Outer Solar System Dust (Theory)

David Nesvorny
(SwRI)

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

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

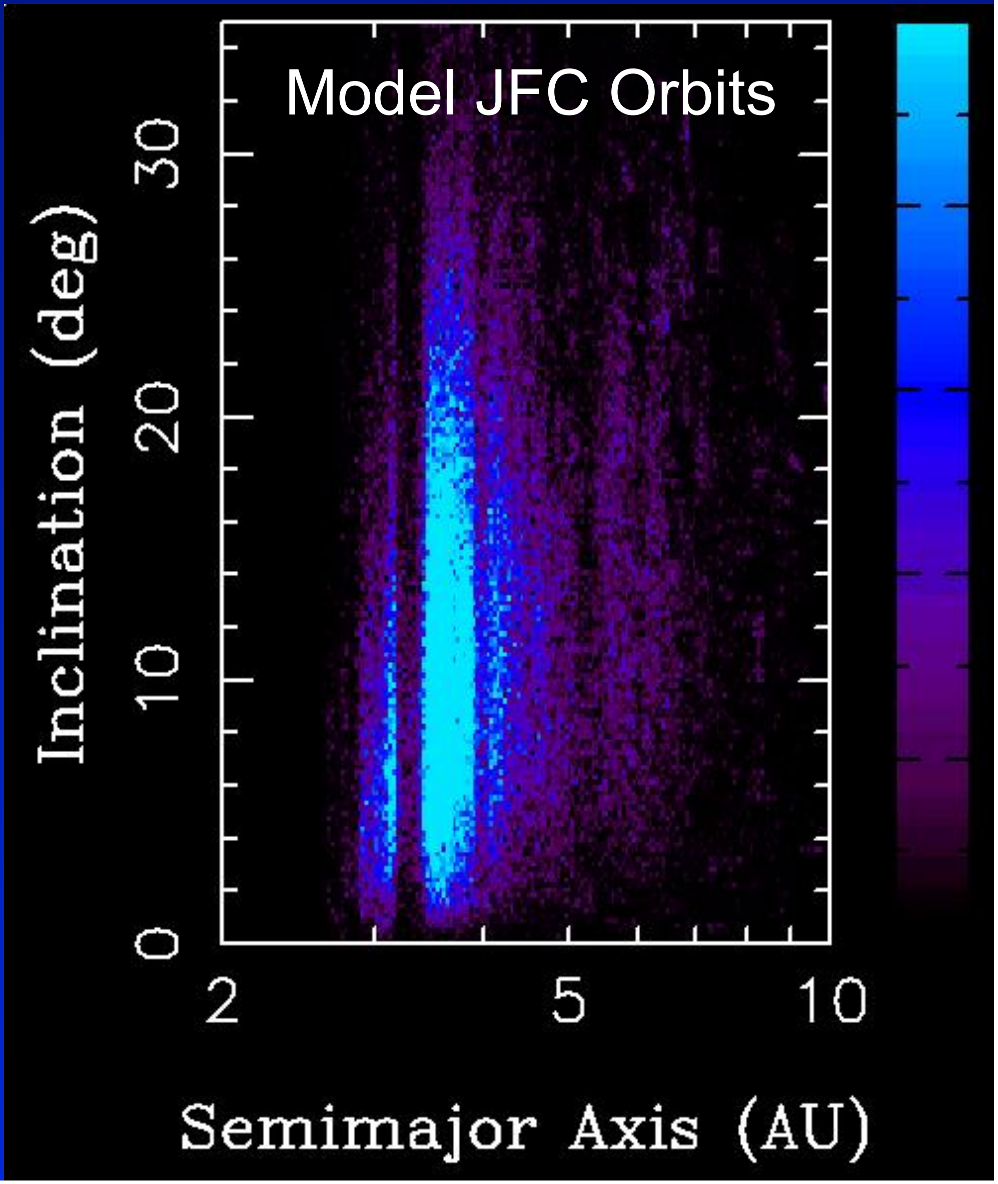
Dynamical Model of Zodiacal Cloud

- 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 Levison & Duncan 1997, Di Sisto et al. 2009



Dynamical Model of Zodiacal Cloud

- Orbit Integrations

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

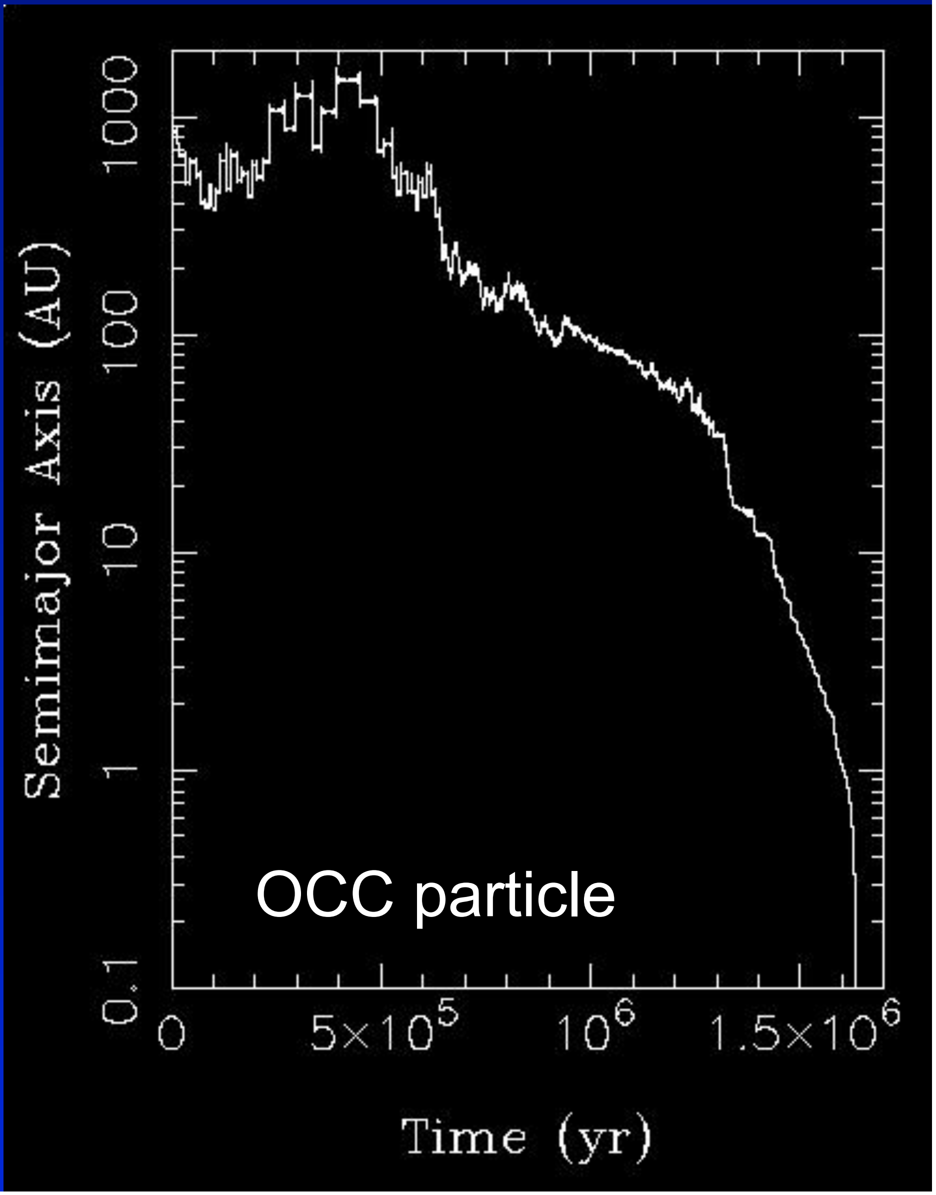
- Radiation pressure, Poynting -Robertson drag, planetary perturbations

- particle diameters:

  D=1-1000 mm

- Collisional removal on $t_{col}(D)$

  ($t_{col}(D)$ consistent with Grun et al. 1985)



