EXOZODIACAL DUST (=HOT DEBRIS DISKS) AROUND NEARBY STARS

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(post-doc at IPAG in 2012 and 2013)

and the **EXOZODI team**:
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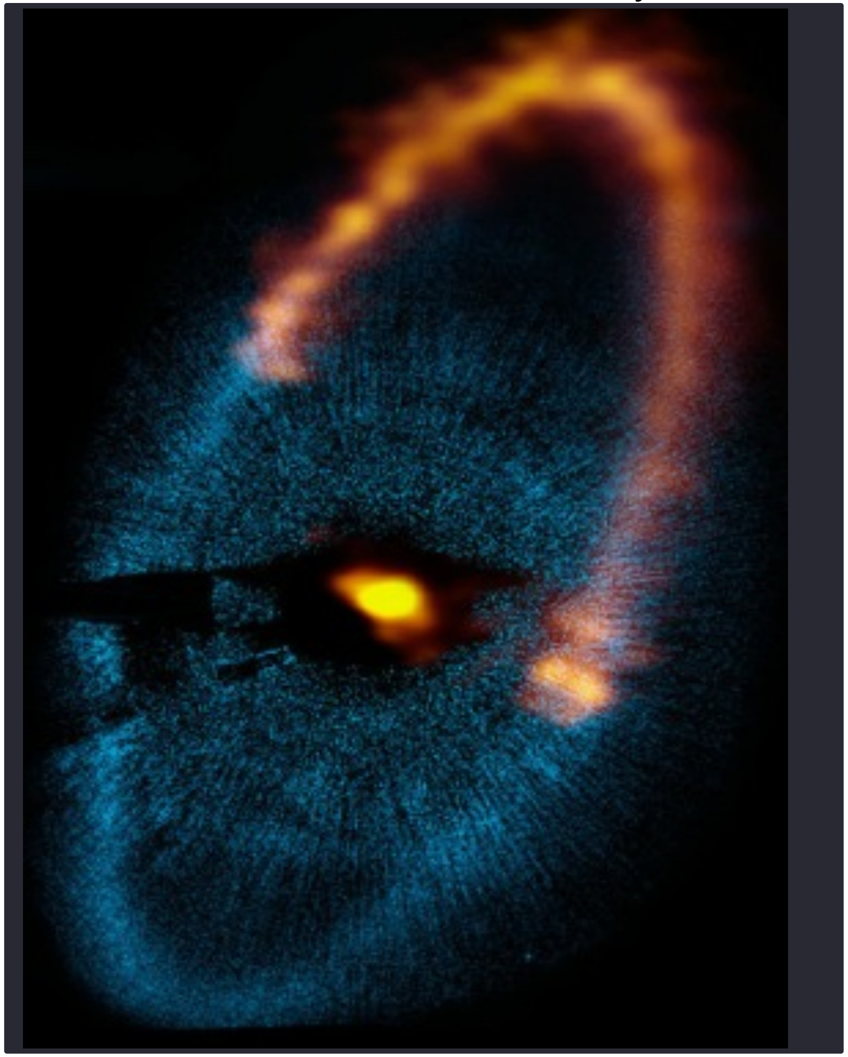
Institut de Planétologie et d'Astrophysique de Grenoble

What is an exozodi?

Star Fomalhaut : composite HST+ALMA image
Kalas et al. 2005, Boley et al. 2012



- Planetary systems have planets, comets, asteroids, and dust
- Cold, outer debris disks are observed at all wavelengths, and are rather well understood (but still a lot to learn)
- EXOZODI refers to the hot and warm dust in the inner regions of planetary systems

Exozodis

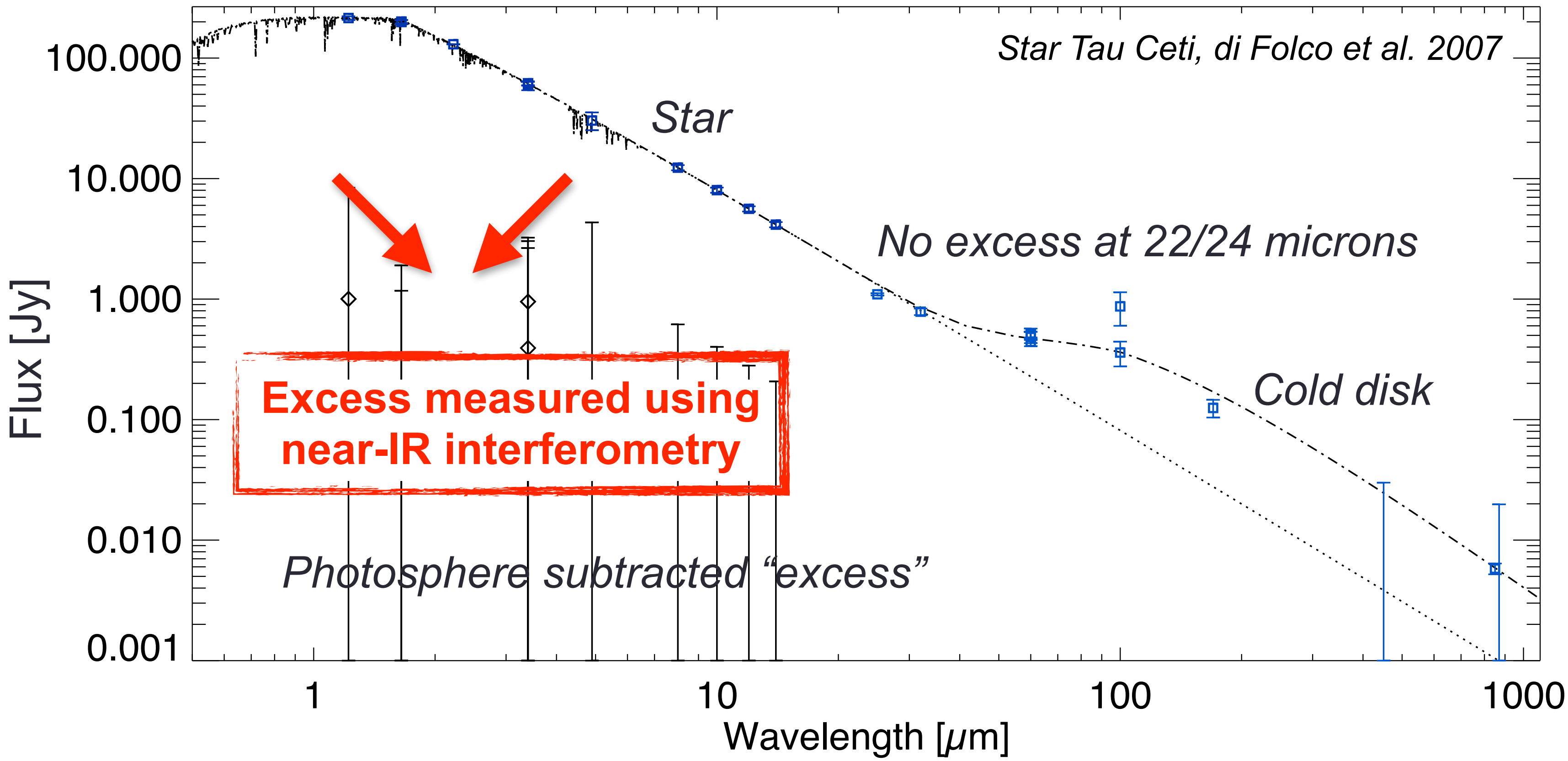
- **Zodiacal dust in the solar system:**
  - location : within a few AU
    (encompassing the habitable zone)
  - mass : tiny
    (~$10^{-8} M_{Earth}$, or a medium-sized asteroid)
  - luminosity: high
    (most luminous circumsolar component)

- **Exozodiacal dust:**
  - how frequent?
  - basic properties?
  - origin?

- **The EXOZODI project:**
  1. near-IR interferometric surveys
  2. radiative transfer modelling
  3. N-body simulations
  4. New code: LIDT-DD (Kral et al. 2013)
     collisions AND dynamics in debris disks

1. Exozodi detection

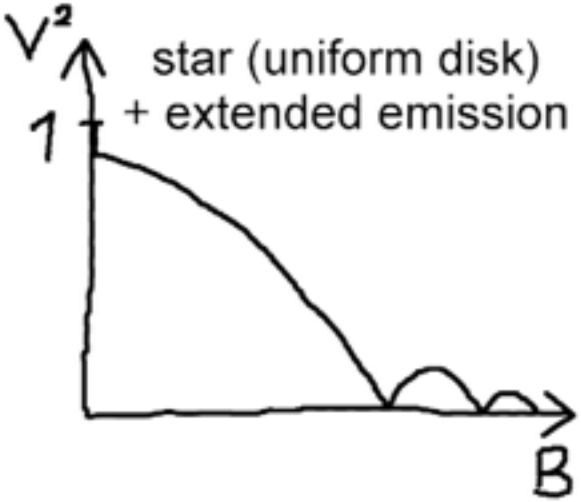
- **How to detect exozodiacal dust?**
  - high contrast
  - high spatial resolution



