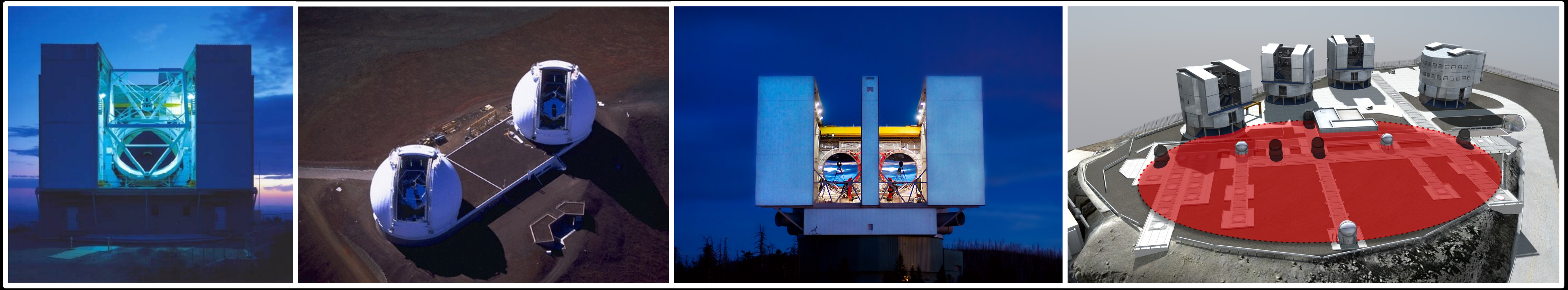
Nulling interferometry



Denis Defrère

Institute of Astronomy, KU Leuven

@ddefrere

Interferometry: principles

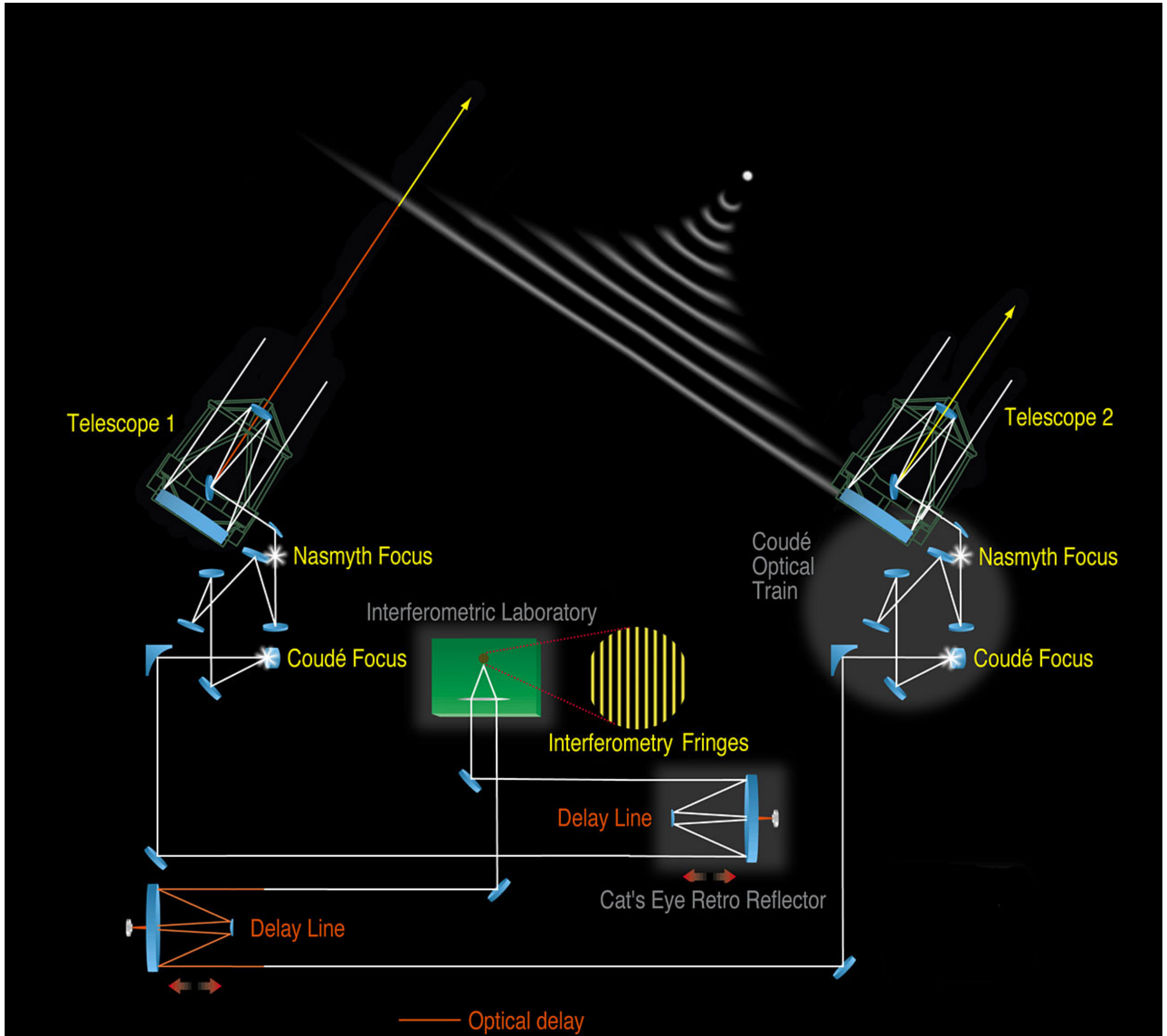
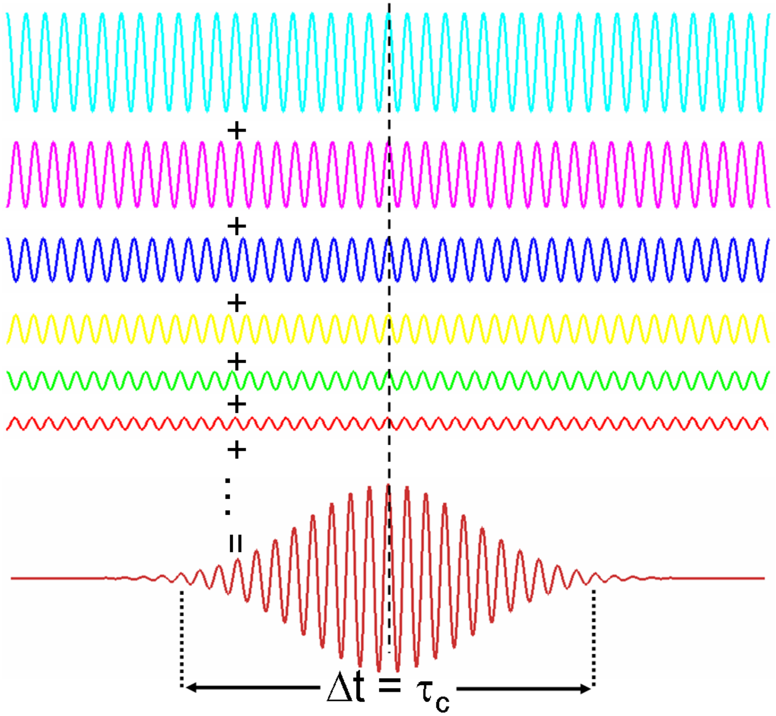


