LIFE

Large Interferometer For Exoplanets

# LIFE: measurement principle and technology requirements

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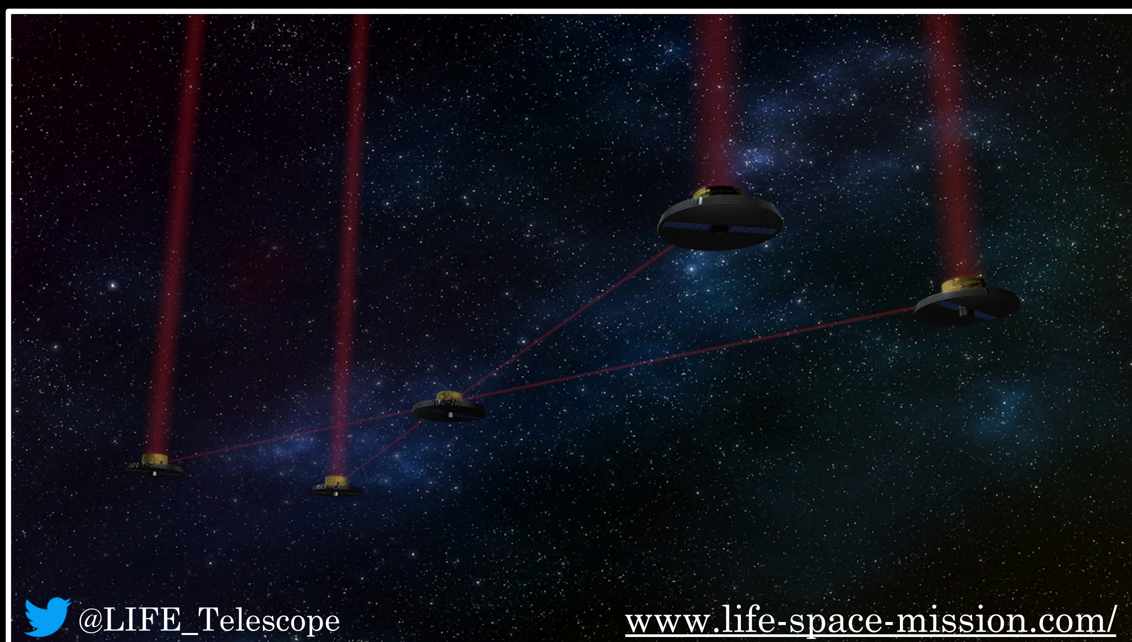
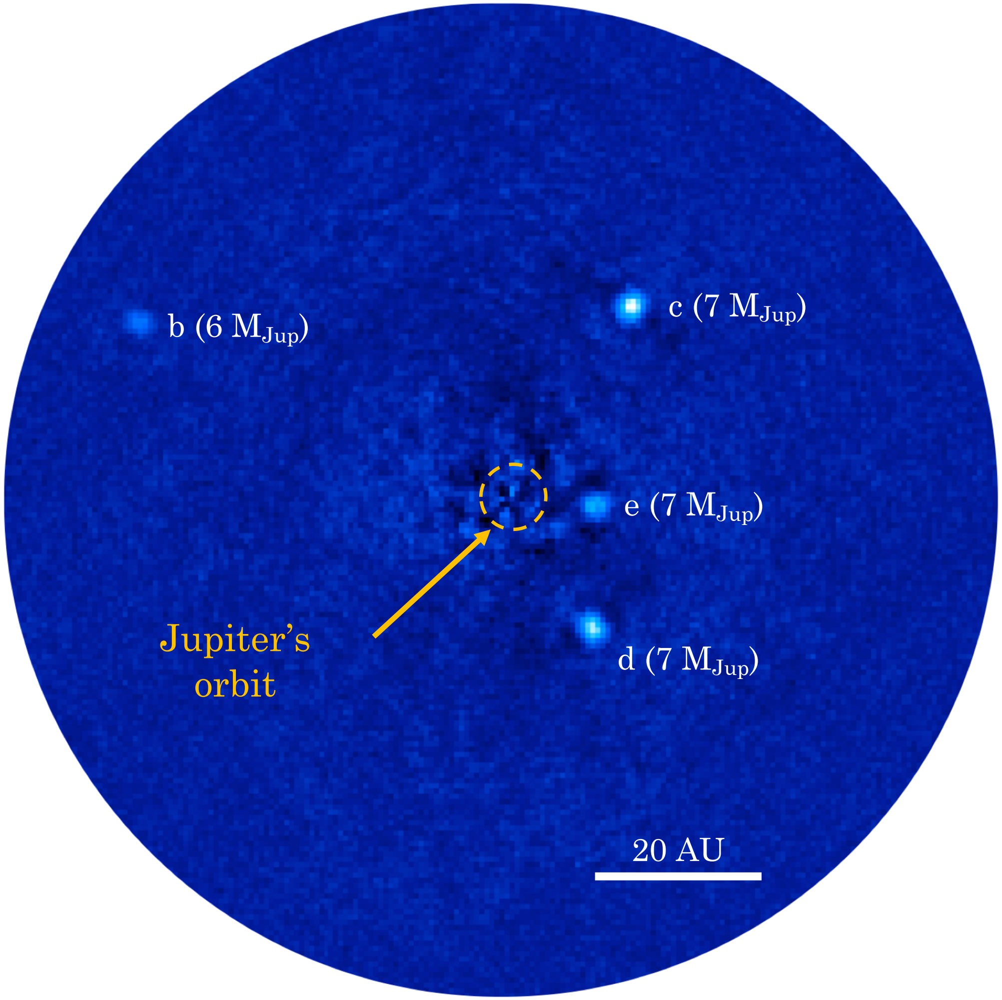
Special thanks to: O. Absil, C. Dandumont, S. Ertel, A. Glauser, P. Hinz, M. Ireland, J. Kammerer, L. Labadie, S. Lacour, J. Loicq, D. Mawet, B. Mennesson, J. Monnier, and S. Quanz




