Herschel's "cold debris disks": Failed planetesimal formation?

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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

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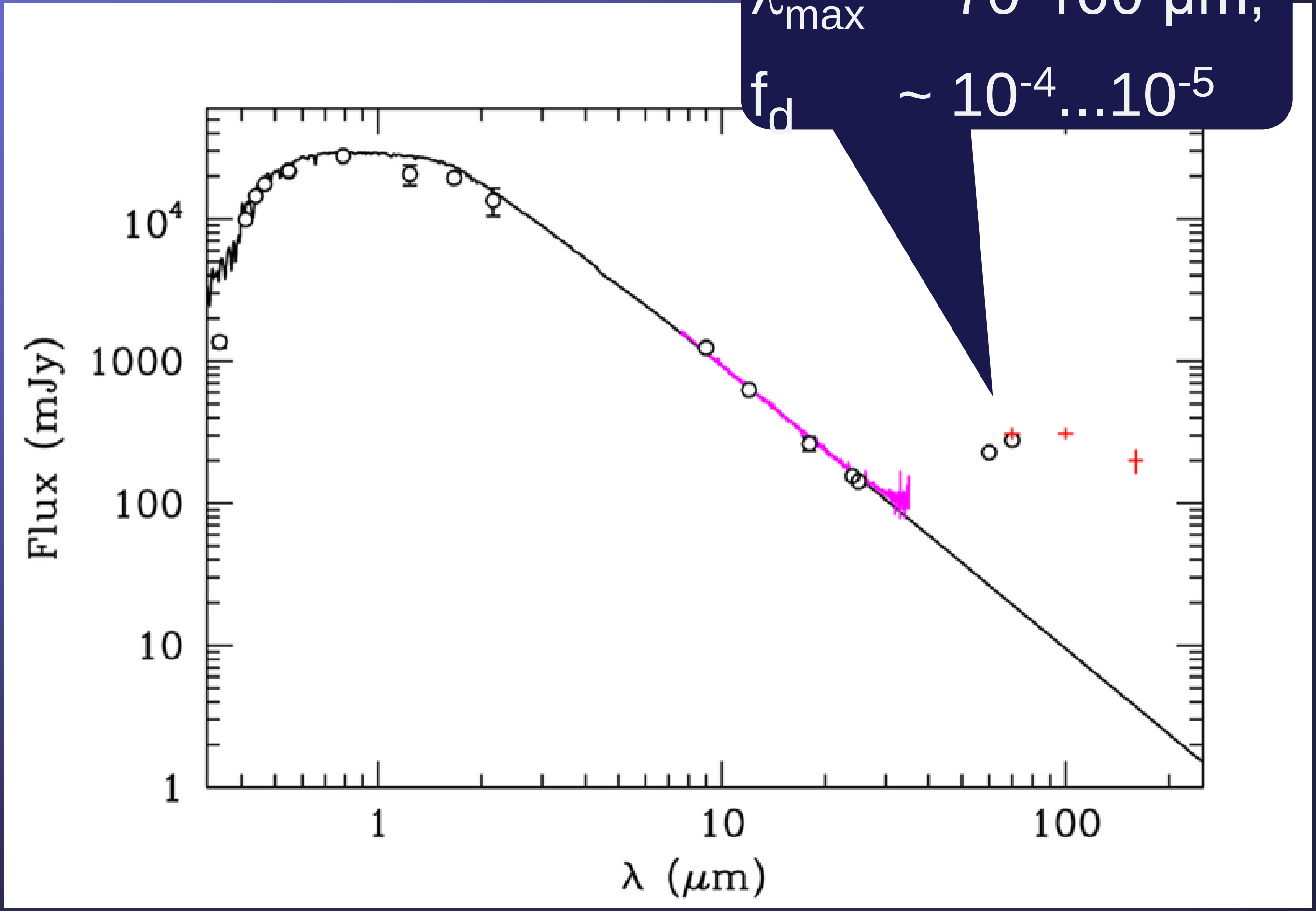
Cold disks

“Classical” debris disks

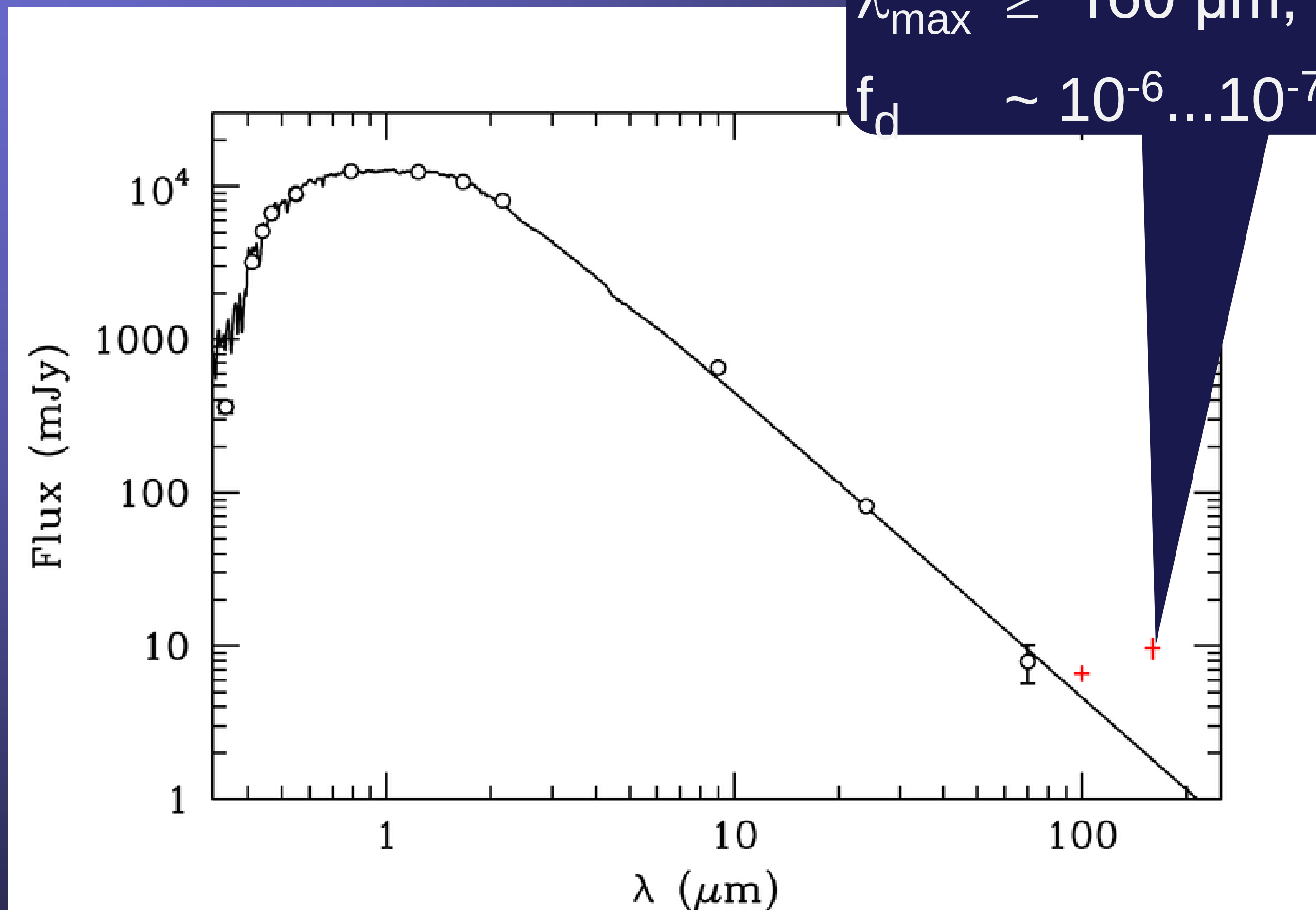


λ_{max} ~ 70-100 μm,

f_d ~ $10^{-4}...10^{-5}$

The class of "cold disks"