Exozodi detection

- Principle of exozodi detection

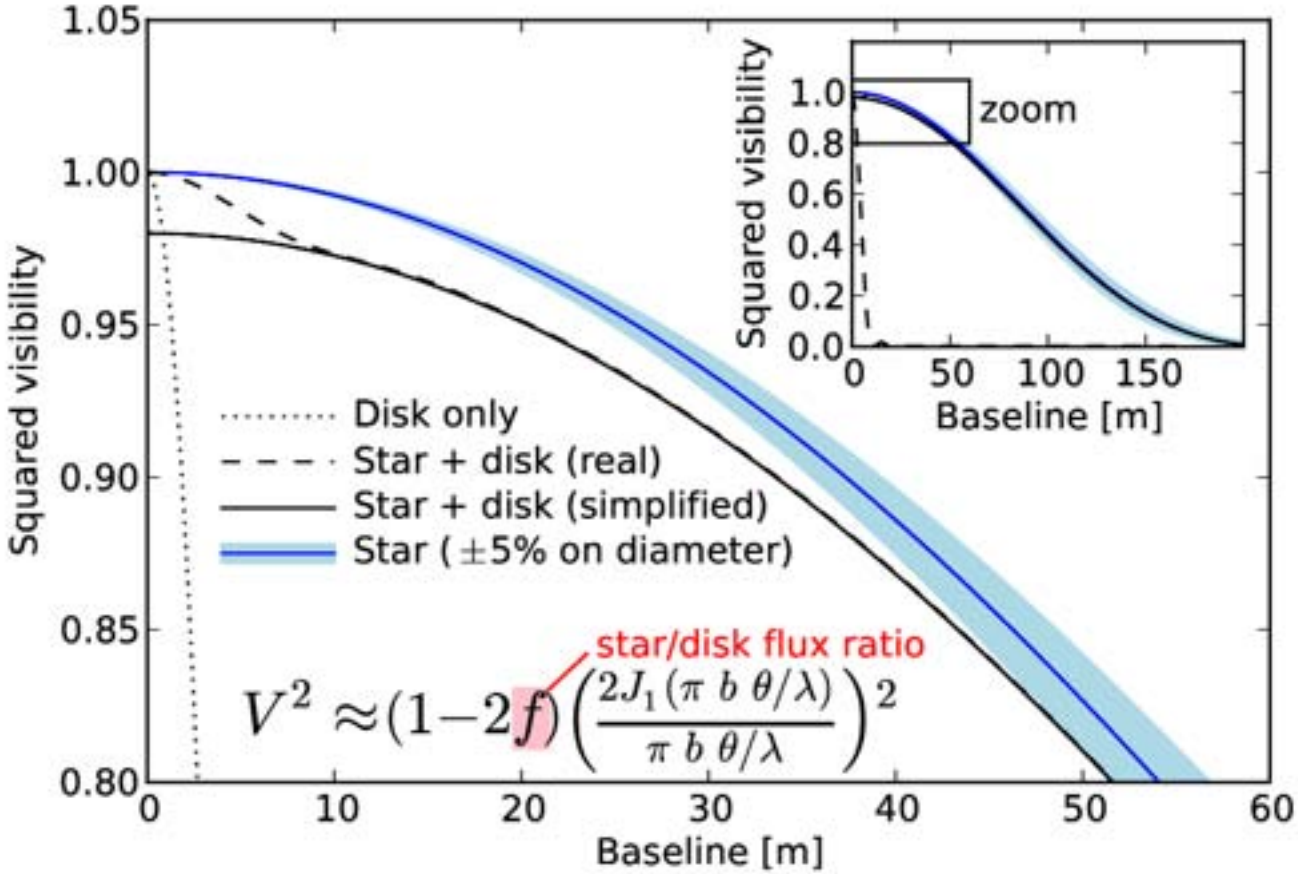
- V: Visibility
- B: Baseline



Courtesy: Steve Ertel

Exozodi detection

- Principle of exozodi detection

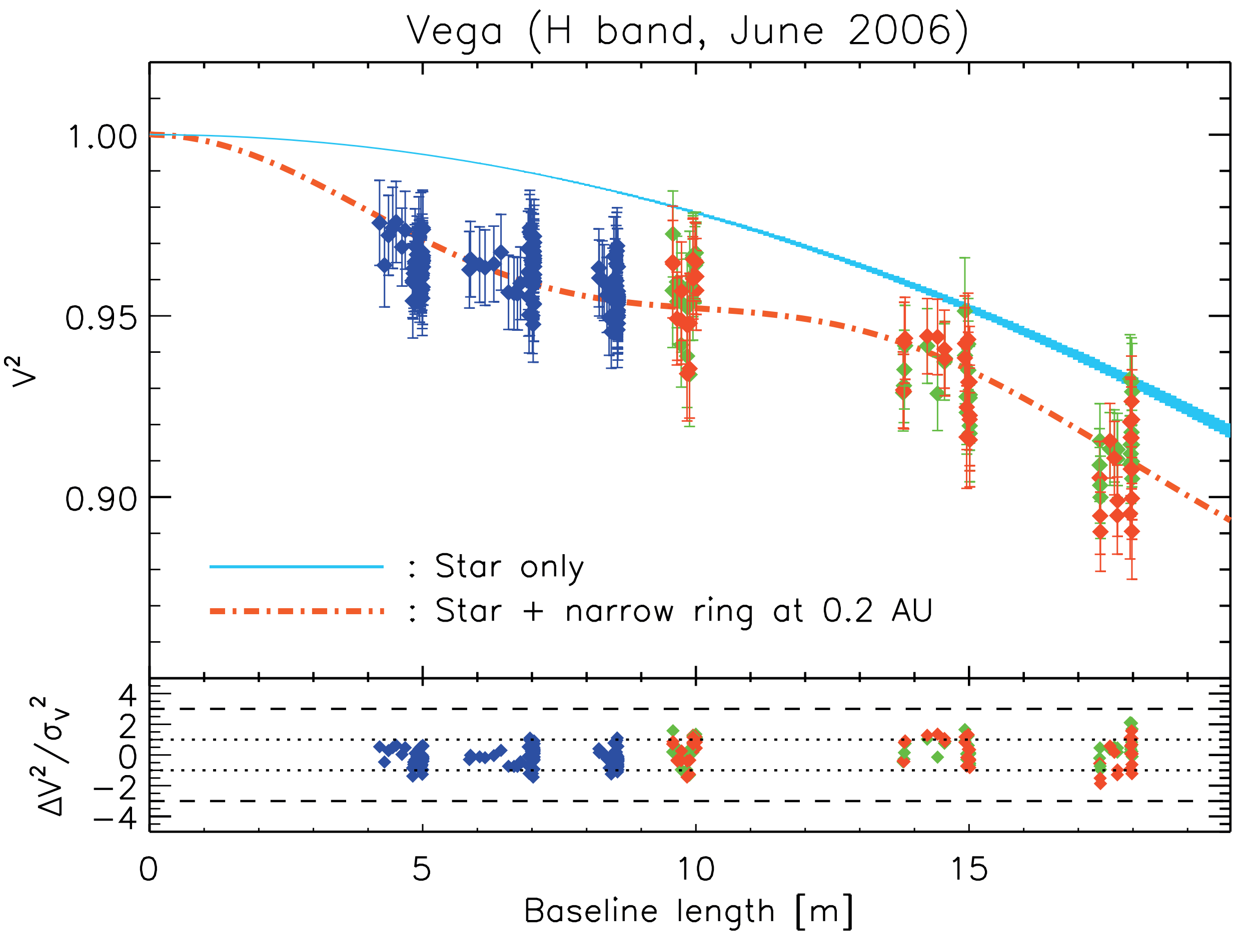


Courtesy: Steve Ertel

A real case example: Vega

Exozodi detection

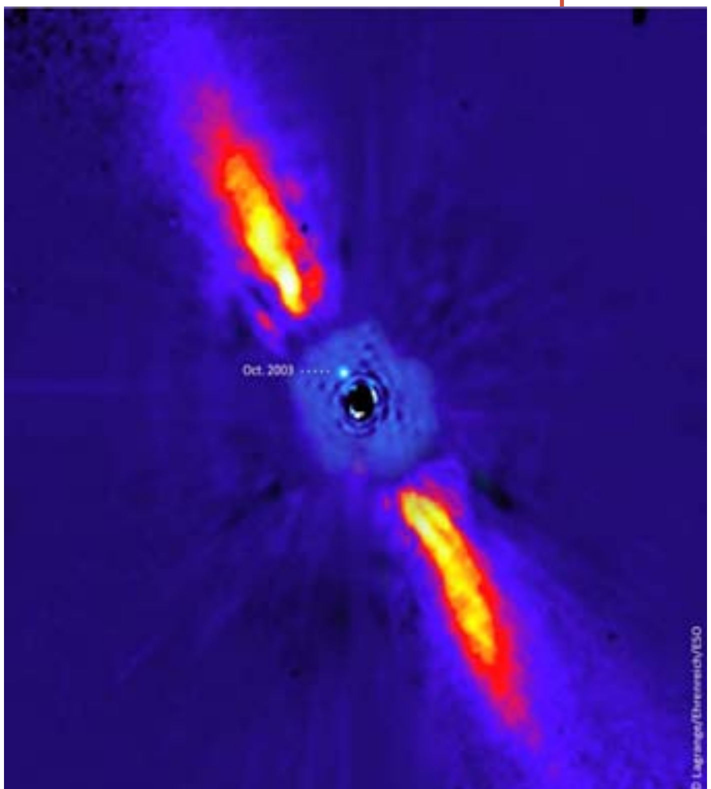
- IOTA interferometer
- H-band



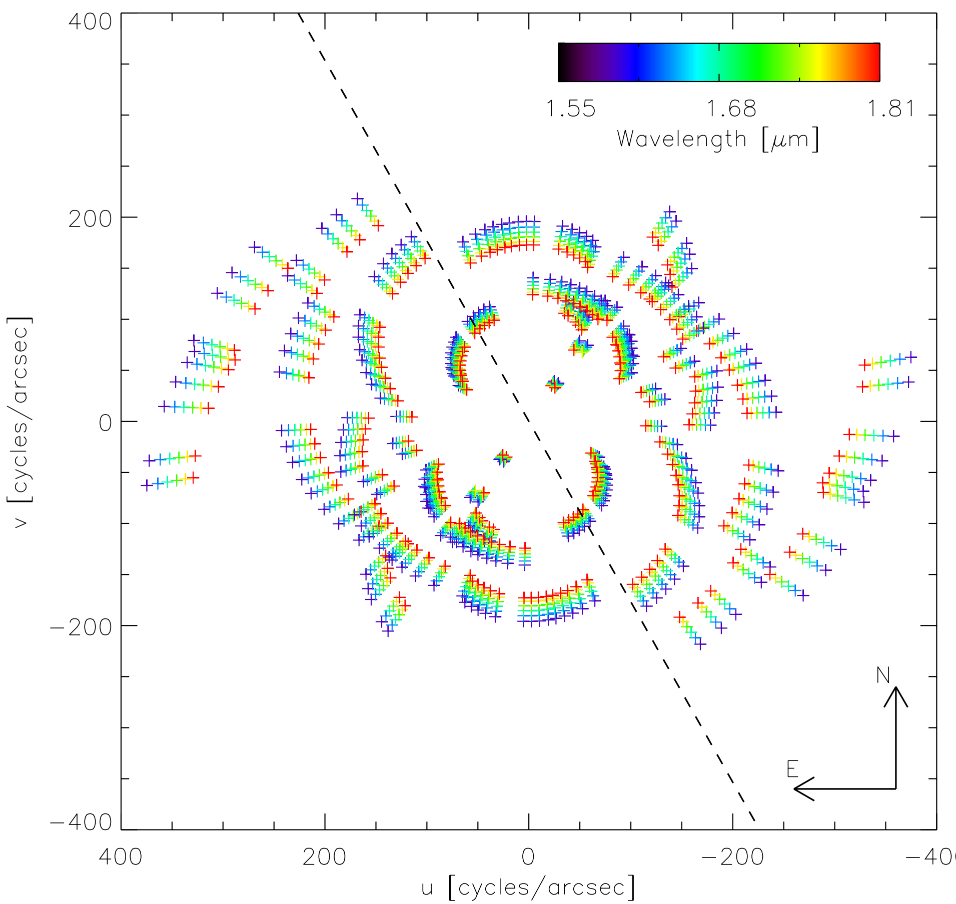
Defrère et al. 2011

Exozodi detection

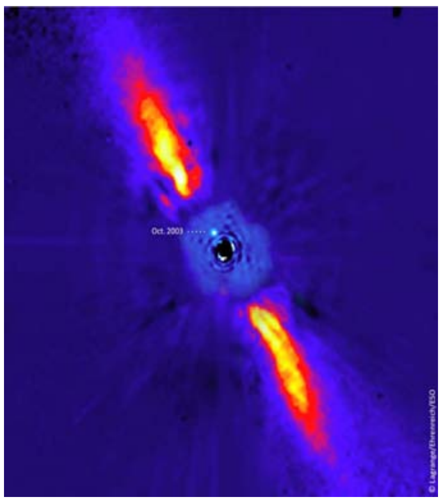
- **Beta Pictoris with PIONIER**
  - sampling of the uv plane