May 14th 2020 – LIFE virtual workshop

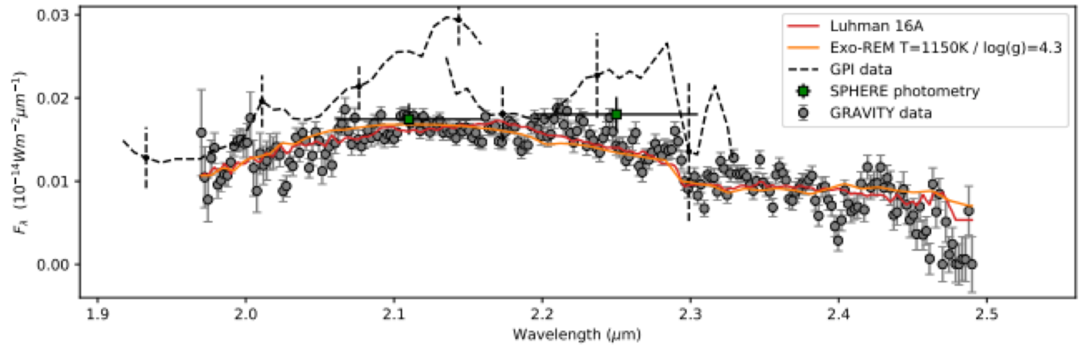
# Exoplanet imaging today



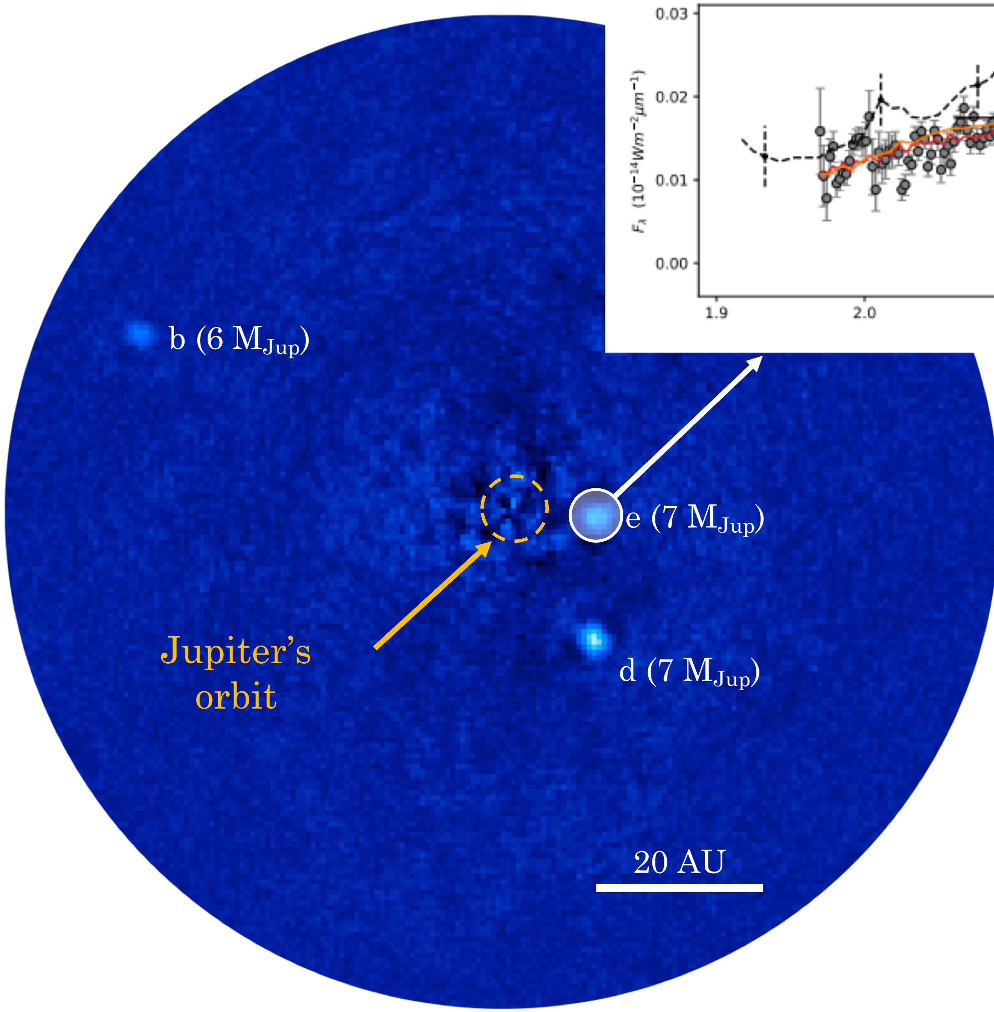

Gomez-Gonzalez et al. 2017

# Exoplanet imaging today

Lacour et al. 2019



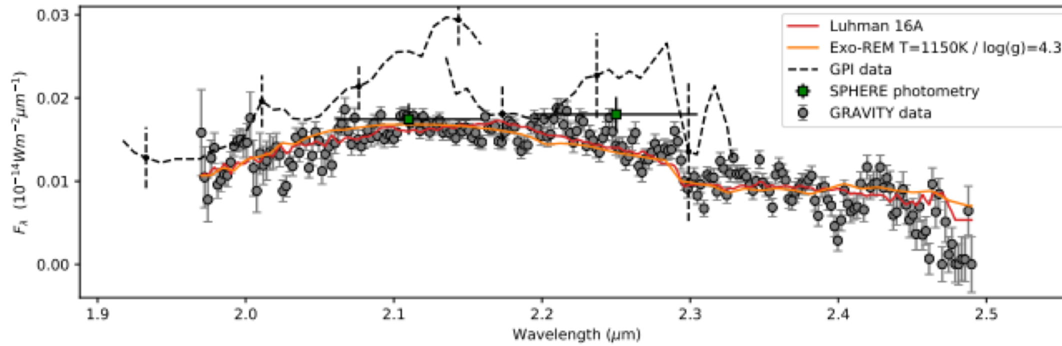

First interferometric characterization of an exoplanet




Gomez-Gonzalez et al. 2017

# Exoplanet imaging today

Lacour et al. 2019

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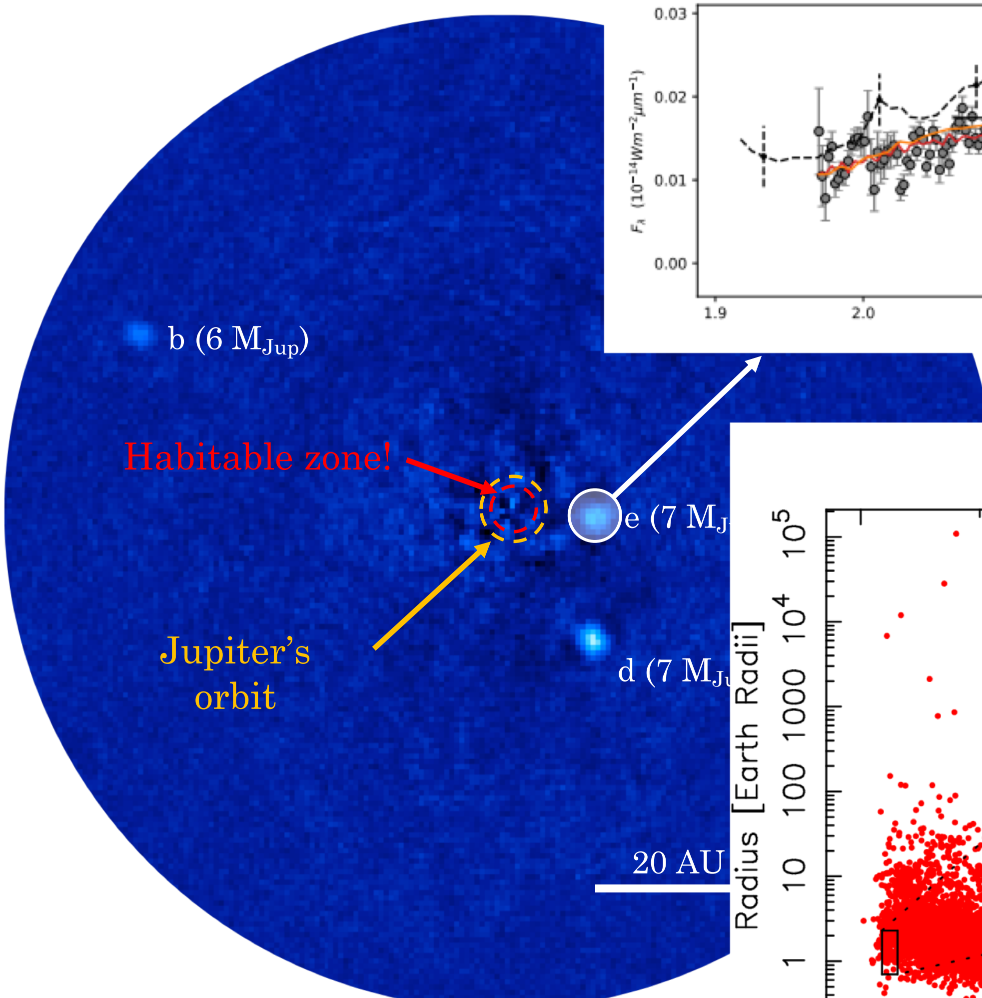
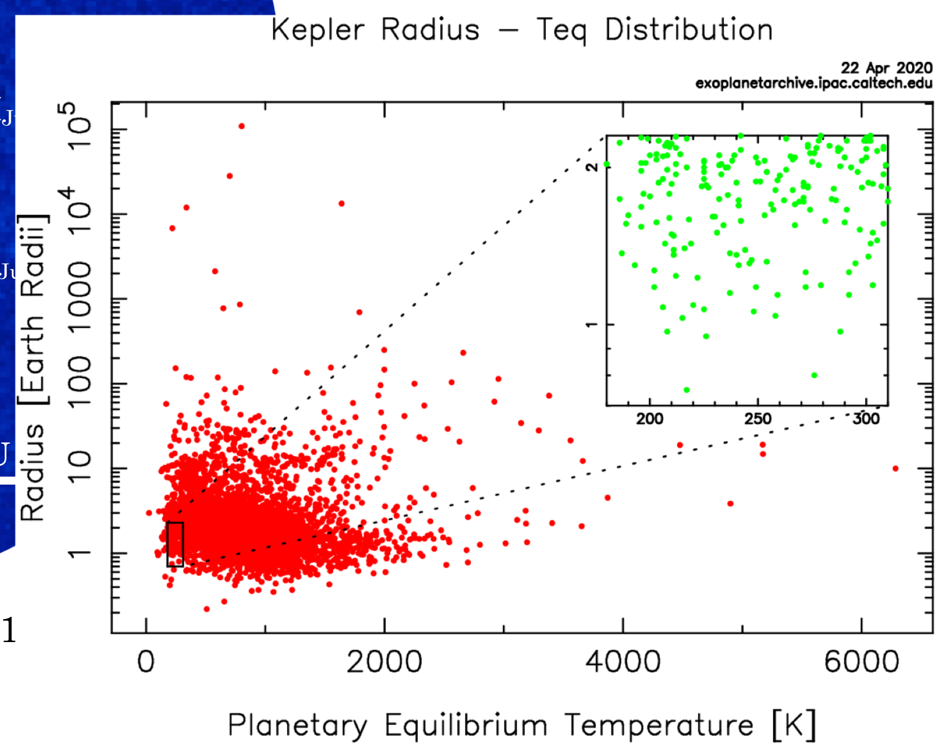


