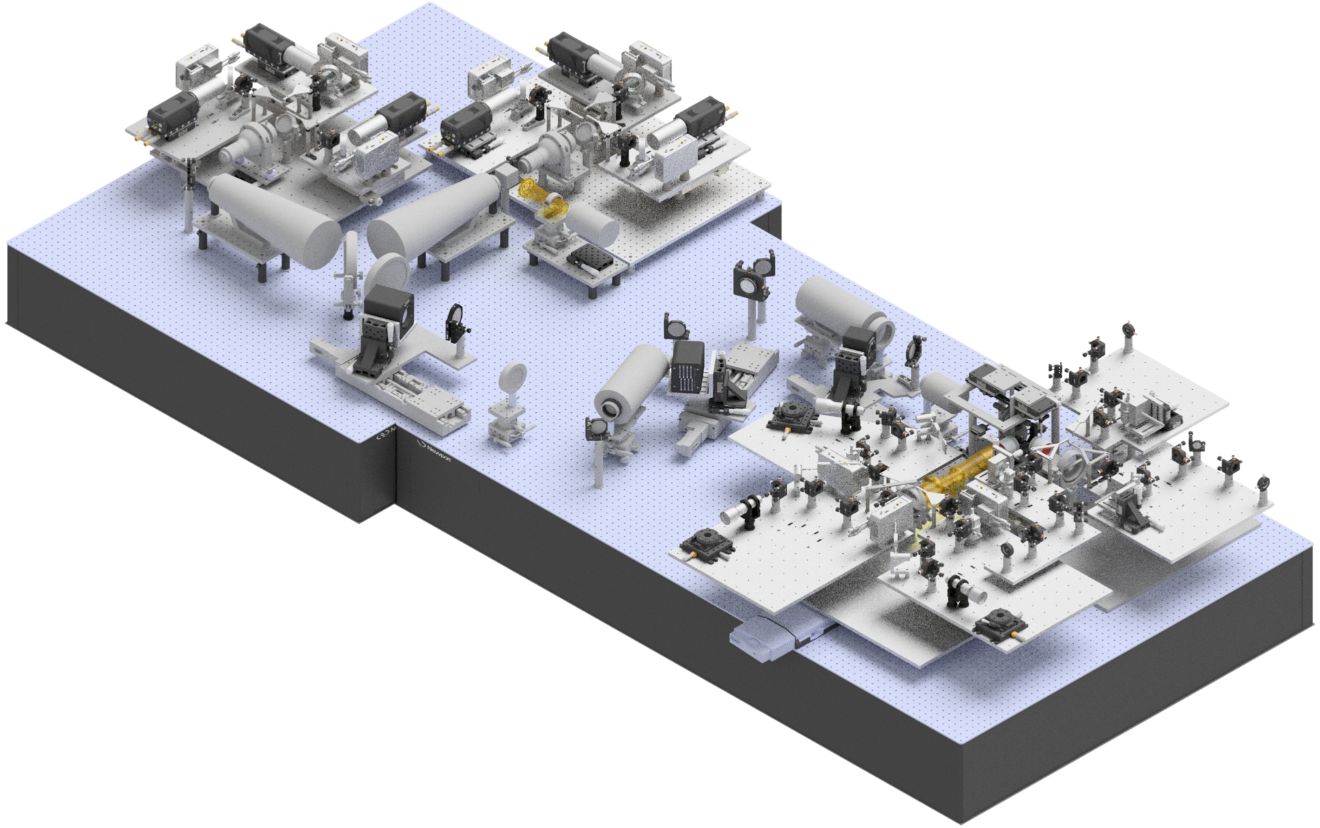
DAO4MATTO: the Real-Time Control solution for a Multi-Conjugate Adaptive Optics test bench

Alessandro Ballone

on behalf of the whole

OAPd
Instrumentation
& Adaptive Optics Group



USCVIII General Assembly - 16/10/2024

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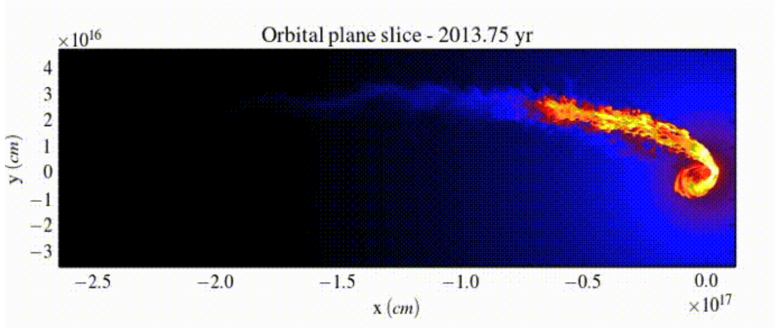
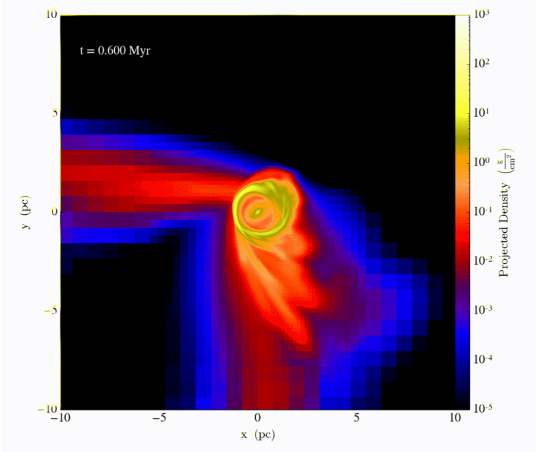
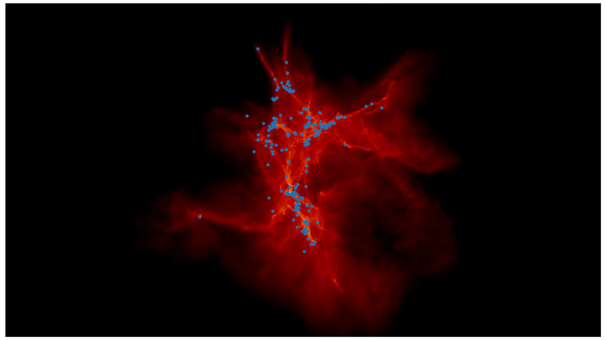
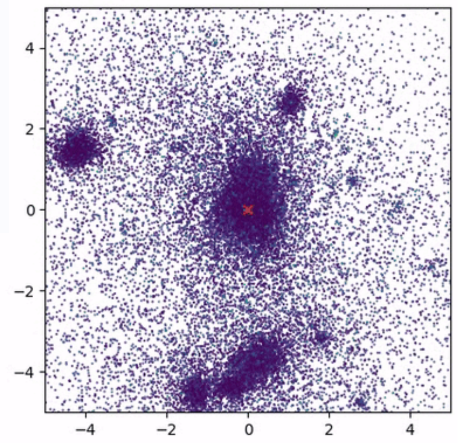
Very happy to be here!

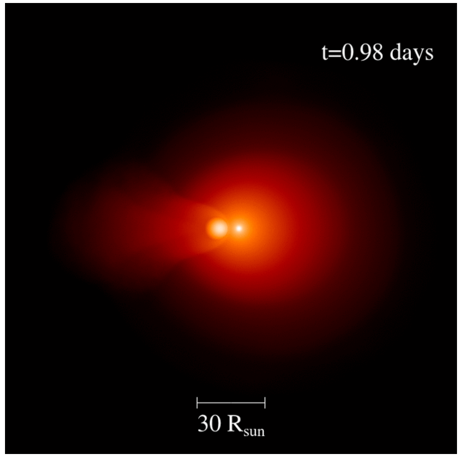
Until 2 yrs ago, I was doing theoretical astrophysics with hydrodynamical and N-body simulations.







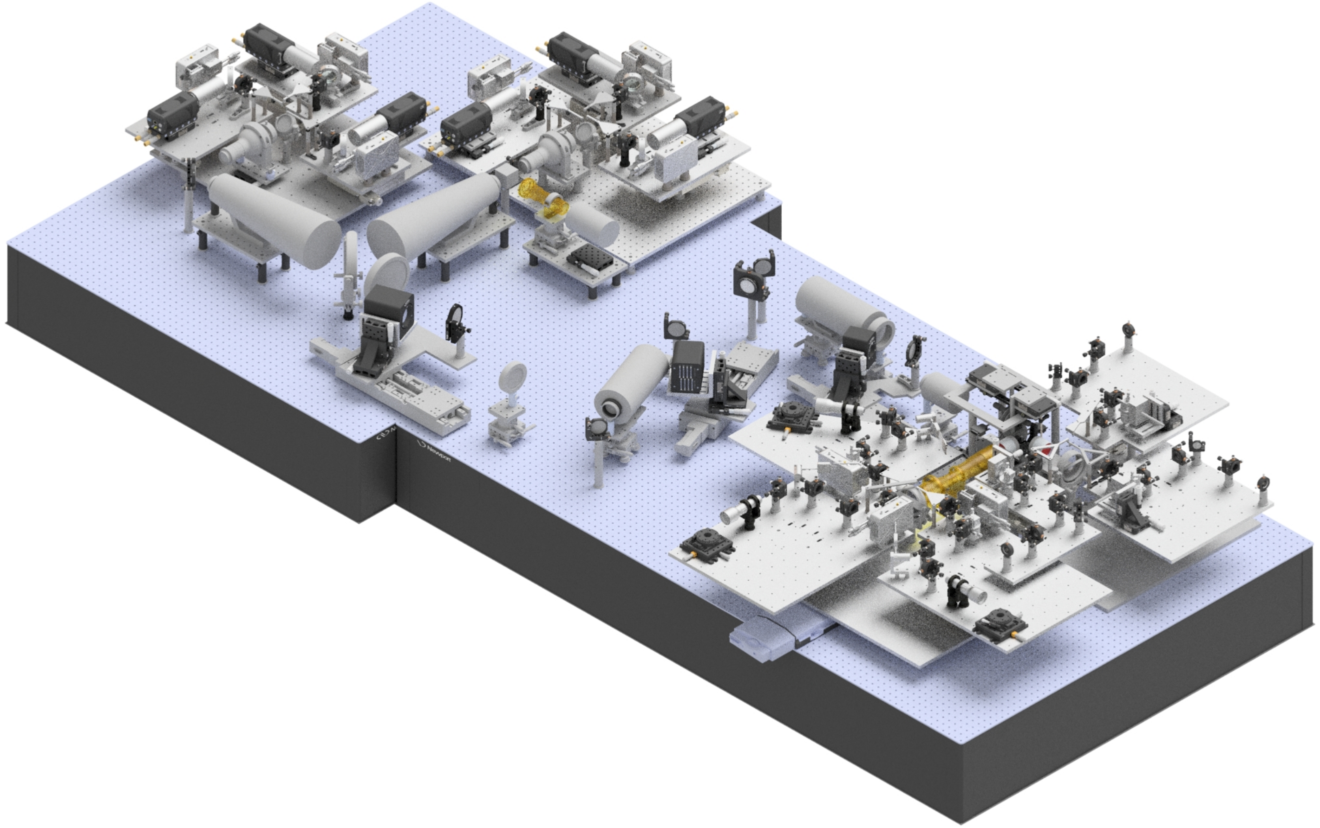




MATTO (**M**ulti-conjugate **A**daptive **T**echniques **T**est **O**ptics) is a wide field adaptive optics bench, to be built starting from 2025.

Its ambitious goal is to serve as an international facility to test current and future MCAO techniques, mostly with off-the-shelf components.

It is probably the only multi-purpose bench that can mimic very large and extremely large telescopes!



