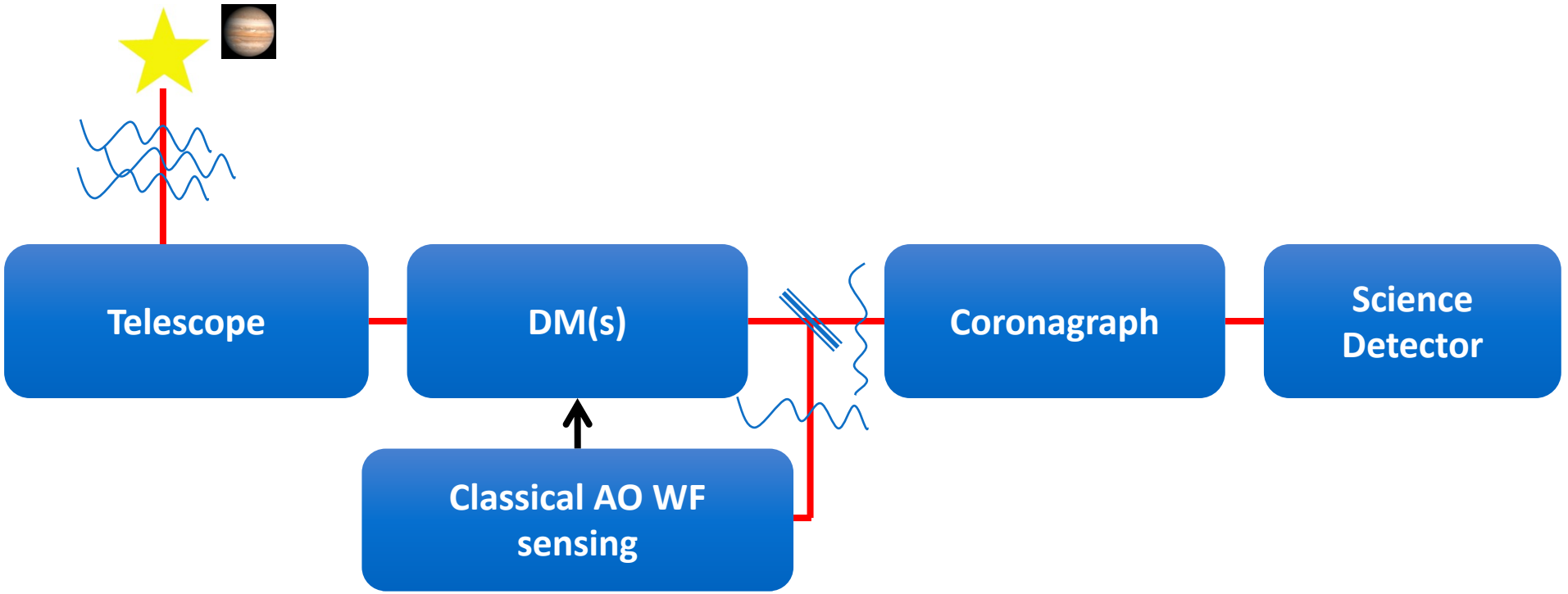
Focal plane wavefront sensing and correction & Coherence differential imaging

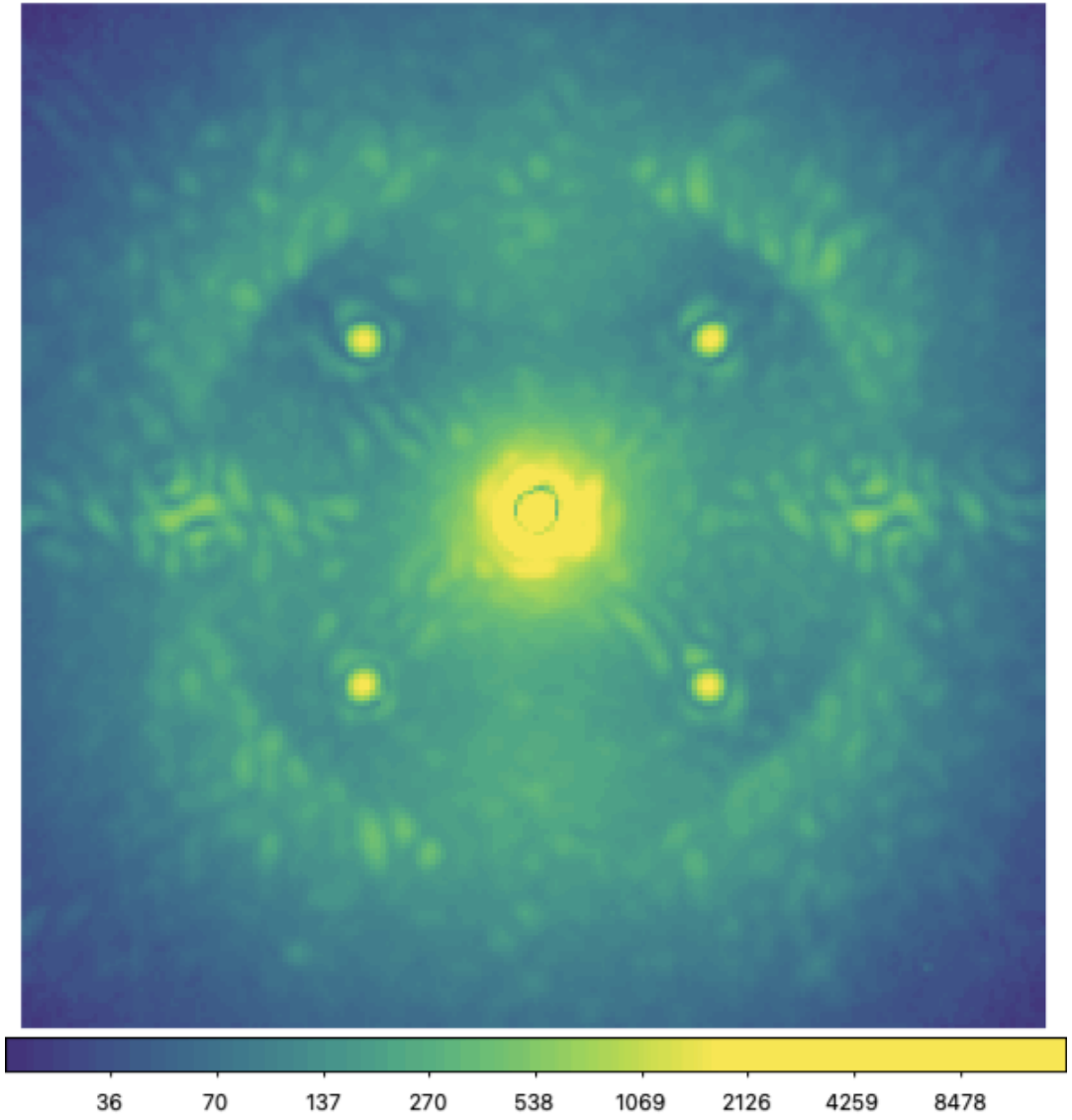
Johan Mazoyer (LESIA)

Axel Potier (JPL), Zahed Wahhaj (ESO), Raphaël Galicher (LESIA), Pierre Baudoz (LESIA), Gael Chavin (OCA)

