DUSTY DISKS WITH HERSCHEL

From Protoplanetary to Debris Systems

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cnrs
dépasser les frontières

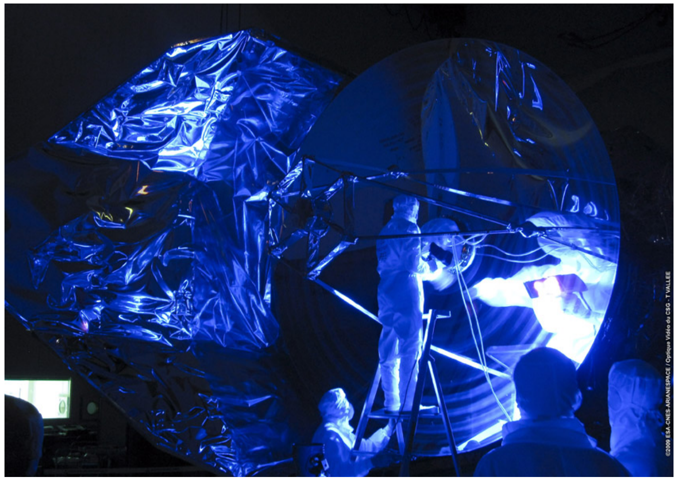
Herschel Space Telescope

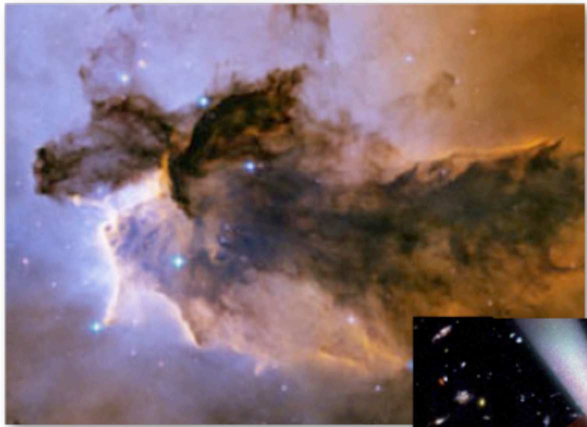
- ESA + NASA far-IR observatory (60 - 600 μm) launched in May 2009

- Largest mirror ever built for an astronomy space telescope: 3.5 meters diameter

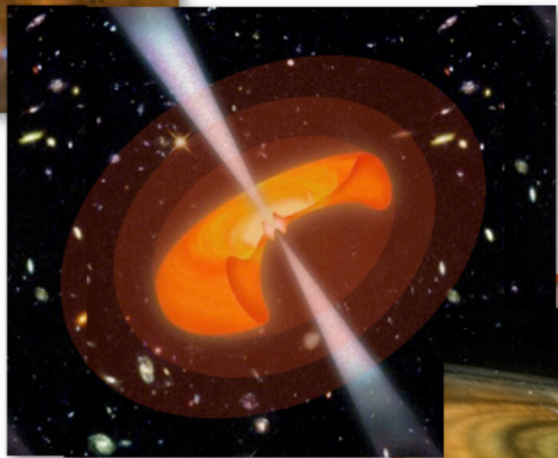
- Three instruments onboard: PACS, SPIRE, HIFI

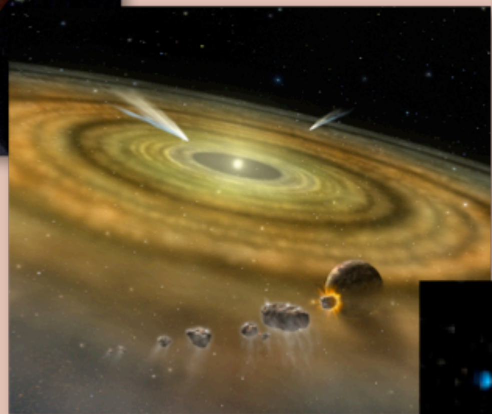
- This talk:
    - PACS Spectroscopy and 70, 100, 160 μm imaging modes
    - SPIRE : 250, 350, 500 μm imaging mode

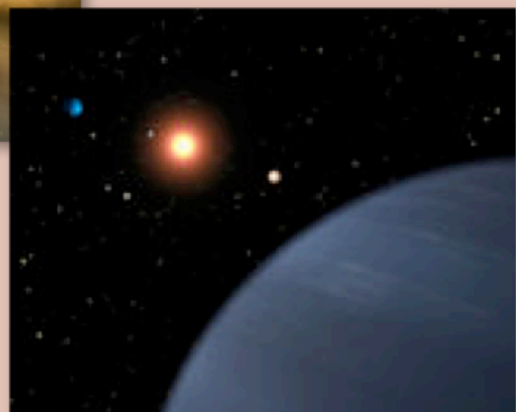




From Clouds,
to Envelopes,
to Disks
to Planets





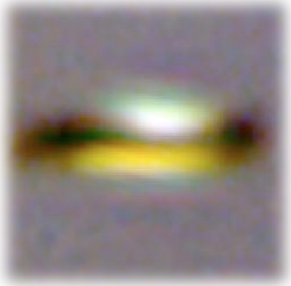


See also talks by:

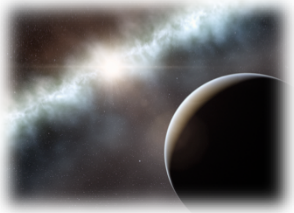
- E. van Dishoeck
- K. Su
- J. Marshall

Outline of this talk

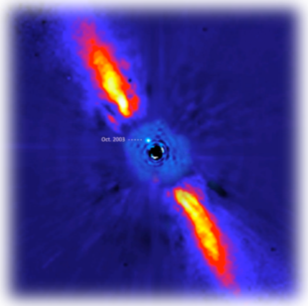
- The protoplanetary period
  TTauri (~ 1 M_{sun}), Herbig Ae/Be (~ 3-10 M_{sun}) stars, < 10 Myrs
  PACS/spectrocopy



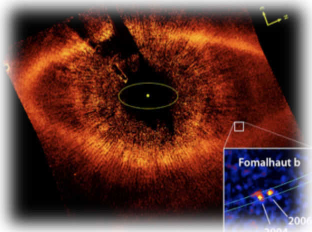
- Disk clearing phase
  PACS/spectroscopy, SPIRE photometry



- Young debris disks in the β Pic moving group (12-20Myrs)
  PACS/spectroscopy & photometry



- Debris disks imaging (up to Gyrs)
  PACS imaging mode



Herschel Key Programs on Disks

- **Protoplanetary disks :**
  - **GASPS** (PI: W. Dent) : 400h, PACS survey (250 disks)
  - **DIGIT** (PI: N. Evans) : 250h, PACS full range scan, mineralogy, includes embedded objects
  - **WISH** (PI: E. van Dishoeck) : water in star forming regions, includes a dozen sources with disks

- **Debris disks:**
  - **DUNES** (PI: C. Eiroa) : 140h, sensitivity limited survey for debris disks (130 FGK nearby stars)
  - **DEBRIS** (PI: B. Matthews) : 140h, flux limited survey for debris disks (350 A to M stars)
  - **GTO** (PI: G. Olofsson) : 6 debris disks

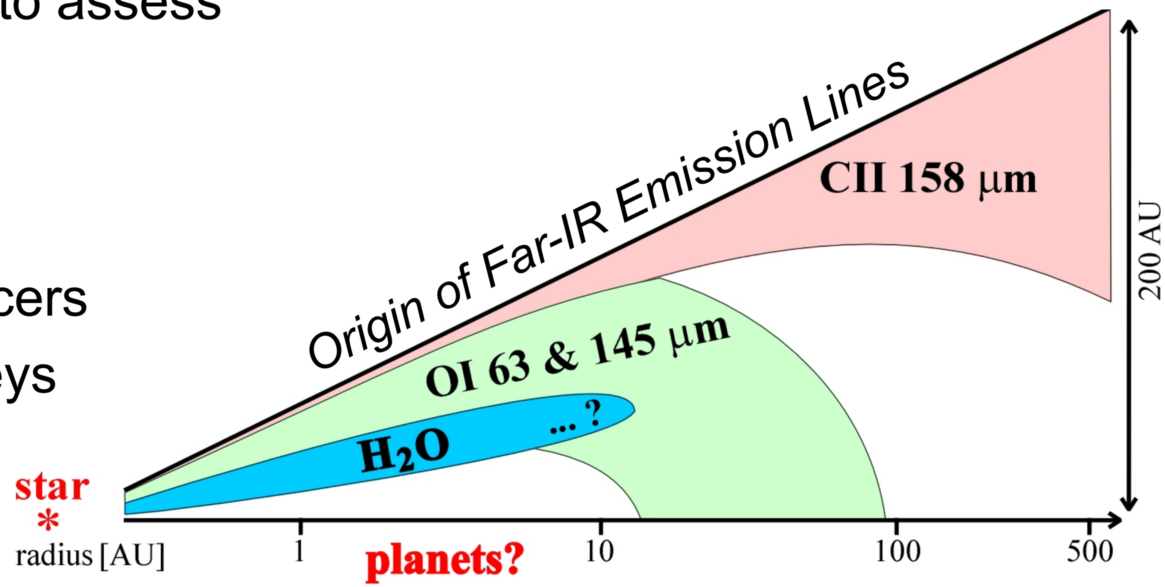
THE PROTOPLANETARY PERIOD

Gas in protoplanetary disks

- Gas evolution :
  - Time scale for gas dispersal and gas-giants formation ?
  - Relative evolution of gas and dust (dynamics of solids, chemistry) ?

- Uncertain gas mass estimates:
  - Gas: ~ 99% of initial mass in disks
  - but notoriously difficult to assess

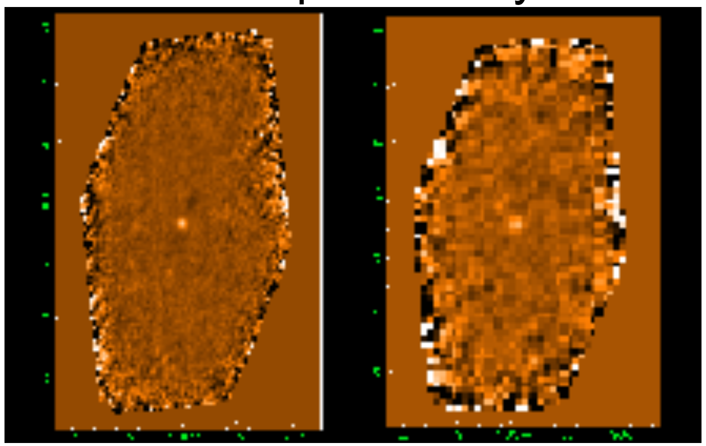
- Herschel:
  - New gas diagnostics: atomic & molecular tracers
  - Sensitivity allows surveys => statistics



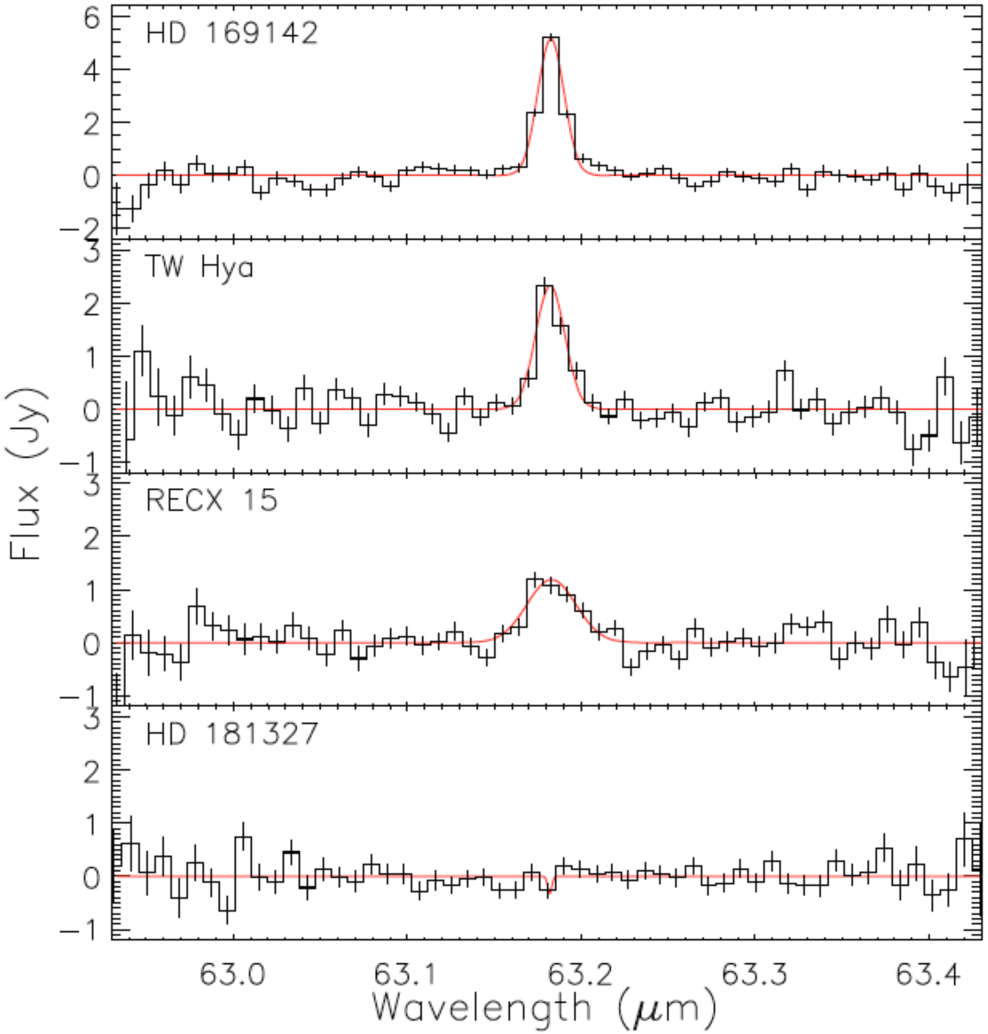
Atomic Oxygen [OI] 63µm: first results

- 4 example sources :
  - HD169142 (A5, 6Myr)
  - TW Hya (K7e, 10Myr)
  - RECX15 (M2e, 9Myr)
  - HD181327 (F5, 12Myr, debris disk)