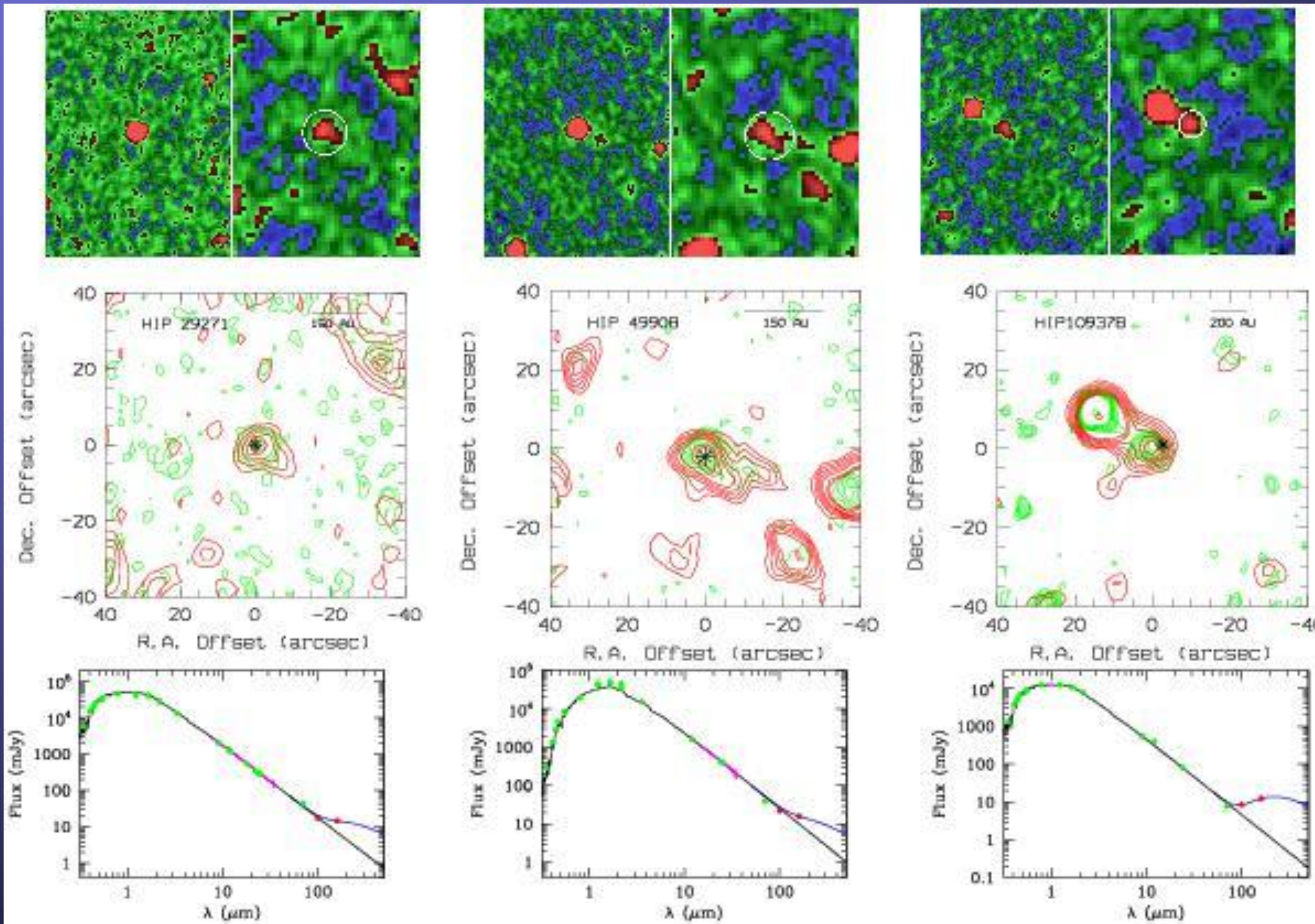
$\lambda_{max} \geq 160\ \mu m$,
$f_d \sim 10^{-6} ... 10^{-7}$

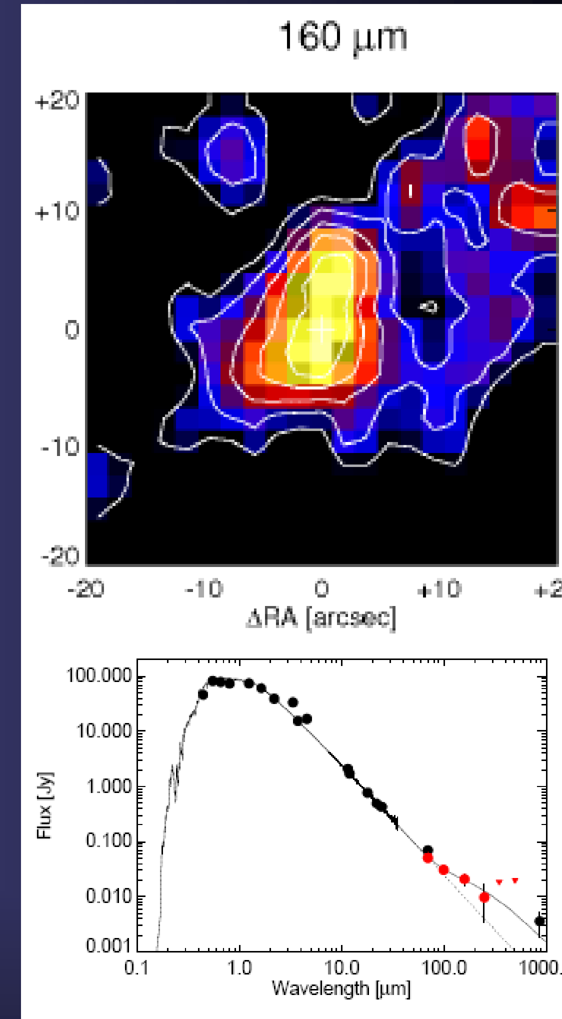


"Cold" are disks with an excess at ≥160 μm, but little or no excess at 100 μm
Cold disks may also be present in the DEBRIS and GASPS samples

