Experimental Comparison of Two Focal Plane Wavefront Sensors Behind Fast AO Residuals

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cnrs — Sorbonne Université — Université de Paris — PSL Université Paris

Context

Exoplanet imaging from ground

+ **8m-telescopes**, VLT (SPHERE), Gemini (GPI), Keck (KPIC), etc

→ young Jupiter-like planets at > ~5AU

+ **40m-telescopes**, ELT (PCS), TMT (PSI, SEIT, ExAO)

→ probing <5AU

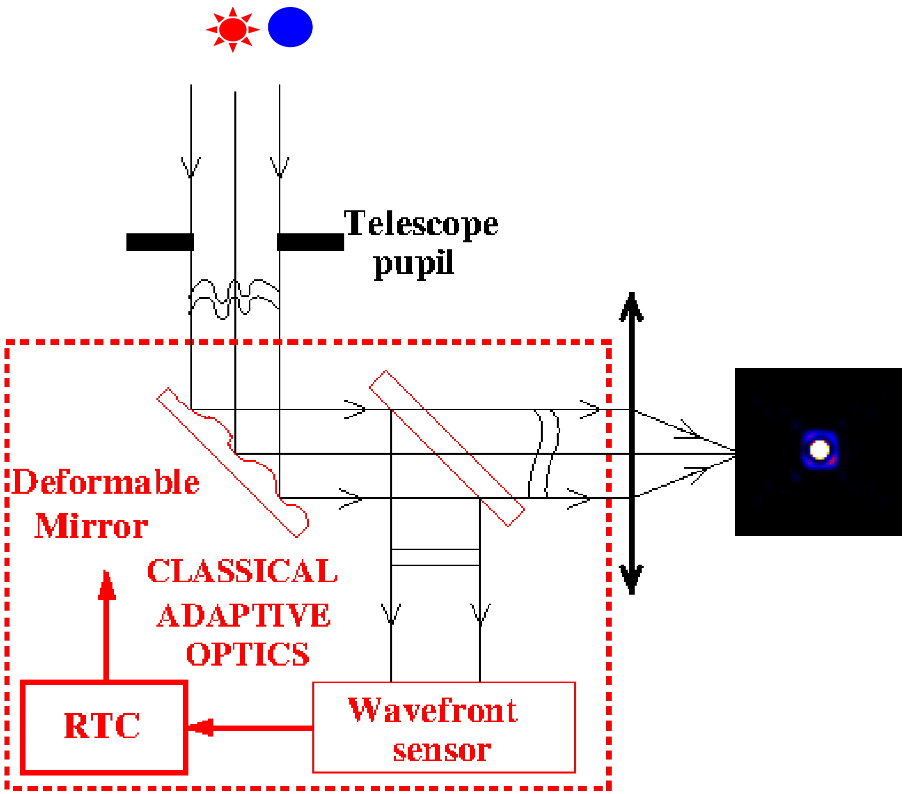
→ fainter exoplanets (lighter/older)

Needs : **High contrast imaging at small angular separation**

Up to 1e9 - 1e10 at 0.1"

Solutions : **Coronagraphs and XAO systems**

Current XAO



Very high strehl
But …

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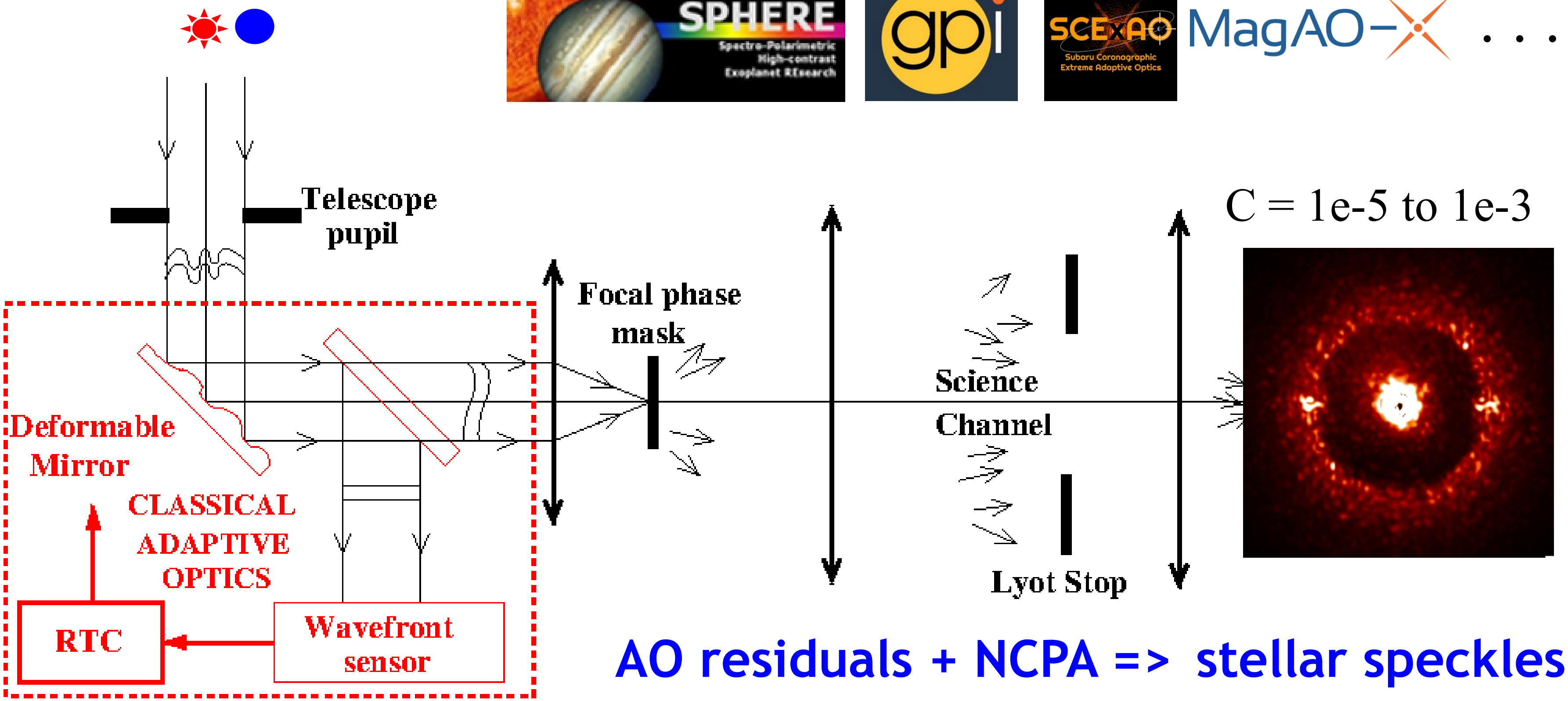
Coronagraph And Wavefront Aberrations

