

On-sky results with OZIRIIS: The 2nd stage AO of PAPHYRUS using a vector Zernike Wavefront Sensor

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Characterising Earth-like exoplanets: need for cascade XAO

- Imaging Earth-like exoplanet requires high angular resolution and contrast →
 - eXtrem Adaptive Optics
 - For Prox b : 38 mas arcsec resolution & 10⁻⁷ contrast
- Need to reduce the temporal error and so faster AO loop → Less flux
- Sensitive wavefront sensor → limited dynamics
 - Solution : using them in a second AO stage !
- Cascade AO:
 - Improve temporal rejection using faster WFS and rejection function combination
- Multistage instruments are under development !
 - RISTRETTO, SAXO+, SCEXAO, PCS ...

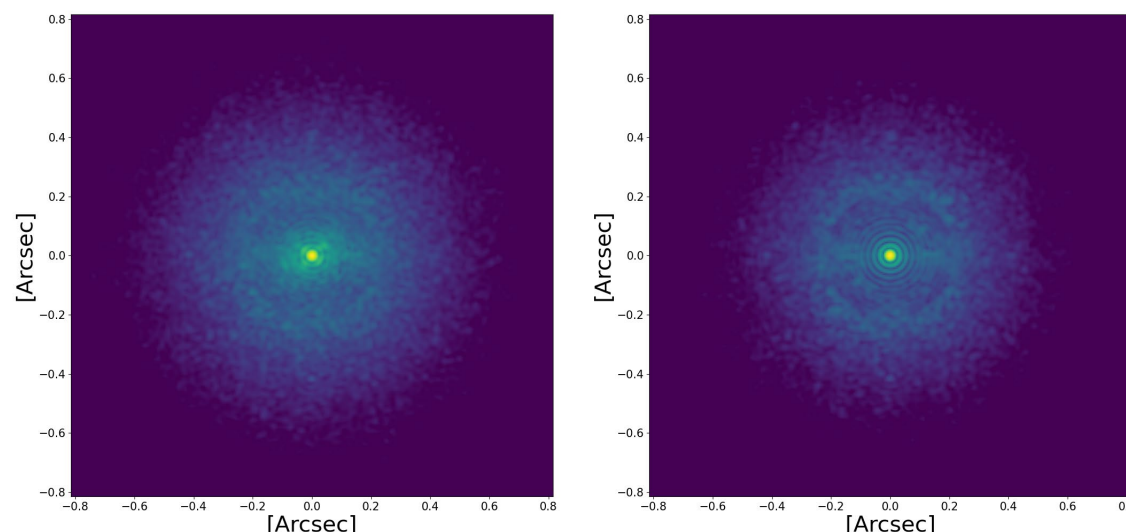


Fig. Simulated output PSFs of a cascade AO system. Left: stage 1, Right: stage 2. stage 1 @500 Hz PWFS 20x20 et stage 2 @2kHz PWFS 10x10. Made with OOPAO (Heritier et al. 2023)

First stage residuals seen by second stage WFS

- Can use vZWFS signal to estimate first stage performance
- Using iterative arctan reconstructor → could have a better estimate of the phase
- However, for now, camera is not cooled down so high error propagation in reconstruction
- Difference between the curves: nonlinearity of the pyramid + optical gain + not well-known influence function from DM1

