Exozodiacal disks

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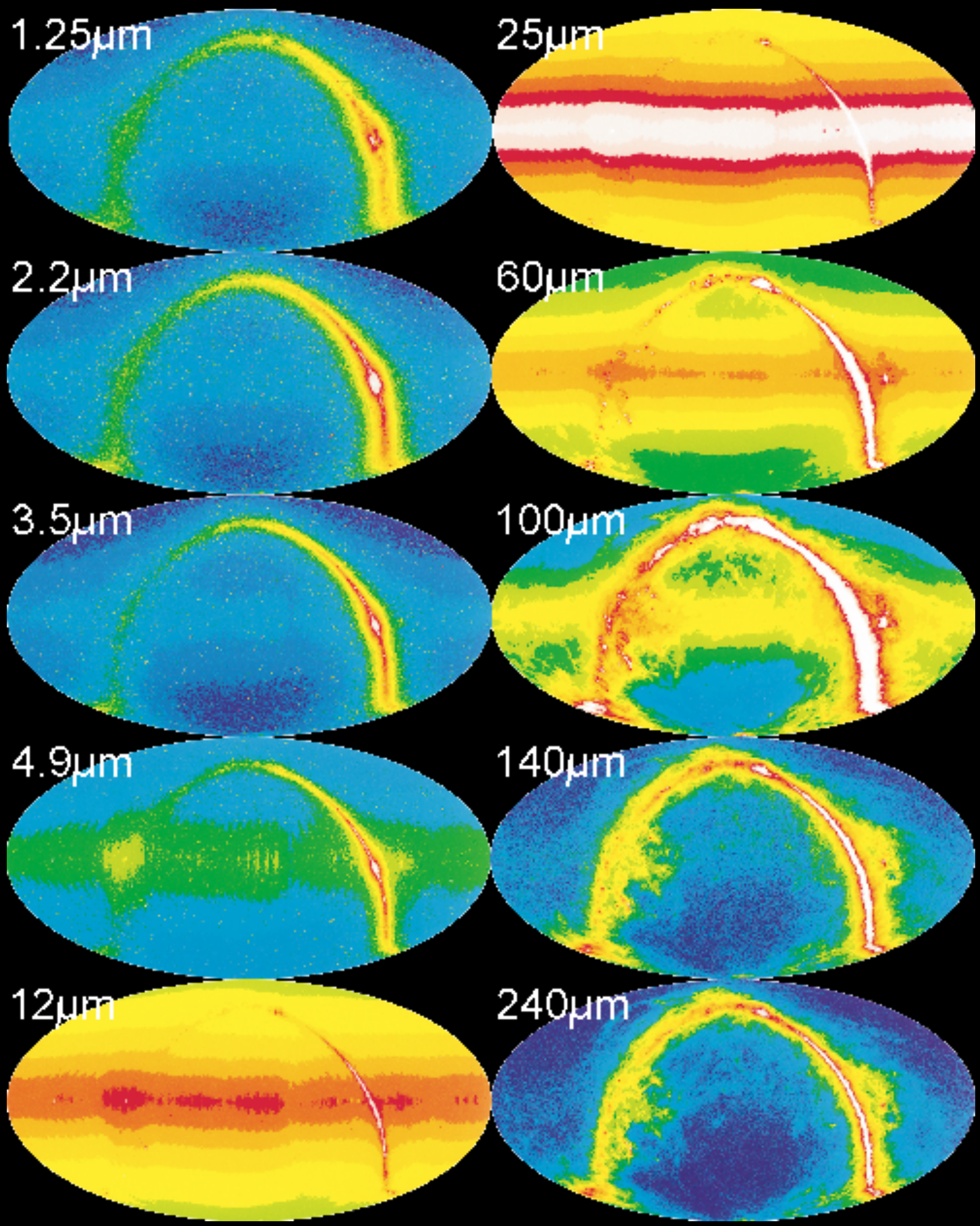
Hi-5 kick-off meeting
Liège, 2 October 2017

The zodiacal dust



COBE/DIRBE (Kelsall et al. 1998)

- Dust inside a few AU
- Continuous transition to F-corona at few $R_{\odot}$,
  T: few 100K to 2000K
  (Kimura & Mann 1998, Hahn et al. 2002)
- Comet evaporation
  (Dermott et al. 2002)
  asteroid collision & P-R drag
  (Nesvorny et al. 2010)
- Complex local structure (planetary interaction, local dust creation)

Exozodis: why do we care?

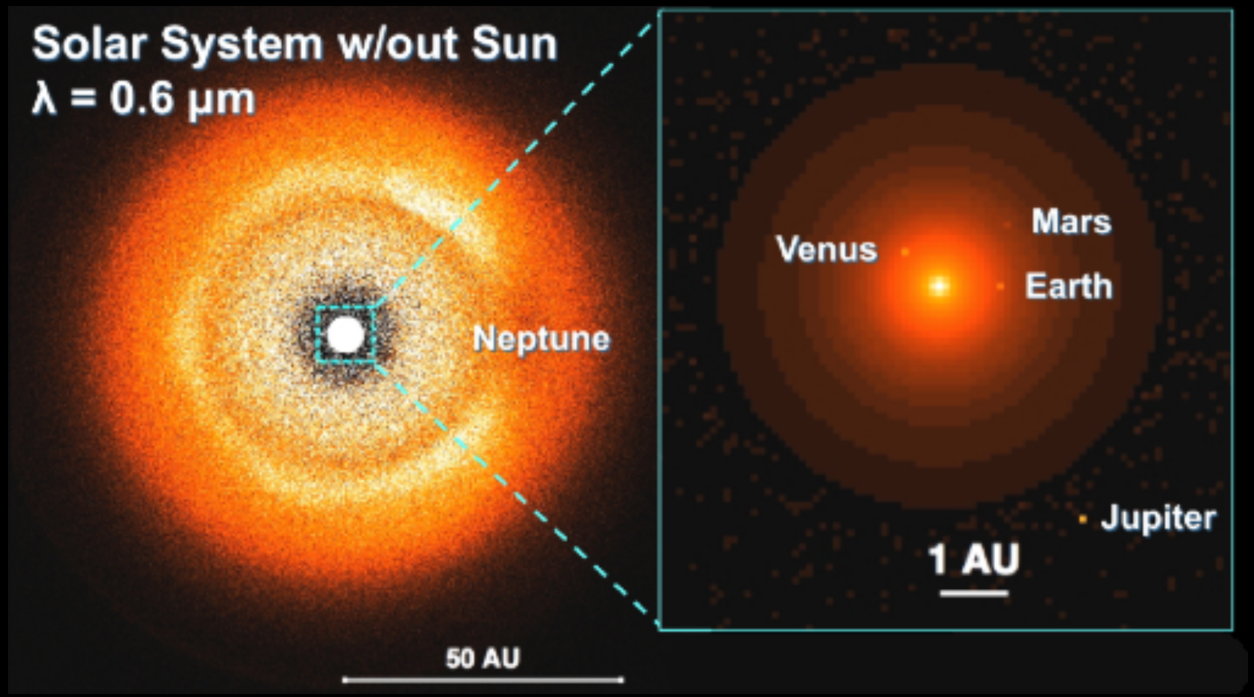
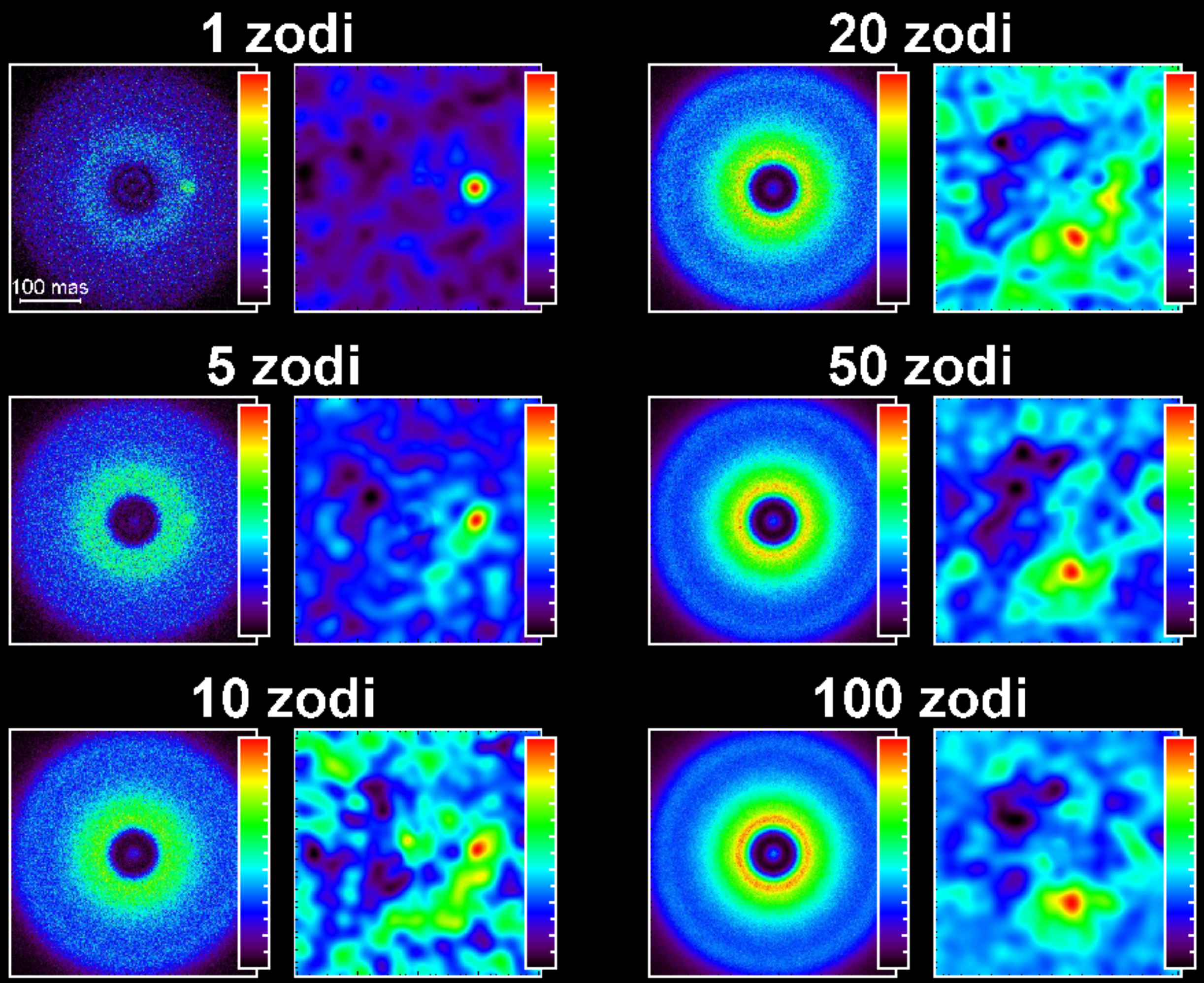


Image credit: M. Rizzo & A. Roberge

- Adds photon noise and confusion for future exo-Earth imaging space missions
- Required aperture size depends on dust levels (range: 5 to 13m) (Stark et al. 2015)