PACS photometry

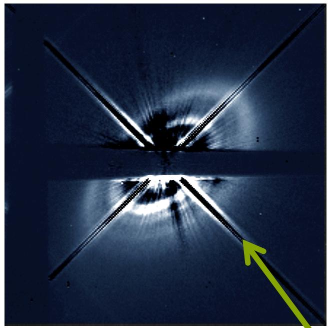


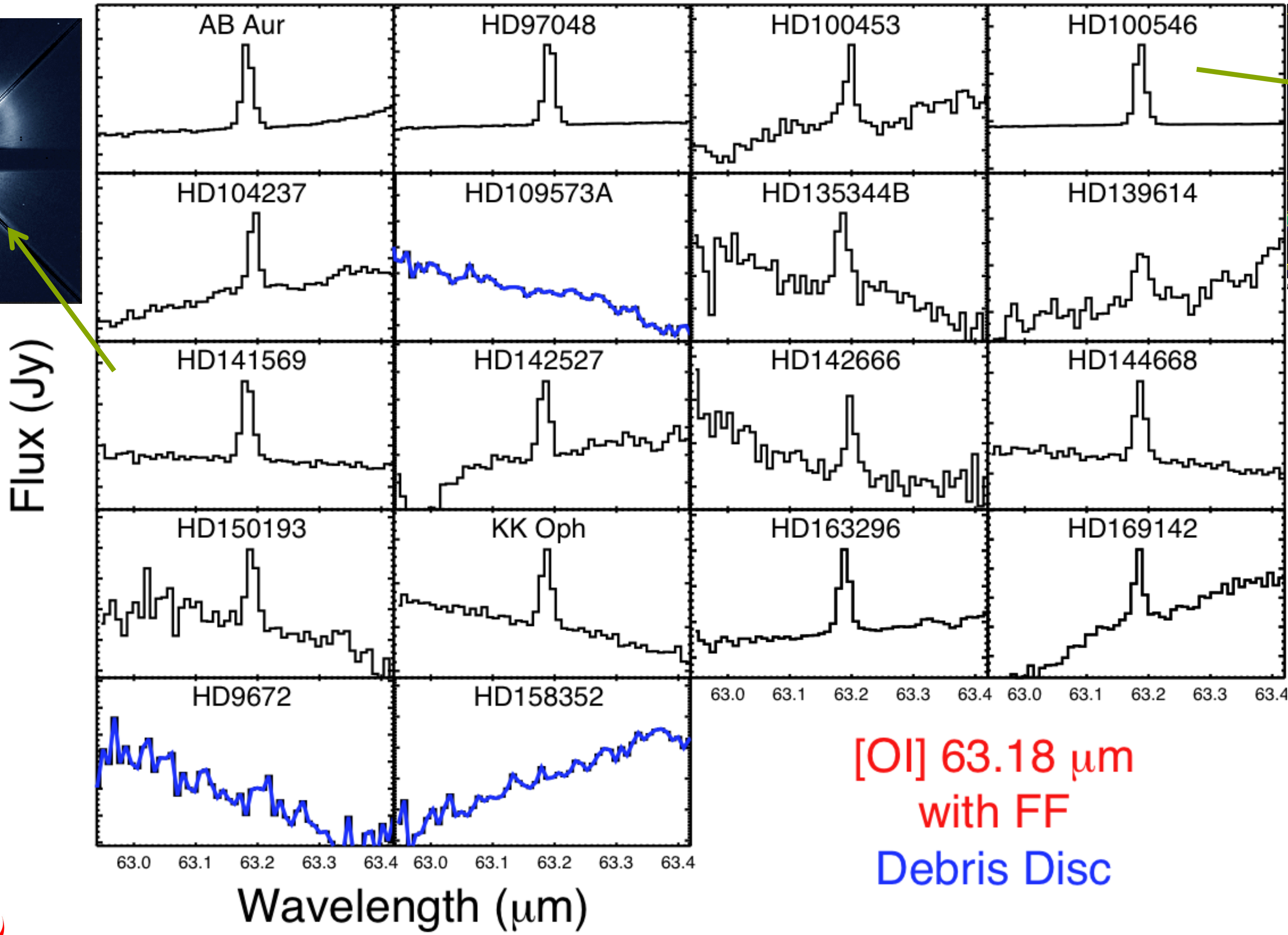
PACS spectroscopy

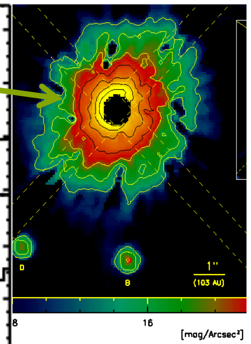


Mathews et al. 2010

[OI] 63µm : Herbig Ae/Be & Young Debris Disks

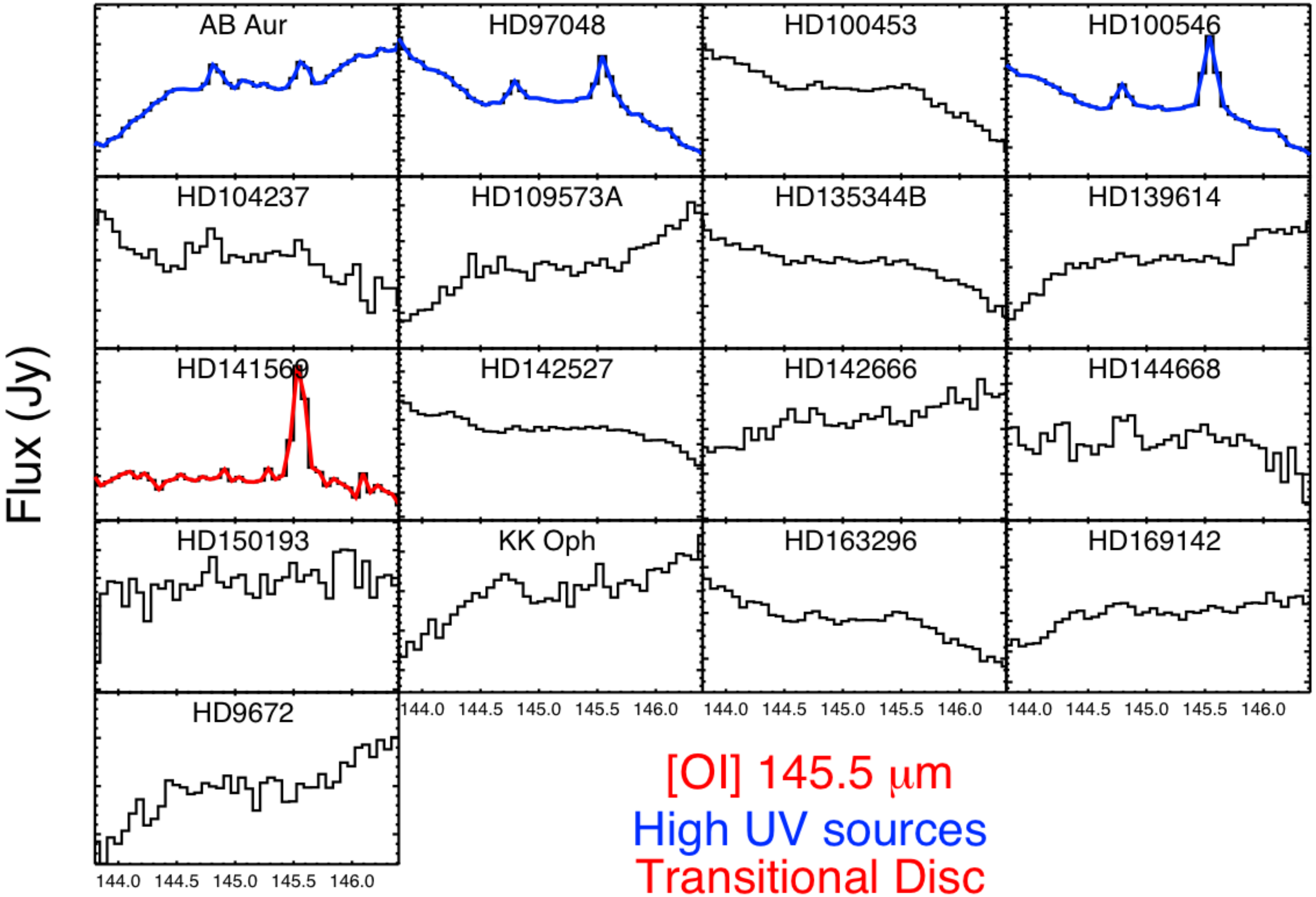






Meeus et al. 2011, in prep.

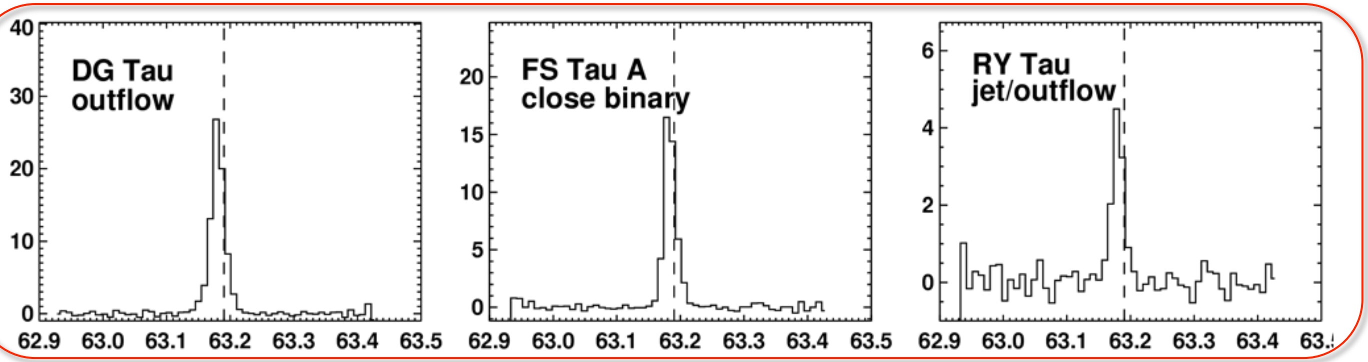
[OI] 145μm & CO J=18-17 : Herbig Ae/Be



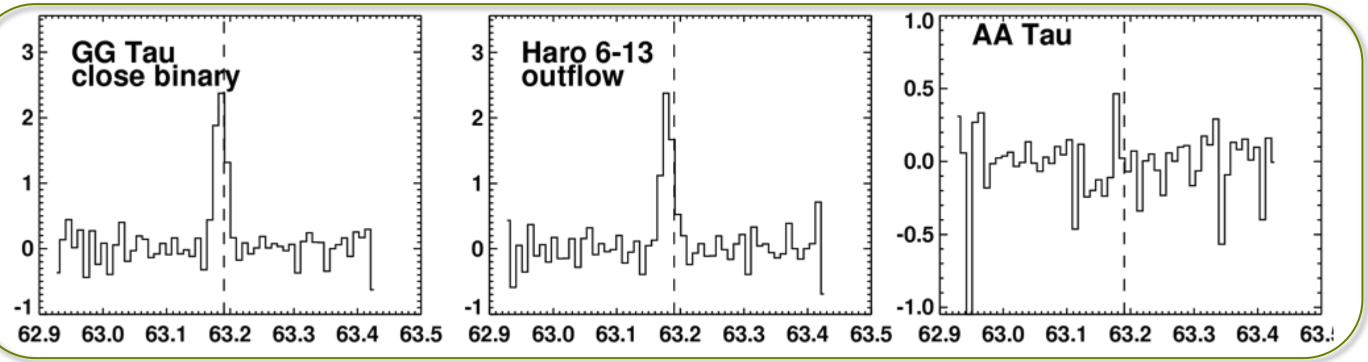
Meeus et al. 2011, in prep.

[OI] 63µm in TTauri stars: Disk and/or Outflows?

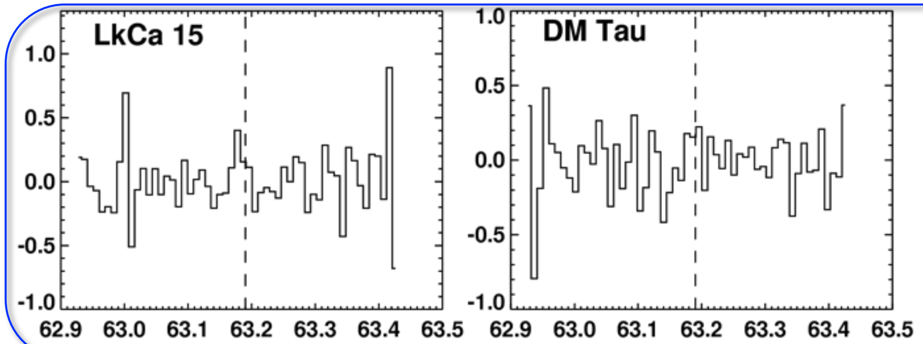
Known Outflow Sources



No or low-outflows



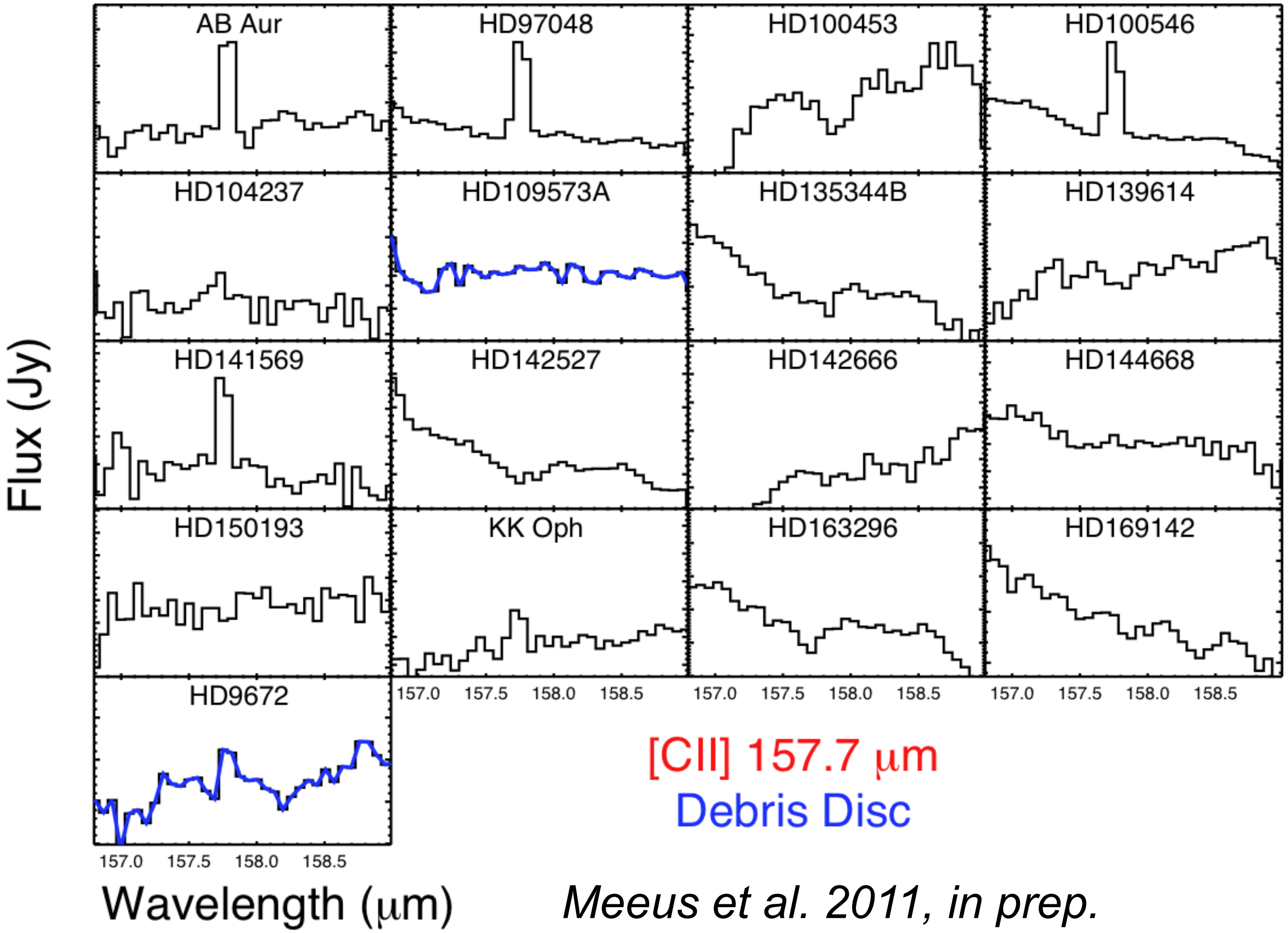
Transition Disks



Howard et al. 2011, in prep.
Podio et al. 2011, in prep.