Current AO systems

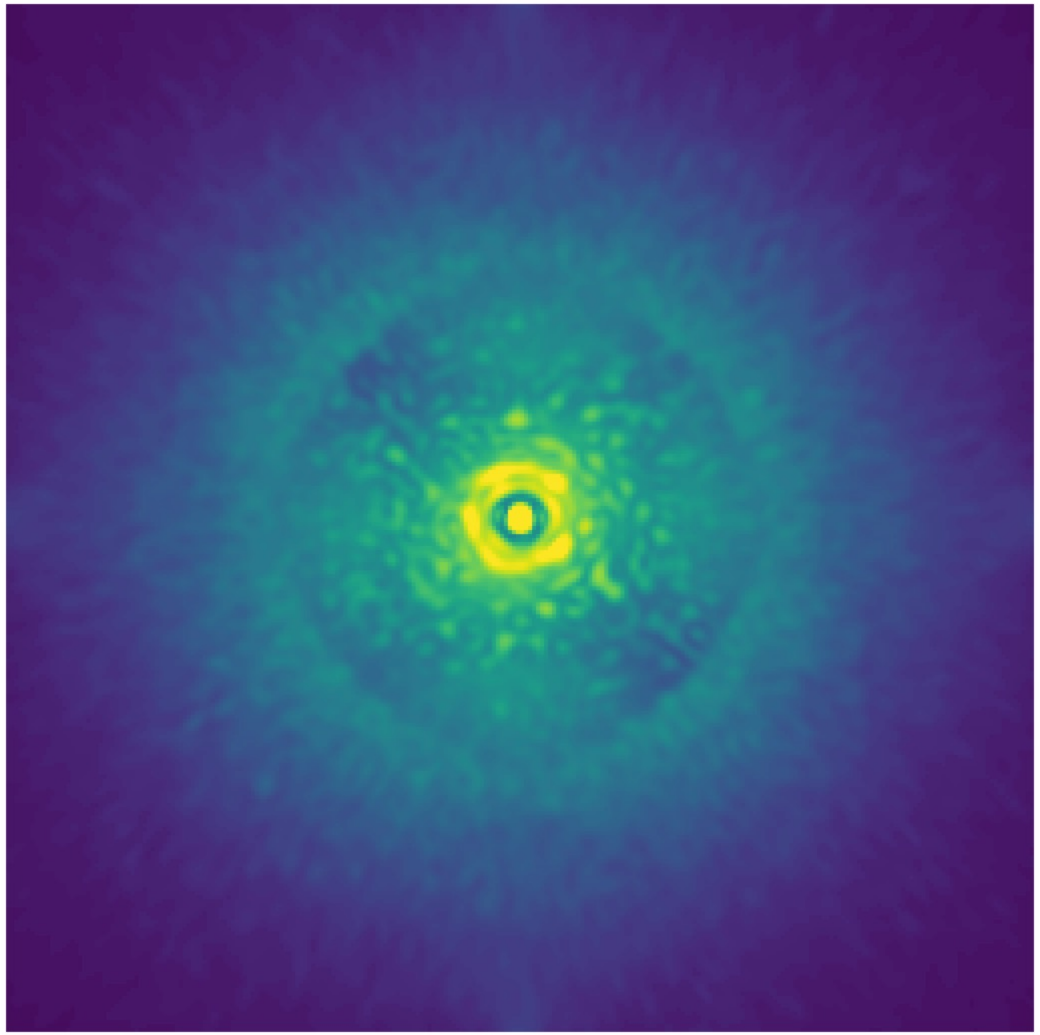


Analysis of the speckles lifetime



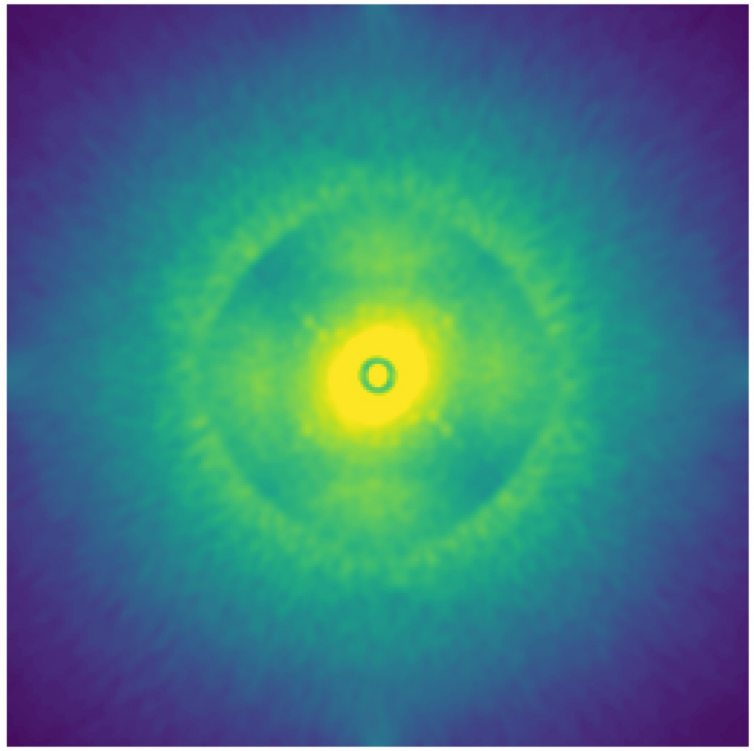
real SPHERE sequence

Analysis of the speckles lifetime

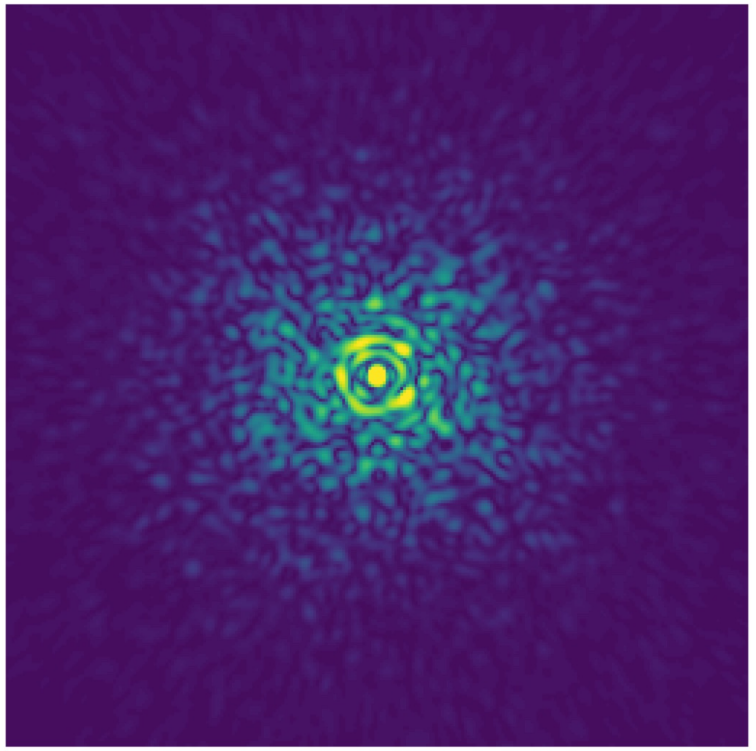


simulated SPHERE sequence

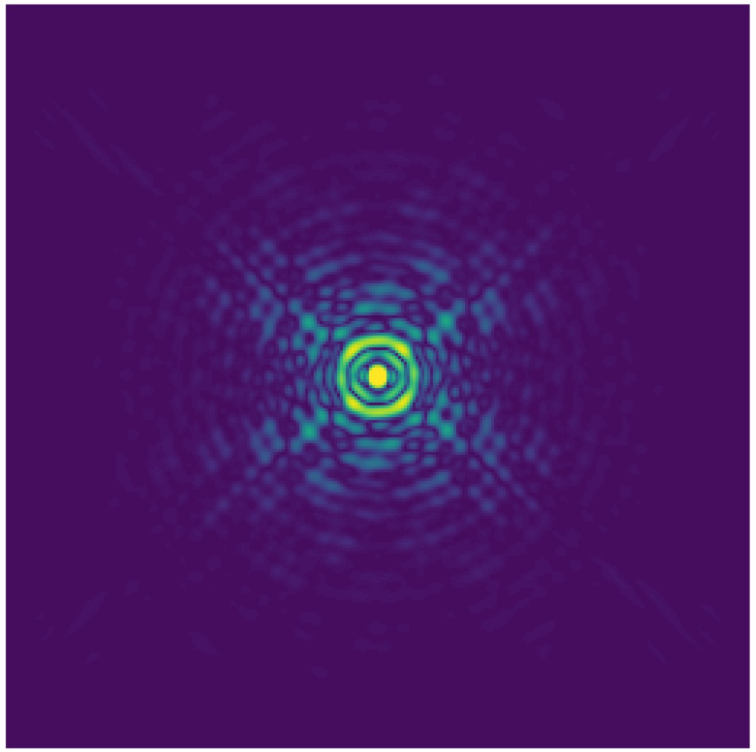
Analysis of the speckles lifetime



Atmospheric residues



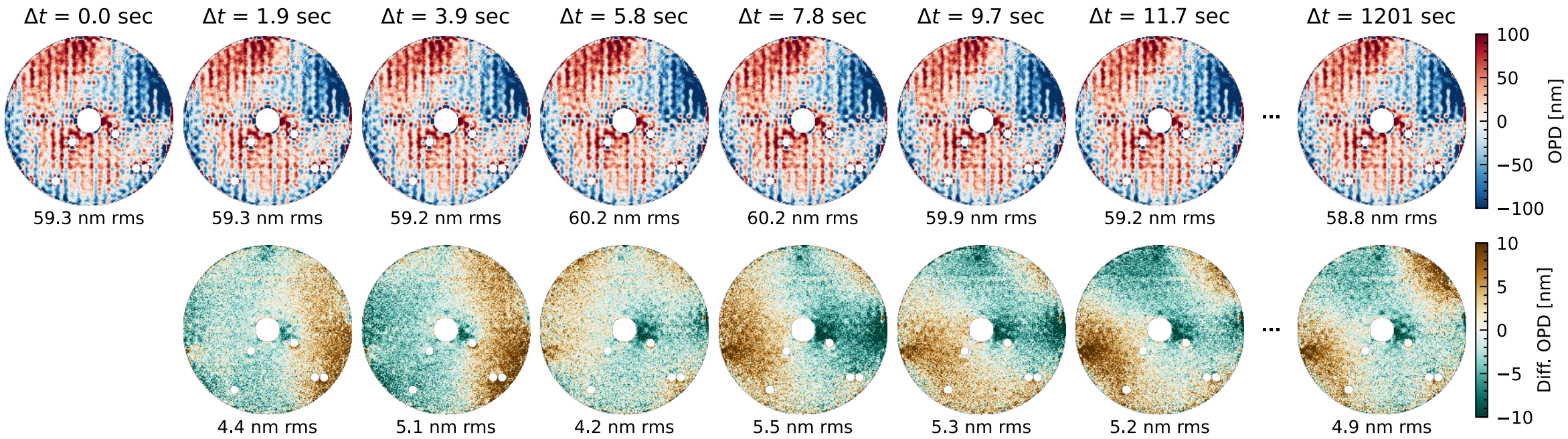
quasi-static speckles



static speckles

simulated SPHERE images

(Quasi)-static aberrations



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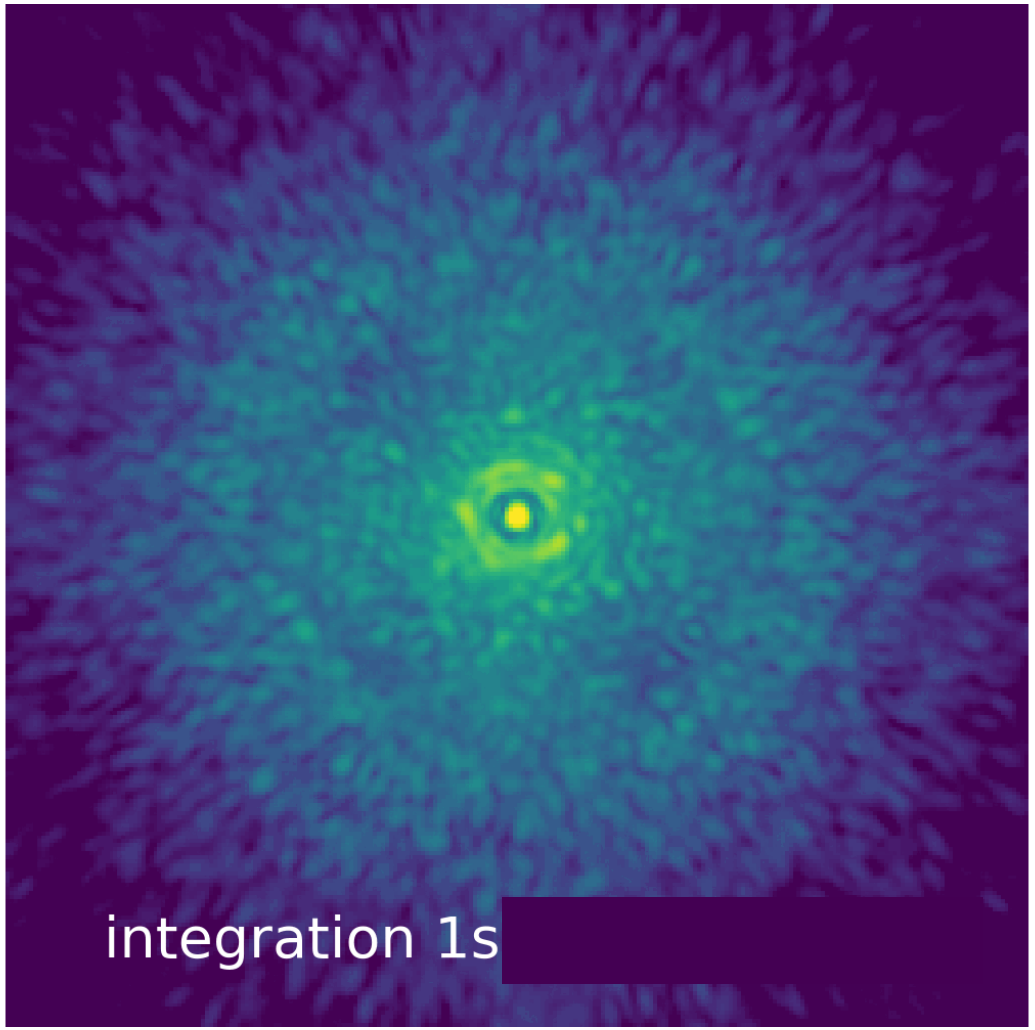
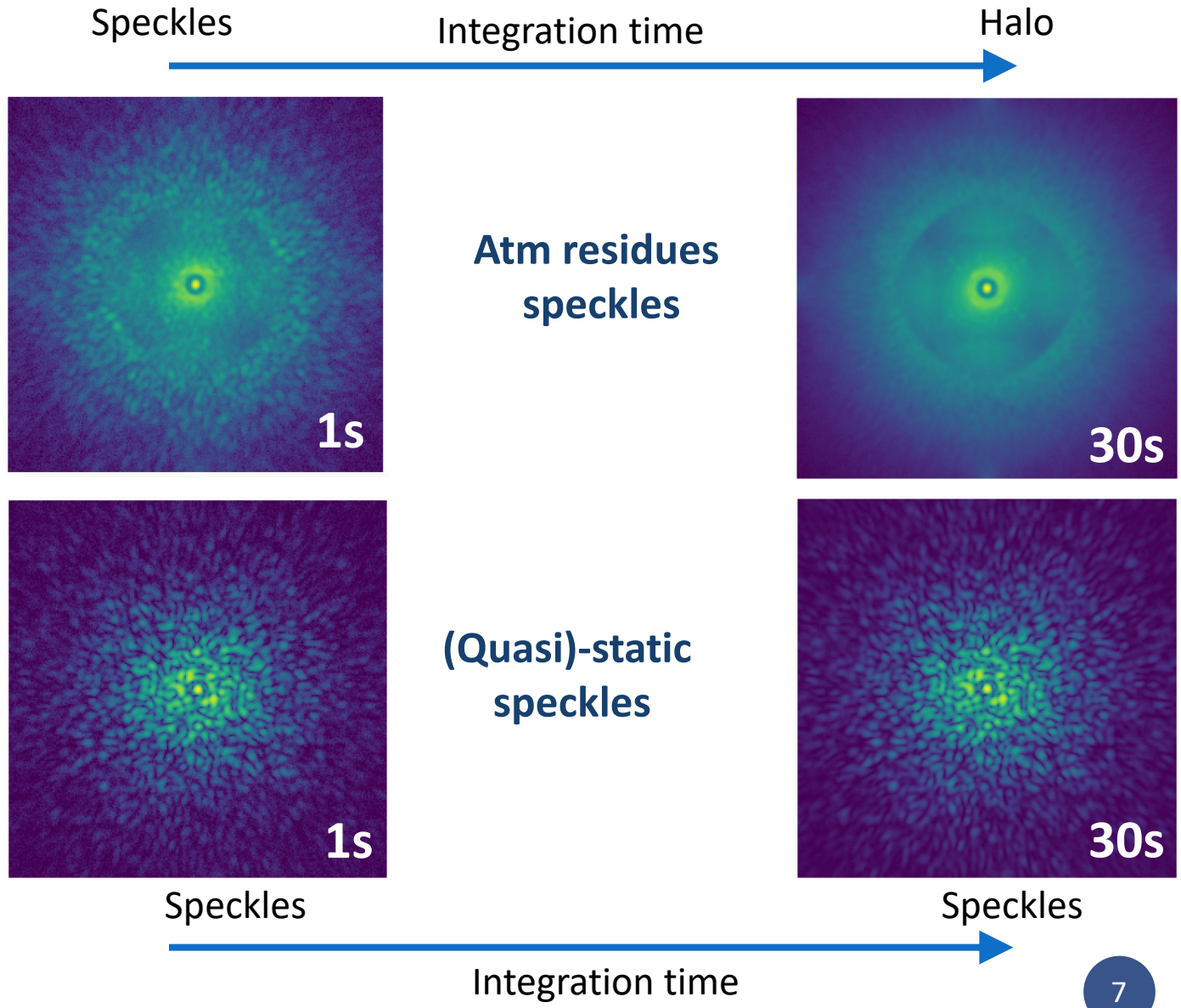
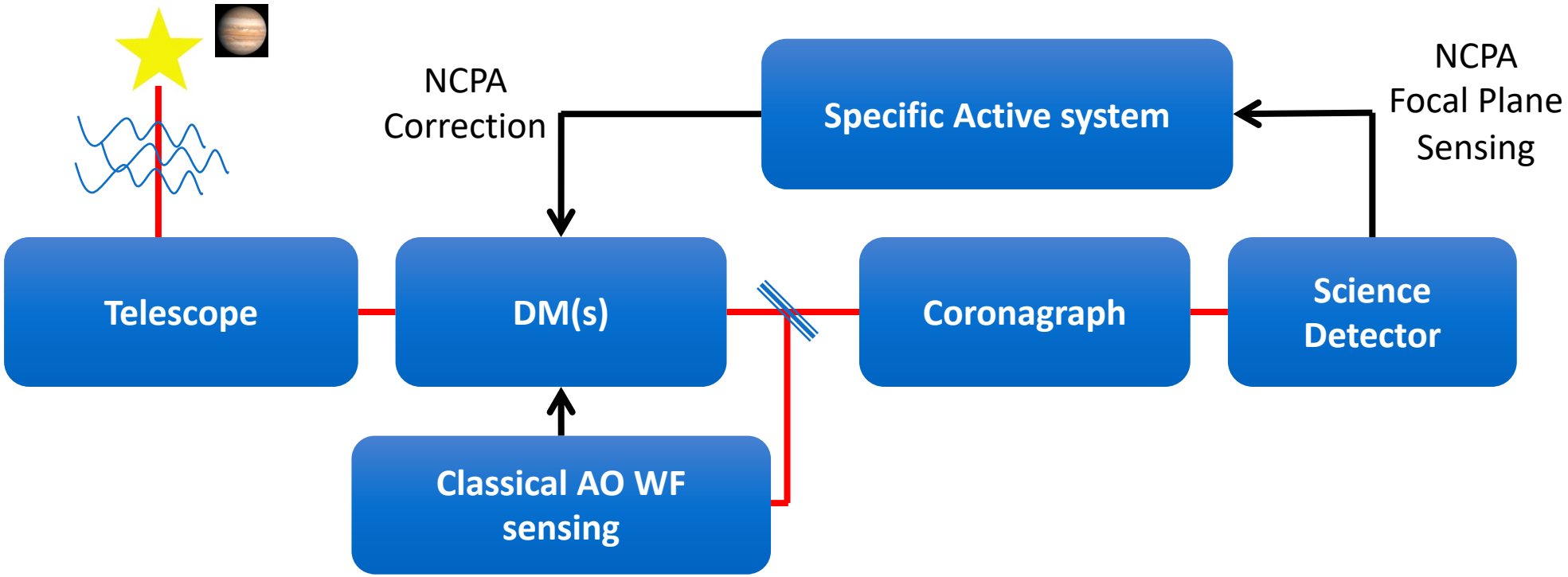
Averaging of AO residuals