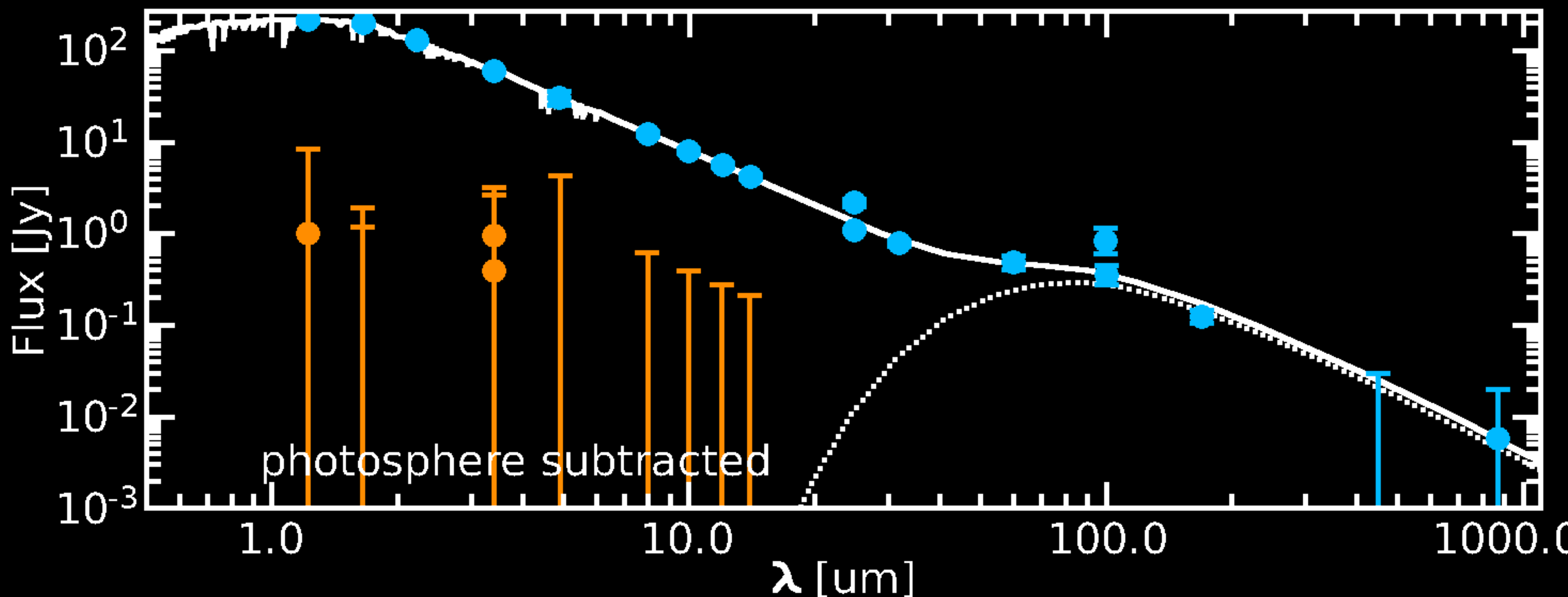


Defrère et al. (2012)

- Most luminous component of planetary systems after star
- Gives insight into architecture and dynamics in the innermost regions (near habitable zone)

Detecting exozodis

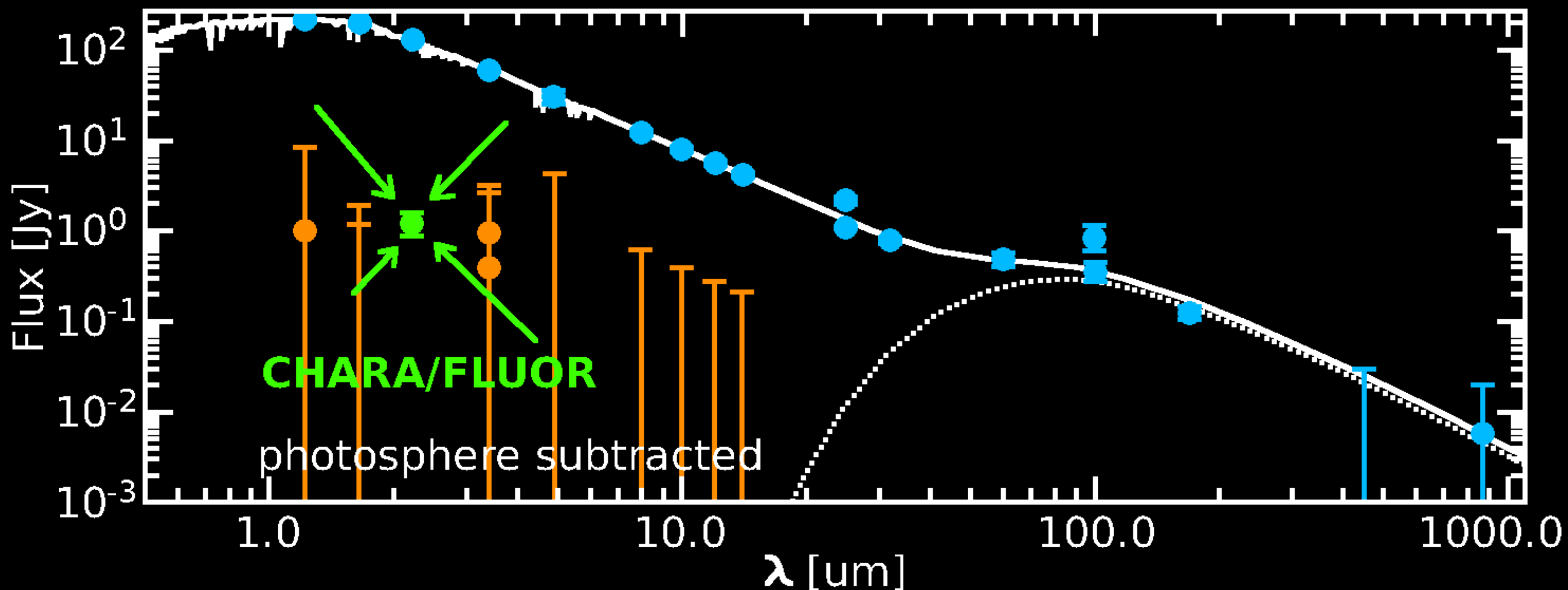
Exozodi detection: challenge



τ Ceti (Di Folco et al. 2007)

- Emits in the mir- to far-IR, outshone by star (typical excess <1%)
- Typical accuracy of photometric calibration and stellar photospheric models is a few %

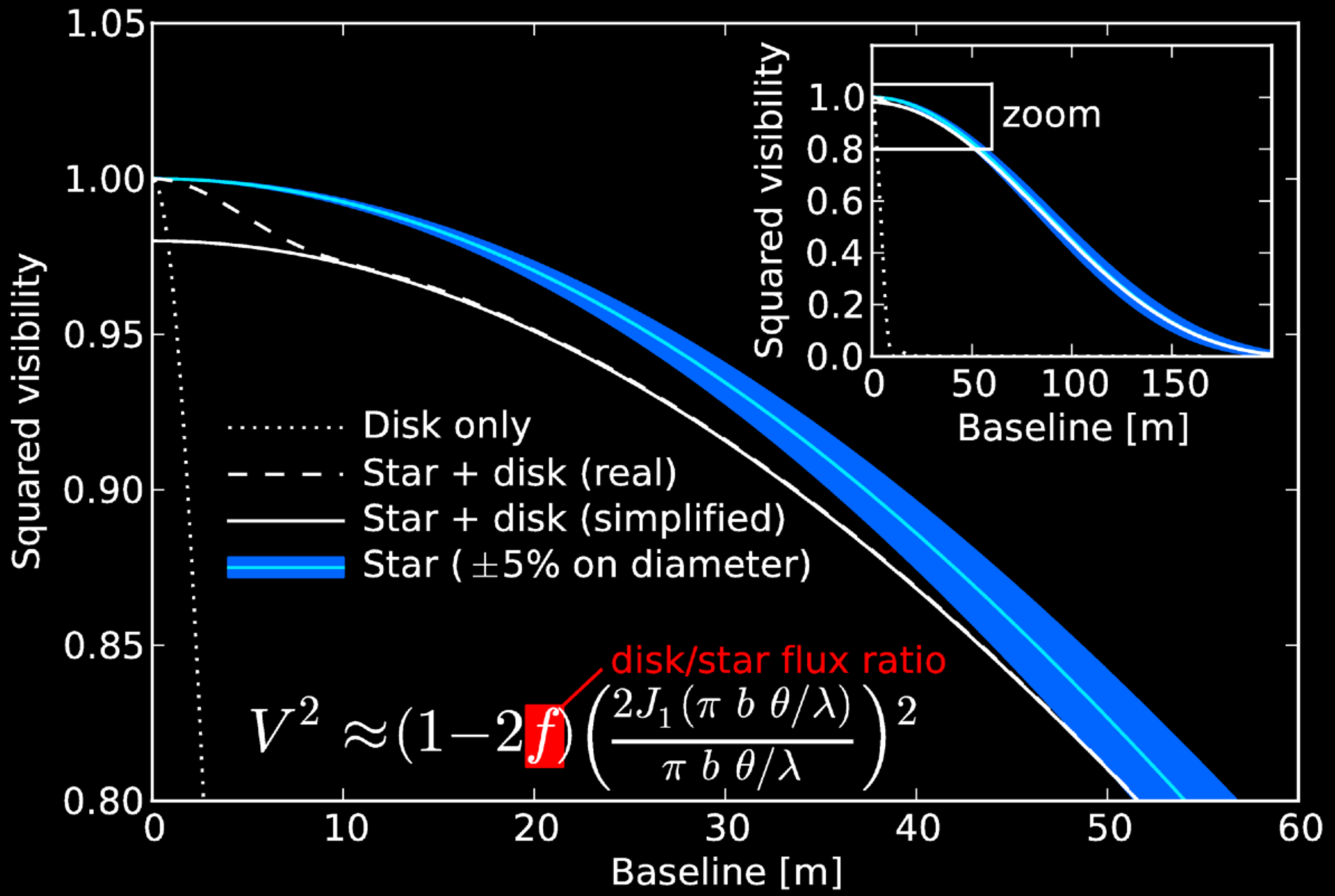
Exozodi detection: solution



τ Ceti (Di Folco et al. 2007)

- Emission alone would be easily detectable (10 mJy to 1 Jy)
- But: ~100 mas separation → spatially disentangle stellar emission and dust emission using near/mid infrared interferometry

Near-IR stellar interferometry

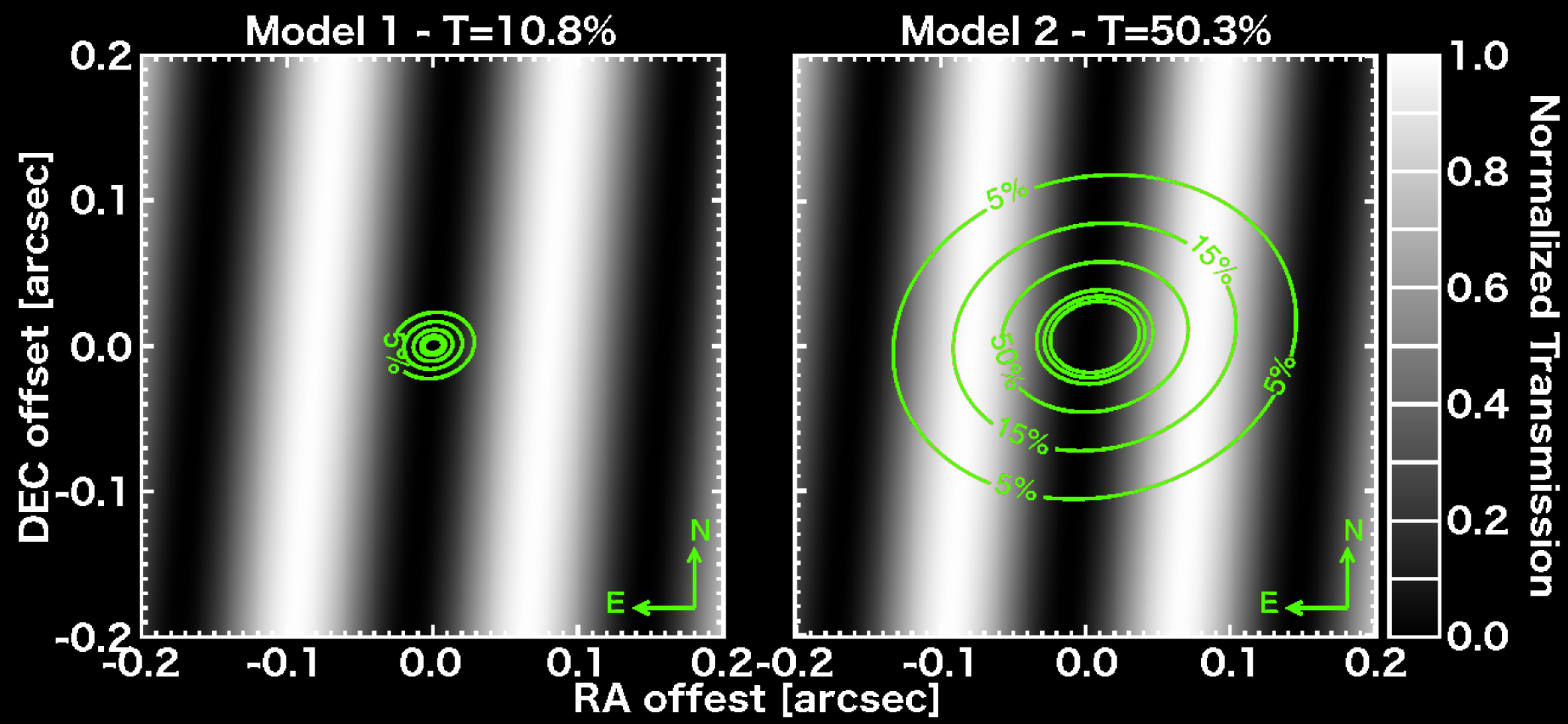


Di Folco et al. (2007), Ertel et al. (2014)

- First detection around Vega in *K* band with CHARA/FLUOR
  (Absil et al. 2006)

- Multiple large surveys and follow-up with CHARA/FLUOR (*K* band, North) and VLTI/PIONIER (*H* band, South)
  (Absil et al. 2013, Ertel et al. 2014, Marion et al. 2014, Ertel et al. 2016, Nuñez et al. 2017, Marion et al. subm.)