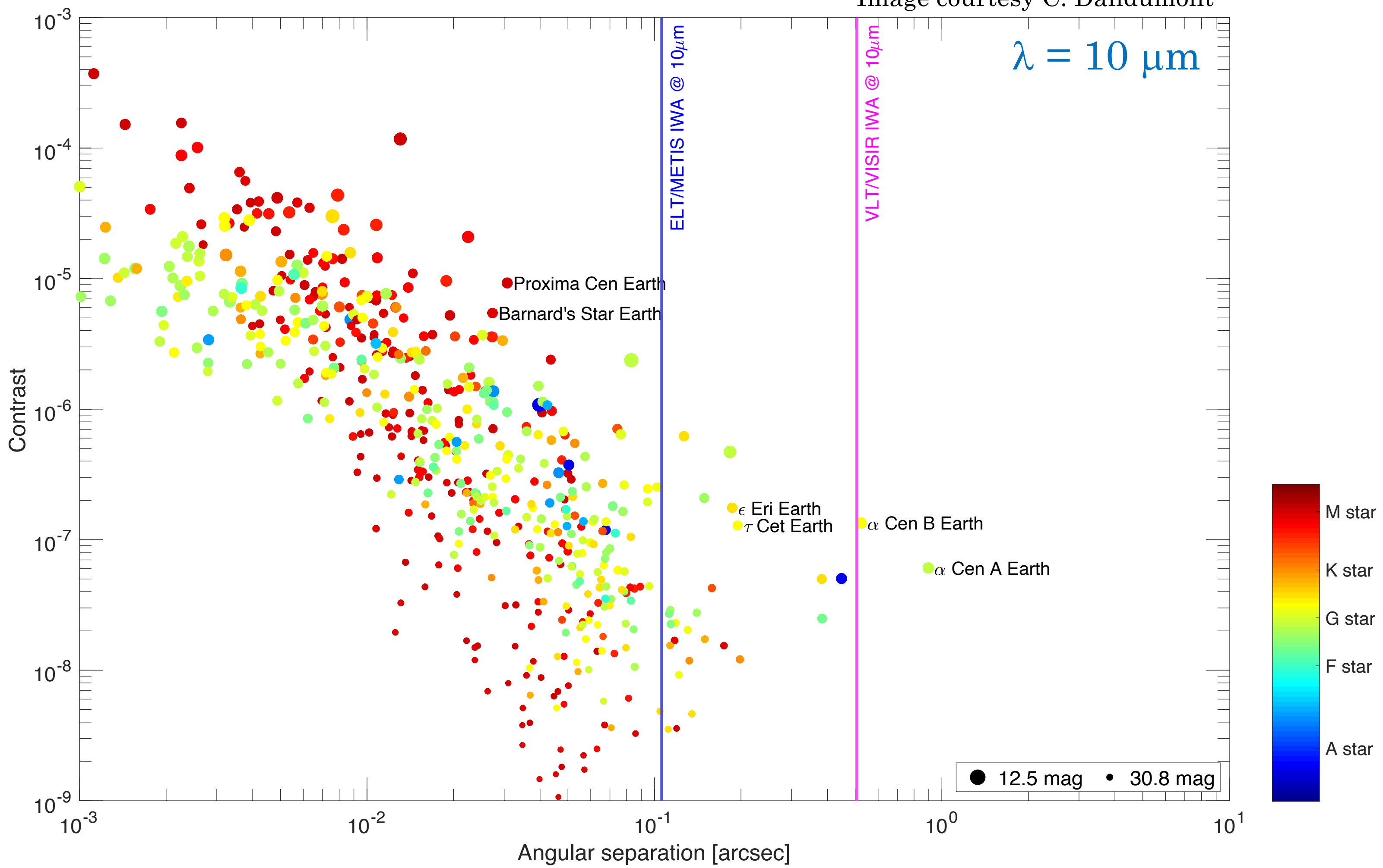

Gomez-Gonzalez et al. 201



# High-level technical requirements

- Angular resolution, contrast, and sensitivity

Image courtesy C. Dandumont




*Random realization of a realistic Universe based on Kepler's statistics and generated by P-pop (Kammerer and Quanz 2018)

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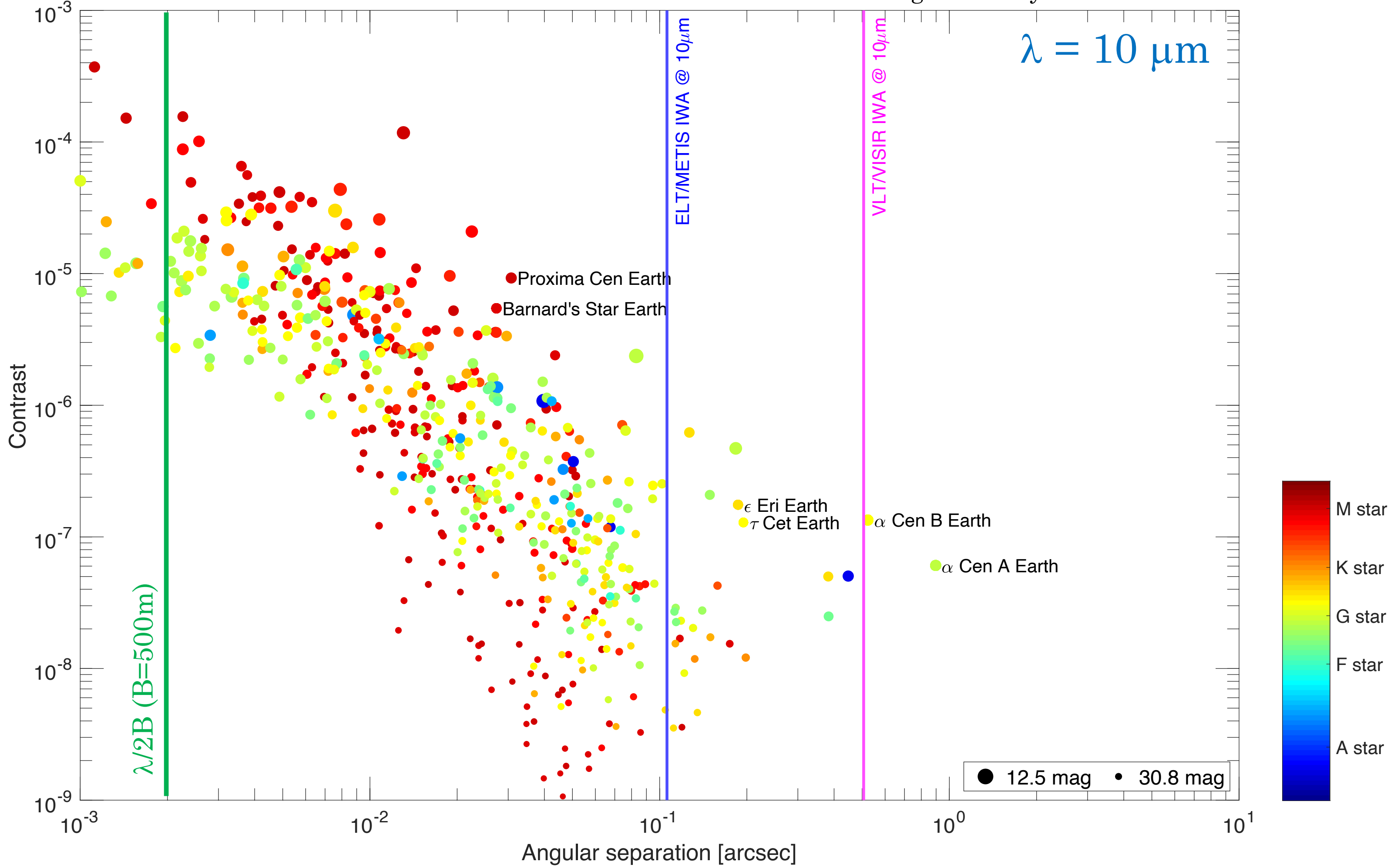


