Transport-dominated debris disks

Properties and implications for Herschel

Alexander "Sasha" Krivov,
Christian Vitense,
Martin Reidemeister,
Jonathan Marshall,
Carlos Eiroa,
Jean-Charles Augereau,
and the DUNES consortium

Outline

- Collision- vs transport-dominated disks
- The Edgeworth-Kuiper disk
- The “cold” debris disks
- The ε Eridani disk
- Summary

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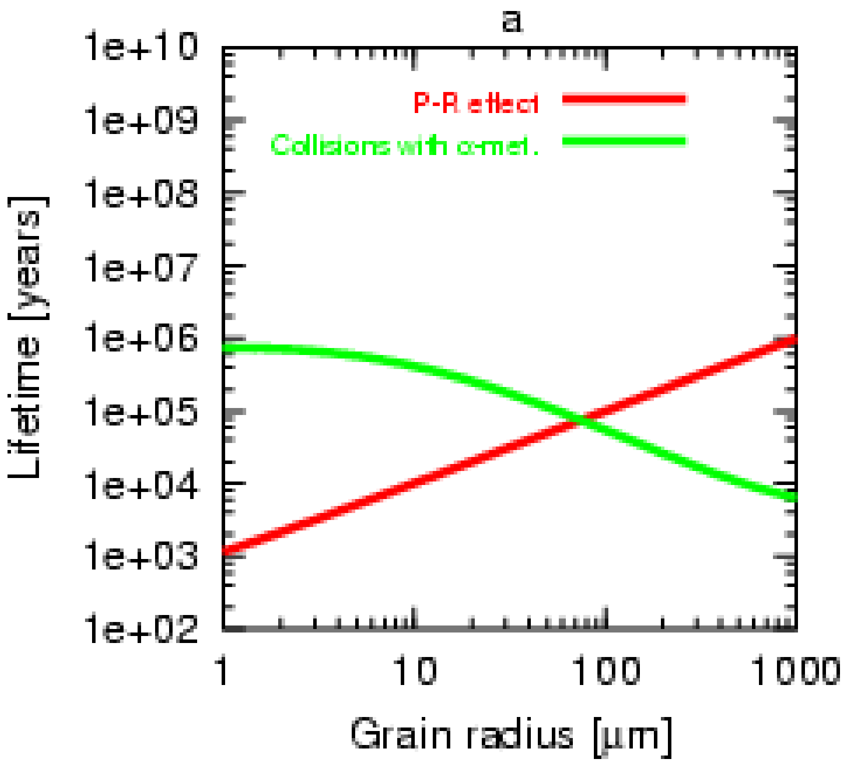
Transport mechanisms

Mechanism	Requirements	Examples
Gas drag	Young debris disks with gas	β Pic disk
Poynting-Robertson drag	Tenuous debris disks	EKB dust disk
Stellar wind drag	Debris disks of late-type stars	ε Eri disk

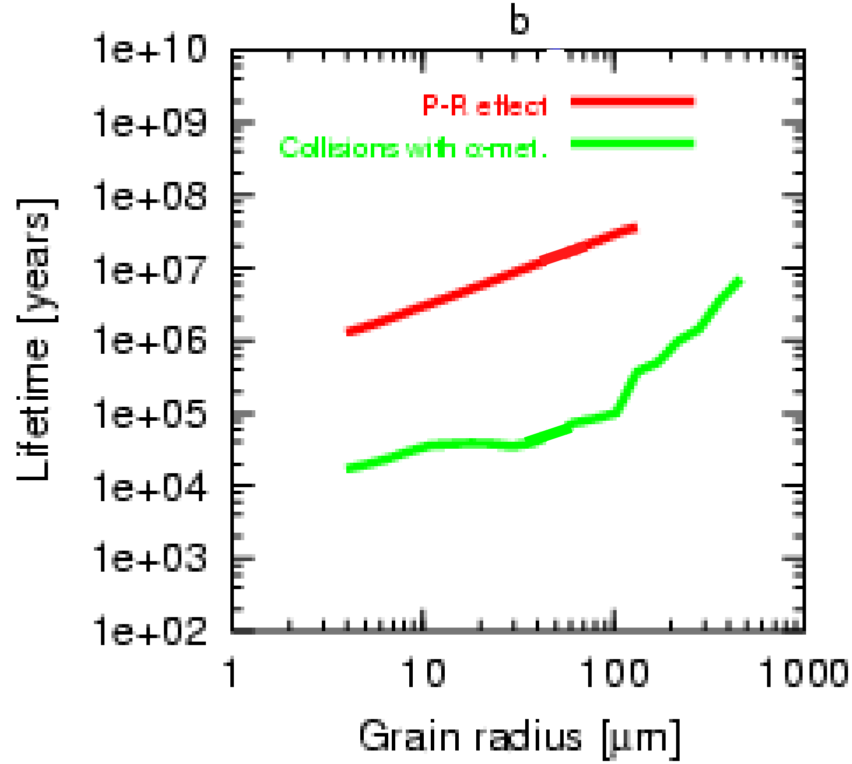
Collision-dominated vs transport-dominated disks

Zodiacal cloud around the Sun



Leinert & Grün,
in Phys.of Inner Heliosphere (1990)

β Pic disk

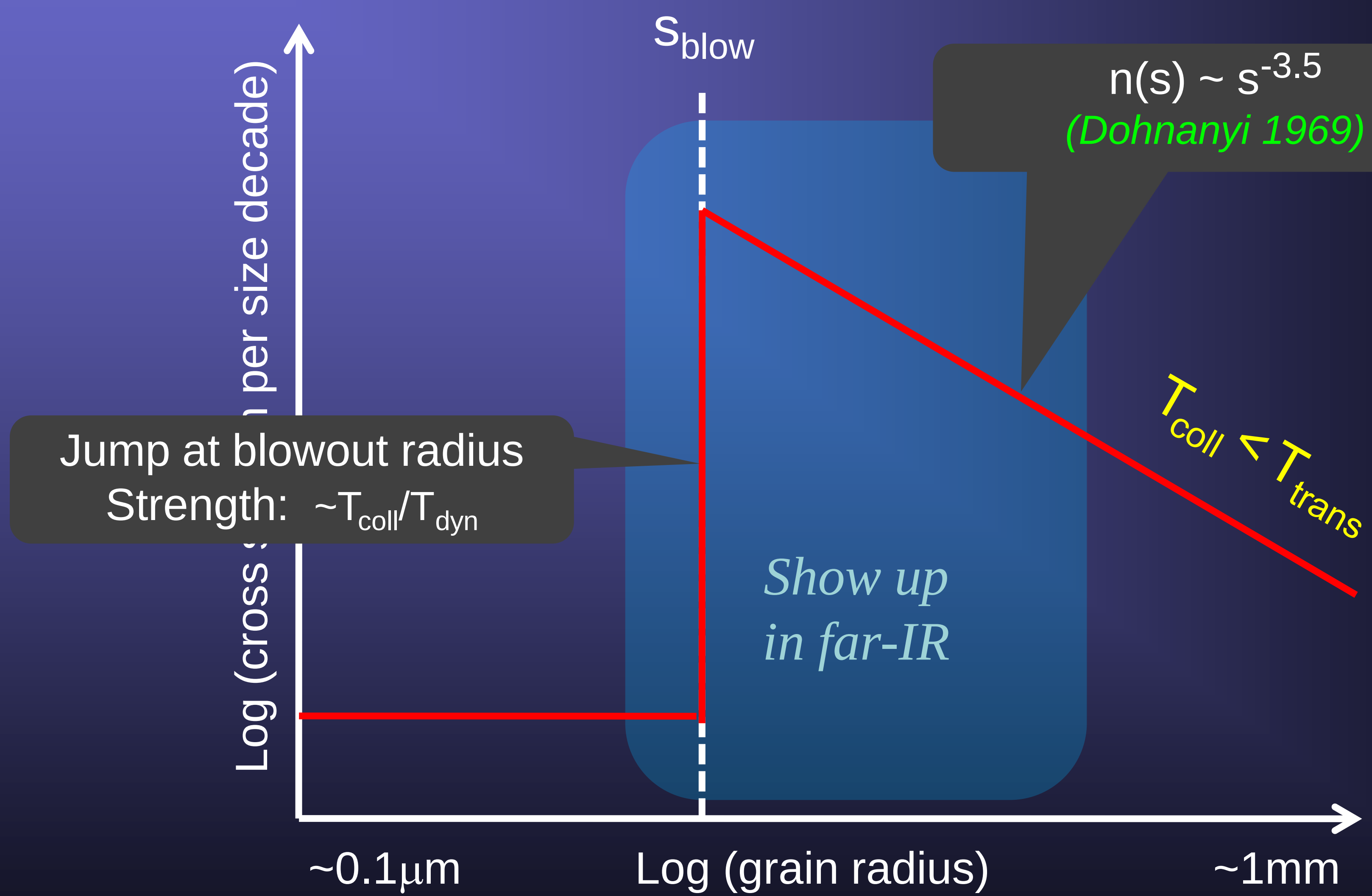


Krivov, Mann, & Krivova,
AAp ***362,*** *1127 (2000)*

A disk is collision-dominated, if $T_{coll} < T_{trans}$
A disk is transport-dominated, if $T_{coll} > T_{trans}$
(this definition depends on the size range considered)

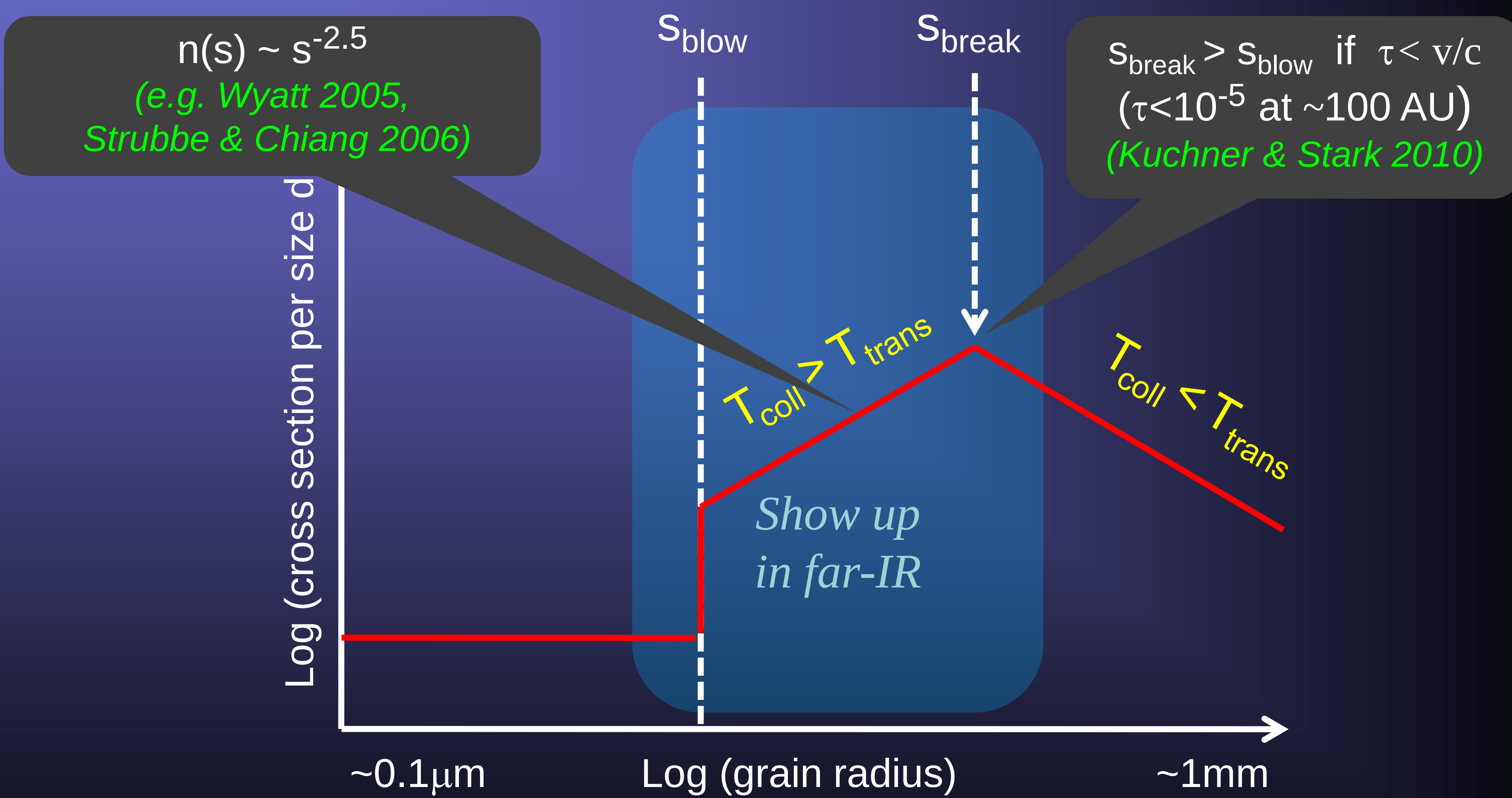
Size distribution

Dense disks (most of the known disks)



Size distribution

Tenuous disks (at ≤ EKB disk level)



