Debris disks – Lessons from Herschel

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Image credit: Acke et al. (2012)

Outline

- Debris disks with Herschel
- Debris disk – planet – star connection
- Debris disks and planetary system architecture
- Debris disk properties
- Serendipitous discoveries
- Conclusions

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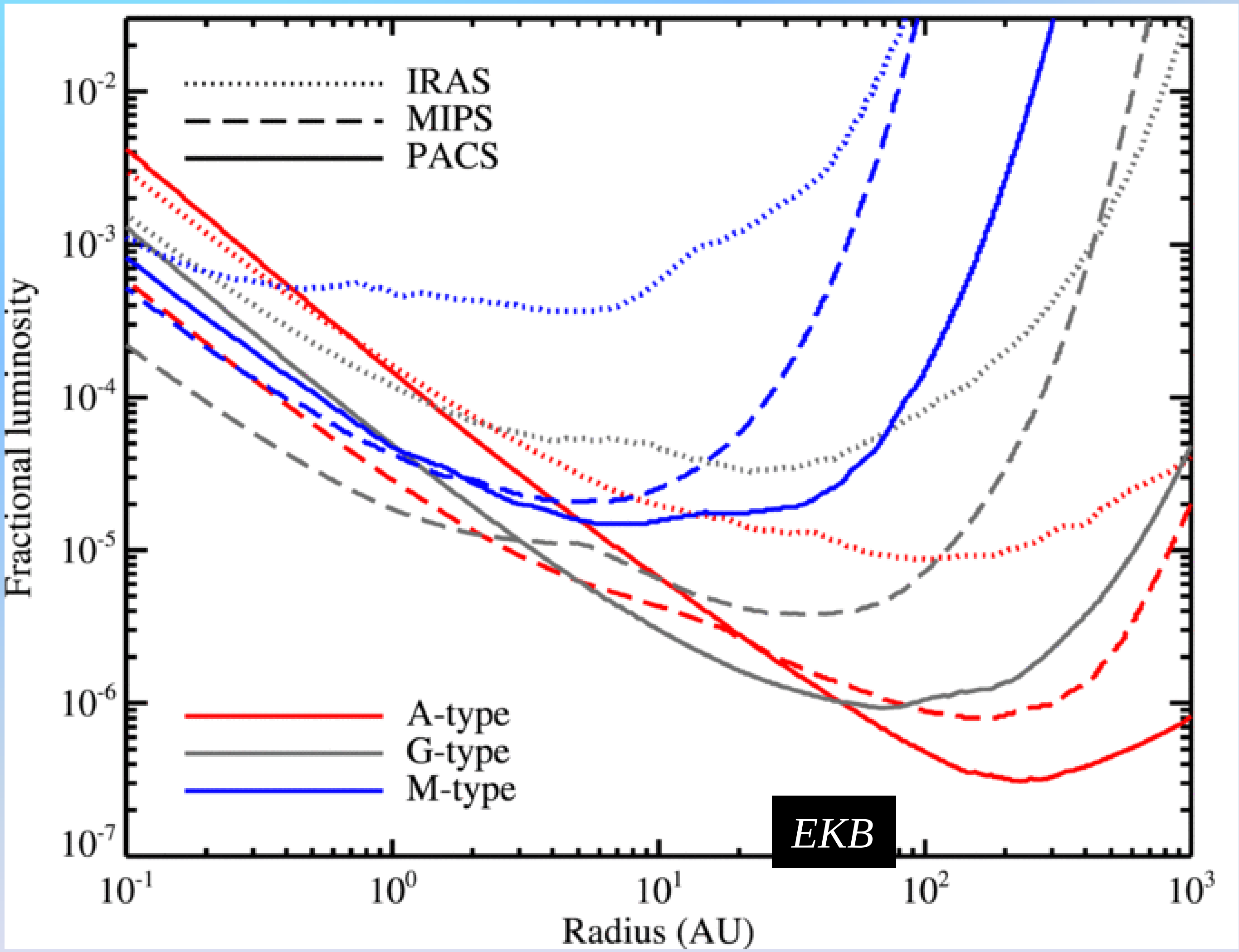
Herschel's debris disks programs

Debris disks targeted
by many programs,
a total of almost 1000 hrs
observing time:

GT (PI Oloffson),
OTKP DUNES (PI Eiroa),
OTKP DEBRIS (PI Matthews),
OTKP GASPS (PI Dent),
OT SKARPS (PI Bryden),
a number of small OTs

Mission: 2009-2013, Mirror: D = 3.5m
PACS instrument: λ = 60-160μm
SPIRE instrument: λ = 250-500μm
HIFI instrument: not used for debris disks

Herschel's sensitivity

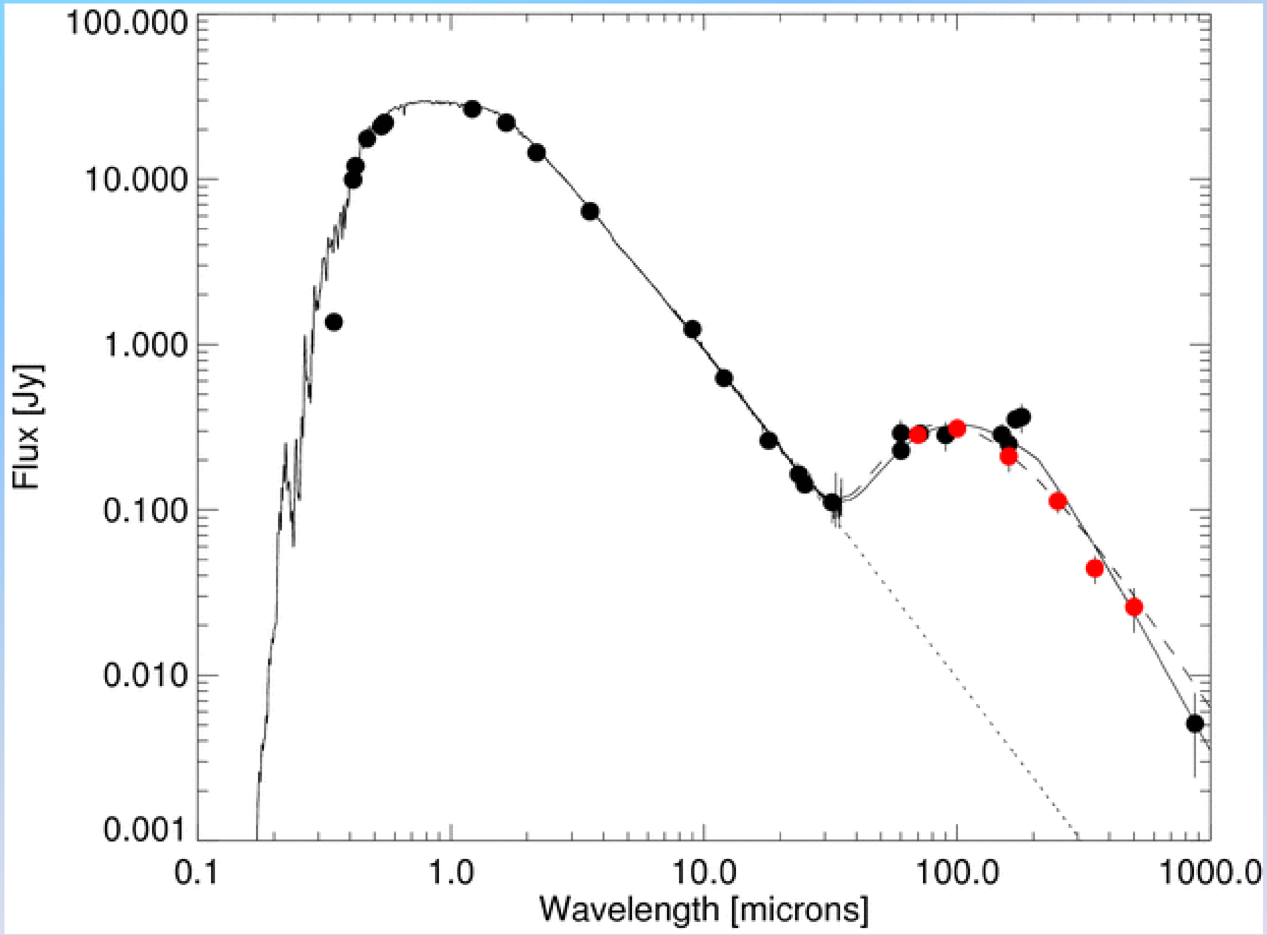


Matthews, Krivov, Wyatt, Bryden, Eiroa,
PPVI chapter (2014)