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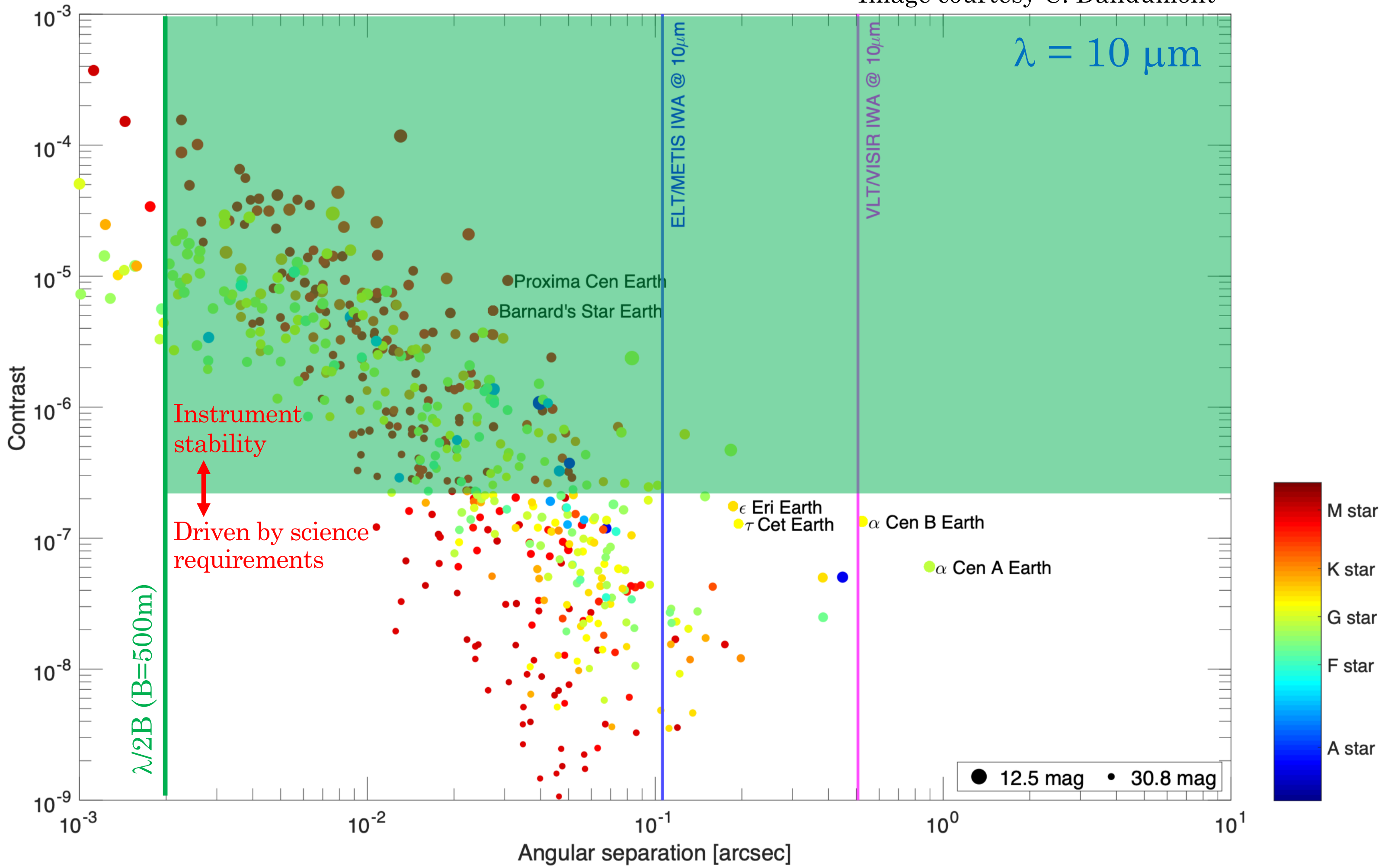




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# Solution: nulling interferometry

- Combine high angular resolution and starlight rejection
- First proposed in 1978 to detect non-solar planets (Bracewell 1978)

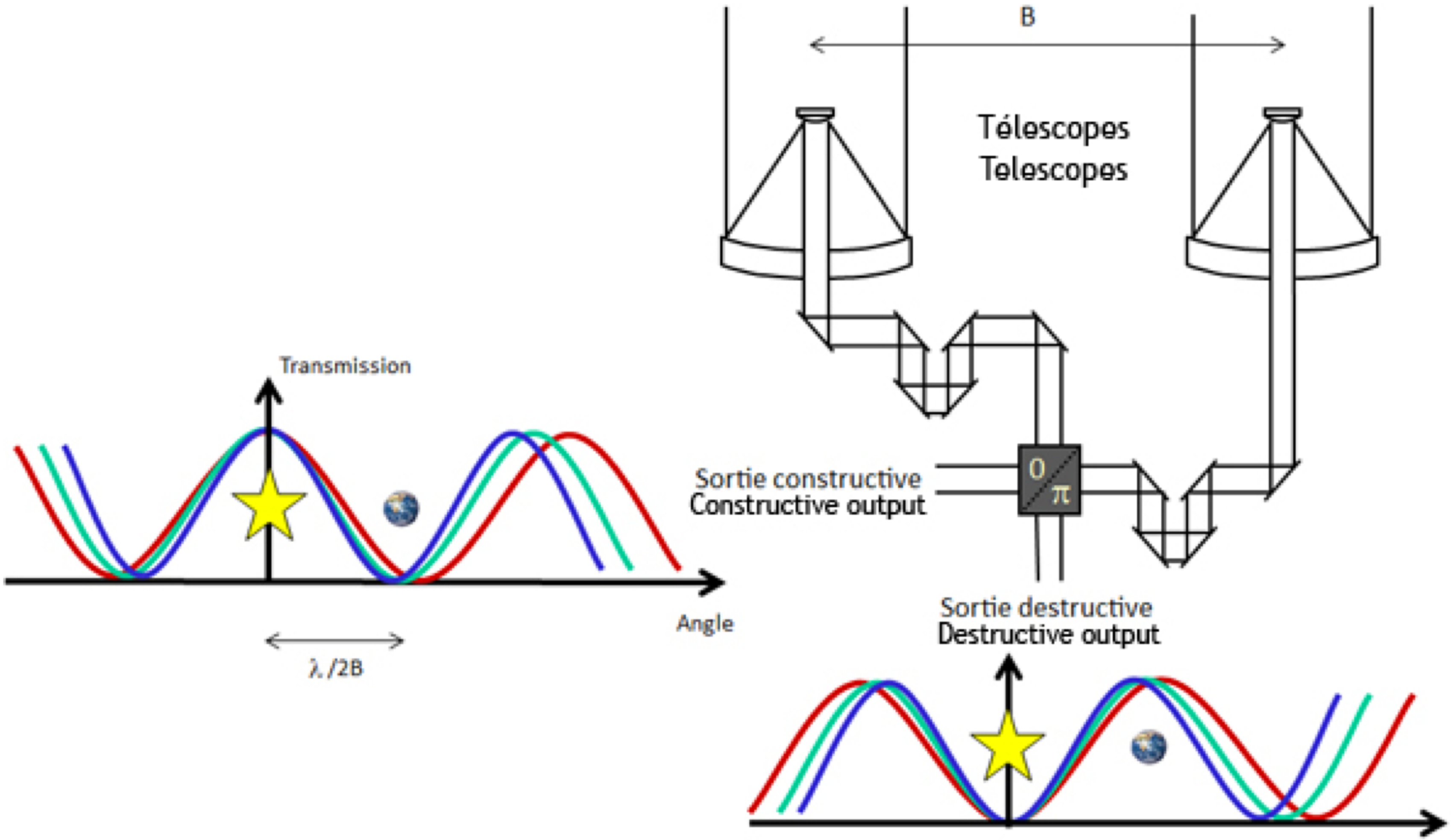
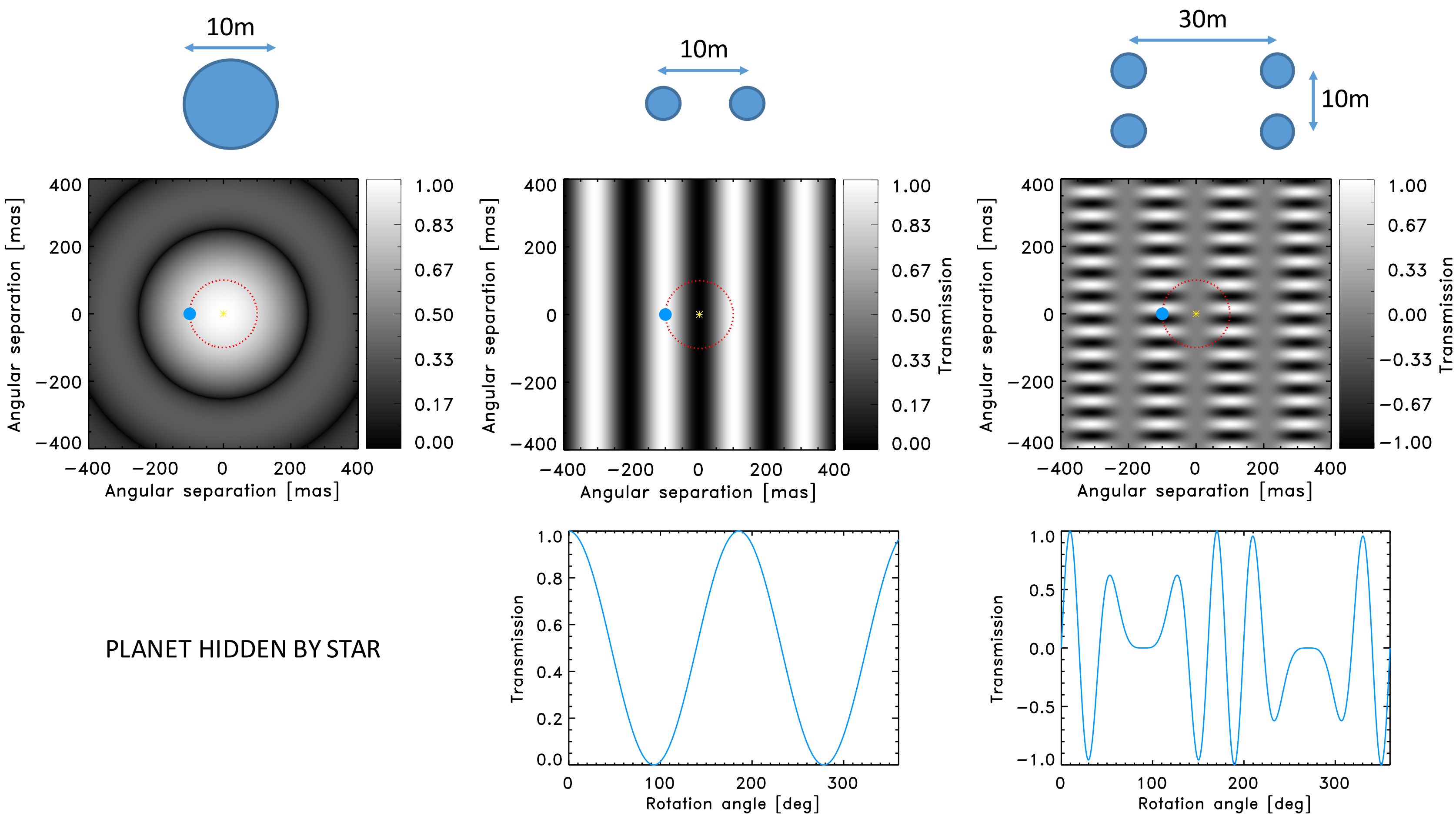



