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GRAVITY+

JMMC
10 - 11 March 2025, Nice, France

Some news from GRAVITY+ and its new AO system

On the behalf of the GRAVITY+ consortium

GRAVITY+ in short

tific revolution to come at the VLTI.

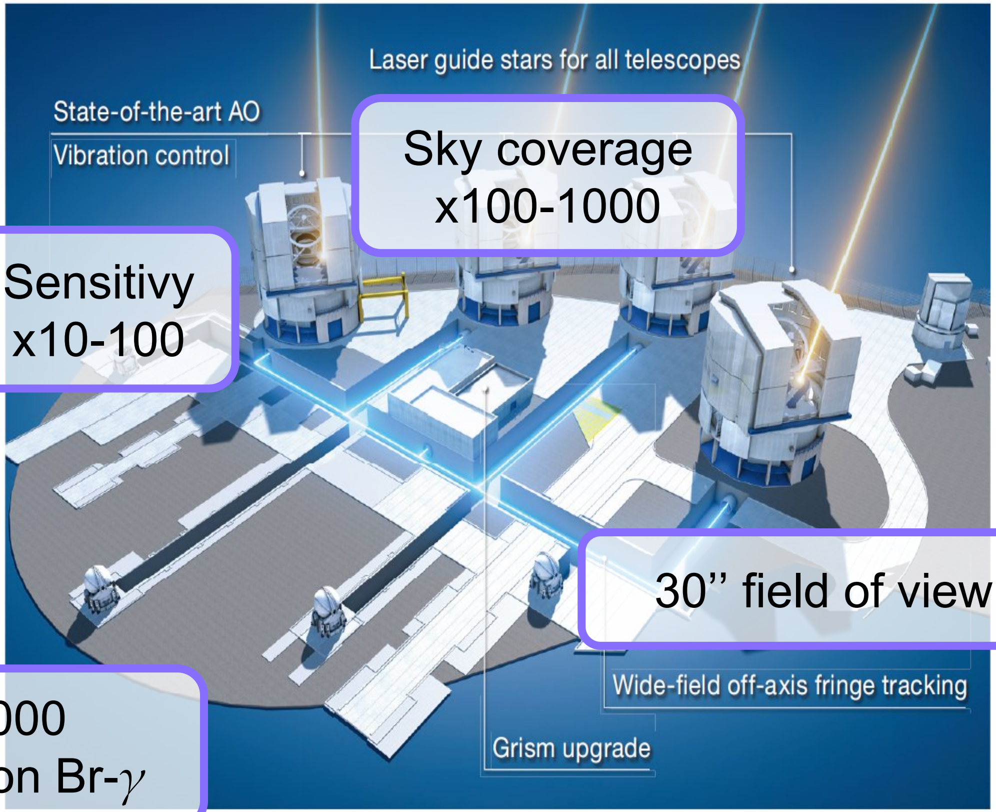
Introduction

The near-infrared interferometric beam-combiner GRAVITY has been in operation at the Very Large Telescope Interferometer (VLTI) for five years (GRAVITY Collaboration et al., 2017). During that time GRAVITY has transformed optical interferometry by delivering ground-breaking results in studies of the Galactic centre, active galactic nuclei (AGN), exoplanets, and young stellar objects (see for example GRAVITY Collaboration et al., 2018a,b,c; GRAVITY Collaboration et al., 2019a,b). GRAVITY can achieve microarcsecond astrometry and detect stars as faint as 20th *K*-band magnitude in the Galactic centre. The current performance is not the ultimate within reach, which motivated the upgrade of the instrument to GRAVITY+. Studies of the performance of the VLTI also highlighted the importance of infrastructure upgrades to increase the overall sensitivity (Mérand, 2018).

the sky coverage with AO, and thereby interferometry at the VLTI. This limitation is addressed in GRAVITY+ by adding LGS and a new AO system to be installed on all UTs. GRAVITY+ will equip UT1, 2, and 3 with a side-launch LGS, the design of

tracking star within 30 arcseconds is almost 100% in the Galactic plane and remains above 25% for Galactic latitudes of 40° (Figure 2).

