Debris Disks Observed with Herschel

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Collaborators: Torsten Löhne, Hiroshi Kobayashi, Sebastian Müller, Martin Reidemeister, Christian Vitense, and the Herschel / DUNES team

Outline

- Debris disks in planetary systems
- Debris disks with Herschel
- The DUNES project
- DUNES results: q^1 Eridani
- DUNES results: HD 207129
- DUNES results: “cold debris disks”
- DUNES results: preliminary statistics
- Summary

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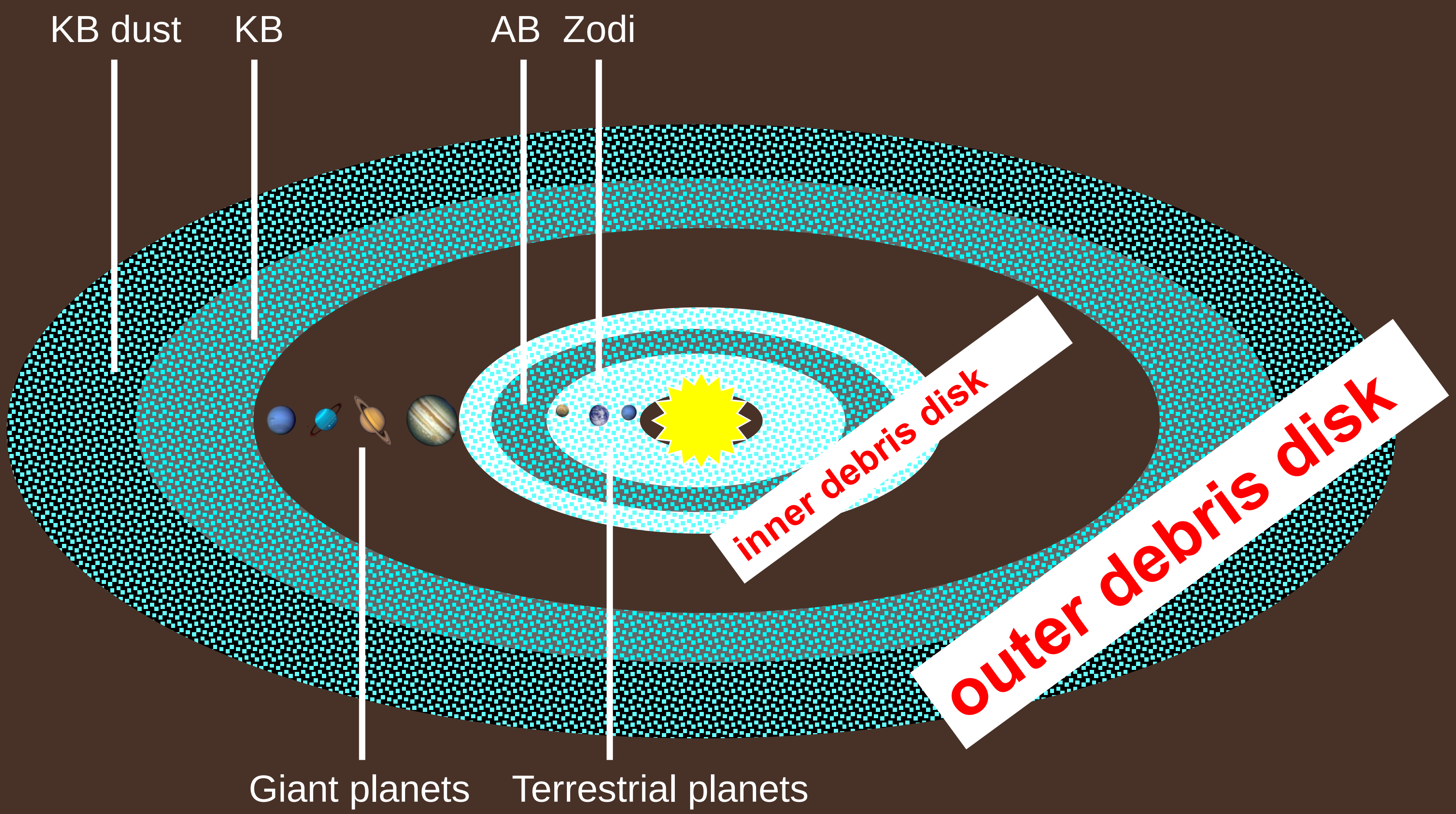
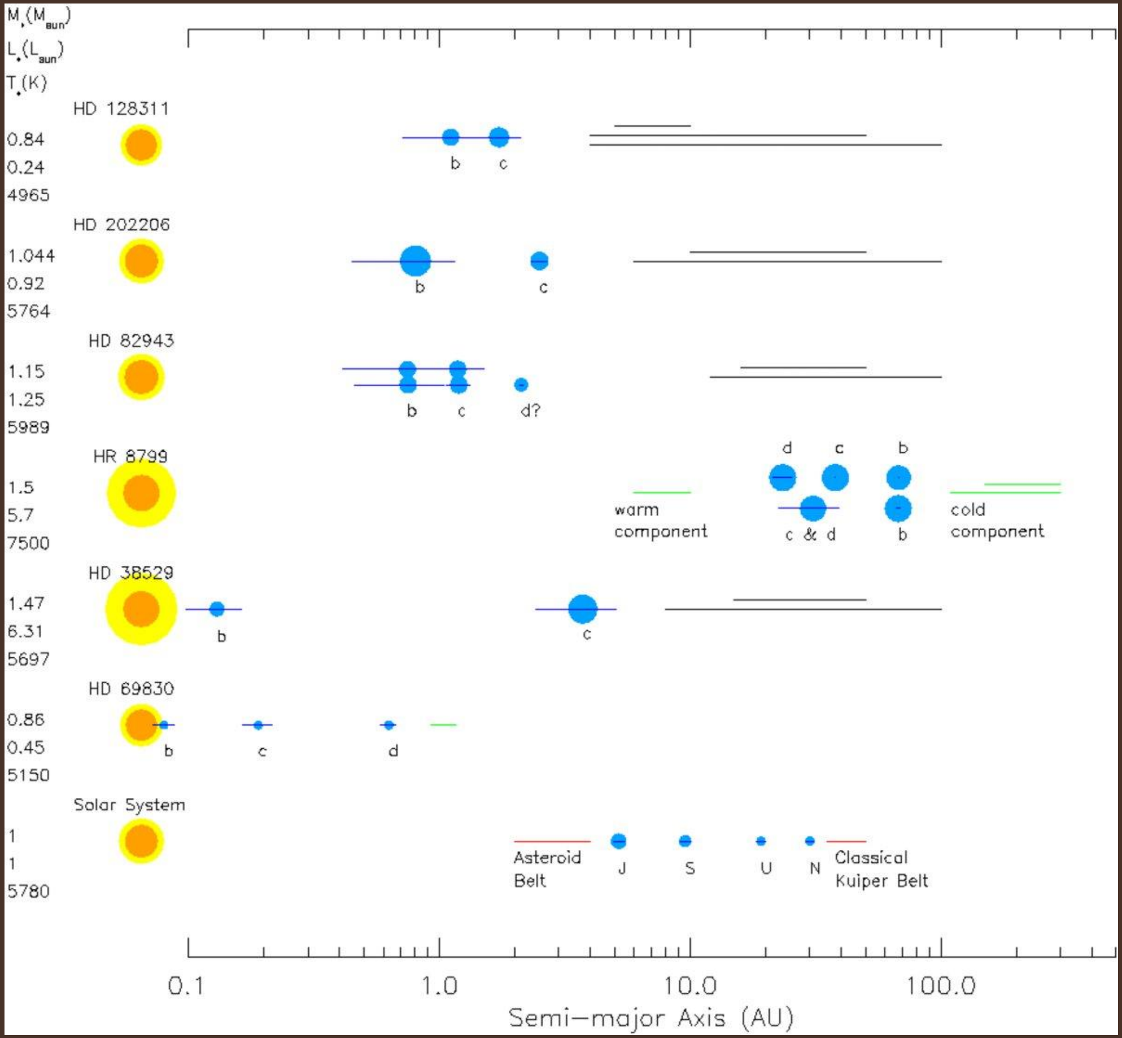
A two-component debris disk of the solar system



Debris disks are components of planetary systems



Known systems with at least 2 planets and a debris disk

Moro-Martín et al., ApJ ***717****, 1123-1139 (2010)*

Tens of systems have at least one known planet and a debris disk

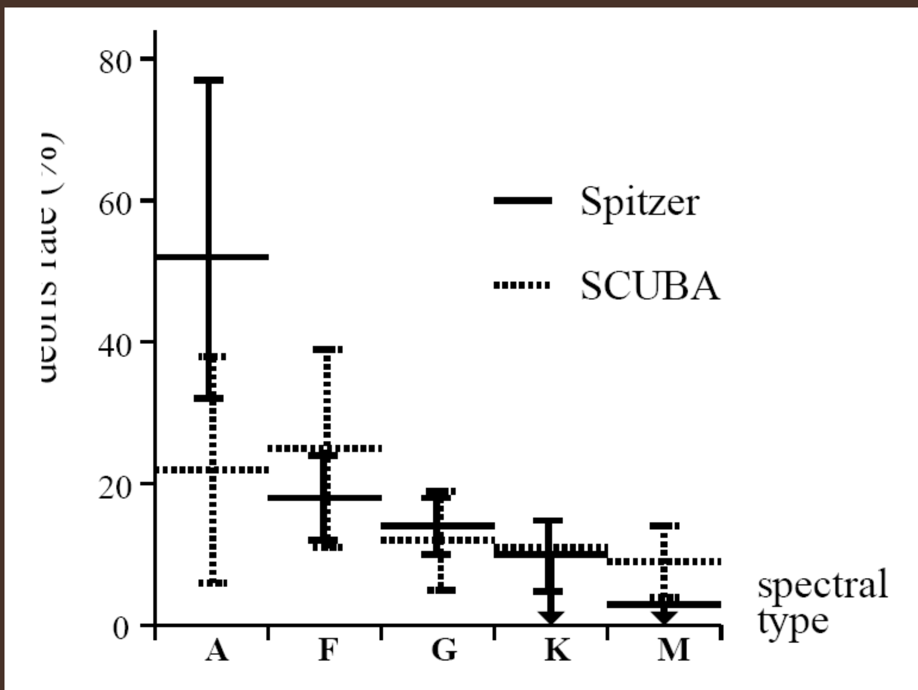
In many systems with known debris disks (more) planets are expected