Herschel detected 100s new debris disks, including tenuous ones almost down to the EKB level

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

Herschel's wavelength coverage

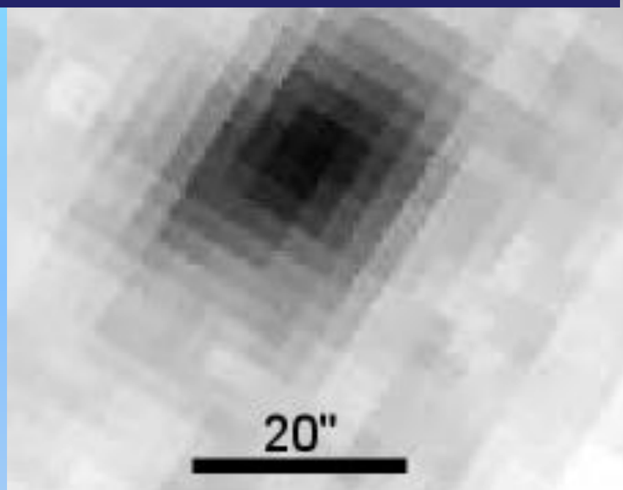


Marshall et al. 2010

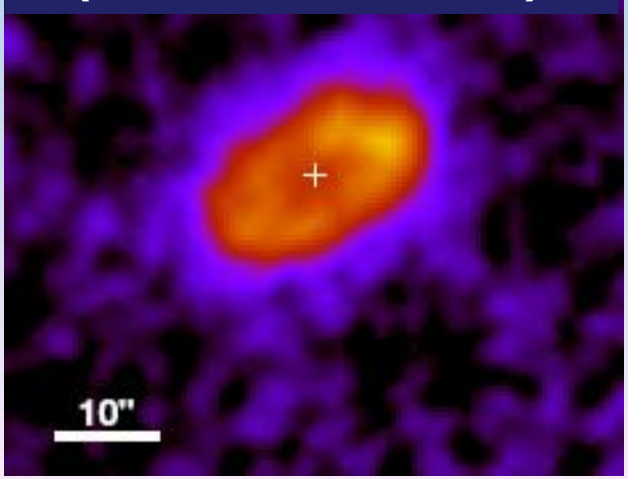
Herschel fills the 100-500 μm gap between previous far-IR and sub-mm data, leading to well-sampled SEDs of 100s of disks

Herschel's resolution

Spitzer/MIPS 70 (Krist et al. 2010)



Herschel/PACS 70 (Marshall et al. 2010)



Spitzer/MIPS
FWHM @ 70μm:
~15 arcsec

Herschel/PACS
FWHM @ 70μm:
~ 4 arcsec

Herschel spatially resolved ~50 debris disks, most for the first time, efficiently probing the disk structure

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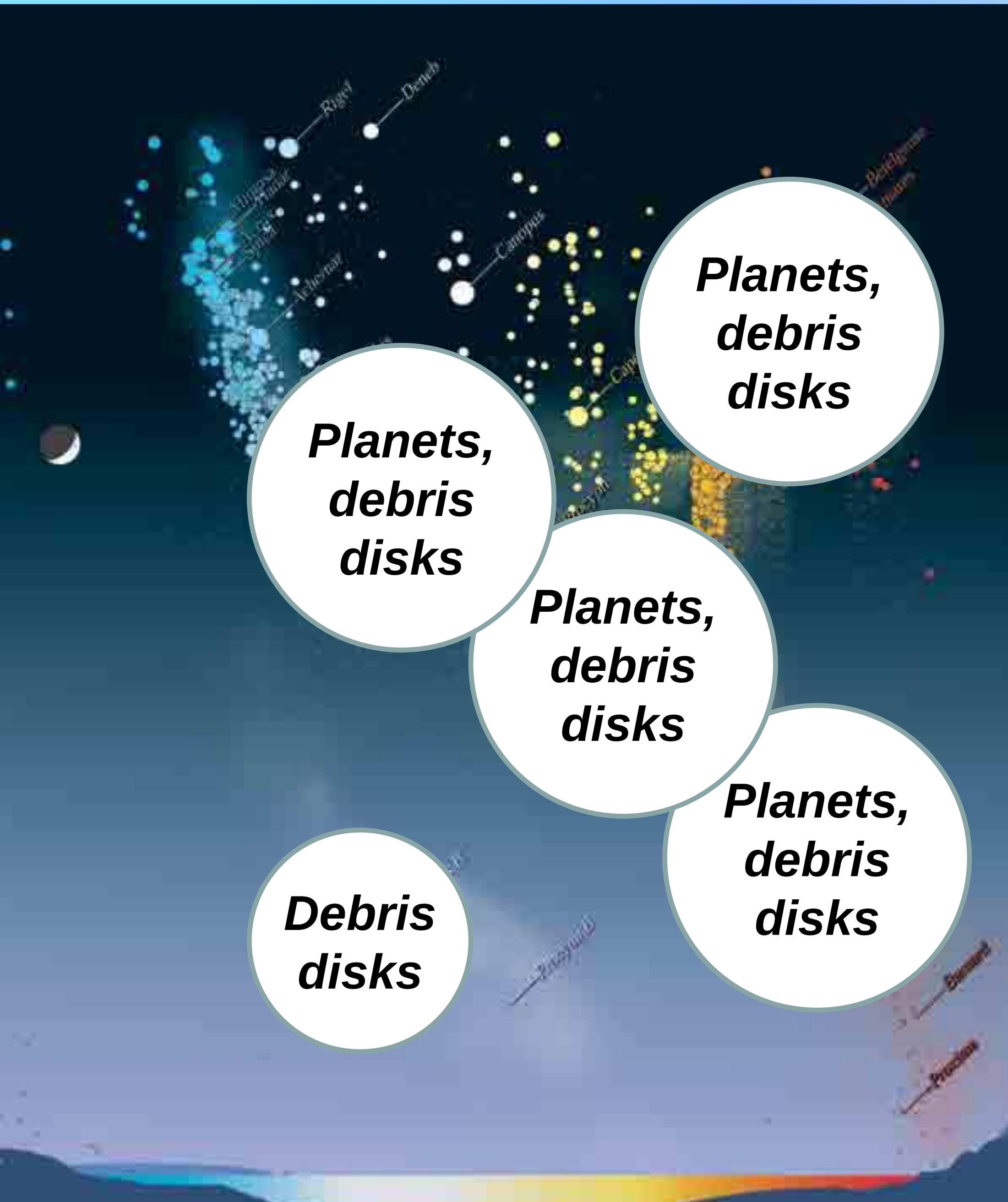
Debris disks at all stages of stellar evolution



Picture credit: Guy Ottewell / Universal Workshop

Herschel ‘s incidence rates around **main-sequence** stars:

