Dust properties of hot exozodis derived from near- and mid-infrared interferometry

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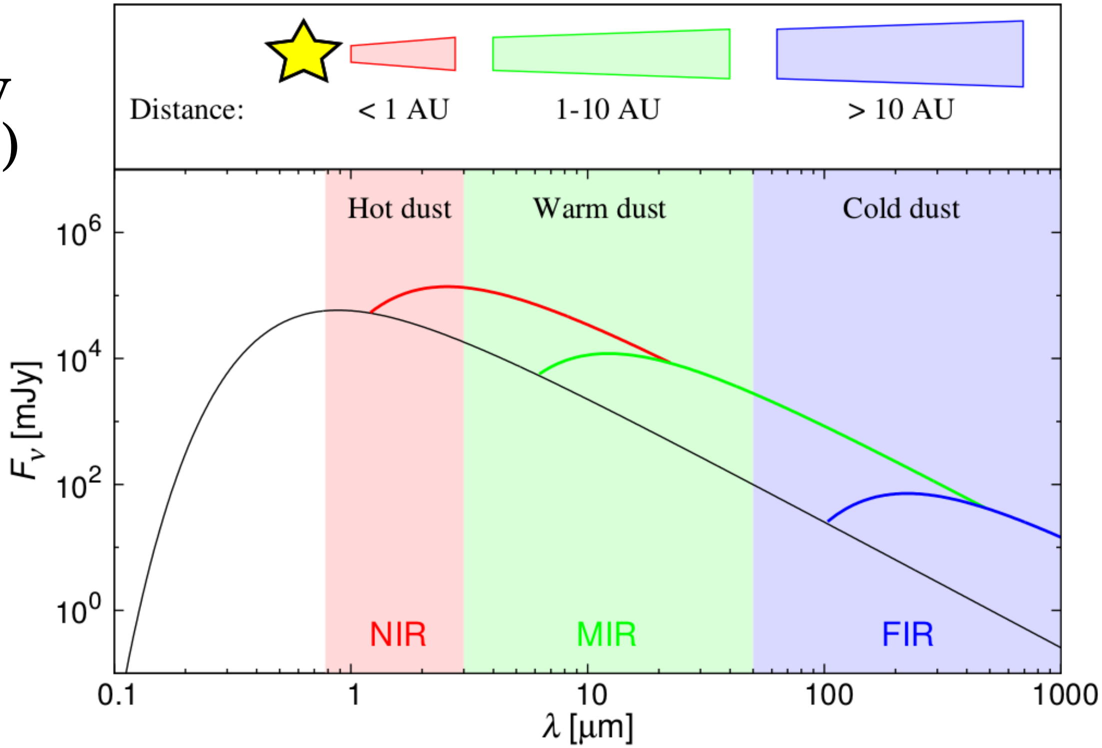
What are hot exozodis?

- Debris discs:
  Dust located in the close vicinity of main-sequence stars (r < 1 au)
- Probably at or close to the sublimation radius (0.01 au – 1 au)
- High temperatures (~1000 K)
  → *hot* dust
- Emission peaks in the NIR and short MIR



Requirements for observations

- High angular resolution (~0.01 as)
- @ NIR and short MIR wavelengths
- High contrast between dust and stellar emission

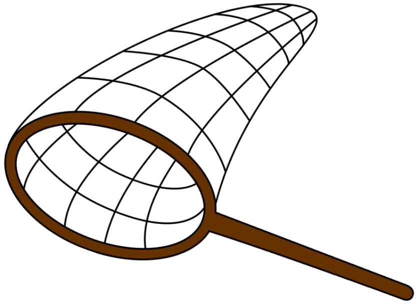
- Long-baseline interferometry (VLTI/PIONIER & CHARA/FLUOR)
  H band @ 1.6 µm K band @ 2.2 µm

Origin of hot exozodis?

- Problem: radiation pressure and sublimation remove dust within short timescales (days to years)
- Solutions:

1. Continous dust delivery

- *in situ* steadystate collisional cascades
- Cometary supply
- Poynting Robertson (PR)-drag



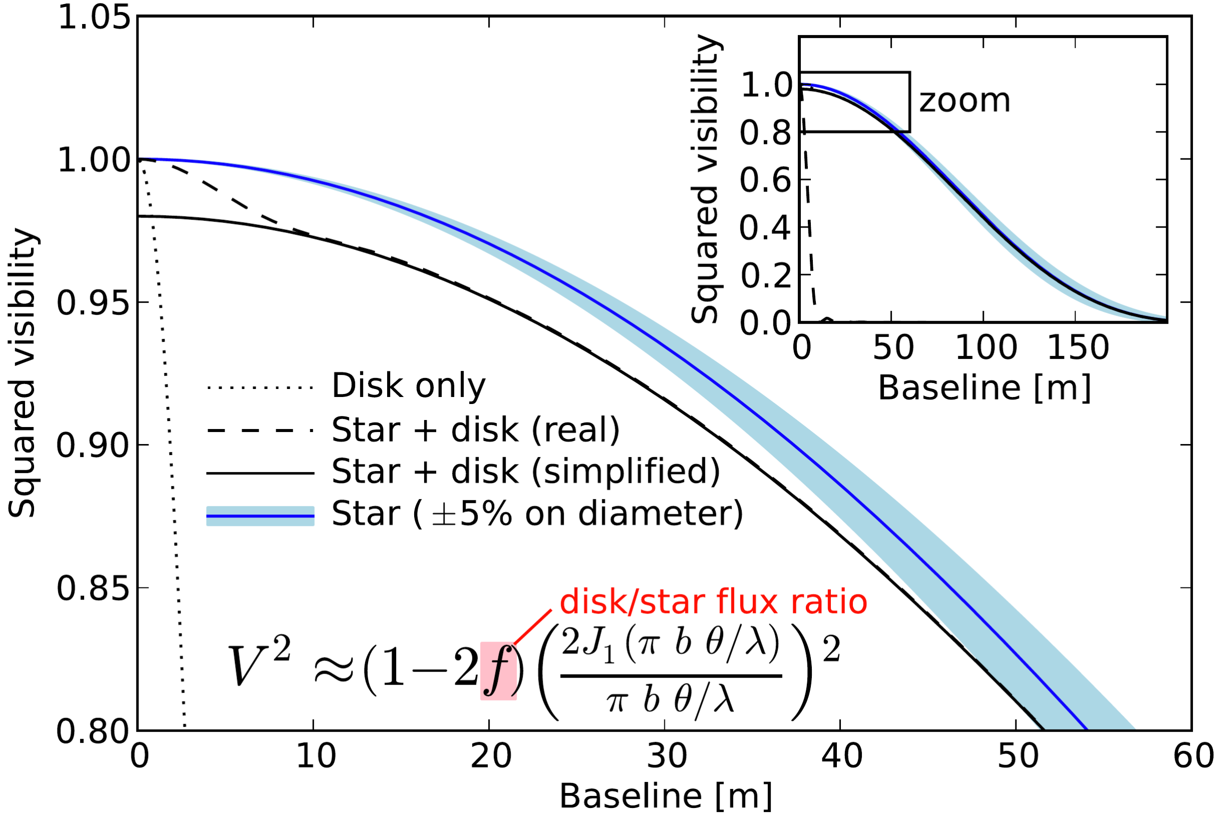
2. Dust trapping

- Gas trapping
- Magnetic fields
- Differential Doppler Effect

Mechanism which fully explain the existence of hot exozodis still unclear

Interferometric observations

- First detected hot exozodi emission: Vega (Absil+ 2006)
- Today: 23 systems with NIR excess associated with circumstellar dust
- Surveys by Absil+ (2013), Ertel+ (2014, 2016), Nuñez (2017)
- VLTI/PIONIER, VLTI/VINCI, CHARA/FLUOR, IOTA/IONIC, KIN, LBTI: AufdenBerg+ (2006), di Folco+ (2007), Absil+ (2008, 2009), Akeson+ (2009), Defrère+ (2011, 2012), Lebreton+ (2013), Mennesson+ (2013. 2014)

