Ottica Adattiva Multi-Coniugata

@ OAPD
(MAORY-NIRVANA-MAVIS)

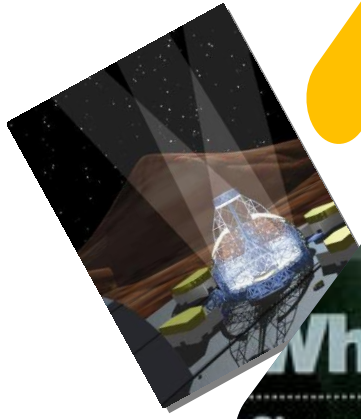
Carmelo Arcidiacono

On behalf of
many others

Uniform correction over a large FoV

Multi-Conjugate Adaptive Optics …

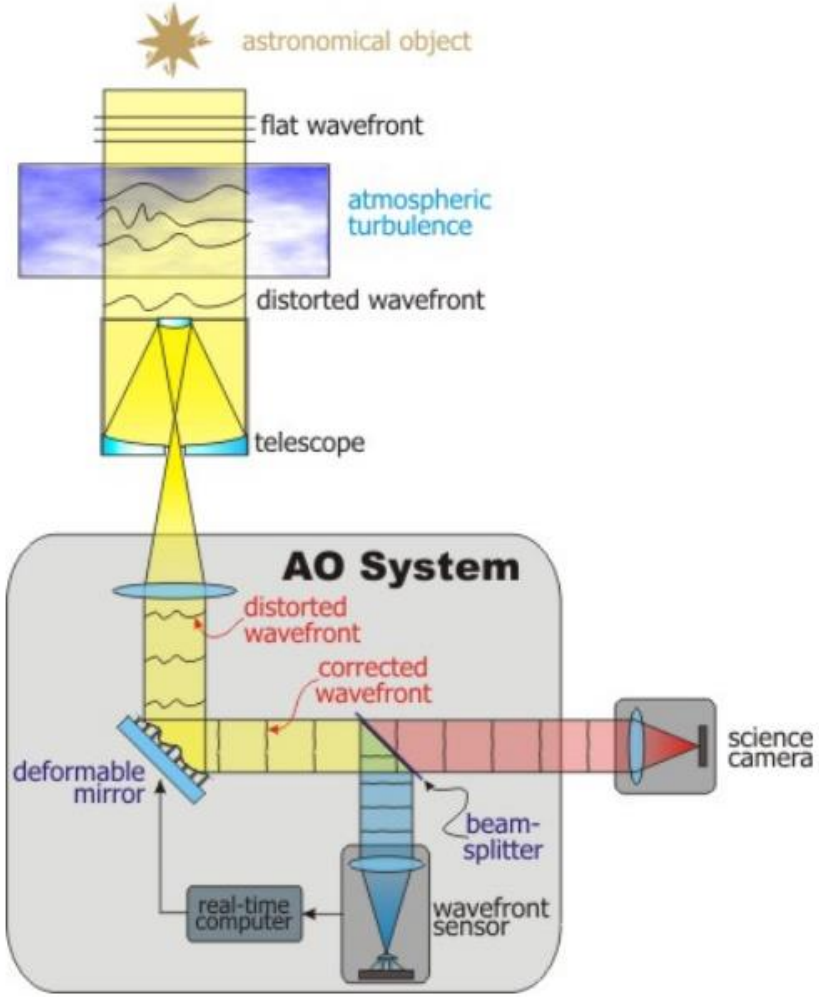
…something in DNA



- Looking back to our historical background: we first yearned to realize a wide field adaptive correction «using solely natural guide stars» in 2000 (~20yy!)
- We actually realized it with the Multi-Conjugate Adaptive Optics experiment (MAD@VLT) – 2007 and later reaching the NIRVANA @ LBT, by implementing the Layer Oriented approach to the MCAO.

Single Conjugate Adaptive Optics
a.k.a. CAO Conventional Adaptive Optics

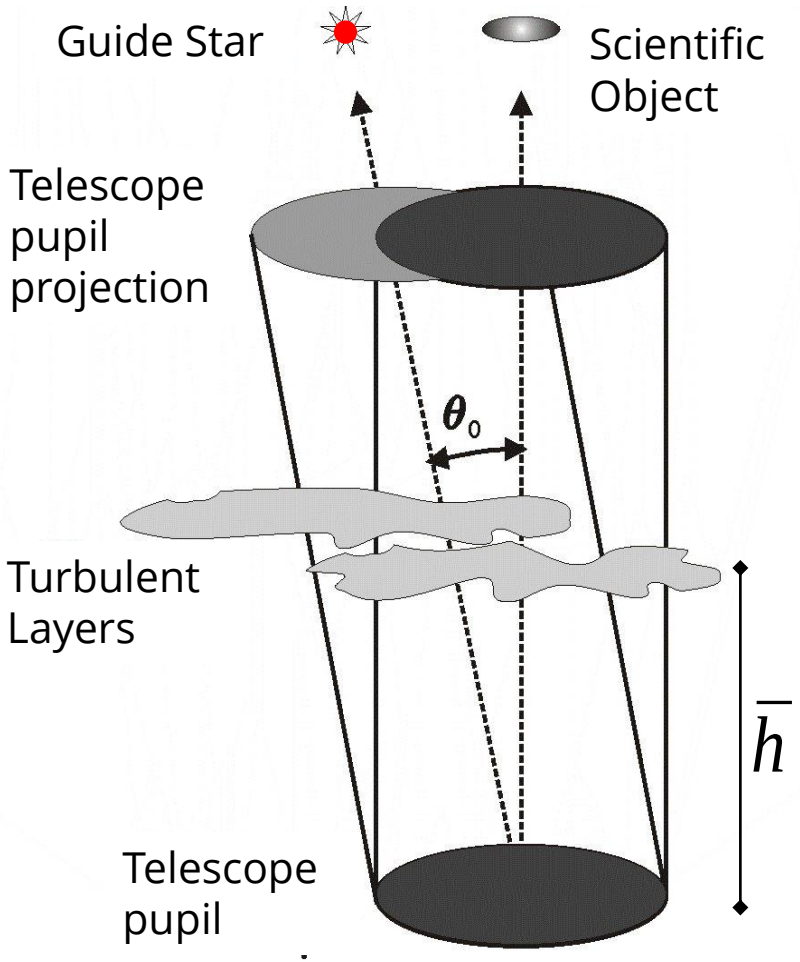
SCAO



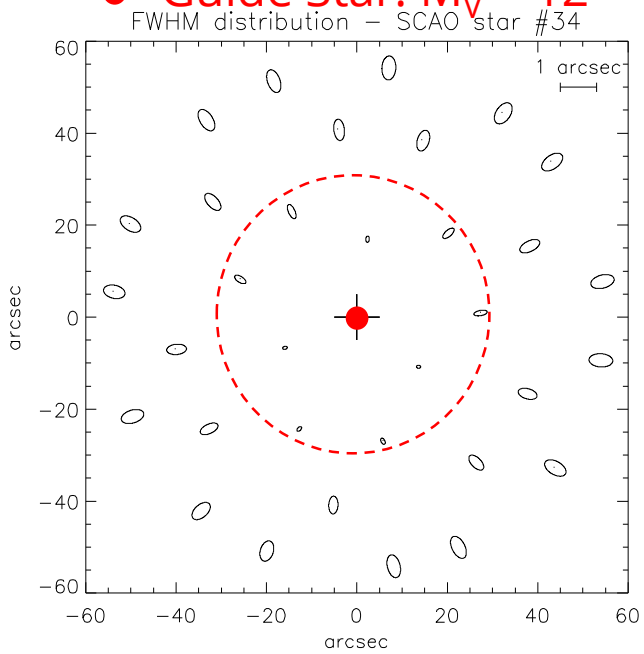
- The WFS measures the optical turbulence along the atmosphere column in the direction of a Guide Star
- One Deformable Mirror (DM), seen both by WFS and Science
- Camera, applies an opposite WF deformation, correcting aberrations

NACO, SPHERE, LUCI_AO, KECK_AO, ...

