The mystery of Herschel's "cold debris disks"

Sasha Krivov,
Torsten Löhne, Carlos Eiroa, Jonathan Marshall,
and the DUNES consortium

DUNES

The DUNES program

DUNES is a Herschel Open Time Key Program to study debris disks around nearby solar-type stars:

- Sample: volume-limited, 133 FGK stars
  - d<20 pc
  - + stars with known planets/disks (d<25 pc)
  - + 106 stars shared with OTKP DEBRIS
- Tools:
  - PACS photometry at 70, 100, 160 μm
  - SPIRE photometry at 250, 350, 500 μm
- Strategy:

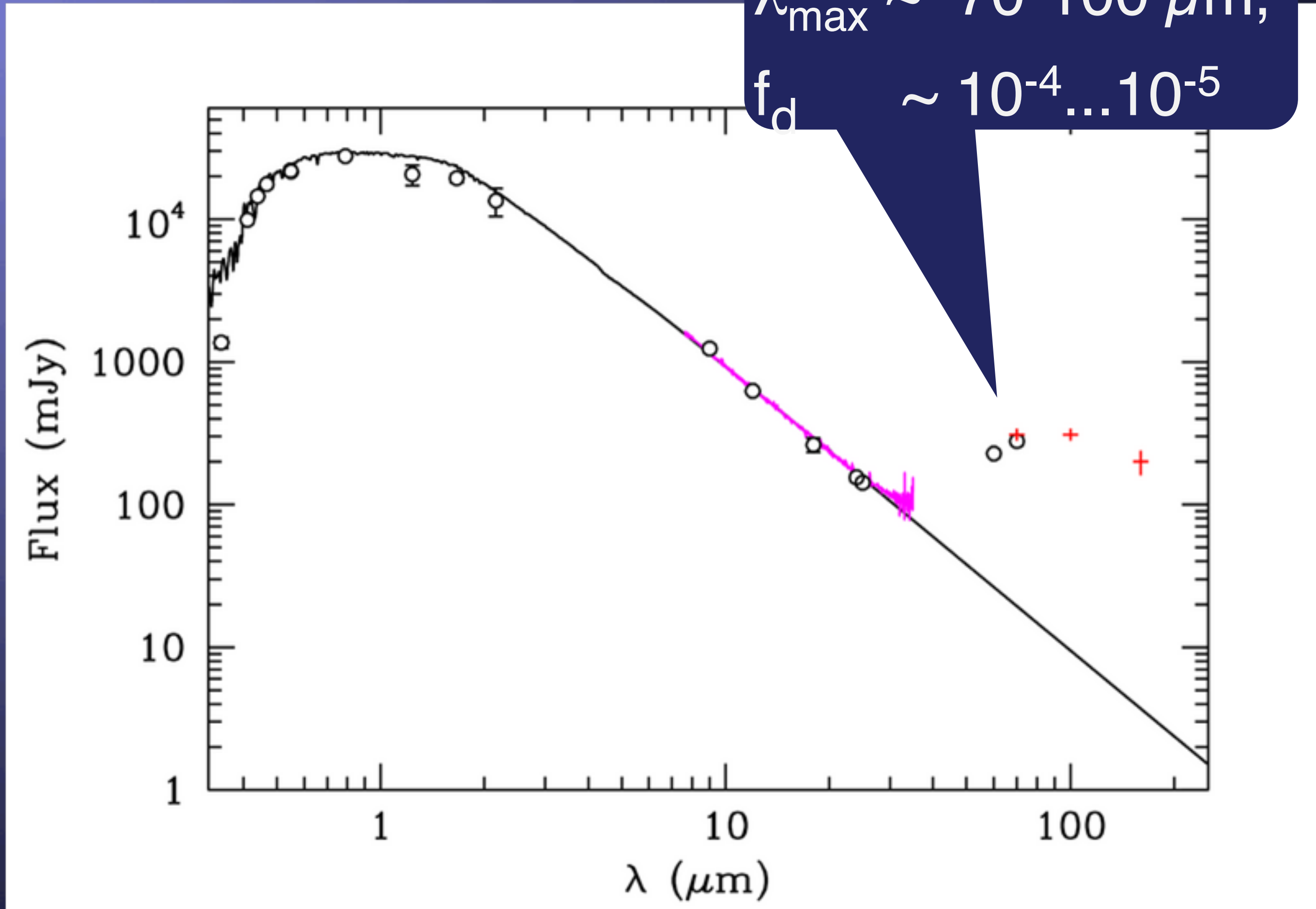
  to integrate as long as needed to reach the 100 μm photospheric flux, only limited by background confusion: F_* (100 μm) $\gtrsim$ 4 mJy

The DUNES people

Olivier Absil, David Ardila, Jean-Charles Augereau, David Barrado, Amelia Bayo, Charles Beichman, Geoffrey Bryden, William Danchi, Carlos del Burgo, Carlos Eiroa (PI), Steve Ertel, Davide Fedele, Malcolm Fridlund, Misato Fukagawa, Beatriz Gonzalez, Eberhard Gruen, Ana Heras, Inga Kamp, Alexander Krivov, Ralf Launhardt, Jeremy Lebreton, Rene Liseau, Torsten Loehne, Rosario Lorente, Jesus Maldonado, Jonathan Marshall, Raquel Martinez, David Montes, Benjamin Montesinos, Alcione Mora, Alessandro Morbidelli, Sebastian Mueller, Harald Mutschke, Takao Nakagawa, Goeran Olofsson, Goeran Pilbratt, Ignasi Ribas, Aki Roberge, Jens Rodmann, Jorge Sanz , Enrique Solano, Karl Stapelfeldt, Philippe Thebault, Helen Walker, Glenn White, Sebastian Wolf

Cold disks

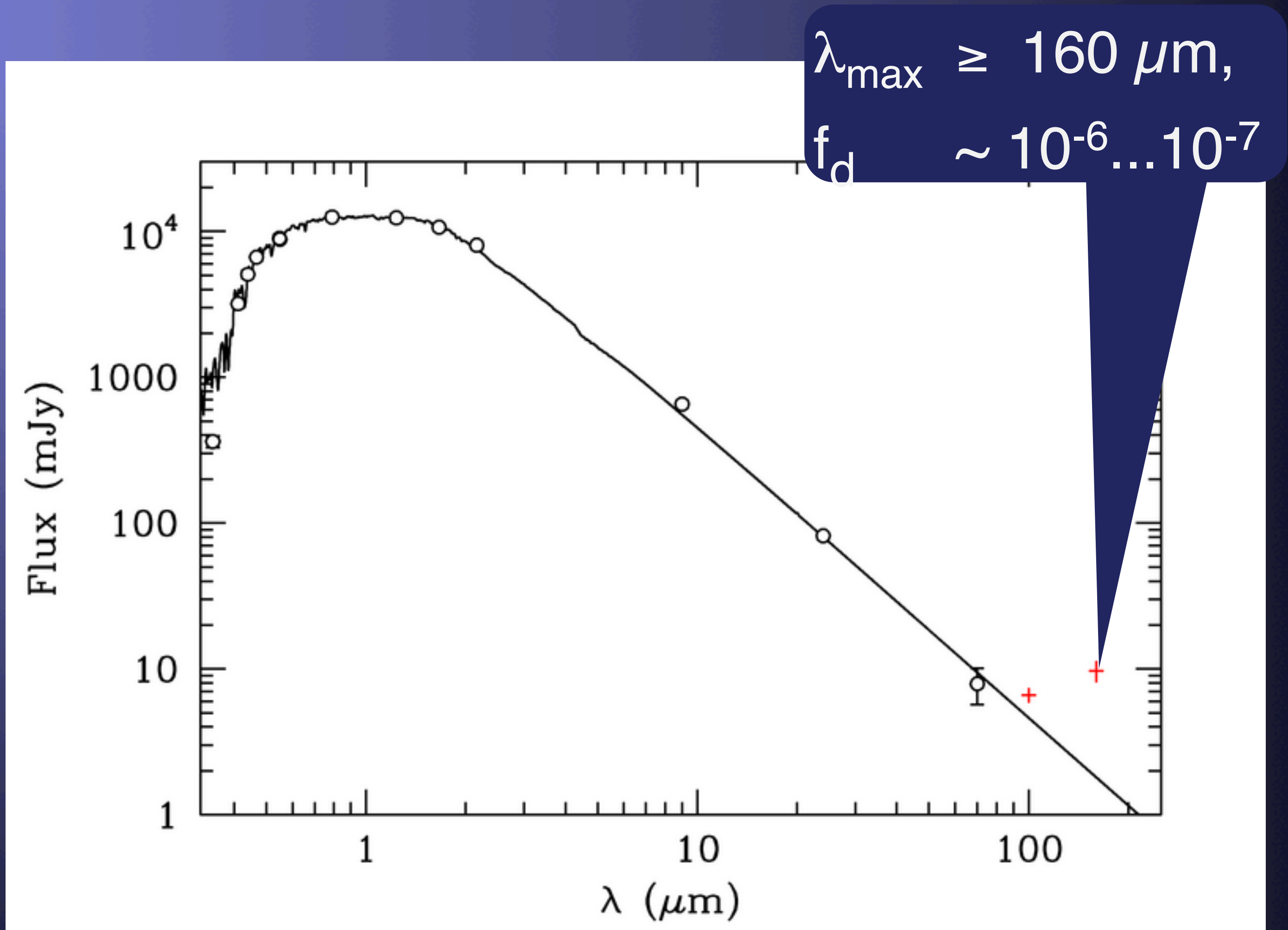
"Classical" debris disks



$\lambda_{max} \sim$ 70-100 μm,

$f_d \sim 10^{-4}...10^{-5}$

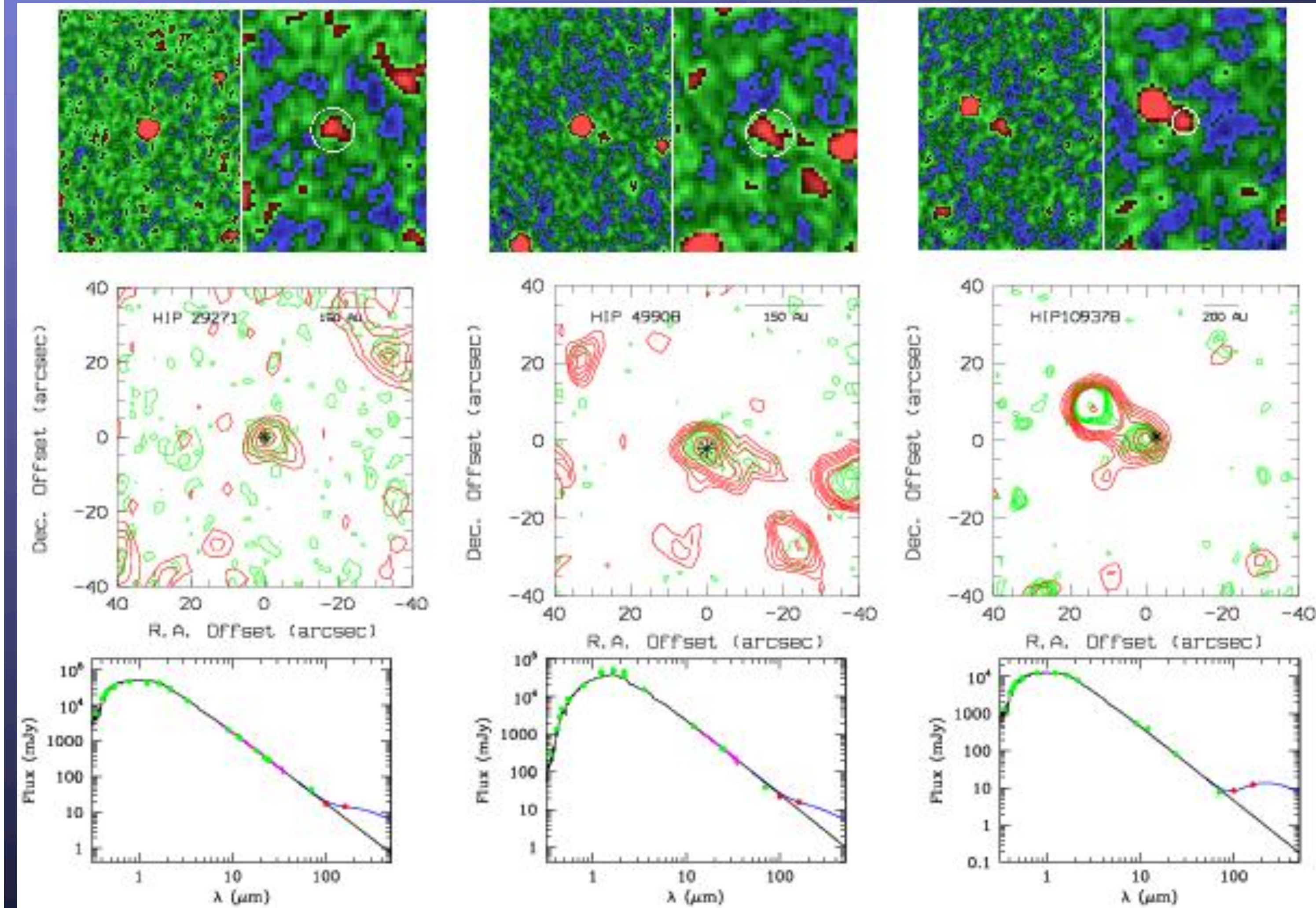
The class of "cold disks"