Dynamical Model of Zodiacal Cloud

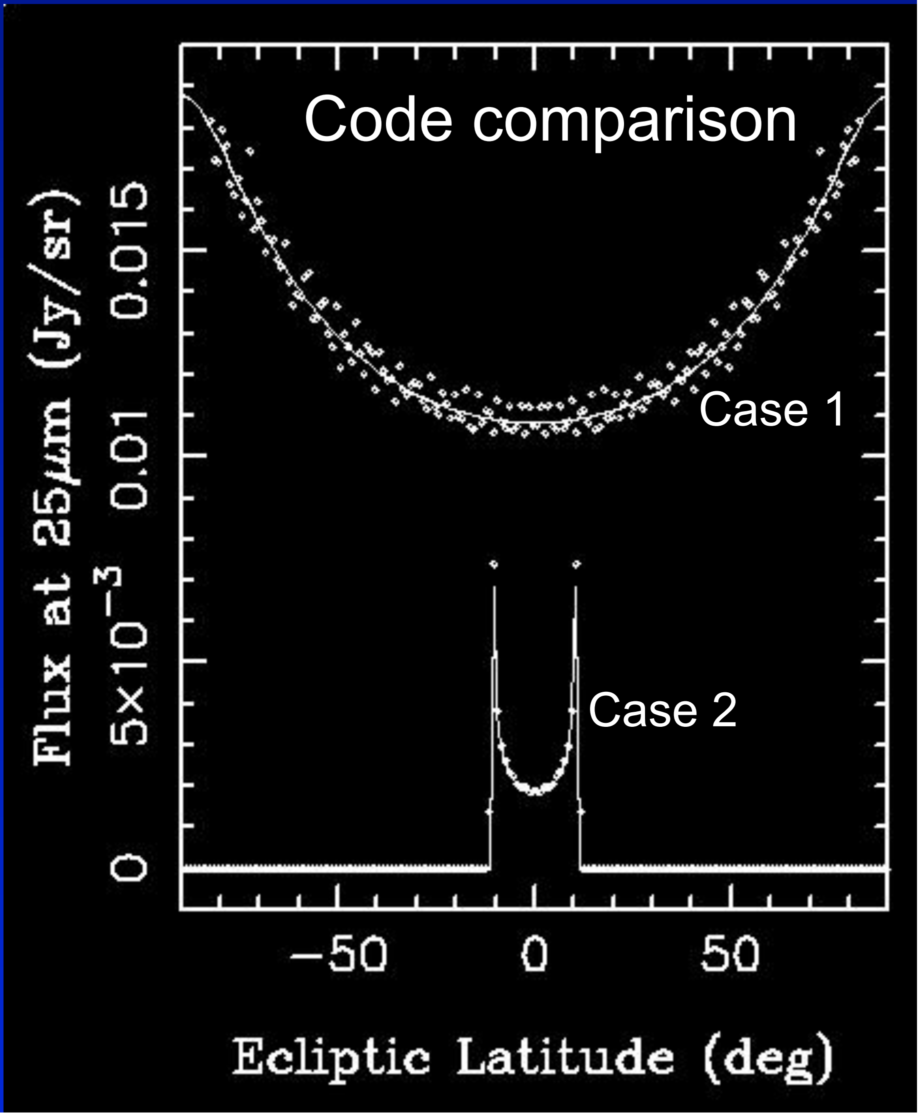
- Thermal emission

  particles assumed to be isothermal, rapidly rotating spheres

  gray-body emission at T(R)

- Synthetic Observations

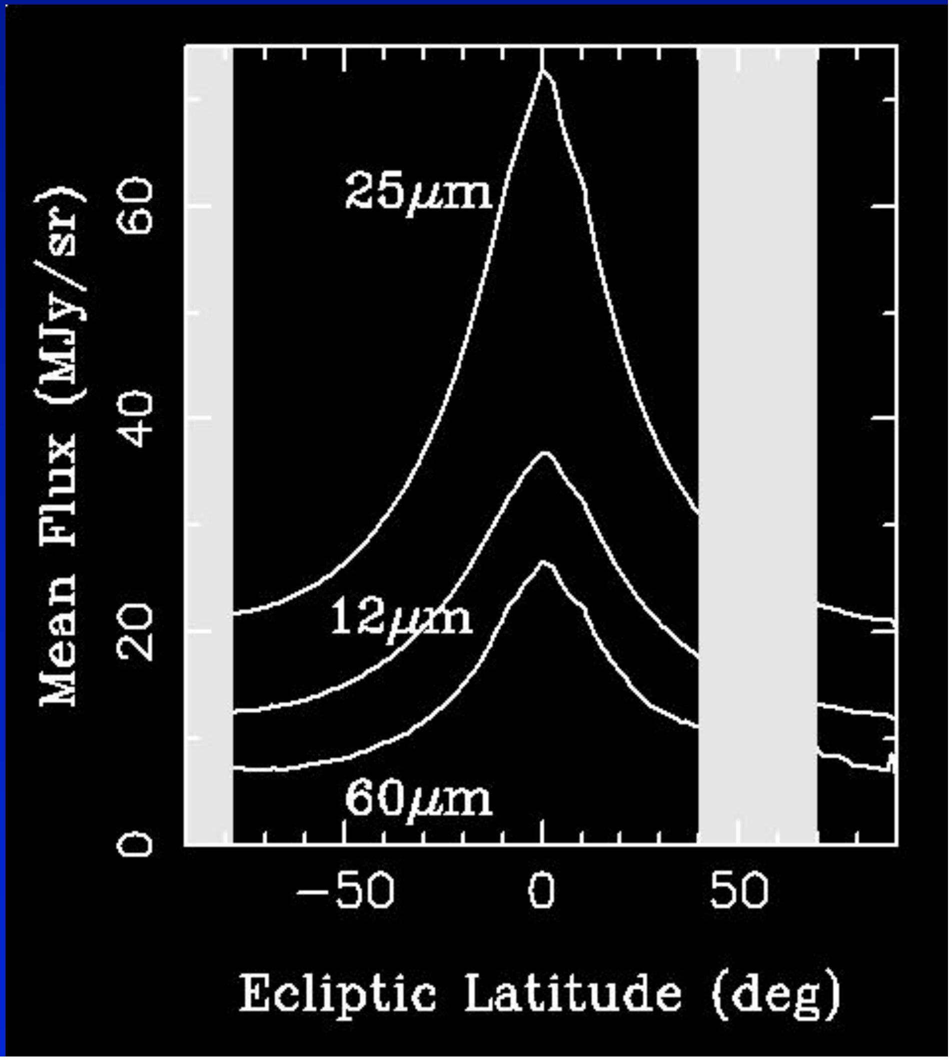
  2 codes (analytic/particle) to mimic IRAS, COBE or any telescopic IR observations
  - particle code similar to SIMUL (Dermott et al. 1988, 2001)



Inner Zodiacal Cloud

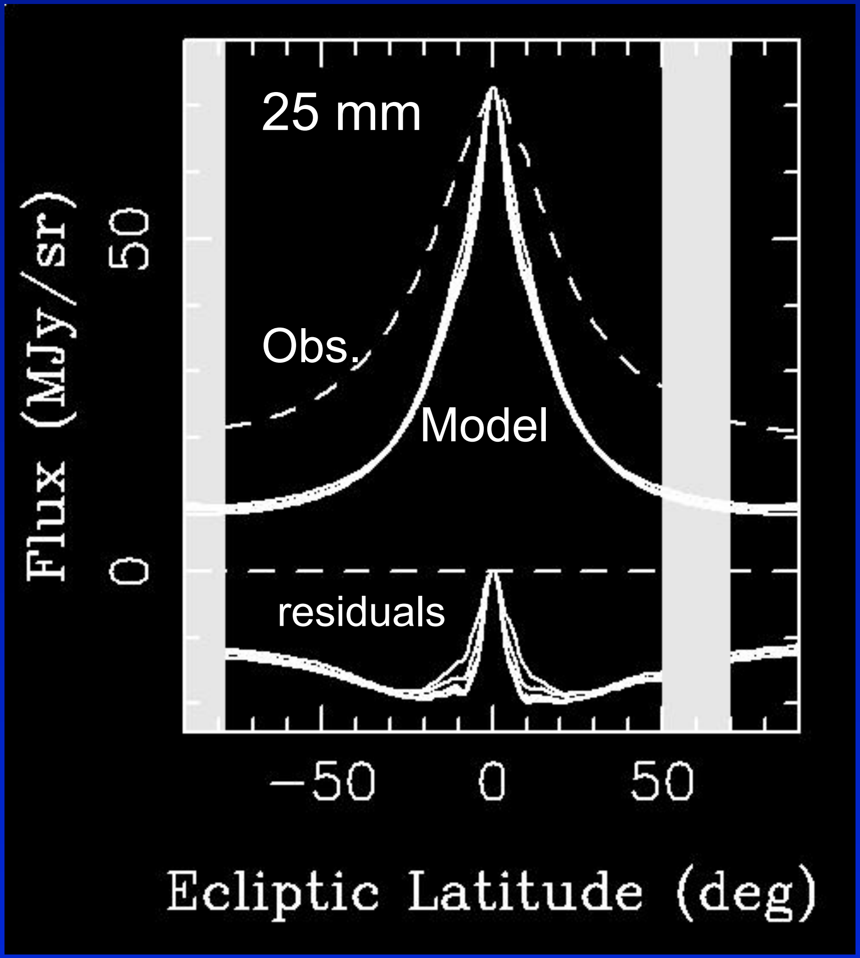
- IRAS observed thermal emission from IZC particles in mid-infrared wavelengths
- Produced full sky coverage by scanning in circles at fixed solar elongation
- We combined IRAS data into representative scans at 90 deg solar elongation