Eiroa et al. 2011

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





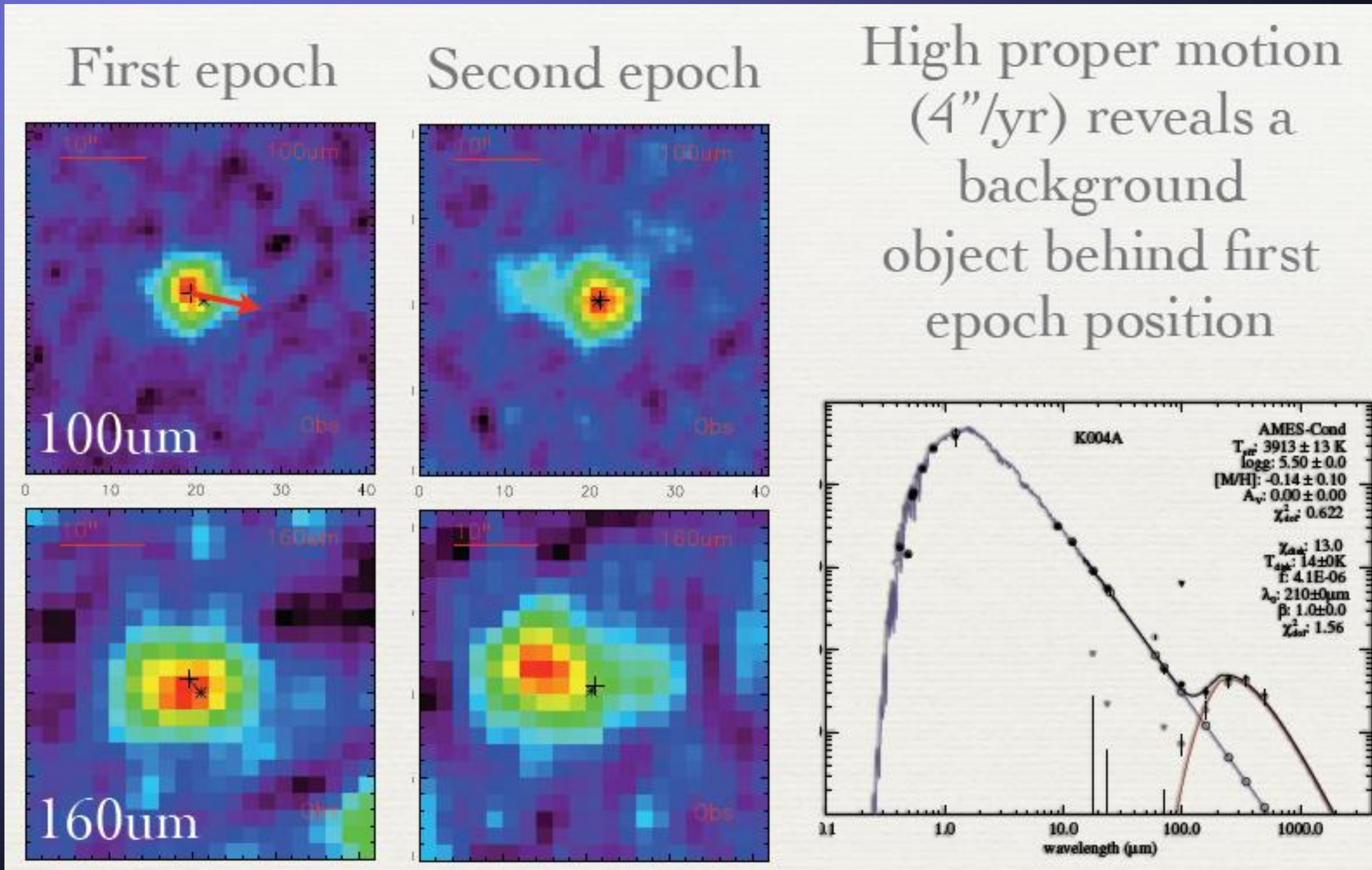
HIP 29271 (α Men), HIP 49908, HIP 109378

Eiroa et al. 2011

HIP 92043

Marshall et al. 2012

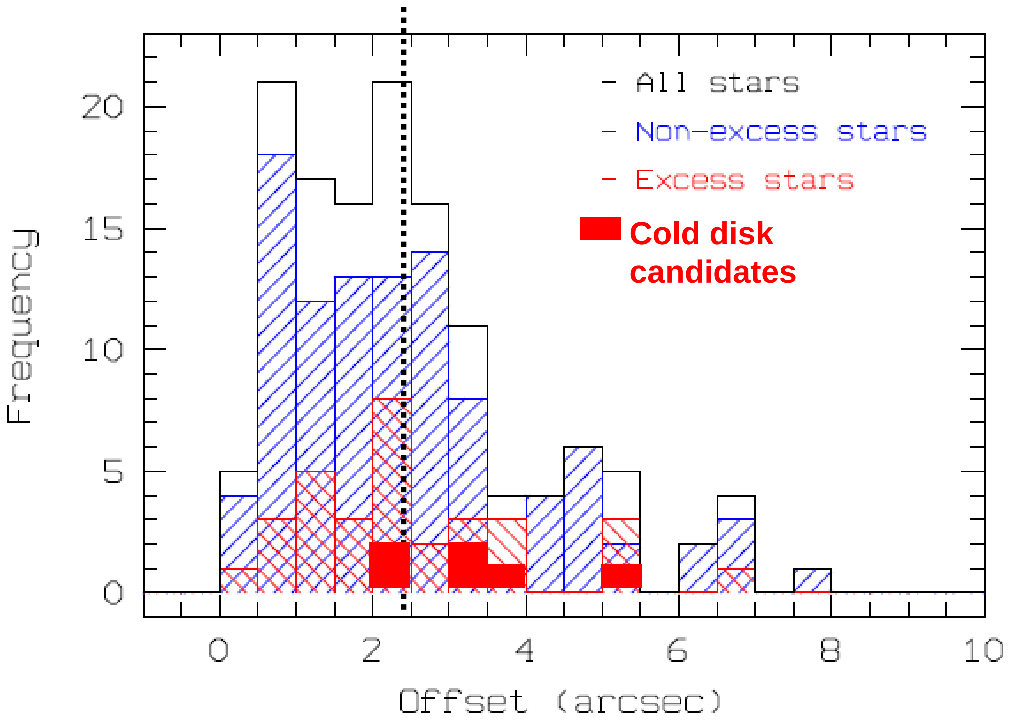
Caution: some of the “disks” may be galaxies



Courtesy Grant Kennedy and the DEBRIS team

However, some of the cold disks are likely to be real

Herschel pointing accuracy: 1σ=2.4”



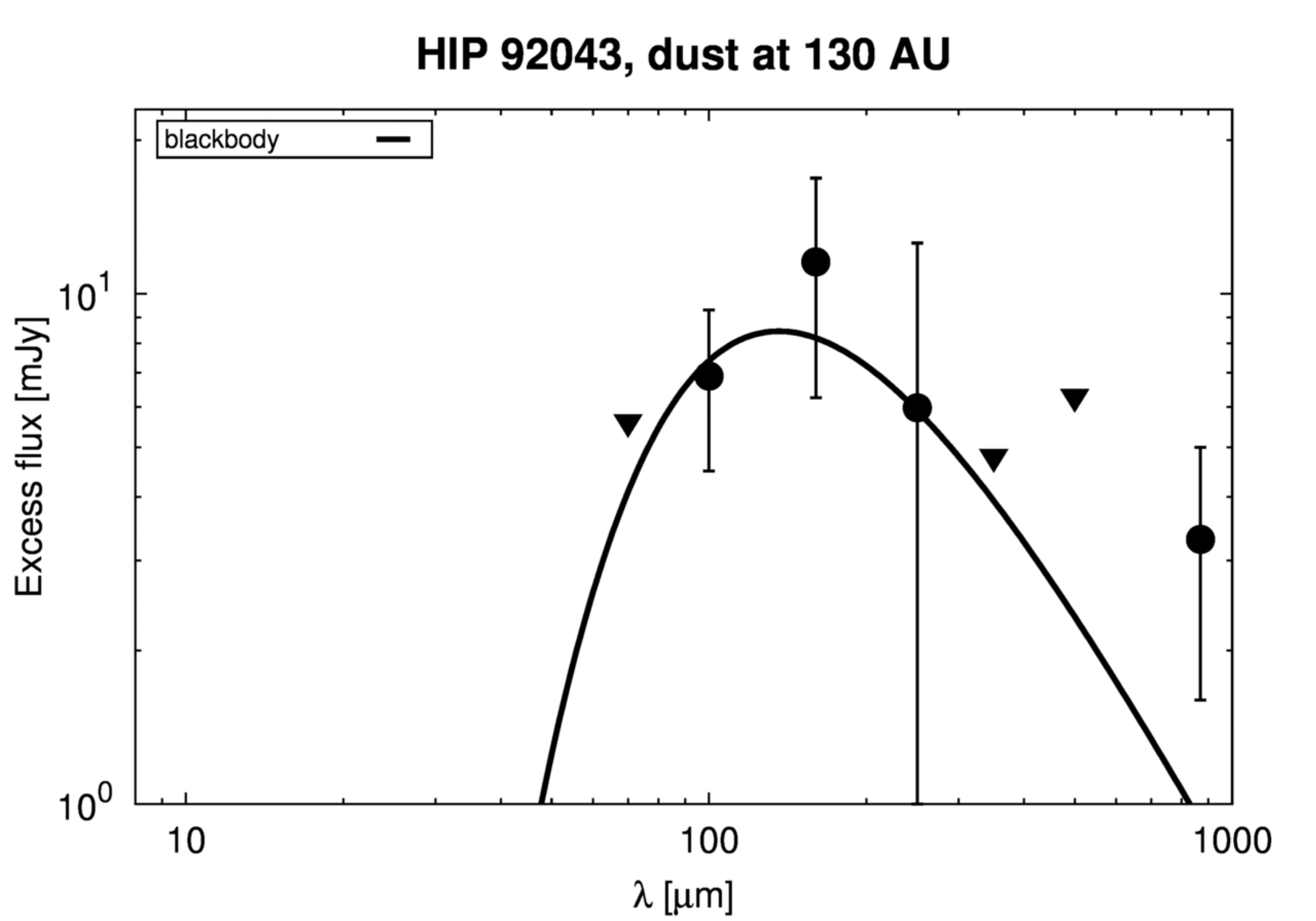
(1) Offset between the optical position of a star and the peak of 100 μm emission is consistent with Herschel pointing accuracy (mean: 3.3”),

