1st ITA - MPIA/Heidelberg - IPAG Colloquium
Signs of planetary formation and evolution
08/10/2012

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Detailed Radiative transfer modeling of exozodis

Introduction: On the origin of exozodiacal dust

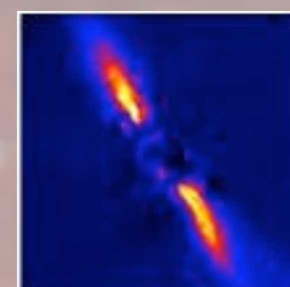
J.-C. Augereau, H. Beust, J.-B. Lebouquin, J. Lebreton, B. Lazareff, G. Zins, P. Thébaut, V. Coudé du Foresto, B. Mollier, O. Absil, D. Defrère, A. Brandeker, S. Charnoz, M. Kama, R. Reche, E. DiFolco, J. Olofsson, J.-P. Berger, J. Vandeportal, Q. Kral, S. Ertel, A. Bonsor, V. Faramaz, U. Marboeuf, Dominik, C.

- The **Zodiacal light**
  - Scattering of sunlight by **dust** orbiting **within ~1AU** from the Sun near the ecliptic plane
  - Disruption and erosion of **comets and asteroids**

- **Exozodis**: extrasolar analogues to our zodiacal cloud
  - *In the **habitable zone** of nearby stars – traces **planets dynamics***
  - *Hot disks + cold disks + exoplanets: **a complete picture of planetary systems***

Vega

Fomalhaut



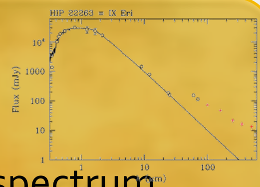
Beta Pictoris

- **THE EXOZODI PROJECT**: ***Near-IR interferometric survey** of exozodiacal disks in both hemispheres with **Chara/FLUOR and VLTI/Pionier***
  - *~200 stars (K < 5) - Observation, statistics + detailed modeling & theoretical investigations*

Building a debris disk model – the GRaTer code

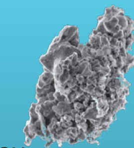
Augereau et al 1999, Lebreton et al. 2012

The star



Spectral type, magnitude,
distance → synthetic stellar spectrum

Dust grains

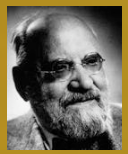


Size: $dn/da \propto a^{-\kappa}$, from a_{min} to a_{max}
Multi-material, possibly porous, grains.
Size-dependent sublimation distances

The disk

2D, Optically thin disk/ring
Inclination, Surface density profile:
2-power law (r_0, α_{in}, α_{out})
Temperature profile at equilibrium
Dust mass

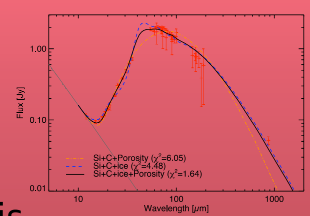
Grains optics

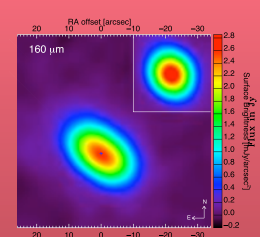


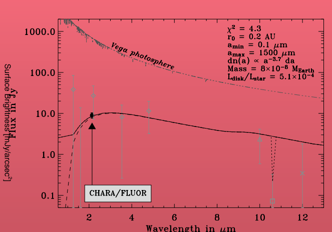
Optical indexes (silicates,
organic refractories, ices, etc.)
Effective medium theory
Mie theory → Q_{abs}, Q_{sca} = f(a, λ, compo.)