[CII], Herbig Ae/Be

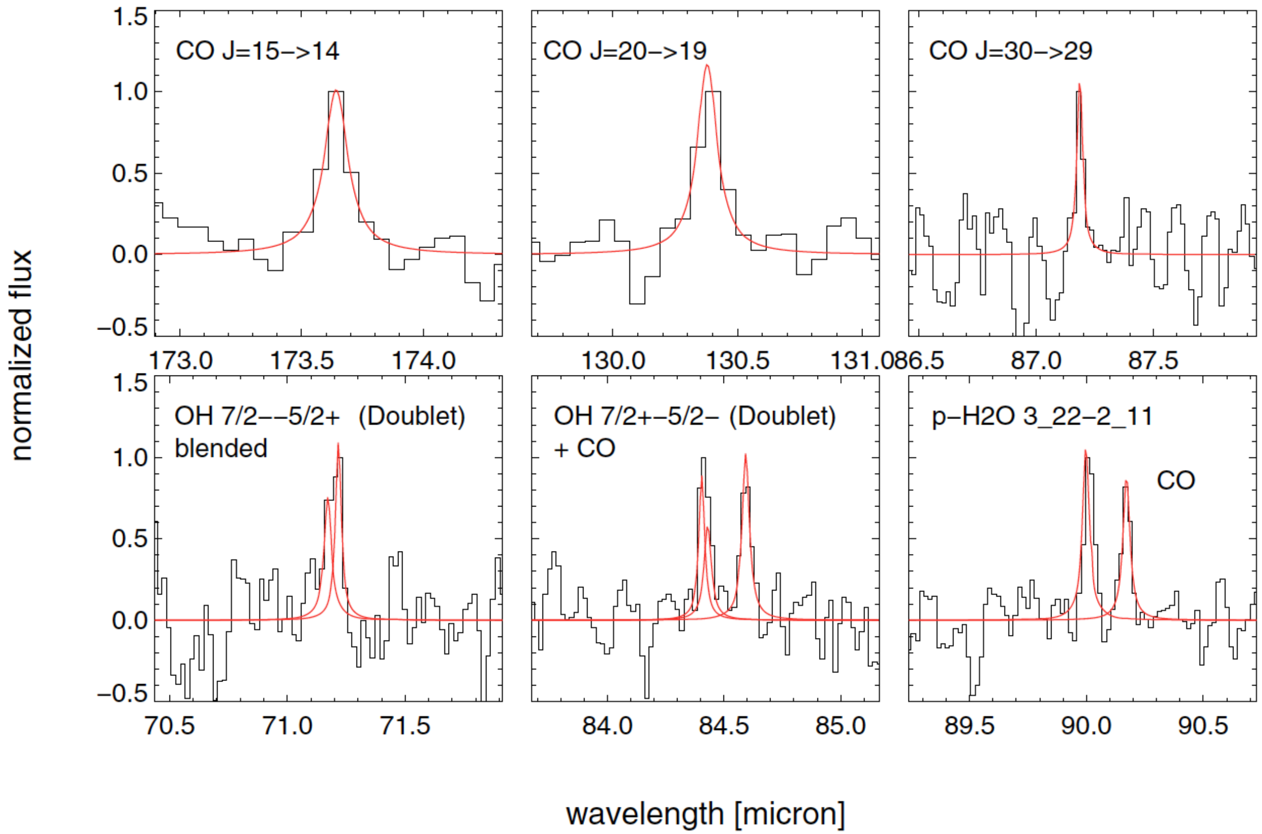
- Caution: possible background contamination
- TTauris: C+ mostly found toward outflow objects

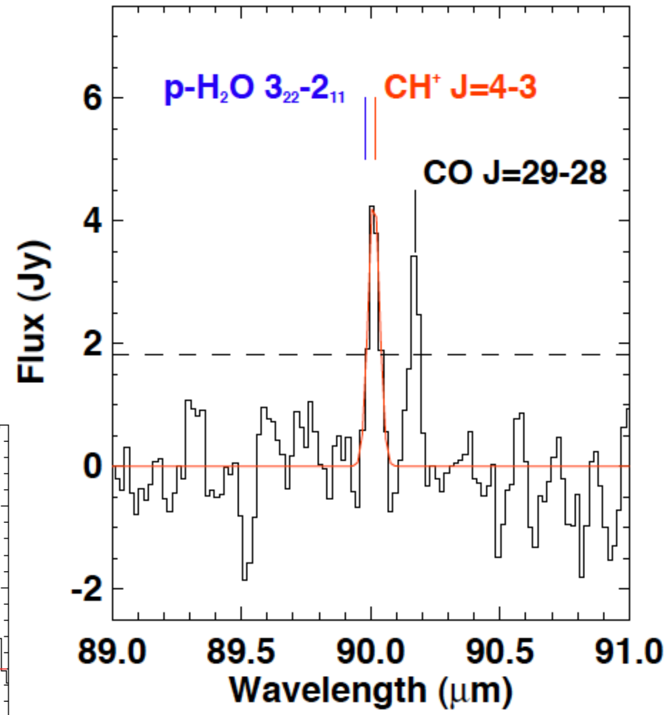


Meeus et al. 2011, in prep.
Howard et al. 2011, in prep.
Podio et al. 2011, in prep.

CO, OH, H_2O, …

- HD100546 :



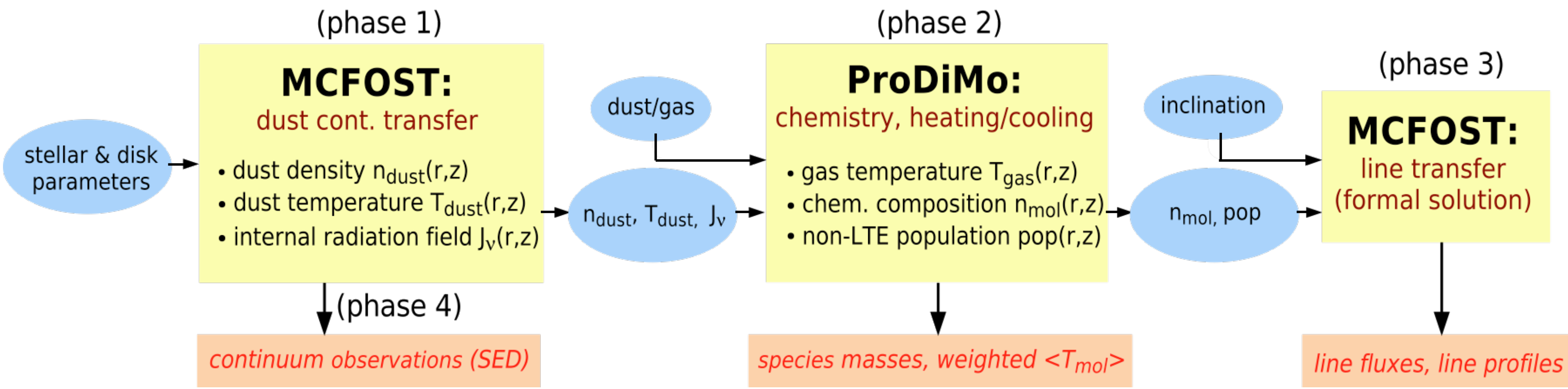


Strum et al. 2010, Thi et al. 2011

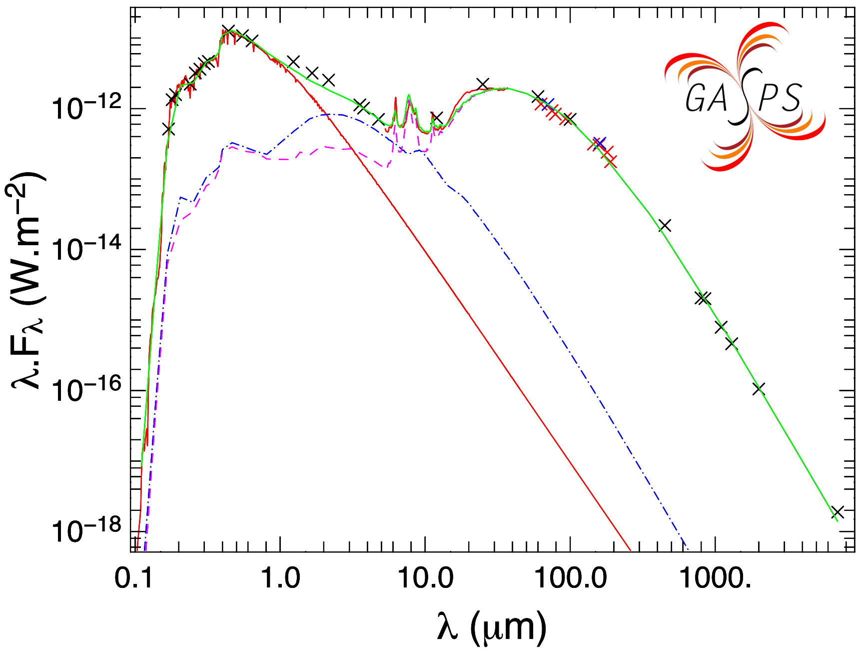
Modeling

- **Interpretation of line observations is complex !**
  → need for detailed modeling

- **Interfaced modeling tools:**
  - *MCFOST*: 3D continuum & line Radiative Transfer (Pinte et al 2006, 2009)
  - *ProDiMo*: thermal balance & chemistry (Woitke et 2009, Kamp et al 2010)



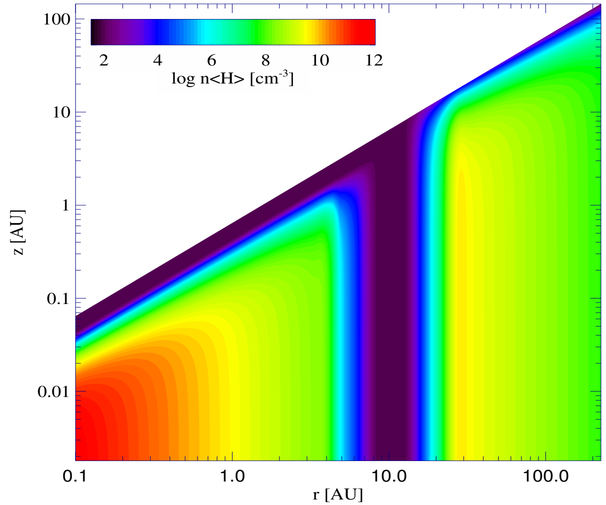
A case study : HD 169142



- **Young Herbig Ae/Be star (6Myr)**
- **Dust modelling** (SED + images)
  → geometry, gap at 10 AU
  → dust properties
  → amount of PAHs
- **Input for gas modelling**
  → low UV excess
  → PAH = main gas heating source
- **Gas dust ratio ≈ 20-50**

	observed	model
[OI] 63 μm	71.7	71.6
CO 2 → 1	0.093	0.092
^{13}CO 2 → 1	0.048	0.048

line fluxes in $[10^{-18}\ \mathrm{W/m^2}]$



Meeus et al. 2010

Adapting the modeling strategy to large numbers of detections: the DENT Grid

- Inverting gas lines or flux ratios to derive disk parameters requires a good understanding of disk structure and diagnostic potential of various tracers.
  → Only possible for well-documented objects.

- For statistical analysis: DENT grid
  - A numerical experiment to investigate the influence of stellar, disk, and dust properties on continuum and line observables
  - Study to what extent these dependencies can be inverted
  - > 300,000 disk models,
    11 free parameters,
    200,000 CPU-hours

Woitke et al. 2010, Kamp et al. 2011, Pinte et al. 2010

DENT grid: diagnostic power of lines

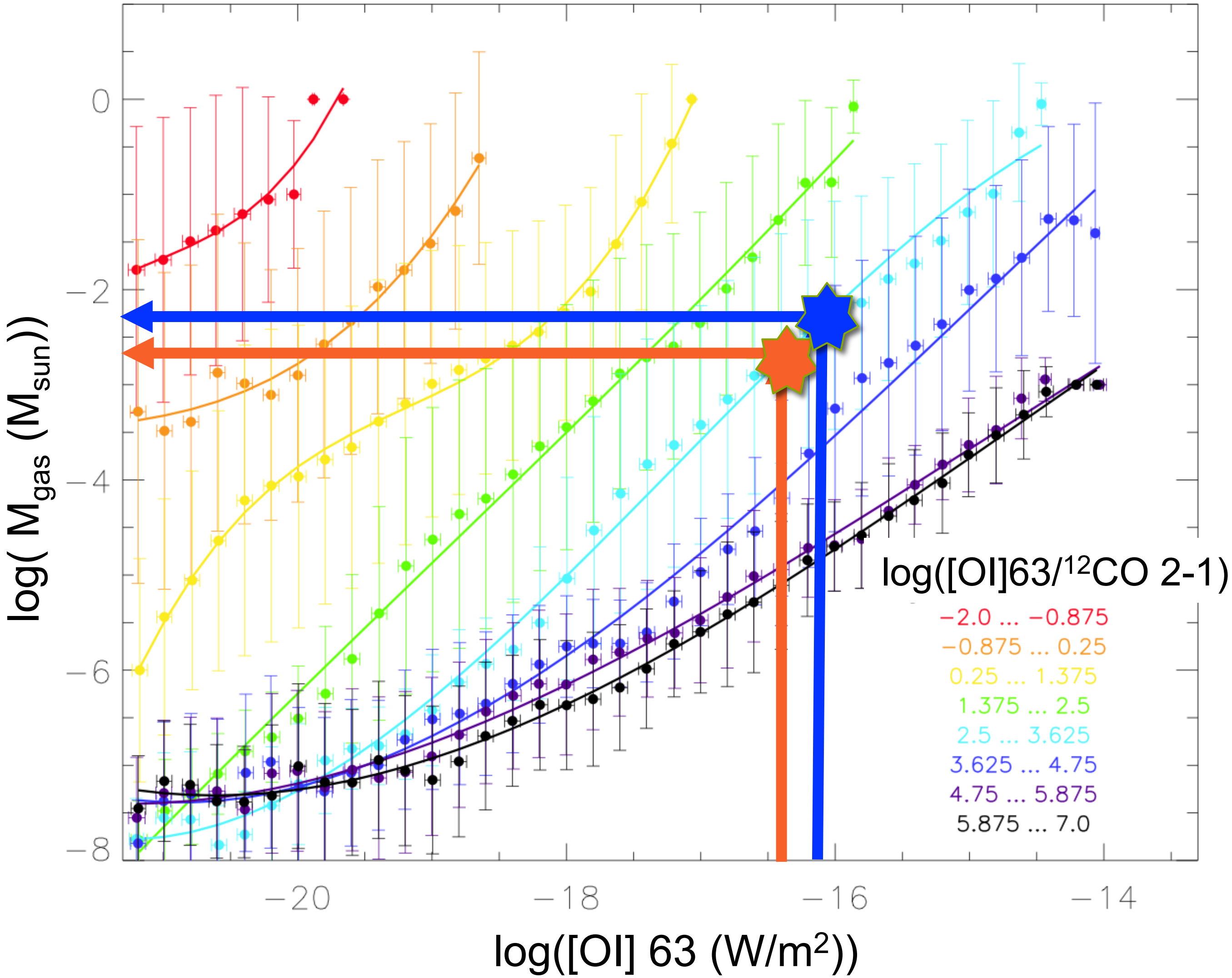
Gas mass estimation with the [OI] 63µm and ^{12}CO 2-1lines

HD 169142, 6 Myr old Herbig Ae

M_{gas} = 6x10^{-3} M_{sun},
vs. 3-7x10^{-3} M_{sun}
from modeling
(Meeus et al. 2010)

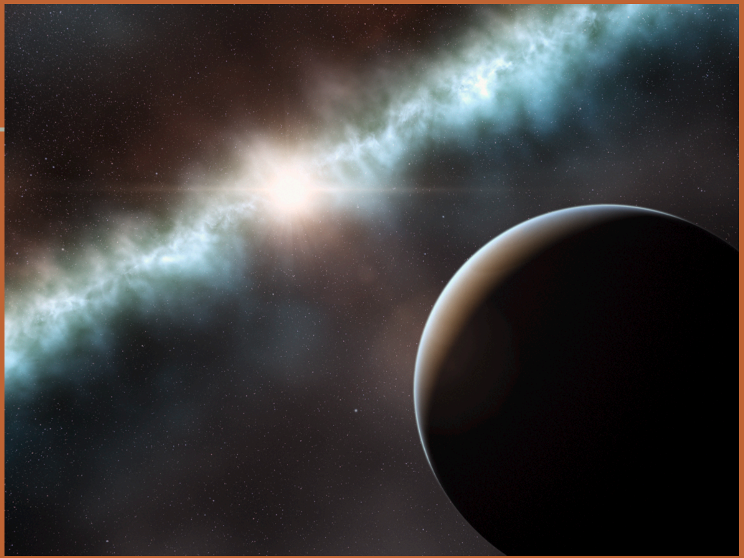
TW Hya, 10 Myr old TTauri star:

M_{gas} = 2x10^{-3} M_{sun},
vs. 0.5-5x10^{-3} M_{sun}
from modeling
(Thi et al. 2010)



Kamp et al. 2011

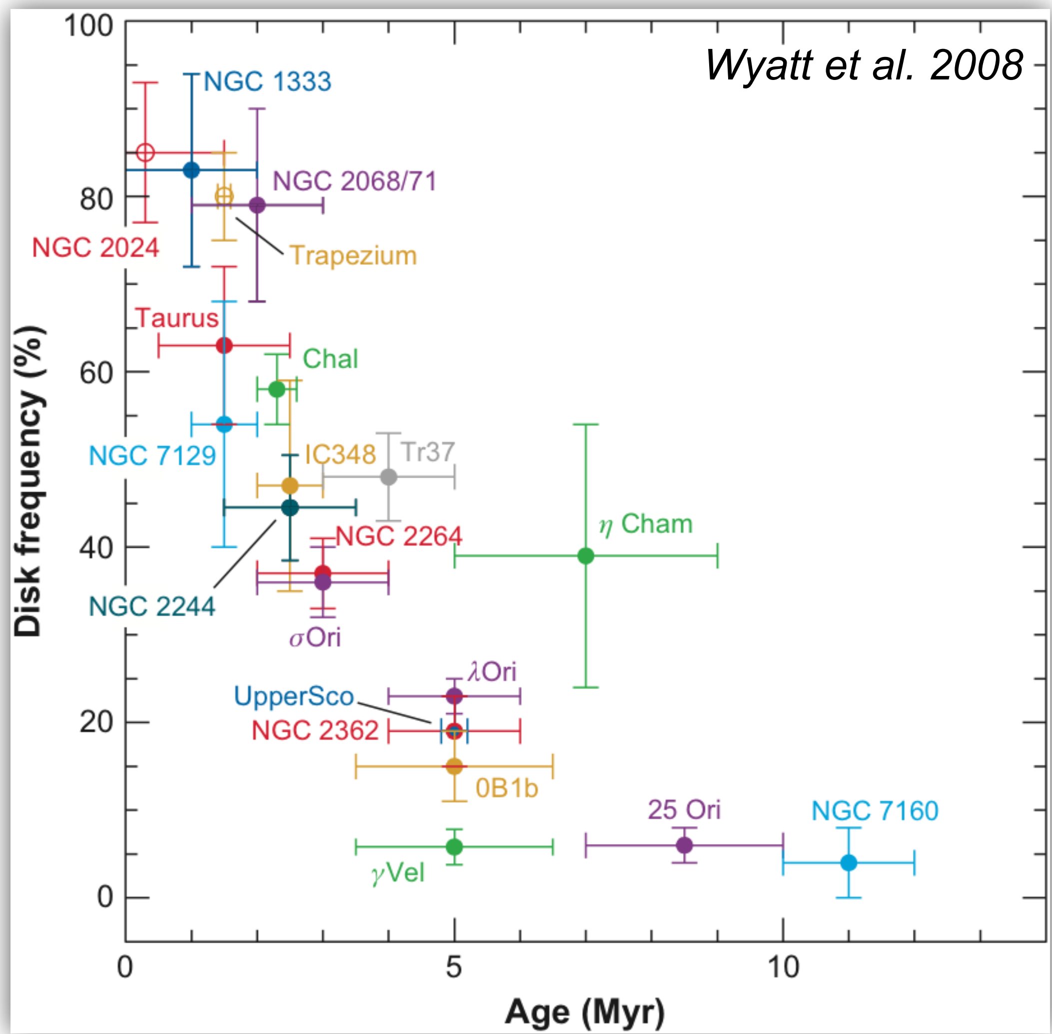
DISK CLEARING PHASE



Inner DUST(!) disk dispersal timescale

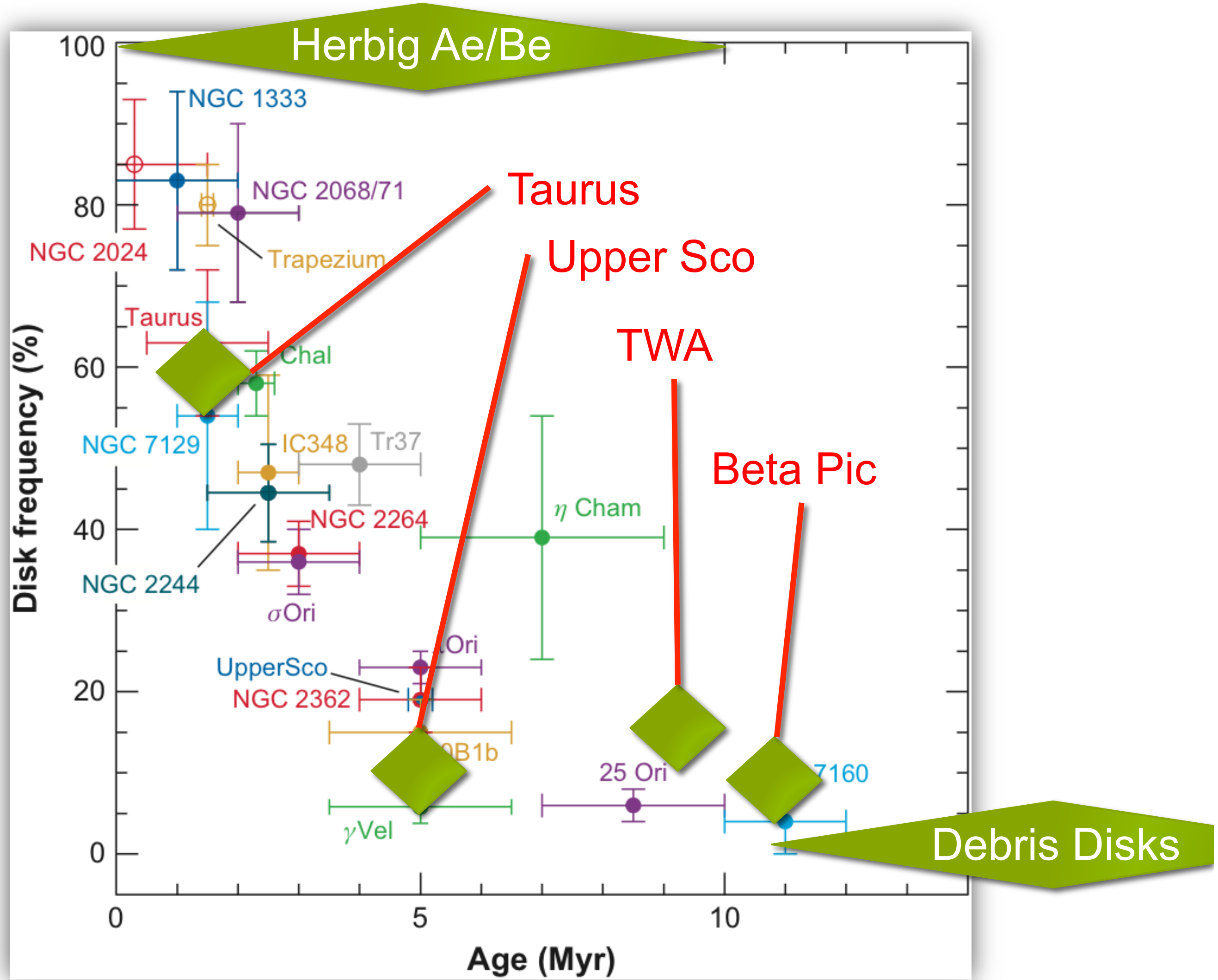
- Young stars loose their inner dust disk within 10 Myr

- What about the gas?



Inner GAS disk dispersal timescale

= [OI] 63 μm detection frequency

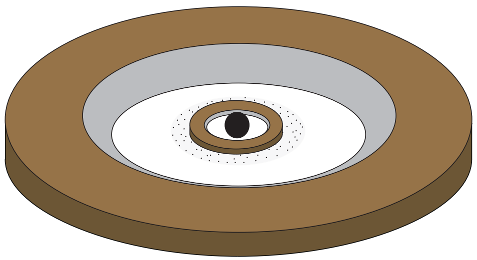


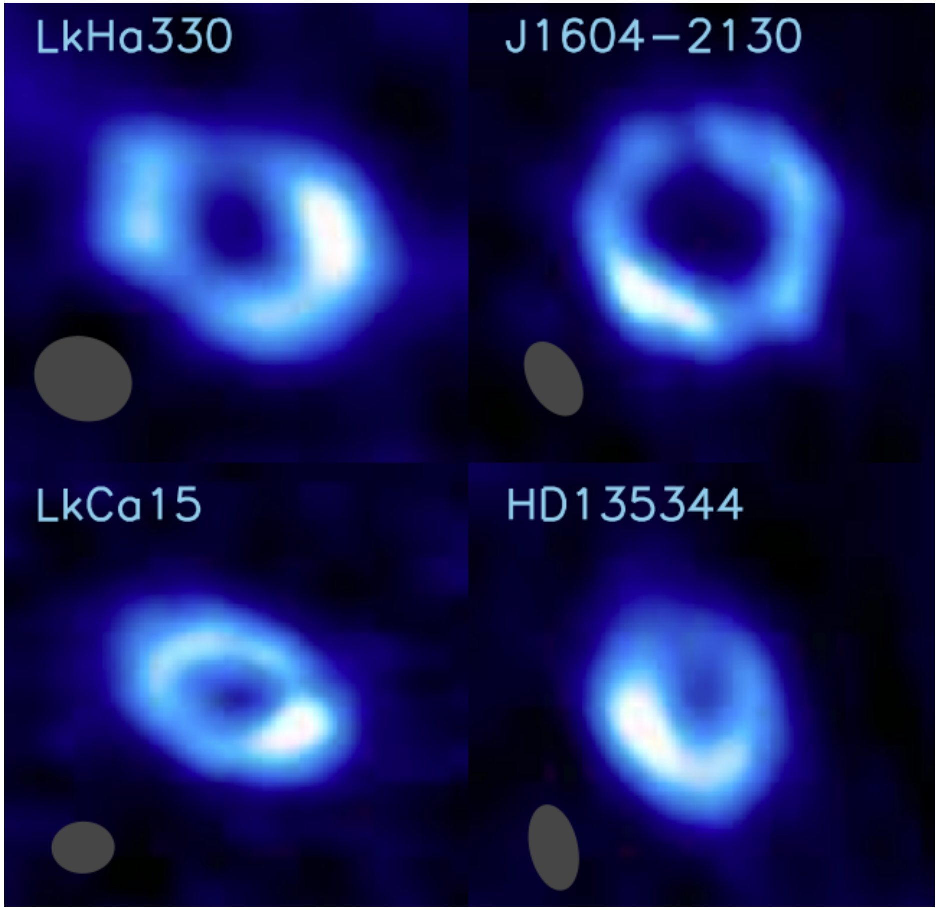
Warning:
- **Preliminary!**
- **Possible contamination**

See also talk by I. Pascucci

Transition (Cold) Disks

- Transition disks around young stars identified as objects lacking warm dust based on SED shape
- Cold disks :
  - A Gap, not a Hole
  - Planet(s) carving a gap?





From Review by Williams & Cieza 2011

T Cha :
a gapped disk with a sub-stellar companion

- Size of the **gap** (0.2 – 7.5 AU) from modeling of Spitzer + VLTI observations *(Olofsson et al. 2011)*

- Detection of a **companion: < 80 M_{Jup} @ 6.7 AU** (detection in *L'*, upper limit in *K*) *(Huélamo et al. 2011)*

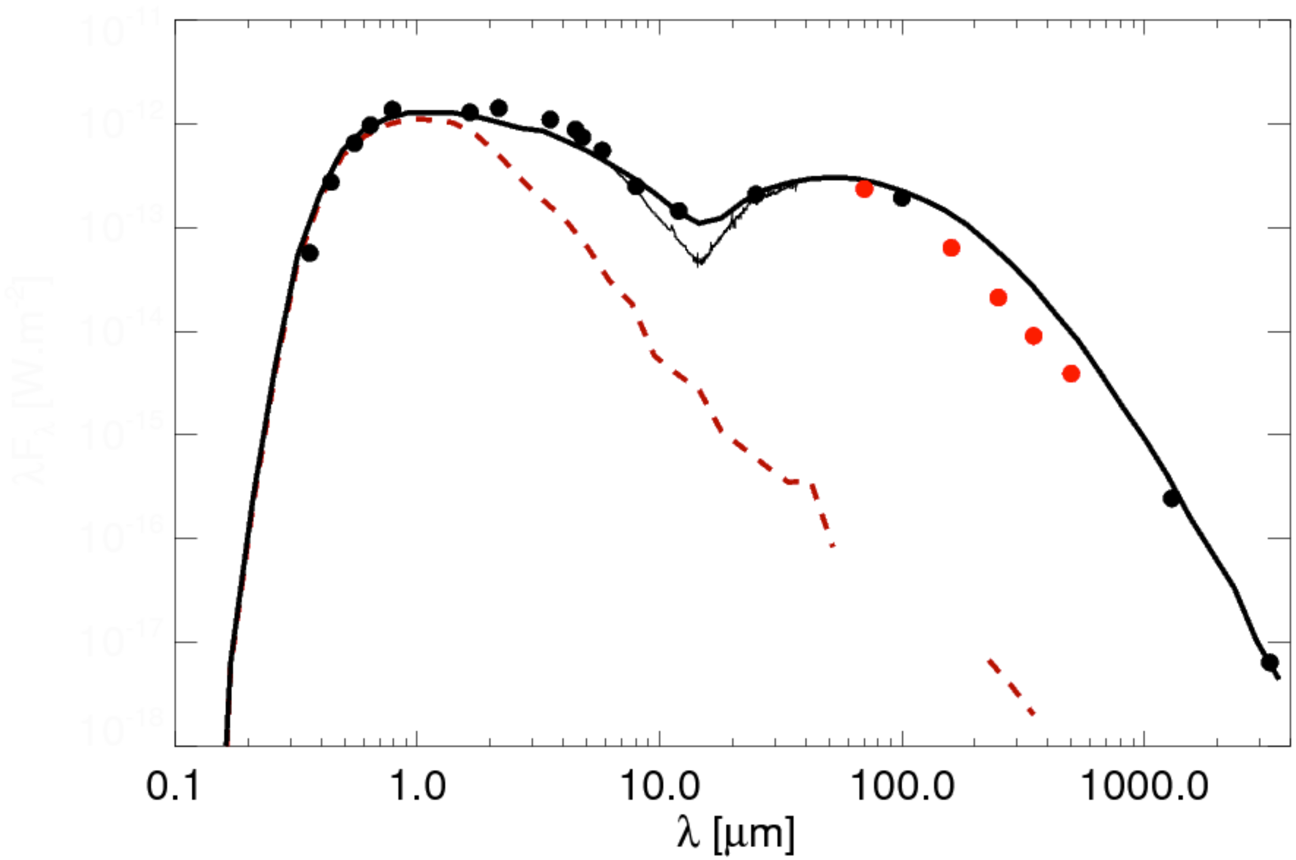
ESO press release

Video at : http://www.eso.org/public/videos/eso1106a/

See also talks by Kraus & Eisner

T Cha: Herschel observations

- PACS + SPIRE photometry rules out previous model for the outer ring:
  - Geometry?
  - Dust properties?