Image credit: ESO

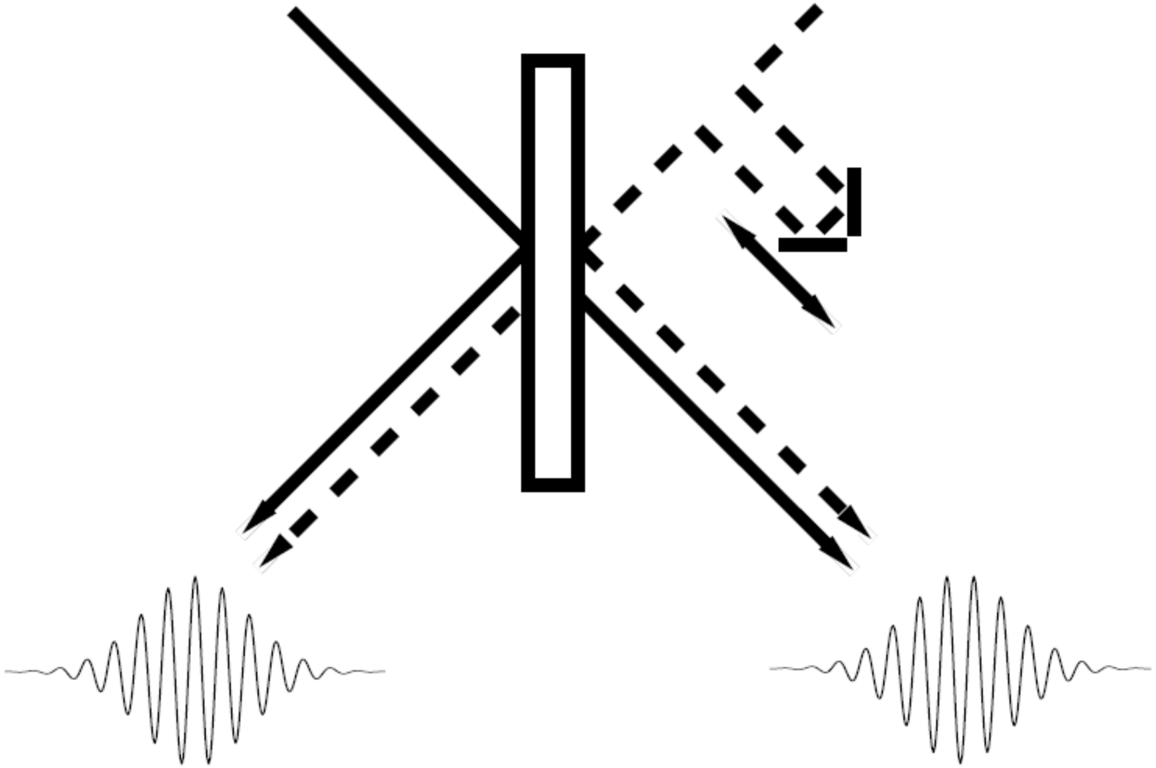


$$\text{Coherence time} = \Delta t = \frac{\lambda^2}{c\Delta\lambda}$$

$$\text{Coherence length} = L = \frac{\lambda^2}{\Delta\lambda}$$

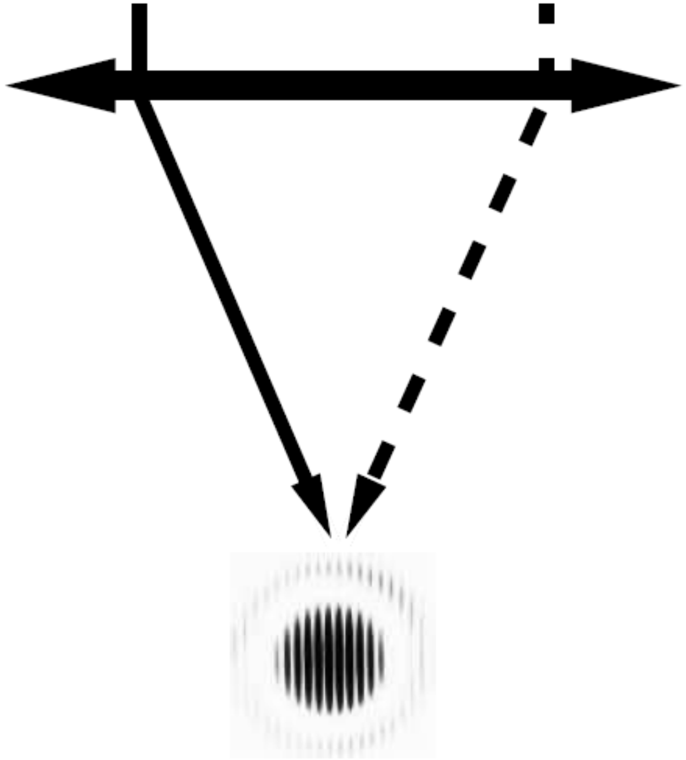
How to code the fringes?

Coaxial
(pupil plane combination)



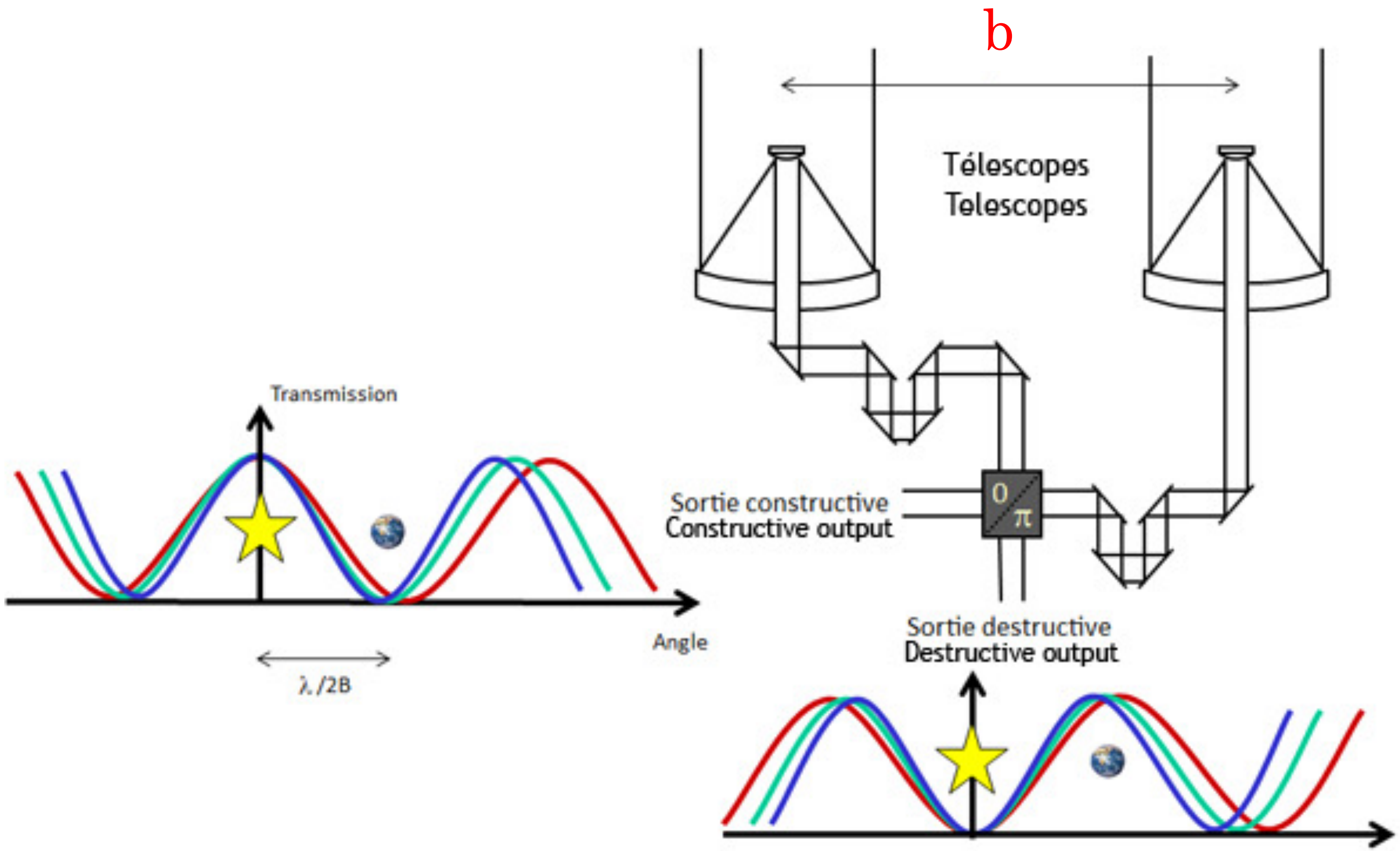
temporal fringes

Multiaxial
(image plane combination)



spatial fringes

Nulling interferometry



Transmission map (2T)