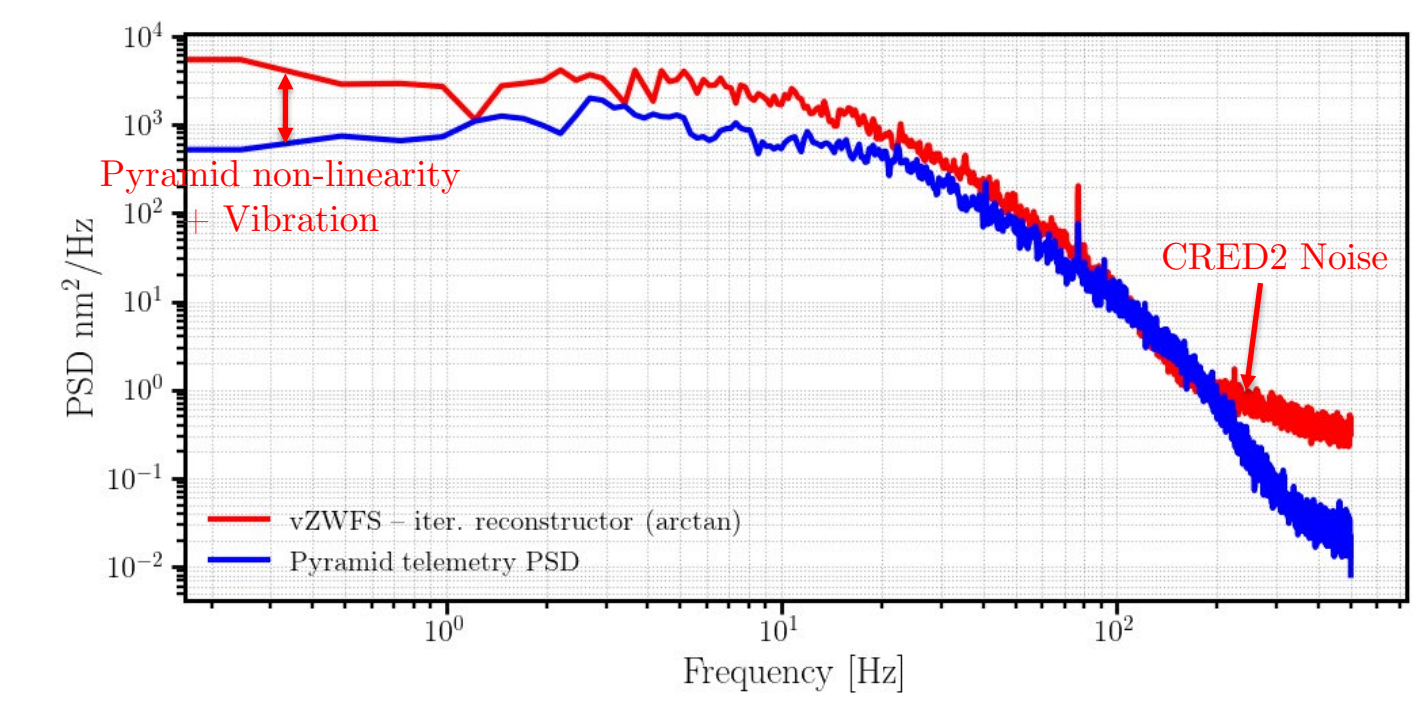


Fig. : First stage closed-loop temporal PSD summed on all actuators: vZWFS vs pyramid telemetry. Target: Arcturus. Observations on January 13th, 2026

Vector Zernike: a sensitive WFS for XAO instruments

- Highly Sensitive + Better dynamics → good candidate for second stage
- Two ZWFS with opposite depth → can use non-linear reconstruction to unwrap the phase