Data:

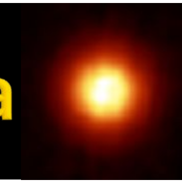
SEDs, Resolved images, interferometric observations
Fitting strategy: Large parameter space, Chi-square minimization, Bayesian analysis







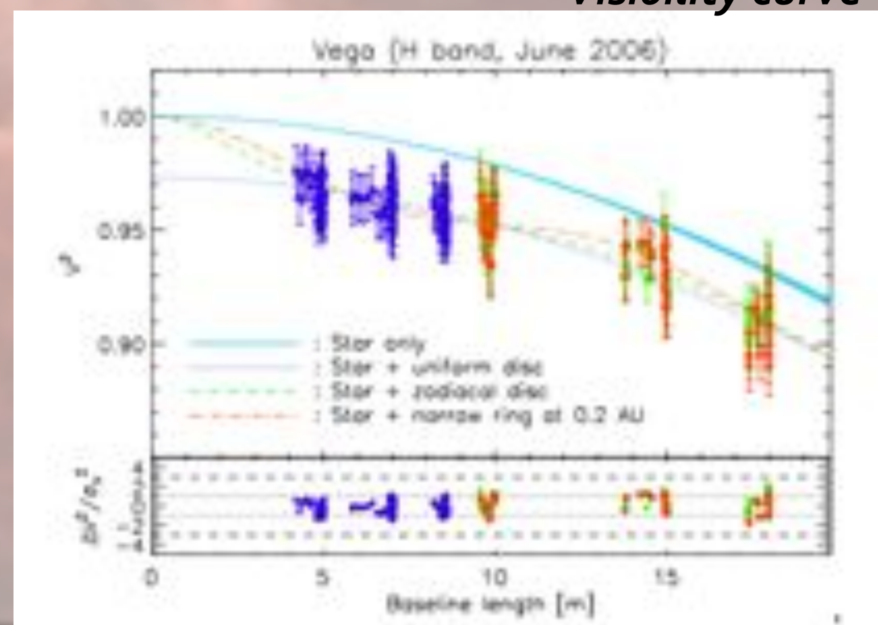
Hot exozodiacal dust resolved around Vega



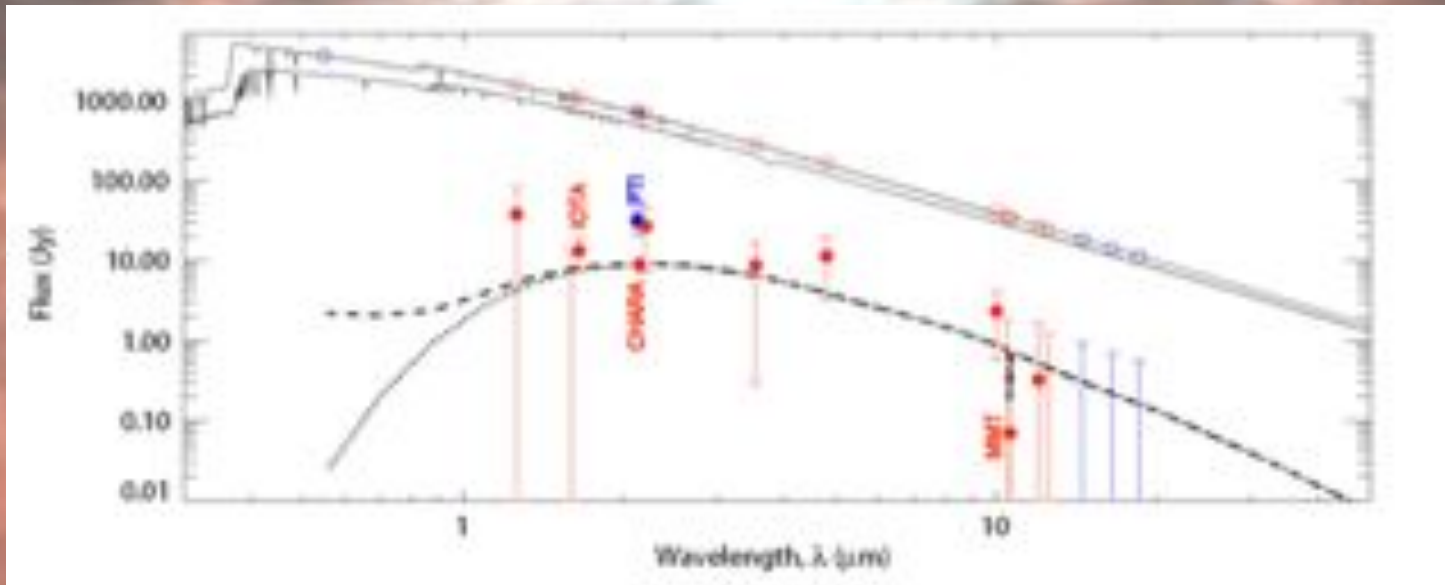
- *Absil et al. 2006*: Short baseline **visibility deficit** discovered with CHARA/FLUOR
  → K-band excess 1.29±0.19%
- *Defrère et al. 2011*: IOTA/IONIC
  → H-band excess 1.23±0.45%