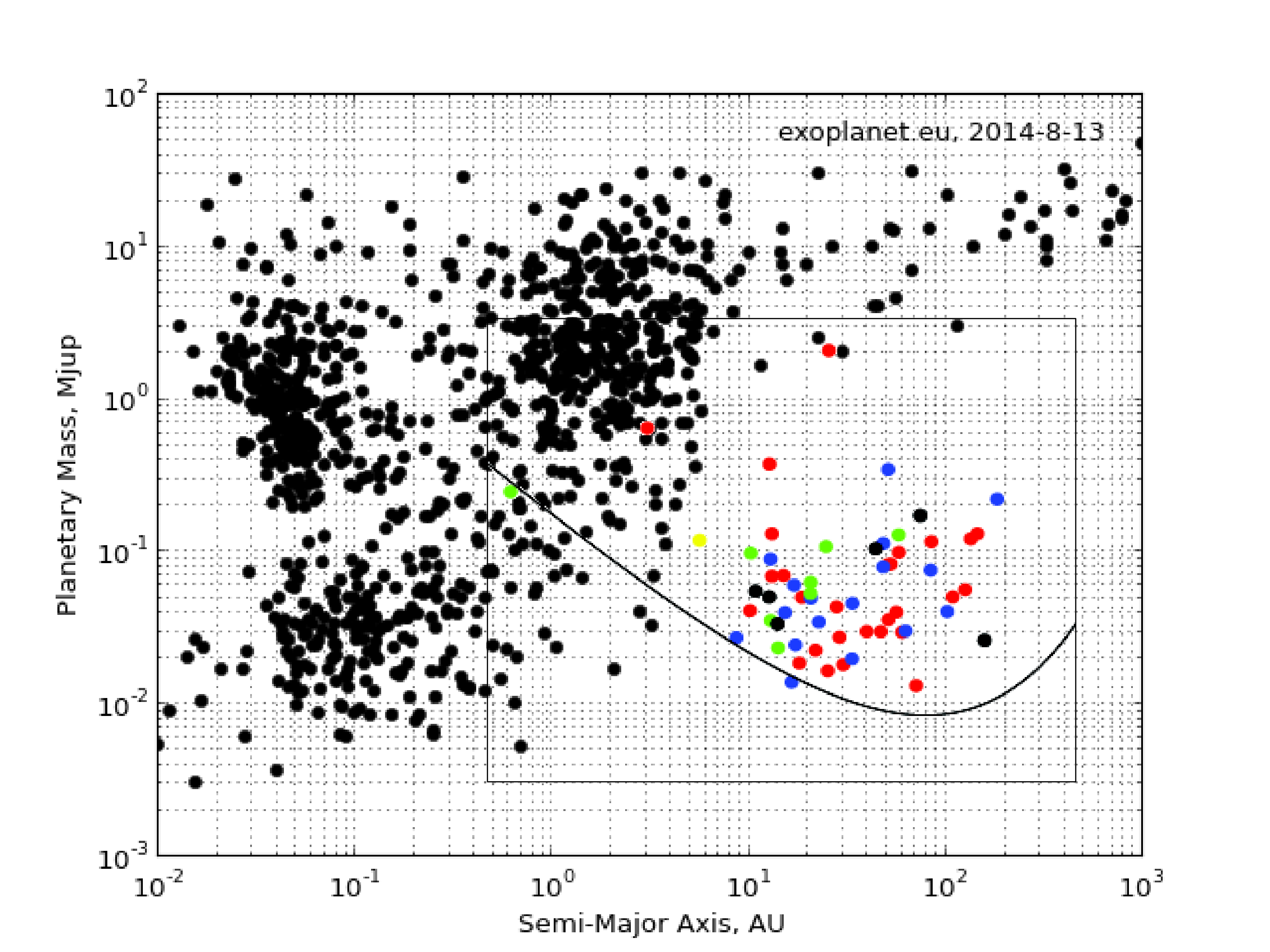
- ❑ 20±2% for FGKs *(Eiroa et al. 2013)*
- ❑ ~25% for A stars *(Thureau et al. in prep.);*
- ❑ remain disputable for Ms (e.g. *Lestrade et al. 2012, Heng & Malik 2013*)

Herschel discovered debris disks around **subgiants** at a rate of 11±2% (*Bonsor et al. 2013, 2014*)

Debris is also known to exist around 1-14% of **white dwarfs** (“polluted” and “dusty” WDs; e.g. *Kilic & Redfield 2007, Barber et al. 2012, Dufour et al. 2012*)

→ ***see also Xu talk***

Parameter space for planets and disks

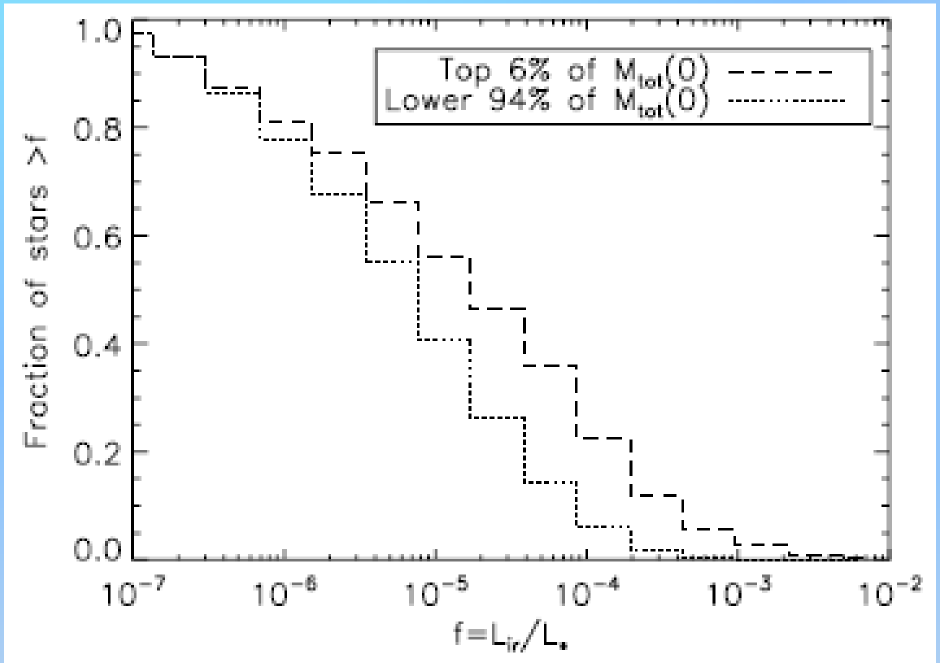


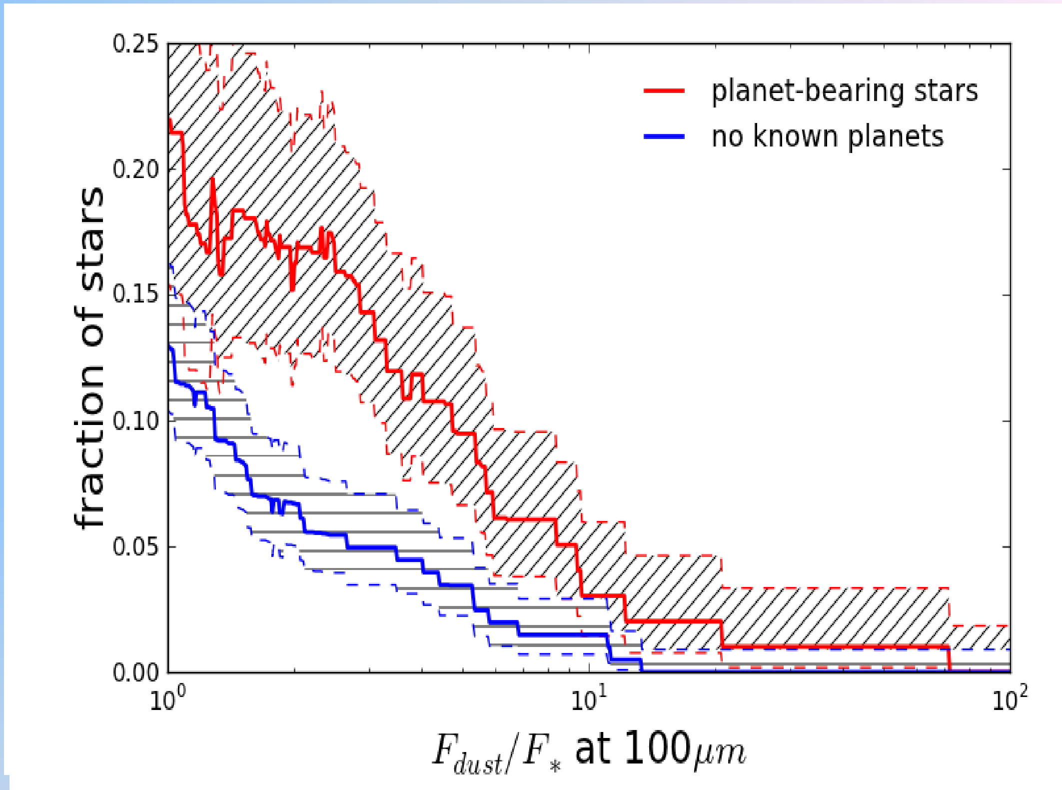
Samples differ, parameter regions do not overlap spatially