Defrère et al. 2012



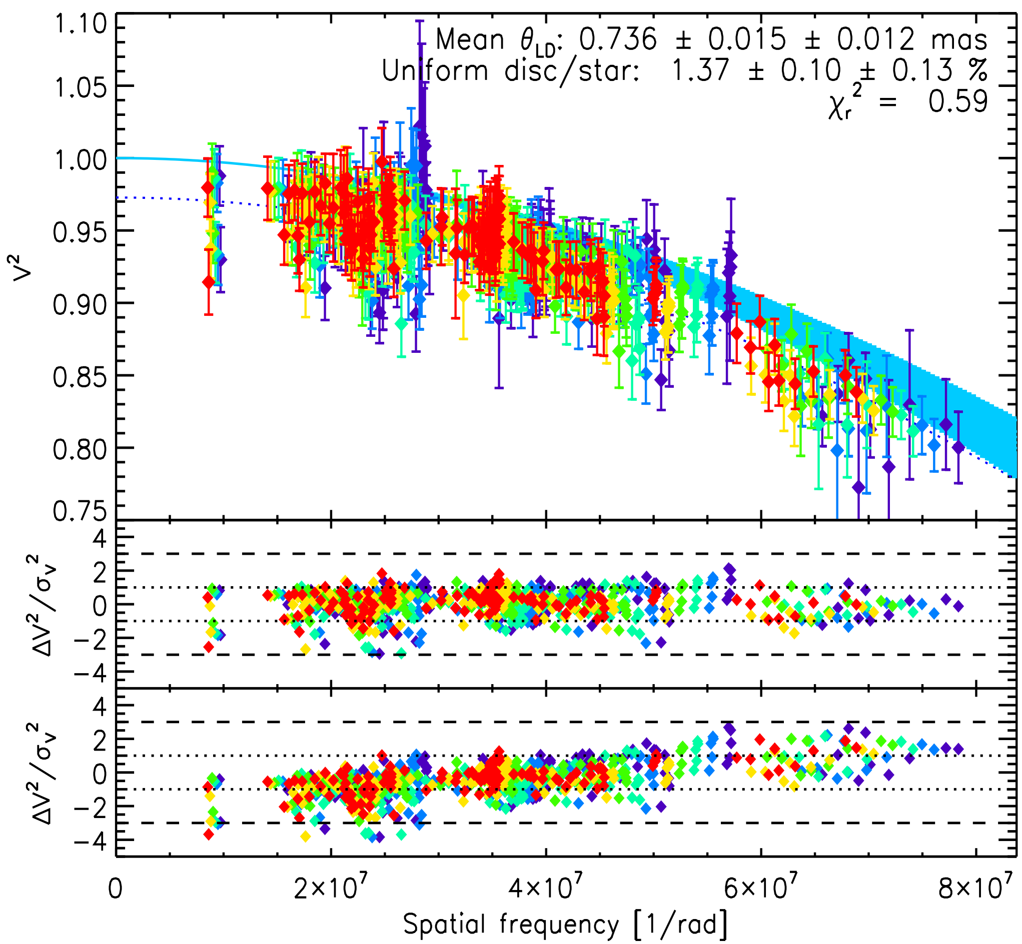
Exozodi detection



Defrère et al. 2012

Beta Pictoris with PIONIER

- 1.37% excess in the H-band within 4 AU (200mas)

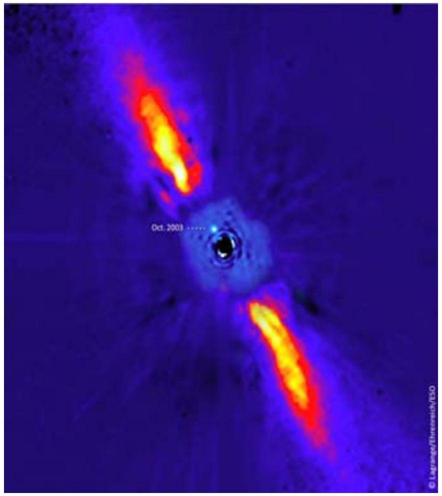


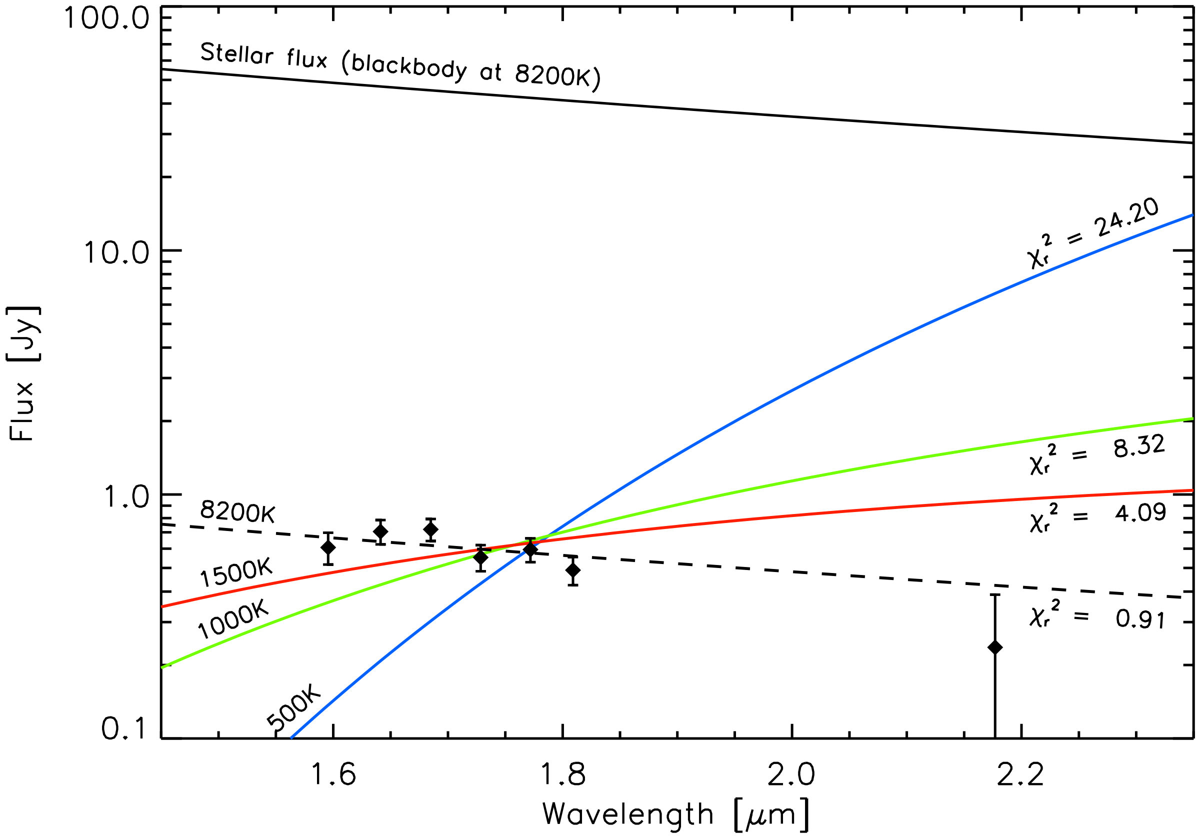
residuals assuming circumstellar emission

residuals assuming NO circumstellar emission

Exozodi detection

- **Beta Pictoris with PIONIER**
  - scattered light dominates over thermal emission

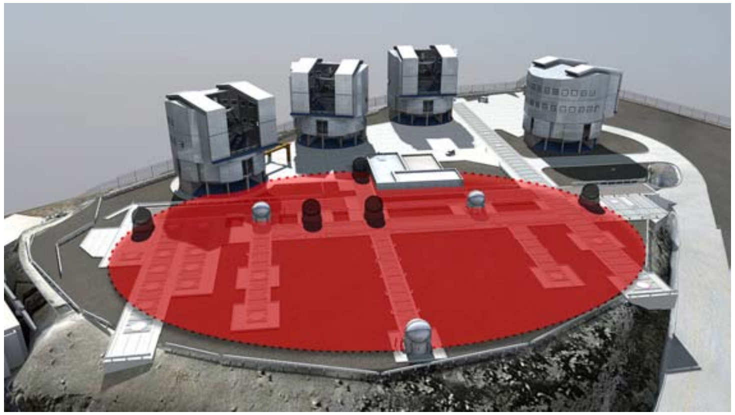




Defrère et al. 2012

2. Surveys for exozodiacal disks

- **The EXOZODI survey:**
  - **CHARA/FLUOR**
    - started in 2005
    - K-band
    - Northern hemisphere (California)
  - **VLTI/PIONIER**
    - executed in 2012
    - H-band
    - Southern hemisphere (Chile)

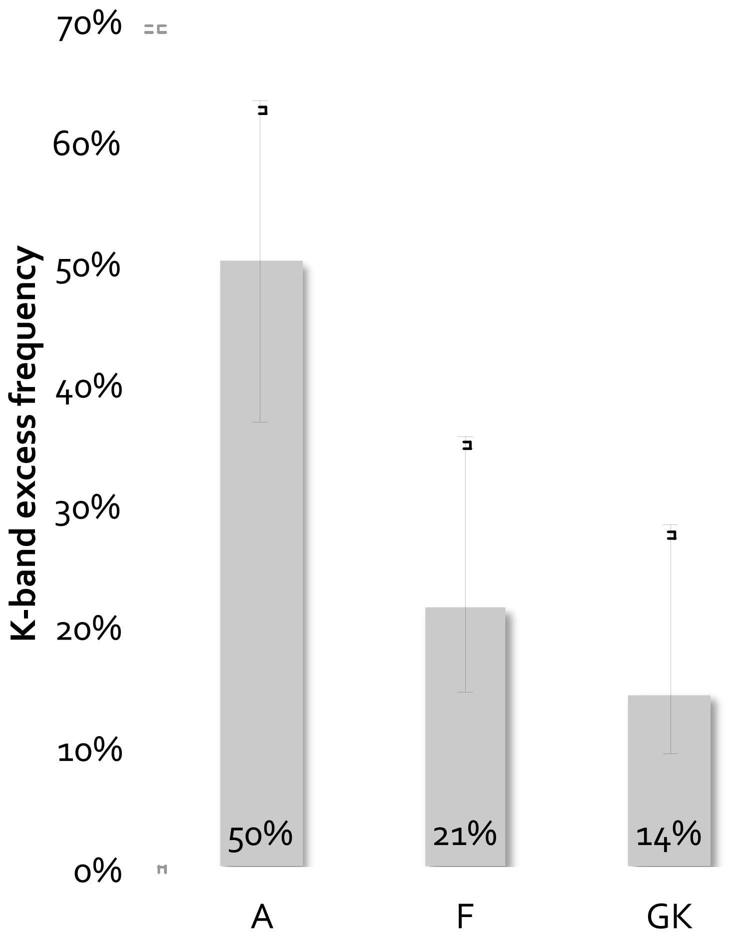


Surveys for exozodiacal disks

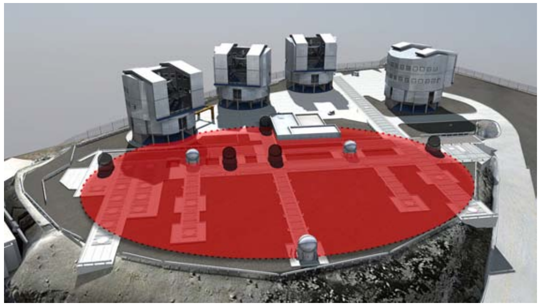
- CHARA/FLUOR interferometer
- K-band
- 42 stars
- 8 year survey

Absil et al. 2013

- **Exozodi detection frequency (K-band)**
  - ~ 30% for A-, F-, and GK-type stars
  - ~ 15-20% for solar type stars



Exozodi detection

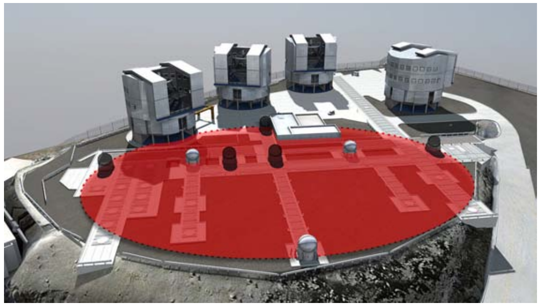


- VLTI/PIONIER interferometer

Ertel et al. in prep.