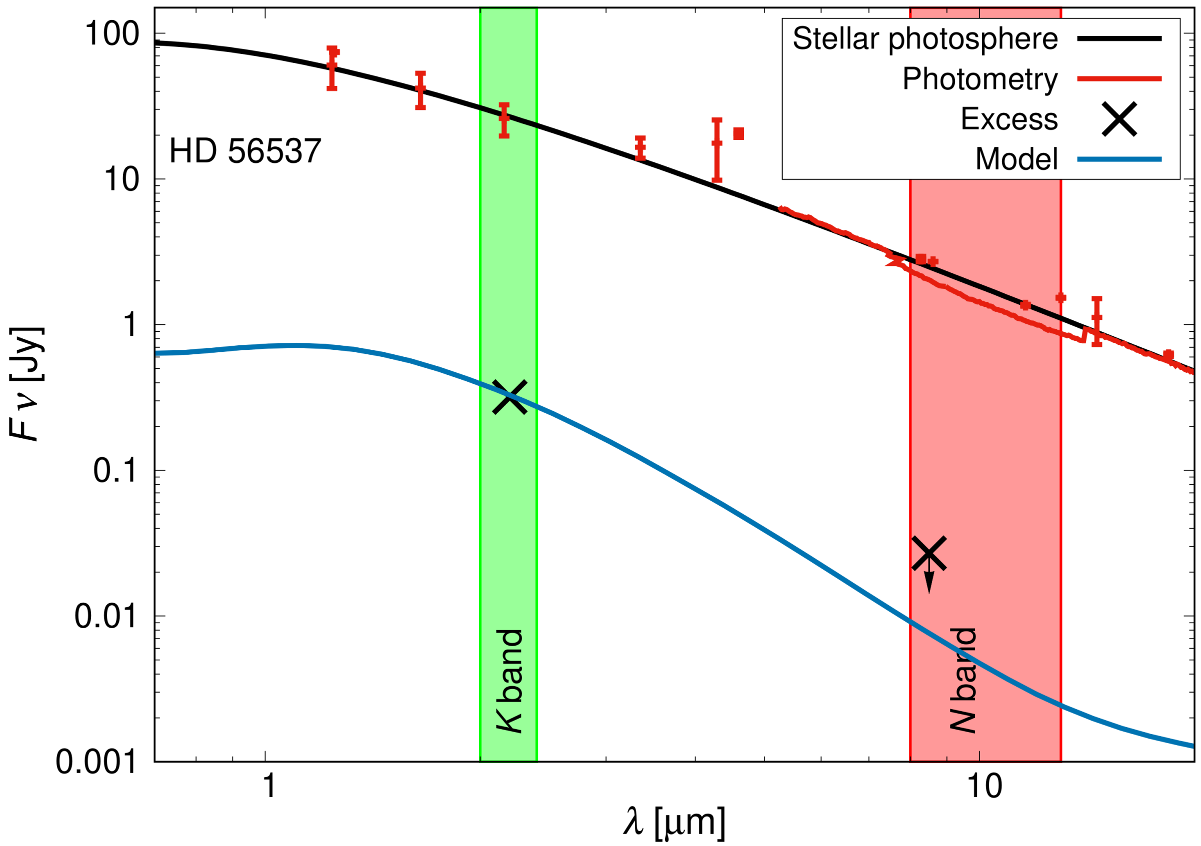


$$V^2 \approx (1-2f)\left(\frac{2J_1(\pi\ b\ \theta/\lambda)}{\pi\ b\ \theta/\lambda}\right)^2$$

- Circumstellar emission (black line) causes visibility deficit compared to bare stellar photosphere (blue line)

(di Folco+ 2004)

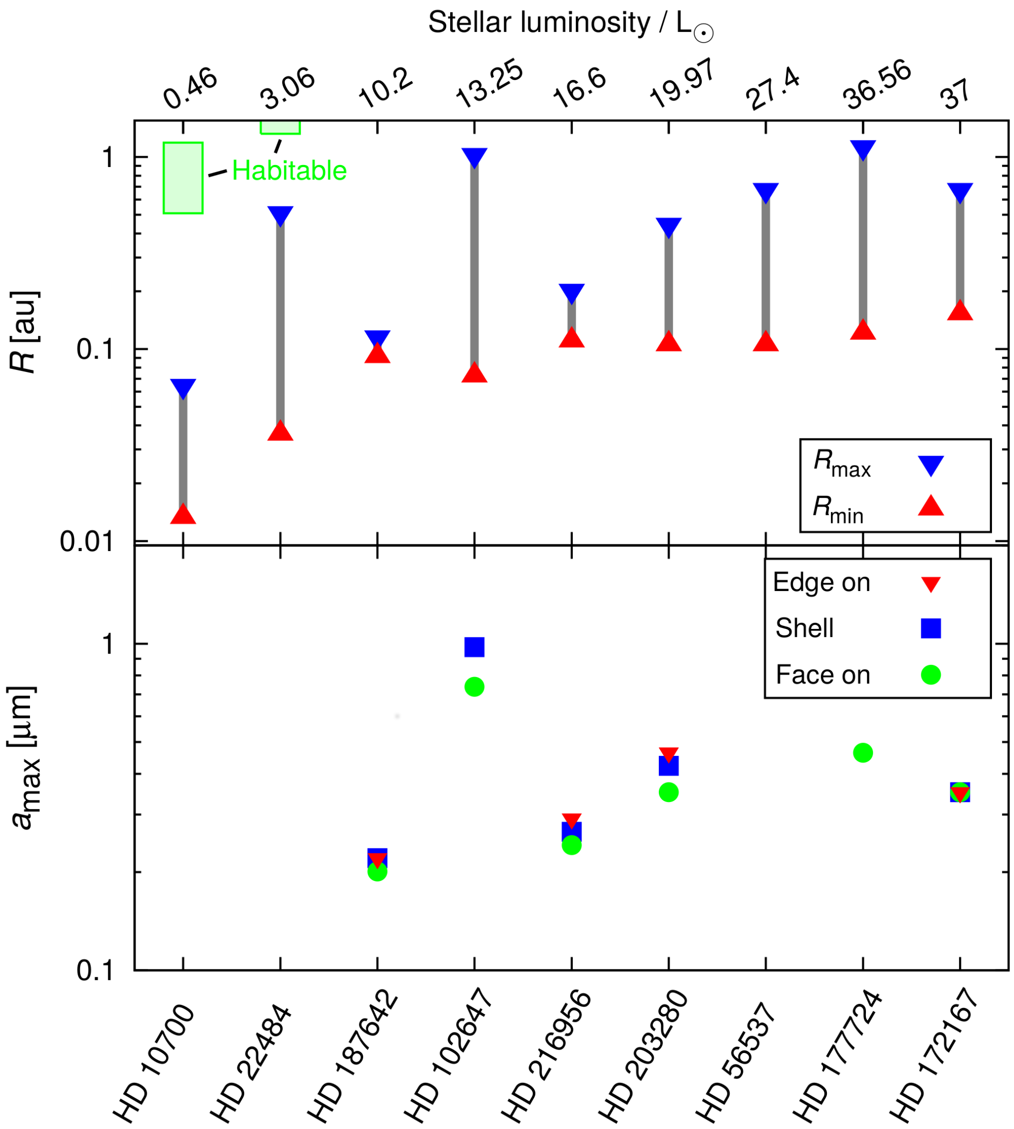
SED modelling - challenges



- Small amount of NIR and MIR data (low-sampled SED)
- K band (2.2 µm; Absil+ 2013) and N band (8.5 µm; Mennesson+ 2014)

- Simple disk model
  - Disk ring with inner radius R, outer radius 1.5 R
  - Single grain size a
  - Geometry: Face-on and edge-on disk, spherical distribution
- SED-modelling, using code **debris** (Ertel et al. 2011)