Figure 1. Overview o



Extreme AO
Contrast 10^{-6}

Sensitivy
x10-100

Sky coverage
x100-1000

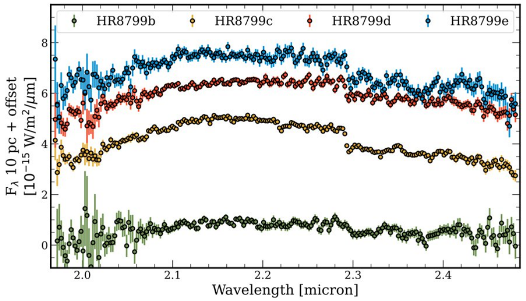
LGS modes
for Rmag < 18

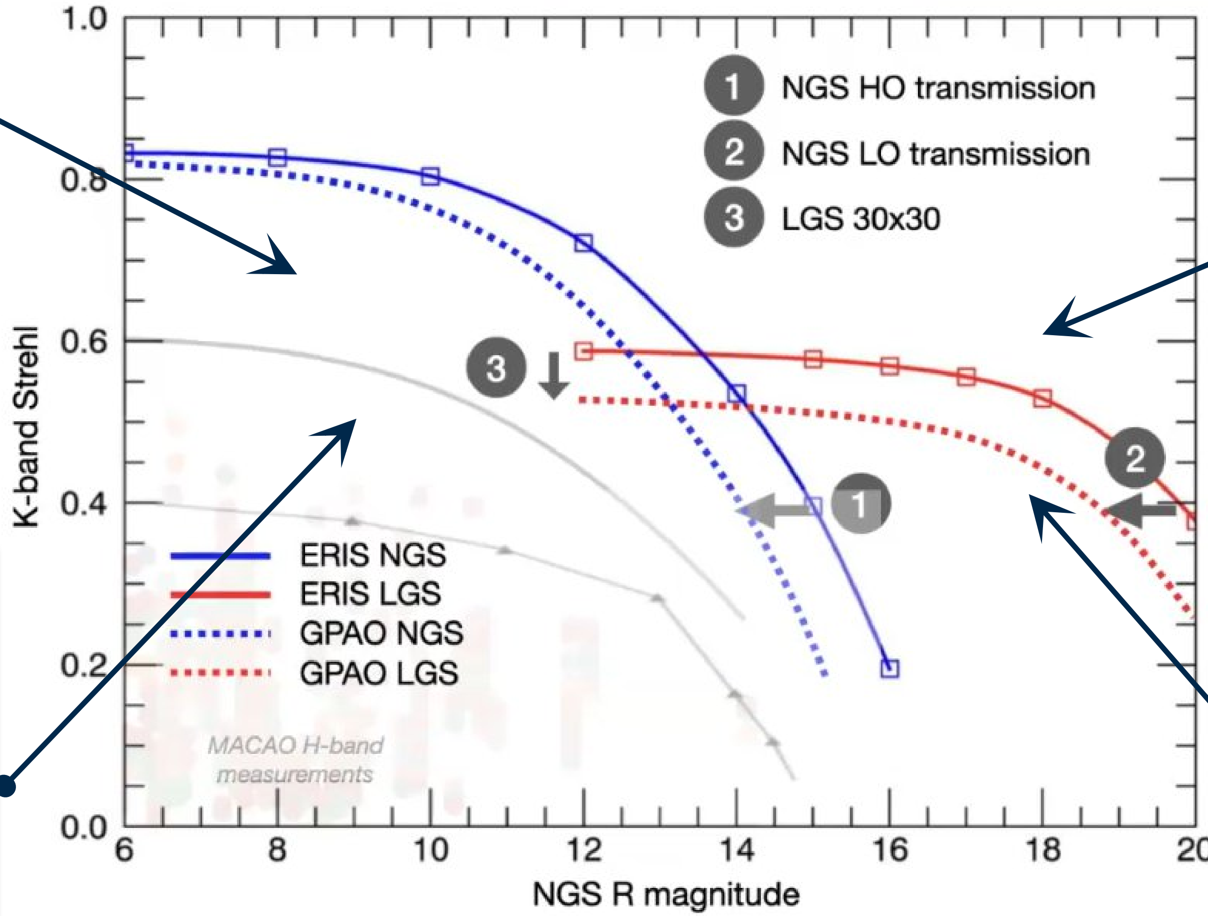
30'' field of view

R~15 000
Centered on Br-γ

GPAO in short – Objectives

Exoplanets





Stellar black holes

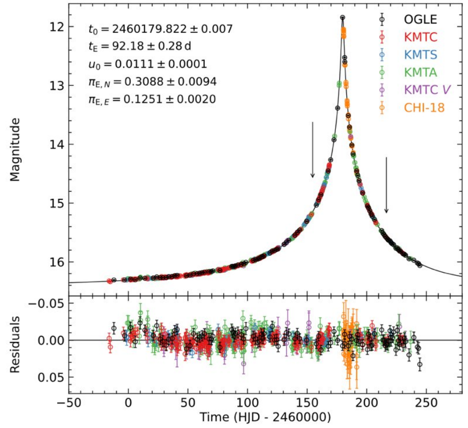
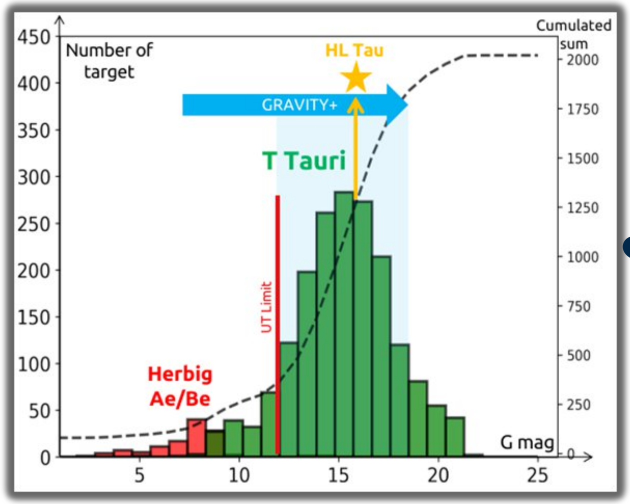
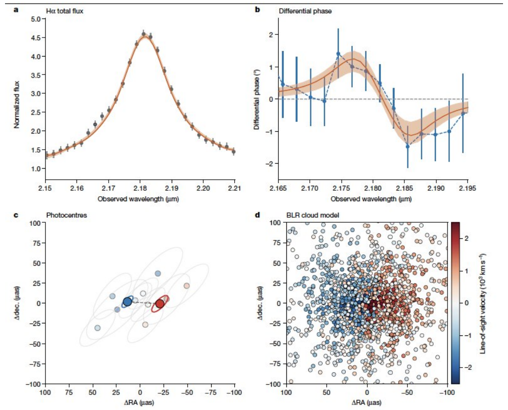


Figure 2. Light curve of OGLE-2023-BLG-0061. The black line marks the best-fit model with $u_0 > 0$. Arrows mark the two epochs of VLTI observations.

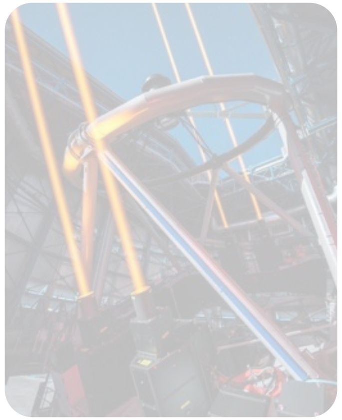
Protoplanetary disks



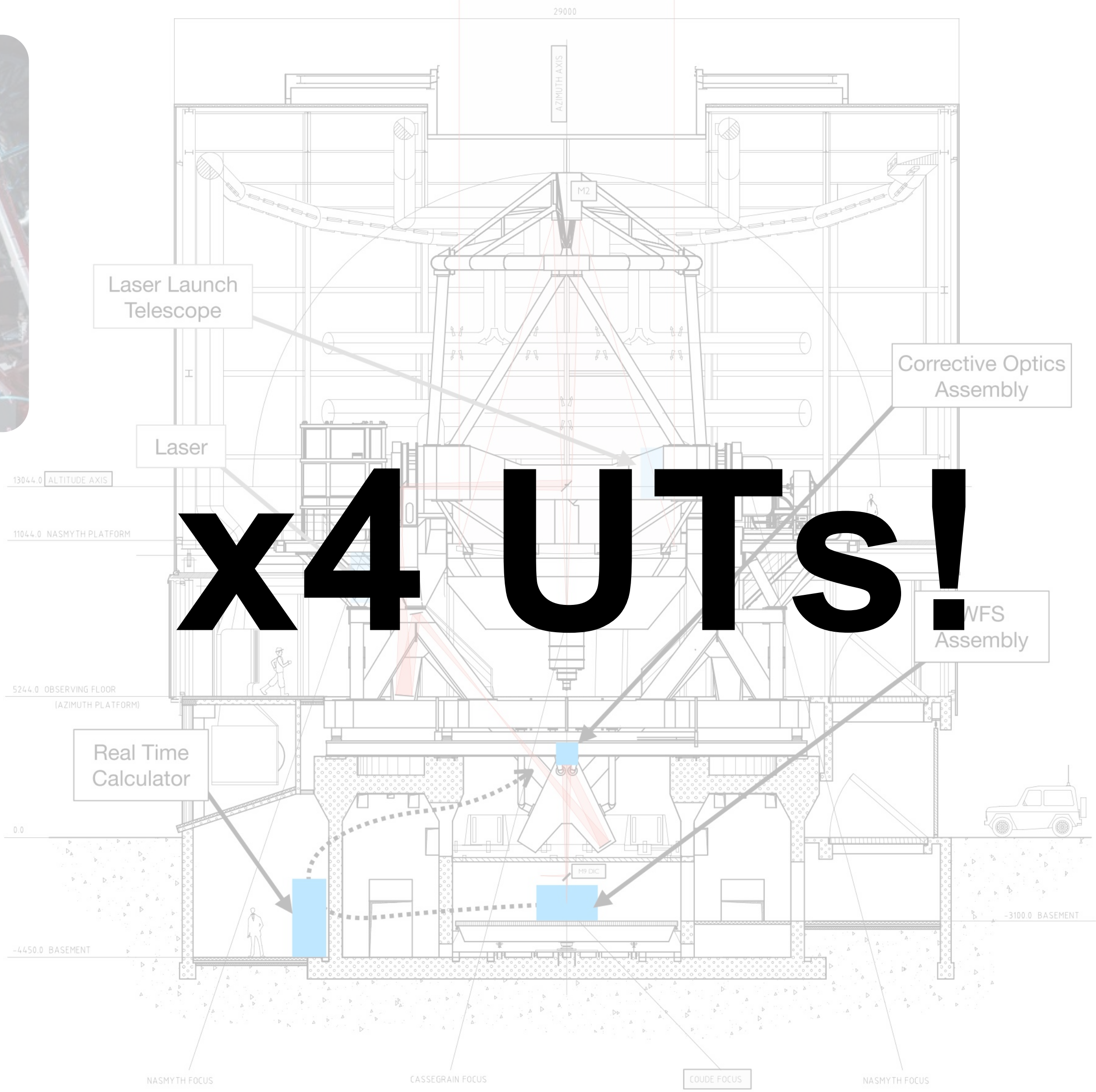
Super massive black holes



GPAO in short – In real life



SPARTA-based
real-time computer
- Updated PSIM model
- New modal control
- New auto-calibration strategies