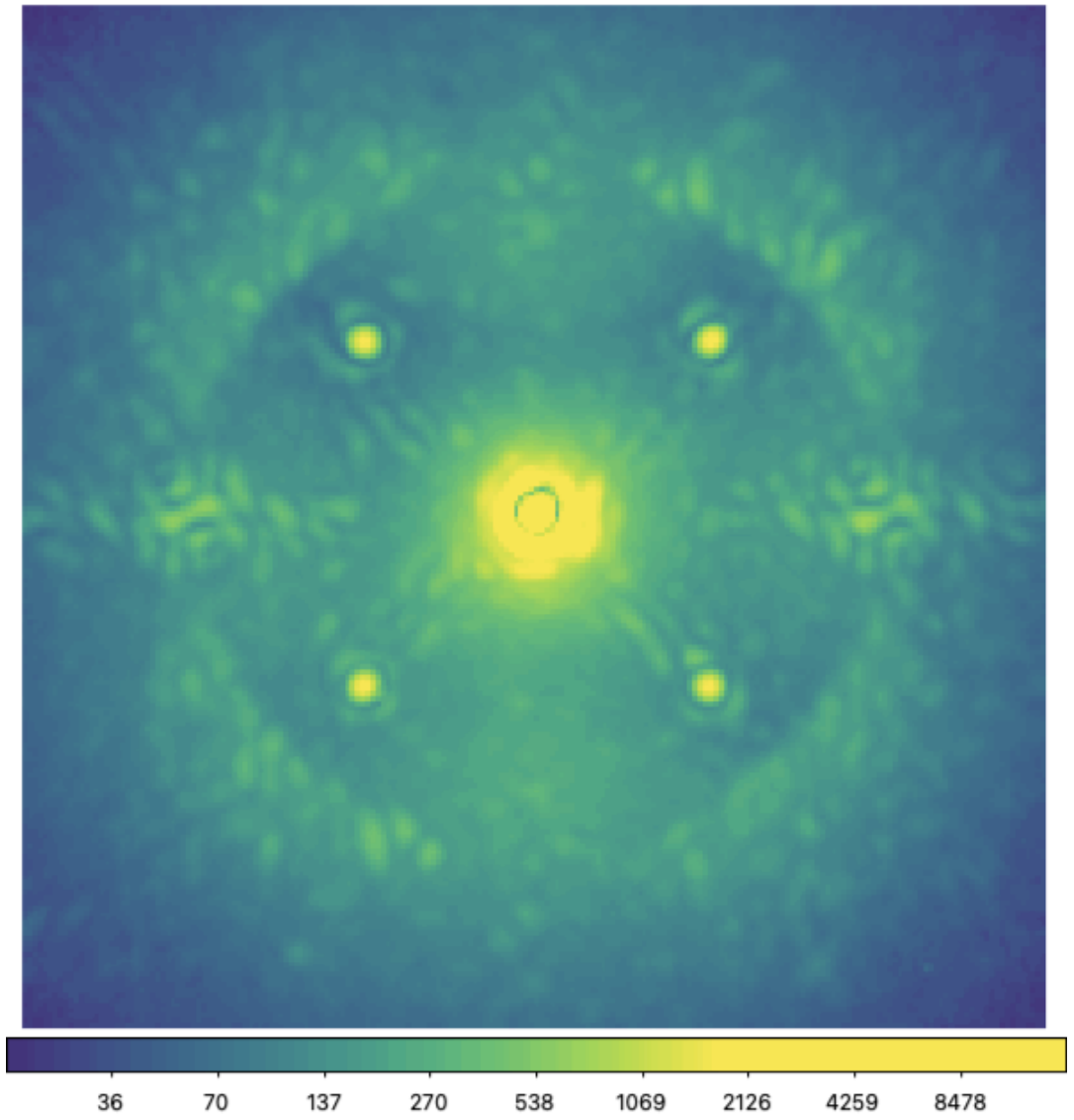
Goal of focal plane correction high contrast techniques

- Correct for aberrations unseen by the Adaptive Optics (Non common path aberrations) => use the science camera as a sensor to retrieve most aberration in the science channel.



Because your sensing method uses the science detector during observations you can only hope to correct for speckles that are varying slower than the typical observations time (a few 10s of seconds)

Analysis of the speckles lifetime



46 seconds integration

real SPHERE sequence

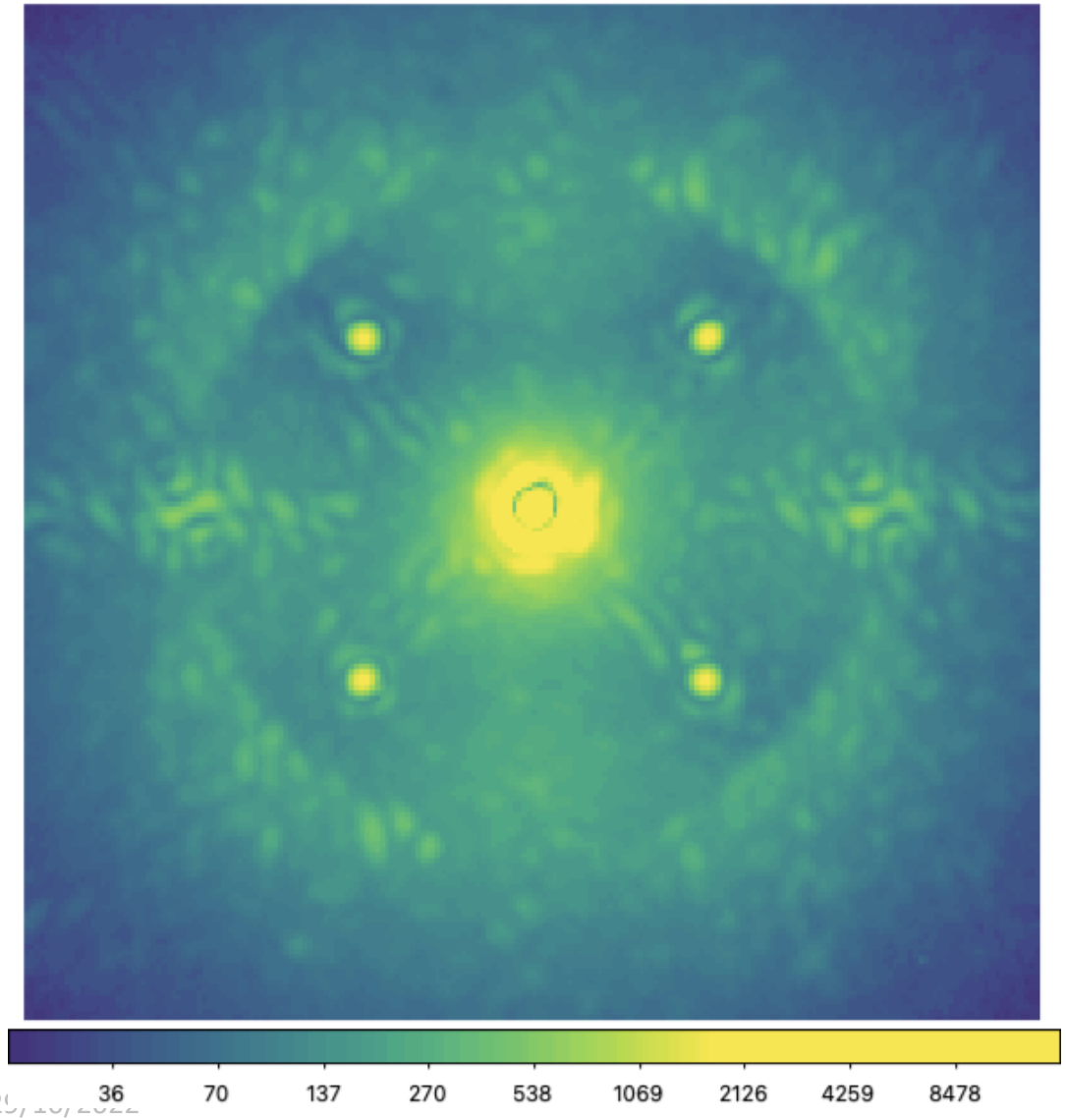
Goal of focal plane correction high contrast techniques

- Correct for aberrations unseen by the Adaptive Optics (Non common path aberrations) => use the science camera as a sensor to retrieve most aberrations in the science channel.