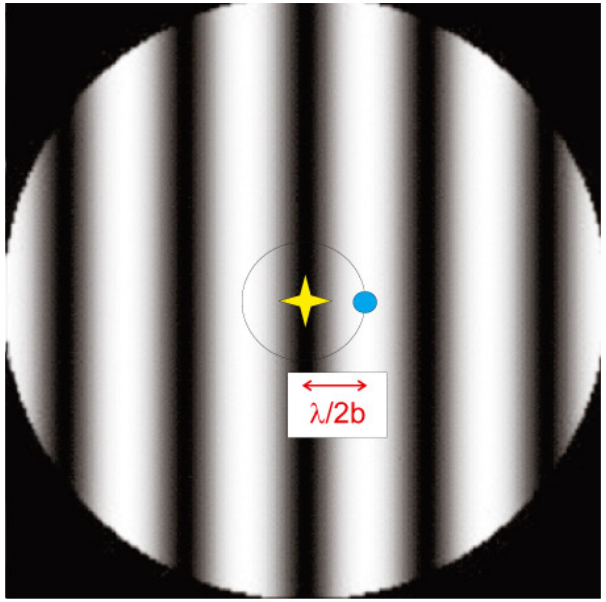
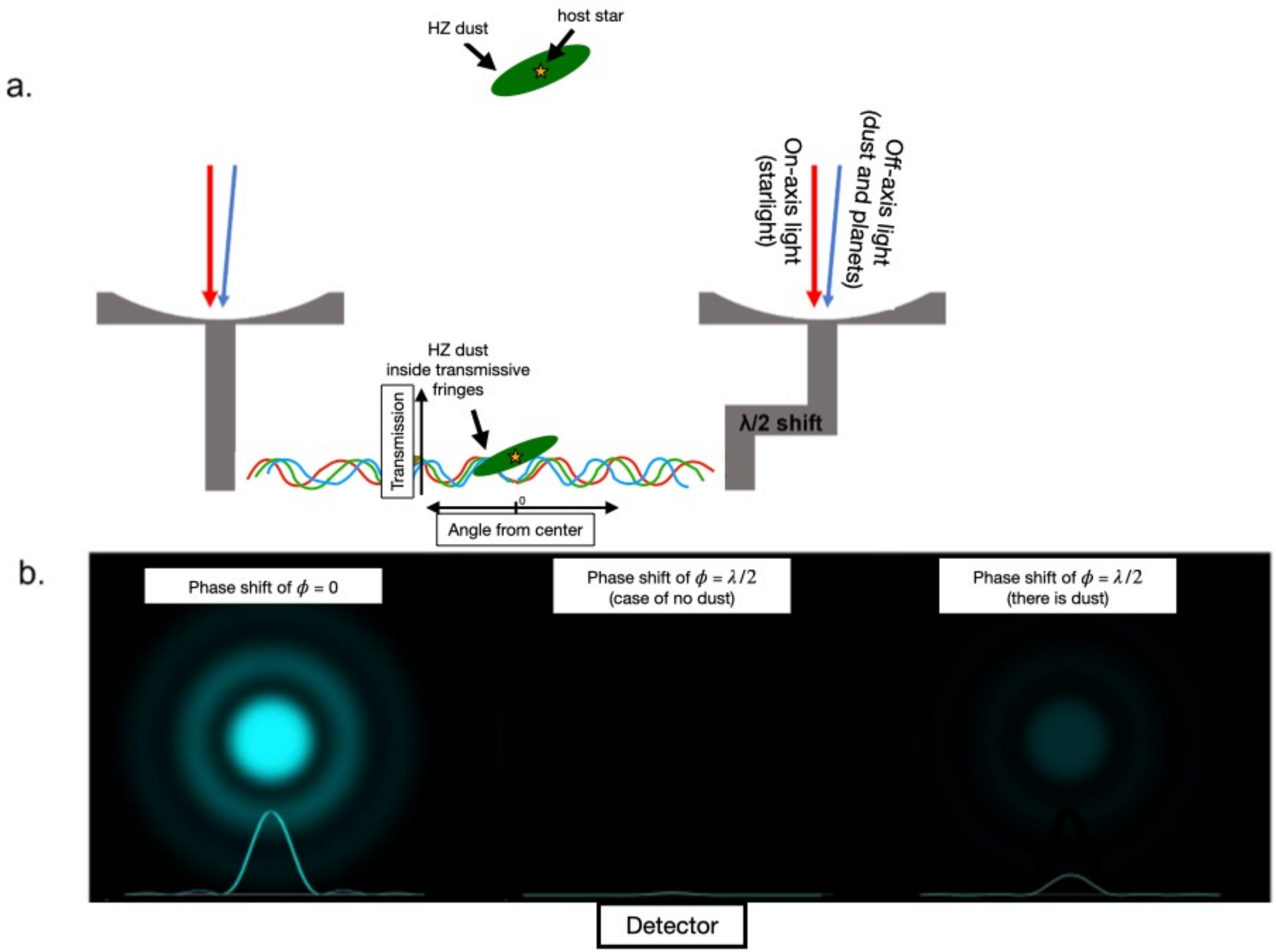


Image credit: O. Absil (Uliège)

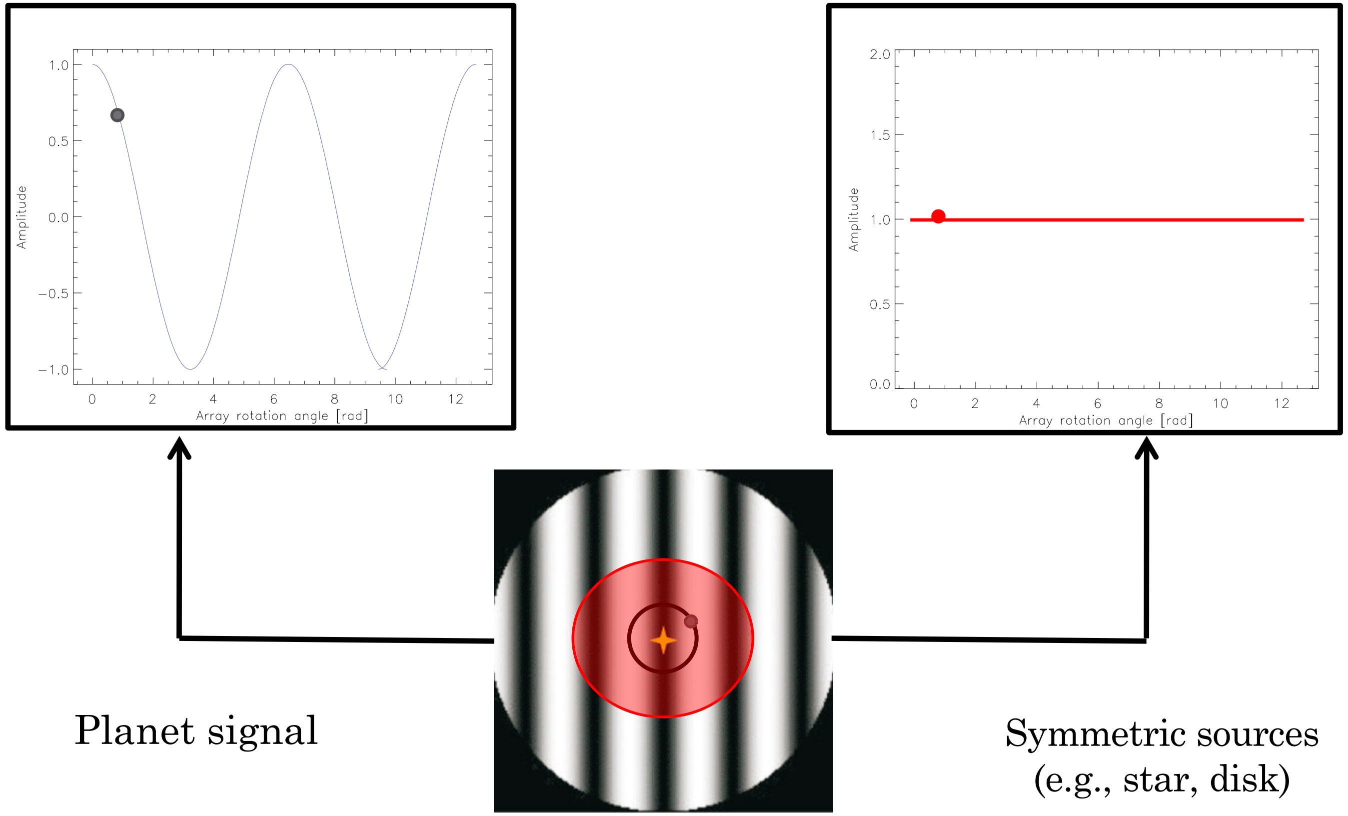
Nulling interferometry



Spalding et al. (2022)

Nulling interferometry: exoplanet detection

- First proposed by Bracewell in 1978 to image non-solar planets with a rotating nuller (Nature, 274, 1978):