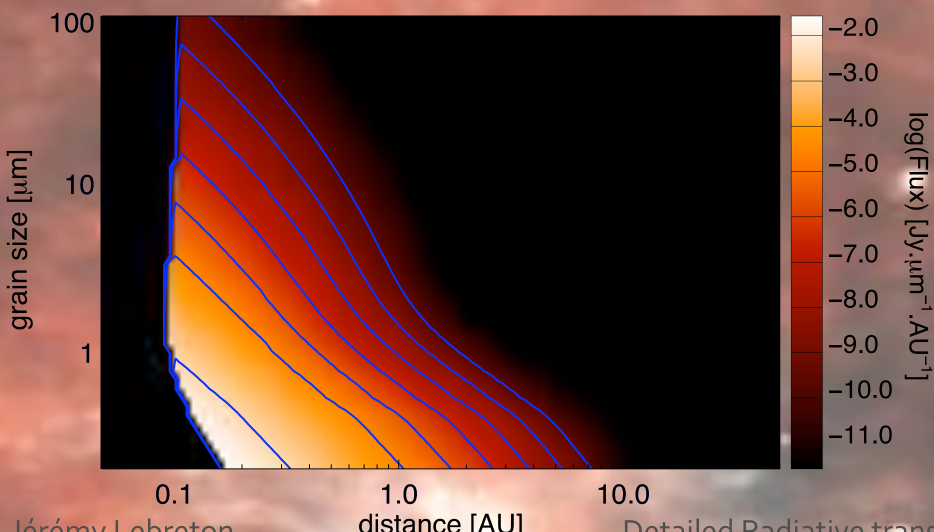
- Thermal emission from **a ring of hot dust within a few AUs**

Visibility curve



Hot exozodiacal dust resolved around Vega





Models:

- **Submicronic** grains ($a_{min} \leq 0.3$ µm)
- Highly **refractive**: amorphous carbon + Olivine ; T_{sub}: 1900, 1200 K resp.
- **Close to the star**: $r_0 = 0.17–0.30$ AU
  (@0.1µm: $r_0 < r_{sub} \sim 0.6$AU)
- $M_{disk} = 8 \times 10^{-8} M_{earth}$: equivalent to **a ~20km diameter asteroid**

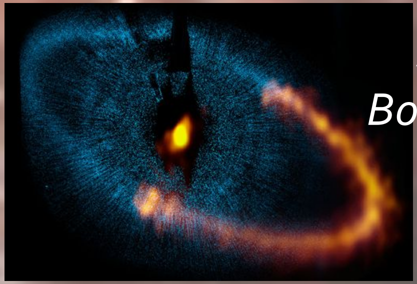
Defrère et al. 2011 (A&A)

An interferometric study of the Fomalhaut inner debris disk

Observations with the Keck Interferometer Nuller and VLTI/VINCI

« On-star » excess emission detected by Spitzer, Herschel and ALMA is resolved from K-band to mid-IR with high precision interferometers