Mid-IR nulling interferometry

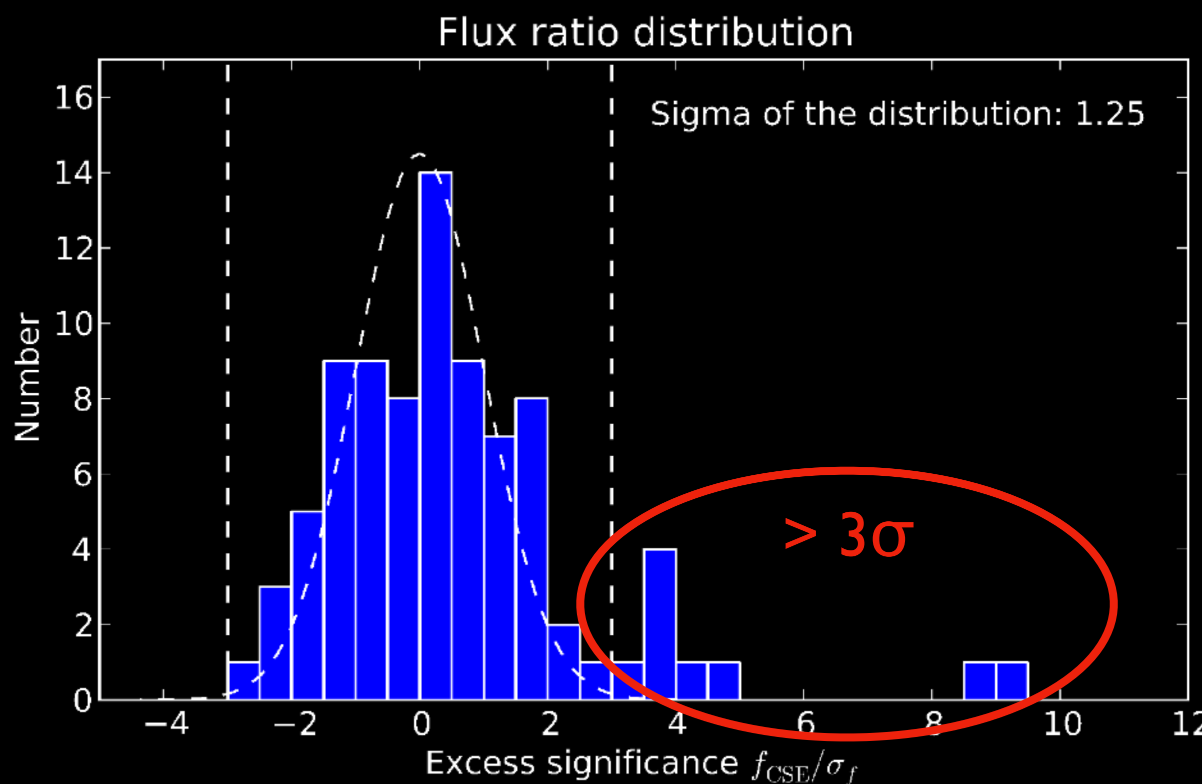


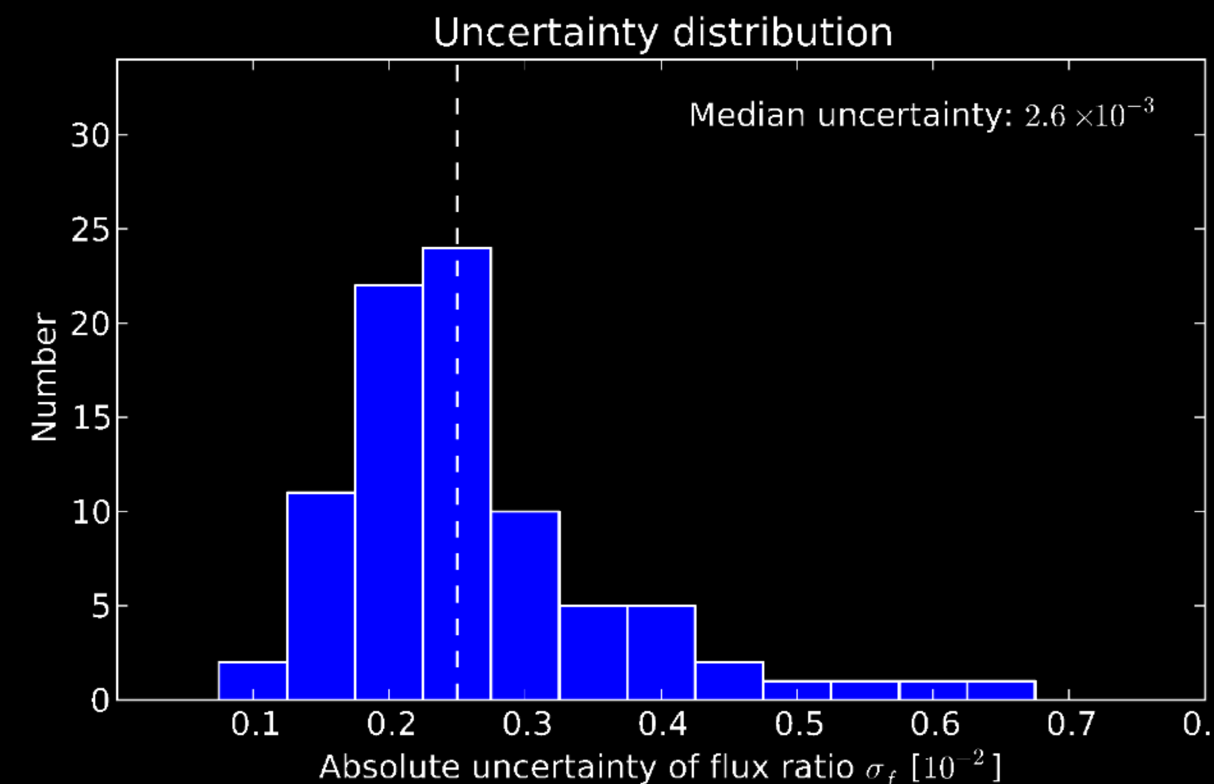
Defrère et al. (2015)

- Habitable zone dust best detectable in *N* band
- NASA funded surveys in preparation for exo-Earth imaging missions
- Keck Interferometric Nuller (KIN, completed),
  Large Binocular Telescope Interferometer (ongoing)

Observational results

Near-IR interferometric surveys

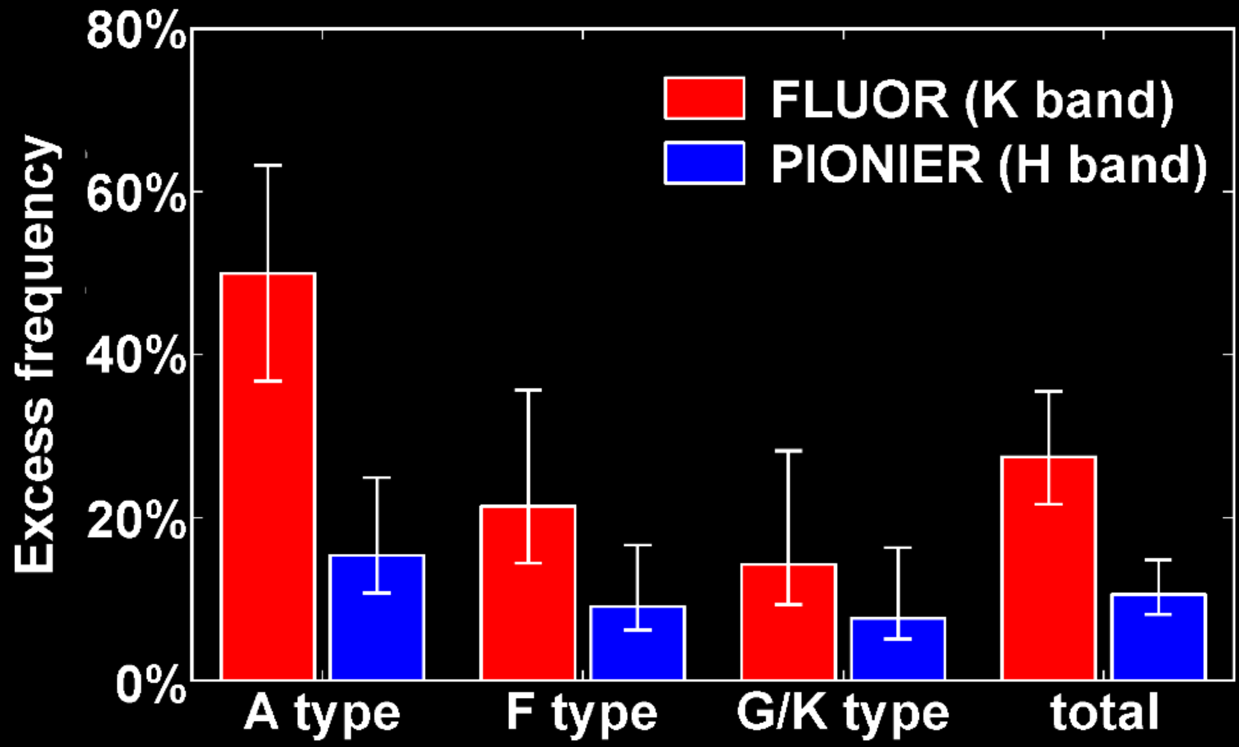


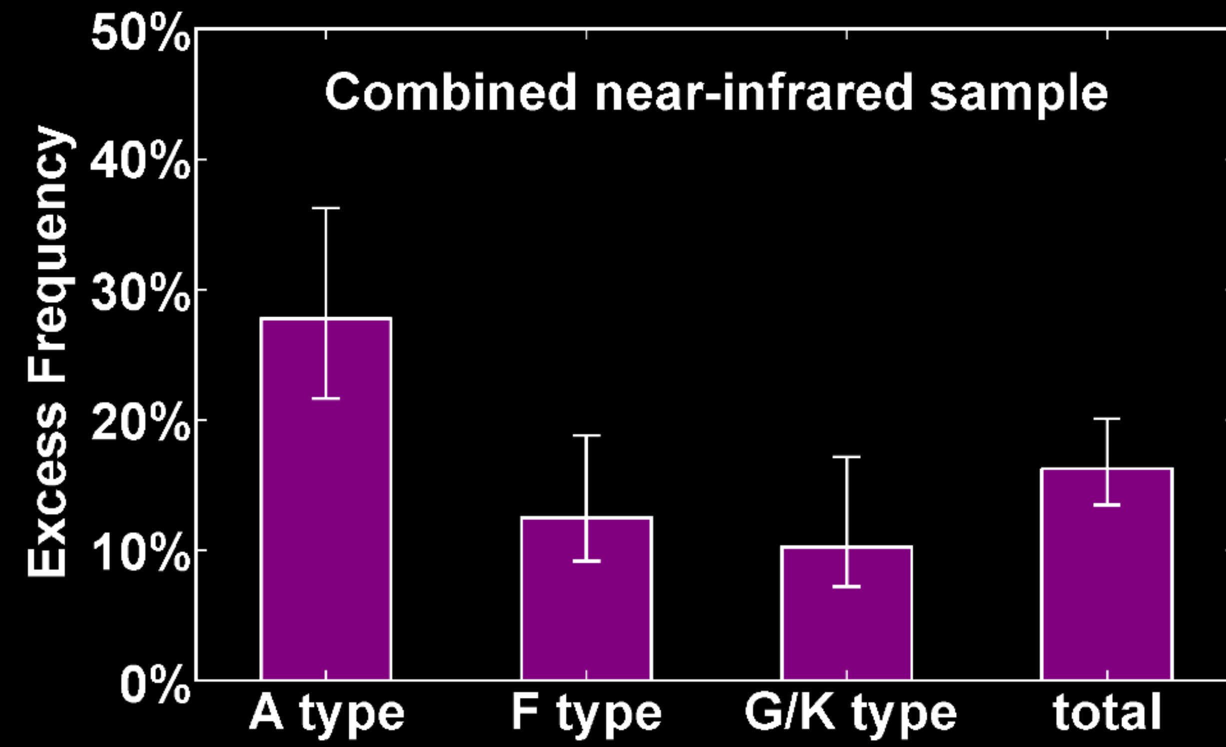


Ertel et al. (2014)