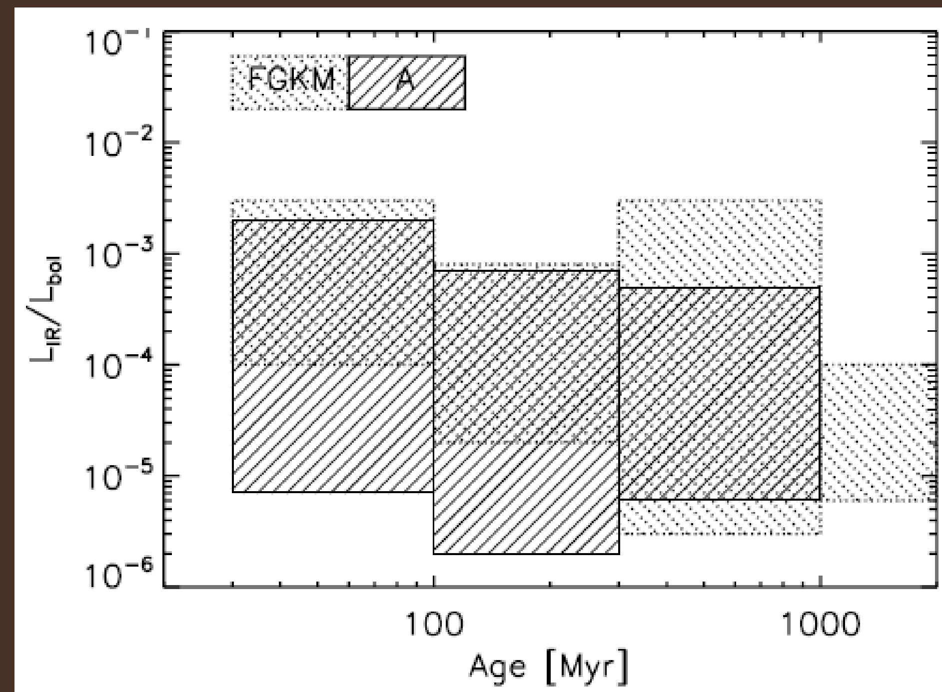
Many systems with known planets may possess as yet unknown debris disks

Systems without planets and/or debris disks may also exist

Greaves et al. (2004, 2006), Beichman et al. (2005, 2006), Kospal et al. (2009), Bryden et al. (2009), Krivov (2010)

Debris disks are common





Spitzer average frequency over Sp and ages: ~15 %

Debris disks are evidence from planetesimals

Dust lifetime is much shorter than stellar age T_{age}...

$$T_{PR} = 7\, r^2\, L_*^{-1}\, \rho\, s$$

$$T_{coll} = 8\, r^{1.5}\, M_*^{-0.5}\, \tau^{-1}\, (s/s_0)^{0.5}$$

for T in Myr, L_* in $L_☼$, M_* in $M_☼$, r in 100 AU, ρ in g cm^{-3},
s in μm, τ in 10^{-5}, s_0 (τ-dominating size) in μm

E.g., for Vega the age is: 350 Myr,

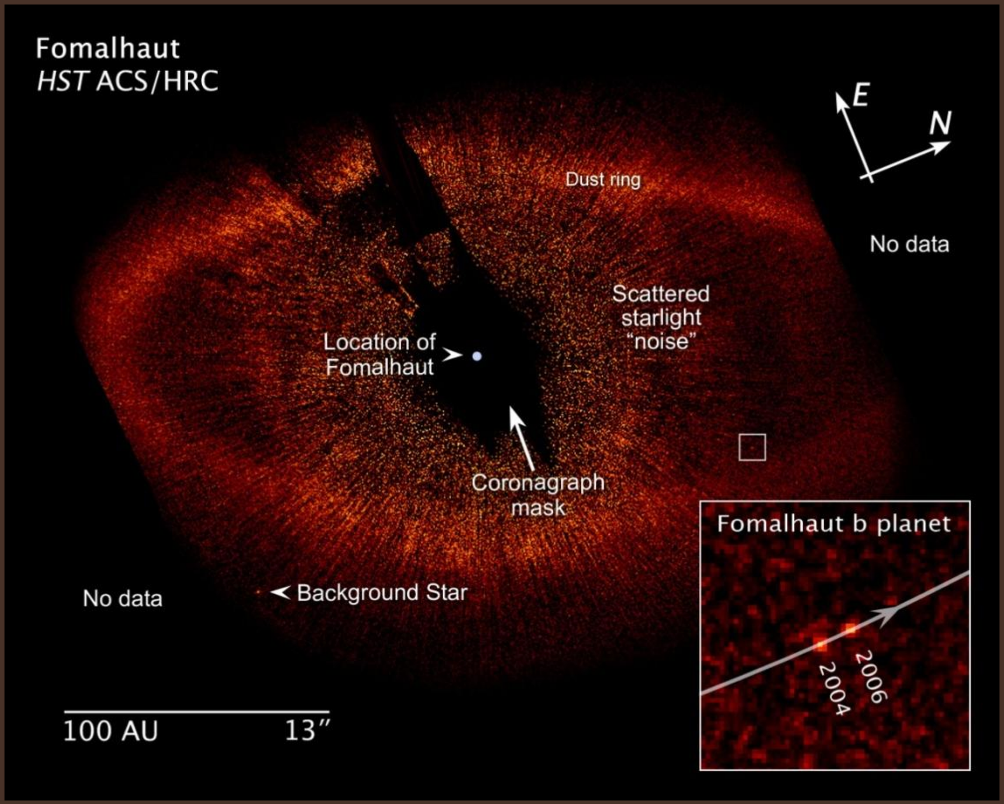
but dust lifetimes are: T_{PR} ~ 5 Myr, T_{coll} ~ 2 Myr

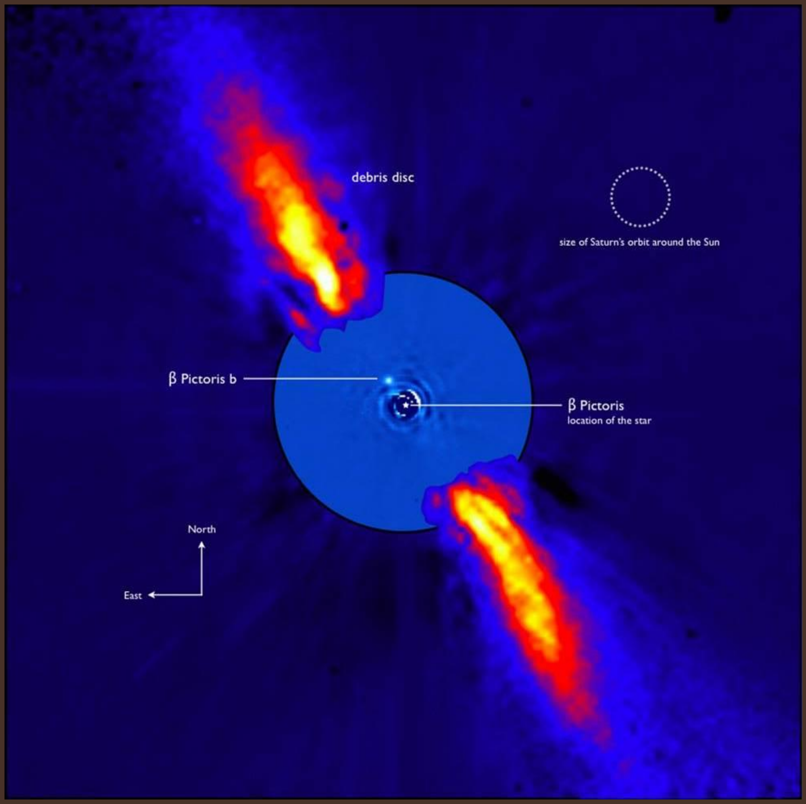
... thus dust has to be replenished by larger debris, "planetesimals", with T_{PR} and T_{coll} longer than T_{age}

For Vega, planetesimal size

must be : s > 1 meter

Debris disk structure can be attributed to planets





Kalas et al., Science ***322****, 1345 (2008)*

Lagrange et al., AAp ***493****, L21-L25 (2008)*

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The Herschel Space Observatory

D = 3.5 m

L = 60-670 μm

May 2009:
Launch

Oct 2009:
First data

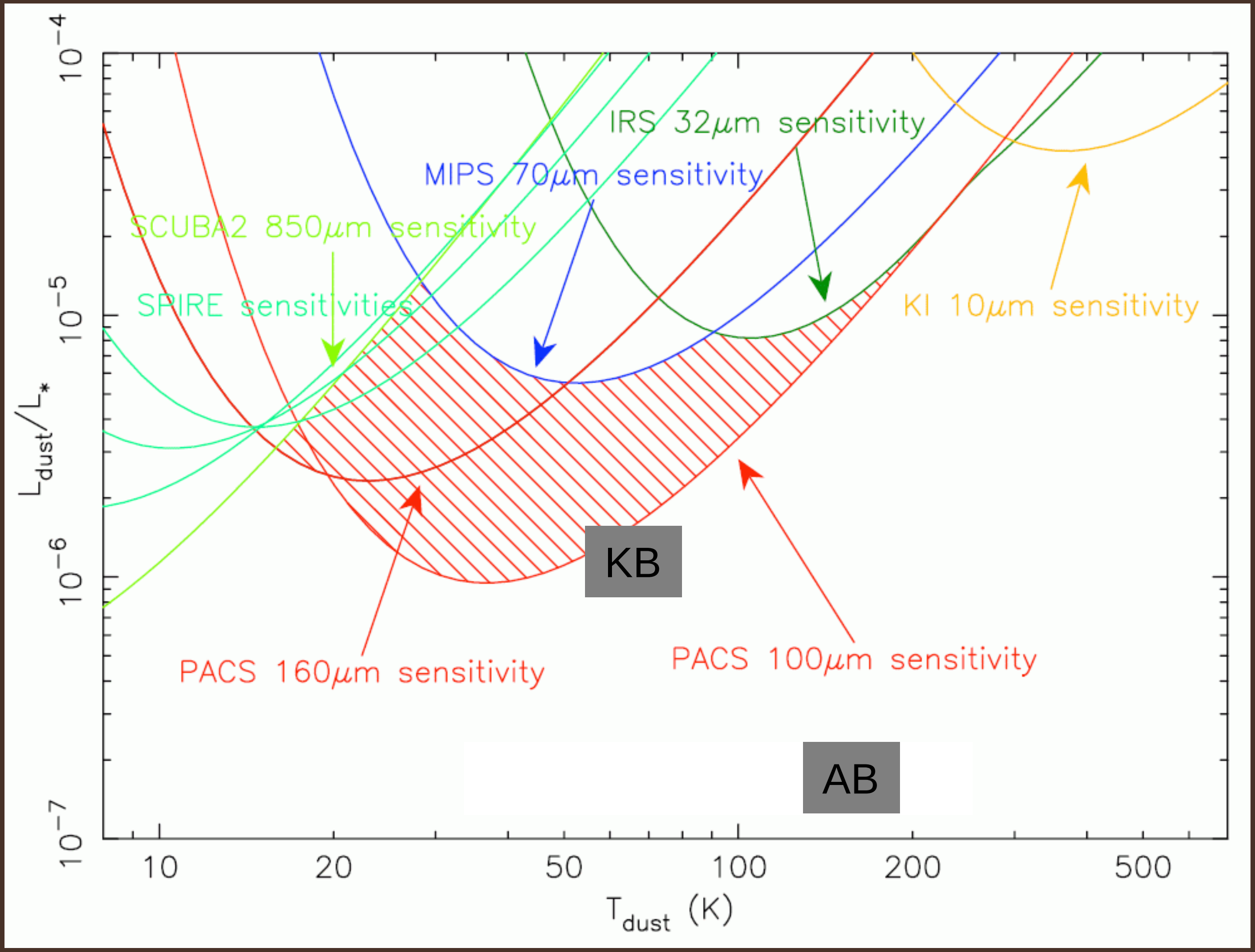
Nov 2009- Dec 2010:
GT and KP observations