Signal modulation

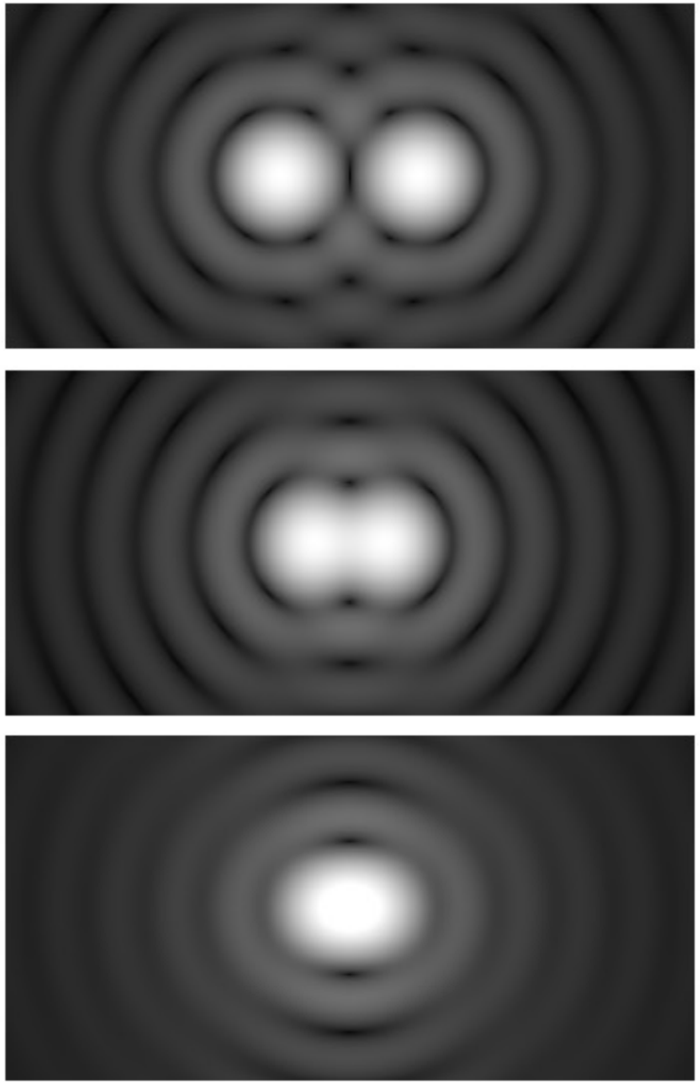
No signal modulation

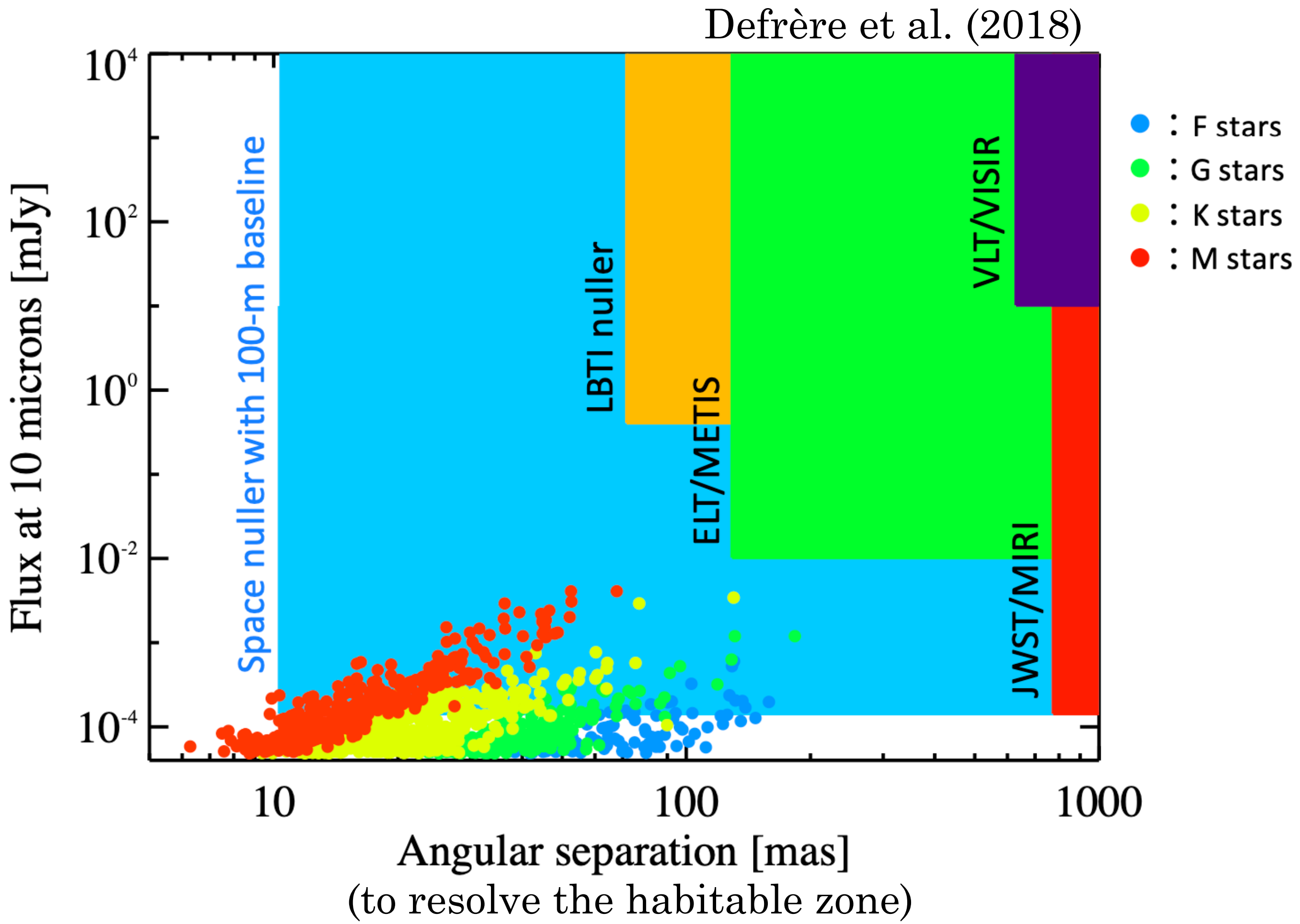
Planet signal

Symmetric sources
(e.g., star, disk)

Why nulling interferometry?

1. Angular resolution:

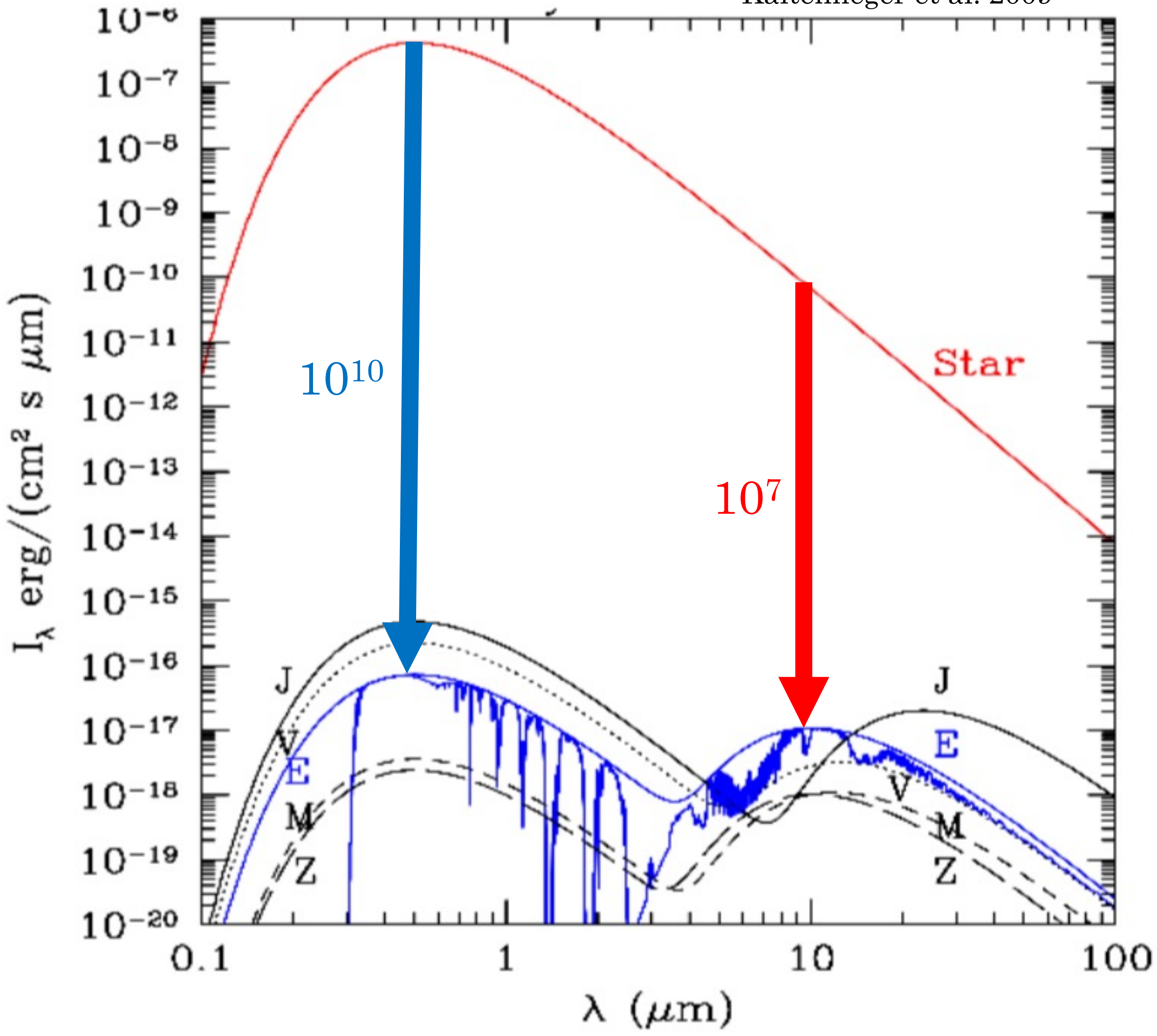




Why nulling interferometry?