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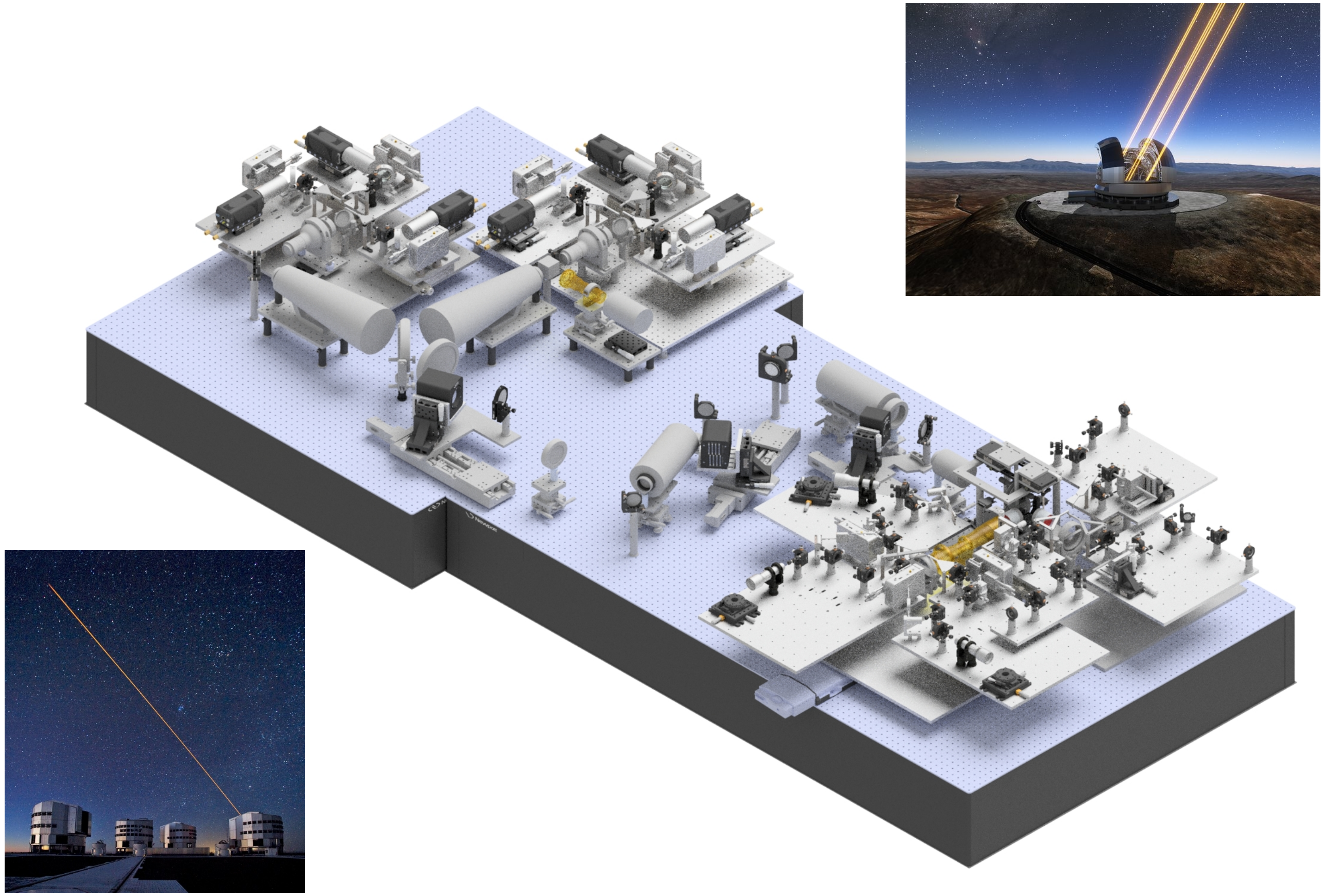


Funded by the Programma Nazionale di Resistenza e Resilienza (PNRR), through the **STILES** Program.

STILES: Strengthening the Italian leadership in ELT and SKA.

About 70M € for many different work packages.

Coordinated by INAF, in collaboration with 7 Italian Universities and international research institutes.

STILES is funding many projects in different INAF institutes!

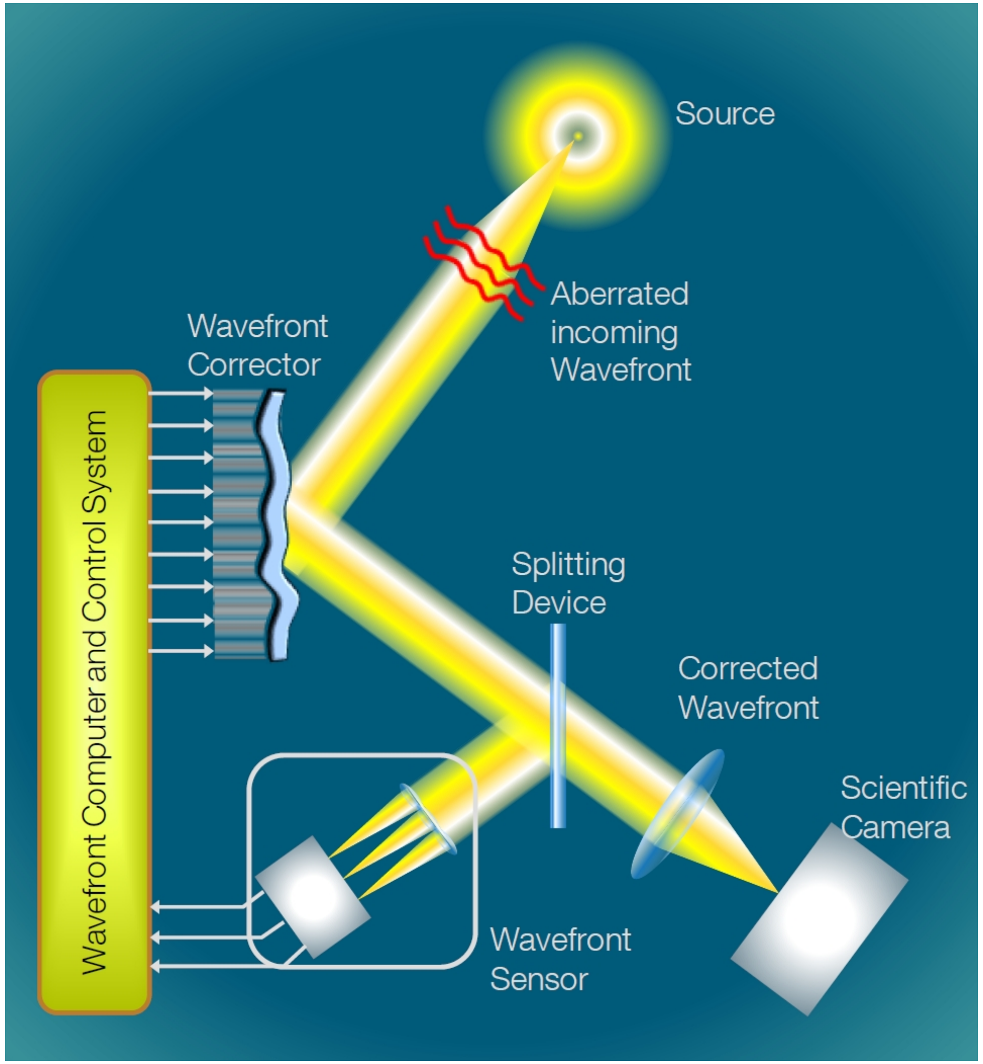
https://pnrr.inaf.it/progetto-stiles/

How does AO work?

1) **measure the distortion** introduced in the incoming wavefront by the atmospheric turbulence
(through a Wavefront Sensor)

2) the measured distortion is **converted in correction commands** of a corrector device
(usually a Deformable Mirror)

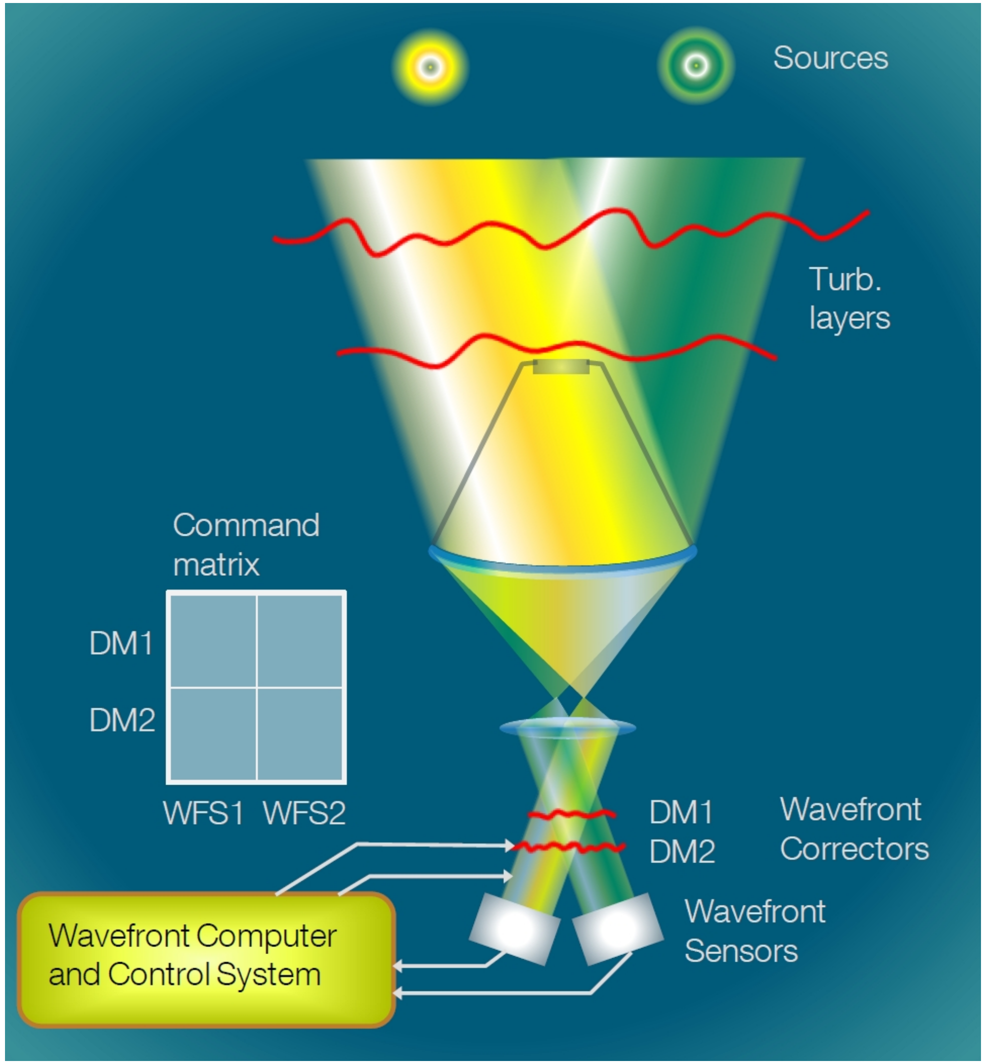
This has to be done very fast (by a **Real-Time Control System**) at the typical time variation frequency of the atmospheric turbulence.



What is MCAO? And most importantly: why MCAO?