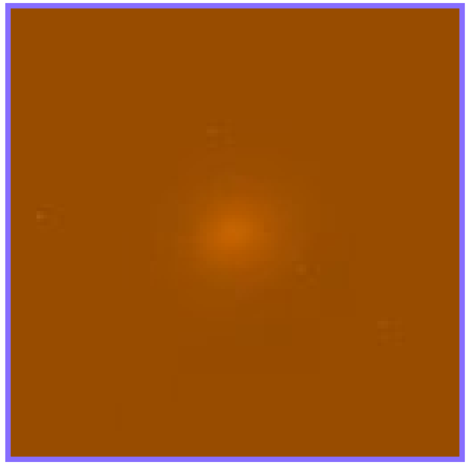
x4 UTs!

ALPAO deformable mirror
- 1432 actuators (43x43 grid)
- 109 mm controlled diameter

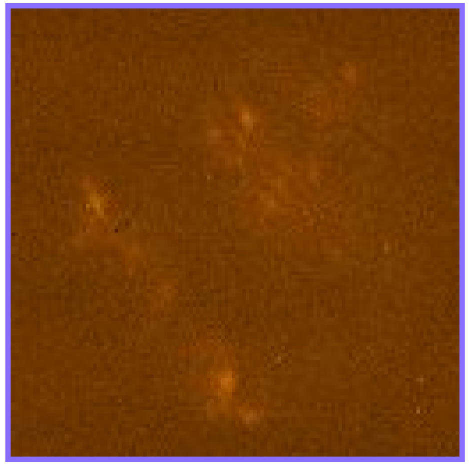
Wavefront sensors:
- 40x40 Visible Natural Guide Star
- 30x30 Sodium Laser Guide Star

NGS in operation – In short: this works!

- We did not break the IR modes

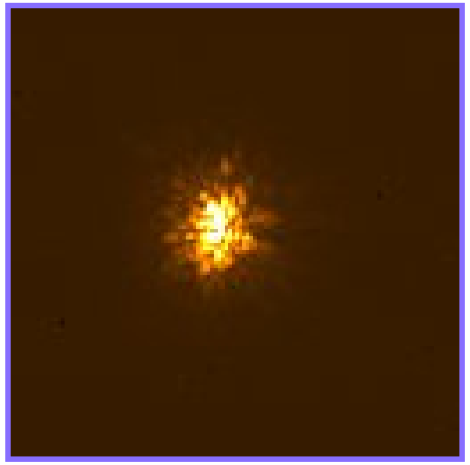


UXTau
(long exposure)



Galactic center
(real time)