SPHERE Spectro-Polarimetric High-contrast Exoplanet REsearch | gpi | SCExAO Subaru Coronagraphic Extreme Adaptive Optics | MagAO-X | . . .



AO residuals + NCPA => stellar speckles

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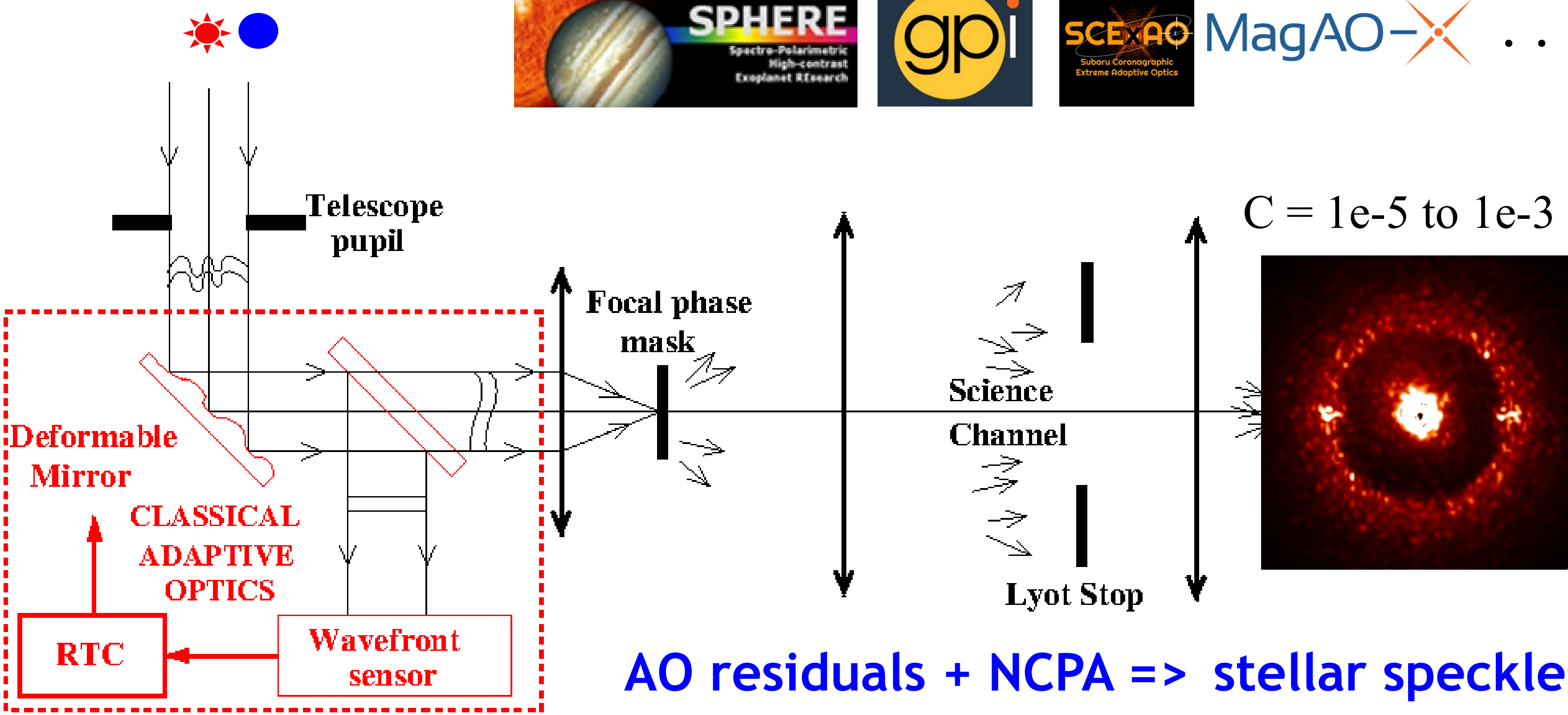
Coronagraph And Wavefront Aberrations



AO residuals + NCPA => stellar speckles

		Aberrations rms at one spatial frequency	Contrast level at one position in the image
λ=1.65 µm	2020 instruments	**1.0 nm**	**1.5e-5**
	Future instruments	**2.6 pm**	**1.0e-10**

AO Residuals, NCPA and Amplitude Aberrations

AO residuals + NCPA + amplitude aberrations => stellar speckles

Residual contrast ≈ variance amplitude

Unseen by AO systems!