Anisoplanatism…

We are probing only the effect of turbulence close to our reference star
(actually, within a turbulence coherence "isoplanatic" angle)



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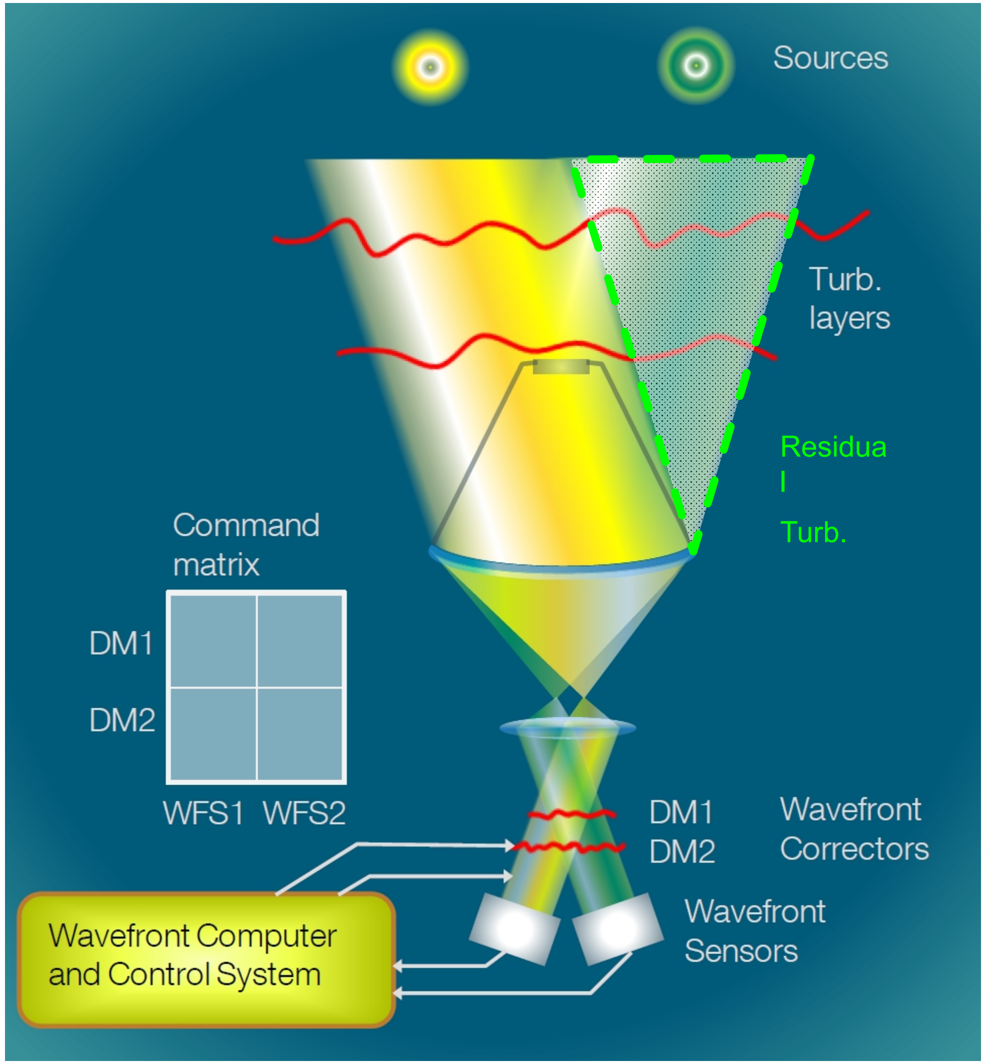

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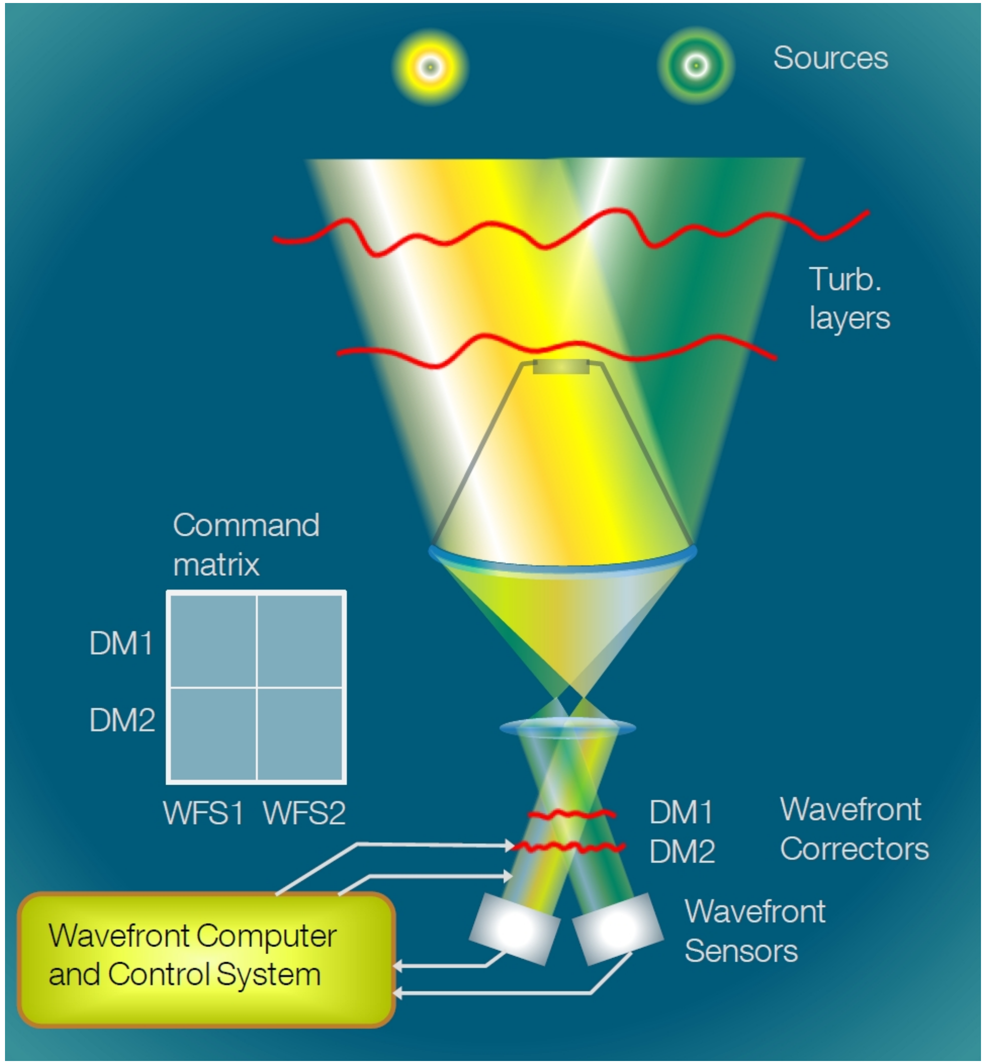
We want to uniformly correct **larger fields of view** and for the **effect of different atmospheric layers**!

Multi-Conjugate Adaptive Optics

And to cover the whole field of view and increase the sky coverage, Laser Guide Stars (LGS) are certainly needed!



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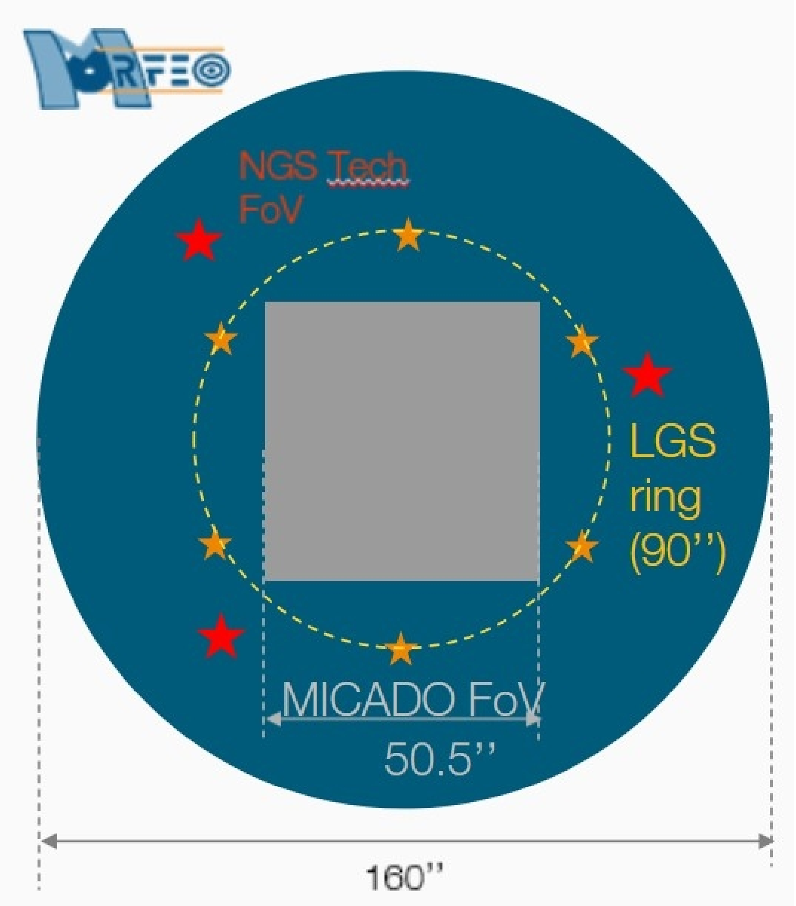

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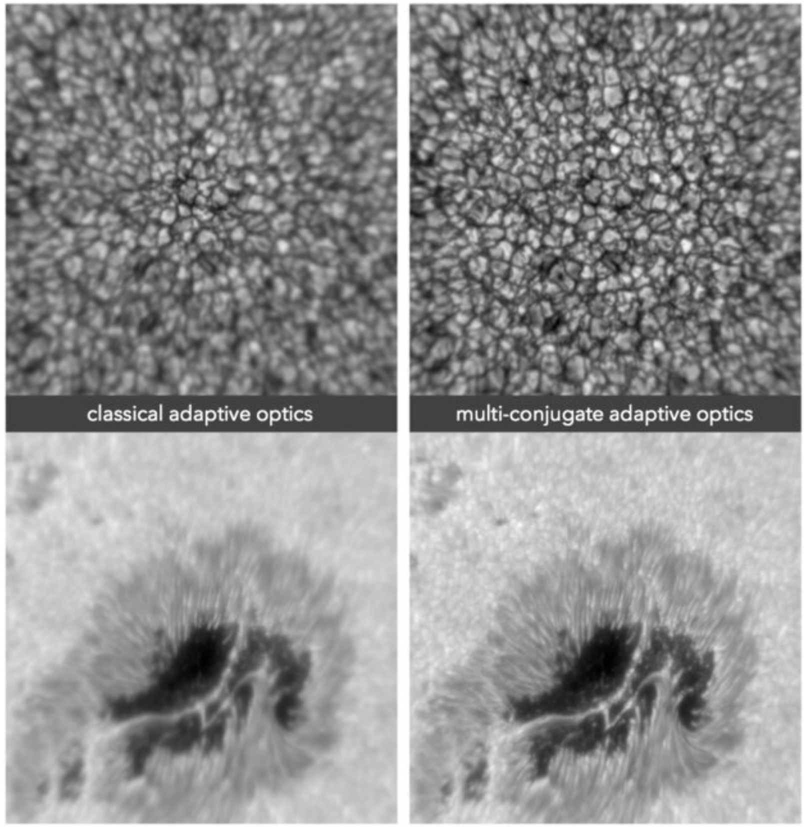

Credit: Schmidt et al. (2017), Inouye Solar Telescope

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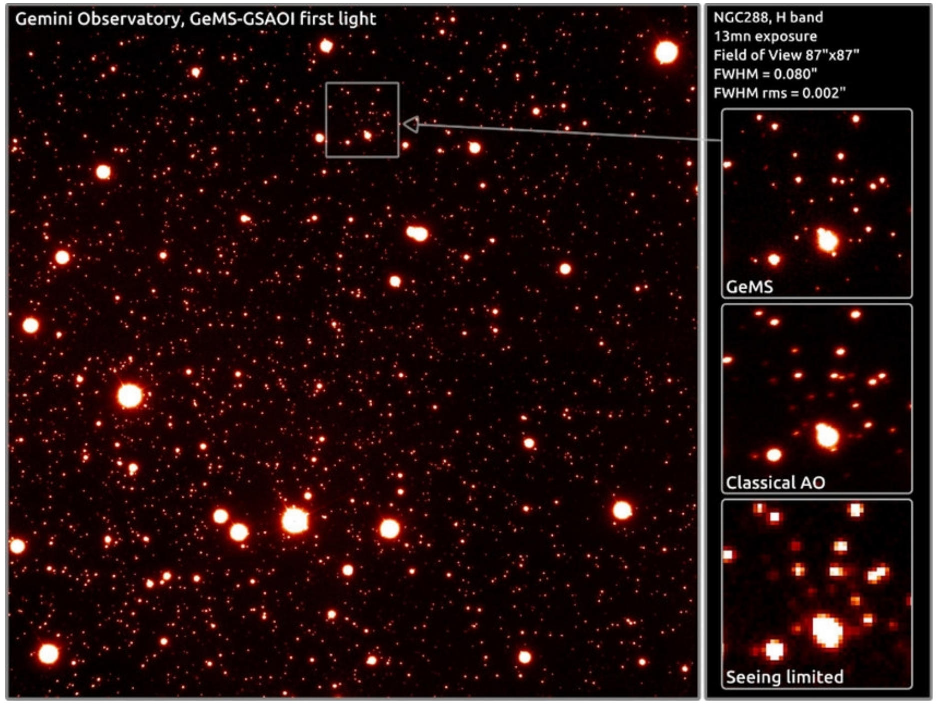

Credit: Neichel & Rigaut (2012), Gemini Observatory

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Multi-Conjugate Adaptive Optics

And to cover the whole field of view and increase the sky coverage, Laser Guide Stars (LGS) are certainly needed!