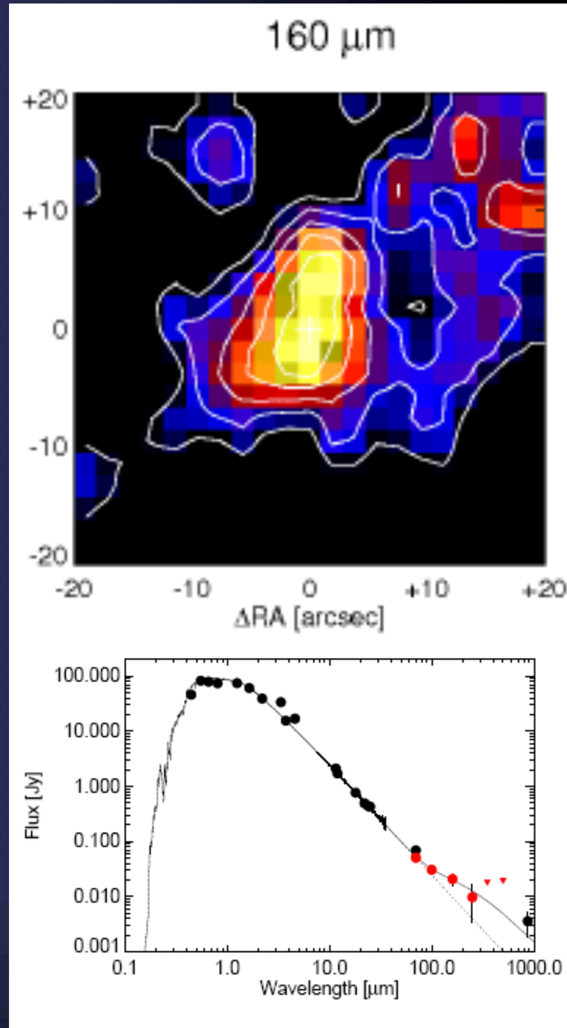


"Cold" are disks with an excess at ≥160 μm, but little or no excess at 100 μm
Cold disks may also be present in the DEBRIS and GASPS samples

Eiroa et al. 2011

~30/133 DUNES stars have disks, ~6 of them are cold





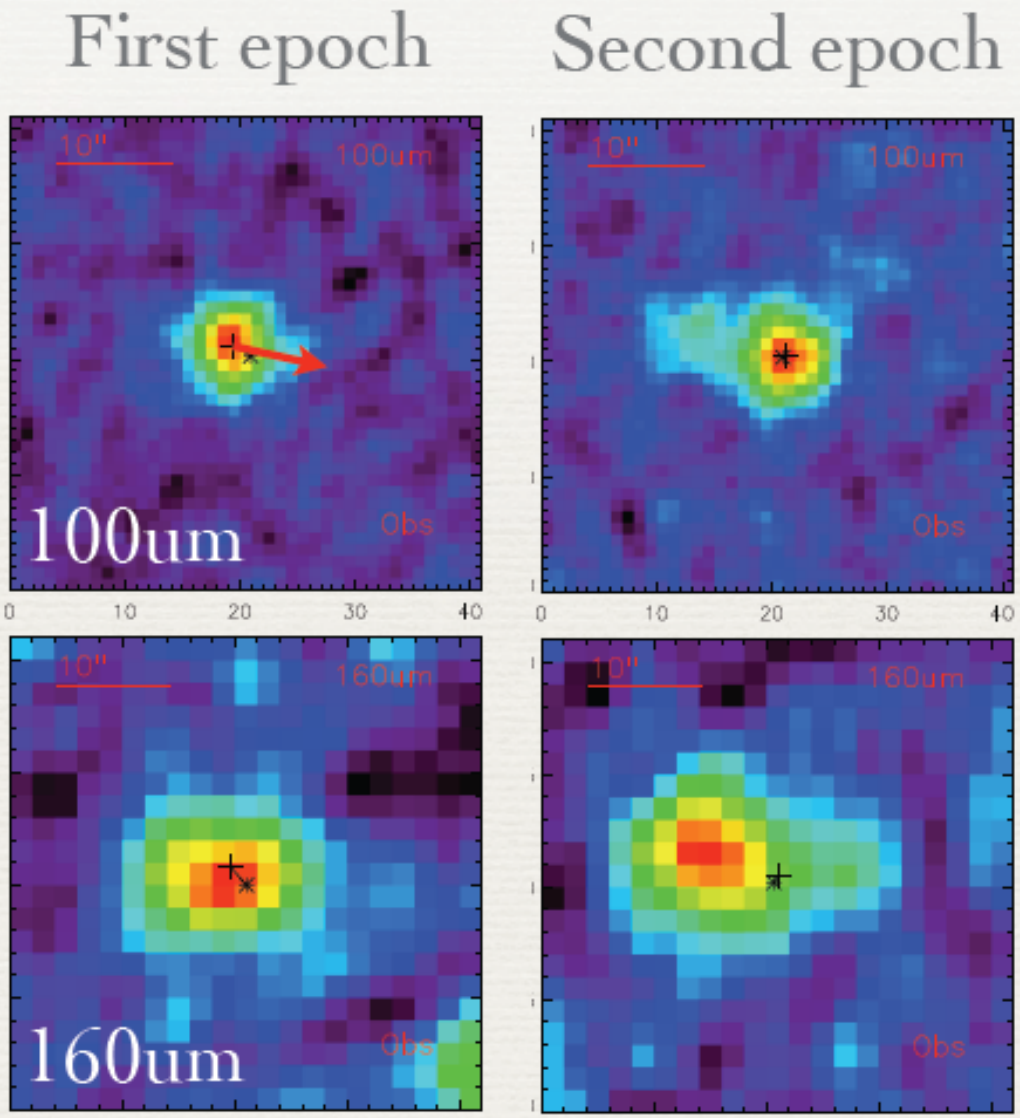
HIP 29271 (α Men), HIP 49908, HIP 109378

HIP 92043

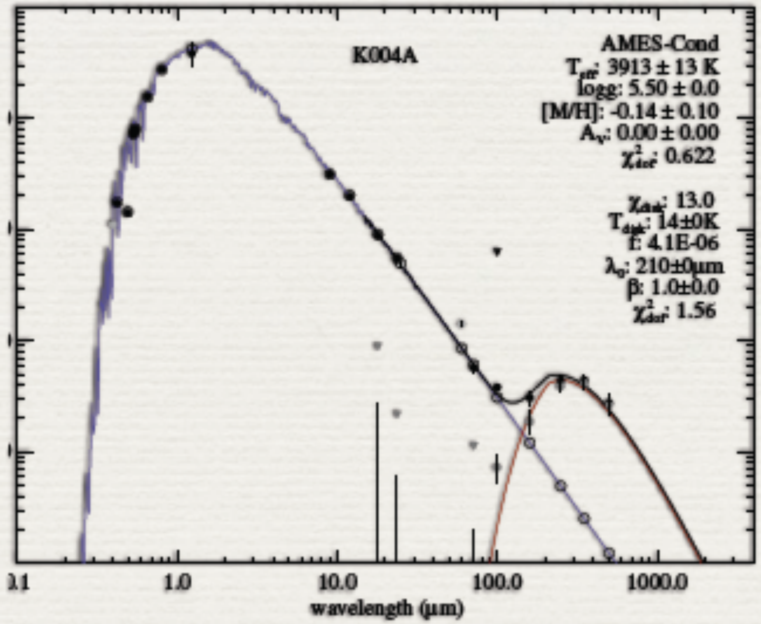
Eiroa et al. 2011

Marshall et al. 2012

A word of caution

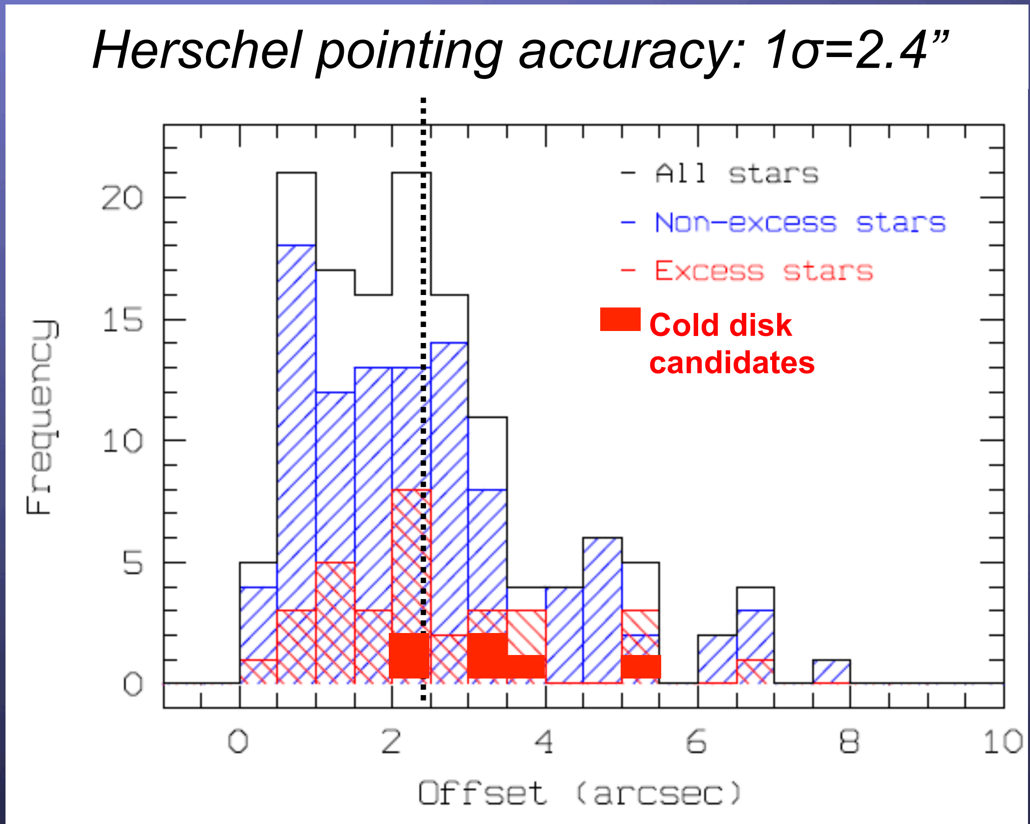


High proper motion (4"/yr) reveals a background object behind first epoch position