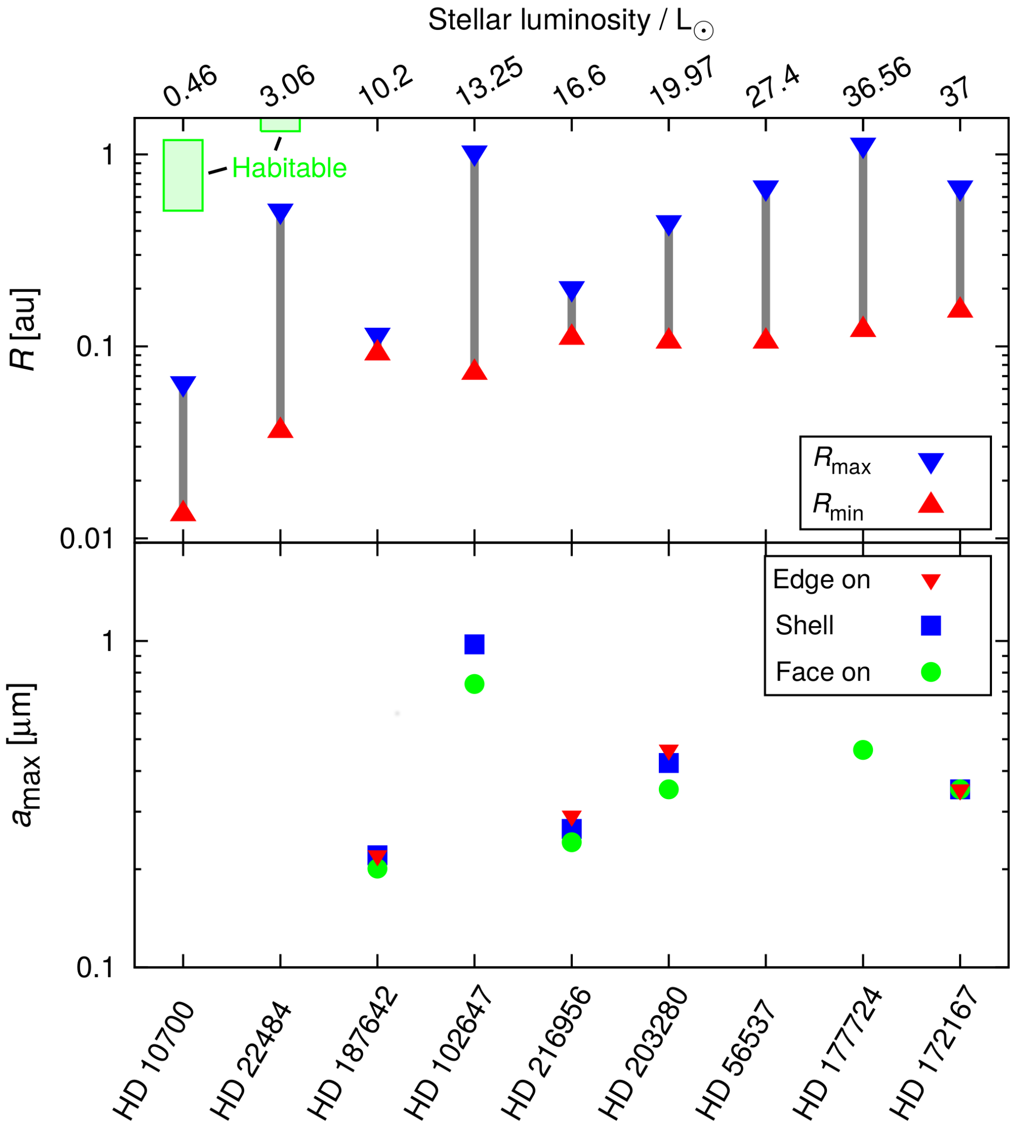
Disk size, grain size, age trend

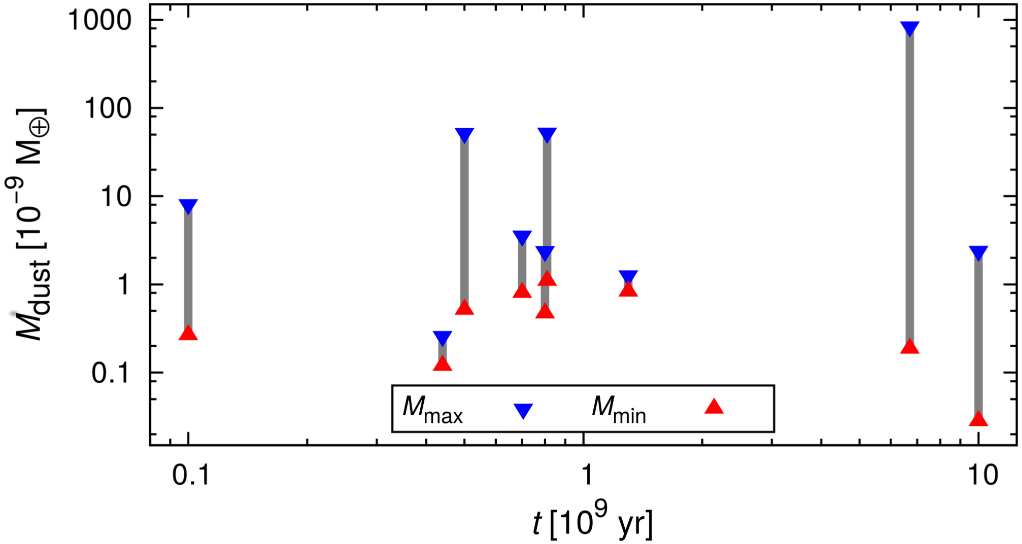


- 0.01 au < R < 1 au
- Correlation $R \propto \sqrt{L}$
- a < 0.5 µm

Kirchschlager+ (2017)

