A near-infrared interferometric survey for bright exozodiacal disks

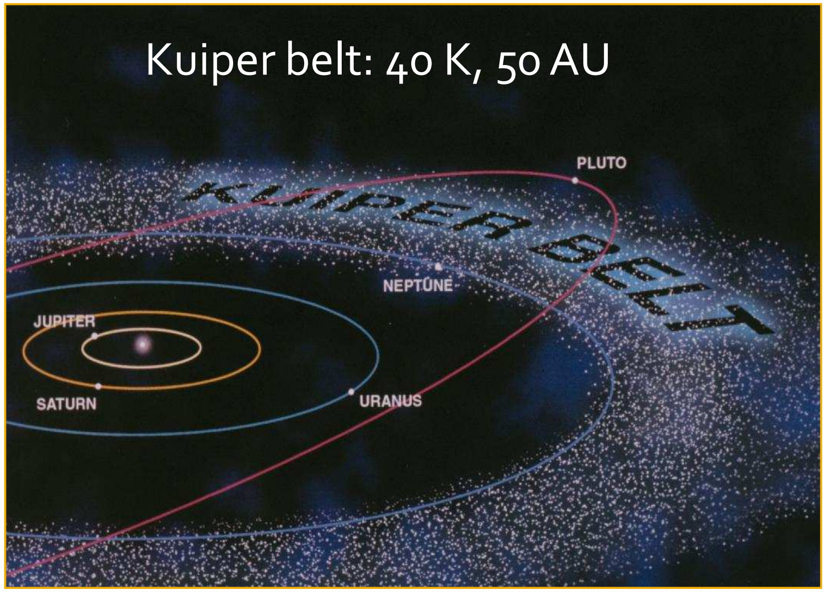
Olivier Absil

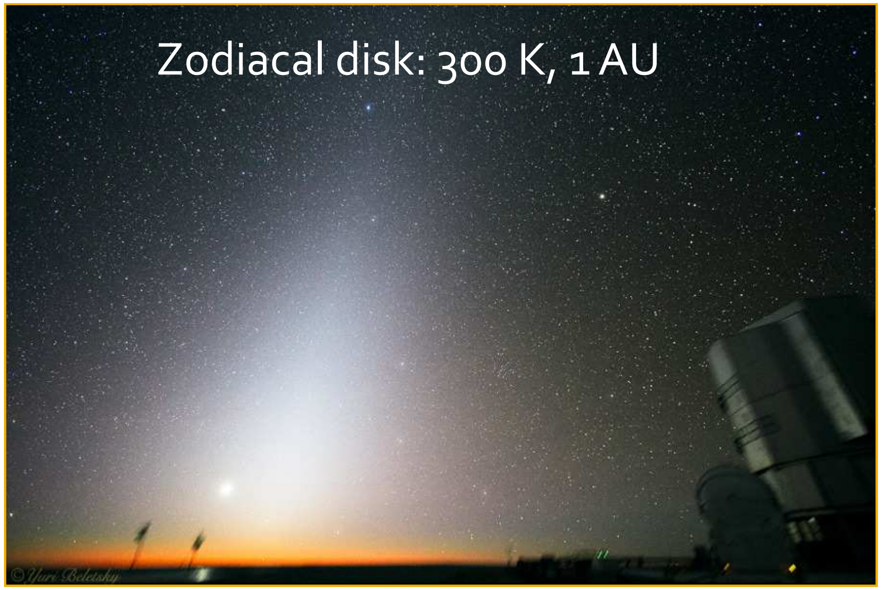
University of Liège

Seminar at OCA – December 6th, 2012

Dust in planetary systems

- We all live in a debris disk!
  - 2[nd] generation dust (asteroids, comets)
- Dust is luminous (**<u>much</u>** more than planets)
- Dust is expected in any planetary system

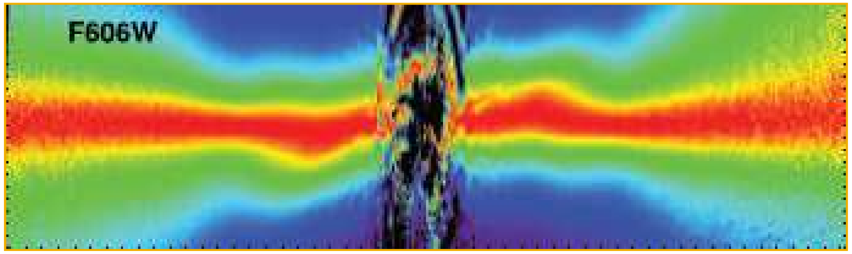


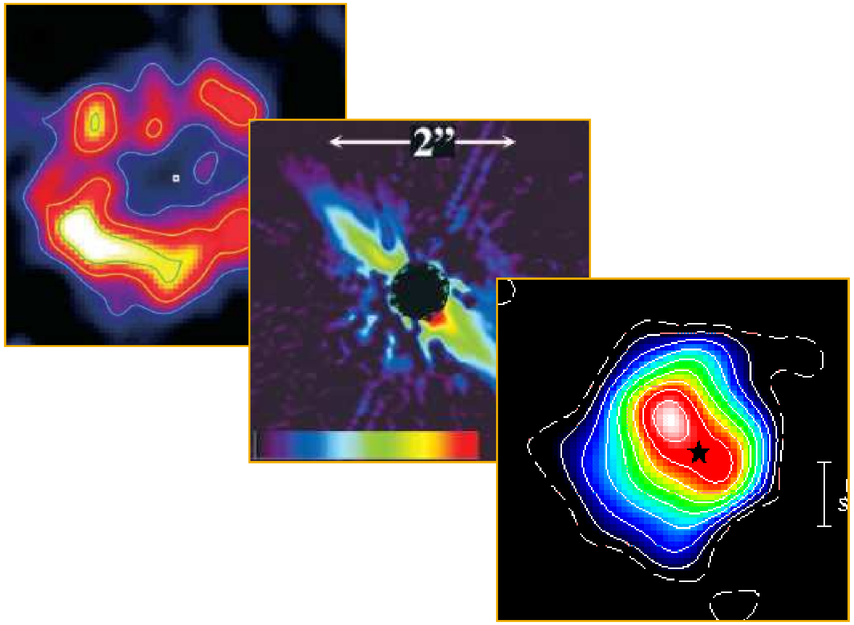


Dust not uniformly distributed

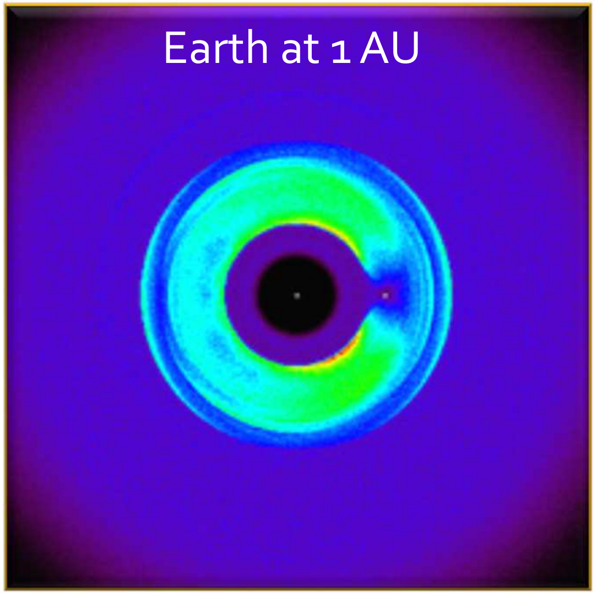
Golimowski et al. 2006; Greaves et al. 2005; Schneider et al. 2005; Holland et al. 1998; Stark & Kuchner 2008; Wyatt et al. 2006

