Advancing exo-zodiacal dust research through improved thermal background subtraction

Hélène Rousseau

PhD student, University of Liège
Research Technologist, LBT Observatory, University of Arizona

Working with:

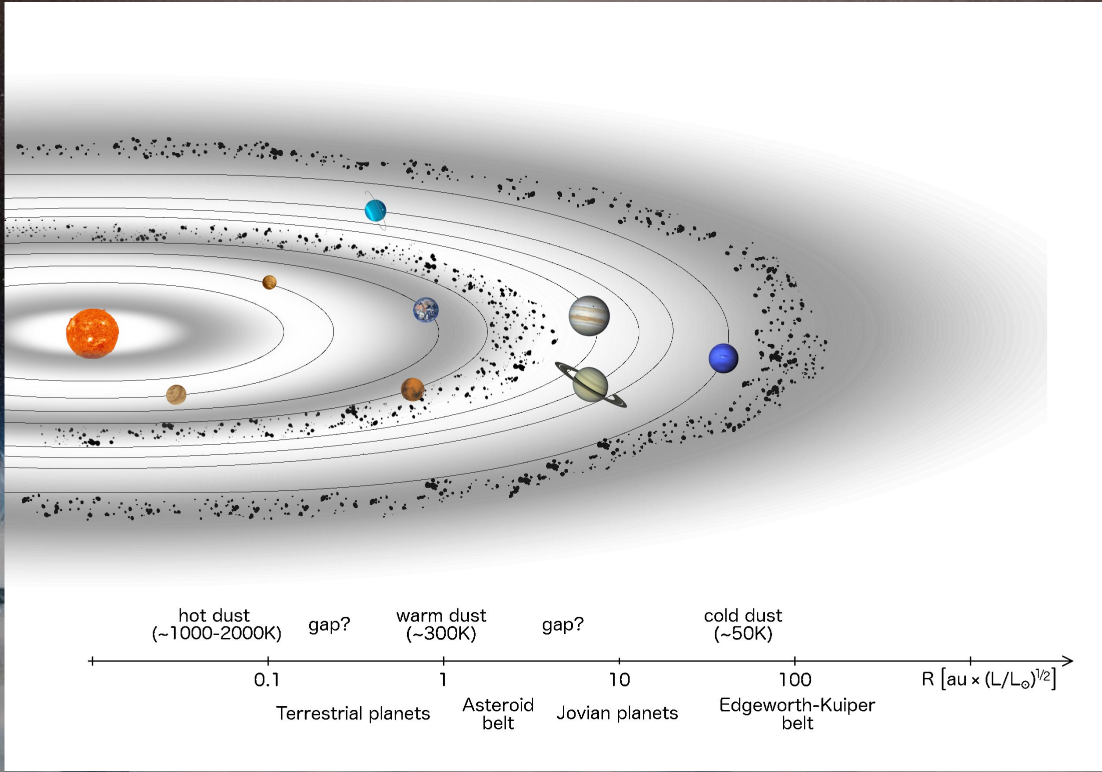
Steve Ertel, Denis Defrère, Virginie Faramaz, Germain Garreau, Kevin Wagner

LIÈGE université

Zodiacal dust in the solar system

- Made of 10-300 µm sized grains
- Emits in the mid and far-infrared
- Outshines rocky planets
- Originates from comets, asteroïds and Poynting-Robertson (PR) drag

Exozodis: Analogs in other systems



A particular type of debris disk

Usual removal processes: radiation pressure & collisional grinding

- Distinctive feature: Proximity to the star & Extremely short timescales
- Survival of an underlying planetesimal population < 1 AU : ~100 yrs (Wyatt 2007, Kral 2017)

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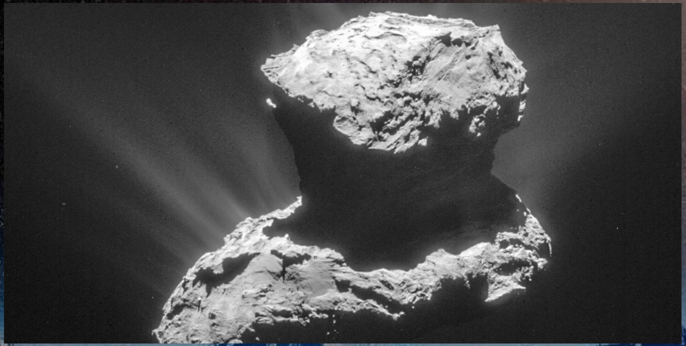
Need an alternative replenishment mechanism

PR-drag & Comets

Comet 67P - Rosetta Mission



NASA

In the Solar System, ~90% of the zodiacal dust thought to originate from evaporation/disruption of comets
(Nesvorný+2010)

PR drag makes grains spiral inwards onto the star
(Kennedy & Piette 2015, Rigley & Wyatt 2020)

Exozodis signs of material travelling from beyond the iceline into the Habitable Zone (volatiles, organics)

PR-drag & Comets

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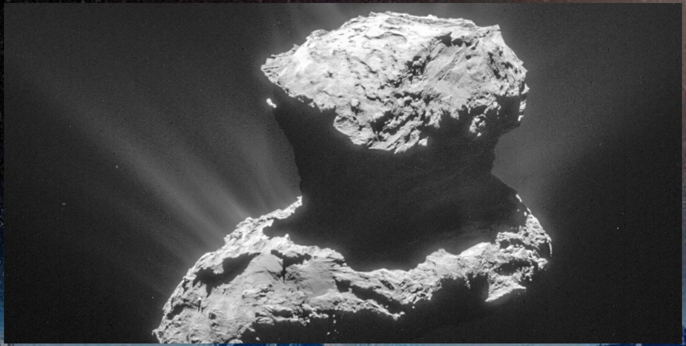

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Theoretical production of star-grazing orbits:

- Scattering by chains of planets, with or without migration (Bonsor+2012, 2014; Raymond+2014)
- Catastrophic LHB-like events (Bonsor+2013)
- Kozai resonance (Bailey+2012)
- Mean-motion resonances (Moons & Morbidelli 1995; Beust & Morbidelli 1996, 2000; Faramaz+2017)

Why are exozodis worthy of interest?