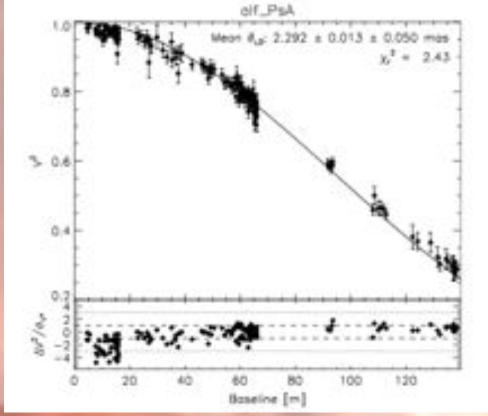
- ~200 Myr nearby (7.7 pc) A4 star
- 140 AU wide cold debris ring.
- Evidence for a hot excess in the inner regions (<20 AU, *Spitzer, Herschel*)



ALMA/HST
Boley et al. 2012

VLTI/Vinci:

- K-band (2.18 um) excess: 0.88±0.12%
- Hot circumstellar dust < 6 AU(FOV)



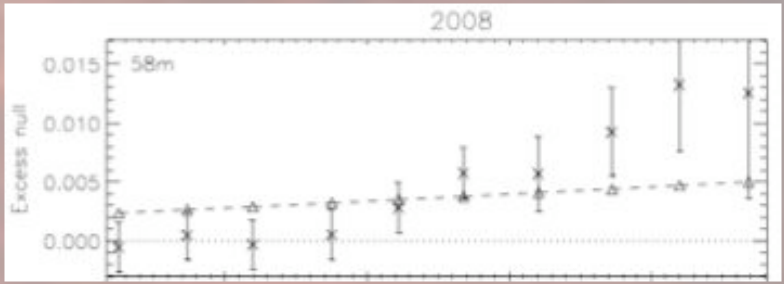
Absil et al. 2010

VLTI visibility curves and residual from the fit of an oblate limb-darkened stellar photosphere

KIN:

- Mid-IR: N-band (8-13 um), 2AU FOV
- 4 subset of observations (2007 / 2008, Long / short baseline)

Mennesson et al. (submitted to ApJ)



KIN excess null depth as a function of wavelength (photosphere substracted). Triangles and dashed line: excess null created by a 260-zodi exozodiacal disk.

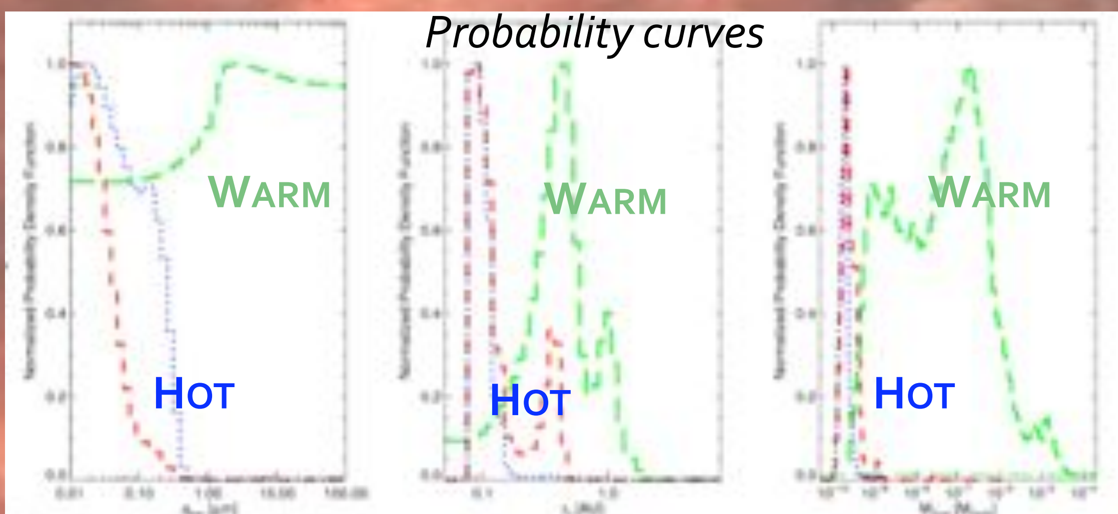
An interferometric study of the Fomalhaut inner debris disk
Radiative transfer modelling with GRaTer