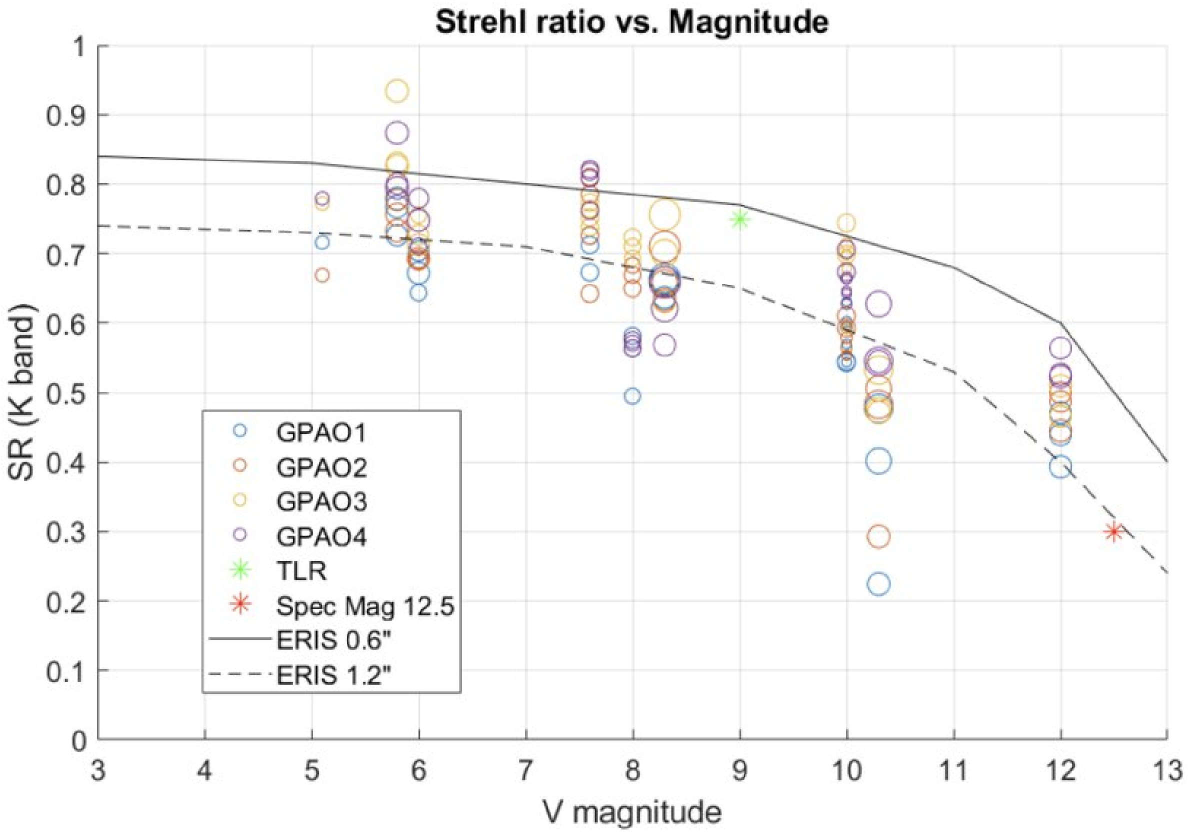
- Strong improvement from MACAO



Open/Close loop

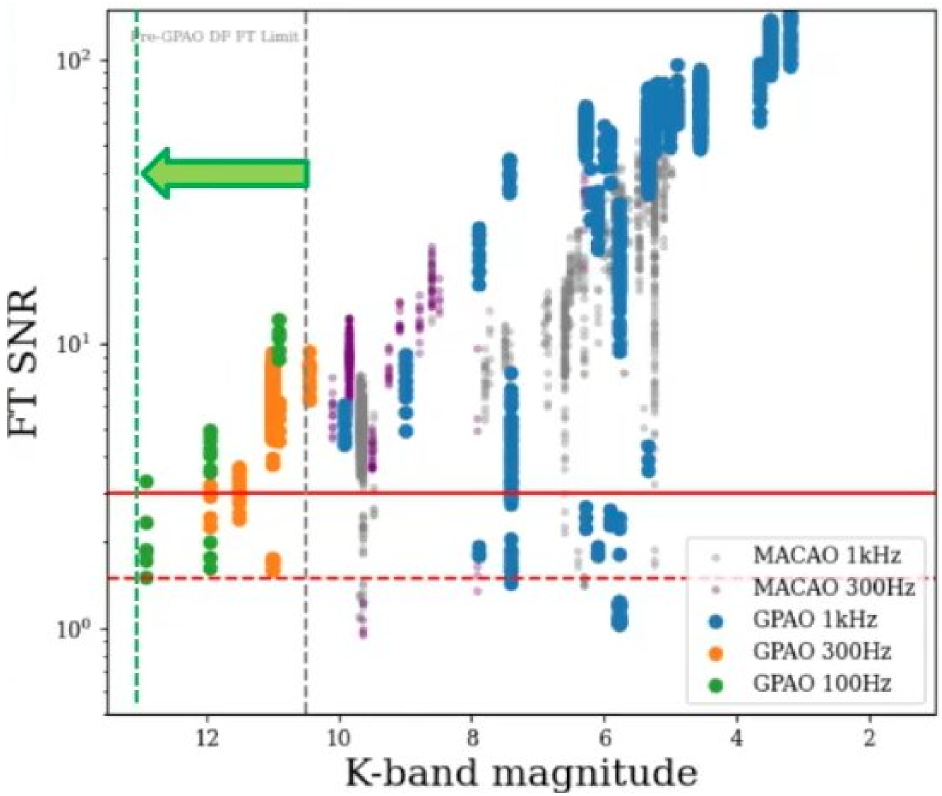
MACAO-like (50 modes)
vs GPAO (500 modes)

NGS in operation – Performances

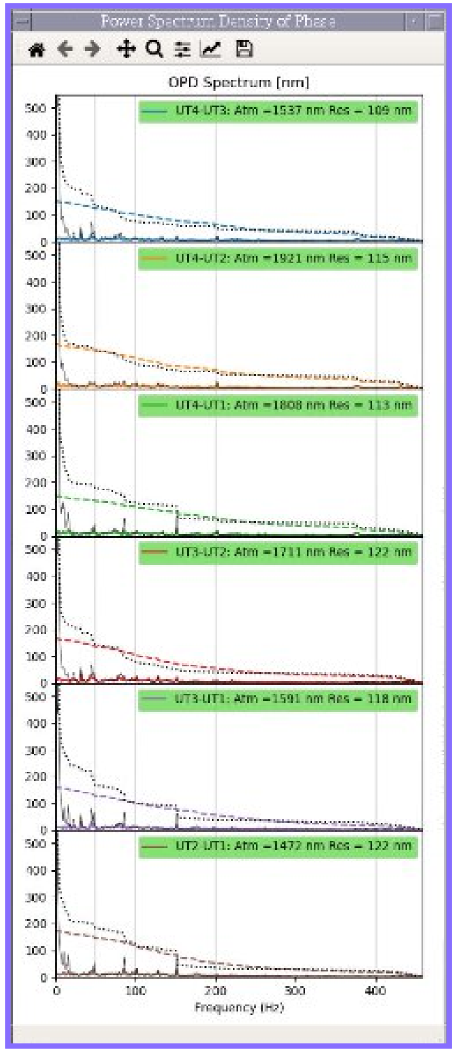


Bright end ⇒ Strehl up to 90%
Faint end ⇒ G = 12.5 limited magnitude

NGS in operation – Performances



Fringe tracking at **K = 13 mag and 100Hz**
Much more robust to weather conditions



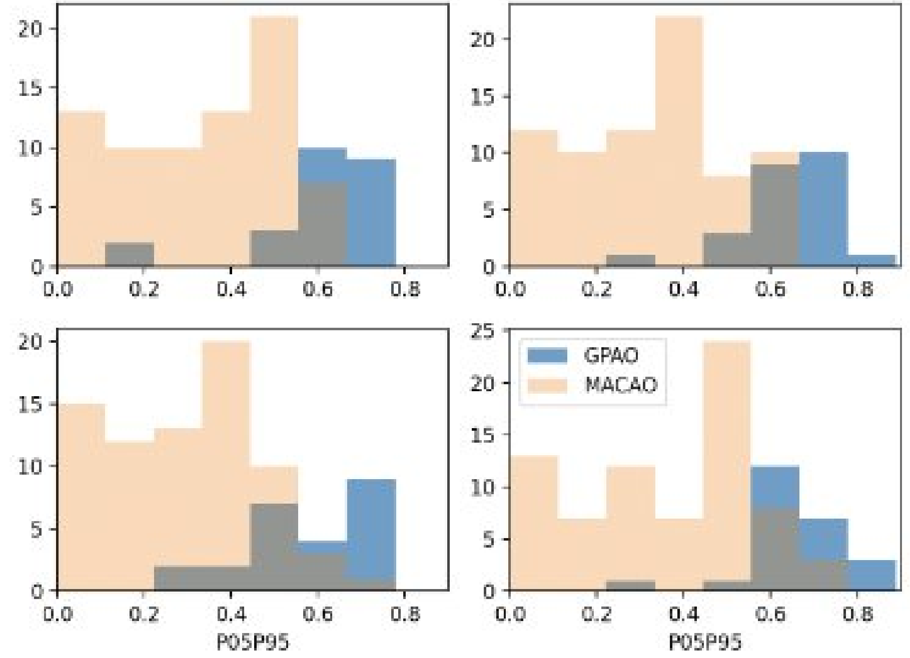
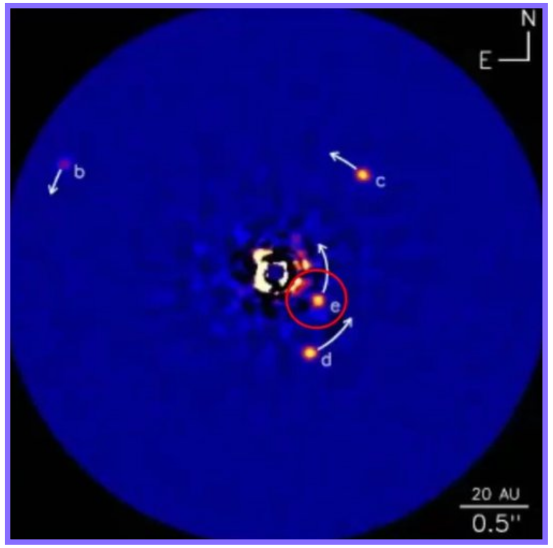


Fig. 7. Comparison between MACAO and GPAO AO of the $P_{5\%}/P_{95\%}$ injection metric histograms for the GRAVITY fringe tracker. The flux dropouts, represented by $P_{5\%}/P_{95\%}$ values close to zero, are significantly reduced by GPAO.