Disk size, grain size, age trend

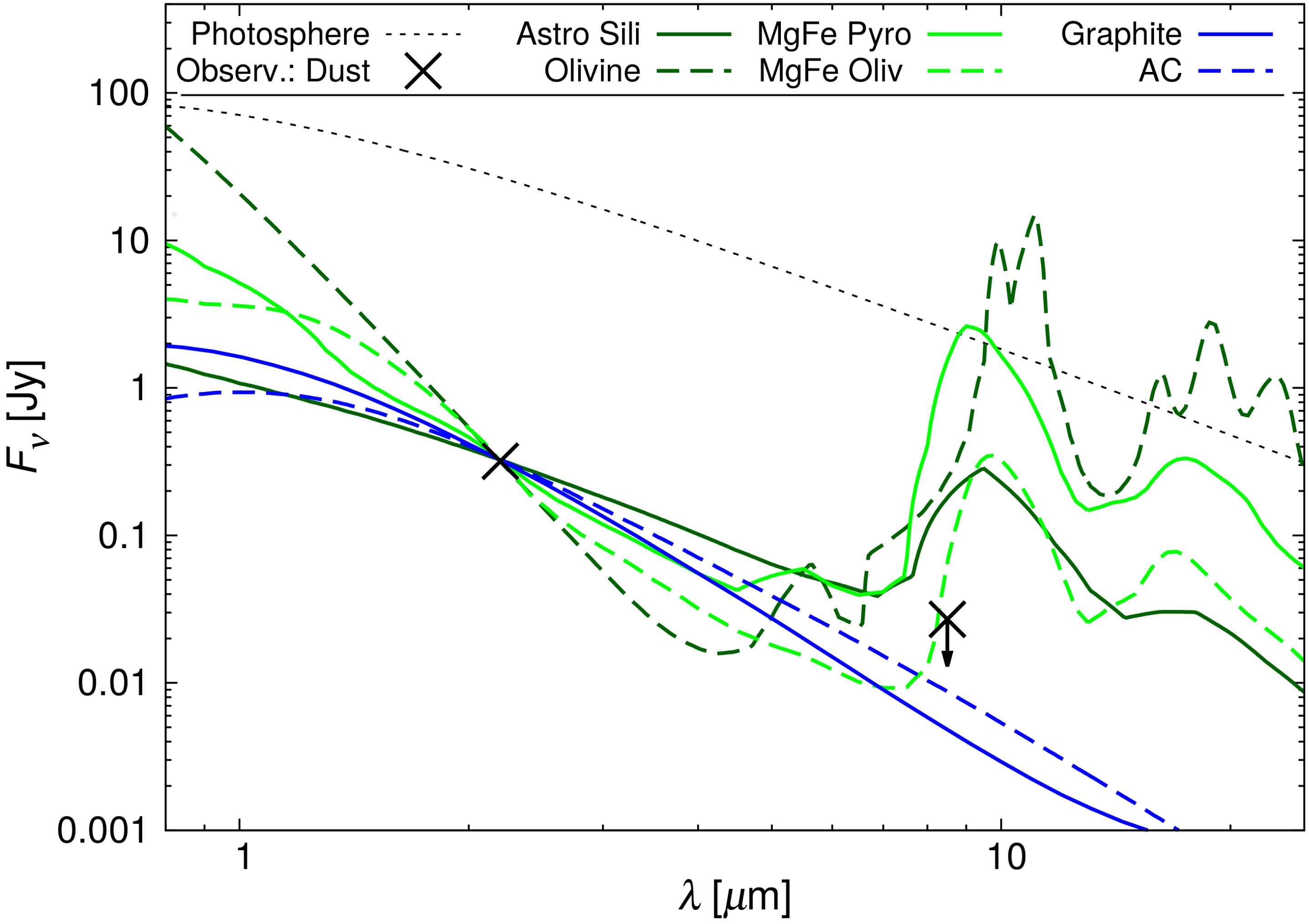




- 0.01 au < R < 1 au
- Correlation $R \propto \sqrt{L}$
- $a < 0.5$ µm
- No significant correlation age – dust mass

Kirchschlager+ (2017)

Material: silicates or carbonaceous dust?