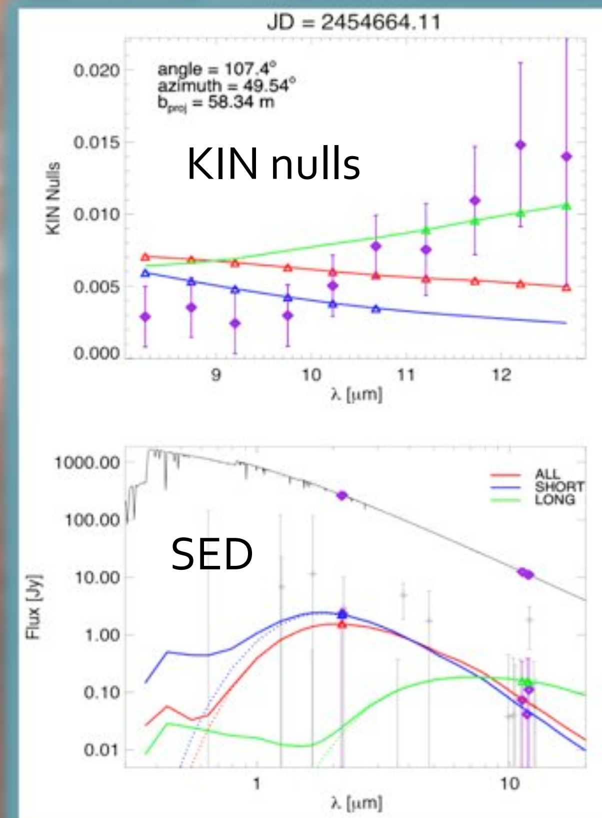
A Bayesian analysis is run on a grid of 1.2 million models to assess the size distribution, the surface density profile and the dust composition.

Two dust populations within a few AUs

→ The « HOT » excess: **very small carbon grains** at the **sublimation radius**.

→ The « WARM » excess (λ > 11 µm): a « classical » dust belt at ~0.5 AU

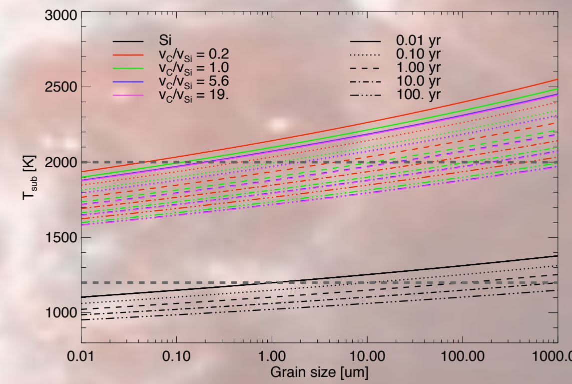




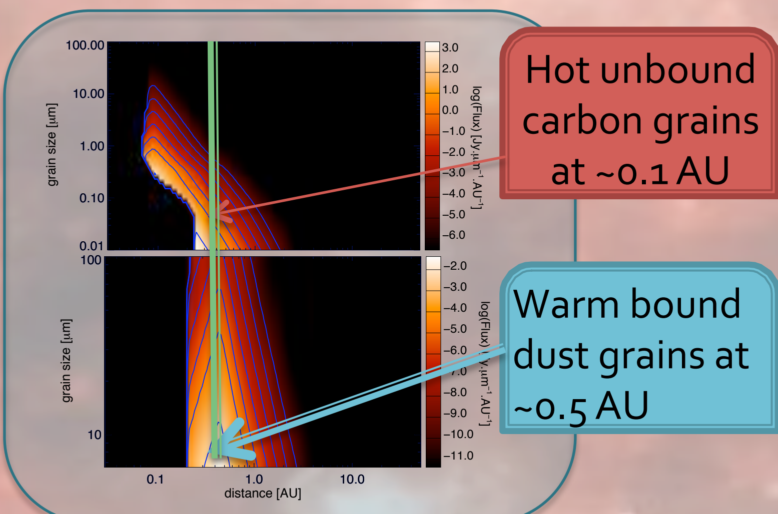
Mennesson, Absil, Lebreton et al., submitted to ApJ

An interferometric study of the Fomalhaut inner debris disk
Model improvements and theoretical investigations

- **<u>Sublimation distances</u>**: How big must a grain be to survive a temperature $T_{sub}(a)$ for some time $t_{survival}$?