July 2010 & July 2011:
AO1 & AO2

May 2013:
End of the mission

Debris disks are targets of several programs:
GTP (PI: Oloffson), OTKP DUNES (PI: Eiroa),
OTKP DEBRIS (PI: Matthews) , GASPS (PI: Dent)

Herschel advantages: sensitivity



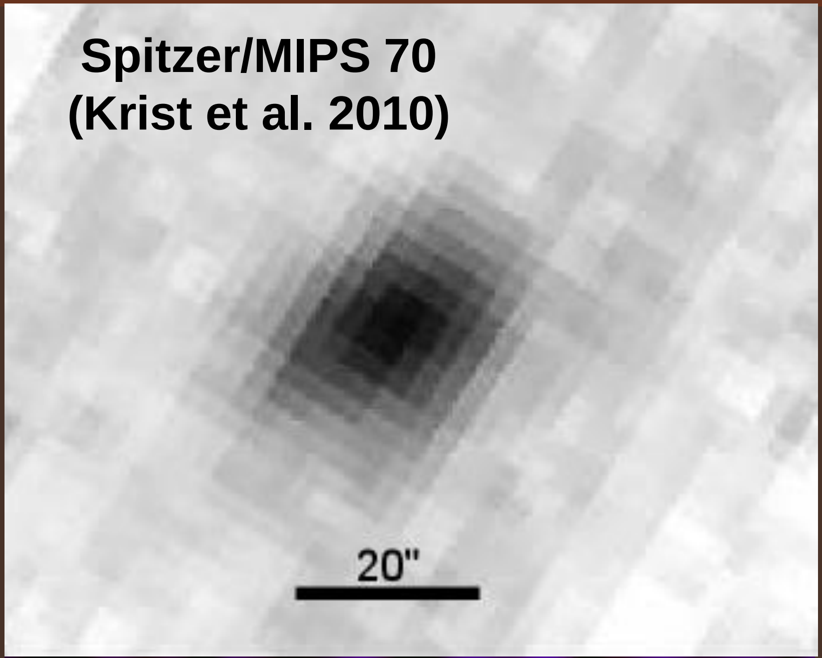
Detection limits (10σ PACS100) for a G5V star at 20 pc vs T_{dust}

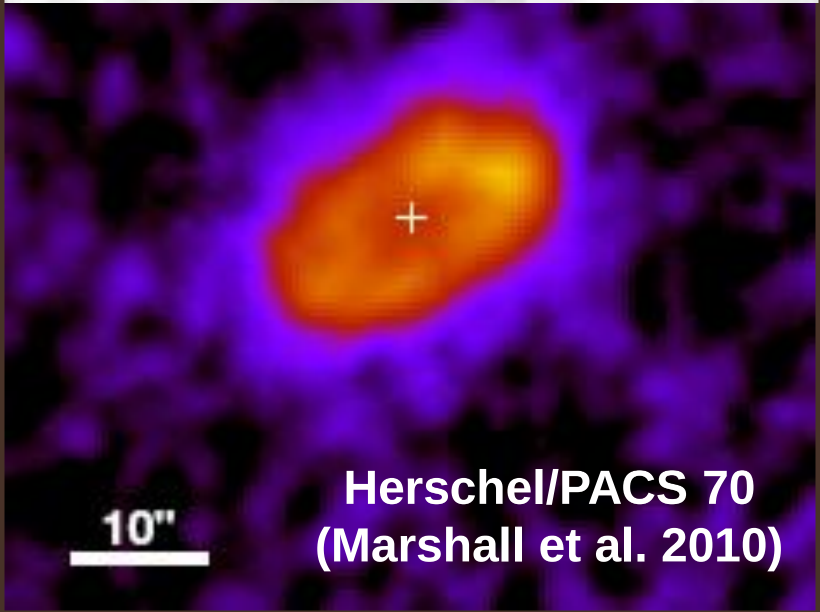
Eiroa et al., DUNES proposal (2008)

Can detect many more debris disks, down to the EKB level

(However, an exact EKB analog would be too warm to be detected)

Herschel advantages: resolution





Spitzer/MIPS @ 70μm:
~4 arcsec (PSF @50% energy)

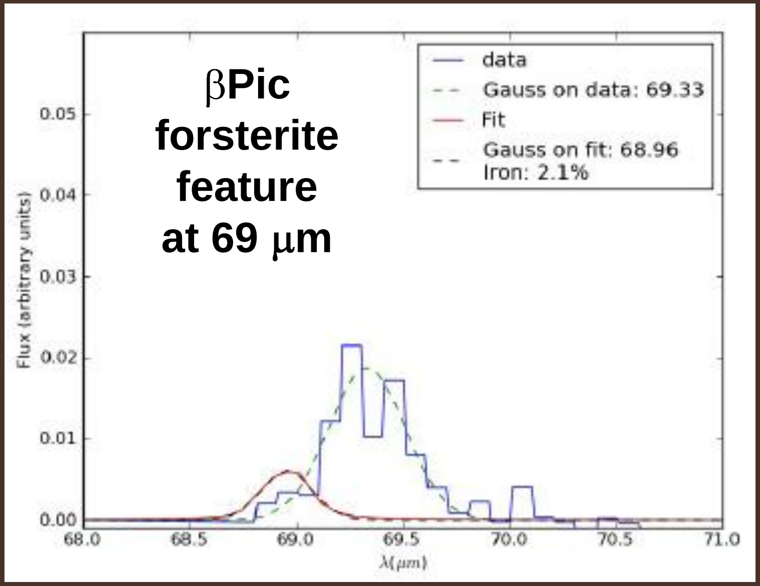
Herschel/PACS @ 70μm:
~15 arcsec (PSF @50% energy)

Unlike Spitzer, Herschel can efficiently probe debris disk structure, which may point to unseen planets

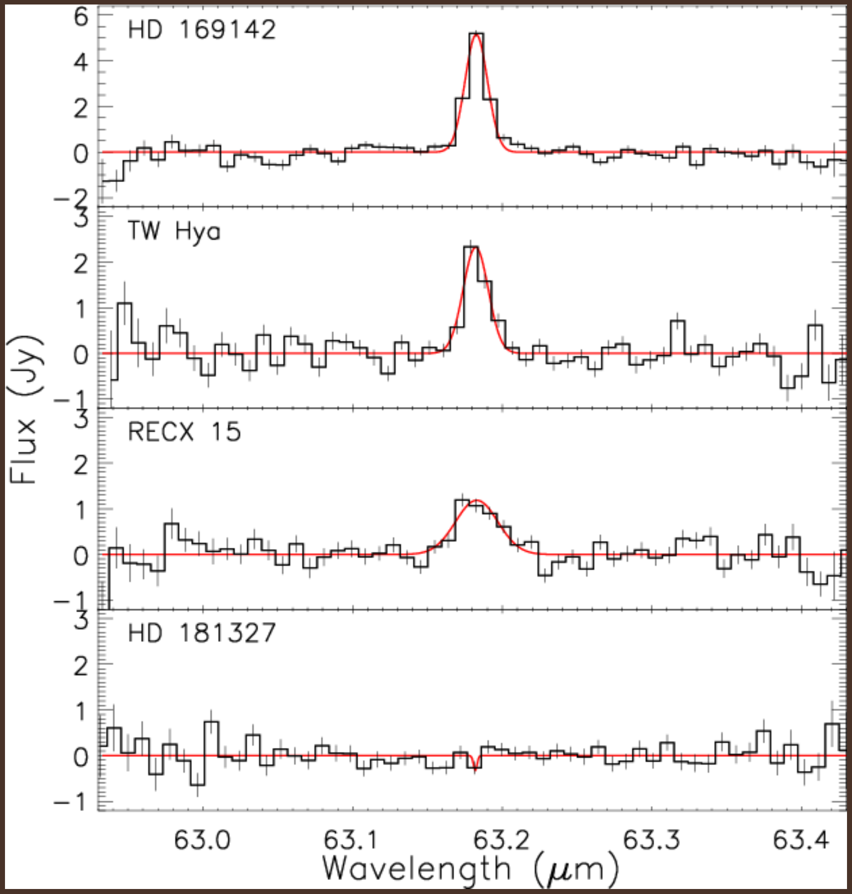
Herschel advantages: “right” spectroscopy

Can probe dust mineralogy in the “right” spectral region where thermal emission peaks

Can trace gas by finding lines such as OI 63



De Vries et al. (2010)



Mathews et al. (2010)

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DUNES: DUst around NEarby Stars

DUNES is a Herschel Open Time Key Programme with the aim of studying cold dust disks around nearby solar-type stars:

i. dependence of planetesimal formation on stellar mass
ii. collisional and dynamical evolution of exo-EKBs
iii. presence of exo-EKBs versus presence of planets
iv. dust properties and size distribution in exo-EKBs.