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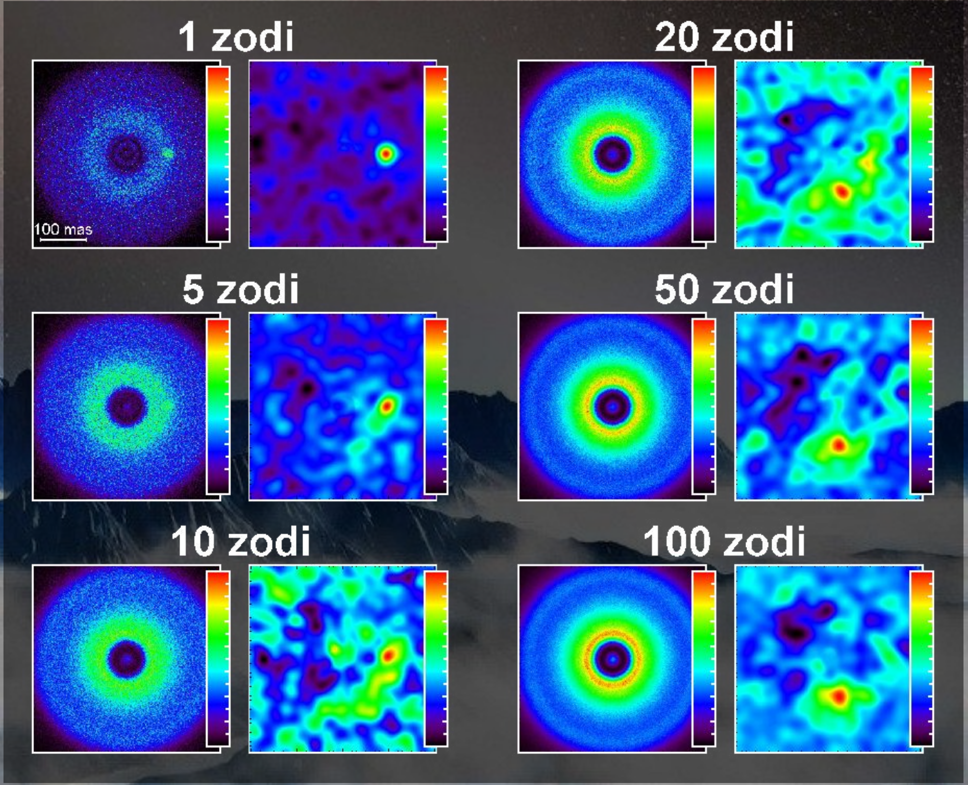
They can be problematic and hide exo-Earths targeted by future characterization mission (e.g., Habitable Worlds Observatory)

They can hide exoplanets in the HZ

Defrère+2012 :

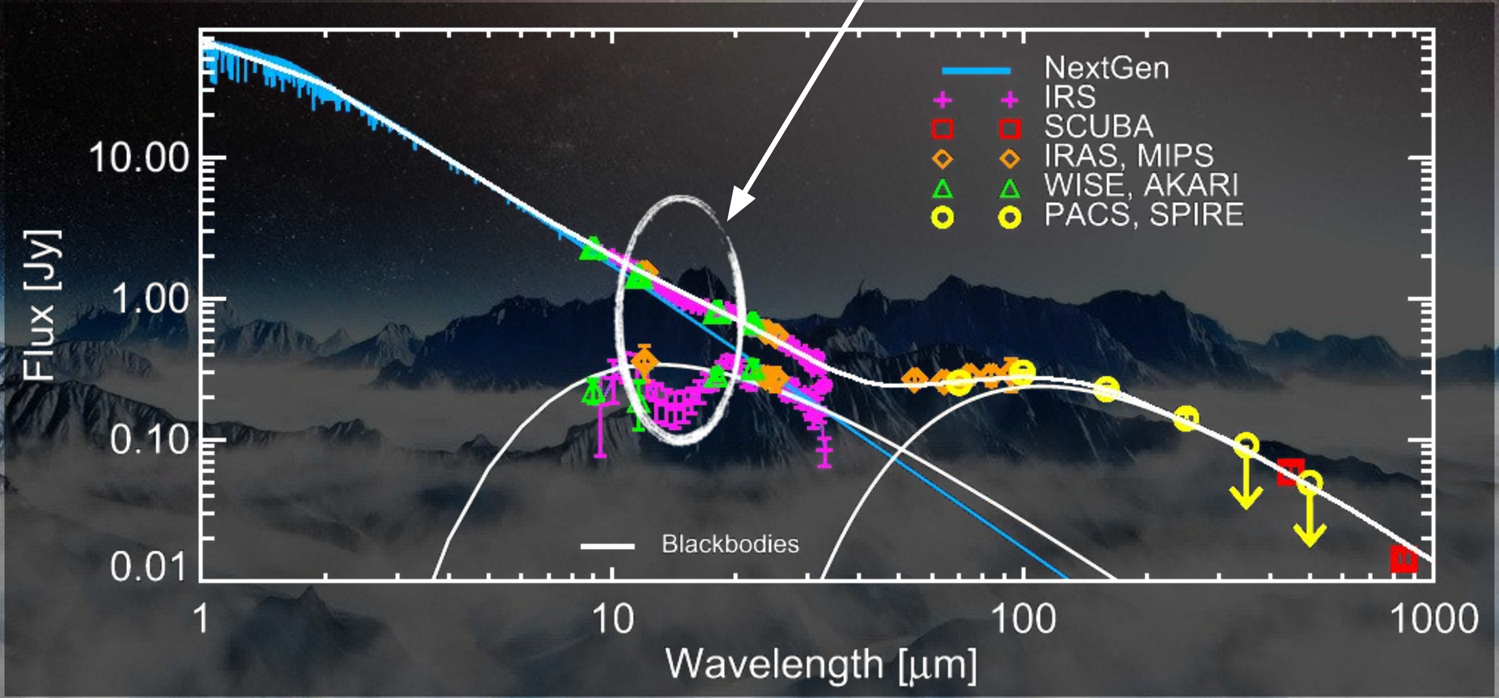
For a HabEx-like mission (4m primary mirror) and
1 Earth at 1 AU at 10 pc

Problematic dust levels:
10-zodis (10 times the Solar System levels)