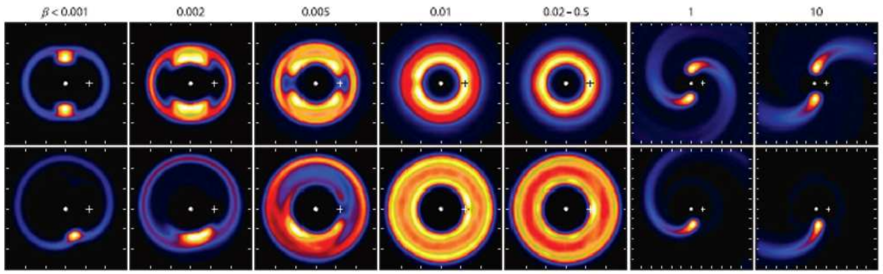
Observations





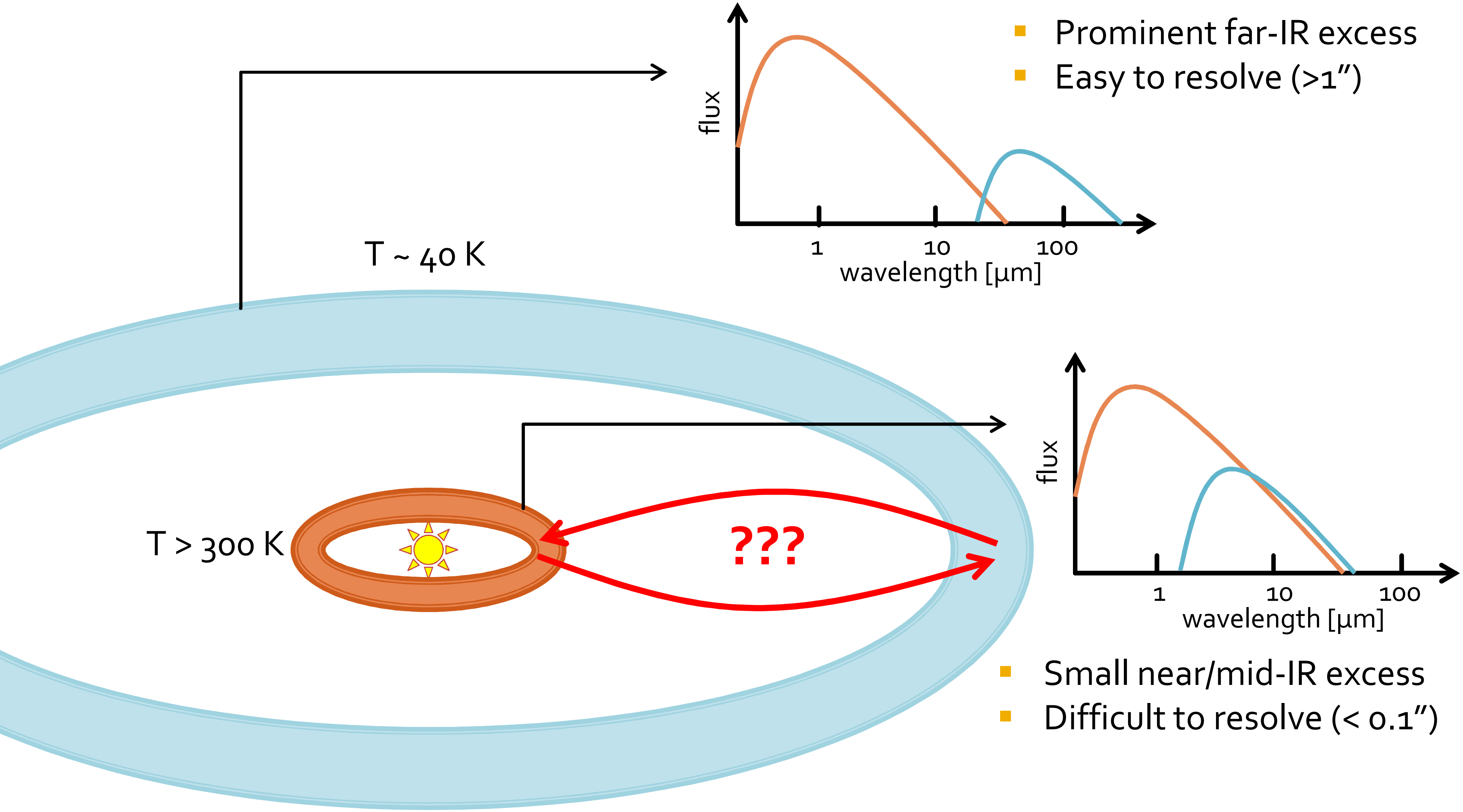
Simulations





Inner vs. outer debris disk

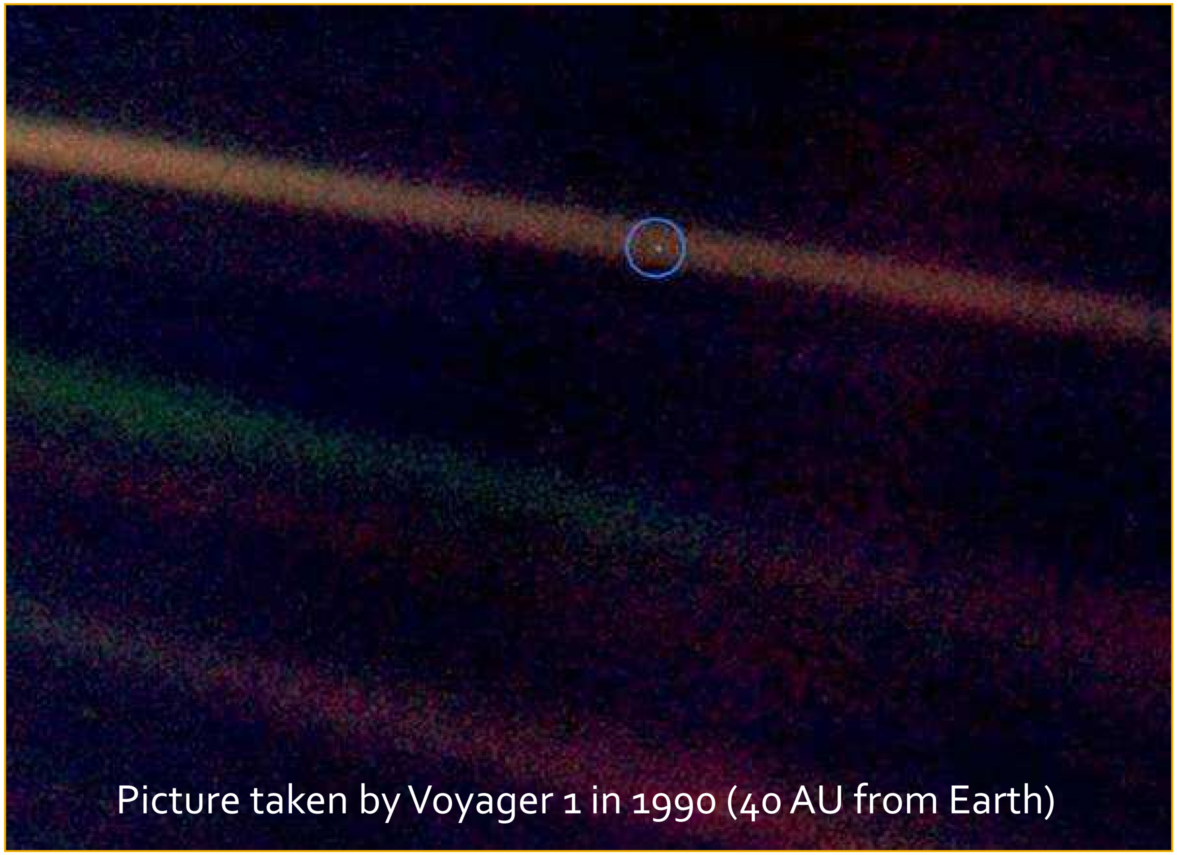
- Prominent far-IR excess
- Easy to resolve (>1″)



- Small near/mid-IR excess
- Difficult to resolve (< 0.1″)

The exozodi problem

- « A mote of dust suspended in a sunbeam »

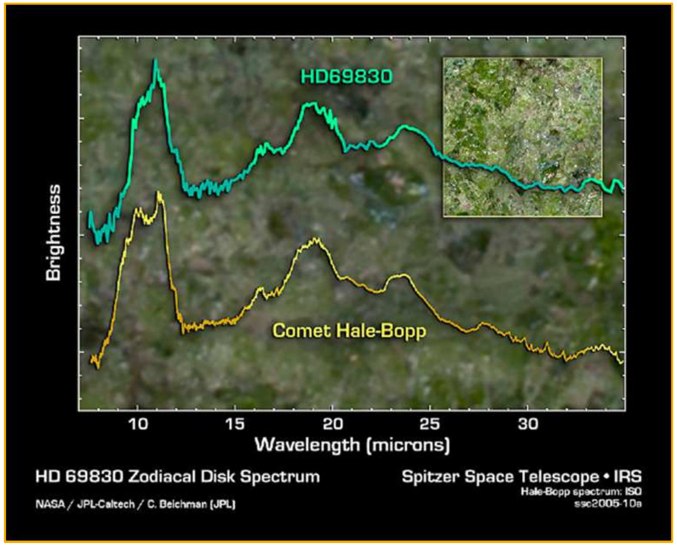


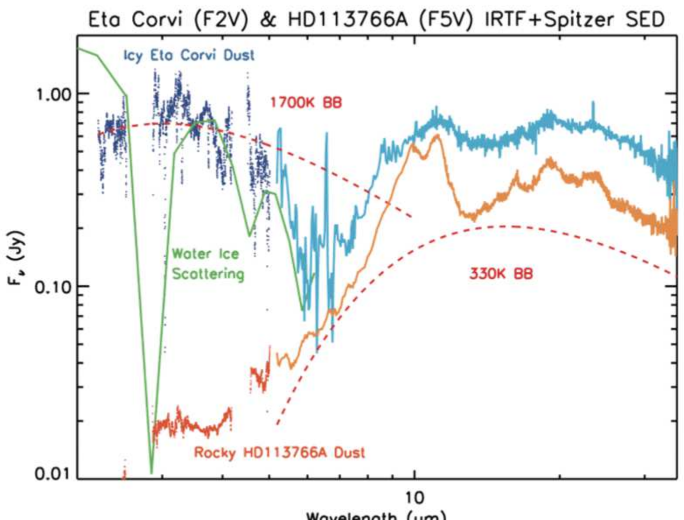
Picture taken by Voyager 1 in 1990 (40 AU from Earth)

Mid-infrared spectro-photometry

Beichman et al. 2006; Lisse et al. 2012

- Spitzer/IRS (5-34 μm)
- Spitzer/MIPS (24 μm)
- Sensitivity
  - ~1000 zodi (8-12 μm)
- Statistics
  - ~1% warm excess
- Limited by
  - Photometric accuracy
  - Model of the stellar photosphere

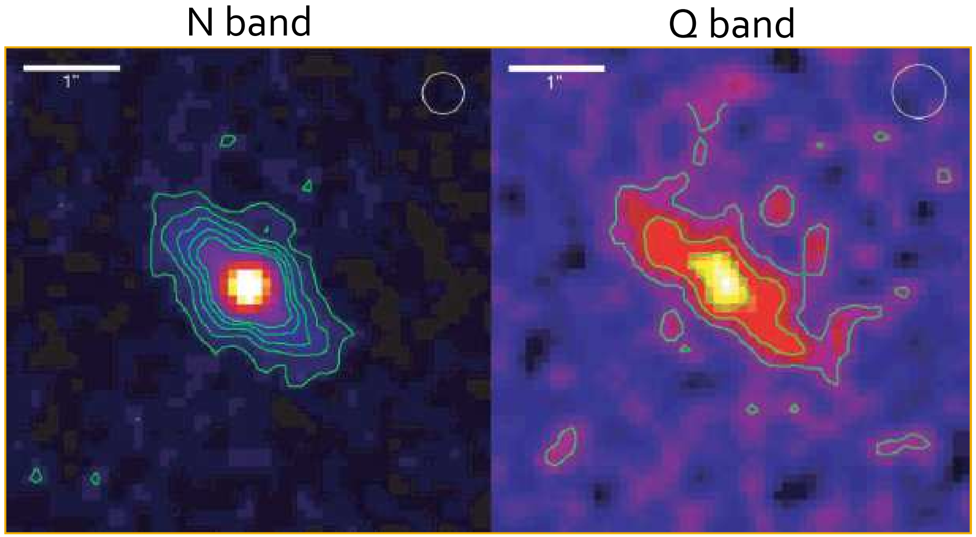


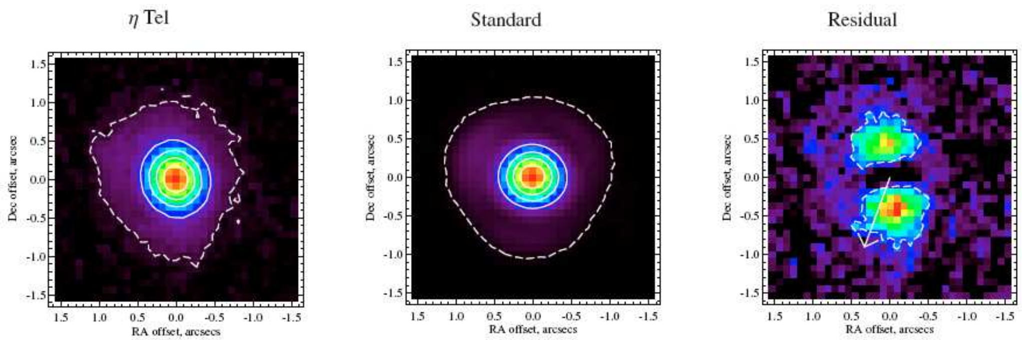


Mid-infrared imaging

Moerchen et al. 2007; Smith et al. 2009

- Bright exozodis resolved only in favorable cases
  - Nearby star
  - Large telescope
- Ground-based → large background
  - Sensitivity ~ 1000 zodi
- Future: JWST/MIRI, ELT/METIS
  - Down to a few zodis?



