge

- High contrast ($\geq 1:100$)
- Small angular separation
  - Inner disc: a few 10 mas
  - Requires IR interferometry

![Graph and image of a disk with flux vs. wavelength and temperature range](image)
Detection strategy

• Disc larger than angular resolution ($\lambda/b$) $\Rightarrow$ incoherent flux
• Induces a visibility deficit at all baselines
• Best detected at short baselines

\[ V^2 \approx (1 - 2f) \left( \frac{2J_1(\pi b \theta / \lambda)}{\pi b \theta / \lambda} \right)^2 \]

Requires very good accuracy ($\sim 1\%$)

Fully resolved at $\sim 200$ m

Fully resolved at $\sim 10$ m
Detection strategy

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![Graph showing detection strategy]

- Fully resolved at $\sim 200$ m
- Fully resolved at $\sim 10$ m
Origin of the survey

• First detection in 2005 around Vega (Absil et al. 2006):
  • Initial excess detection of 1.29% +/- 0.19% in the K-band
  • Confirmed 1-year later by IOTA/IONIC in the H-band (Defrère et al. 2011)
First results of the survey

- Survey initiated in Fall 2006:
  - Paper 2 (di Folco et al. 2007): two stars – one detection ($\tau$ Ceti, G8V, $\sim$10Gyr,).
  - Paper 3 (Absil et al. 2008): 7 additional stars -- one detection ($\zeta$ Aql, companion thought to be a possibility at that time)
Survey overview
1. The target sample

• Selection criteria:
  ✓ Well sampled across spectral types;
  ✓ Similar quantity of stars with and without outer dust disks;
  ✓ No binary (<5”).

• The final sample:

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>F</th>
<th>G-K</th>
<th>Total</th>
</tr>
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<tbody>
<tr>
<td>Outer reservoir</td>
<td>7</td>
<td>7</td>
<td>5</td>
<td>19</td>
</tr>
<tr>
<td>No outer reservoir</td>
<td>5</td>
<td>8</td>
<td>10</td>
<td>23</td>
</tr>
<tr>
<td>Total</td>
<td>12</td>
<td>15</td>
<td>15</td>
<td>42</td>
</tr>
</tbody>
</table>
## Survey overview

### 2. Observing schedule

<table>
<thead>
<tr>
<th>Year</th>
<th>Observations</th>
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<tbody>
<tr>
<td>2006</td>
<td>91 OBs on 14 stars</td>
</tr>
<tr>
<td>2007A</td>
<td>fire shutdown</td>
</tr>
<tr>
<td>2007B</td>
<td>8 OBs on 14 stars</td>
</tr>
<tr>
<td>2007</td>
<td>85 OBs on 17 stars</td>
</tr>
<tr>
<td>2009</td>
<td>108 OBs on 20 stars</td>
</tr>
<tr>
<td>2010</td>
<td>76 OBs on 12 stars</td>
</tr>
<tr>
<td>2011A</td>
<td>127 OBs on 14 stars</td>
</tr>
</tbody>
</table>
Examples of new detections
Examples of new detections
Examples of marginal detections

For bet_Leo - base S1-S2:
- Disk/star: $0.94 \pm 0.25 \pm 0.06\%$
- $\chi^2 = 5.50$
- Mean $\theta_{LS} = 1.342 \pm 0.013$ mas

For ups_And - base S1-S2:
- Disk/star: $0.53 \pm 0.17 \pm 0.01\%$
- $\chi^2 = 2.62$
- Mean $\theta_{LS} = 1.114 \pm 0.009$ mas
Examples of non-detections
ε Cep: a clear binary

2008-2009 FLUOR data

2010 coronagraphic image (Palomar)

Mawet et al. 2011

K8-M2 companion

K=7.8

>8.6 AU (>320 mas)
Statistical analysis

Bimodal distribution:
- Gaussian non-detection
- Group of detection peaked at 4-$\sigma$

No negative detection below 3-$\sigma$
Statistical analysis

Bimodal distribution:
- Gaussian non-detection
- Group of detection peaked at $4\sigma$

No negative detection below $3\sigma$
Statistical analysis
1. Excess frequency vs spectral type

- A: 54%
- F: 21%
- GK: 14%
Statistical analysis
1. Excess frequency vs spectral type

![Graph showing occurrence rate vs spectral type for A stars and FGK stars.](image-url)
Statistical analysis

2. Excess frequency vs cold dust presence

- Outer reservoir: 37%
- No outer reservoir: 23%
Statistical analysis

2. Excess frequency vs cold dust presence

- Spectral type matters for stars with no outer reservoir
- Different mechanism?
- Only 5 A stars without outer reservoir

![Bar chart showing K-band excess frequency for A stars, F stars, and GK stars with and without outer reservoirs.](chart.png)
Statistical analysis

3. Excess frequency vs age and fractional age

- No significant trend
Statistical analysis

3. Excess frequency vs stellar metallicity

- No significant trend
Statistical analysis

4. Excess frequency vs fractional luminosity
Statistical analysis
4. Excess frequency vs fractional angular velocity

- Near-IR emission of winds from <1.5 R* (would not be resolved)
- Mass-loss of A stars expected to be very low.
The quest for hot dust continues

- FLUOR is now JOUFLU (see Scott’s and Mennesson’s talks)
- Ongoing survey in the Southern hemisphere with VLTI/PIONIER
  - Spectral information (H and K bands)
  - ~100 stars observed (Ertel et al., in prep)
  - First detection: β Pic (Defrère et al. 2012):
The quest for warm dust too

• LBTI is underway:
  ✓ Will reach the level required to prepare future exoEarth imaging instruments (10 zodis at 10 microns)
  ✓ First null data obtained in September 2012 (in open-loop)
  ✓ See next talk!
THANK YOU
The problem for direct imaging

- Visible: $10^{-10}$ fainter
- IR: $10^{-7}$ fainter

Current state of the art:
- Fomalhaut b: $10^{-9}$, but 150x separation
- HR 8799b: $10^{-4}$ but 17x sep.

Our Zodiacal dust cloud:
- 1 zodi = ~300x Earth at 550 nm and 10 µm.