- Over 200 stars systematically searched by now
- Typical detections at the 1% excess level, significance from 3σ to 10σ
- Availability of closure phases from PIONIER rules out companions (Marion et al. 2014)

Statistics from near-IR surveys

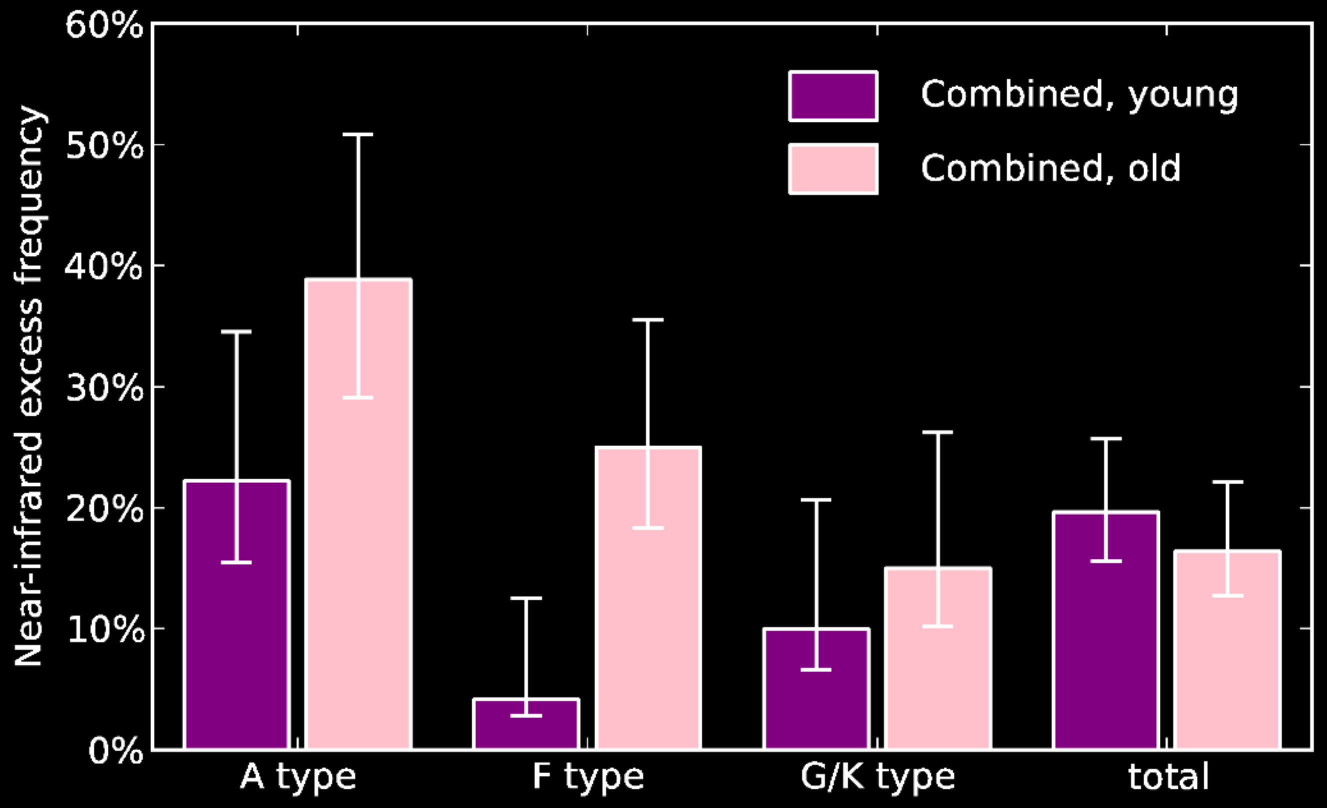


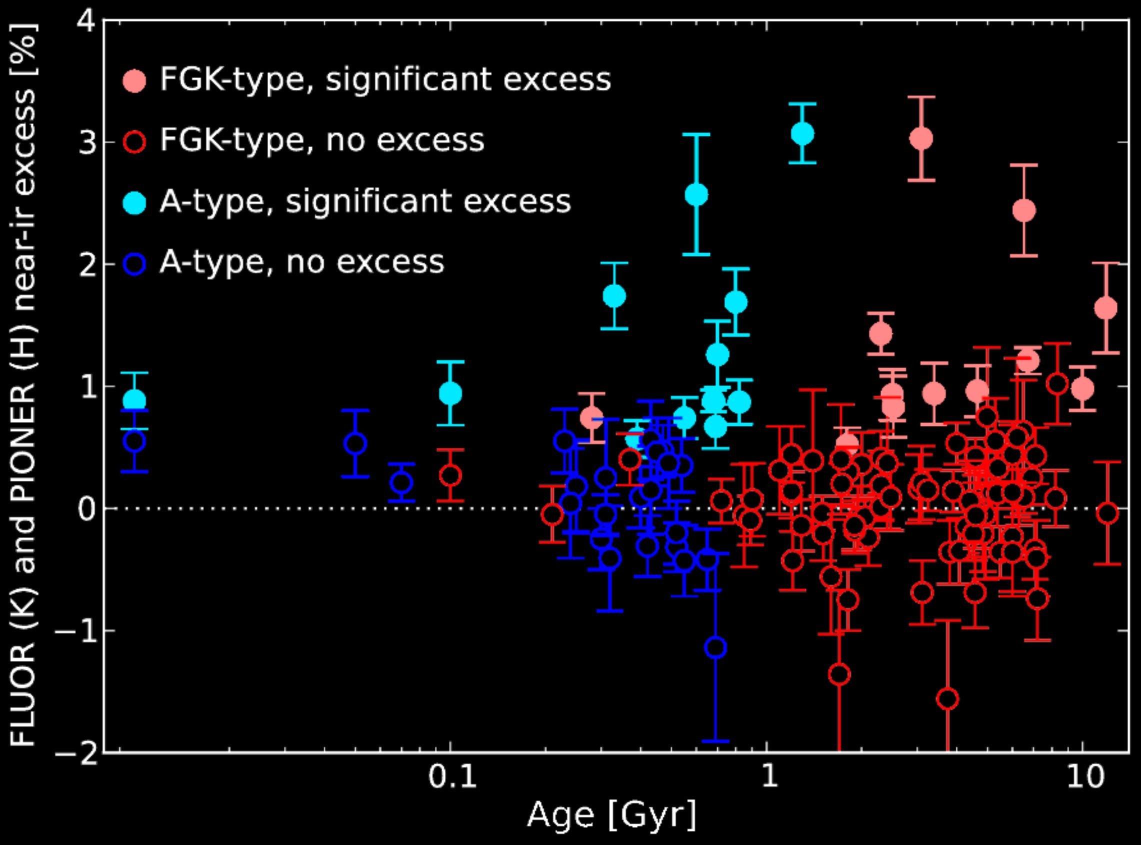


Ertel et al. (2014)

- Detection rate ~20%, higher in *K* band than *H* band
- Trend with spectral type
- No correlation with presence of Kuiper belts (Ertel et al. 2014)
  but (weak) correlation with asteroid belts (Marion et al. subm.)

Correlation with stellar age?

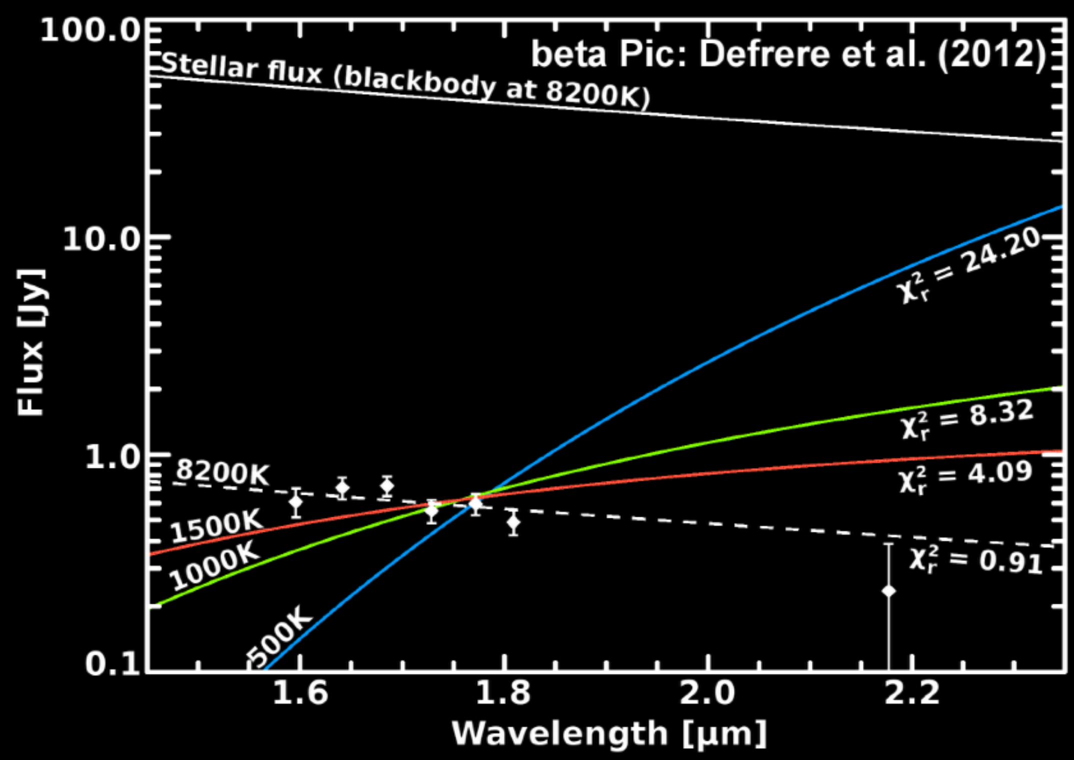




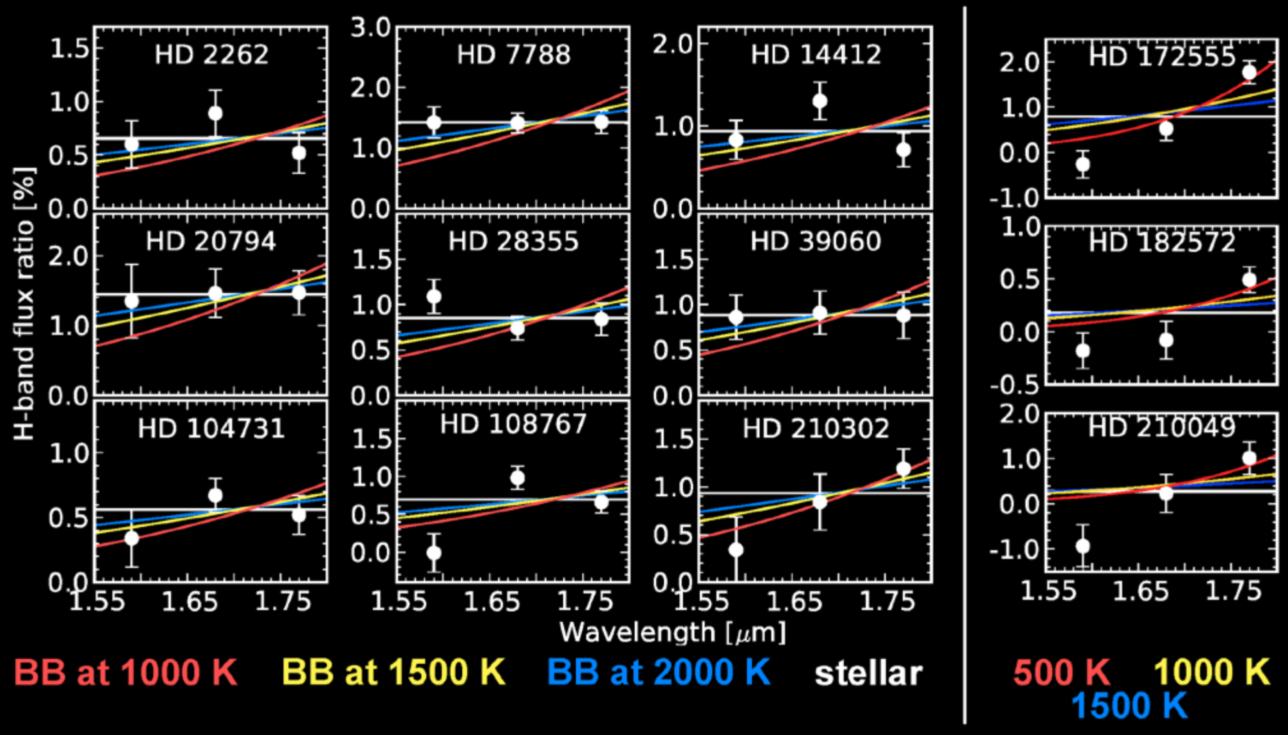
Ertel et al. (2014)