Courtesy Grant Kennedy and the DEBRIS team

Some of the cold disks must be real



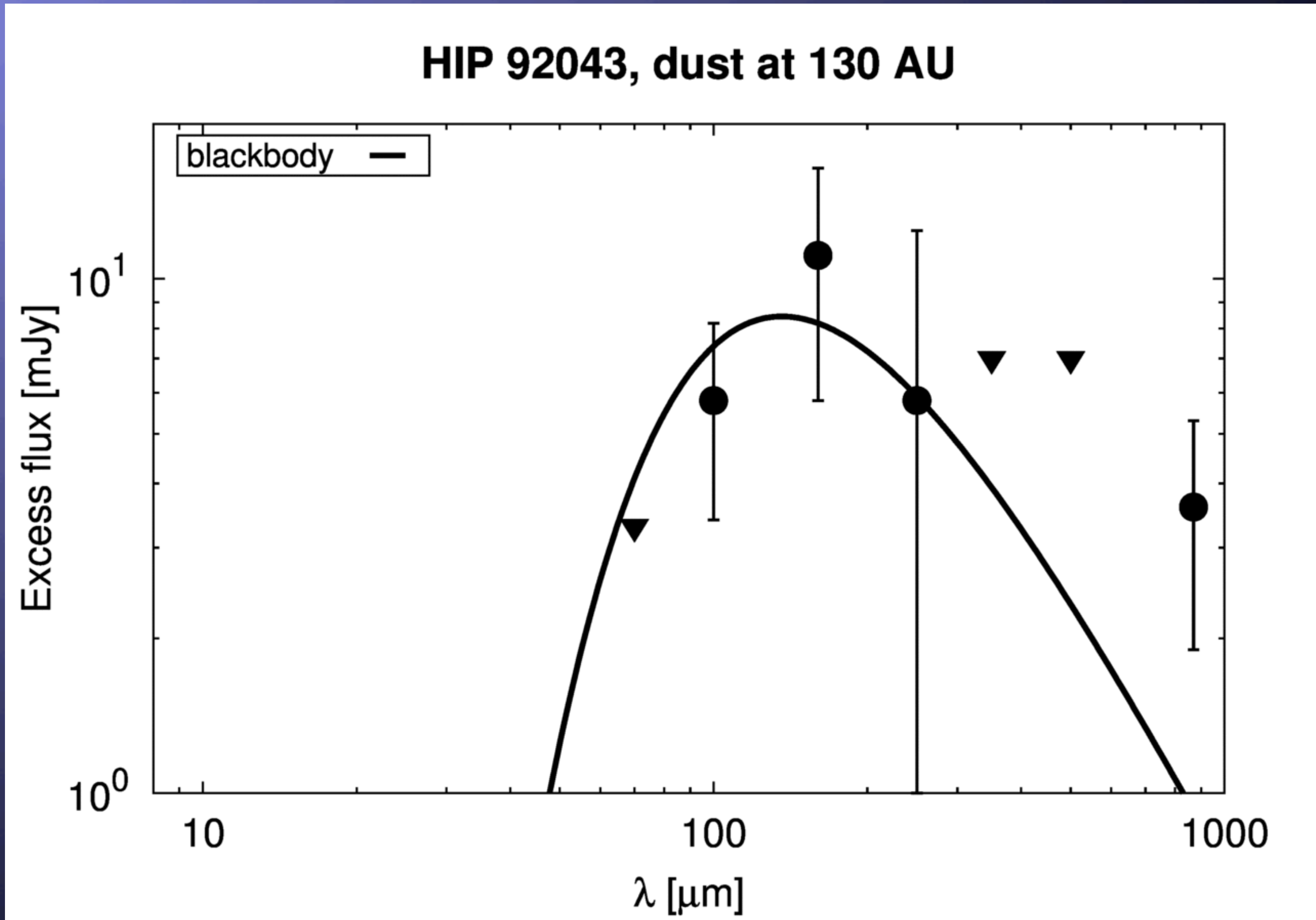
(1) Offset between the optical position of a star and the peak of 100 μm emission is consistent with Herschel pointing accuracy (mean: 3.3”),

(2) Measured flux at 100 μm is consistent with photospheric prediction (mean deviation: 1.1 mJy), so we are sure at 100μm we see the star, and

(3) Offset of the 160 μm emission peak from the100 μm one is small (mean: 2.9”), so the chance that 160 μm emission is associated with the star is high

Binomial probability of having ≥ 6 “false disks” in a sample of 133 targets is <5%

Dust in the cold disks is "subthermal"



Disk radii are inferred from the images (in resolved cases)
or constrained by the fact the disks are unresolved (for unresolved disks)

SEDs + disk radii suggest that dust is colder than blackbody

Working plan

The first step:

find grain sizes and materials that would be consistent with data

For instance: take HIP 92043, place dust at 130 AU, and try to find sizes and compositions that reproduce PACS & SPIRE points

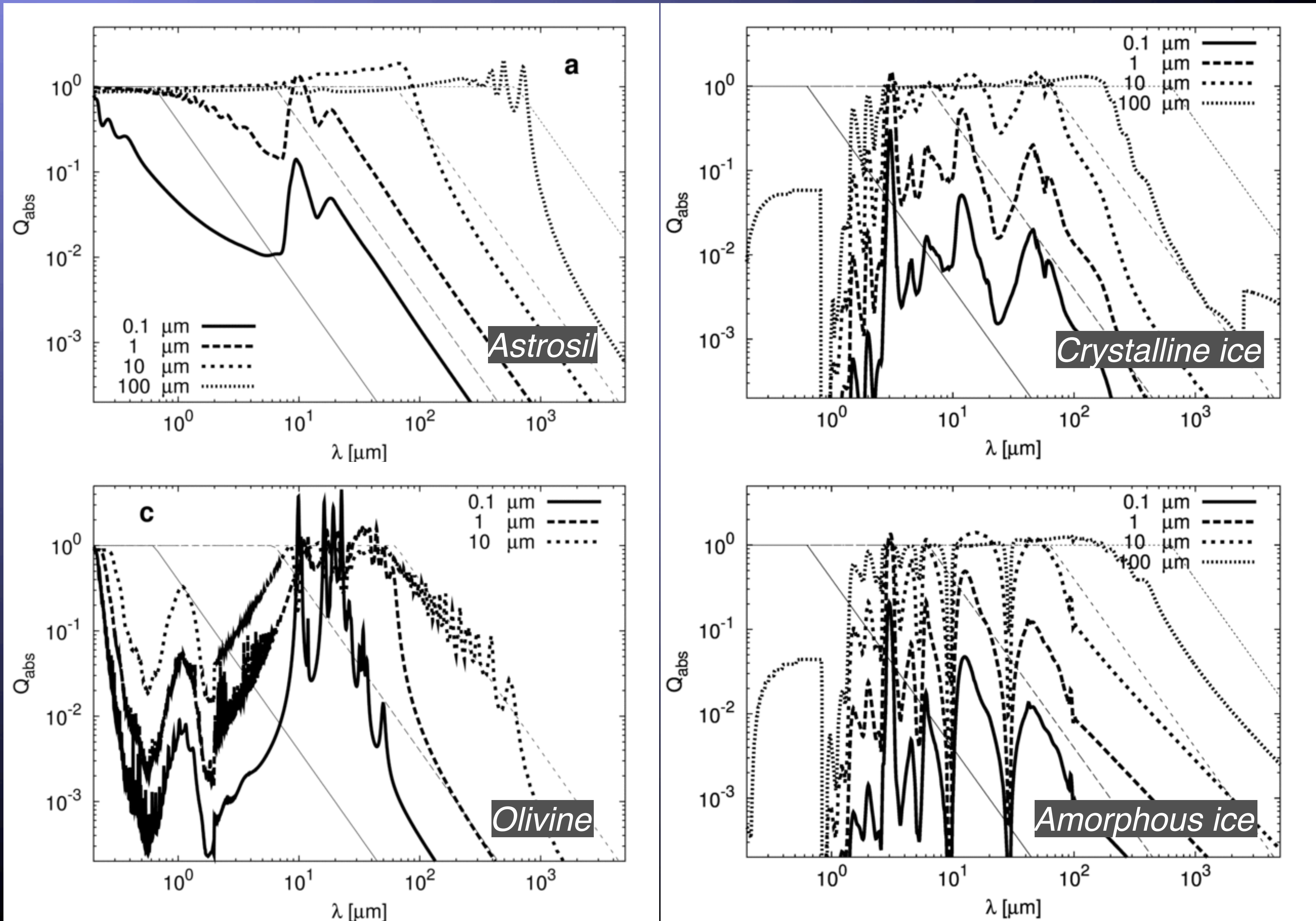
The second step:

find a disk that would produce and sustain such a dust

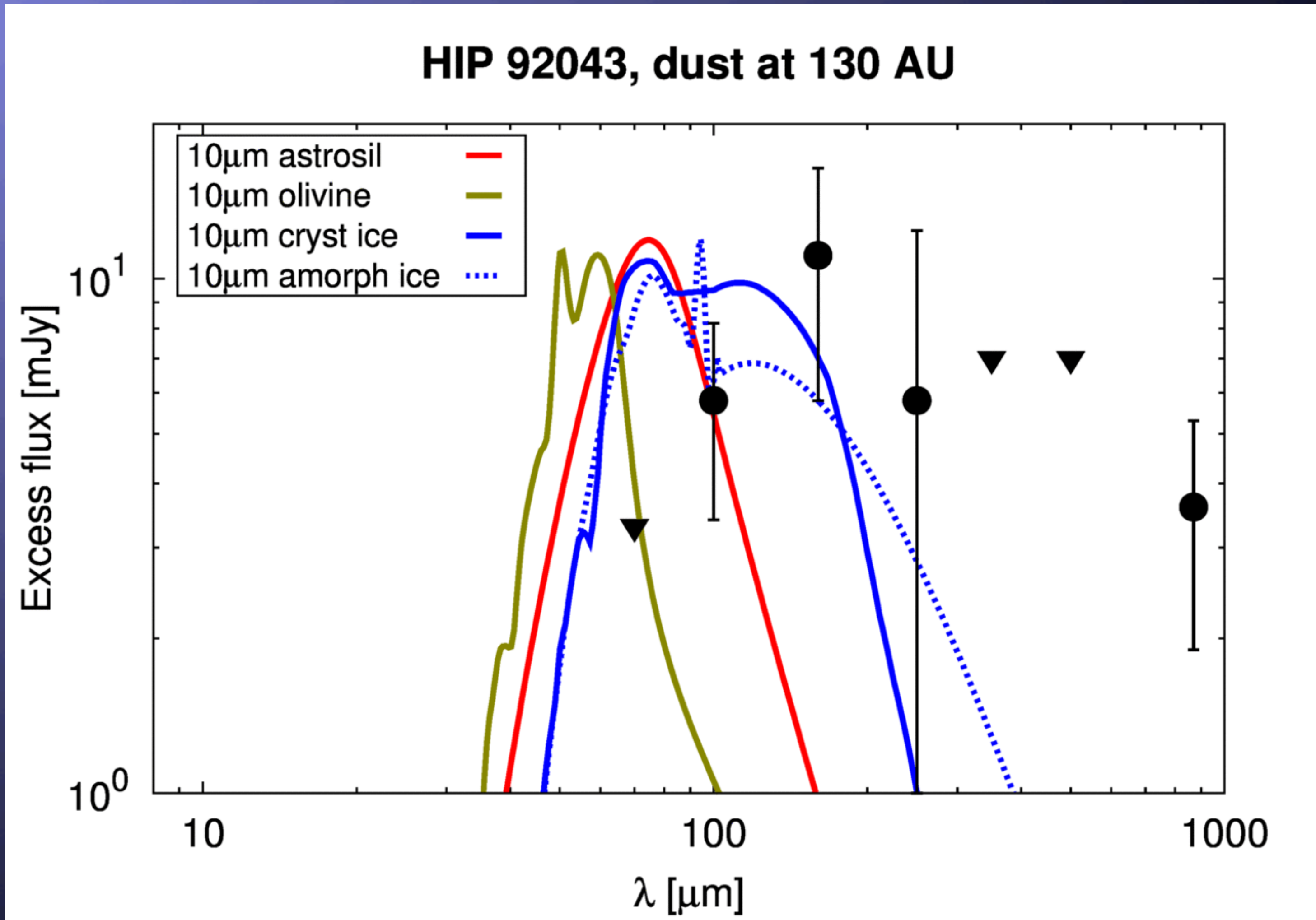
To this end, vary properties of planetesimal belts
(dynamical excitation, largest planetesimal size, strength, ...)

Step I:
What kind of dust are they made of?

