Herschel's view on the Fomalhaut debris disk

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Fomalhaut

- 2 $M_\odot$, A3V, 200 Myr, 7.7pc
- Disk discovered 1985 with IRAS, one of the “big four”
- One of the most important imaging targets
SCUBA @ 850µm

- edge-on doughnut
- diameter 315 AU
- cavity
- clumps due to large collisions?
  - probably not

Holland et al 1998
Holland et al 2002
Wyatt & Dent 2002
Spitzer @ 24, 70, 160µm

Inner hole partially filled
Asymmetry

Stapelfeldt et al 2004
CSO/SHARK II @ 350µm

- i=70 degrees
- center displaced by 8 AU, planet with e=0.06?

Marsh et al 2005
Size distribution

\[ f(a) \propto a^{-3.5} \]

Ricci et al 2012
Prior Art: Hubble @ optical

Kalas et al 2005, 2008
Chiang et al 2009
<table>
<thead>
<tr>
<th></th>
<th>HST/optical</th>
<th>Herschel/70µm</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>141 ± 2</td>
<td>137 ± 0.9</td>
</tr>
<tr>
<td>(e)</td>
<td>0.11 ± 0.01</td>
<td>0.125 ± 0.006</td>
</tr>
<tr>
<td>(i)</td>
<td>65.6 ± 0.4</td>
<td>65.6 ± 0.5</td>
</tr>
<tr>
<td>(\Omega)</td>
<td>156.0 ± 0.3</td>
<td>156.9 ± 0.5</td>
</tr>
<tr>
<td>(\omega)</td>
<td>31 ± 6</td>
<td>1 ± 6</td>
</tr>
<tr>
<td>Offset</td>
<td>15 ± 1</td>
<td>17.2 ± 0.9</td>
</tr>
</tbody>
</table>
Photometry and SED

400 AU aperture, uncertainties 10%
10% calib. errors

Added values from SPITZER, stellar photometry, and SCUBA
3 component model

1. Source ring of colliding planetesimals with equilibrium cascade and redistribution by radiative forces.

2. Central unresolved component

3. Powerlaw surface density to reproduce residual emission inside the source ring (PR grains?)
Semi-analytical model for the dust

Fig. by M. Wyatt

\[ F = -\frac{GM_*}{r^2} (1 - \beta) \]

\[ \beta = \left| \frac{F_{\text{rad}}}{F_{\text{grav}}} \right| \propto \frac{\sigma}{m} \propto \frac{1}{s} \]
Radial distribution of particles
Radial distribution of particles

\[ f(a) \propto a^{-3.5} \]

f(replenishment)
Constructing the SED

Big grains, 73% of Flux
Blowout grains, 27% of Flux
Modeling results: Main Ring

- Source ring from 133 to 153 AU
- Contains $8 \times 10^{25}$ g below 5000µm.
- Many grains below the blow-out size (13µm) needed to get the SED, the color, and the extend of the images correct
- Replenishment time $\sim$1700 yr
- Mass in blowout grains $\sim 3 \times 10^{24}$ gram
- Mass loss rate (= mass production rate): 2000 1km comets/day
- $\sim 10^{13}$ comets to sustain over 200Myr
Modeling results:
Inner disk and central point

**Inner disk**
- $8 \times 10^{25} g$ in grains up to 5000 $\mu$m
- Surface density increases linearly with $r$
- 21-29% of flux in HERSHEYEL images

**Central point**
- 50% of stellar flux at 70$\mu$m
Grain model

- Icy grains with 25% vacuum by volume
- Amount of dust in blowout grains is robust and nearly independent of the grain model (including pure silicate models)
- Because heating and radiation pressure are both due to absorption properties.
Scattering constraints
Interaction of large grains with radiation has three components:

- Absorption: 40-45%
- Reflection: 5-10%
- Diffraction: 50%
Scattering constraints

- Single scattering albedo very low (few %, Kalas et al. 2005)
- Can only be understood if the grains are:
  - extremely small (<0.1 μm)
  - large enough such that the diffraction spike is invisible (Min et al. 2010)
- Large fluffy aggregates
  - Absorption properties scale with the small constituents: Warm and will be blown out
  - Scattering properties scale with the large aggregate size: Diffraction spike outside of observable domain

Reflection curve
Thank You!