- **PIONIER large survey for exozodiacal dust:**
  - **PIONIER provides:**
    - high efficiency (~ 70 minutes / target)
    - single V^2 accuracy ~ 1%
    - high sensitivity
      - down to H=5 with very high V^2 accuracy
      - few hundreds of nearby stars available
  - **The EXOZODI survey:**
    - all-sky, unbiased, magnitude-limited sample of 92 stars, 88 of which have no closure phase signal.
    - evenly spread between spectral types A, F and G-K
    - ESO periods P89 and P90 (2012). About 11 nights.
    - H-band, small dispersion (3 spectral channels)
    - lead by Steve Ertel, Olivier Absil and Jean-Baptiste Lebouquin, with important contribution from Johan Olofsson

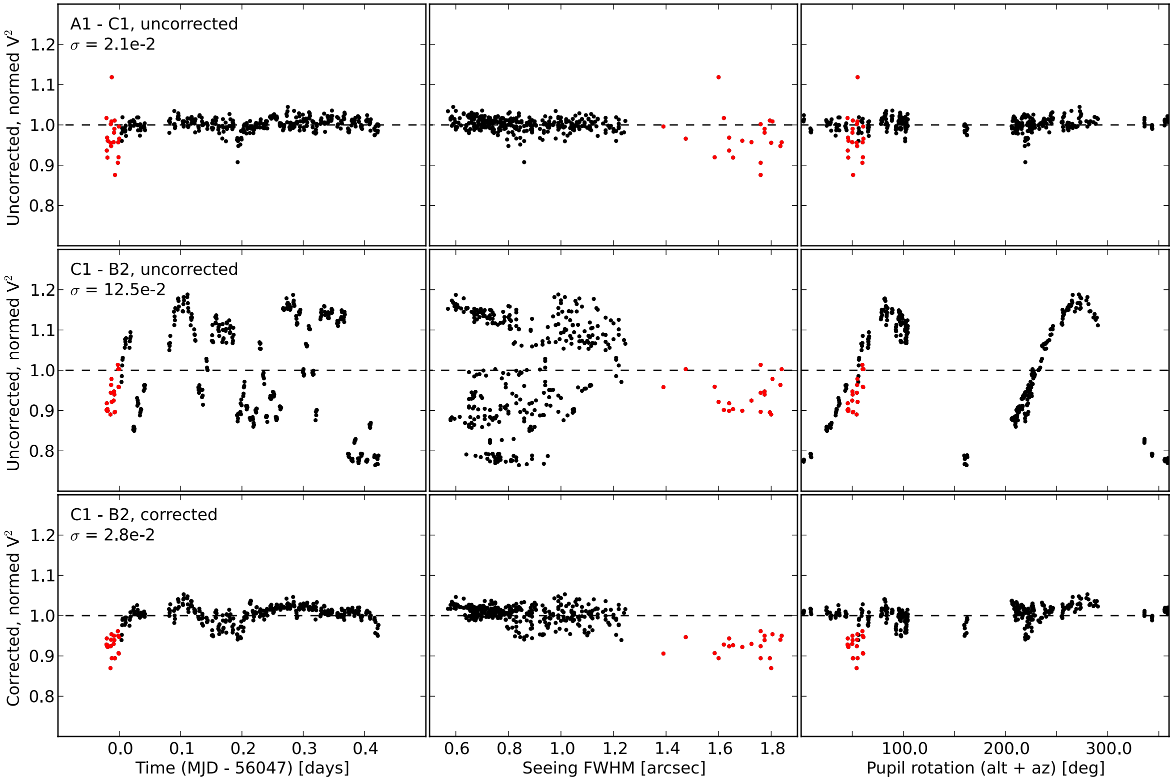
Surveys for exozodiacal disks



- VLTI/PIONIER interferometer

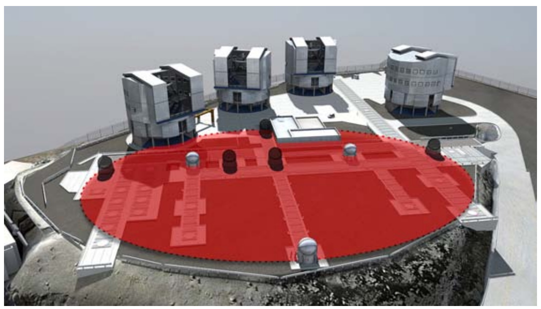
Lebouquin et al. 2012, SPIE
Ertel et al. 2014, in prep.

- **Pointing dependent Transfer function**
  - effect could be seen because
    - all-sky survey
    - many targets/calibrators in one night
  - empirical correction

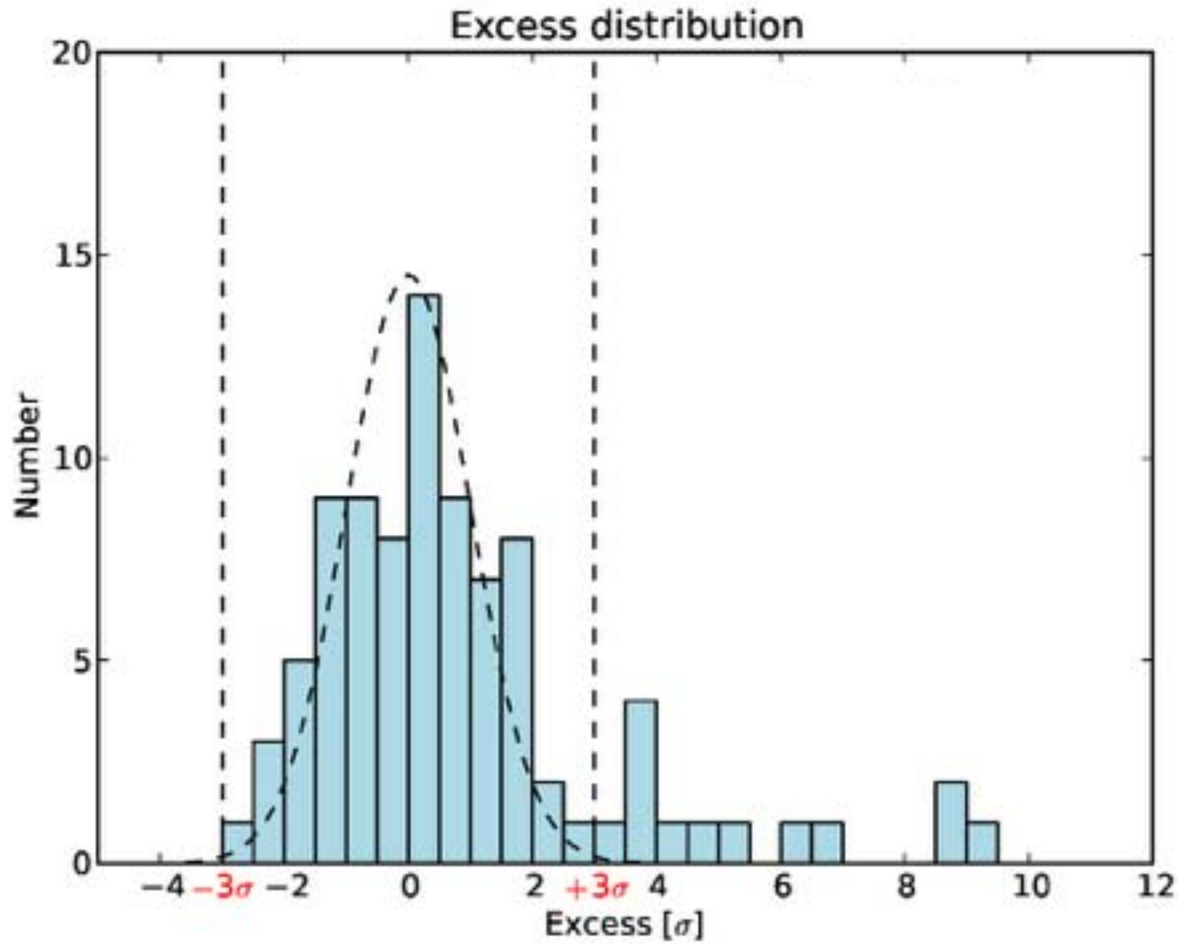


Surveys for exozodiacal disks

• Excess distribution

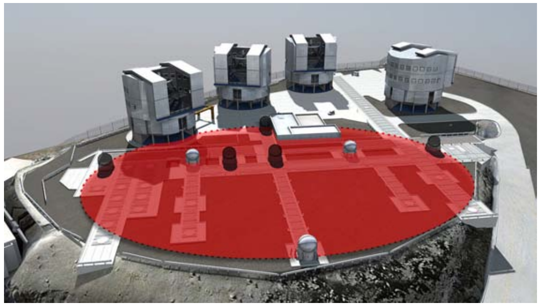


- VLTI/PIONIER interferometer



Ertel et al. in prep.

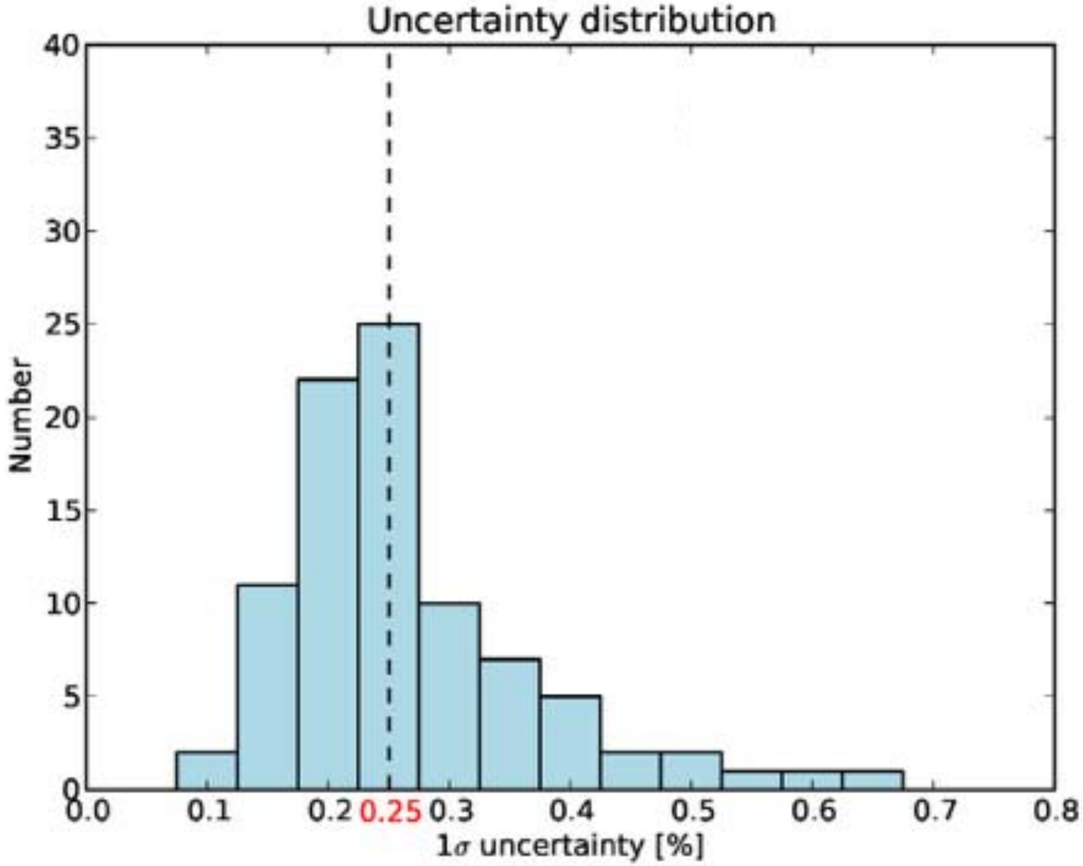
Surveys for exozodiacal disks



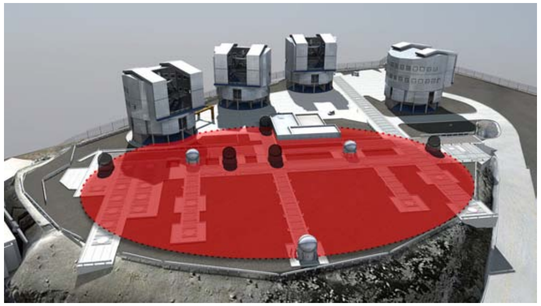
- VLTI/PIONIER interferometer

Ertel et al. in prep.