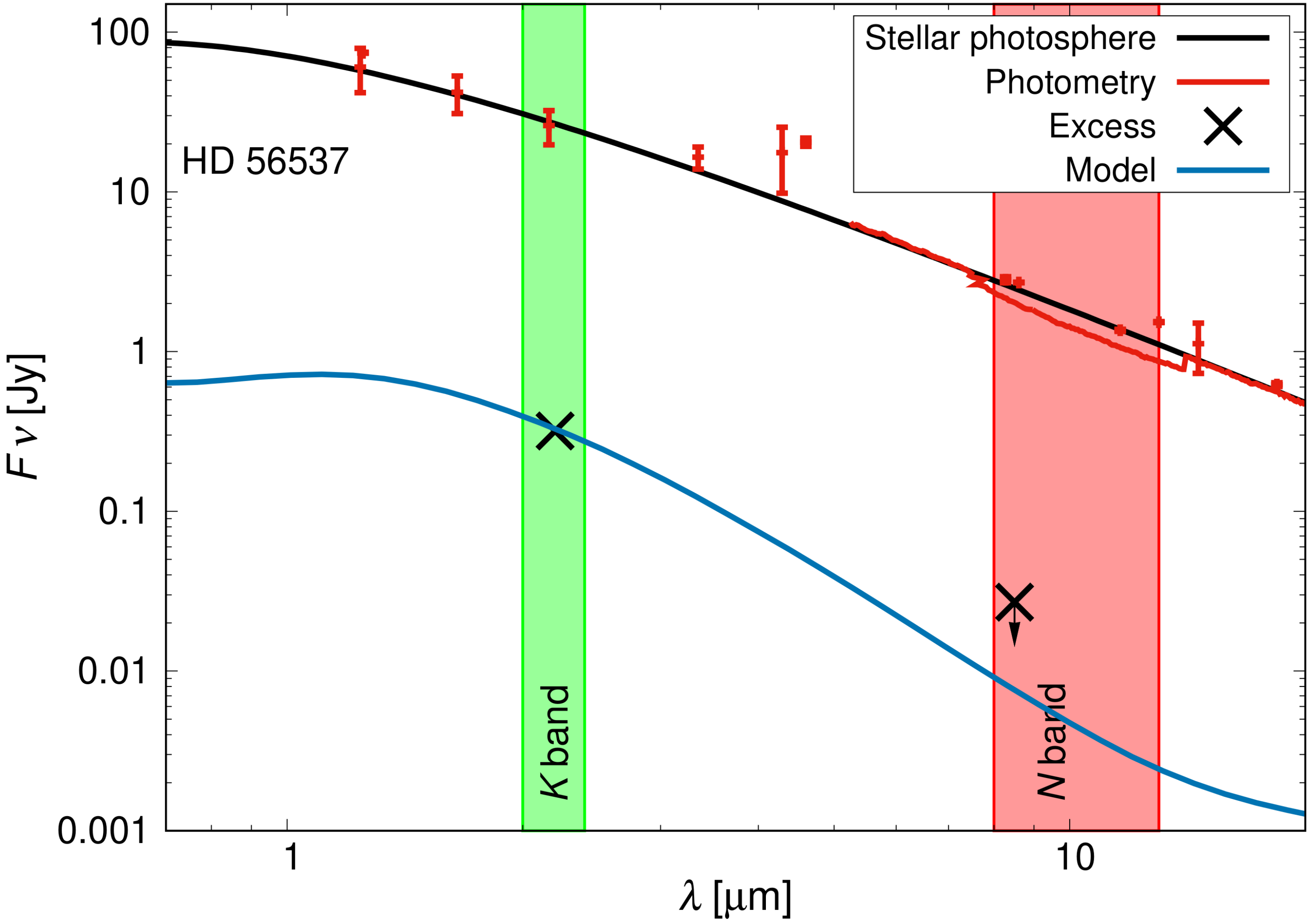
- Low fluxes around ~10 micrometer

Green: silicates ✗

Blue: carbon ✓

We need more observations

- For better constraints on dust properties
- Intermediate wavelengths



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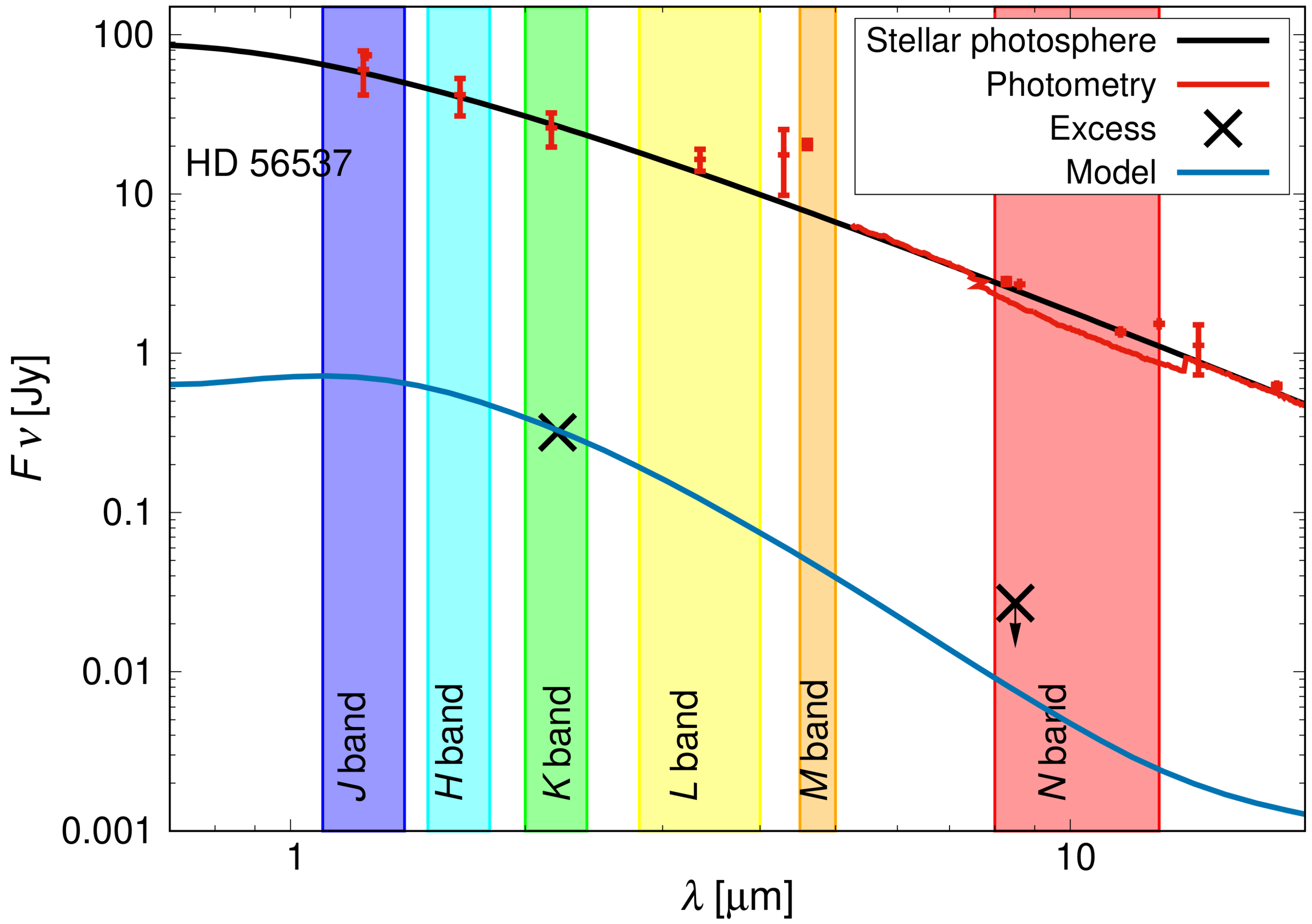
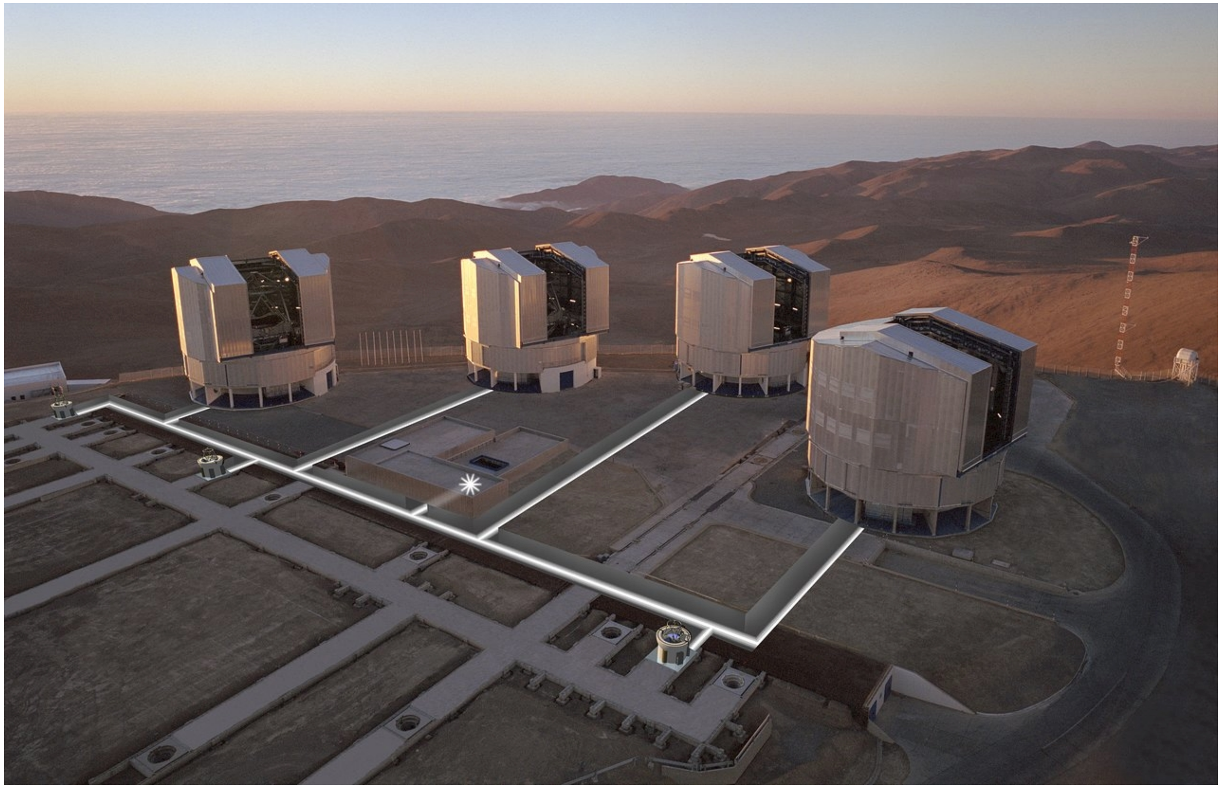
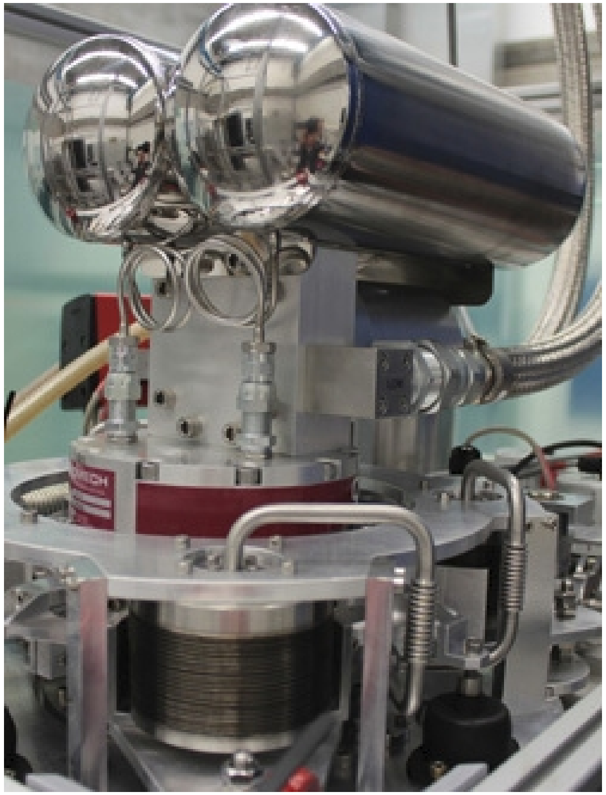


VLTI/MATISSE

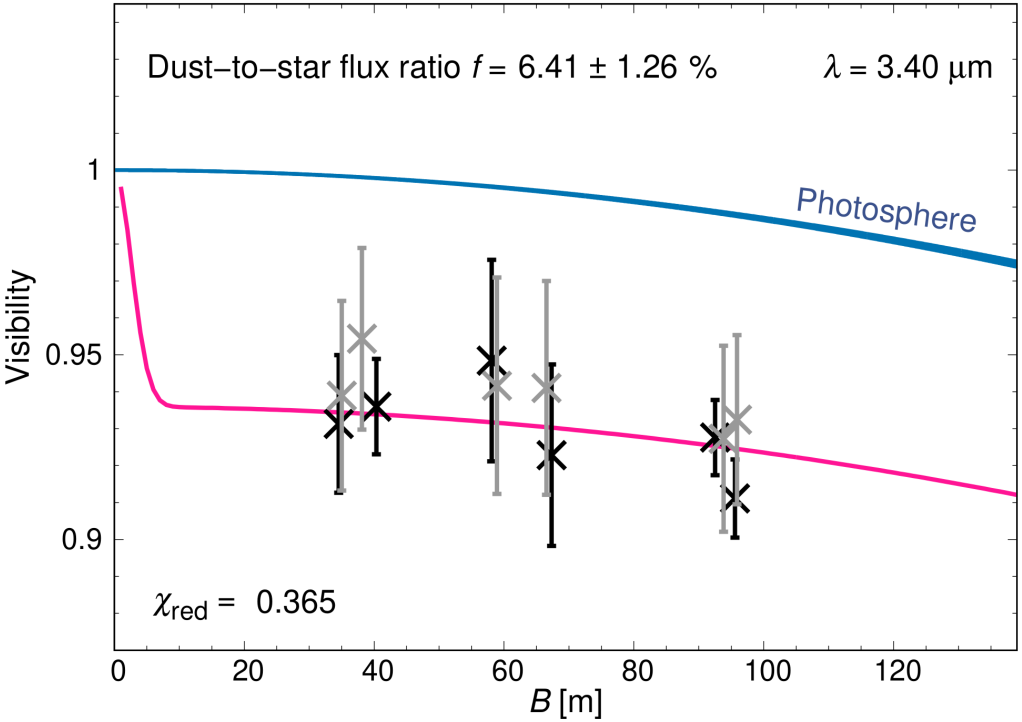




- MATISSE (Multi AperTure mid-Infrared SpectroScopic Experiment)
- Second generation MIR interferometer, operating since April 2019
- L/M (λ = 3 - 5 µm) and N band (λ = 8 - 13 µm)