Image courtesy O. Absil

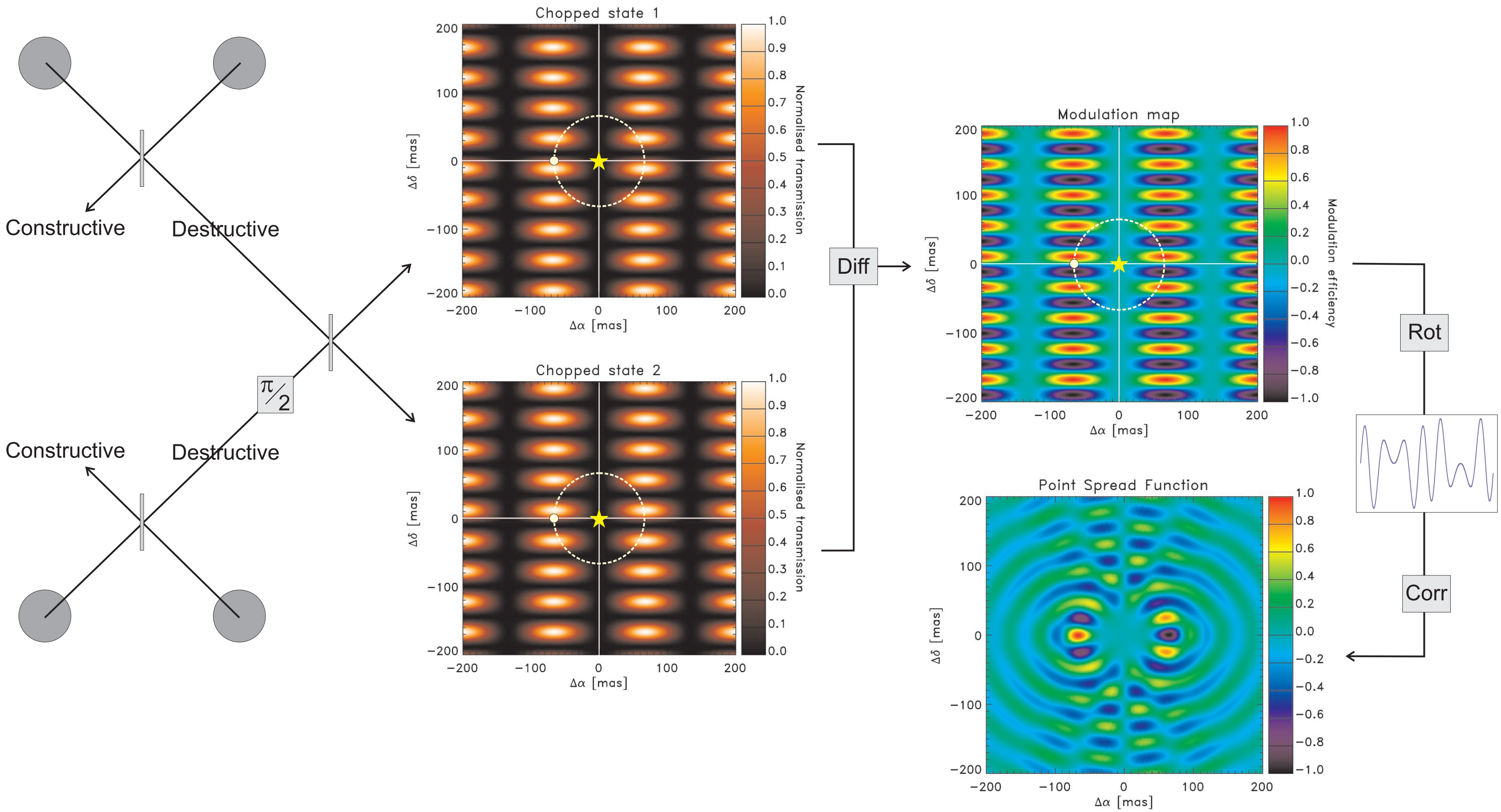
# Solution: nulling interferometry

- Transmission map for 2 and 4 telescopes




Earth-Sun system @ 10pc observed at 10 μm

# Fast planet modulation with chopping




Absil 2006, Cockell et al. 2009

# LIFE: why space?

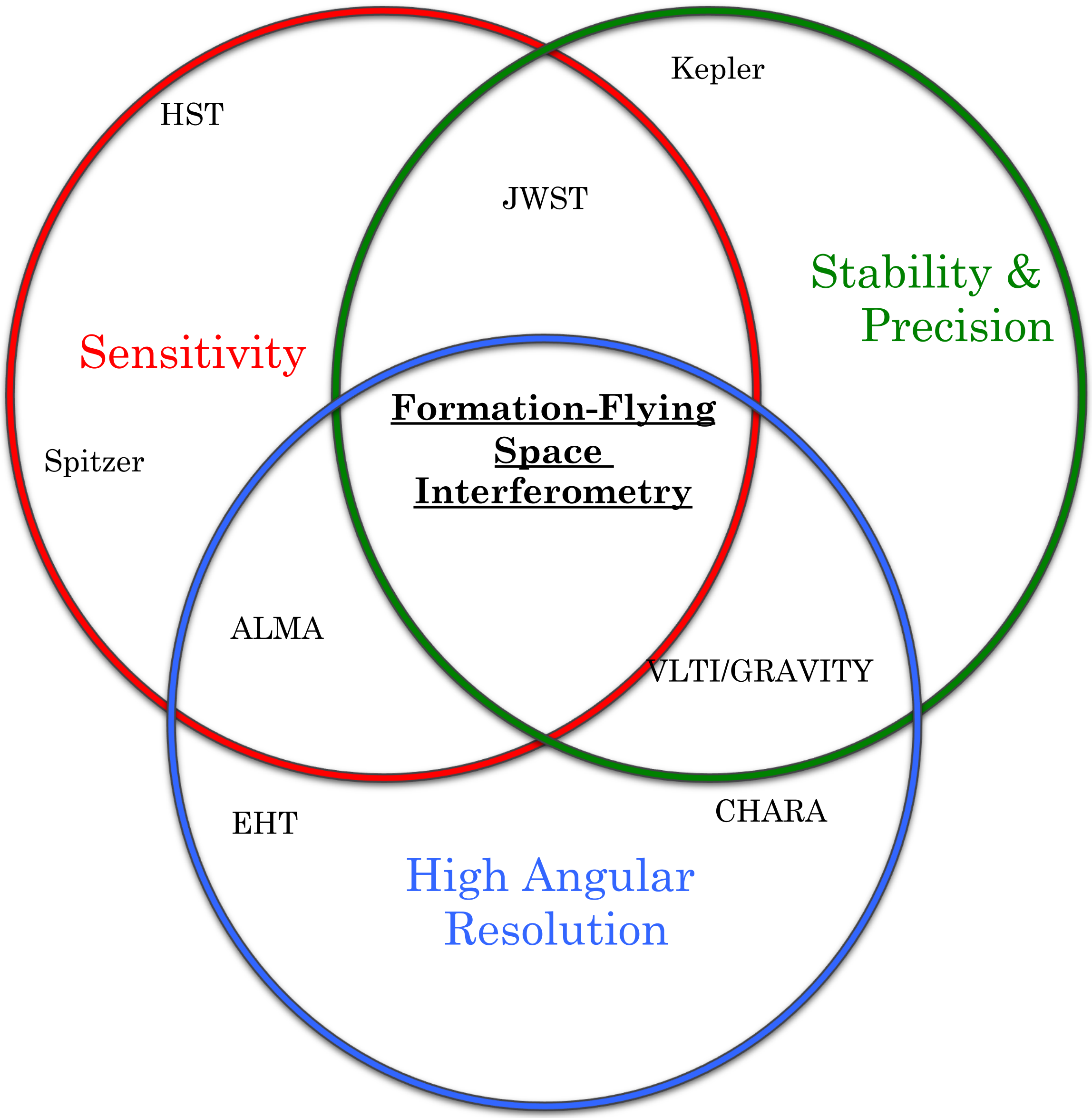



Image courtesy J. Monnier (Monnier et al. 2019)

# Overview of technological requirements

- Formation flying => angular resolution
- Starlight suppression => contrast
- Passive cooling, low thermal noise, and ultra-low noise mid-IR detectors

  => sensitivity

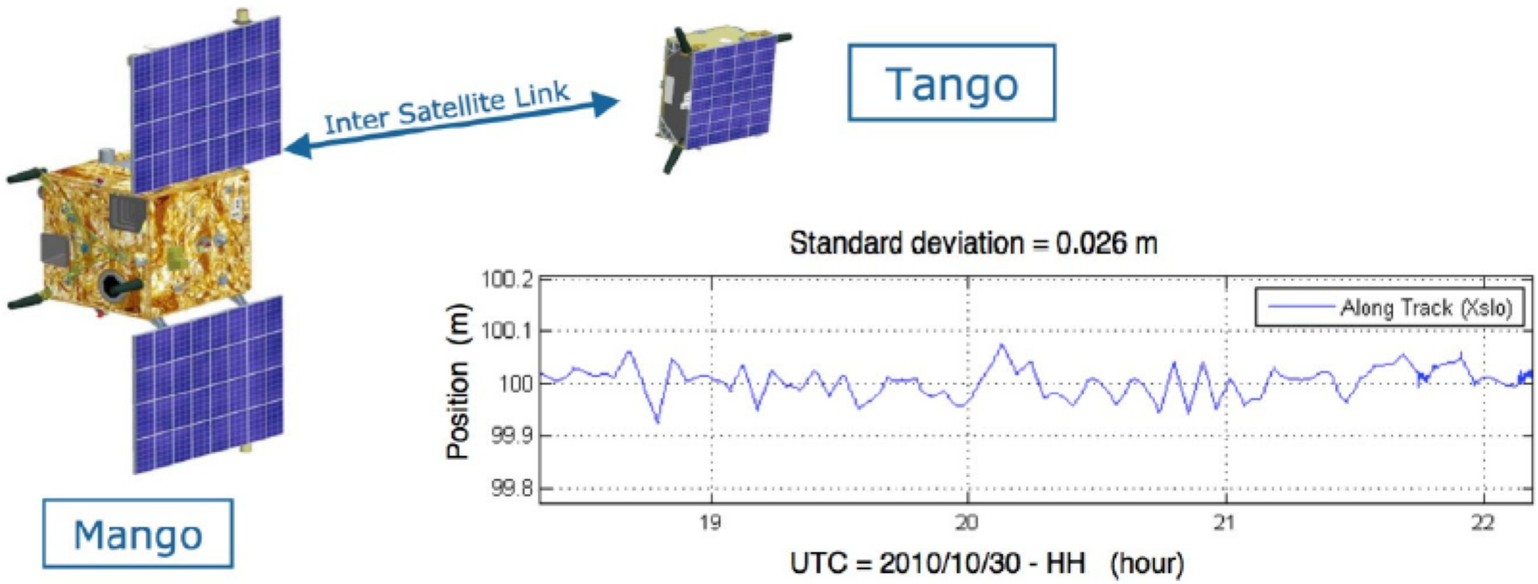
# Formation flying (1/3): requirements

- High-level requirements and features:
  - Control: 2 cm / 20 arcsec
  - At least 4 spacecraft
  - **Rotation** and fault recovery