- **<u>Origin of the dust:</u>**



- **Accumulation** of grains at the **sublimation radius** after **Poynting-Robertson drag** migration?
  - → max[dM/dt] ~10^{-11} M_{Earth}/year
  - → but incompatible with unbound grains

- Disruption of **sublimating aggregates** → optical depth enhancement?
  - → Mass fluxes are compatible if $t_{surv}=t_{subl}$ for short grains
  - → Need a mechanism **to trap the grain** for long enough
  - → **Gas** drag / pressure gradient? Possible if $M_{gas} >> M_{dust}$

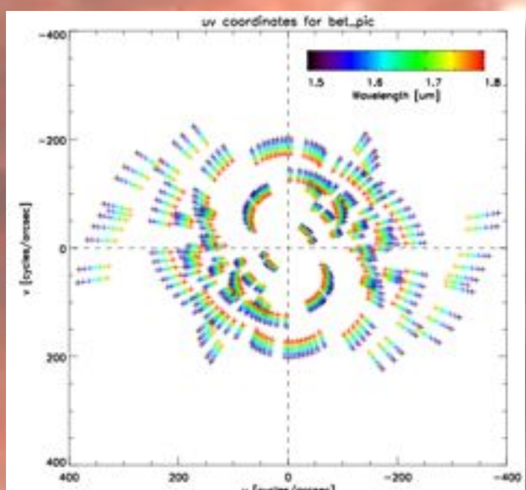
- Where is the **parent-belt**?
  - → An asteroid population can only survive further than a few AUs: the « warm » dust seen at long wavelengths?

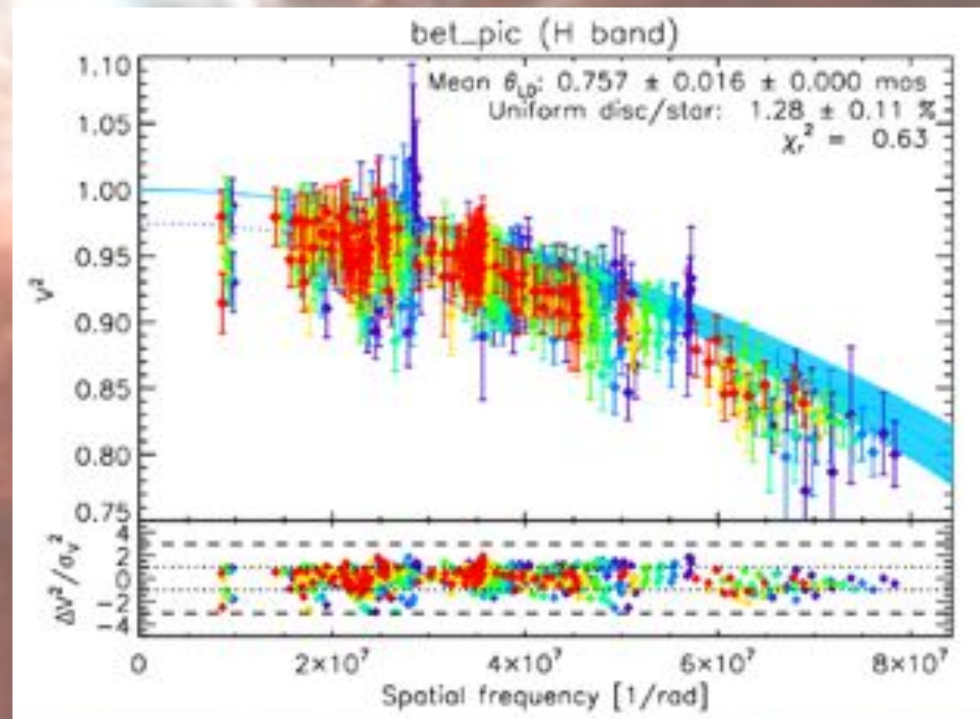
Lebreton, van Lieshout et al., in prep.