SCAO



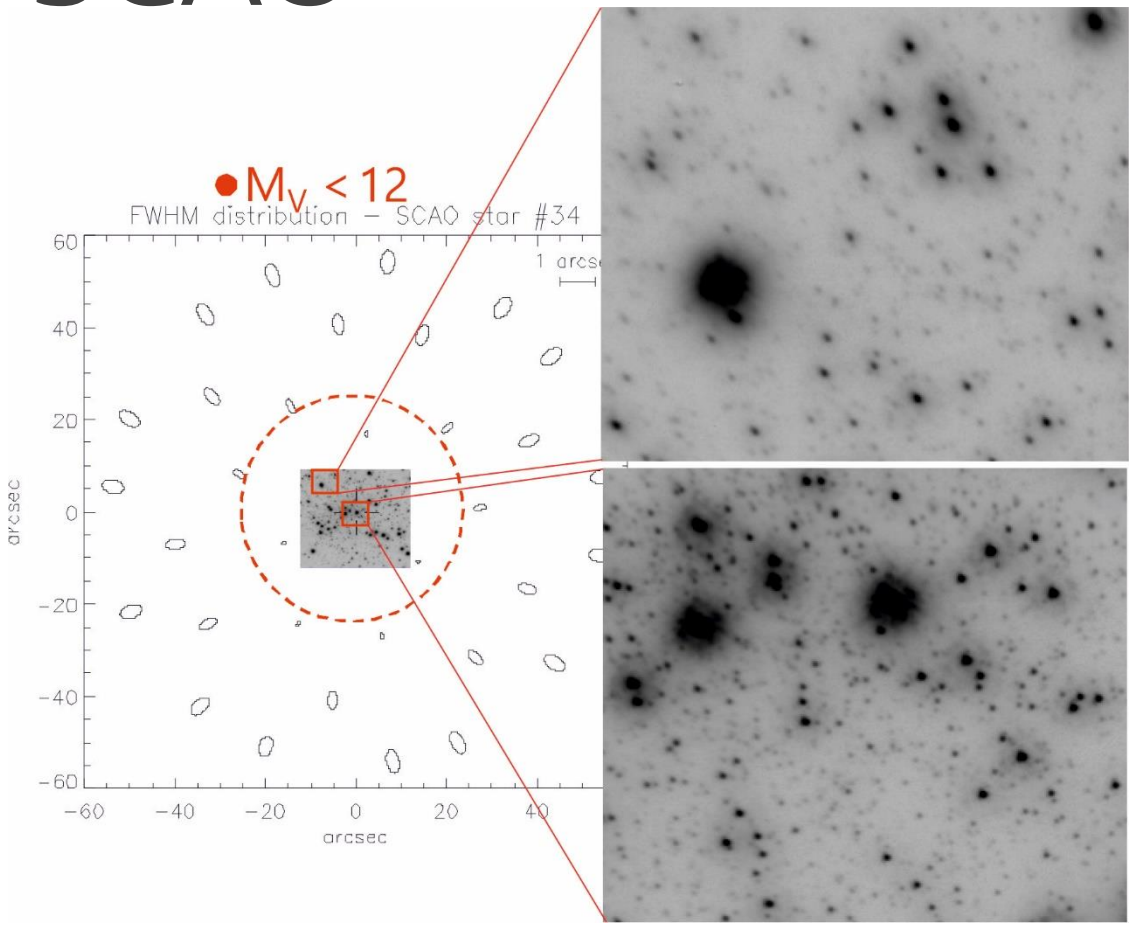
- Guide Star: $M_V < 12$



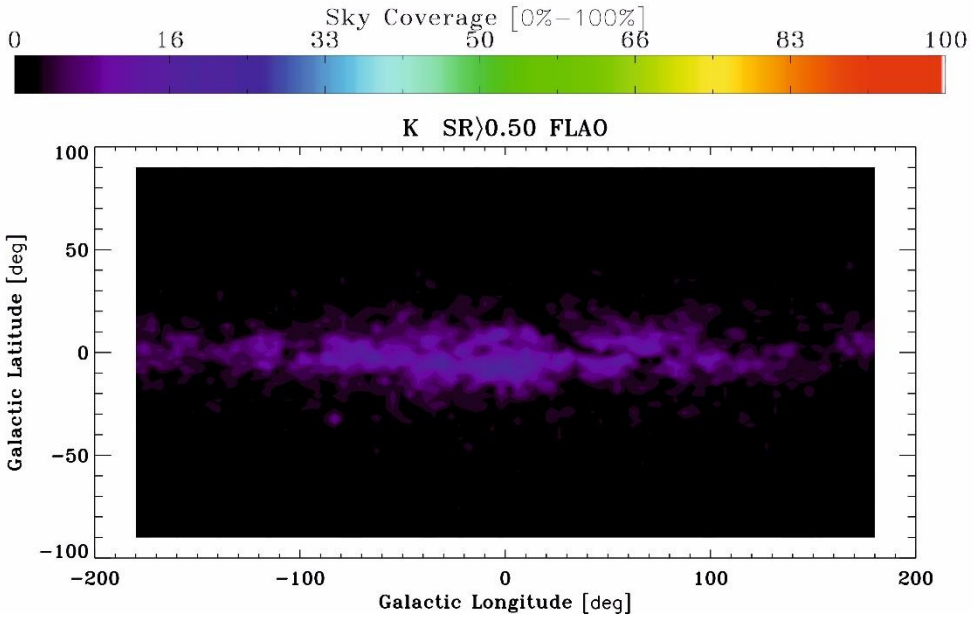
- The correction quality decreases with the distance from the Guide Star because of the different projection on the high altitude layers
- The corrected FoV is of the order of the isoplanatic angle $\theta_0 = 0.314\ r_0 / h$
- PSFs are elongated towards the direction of the reference star
- Guide Star Limiting Magnitude 12 (15 for field stabilization)

.... See the next slide for an example .....

SCAO

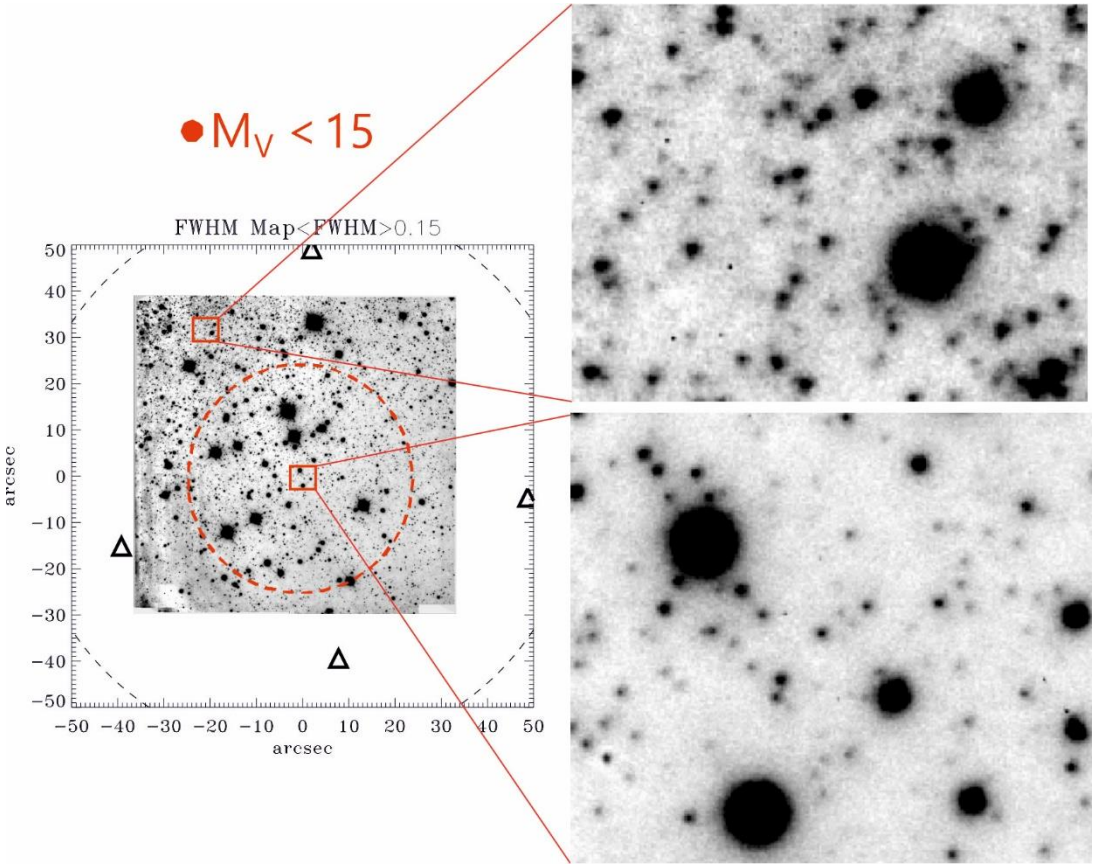


*M15 core, 23”x23” data J band
PISCES+FLAO @ LBT, inset 6 ”x5”

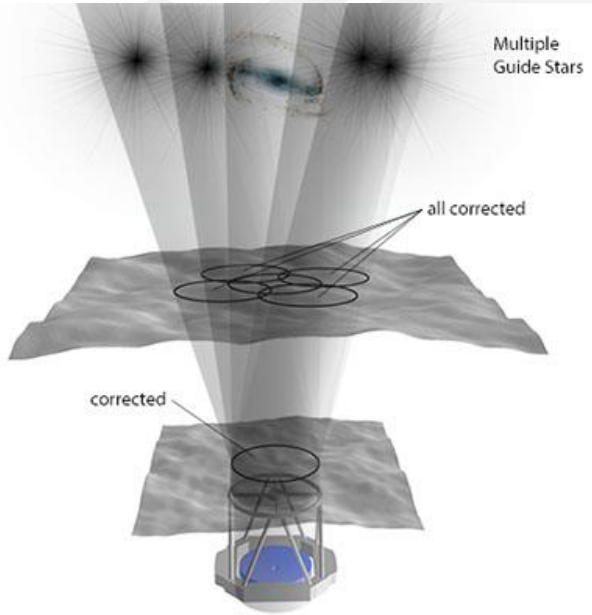


- Challenging photometry because of the large PSF field-variation
- Sky coverage < few %, limited to the galactic plane

MCAO

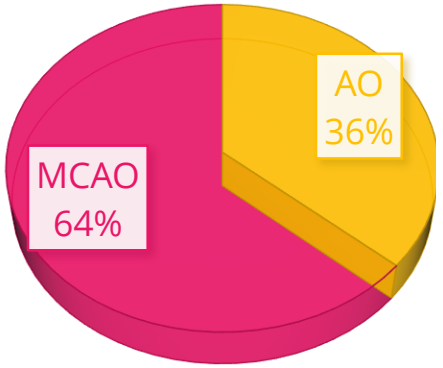


*NGC 6388 halo,65”x63”, Ks band, MAD @ VLT, inset 6 ”x5”



Multi-Conjugate Adaptive Optics

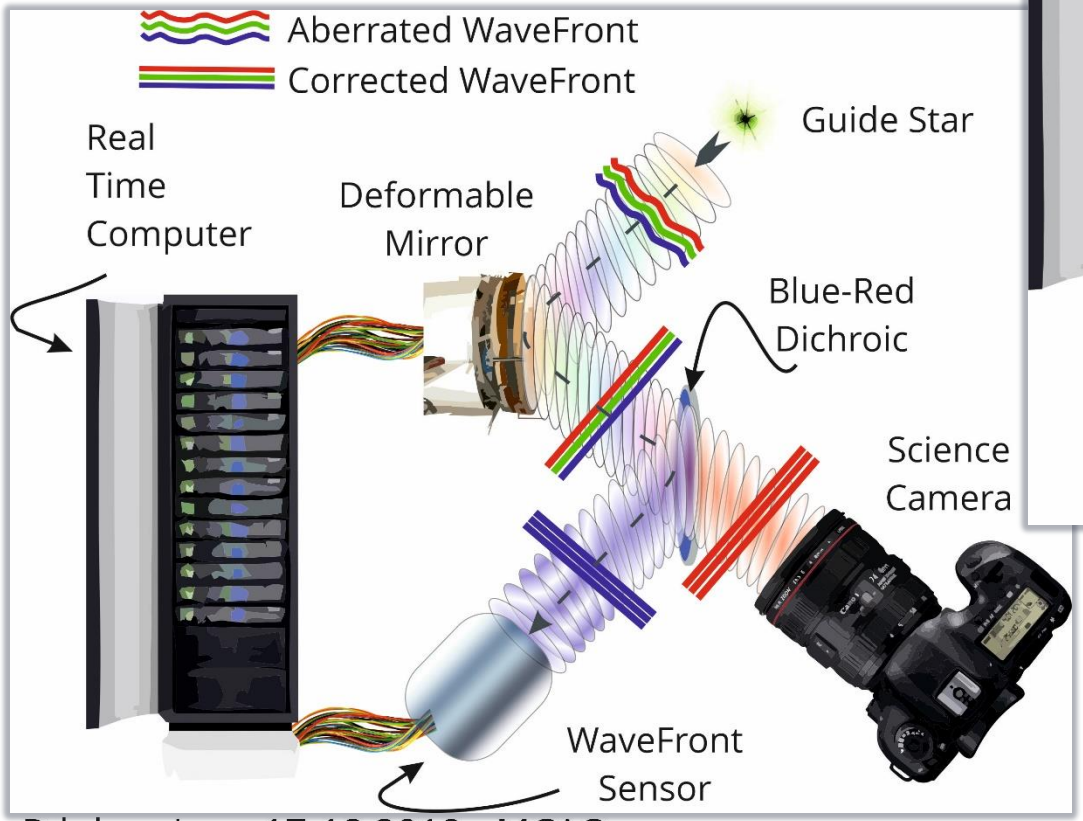
- In MCAO mode we get a uniform PSF over the field by correcting the turbulence volume using multiple reference and multiple deformable mirrors
- Data reduction software can deal with the residual field aberration, enabling accurate photometry