- Dig a “dark hole” : a region in the focal plane with a higher contrast. Can be as large at the correction zone of SPHERE DMs, or can be smaller if we want to locally increase contraste

- Correct for
  - **Static aberrations** (can be done before science sequence)
  - **Quasi static aberrations** things that varies at the same time scale as the science images exposure time (a few 10s of seconds), during the science sequence
  - **All aberrations faster than the science image exposure time and uncorrected by the AO cannot be corrected**

Image creation



in the entrance pupil of the corono

telescope aperture

aberrations

$$E_{PP} = P \exp(i \varphi)$$

$$E_{PP} \sim P (1 + i \varphi)$$

in the focal plane

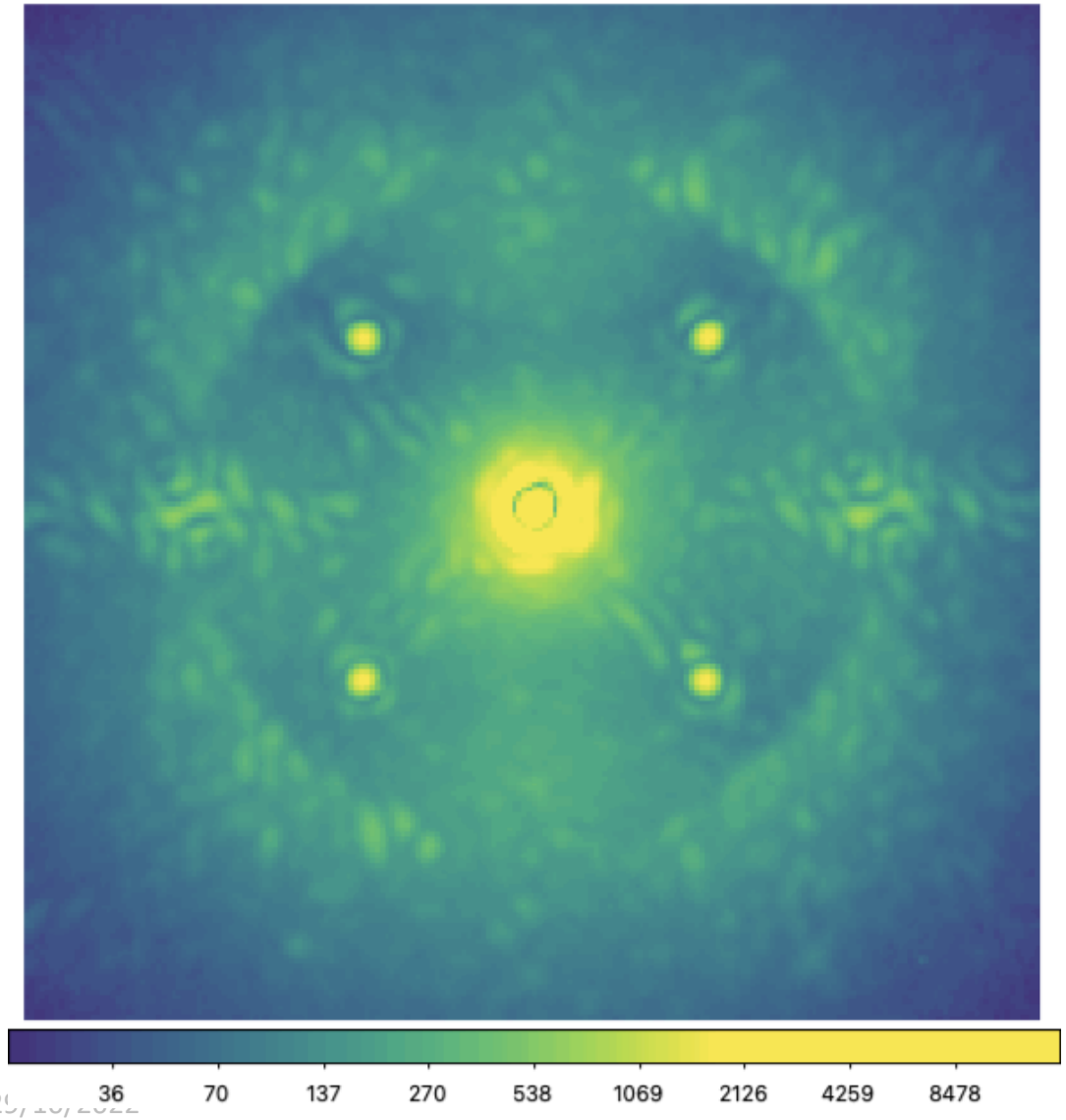
$$E_{FP} = FT[P] + FT[Pi \varphi(t)]$$

the non aberrated PSF (static part)

the speckles ! (dynamic part)

Nornally a good coronagraph brings that part to ~0

Image creation



telescope aperture

aberrations

DM phase

in the entrance pupil of the corono

$$E_{PP} = P \exp(i \varphi + i \varphi_{DM})$$

$$E_{PP} \sim P (1 + i \varphi + i \varphi_{DM})$$

in the focal plane

$$E_{FP}=FT[P] + FT[Pi \varphi(t)]+FT[Pi\varphi_{DM}(t)]$$

the non aberrated PSF (static part)

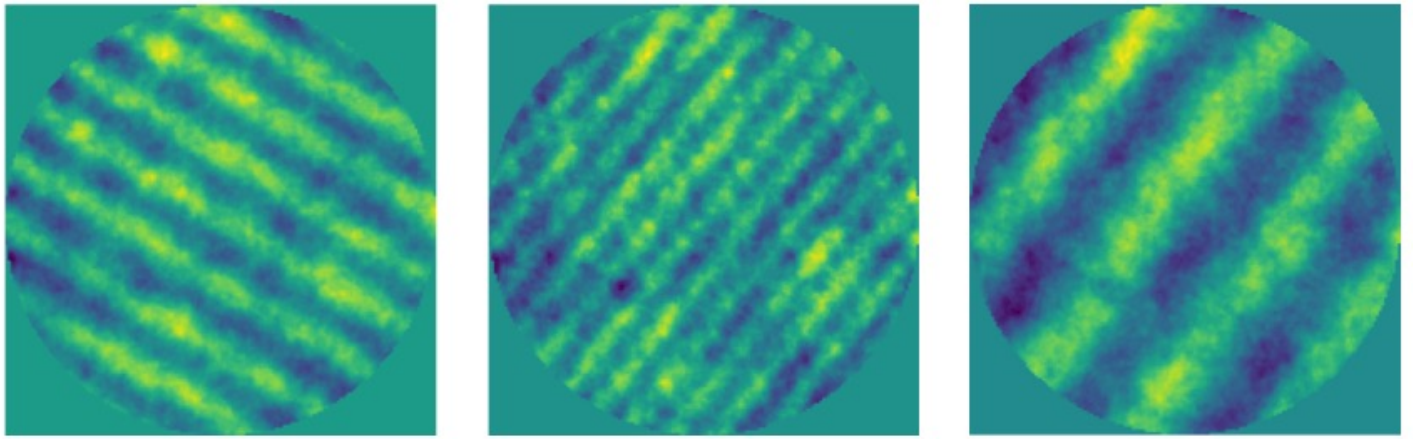
the speckles ! (dynamic part)

the DM correction in FP

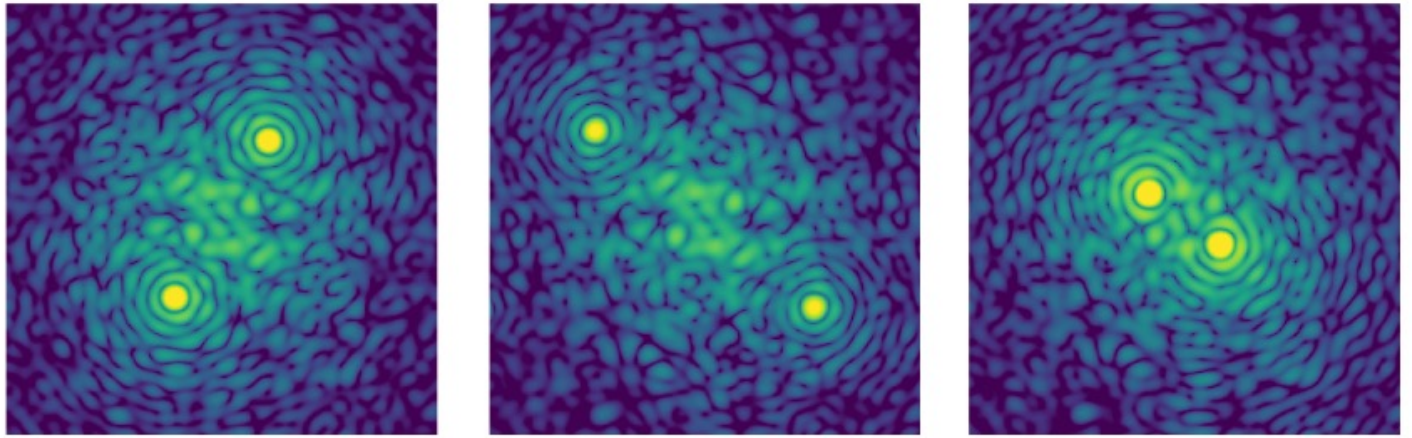
Normally a good coronagraph brings that part to ~0 but not totally