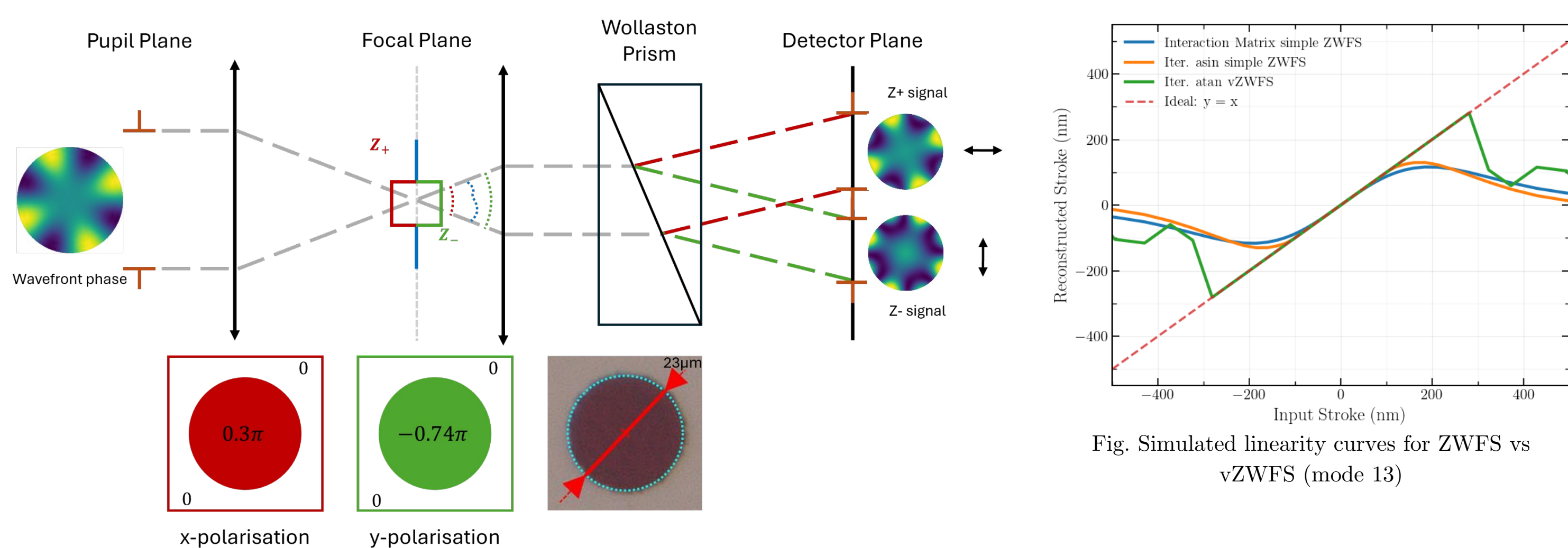


Fig. Simulated linearity curves for ZWFS vs vZWFS (mode 13)

Fig. vZWFS principle with metasurfaces from JPL (Wallace and Wenger 2025)

- Testing the on-sky performance of such systems is crucial for future XAO instruments like PCS!

Calibration of second stage closed-loop

- Internal calibration of the ZWFS + flatten DM2:
 - Calibrate Valid pixels map
 - Calibrate interaction matrix
 - Simulate reference image (from pupils' images)
- On-sky Calibration:
 - Reselect valid pixels
 - Simulate new reference image
- On-sky closed loop:
 - For now, use only one pupil
 - Reconstruction through interaction matrices