# Formation flying (2/3): state-of-the-art

- Flight:
  - PRISMA (**2 spacecraft**), RMS of a few cm, over 4 hours (limited by accuracy of radio sensor)
  - PROBA-3 in 2022 (goal 100 µm RMS) **=> exceed control requirements**

- Lab: Formation Control Testbed (3 spacecraft, 2D), rotation, 5cm/60 arcmin



# Formation flying (3/3): ongoing activities

- SunRise: Sun Radio Interferometer Space Experiment (UMichigan):
  - 6U CubeSat flying at 10-km from each other
  - Study the Sun

- Formation Flying Ground and Cubesat Demonstrator (Hansen and Ireland 2020):
  - Demonstrate a full, 6-axis moveable telescope space interferometer demonstrator.
  - Create a cubesat-compatible metrology system (time of flight + interferometry).

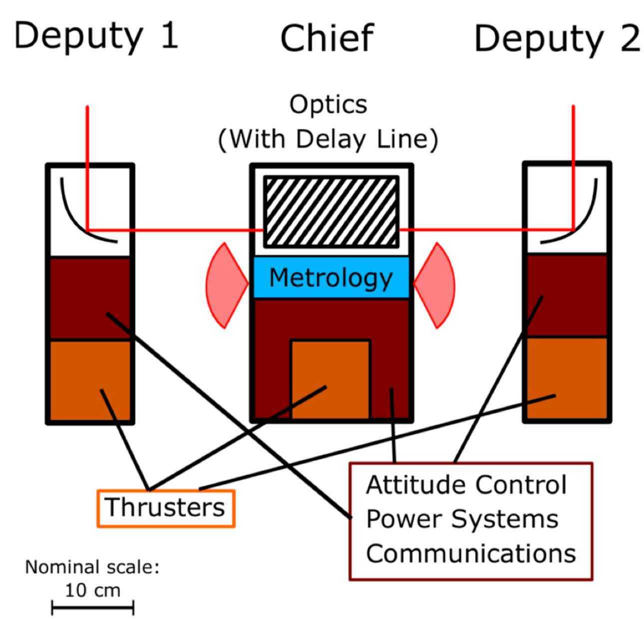
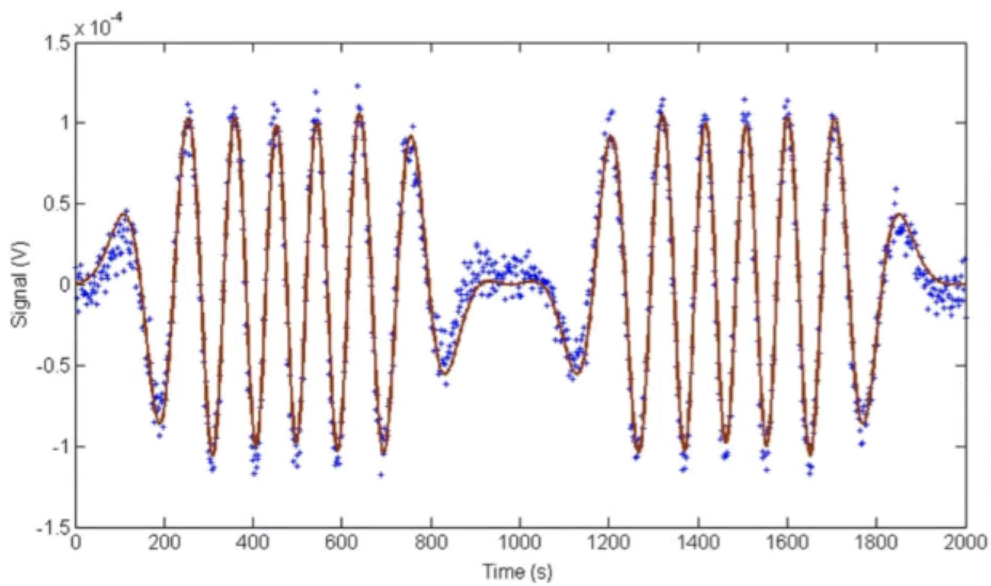