- **Excess distribution**
  - 1 sigma median excess uncertainty: 0.25% of the stellar flux



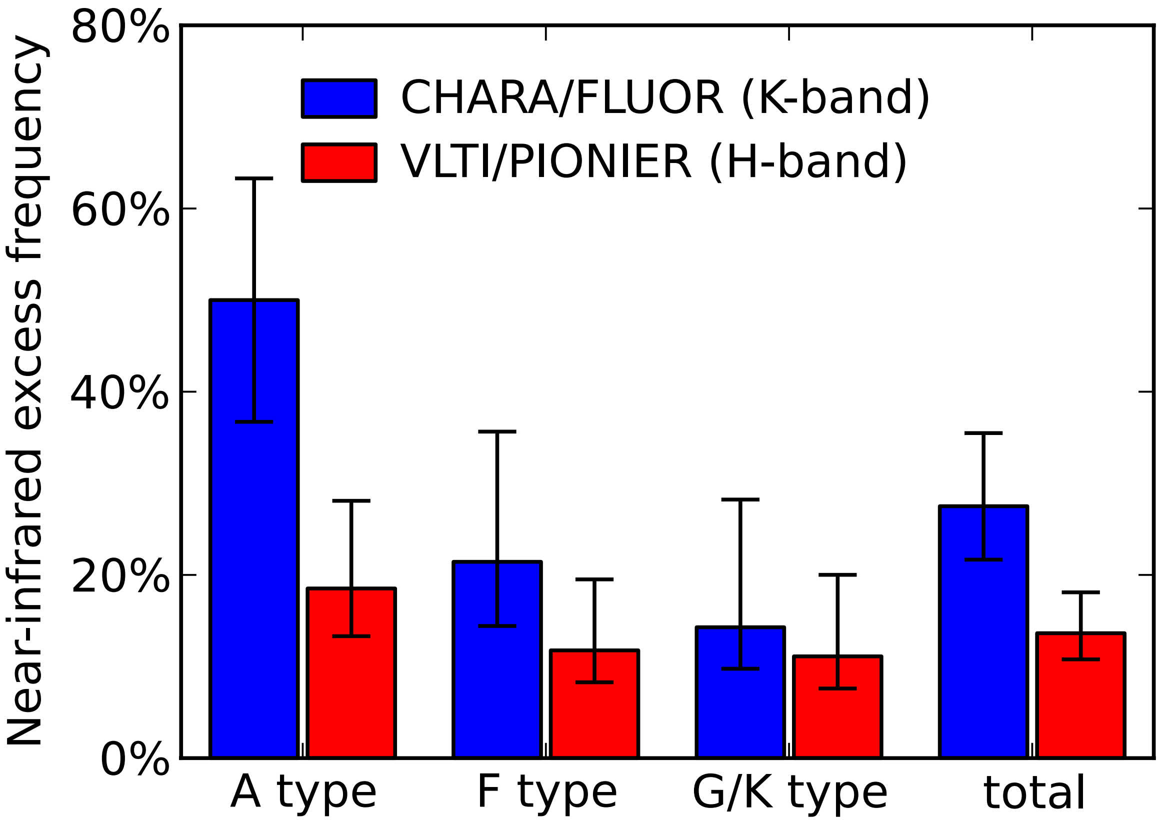
Surveys for exozodiacal disks



- VLTI/PIONIER interferometer
- H-band
- 88 stars
- 1 year survey

Ertel et al. in prep.

- **Exozodi detection frequency with PIONIER**
  - ~ 15% for A, F, and GK stars
  - ~ 12% for solar type stars

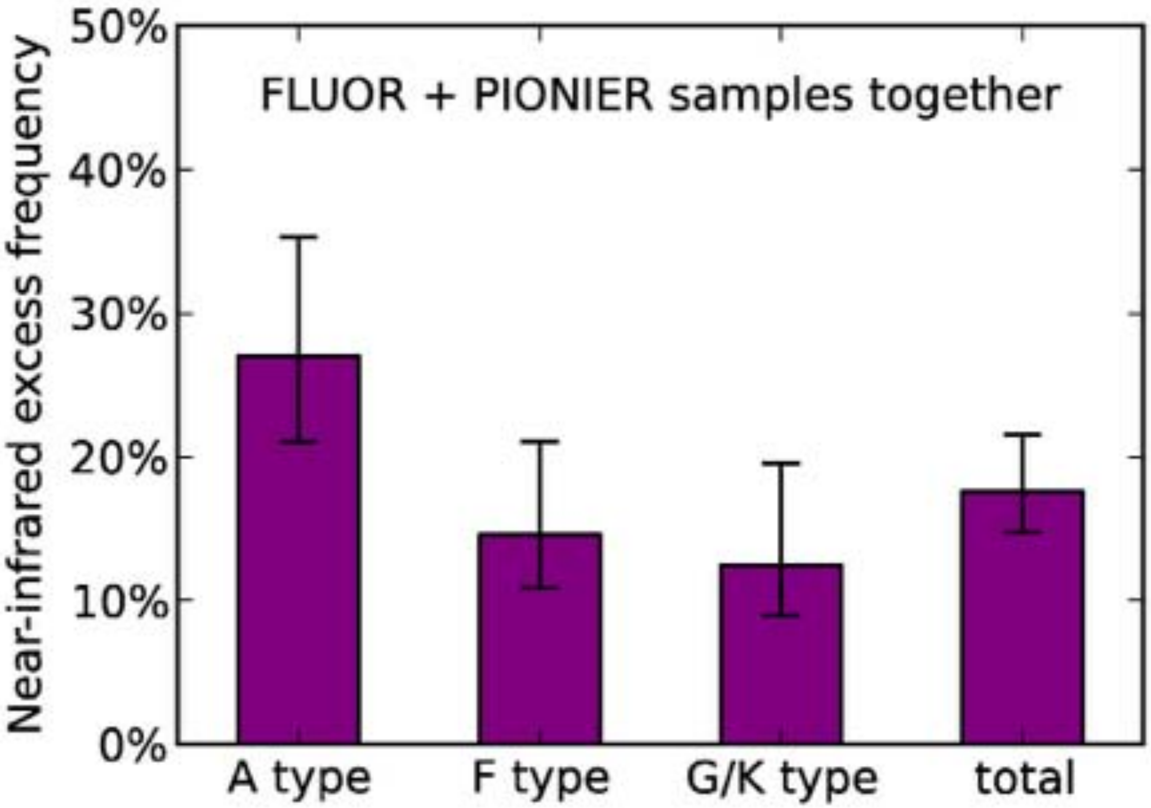


Surveys for exozodiacal disks

- CHARA/FLUOR + VLTI/PIONIER data
- 130 stars in total

Ertel et al. in prep.

Merging the CHARA/FLUOR and VLTI/PIONIER samples

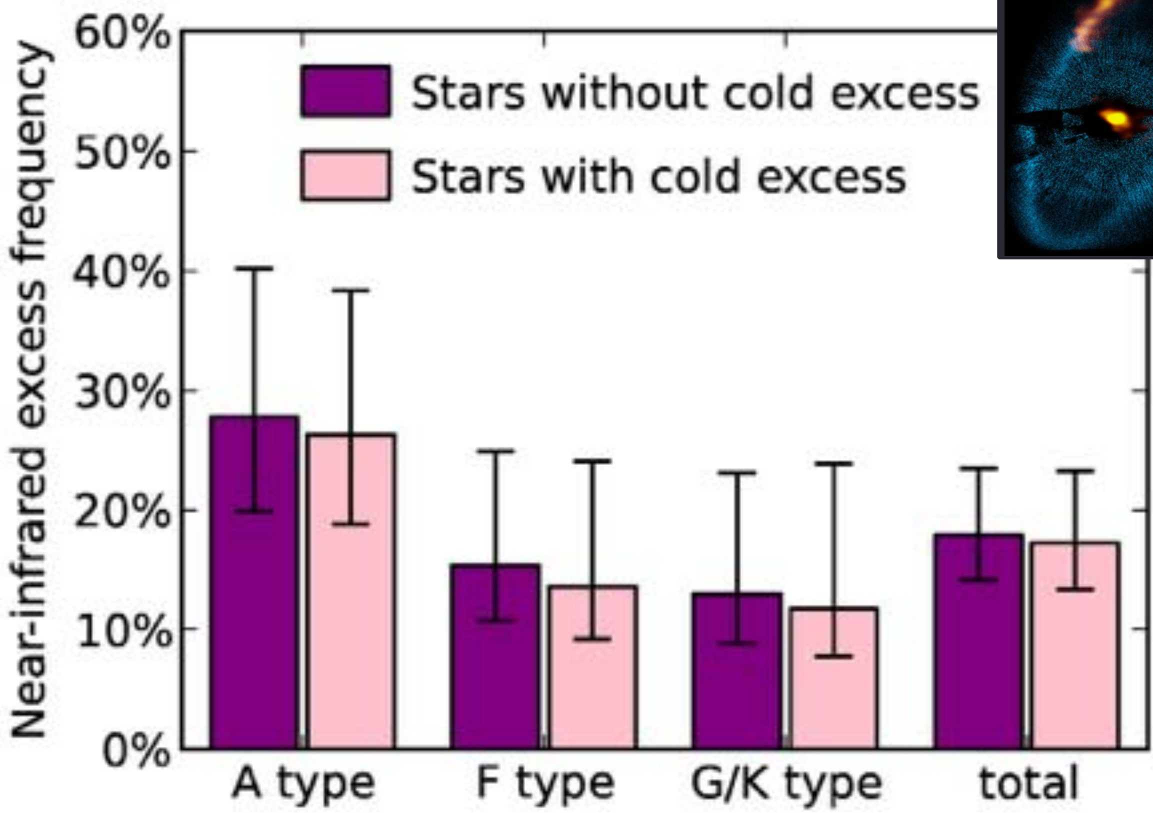


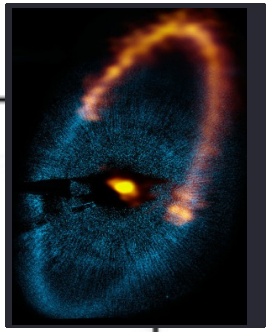
Surveys for exozodiacal disks

- CHARA/FLUOR + VLTI/PIONIER data
- 130 stars in total

Ertel et al. in prep.