2. Planet/star contrast

Kaltenneger et al. 2009

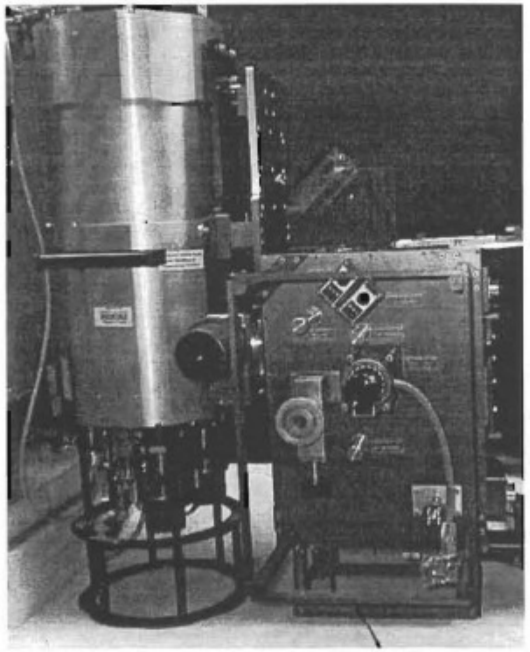


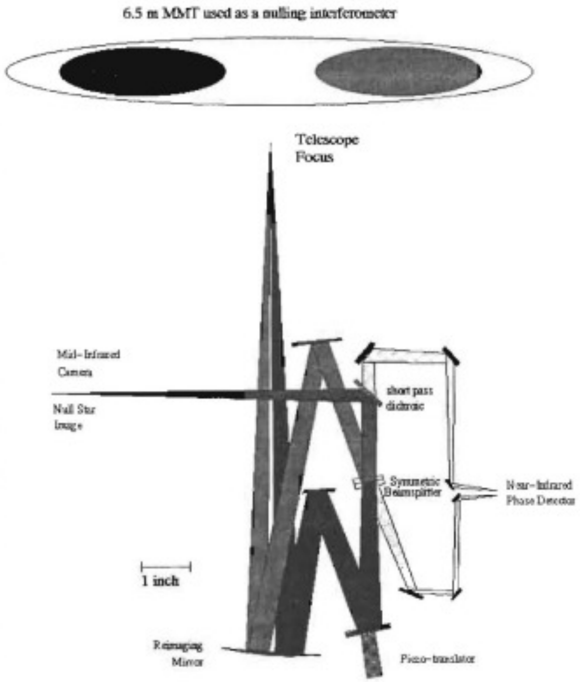
- Visible: 10^{-10} fainter
  - IR: 10^{-7} fainter

IR: ~10^{9} fainter than the atmospheric background

The 1st-generation nulling interferometer

- First on-sky telescope implementation by Hinz et al. in 1998 on the Multiple Mirror Telescope in Arizona (Hinz et al., Nature, 395, 1998):



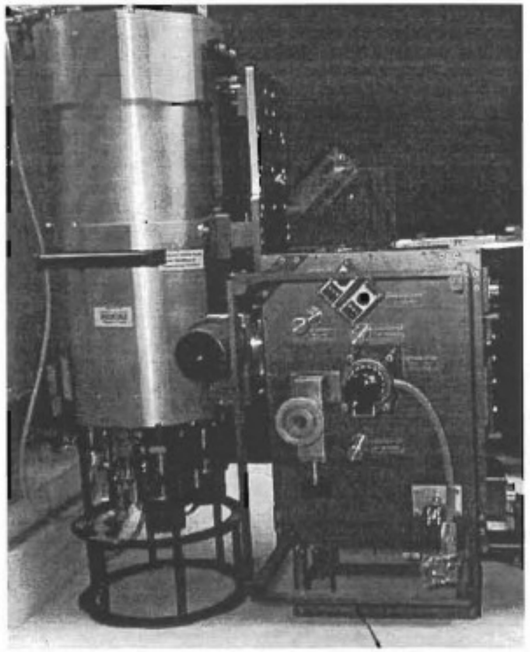


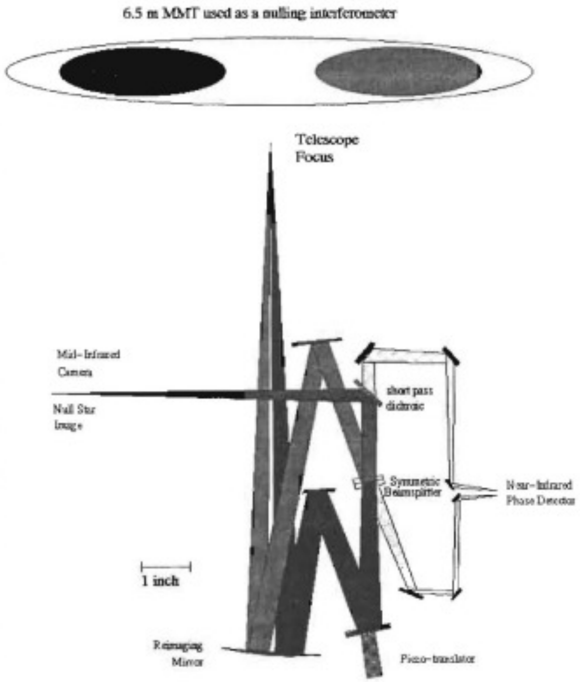
Optical layout of the Bracewell Infrared Nulling Cryostat (BLINC)

Multiple Mirror Telescope – Mount Hopkins (Arizona)

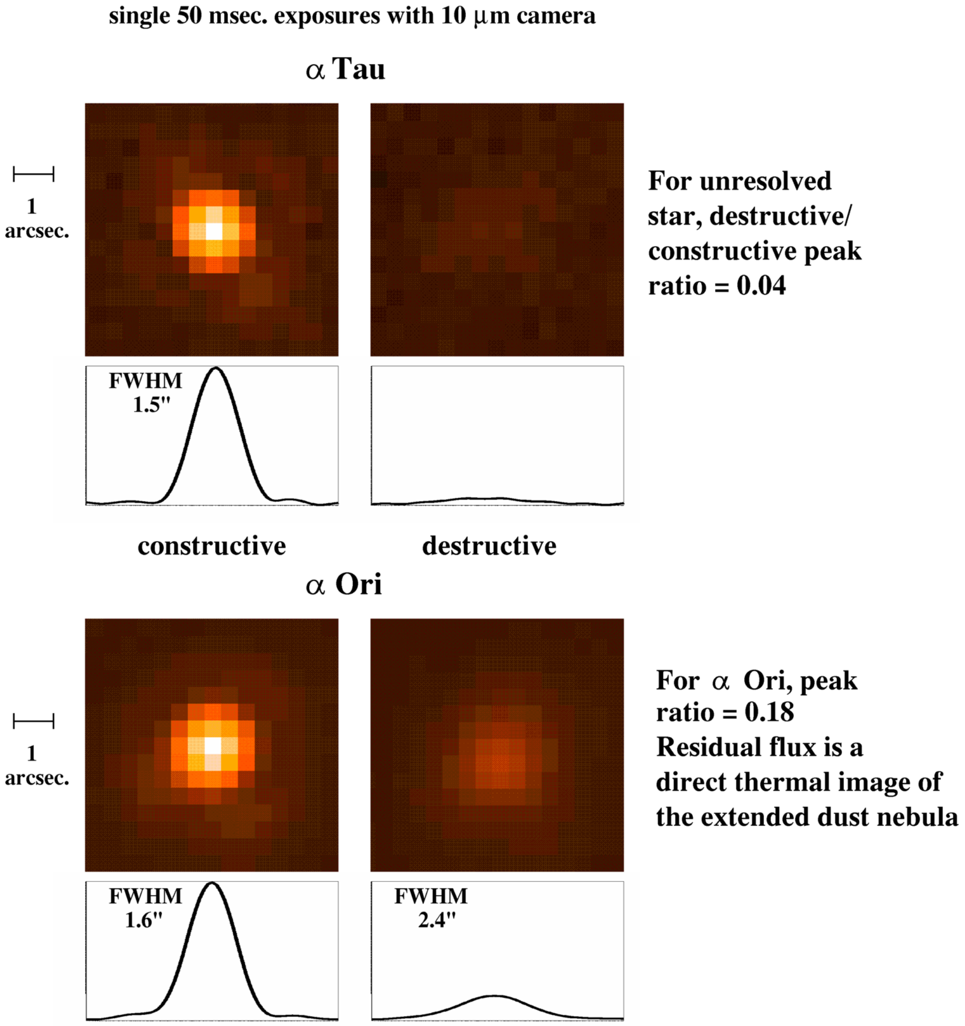
The 1st-generation nulling interferometer