(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 has a ~ blackbody temperature

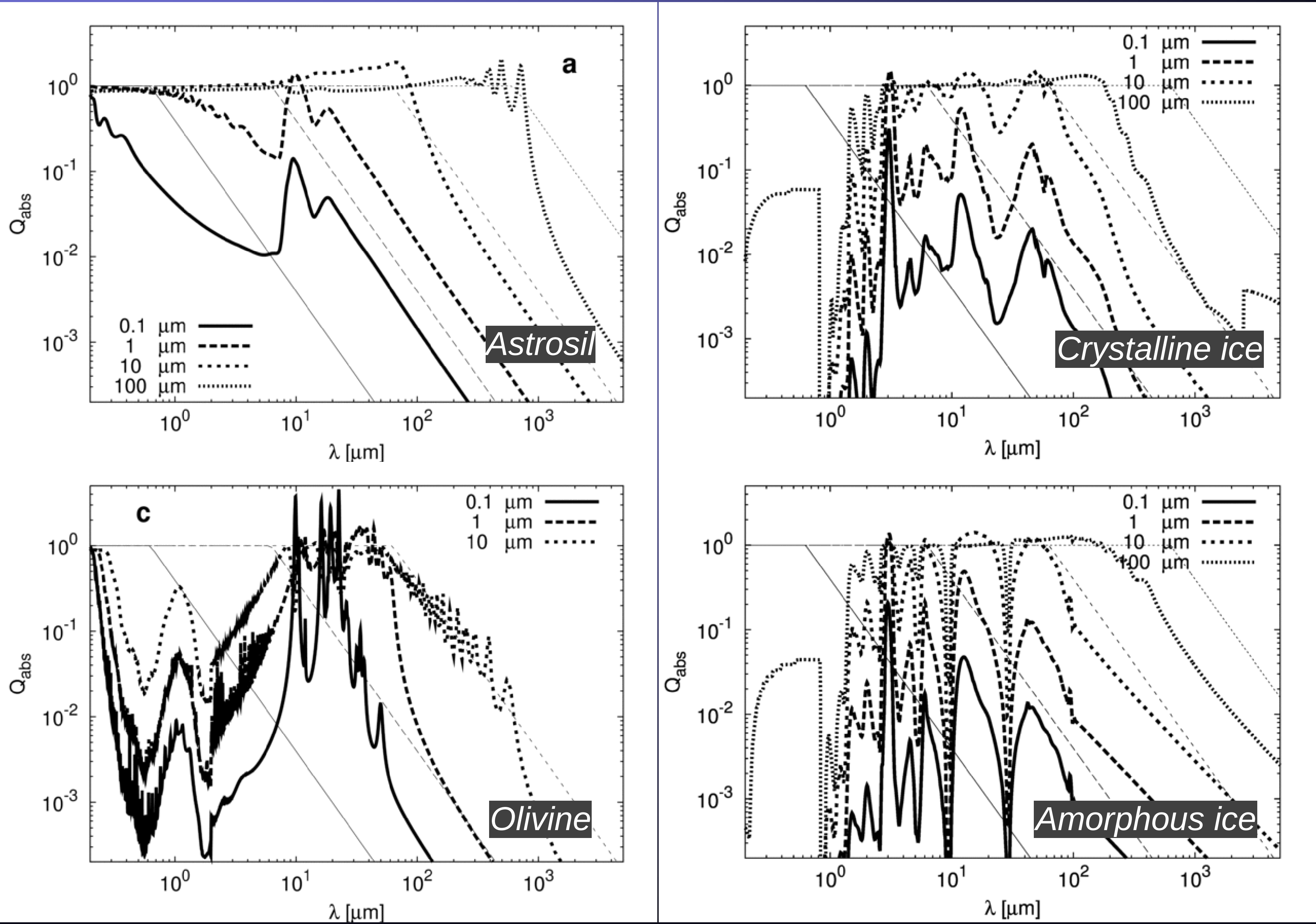


Disk radii are inferred from the images (in resolved cases)
or constrained by the fact the disks are unresolved (for unresolved disks)