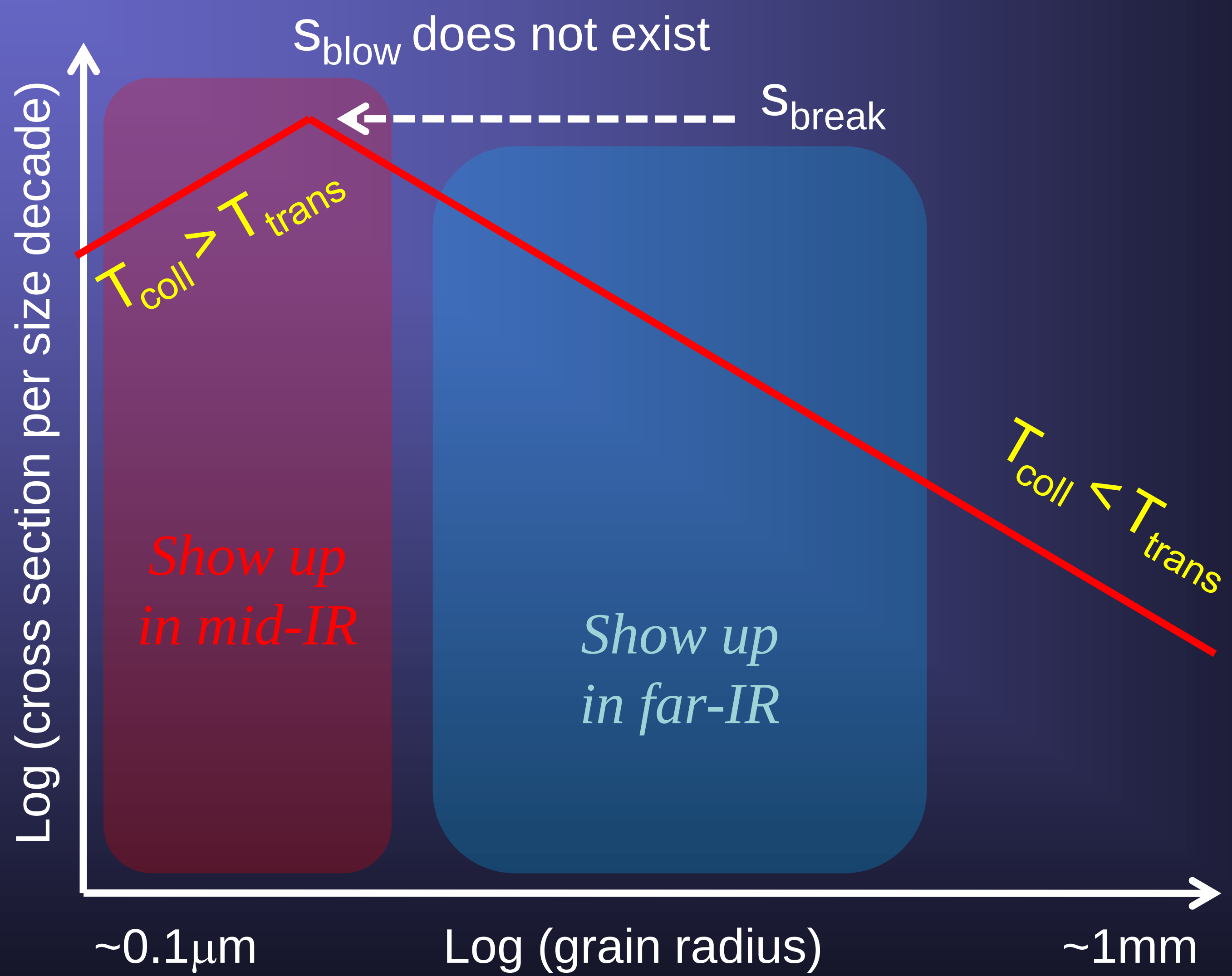
Size distribution

Disks with sufficiently low optical depth (or fractional luminosity) are transport-dominated at all dust sizes

They will be dominated by much bigger grains

Size distribution

Dense disks around late-type stars (e.g., ε Eri)

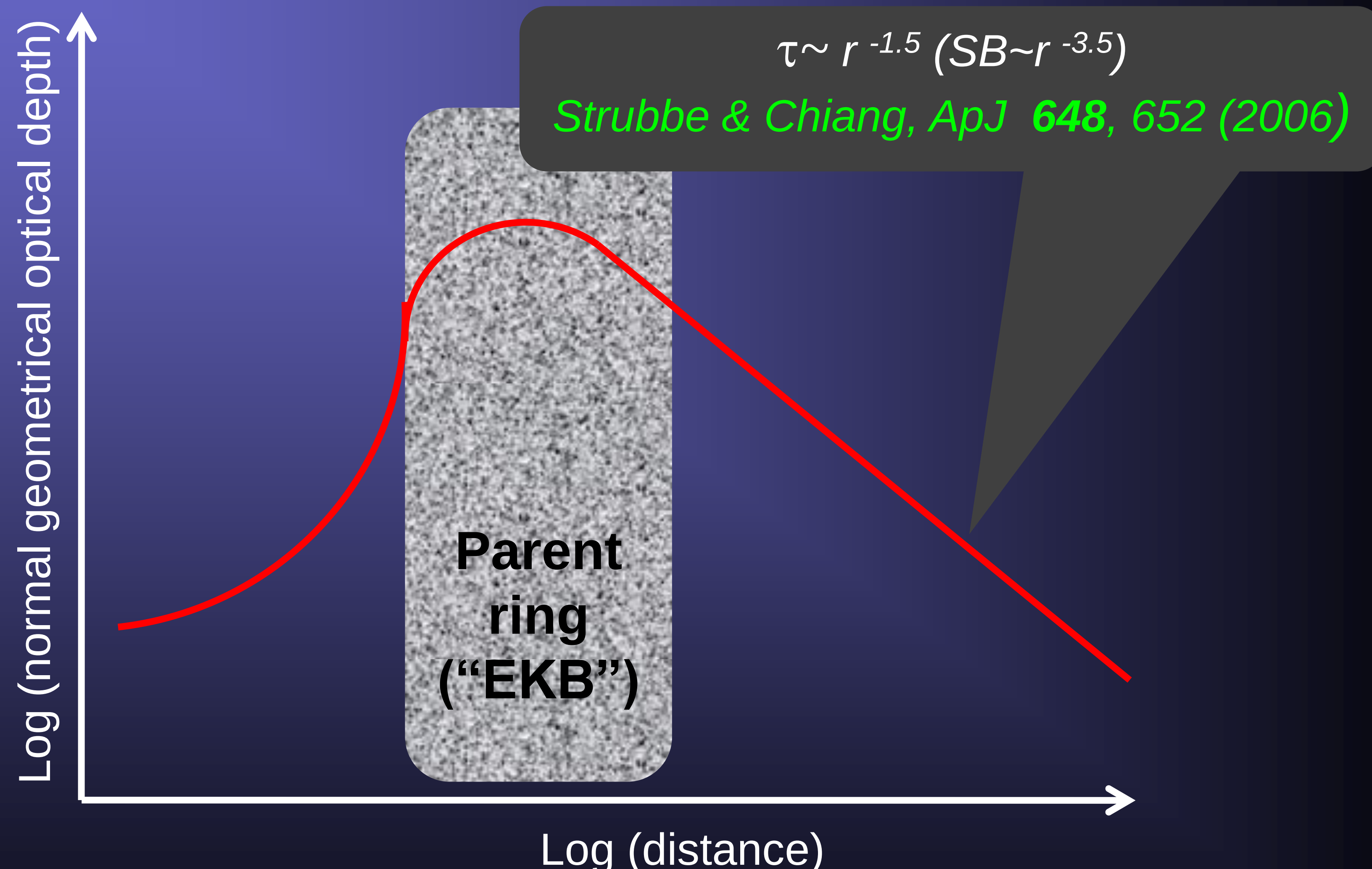


Size distribution

Disks around late-type stars
are transport-dominated
even at high optical depths
(or fractional luminosities),
but only at small dust sizes
(relevant for near- and mid-IR observations)

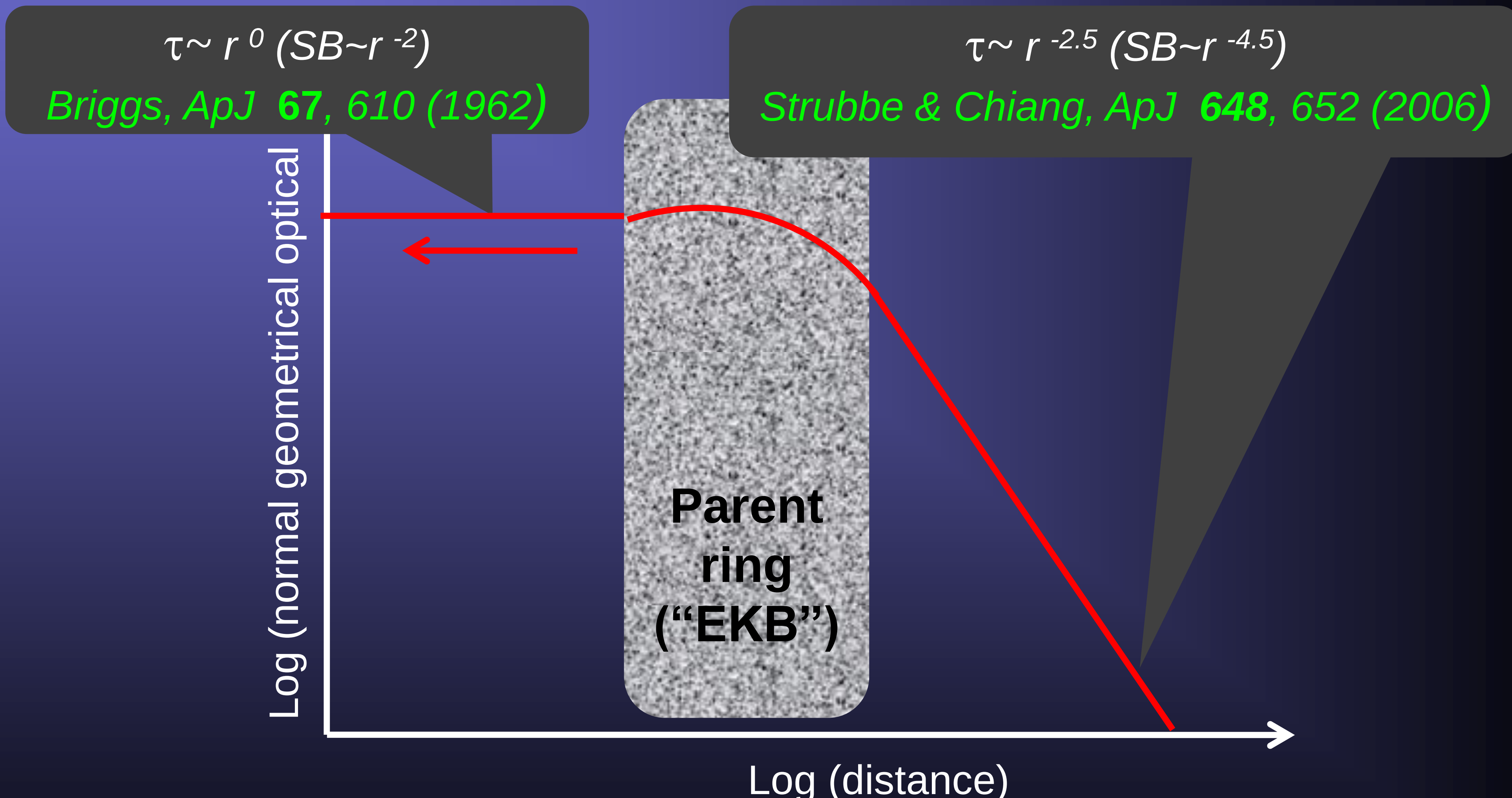
Radial distribution

Dense disks (most of the known disks)



Radial distribution

Tenuous disks

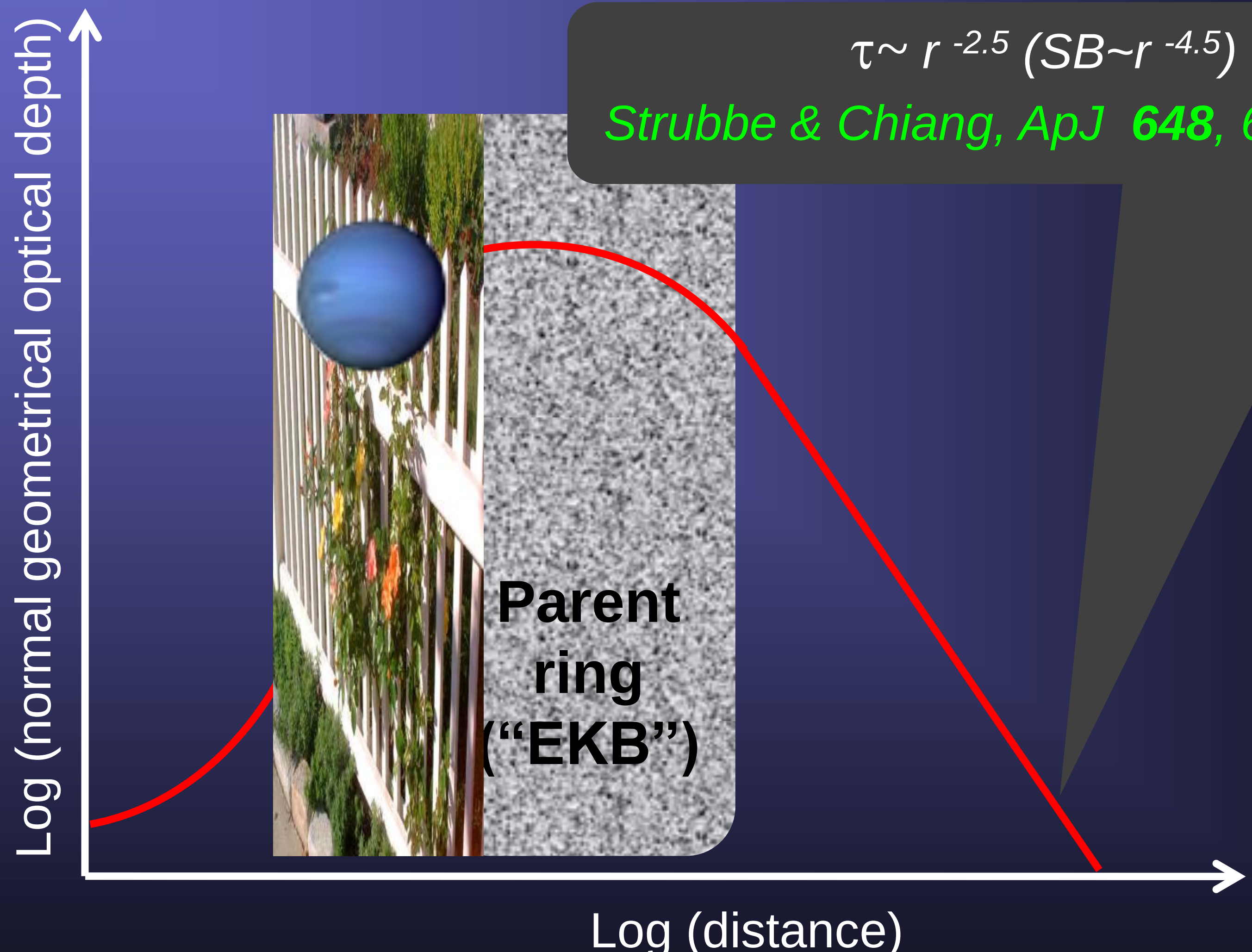


Radial distribution

Tenuous disks with planets

$\tau \sim r^{-2.5}$ ($SB \sim r^{-4.5}$)