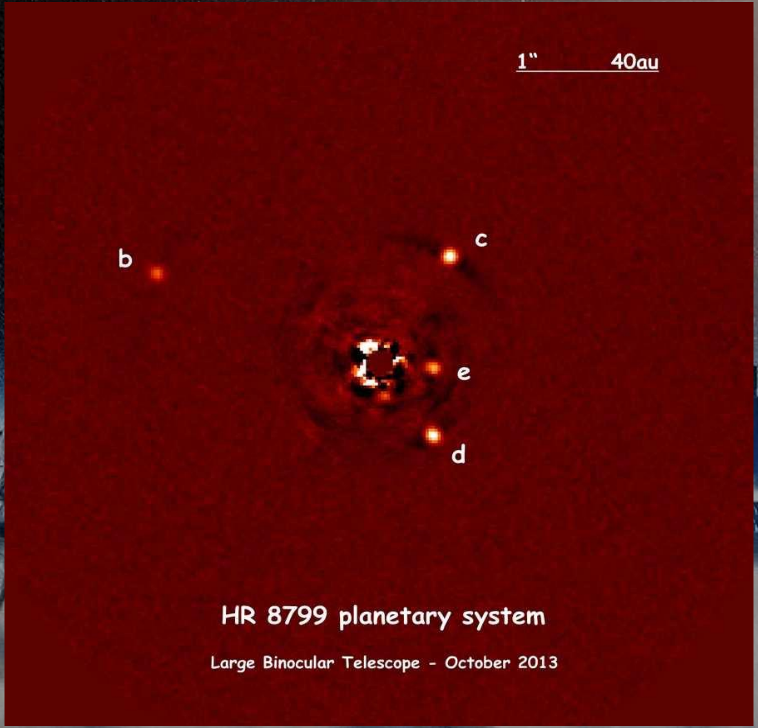


How to observe exozodis

~HZ dust, ~2500 x Solar system!

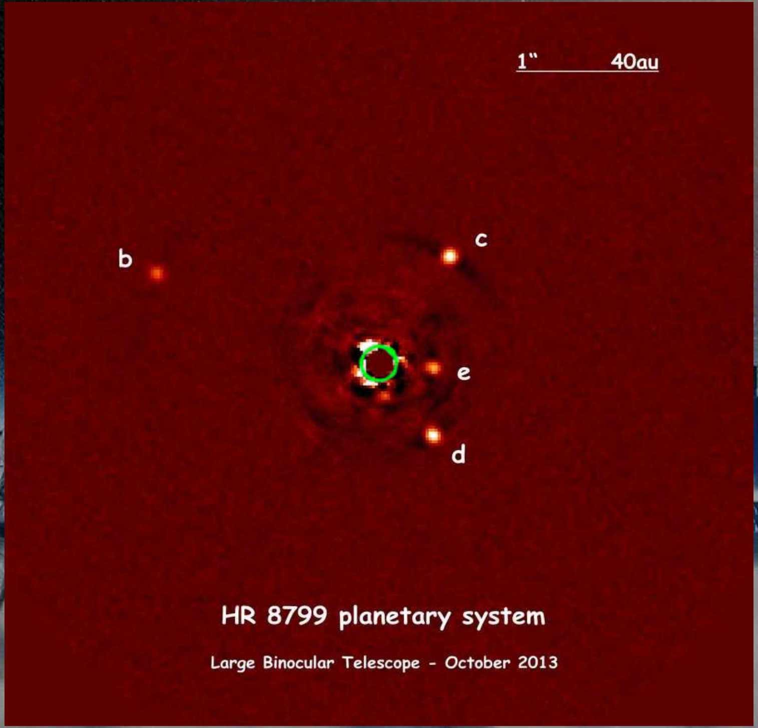


How to observe exozodis



- Dust in the habitable zone
- Excess too faint to be detected with photometry or spectroscopy
- Need interferometry to resolve the habitable zone

How to observe exozodis



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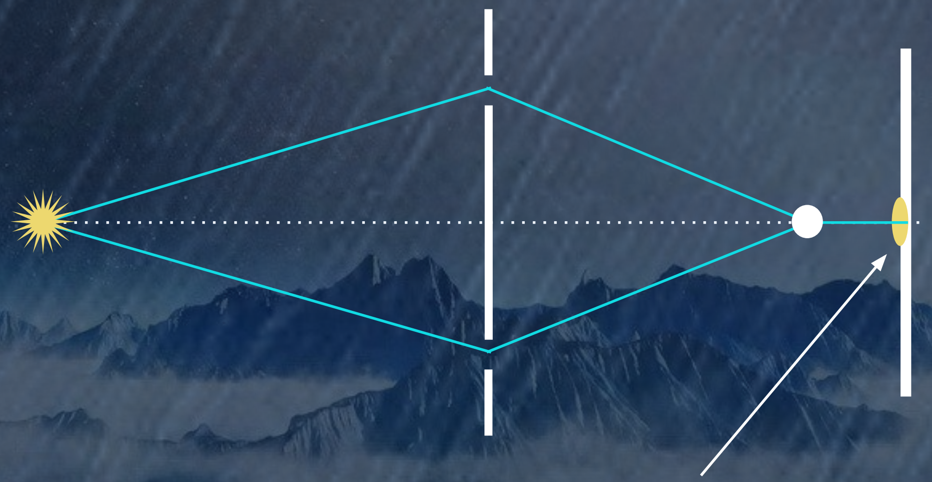
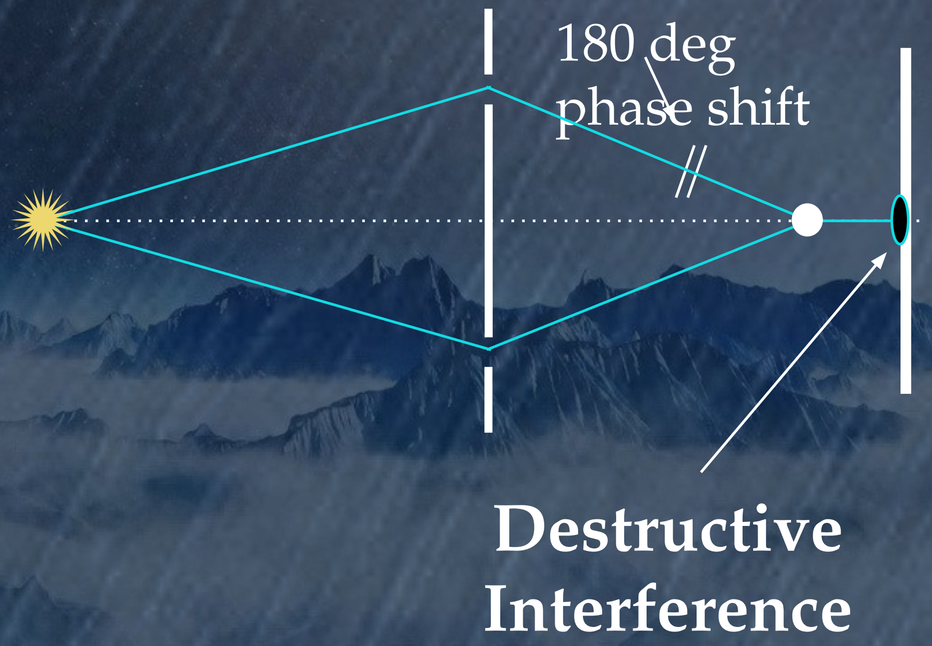
- Excess too faint to be detected with photometry or spectroscopy
- Need interferometry to resolve the habitable zone
- Standard coronographs mask the region of interest