All developed at OAPd!

MAVIS

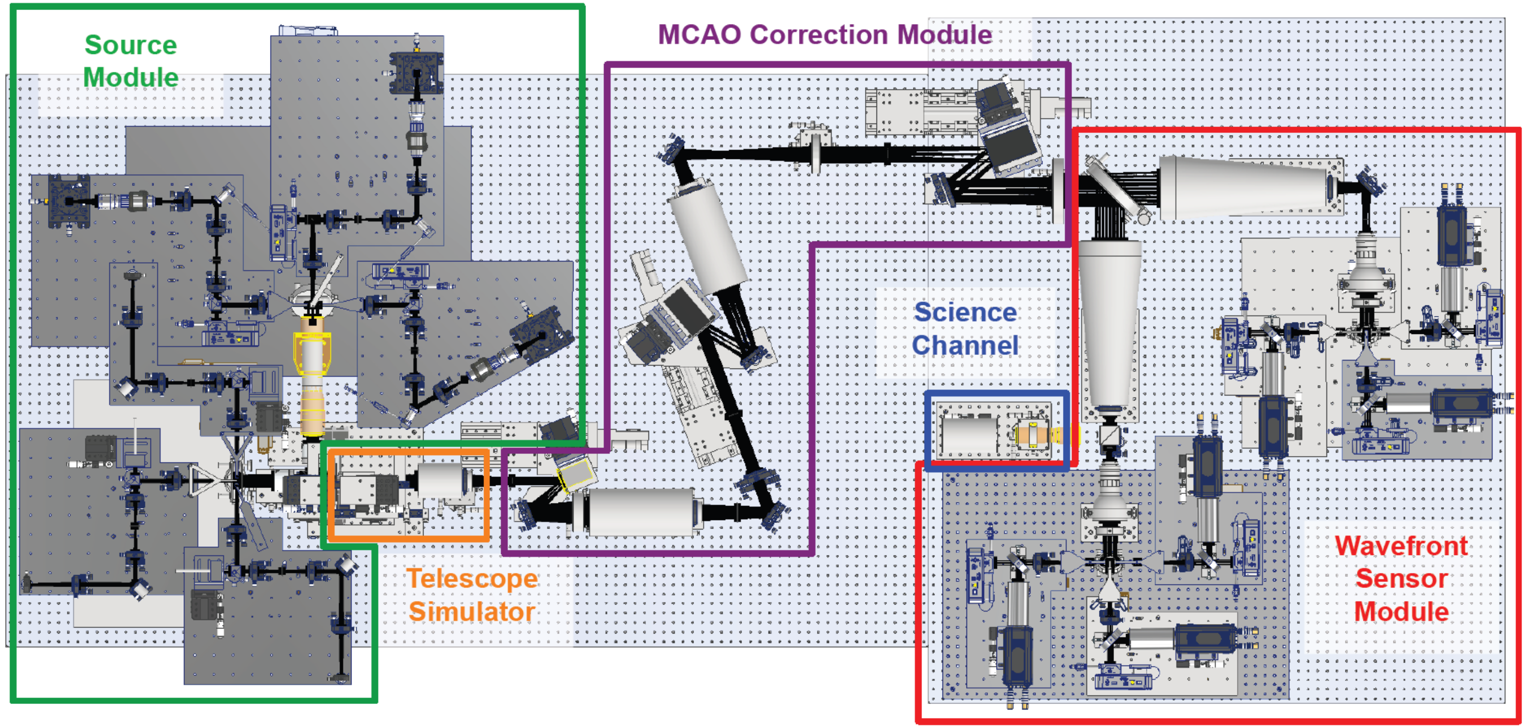
LINC NIRVANA

MORFEO
Multiconjugate adaptive Optics Relay For ELT Observations

MATTO needs to adapt to:

- source types, numbers, positions
- (new!) wavefront sensing techniques
- telescope sizes (the whole system has to be “rescalable”)
- new technologies or future upgrades
- different atmospheric characteristics

The magic word is...
MODULARITY!



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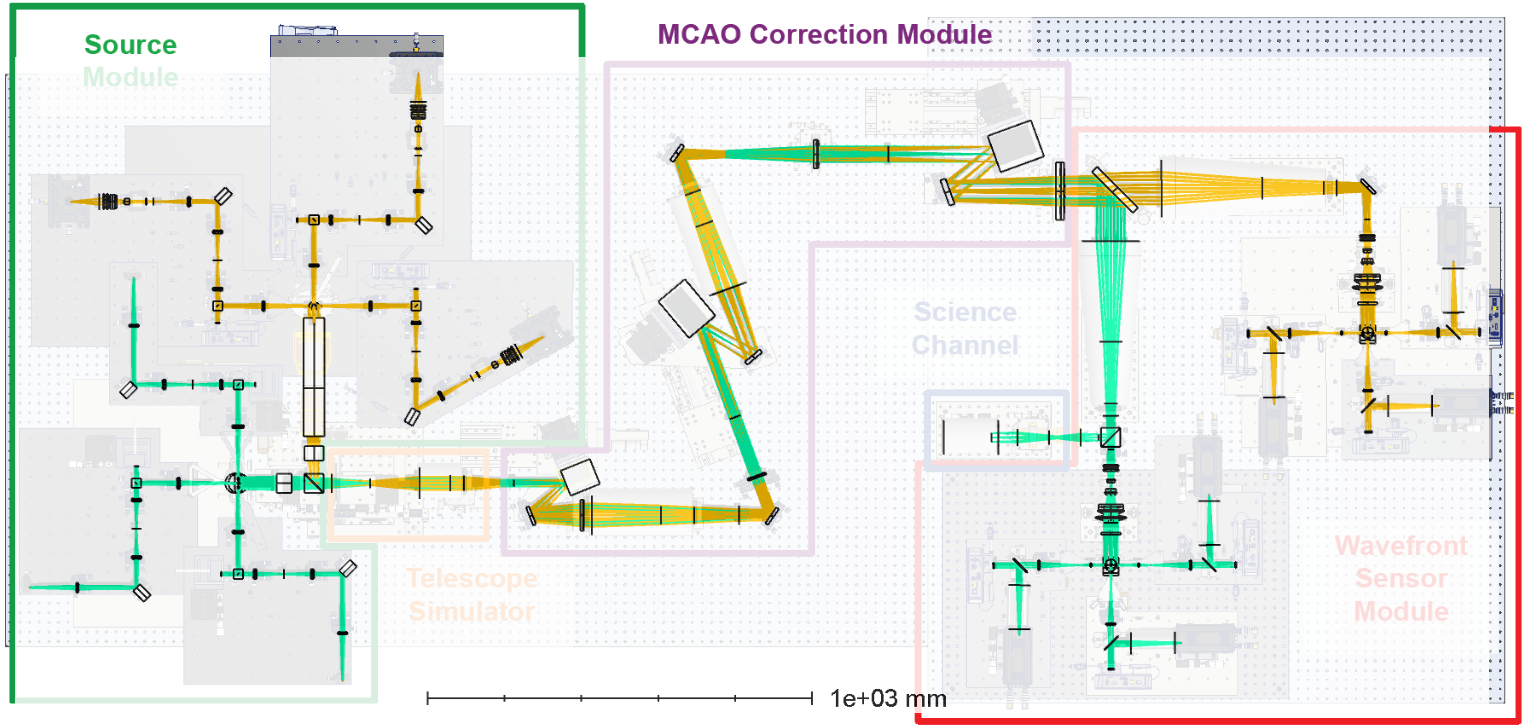
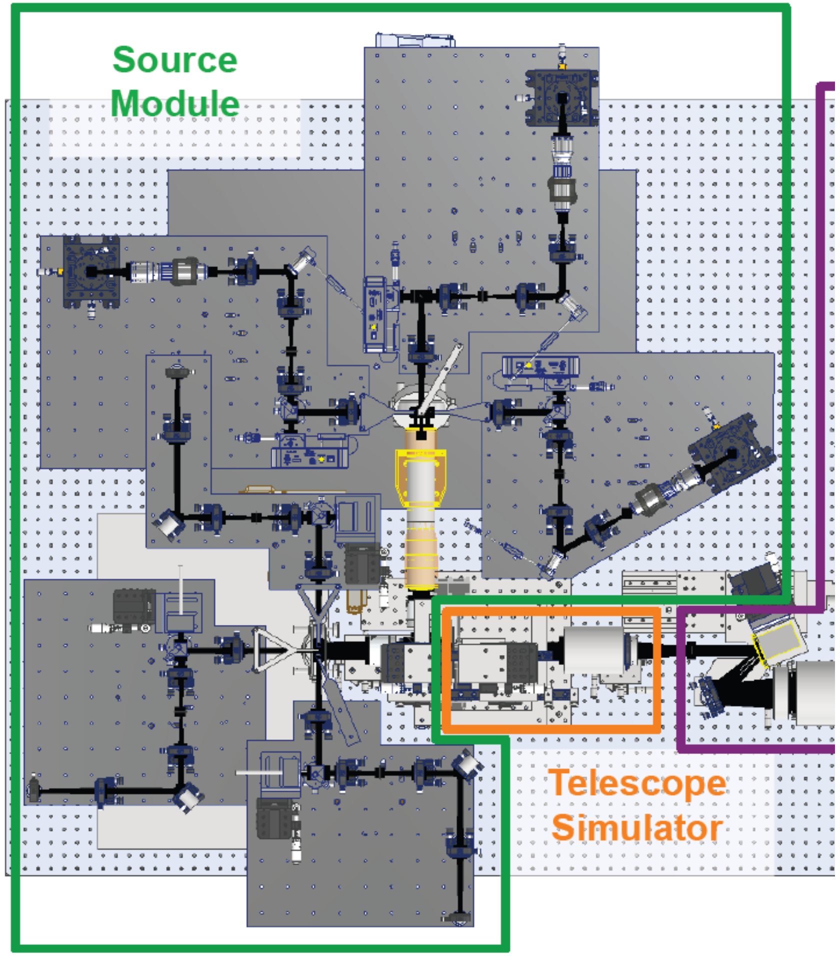


The control system **operationally** needs to:

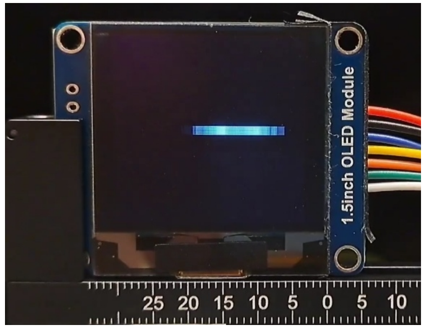
- simulate the sources

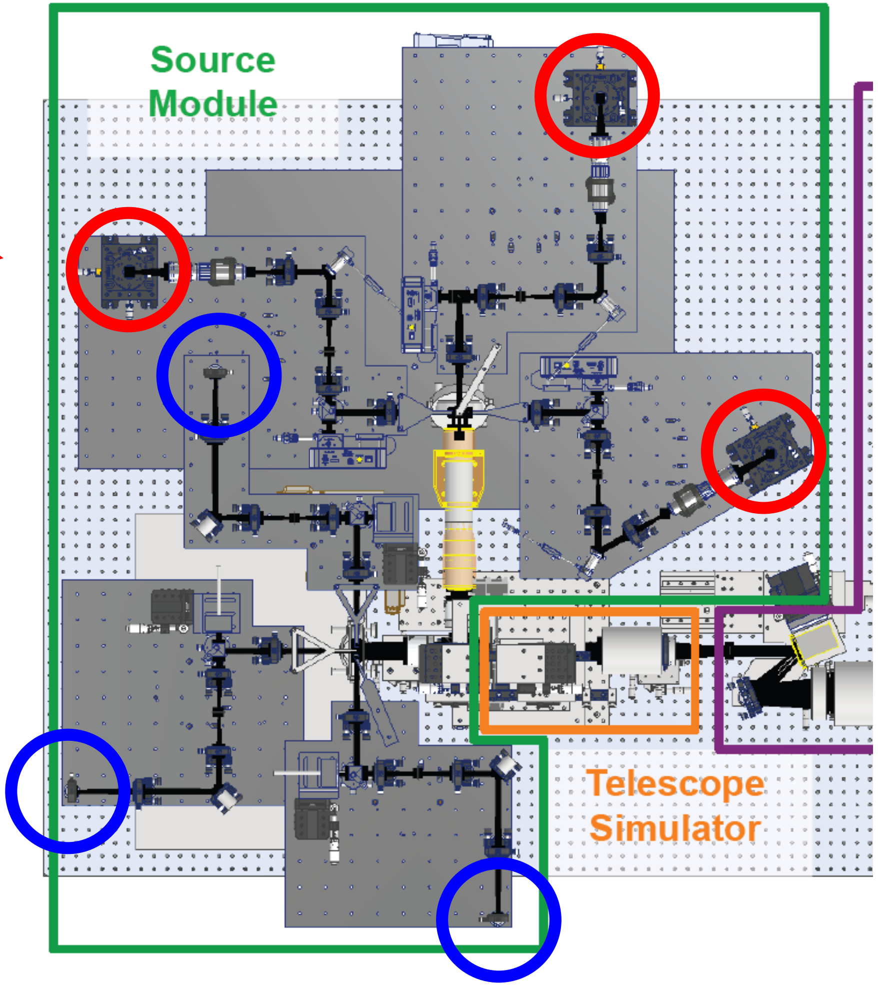


The control system **operationally** needs to:

- simulate the sources

- ***3 normal LEDs*** for the NGSs
- ***3 OLED screens*** for the LGSs (elongated!)

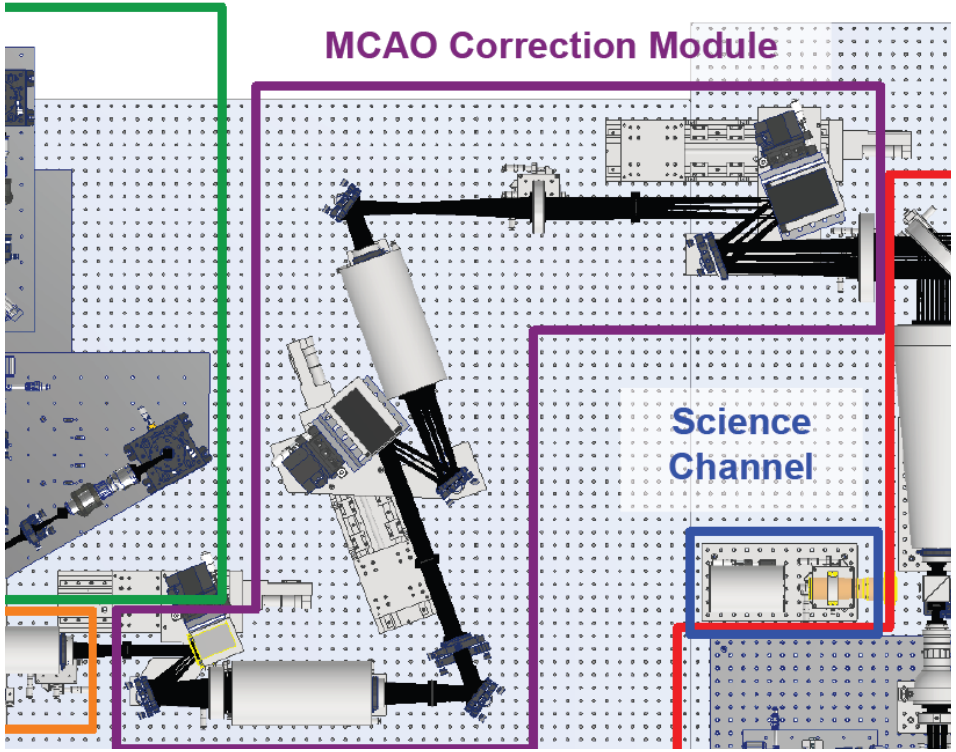




The control system **operationally** needs to:

- simulate the sources

- move optical elements on motorized stages, to rescale the system



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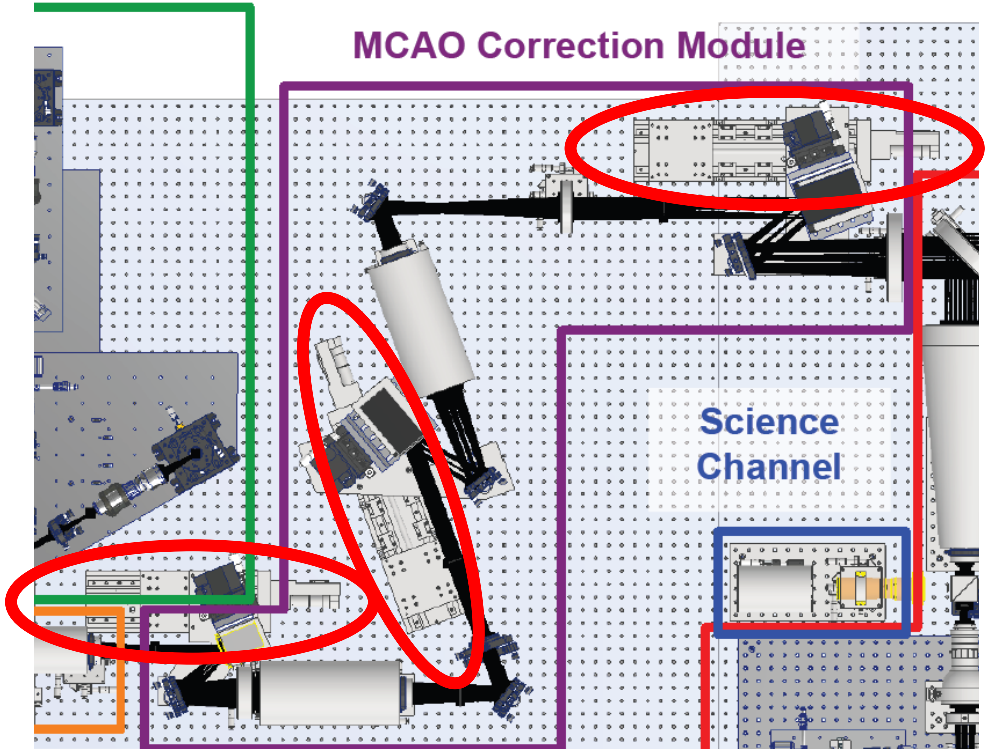
E.g., ***linear stages*** to adjust the conjugation of the correction Deformable Mirrors



The control system **operationally** needs to:

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- introduce simulated turbulence

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- introduce simulated turbulence

If done in a controlled way, this means simulating a turbulent phase distortion history and inputting it on some physical wavefront aberrators.

Needs to be very fast.
Typical turbulence coherence time frequency ~ **1 kHz**!!!

The control system **operationally** needs to:

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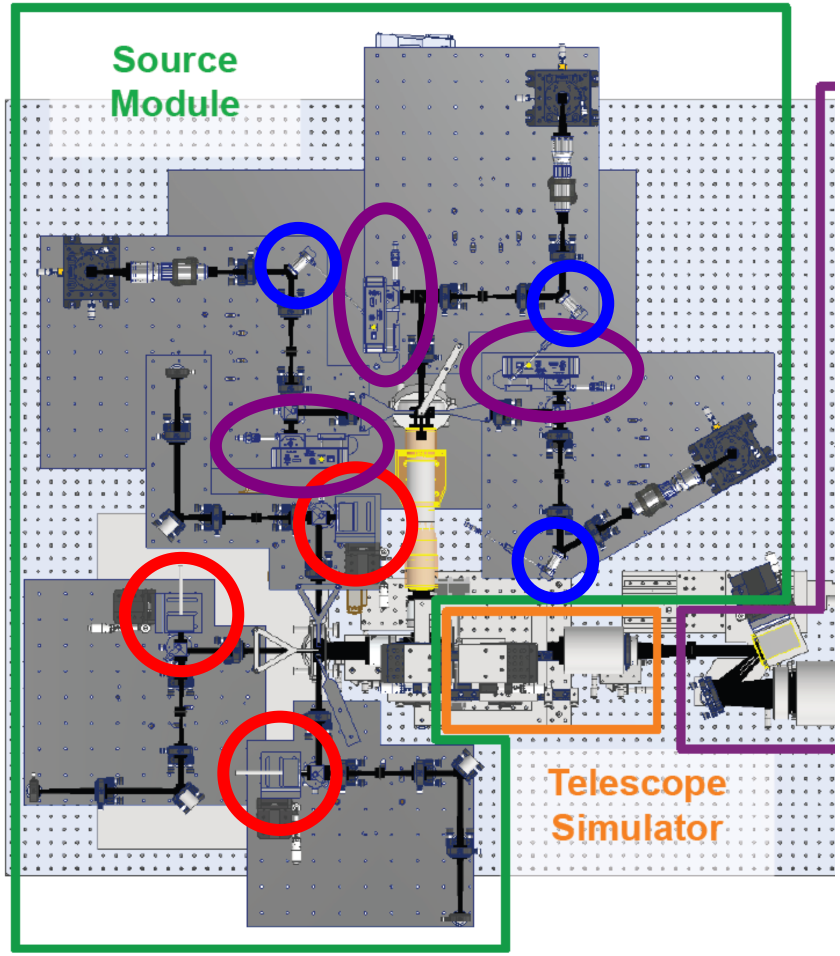
Aberrators:

- *3 Deformable Mirrors (97 actuators)* for the NGSs
- *3 Tip-Tilt Mirrors* + *3 fast Spatial Light Modulators* for the LGSs



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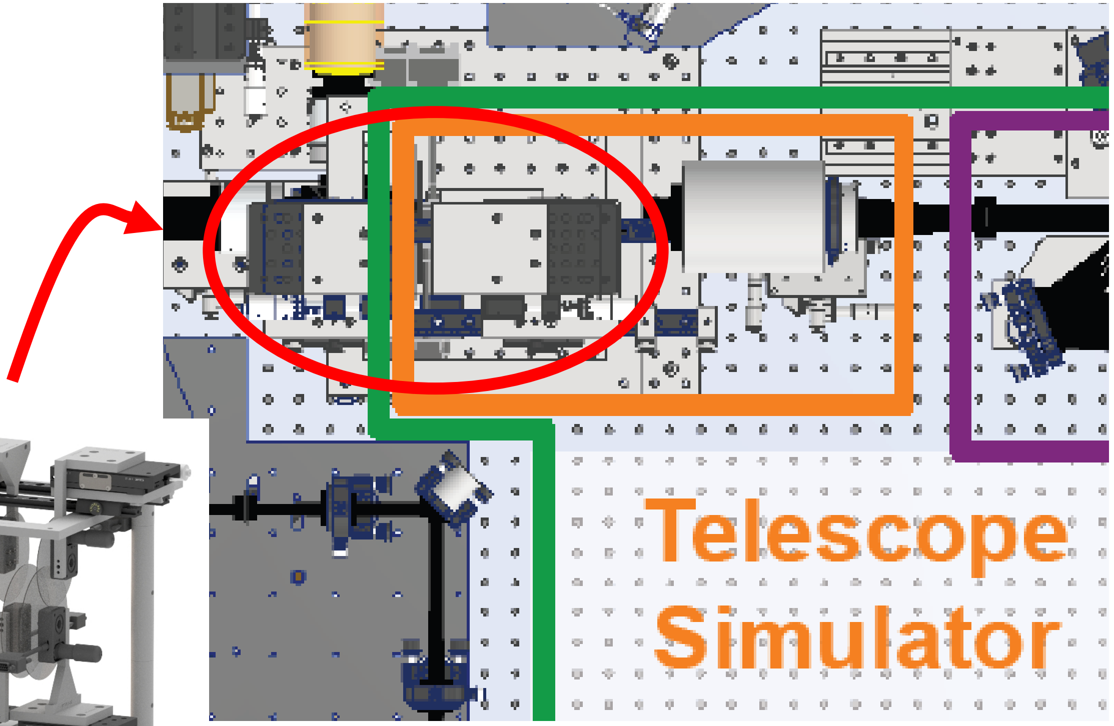