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Residual contrast ≈ variance of AO residual / √N
N = exposure time / coherence time

Ex: $\sigma_{\text{AO residual}}$ = 1nm and t_c=3ms => ~1h to reach 1pm

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Need to

→ use long exposure and very efficient AO systems

→ estimate and compensate any aberration in the science channel

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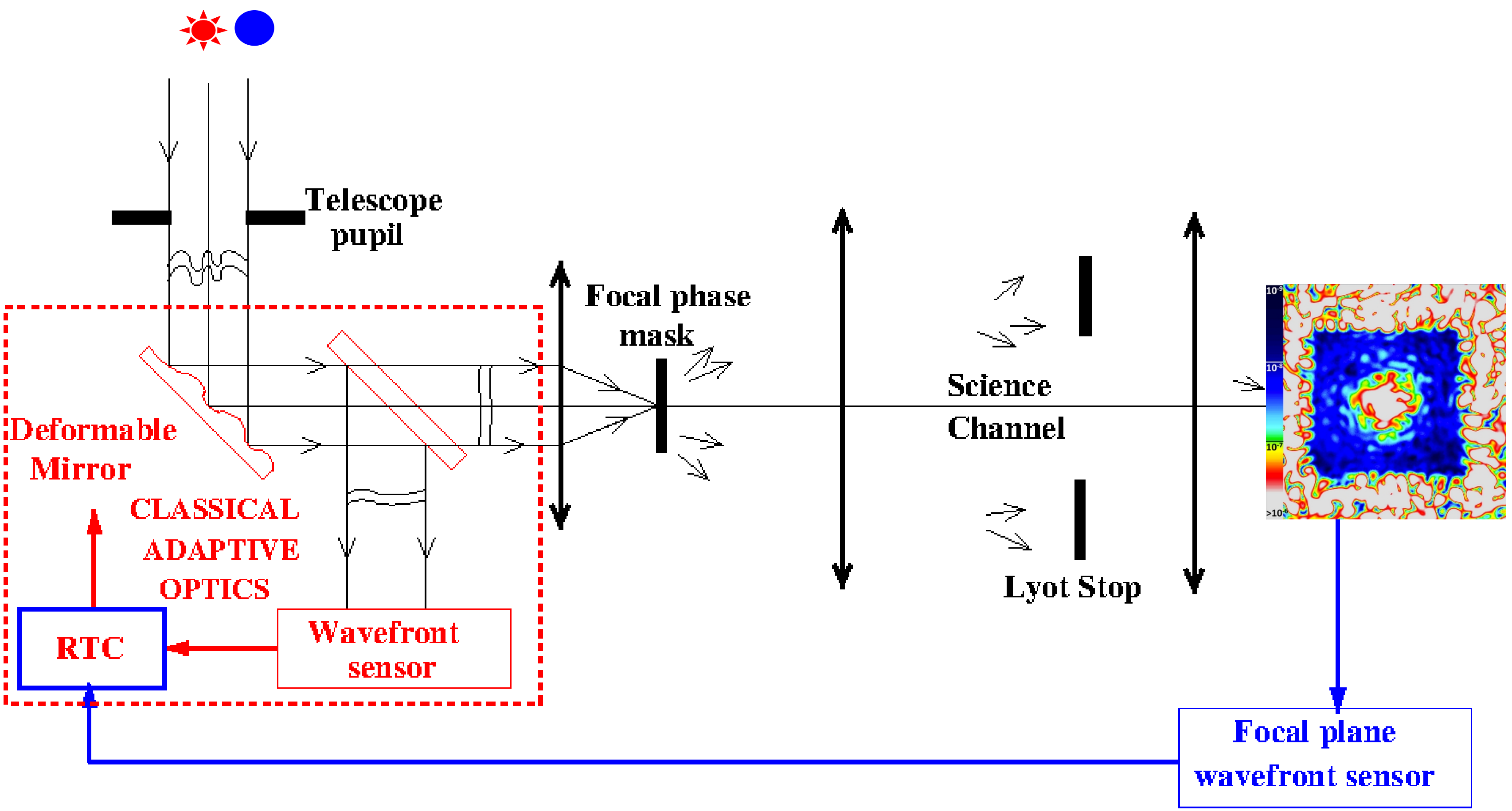
Focal Plane Wavefront Sensing and Control (1/2)



Focal Plane Wavefront Sensing and Control (2/2)

Focal plane wavefront sensing : retrieve electric field from intensity

→ Spatial modulation : Self-coherent camera (SCC), modal WFS, Kernel

→ Temporal modulation : Pair-wise (PW), speckle nulling, phase retrieval

Focal plane wavefront control : minimizing starlight in science image
≠ minimizing pupil phase aberrations!