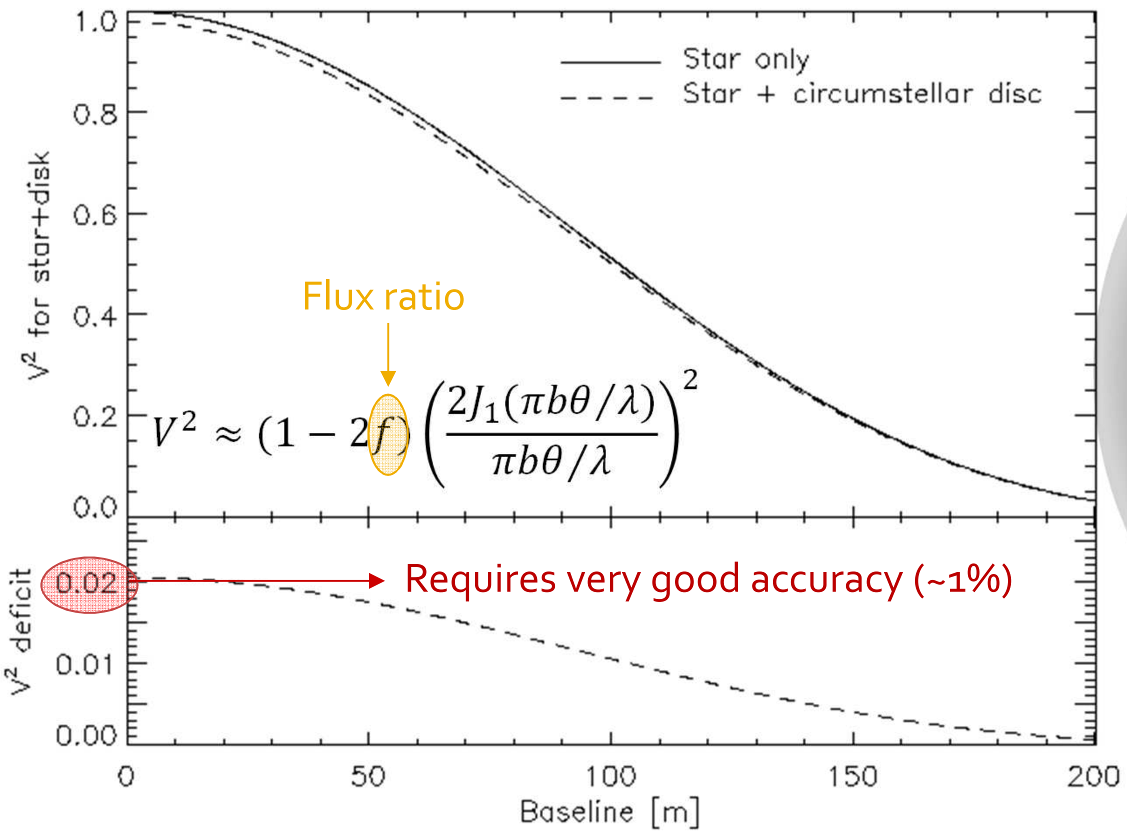


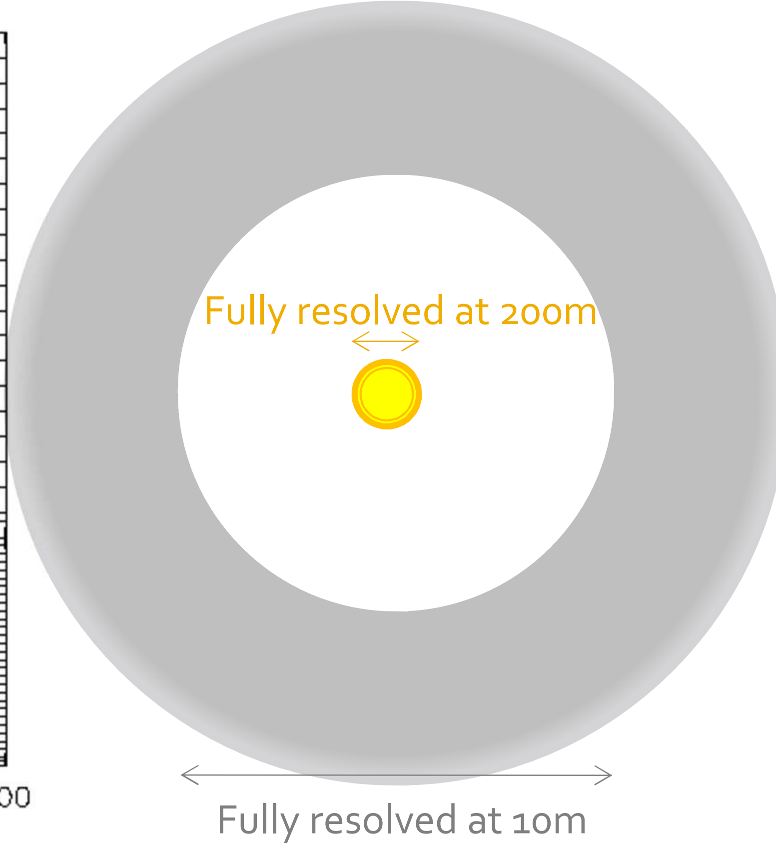
Near-IR interferometry

Principle and first results

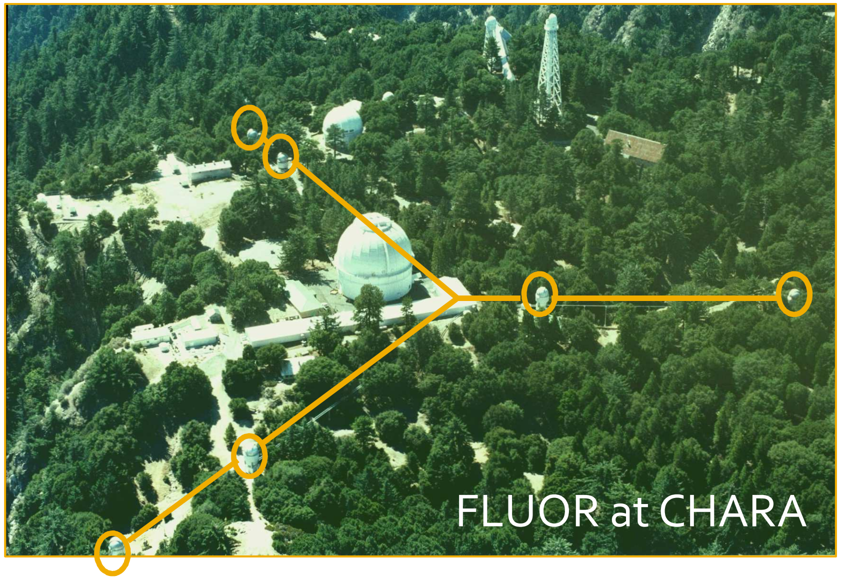
Principle of exozodi detection

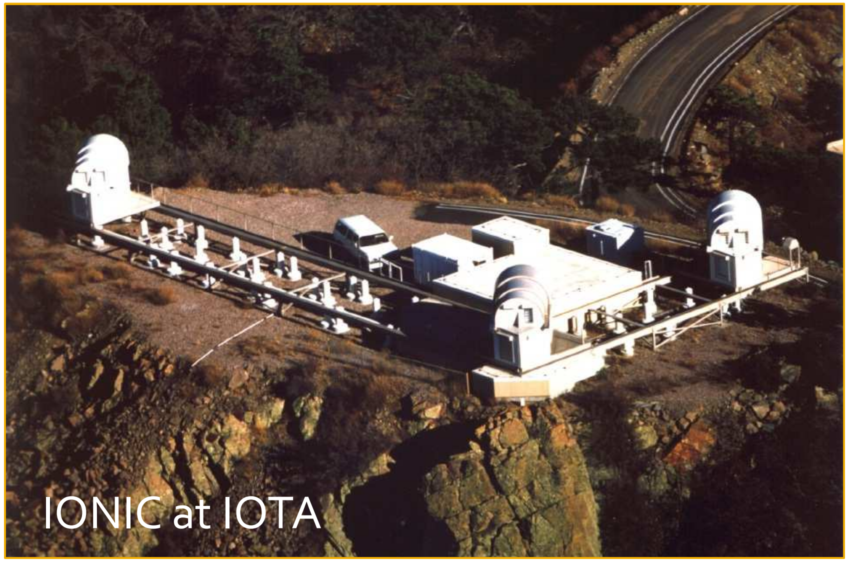
- Disk larger than λ/B → visibility loss
- Best detected at short baselines (~10-30m)

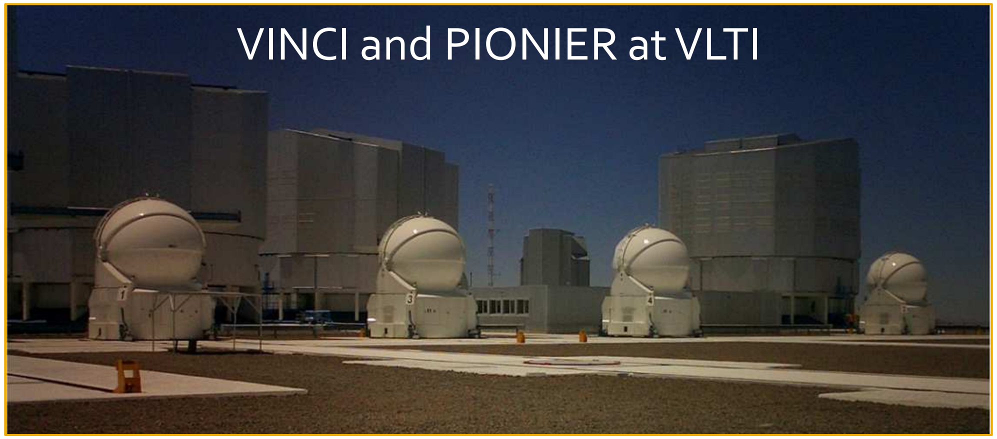




High precision interferometers

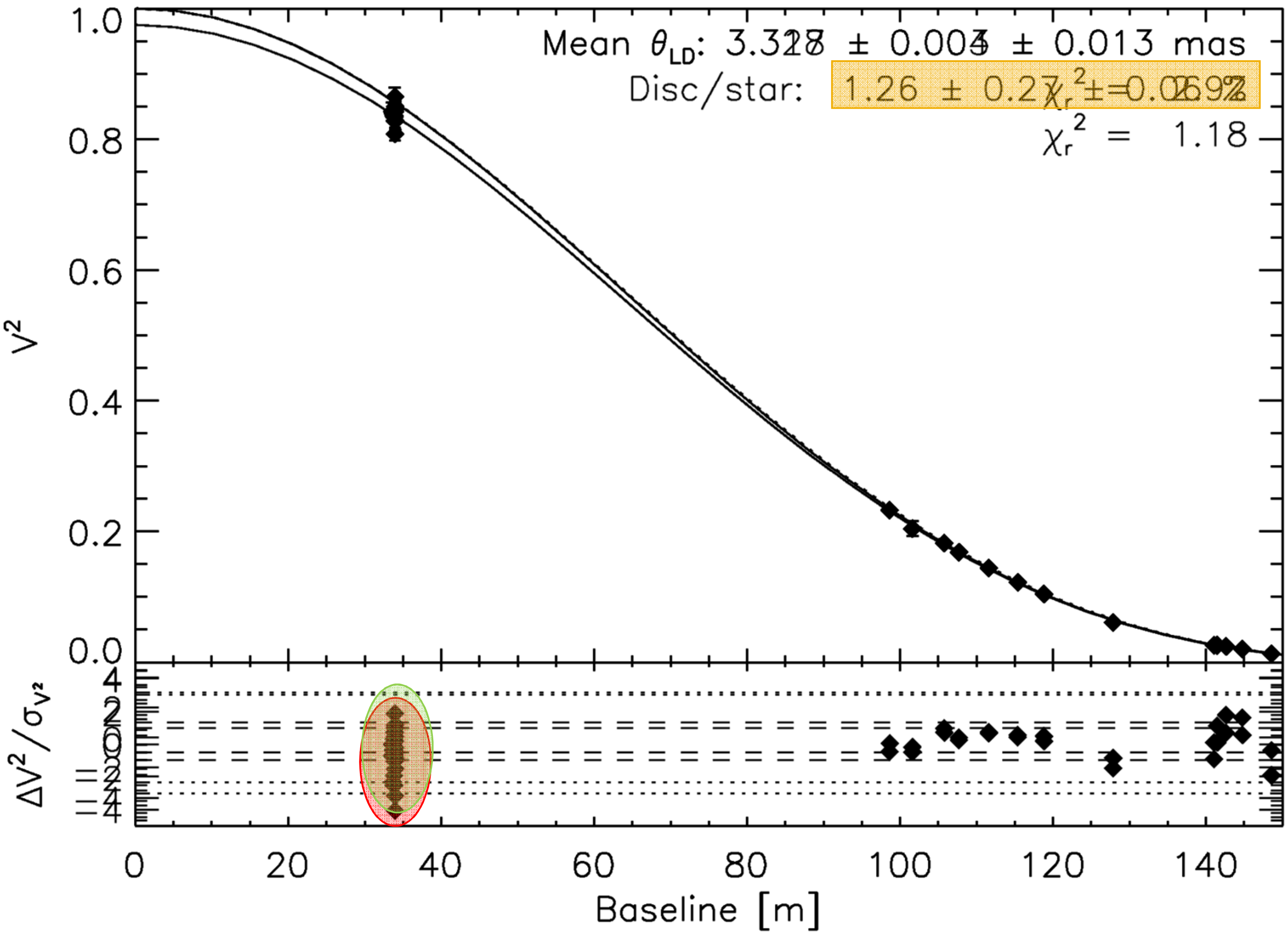






Vega viewed by CHARA/FLUOR

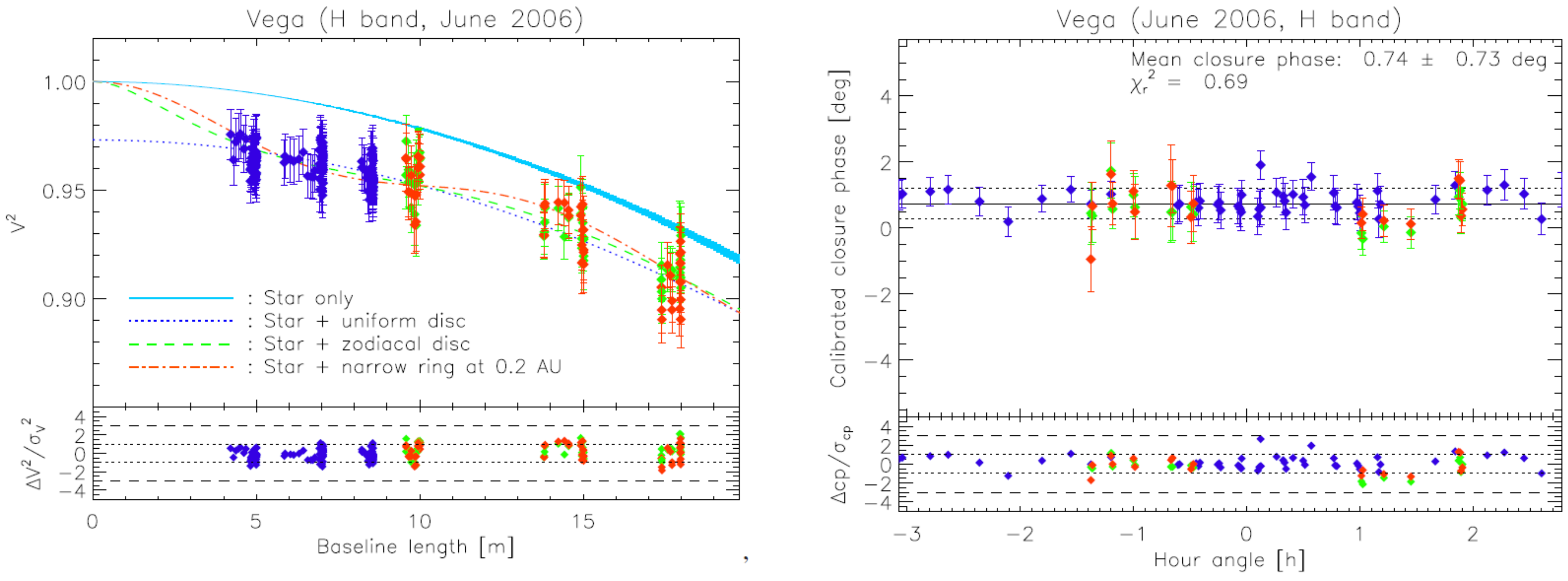
Absil et al. 2006



Morphology?