- No clear correlation with age
- If any, detection rate and excess increase slightly with age

Colors of near-IR excesses



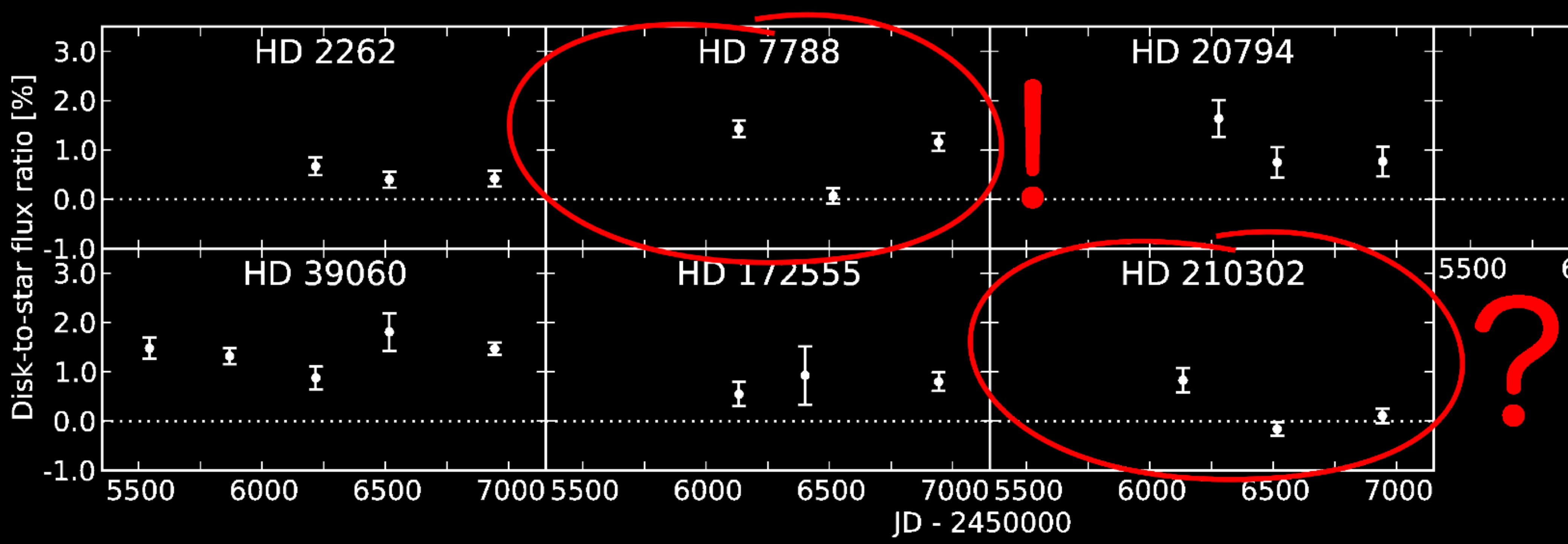
Defrère et al. (2012)



Ertel et al. (2014)

- Mostly flat spectral slopes, suggests VERY hot dust or scattered light
- Scattered light ruled out by single aperture polarimetric measurements (Marshall et al. 2016)

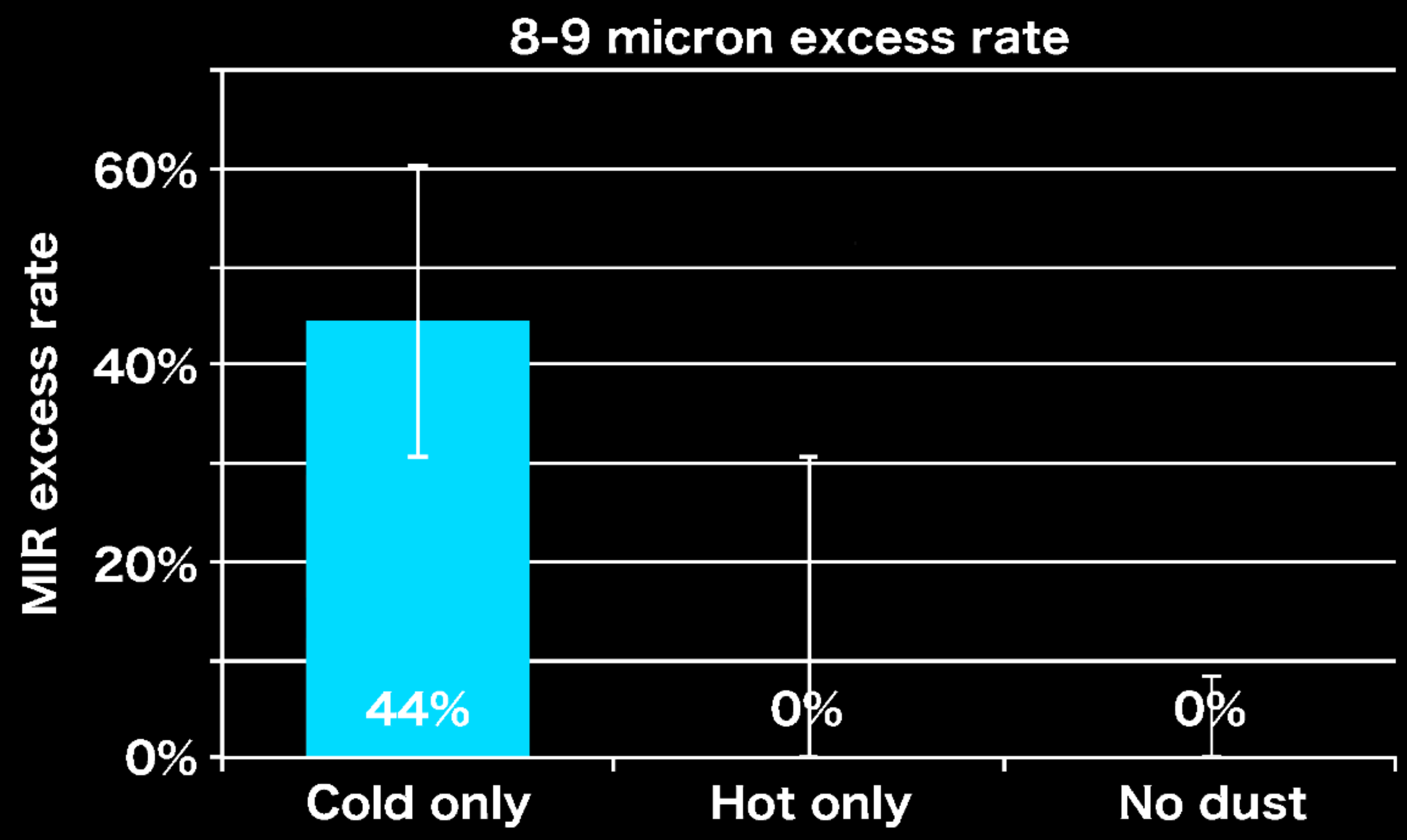
Variability?



Ertel et al. (2016)

- Detections in general repeatable (Ertel et al. 2016)
- Strong variability detected in some cases
- Time scale ~1 year or shorter? (Ertel et al. 2016, Nuñez et al. 2017)

Statistics from mid-IR survey



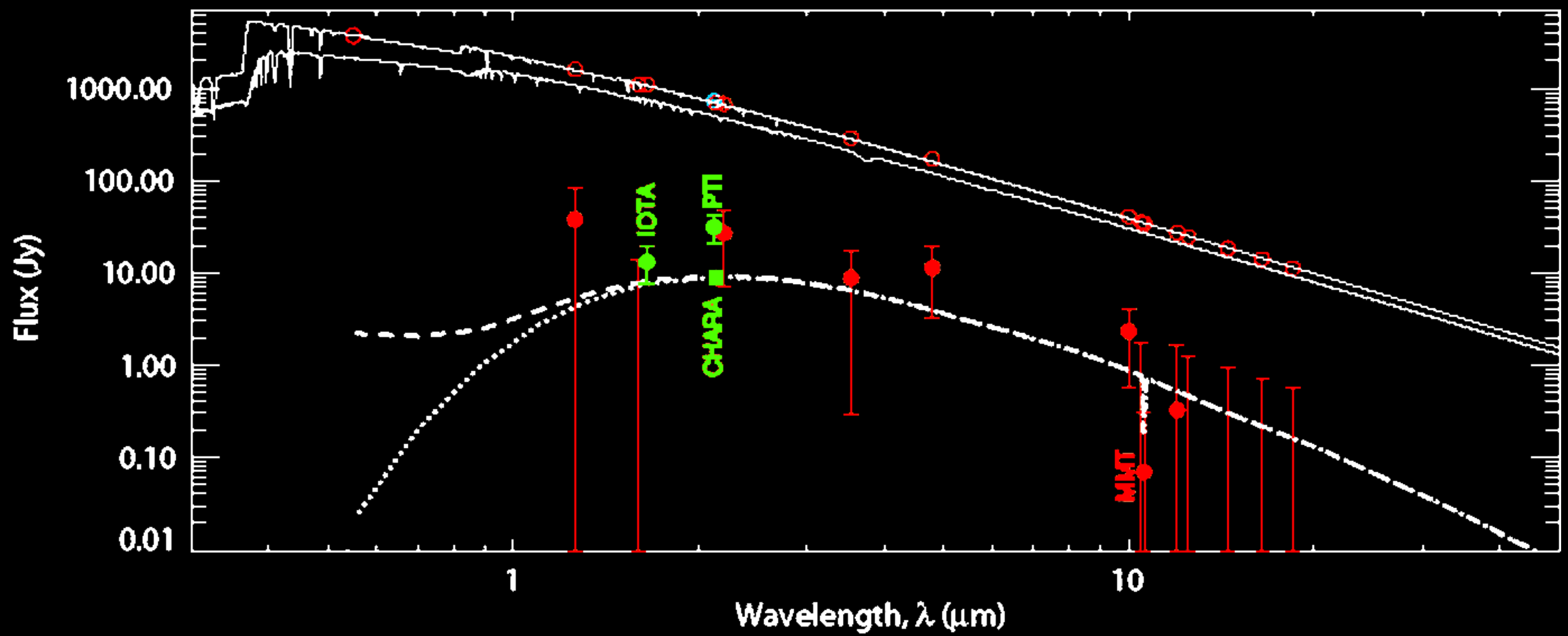
- 47 stars observed with Keck Interferometric Nuller, only 5 detections Sensitivity ~100 zodis (Millan-Gabet et al. 2011, Mennesson et al. 2014)
- Poor statistics, but massive warm dust seems related to massive Kuiper belts, anti-correlated with near-IR detections!

More mid-IR observations

- NASA funded LBTI/HOSTS survey ongoing
- Sensitivity 5+ times better than KIN
- 35+ stars, 29 observed by now, 4 new detections (Ertel et al., in prep.)