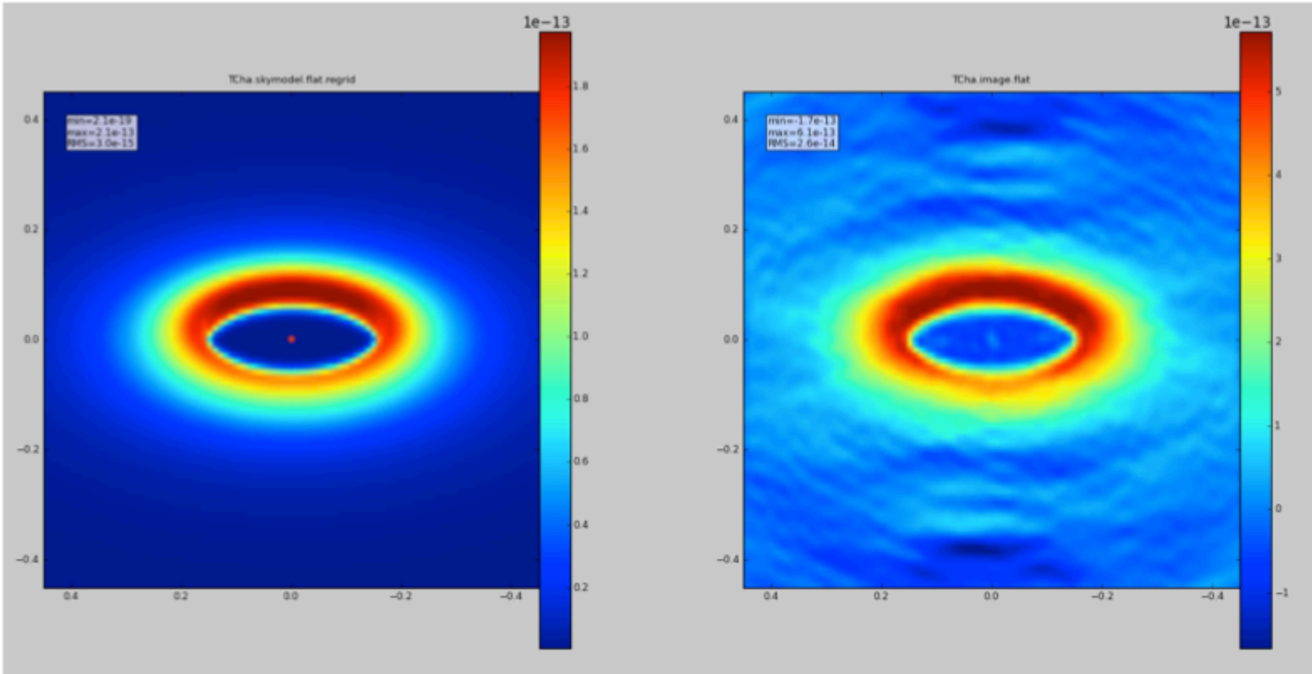


Cieza et al. in prep.

T Cha: Herschel observations

- PACS + SPIRE photometry rules out previous model for the outer ring:
  - Geometry?
  - Dust properties?

- Need resolved observations to measure the size of the cavity

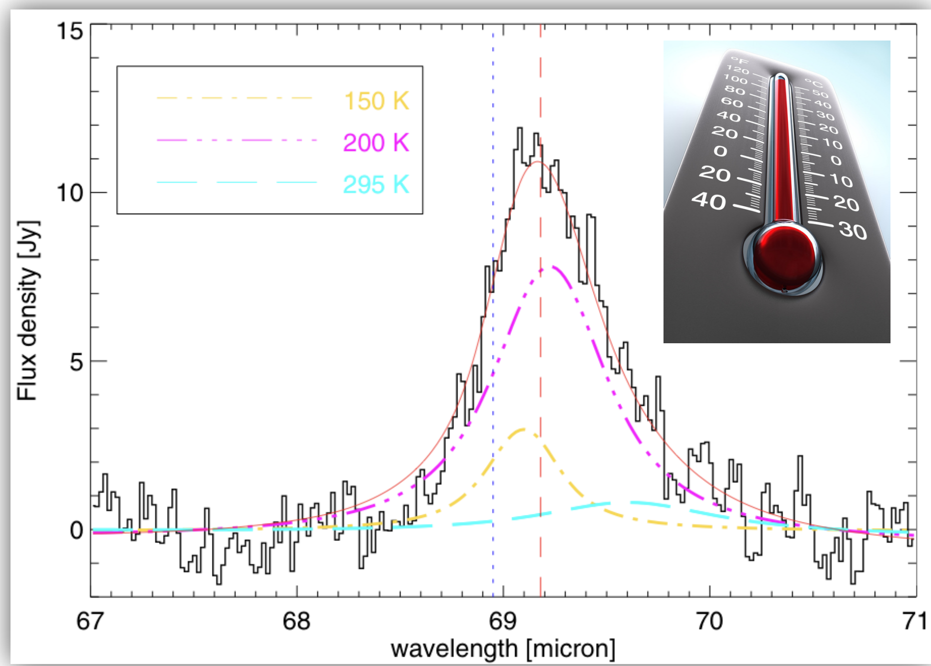


(Full) ALMA prediction, 1.3mm,
4h integration time,
4 AU resolution

Cieza et al. in prep.

HD 100546 :
another gapped disk, with a proto-planet at ~10AU ?

- Silicate enter protoplanetary disks as amorphous grains, and are then partially annealed
- Herschel: 69 µm solide-state feature from crystalline silicate grains (forsterite)
- This feature is a thermometer: T ~ 150 – 200 K.

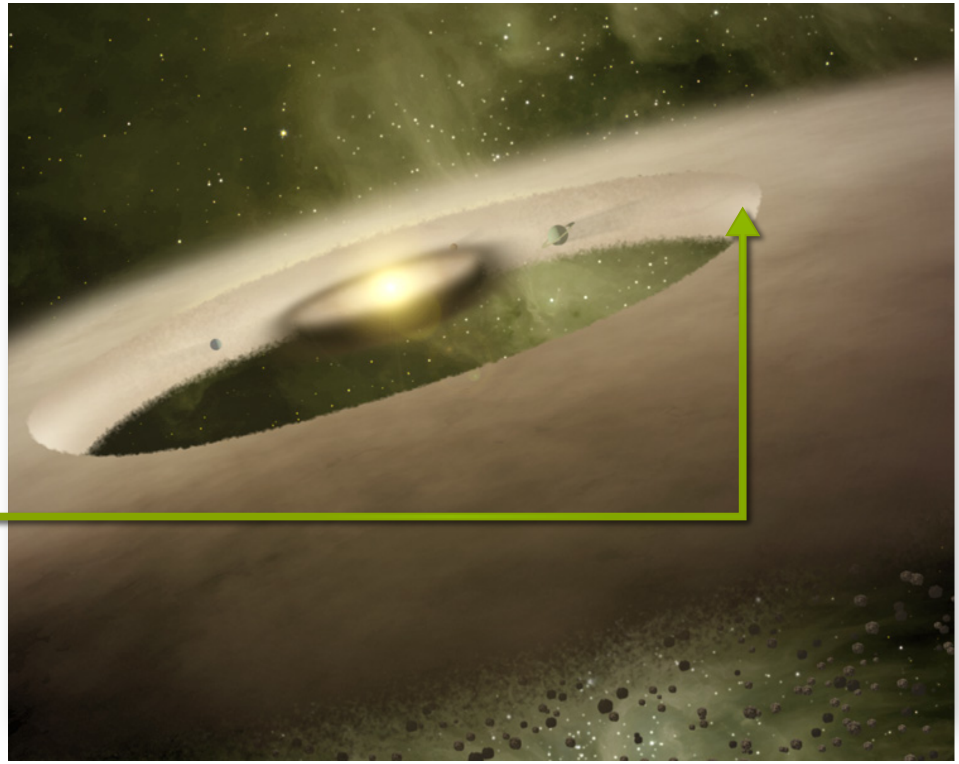


Sturm et al. 2010,
Mulders et al., 2011, submitted

HD 100546 :

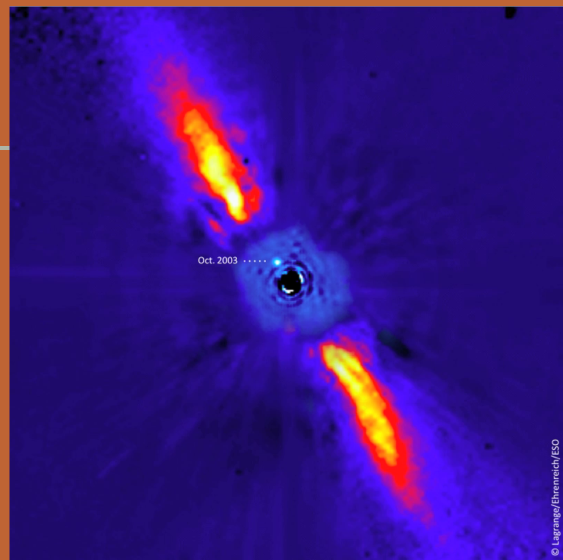
another gapped disk, with a proto-planet at ~10AU ?

- Silicate enter protoplanetary disks as amorphous grains, and are then partially annealed
- Herschel: 69 µm solide-state feature from crystalline silicate grains (forsterite)
- This feature is a thermometer:
  T ~ 150 – 200 K.
  Locates the silicate crystals at the rim of the outer disk, and abundance enhanced by ~ 10.
- Too low temperature for local crystallization.
  Crystallization by collisional cascades or shocks induced by the suggested giant planet?



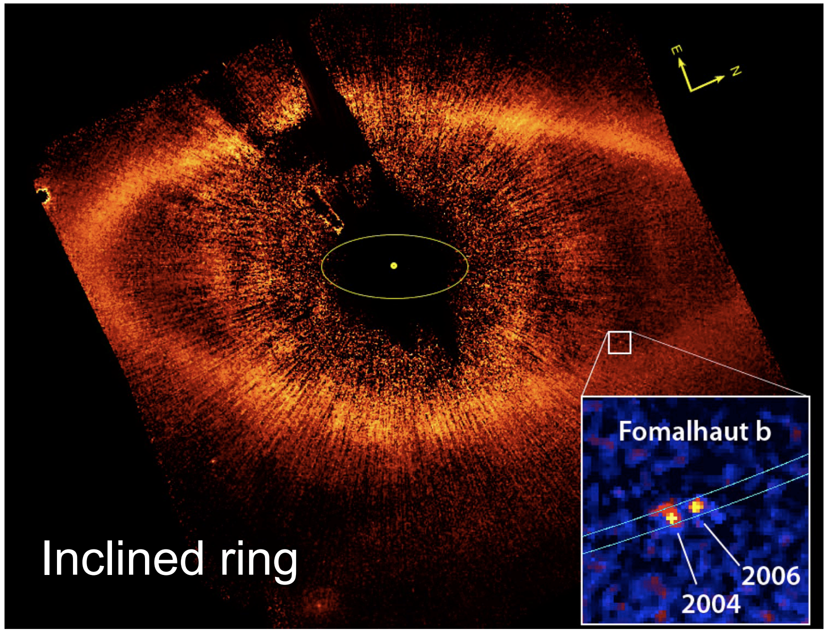
Sturm et al. 2010,
Mulders et al., 2011, submitted

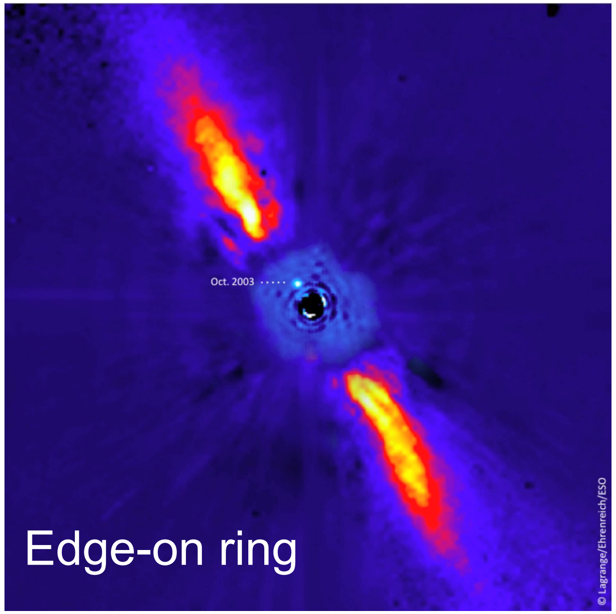
YOUNG DEBRIS DISKS IN THE BETA PIC MOVING GROUP (12-20 Myr)

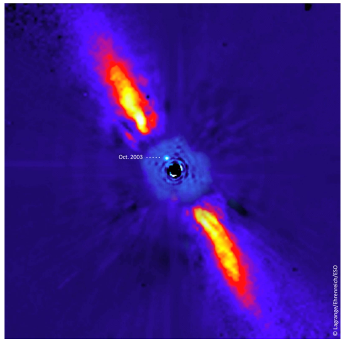


Debris disks

- Dust (and Gas?) are “second-generation”. Kuiper belts analogs
- Collisions between asteroids, and comet outgasing
- Planetesimals are formed, possibly planets too
- β Pic Moving Group is 12 – 20 Myr:
  terrestrial planet formation period?