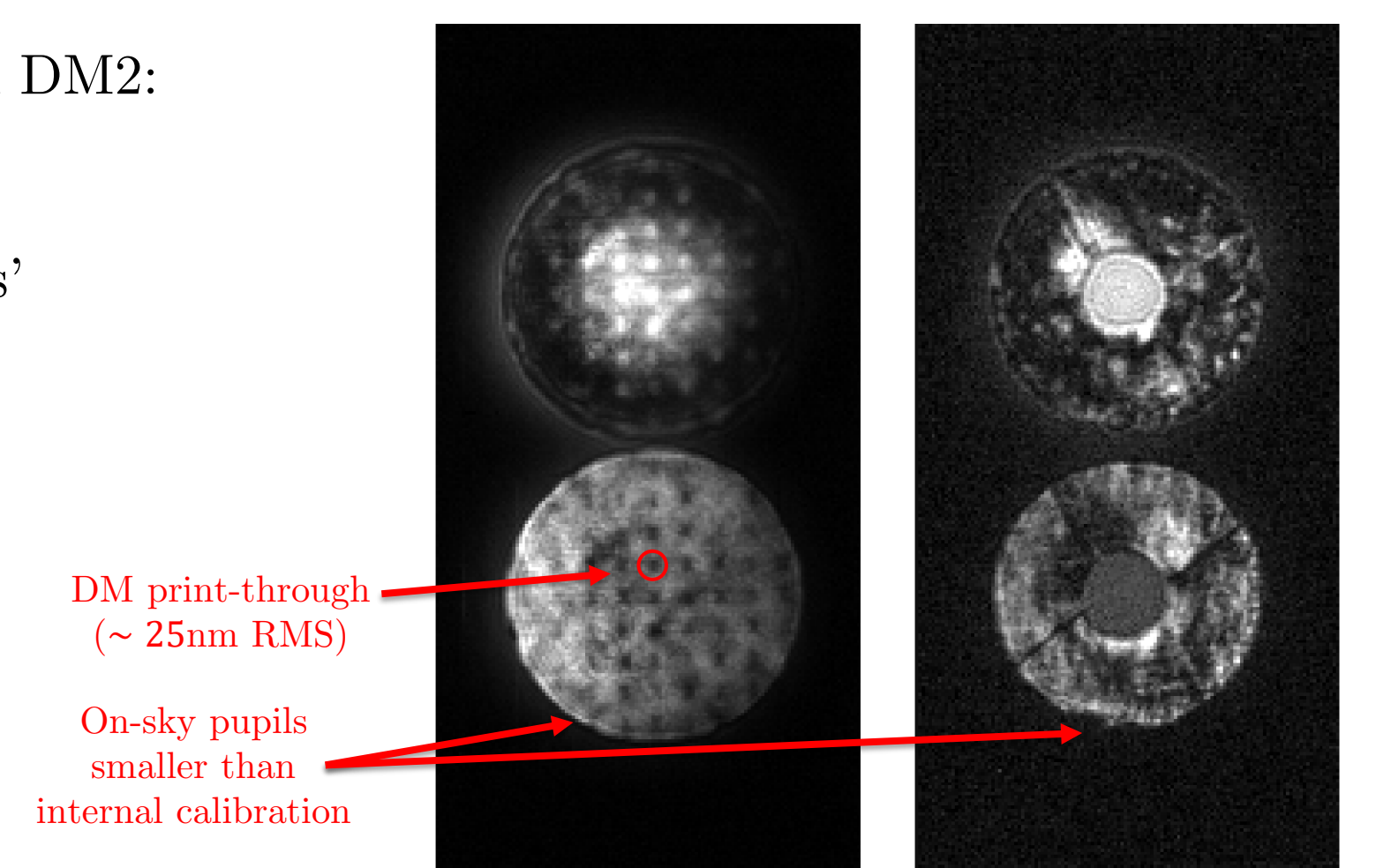


Fig. : Left : reference vZWFS signal on calibration unit, Right: signal during on-sky closed loop