Manhattan + GPAO ⇒ Piston mode sensibly improved
<120nm RMS in NGS_VISc

NGS in operation – Early science

Exoplanets



HR8799

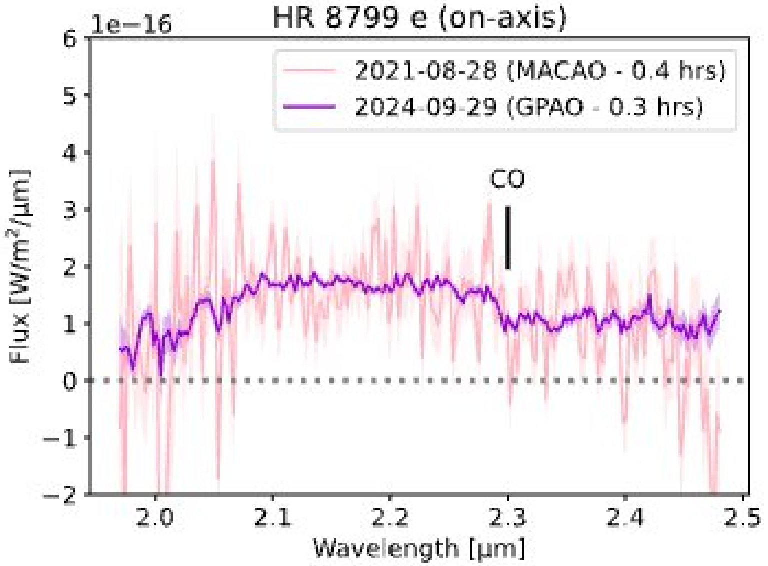


Fig. 9. Two GRAVITY on-axis spectra of the young giant planet HR 8799 e, one obtained with the new GPAO system and one obtained with the old MACAO system. An improvement in the SNR of a factor of ~ 10 in a comparable exposure time can be seen clearly.

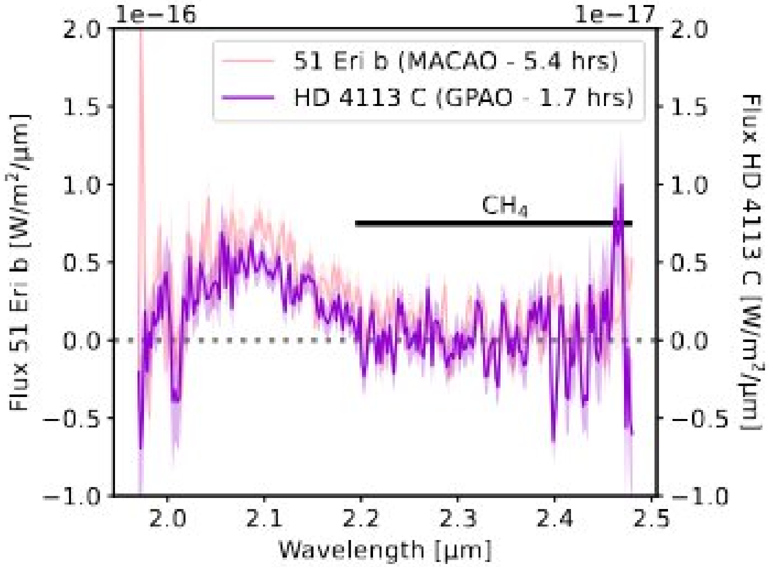
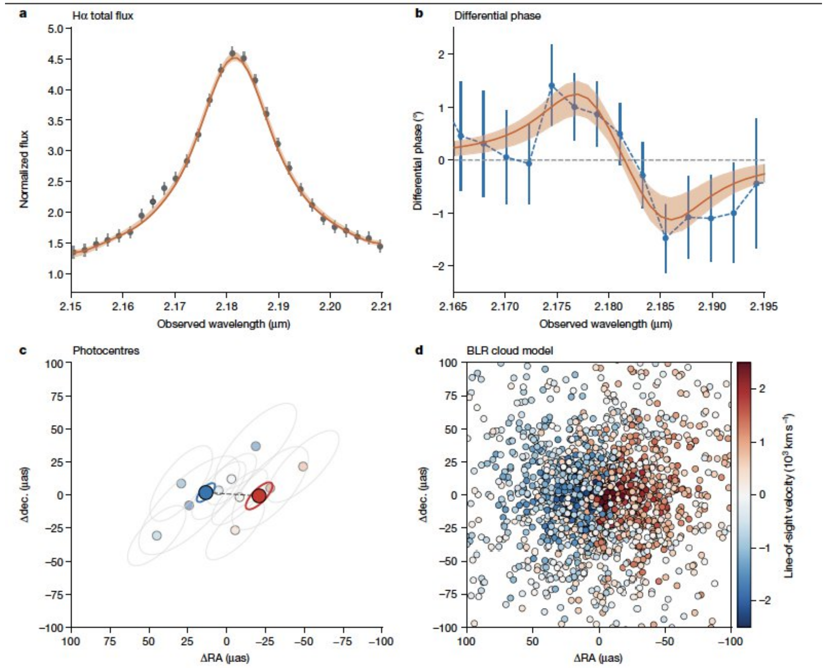


Fig. 10. GRAVITY off-axis spectrum of the brown dwarf companion HD 4113 C obtained with the new GPAO system compared to the off-axis spectrum of the exoplanet 51 Eri b obtained with the old MACAO system. We note the two different y-axes for the two objects, showing that a spectrum with a similar SNR can now be obtained with the new GPAO system for a ~ 10 times fainter object as compared to the old MACAO system.

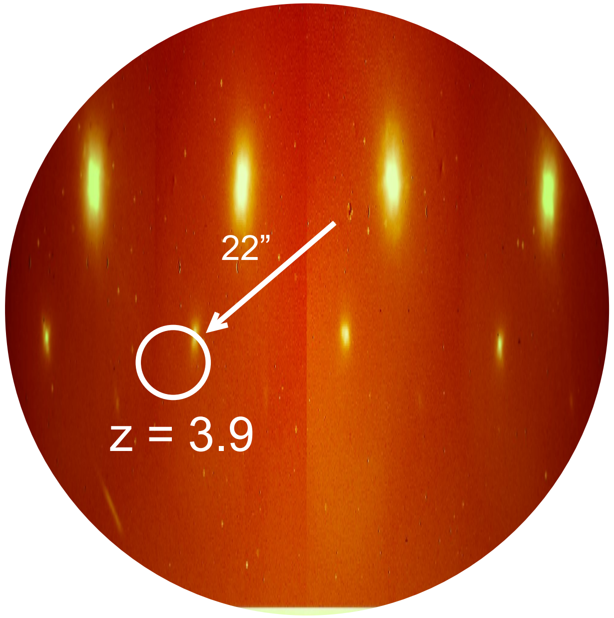
Active Galaxy nuclei / supermassive black hole

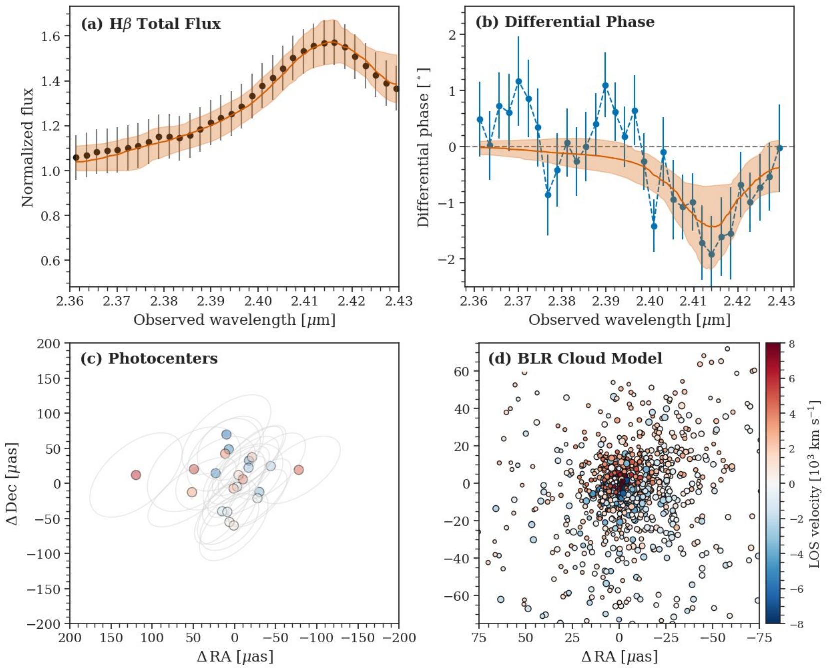
GRAVITY Wide
Super massive black hole
dynamical mass @ z=2