Strubbe & Chiang, ApJ ***648****, 652 (2006)*



Radial distribution

Transport may primarily affect
the size distribution
rather than the radial distribution

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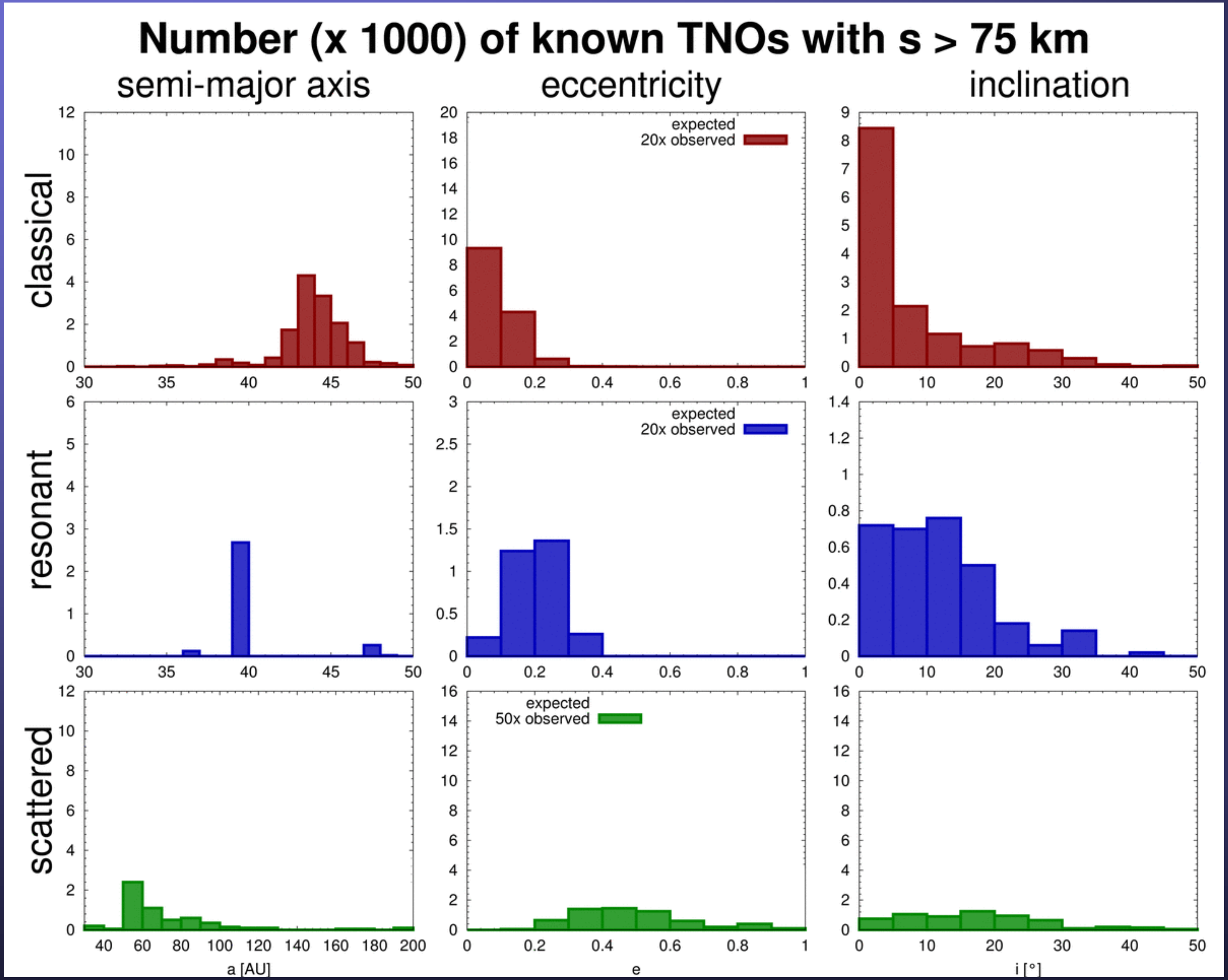
Known EKB…

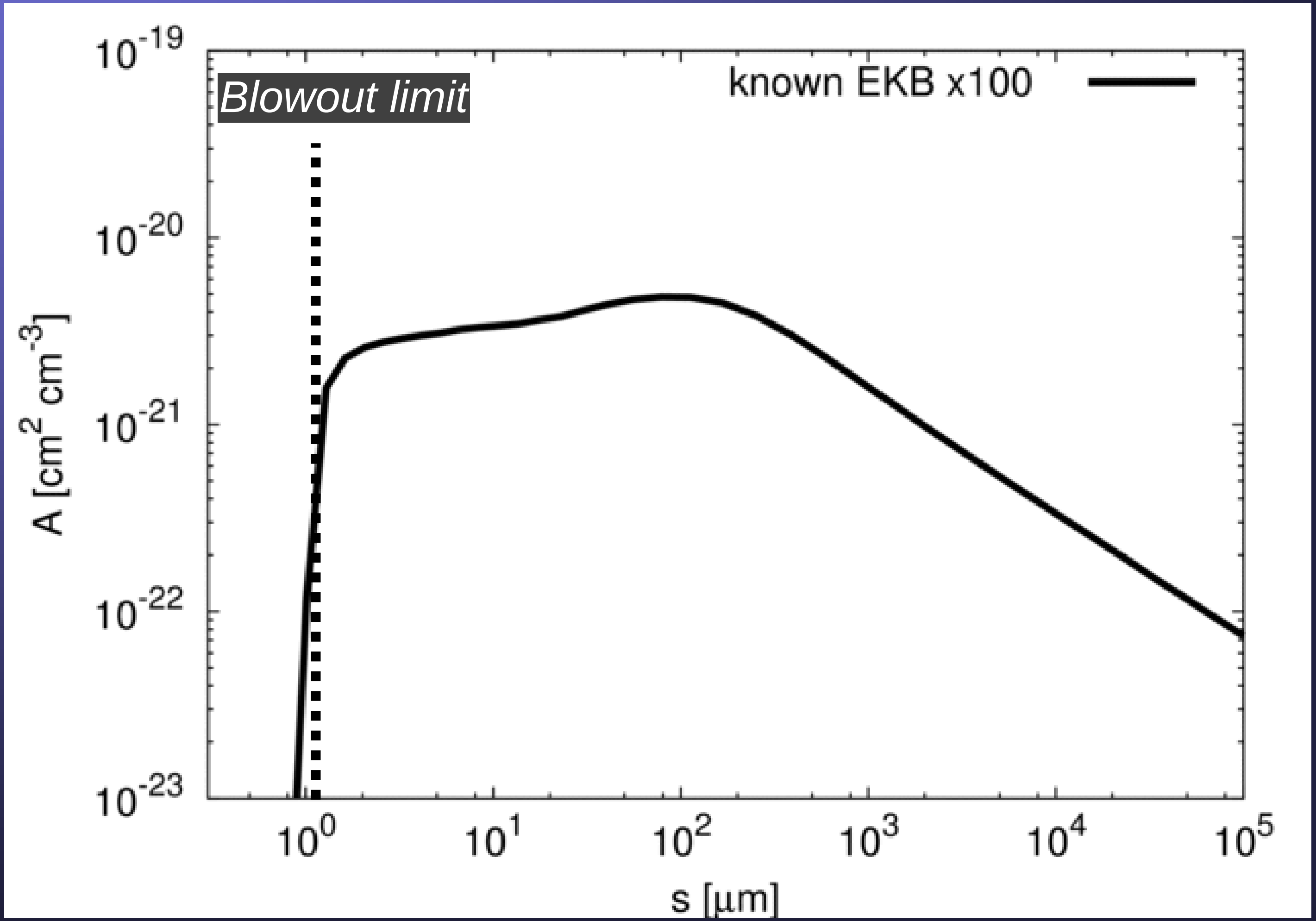


Mass of the known EKB $\approx 0.007\ M_{\oplus}$

Vitense, Krivov, & Löhne, AAp (in press, astro/ph 1006.2220)

… and its simulated dust disk

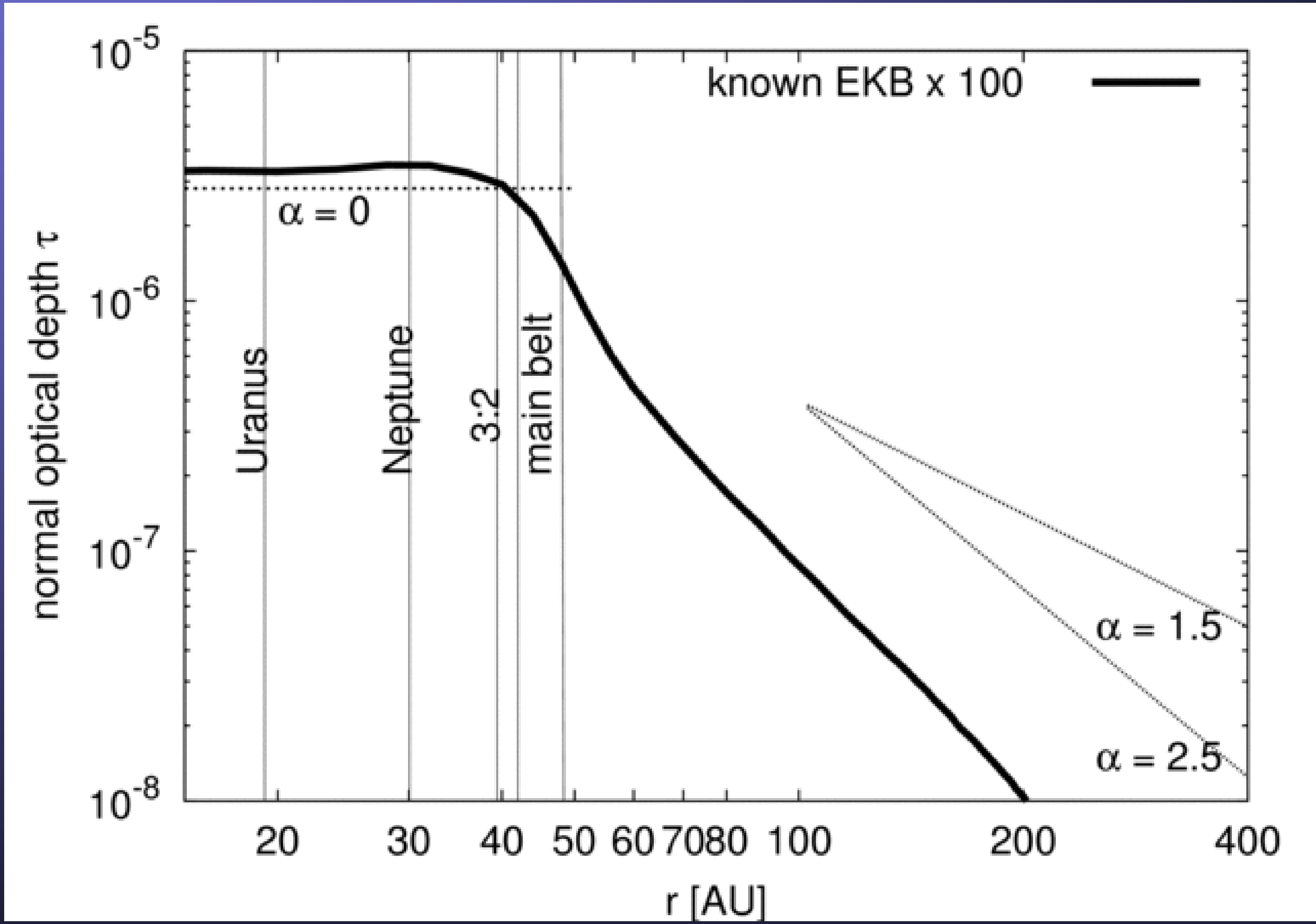
Size distribution



Vitense, Krivov, & Löhne, AAp (in press, astro/ph 1006.2220)