Absorption efficiency for different sizes and materials

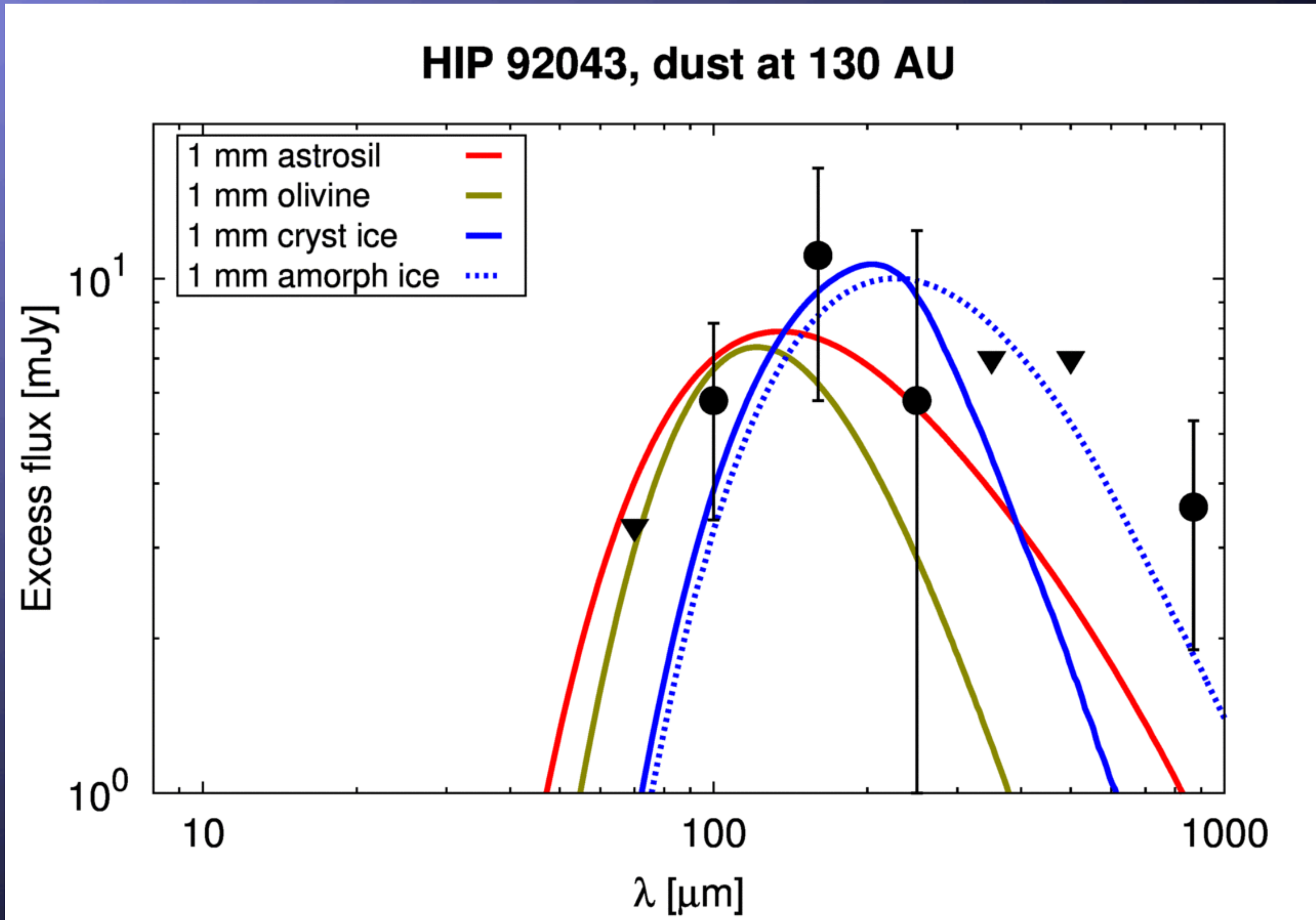


Tests with different grain sizes and materials



10 μm grains, even of pure ice, are far too warm

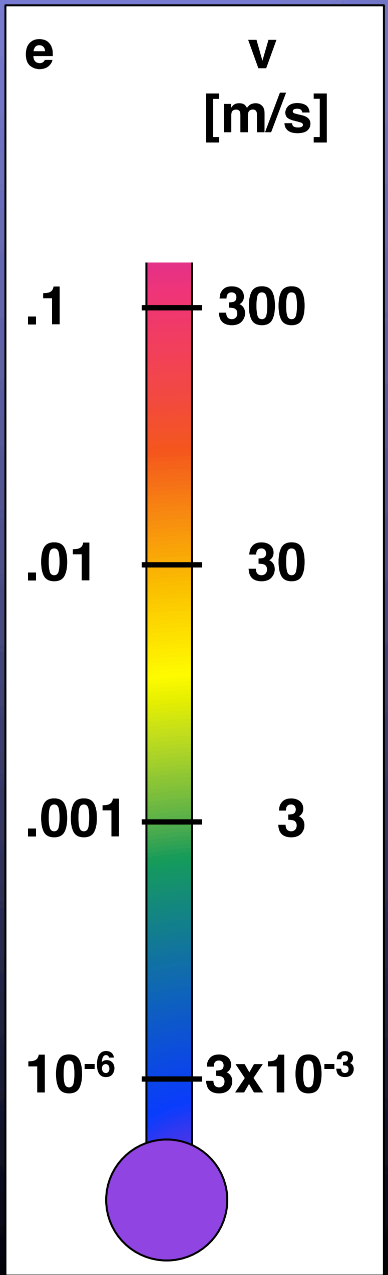
Tests with different grain sizes and materials

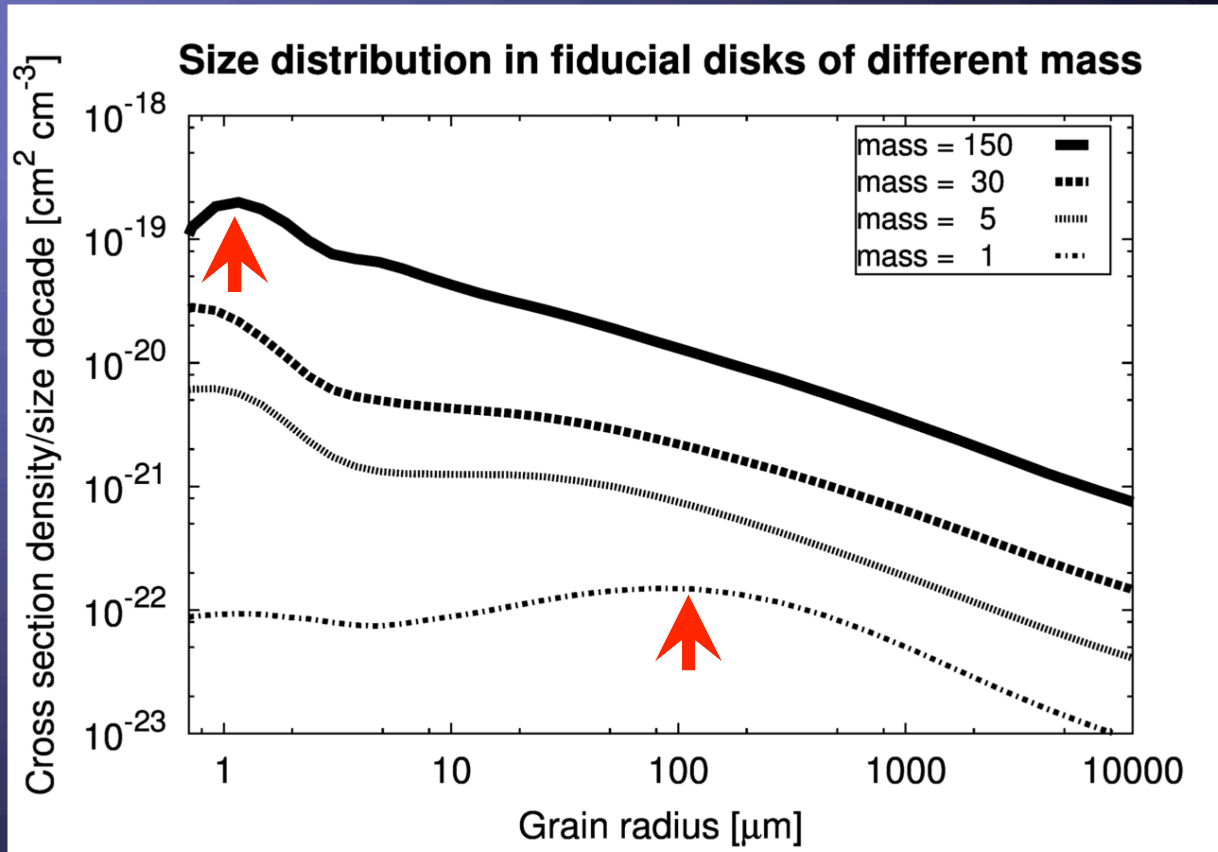


1 mm silicate grains are still somewhat too warm, but icy are OK
Thus the grains must be large and “reflective” (low abs in vis, high in far-IR)

Step II:
How to make the grains large?

1. Dynamical excitation at the Kuiper-belt level (e~0.1)

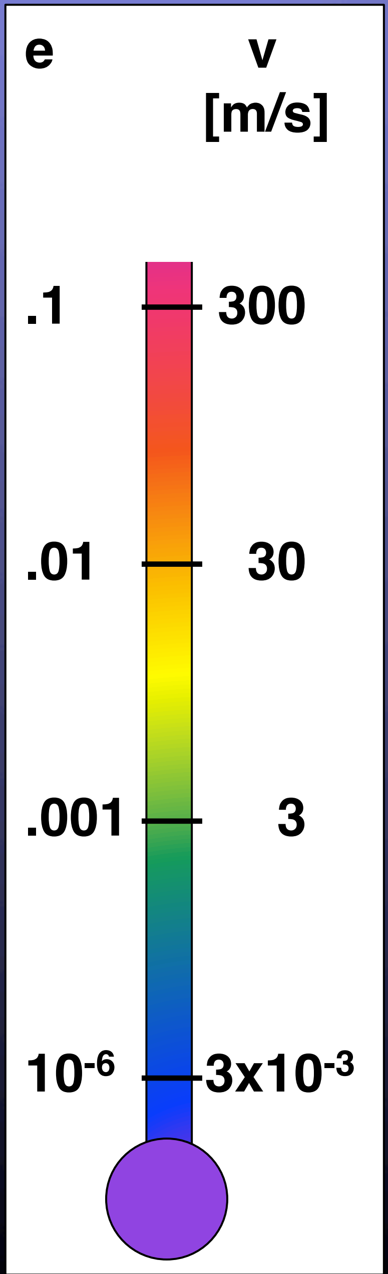


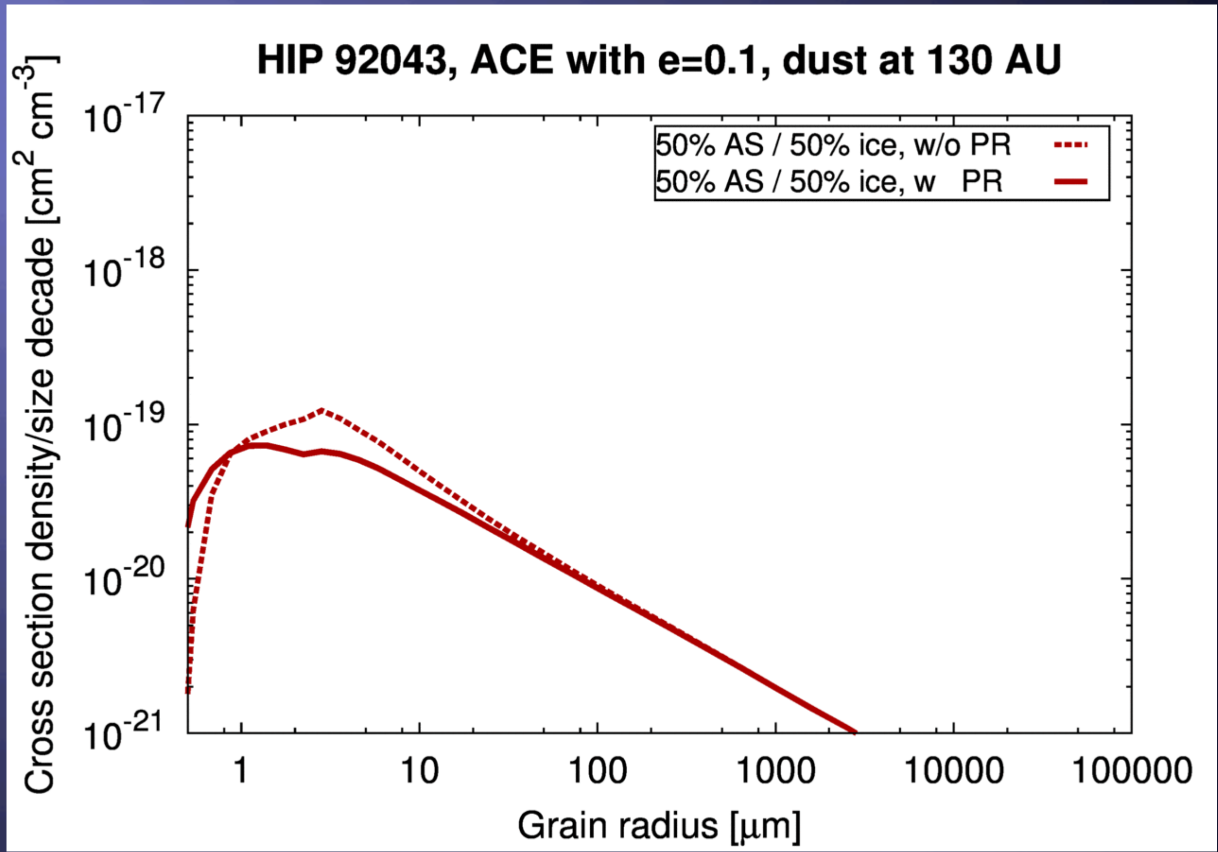


Disks with low optical depth are transport-dominated
Small grains in such disks are depleted

Vitense et al. 2010, Kuchner & Stark 2010, Reidemeister et al. 2011, Wyatt et al. 2011