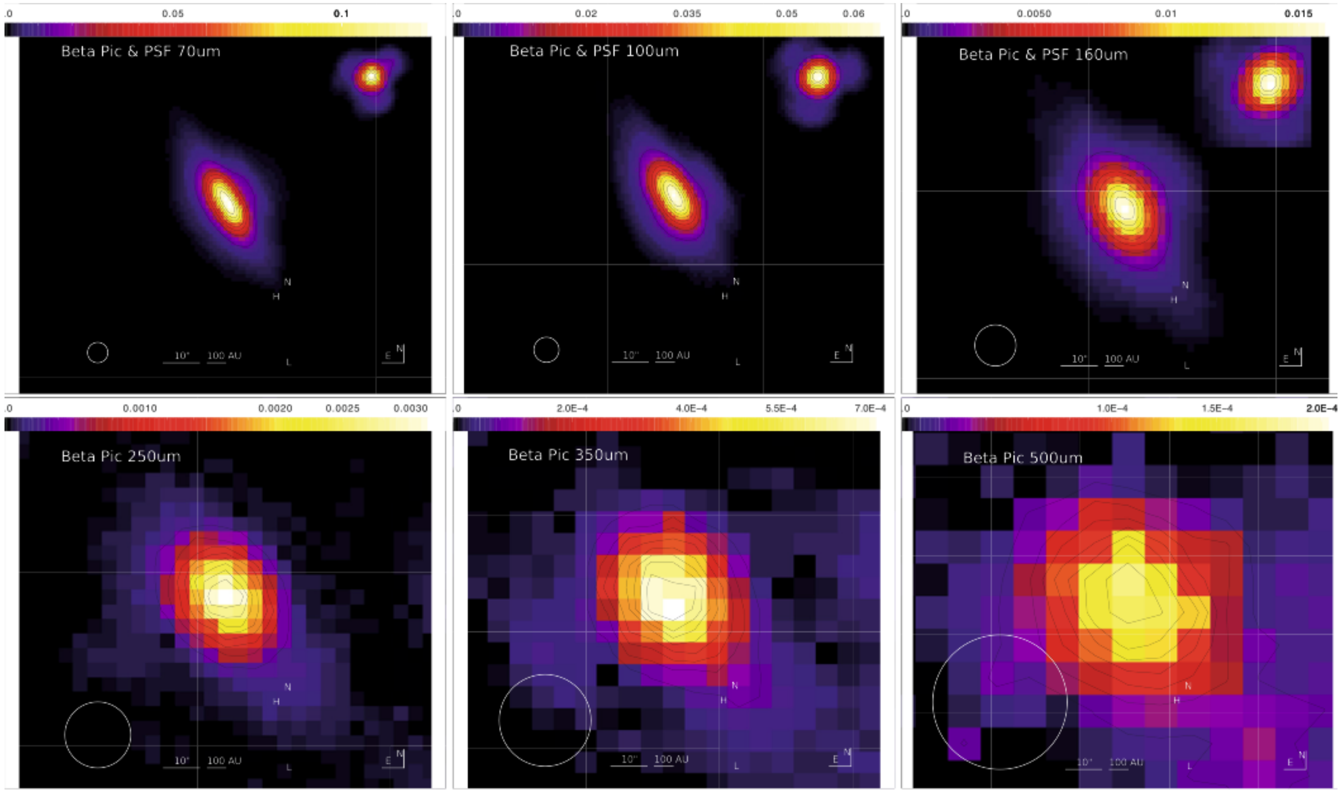






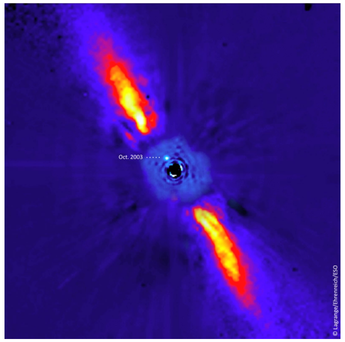
β Pictoris disk in the far-IR

- Inclination consistent with optical image
- No asymmetry

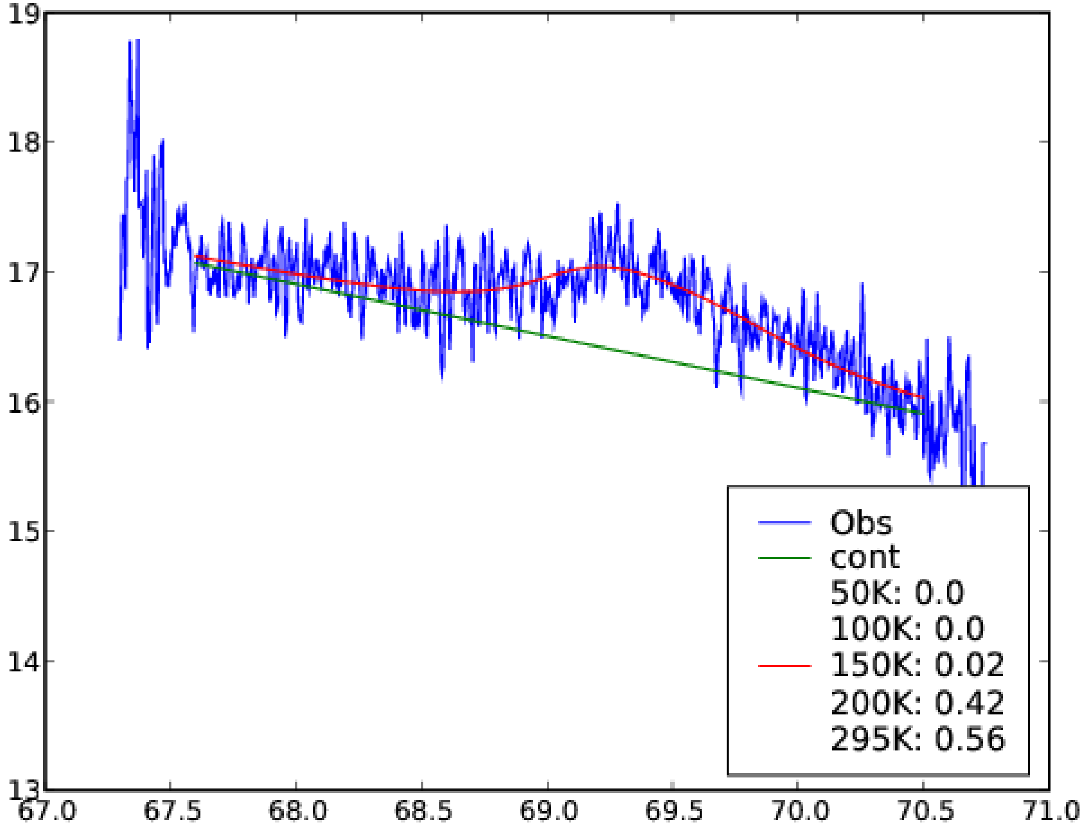


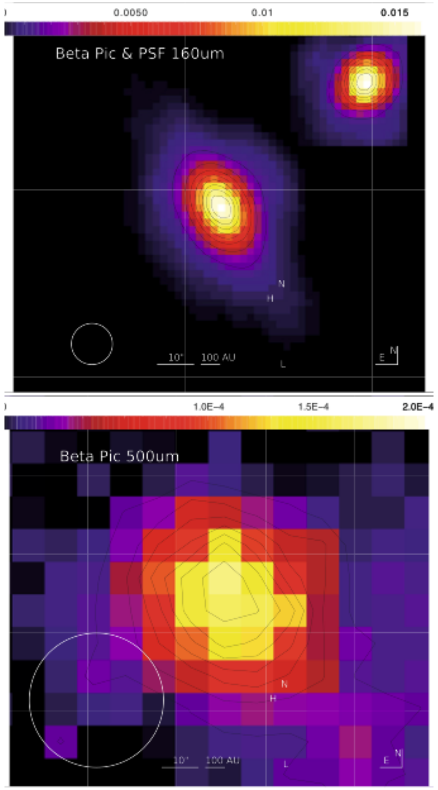
Vandenbussche et al. 2010
de Vries et al., in prep.

β Pictoris disk in the far-IR



- Inclination consistent with optical image
- No asymmetry
- 69 µm crystalline forsterite feature.
  Also detected with Spitzer (< 35 µm), and spatially resolved at 10 µm

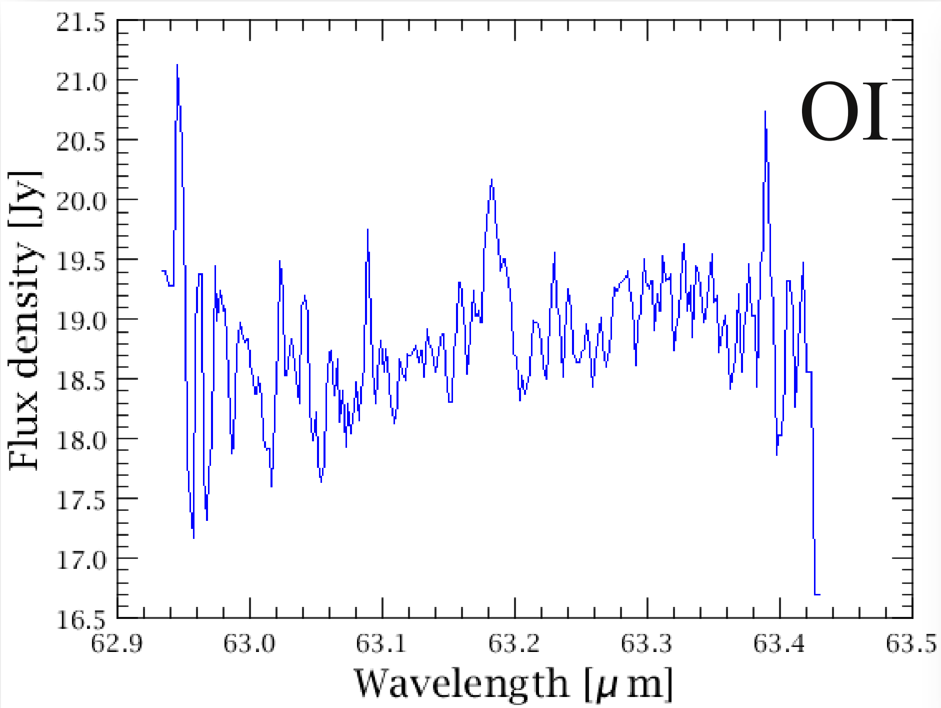


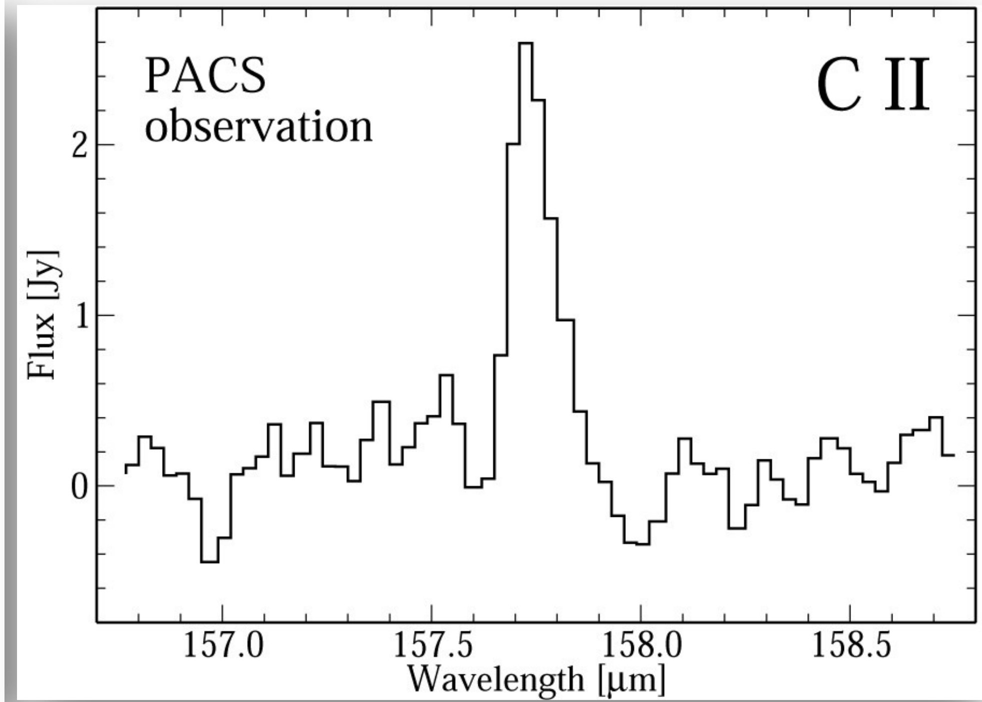


Vandenbussche et al. 2010
de Vries et al., in prep.

The β Pictoris puzzle

- Herschel:
  - [OI] 63 μm detected
  - [CII] also detected, but emission 6 times stronger than expected
- Analysis of FUSE data by Roberge et al. 2006 suggests that the gas is produced from C-rich material compared to solar analogues.
- Detailed modeling of Herschel data rather suggests C/O < 1 (Brandeker in prep.)



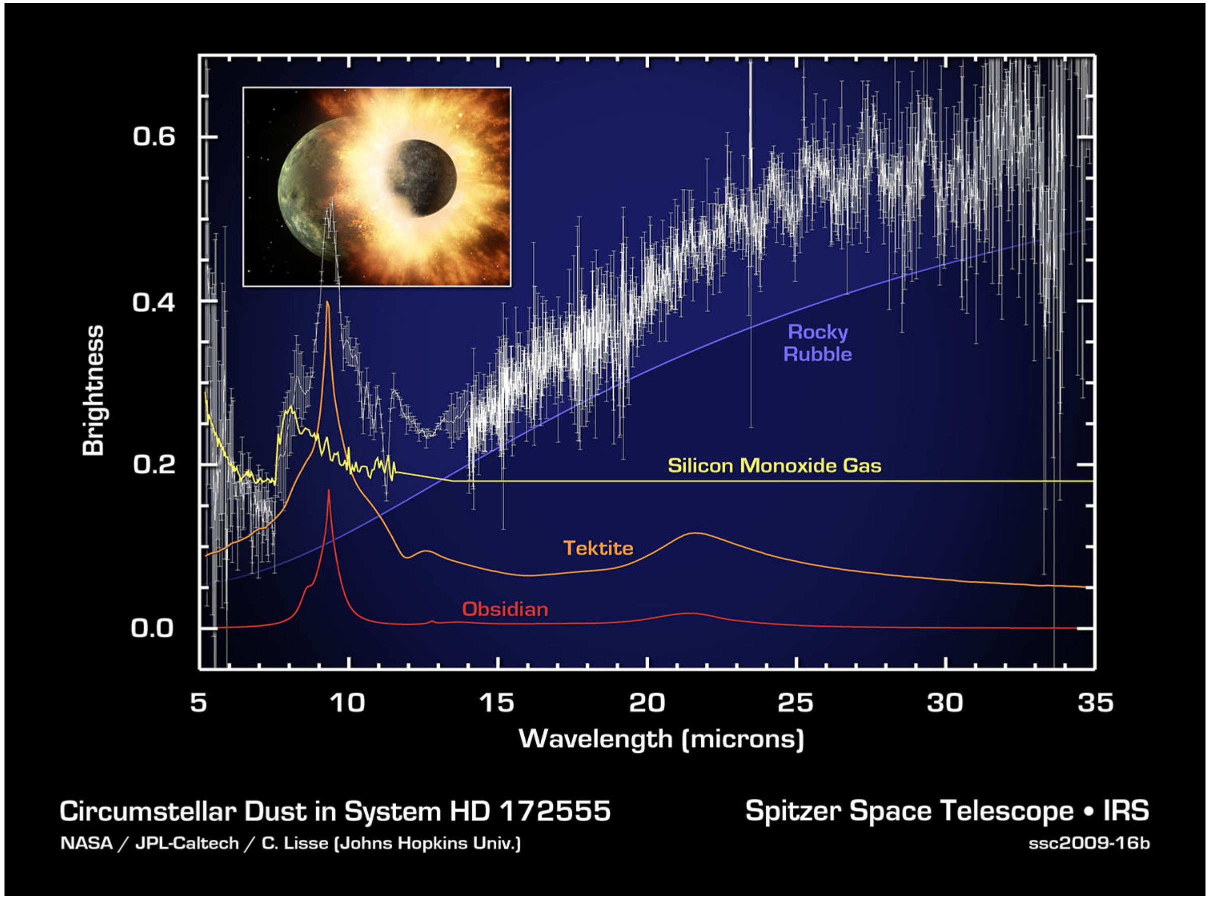


Brandeker et al., in prep., See also Kamp et al. 2003 (ISO results)

HD 172555 :
a giant hyperbolic velocity collision, at 12 Myr ?

- **Spitzer** (Lisse et al. 2009):
  - hot dust within the terrestrial planet formation region (5.8 ± 0.6 AU), mass equivalent to ~ 150 – 200 km-radius asteroid
  - silica species + tentative detection of SiO gas

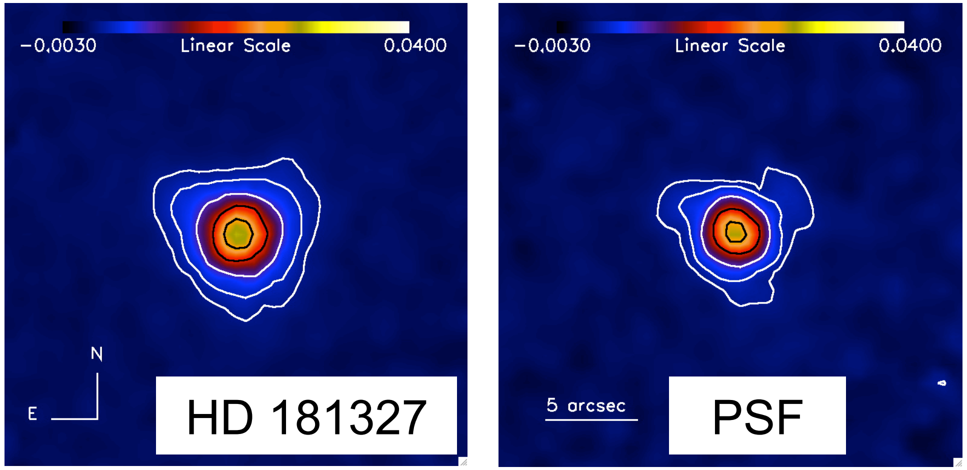
- **Herschel**: tentative detection of [OI] 63 μm feature