Nulling Interferometry



Nulling Interferometry



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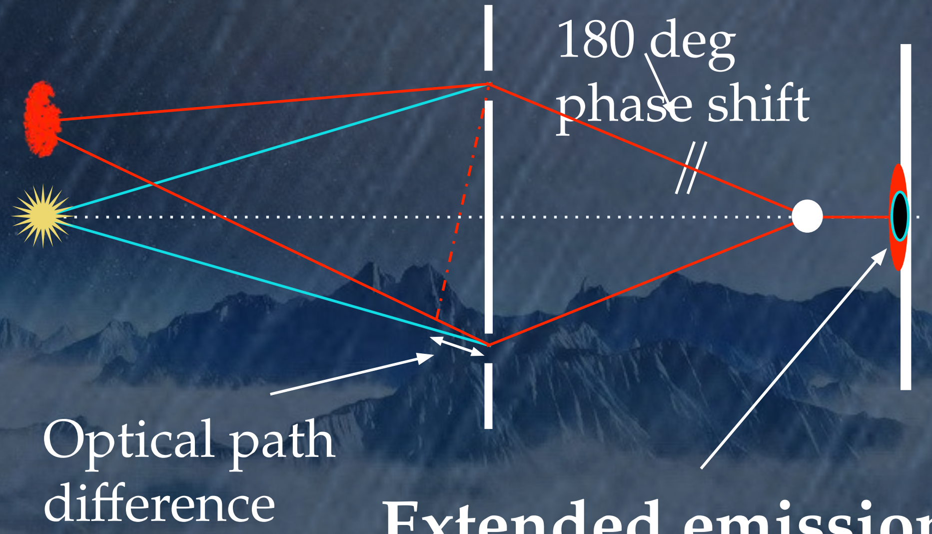
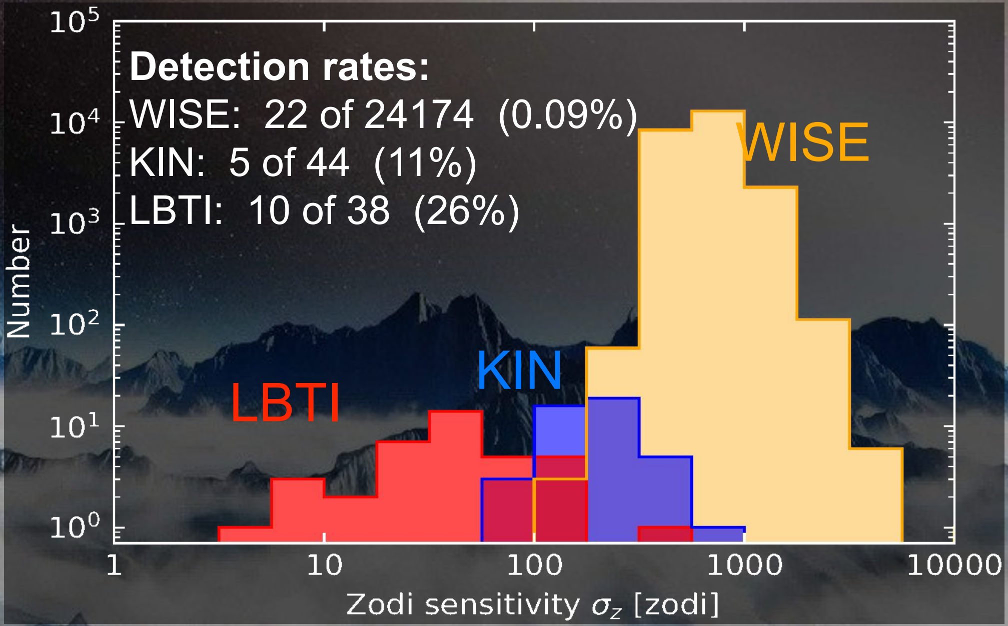
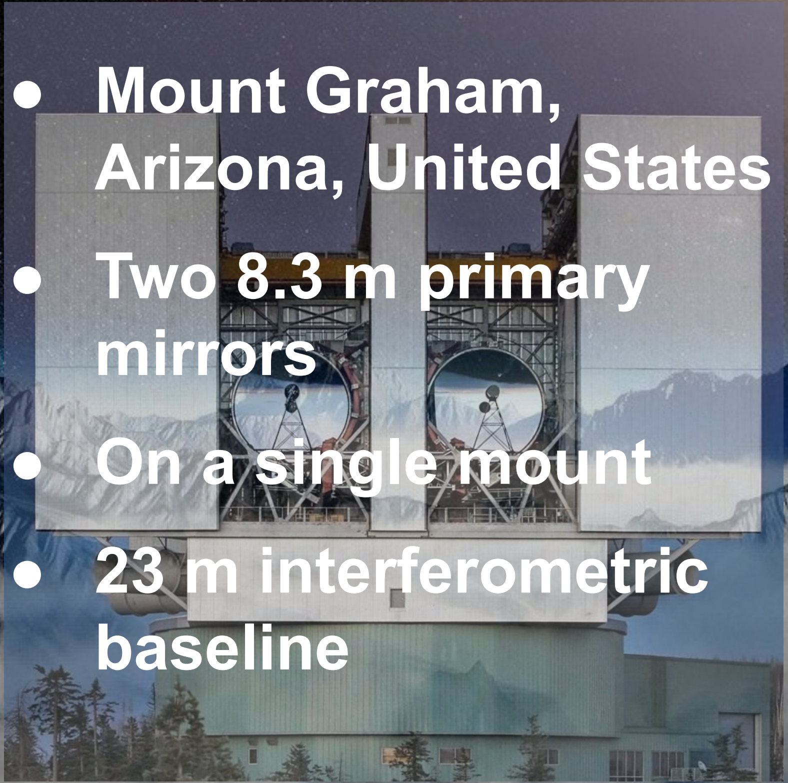