- **Hot and cold dust not correlated**



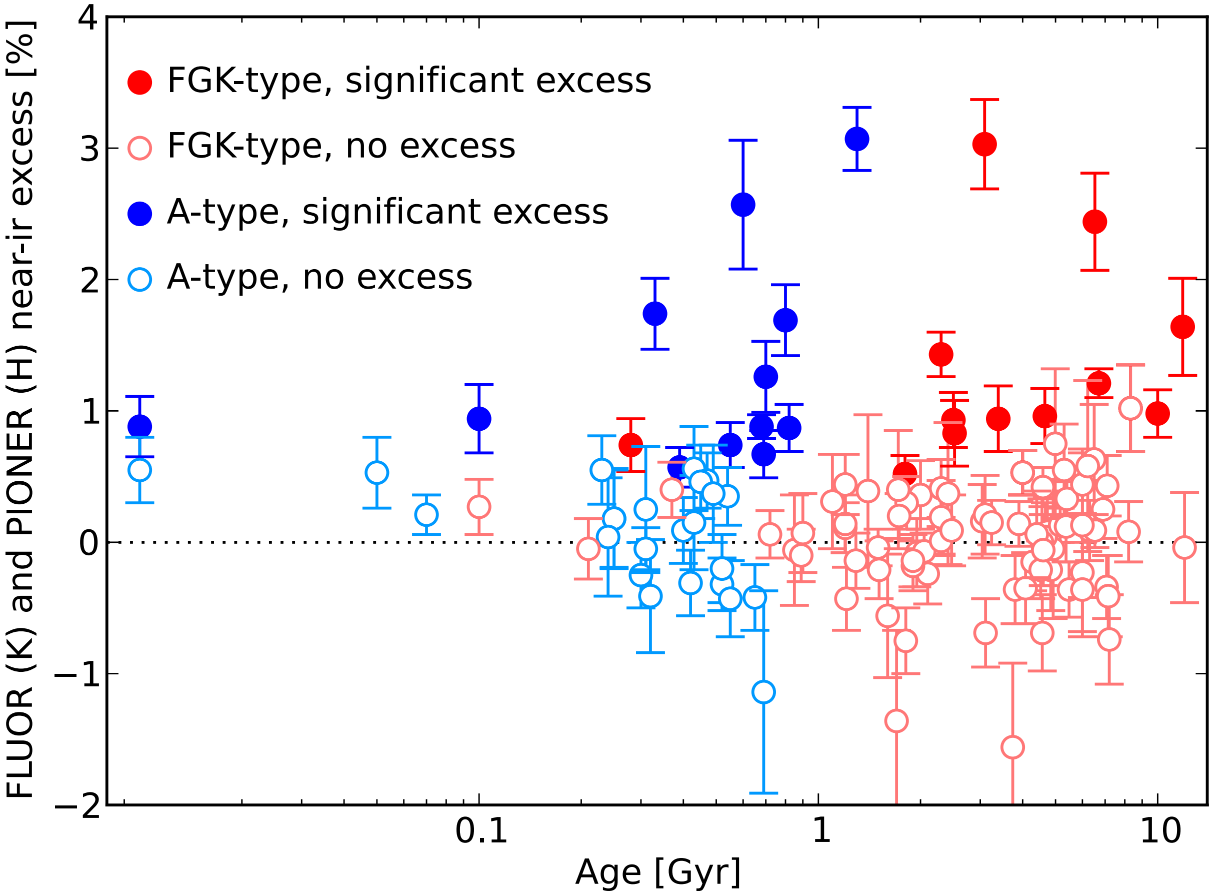


Surveys for exozodiacal disks

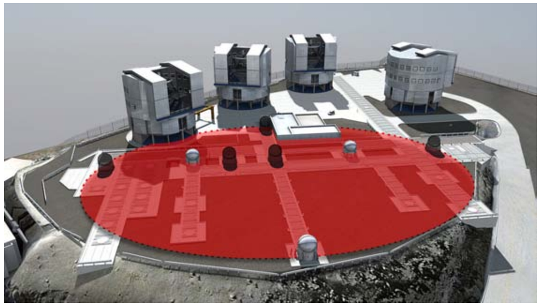
- CHARA/FLUOR + VLTI/PIONIER data
- 130 stars in total

Ertel et al. in prep.

- **No clear age dependence seen**
  - possible increasing detection rate with increasing age



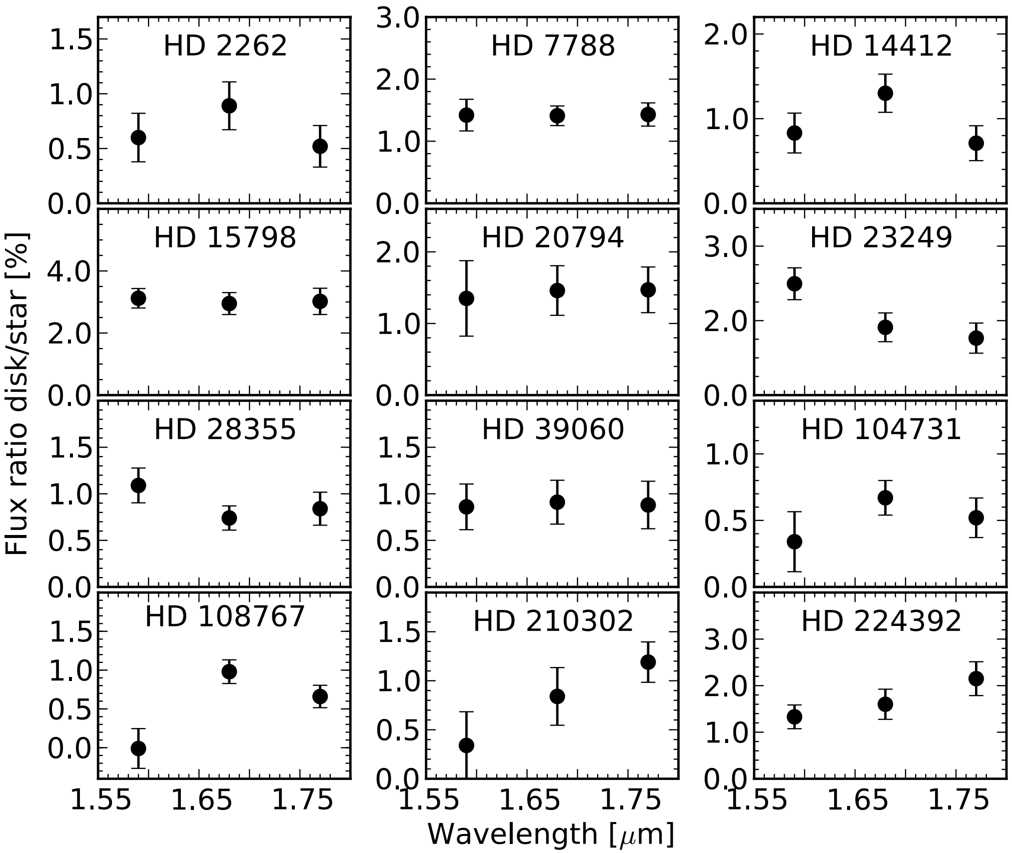
Surveys for exozodiacal disks



- VLTI/PIONIER interferometer

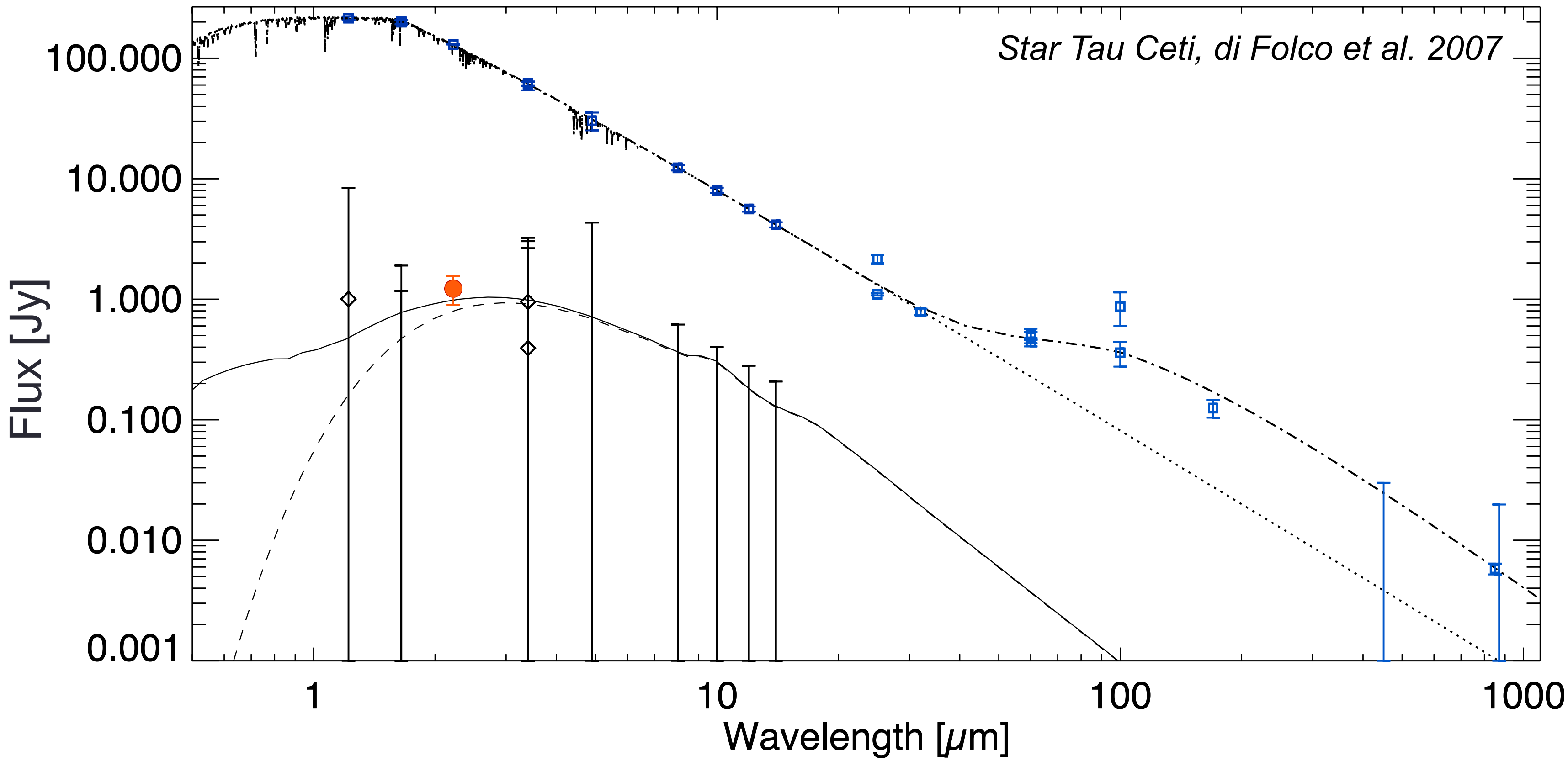
Ertel et al. in prep.