IRAS data

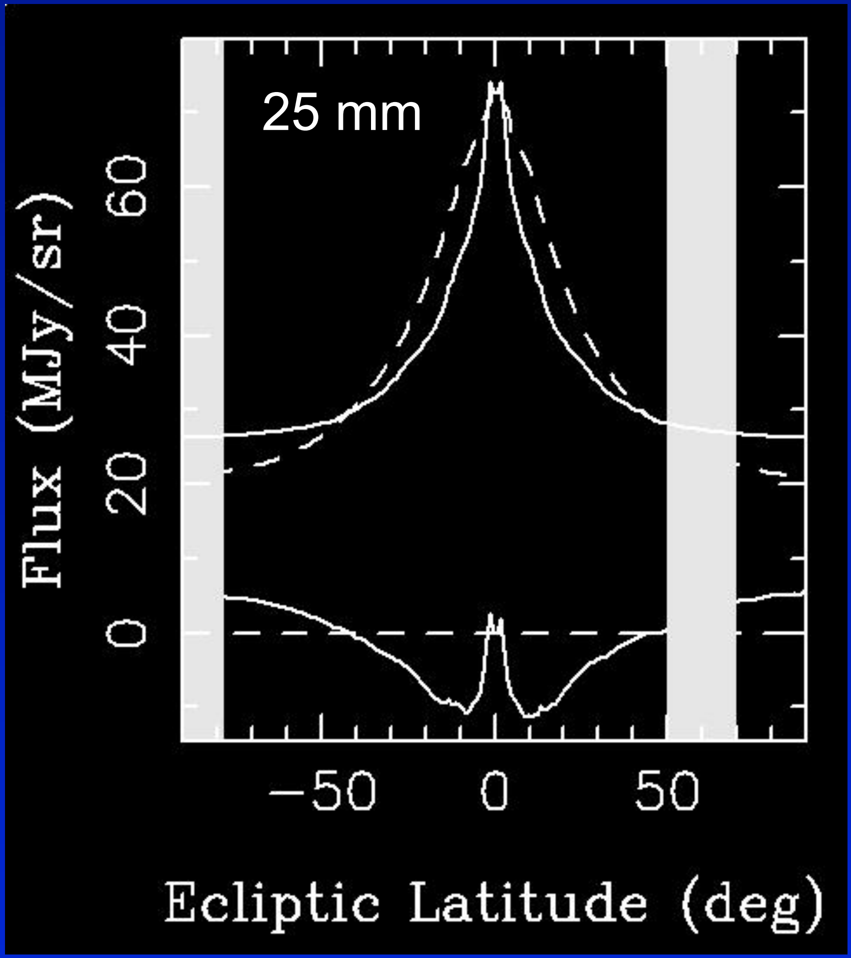


Results: Not so good fits for asteroids

Asteroid particles (various D)