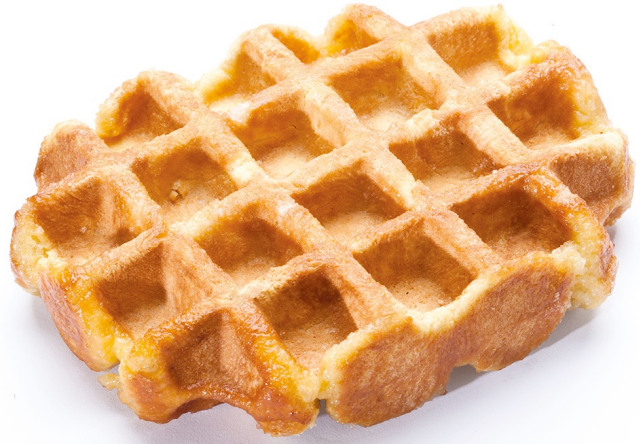
Waffles

Random φ_{up} and cosinus ripple φ_{DM} in pupil plane

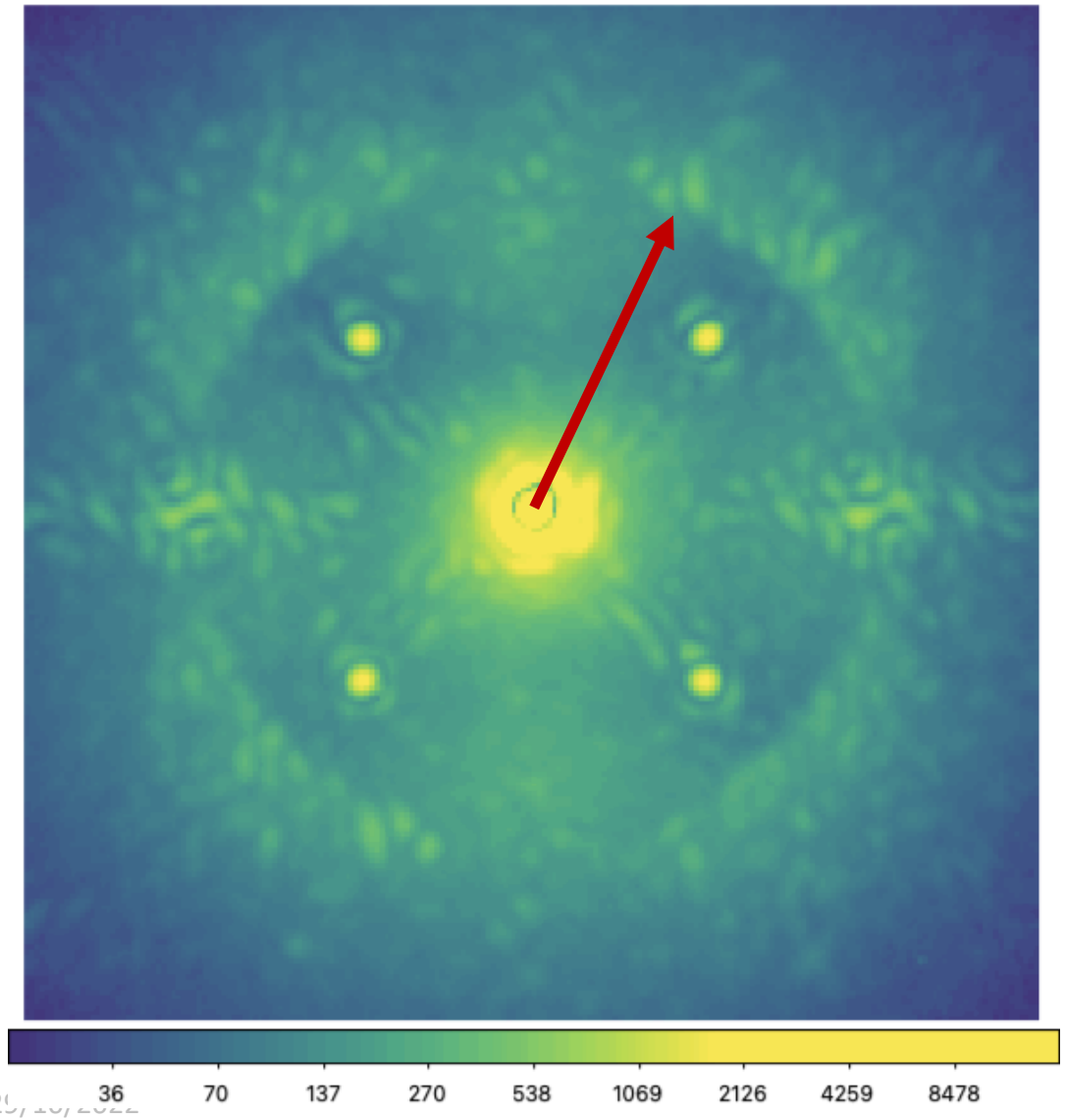


Stellar intensity in coronagraph focal plane $I_{D,S}$





Dark hole shape



telescope aperture

aberrations

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the DM correction in FP

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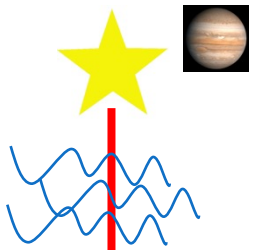
Electrical Field conjugation

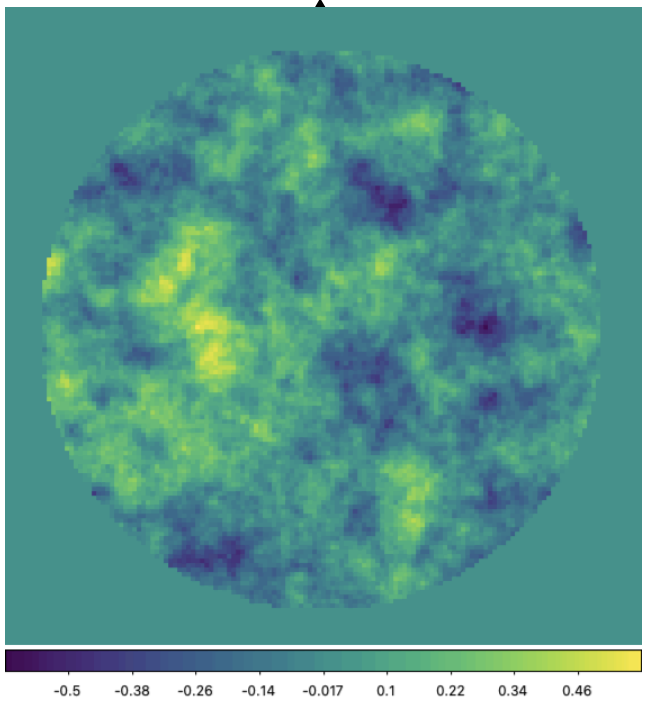


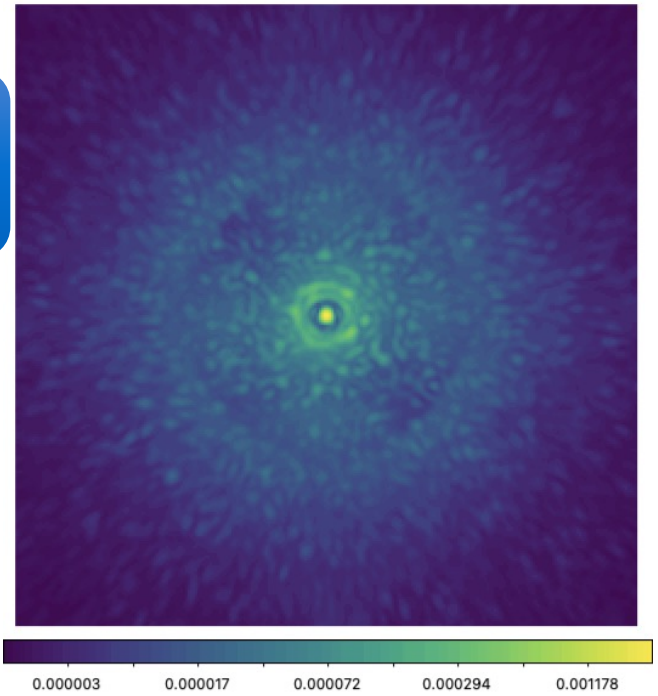
NCPA Correction

Specific Active system

NCPA Focal Plane Sensing

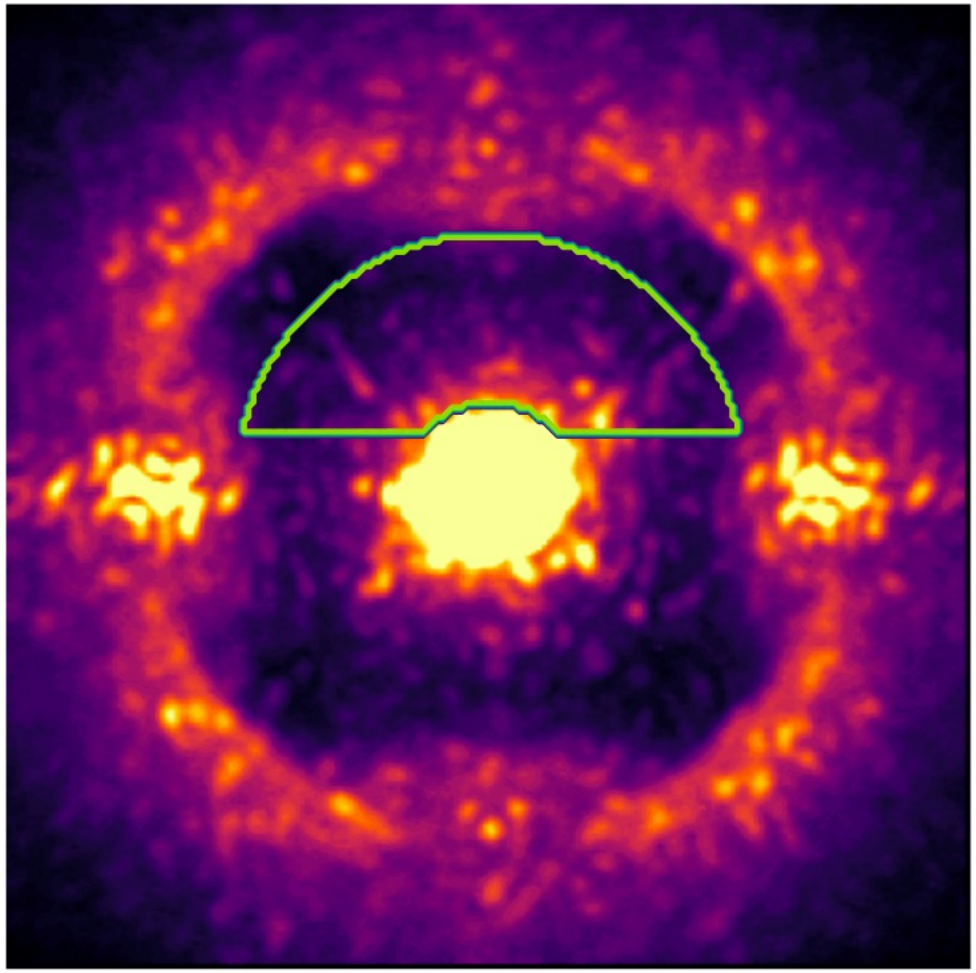
Telescope | **DM(s)** | **Coronagraph** | **Science Detector**





Contrast improvment

Raw image



4 iterations

For the moment each iteration is ~4 probes of 1 minute. Can be reduces (less probes and faster)

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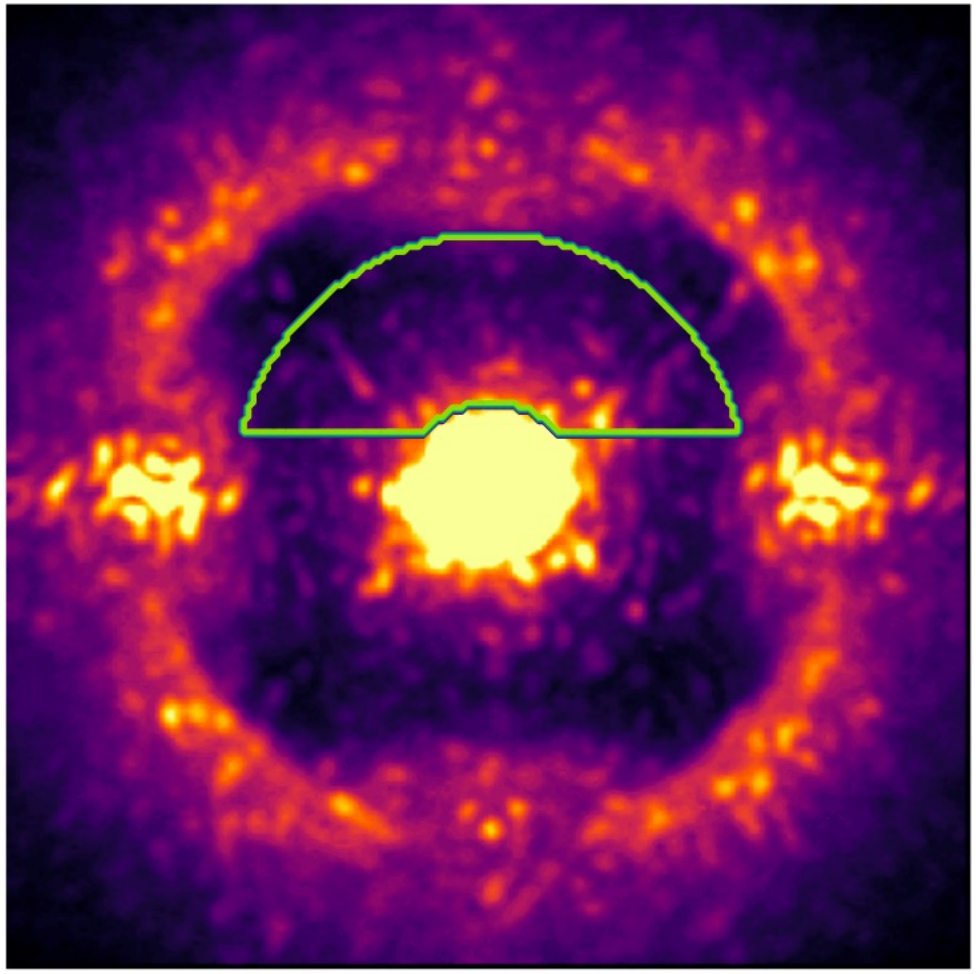
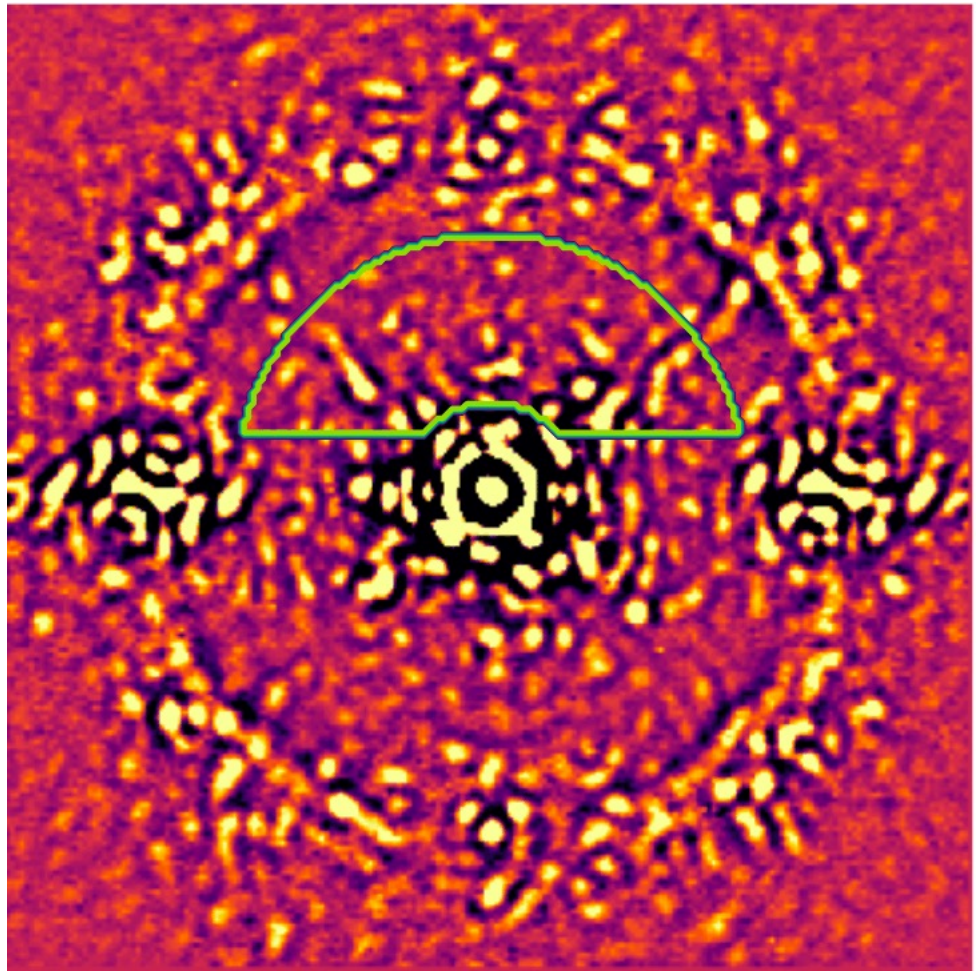
Contrast improvment