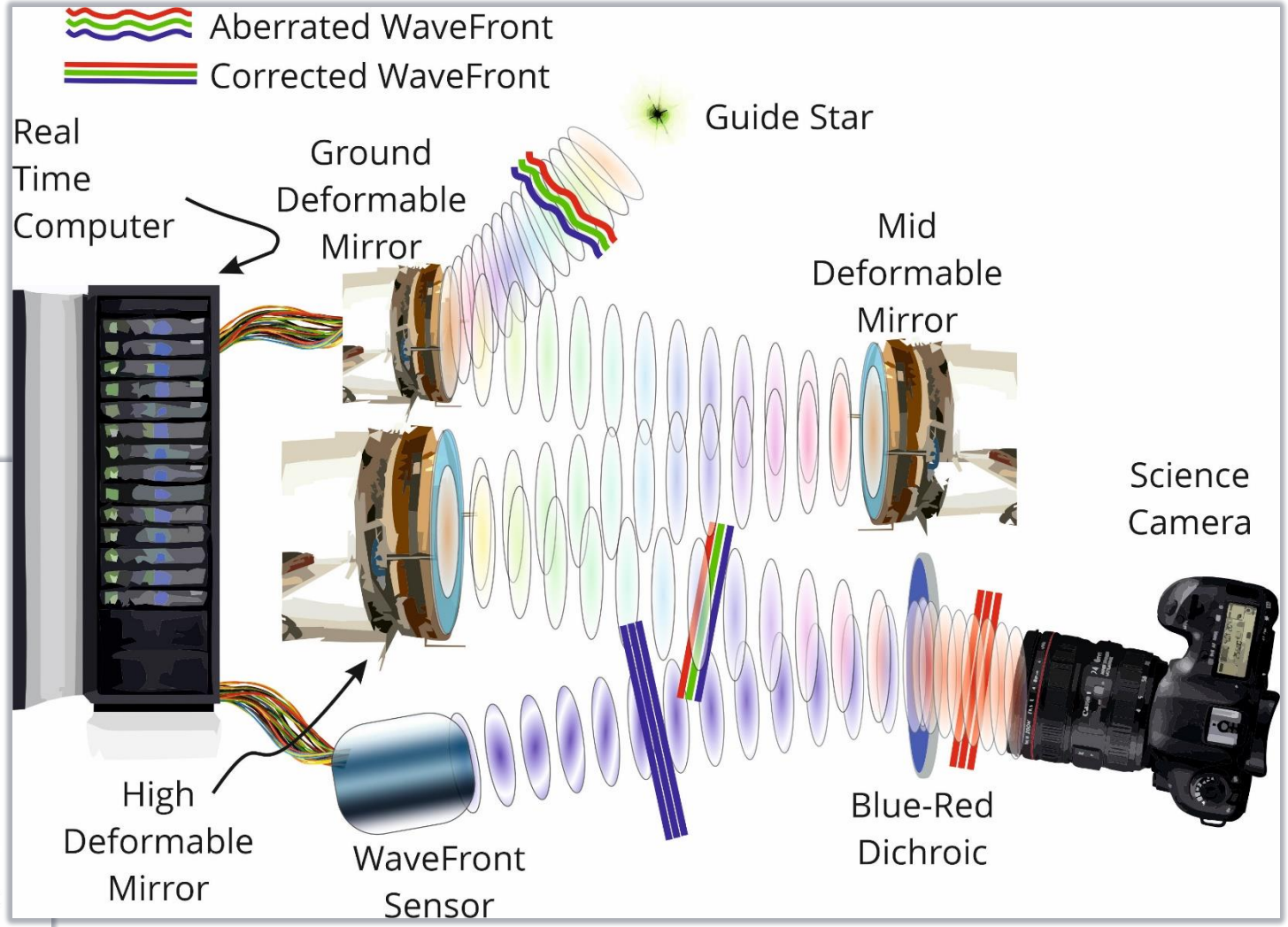


*Refereed GC Paper by AO mode

SCAO vs MCAO

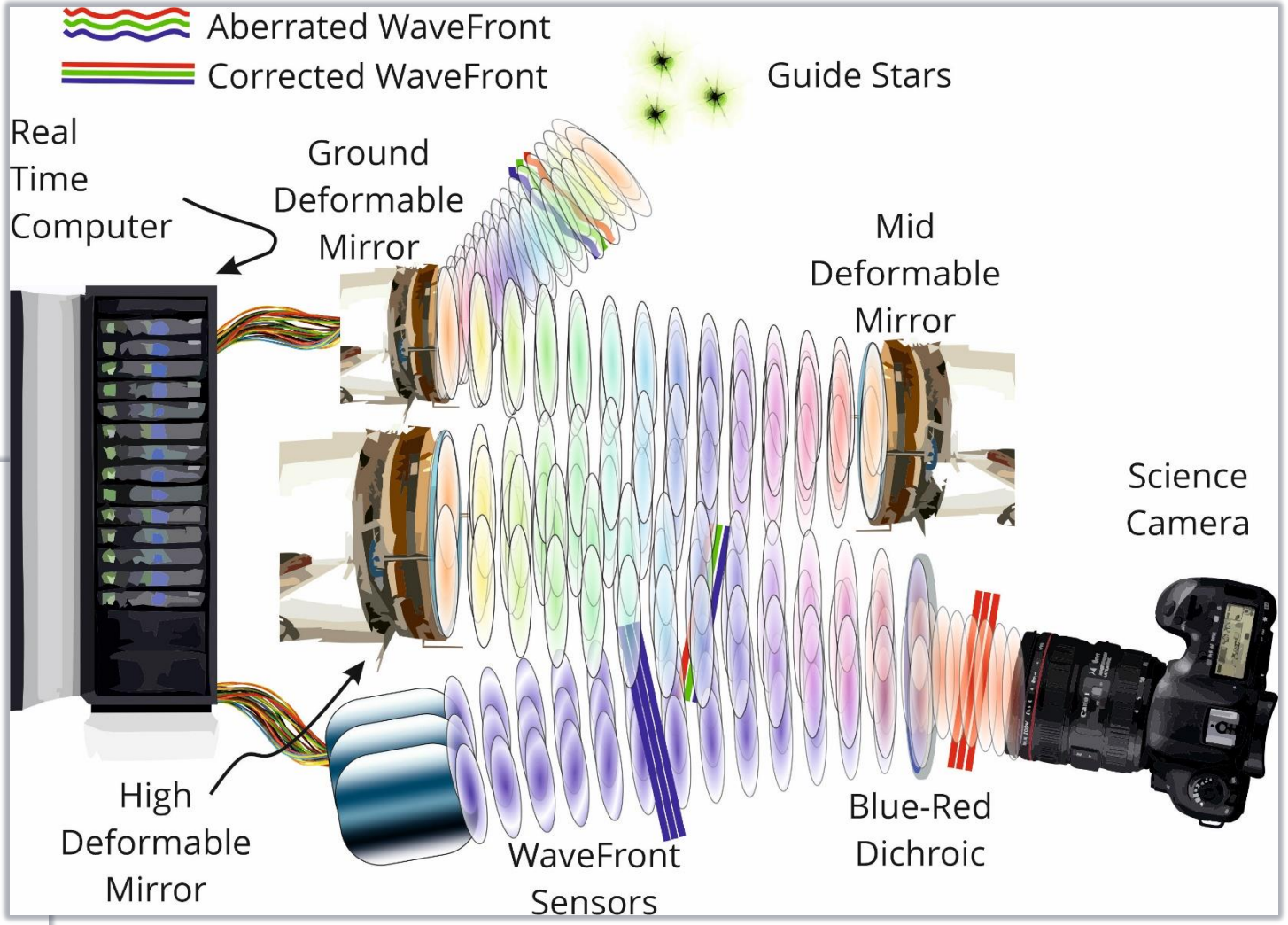
To correct the turbulence volume the MCAO needs to apply field dependant correction inserting multiple deformable mirror conjugated out of the pupil plane.