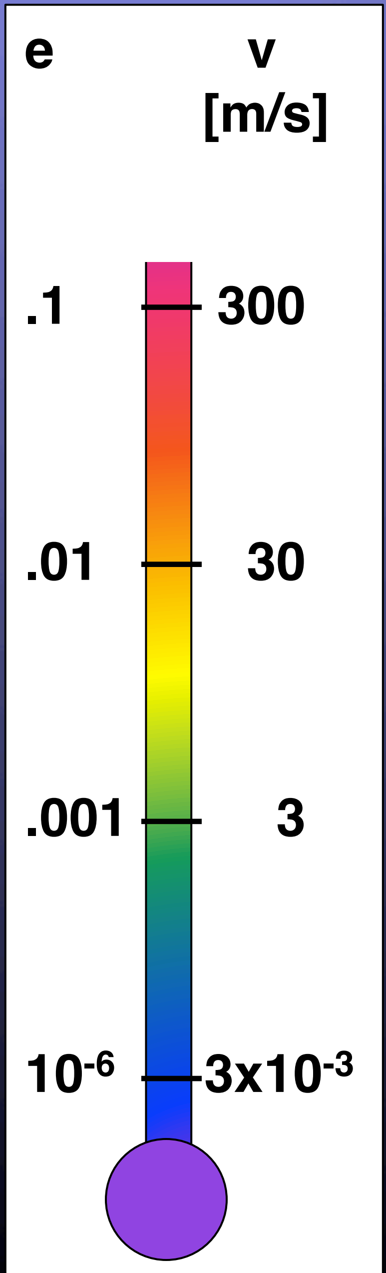
1. Dynamical excitation at the Kuiper-belt level (e~0.1)

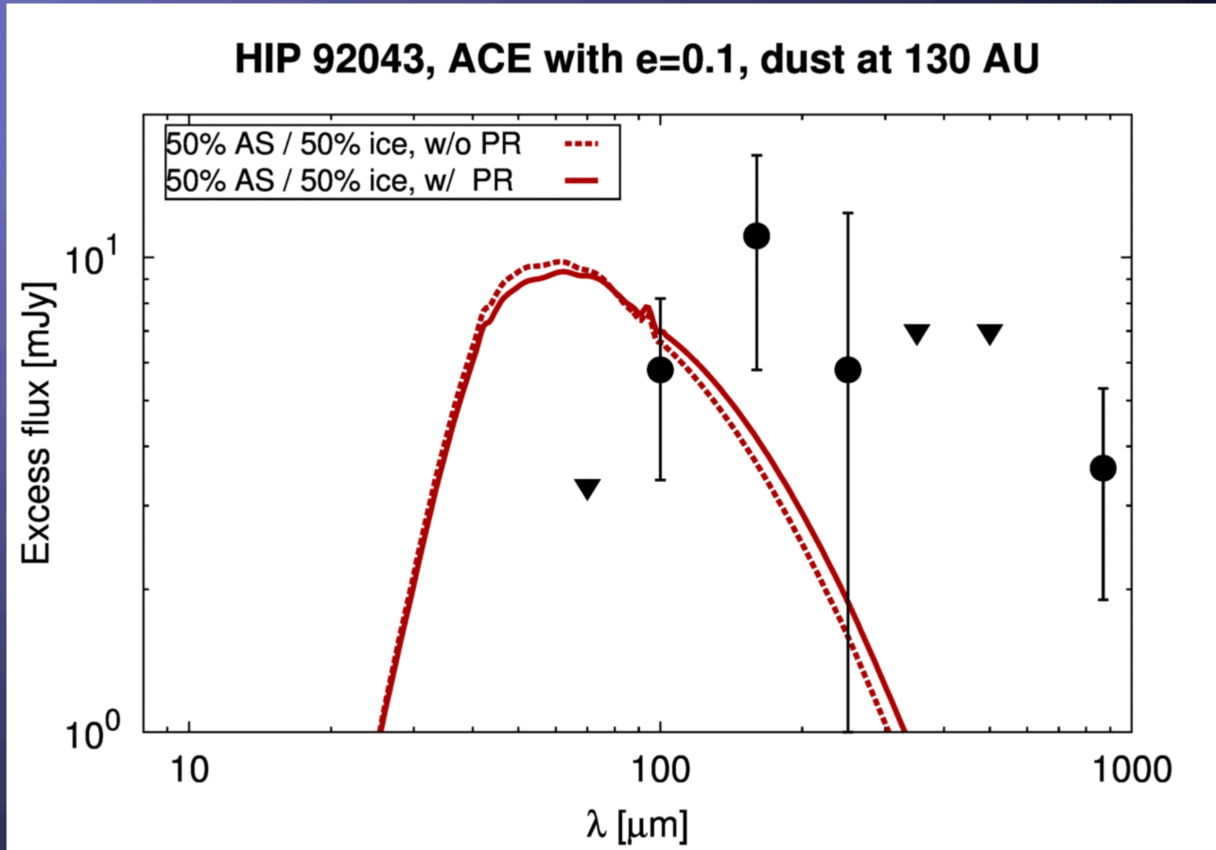




The optical depth of the cold disks is low,
but not low enough to see a shift toward larger sizes...

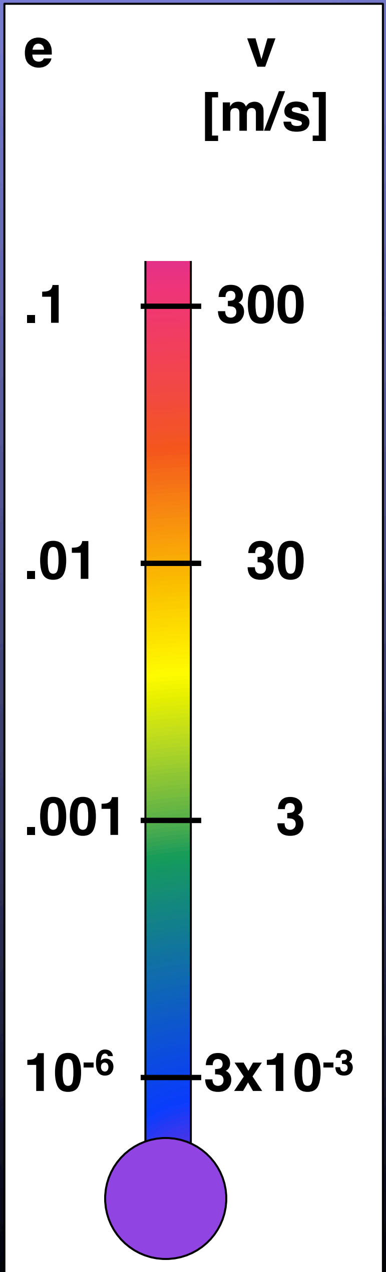
1. Dynamical excitation at the Kuiper-belt level (e~0.1)

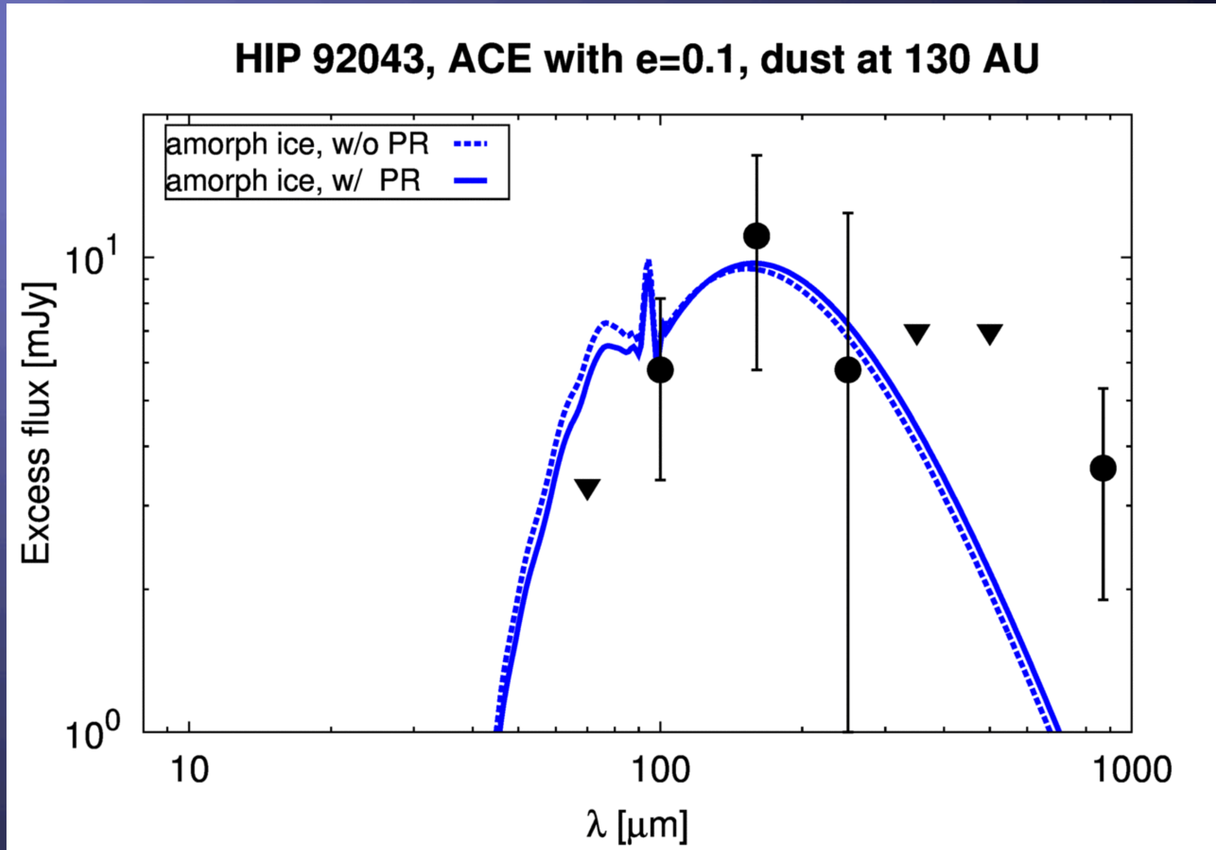




... so that the SED for silicate/ice mixture is far too warm

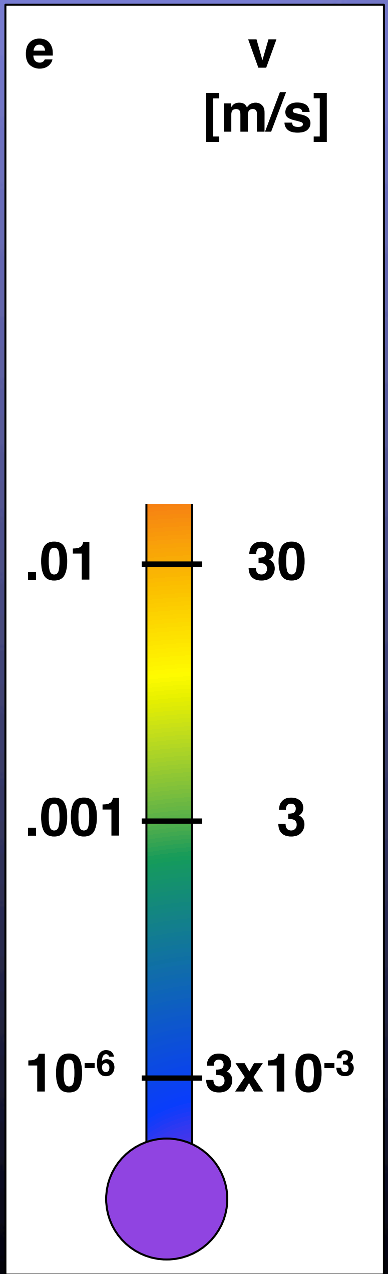
1. Dynamical excitation at the Kuiper-belt level (e~0.1)