Raw image



After high pass-filter



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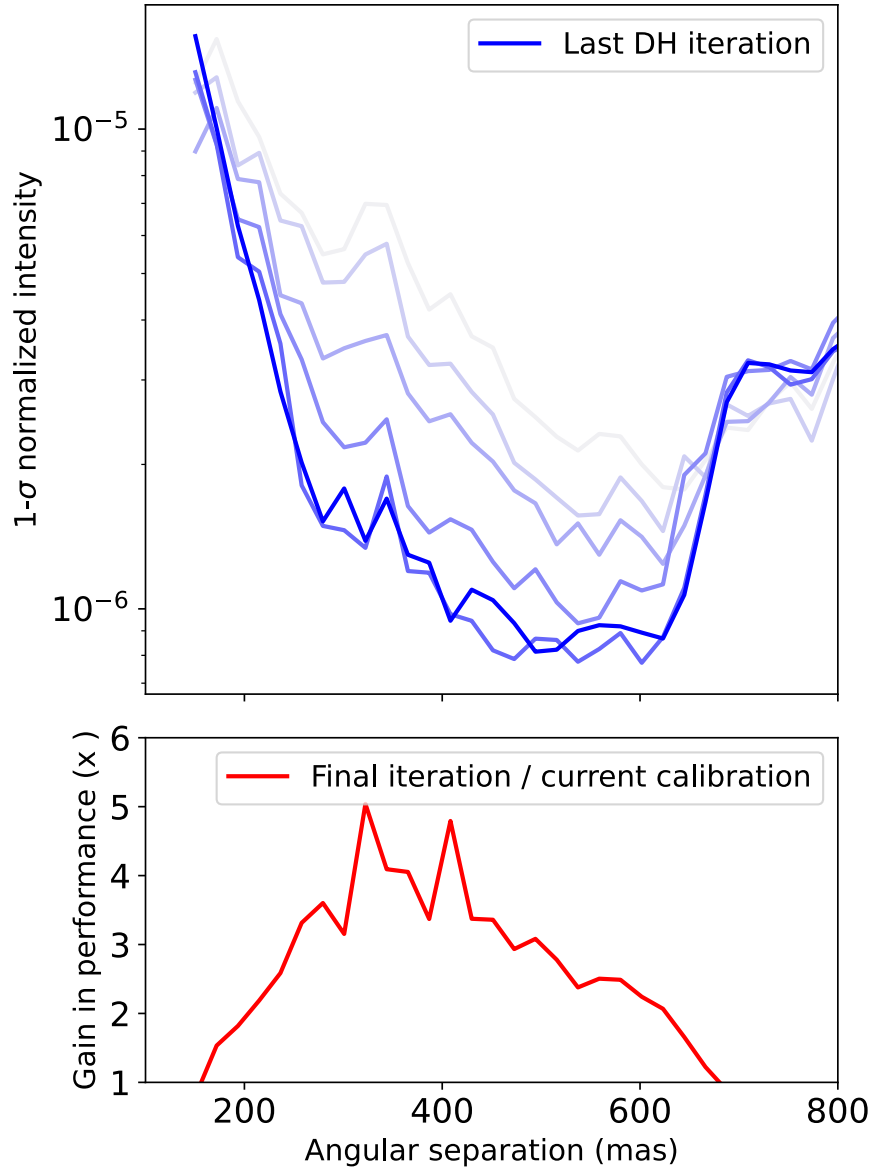
Contrast improvment



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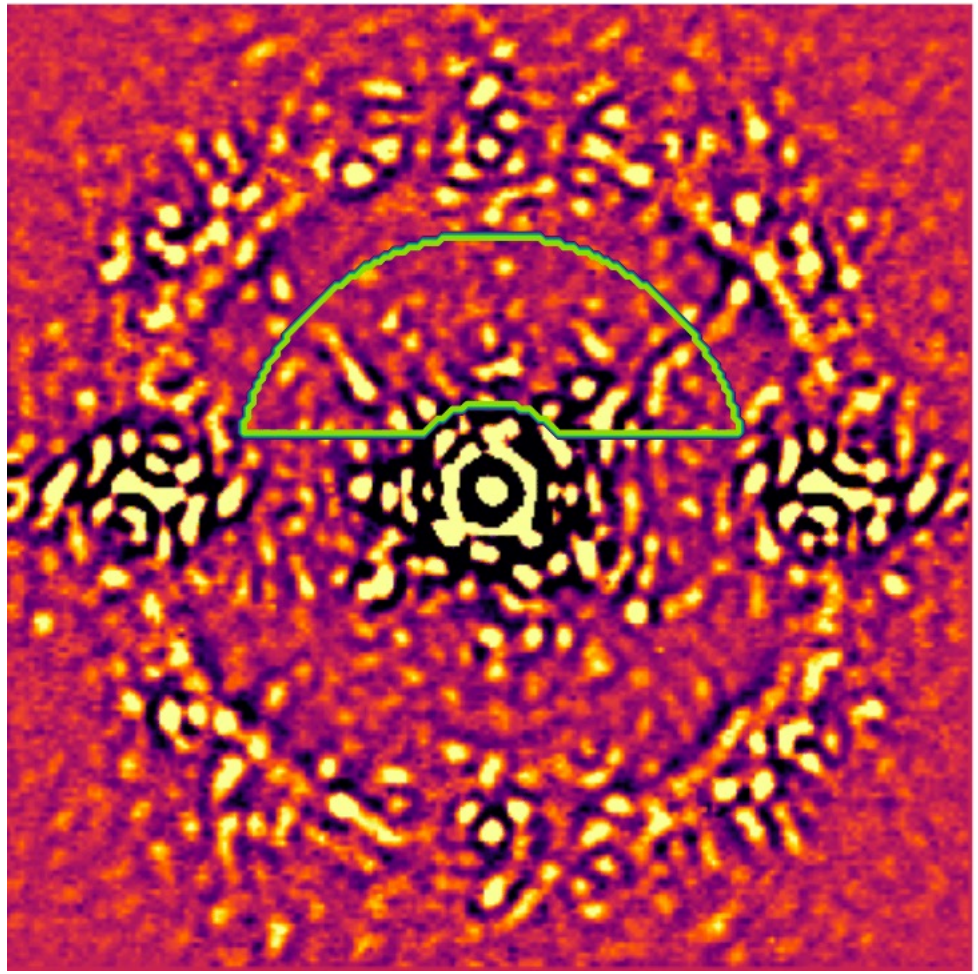

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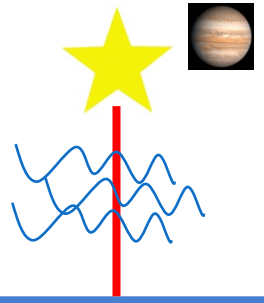
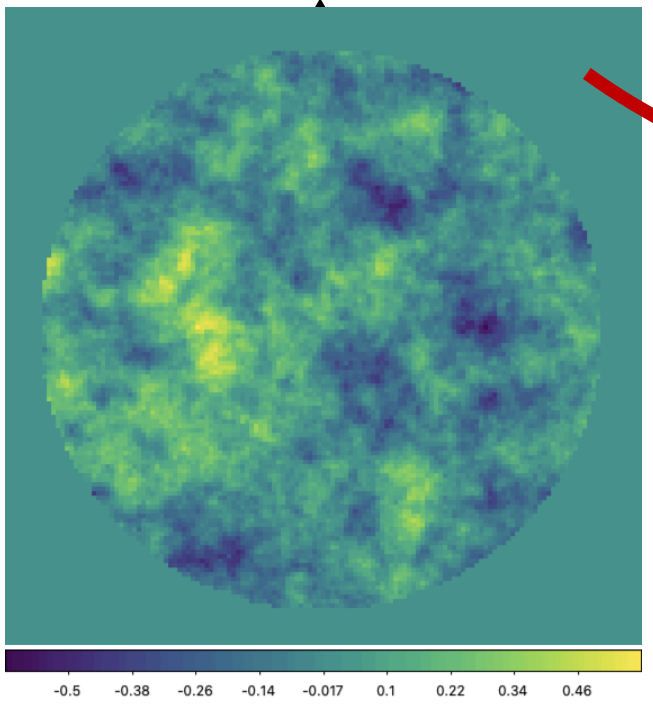
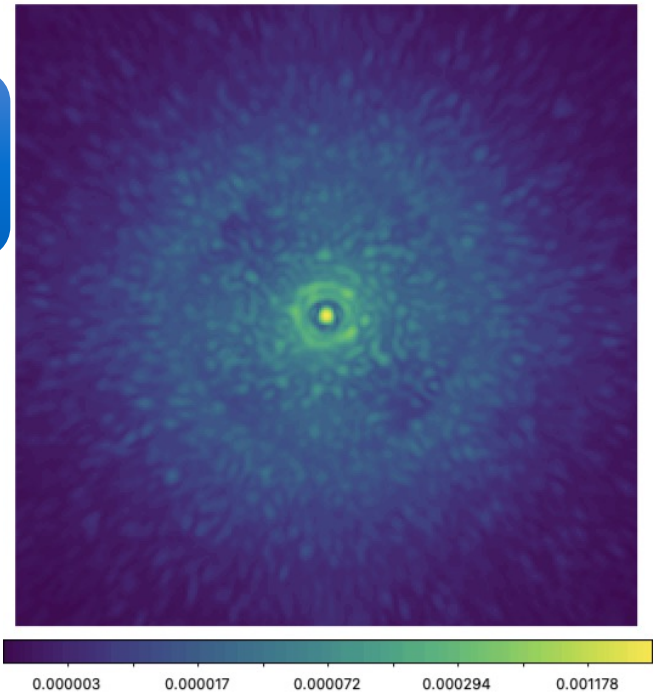
Electrical Field conjugation



correction of the DM necessary to correct this electrical field





effect of the probe on the electrical field in focal planet

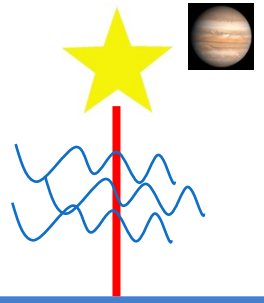
Estimation problem

Currently : simple linear models

=> Can be enhanced via Neural Networks :