Extended emission transmitted

Previous missions on exozodis



HOSTS/LBTI

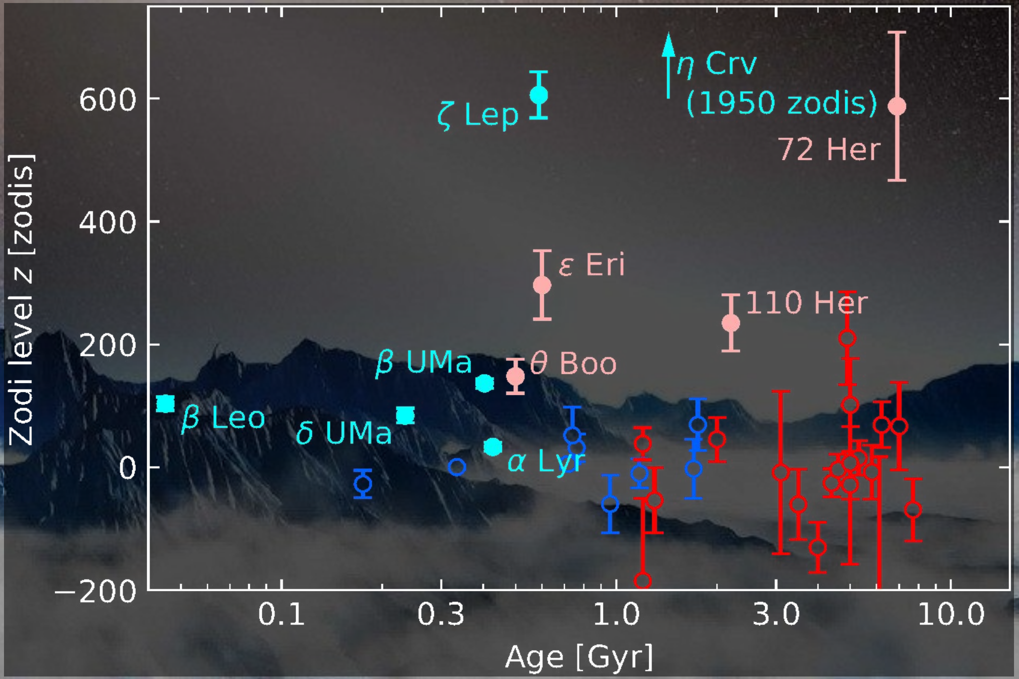


- **Mount Graham, Arizona, United States**
- **Two 8.3 m primary mirrors**
- **On a single mount**
- **23 m interferometric baseline**

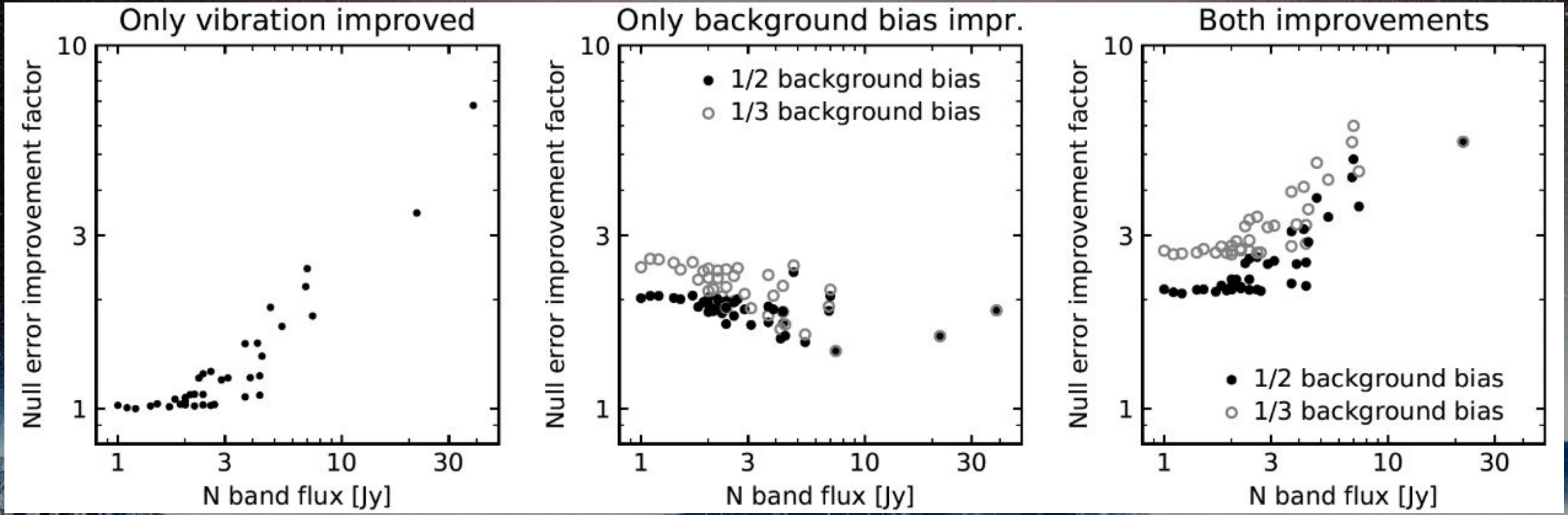
- Primary mission of the LBTI funded by NASA
- N’ band (11 microns)
- Nulling interferometry
- 38 nearby stars
- September 2016 - May 2018

HOSTS results & limits

- 38 stars / 10 detections
- 1σ upper limit: 9 zodis
- **95% confidence: 27 zodis**
- **Sensitivity limited by measurements uncertainties**