- First on-sky telescope implementation by Hinz et al. in 1998 on the Multiple Mirror Telescope in Arizona (Hinz et al., Nature, 395, 1998):





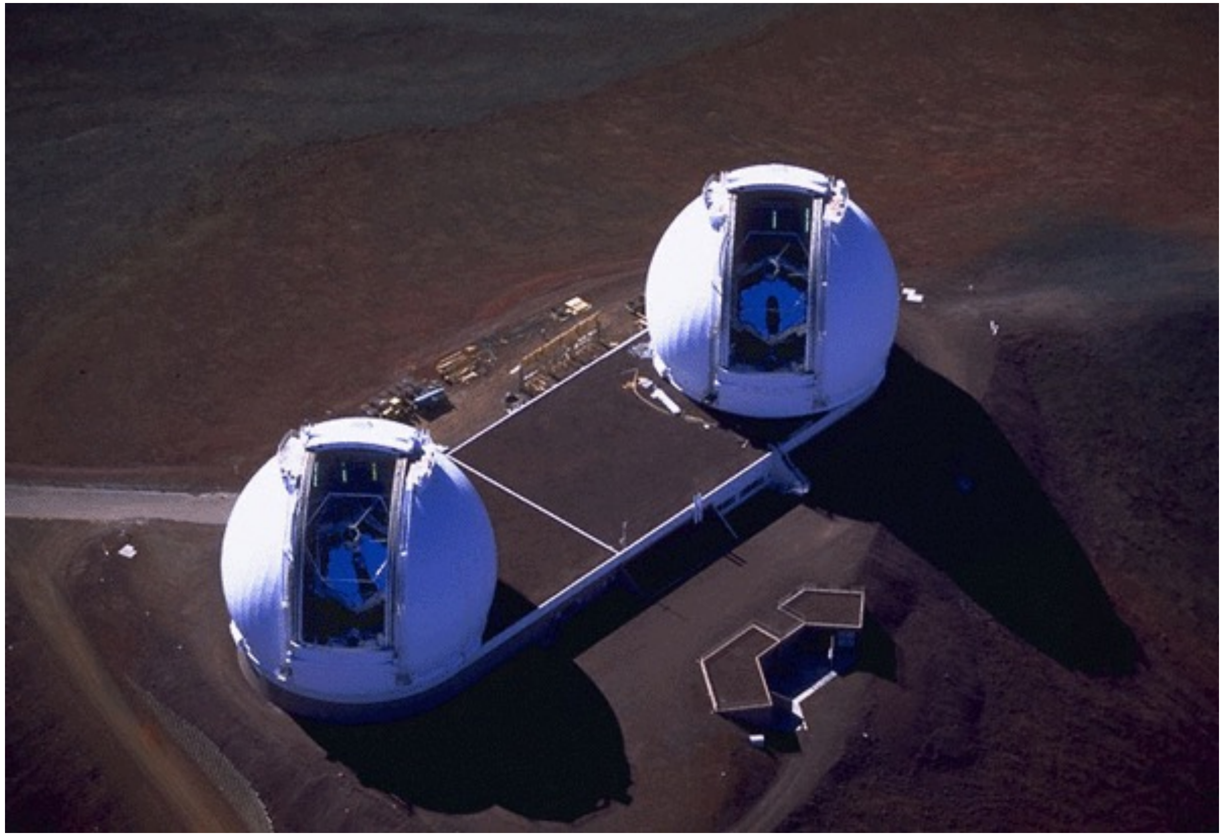
Optical layout of the Bracewell Infrared Nulling Cryostat (BLINC)



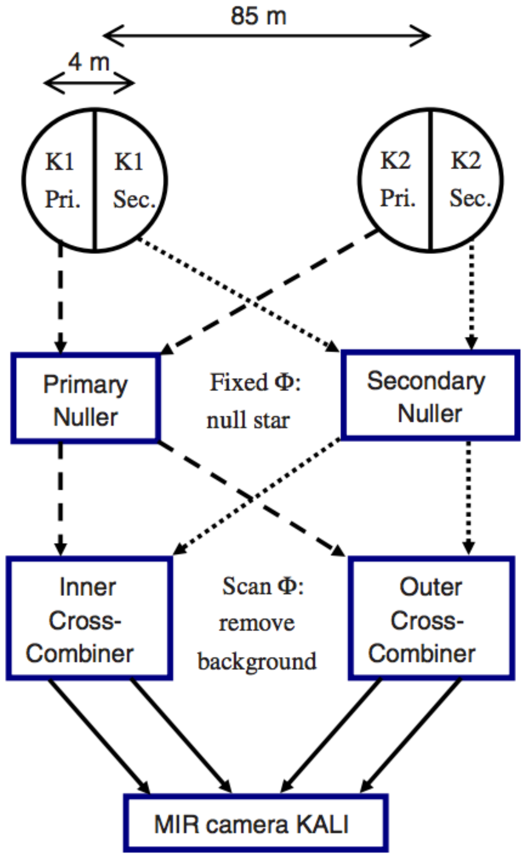
The 2nd-generation nulling interferometer

- First telescope implementation of a four-beam interferometric nuller (Colavita et al. 2010);

- <u>Main scientific goal</u>: measure emission from exozodiacal dust around nearby main-sequence stars (Millan-Gabet et al. 2013, Mennesson et al. 2014);

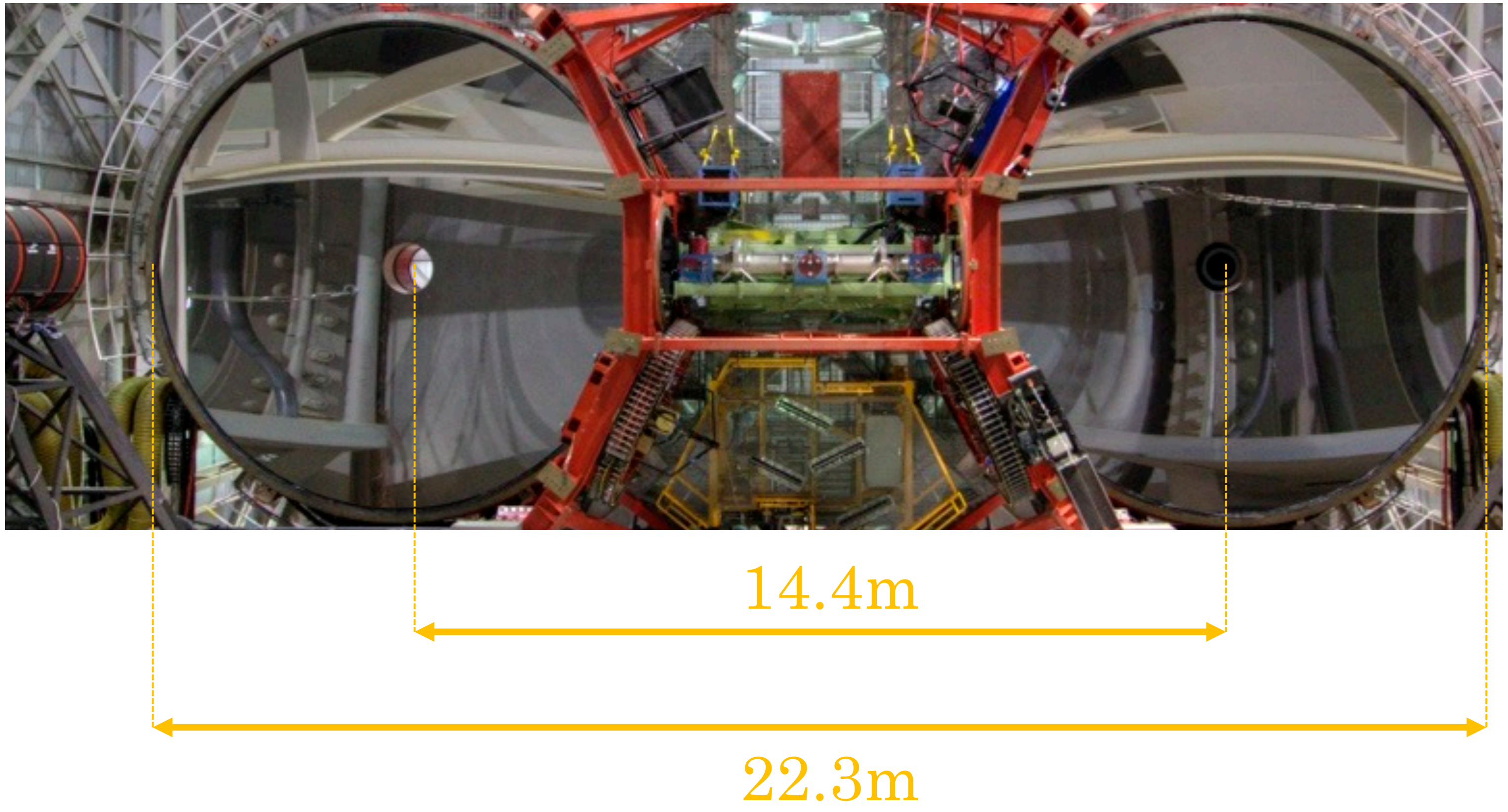


Keck telescopes – Mauna Kea (Hawaii)