Defrère et al. 2011

- H-band short baseline data (IOTA/IONIC)
  - No closure phase → not a point-like source
  - Dust distribution not constrained



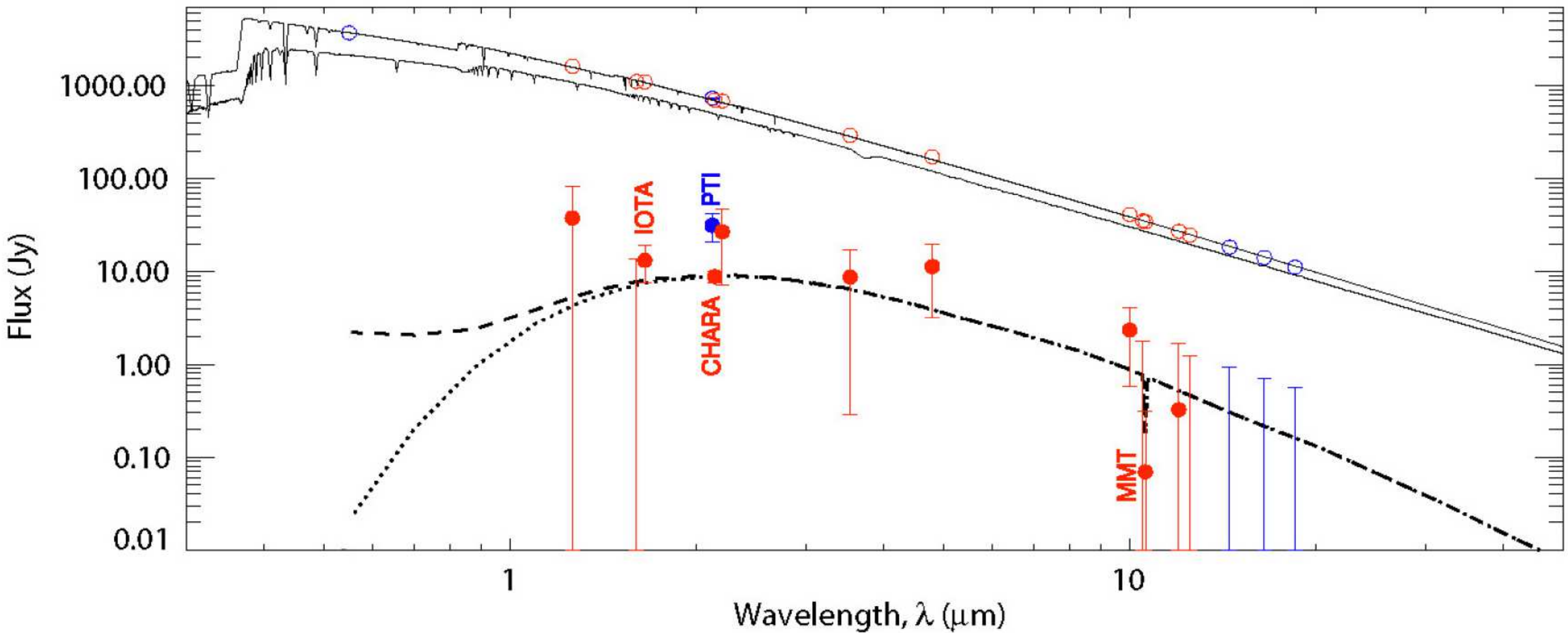
Possible sources of near-IR excess

- Point-like source?
  - No closure phase signal
  - RV and astrometry stable
  - Very low probability for background star
- Stellar wind / circumstellar gas?
  - A stars: very weak winds ($\sim 10^{-12..14}\ M_{\odot}/yr$)
  - Free-free emission: should be stronger at mid-IR
  - Ae/Be phenomenon: no evidence for Hα emission
- Circumstellar dust?
  - Thermal emission & reflected flux
- New, unknown phenomenon?

Radiative transfer modeling

Defrère et al. 2011

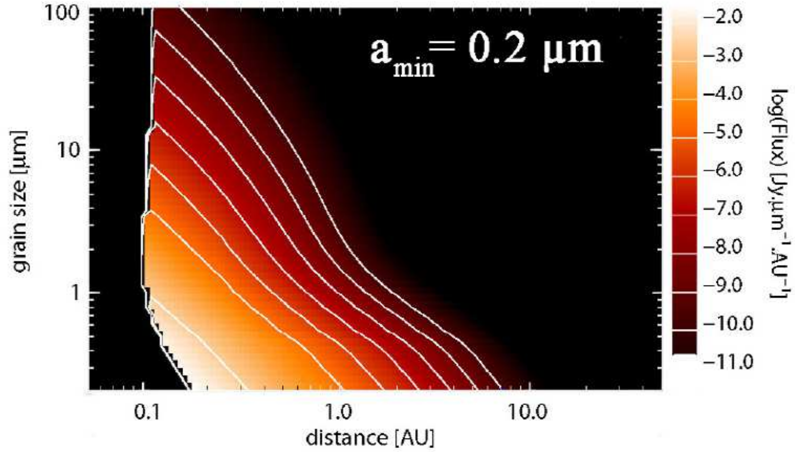
- H- and K-band interferometry
- N-band nulling interferometry (MMT/BLINC)
- Archival near- to mid-IR spectro-photometry

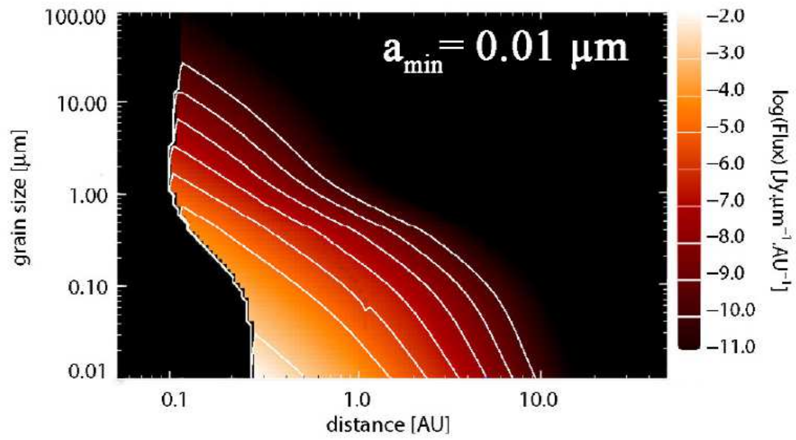


Most probable dust properties

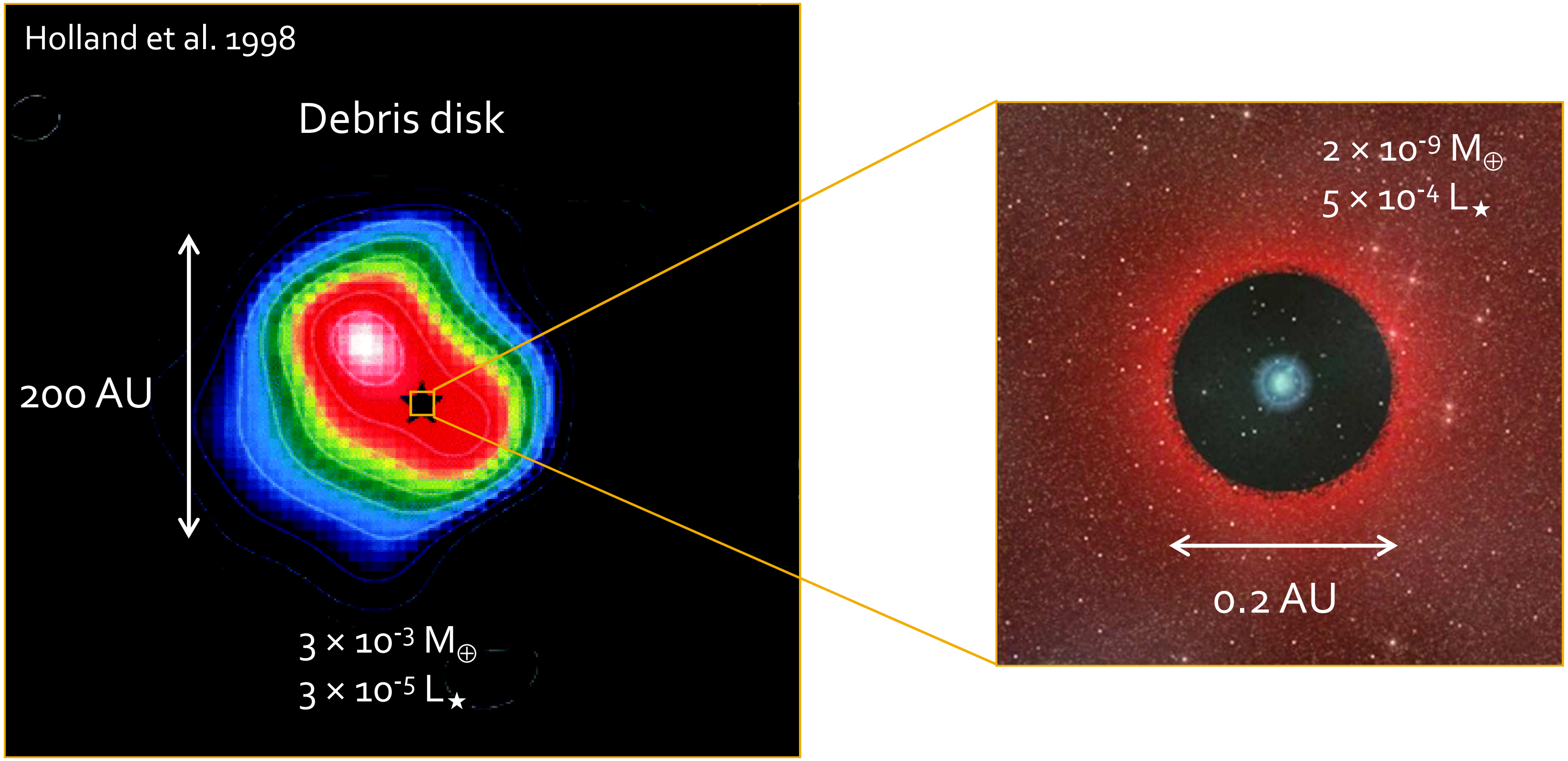
Defrère et al. 2011

- Bayesian χ^2 analysis of large parameter space
  - Grains < blowout size
  - Hot grains (> 1000 K)
  - Presence of carbons ≥ 10%
  - Distance: ~ 0.1 – 0.5 AU
  - Steep density power law: $\alpha < -3$ → ring?
- Mass: $\sim 2\times10^{-9}\ M_{Earth}$
- Luminosity: $\sim 5\times10^{-4}\ L_{star}$



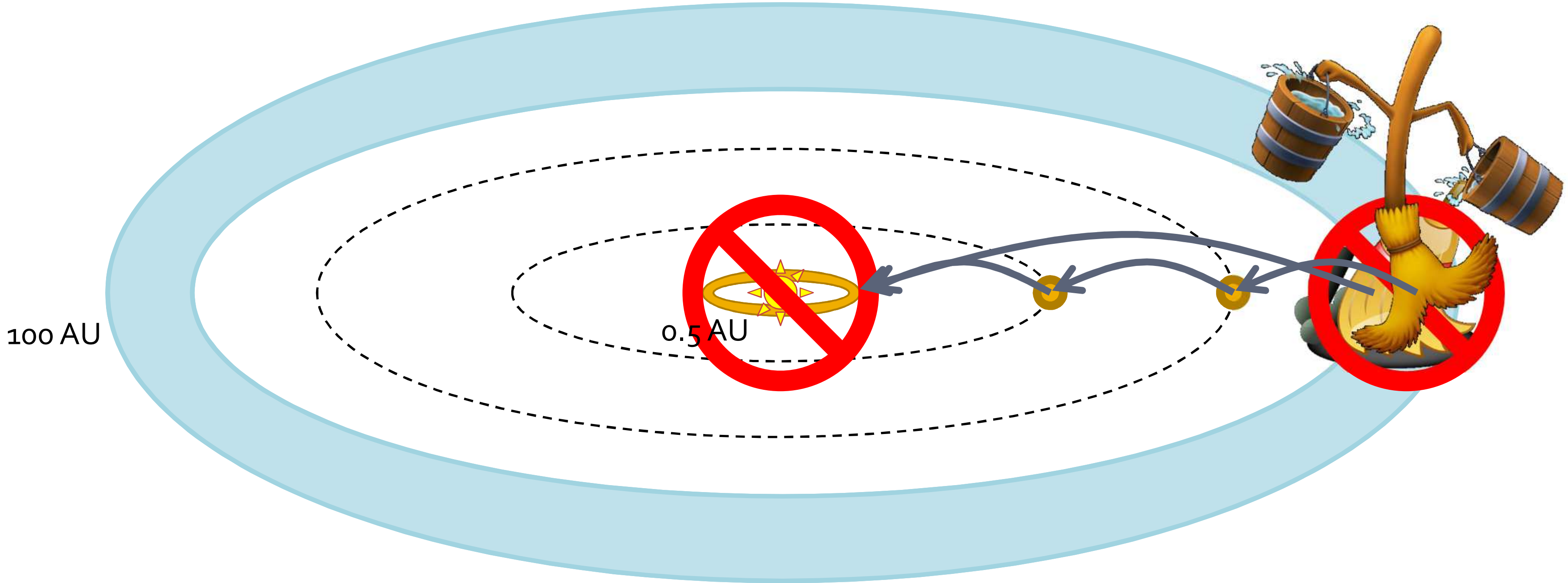


New view of Vega



Origin of hot dust: steady state?