We need more sensitivity

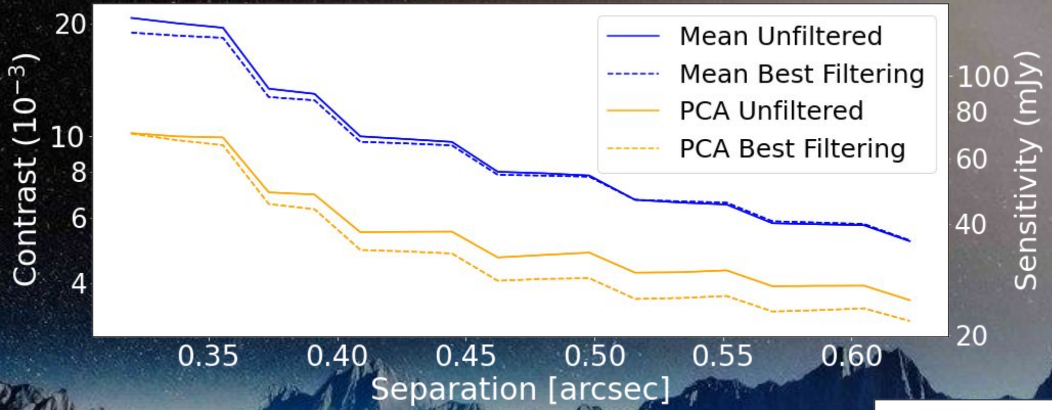


Major limitation : Thermal Background Subtraction

New PCA Background Subtraction

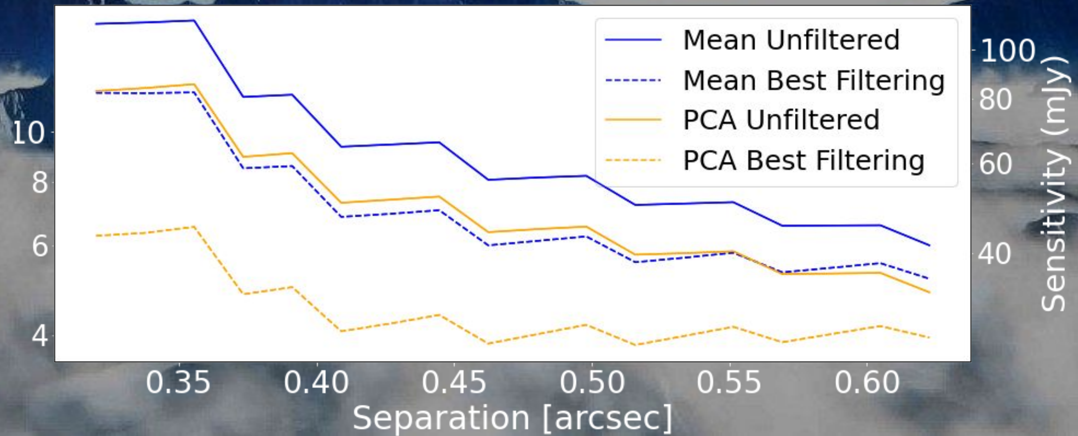
High Contrast Imaging (Rousseau et al. 2024)

ADI



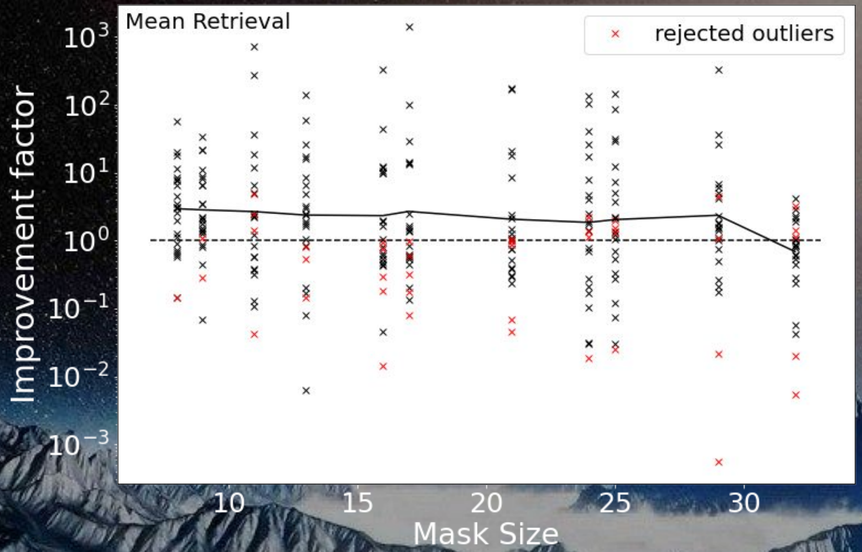
Improvement by a factor 1.5-2

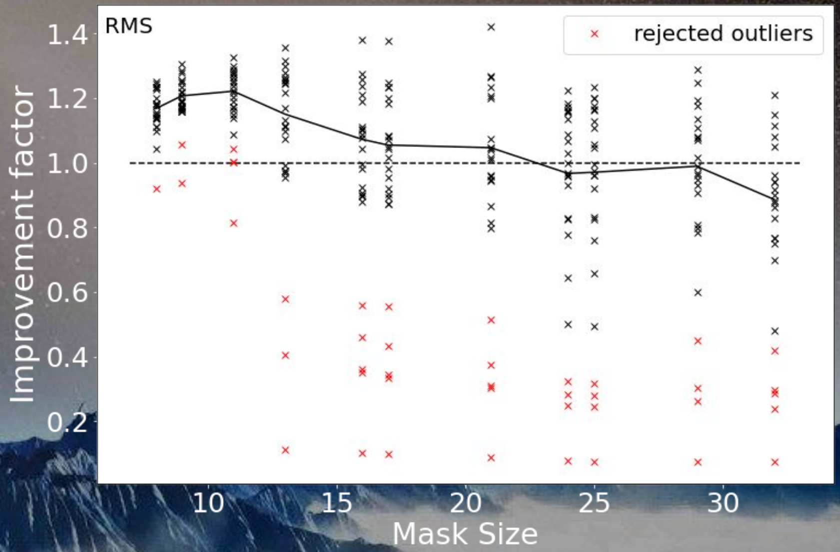
RDI



Background-limited regime

Aperture Photometry (Rousseau et al. 2024)