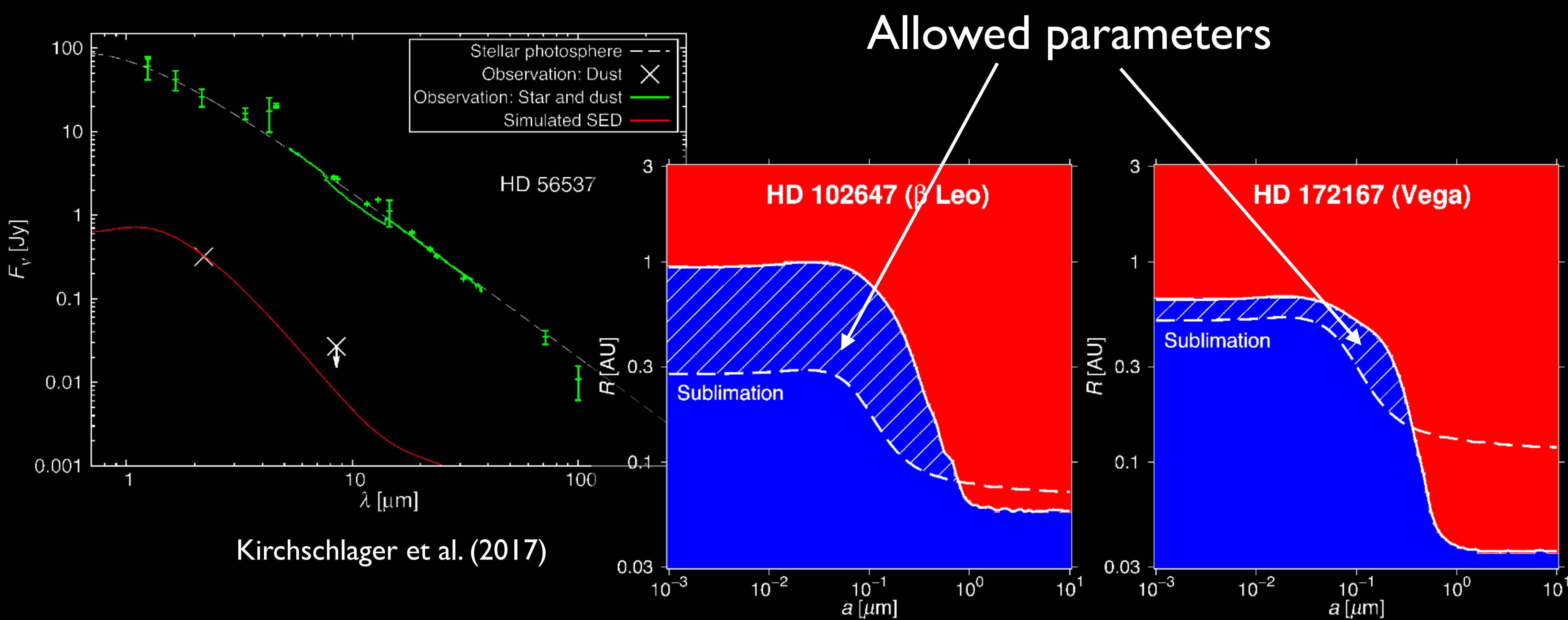
Modeling exozodis

Near-IR excess fit with RT model



- Very hot dust (~2000K), so very close to star
- Small, (sub-)micron sized grains
- Massive (~1000 times the Solar system level)

Combining near-IR and mid-IR



Kirchschlager et al. (2017)

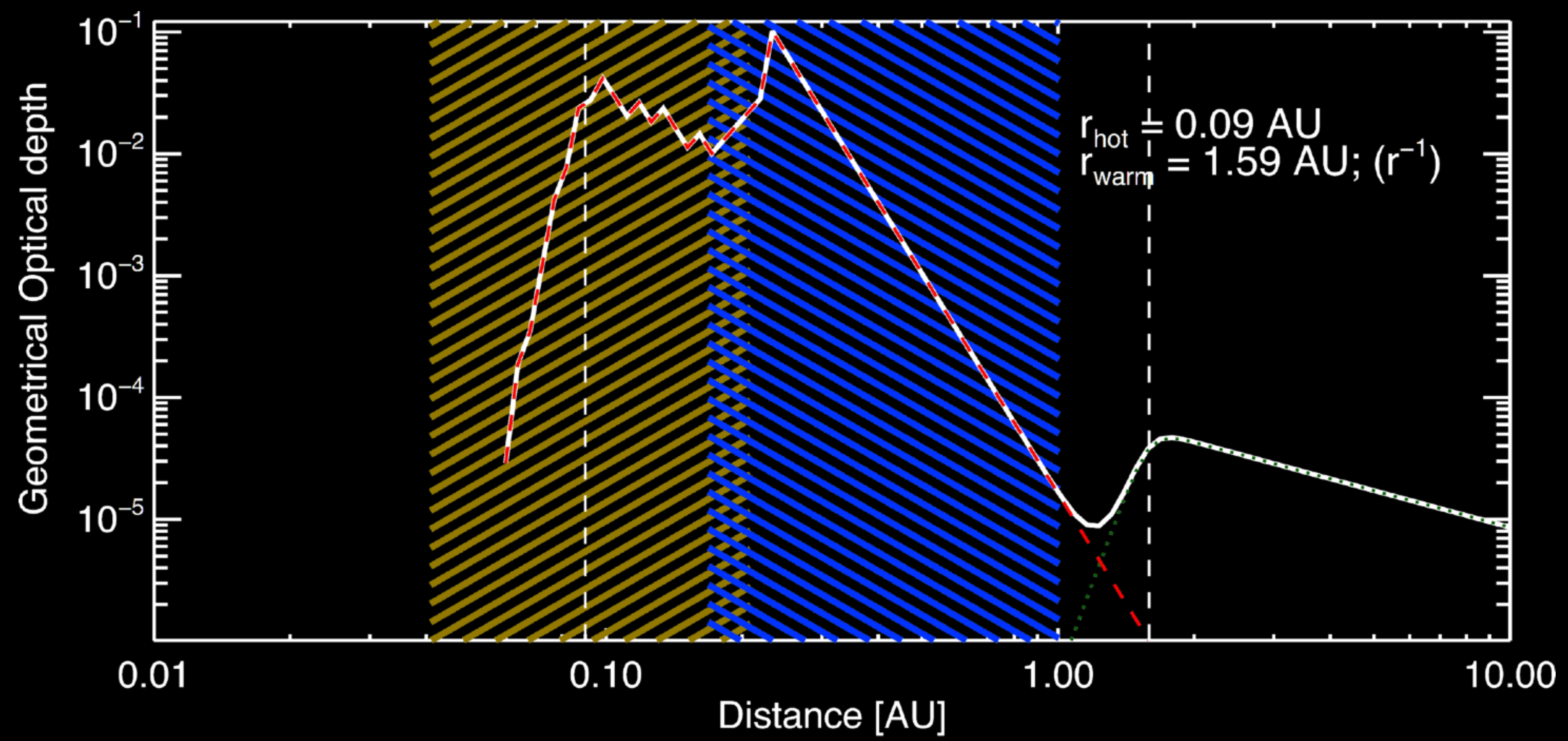
- Confirms small grain sizes for a sample of stars
- Slightly relaxed radial location constraints

We have a problem here!

- Very short dynamical/collisional life time
  → fast removal, not primordial, high replenishment rate
- Sub-blow-out size grains
- High detection rate, must be common
- Must happen at ~any age of the system (10 Myr to 10 Gyr)
- Seems unrelated to other dust in the system

→ where does the hot dust come from?

Massive asteroid belt?



Fomalhaut, Lebreton et al. (2014)

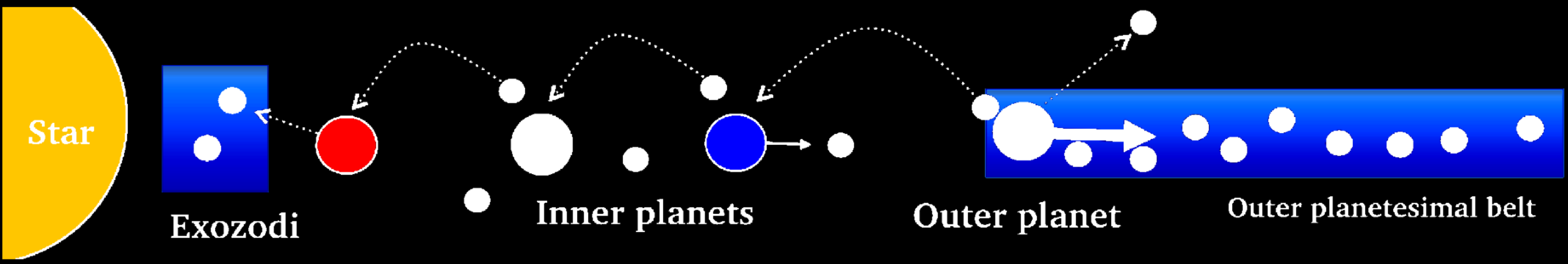
✓ Replenishment from massive asteroid belt analog can work, needs realistic sublimation physics

✗ Does not explain sizes << blow-out

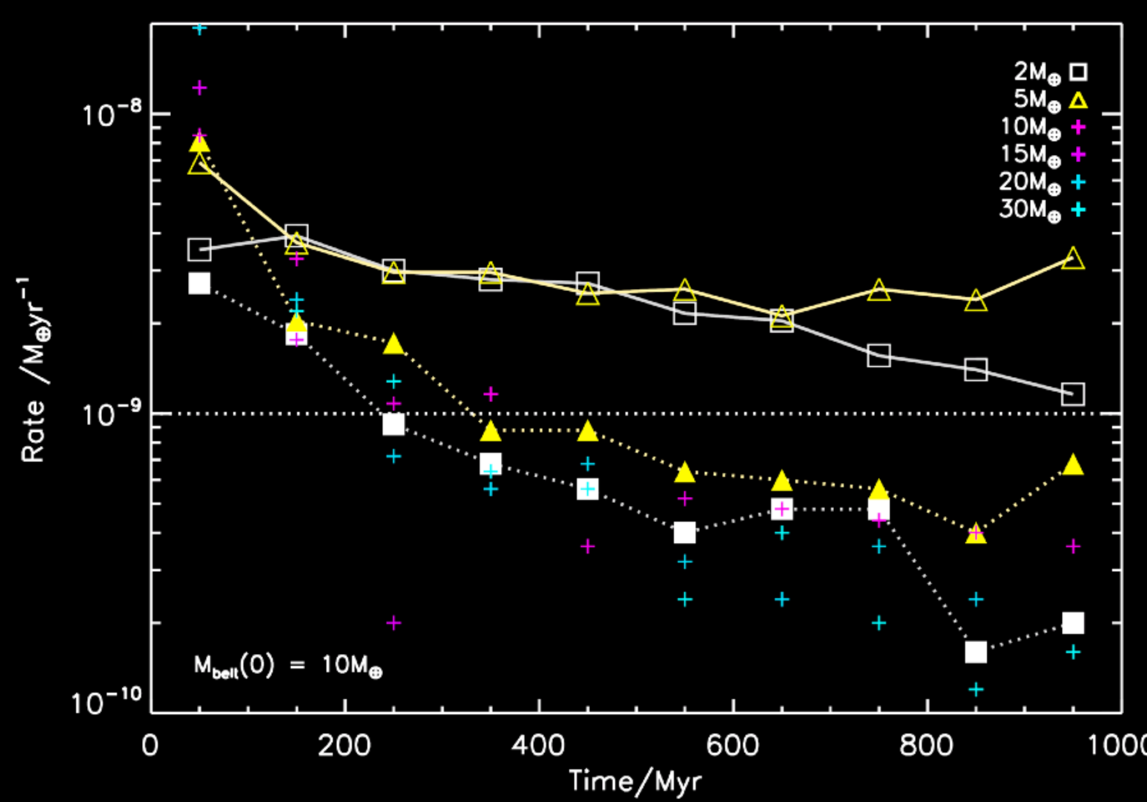
✗ Does not explain systems without such belts and old systems

Scattering from Kuiper belt?