… and its simulated dust disk

Radial distribution



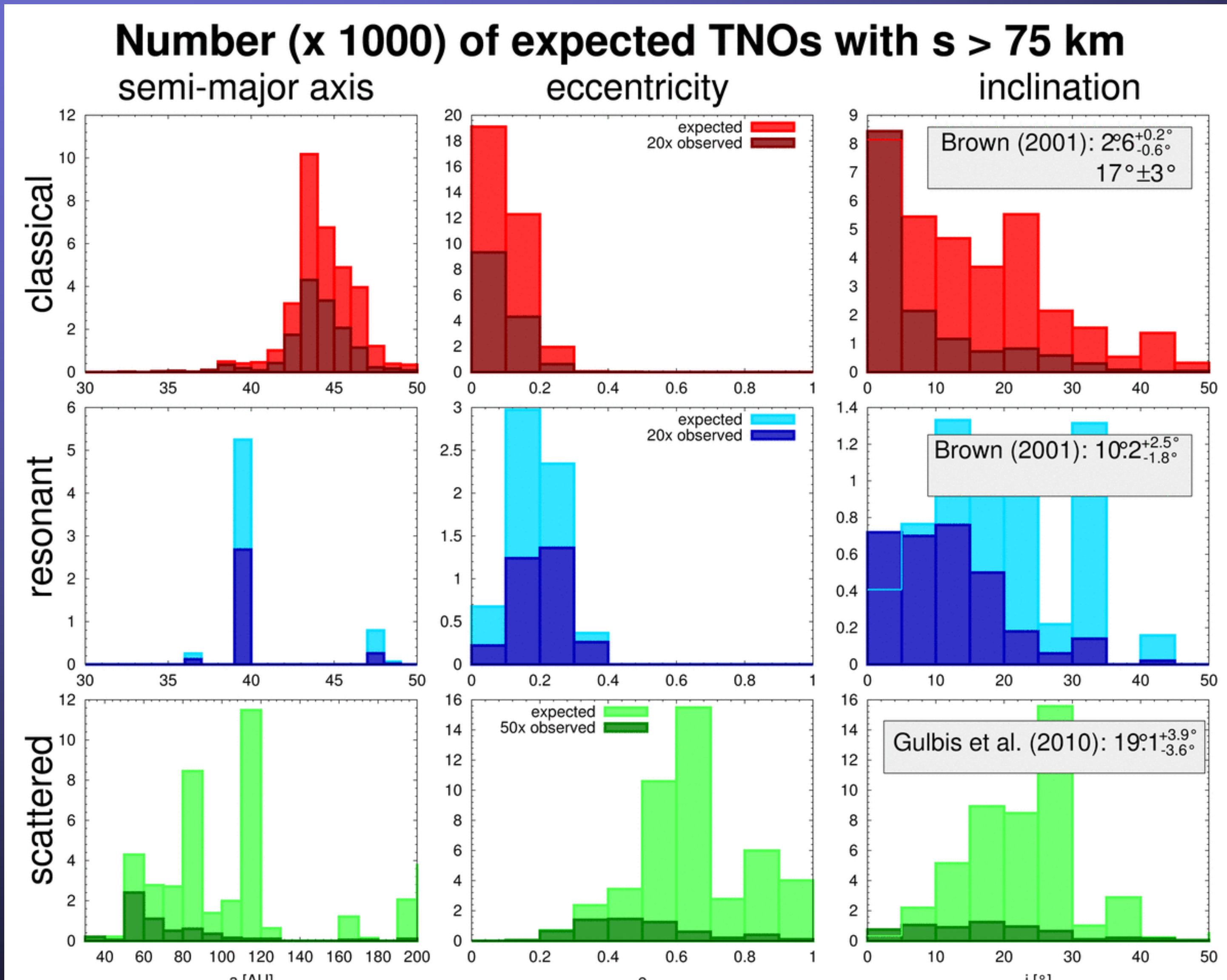
Vitense, Krivov, & Löhne, AAp (in press, astro/ph 1006.2220)

… and its simulated dust disk

The dust disk from the known TNOs would have fractional luminosity ~3×10^{-8} and would be transport-dominated

Vitense, Krivov, & Löhne, AAp (in press, astro/ph 1006.2220)

“True “(debiased) EKB…



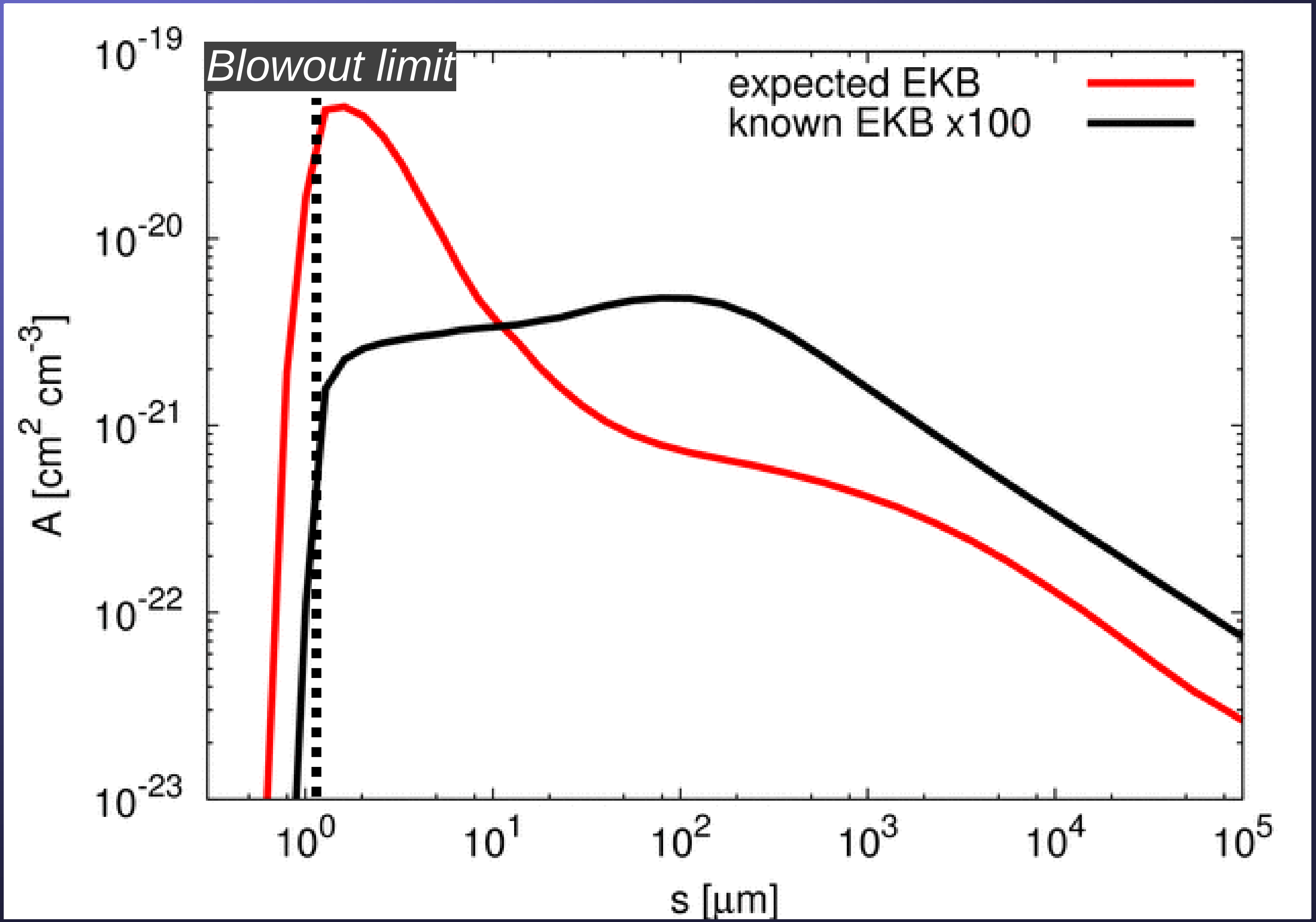
Mass of the known EKB $\approx 0.007\ M_{\oplus}$

Mass of the “true” EKB $\approx 0.12\ M_{\oplus}$

Vitense, Krivov, & Löhne, AAp (in press, astro/ph 1006.2220)

… and its simulated dust disk

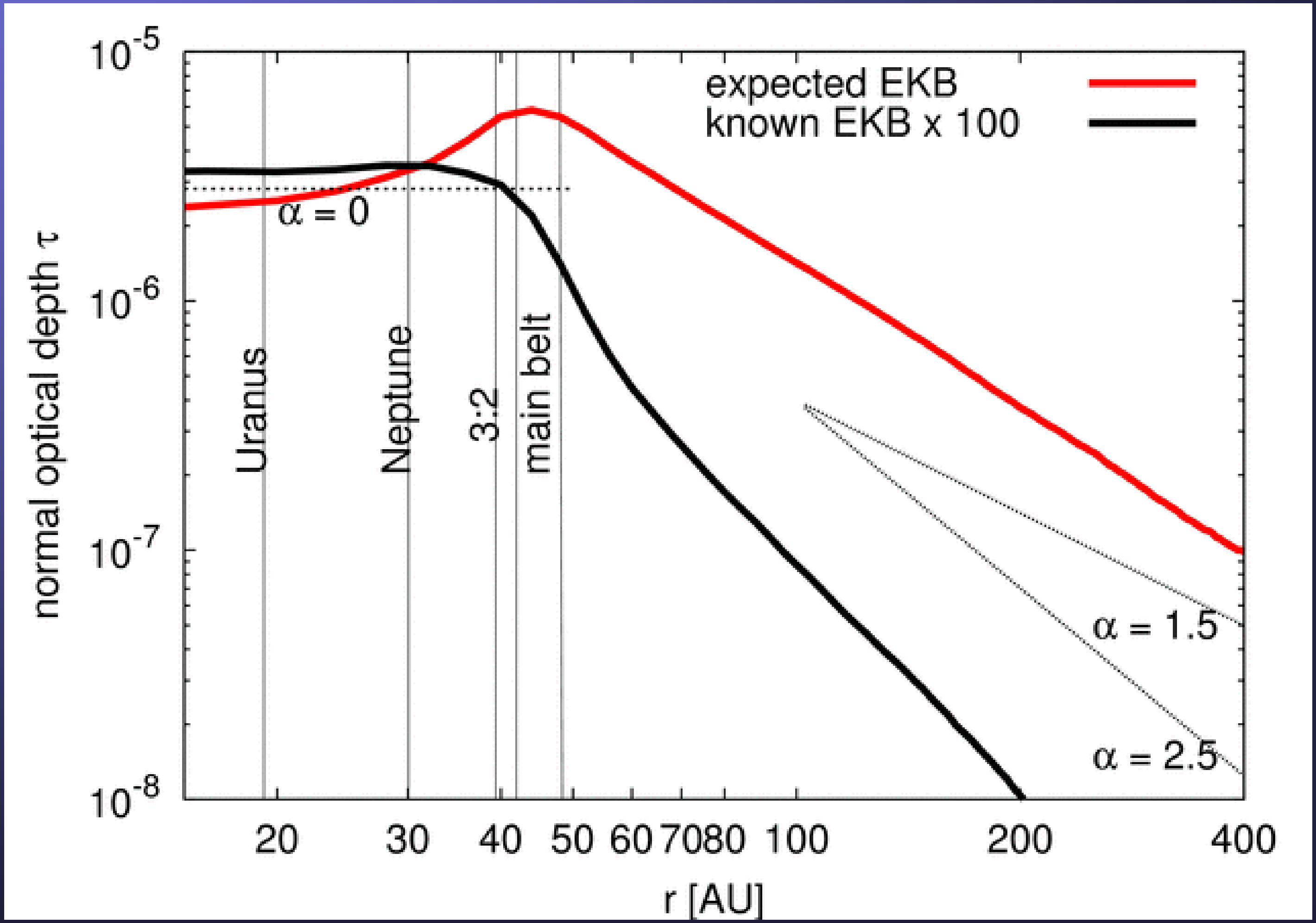
Size distribution



Vitense, Krivov, & Löhne, AAp (in press, astro/ph 1006.2220)