DUNES: people

Olivier Absil, David Ardila, Jean-Charles Augereau, David Barrado, Amelia Bayo, Charles Beichman, Geoffrey Bryden, William Danchi, Carlos del Burgo, Carlos Eiroa, 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

DUNES: sample, tools, strategy

- Sample: volume-limited, 133 FGK stars
  - d<20 pc
  - stars with known planets (d<25 pc)
  - Spitzer debris discs (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
  - EKB analog at 10 pc (100 µm): ~7–10 mJy

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q^1 Eri before Herschel

STAR

- Spectral type: F8
- Distance: 17.4 pc
- Age : ~ 2 Gyr

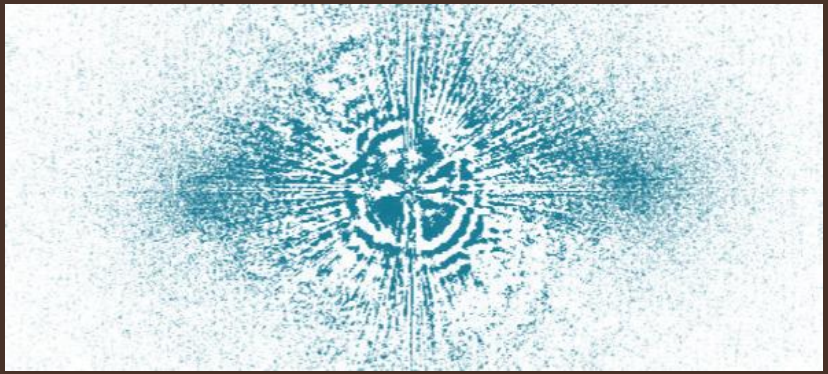
JUPITER-MASS PLANET

- M sin i: 0.9 M_{Jup}
- Semi-major axis: 2.0 AU
- Eccentricity : 0.1

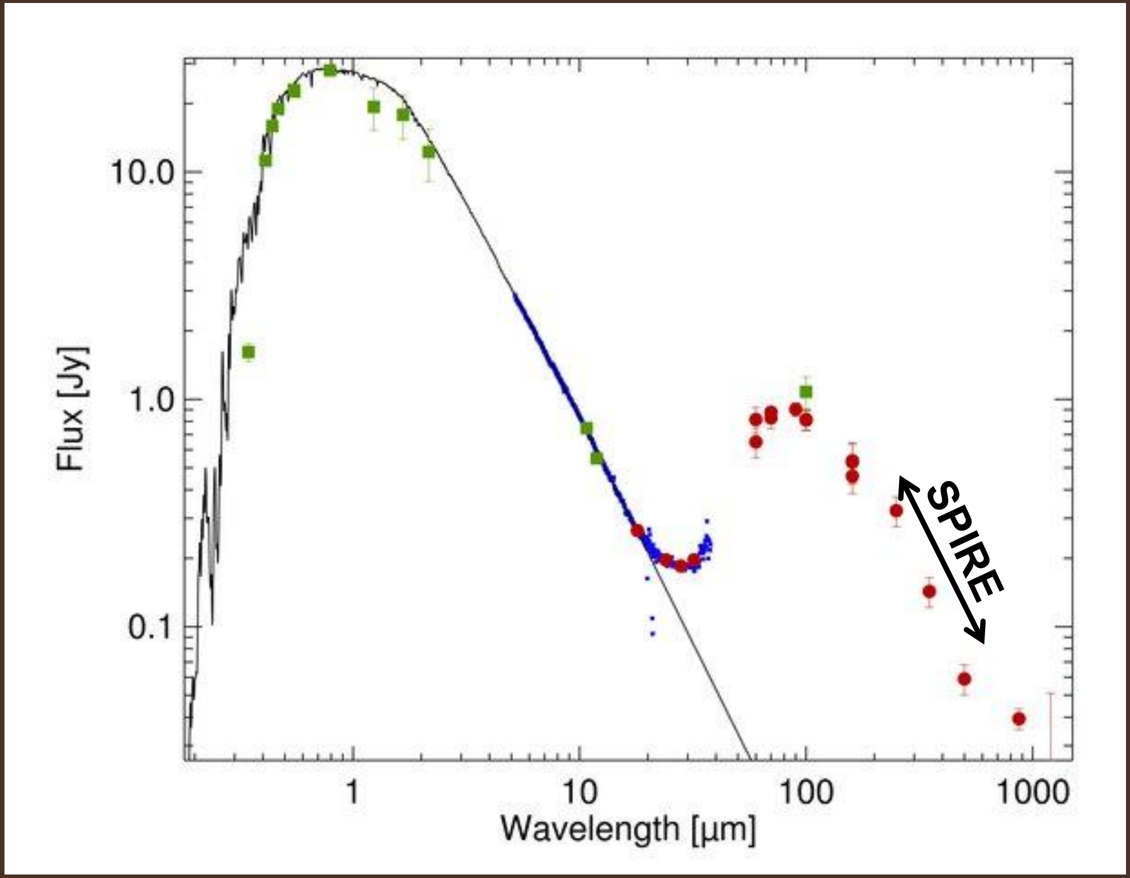
Mayor et al. 2003, Butler et al. 2006

KUIPER-LIKE BELT

- IRAS, ISO, Spitzer, AKARI: very dusty, with a luminosity of 1000 x Kuiper Belt
- Sub-mm APEX/LABOCA images: disk extent is up to several tens of arcsec *(Liseau et al. 2008)*
- HST images suggest a peak at 83AU *(Stapelfeldt et al. 2010)*



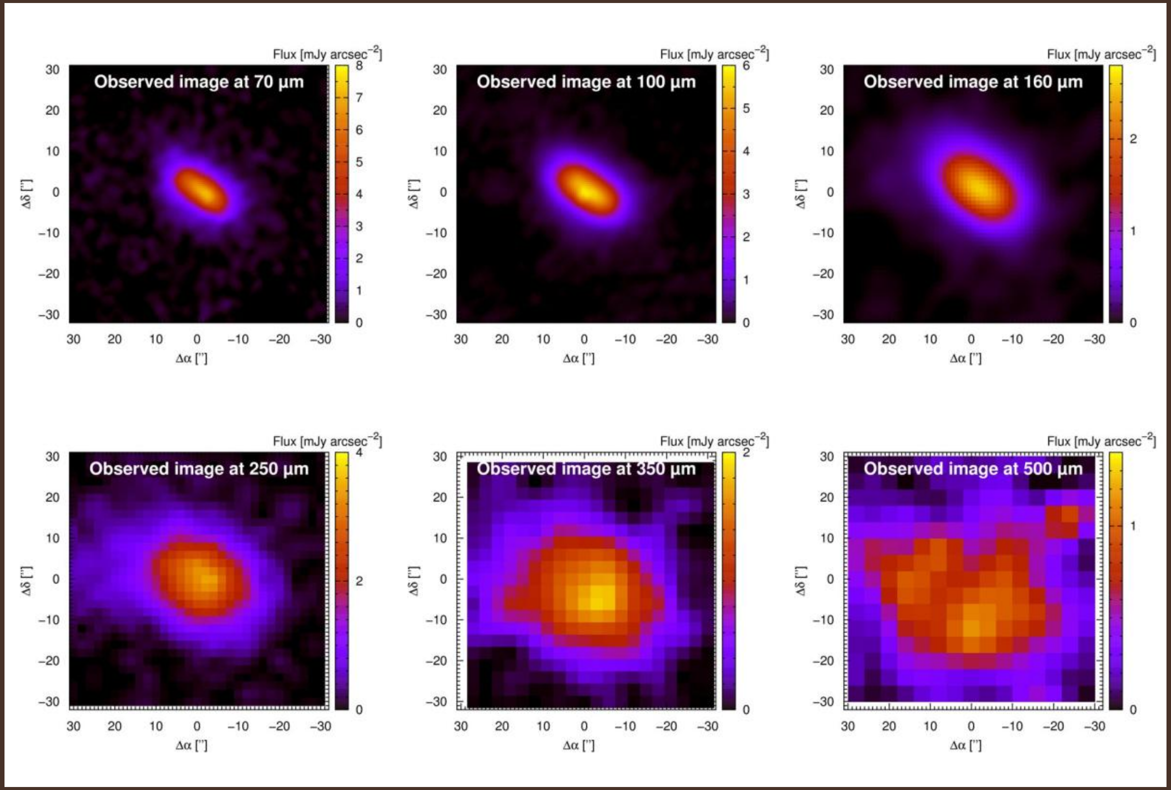
q^1 Eri: Herschel photometry



Liseau et al., AAp **518,** *L132 (2010)*

Herschel photometry makes the SED very well "populated"