- **Color of the excess across the H-band**
  - flat disk to star contrast: suggests important contribution from scattered light



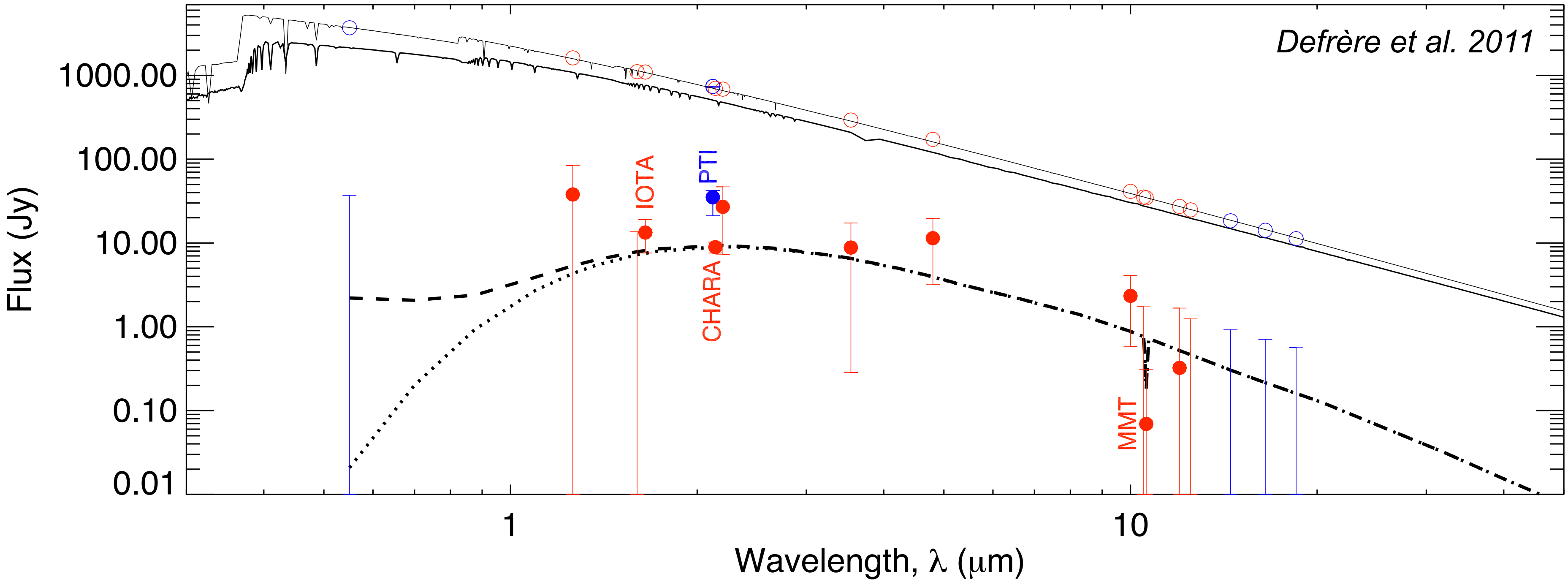
3. Radiative transfer modelling

- **Methodology:**
  - radiative transfer code GRaTer (Augereau et al. 1999, Lebreton et al. 2012)
  - disk properties around the sublimation distance (Lebreton et al. 2013)
  - grids of models, bayesian analysis



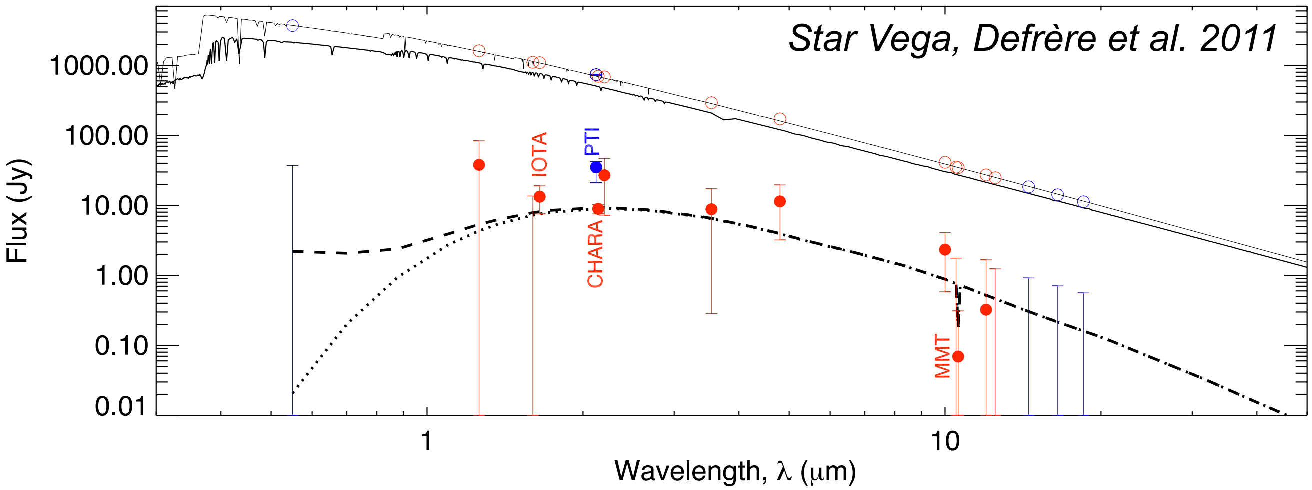
Radiative transfer modelling

- **Vega:**
  - H- and K-band interferometry
  - N-band nulling interferometry (MMT-BLINC)
  - archival near- and mid-IR spectro-photometry

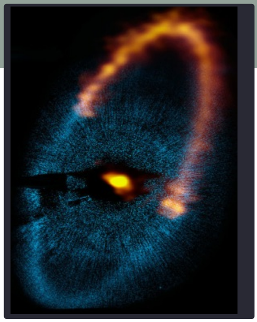


Radiative transfer modelling

- **General properties:**
  - very small grains (sub micron-sized < blow out size)
  - carbon-rich
  - accumulated next to the sublimation distance (0.1-0.5 AU)
  - dust mass (M_{dust}) : ~10^{-10} - 10^{-9} M_{Earth}
  - dust mass rate (dM_{dust}/dt): ~10^{-10} - 10^{-9} M_{Earth}/year

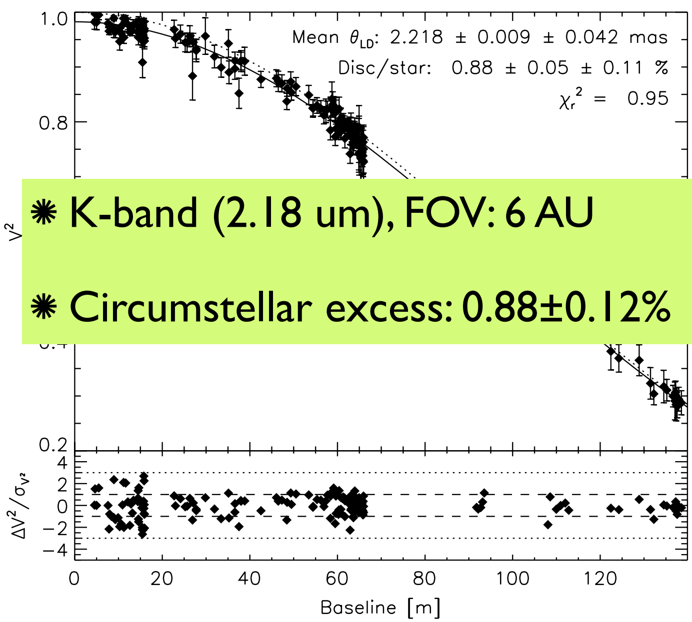


- Vega:
  - Absil et al. 2006
  - Defrère et al. 2011
- Tau Ceti:
  - Di Folco et al. 2007
- Fomalhaut:
  - Absil et al. 2009
  - Mennesson et al. 2013
  - Lebreton et al. 2013

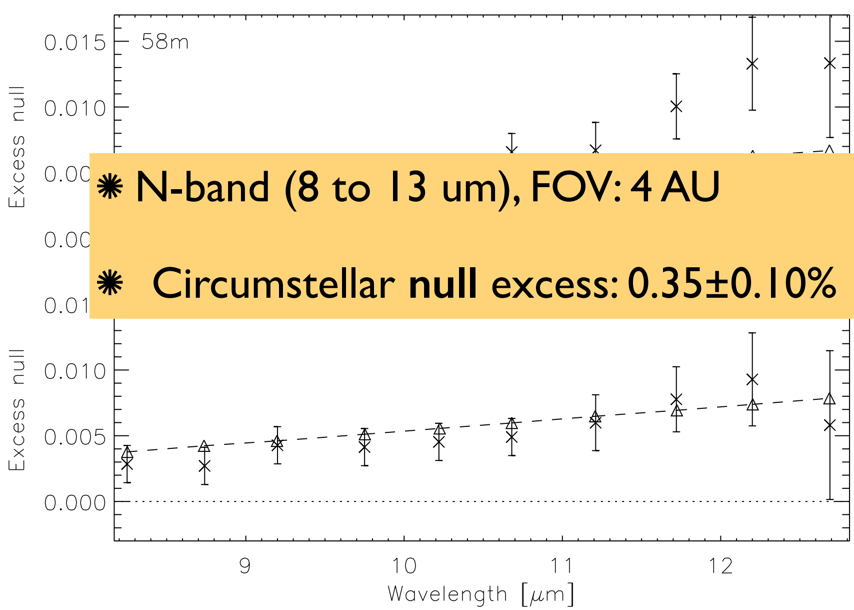


Radiative transfer modelling

- # Fomalhaut
  - panchromatic and spectrally dispersed data make a big difference



- K-band (2.18 um), FOV: 6 AU
- Circumstellar excess: 0.88±0.12%

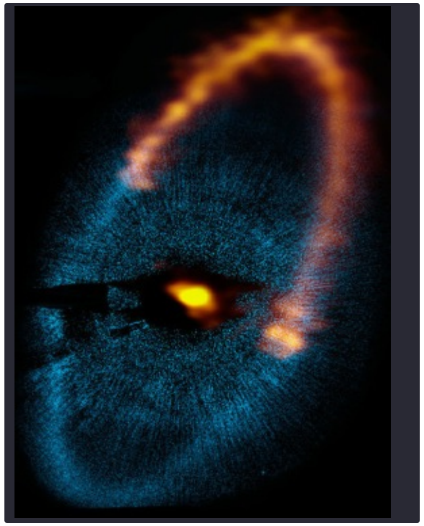


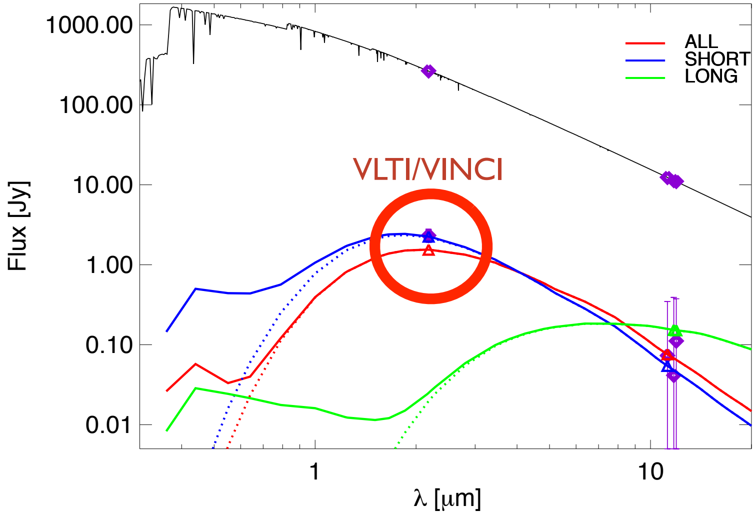
- N-band (8 to 13 um), FOV: 4 AU
- Circumstellar **null** excess: 0.35±0.10%

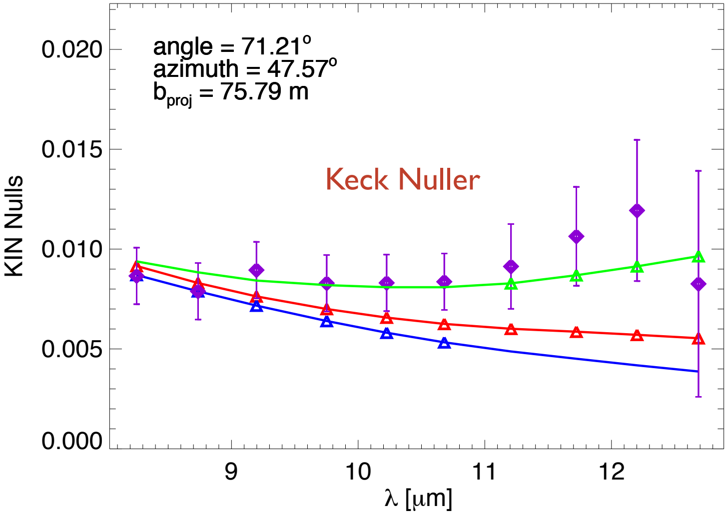
Fomalhaut

- a single dust population fails to reproduce everything together

Radiative transfer modelling







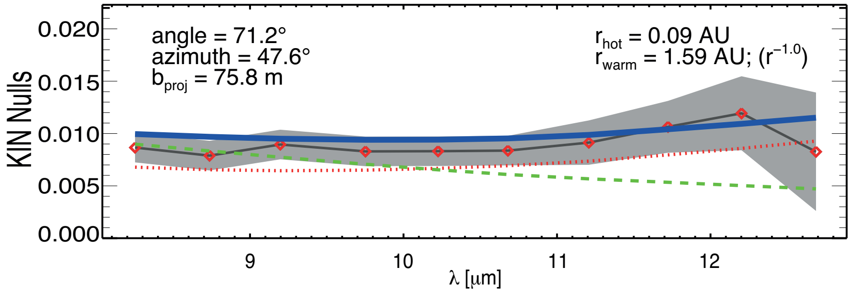
Mennesson et al. 2013
Lebreton et al. 2013