GRAVITY, Shimizu+, Nature 627 (2024)

GRAVITY+
GPAO & G-Wide
J0529 @ **z=4**



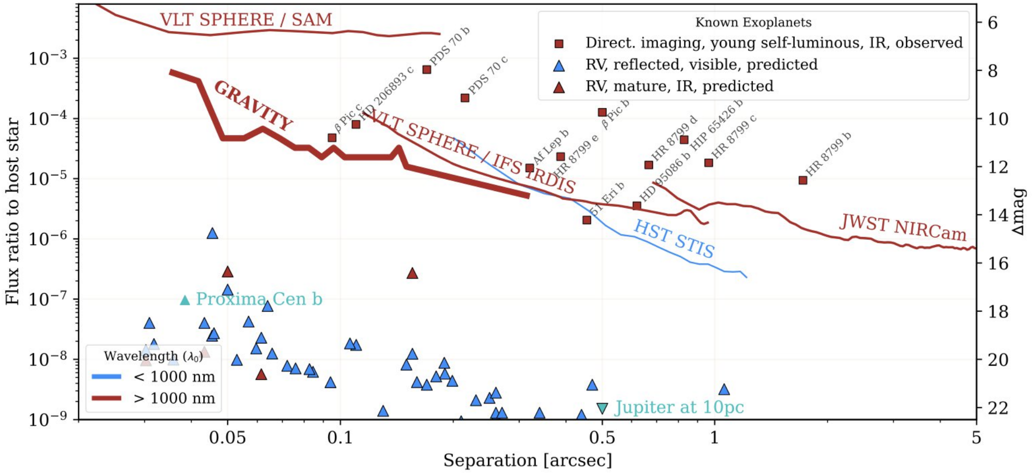


- Strong dip in differential phase indicative of dominant radial motion
- Initial modelling suggests much smaller BLR and SMBH by 1 dex compared to traditional methods

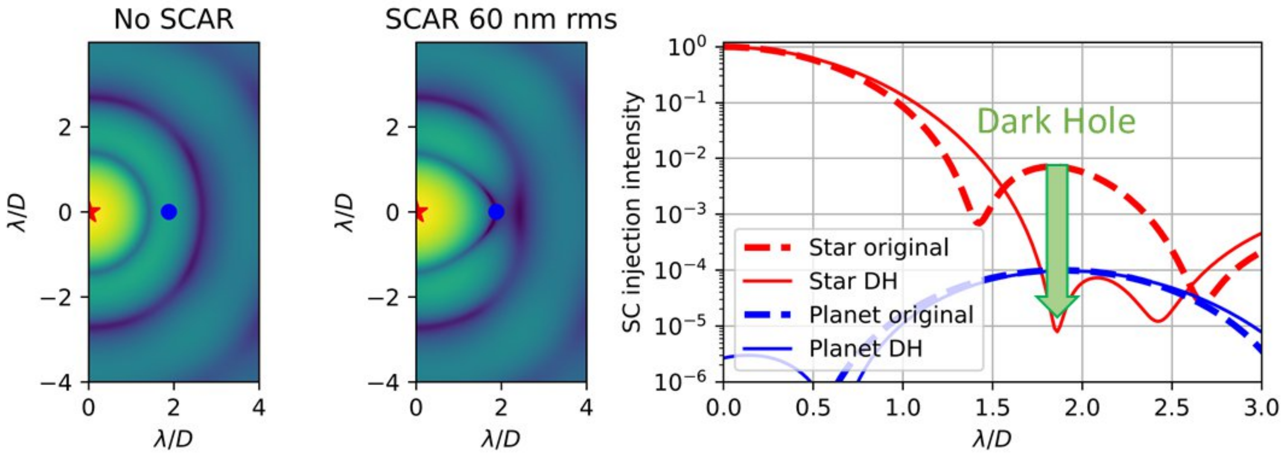
NGS in operation – Early science

When extreme AO meets interferometry

Current ExoGRAVITY detection limits



Pourré+, A&A 686 (2024)



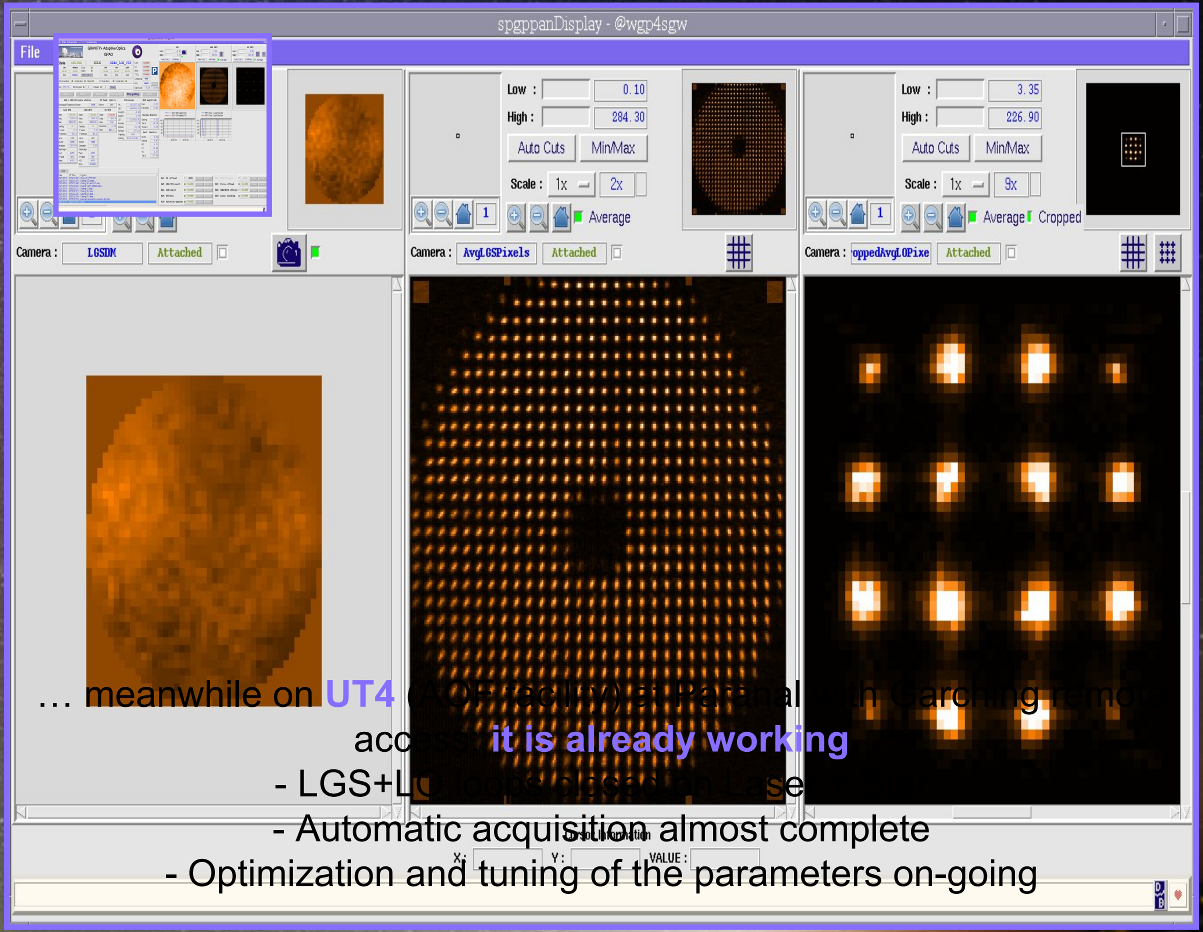
Lacour+ (in prep)

Coming soon: Laser Guide Stars (LGS)

LGS currently being integrated at ESO/Garching…

Laser installation ⇒ August/September
Laser commissioning ⇒ September/October
GPAO LGS commissioning ⇒ November/December

STAY TUNED!