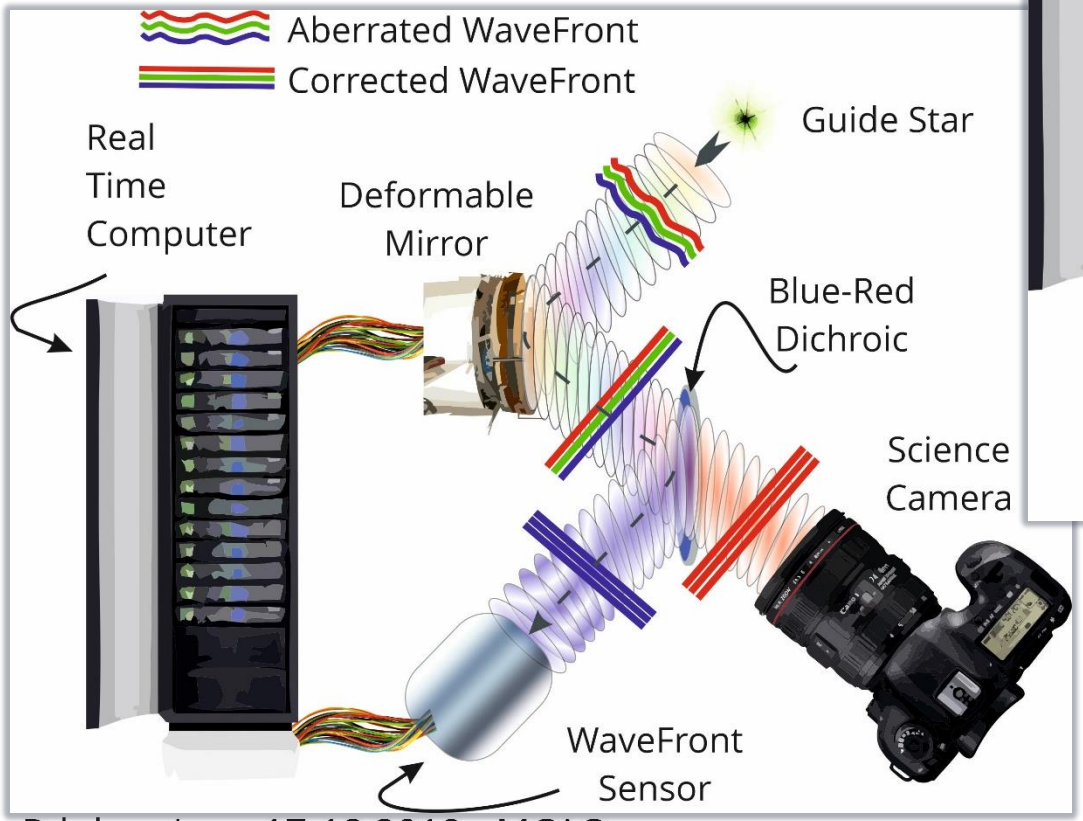




SCAO vs MCAO

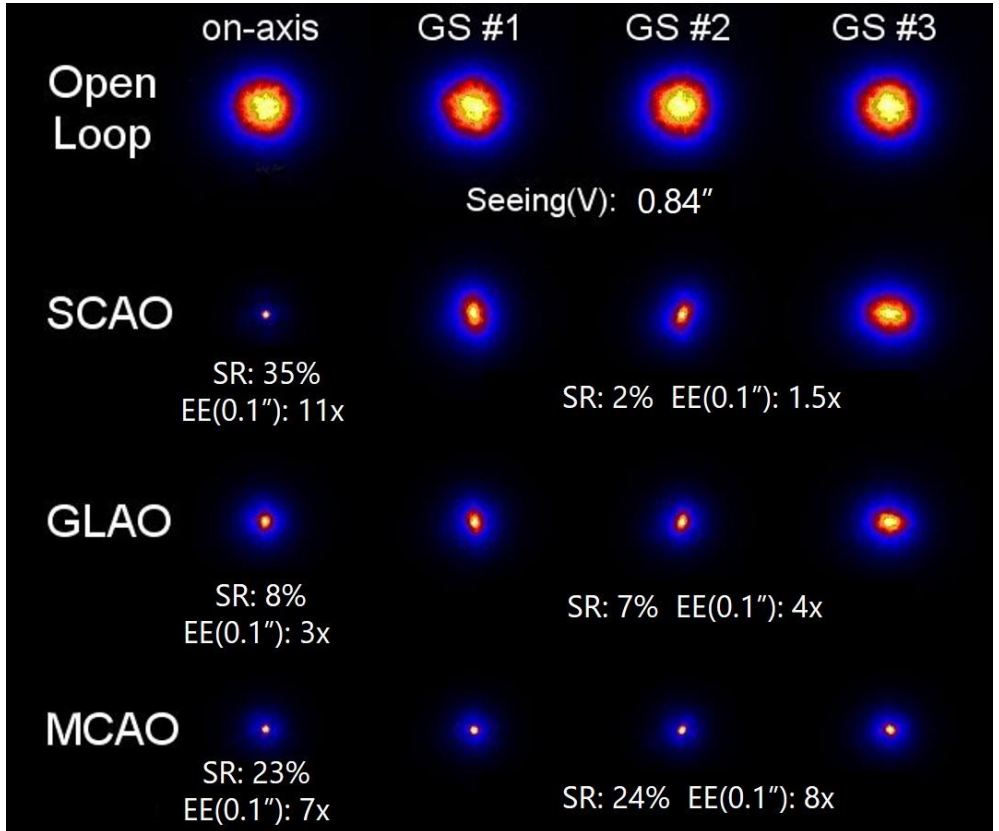
The multiple reference stars sense the turbulent volume above the telescope and illuminate different portions of the DM, enabling Closed Loop control.





Adding complexity

- Adding References to sense the atmospheric turbulence volume
- Adding Deformable Mirrors to apply field dependant correction
- Firing lasers to generate low (Rayleigh <10km) or high (Sodium 90km) artificial stars



GLAO

Multiple references
1 DM
Large FoV

MCAO

Multiple references
2-3 Deformable mirrors

ARGOS

GeMS

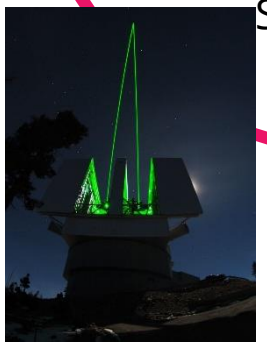
MAVIS

LINC NIRVANA

MAORY

Rayleigh LGS

Artificial Reference based on Rayleigh Scattering

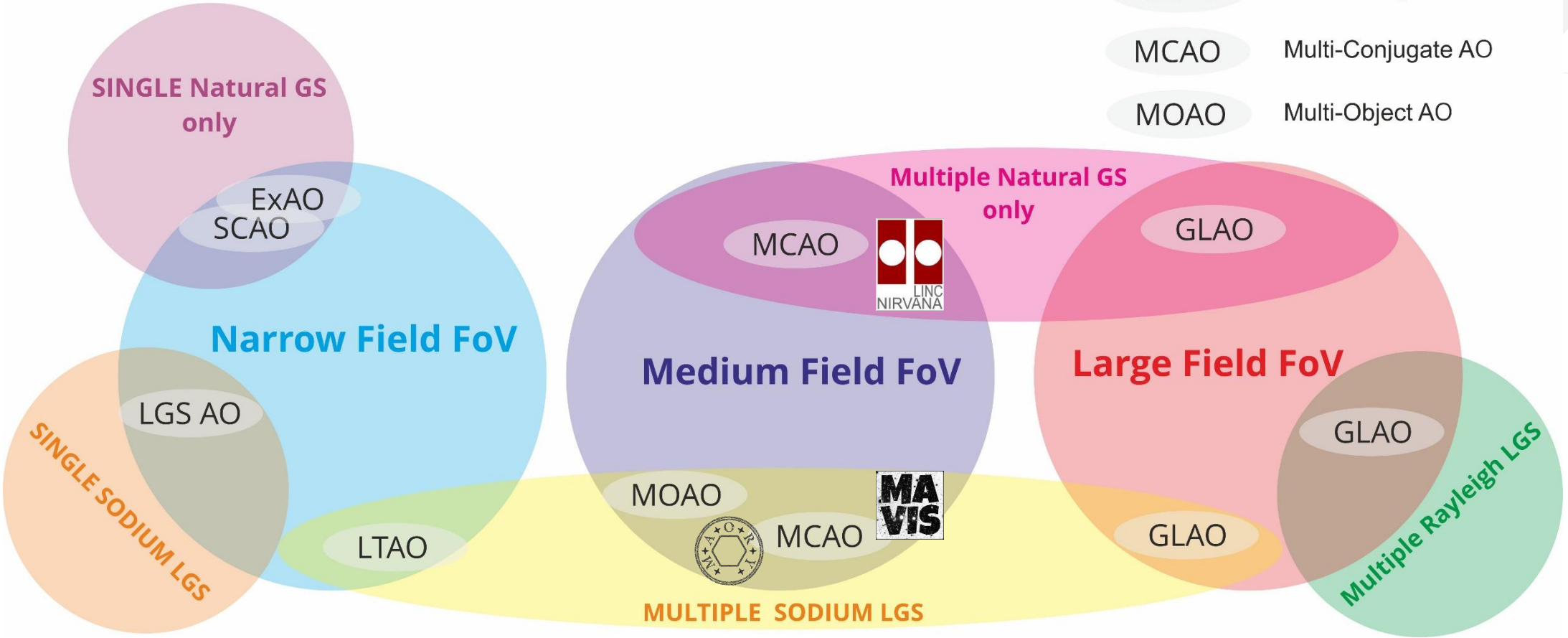


Sodium LGS

Artificial Reference based on Sodium Layer Excitation

Adaptive Optics Zoo

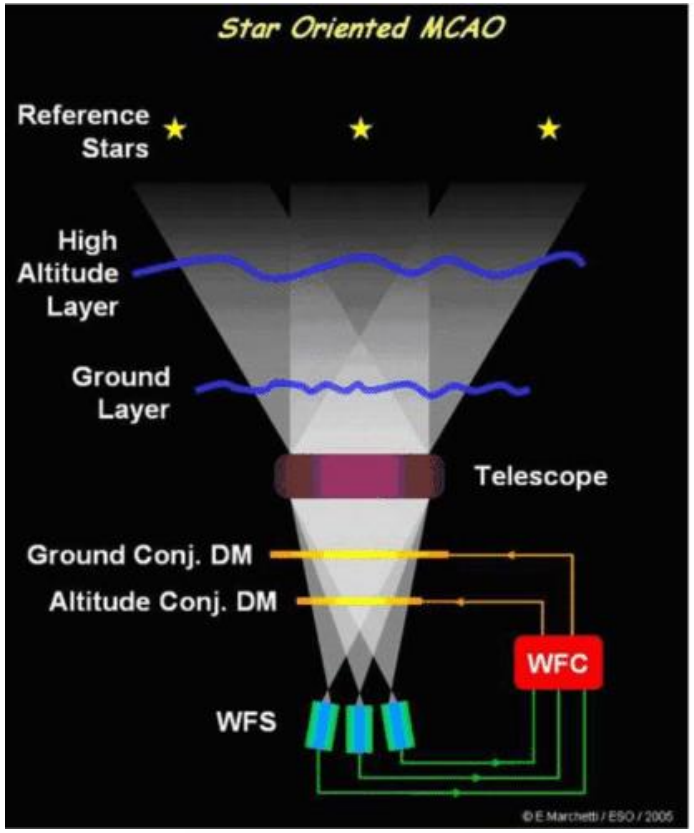
SCAO	Single Conjugate AO
ExAO	Extreme AO
LTAO	Laser Tomography AO
LGS AO	Laser Assisted AO
GLAO	Ground Layer AO
MCAO	Multi-Conjugate AO
MOAO	Multi-Object AO