Thus only ~40 systems known to have **both** planets and disks

Yet correlations expected, as planets and disks form and evolve together

Planet–disk brightness correlation





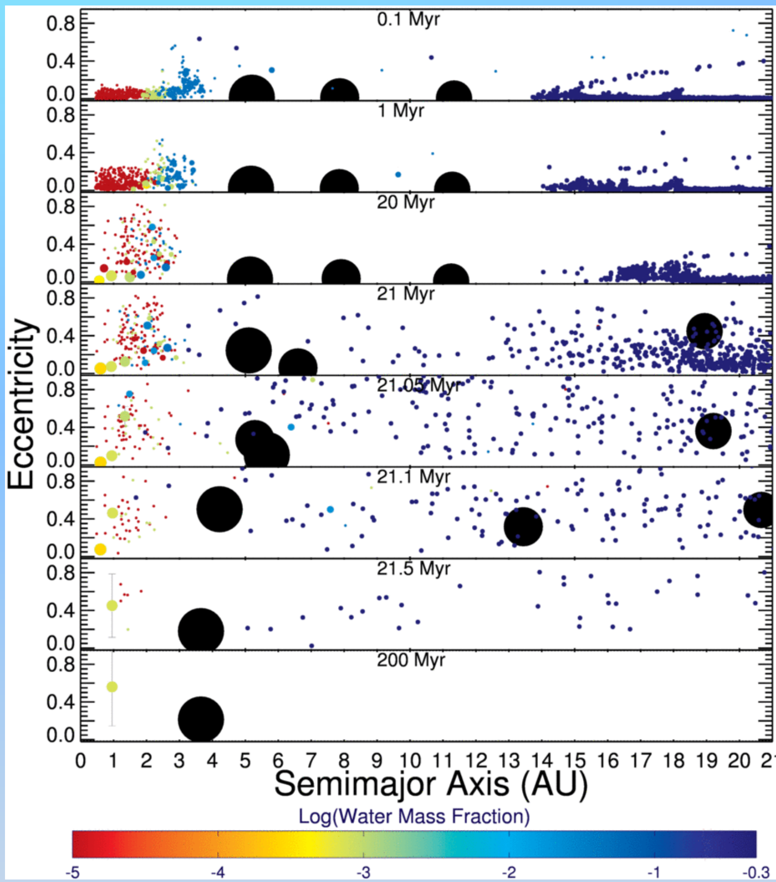
Both debris disks and planets form in the same PP disk. The amount of solids, Z, largely determines both planet and disk outcomes. Implies brighter disks around planet-bearing stars

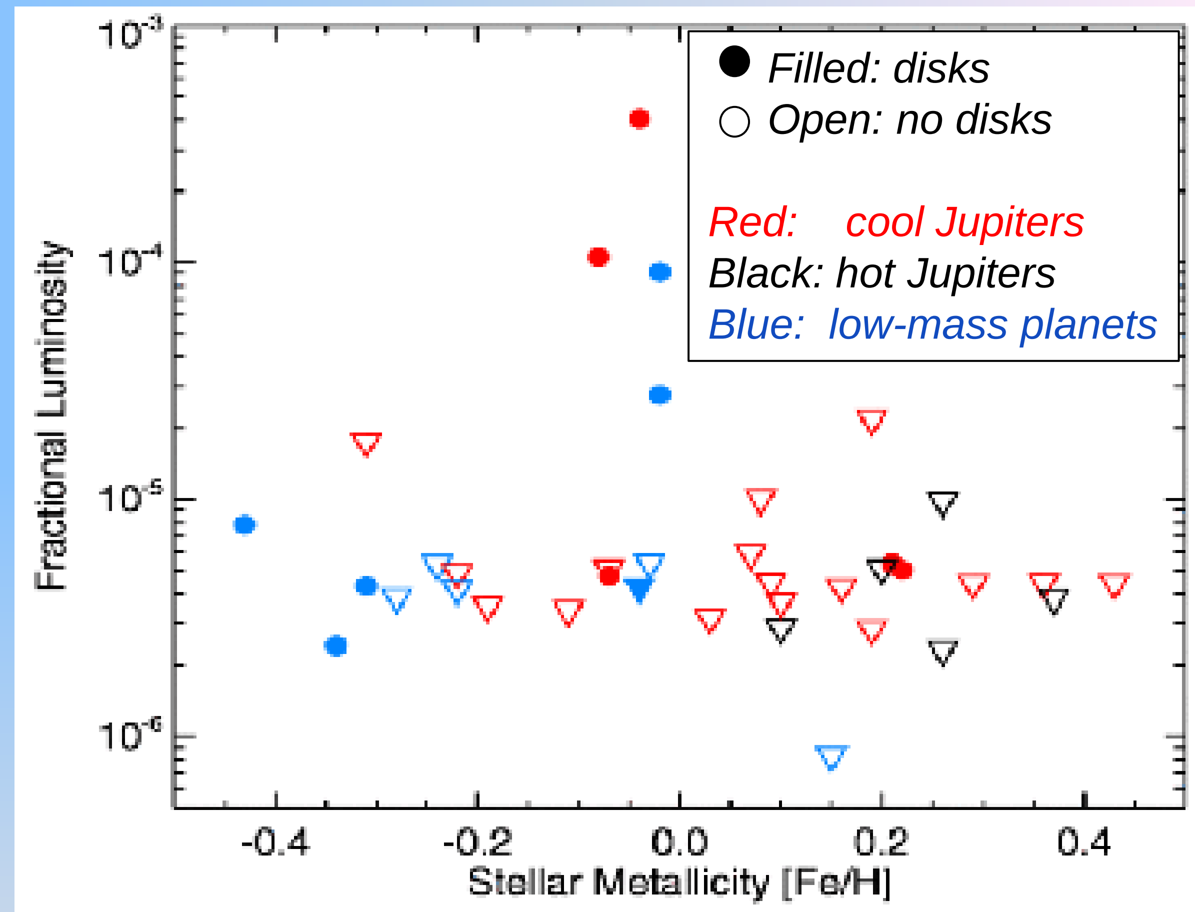
Wyatt et al. 2007

Indeed, debris disks of planet-host stars are brighter

Bryden et al. 2014

Low metallicity–low-mass-planet–disk correlation





Disks, however, can be disrupted by planets, if massive. This predicts co-existence of disks with low-mass planets

Raymond et al. 2011, 2012

There is a correlation between the presence of debris disks, lower planet masses, and lower stellar metallicities

Maldonado et al. 2012, Wyatt et al. 2012, Marshall et al. 2014

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What creates inner gaps and are they empty?