MATISSE observation of κ Tuc (HD 7788)

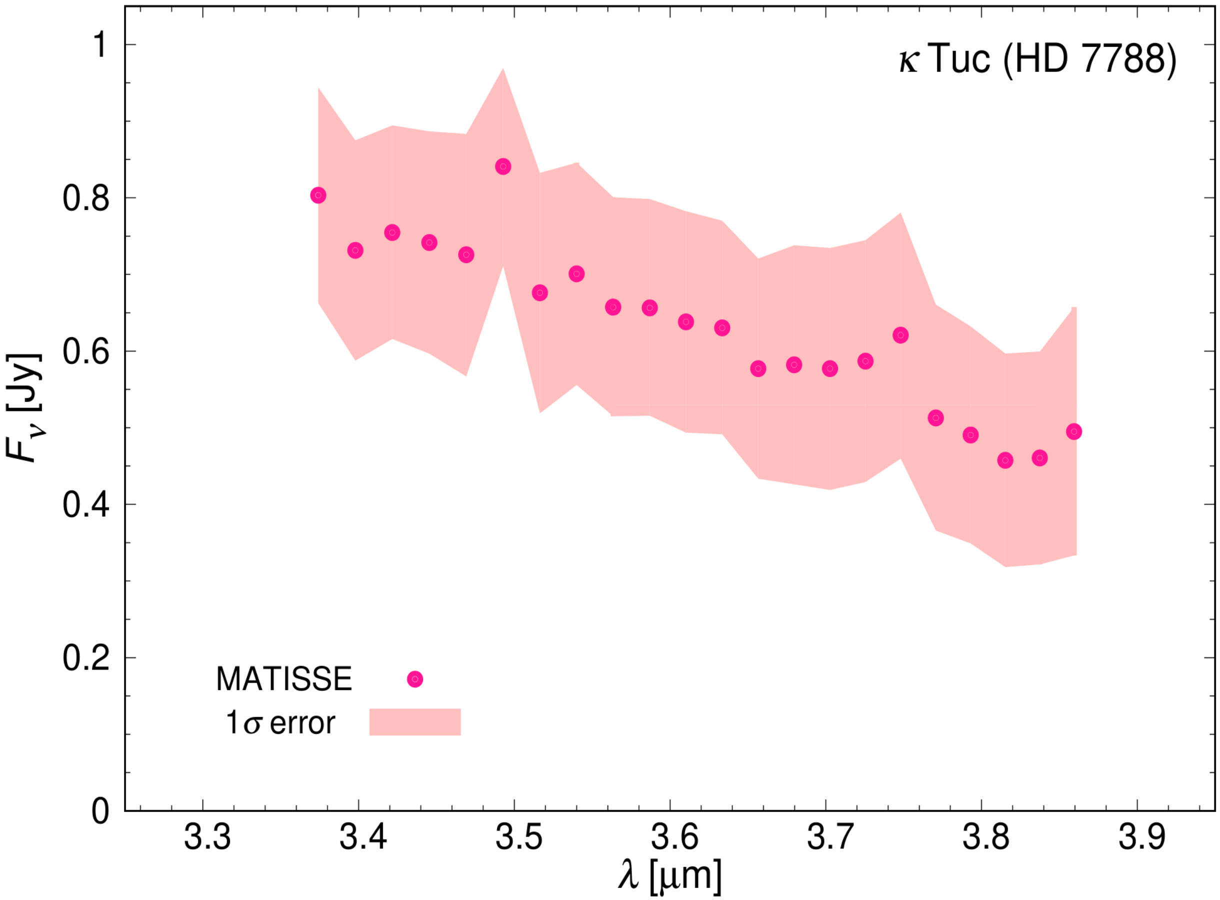
- Observations on 9 and 11 July 2019 (2 x 1 h) in LOW resolution:
  - L/M band (3.2 – 4.5 µm, λ_c ~ 3.9 µm)
  - N band data ignored (too noisy)
- Medium configuration of ATs (Baselines *B* ~ 30 - 95 m)
  - Star (mostly) unresolved
  - Expected circumstellar emission resolved



- Closure Phases: ~ 0 ⟶ Stellar companion can be ruled out
- Visibility drop from dust emission

Kirchschlager+ (2020)

Significant flux of circumstellar material



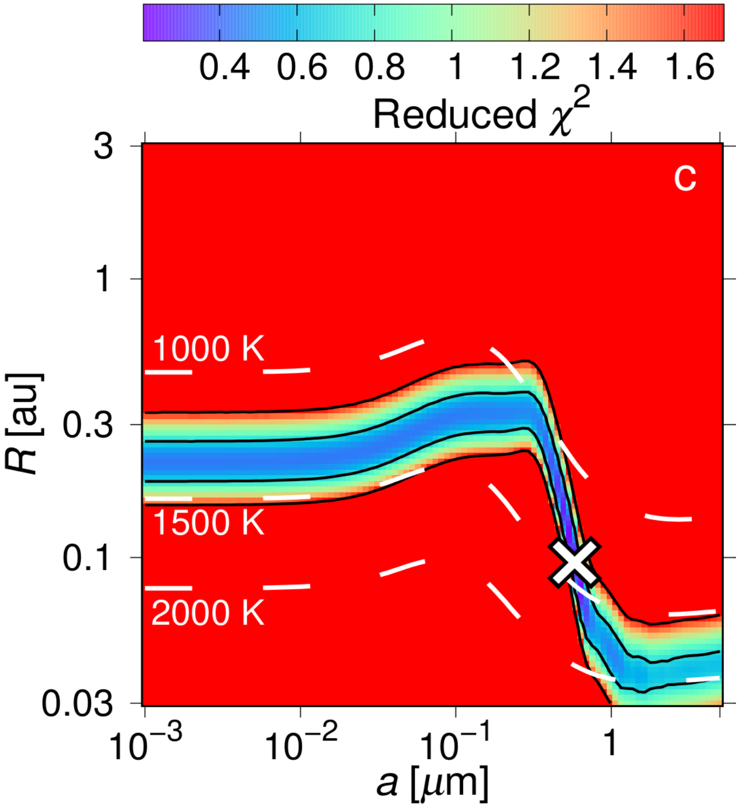
- *f* between 5 and 7 %
- Significant detection at a wavelength λ if $f/\Delta f > 3$