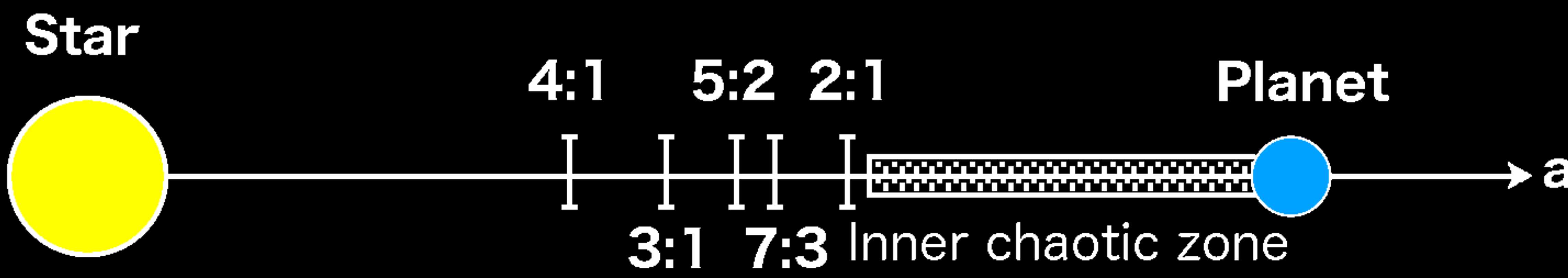
Bonsor et al. (2012, 2013, 2014)



- ✓ Belt may be faint, undetected
- ✓ Can sustain scattering Gyr time scale when planet is migrating
- ✗ Requires very specific architecture of the system (how common?)
- ✗ Does not explain sub-blow-out sized grains



MMR with inner belt?



Faramaz et al. (2017)

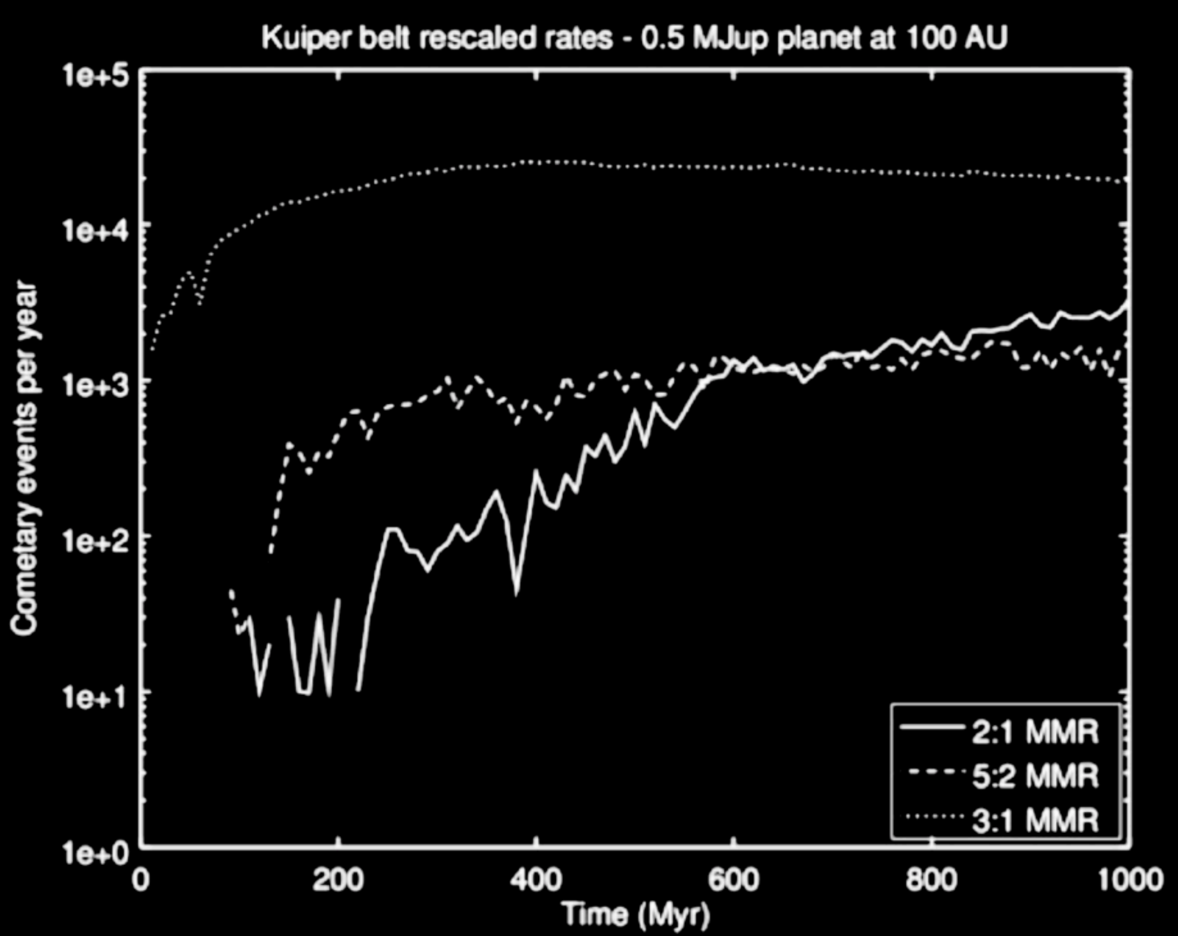
- Mean Motion Resonances between <u>inner belt</u> and planet
  (Faramaz et al. 2017)

✓ Belt may be faint, undetected

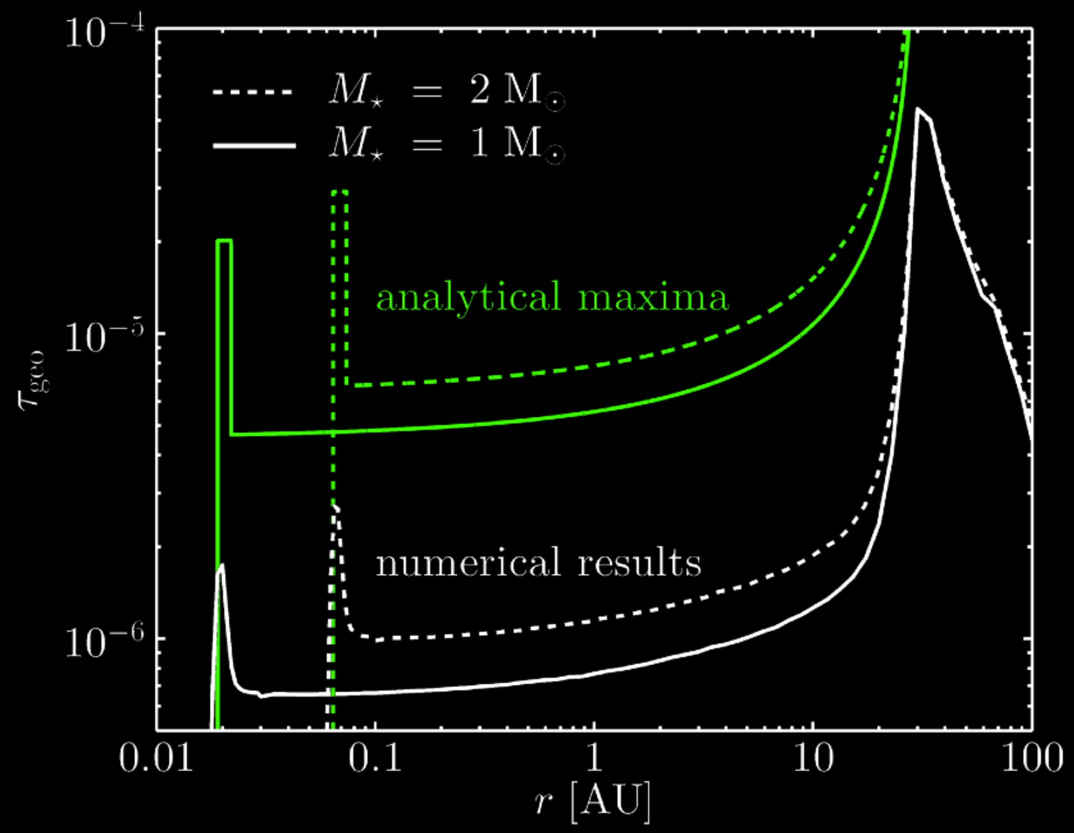
✓ Can sustain scattering Gyr time scale

✓ Less constraining on architecture?

✗ Does not explain sub-blow-out sized grains



Processes to increase dust lifetime?



Realistic dust sublimation
(van Lieshout et al. 2014)

✓ Increases life time of hottest dust

✓ Decreases minimum grain size

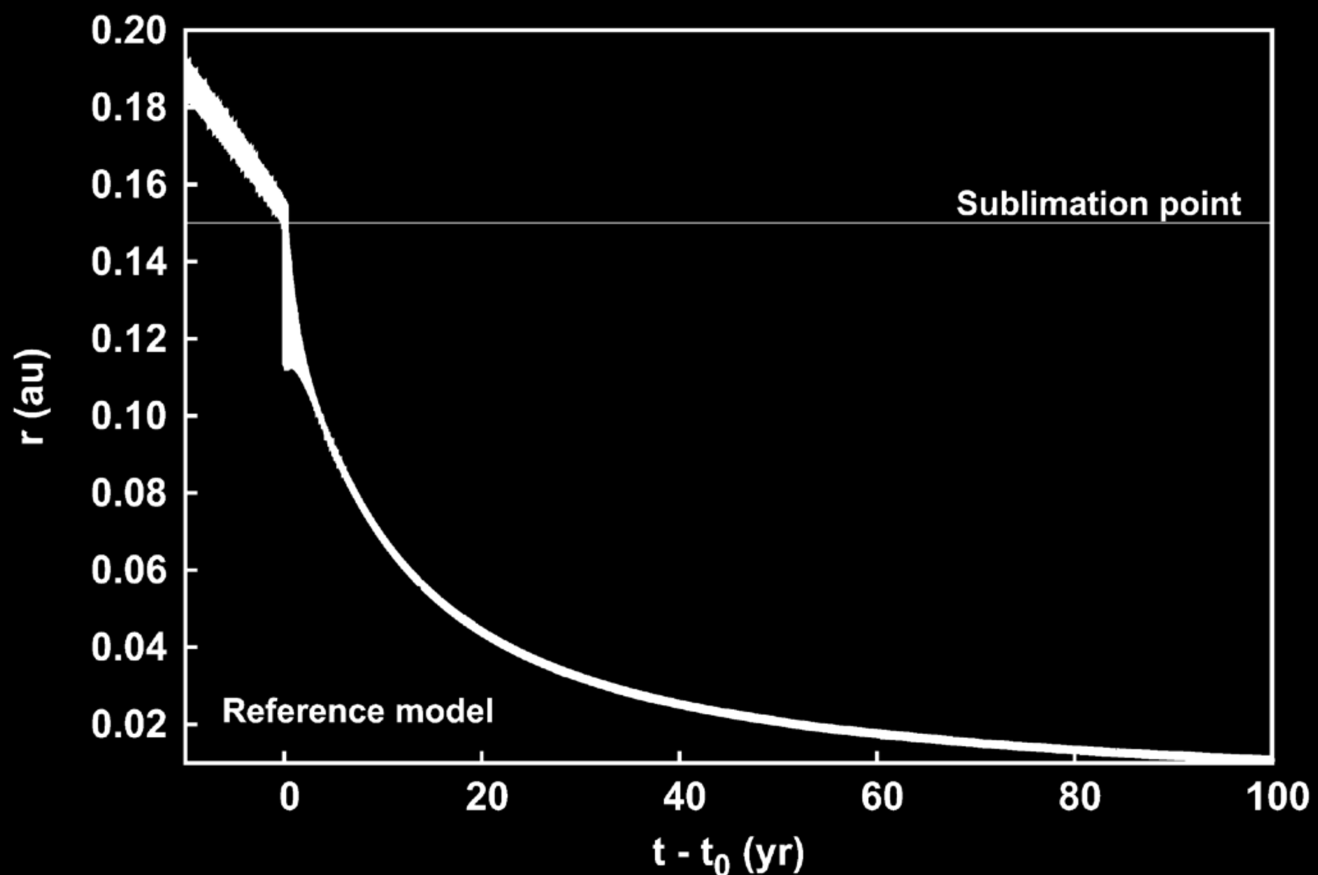
✗ No big effect on SED (for this specific scenario)

