Outer Solar System Dust (Theory)

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Inner Zodiacal Cloud (IZC) dust at r<5.2 AU

Outer Zodiacal Cloud (OZC) dust at r>5.2 AU
Dynamical Model of Zodiacal Cloud

- **Sources**

  Main-belt asteroids (MBA)
  Kuiper belt objects (KBO)
  Jupiter-family comets (JFC)
  Halley-type comets (HTC)
  Oort-cloud comets (OCC)

- Orbits of source objects corrected for biases

- E.g., orbits of active/dormant JFCs taken from integrations of objects evolving from the Kuiper belt  
Dynamical Model of Zodiacal Cloud

- **Orbit Integrations**
  
  Particles launched from their source objects and tracked by $N$-body code

- Radiation pressure, Poynting-Robertson drag, planetary perturbations

- Particle diameters:
  
  $D = 1$-1000 mm

- Collisional removal on $t_{\text{col}}(D)$
  
  ($t_{\text{col}}(D)$ consistent with Grun et al. 1985)
Dynamical Model of Zodiacal Cloud

- **Thermal emission**
  
  particles assumed to be isothermal, rapidly rotating spheres
  
  gray-body emission at T(R)

- **Synthetic Observations**

  2 codes (analytic/particle) to mimic IRAS, COBE or any telescopic IR observations
  - particle code similar to SIMUL (Dermott et al. 1988, 2001)
Inner Zodiacal Cloud

- IRAS observed thermal emission from IZC particles in mid-infrared wavelengths
- Produced full sky coverage by scanning in circles at fixed solar elongation
- We combined IRAS data into representative scans at 90 deg solar elongation

![IRAS data graph](image)
Results: Not so good fits for asteroids

Asteroid particles (various D)  Asteroid + OCC particles

Ecliptic Latitude (deg)

Flux (MJy/sr)
Results: Great fits for JFCs

JFC particles (various D)

94% JFC + 6% OCC

Flux (MJy/sr)

Ecliptic Latitude (deg)

10mm

1mm

residuals

100mm
Results: JFC fits at IRAS wavelengths

Implication: JFCs produce ~90%, D~100 mm
Results: Asteroids/OCC contribute <10%
Implications for Outer Zodiacal Cloud

- Asteroids do not contribute to OZC at a significant level
- JFC do because ~60% of JFC particles are located beyond 5 AU
- Use IRAS calibration of JFC particles in the IZC and extrapolate results to > 5 AU
JFC distribution drops with R, Pioneer fluxes constant for R>5AU
Evidence for KB dust from Pioneer fluxes

Landgraf et al. (2002): \( \sim 6 \times 10^{11} \) s\(^{-1} \) particles >10mm produced in KB
Simple two-source model (KB + JFC)
Model IR fluxes as observed from 5 AU
(KB particles, 90 deg solar elongation)

released with $i=5$ deg

70mm
160mm
850mm

i=20 deg

Flux (MJy/sr)

Ecliptic Latitude (deg)
Model IR fluxes as observed from 5 AU
(90 deg solar elongation)

JFC particles

KB particles, $i=20$deg

Flux (MJy/sr)

Ecliptic Latitude (deg)
Summary

- Inner ZC produced by (spontaneous) disruptions of JFCs; minor contribution from asteroids, OCCs, etc.

- Outer ZC beyond 10 AU has a dominant KB contribution; flat (or perhaps slightly rising) radial # density for r>10 AU

- Latitudinal profile of the outer ZC emission sensitive to the inclination distribution of KB particles at 30-50 AU

- Nominal 70-mm model fluxes ~1-3 MJy sr⁻¹ near the ecliptic, but large uncertainty due to unknown SFD
How to explain nearly constant Pioneer fluxes at \( r > 5 \text{ AU} \)?

- Main mass loss in JFCs is their disruptions/splitting events (Weissman 1980, Boenhardt 2004, Di Sisto et al. 2009)

- In our simple model of IZC, JFCs disrupt within \( \sim 10 \text{ ky} \) after becoming visible
  - released JFC particles initially concentrate at heliocentric distance \( r=3-5 \text{ AU} \)

- Recently, Di Sisto et al. (2009) suggested that splitting events have a very weak dependence on \( r \) (\( \sim 1/r^{1/2} \))
  - more JFC particles released at large \( r \)