- Local production?
- Connection to outer disk?
  - Poynting-Robertson drag?
  - Multiple scattering of comets?



N-body simulations for Vega

Bonsor et al. 2012

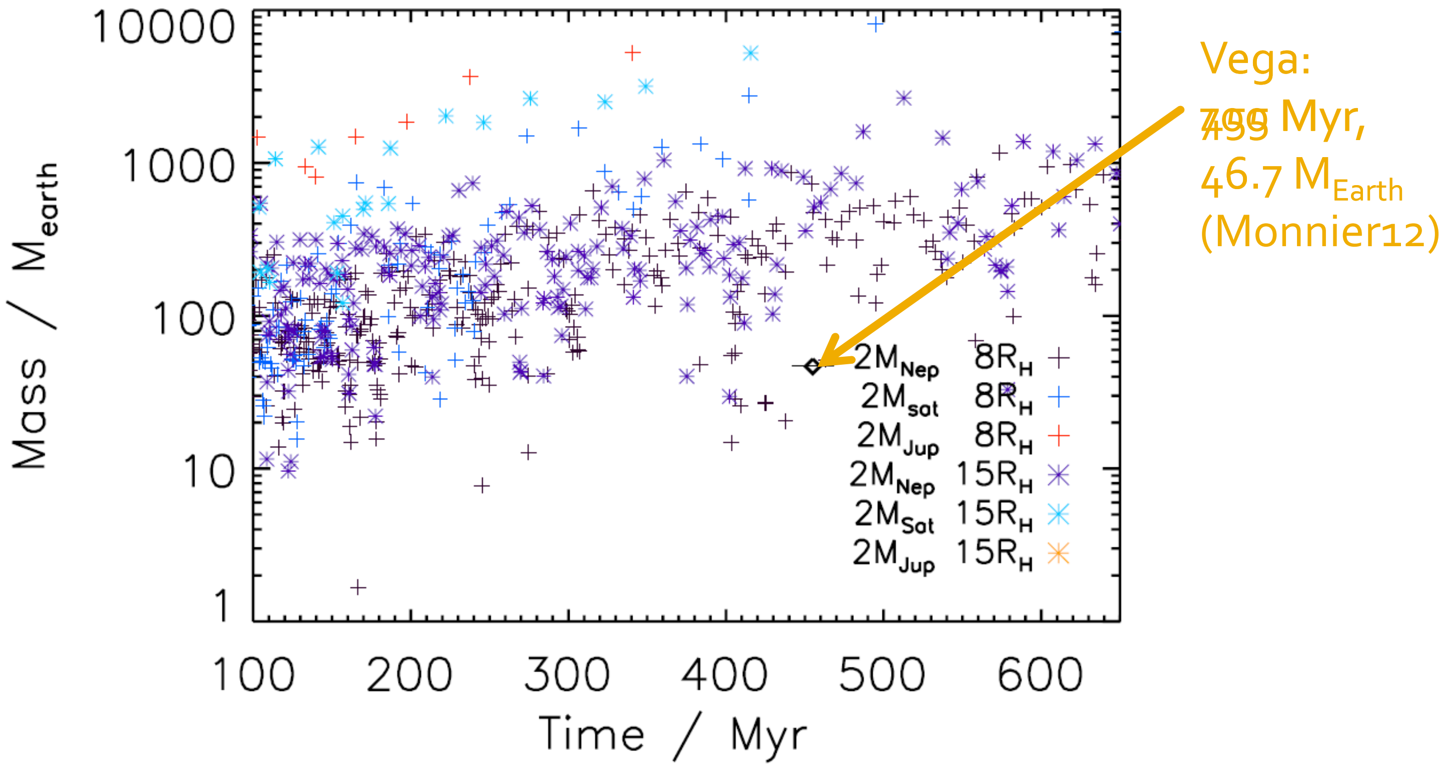
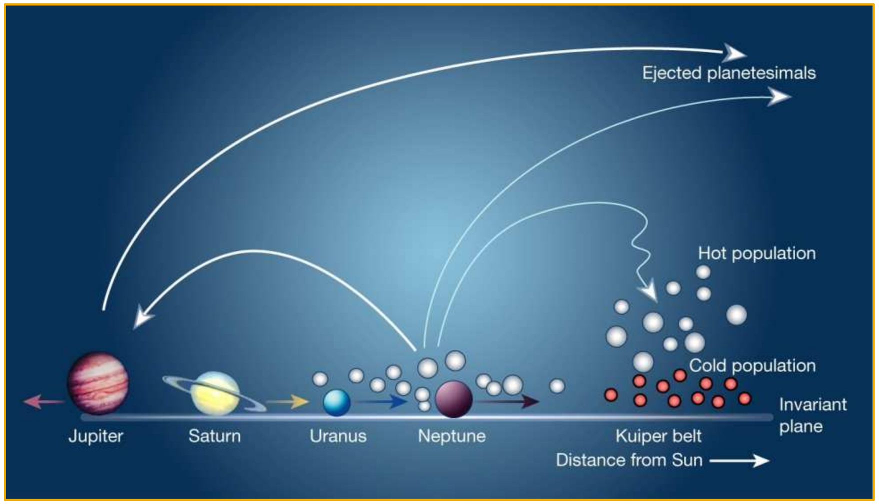


Fig. 12. Total outer belt mass required if scattering by a chain of equal mass planets, as shown in Fig. 9, or detailed in Table 3, is to replenish an exozodi inside of 1 AU around Vega at the required rate of 10^{-9} $M_{\oplus}$/yr.

Origin of hot dust: transient?

- Isolated event?
  - Large collision (e.g. Earth-Moon)
  - Break-up of giant comet
- Dynamical perturbations?
  - Falling Evaporating Bodies
    - Asteroid belt disturbed by MMR with massive planet
  - Late Heavy Bombardment
    - Global rearrangement
- Statistical study may help



A near-IR survey

CHARA/FLUOR observations

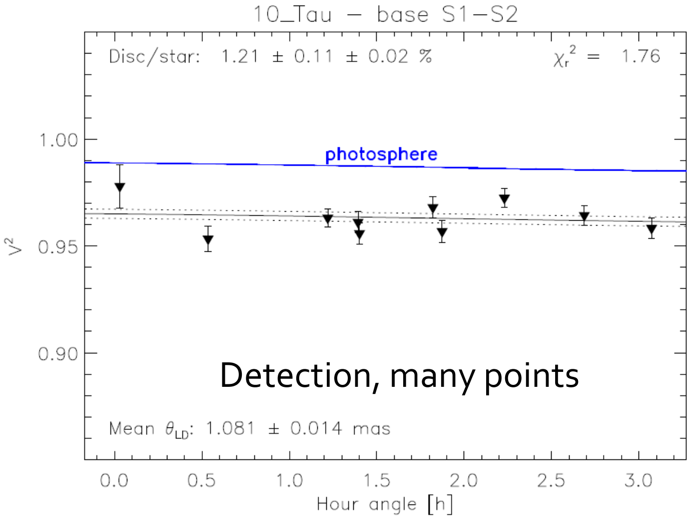
Survey at CHARA/FLUOR

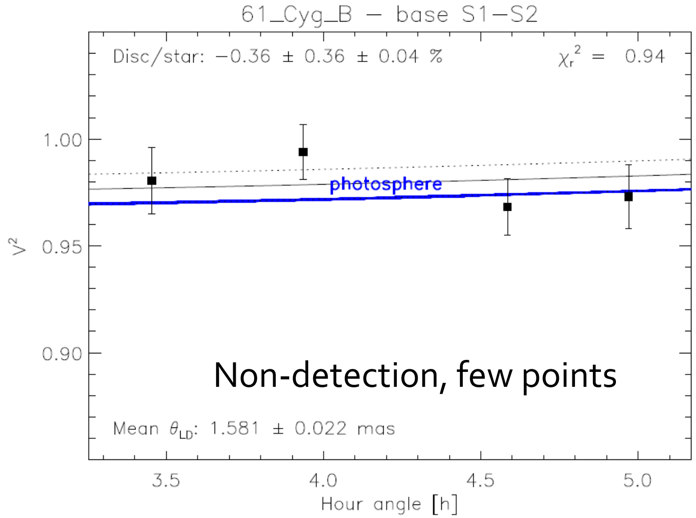
- Magnitude-limited sample
  - (All) northern stars with far-IR excess and $K<4$
  - ~ same amount of "non-dusty" stars
- Evenly spread between spectral types A, F and G-K
- Diameters predicted from surface-brightness relationships

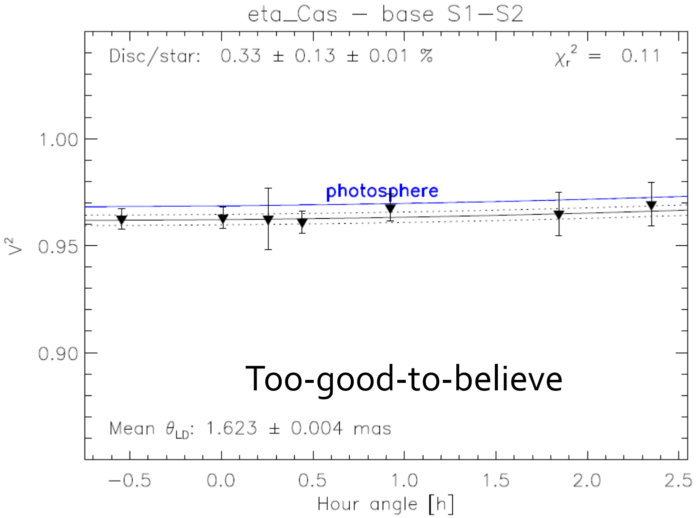
	Dusty	Clean	Total	<Kmag>
A	8	4	12	2.4
F	6	9	15	2.7
GK	8	7	15	2.7
Total	**22**	**20**	**42**	**2.6**

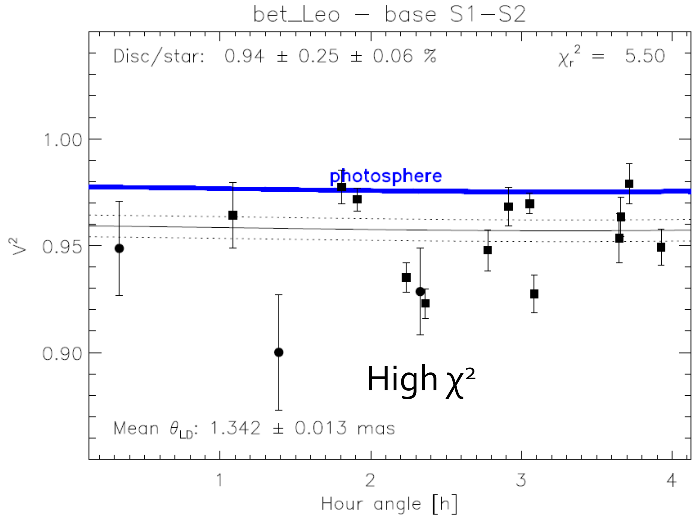
Examples (V² vs hour angle)

