The mystery of Herschel’s “cold debris disks”

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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: $F_\star (100 \mu m) \geq 4$ mJy
The DUNES people

Cold disks
“Classical” debris disks

\[ \lambda_{\text{max}} \sim 70-100 \, \mu m, \]

\[ f_d \sim 10^{-4} \ldots 10^{-5} \]
The class of “cold disks”

\[ \lambda_{\text{max}} \geq 160 \, \mu\text{m}, \]

\[ f_d \sim 10^{-6} \ldots 10^{-7} \]

“Cold” are disks with an excess at \( \geq 160 \, \mu\text{m} \), but little or no excess at 100 \( \mu\text{m} \). 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

A word of caution

First epoch

Second epoch

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 the 100 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.
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, ...)

Working plan
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 ($e \sim 0.1$)

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
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 ($e \sim 0.1$)

... so that the SED for silicate/ice mixture is far too warm
1. Dynamical excitation at the Kuiper-belt level ($e \sim 0.1$)

... and even the SED for pure ice is too warm
2. Low dynamical excitation ($e \sim 0.01 \ldots 0.001$)

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

$\textit{Thebault} \ & \textit{Wu} \ 2008$

\[ s_{\text{min}} = b \ s_{\text{blow}} \]

\[ b \sim 1/e \]
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
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 ($e \sim 0.01 \ldots 0.001$)

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?

To suppress fragmentation, need $v < 30 \text{ m/s}$, thus $s_{\text{max}} < 30 \text{ km}$.

“Classical” debris disks

(assume size distribution index $3 < q < 4$)
Summary

• About one-fifth of the DUNES debris disks appear to be “cold”, with SEDs peaking longward of 160\(\mu\)m. 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 \(\sim0.01\ldots0.001\)). 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.