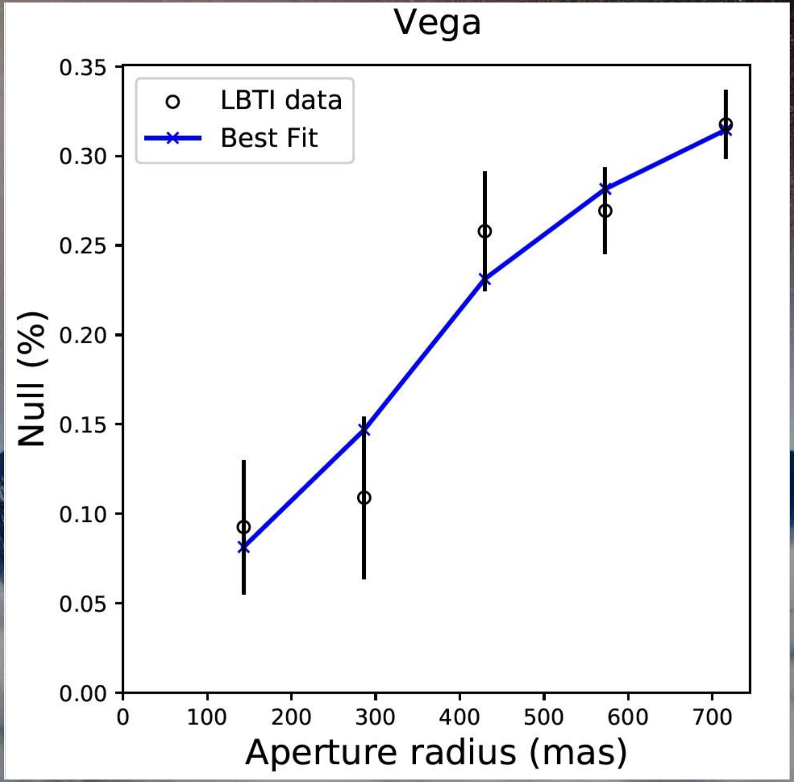
Factor 2 to 3 improvement on the mean retrieval

This improved sensitivity is essential to further studies of exozodis and HZ environments

Exozodis can show radial structures

- Null as a function of radius
- Radial break barely fitted by a wide disk.
- Could be induced by a planet.

Improved sensitivity could break degeneracy



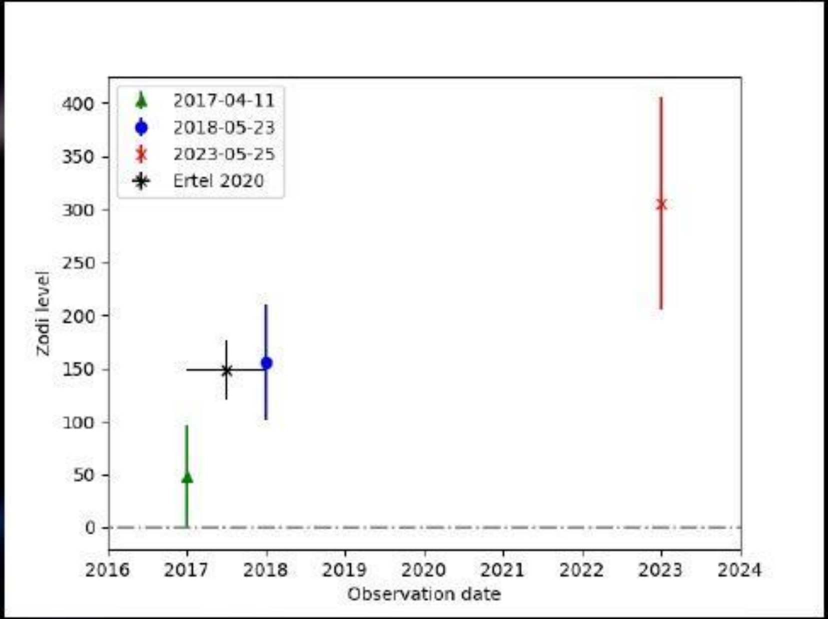
Faramaz et al. (in prep)

Exozodis can be variable

Credit Germain Garreau

Zodis level estimation

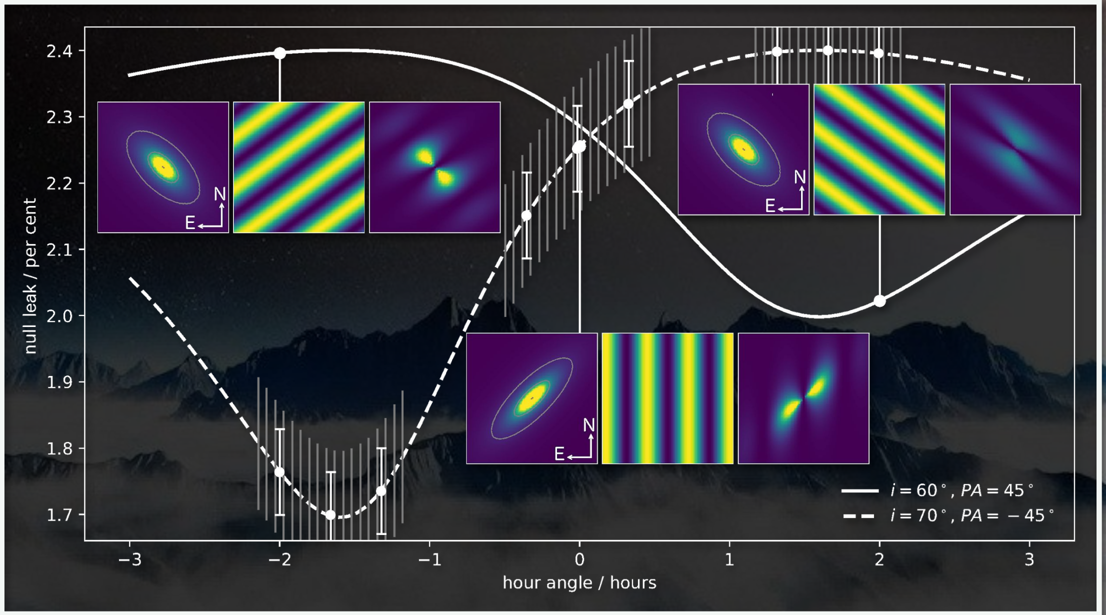
- Estimation of dust density in zodi
  - Estimation at 8 pixels radius (Habitable zone of θ Boo)
  - Model from Kennedy 2015
- Increase in dust density
  - From ~150 to ~300 zodis between 2018 and 2023