Aberrators:

- 4 photo-lithographically etched phase screens, mounted on ***fast rotating stages***

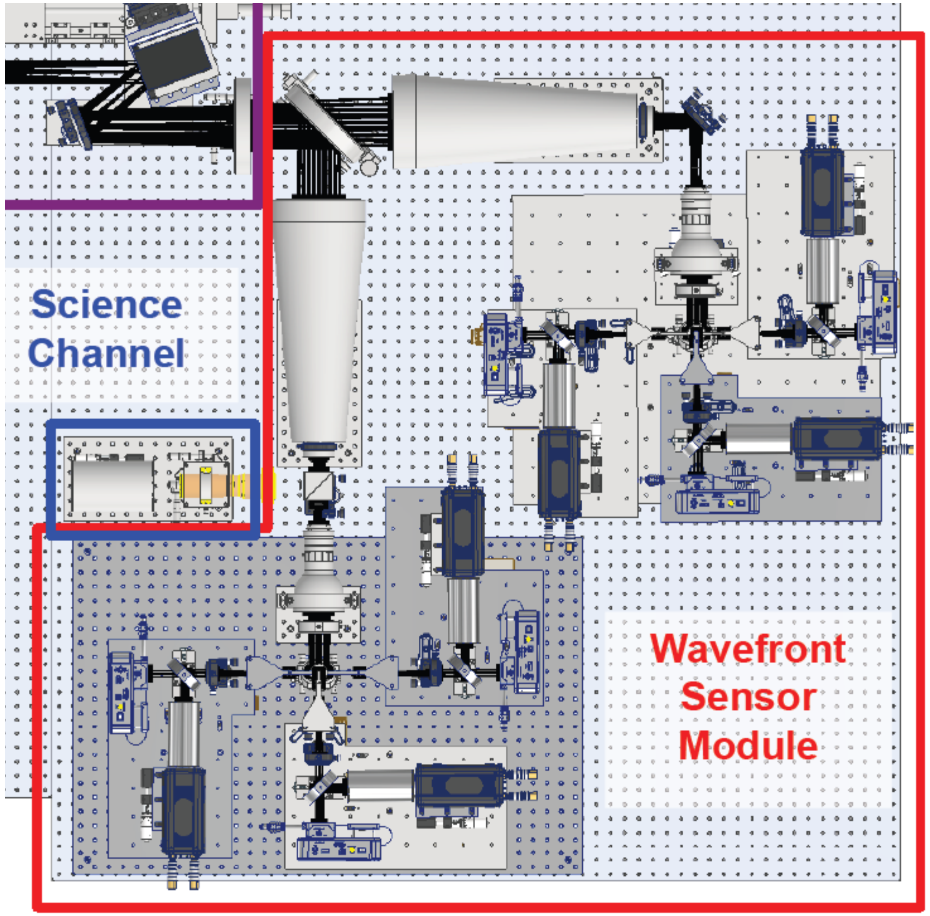
The control system **operationally** needs to:

- simulate the sources

- move optical elements on motorized stages, to rescale the system

- introduce simulated turbulence

- measure the wavefront distortion



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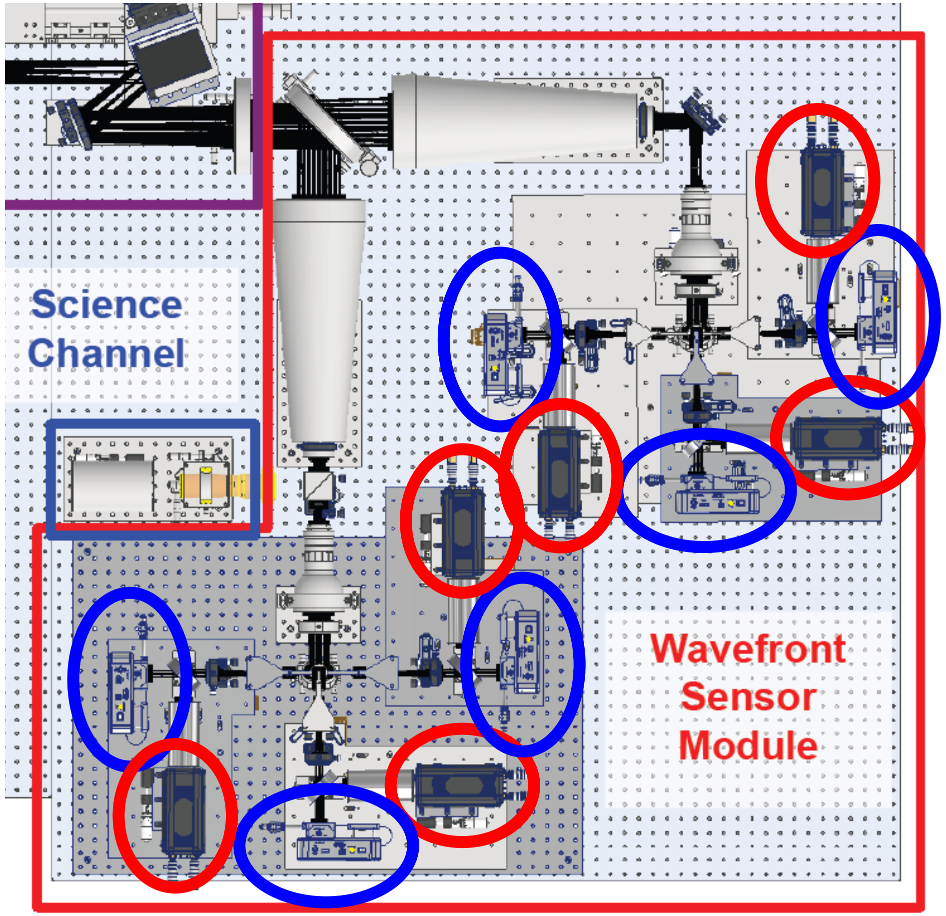

- ***6 stable Spatial Light Modulators*** (phase masks)

+

- ***6 GigE Vision technical cameras***

to mock any type of Wavefront Sensing Technique

The control system **operationally** needs to:

- simulate the sources

- move optical elements on motorized stages, to rescale the system

- introduce simulated turbulence

- measure the wavefront distortion

- correct the wavefront distortion

a) build an **Interaction Matrix** (corrector commands → wavefront shape)

b) pseudo-invert the Interaction Matrix to get a **Reconstruction Matrix** (wavefront shape → corrector commands)

At AO loop rates (≥ 1 kHz!!!)
perform **Matrix-Vector-Multiplications** (MVMs)
to move from measured wavefront aberrations
to compensating commands.

In MCAO this has to be done "tomographically",
i.e. for every layer of atmosphere

The control system **operationally** needs to:

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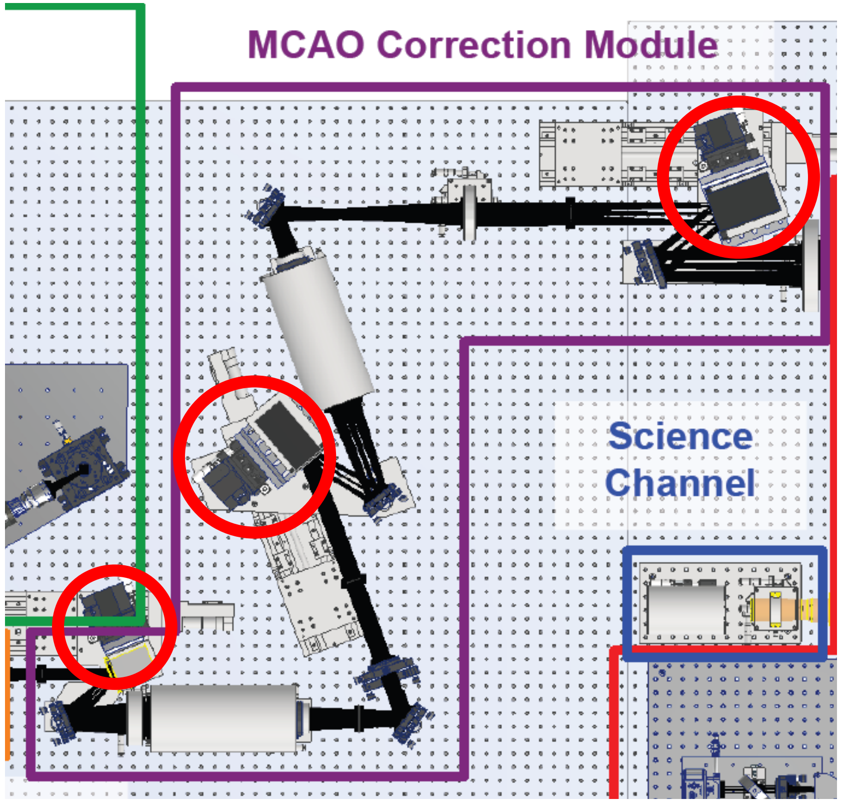
- introduce simulated turbulence

- measure the wavefront distortion

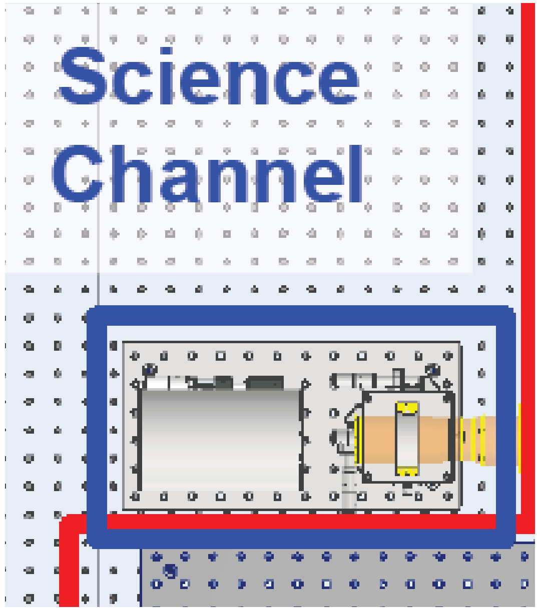
- correct the wavefront distortion



- ***3 Deformable Mirrors (~200, 450, 800 actuators)*** for the wavefront correction (and possibly to introduce the simulated turbulent distortion).

The control system **operationally** needs to:

- simulate the sources
- move optical elements on motorized stages, to rescale the system
- introduce simulated turbulence
- measure the wavefront distortion
- correct the wavefront distortion
- **check the AO system performance**



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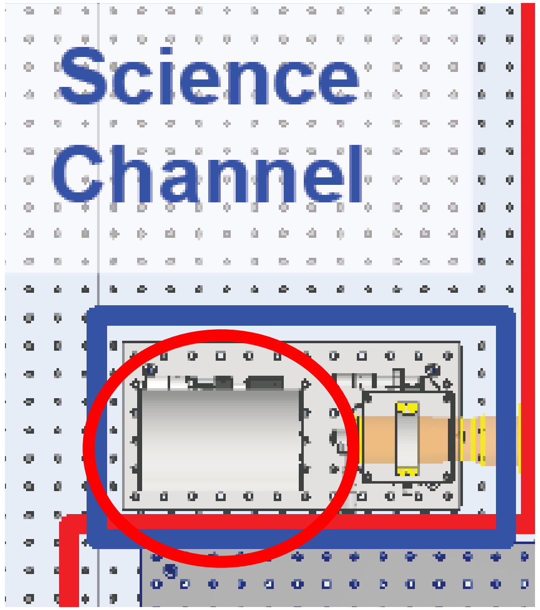


- ***1 GigE Vision "Scientific" Camera***, with high resolution

DAO4MATTO: Real-Time Control

Many devices, some to be controlled typical coherence time frequency ~ **1 kHz**!!!