→ Electric field conjugation

→ Active Compensation of Aperture Discontinuities

→ Non linear dark hole, ...

Our objective

Probe & compare in Lab PW/EFC and SCC behind AO residuals

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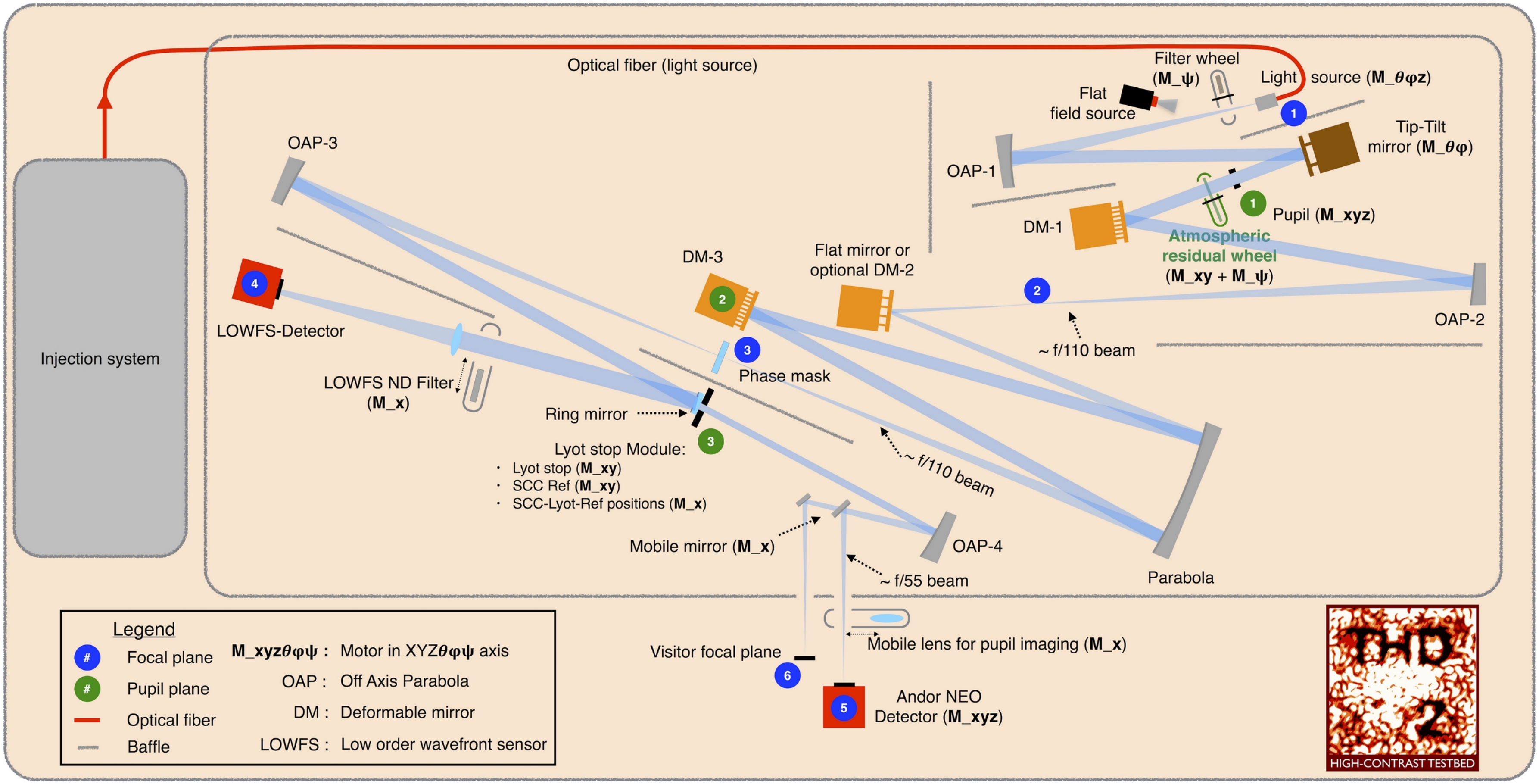
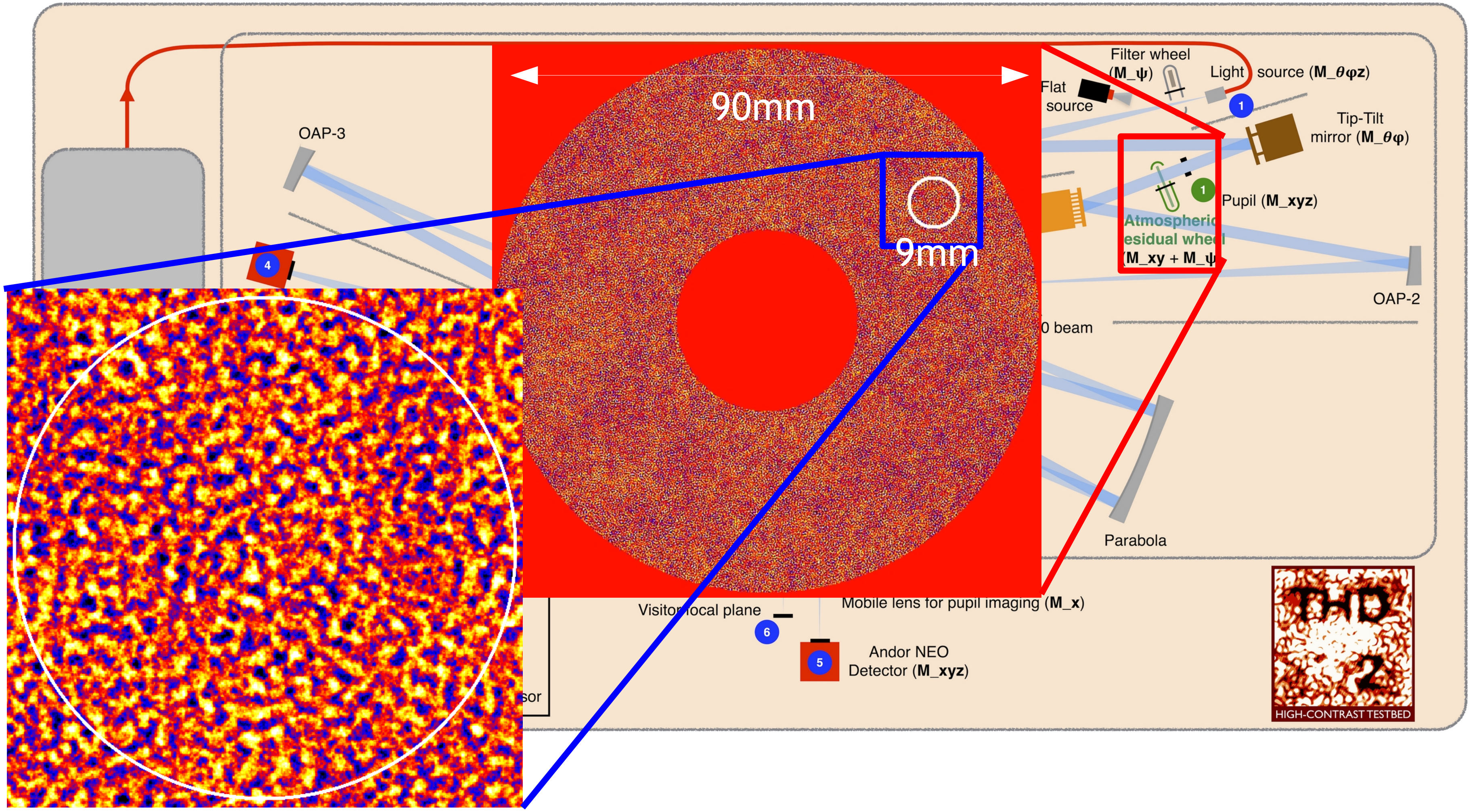
THD2 bench