… and its simulated dust disk

Radial distribution



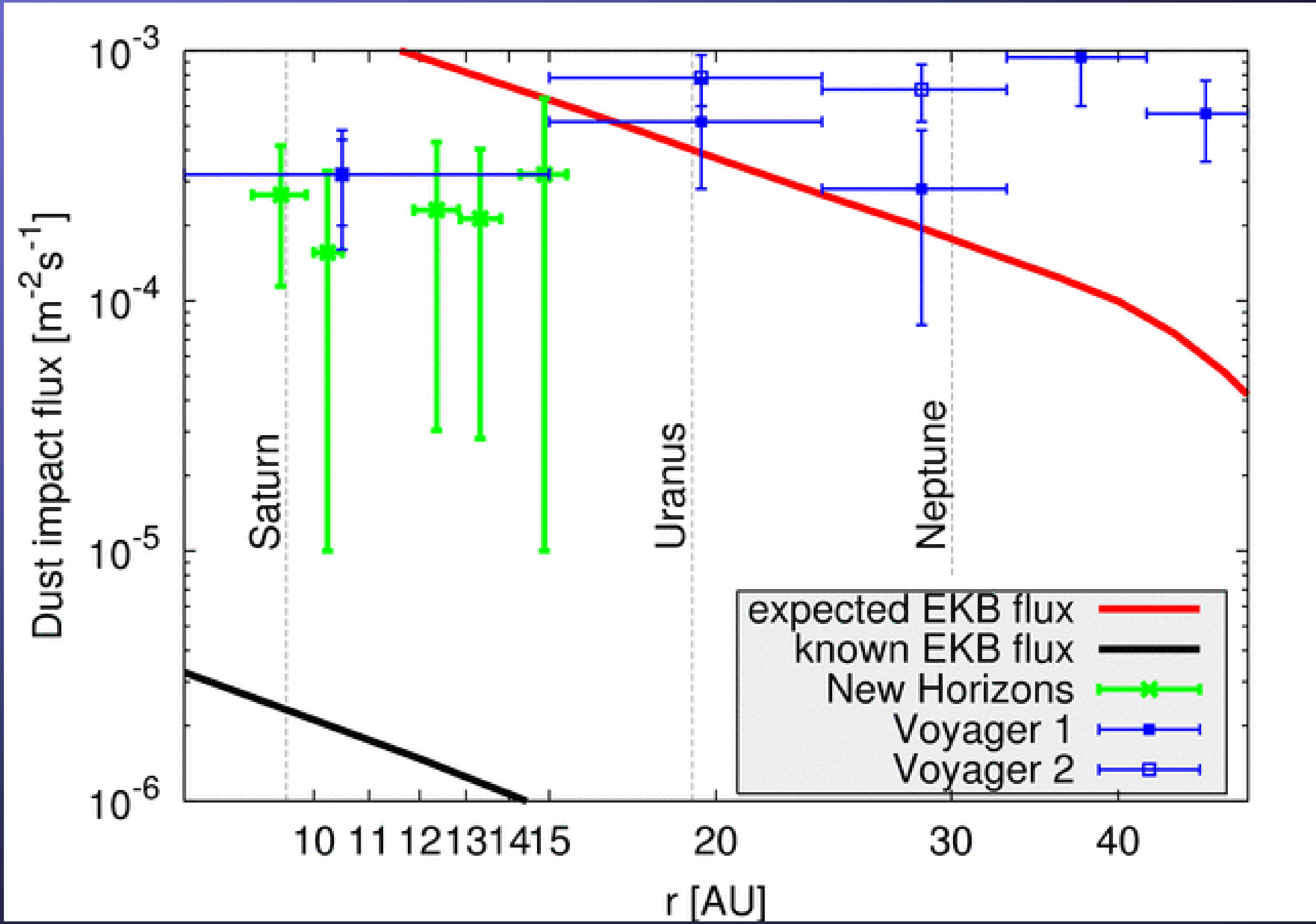
Vitense, Krivov, & Löhne, AAp (in press, astro/ph 1006.2220)

… and its simulated dust disk

The dust disk of the "true" EKB may have fractional luminosity ~1×10^{-6} and can still be collision-dominated!

Vitense, Krivov, & Löhne, AAp (in press, astro/ph 1006.2220)

Model “calibration” by dust measurements in-situ



Voyager data : *Gurnett et al., GRL* ***24****, 3125 (1997)*

New Horizons data: *Poppe et al., GRL* ***37****, 11101 (2010)*

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  Poster by Marshall
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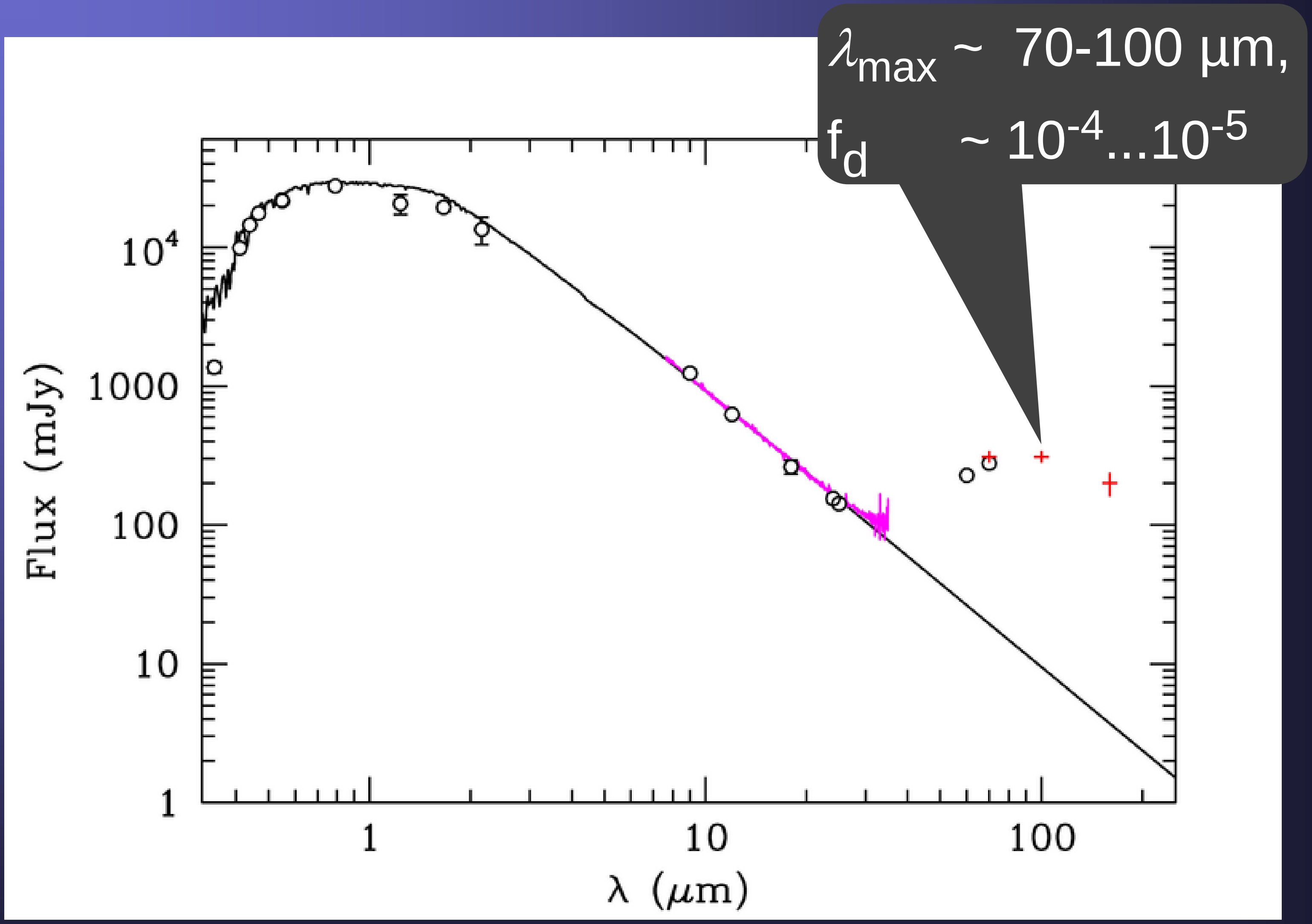
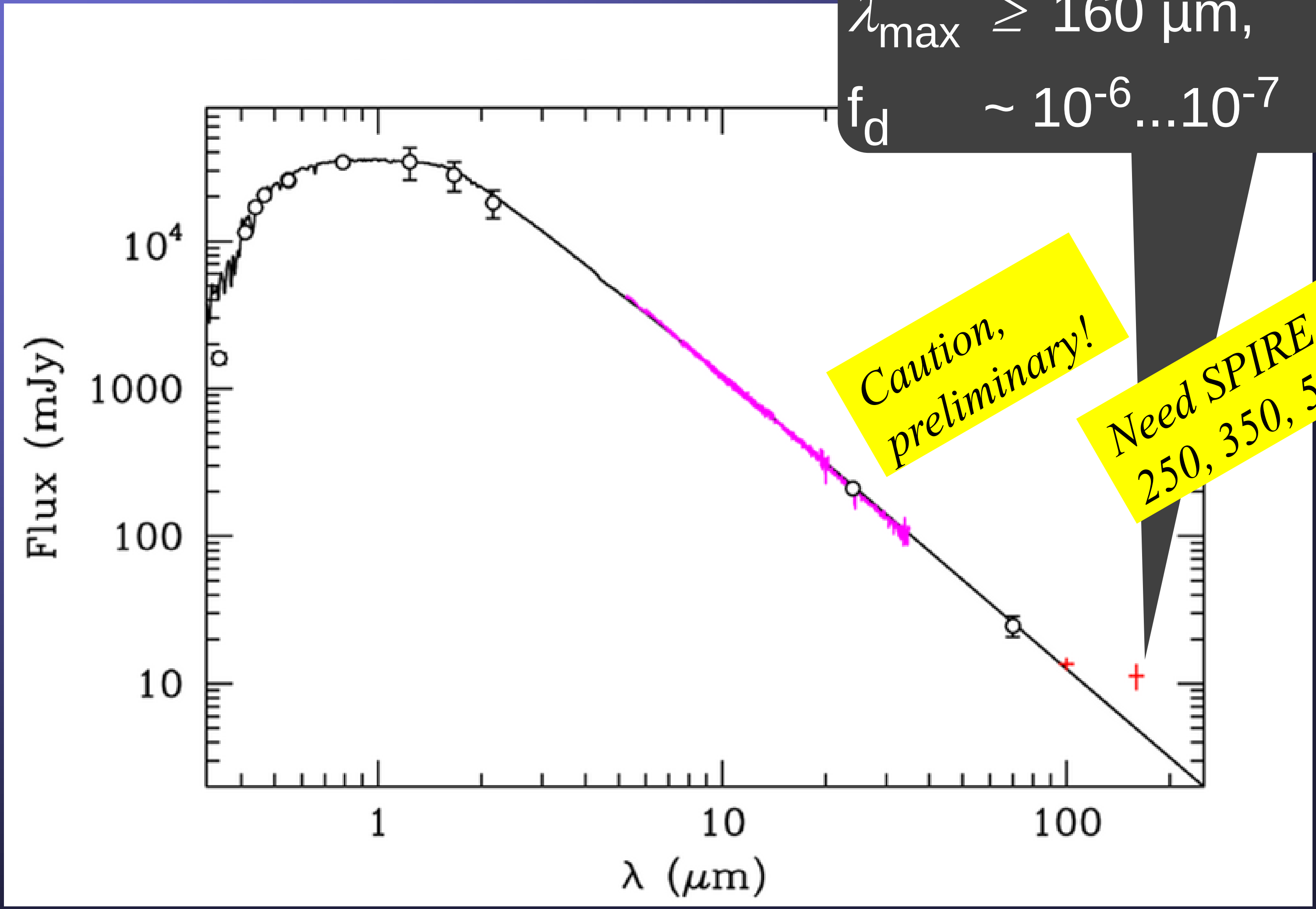
Some of the Herschel/DUNES disks are “normal”…



Marshall et al., in prep.

…but some others are tenuous and astonishingly cold



$\lambda_{max} \geq 160$ μm,

$f_d \sim 10^{-6}...10^{-7}$

Marshall et al., in prep.

Challenges of the cold disks

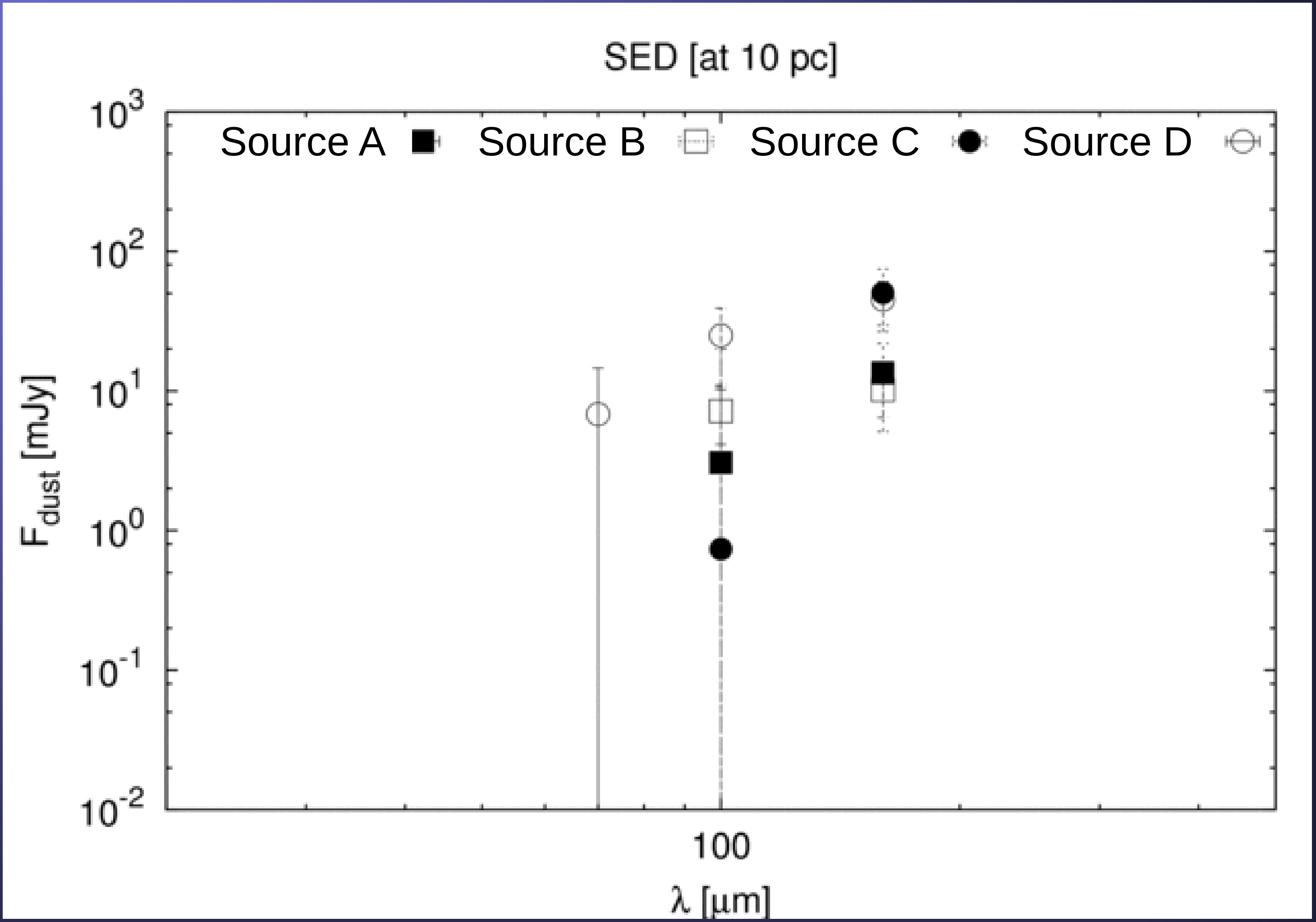
If the dust was emitting as a blackbody,
max at 160 μm would require dust to be at

23 AU from a K8 star
76 AU from a G2 star
190 AU from an F1 star

But the dust is not emitting as a blackbody!
A realistic size distribution includes smaller and hotter grains.
The inferred distances would be too large...