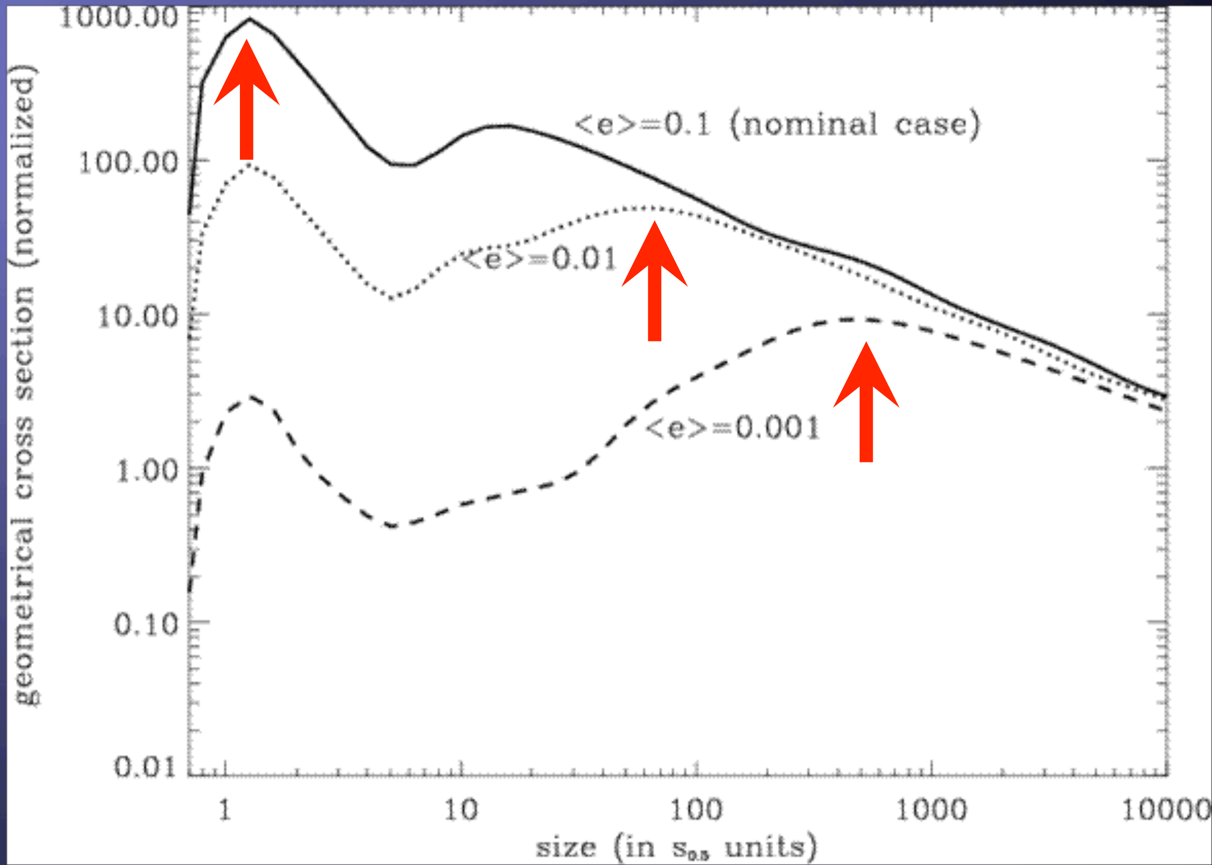




... and even the SED for pure ice is too warm

2. Low dynamical excitation (e~0.01…0.001)





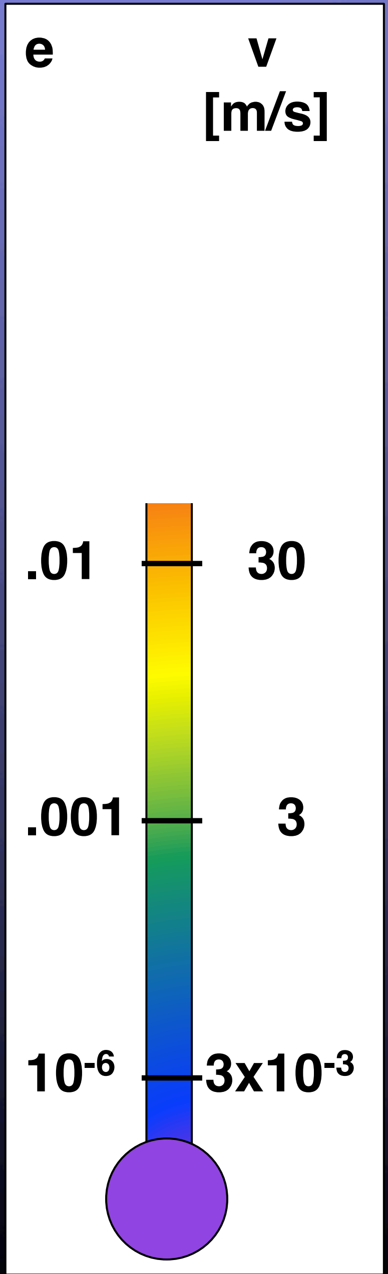
Production of small grains is inhibited, but their loss rate is high

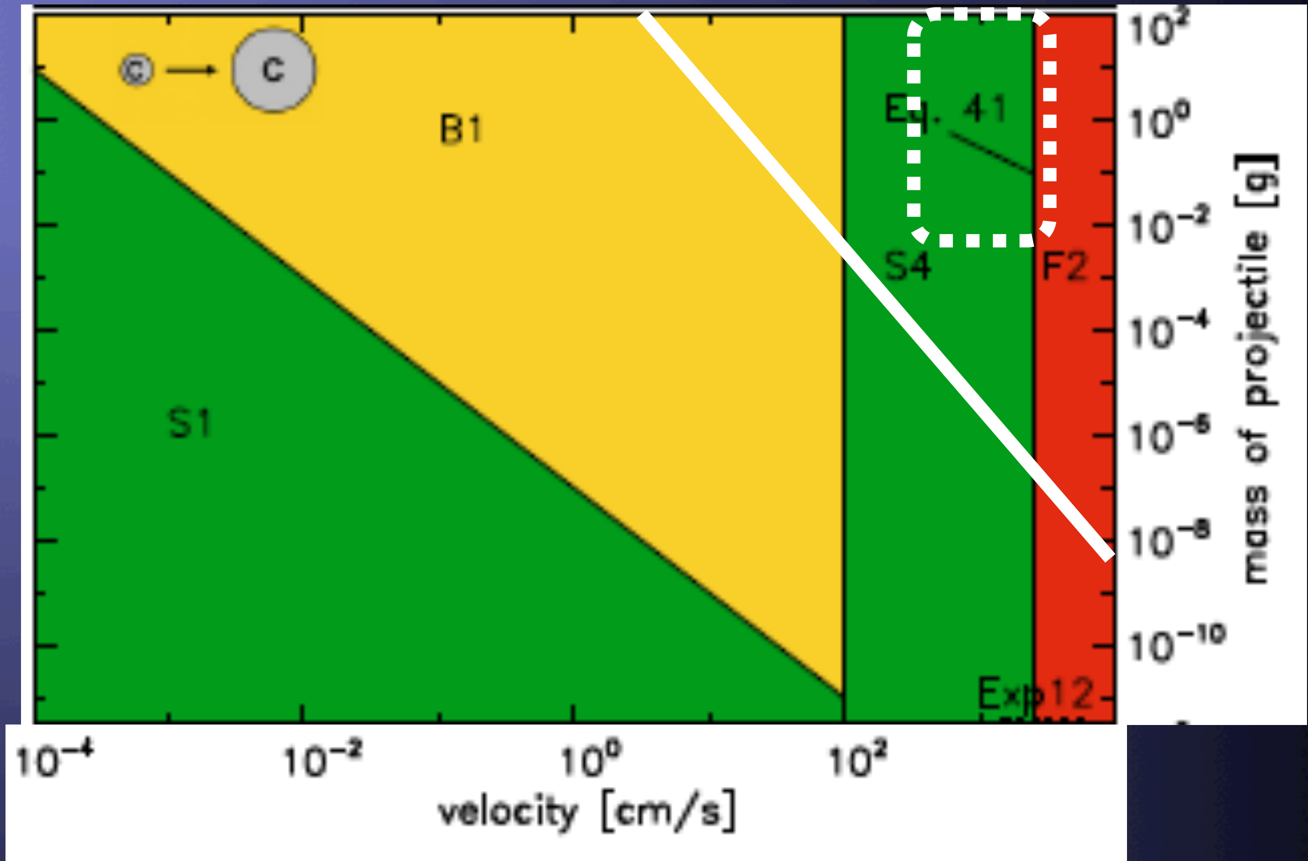
Thebault & Wu 2008

$s_{min} = b\, s_{blow}$

$b \sim 1/e$

2. Low dynamical excitation (e~0.01…0.001)

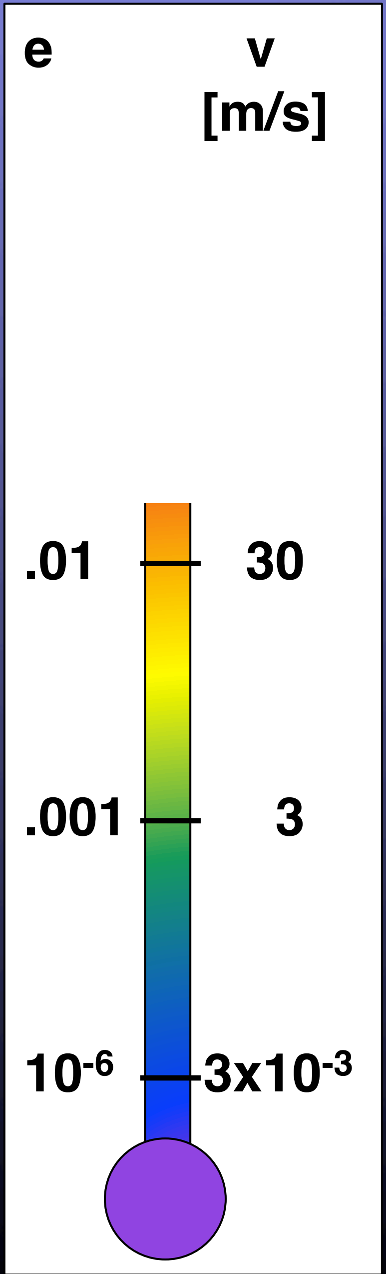


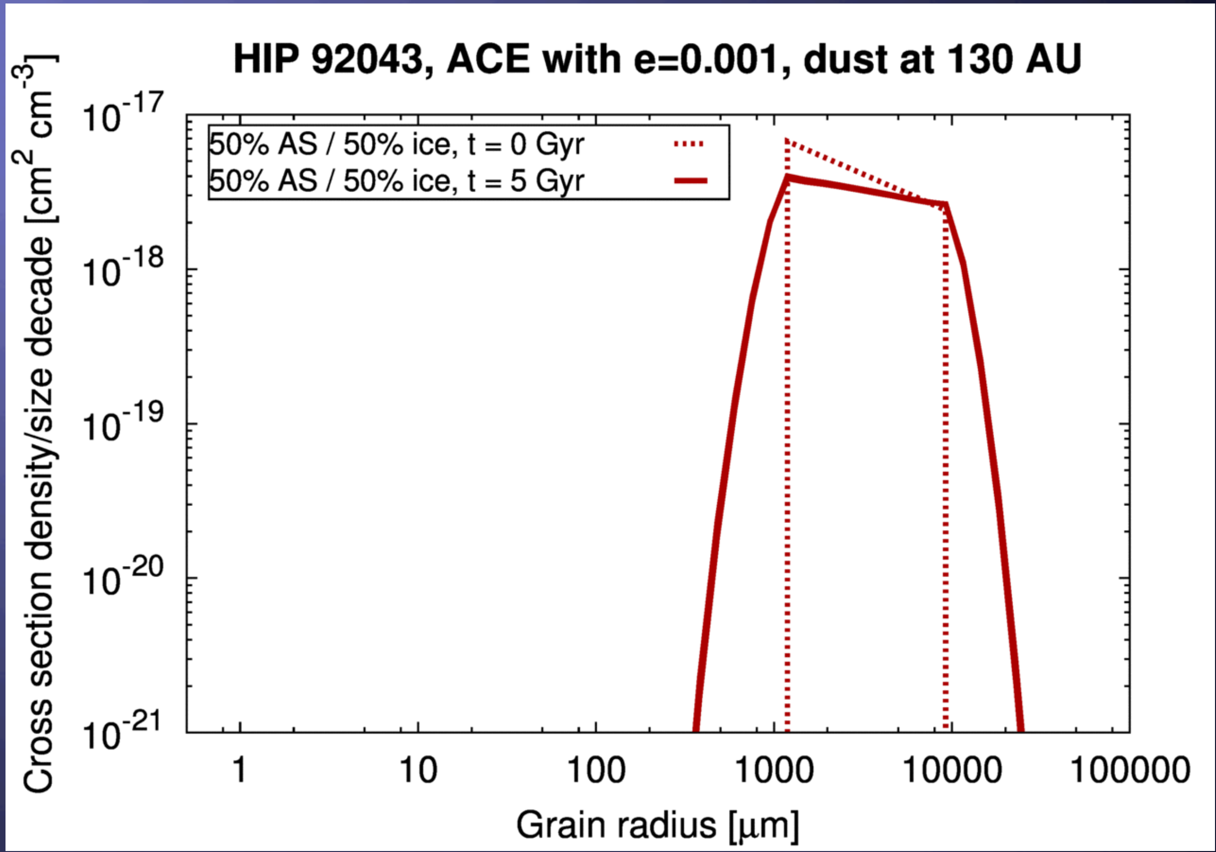


In this regime we might expect gentle collisions, with moderate amount of sticking and fragmentation...