http://thd-bench.lesia.obspm.fr/

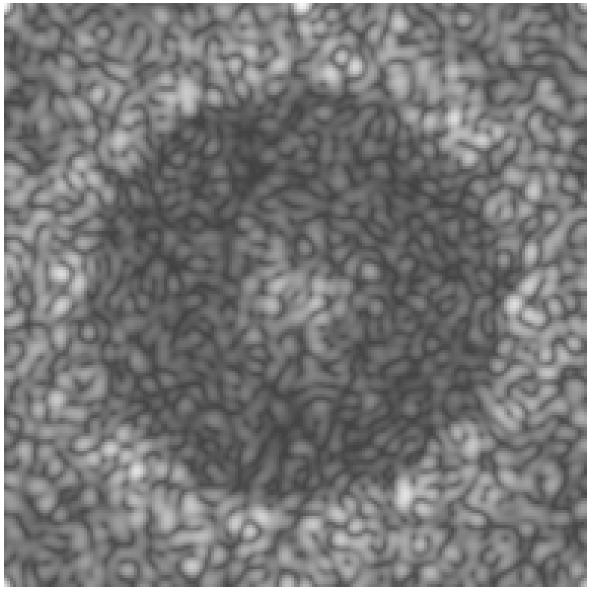
THD2 bench



Simulating SAXO/SPHERE-like system in good conditions

Ao residuals and static speckles in the Lab

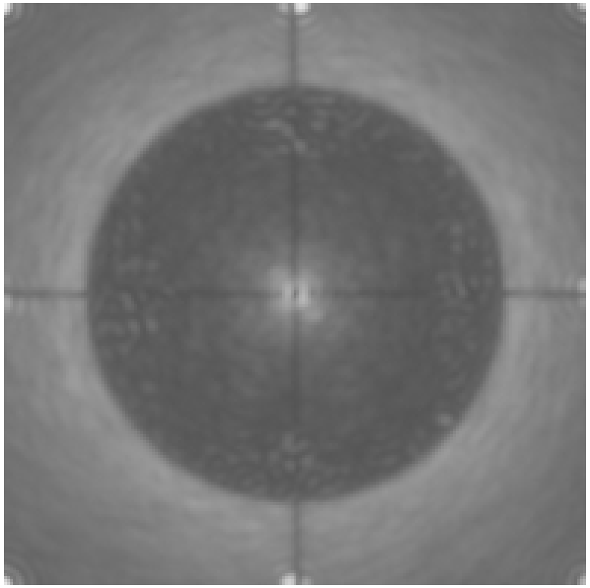
Monochromatic coronagraphic Lab images



AO residuals only

Short exposures

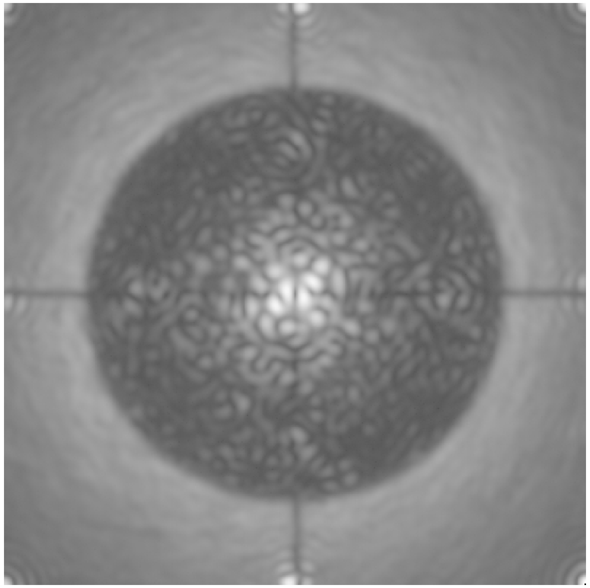
Frozen turbulence/speckles



AO residuals only

Finite long exposure

Unaveraged AO residual speckles (~1nm phase)



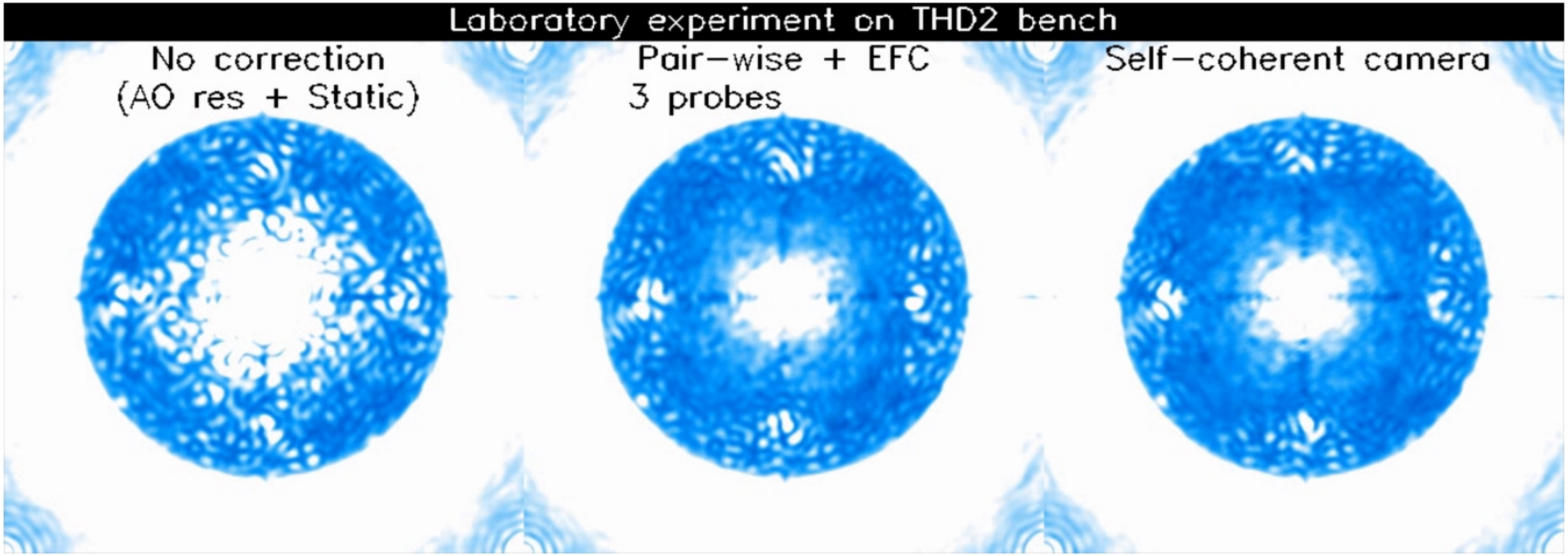
AO residuals only
+ 6nm static phase
+ 0.4% static amplitude

Finite long exposure

Unaveraged AO residual + static speckles (=NCPA)

Full dark hole correction (1/3)