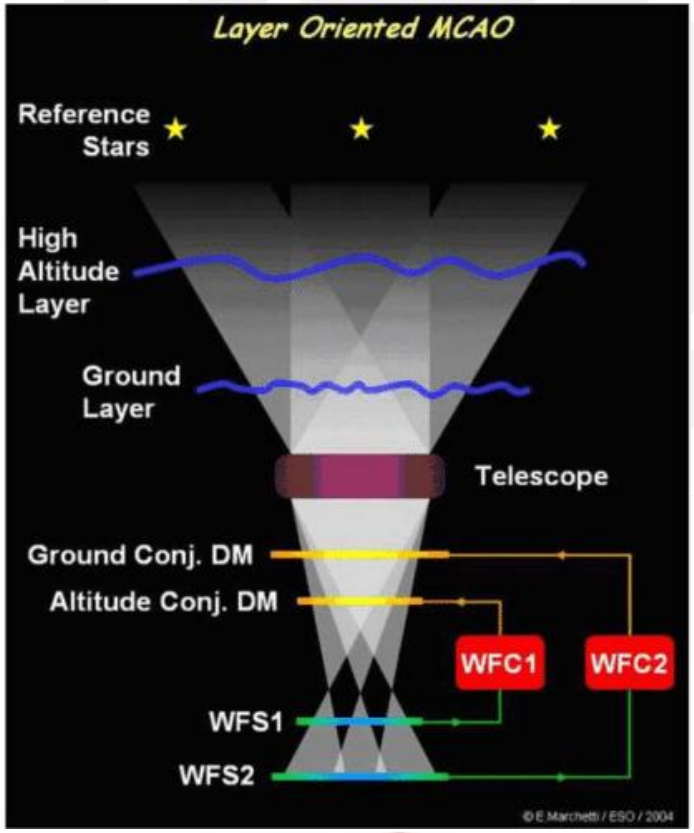


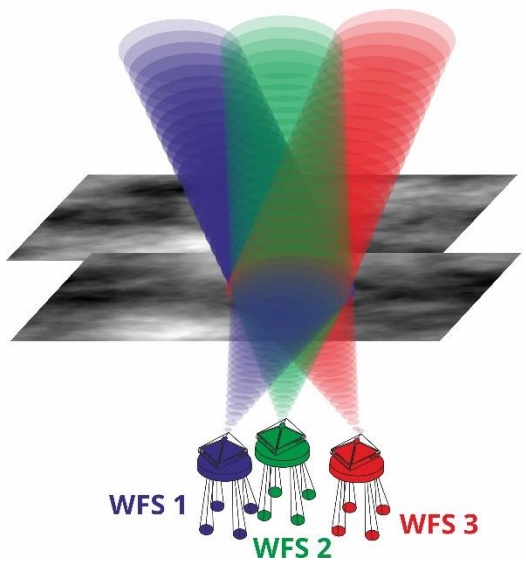
Layer Oriented vs Star Oriented

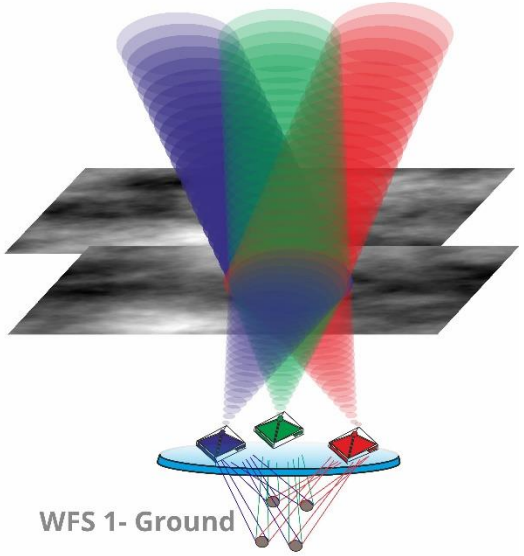
- In the **Star Oriented** the turbulence volume is resolved through as many measurements as Guide Star. The volume is then projected on the layer optical conjugated to multiple deformable mirrors.
- In the **Layer Oriented** the turbulence volume is not resolved. The WFSs directly measure of the turbulent layers also optically conjugated to as many deformable mirrors.

While the Star Oriented, thanks to optimal tomographic reconstruction, may achieve somewhat higher performance, the Layer Oriented gains in term of sky coverage thanks to the optical light co-addition and WFS exposure time tuning.



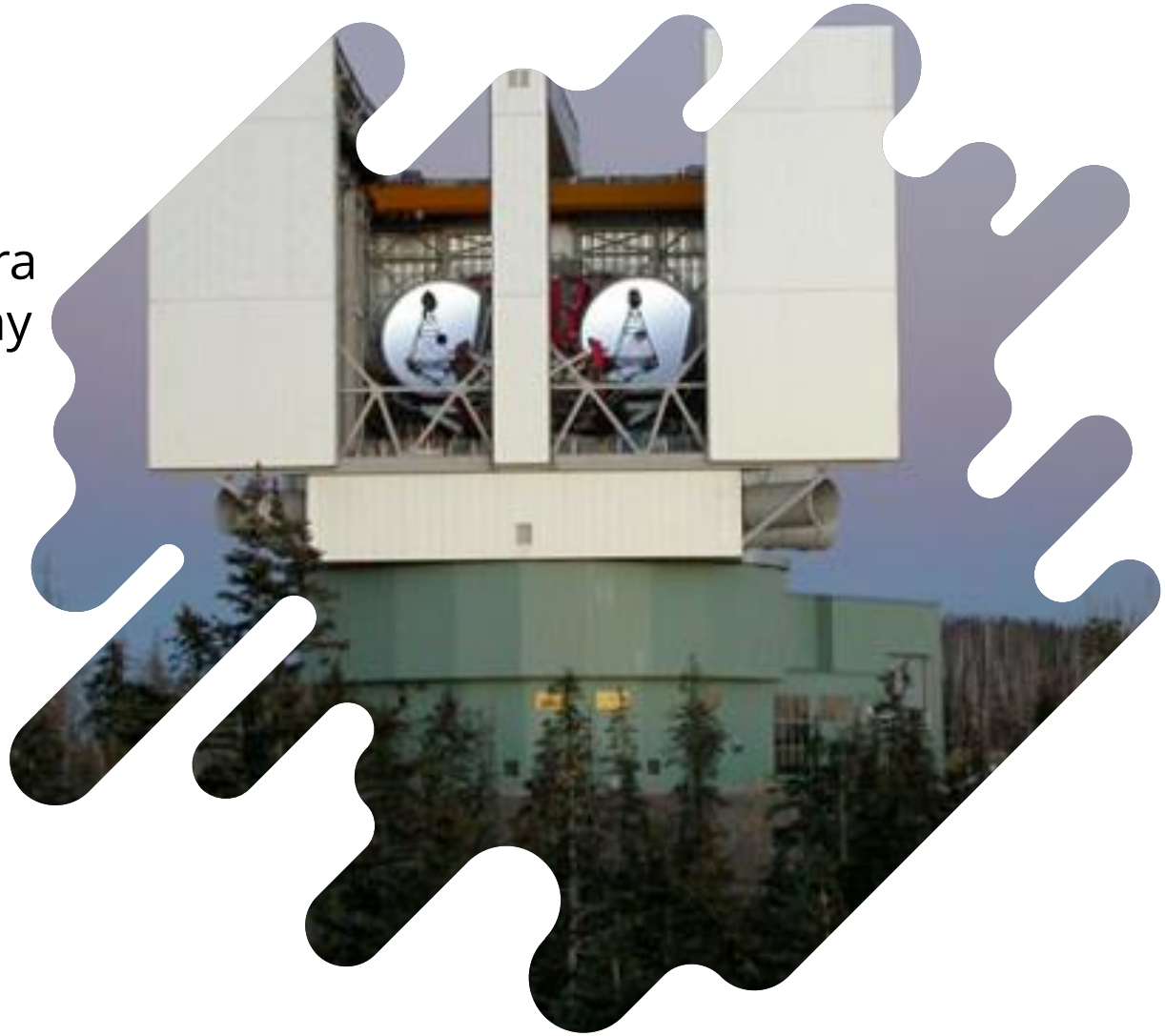






LINC-NIRVANA

LINC = Lbt INterferometric Camera
NIRVANA = NearInfraRed&Visible Adaptive camera and iNterferometer for Astronomy



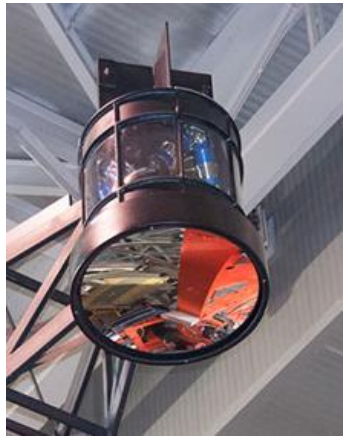
1) LN is a twin of multi-conjugate adaptive optics (MCAO) module and interferometric beam combination.