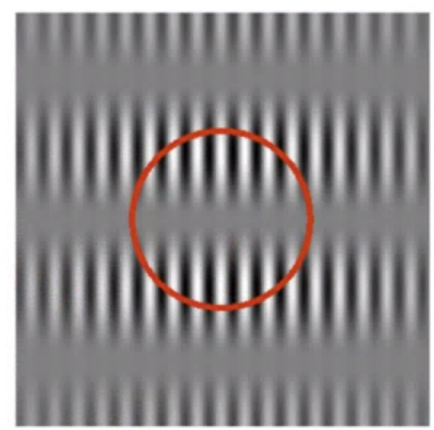

Image courtesy M. Ireland

# Starlight suppression

- High-level requirements and features:
  - Null depth $10^{-5}$ with stability $10^{-6}$ over ~50000s (5-20 microns)
  - Control: amplitude 0.05% RMS, phase: 1nm RMS (conservative, might be relaxed by post-processing)

- State-of-the-art at 10 µm:
  - <u>Lab</u>: null depth of $8 \times 10^{-6}$, $10^{-8}$ (after post-processing) @ room temperature and 10% bandwidth (Martin et al. 2012);
  - <u>On-sky</u>: null depth of ~$10^{-2}$, stability $10^{-4}$ (after post-processing) with LBTI, limited by thermal background (Defrère et al. 2016)



# Ultra-low noise mid-IR detectors

- High-level requirements and features:
  - Direct impact on maximum spectral resolution
  - Low readout noise, high QE
  - Requirements under study, likely ~5x better than JWST's MIRI

- State-of-the-art:
  - Flight: Spitzer IRAC Si:As detector
  - Lab: JWST/MIRI's band-impurity detectors (~14 e- rms)

# Passive cooling and thermal noise

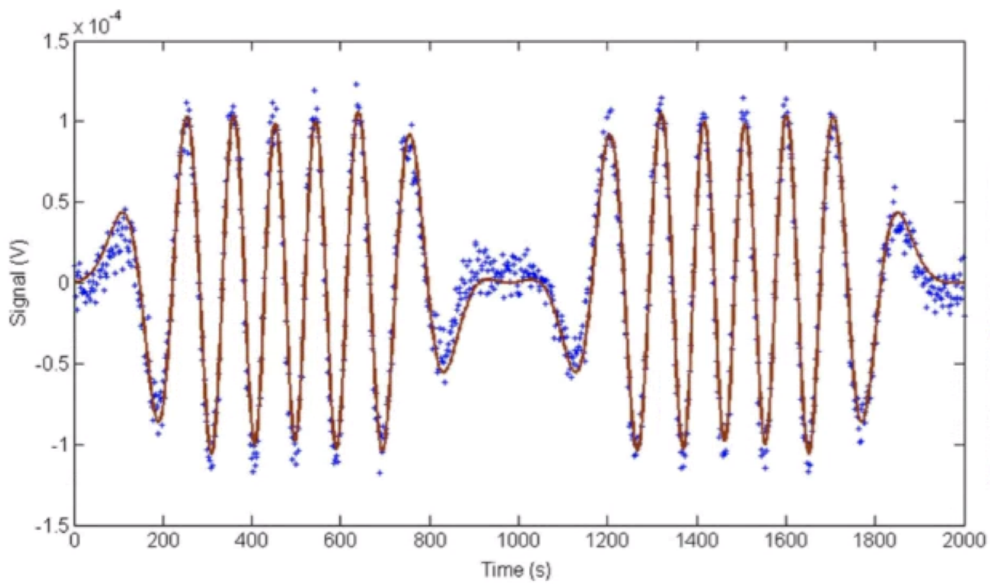
- High-level requirements and features:
  - Optics at 40K to preserve performance at 20 microns;
  - Baffling, cleanliness, and surface finish requirements to mitigate scattered light (<10 ph/s/bin);
  - Thermal stability

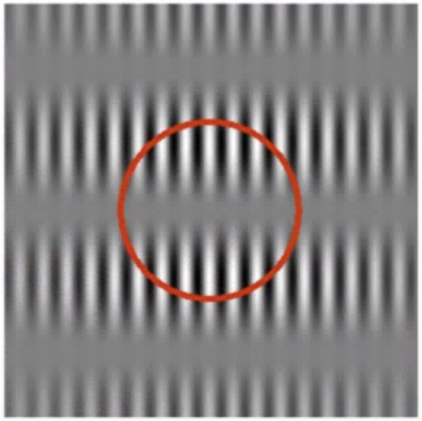
- State-of-the-art:
  - Herschel/Planck passively cooled at 40K


Cryogenics (ESA's Herschel)

# Current activities and plans: NICE

- Nulling Interferometric Cryogenic Experiment for LIFE
- ETH's cryogenic testbench
- Goals of the testbench:
  - Enhance technology readiness level of broadband nulling interferometry for LIFE and ground based nullers
  - Demonstrate broadband nulling at cryo and beyond 10% bandwidth @10µm

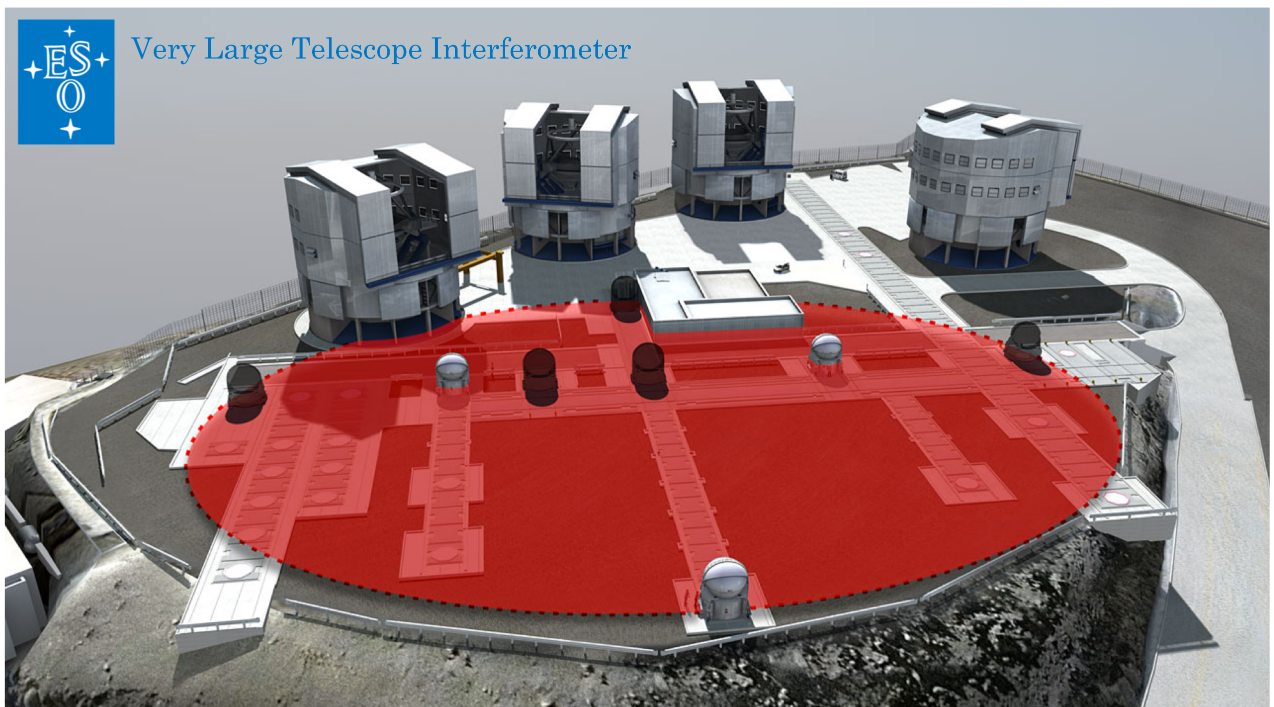


# Current activities and plans: VLTI

- First high-contrast nulling instrument for the VLTI : Hi-5 (Defrère et al. 2018) and VIKING (Martinache and Ireland 2018)
    - Precision spectroscopy (L-band) and astrometry
    - Constrain planet formation models (access to the snow line)

- Demonstrate LIFE's beam combination scheme, data acquisition and reduction techniques



# Current activities and plans: LBTI

- LBTI completed the exozodiacal dust survey using 10-µm nulling interferometry (Ertel et al. 2020)
- Best-fit median dust density around Sun-like stars of 3 zodis and below 27 with 95% confidence level (good news for LIFE!)