The special case of β Pictoris

Hot circumstellar material resolved around β Pic with VLTI/PIONIER

β Pic observed 4 times since Nov. 2010 with PIONIER (Lagrange et al.):
→ 4 nights for 29 OBs
→ 3 different configurations
→ 7 channels dispersed over the H band
→ 5 x 1218 visibility measurements





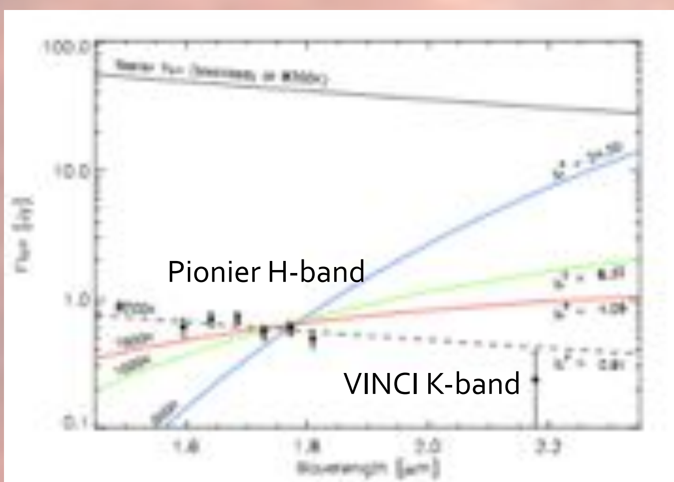
Defrère, Lebreton, Absil et al, recommended for publication in ApJ

The special case of β Pictoris

Hot circumstellar material resolved around β Pic with VLTI/PIONIER

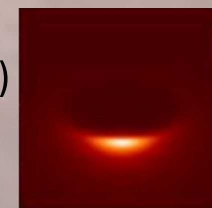
Spectral behavior is indicative of very « hot » dust

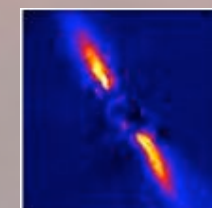
→ **8200K blackbody**
or equivalently
light scattered from the star



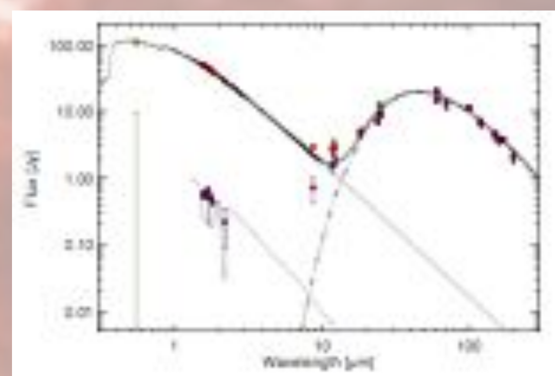
- <u>Detailed radiative transfer models</u>: can there be enough light scattered from the outer disk?

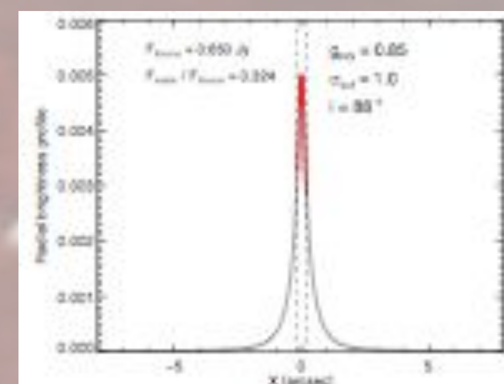
→ **Near edge-on** configuration
→ **Strong anisotropy** (Mie theory)





~50% of the K-band emission can originate from light scattered from the outer disk in Pionier FOV





→ Additional hot exozodiacal dust from Falling Evaporating Bodies?