On-sky closed loop with OZIRIIS

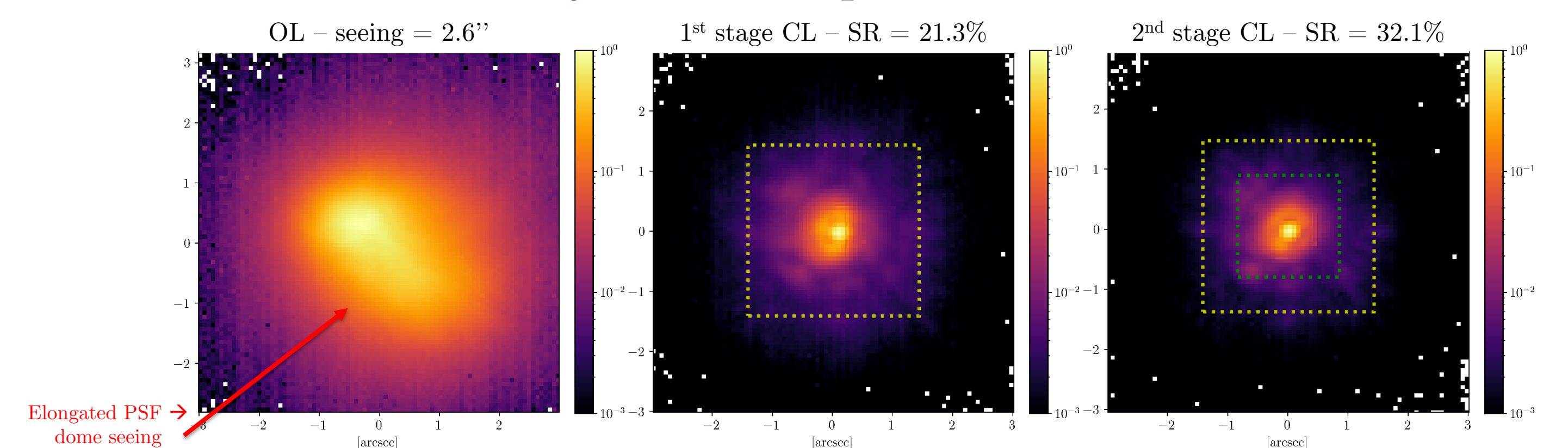


Fig. IR PSFs in open loop, after closing the first stage, and after closing the second stage. First loop running @500Hz, second loop @400Hz, 10 corrected modes with second stage. Dotted squares : correction zone of the two stages. Target: Arcturus, Observation on January 21st, 2026

- CL1: 500Hz, $g = 0.6$, modulation: $5\lambda/D$
- CL2: 400Hz, $g = 0.2$, controlled modes = 10
- Visible improvement of PSF and SR:
 - Mainly due to NCPA correction between on-sky and internal source branch
 - Reduction of the jitter when closing second loop
- Elongation of OL PSF due to dome seeing