Güttler et al. 2010

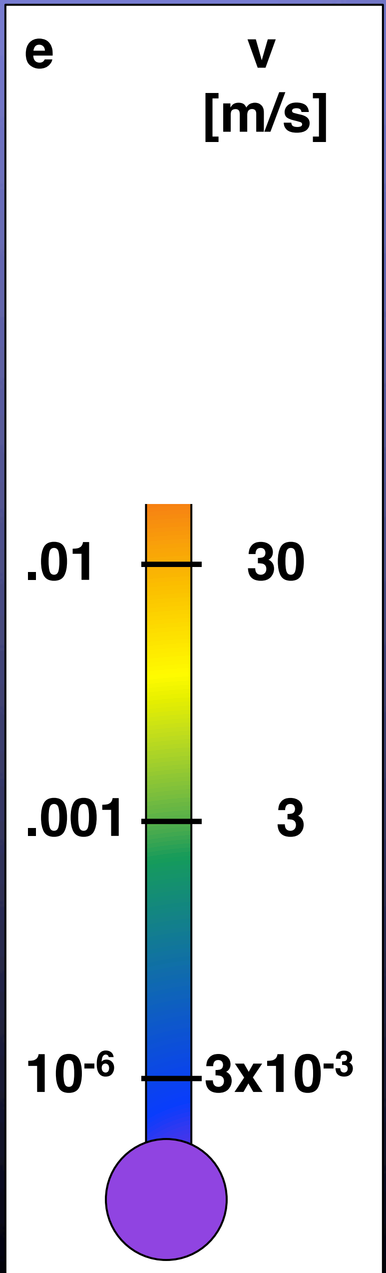
2. Low dynamical excitation (e~0.01…0.001)

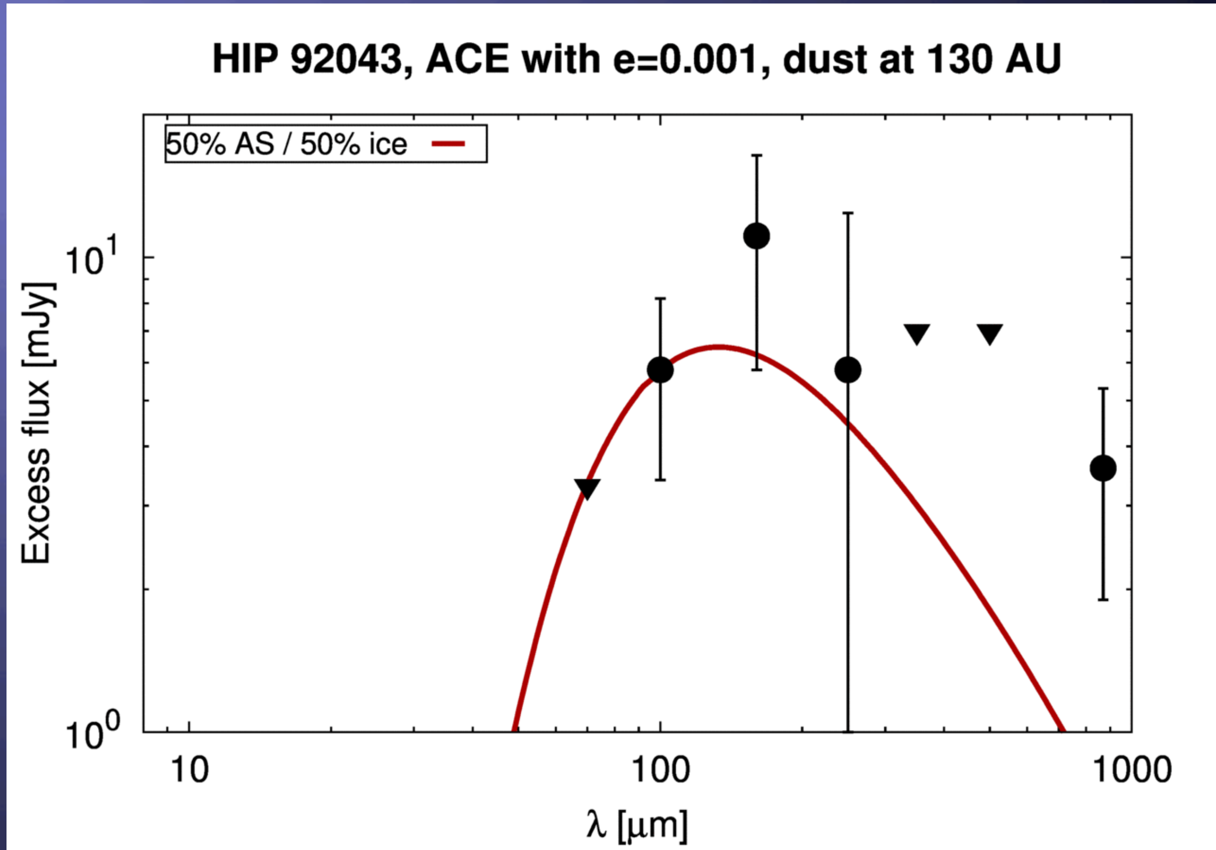




We assume a belt of primordial grains 1mm – 1cm,
with ~ lunar mass (or larger if bigger objects are also present)
It can indeed survive several Gyr of evolution

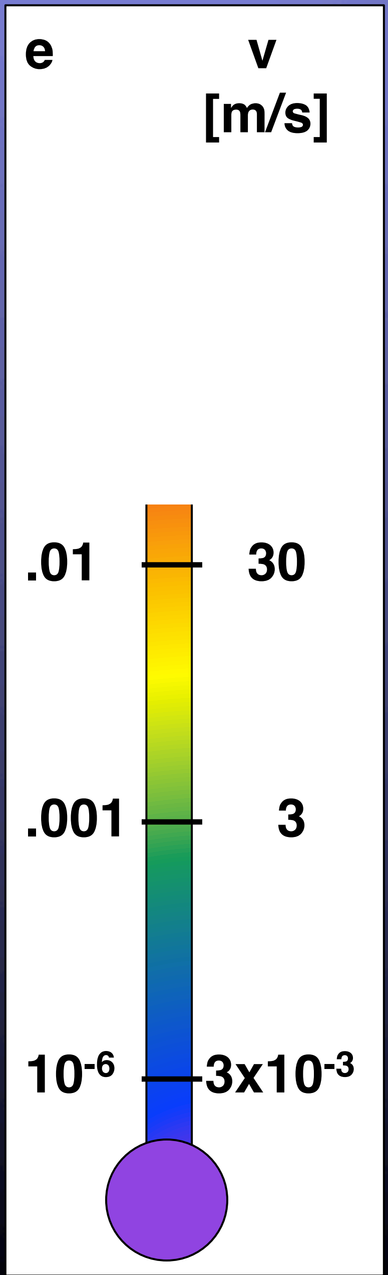
2. Low dynamical excitation (e~0.01…0.001)

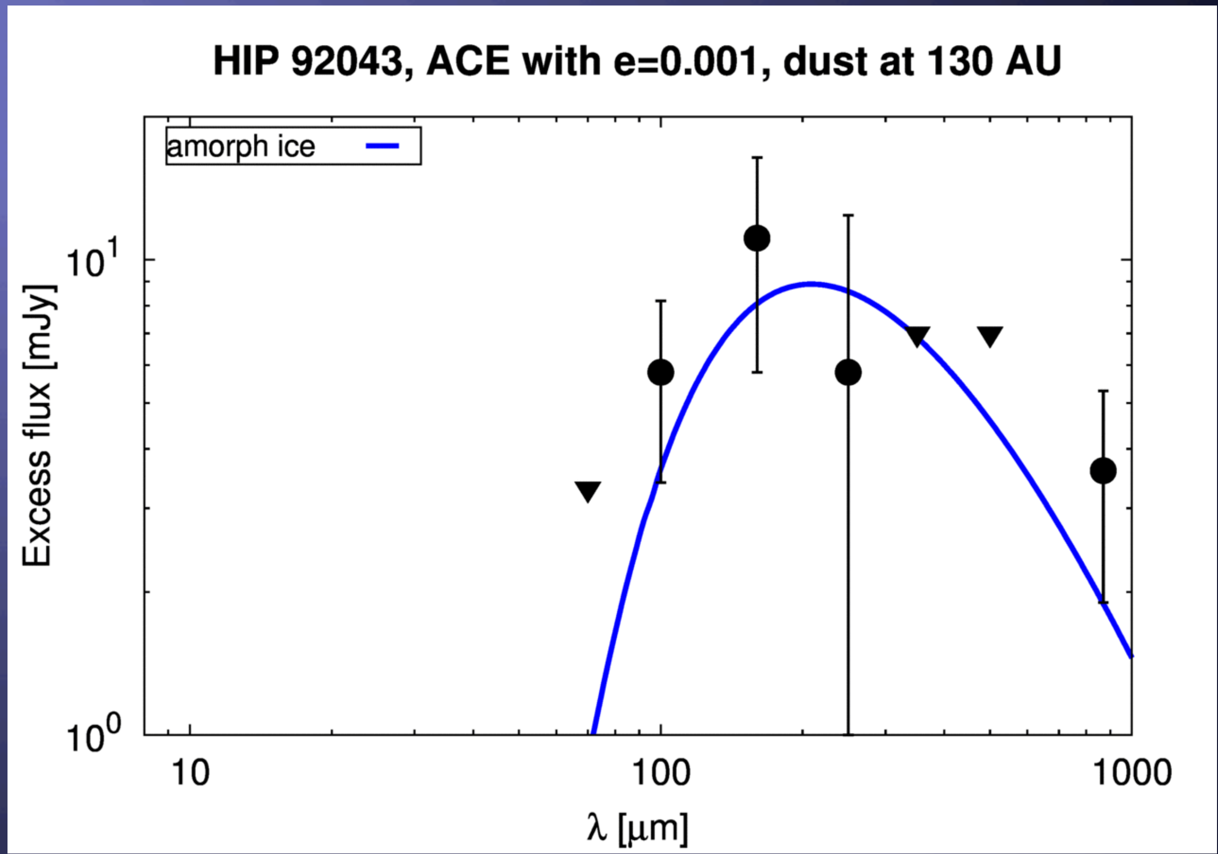




The SED of such a belt is close to what we need, even for “standard” material compositions

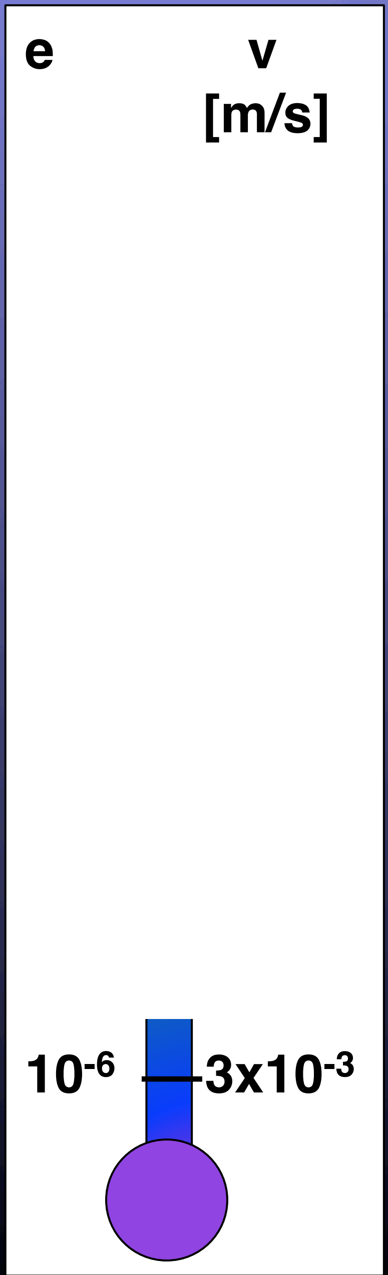
2. Low dynamical excitation (e~0.01…0.001)