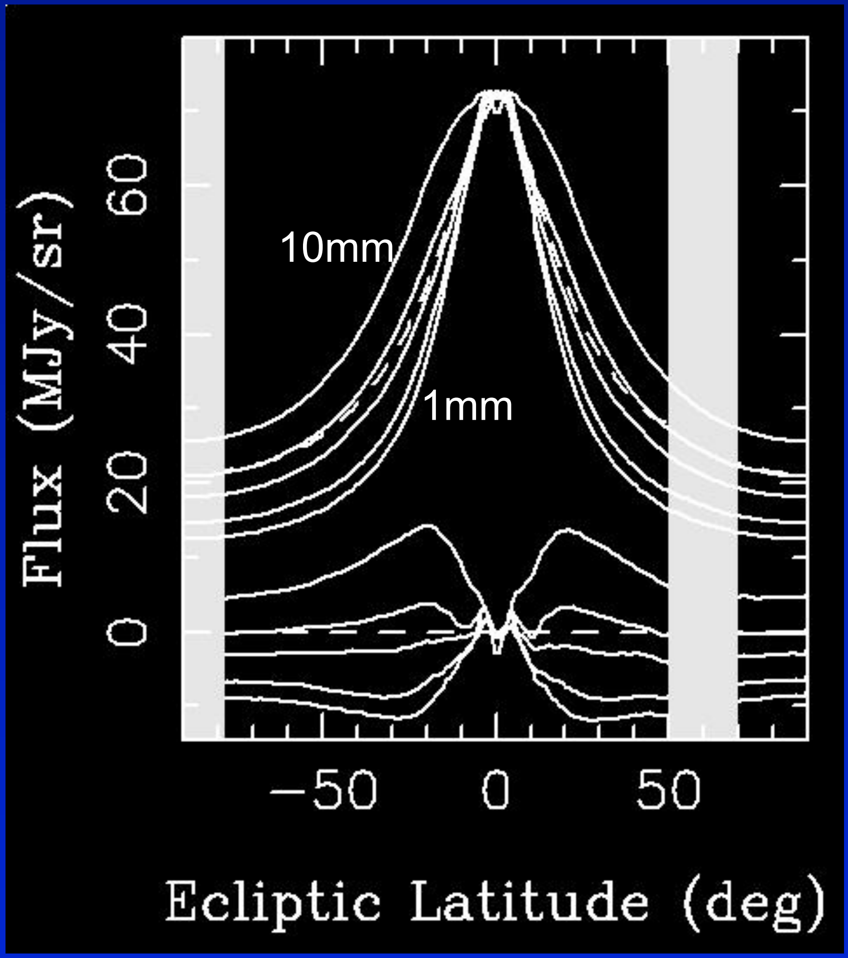


Asteroid + OCC particles

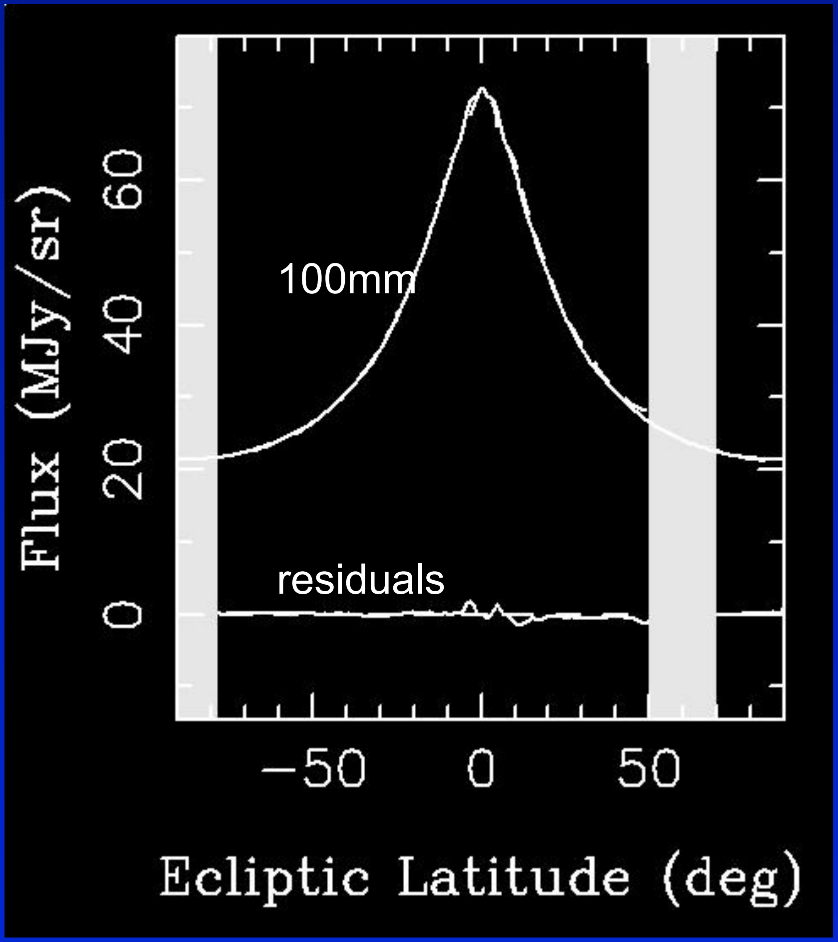


Results: Great fits for JFCs

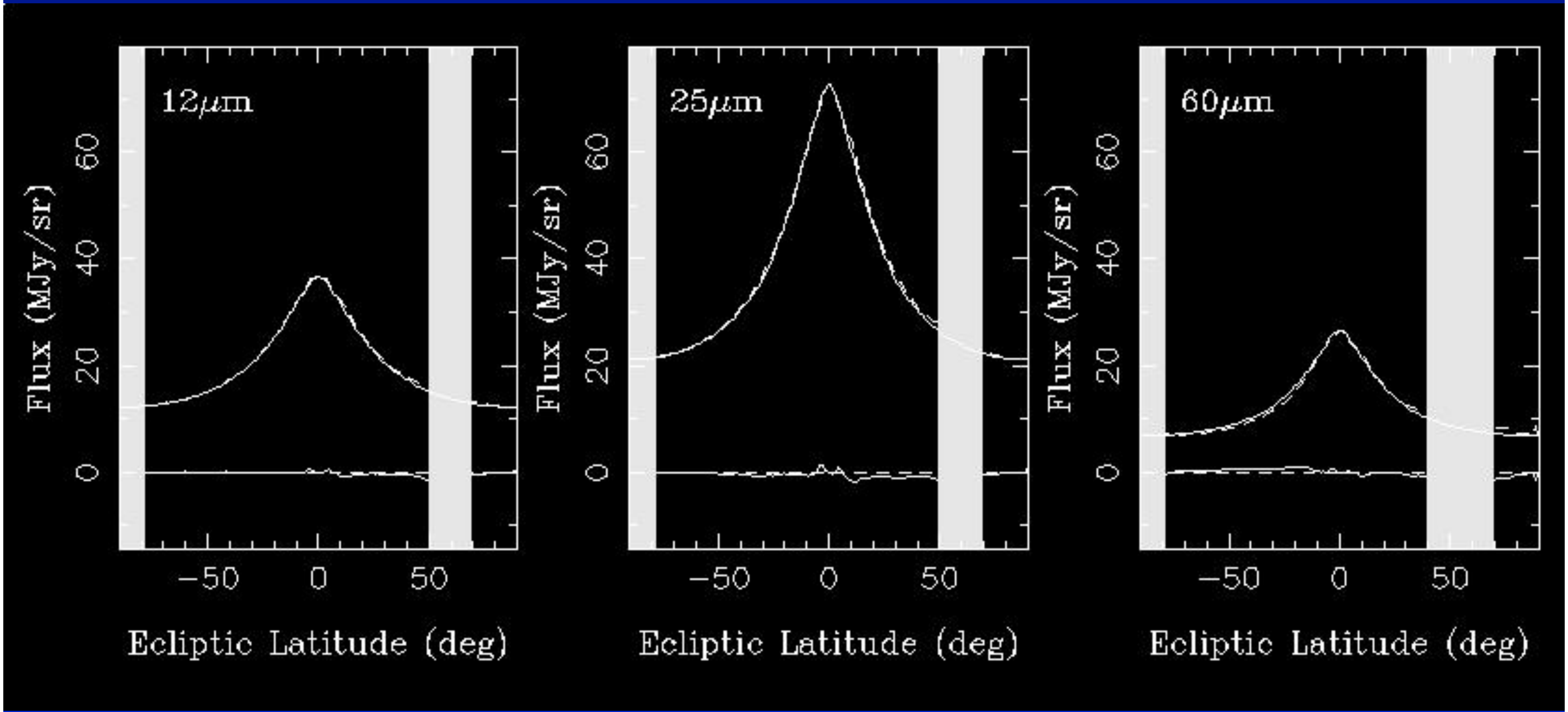
JFC particles (various D)