3 x servers (OS: Linux) with 6 cutting-edge AMD EPYC 9648X CPUs

+

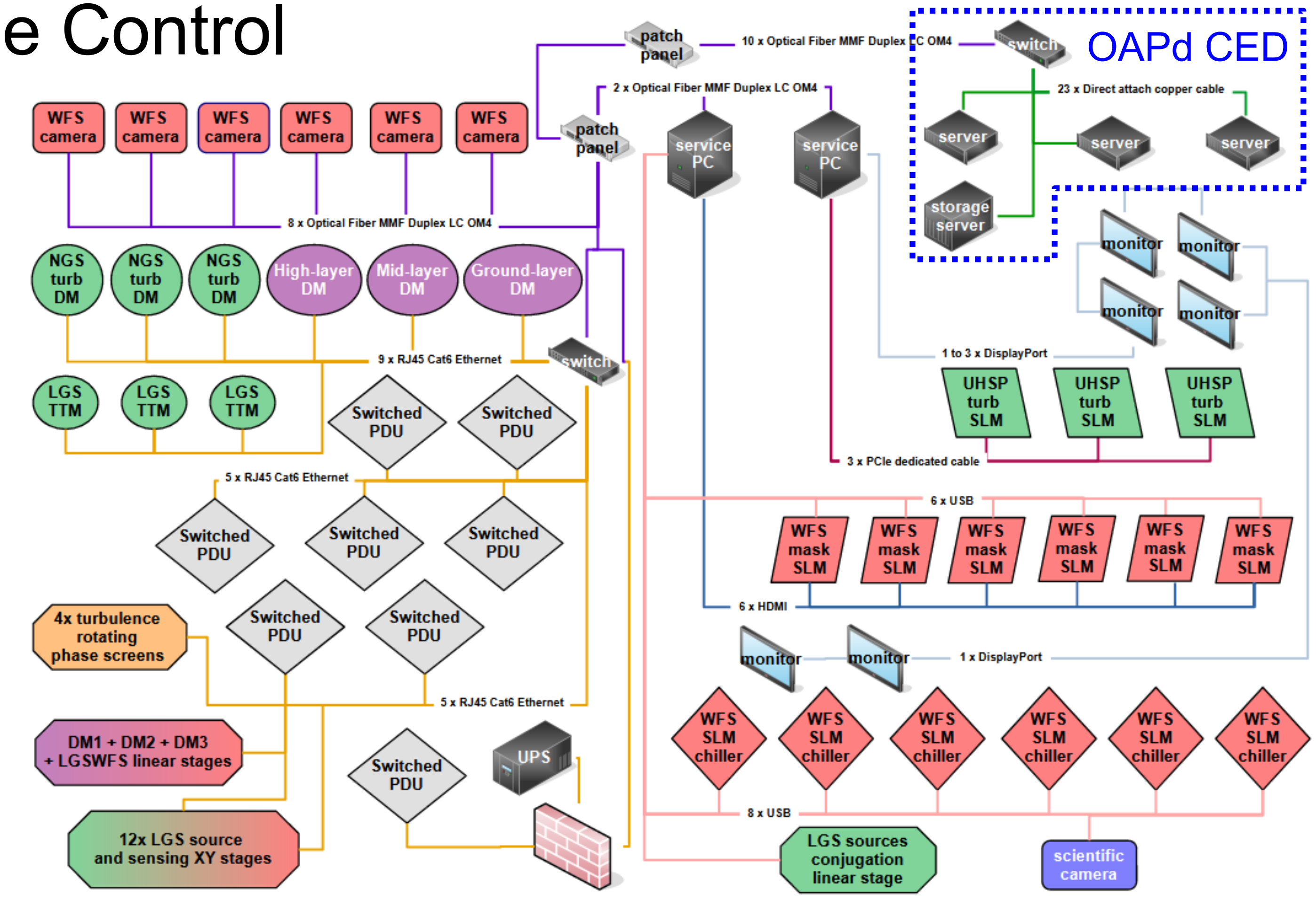
1 x storage server

+

2 x AMD/Intel workstations (OS: Windows) for additional interface

+

1 x 25Gb/s and 1 x 1Gb/s network switches



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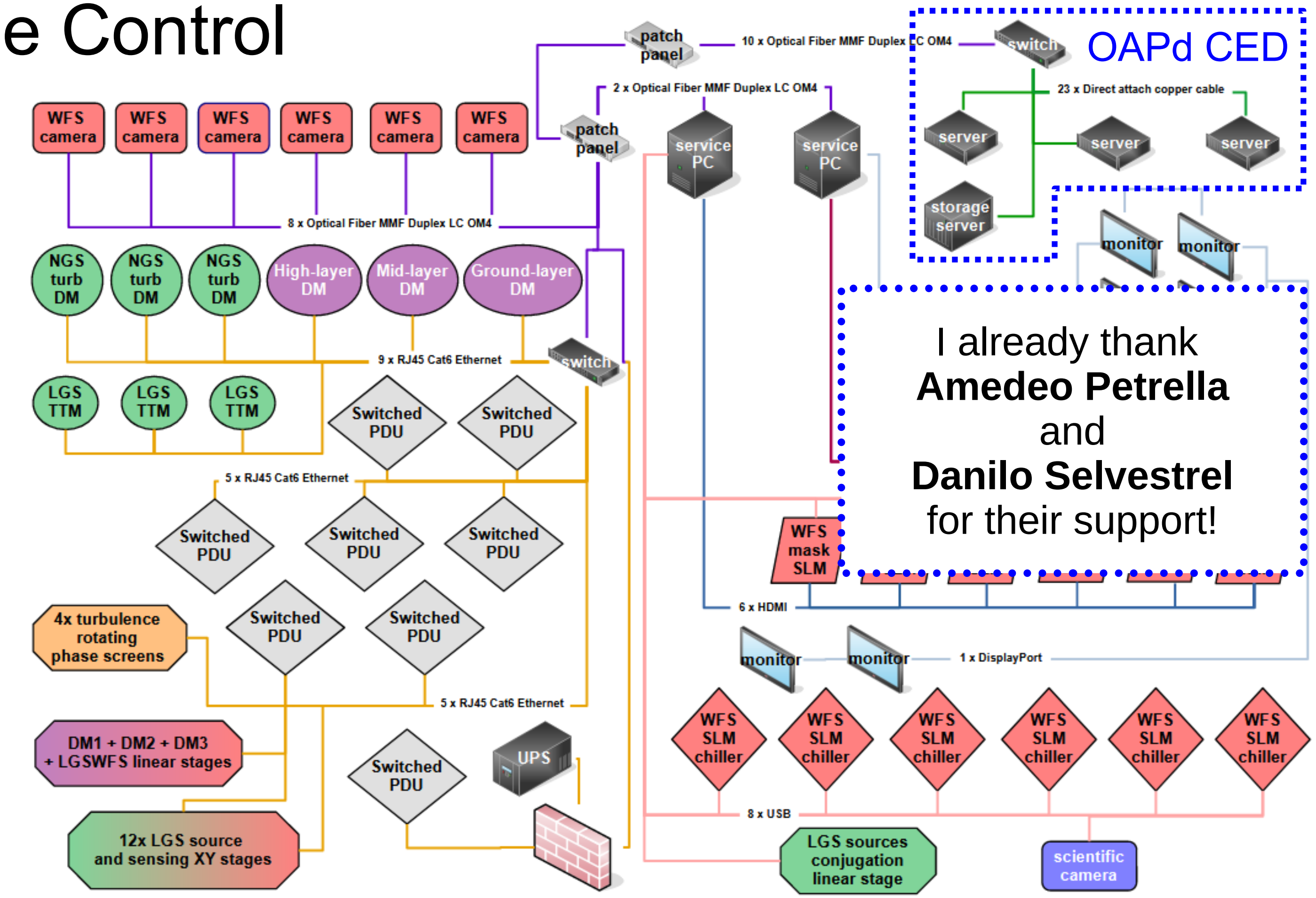


I already thank **Amedeo Petrella** and **Danilo Selvestrel** for their support!

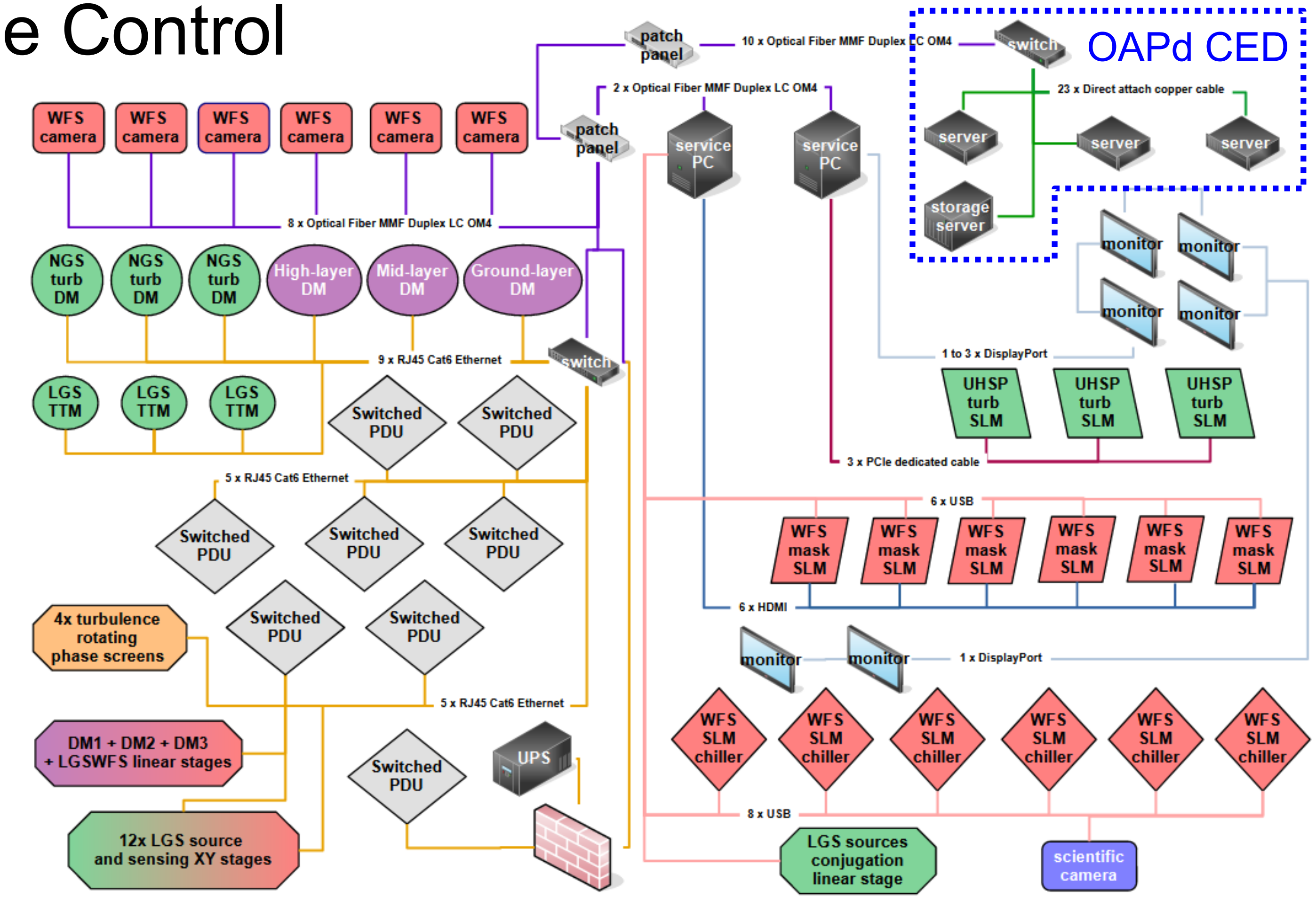
DAO4MATTO: Real-Time Control

MATTO is multi-purpose → needs to <u>adapt</u> to different experiments

MATTO is a facility → long lived, can/will be <u>upgraded</u> with new devices

Again, the magic word is…
MODULARITY!