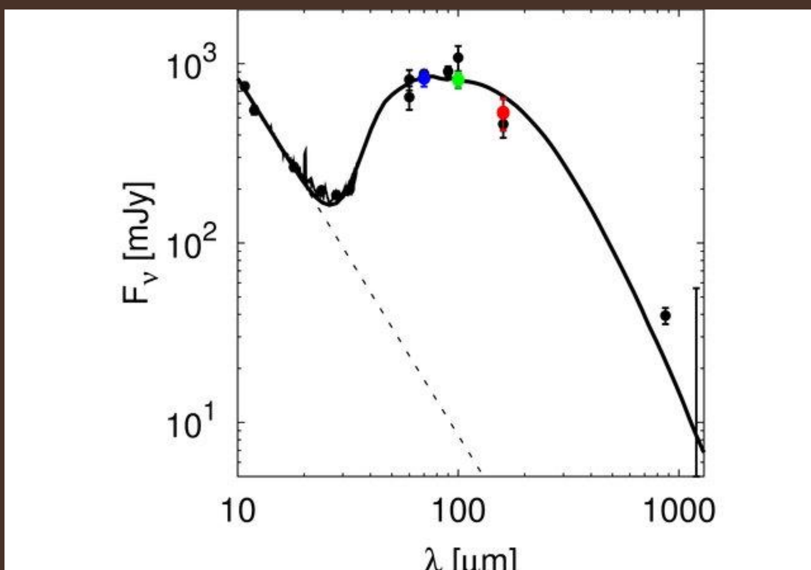
q[1] Eri: Herschel images

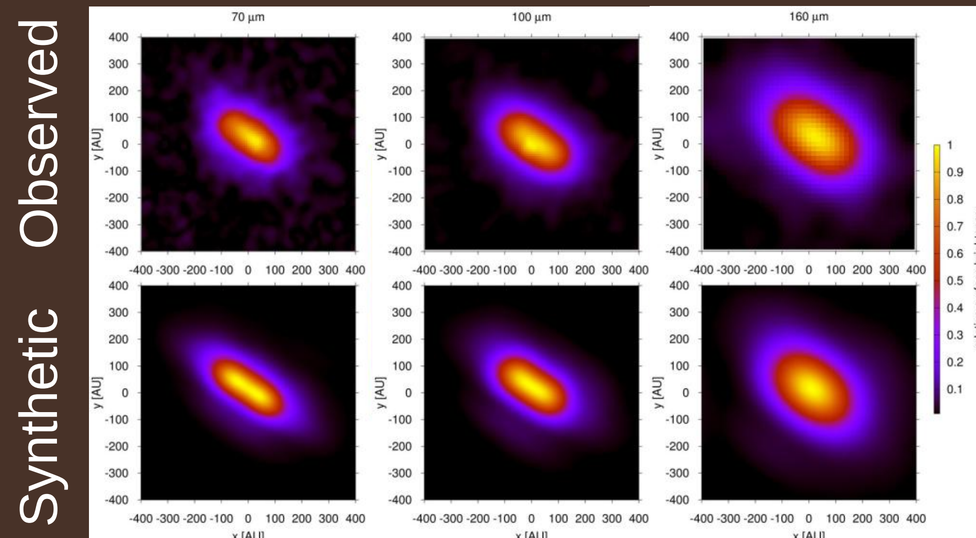


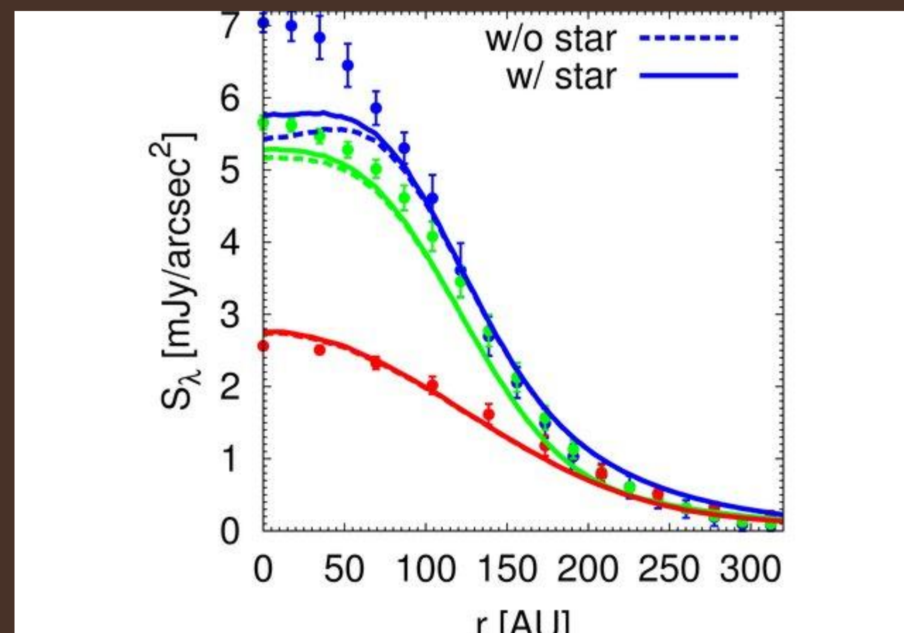
Herschel
PACS and SPIRE
images
break the degeneracy
between grain sizes
and location of dust

Liseau et al., AAp **518,** *L132 (2010)*
Augereau et al., in prep.

q^1 Eri: modeling results







q^1 Eri: conclusions

Consistent with a steady-state collisional dust production

Dust disk & grain properties:

- Mass: 0.02 M_{earth}, one of the dustiest disks at its age
- Possible hints for ice: best fit with 50-50 sil-ice mixture
- Possible hints for material strength: weaker dust (Q_D*~10^7erg/g)

Parent belt:

- Location: 75-125 AU
- Eccentricities: 0.0…0.1
- Mass : ~1000 M_{earth} (if 2 Gyr), but ~100 M_{earth} (if 0.5Gyr)

  Probing collisional history: support to delayed stirring (self-stirring by Plutos, stirring by q^1Eri c, or even q^1Eri b)

Augereau et al., in prep.

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HD 207129 before Herschel

Star

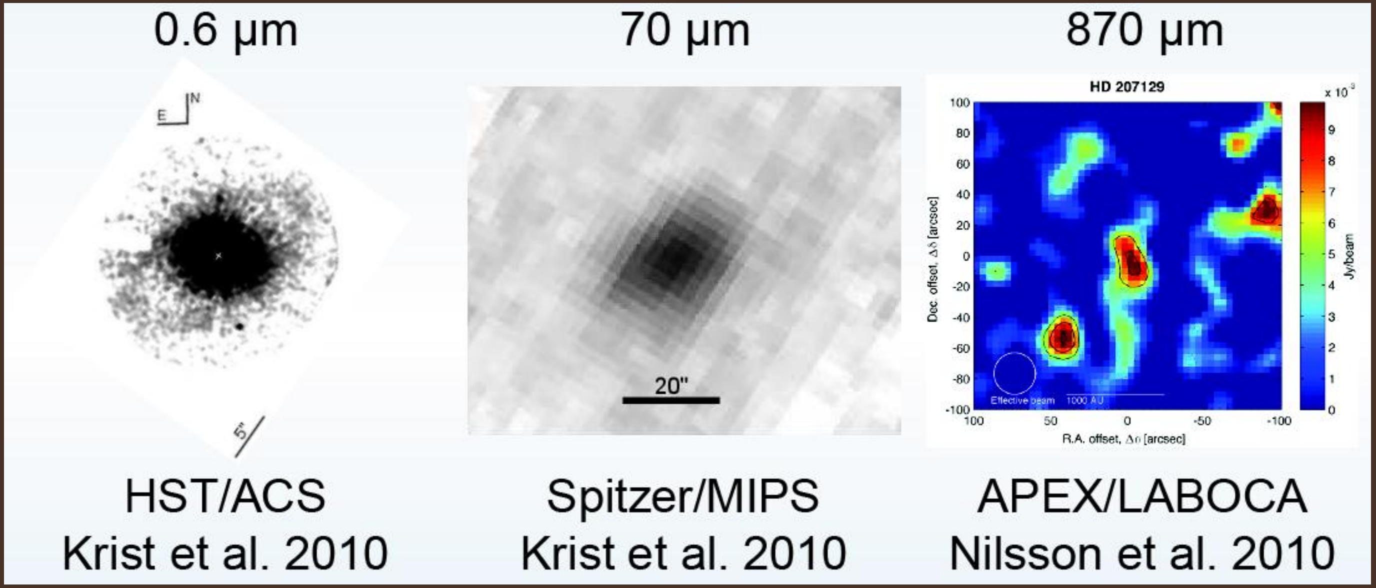
- Spectral type: G2V
- Distance: 16.0 pc
- Age : ~ 1 Gyr

Planets

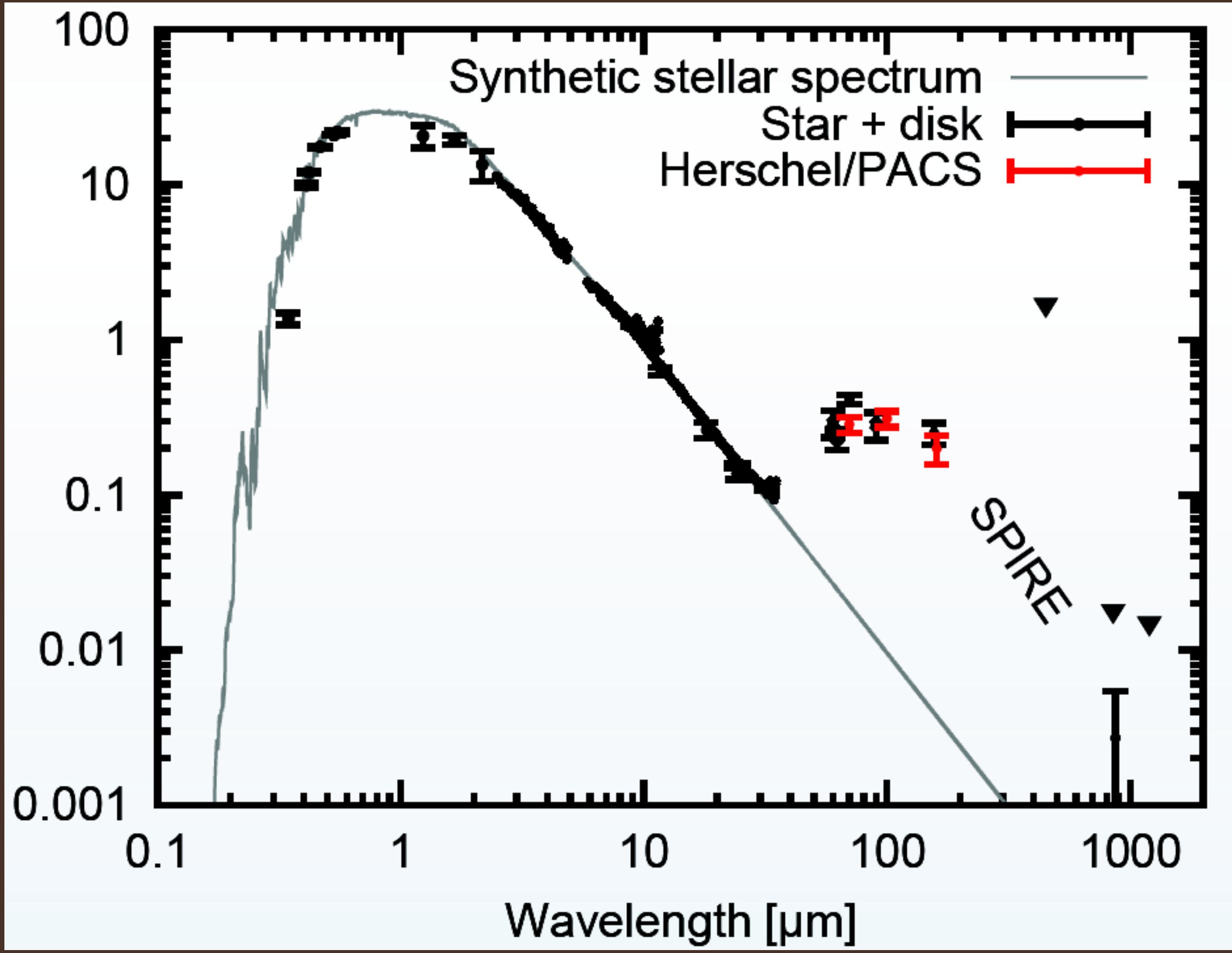
- None (so far)

Kuiper-like belt

- IRAS, ISO, Spitzer, AKARI: very large, but tenuous disk
- Sub-mm images *(Sheret et al. 2004, Nilsson et al. 2010)*
- HST images suggest a peak at ~160AU *(Krist et al. 2010)*