2) LN operates in Fizeau-mode, delivering IMAGES with the 23m baseline and 12m effective collecting area->5mas/px **J**, **H**, **Ks** on a 10”x10” camera [2k×2k HAWAII-2 detector]

Two couple of independent Layer Oriented wavefront sensors retrieve the info about the turbulence **VOLUME** using multiple natural guide stars.
GWS WFS is a multi-12- pyramids on 6’ FoV
HWS WFS is a multi-8- pyramids on 2’ FoV

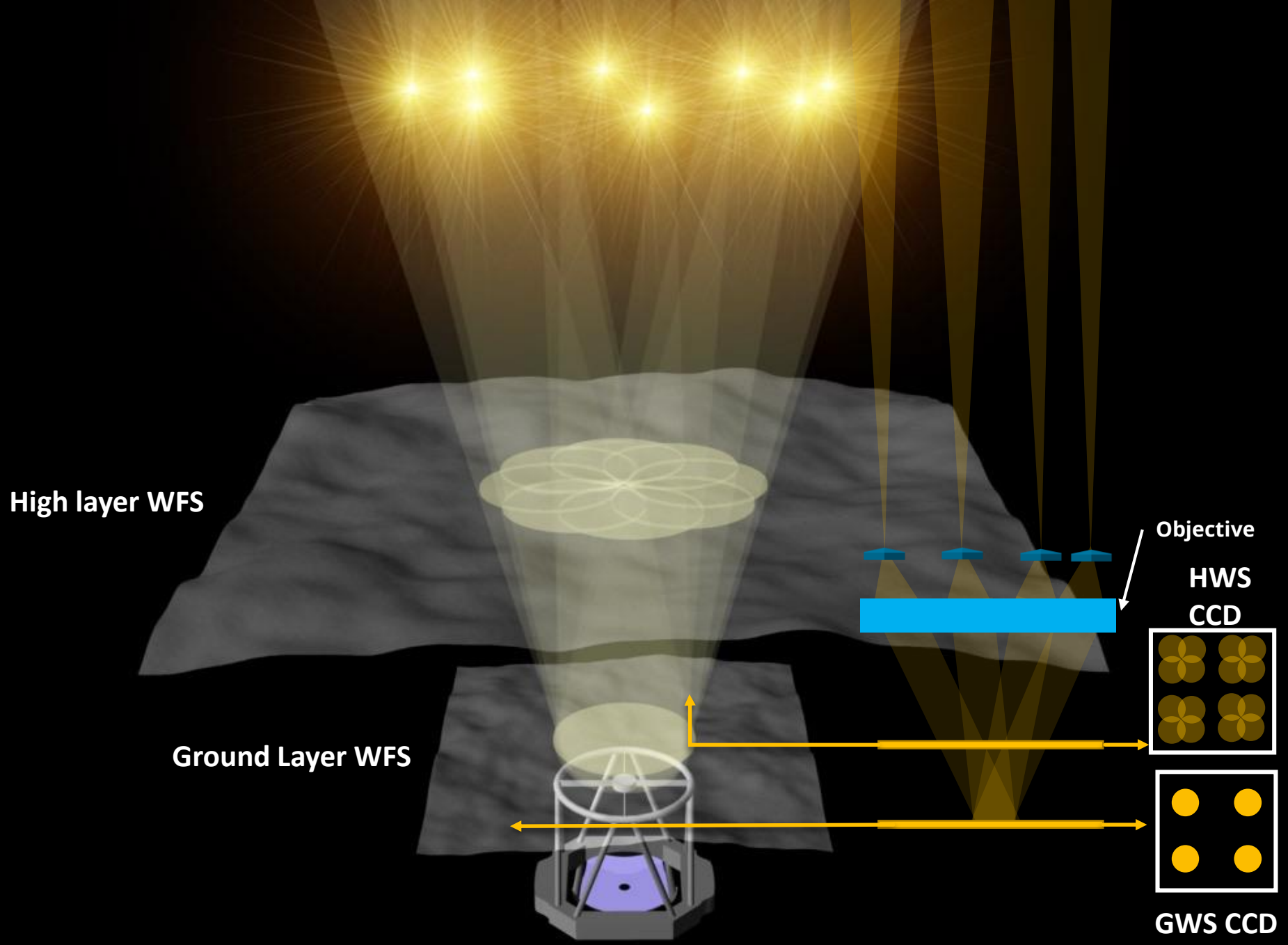
Multipyramid WFS

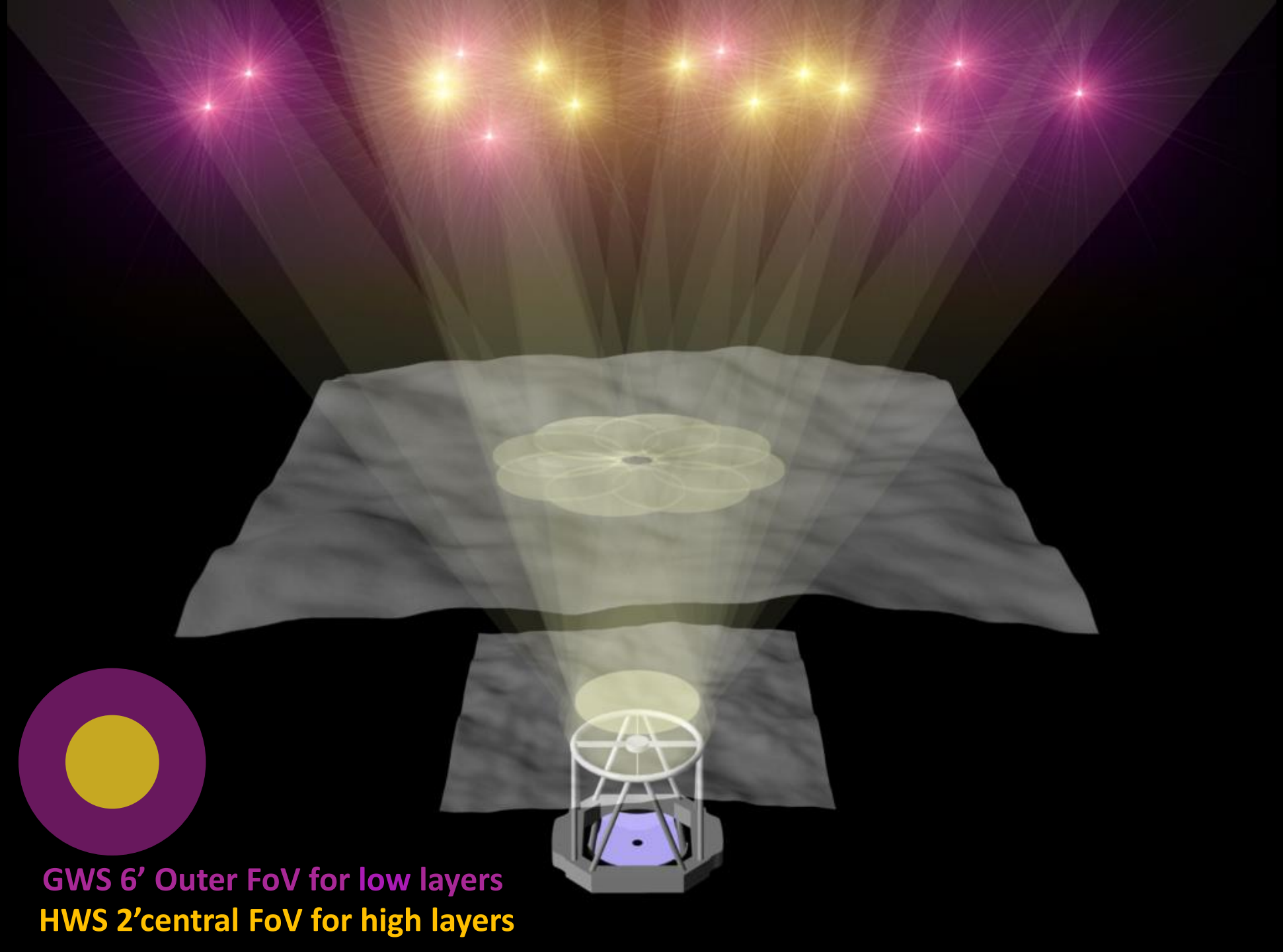
Two couple of deformable mirrors, conjugated at different altitudes, update their shape to follow the wavefront evolution.



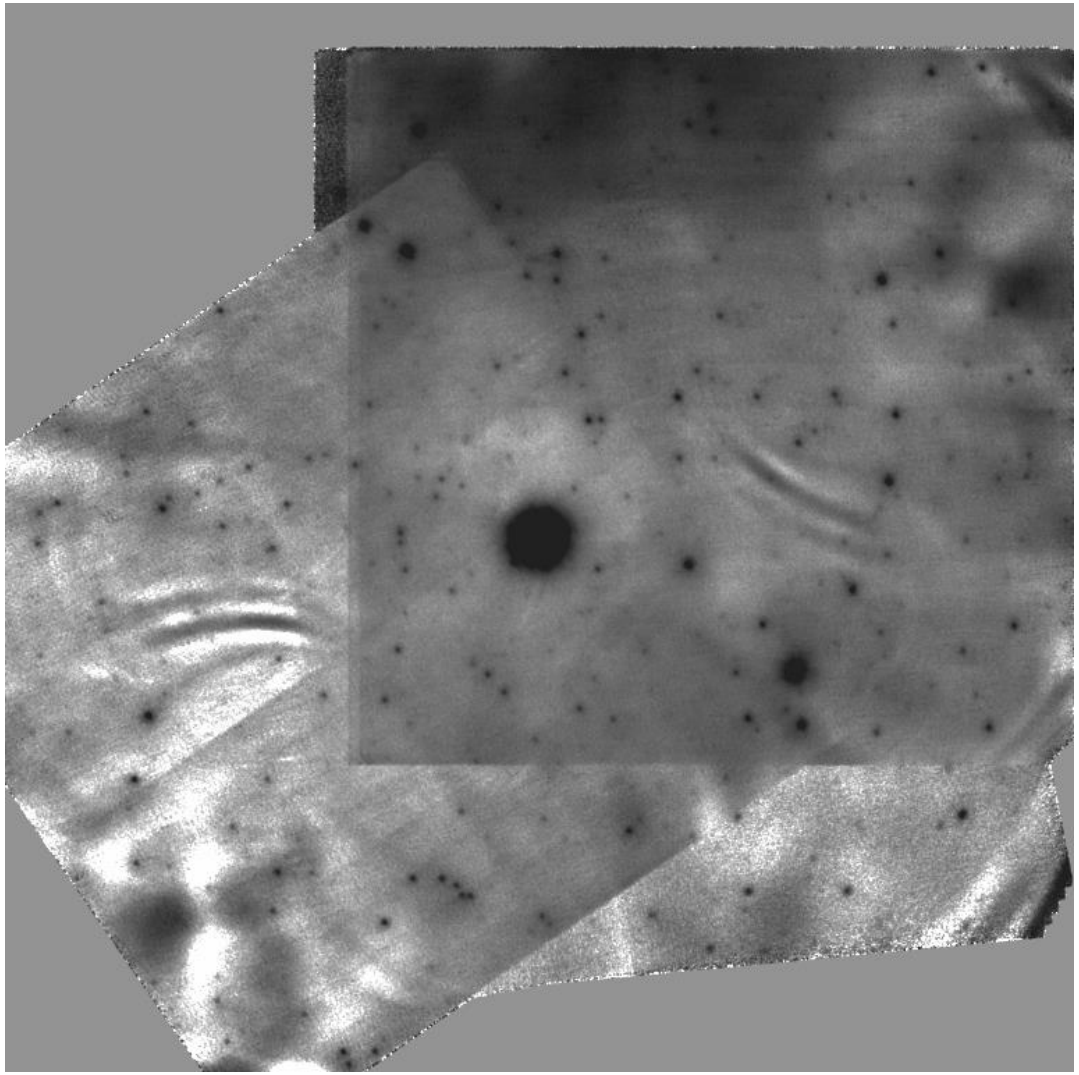
Adaptive Secondary 672 act – ground layer

Xinetics 349 – High layer


High layer WFS
Objective
HWS
CCD
Ground Layer WFS
GWS CCD


GWS 6’ Outer FoV for low layers
HWS 2’central FoV for high layers

Example of commissioning result and comments



Nov 2018 MCAO data on M31, Ks Band, FoV 14″x14″, SR=18% in the final image (best pics 25%).
T exp = 30min, Faintest stars 20.0 (Calibrated on 2MASS), FWHM=0″.073

On the LN instrument many of us learnt many different aspects related to AO and astronomical instrumentation in general:

- Ground WFS full AIV x2;
- Pathfinder experiment (GWS + Adaptive secondary);
- Calibration of the multiple pyramid WFS;
- Control Engineering for the loop stability and performance optmization.
- alignment to the telescope and commissioning.