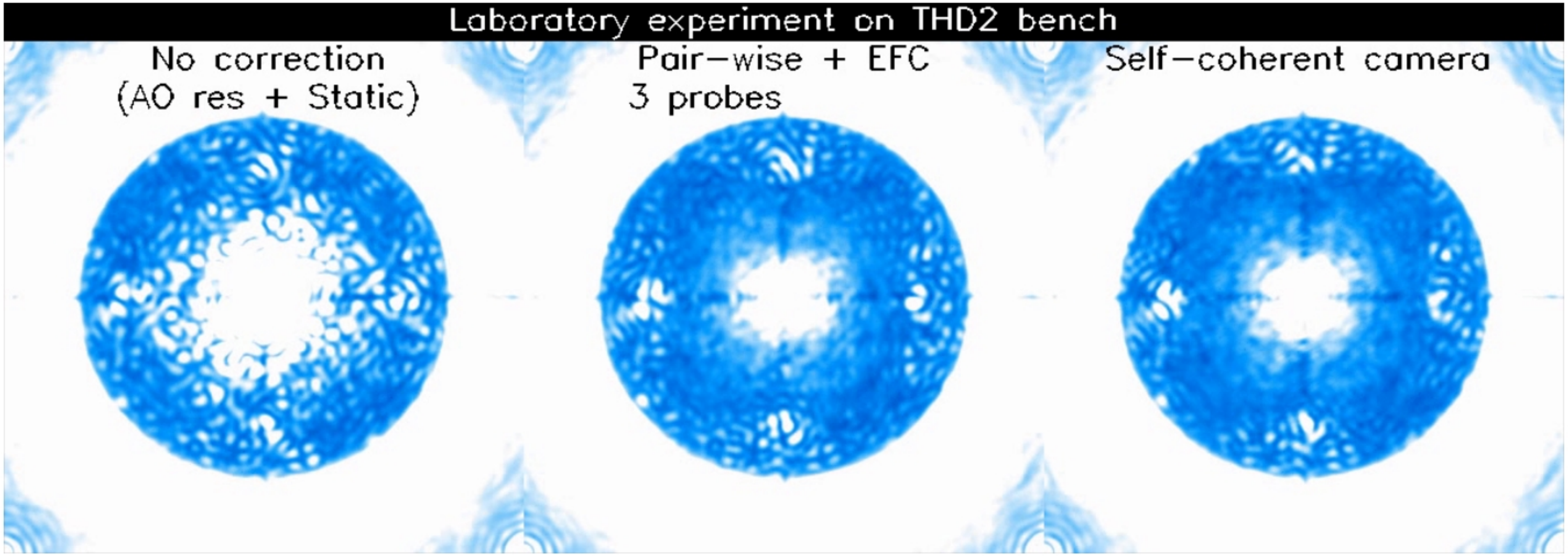
Correction with one DM in pupil plane : optimization in the full FOV (full dark hole)
→ Minimization of phase speckles only



+ images with no correction (left)
+ images after each iteration of pair-wise estimation + EFC correction (middle)
+ images after each iteration of SCC estimation/correction (right)

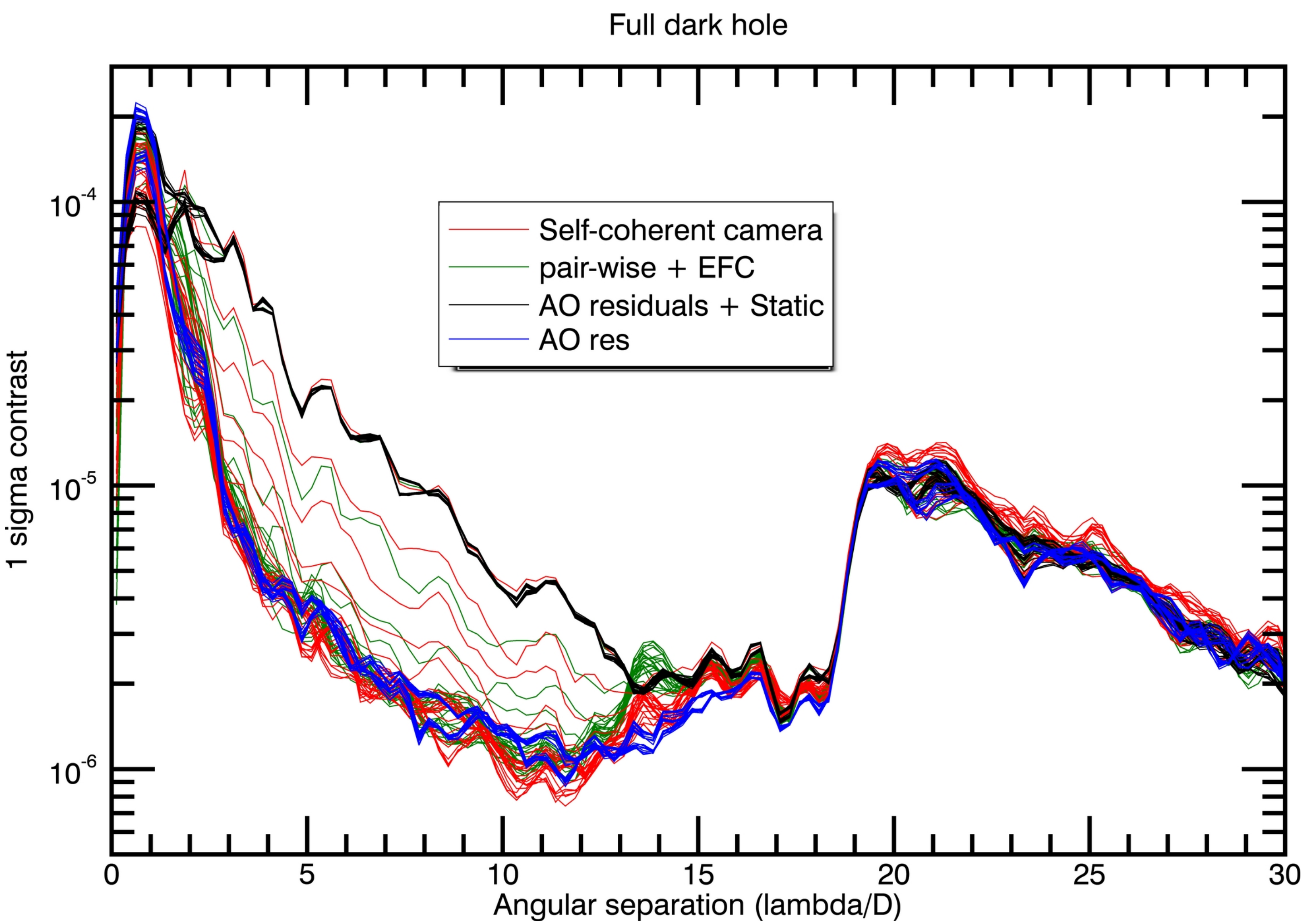
Full dark hole correction (2/3)