HD 207129: Herschel photometry

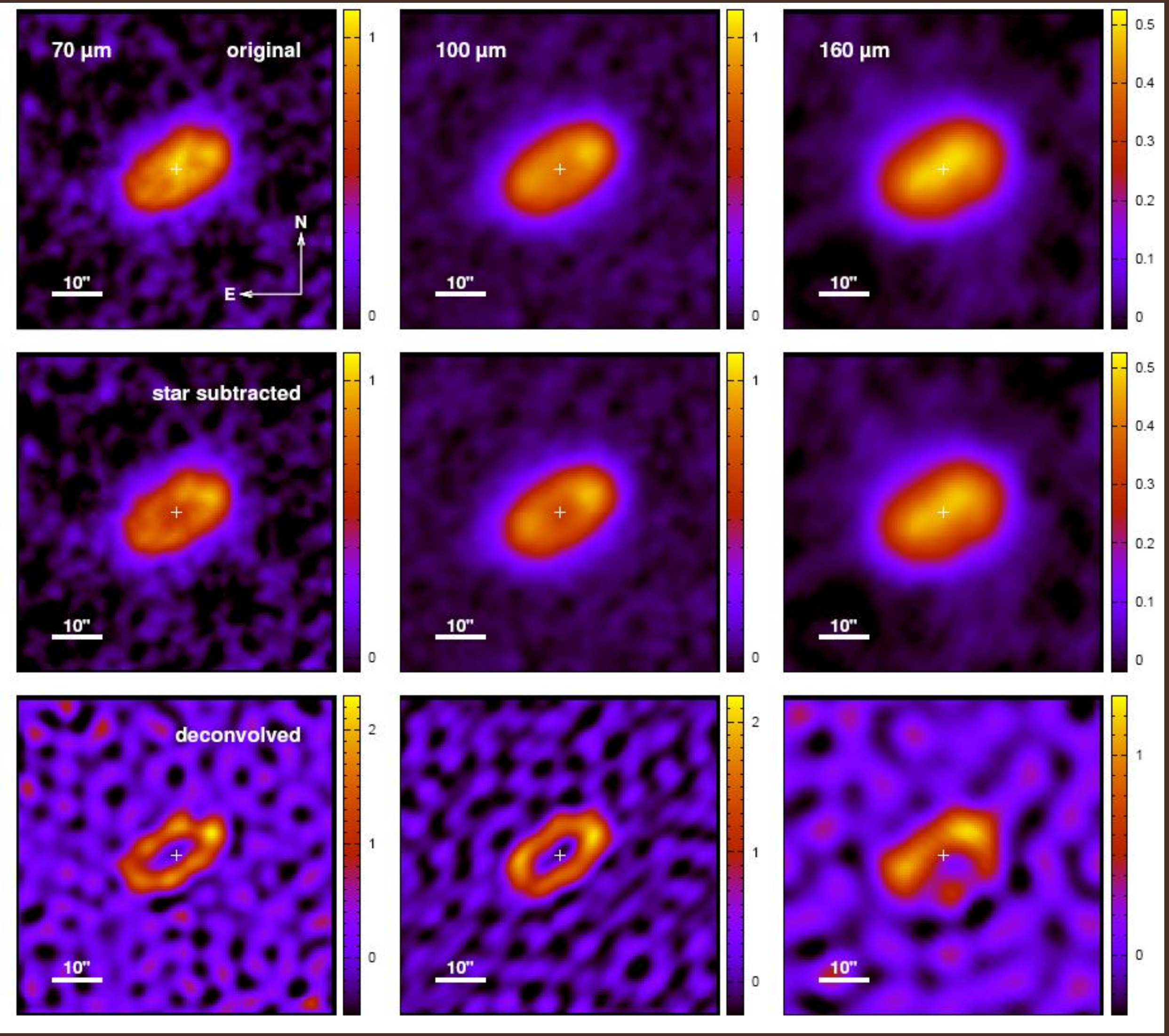


Marshall et al., in prep.

PACS data
consistent with Spitzer

SPIRE data
being reduced
(taken on
09 Nov 2010)

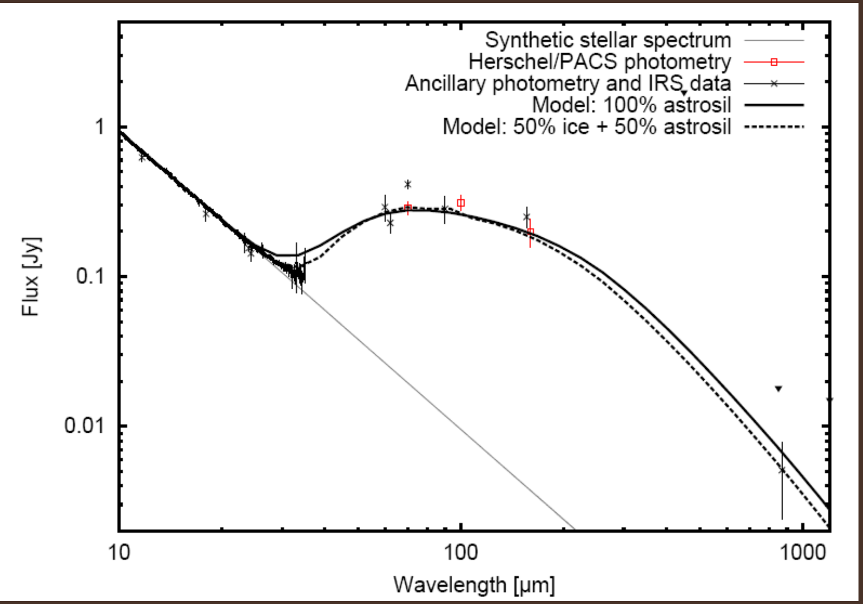
HD 207129: Herschel images

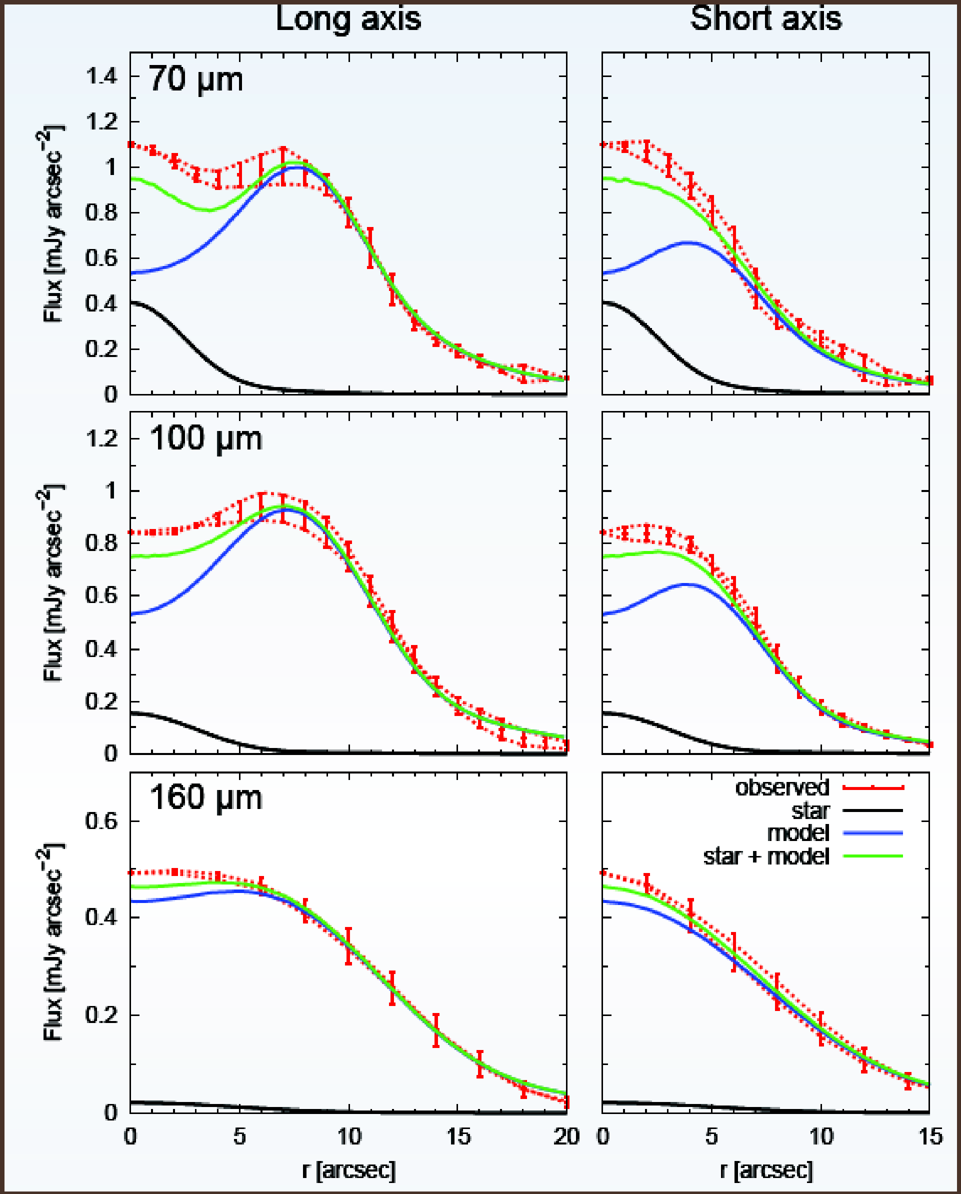


Ring-like structure resolved in far-IR for the first time!

Marshall et al., in prep.

HD 207129: modeling results





Marshall et al., in prep.
Löhne et al., in prep.

HD 207129: conclusions

Consistent with a steady-state collisional dust production

Dust disk & grain properties:

- Mass: 0.006 M_{earth}
- Possible hints for ice (similar to q^1 Eri)
- Possible hints for material strength (similar to q^1 Eri)

Parent belt:

- Location: 144 ± 32 AU, the largest known
- Eccentricities: 0.0…0.1
- Mass : ~25 M_{earth}

Löhne et al., in prep.

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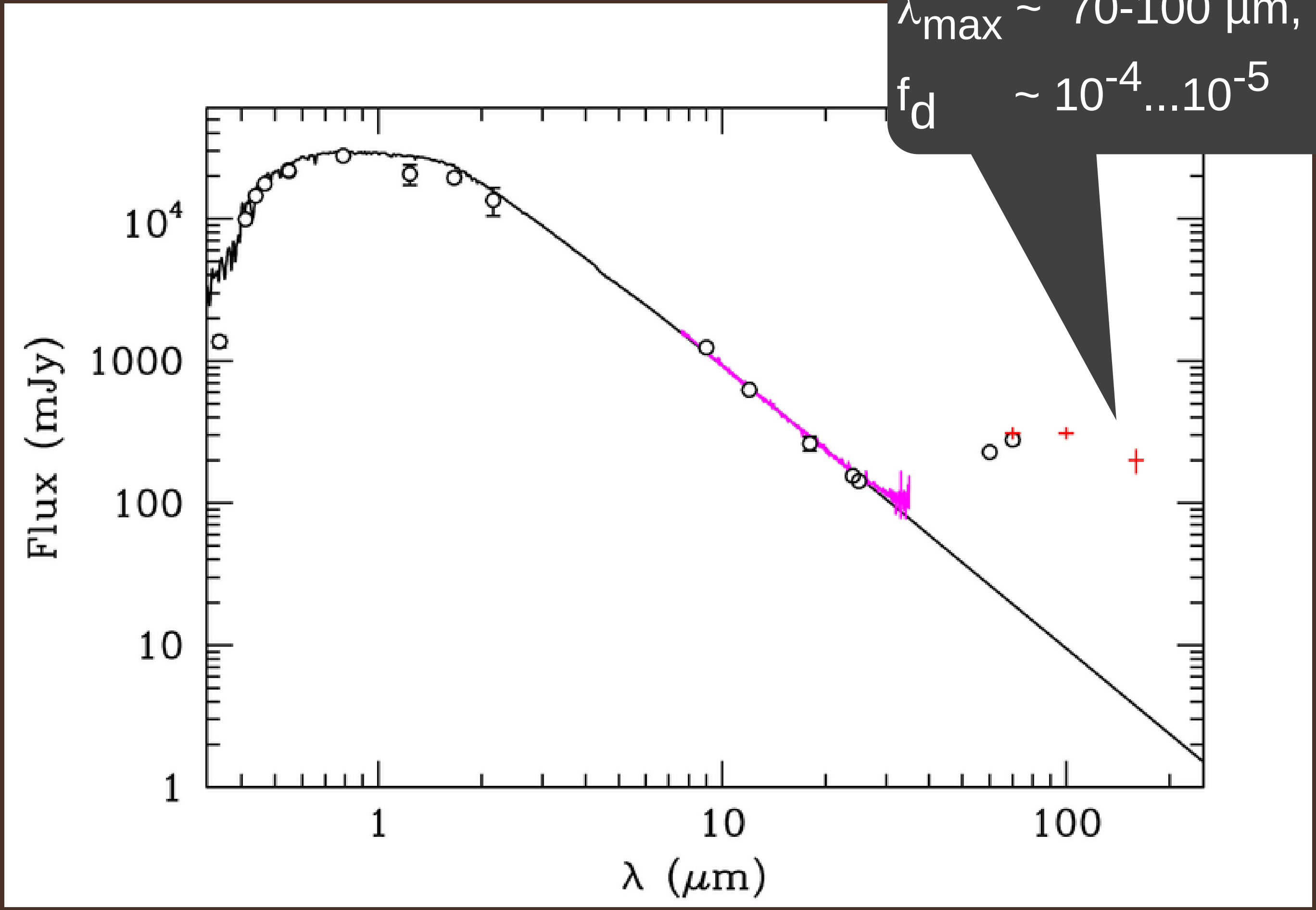
Some Herschel/DUNES disks are "normal"…