Absil et al., in prep





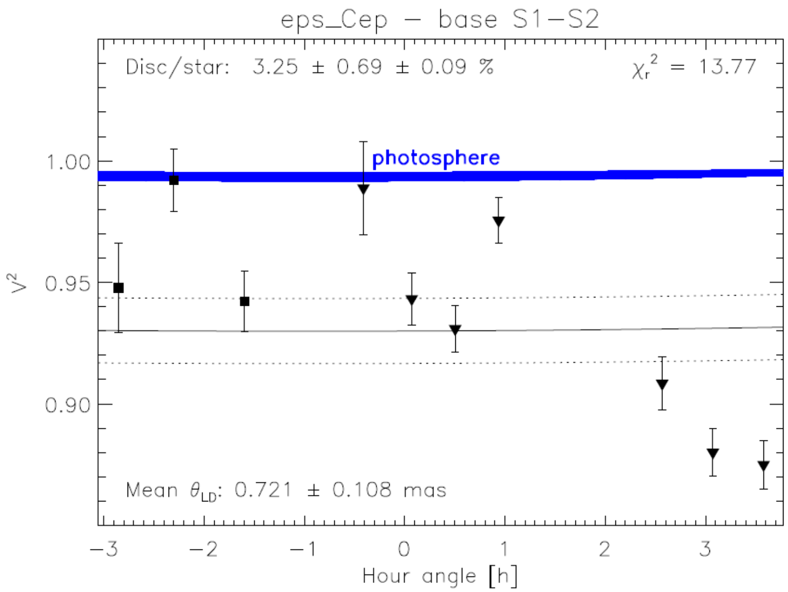


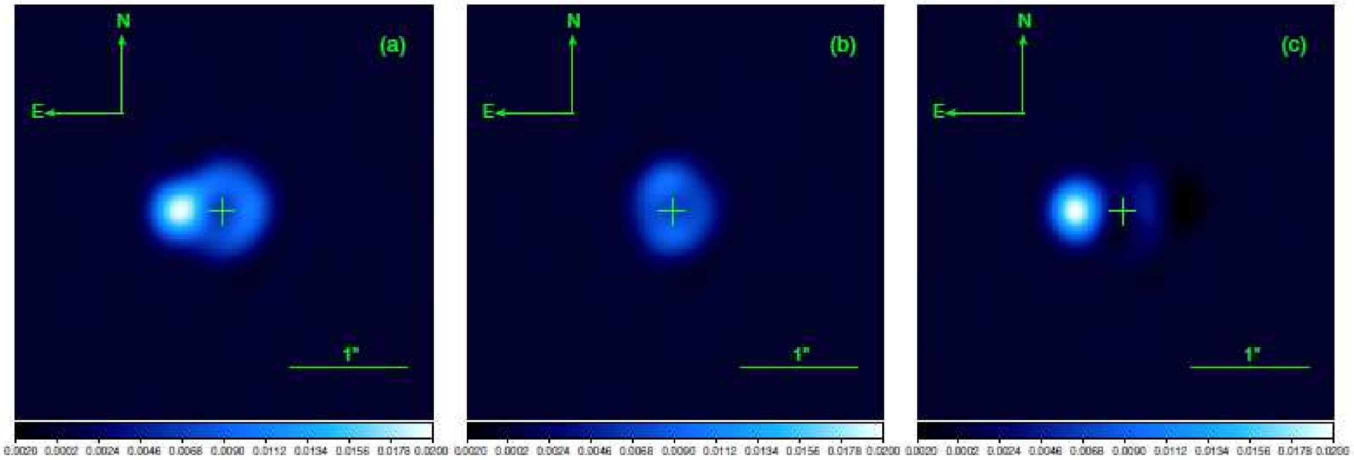


eps Cep: a faint close companion

Mawet et al. 2011

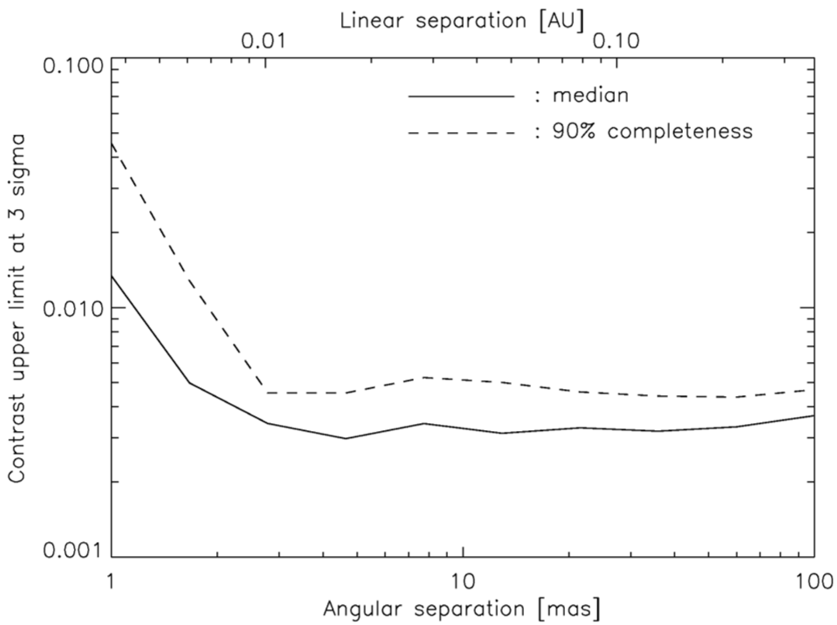
- Wavy pattern in visibilities (→ large χ^2)
- Confirmed with coronagraphy
  - 330 mas separation
  - 2% flux ratio



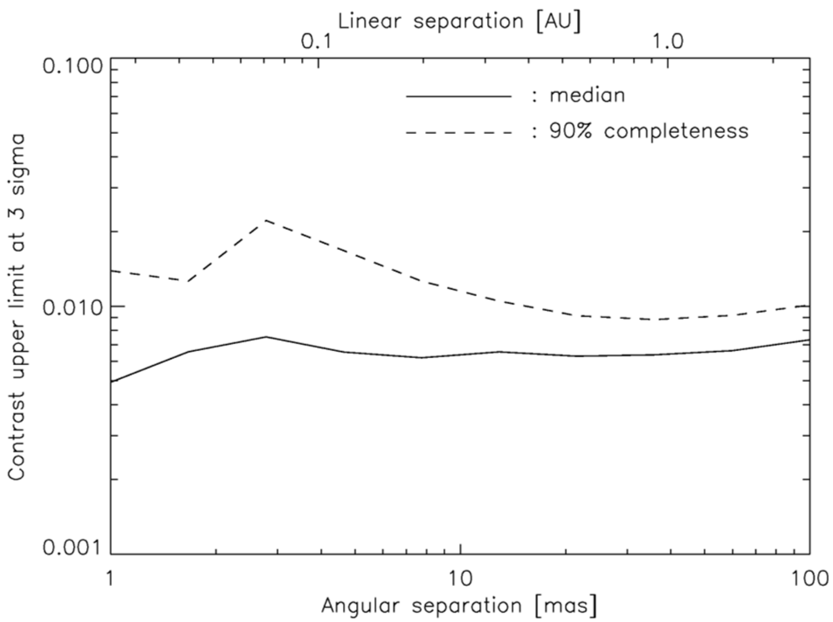


More follow-up examples

tau Cet



zet Aql

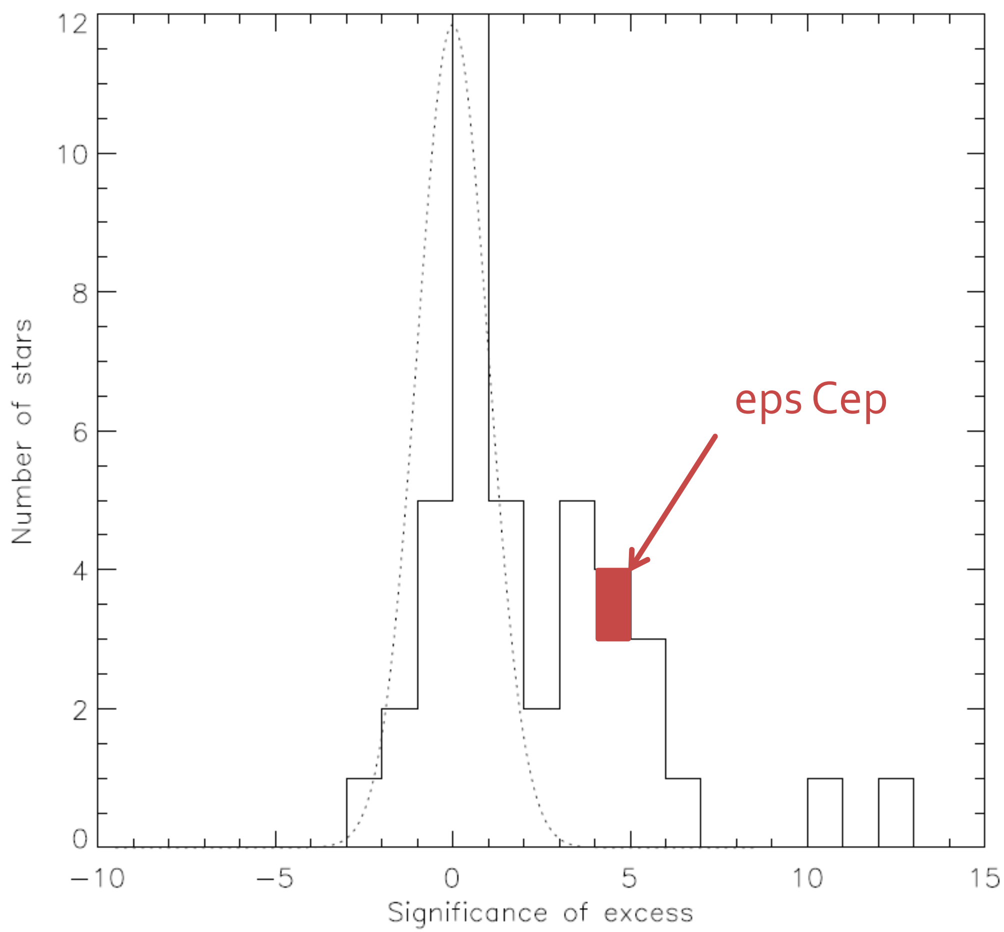


Caveat: not all excesses followed up!

Survey summary (41 stars)

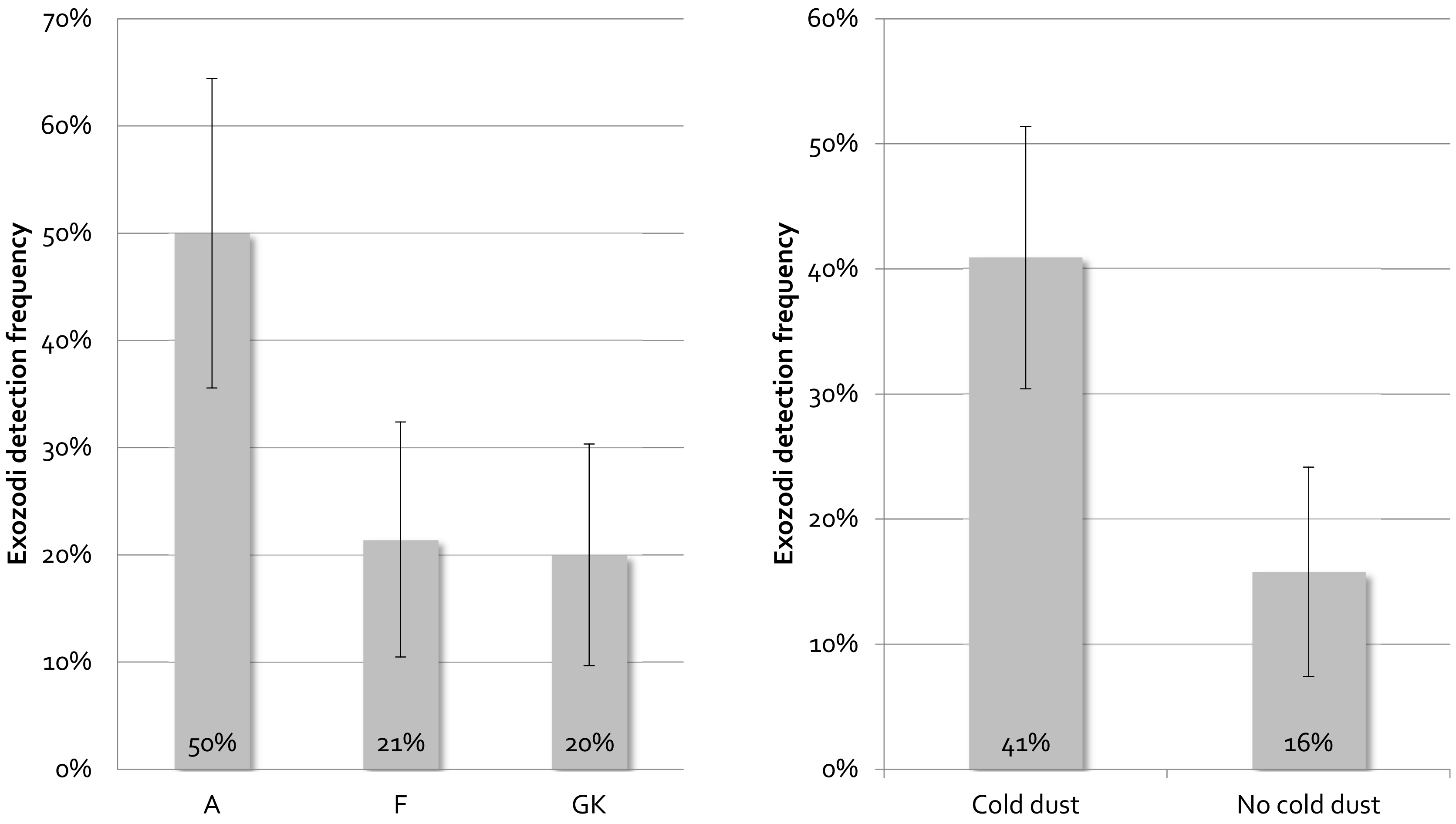
Absil et al., in prep

- Mean sensitivity (at 1σ) = 0.3%
- $0.3 < \chi_r^2 < 3$ for most targets
- Distribution core looks ~ Gaussian
  - No target with significance < -3σ
- Detection threshold set at 3σ
  - 12 excesses out of 41 stars → ~30%