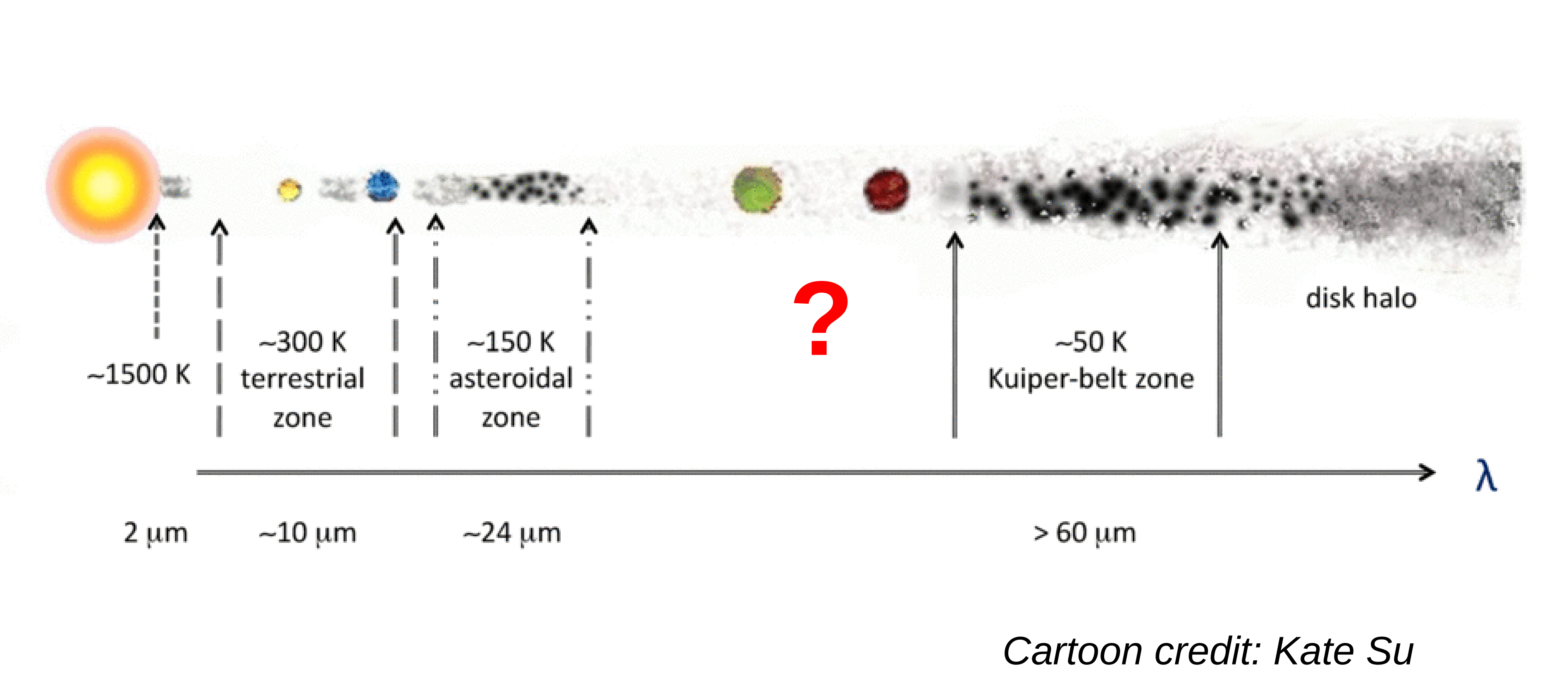
Background cartoon: Kate Su

All debris disks have EKB-sized cavities.

Were planetesimals in the gaps

- scattered by planets residing there *(Quillen 2007)?*
- collisionally depleted *(Wyatt et al. 2012)?*
- unable to form *(Rice et al. 2006)?*

Multicomponent debris disks

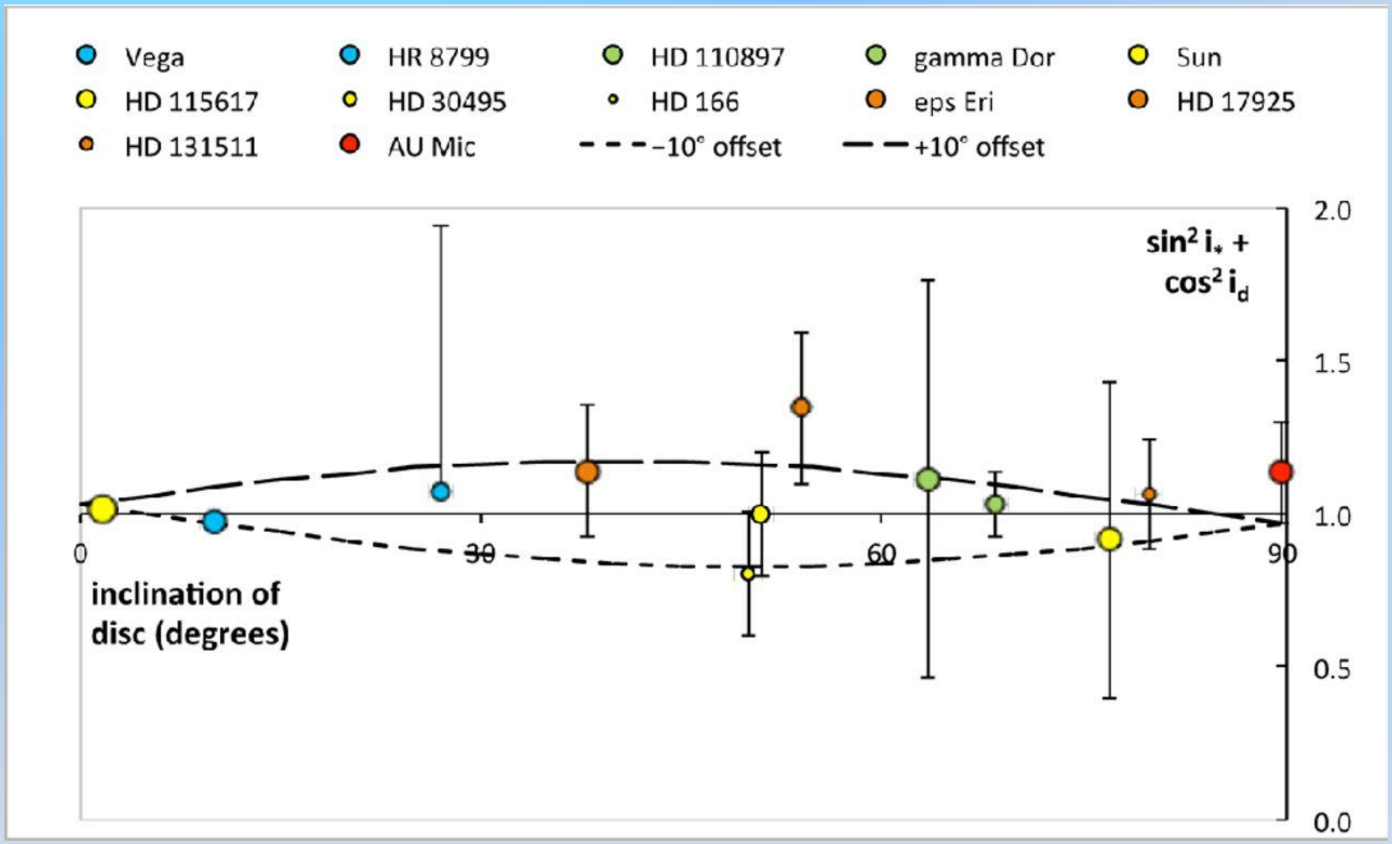


About 2/3 of the debris disks have more than one component
(Morales et al. 2011, Ballering et al. 2013, Chen at al. 2014, Pawellek et al. 2014)

Suggests gaps to be populated by Jupiter- or lower-mass planets, some of which may be detected by GPI and SPHERE

Hot dust is a separate story → ***see Ertel talk***

Star-disk alignment



Plot of $\sin^2 i_{star} + \cos^2 i_{disk}$ against disk inclination, where y-values ≠ 1 indicate that the disk and star are misaligned.