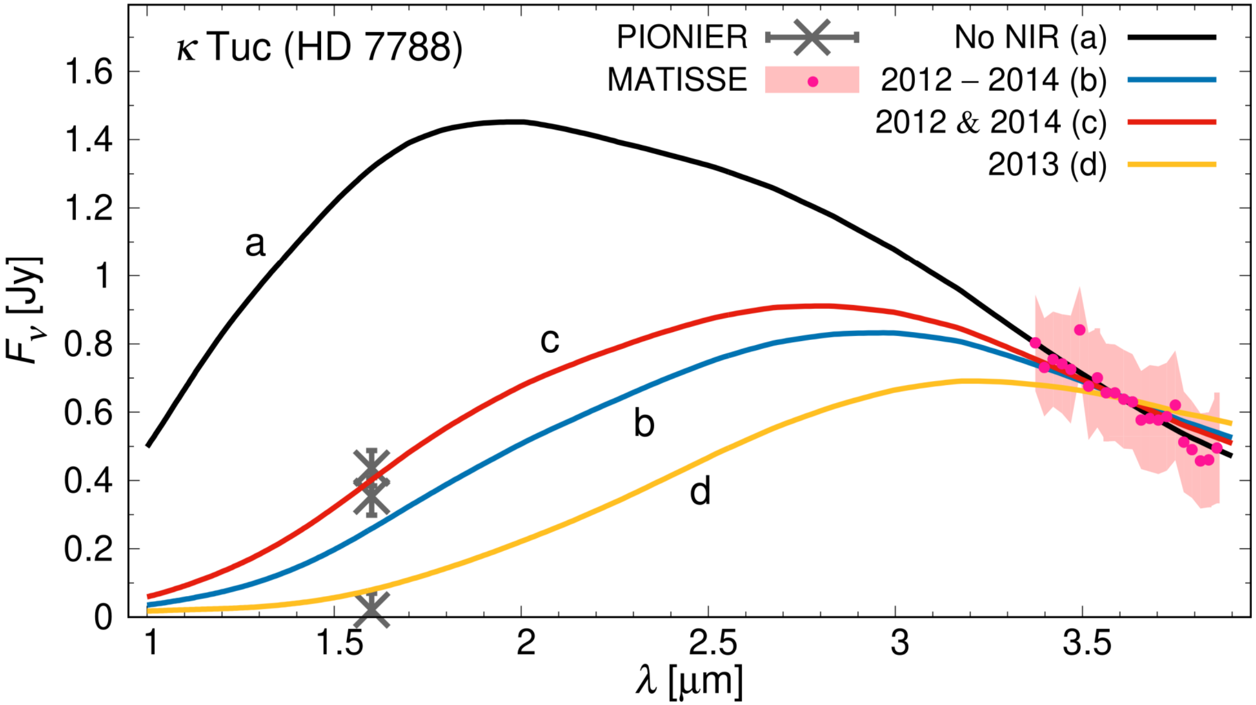
  → λ = 3.37 – 3.85 μm
- Spectral index: α = 3.92

Kirchschlager+ (2020)

- Calculation of real dust fluxes
- For the central star κ Tuc: Dust fluxes between 0.5 and 0.9 Jy

SED modelling - MIR 2019 + NIR 2012 & 2014





<u>Best-Fit:</u>

a = 0.58 µm

R = 0.1 au

M_{dust} = 2.0E-9 $M_\oplus$

T_{dust} = 1430 K

Grain size not constrained within 1σ confidence level

Kirchschlager+ (2020)

Prospects for the observation of hot exozodis using MATISSE

- MATISSE is able to observe/detect hot exozodis!
- Further confirmation of the existence of hot dust
- Given the dust-to-star flux ratio of up to 7 % in L band is not unusual, MATISSE will most likely allow the discovery of new hot exozodis
- GRA4MAT will probably increase the sensitivity

- Observations of 7 hot exozodis in September and October 2022
- In particular: -First observation of Fomalhaut in MIR
  -Reobservation of κ Tuc in Sep and Oct 2022
  (temporal variability in MIR?)

WORK IN PROGRESS

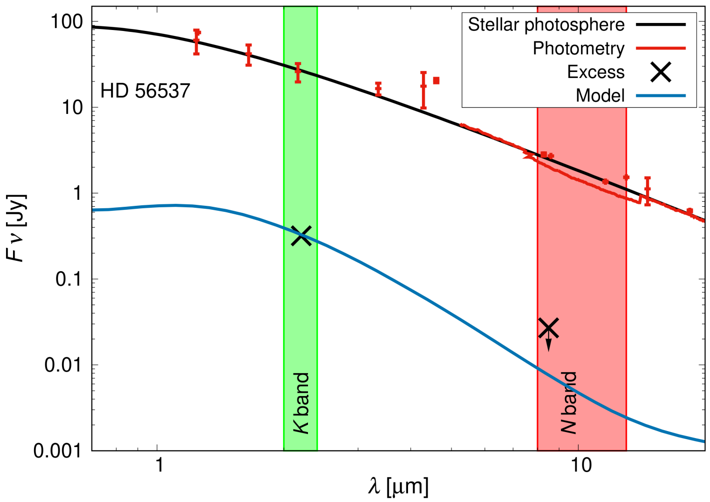
Are large dust grains in hot exozodis?

- Goal: reproduce KIN flux (not upper limit), taking into account larger field of view

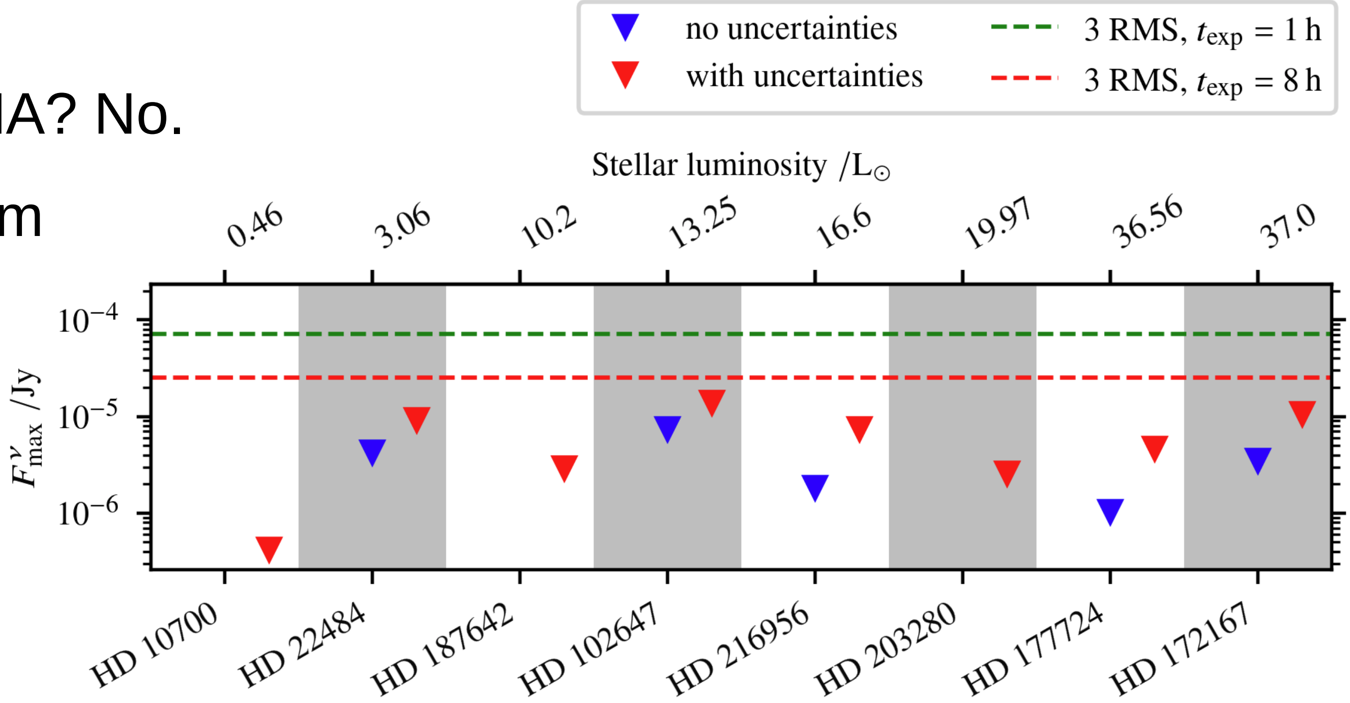
- Allows the presence of 10 to 1000 µm grains:

- Relative flux contribution up to
  - 50% at λ = 4.1 µm
  - 90% at λ = 11.1 µm

- Observable with ALMA? No.