94% JFC + 6% OCC



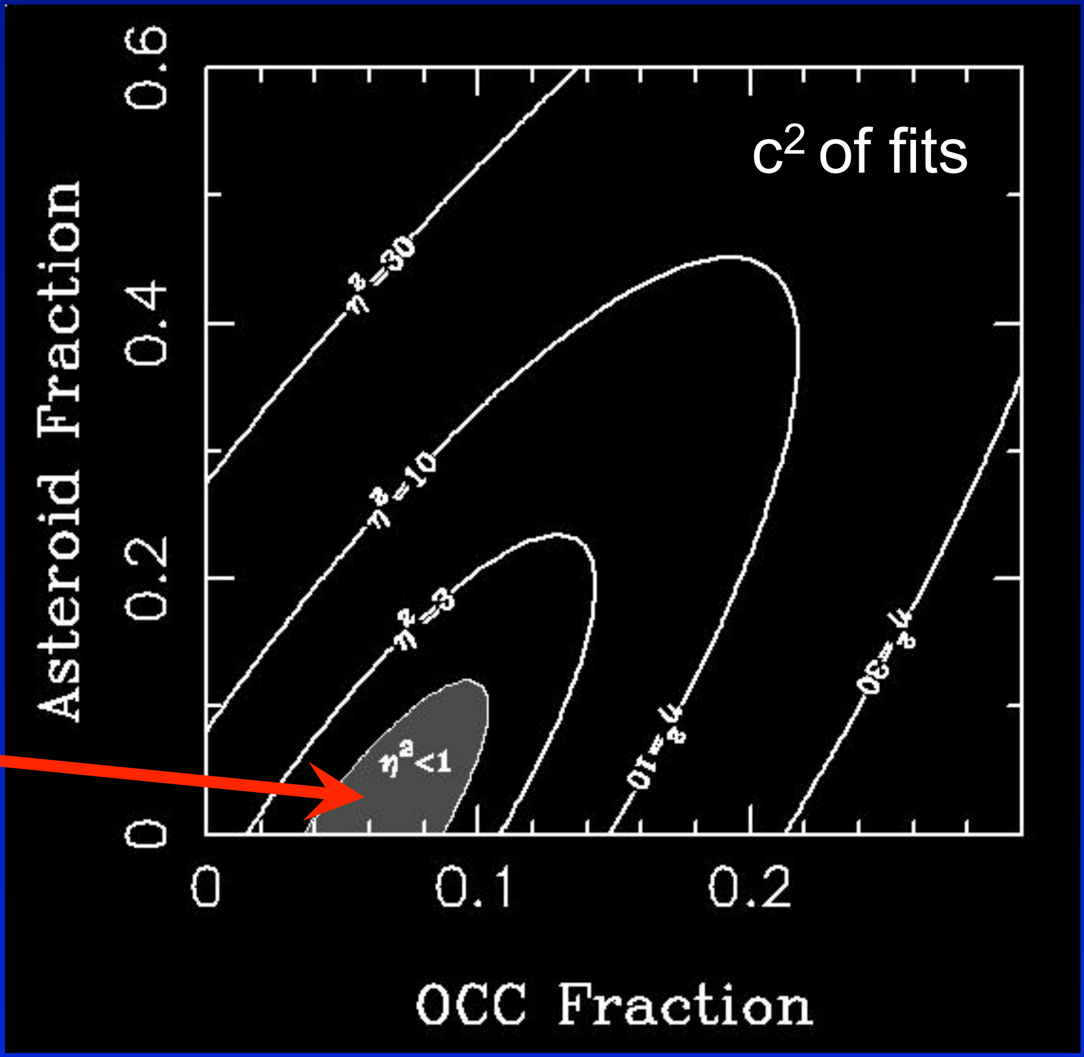
Results: JFC fits at IRAS wavelengths



Implication: JFCs produce ~90%, D~100 mm

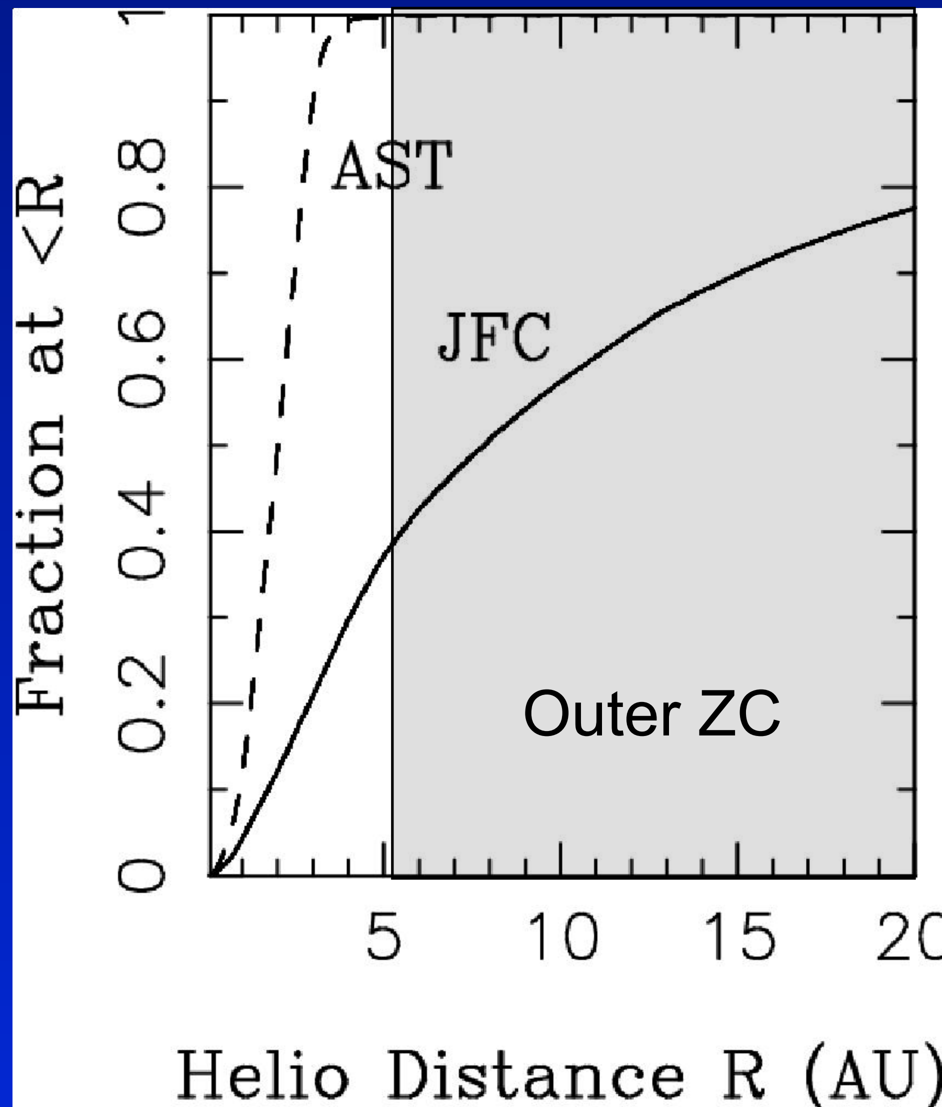
Results: Asteroids/OCC contribute <10%

Best results

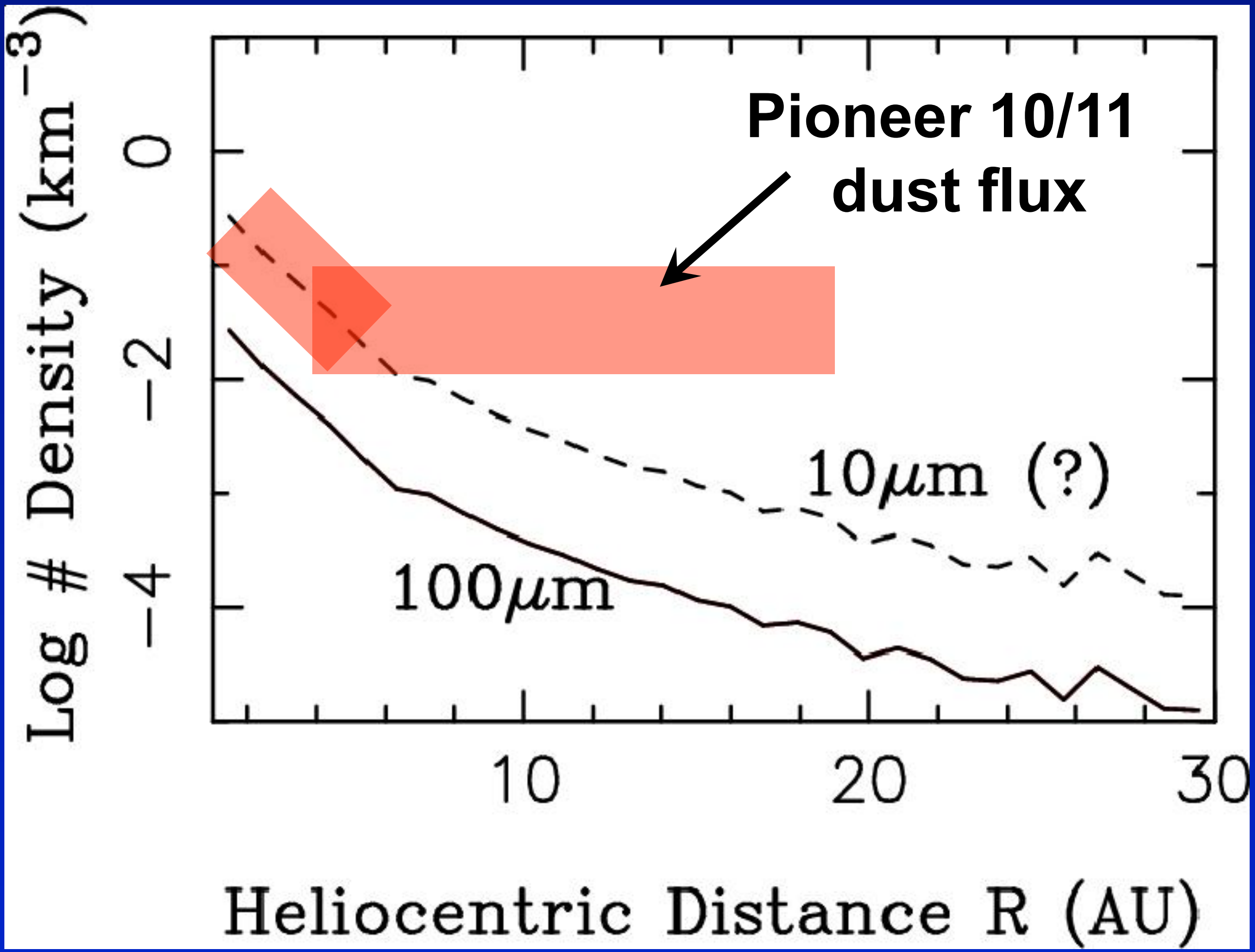