The disks are found to be well aligned with stellar equators (tilt <10 deg)

In a few cases where planets have been imaged, the disks are also aligned with planetary orbits

Greaves et al. 2014

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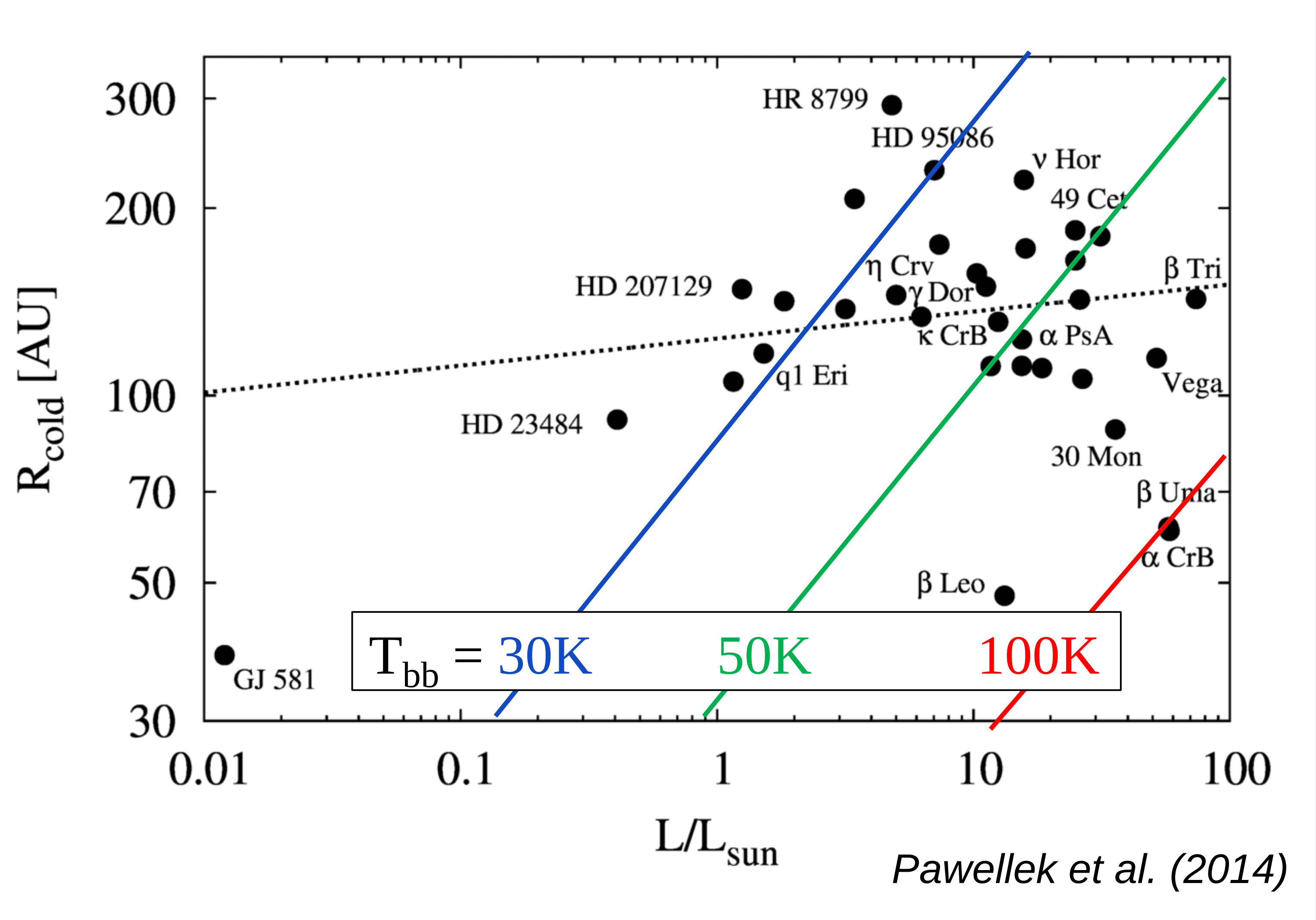
Disk radii: probing planetesimal location

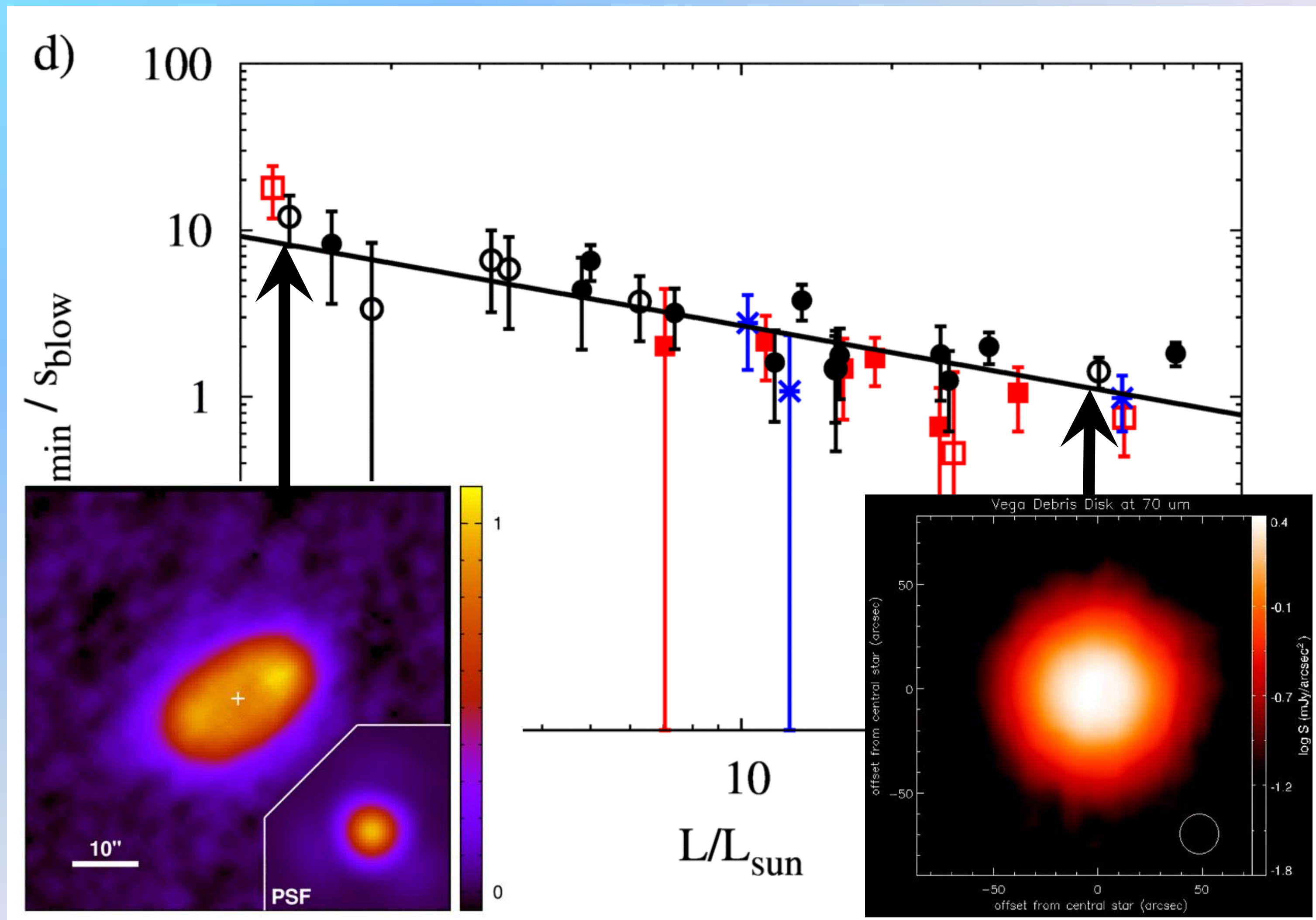


Large scatter, no significant trend

Disk dimensions not set by ice lines or other T-dependent processes

→ ***see Pawellek poster***

Dust grain sizes: probing disk physics



Grain size in blowout units decreases with stellar luminosity
Spatial appearance of disks also changes with luminosity
→ ***see Löhne talk, Pawellek poster***