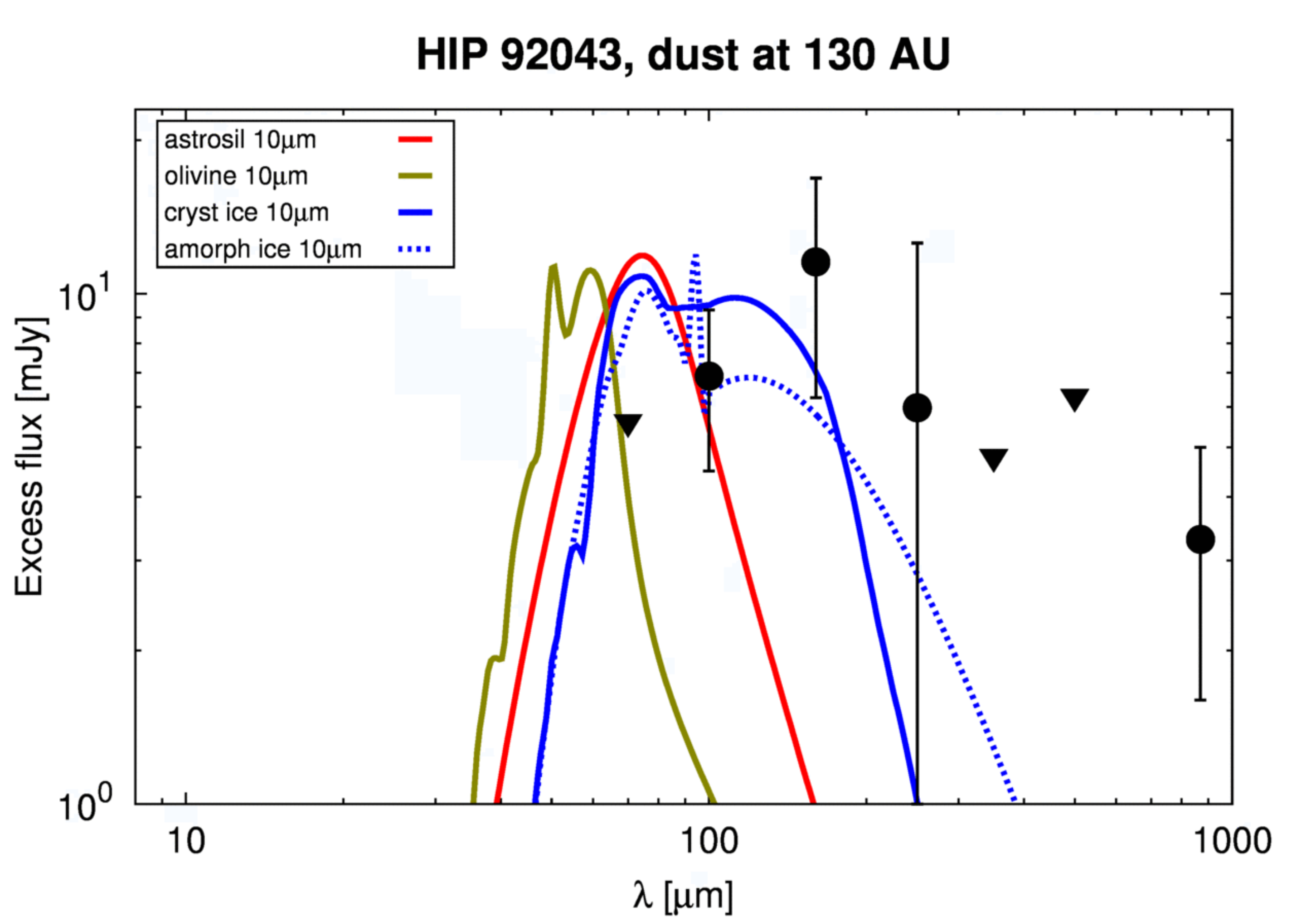
SEDs + disk radii suggest that dust is nearly as cold as blackbody

What kind of dust are they made of?

Absorption efficiency for different sizes and materials

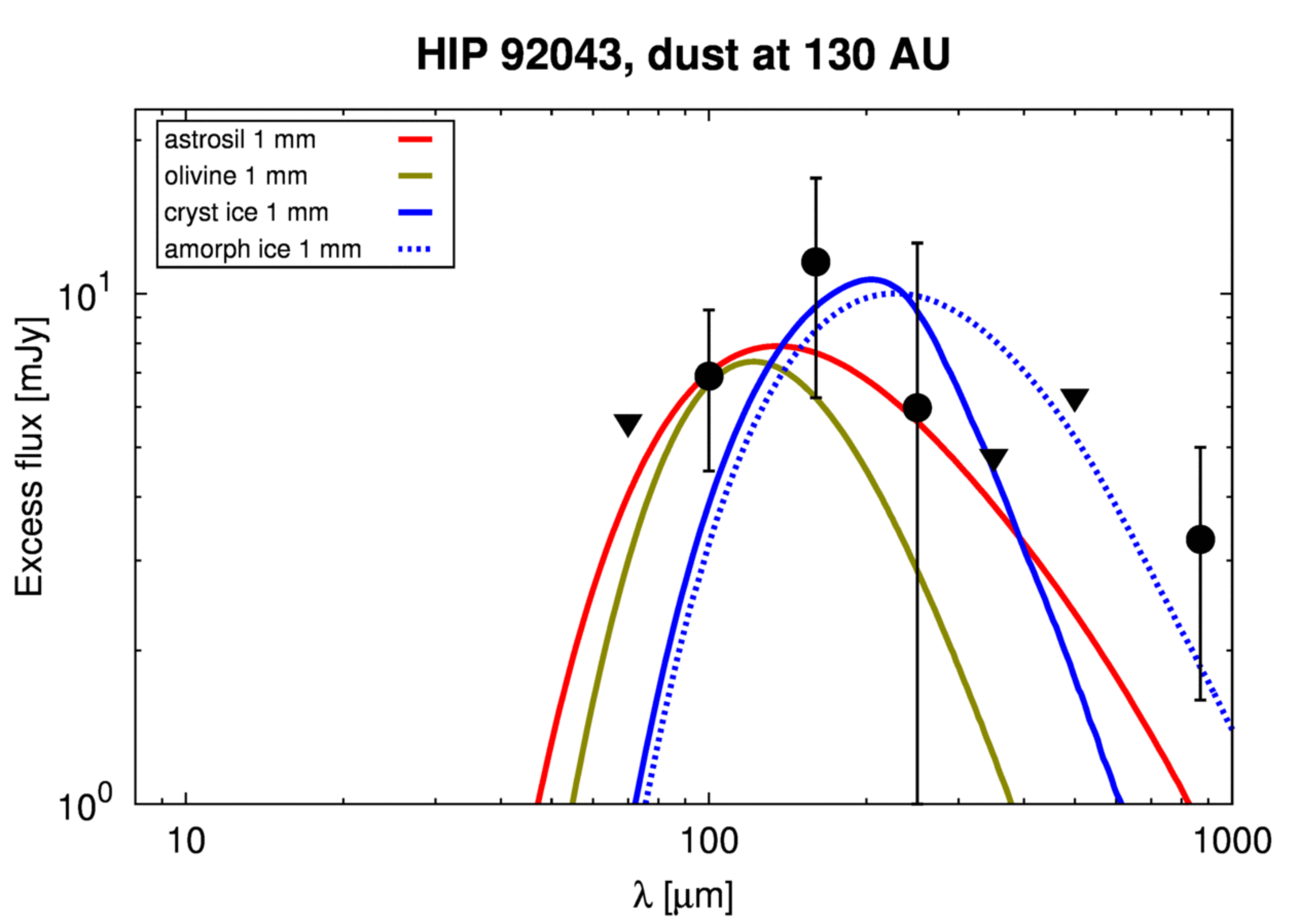


Tests with different grain sizes and materials



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

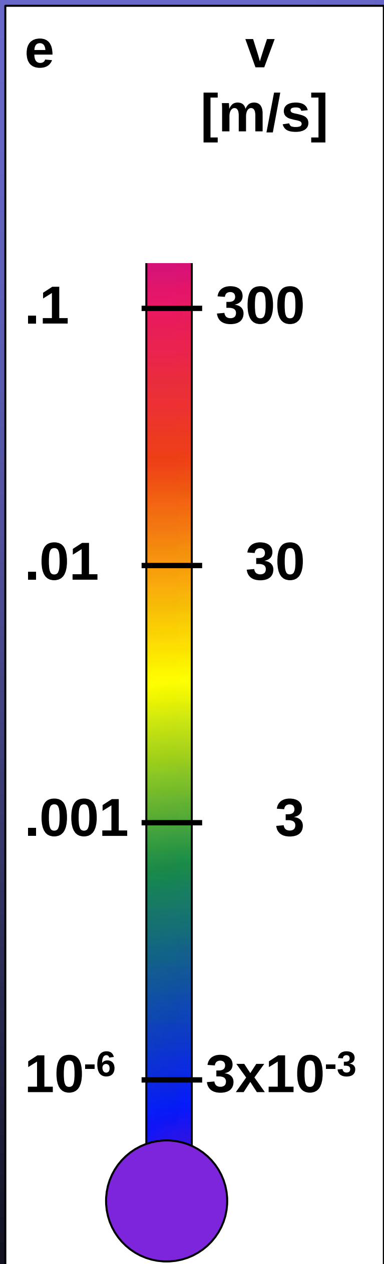
Tests with different grain sizes and materials



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)

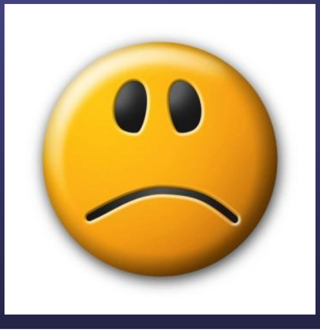
How to get rid of small grains?

