The Fomalhaut Debris Disk

- Fomalhaut is a bright A3 V star 7.7 pc away
- IRAS discovered an IR excess indicating a circumstellar disk
- Interesting because Fomalhaut is a MS star...why hasn't dust settled or been blown away?

IRAS 12 micron
http://ssc.spitzer.caltech.edu/documents/compendium/fomalhaut/
Fomalhaut in sub-mm

- Holland et al. (1998) resolved Fomalhaut at 850 µm
- Total dust from only a few Lunar masses (indicating planets within should already have formed)
- Main dust emission from ring at ~100 AU (comparable to Kuiper belt comets wrt Sun)
- Central cavity approximately size of Neptune's orbit.
- Determined the disk is a ring or torus of 280 AU diameter 20° from edge-on
- Ring is clumpy. Southern “lobe” has higher flux
The Fomalhaut Debris Disk

- Barrado y Navascues (1998) isolated the Castor co-moving group (including Fomalhaut and Vega) using location on HR, stellar activity and Lithium abundances.
- Found the group was ~200 Myr old, and that different A stars had different IR excesses.
- This indicates these disk emissions do not depend on age (as with proto-planetary disks), so disk is probably due to collisions of large bodies!
What's Going On?

Collisional cascade model:

- Planetesimals form from accruing dust grains in the first 10Myr or so (nothing new)
- Planetesimals start colliding, reversing the process and creating more IR-radiant dust
- Net destruction over growth
- Likely due to an increase in relative velocity from removal of gas and gravitational perturbations from larger planetary bodies
- With higher rel. velocities, large collisions lead to a collisional cascade
- Only grains big enough to survive radiation pressure stay in the debris disk (> a few microns)
- Collisional time scale shorter than that of Poynting-Robertson drag, so the dust could exist in a disk before losing angular moment and spiraling in

**Figure 8.** Inferred size distribution of planetesimals in Fomalhaut’s disc: a collisional cascade extends from ~4 km planetesimals down to 7 μm dust grains. Smaller dust grains are blown out of the system by radiation pressure. At submm and shorter wavelengths, we only see those members smaller than 0.2 m. Planetesimals larger than ~4 km have an unknown primordial size distribution, however a reasonable distribution may be one that extends up to 1000 km with the same slope as the cascade (see Section 5.3). Planetesimals larger than ~1000 km, if they exist, must have grown by runaway growth and would form a separate population (see Section 7.2).

Wyatt and Dent. 2002
**Disk Clumpiness**

- Debris disks from impacts will tend to be clumpy as material moves away from impact site
- Debris would form an expanding clump from impact site
- Work done to model clumps as a function of collision parameters can not fully explain the single 30 mJy clump seen in Fomalhaut
- Wyatt and Dent suggest clump in Fomalhaut due to resonance with inner planet, probably not left over from a collision

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**Figure 11.** The clump function, $N(\theta < 180^\circ, > F_{\text{cl}})$, of the Fomalhaut disc, i.e. the number of clumps we expect to see that are brighter than $F_{\text{cl}}$ but smaller than $180^\circ$ in azimuthal extent. The solid, dotted and dashed lines correspond to the models for the collisional properties of Ice, Weak Ice and Basalt described in the text. The two lines for each model assume that the size distribution with $q_{\text{d}} = 1.84$ extends up to maximum planetesimal sizes of 4 km and 1000 km. The intrinsic clumpiness of the disc [the $F_{\text{cl}}$ at which $N(\theta < 180^\circ, > F_{\text{cl}}) = 1$] is shown by the horizontal long-dashed line. Its observed clumpiness, $F_{\text{cl}} = 30$ mJy, is shown by the vertical long-dashed line. For collisions to be the likely cause of this clumpiness we would expect the clump function to pass through the intersection of these lines.

Wyatt and Dent. 2002
Disk Clumpiness

- Wyatt et al. 2002 propose ~5% of planetesimals in debris disk became trapped in resonance with an inner planet.
- Inner Planet migrated out with the clearing of residual planetesimal disk.
- Mass and age of Fomalhaut debris disk comparable to that of Neptune's migration and resonant trapping of Kuiper belt objects.

Staplefield et al. 2004
Fomalhaut with Spitzer in IR

- Subtraction of best-estimate PSF of star in 24 µm shows compact residual excess emission inward
- 24 µm compactness at r<20 AU could be an inner asteroid belt? (sub-mm cavity makes this tenuous)
- Slope of spectrum between 20 and 30 µm suggests $1/r$ radial density distribution

Stapelfeldt et al. 2004
Fomalhaut Recently Resolved in Optical!

- Center of ring offset from star by 13.4 AU ± 1
  - Compelling evidence for interaction with an inner planetary body.
  - Disk has estimated eccentricity of 0.11 ± 0.01 after correcting for inclination i = 65.6° ± 0.4°
- Clumpy ring with inner radius at ~133 AU
  - Clumpiness from CM of collided bodies or gravitational interaction with inner planet?
Lots of Work to be Done!

- Lot's 'o data for modeling dust-producing collisions and subsequent gravitational perturbations
- Debris rings become a planet detection tool
- Could debris rings be a natural stage in planet formation?
- How do debris rings effect terrestrial planet formation?
- Great science goals for JWST
References

• Barrado y Navascues, D. 1998. AA, 339, 831
• Kenyon, S.J. and B.C. Bromley. 2001. AJ, 121, 538