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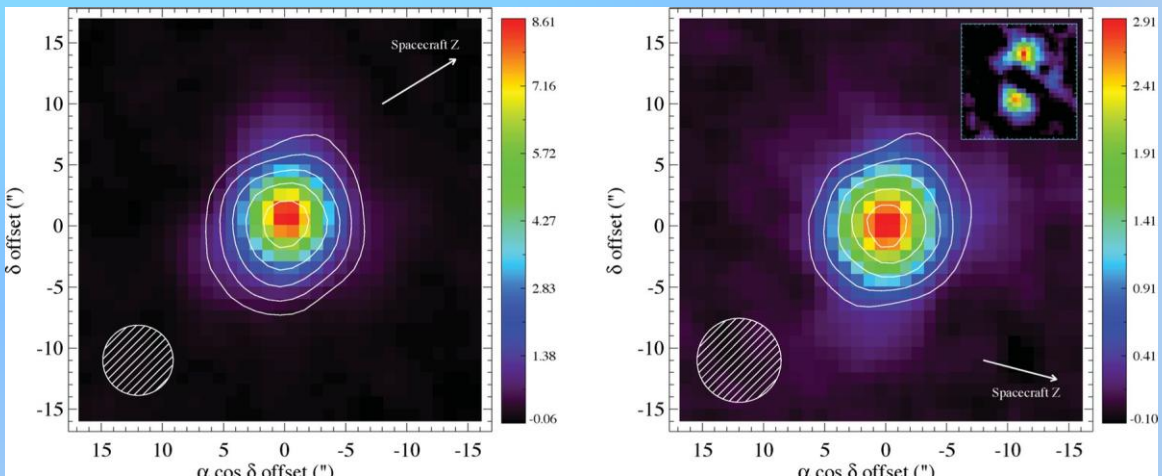
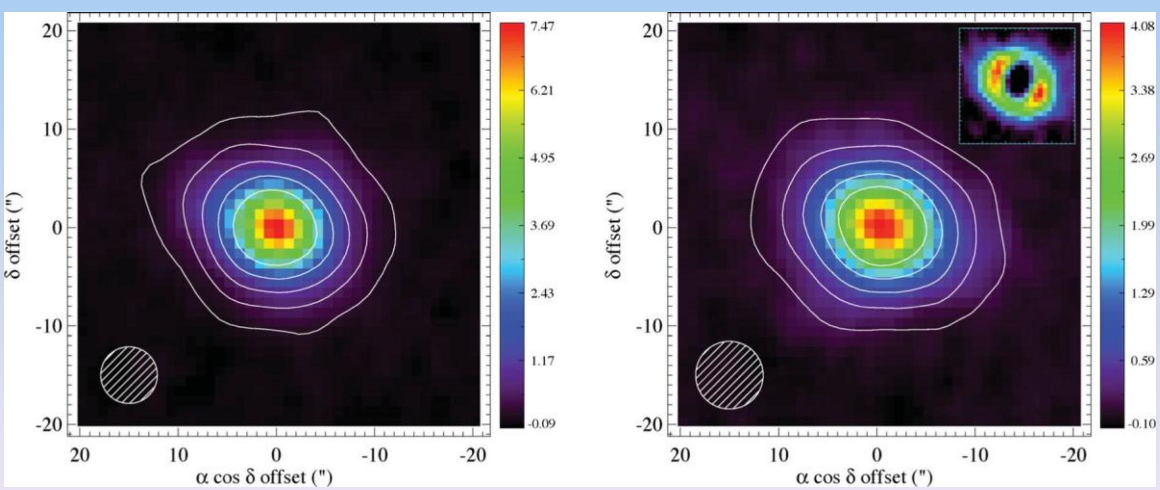
Circumbinary debris disks – coplanar and… polar