Lebreton et al. 2013

Radiative transfer modelling

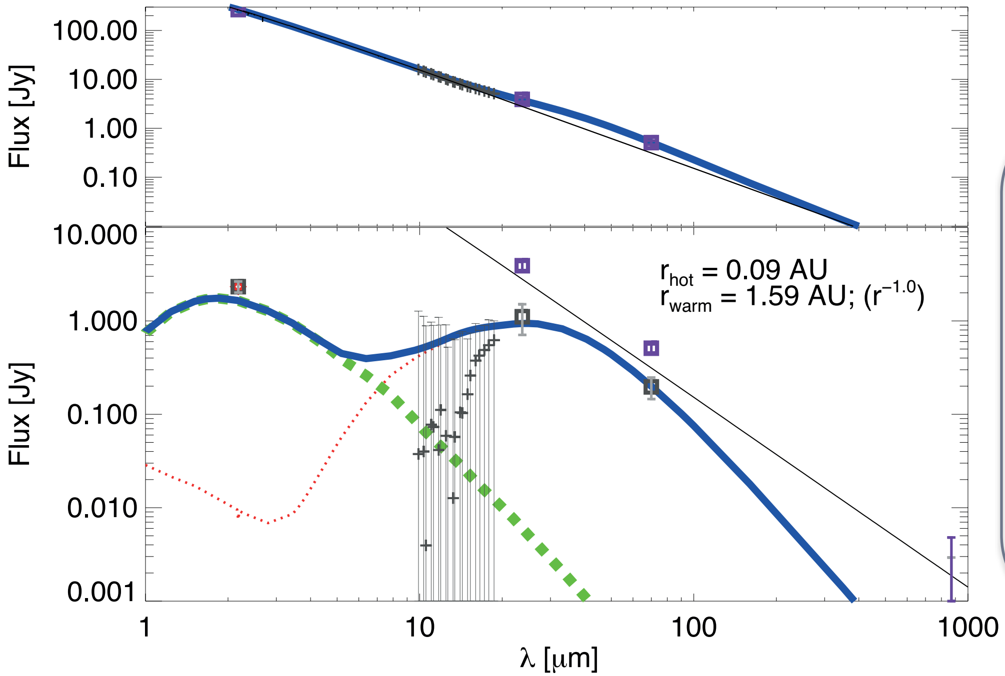
- **Fomalhaut**
  - two dust populations

KIN excess null depths



Spectral Energy Distribution

VLTI/VINCI, MIPS 24, Herschel 70 μm, (ALMA 870 μm)



	HOT	**WARM**
Material	C	C+Si
Size (μm)	> 0.02	> 3
Distance (AU)	0.09-0.23	[1.5, 2.5]
Mass (M_{Earth})	2.5×10^{-10}	2×10^{-6}

χ^2_r = 1.6 (dof=30)

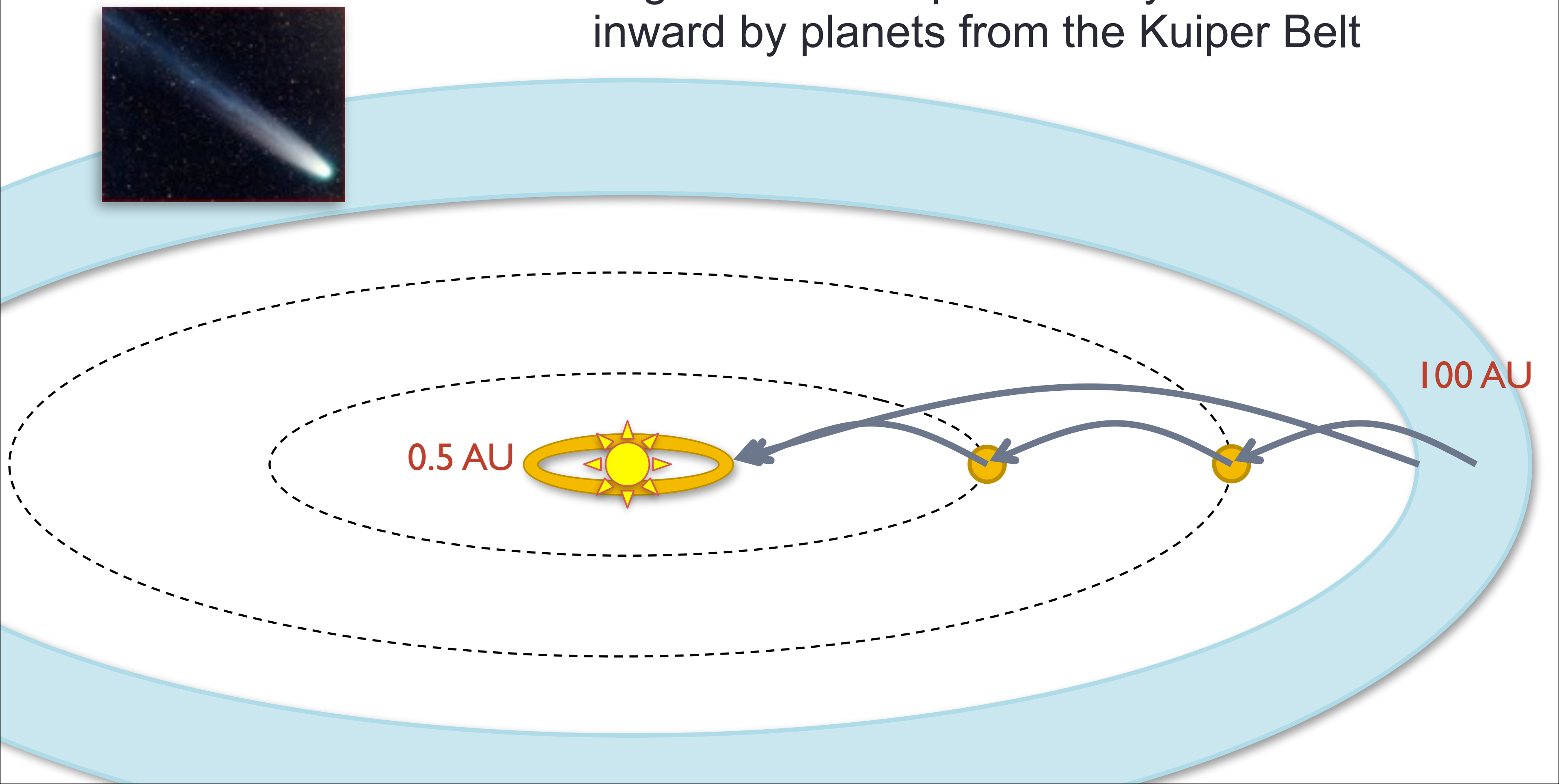
4. Origin of the exozodiacal dust

- **The conundrum:**
  replenishment in steady-state by collisions between planetesimals does NOT work for exozodiacal debris disks.

- **Possible solutions:**
  - **dynamical instabilities (e.g. LHB)**:
    unlikely to explain our statistics : *<0.1% chance to observe a system in the aftermath of a dynamical instability, Bonsor et al. (2013)*
  - **link with the outer planetary system**
  - **something else…?**

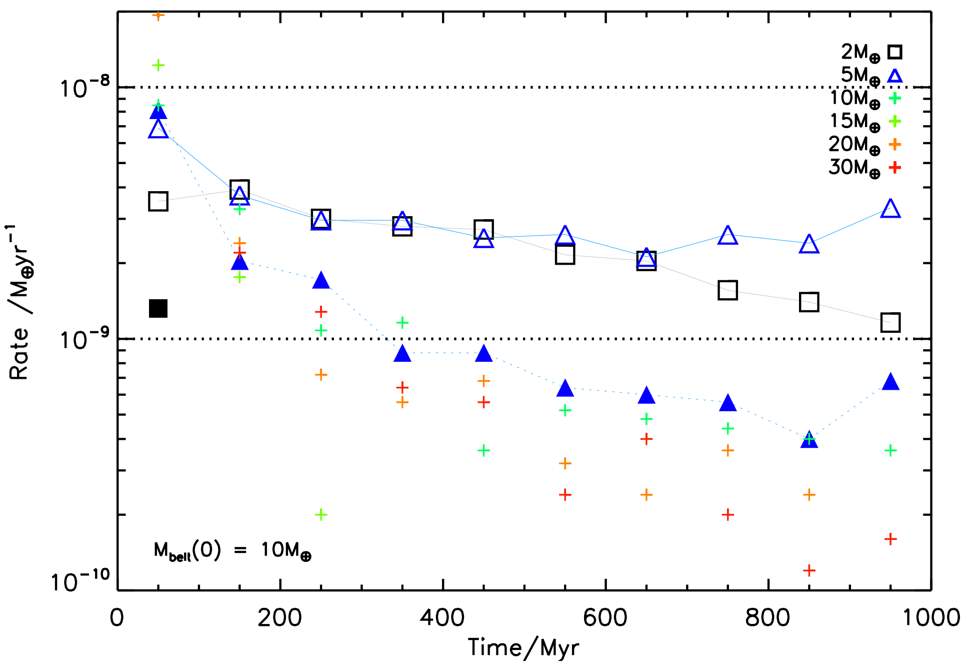
Origin of the exozodiacal dust

- **Steady-state scattering by a chain of (unseen) planets**
  - Solar System's zodiacal cloud is thought to originate from Jupiter Family comets scattered inward by planets from the Kuiper Belt



Origin of the exozodiacal dust

- **Steady-state scattering by a chain of (unseen) planets**
  - Without planet migration: mass flux is insufficient to sustain Vega' exozodi for example
  - With planetesimal driven migration: mass flux might be sustained long enough



Bonsor et al. 2012
Bonsor et al. 2014, submitted

Concluding remarks

Publications by the EXOZODI team:

- Absil et al. 2006
- Di Folco et al. 2007
- Absil et al. 2008
- Absil et al. 2009
- Defrère et al. 2011
- Bonsor et al. 2012
- **Defrère et al. 2012**
- Olofsson et al. 2013
- Mennesson et al. 2013
- Lebreton et al. 2013
- Absil et al. 2013
- Bonsor et al. 2013
- Bonsor et al. 2014
- **Ertel et al. 2014**

+

- Thébault 2012
- Thébault et al. 2013
- Kral et al. 2013
- Beust et al. 2013

- PIONIER + FLUOR : Hot, exozodiacal dust is found around 15-20% of solar-type stars. They appear randomly (e.g. no correlation with age or presence of cold dust)
- Grains seen in the near-IR are small, carbonaceous, and close to the sublimation distance
- Spectrally dispersed interferometric data are essential in the near-IR to mid-IR
- Their origin is still quite mysterious. Our preferred scenario involves a link with the outer planetary system