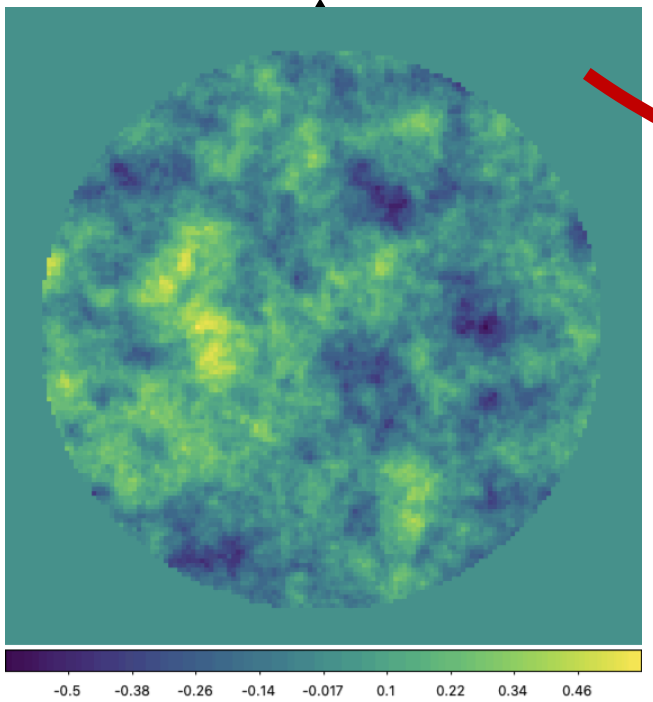
Yann Giuterrez PhD (LESIA / ONERA)

COFFEE / MEDUSAE



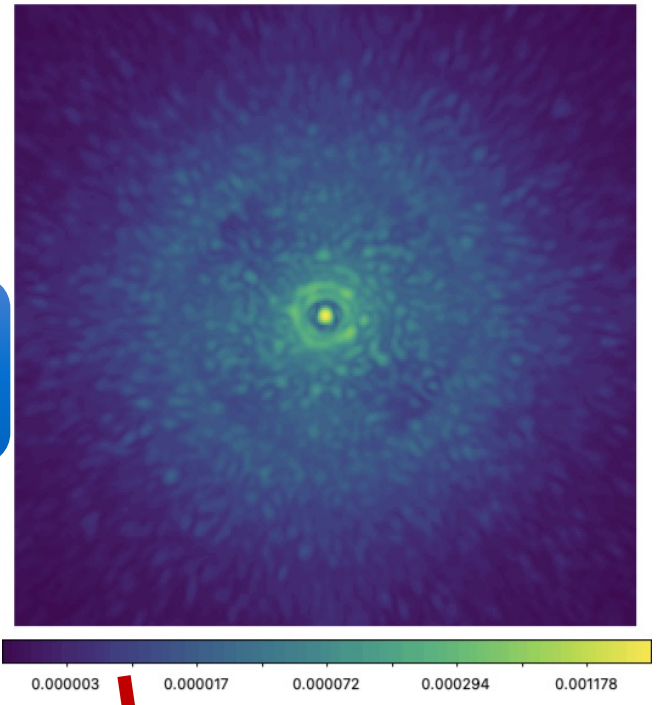
(Former-) ONERA Researchers involved : Marie Ygouf, Faustine Cantalloube, Olivier Herscovici-Schiller, Laurent Mugnier (among others)

Telescope — **DM(s)** — **Coronagraph** — **Science Detector**



effect of the DM on the electrical field in focal planet
Estimation problem for correction

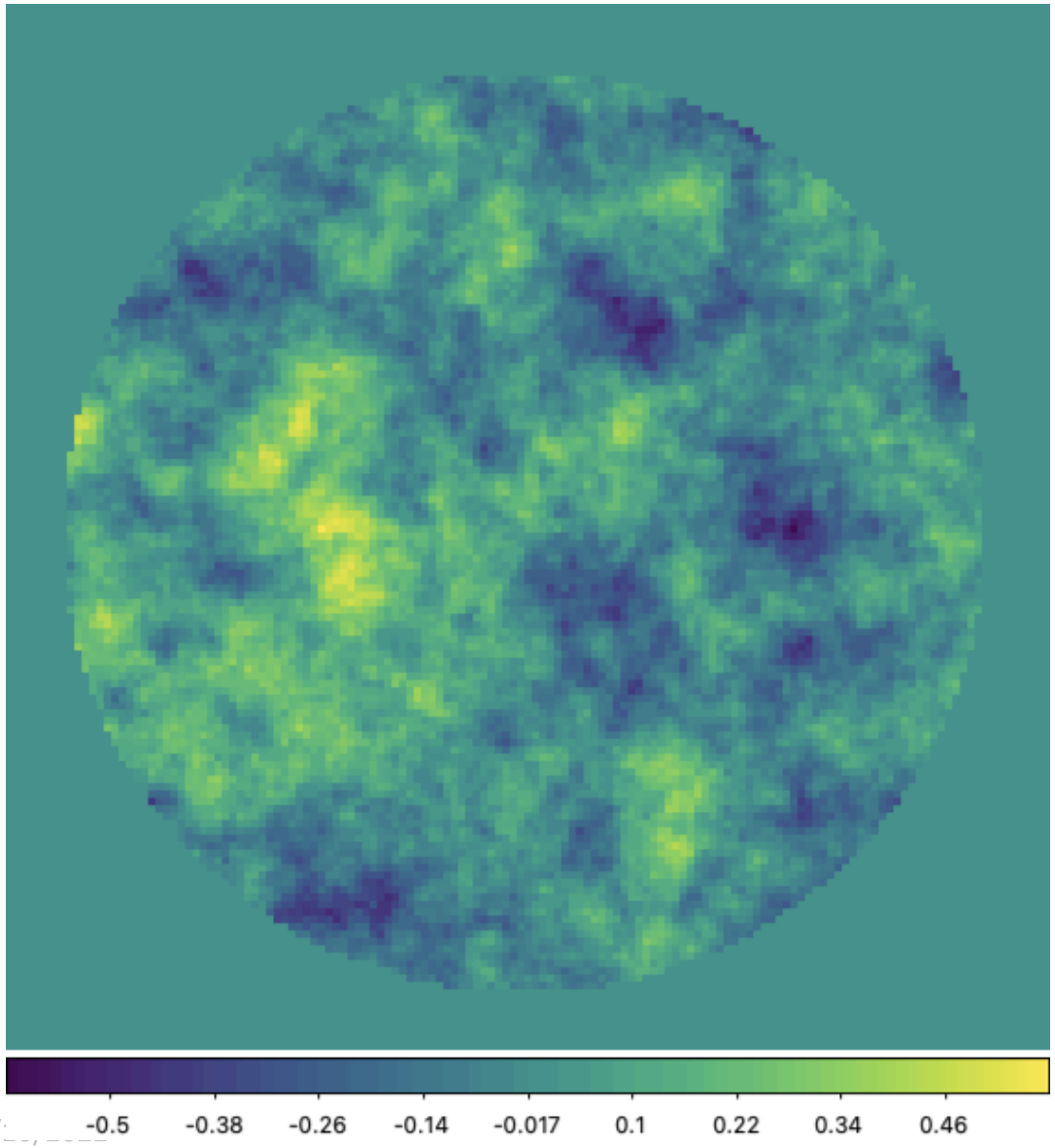
COFFEE

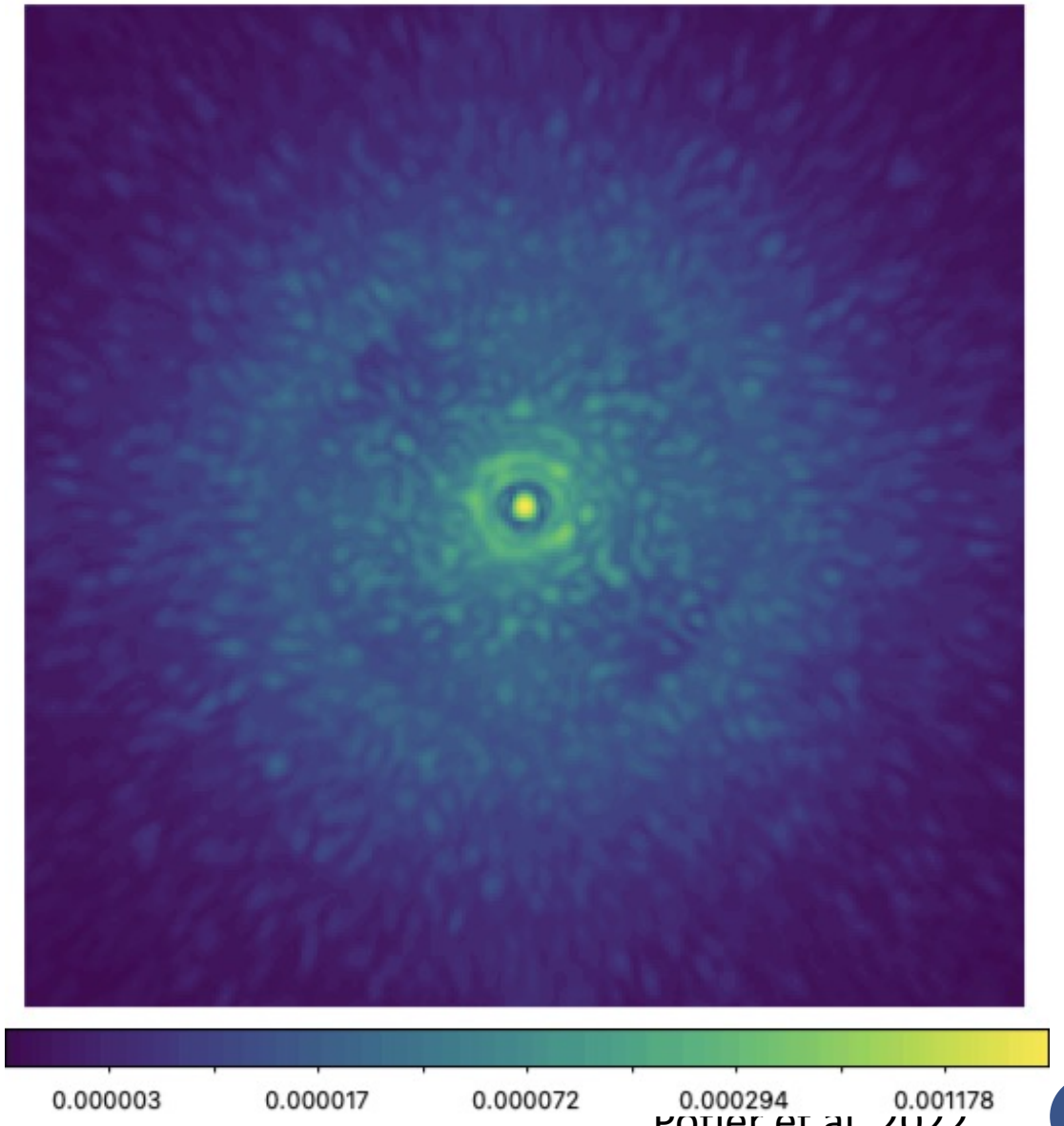


MEDUSAE

Coronagraphic model to estimate both ebarrations and planets
Estimation problem for Post-processing