Defrère, Lebreton, Absil et al, recommended for publication in A&A

Conclusions

- *EXOZODI PROJECT:*
  - *So far 12 interferometric detections out of 41 stars (29^{+8}_{-6} %)*
  - *Cold & hot dust correlated for late type stars, for early type stars not*
- *Detailed radiative transfer modelling:*
  - *Excesses are caused by thermal emission from very hot sub-micrometer dust particles within ≤1 AU (Vega, Fomalhaut)*
  - *When edge-on: contribution from scattering in the outer disk (β Pic)*
- Origin of the dust:
  - ***Poynting-Robertson** transport and **disruption of sublimating aggregates***
  - *BUT need to preserve **unbound grains** from blowout → **gas drag**?*
  - *Alternative scenario: **Dynamical scattering***

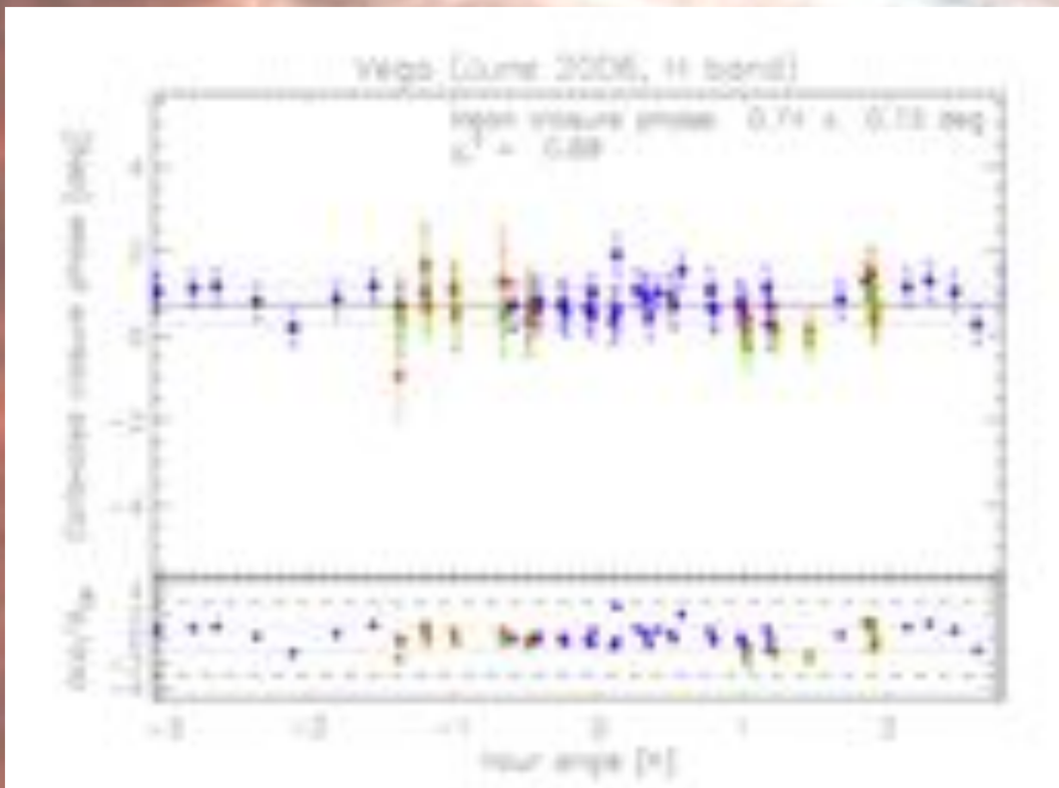
→ STAY FOR AMEY BONSOR AND VIRGINIE FARAMAZ'S TALKS!

***VEGA**: Defrère et al 2011, Bonsor et al. 2012; **β PIC**: Defrère et al. 2012 (accepted); **FOMALHAUT**: Mennesson et al. (submitted), Lebreton et al. (in prep.); **SURVEY**: Absil, Ertel et al. (in prep)*

Thank you very much for your attention!

Supplementary slides

Vega



- Closure phase consistent with central symmetry at the contrast level considered
- **COMPANION**? Range of possible orbital parameters not compatible with Hipparcos astrometry