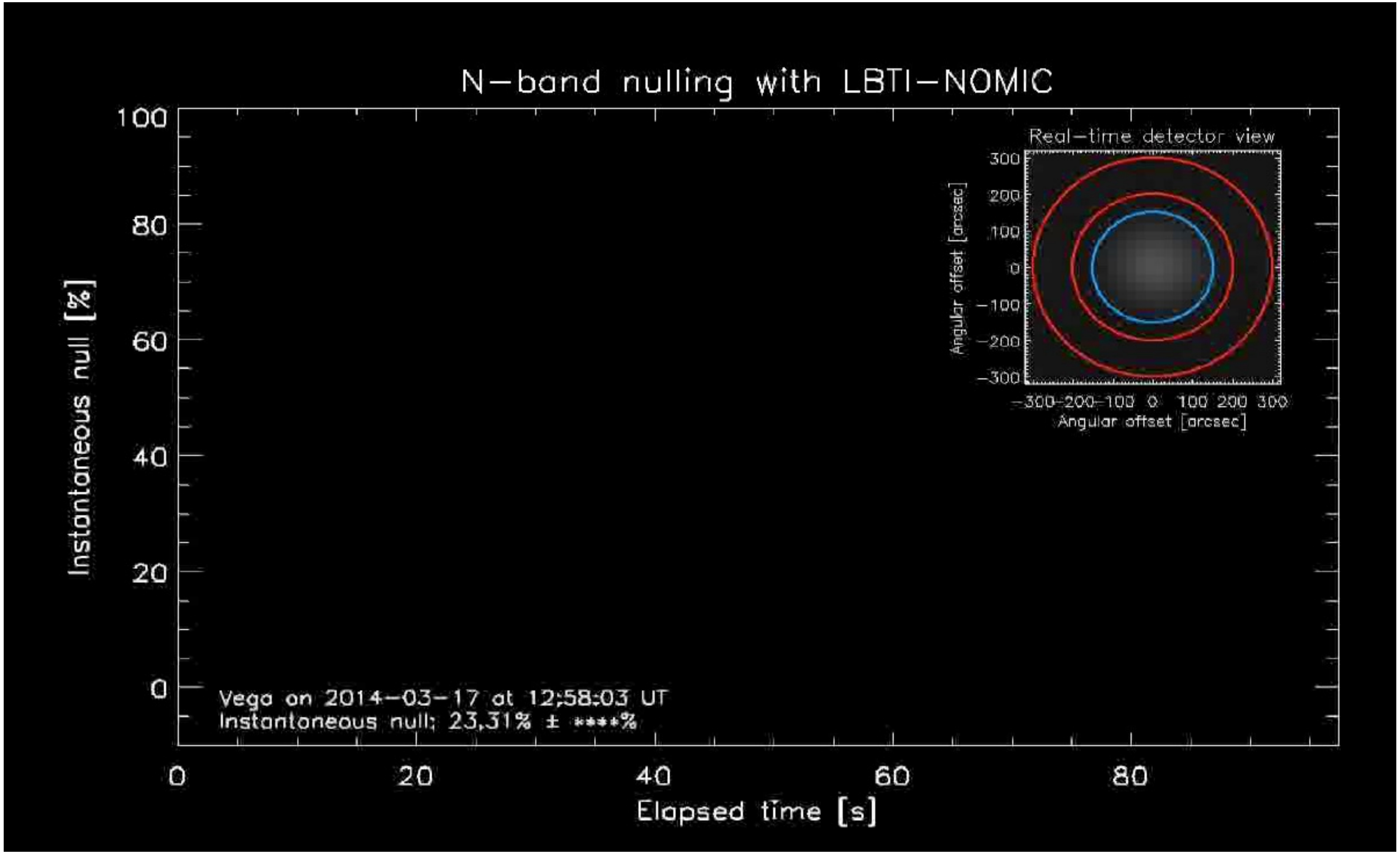
The 3rd-generation nulling interferometer

- The Large Binocular Telescope Interferometer (LBTI, Hinz et al. 2016, Defrère et al. 2016);
- Main scientific goal: measure and put limits on emission from exozodiacal dust around nearby main-sequence stars (Ertel et al. 2018, 2020);



Large Binocular Telescope – Mount Graham (Arizona)

The 3rd-generation nulling interferometer



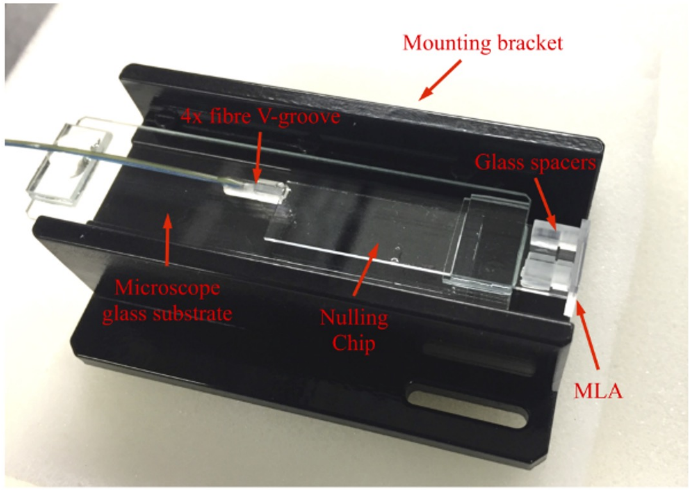
See movie here: https://youtu.be/WdZEjOtqVmM

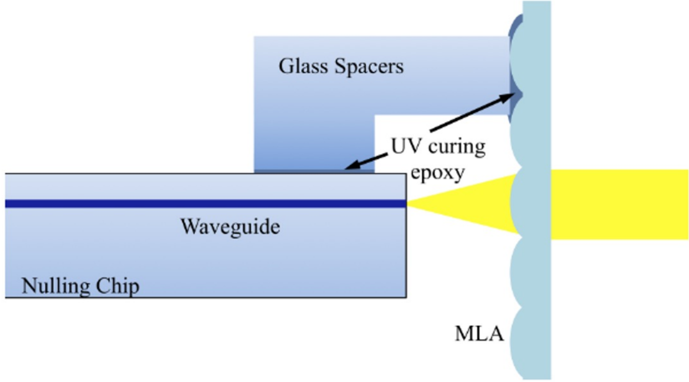
Single-aperture nulling instruments

- Palomar Fiber Nuller (PFN): K band (2.2 microns), multi-axial combination, fiber injection (Mennesson et al. 2011)

- GLINT @ SCExAO: H band (1.6 microns), first on-sky photonic nuller (Norris et al. 2019)

Subaru telescope (left) – Mauna Kea (Hawaii)