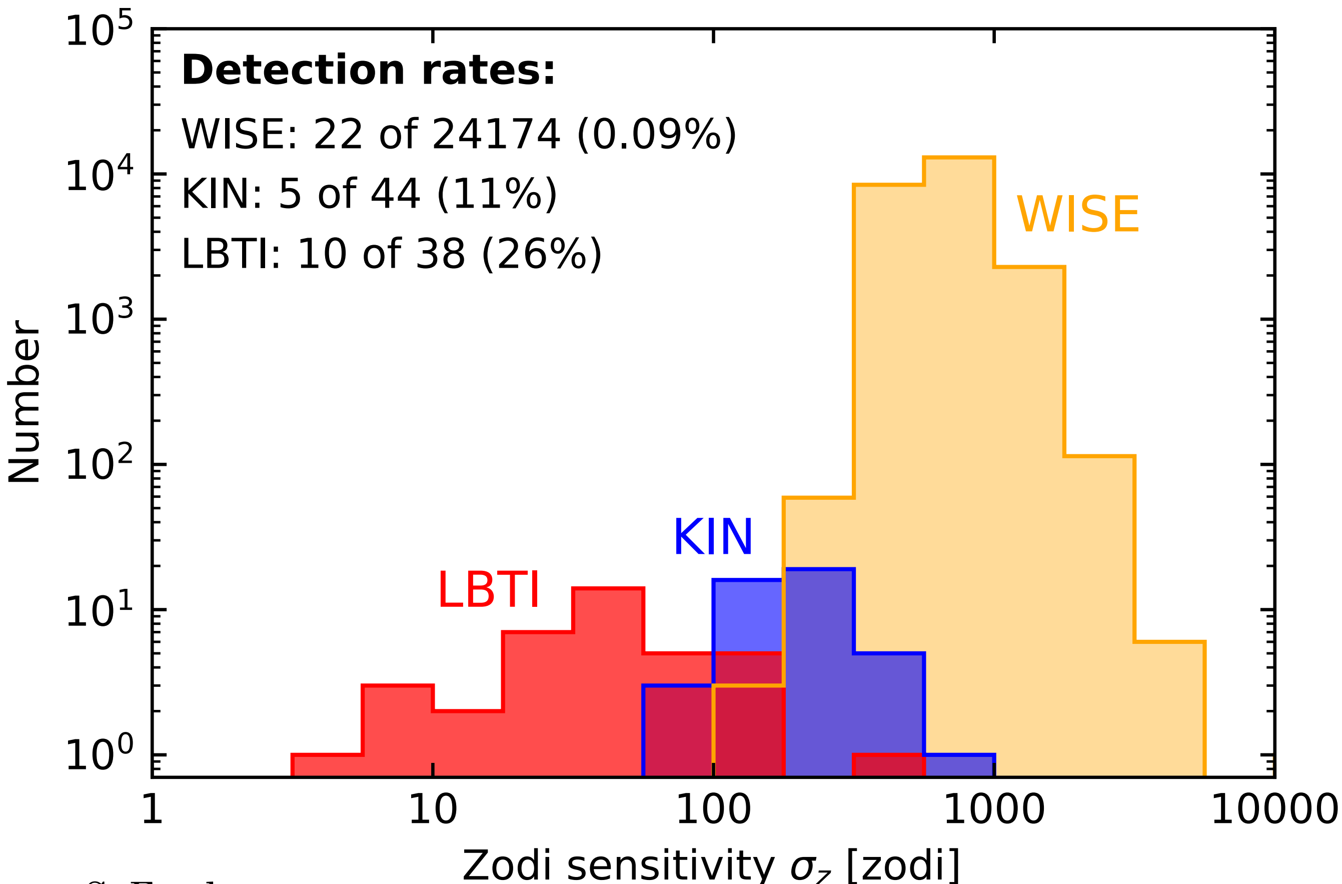
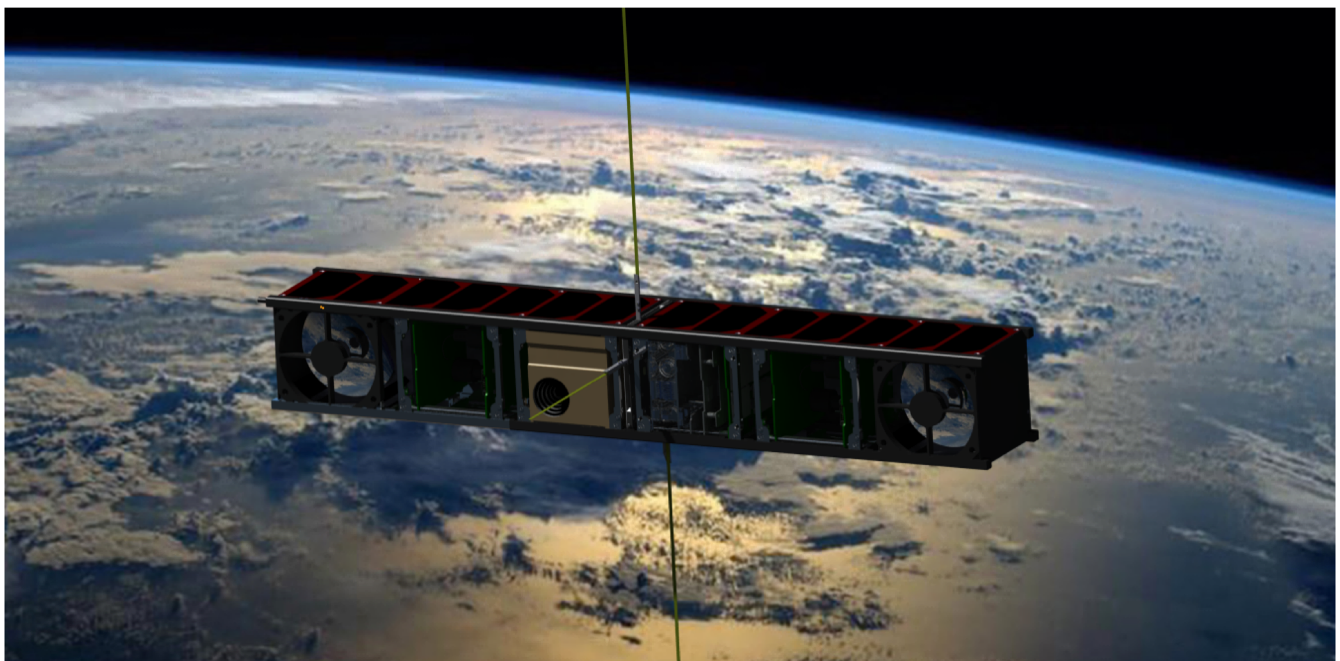



Image courtesy S. Ertel.

# Other activities

- Vortex fiber nuller (Keck), GLINT (Subaru)
- Beam combination development Ongoing < 5µm (ANU, Macquarie, Cologne, IPAG)
- PICSAT (3U CubeSat)
  - Inject light into a single-mode fiber in space
  - Photometry : accuracy $10^{-3}$ ($10^{-4}$) over 1h

PicSAT



# Summary

- New era of exoplanet characterization with long-baseline interferometry

- Significant progress in key technologies over the past decades (formation flying, starlight suppression, ground-based nulling, …)

- New projects just started to enable LIFE: NICE (ETH testbench), SCIFY (ERC CoG project, 2020-2025), formation flying with CubeSats.

- Need more technology support programs (broadband coverage, spatial/modal filters, beam combination technologies, low noise detectors,…)

- Interested? Contact us!
  - LIFE science: S. Quanz (sascha.quanz@phys.ethz.ch)
  - NICE: A. Glauser (glauser@phys.ethz.ch)
  - LIFE technology and SCIFY: D. Defrère (ddefrere@uliege.be)

# Announcements