Planetesimals can hardly form outside ~100 AU
Resolved images also suggest radii of ~100 AU

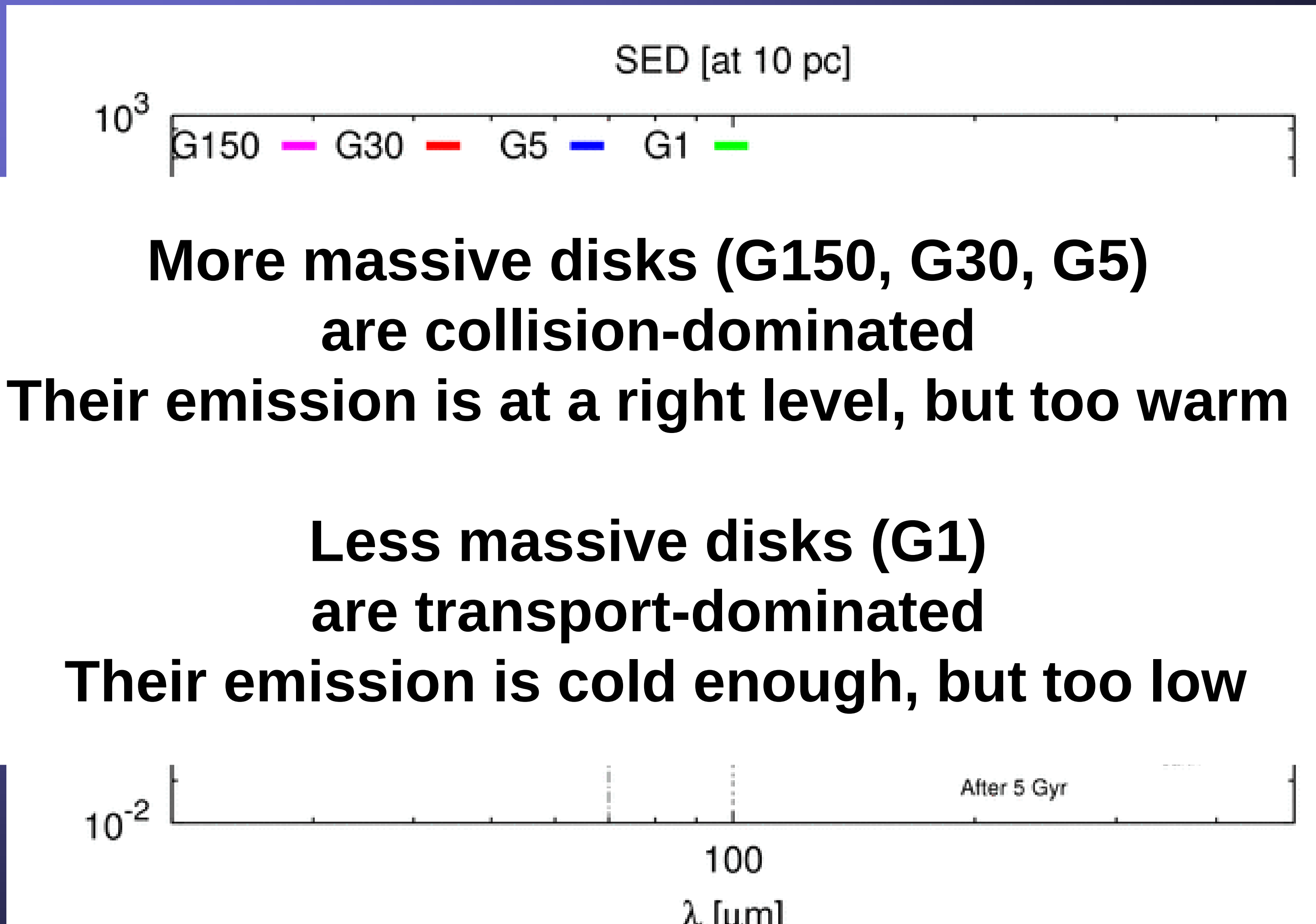
Attempts to understand the cold disks



Excess flux of four most reliable cold disks observed by DUNES

Krivov et al., in prep.

Attempts to understand the cold disks



More massive disks (G150, G30, G5)
are collision-dominated
Their emission is at a right level, but too warm

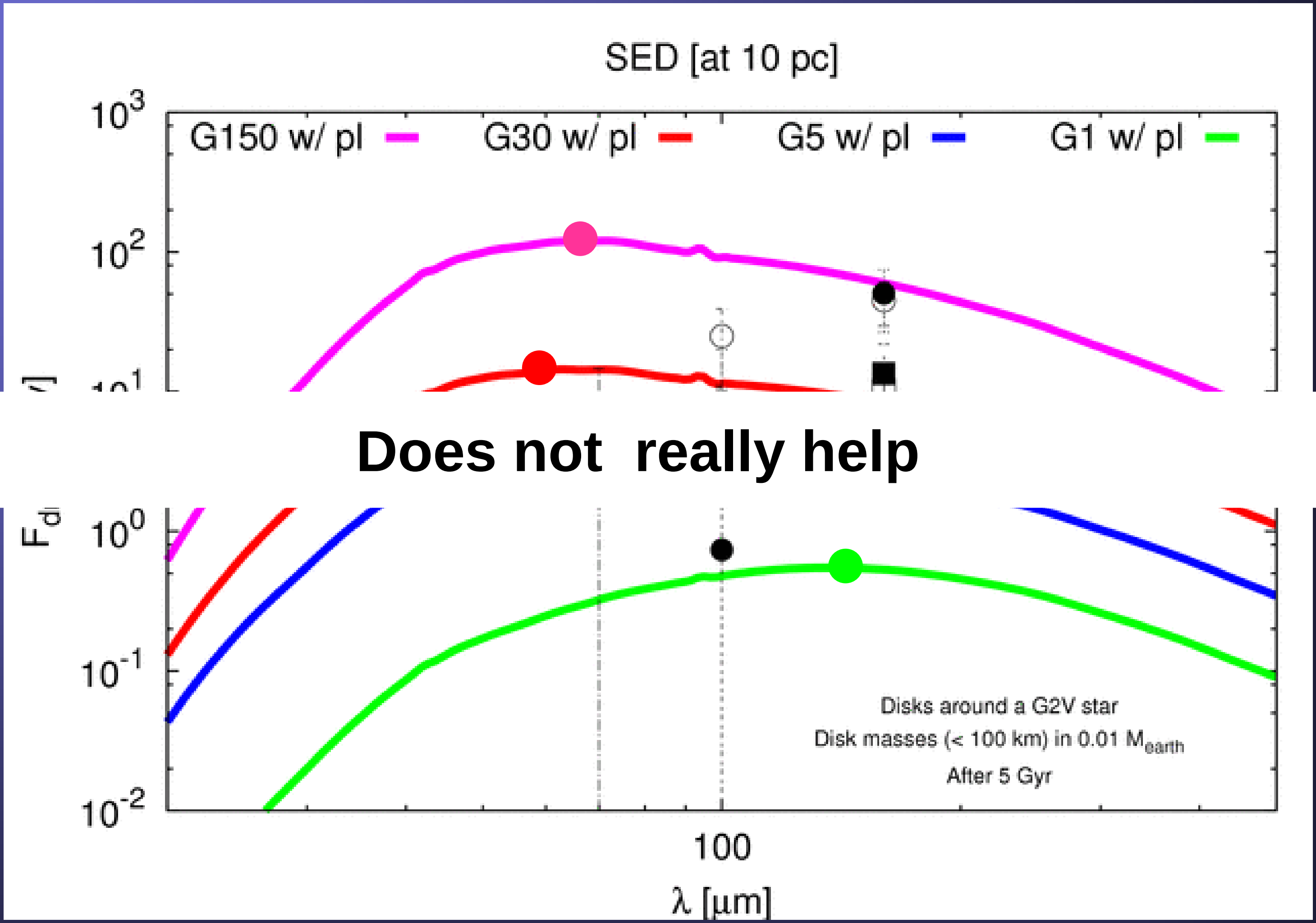
Less massive disks (G1)
are transport-dominated
Their emission is cold enough, but too low

Tried planetesimal belts at r=100AU, Δr=0.2, e~0.1, 50%ice+50%sil

G150 = 1.50 $M_\oplus$ G30 = 0.30 $M_\oplus$ G5 = 0.05 $M_\oplus$ G1= 0.01 $M_\oplus$

Krivov et al., in prep.

Attempts to understand the cold disks

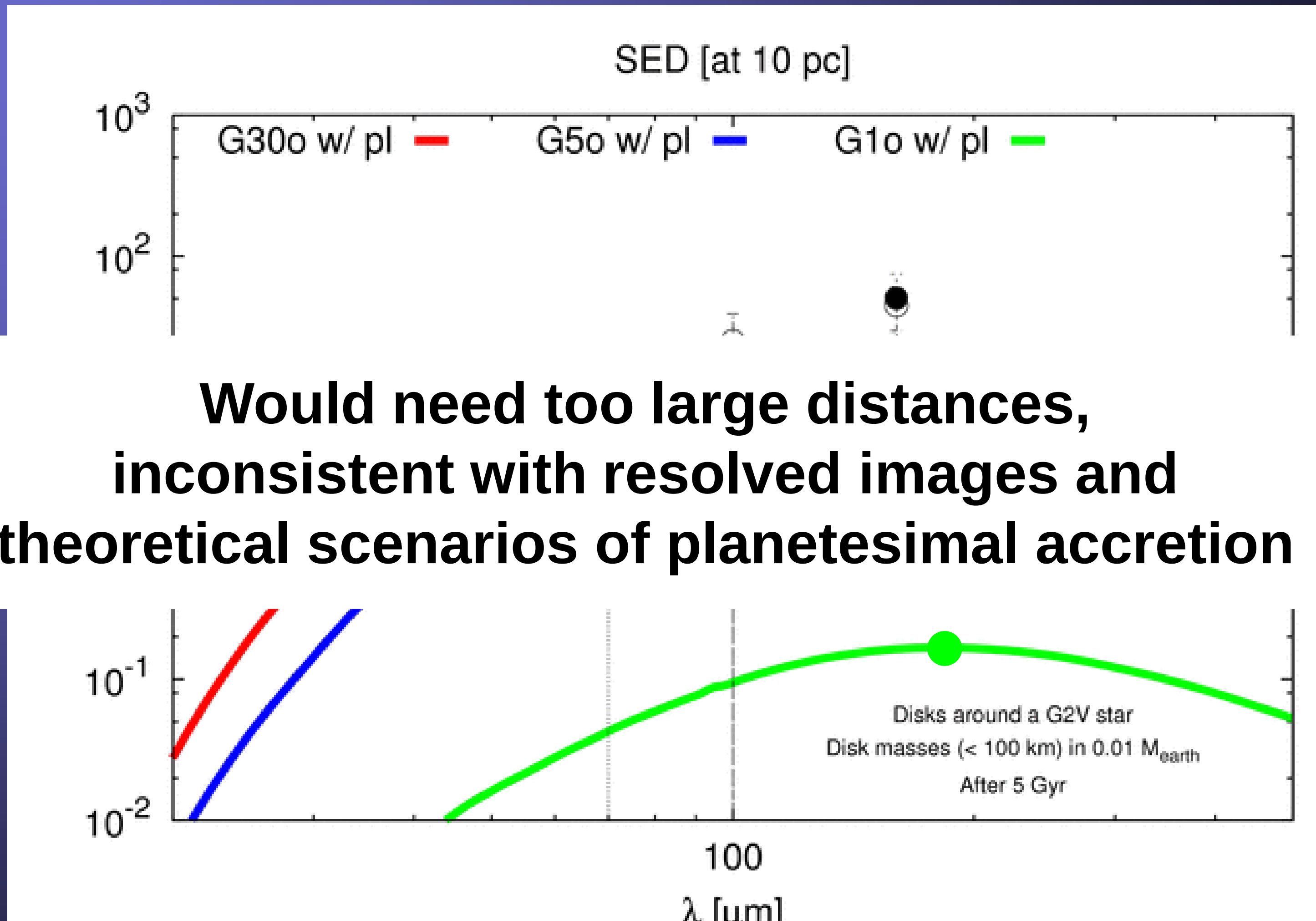


Does not really help

Tried to exclude dust in the inner parts of a dust disk (< 60 AU) assuming that each belt is shaped by a Fomalhaut-like planet

Krivov et al., in prep.