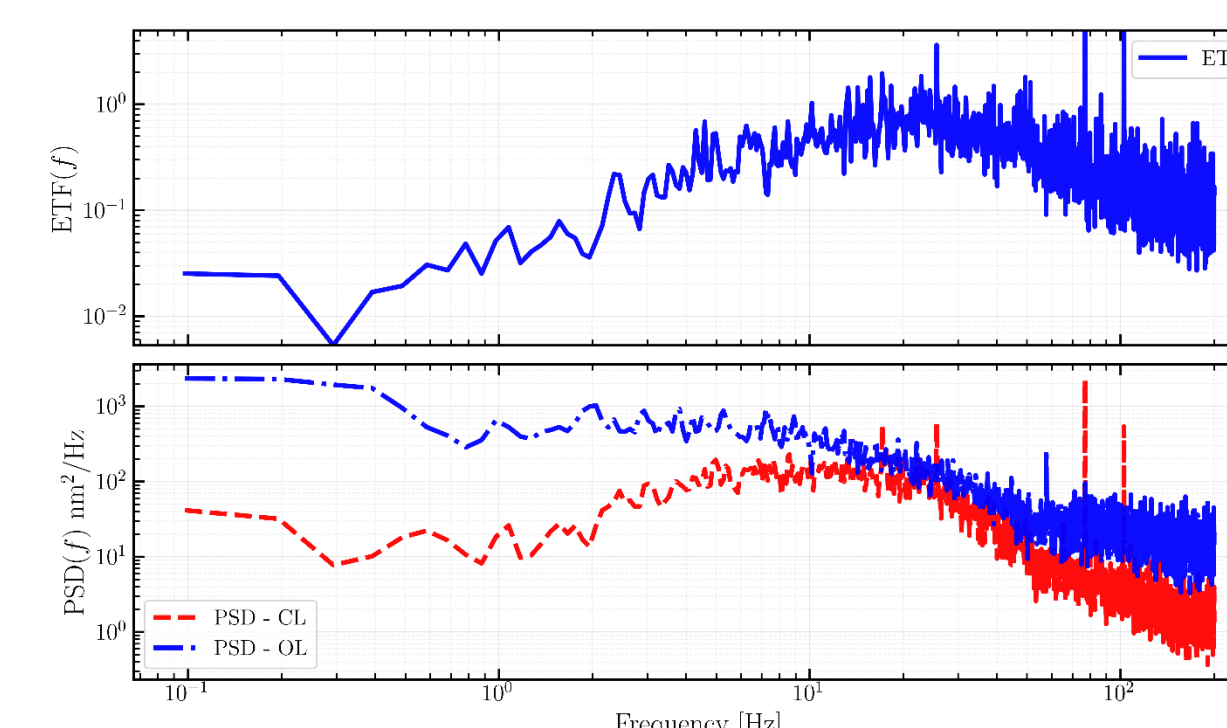
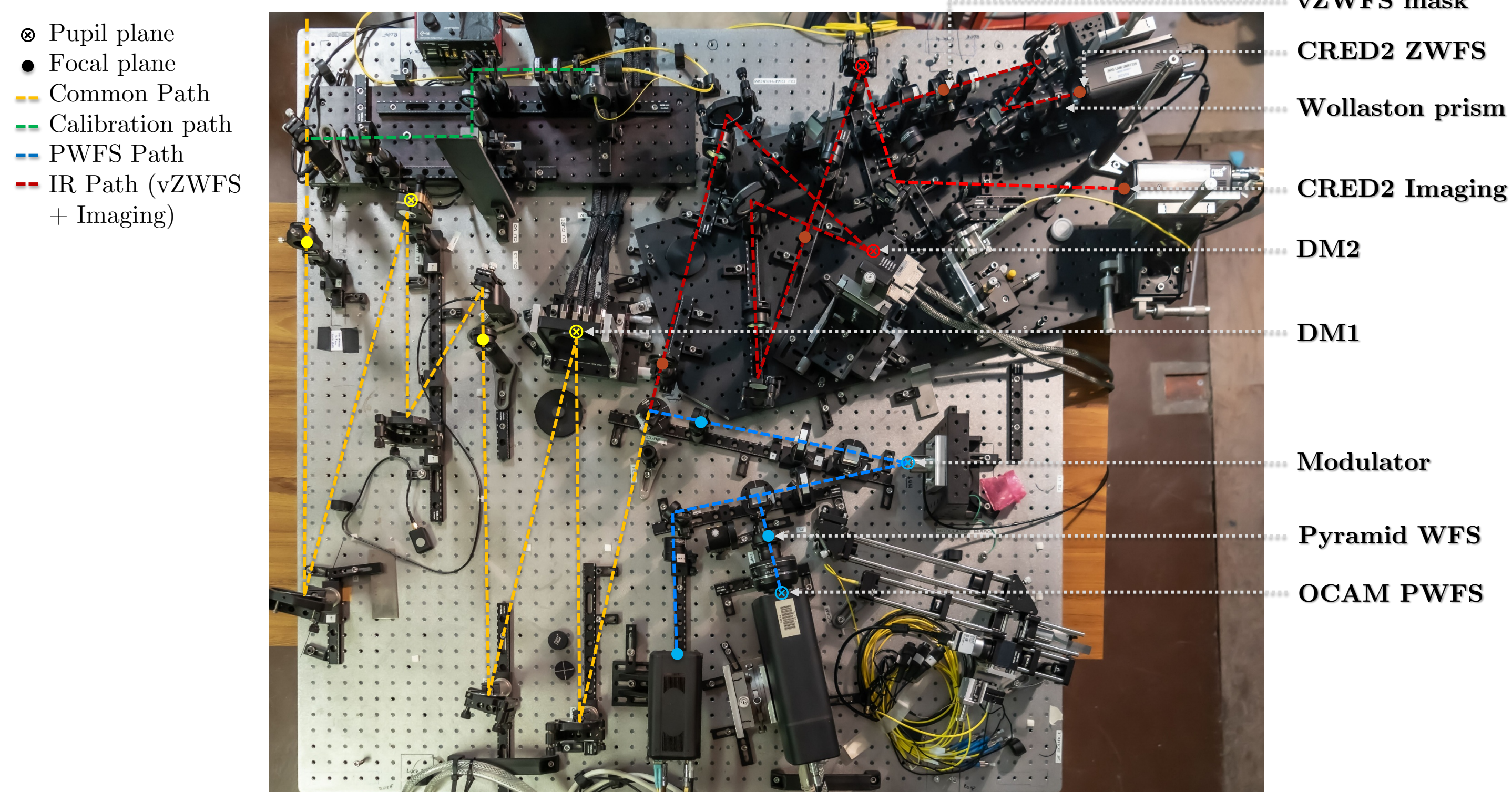
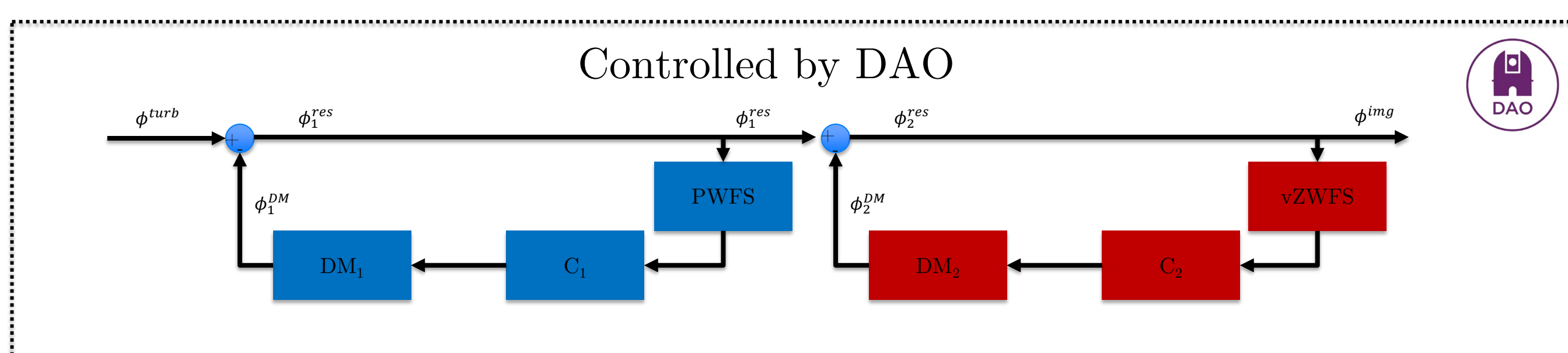