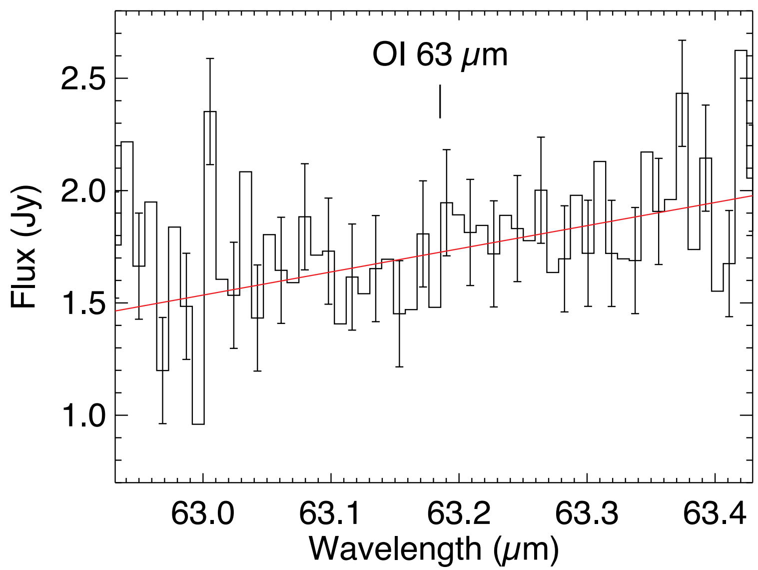


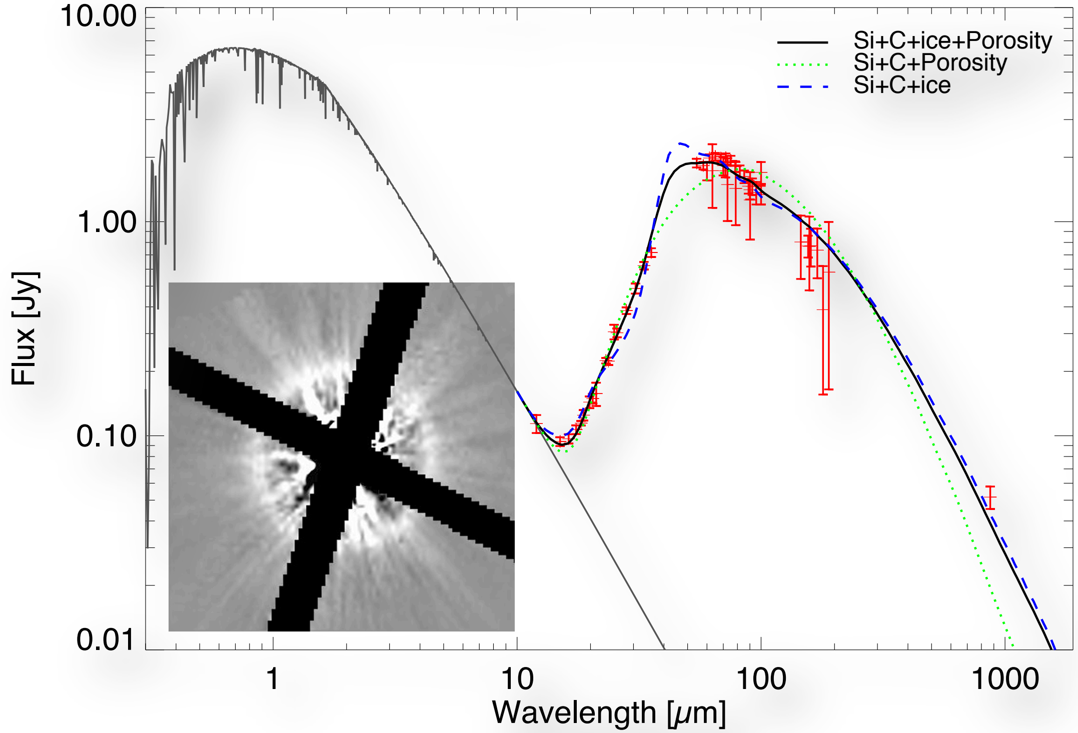
HD 181327

- No gas detected: < 14 M_{Earth}
- A Kuiper Belt analogue, resolved with HST and Herschel/PACS
- SED fit: significant amount of water ice, and porous grains

Herschel/PACS: 70 microns



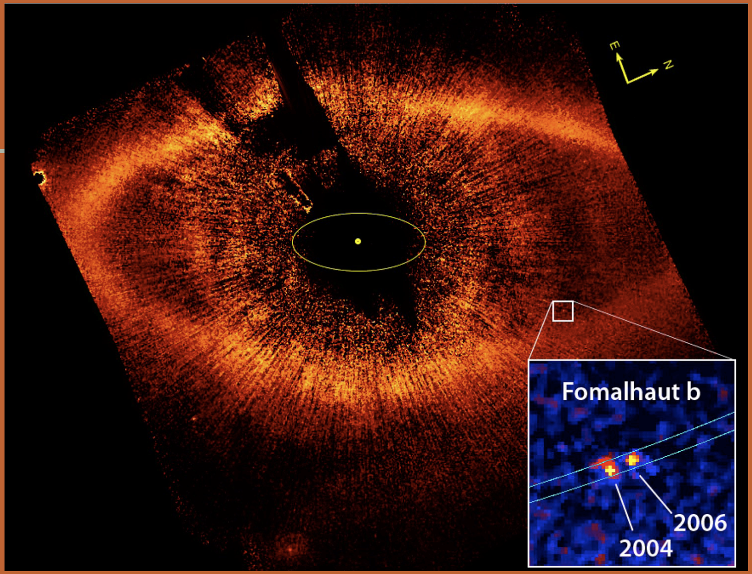




Lebreton et al., in prep.

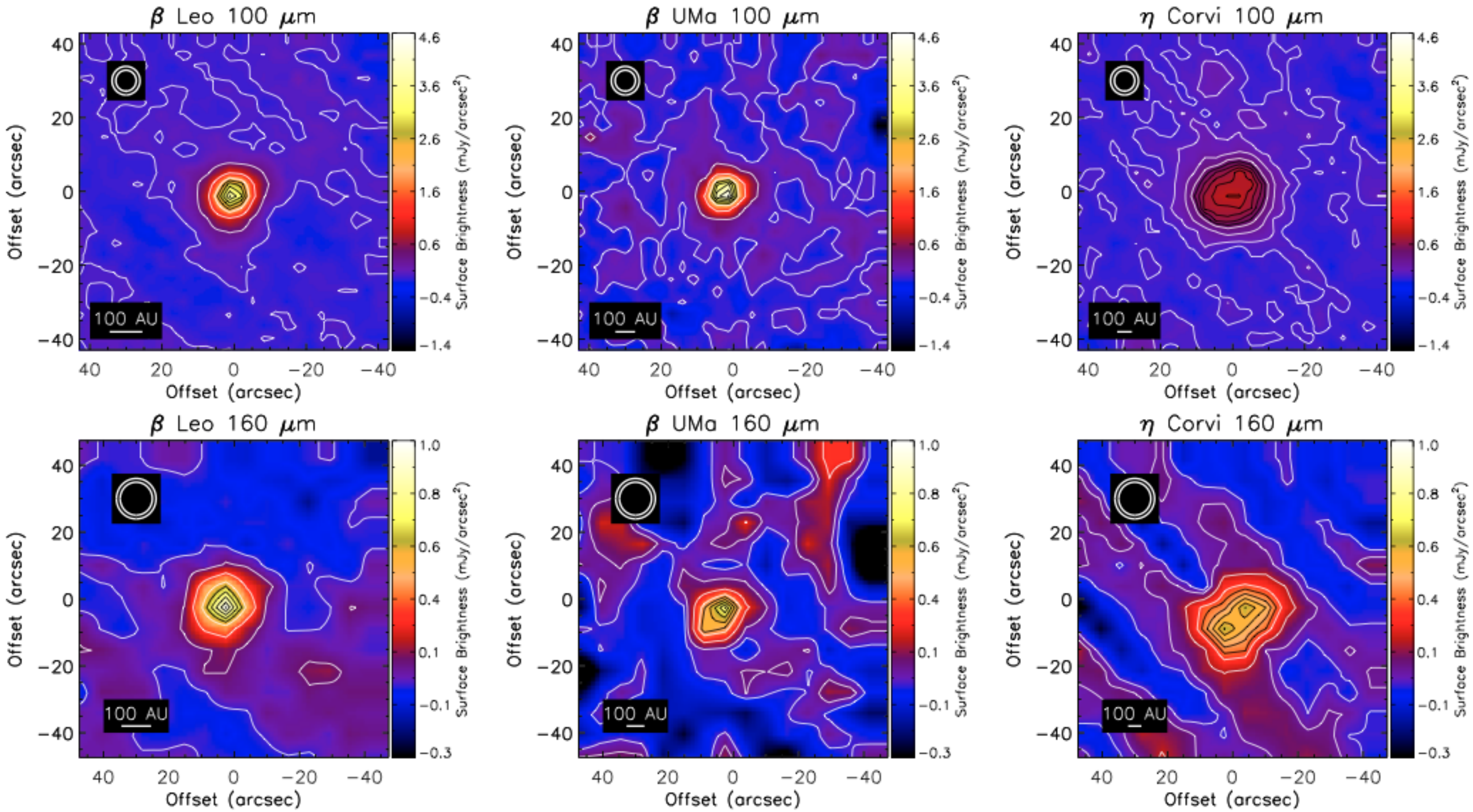
DEBRIS DISKS (aka PLANETARY SYSTEMS)

The resolving power of Herschel



Resolved debris disks: early highlights

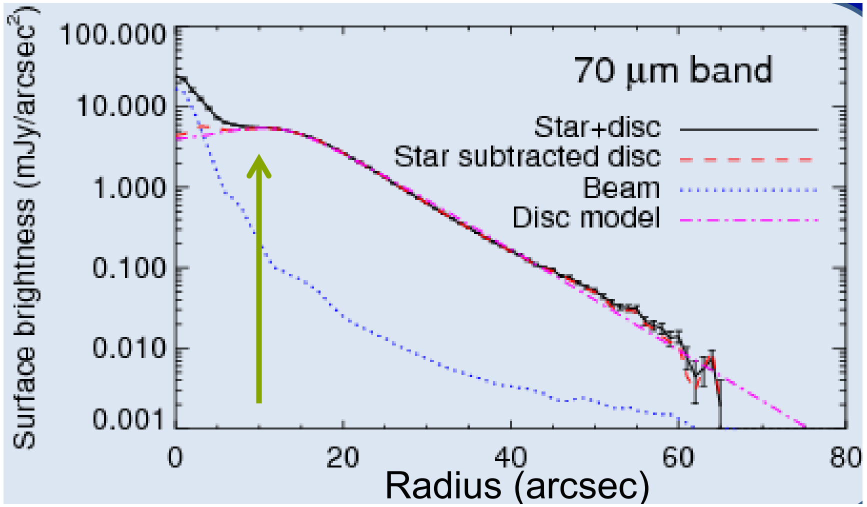
- Measuring the size for some nearby debris disks for the first time



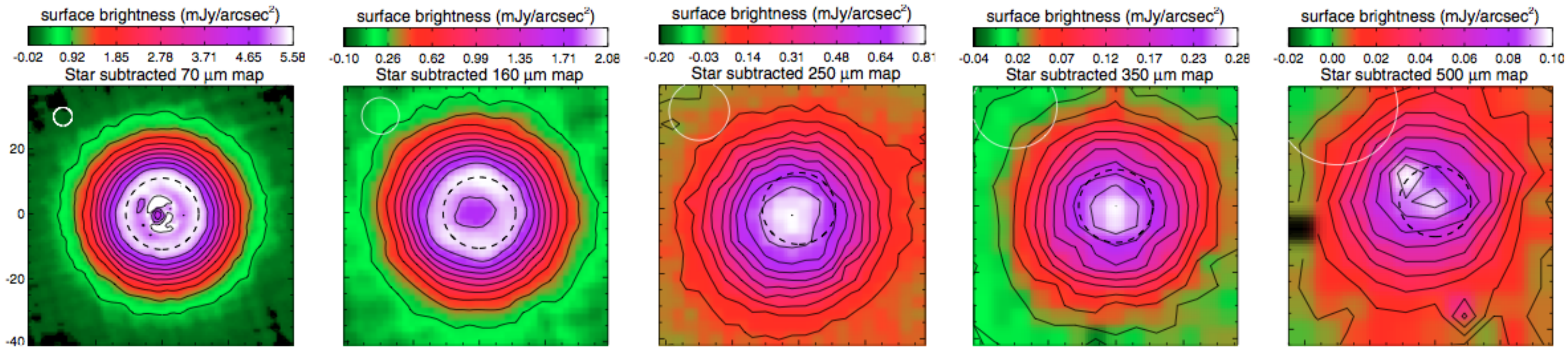
Matthews et al., 2010

See also talks by Millan-Gabet and Hinz

Vega's Kuiper Belt



- The Vega prototype:
  - a planetesimal birth ring at 85 AU (Kuiper Belt)
  - an external halo of barely bound grains due to radiation pressure
- No sign of asymmetries contrary to sub-mm images: disk emission still dominated by small blown-out dust grains at FIR wavelengths

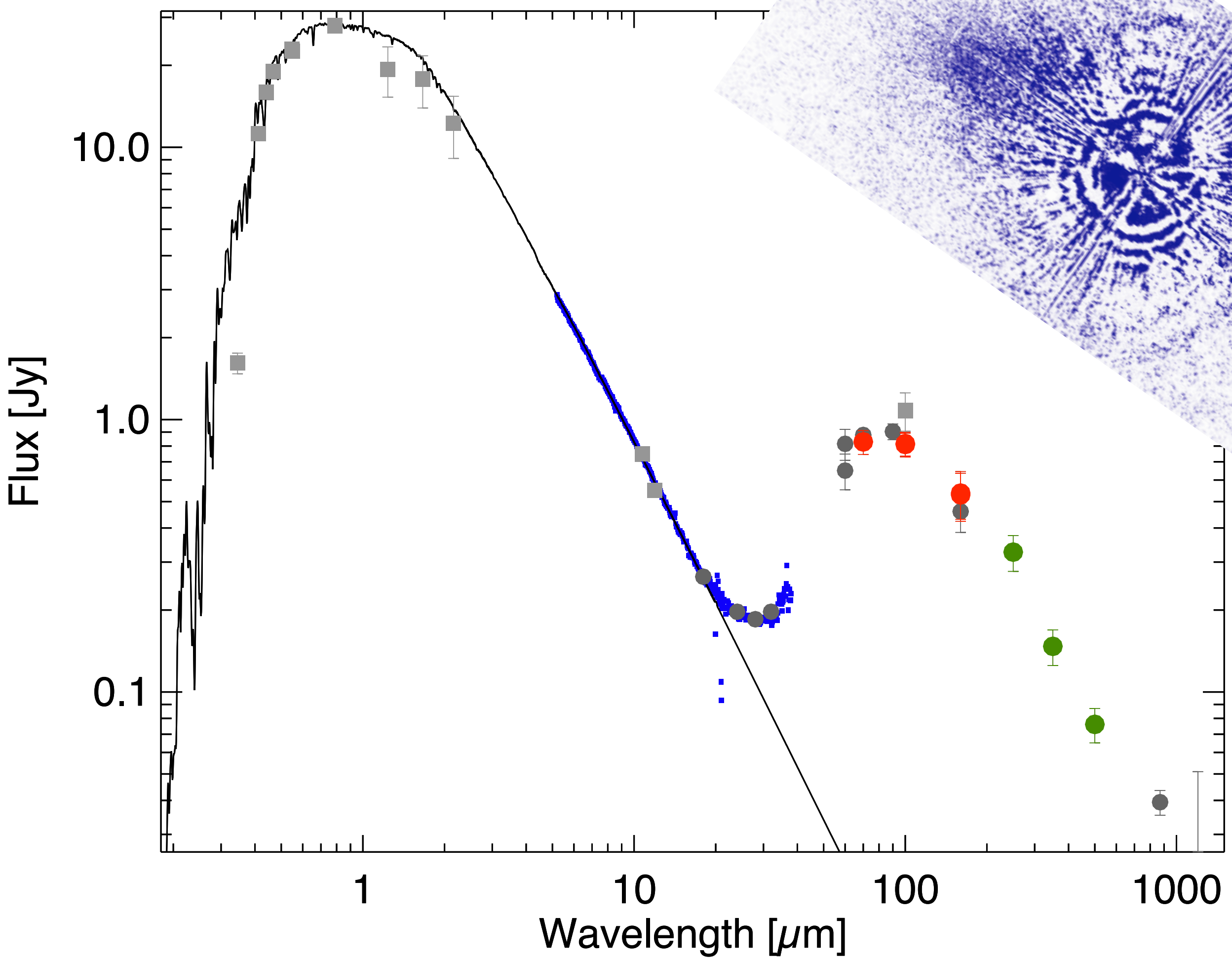


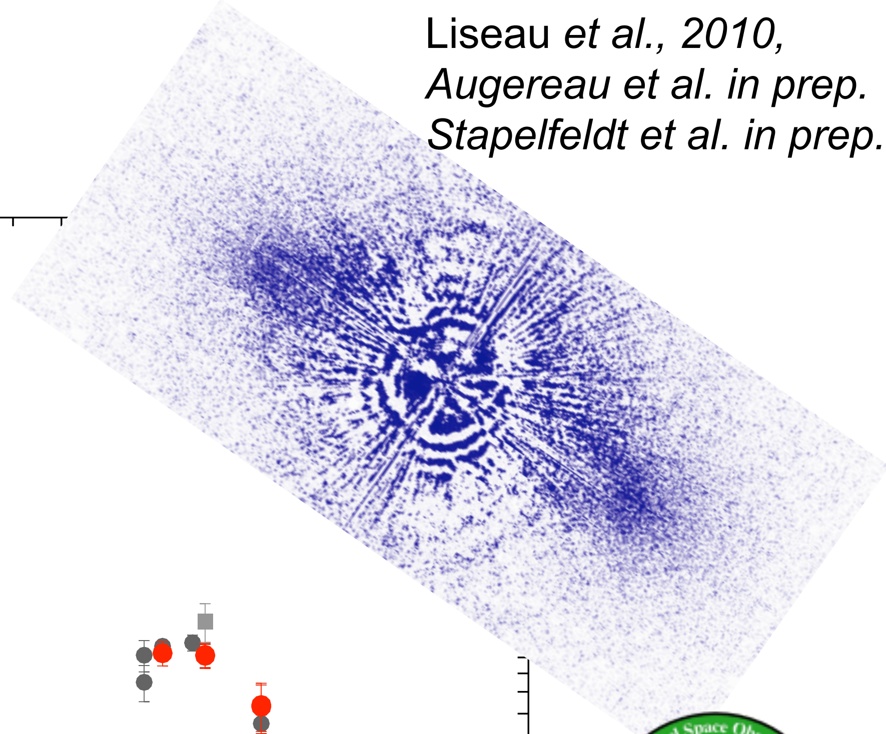
Sibthorpe *et al., 2010, see also Talk by K. Su*