We can play with dynamical excitation of the disk



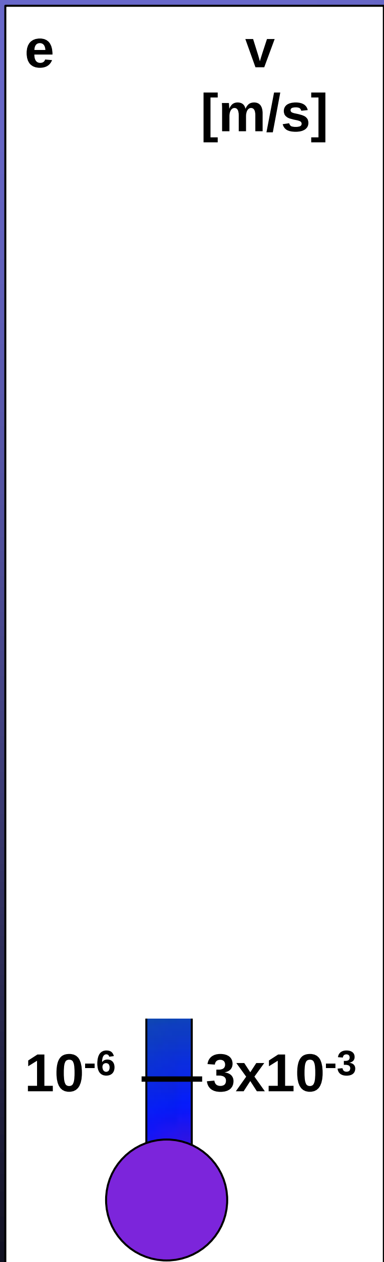
If the dynamical excitation of dust-producing planetesimals is at the Kuiper-belt level (e~0.1), unwanted small grains are only depleted in disks with low optical depth, since these are rapidly removed by Poynting-Robertson drag

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



Modeling shows:
the optical depth of our cold disks is not low enough for this mechanism to work...

We can play with dynamical excitation of the disk



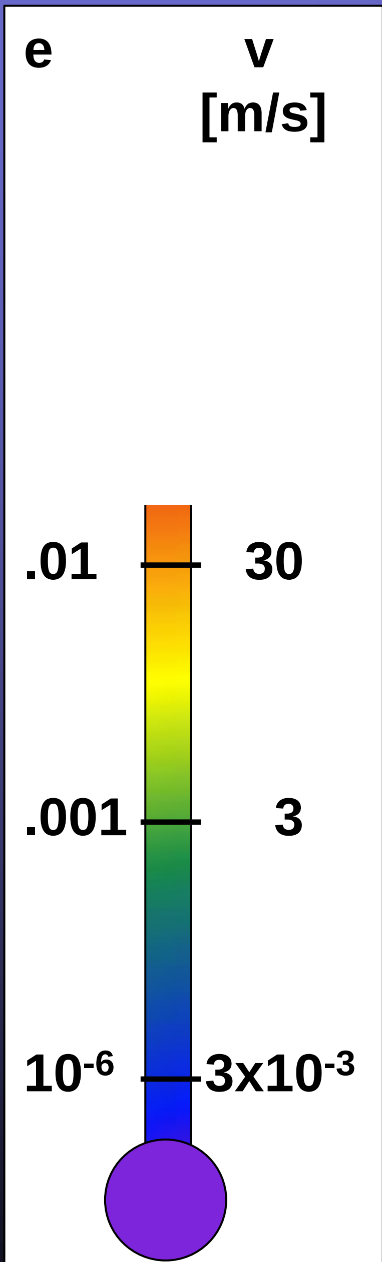
Need "right" values of too many parameters.
Can such disks exist in reality? Questionable...

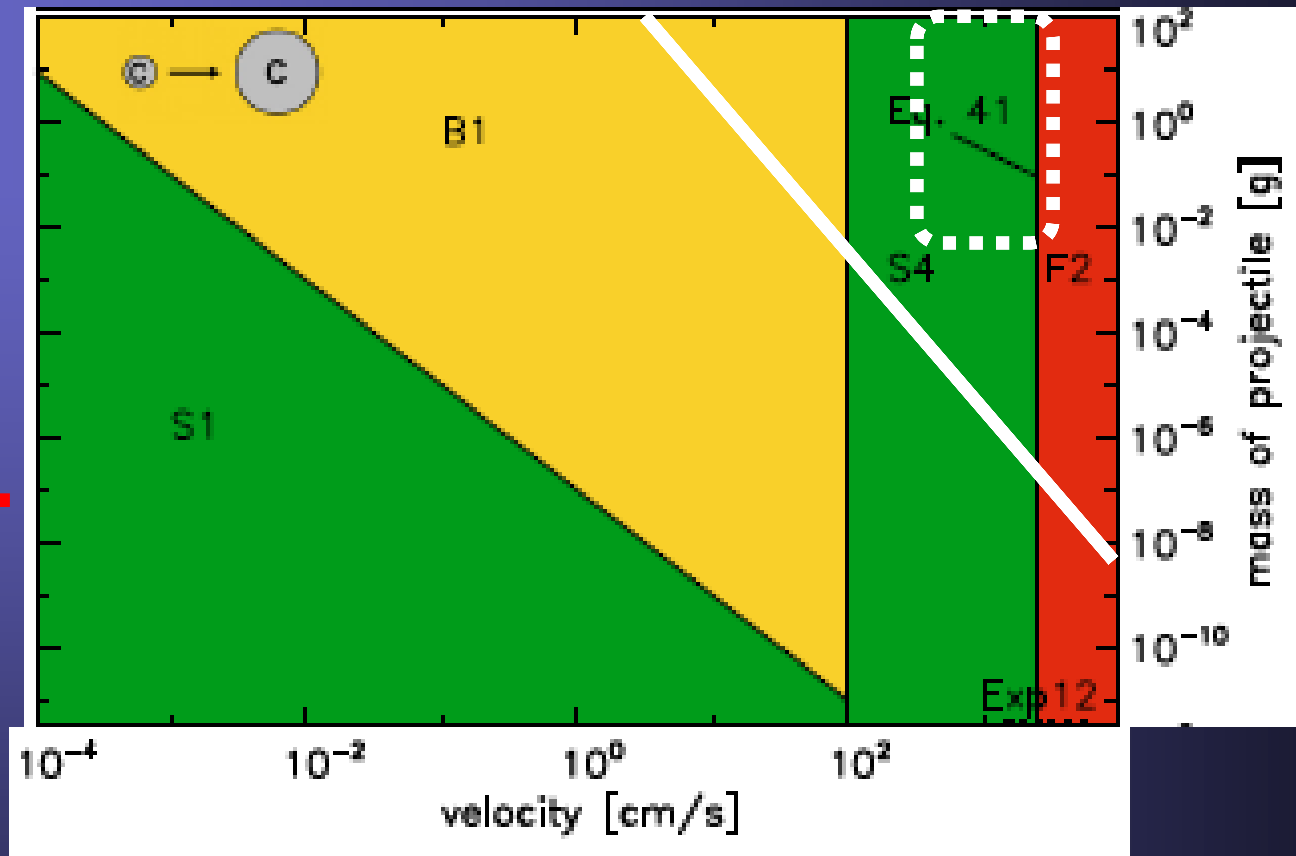
If the dynamical excitation of dust-producing planetesimals is extremely low ($e \sim 10^{-4} \ldots 10^{-6}$), we may have a razor-thin, radially optically thick disk. The inner part of the disk shields the outer part. Sufficiently low dust temperature, yet sufficient flux, are reached at $\tau \sim 1$