Fig. : ETFs and temporal PSDs on the first stage summed on the 20 controlled modes. Target: Dubhe, Observation on January 21st, 2026

OZIRIIS: the second stage of PAPHYRUS at OHP



- Calibration unit with 2 sources : infrared 1550nm, visible 635nm
- DM1 17x17, DM2 11x11
- Visible branch : <950nm
- IR branch bands : 950nm-1500nm for imaging, >1500nm for WFS
- Cascade adaptive optics, 2 integrators



Perspectives

- Data from this series of tests will be analysed more precisely to obtain ETF, simulation comparison and better understanding of the system
- New on-sky tests will be performed to improve the performance of the system in terms of number of modes corrected, stability and speed of the loop.
- Other tests with non-linear reconstructors such as NN are planned

Acknowledgments: This work benefited from the support of the French National Research Agency (ANR) with APPLY (ANR-19-CE31-0011) and LabEx FOCUS (ANR-11-LABX-0013); the Programme Investissement Avenir F-CELT (ANR-21-ESRE-0008), the Action Spécifique Haute Résolution Angulaire (ASHRA) of CNRS/INSU co-funded by CNES, the ECOS-CONYCIT France-Chile cooperation (C20E02), the ORP-H2020 Framework Programme of the European Commission's (Grant number 101004719), STIC AmSud (21-STIC-09), the french government under the France 2030 investment plan, the Initiative d'Excellence d'Aix-Marseille Université A*MIDEX, program number AMX-22-RE-AB-151