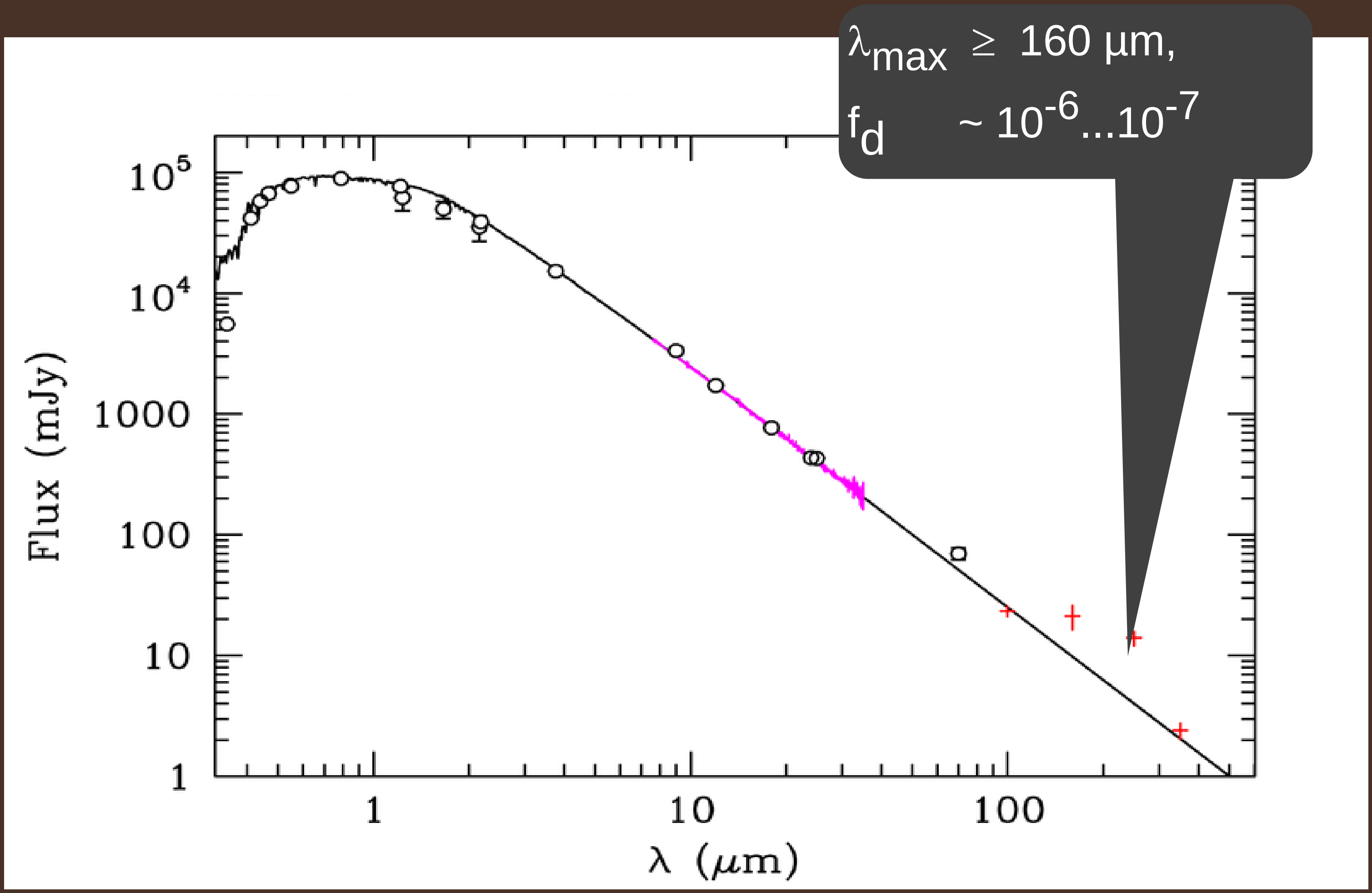


λ_{max} ~ 70-100 μm,

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

Marshall et al., in prep.

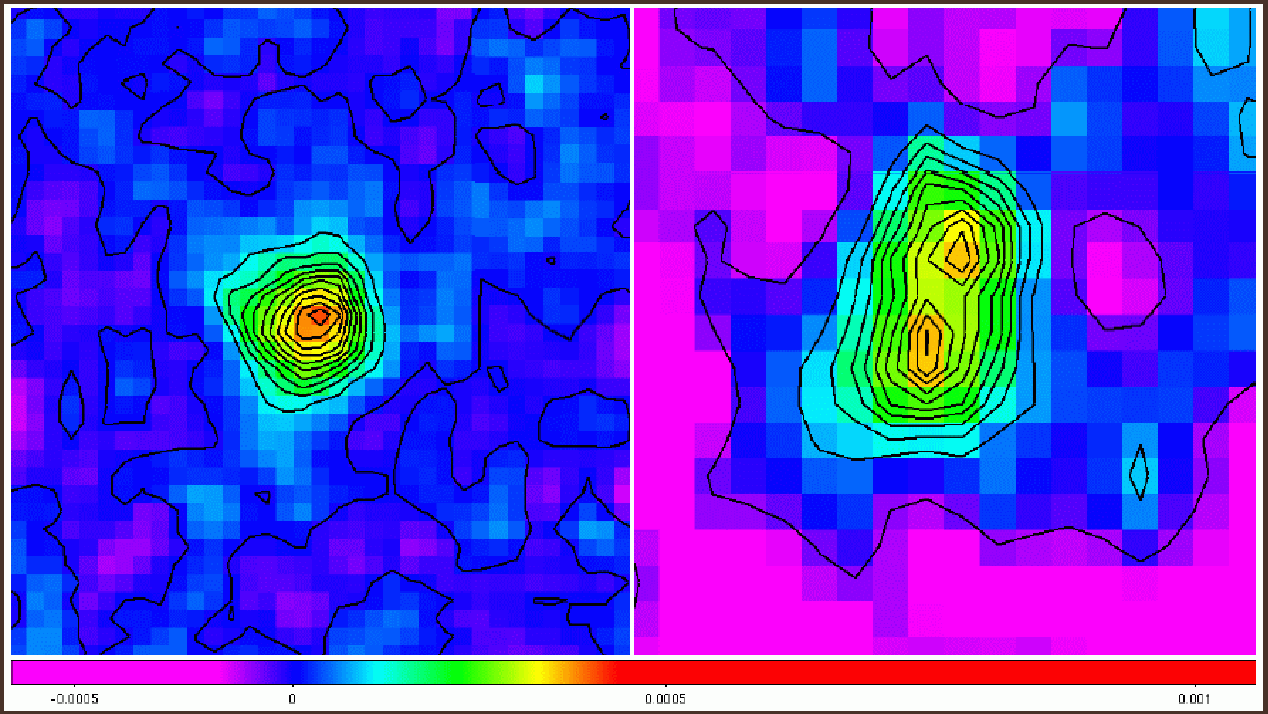
…but some others are tenuous and very cold



Marshall et al., in prep.

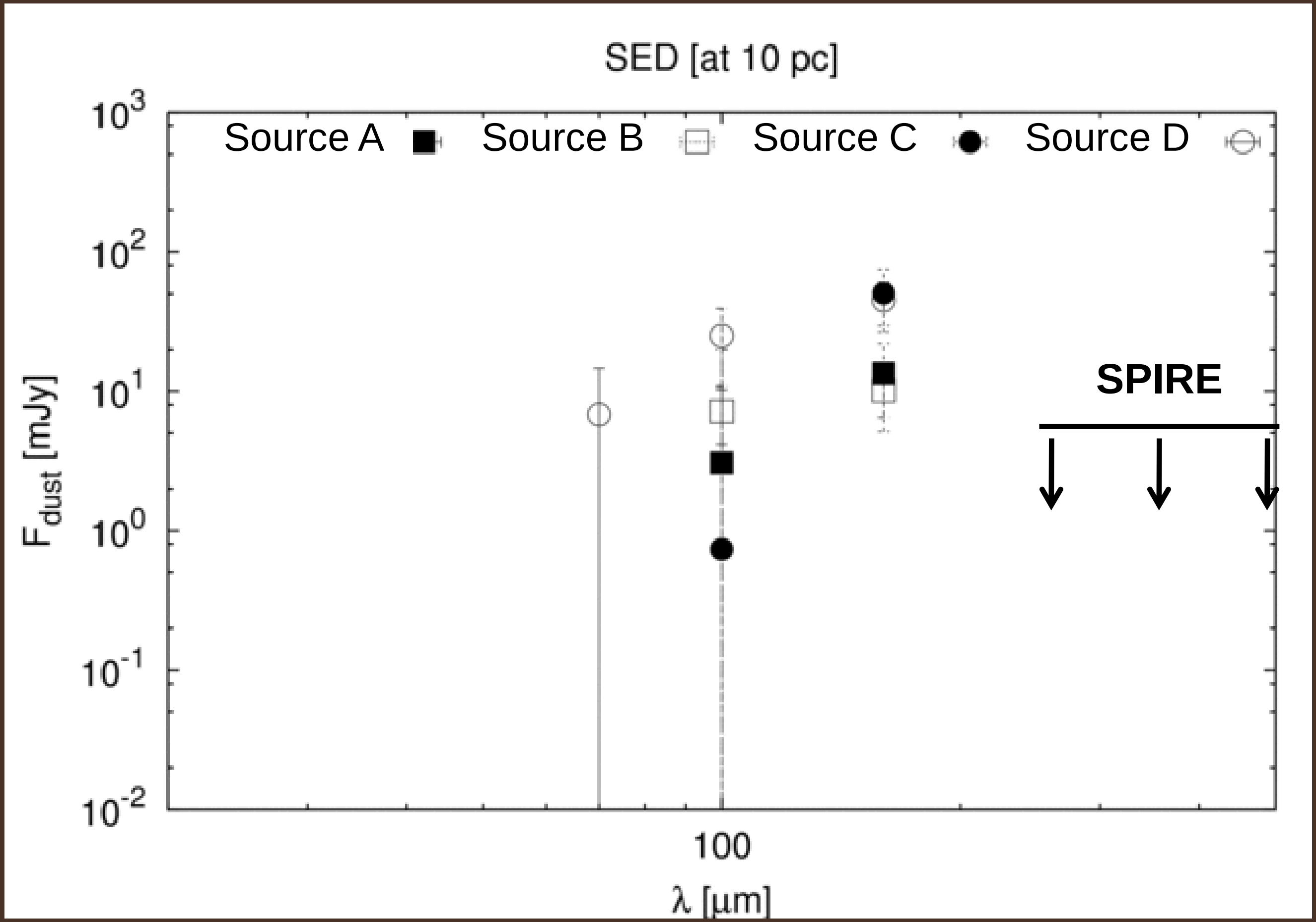
Challenges of the cold disks

Max at 160 µm would require dust to be typically at distances >> 100 AU,
but resolved images suggest radii of ~100 AU



Marshall et al., in prep.