LN offers us the unique opportunity to test concepts in the perspective of the new instrumentation as MAVIS and MAORY:

- Calibration concepts (Simulated Interaction Matrix)
- Control concepts (Rotation of the Interaction Matrix)

THE PADOVA LN TEAM

Jacopo, Valentina, Maria, Luca

AIV GWS, Commissioning

Carmelo, Kalyan

Calibration, control engineering, Commissioning

Roberto, Marco

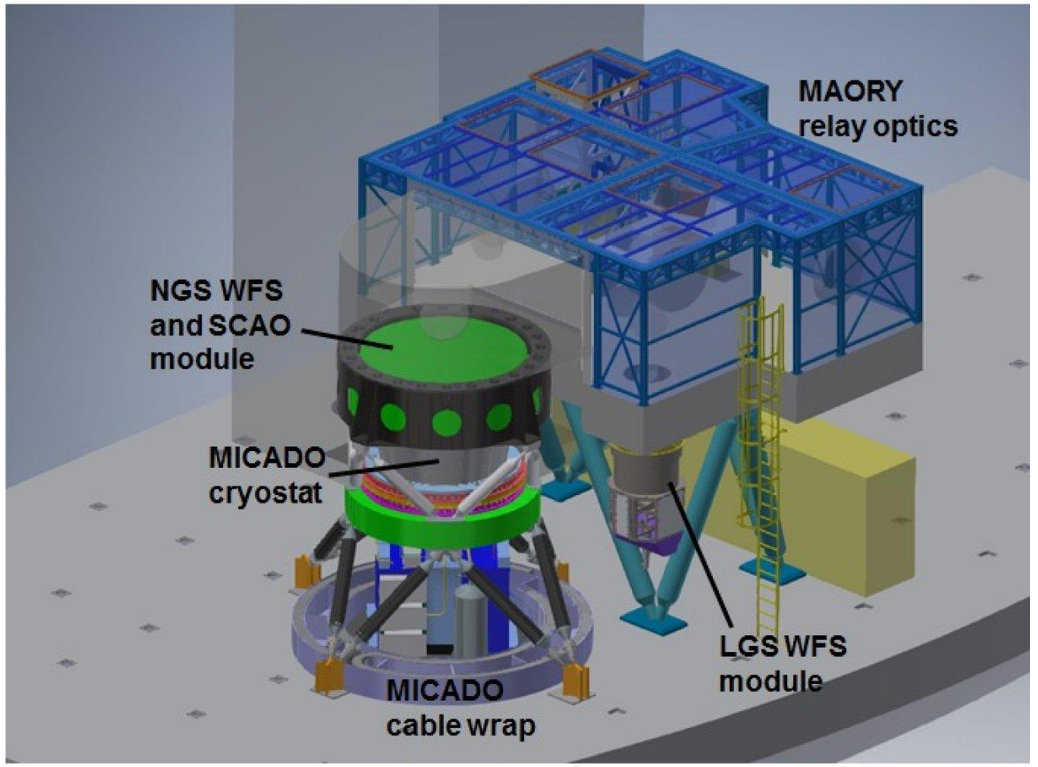
Creative Director

MAORY

"Multi-conjugate Adaptive Optics RelaY for the ELT"

the MCAO module of the ELT
INAF+IPAG+ESO

MAORY exploits the M4/M5 of the ELT
Multi Laser Assisted, multi reference,
Multi deformable mirror.



- MCAO mode:
  - Wavefront sensing by up to 6 Laser Guide Stars + 3 Natural Guide Stars;
  - Wavefront correction by 1 or 2 Deformable Mirrors in MAORY + M4/M5;

- SCAO mode *(Developed in collaboration with MICADO Consortium)*:
  - Wavefront sensing by 1 bright NGS;
  - Wavefront correction by M4/M5;
  - Required to achieve peak performance when bright NGS is available

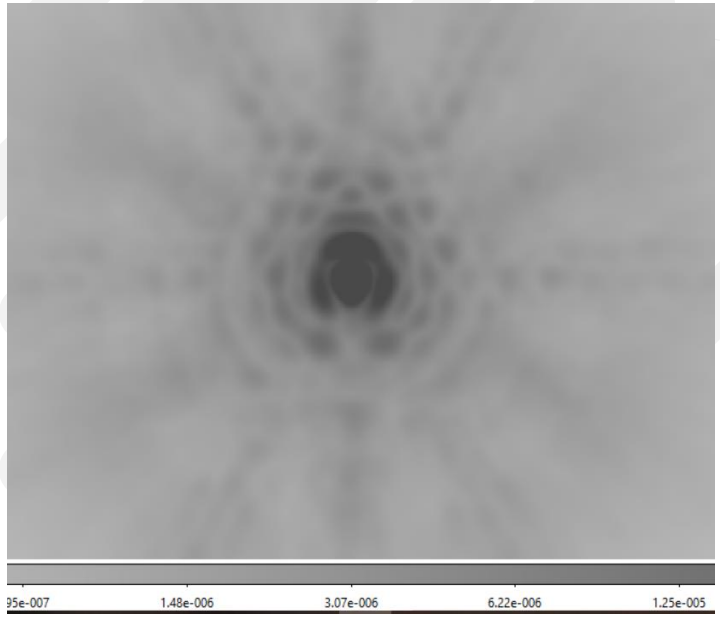
Expected AO performance

Expected MCAO performance (telescope included)
Assumptions: wavelength 2.2 μm, one deformable mirror in MAORY, 6 LGS, full M1

Strehl ratio	Sky coverage	Conditions
SR ≈ 0.3 (TBC)	50% (TBC)	Median seeing 0,67 arc sec As close to zenith as possible Field of view 1 arcmin
SR ≈ 0.15 (TBC)	50% (TBC)	Sub-optimal seeing Zenith distance 30° Field of view 2 arcmin
SR ≈ 0.4-0.5 (TBC)	Not applicable	Best seeing Zenith distance 30° Field of view 20 arcsec

With 2 deformable mirrors in MAORY, performance under median conditions is comparable to performance under best conditions with 1 deformable mirror

Expected SCAO performance: SR > 0.6 (goal > 0.7)
Conditions: on-axis, zenith angle < 30°, guide star magnitude V < 12, median seeing



H band PSF in MCAO 0”.11x0”.14;

It will feed MICADO and a second wide field instrument, still not defined.

MICADO imaging I , J, H, Ks;
1.5 or 4 mas/px;

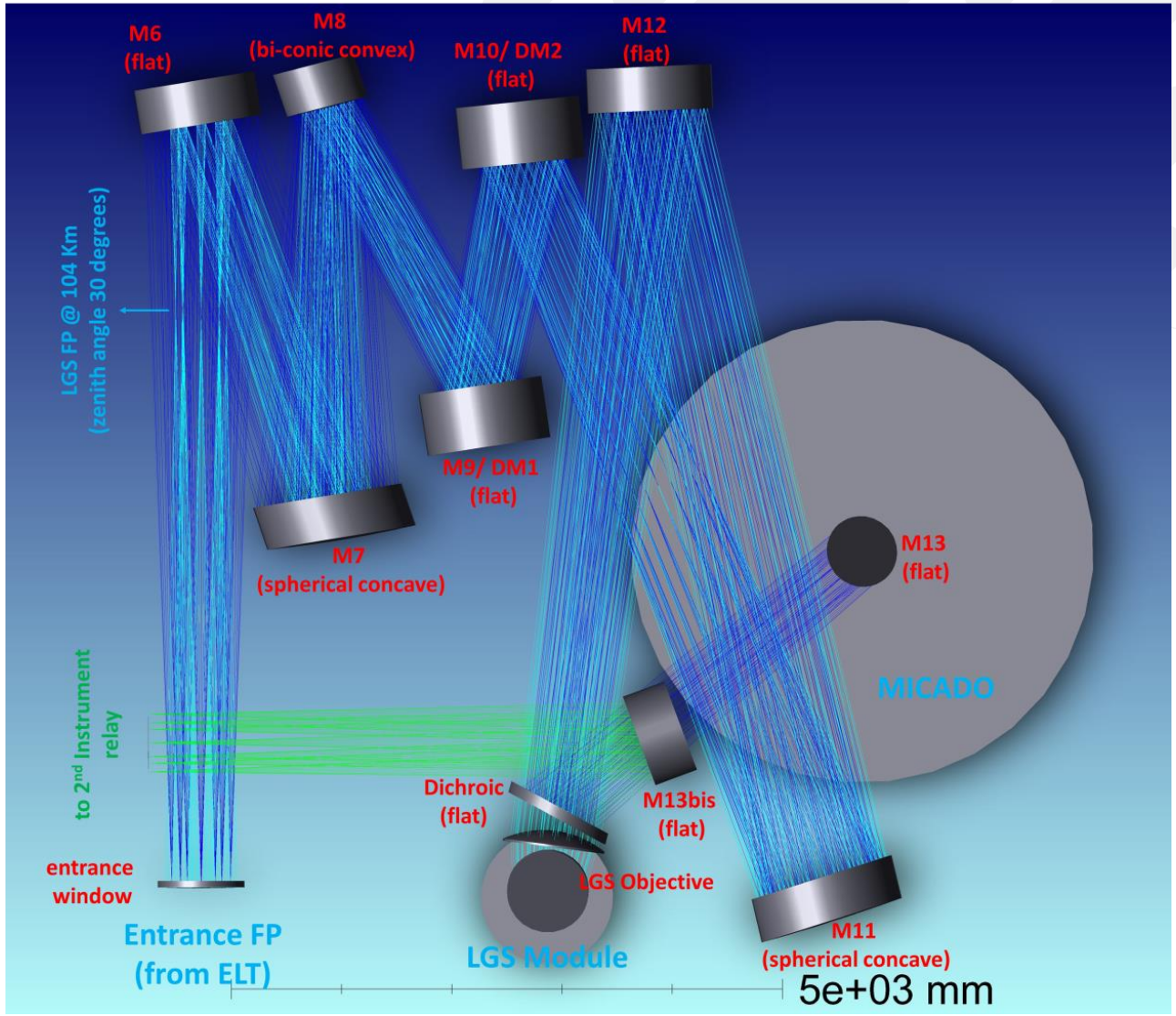
Single Slit mode R~8000;
FoV 20”x20” or 50”x50”