Garreau et al. (in prep)

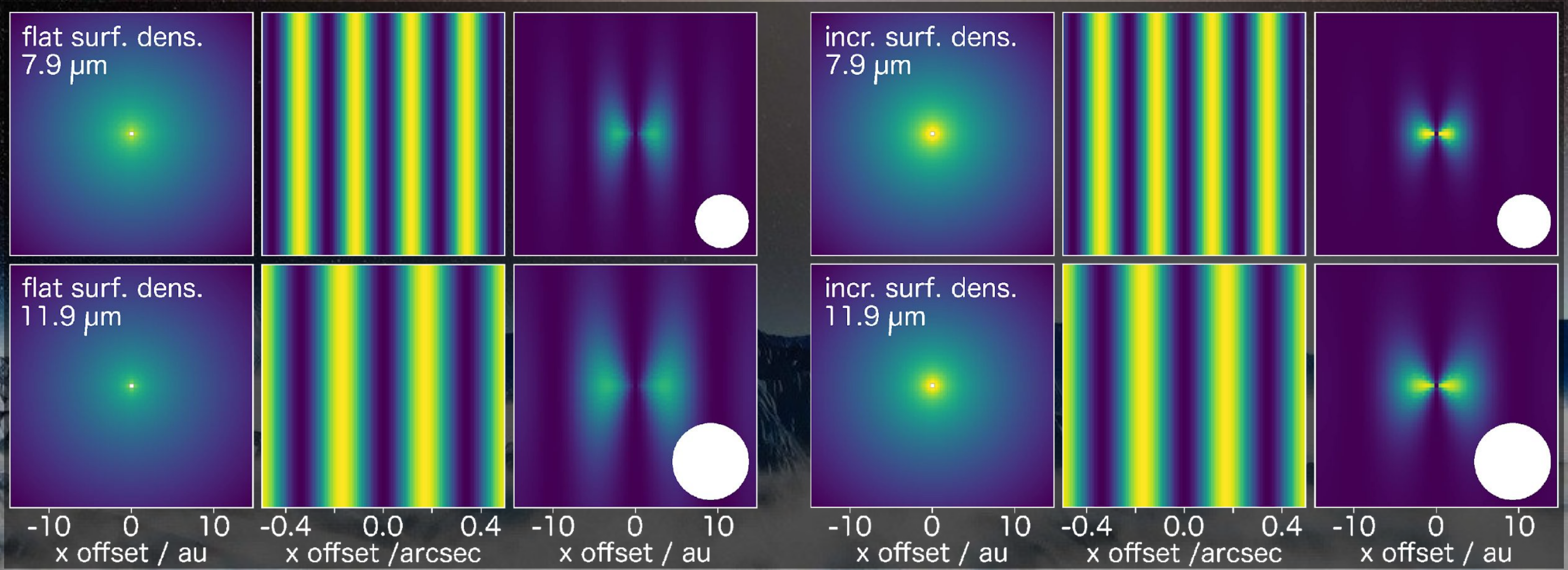
Exozodis can have diverse geometries

For the same dust levels, a puffy disk will pose less risks for HZ exoplanet characterization



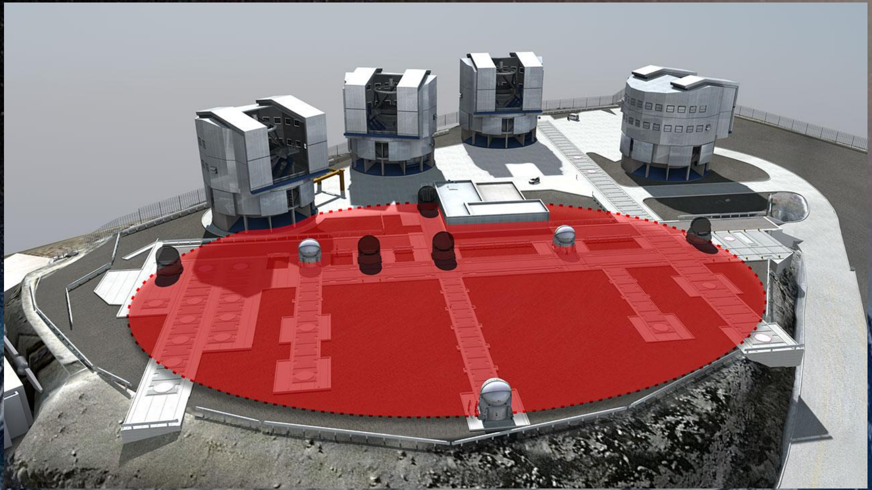
Strategy: observation over large range of parallactic angles.
Ongoing efforts with the LBTI (PI: V. Faramaz)

Exozodis can have various grain Sizes & Composition



Strategy: observations at different wavelengths.
Ongoing efforts with the LBTI (PI: V. Faramaz)

VLTI/NOTT: new high-contrast nulling instrument for the VLTI



PCA background subtraction will be adapted to this instrument, and can be adapted for future ELT

- Under development (ERC funded, 2020-2025; PI: D. Defrère)
- Thermal near-infrared: L-band (missing link between K-band CHARA/PIONIER and N-band LBTI/Keck)
- Access to Southern target inaccessible by the LBTI
- NASA Astrophysics Decadal Survey Precursor Science: Securing revolutionary exozodi research with VLTI/NOTT (PI: S. Ertel)

Conclusion & Perspectives

- Exozodiacal dust can easily outshine Earth-like planets

- HOSTS survey has shown exozodiacal dust is not necessarily preventing exo-Earth imaging.

- Need further characterization of exozodiacal dust population for future direct imaging mission (HWO)

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Improved sensitivity with PCA background subtraction will help:

- Re-observe and/or re-analyze detections from the HOSTS survey
- Check for variability and obtain more sensitive observations
- Characterize the dust distribution
- Characterize the dust composition

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I will be on the job market in March 2025!
Please get in touch if you have postdoc opportunities for me!