@870 µm

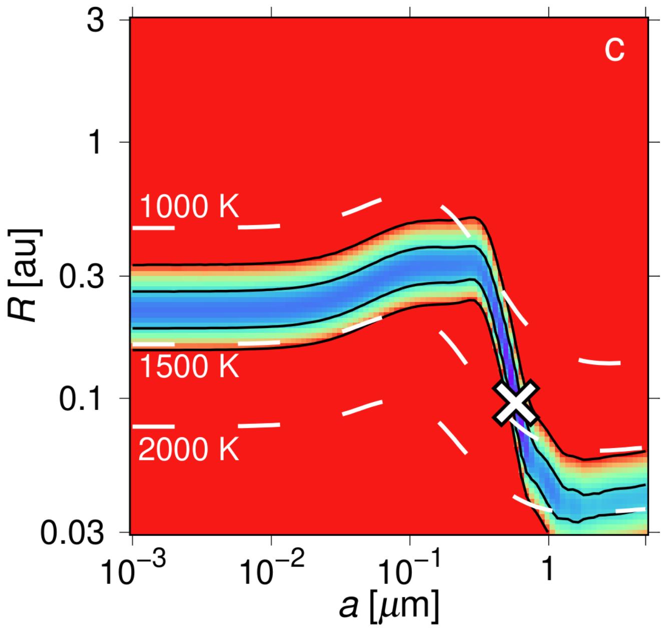


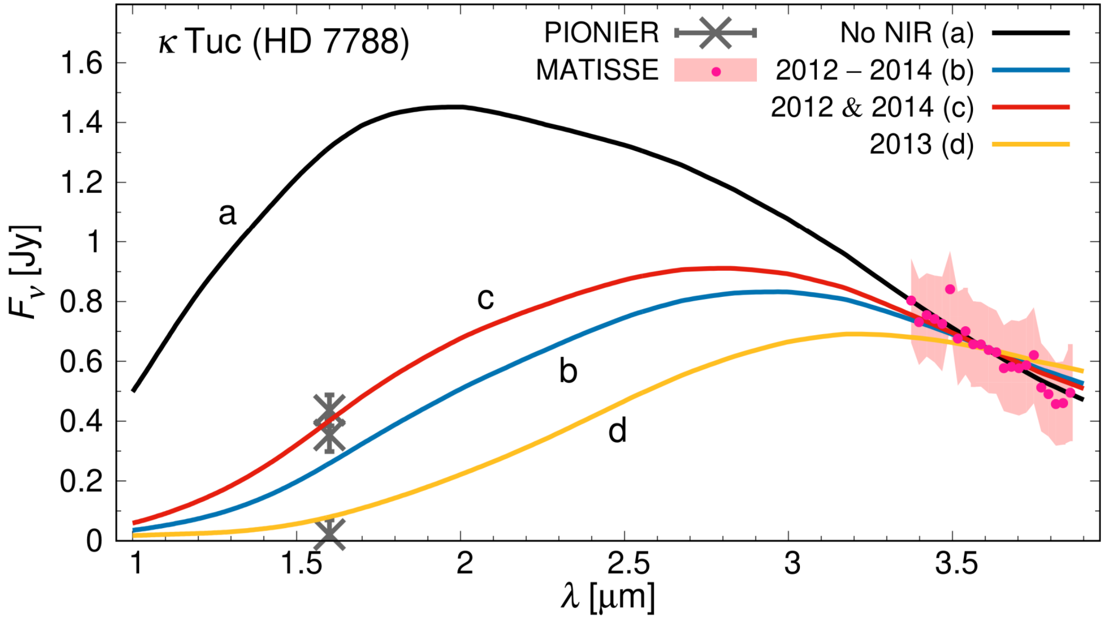
Stuber, Kirchschlager +, in prep.

Main messages from observations

- Disc radius close to sublimation radius
- Grain size not well constrained
- Carbonaceous material required
- Future MATISSE (+GRAVITY) observations will help to further constrain zodi properties

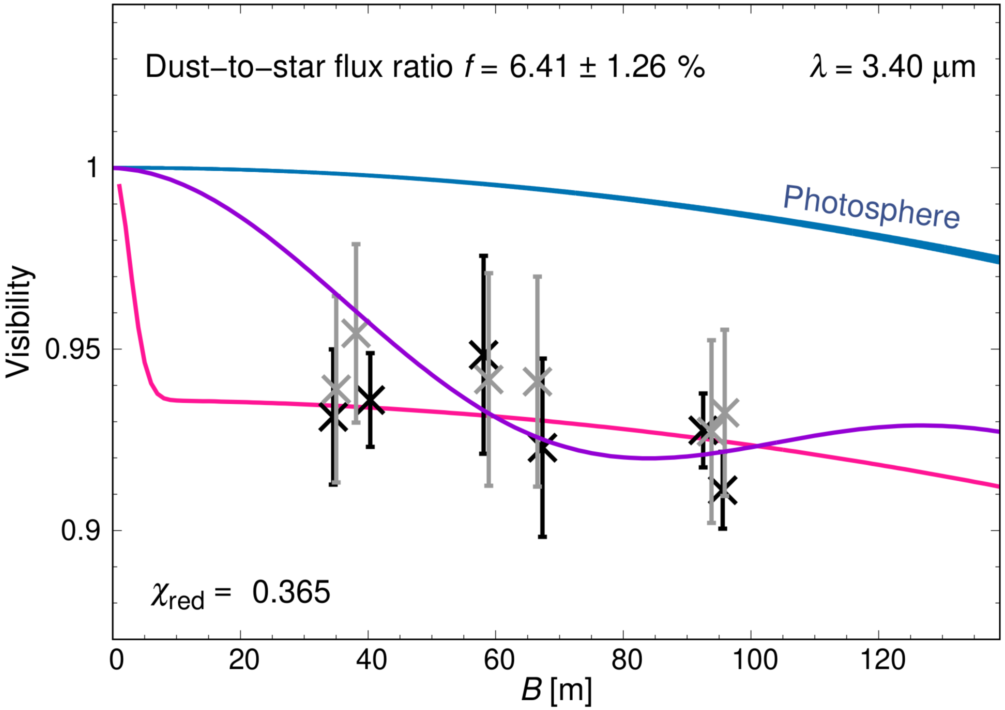
Thank you for your attention!

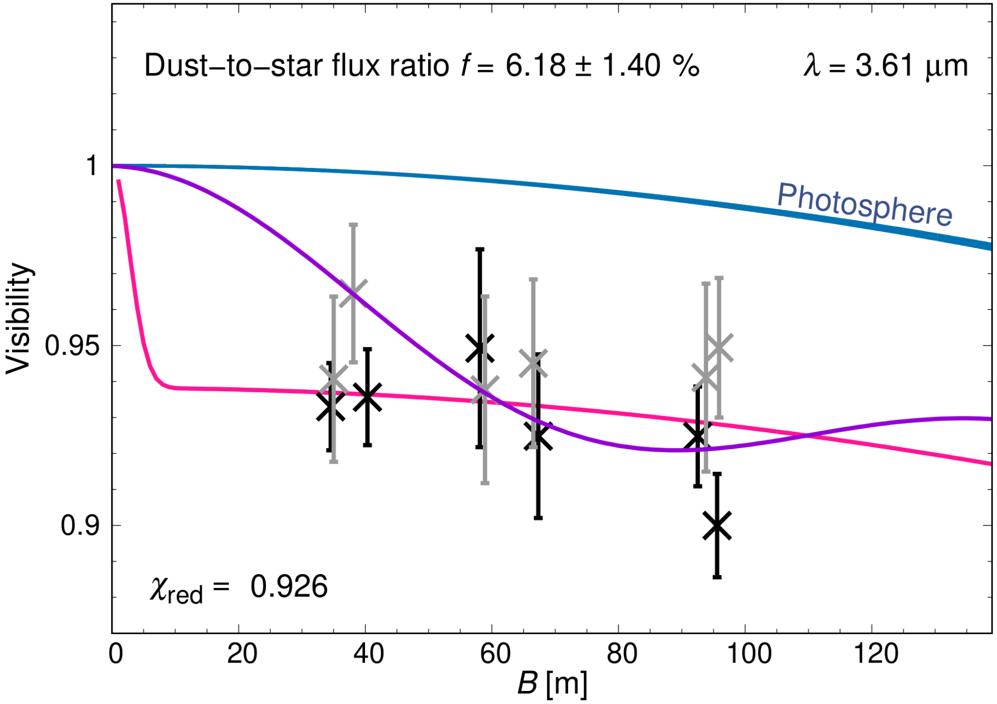




Visibilities of disc model

Calculate the visibility of the maps (thermal emission + scattering) of the best-fit disc model





- Approximates the obs. data and the visibilities of the model of uniform circumstellar emission
- Disc model is compatible with the interferometric data