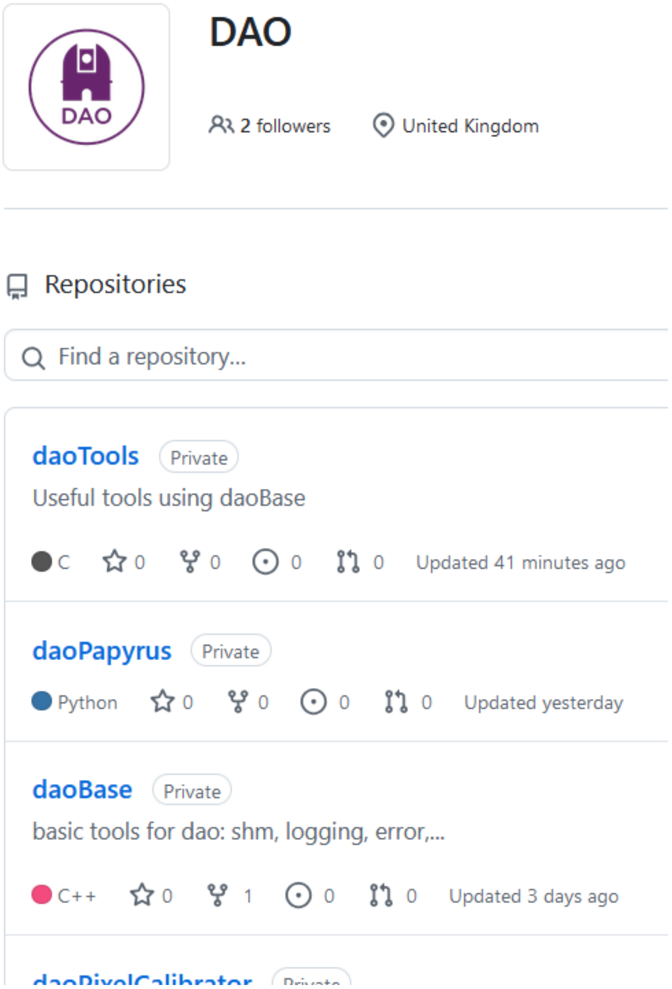
We will develop our own RTC SW, based on the **DAO** (Durham Adaptive Optics) RTC package (in collaboration with CfAI)



DAO4MATTO: Real-Time Control

DAO (Durham Adaptive Optics) RTC package:

- Inspired by CACAO (Guyon+18), using NUMA-based **shared memory** data exchange between processes → **Very modular!**
- **Open source** (soon to be publicly released)
- C/C++ and Python based (low latency and jitter)
- Already **compatible with a large number of devices**
- Already provided with a large collection of H/SRTC functionalities
- Currently used and developed for other AO projects, including **HARMONI**'s HRTC [3]

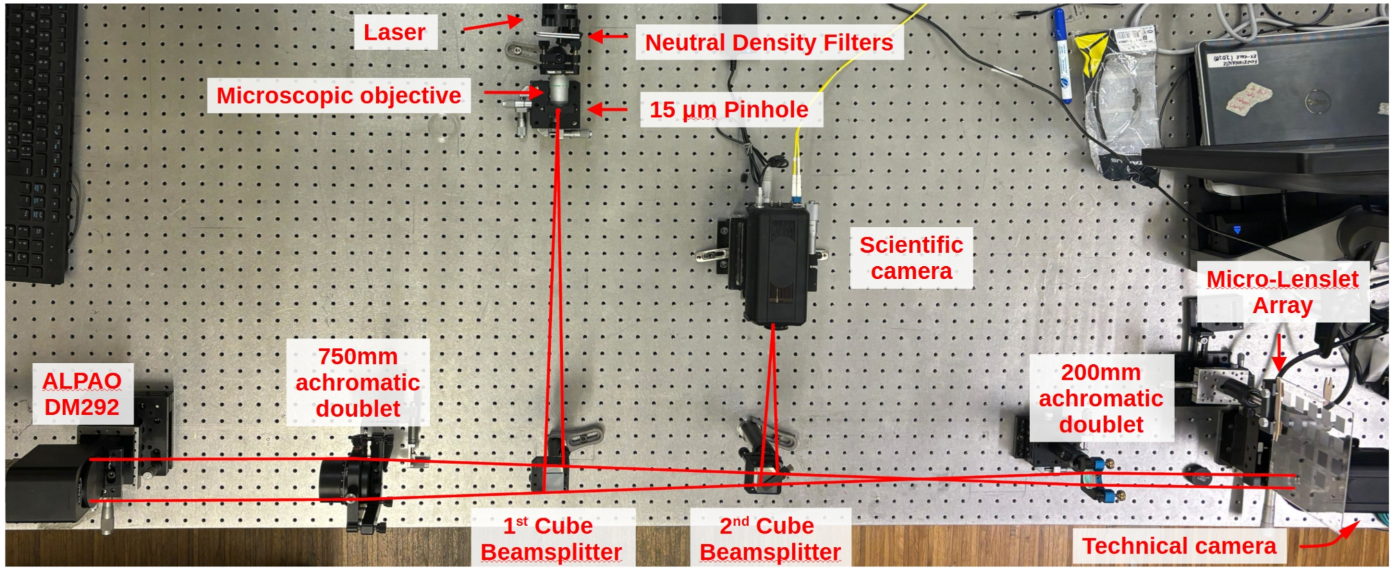


DAO4MATTO: Real-Time Control

A very preliminary prototype of DAO4MATTO, to test DAO's functionalities, has been already implemented!

Single-conjugate AO system

- 1 ALPAO DM292 (292 actuators) Deformable Mirror
- 1 Shack-Hartmann Wavefront Sensor
- 2 FLI C-Blue One 1.7 technical and performance cameras



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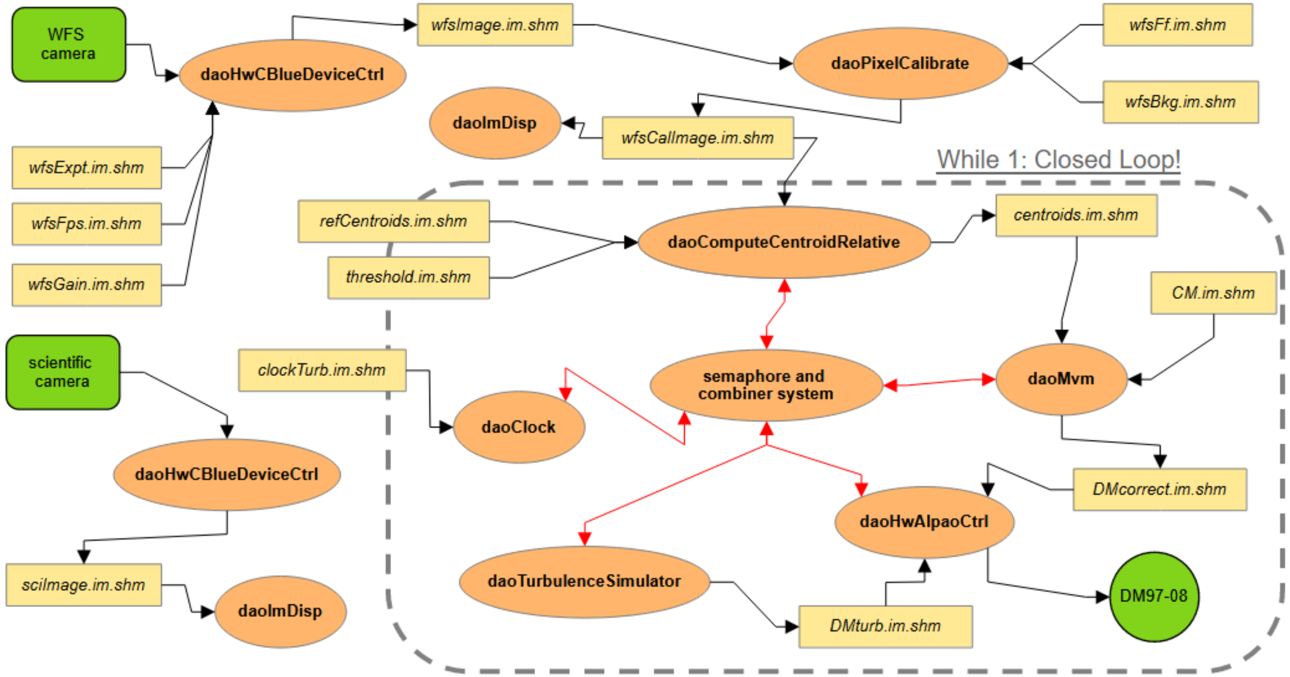

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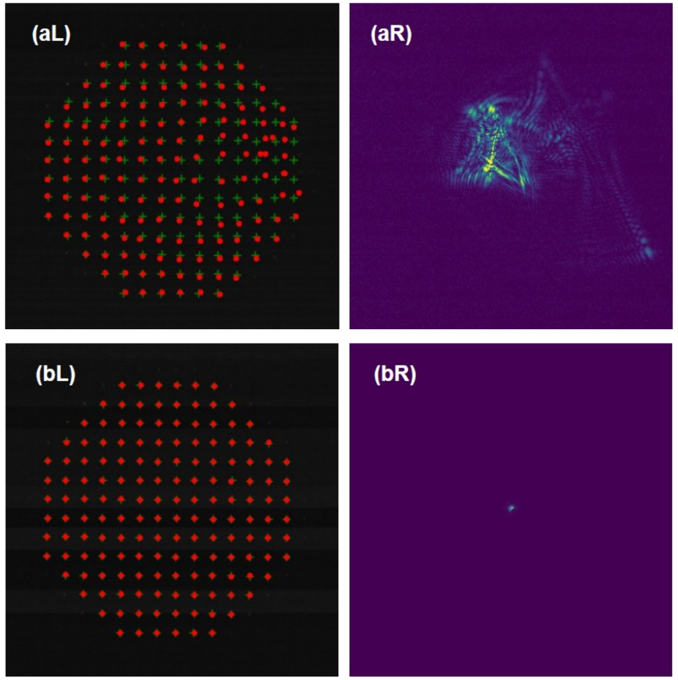
OPEN LOOP

Wavefront (SH centroids)

pupil plane

CLOSED LOOP



PSF

focal plane

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Summary:

- MATTO is a new facility for testing Multi-Conjugated Adaptive Optics at Very and Extremely Large Telescopes.
- At OAPd, but for the whole INAF and for any international institute wishing to use it!

- Very ambitious and multi-purpose → Maybe less demanding, but possibly as complex as a on-sky telescope instrument…

- DAO4MATTO is its Real-Time Control System. Equivalently complex!

- Work in progress, but a first complete version ready by the end of 2026.

STAY TUNED!

Questions? Suggestions?

Ballone et al. (2024), Proceedings of the SPIE, Volume 13101

Viotto et al. (2023), Proceedings of the Adaptive Optics for Extremely Large Telescopes (AO4ELT7), 7th Edition

The research activities described in this paper were carried out with the contribution of the Next Generation EU funds within the National Recovery and Resilience Plan (PNRR), Mission 4 - Education and Research, Component 2 - From Research to Business (M4C2), Investment Line 3.1 - Strengthening and creation of Research Infrastructures, Project IR0000034 – “STILES - Strengthening the Italian Leadership in ELT and SKA”.