Attempts to understand the cold disks



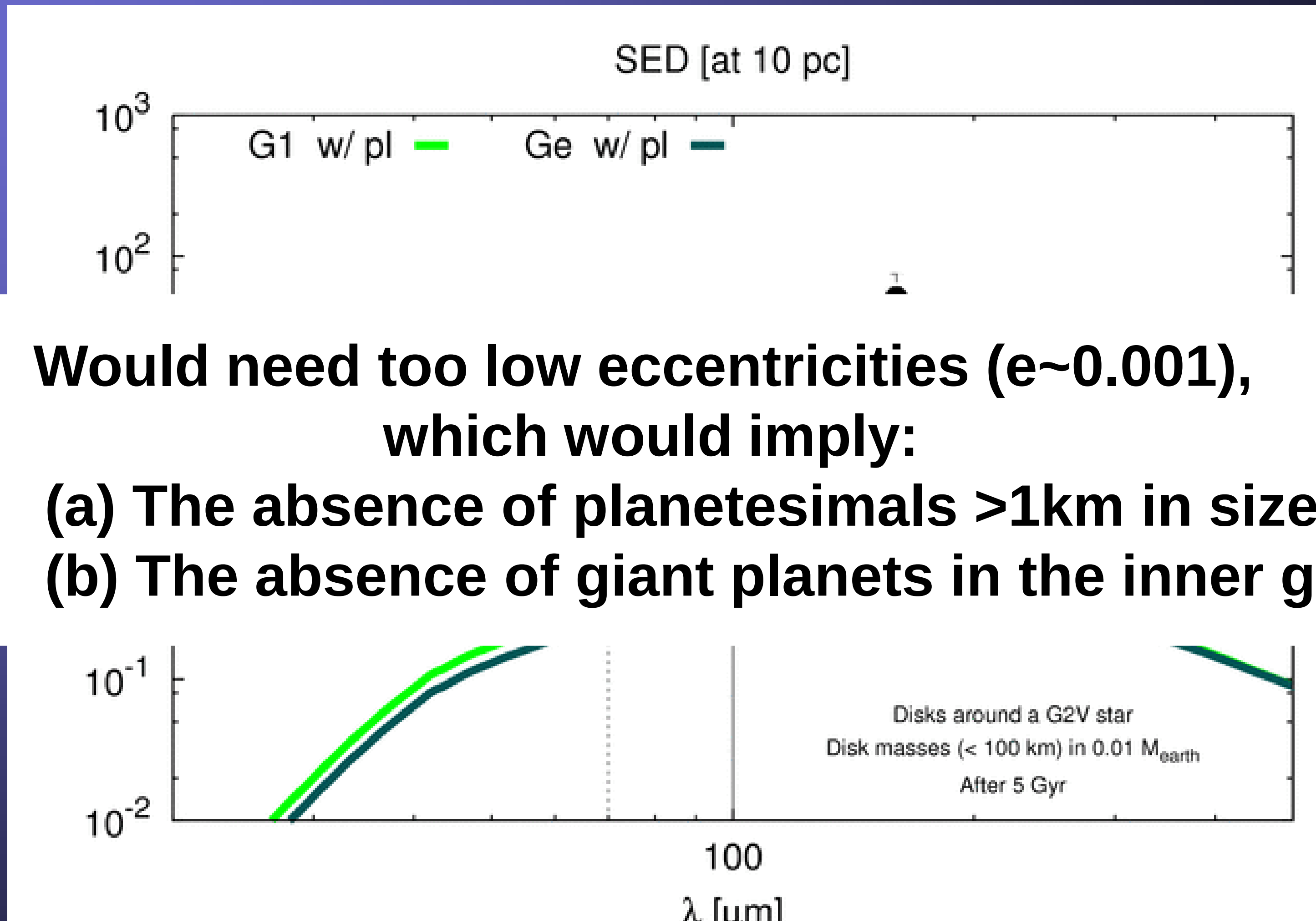
Would need too large distances, inconsistent with resolved images and theoretical scenarios of planetesimal accretion

Tried planetesimal belts at a larger distance: r=150AU

G30o = 0.30 $M_\oplus$ G5o = 0.05 $M_\oplus$ G1o= 0.01 $M_\oplus$

Krivov et al., in prep.

Attempts to understand the cold disks

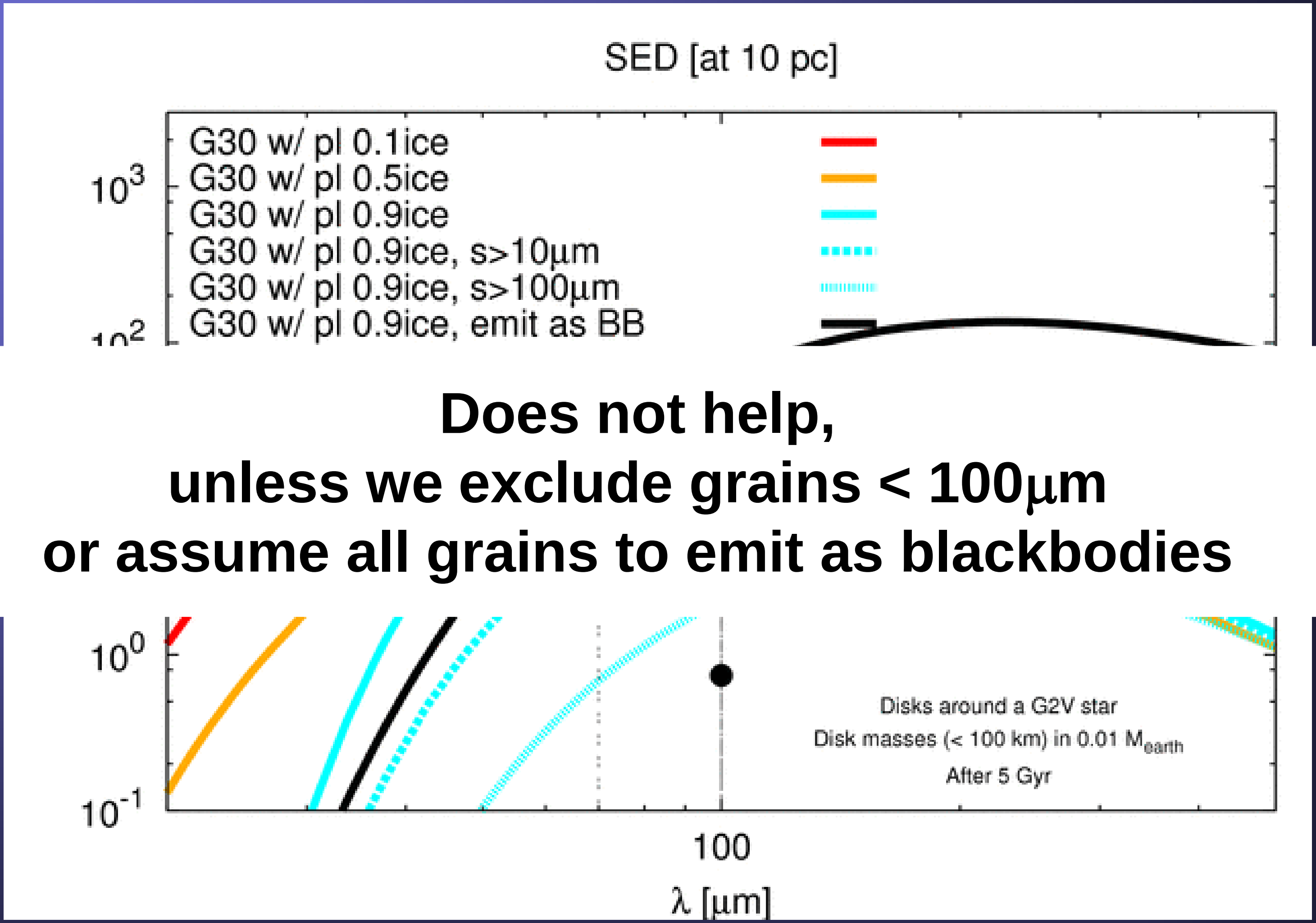


Would need too low eccentricities (e~0.001), which would imply:
(a) The absence of planetesimals >1km in size
(b) The absence of giant planets in the inner gap

Tried belts with low excitation *(Thebault & Wu 2008)*:
Ge= 0.01 $M_\oplus$ (e = 0.02) vs G1= 0.01 $M_\oplus$ (e = 0.1)

Krivov et al., in prep.

Attempts to understand the cold disks



Does not help,
unless we exclude grains < 100μm
or assume all grains to emit as blackbodies

Tried other dust compositions, large grains only, and blackbody

Krivov et al., in prep.

Attempts to understand the cold disks

Thus the “cold disks” remain unexplained:
- Any mechanisms to remove μm-sized grains?
- Or their far-IR emission stronger that expected?

On any account, these disks seem to be collision- rather than transport-dominated

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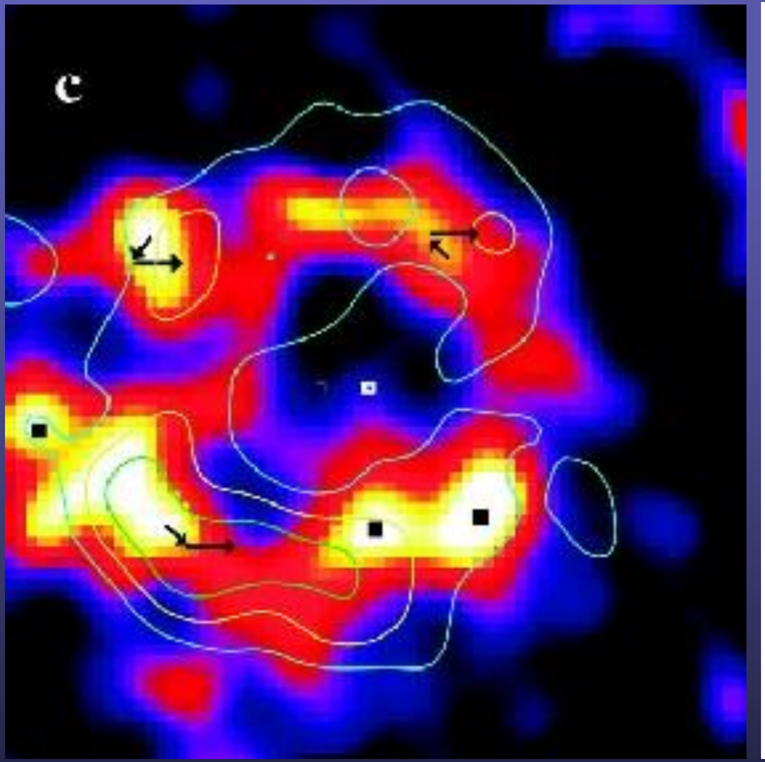
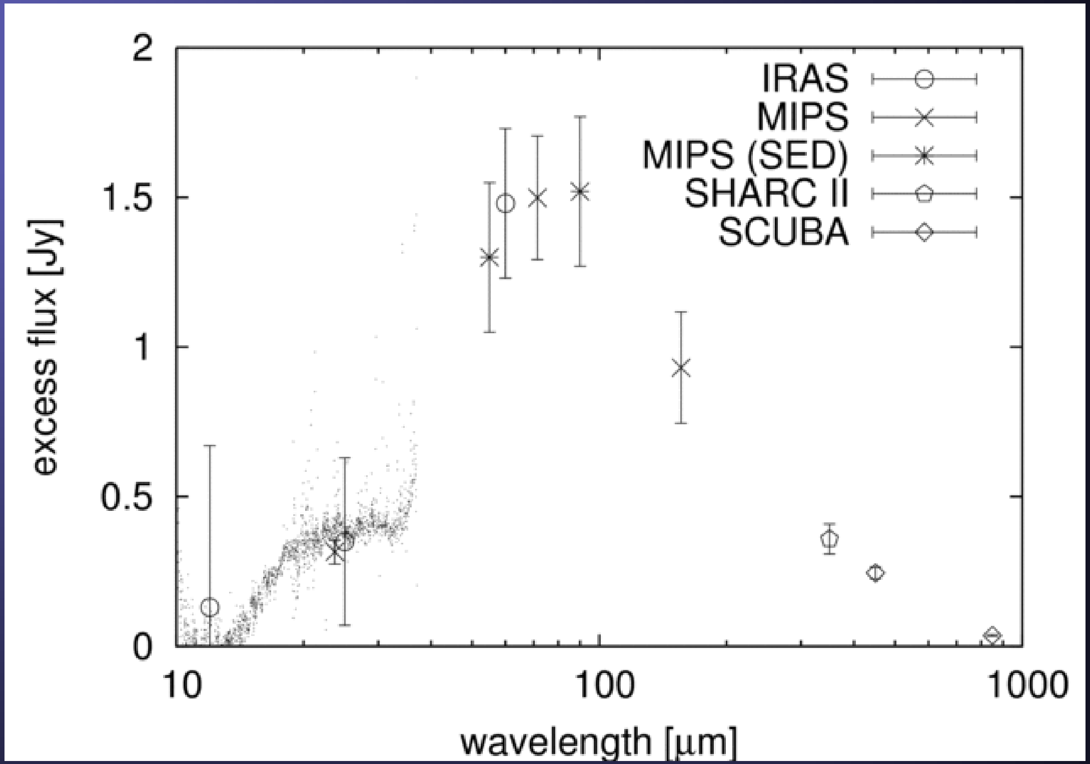
The ε Eri system and its puzzling warm dust