In this regime we might expect mostly bouncing collisions, neither fragmentation nor growth

Güttler et al. 2010

Low dynamical excitation (e~0.01…0.001)

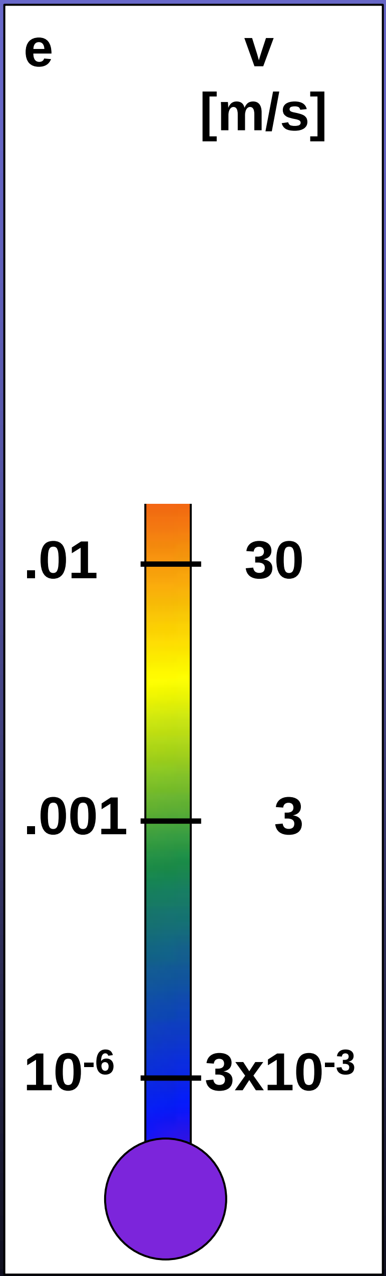


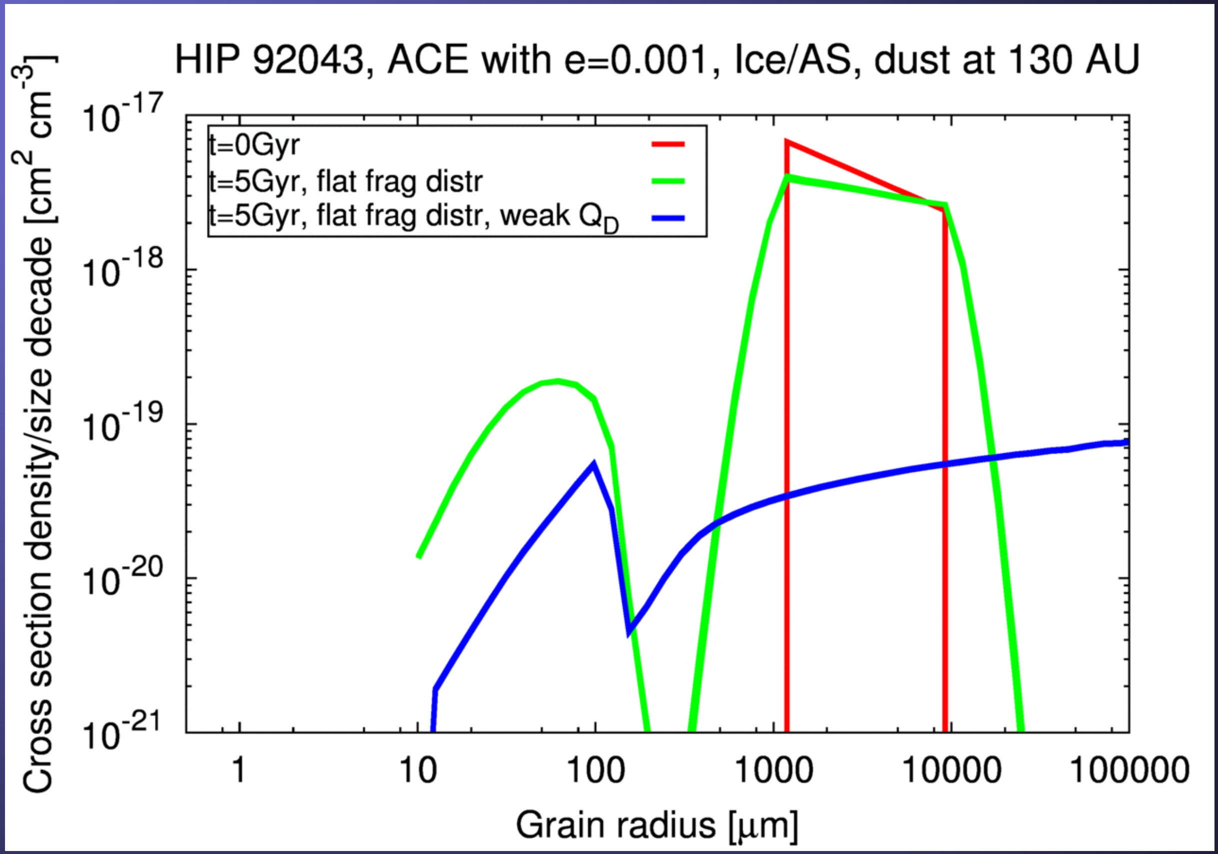


In this regime we might expect gentle collisions, with moderate amount of sticking and fragmentation...

Güttler et al. 2010

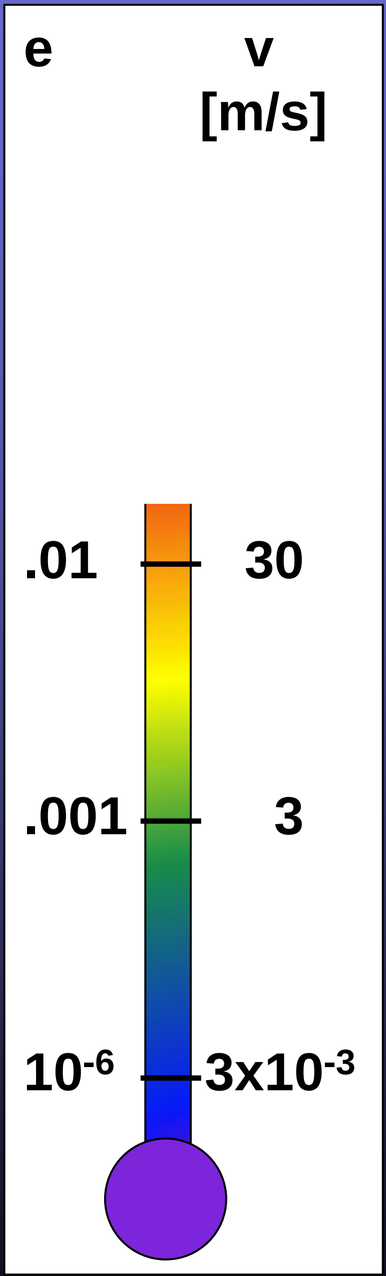
Low dynamical excitation (e~0.01…0.001)

