Debris Disks: Now and the future

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Outline

- What are debris disks?
- Recent results: surveys
- Now and the near future: ALMA
- Future missions: sub-arcsec imaging in mid-IR
- Conclusions
Evidence for a disk?

- Infrared emission from a star brighter than the photosphere (e.g. 70K excess for Fomalhaut)

**Observables**

- **Optical**
  - scattered light (Hubble)

- **Far-IR**
  - dust emission (*Herschel/PACS*)

- **Submm**
  - dust emission (*JCMT/SCUBA-2 and ALMA*)
## Descendant of proto-planetary disk

<table>
<thead>
<tr>
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<th>Proto-planetary disk</th>
<th>Debris disk</th>
</tr>
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<tbody>
<tr>
<td><strong>Age</strong></td>
<td>&lt; 10 Myr</td>
<td>10 Myr – 10 Gyr</td>
</tr>
<tr>
<td><strong>Optical depth</strong></td>
<td>Optically thick</td>
<td>Optically thin</td>
</tr>
<tr>
<td><strong>Dust mass</strong></td>
<td>&gt; 10 $M_{\text{Earth}}$</td>
<td>&lt; 1 $M_{\text{Earth}}$</td>
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<tr>
<td><strong>Gas mass</strong></td>
<td>$\sim$100x dust mass</td>
<td>Very little (usually...)</td>
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<tr>
<td><strong>Structure</strong></td>
<td>Dust from 0.1 – 1000 AU</td>
<td>Confined to 30 – 100 AU ring</td>
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<td><strong>Dust origin</strong></td>
<td>Primordial?</td>
<td>Secondary (short lifetime)</td>
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Onset of the debris phase
(Panić et al. 2013, MNRAS 435, 1037)
Debris disks and planets

- Structure provides indirect information on the architecture (and evolution) of a possible planetary system

- Structure also can be used to predict and identify perturbers, such as planets
Observations probe different zones

- Different wavelength observations probe multiple components of a disk

If a single component dominates (such as a Kuiper belt) then multi-wavelength observations probe different grain sizes
Observations probe different zones

- Different wavelength observations probe multiple components of a disk

If a single component dominates (such as a Kuiper belt) then multi-wavelength observations probe different grain sizes
Multi-wavelength surveys

Why carry out surveys of debris disks?

Statistics, resolved images, detection of gas and the possible discovery of new classes of object...

- IRAS, ISO, & SCUBA: photometry and “imaging” → early information on basic properties
- Spitzer: Surveys of A-stars → studying dust evolution
- Herschel: DUNES and DEBRIS → 50% of debris disks are resolved
- JCMT: SONS → cold and massive disks
Diversity of disks!

Sample of 110 nearby stars:

- Imaged new (cold) debris disks at 850µm
- 43/100 disks so far detected
- Many of the detected disks have been resolved
- Wide range of morphologies and typically a few times the size of KB in our Solar System (but more massive)
Key results so far (and issues...)

- Disk incidences are reasonably well measured by *Spitzer* and *Herschel*

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Absil et al. 2013, A&A 555, 104  
Thureau et al. 2014, *in prep*  
Sibthorpe et al. 2014, *in prep*  
Liu 2004, Science 305, 1442  
Matthews et al. 2014, *in prep*
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*Comparable to planet rate discovered by Kepler*

Except for very young M stars, these remain elusive!

Generally good agreement at all wavelengths
Key results so far (and issues…)

- Disk incidences are reasonably well measured by Spitzer and Herschel

- Evidence of declining disk mass and luminosity over time
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- Tentative correlation between low-mass planets and debris disks

Nearest 60 G stars:

4/6 with low-mass planets have debris

0/5 with high mass planets have debris
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Nearest 60 G stars:
4/6 with low-mass planets have debris
0/5 with high-mass planets have debris

Planets start off at 5-10 AU and migrate inwards → many planetesimals end up beyond the outermost planet in a dynamically stable system

Key results so far (and issues...)

- An improvement in angular resolution is key to understanding disk structure.

Images give inclination and position angle.

Can derive other physical parameters such as dust luminosity and mass, and information about dust grain sizes and composition.

Spectral energy distribution
Fit for $T_{\text{dust}}$, $r_{\text{disk}}$, and spectral slope.

NAME FOMALHAUT

AME-Cend
$T_{\text{dust}}$: 8577 ± 99 K
$R$: 1.86$R_{\odot}$
$Z_{\text{dust}}$: 0.273
Significance(σ): 49.5
$T_{\text{dust}}$: 39±2K
$f$: 5.2E-05
$\lambda_c$: 58±17μm
β: 1.2±0.1
$X_{\text{dust}}$: 3.12
Key results so far (and issues...)

- Debris disks are faint

It is quite possible that **ALL** stars have a debris disk at some level (below current detection thresholds)
Key results so far (and issues...)

• An improvement in angular resolution is key to understanding disk structure

• Debris disks are faint

Lack of both sensitivity and resolution to study the warmer inner regions – probing the realm of terrestrial planets and the “habitable zone”

• Warmer inner regions of exo-systems – Asteroid Belt analogs?
Key roles for ALMA

- Resolving disks is key to understanding the underlying structure of debris disks

- Unambiguous identification of dust trapped in resonances with a planet

- Sensitivity to detect perturbations within disks on short timescales e.g. rotation of $\varepsilon$ Eridani clumps in 1 month!

...But deep spectroscopy will be important to study comet collisions that should produce $H_2O$ and CO
The role of ALMA

- Distinguish between models that have VERY different implications for the structure and evolution of a planetary system

Belt shepherded by planets  
Outward migrating planet at inner edge  
Late heavy bombardment  
Planets still growing in outer regions
Sub-arcsec observations in the mid/far-IR

- Explore the warmer inner regions, but also have the range to characterise systems with multiple dust belts

- Would have information on zodiacal and asteroid belt dust – regions that could affect the evolution of habitable planets
Sub-arcsec observations in the mid/far-IR

- What are the requirements?

The angular resolution to resolve structure in Kuiper and asteroidal belts around other stars.

For example, an asteroid belt at 10 pc has a diameter of ~1 arcsec – so a facility like FIRI at 40µm would be perfect.

<table>
<thead>
<tr>
<th>FIRI (100m baseline)</th>
<th>30µm</th>
<th>40</th>
<th>100</th>
<th>200</th>
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<tr>
<td>FWHM beam (arcsec)</td>
<td>0.07</td>
<td>0.1</td>
<td>0.25</td>
<td>0.5</td>
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Sub-arcsec observations in the mid/far-IR

- What are the requirements?

Sensitivity to reach very low dust mass levels.

A facility such as FIRI will be able to measure the equivalent of both our Kuiper and Asteroid Belts around nearby stars.

Also:

Line-rich wavebands (covered by the 30-300µm range – OI at 63µm, for example)

Perhaps even a coronograph for the brightest, nearby stars... (or at least very good control of the PSF)
Summary

- Studying debris disks provides a unique insight into the evolution of a planetary system
- Observations have increased enormously over the past decade
- Theory needs to address issues such as the main mechanism that stirs debris disks (planets, planetesimals or both?)
- Recent results suggest a positive correlation between debris disks and planets; however, whether dusty debris implies a planetary system must exist remains an open question.
- ALMA and JWST in the near future and FIRI downstream will be important for taking this research to the next level
Acknowledgements

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