Implications for Outer Zodiacal Cloud

- 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

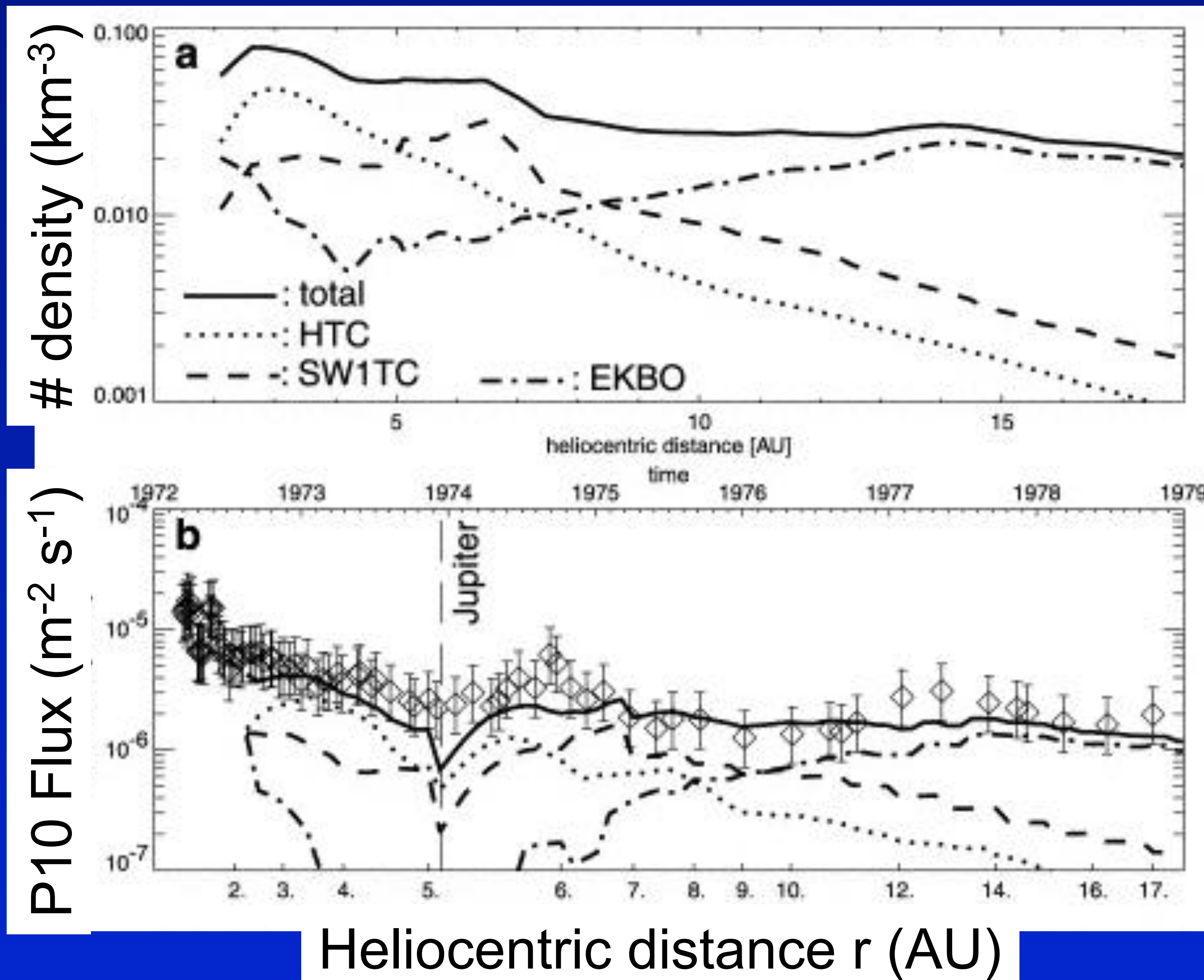


Distribution of JFC particles beyond 5 AU



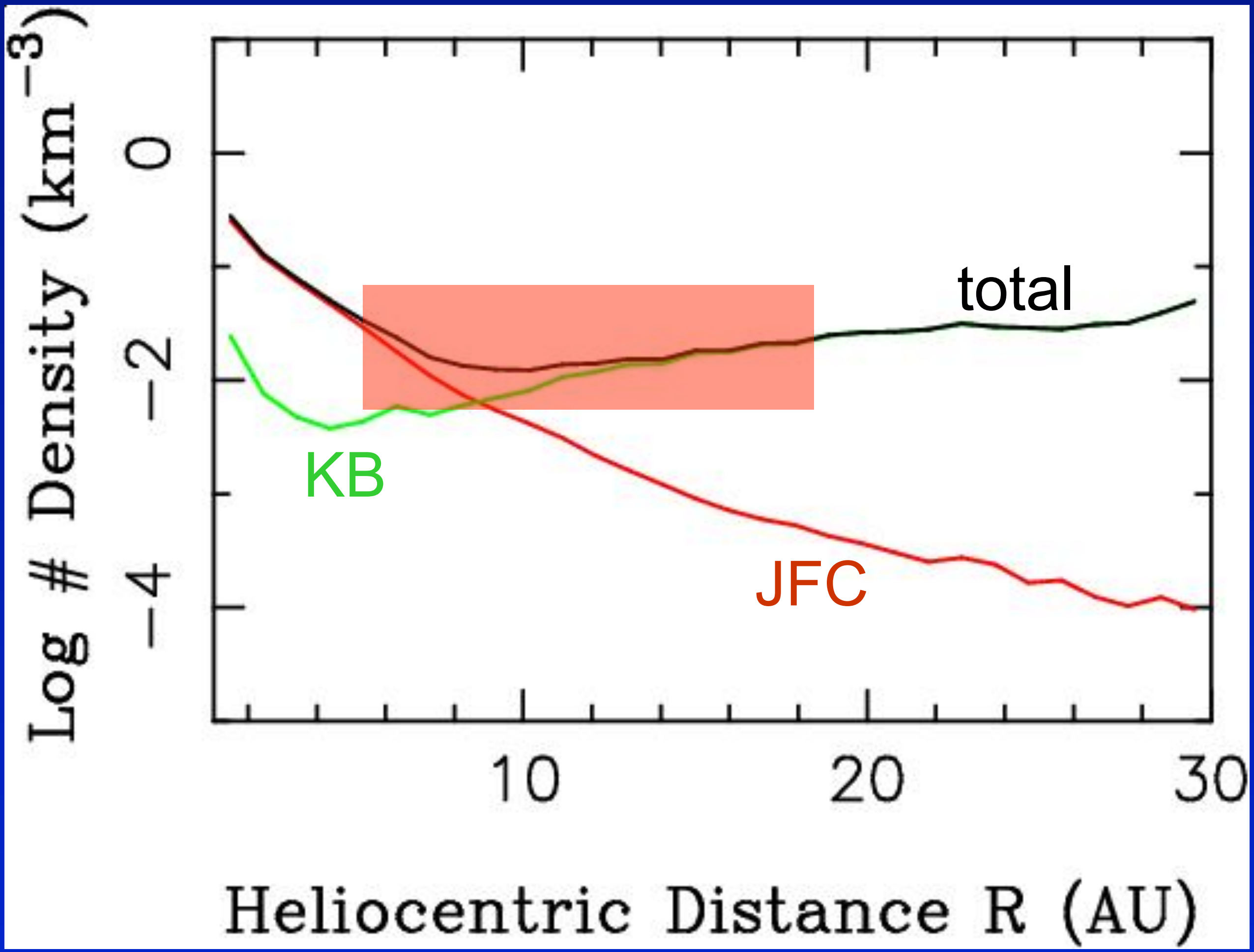
JFC distribution drops with R, Pioneer fluxes constant for R>5AU