q1 Eri : a nearby star with a radial velocity planet

- A Jupiter-mass planet at 1 AU and a Kuiper Belt at 75-85 AU

Liseau *et al., 2010,*
Augereau et al. in prep.
Stapelfeldt et al. in prep.





q1 Eri : a nearby star with a radial velocity planet

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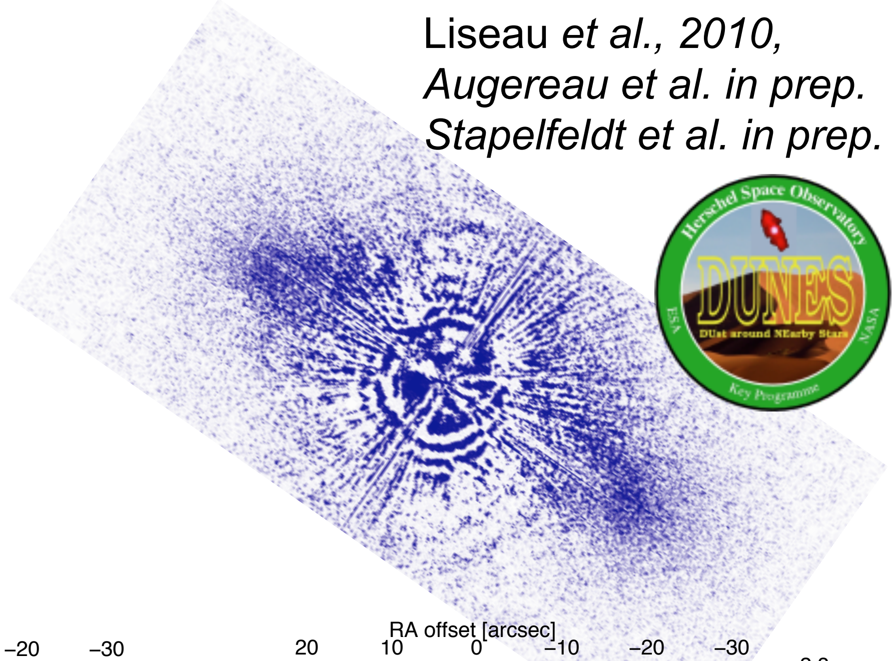
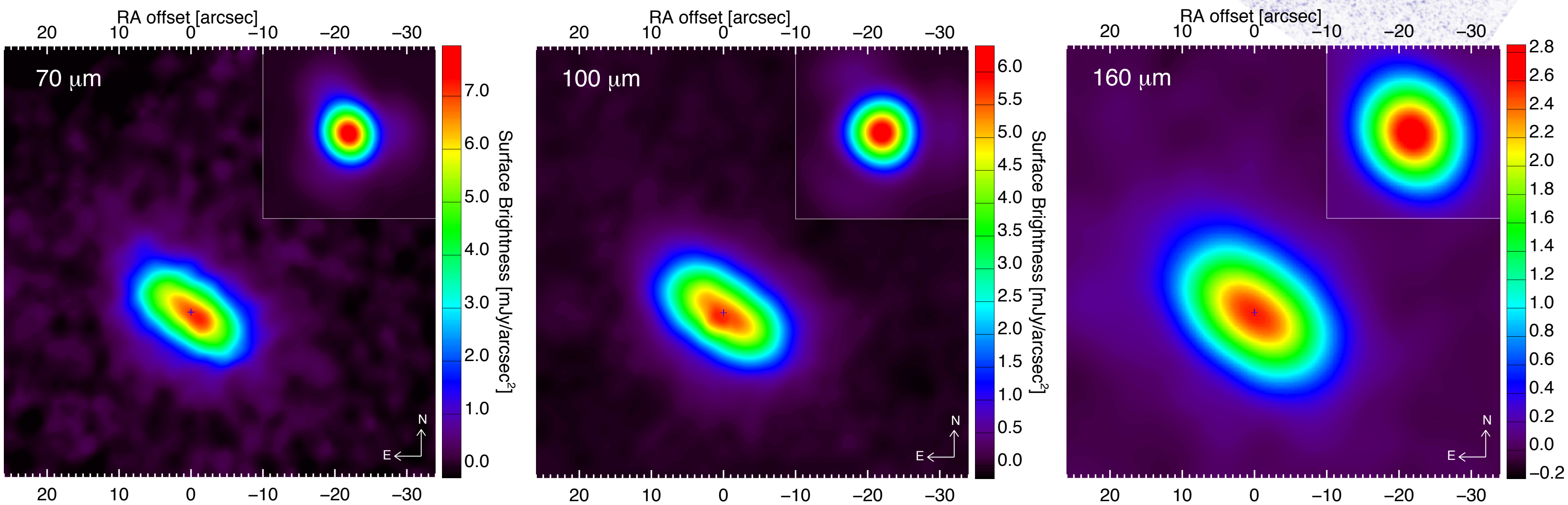
- Ring-like structure evidenced by modeling and deconvolution
- Possible recent dynamical stirring of the disk if age of 2 Gyr confirmed





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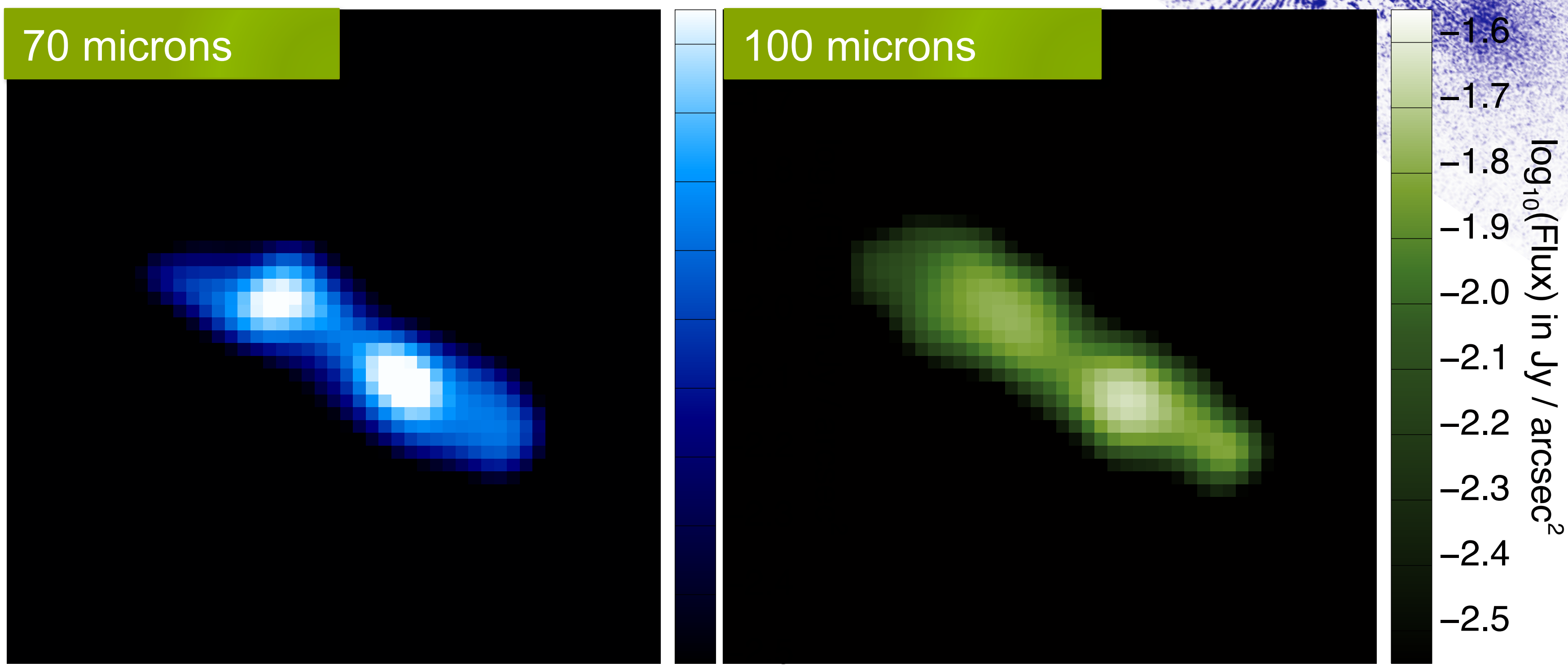
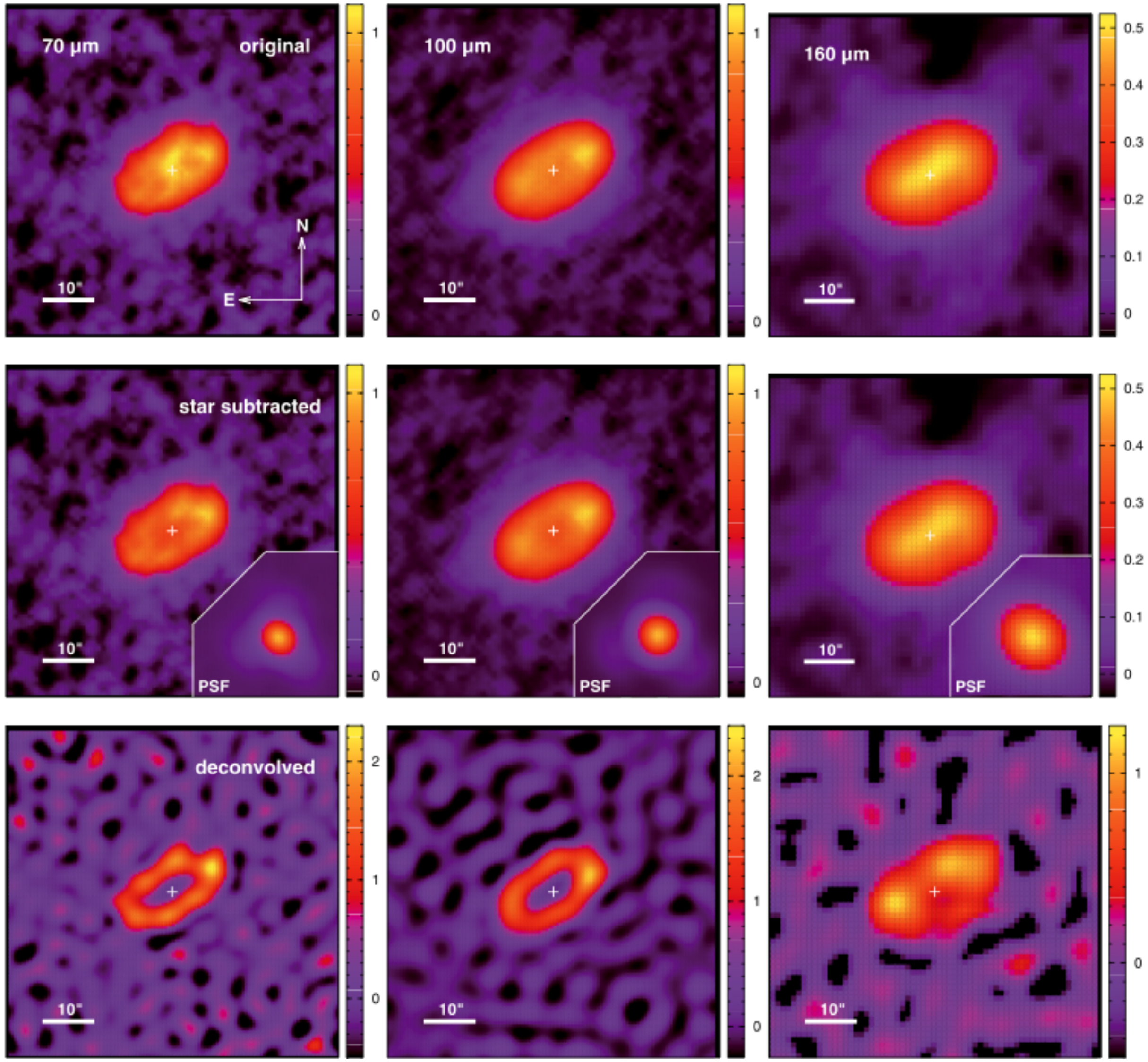
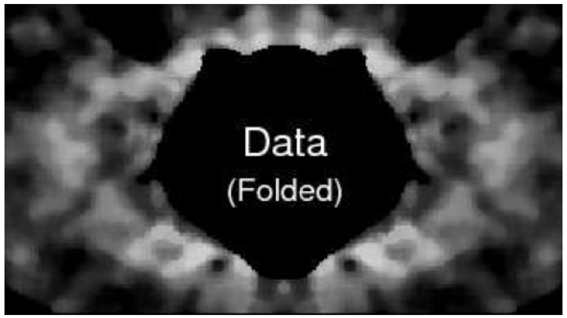


HD207129

- Unusually extended ring (140 – 160 AU radius) for a solar-type star



HST/STIS for comparison (not to scale)



Krist et al. 2010

See also talk and paper by J. Marshall + Loehne et al. in prep.

Conclusion

- Some specific conclusions:
  - *Herschel/PACS gives a wealth of Far-IR lines. [OI] 63 μm is the strongest (by factor 5-10)*
  - *Combining fine-structure lines, CO sub-mm lines and dust observations + detailed modeling is a powerful diagnosis*
  - *Herschel resolves nearby disks, and breaks degeneracy in debris disk modeling*
- Modeling and interpretation are ongoing, and data reduction is still improving. More to come soon.

Thank you for listening

Herschel Meeting on Star and Planet Formation in March 2012, Grenoble, French Alps

- Thanks to the GASPS, DIGIT, DUNES and GTO team members for their contribution to this talk, and especially (in random order): W.F. Thi, G. Meeus, C. Howard, G. Mathews, J. Olofsson, C. Pinte, F. Ménard, P. Rivière, J. Marshall, I. Kamp, C. Dominik, A. Brandeker, B. Vandenbussche