Magnetic dust trapping
(Rieke et al. 2016)

✓ Increases dust life time

✓ Very small grains

✓ Very hot dust



Emerging big picture

Warm dust

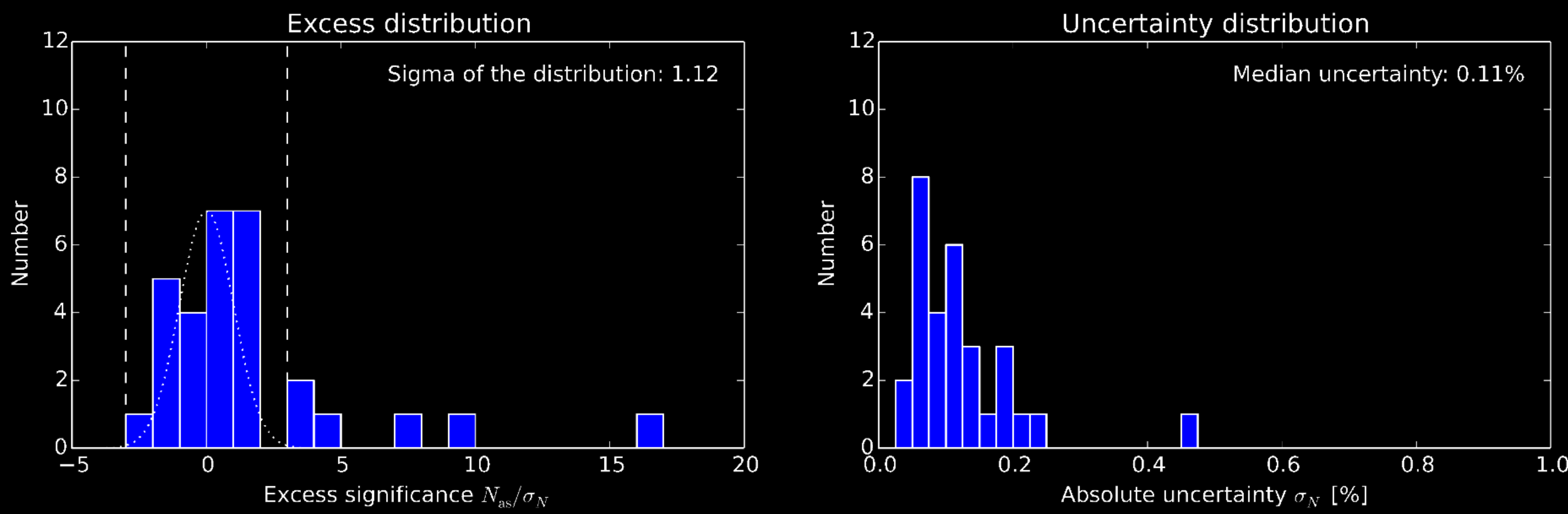
- Delivered from outer Kuiper/Asteroid belt by PR drag
- Some contribution from comet evaporation?
  Relative importance to be understood …
- Interaction with inner planets?
  To be understood, much to learn …

Hot dust

- Delivered by comets, trapping mechanism critical
- PR/stellar wind drag negligible?
- Dynamics of outer system more relevant, inner planets little impact?
  To be understood, much to learn …

Outlook - What’s next?

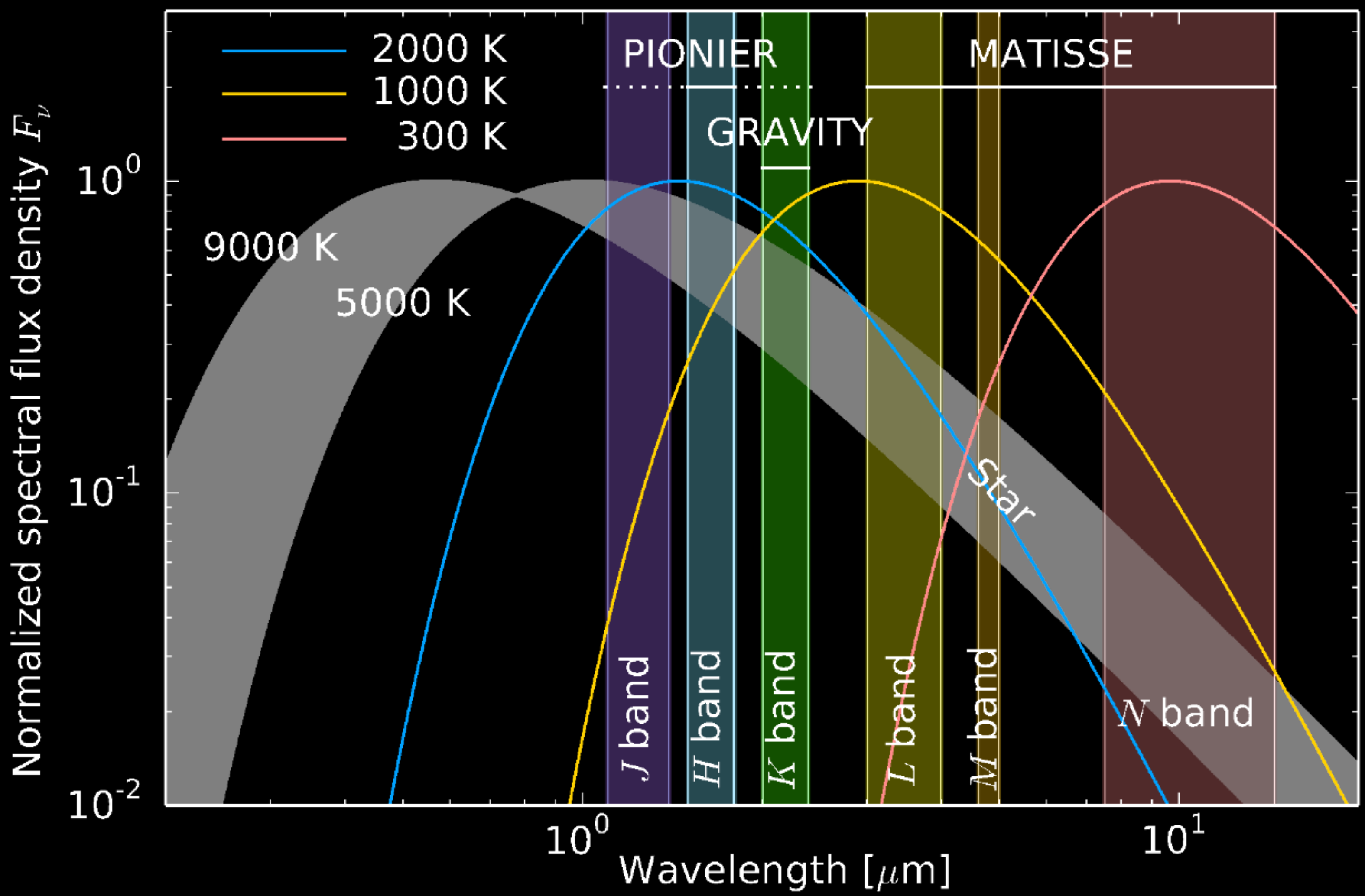
HOSTS survey @ LBT



Ertel et al. (in prep.)

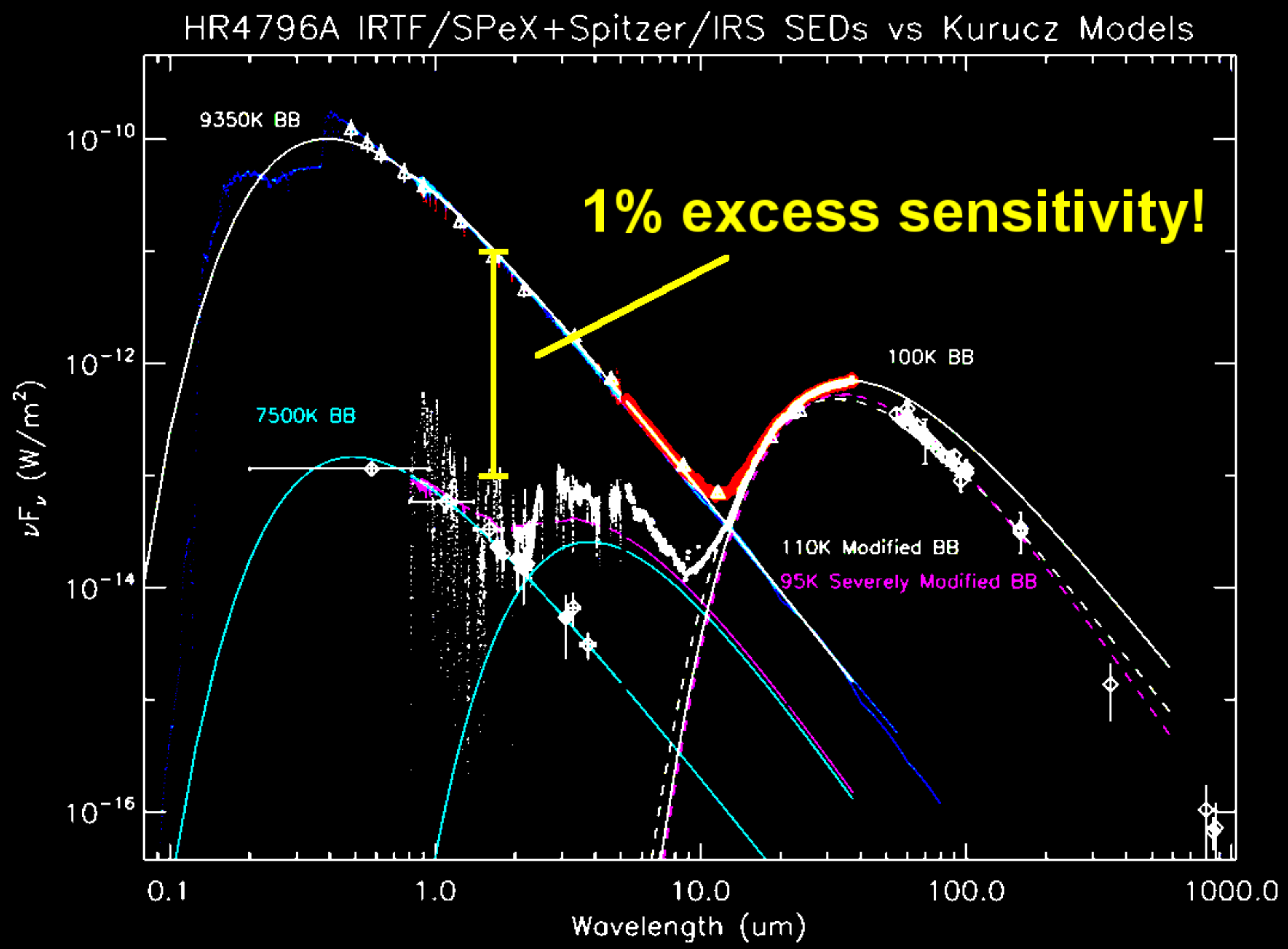
- Survey well underway, 29 stars observed (Ertel et al. in prep.)
- Median HZ dust level < 4 zodis (stars without prev. known dust)
- Detections: η Crv, β Leo, β UMa, δ UMa, θ Boo, 110 Her, ε Eri
  (Defrère et al. 2015, Hinz et al. in prep., Ertel et al. in prep.)
- **NO** detection for Vega (< 35 zodis, 3σ)!!!

2nd generation VLTI instruments



- Spectra from the K to N band, connect nIR and mIR excesses
- First GRAVITY data promising (Defrère et al., in prep.)
- MATISSE covers key wavelength range, but what accuracy?
- Dream instrument: thermal IR high-contrast imager

High-accuracy spectroscopy



Lisse et al. (2017)

IRTF/SPeX data of most Northern targets obtained, analysis ongoing
(Lisse et al. in prep.)

Summary

- Detecting exozodis is now routine in both nIR and mIR
- Growing surveys, more detections to understand
  → Exozodis are common
  → Few correlations so far, more for mIR detections than nIR
- Explanations in the mIR easier than in the nIR
  → Some picture emerging, but still challenges
- Near future looks very promising
  → LBTI results coming up very soon, strong impact expected
  → VLTI & spectroscopy to make the nIR - mIR connection