Evidence for KB dust from Pioneer fluxes



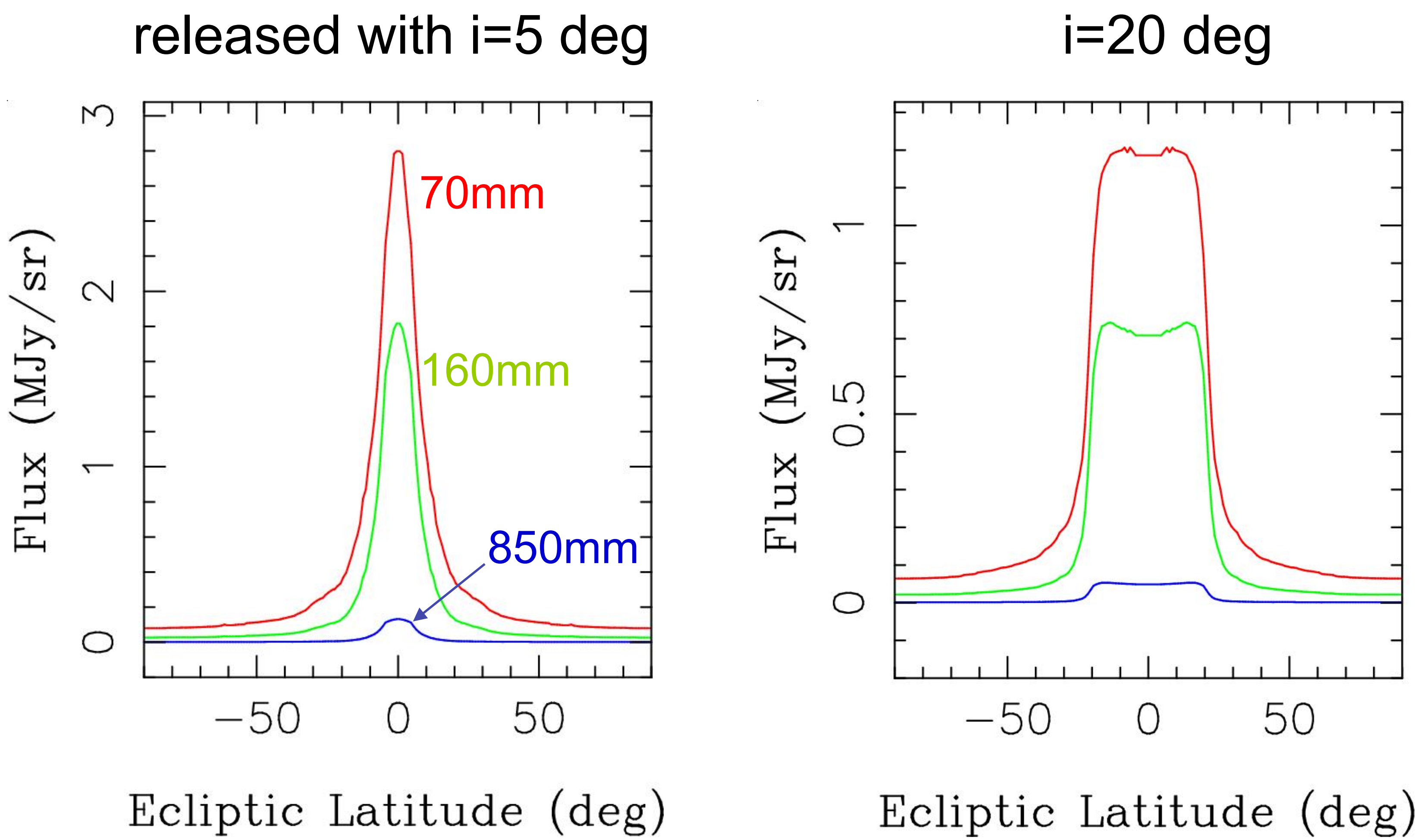
Landgraf et al. (2002): ~6×10^{11} s^{-1} particles >10mm produced in KB

Simple two-source model (KB + JFC)



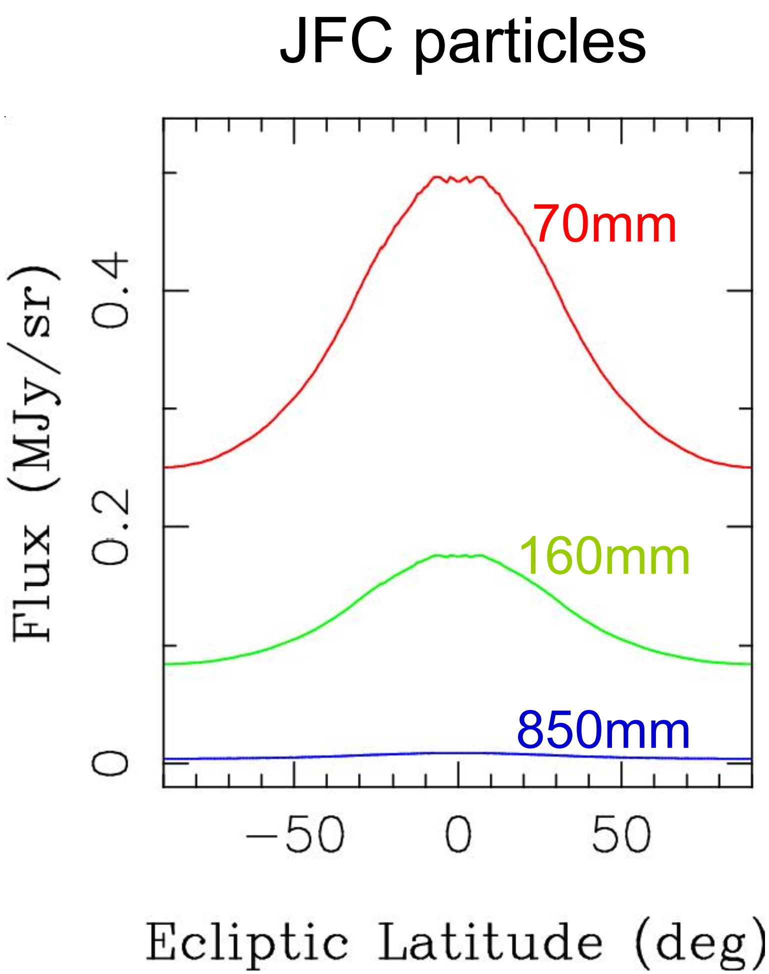
Model IR fluxes as observed from 5 AU

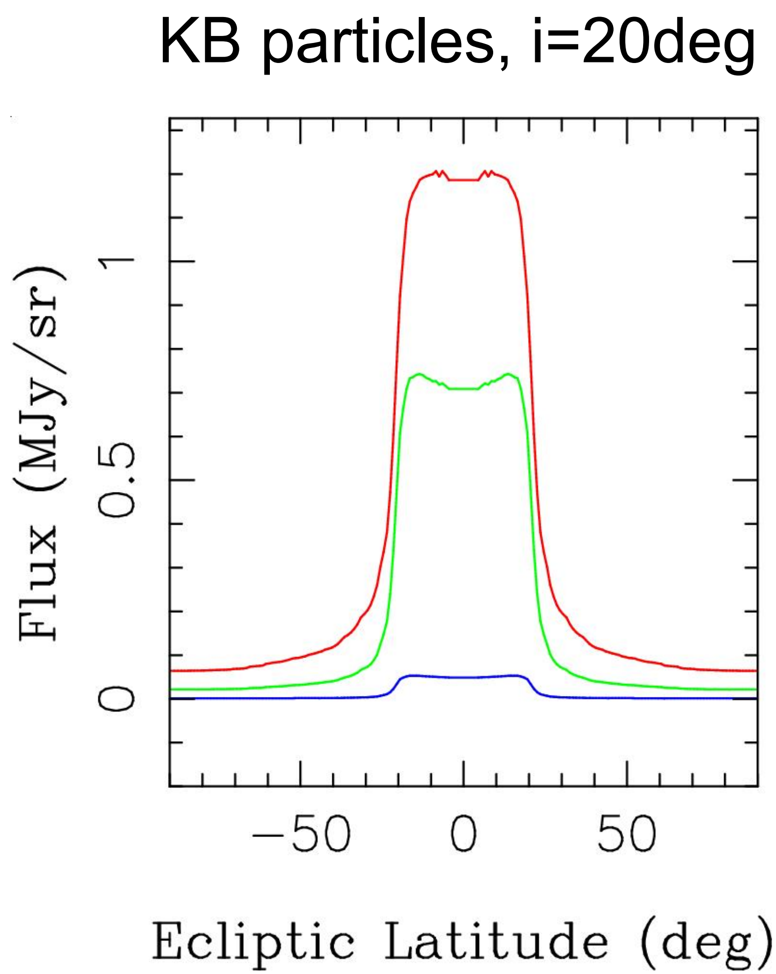
(KB particles, 90 deg solar elongation)



Model IR fluxes as observed from 5 AU

(90 deg solar elongation)