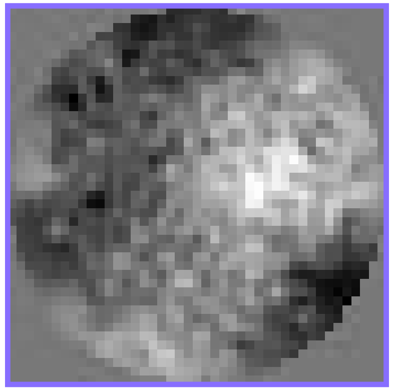
… meanwhile on **UT4** (AOF facility) at Paranal with Garching remote access: **it is already working**

- LGS+LO loops closed on Laser
- Automatic acquisition almost complete
- Optimization and tuning of the parameters on-going

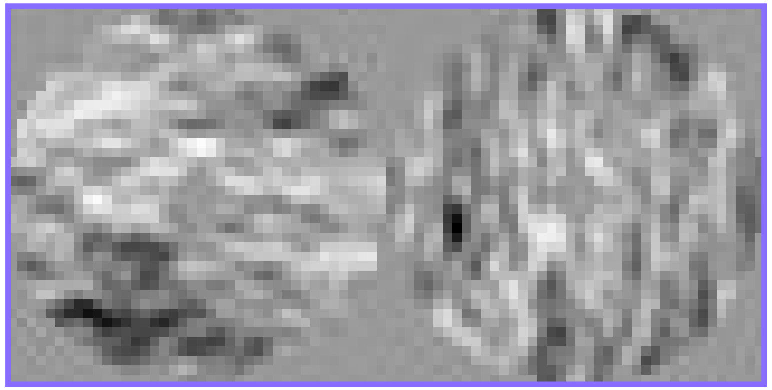
Picture taken during the January 2026 VLTI run ϑ

Adaptive optics: some perspectives

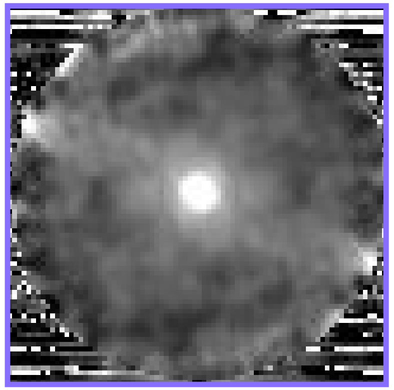
1. We have access to awesome telemetry… → 2. … that has many things to tell…