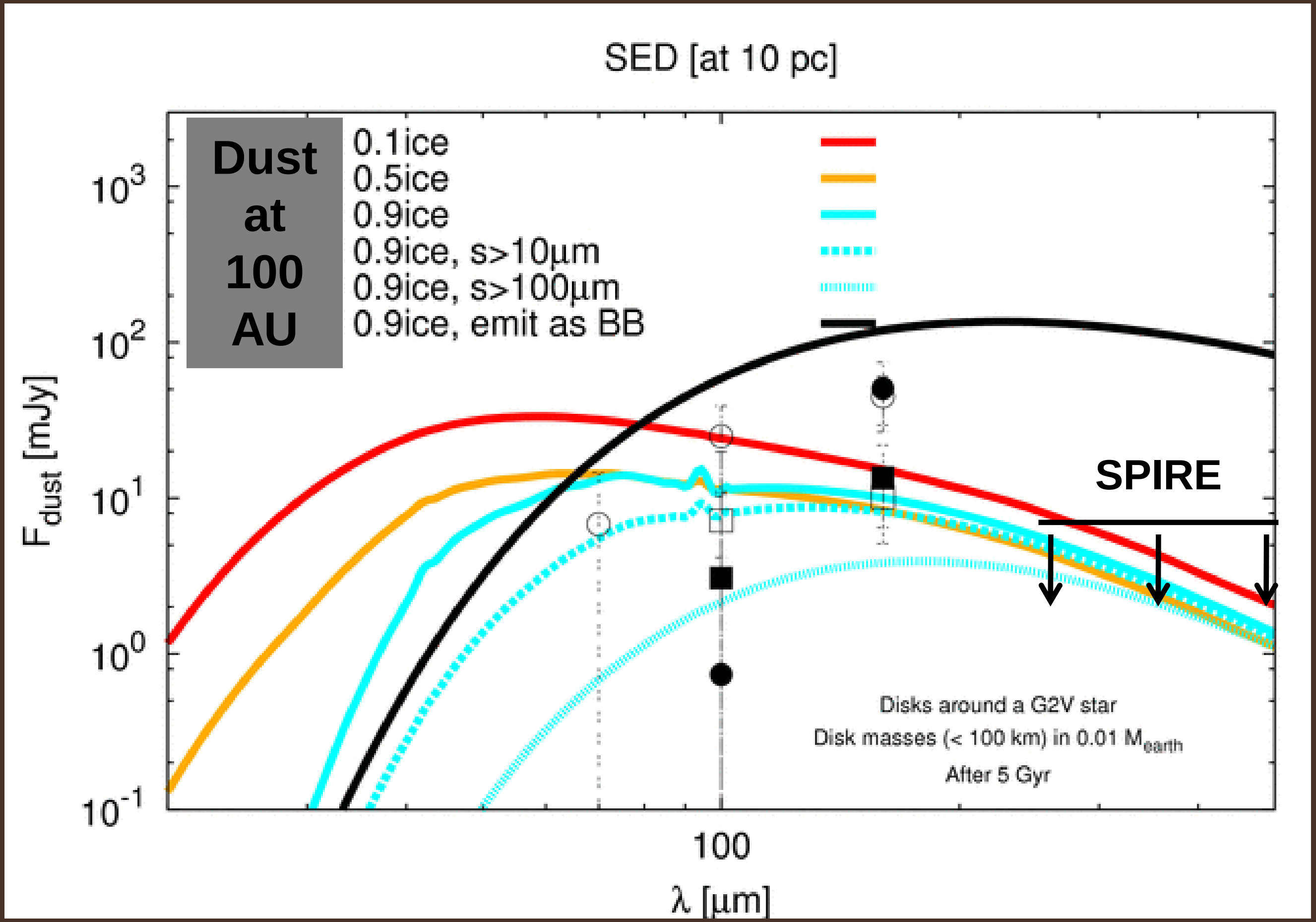
Attempts to understand the cold disks



Excess flux of four most reliable cold disks observed by DUNES

Krivov et al., in prep.

Attempts to understand the cold disks



Tried various dust compositions, large grains only, and blackbody.
Result: grains must be > 100μm, not what collisional models predict!

Krivov et al., in prep.

Cold disks: conclusions

"Cold disks" are not yet understood

Previously unknown physical regime
(e.g., Saturn ring-like systems
of non-exited macroscopic grains
with gentle collisions)?

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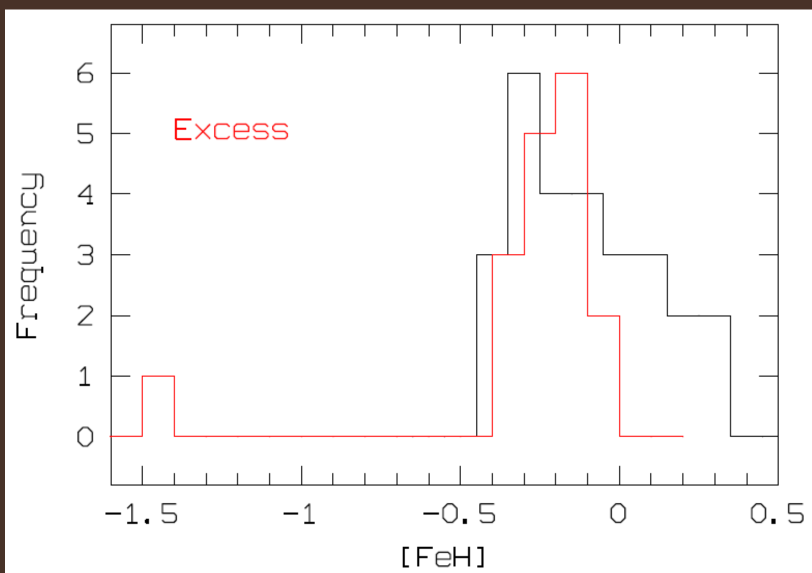
Results (31 Aug 10, 1/3 of the sample)

	F-type	G-type	K-type	Total
Observed	11	21	18	50
Non-excess	5	13	12	30
Excess (new)	6 (1)	7 (3)	4 (4)	17 (8)
-- resolved (new)	3 (2)	4 (3)	1 (1)	8 (6)
-- cold disks	1	3	4	8
-- w/ planets	1	3	2	6 (1 +1?)
“Peculiar”	0	1	2	3

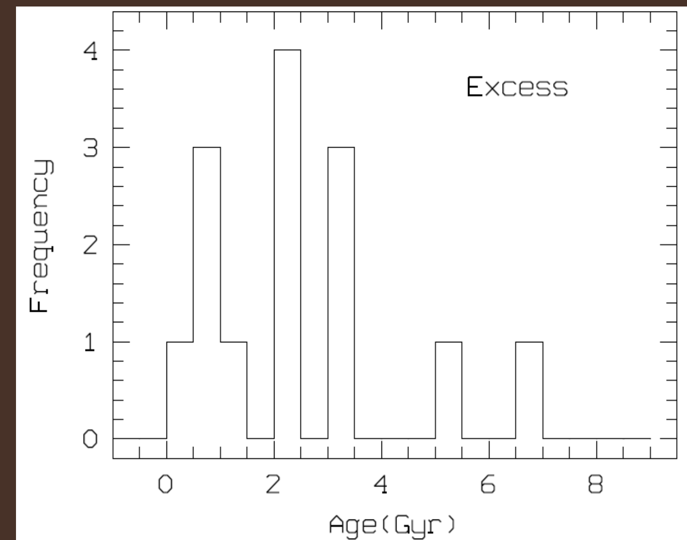
Fraction of photosphere detections: 100%, fraction of excesses: ~30%
Many new disks, incl. new resolved disks, especially around K stars

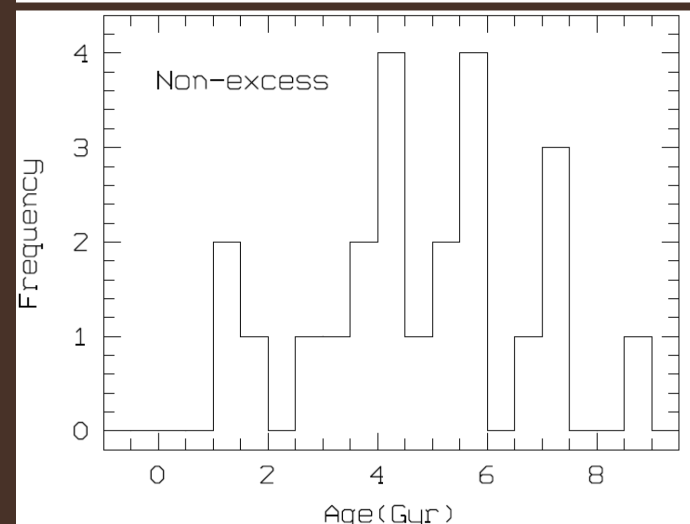
Trends?

No significant correlation with metallicity



Decay with age





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- Debris disks (DDs) are ubiquitous components of planetary systems that help to access planetesimal properties and find unknown planets
- Herschel can boost debris disk studies due to its spectral range, sensitivity, and resolution
- First results from Herschel (caution, preliminary!):
  - yielded a dozen of new well-resolved DDs
  - seems to have discovered a new class of DDs, “cold DDs”, possibly in a new physical regime
  - nearly doubled the DD frequency, suggesting that fraction of solar-type stars with DDs is ~30%