Correction with one DM in pupil plane : optimization in the full FOV (full dark hole)
→ Minimization of phase speckles only



Same movies but "real time" as PW/EFC needs at least 4 images for 1 iteration

Full dark hole correction (3/3)



PW/EFC and SCC can correct for statics behind AO residuals

PW/EFC seems to correct in less iteration: 3 or 4 instead of 4 or 5 for SCC

PW/EFC is longer in time because it needs 4 images while SCC needs one image

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Conclusions

Demonstration in Lab

→ Focal plane WFS can correct for statics behind AO residuals

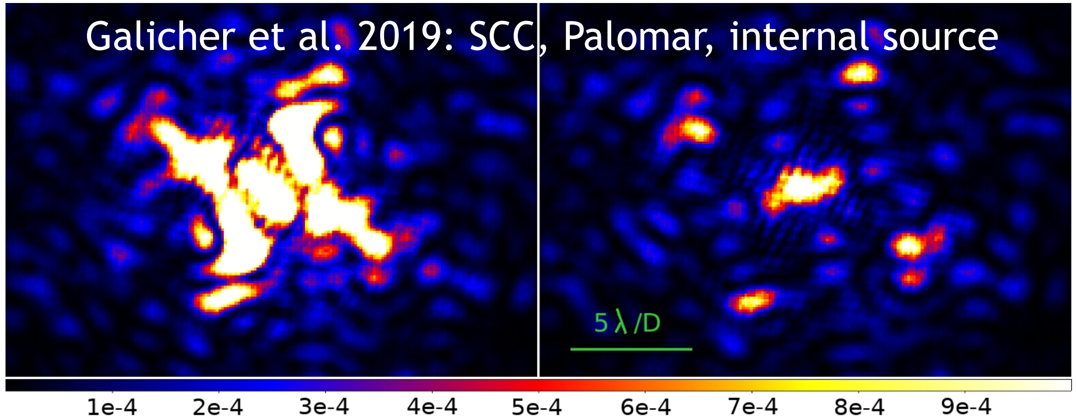
→ Temporal modulation focal plane WFS is slower than spatial modulation FPWFS because they need more images per iteration

Next step : onsky demonstration

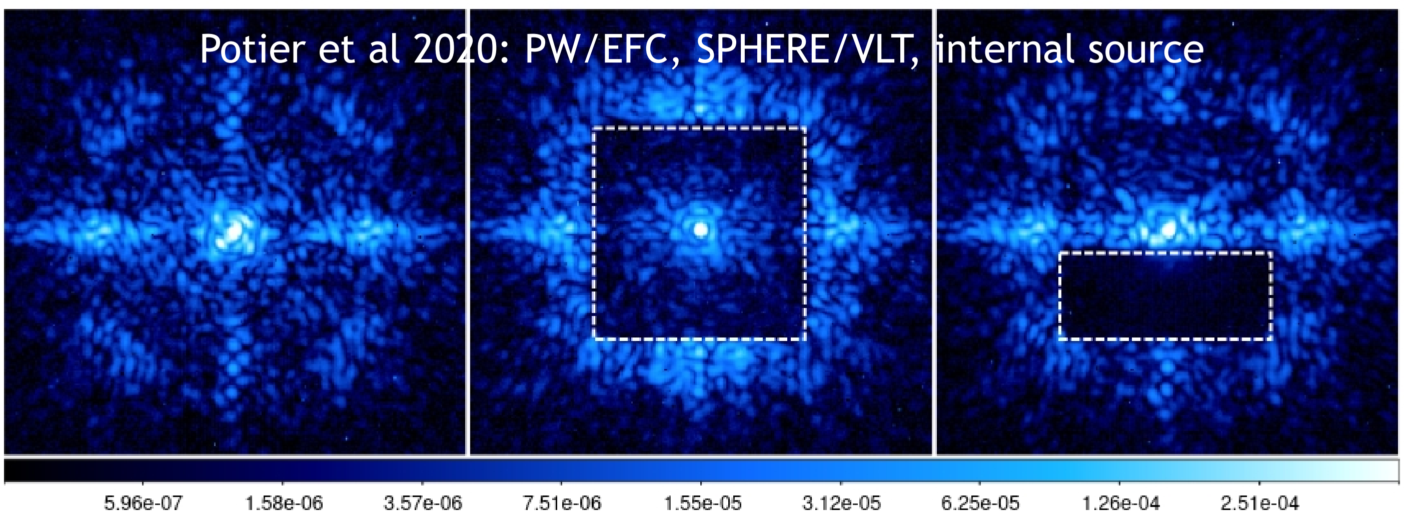
Preliminary results

→ Spatial modulation: Galicher et al. 2019

→ Temporal modulation: Potier et al. 2020



Thank you



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