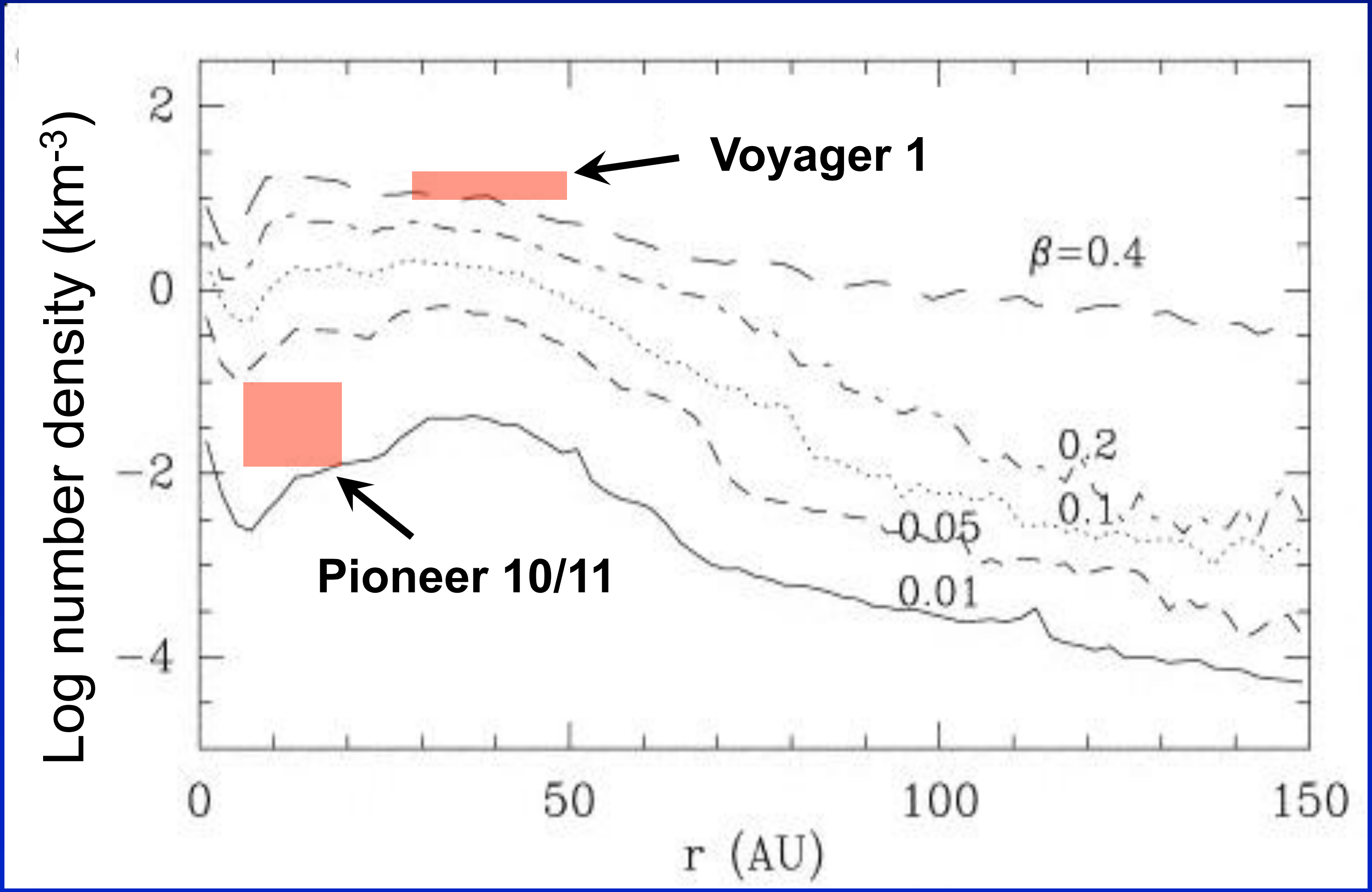
Summary

- 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

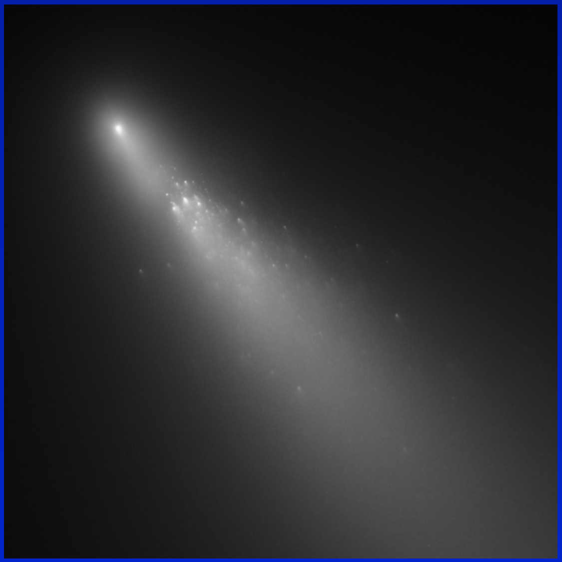


Moro-Martin & Malhotra (2003)

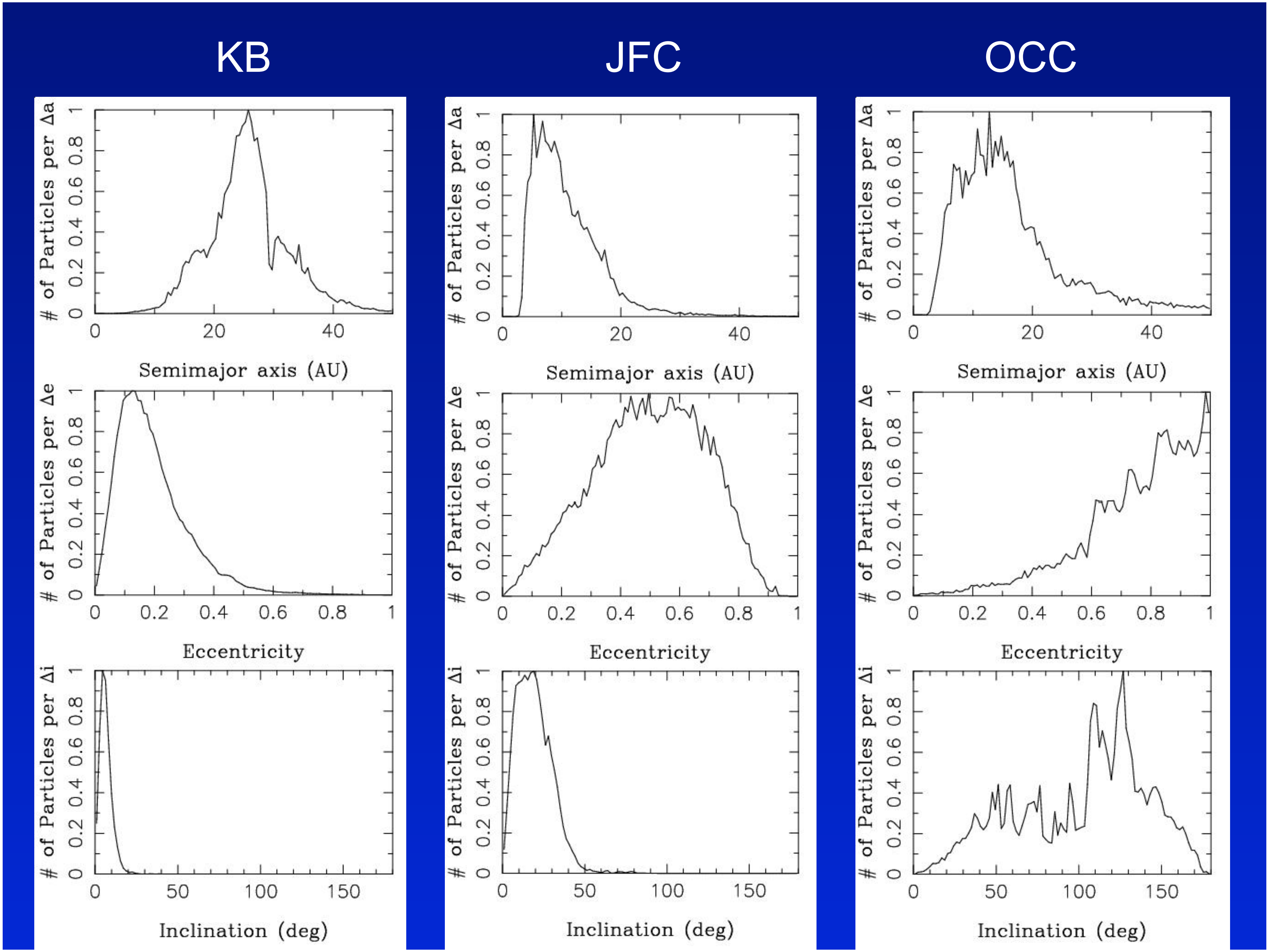
How to explain nearly constant Pioneer fluxes at r > 5 AU?

- 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 ~10 ky after becoming visible
  → released JFC particles initially concentrate at heliocentric distance r=3-5 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


KB
JFC
OCC
# of Particles per Δa
Semimajor axis (AU)
# of Particles per Δe
Eccentricity
# of Particles per Δi
Inclination (deg)
0
0.2
0.4
0.6
0.8
1
20
40
50
100
150