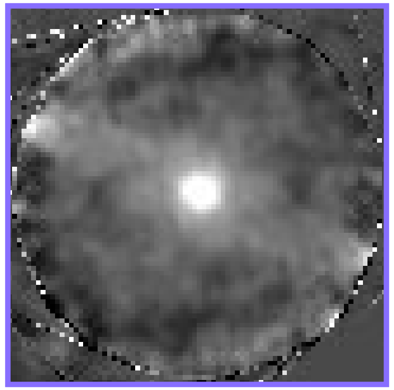
DM command



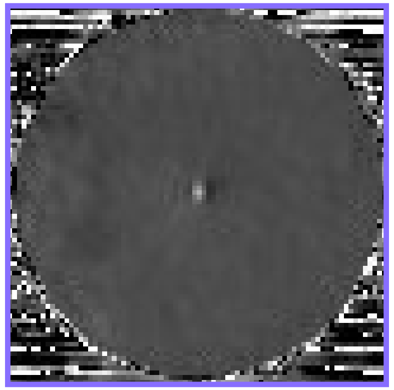
SH-WFS pseudo open loop slopes



2D+t slopes correlation



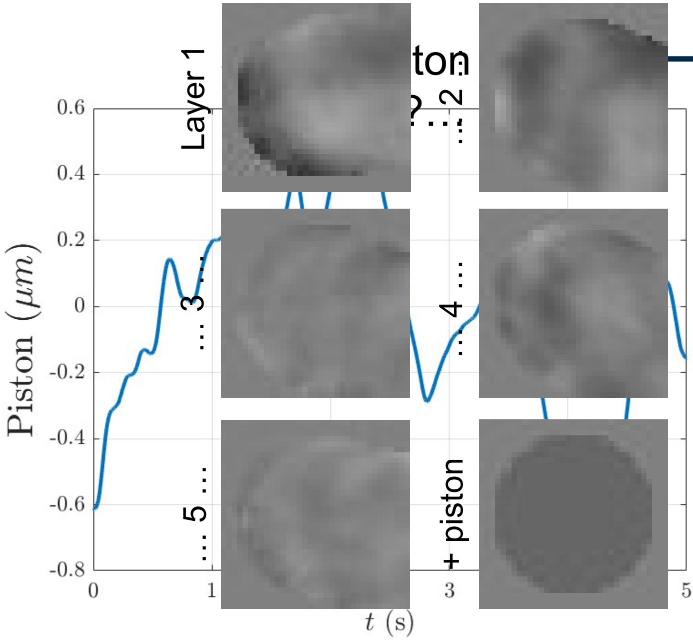
9-layer model

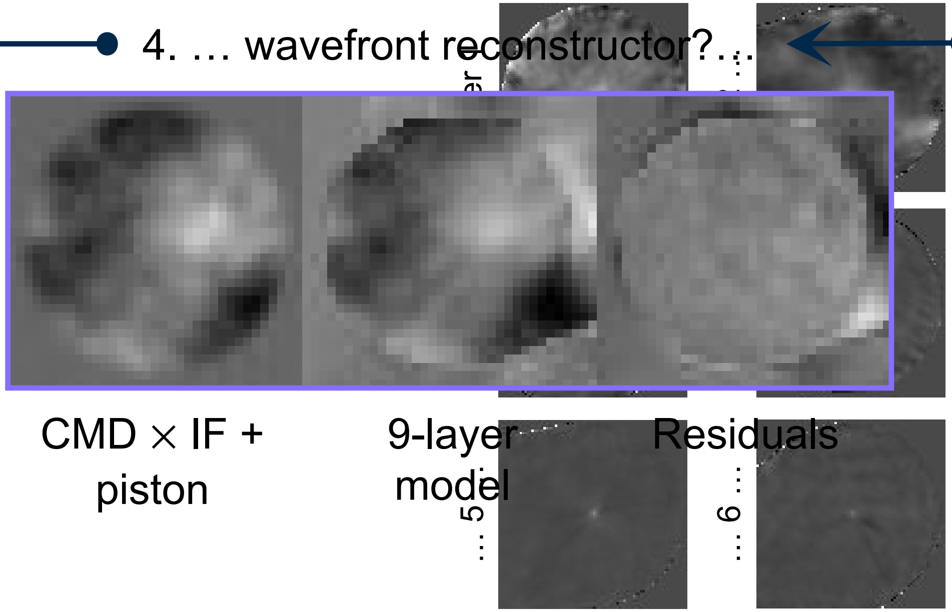


Residuals

3. … a “pseudo” turbulence profiler?…

4. … wavefront reconstructor?…

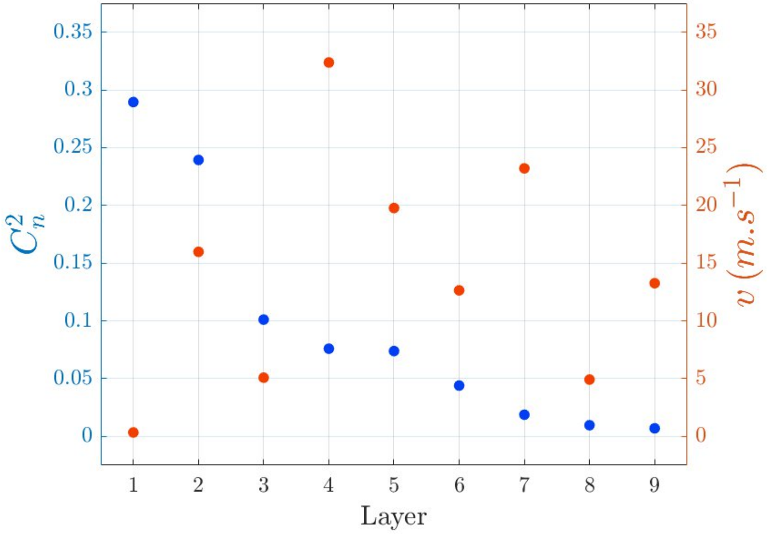




CMD × IF + piston

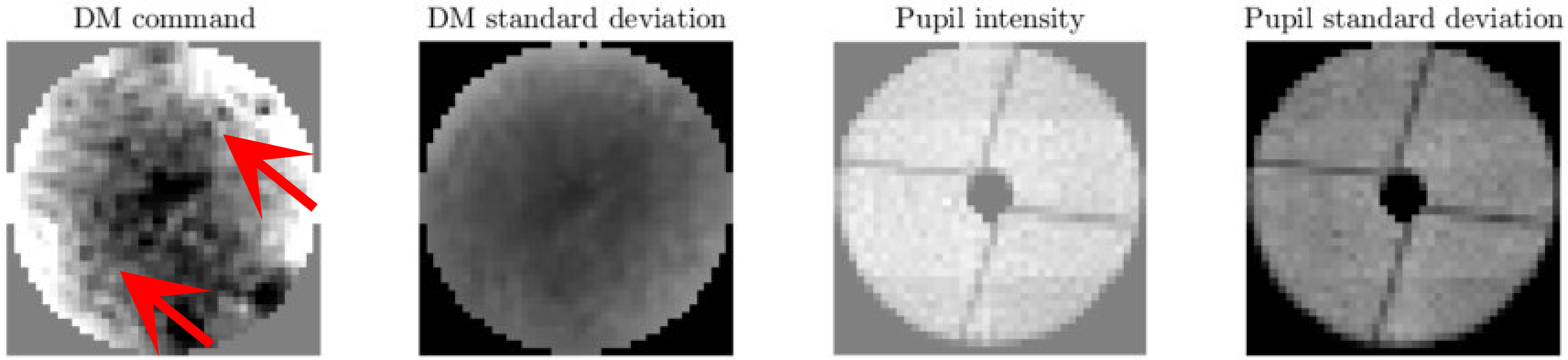
9-layer model

Residuals

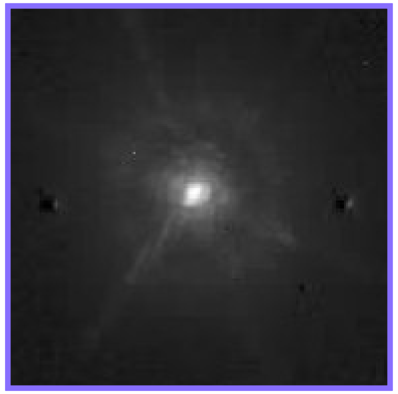


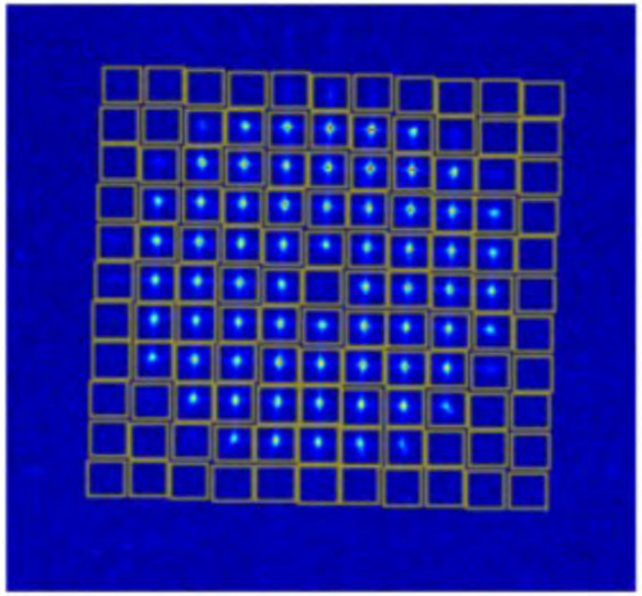
Adaptive optics: some perspectives

1. We have access to awesome telemetry…



2. … that can be combined to GRAVITY technical cameras…





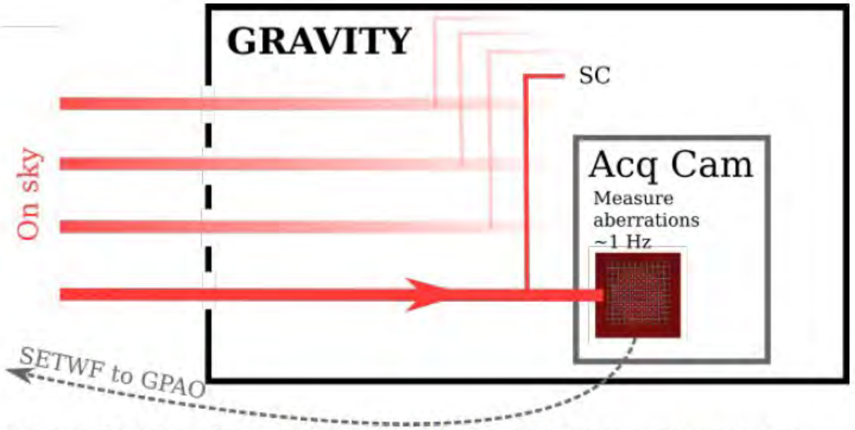


Figure 19: Tracking of NCPA with the SH during observations

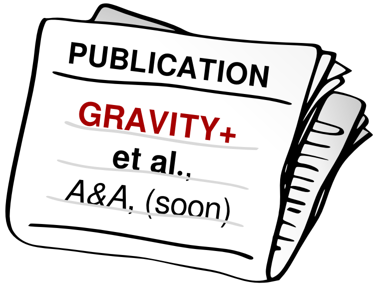
3. … toward a low wind effect mitigation strategy?…

4. … toward new monitoring tools?…

5. … toward a dynamic control of the non-common path aberrations?…

Conclusion

- NGS modes ⇒ working great!
- LGS modes ⇒ will be working great!
- Many more science to come
  - In high angular resolution astrophysics
  - In adaptive optics



First Light for the GRAVITY+ Adaptive Optics: Extreme Adaptive Optics for the Very Large Telescope Interferometer

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Thank you for your attention!