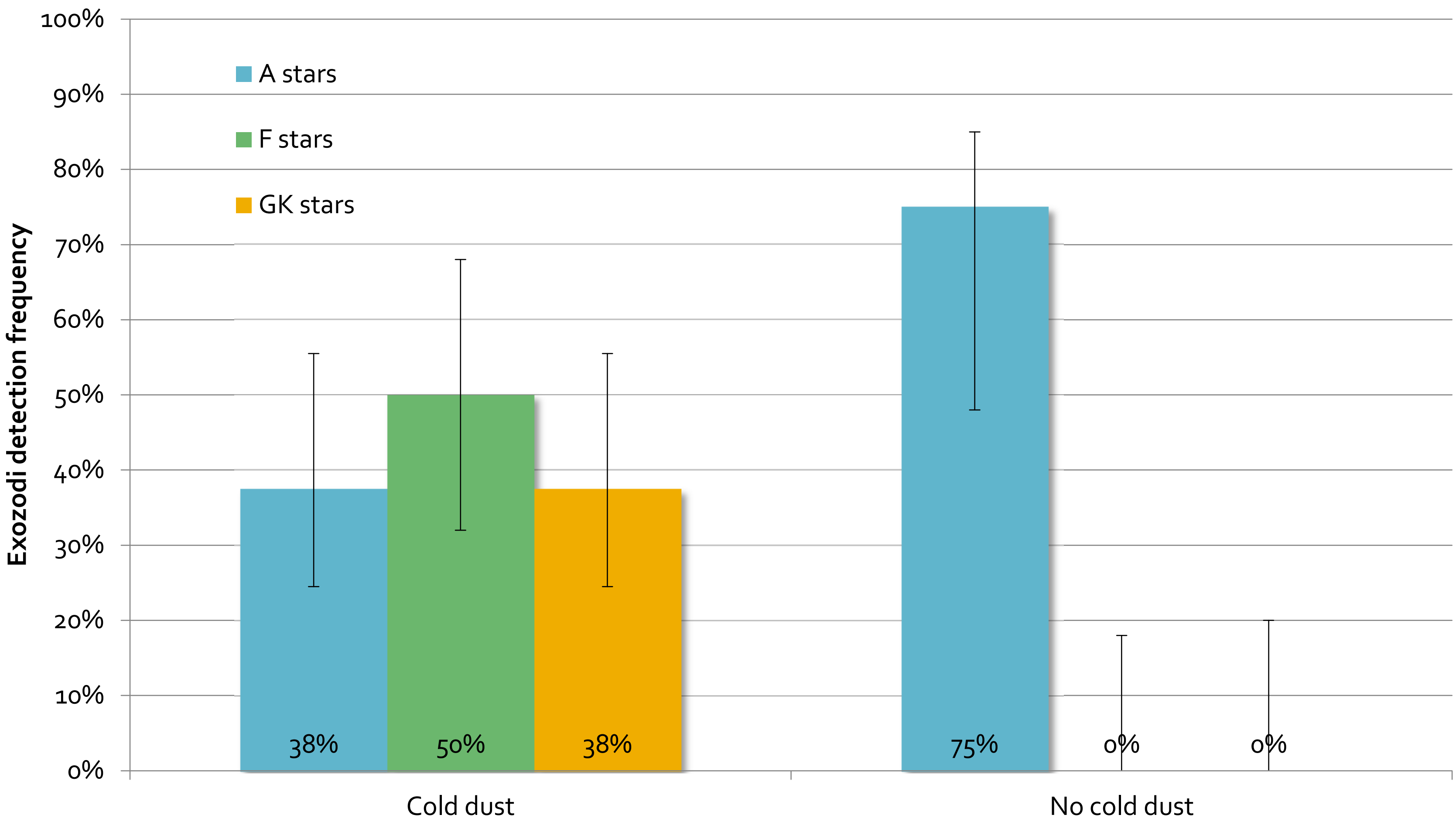
Statistical trends

Absil et al., in prep



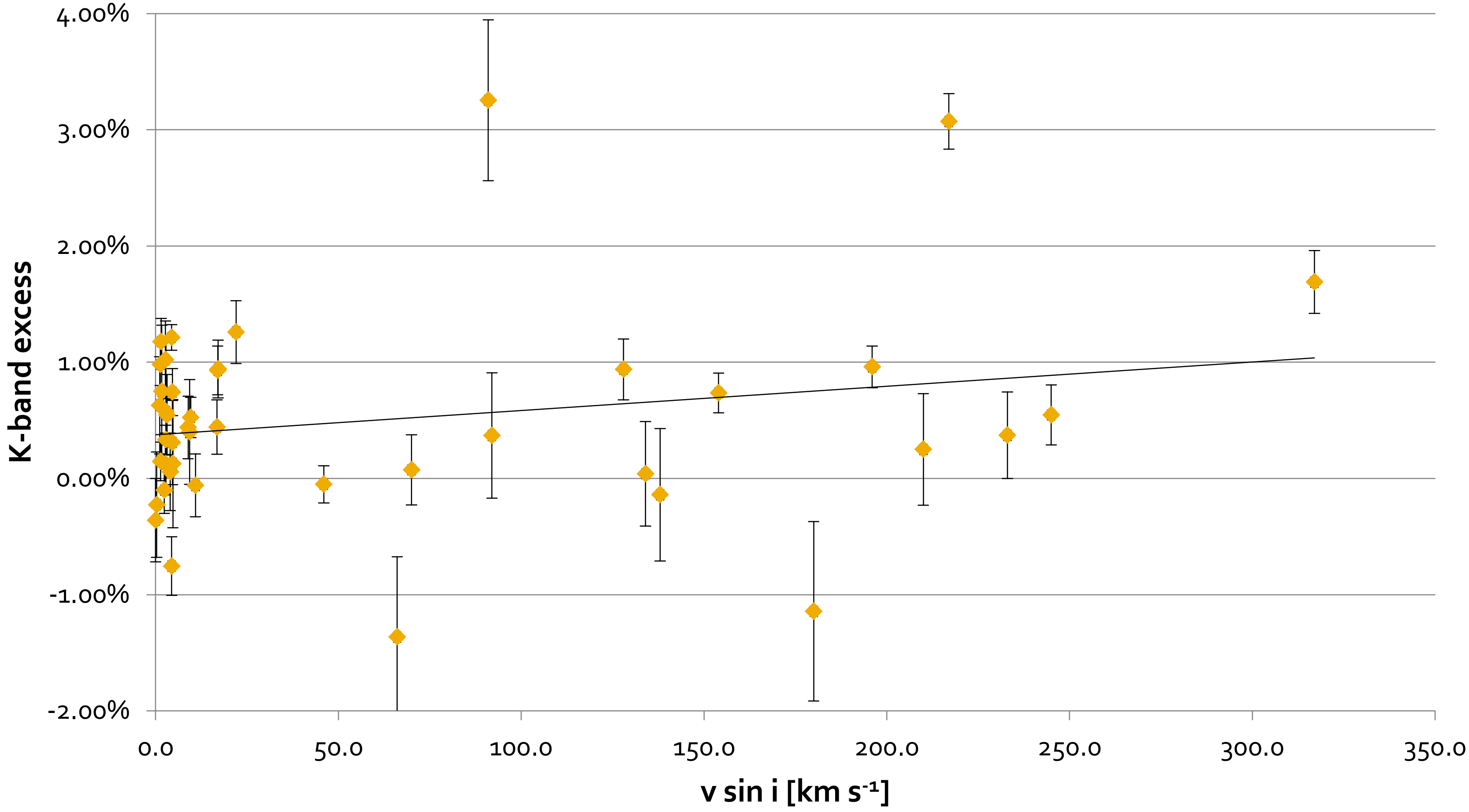
Correlation type/cold dust/hot dust

Absil et al., in prep



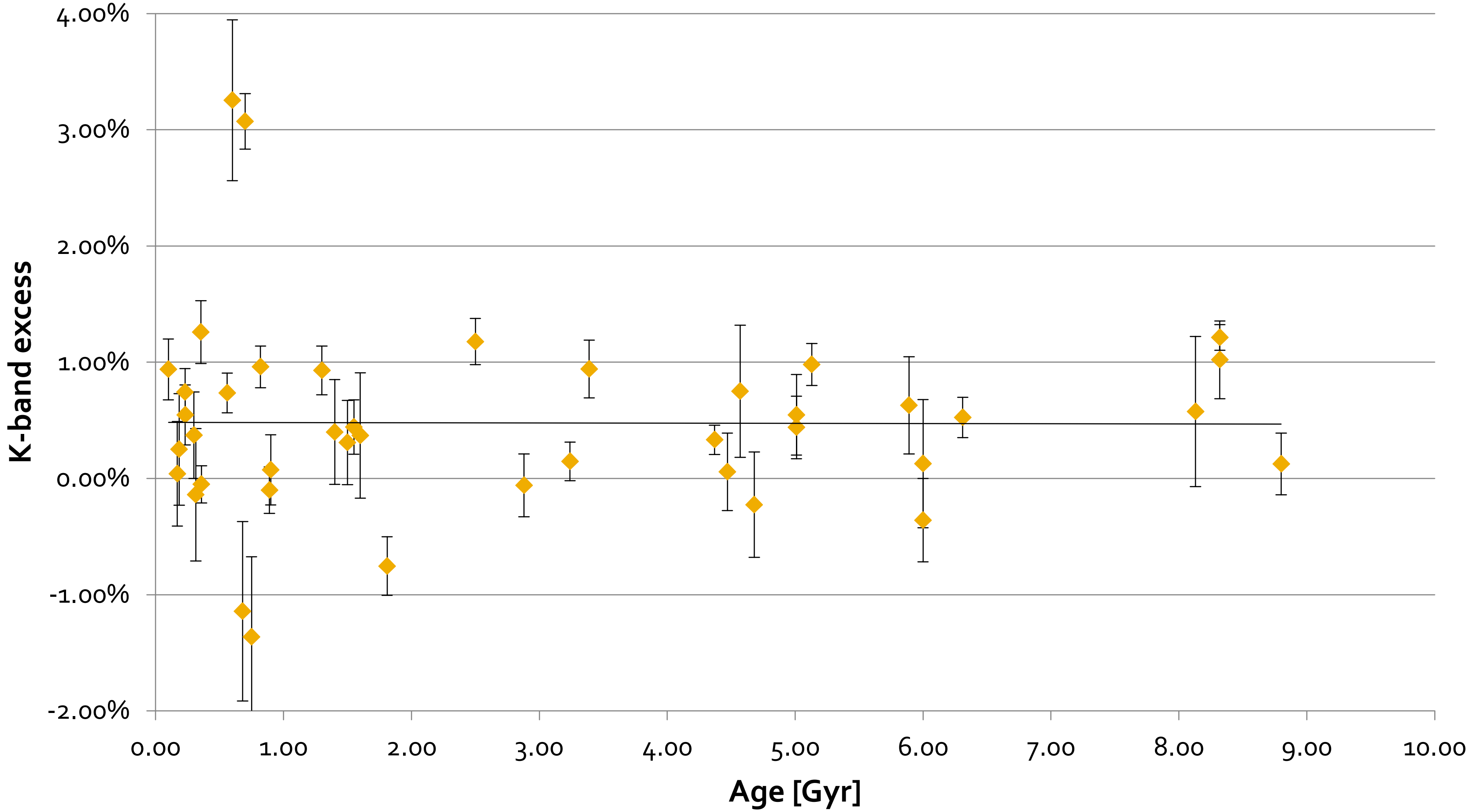
Correlation vs rotational velocity?