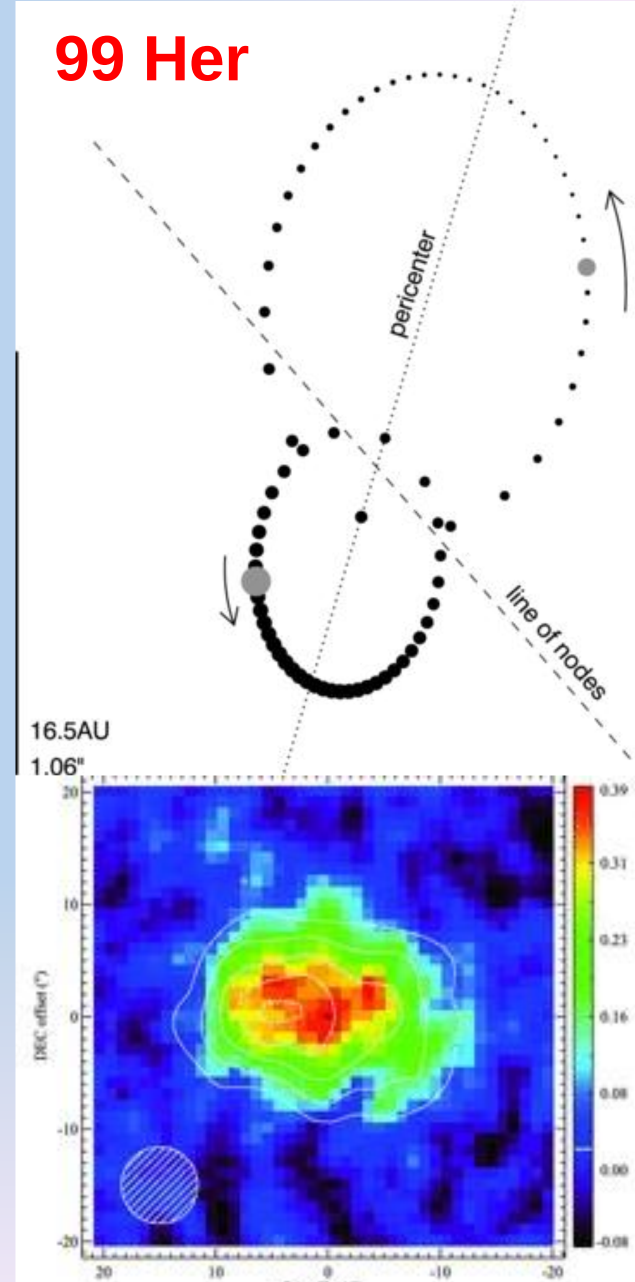
α CrB



β Tri

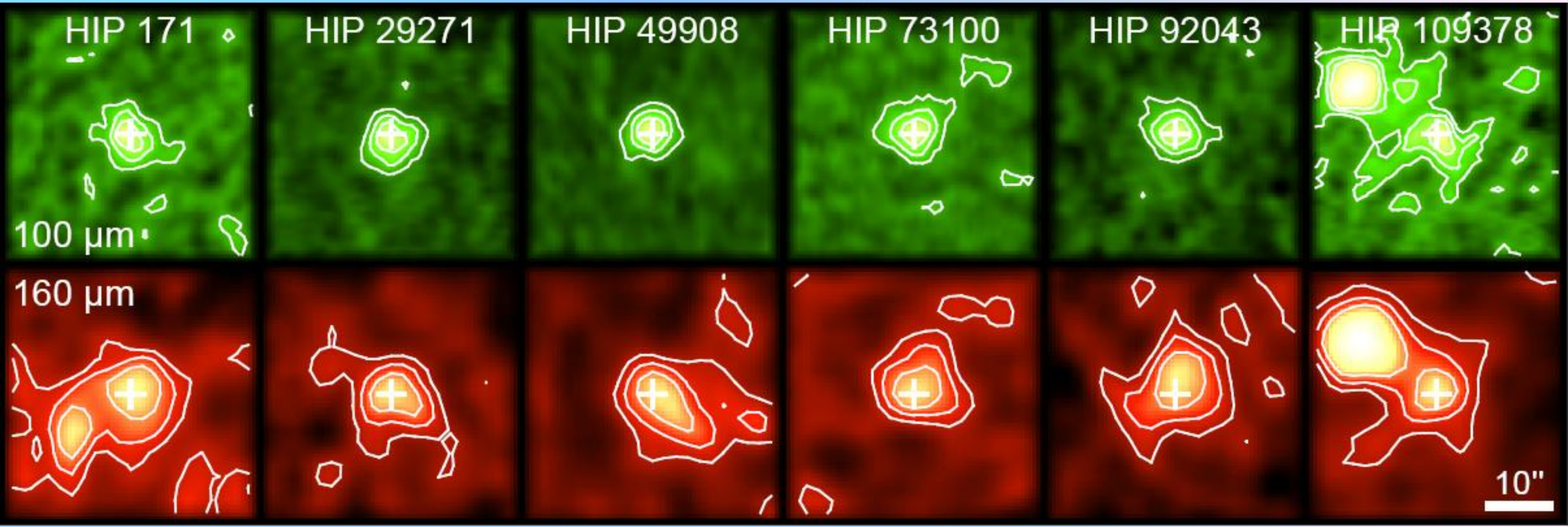


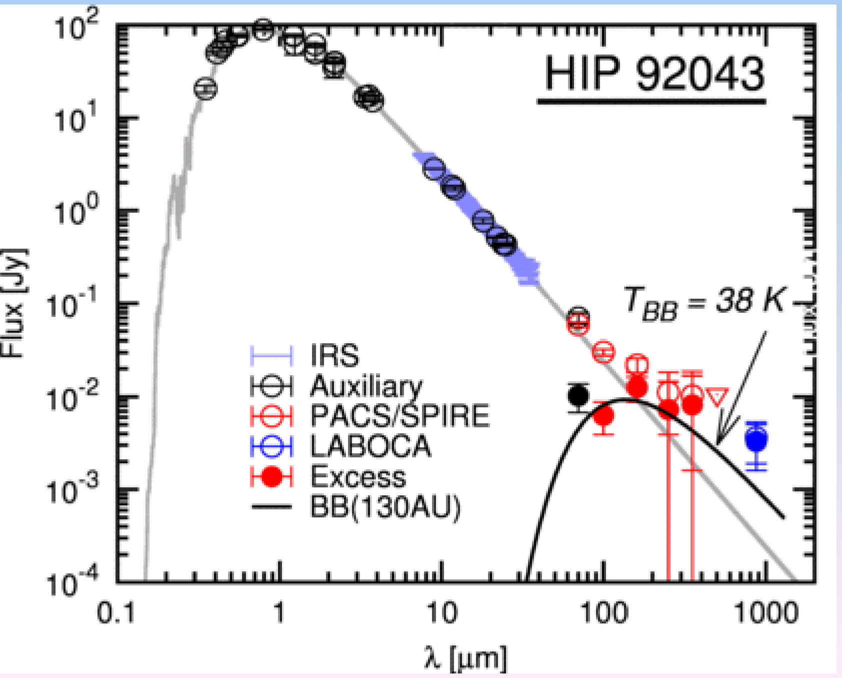
Kennedy et al. (2012b)



Kennedy et al. (2012a)

Herschel's "cold debris disk" candidates





Eiroa et al. (2011), Krivov et al. (2013)

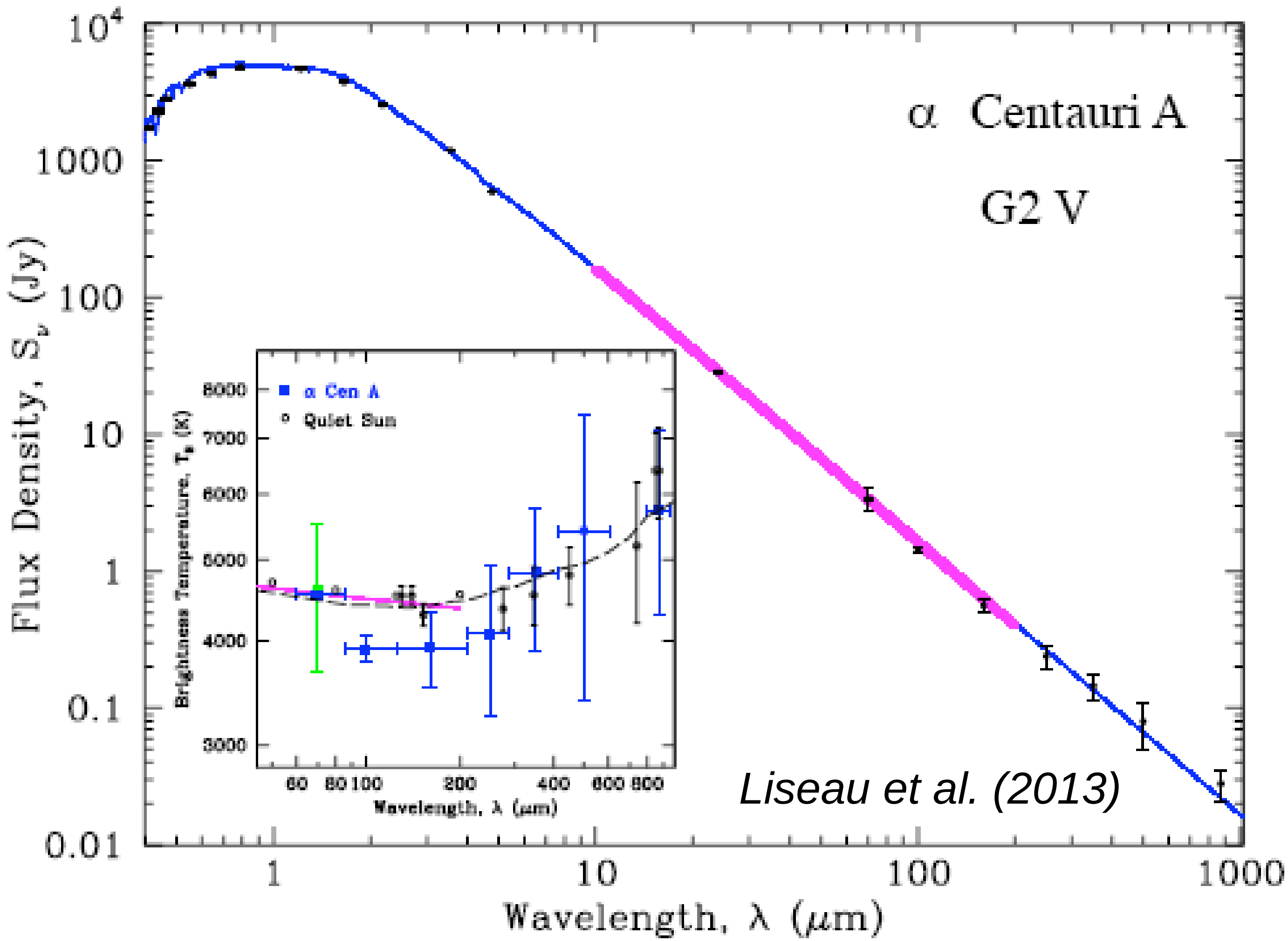
Probing stellar atmospheres

LETTER TO THE EDITOR

α Centauri A in the far infrared*

First measurement of the temperature minimum of a star other than the Sun

R. Liseau[1], B. Montesinos[2], G. Olofsson[3], G. Bryden[4], J. P. Marshall[5], D. Ardila[6,7], A. Bayo Aran[8,9], W. C. Danchi[10], C. del Burgo[11], C. Eiroa[5], S. Ertel[12], M. C. W. Fridlund[13], A. V. Krivov[14], G. L. Pilbratt[13], A. Roberge[15], P. Thébault[16], J. Wiegert[1], and G. J. White[17,18]



Liseau et al. (2013)

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Conclusions

- Debris disks are as common as planets at all stages of stellar evolution, from main sequence to white dwarfs
- Overlap with exoplanet searches is increasing, uncovering correlations between disks and planets
- Debris disks help understand architecture of planetary systems
- Debris disk constraints on planetesimal and planet formation processes become more tangible