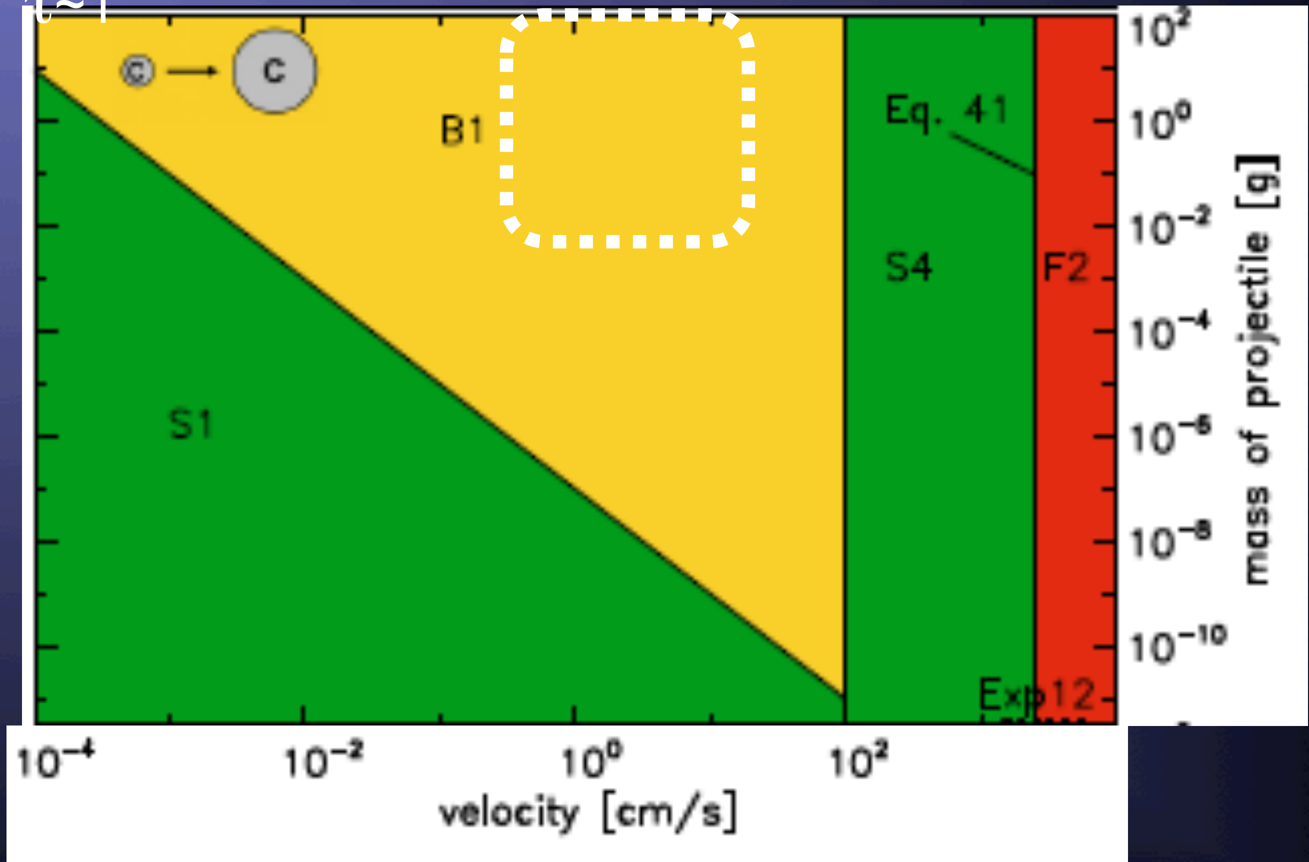


Including ice further improves the SED

3. Razor-thin, radially optically thick ($e \sim 10^{-4} \ldots 10^{-6}$)



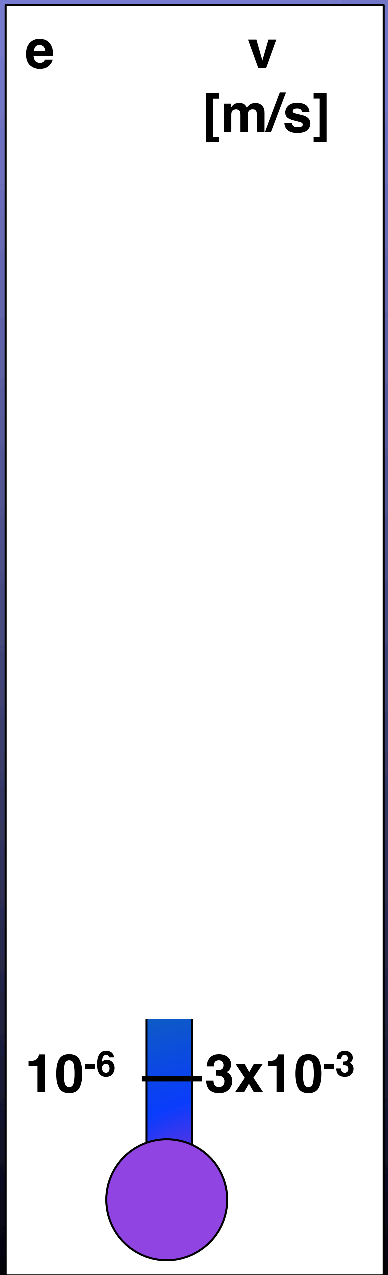
Squeeze the disk vertically to make it optically thick
The inner part of the disk shields the outer part
Lower dust temperature, yet sufficient flux, are reached at $\tau \sim 1$

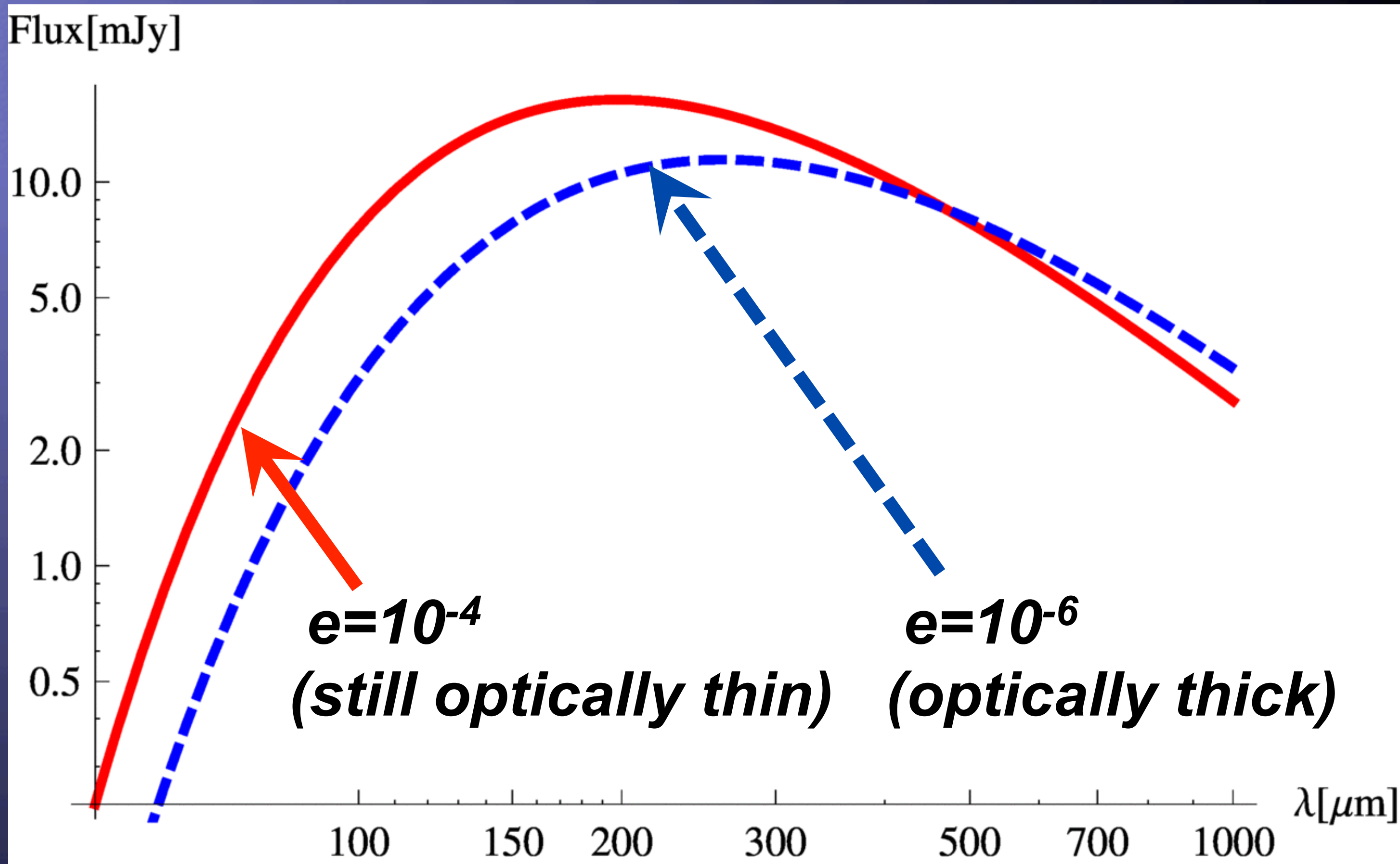


In this regime we might expect mostly bouncing collisions

Güttler et al. 2010

3. Razor-thin, radially optically thick ($e \sim 10^{-4} \ldots 10^{-6}$)

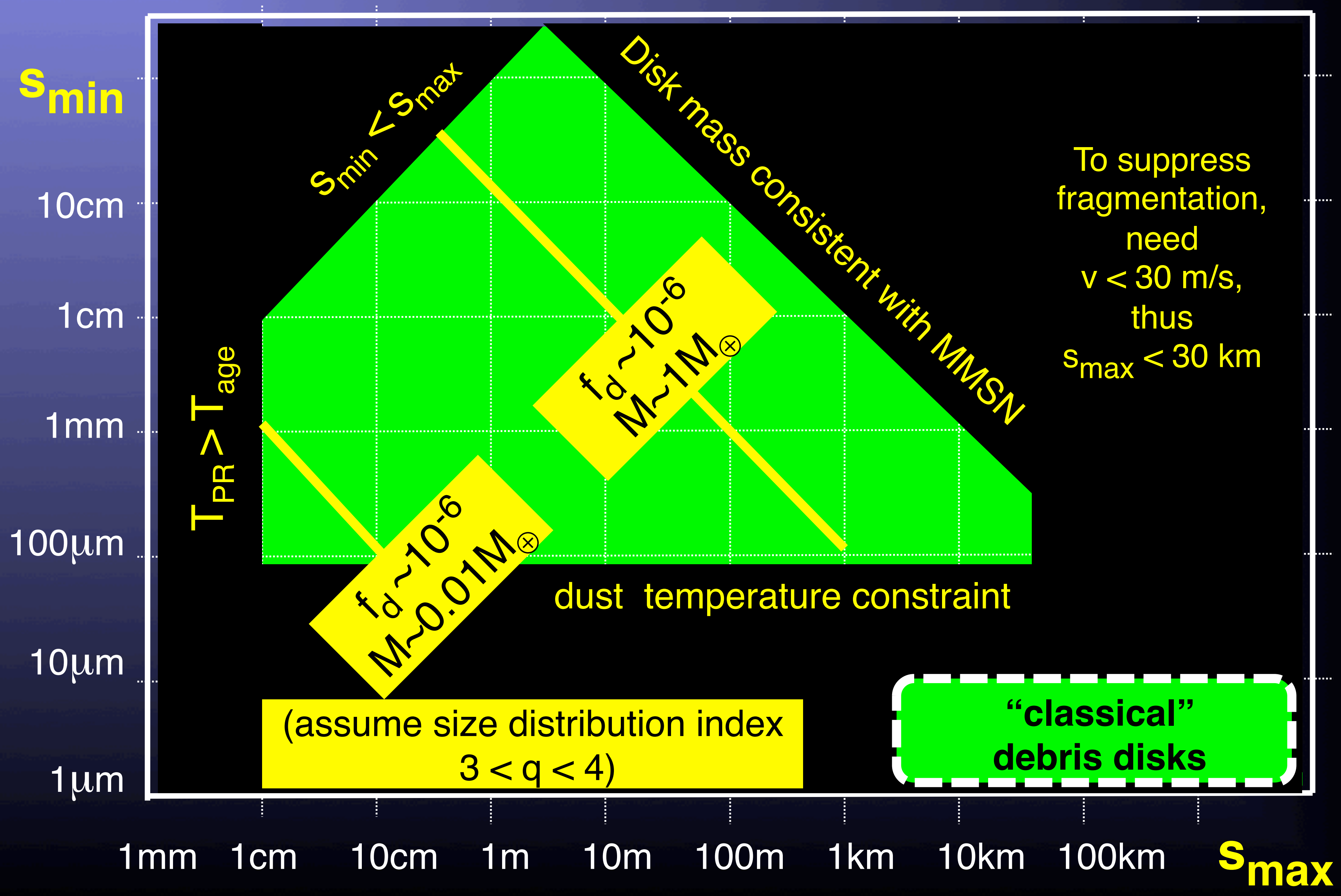




Difficulty: need "right" values of too many parameters.
Can such disks exist in reality? Questionable...

Summary

Dust, pebbles, boulders, planetesimals?



Summary

- About one-fifth of the DUNES debris disks appear to be "cold", with SEDs peaking longward of 160μm. Cold disks may also be seen by DEBRIS and GASPS

- Dust in cold disks appears to be subthermal. This implies large grain sizes and perhaps materials with low absorption in the visible

- Absence of small grains is in contradiction with standard debris disk models. However, it can plausibly be explained by assuming low dynamical excitation of solids (eccentricity ~0.01... 0.001). This requires the planetesimals, if these are present, to be smaller than a few kilometers in size. The emitting mm- or cm-sized grains can even be primordial