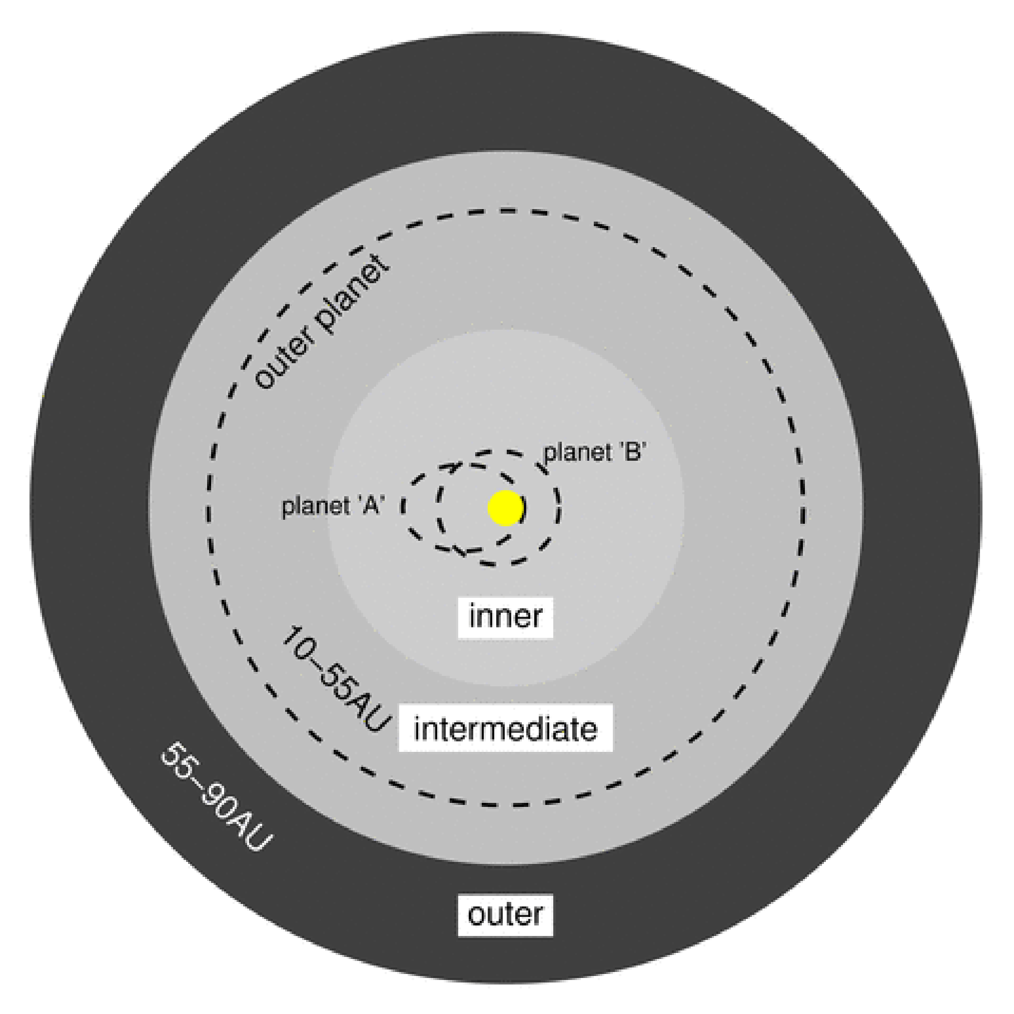
One known RV planet with a=3.4 AU *(Hatzes et al. 2000)*
One presumed planet at ~40 AU *(Liou & Zook 1999)*
A "Kuiper belt" at ~60 AU *(Gillett 1986, Greaves et al., 1998, 2005)*
Warm dust down to a few AU *(Backman et al. 2009)*





Warm dust that produces the IRS spectrum is located at a few AU
An "asteroid belt" there would be destroyed by the known RV planet

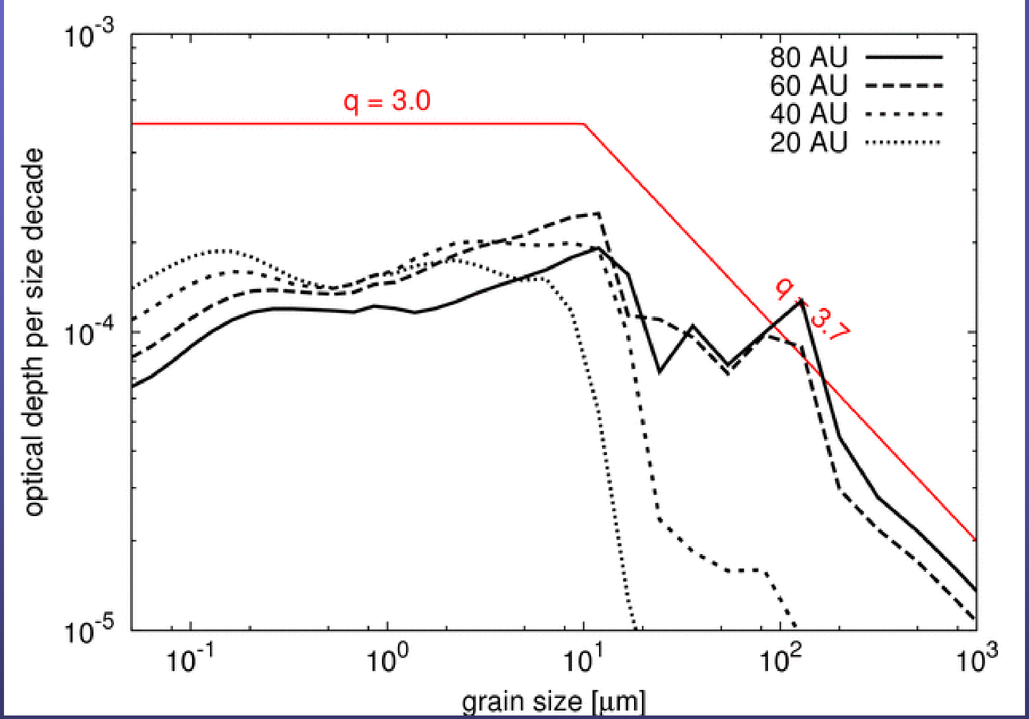
Possible solution

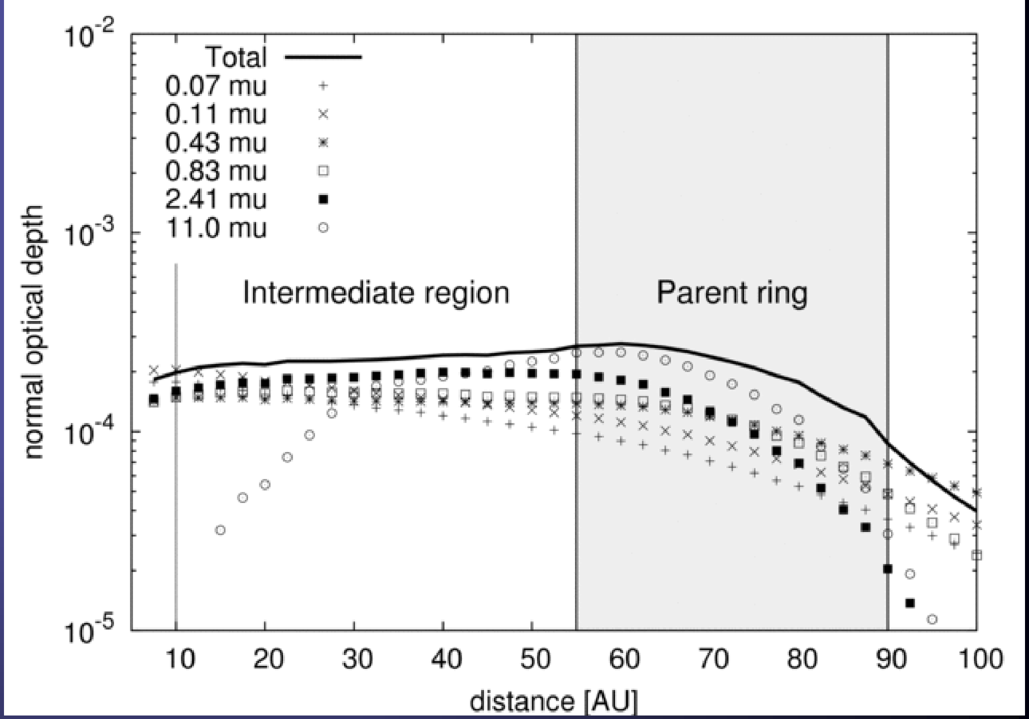


Warm dust could be transported from the "Kuiper belt"

Reidemeister, Krivov, Stark, et al., AAp (submitted)

Modeled size and radial distribution

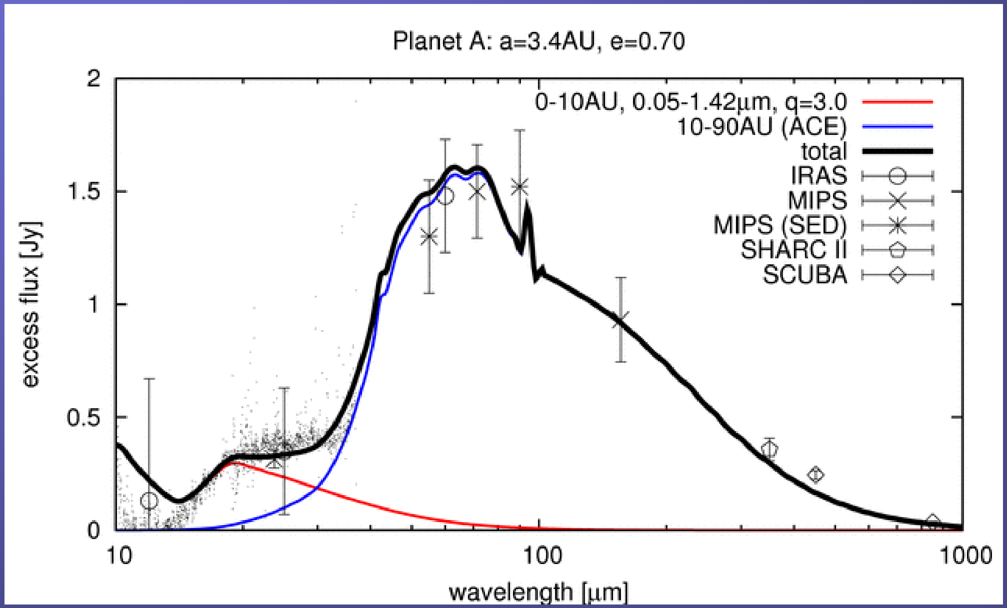


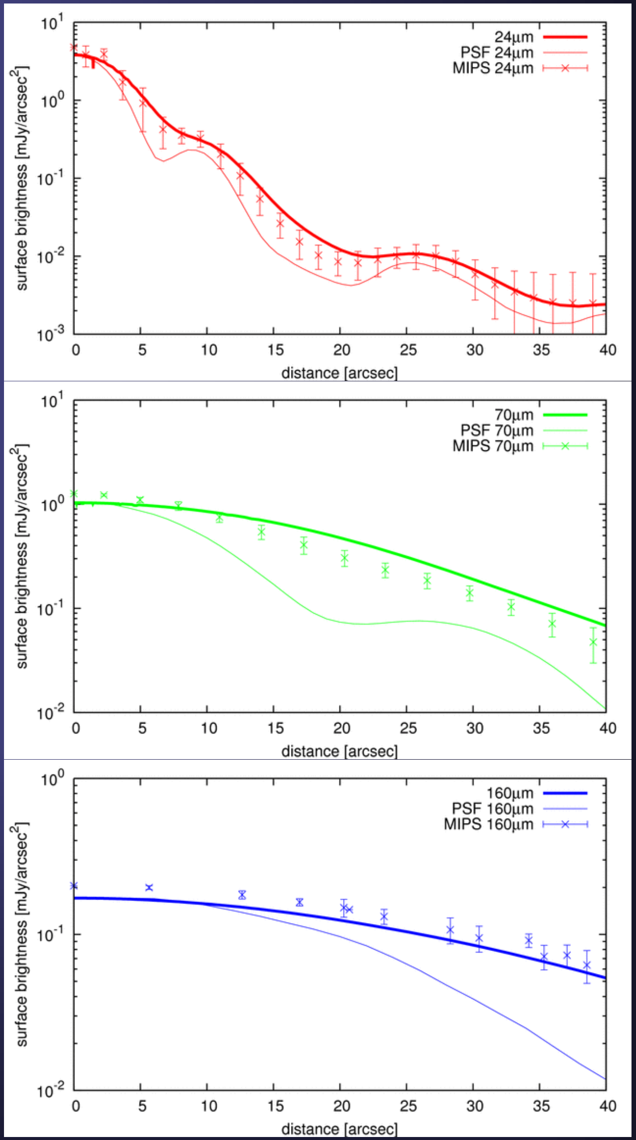


The disk is transport-dominated, despite $\tau \sim 2\text{x}10^{-4}$

Reidemeister, Krivov, Stark, et al., AAp (submitted)

Modeled SED and brightness profiles





The model reproduces all pre-Herschel data:
SED from mid-IR to sub-mm,
Spitzer/IRS spectrum,
Spitzer/MIPS radial profiles.
Will it be consistent with Herschel data?

Reidemeister, Krivov, Stark, et al., AAp (submitted)

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- Transport mechanisms in debris disks include P-R drag (in tenuous disks) and stellar winds (in disks of late-type stars)
- A debris disk is transport-dominated, if the transport timescale of dust is shorter than its collisional lifetime
- Sufficiently tenuous disks and all disks around late-type stars can be transport-dominated
- Properties of transport-dominated disks differ significantly from those of collision-dominated disks. The main effect of transport is modification of size distribution of dust. In tenuous disks, big grains become more important
- Herschel enters the realm of transport-dominated disks!