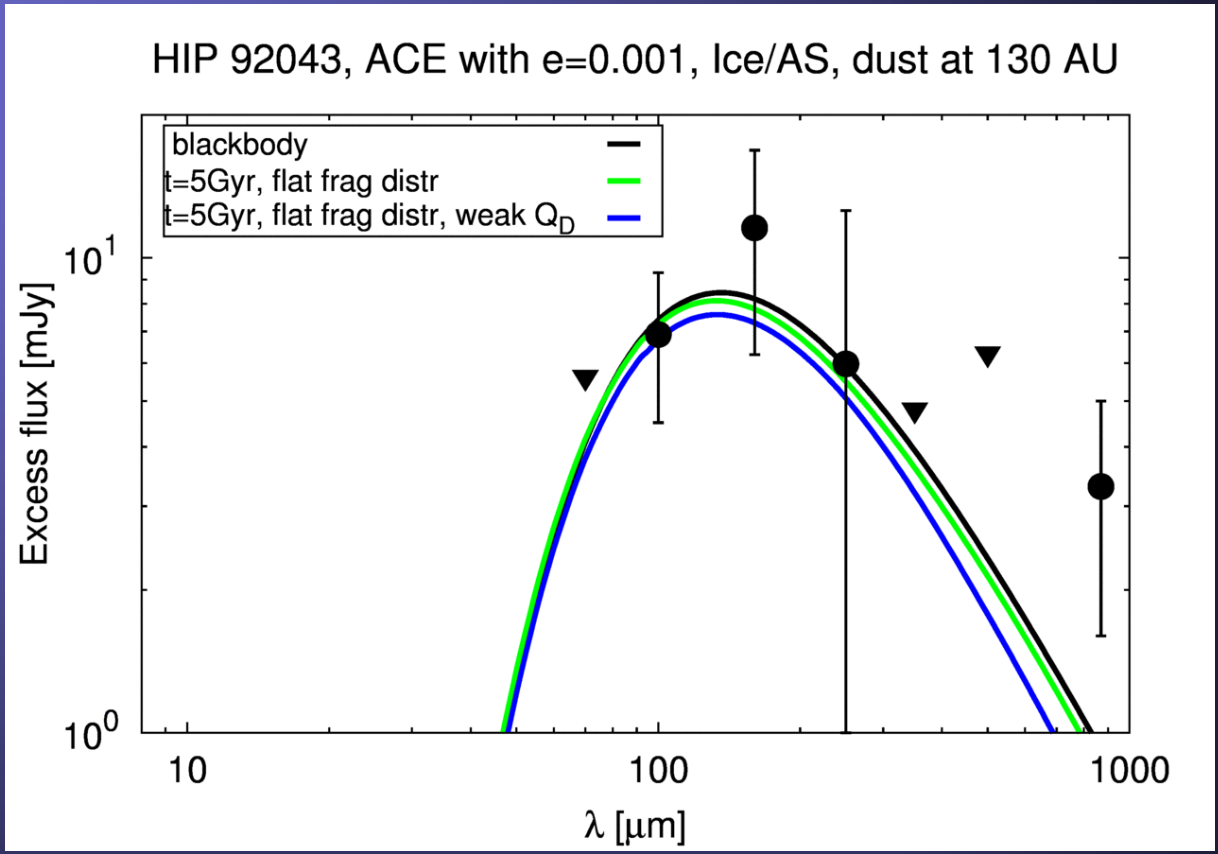




We assume a belt of primordial grains 1mm – 1cm,
with ~ lunar mass (or larger if bigger objects are also present)
It can indeed survive several Gyr of evolution

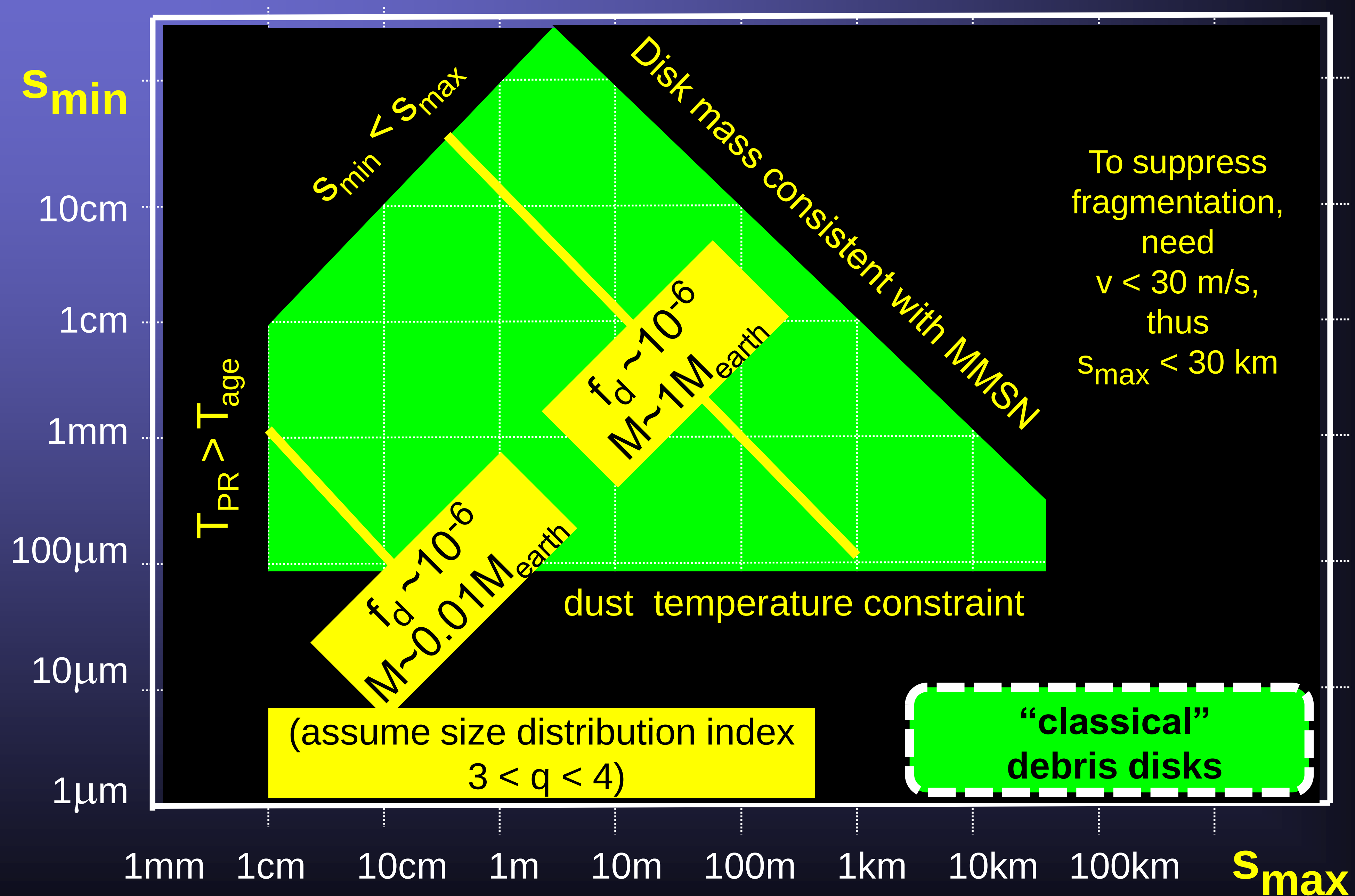
Low dynamical excitation (e~0.01…0.001)





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

Dust, pebbles, boulders, planetesimals?



Summary

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 have a nearly blackbody temperature. This implies large grain sizes (and perhaps materials with low absorption in the visible , e.g. icy)
- 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