Coherent Differential imaging





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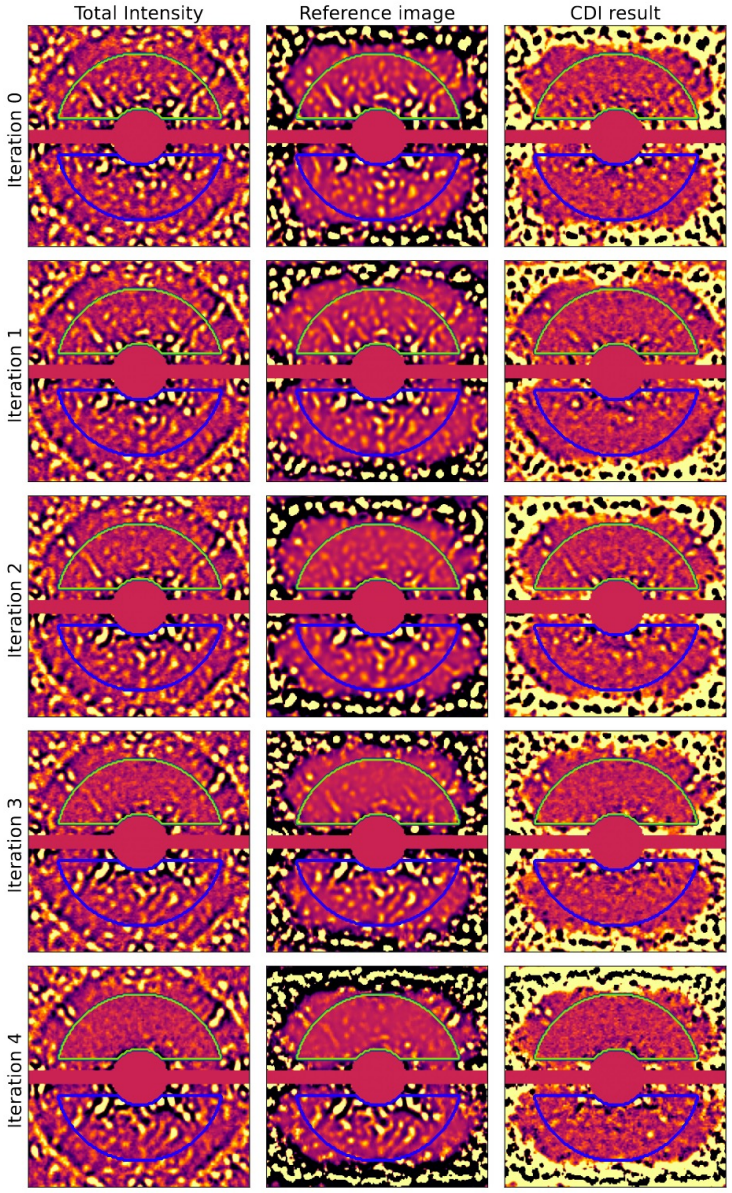
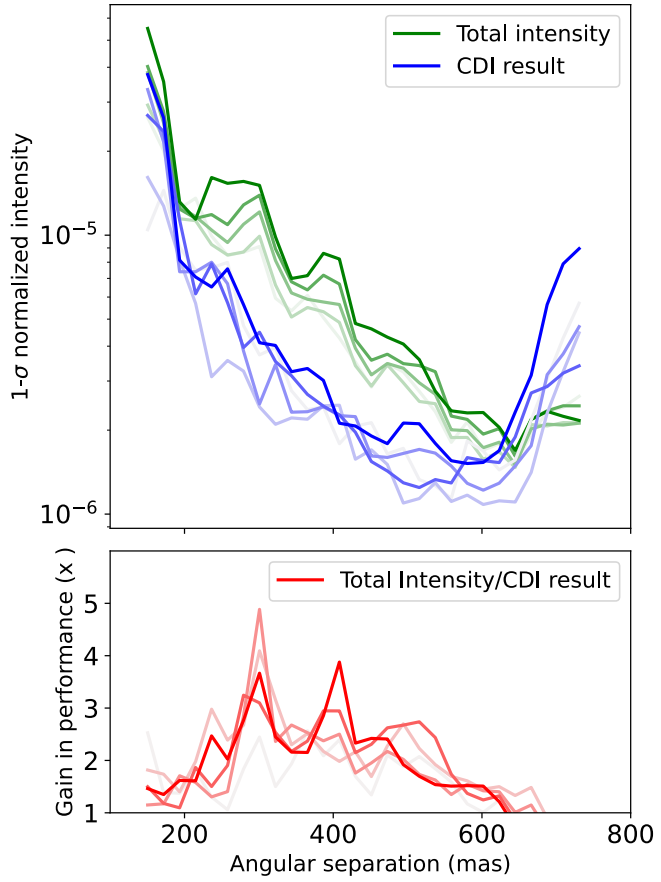
Coherent Differential imaging

Planet or disks are not impacted !





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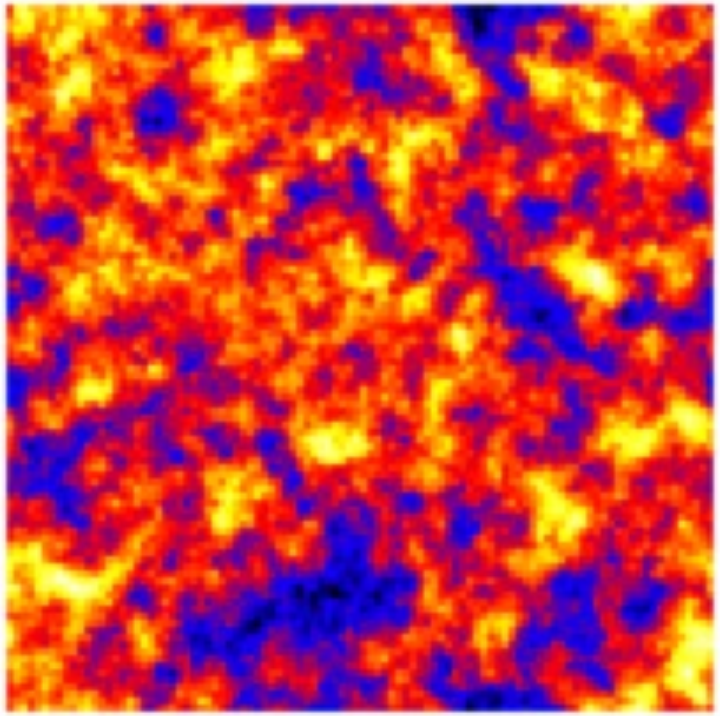
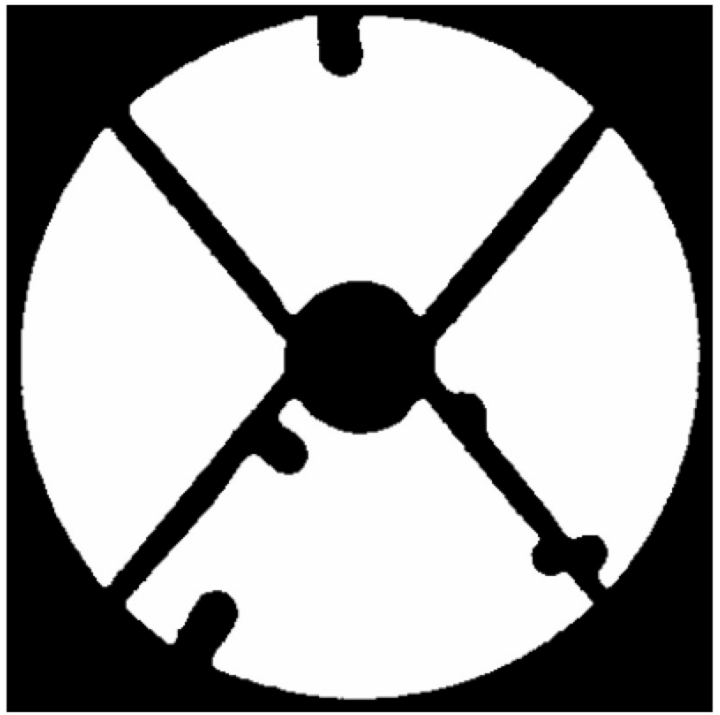
Phase and amplitude aberrations

Phase : temporal delay between part of the aperture



Field = exp(i φ) * P

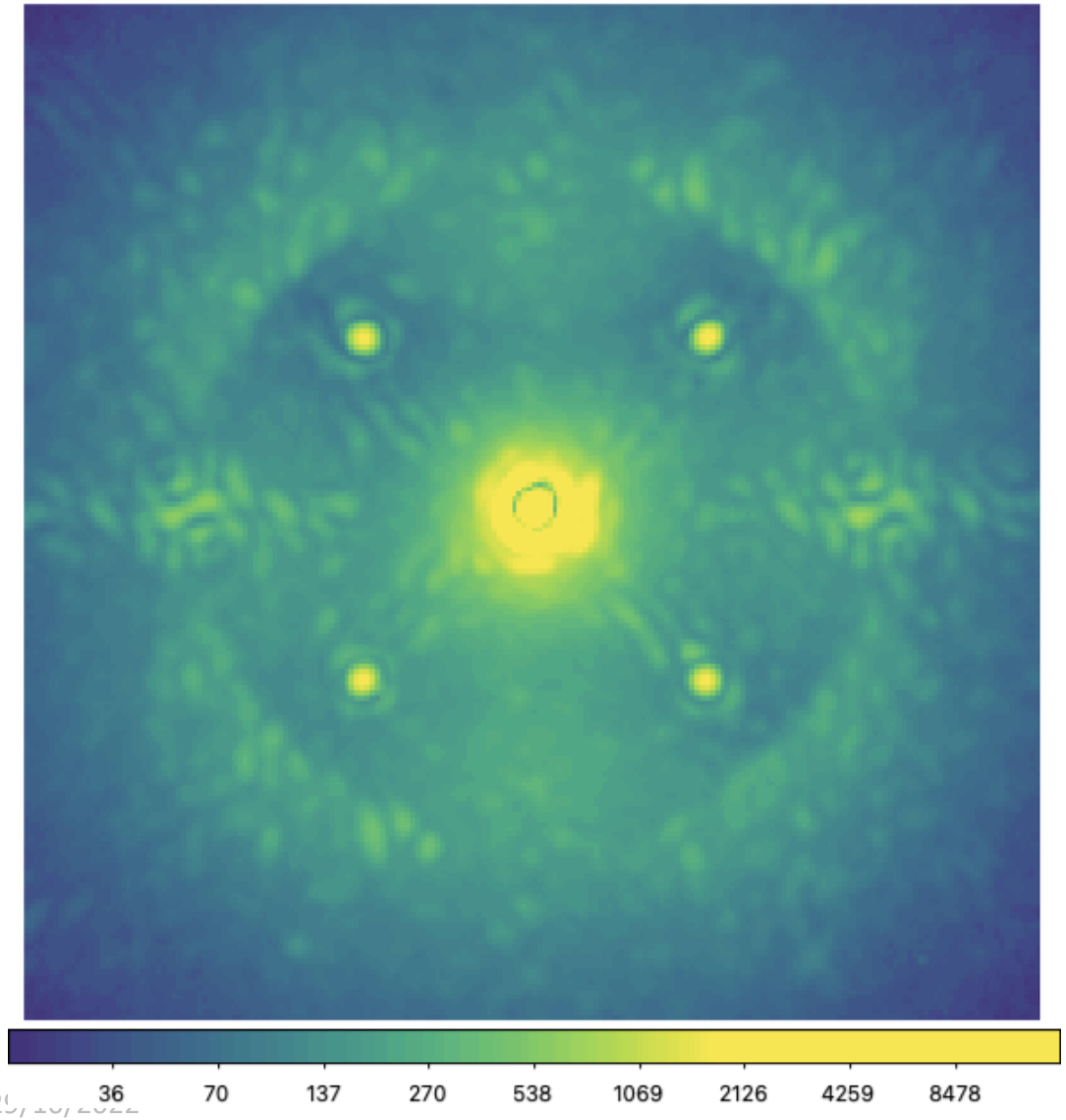
Amplitude : local difference in the transmission



Field = exp(a) *P

Phase and amplitude Field = E exp(a + i φ) = E exp (ϕ_C)

Dark hole shape



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