Absil et al., in prep



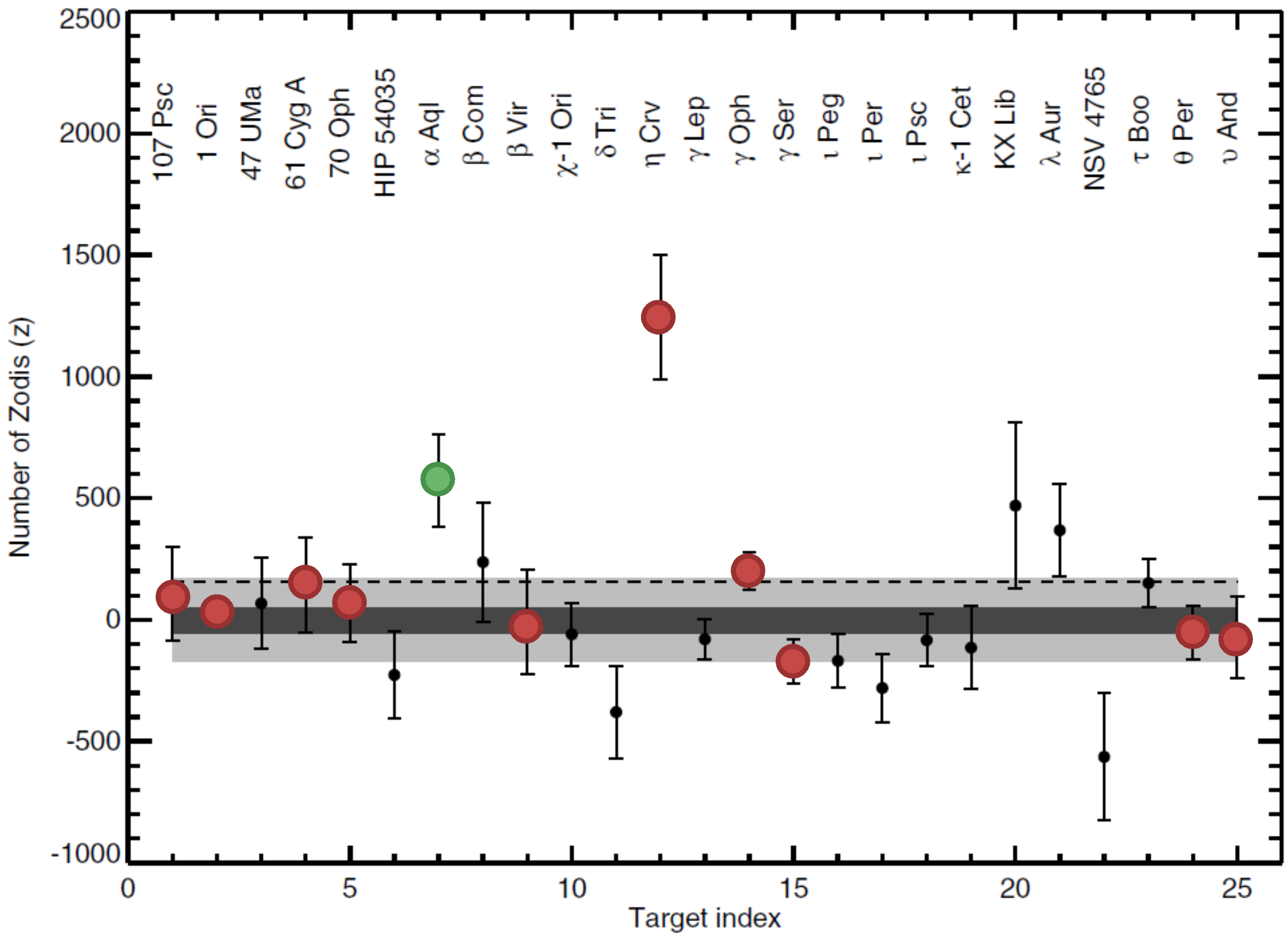
Correlation vs age?

Absil et al., in prep



Comparison with KIN

Millan-Gabet et al. 2011



More KIN follow-up to come…

Extending the survey

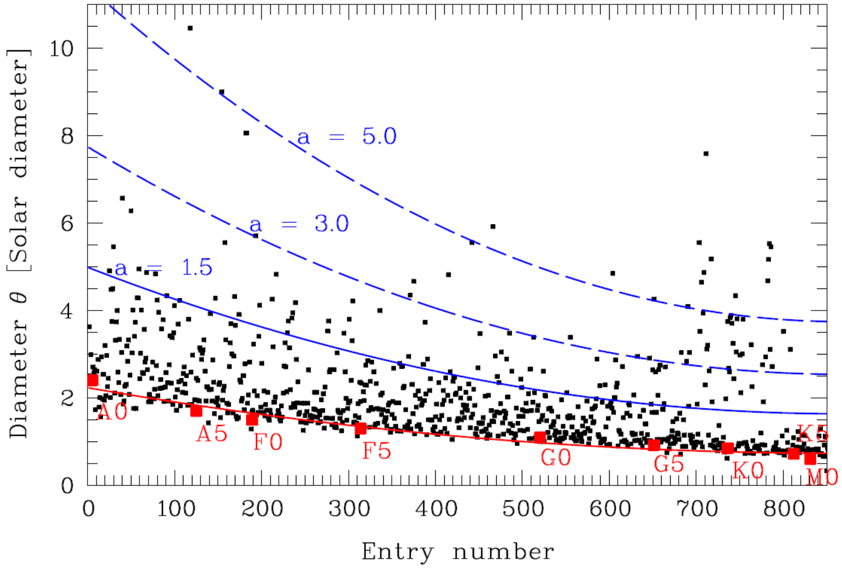
First results with VLTI/PIONIER

Enlarging the statistical sample

- New targets: Spitzer, Herschel cold disks
- Go fainter
  - Refurbished FLUOR → "JOUFLU"
  - New camera, upgraded optics
  - Expect high-precision down to K~5 (good conditions)
- Go South
  - PIONIER at VLTI
  - High-precision V^2 down to H~5 (good conditions)
  - Same fringe scanning principle as FLUOR
  - 6 (short) baselines at a time → huge gain in speed

Target sample selection

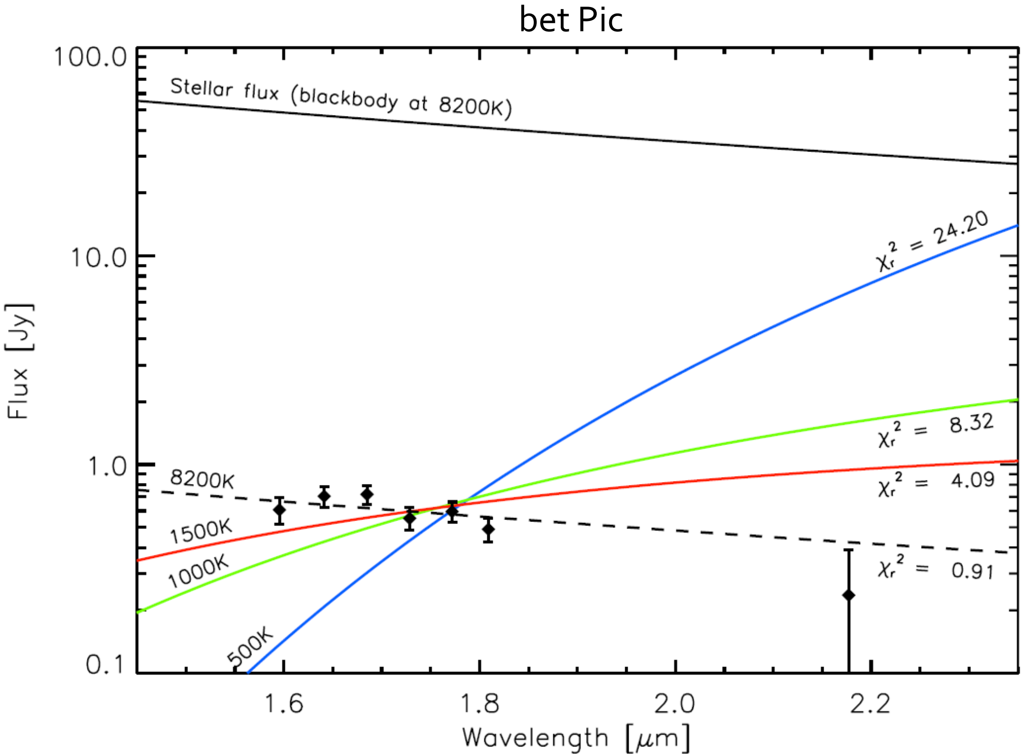
- Goal: no bias on inner/outer disk connection study
- One non-dusty "control" star for each dusty target
  - Same spectral type
  - Similar magnitude
  - Proximity on the sky
- No binaries, bloated stars
- Distribute evenly between A, F and G-K
- Final sample: ~100+100 stars (whole sky)



New feature: low-res spectra

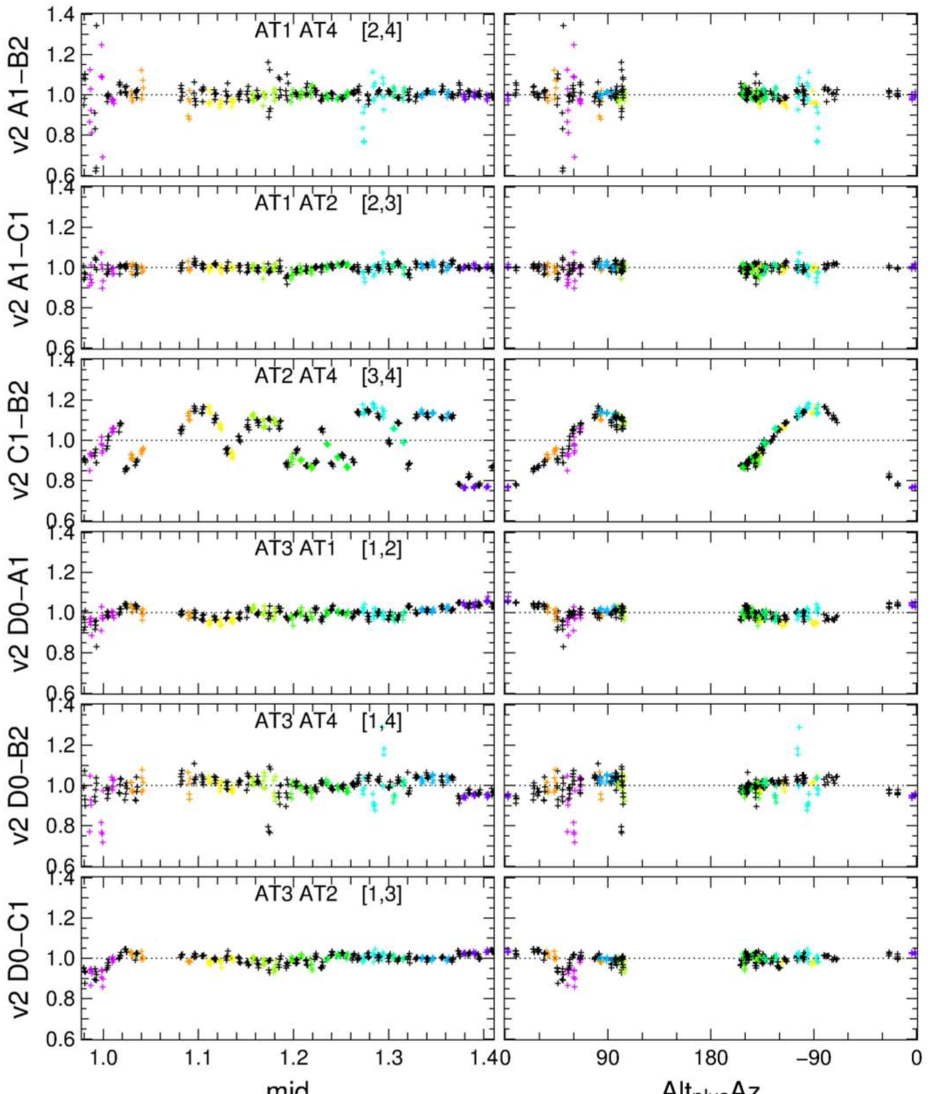
Defrère et al. 2012

- Dispersed fringes with PIONIER (soon FLUOR)
  - Flux ratio measurements across H and/or K band
  - Direct constraint on dust temperature



PIONIER survey status

- A lot of time spent on TF stability analysis
  - DRS validated
  - PIONIER stability validated
  - VLTI polarization effect identified
  - V^2 accuracy on spec after correction
- 4 × 3n awarded in 2012
  - 3 runs carried out
  - 74 stars observed



How to go deeper?