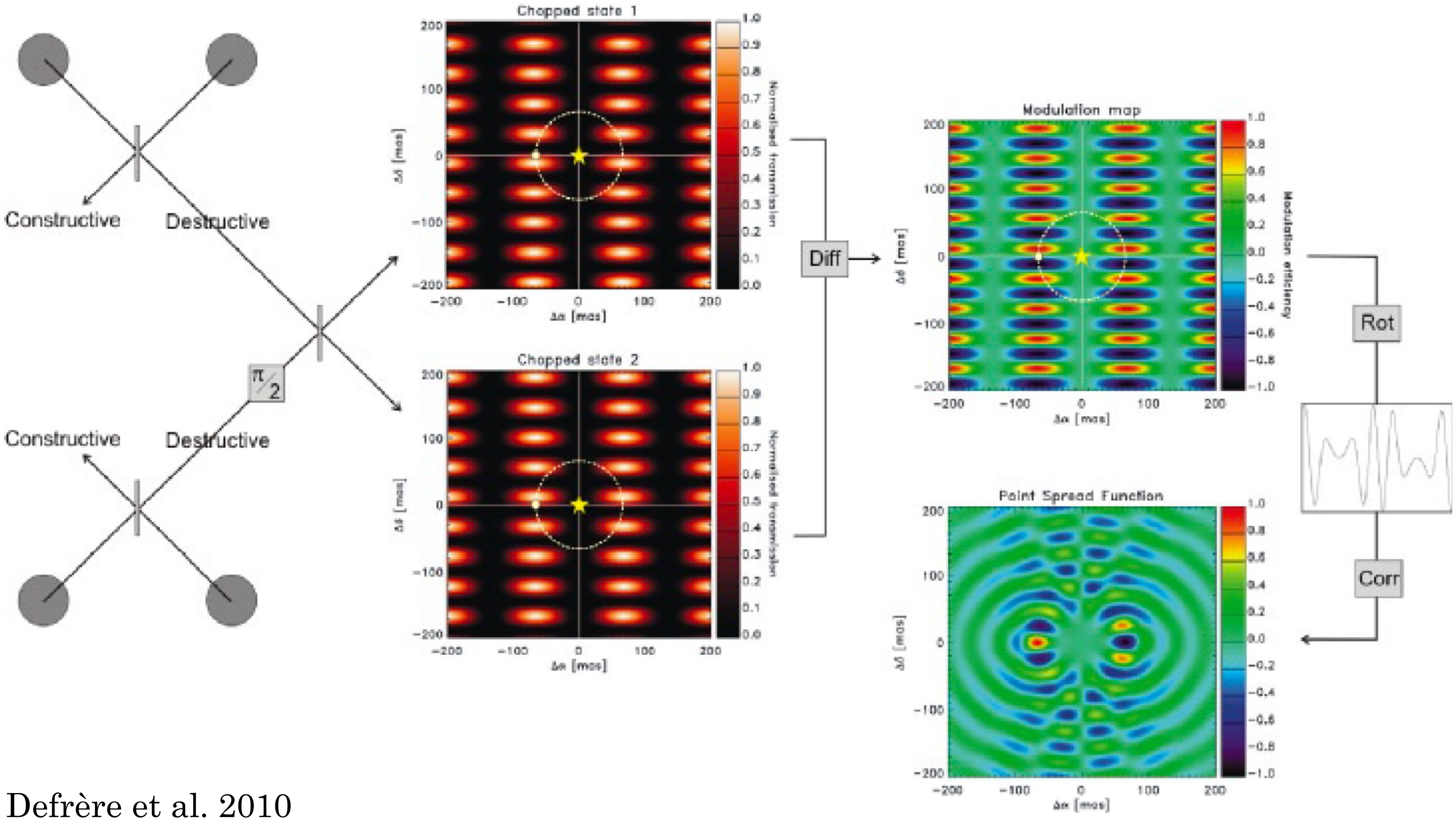
Next generation: Asgard/NOTT

- First nuller on the Very Large Telescope Interferometer (VLTI, Defrère et al. 2018)
- Thermal near-infrared (3.8 microns) integrated optics nulling combiner
- <u>Main scientific goals</u>: characterize young giant exoplanets, measure and put limits on emission from exozodiacal dust around nearby main-sequence stars;
- International consortium led by KU Leuven

Cerro Paranal (Chile)

KU LEUVEN

Asgard/NOTT: measurement principle



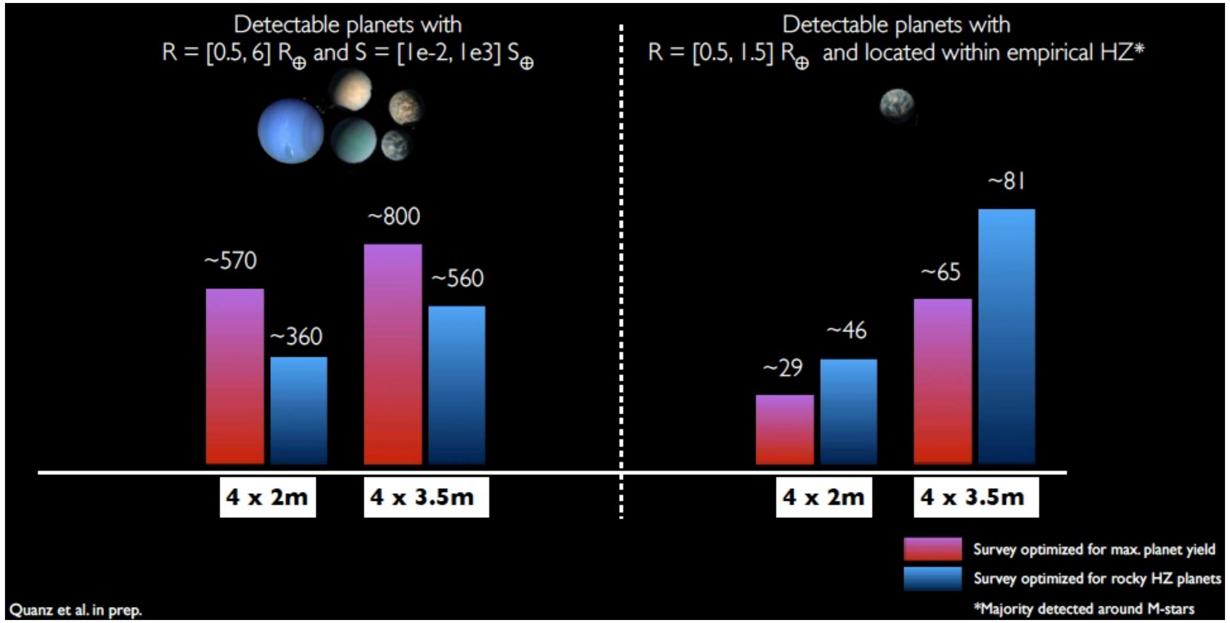
Defrère et al. 2010

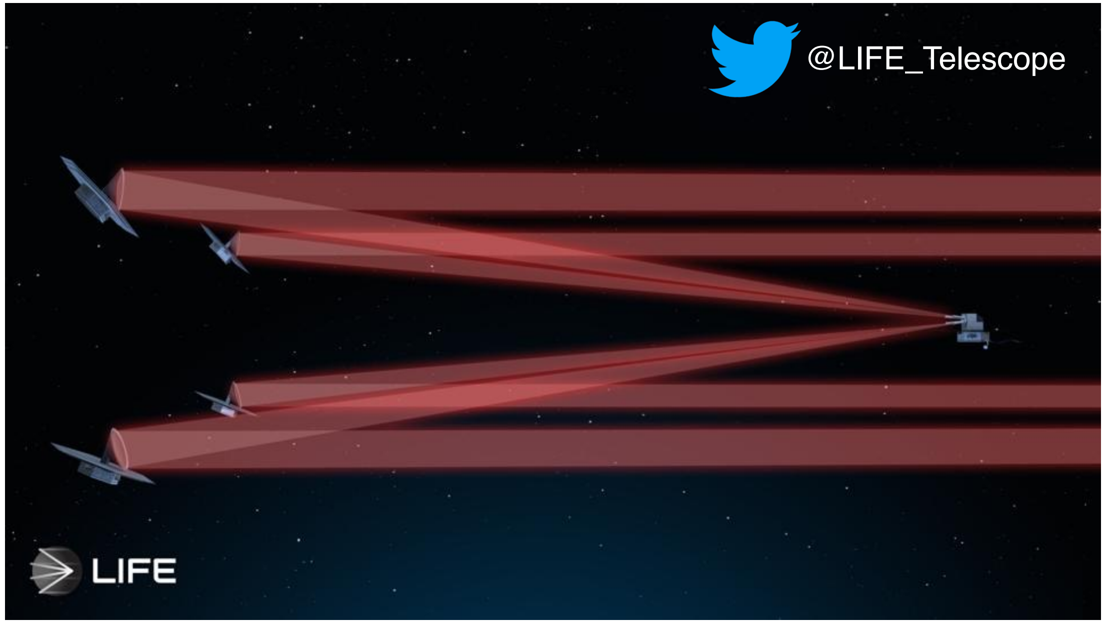
Going to space

- Required to image a large sample of rocky exoplanets (100+ targets)

- Key features and technologies
  - Mid-infrared (4 to 18 μm)
  - Spectral resolution (~50)
  - Formation flying (array rotation and collision avoidance)
  - Passive cooling (~40K) and low noise detectors

- International consortium led by ETH Zurich





*assuming 2.5 years search phase

Summary

- Interferometry is a direct imaging technique, complementary to AO imaging
- Nulling interferometry to remove the stellar light, like coronagraphy for single-dish imaging
- Several ground-based nulling instruments (MMT, Keck nuller, LBTI), proved key technologies and shed new light on exozodiacal disks
- Asgard/NOTT, new ERC-funded project under development for the VLTI (with the goal of imaging young exoplanets near the snow line)
- Space nulling required for the direct characterization of a large sample of rocky exoplanets

Further references

- Unveiling exozodiacal light (includes the history of nulling, Spalding et al. 2022): link
- Review and scientific prospects of high-contrast optical stellar interferometry (Defrère et al. 2020): link
- Theory of nulling interferometry (Serabyn): link
- LIFE space mission website: life-space-mission.com
- Asgard/NOTT website: denis-defrere.com/asgard.php
- More information: denis-defrere.com/teaching.php