MAORY

First Light 2025

STATUS: End of the Phase B

1) Optical design refreshed by Demetrio
2) Level of complexity: very high, because of the tolerances (50 micro arc sec astrometric precision, 5mas resolution), degrees of freedom (~7000 actuators) , 12 WFS, 6 LGS, …
3) Padova involvement is strong and covers different areas



THE OaPd TEAM

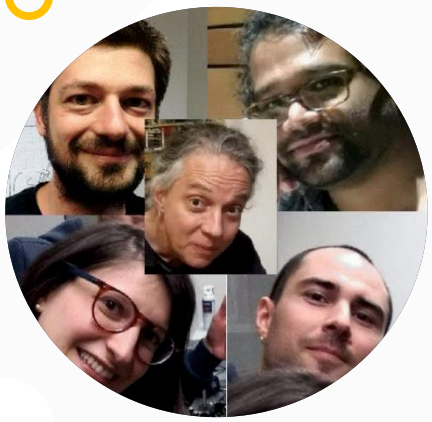
Yes, it's big ..

Valentina, Demetrio,
Jacopo, Bernardo, Andrea

System Engineering

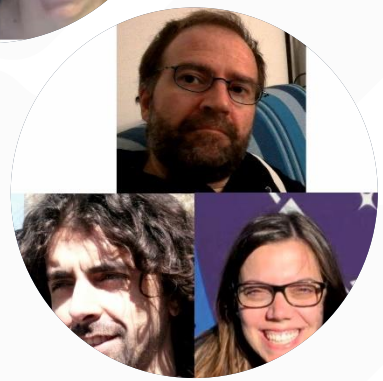
Demetrio, Davide,
Simone, Roberto

Optics



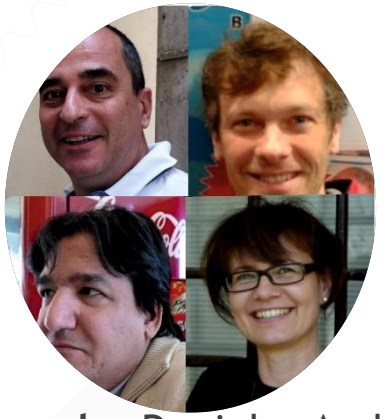
Jacopo, Kalyan,
Maria, Luca, Federico

MAIV



Carmelo, Marco, Elisa

Science Operation
[Tech]



Bernardo, Daniela, Andrea x2

Software Engineering

Elisa, Simone, ..

Ingot WFS

Andrea

Real Time Computer

Simone, Valentina,
Carmelo, Dino, Daniele

Science Team

Enrico, Simonetta

Product Assurance

MAVIS

MCAO **A**ssisted **V**isible **I**mager
and **S**pectrograph
on sky mid-2025

To be installed at the Nasmyth focus of the VLT
Adaptive Optics Facility

- Where: VLT UT4
- What: key technical components are
  - **Deformable Secondary Mirror** (1170 act)
  - **4 Sodium Laser Guide Stars**

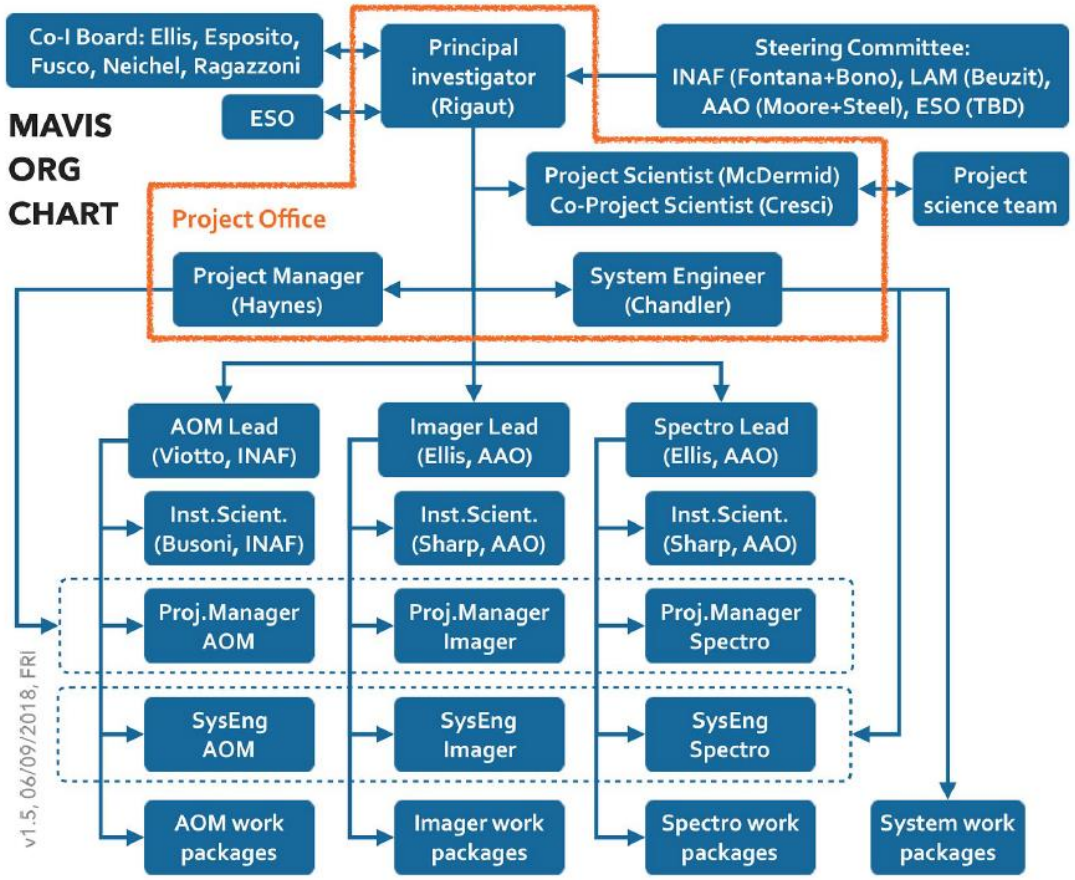
AOF is serving now:

- MUSE: Optical IFU
- HAWK-I: Wide-field IR imager
- ERIS (from 2020): 1-5μm imager/IFU

The Consortium

- Reply to ESO call in 2nd semester 2018
- Kick-off: @ESO (Garching) on Jan 31 & Feb 1, 2019
- Asiago Busy week May 2019 to boost activity and communication

Organizational chart and governance structure of the MAVIS project



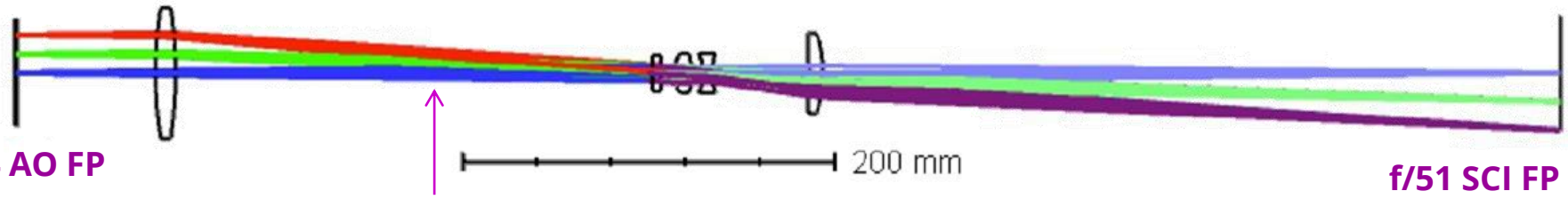
Camera		
Spectral response	Optimized from 450 to 950 (99% SR)	Sensitive also to U and B
Scale	0.49 “/mm	7.4 mas/px
Field of View	30”	
Exit F/#	51	

Detector	
Type	CCD bulk Si, back-illuminated
Size	4K x 4K
Pixelsize	15µm
Spectral response	400nm to 950nm

STRAWMAN MAVIS REQUIREMENTS
(from ESO TLRs)

Field of view	30”x30”
Angular resolution	FWHM ~ 20mas at V band
Wavelength	VRI, extended to UBz
Strehl ratio	15% at V under median seeing conditions
Sky coverage	> 50% at Galactic Poles (feasibility TBC) → SR >7%
Imager	~ 7mas pixel size. Broad and narrow band filters. Tuneable filters - to be explored
Spectrograph	Fibre + Starbugs: Highly multiplexed point-source capabilities, multiplexed compact IFUs (0.5’’ FoV) and larger FoV IFUs. R = 5,000 - 10,000. Alternatively, 3”x3” IFU with 25 mas spaxels (plus 7” FoV, 60 mas mode).

Imaging module



Collimated beam size <15mm

Davide provided different possible Optical Design solutions

The detector would be 4k x 4k

Filters:

- A set o BB and NB filters will be included
- Minimum for TLR: 7 BB + 15 NB filters (not defined yet)
- Current assumption: 3 filter wheels x 9 slots
- Alternative solution: tunable filter R ~ 100-1000 could allow full-frame spectral info (option to be evaluated)

Spectroscopy module

TLRs

- **FoV**: 3”x3”
- **Diffraction limit**: in R
- **Resolution**: R>5000
- **Wavelength range**: 350-950 nm

Spatial sampling: 9.5 mas/spaxel

THE MAVIS TEAM

SUBTITLE HERE

AO Module Responsible

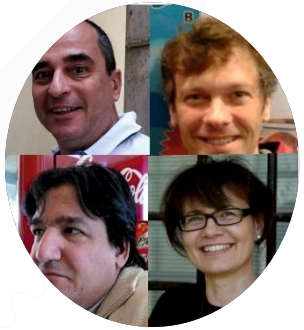
Valentina

Project Management

Maria, Simonetta

Calibration

Kalyan



Instr. Contr. Softw

Bernardo, Andrea Bar., Daniela, Andrea Bal

AIV

Luca, Federico

SCIENCE

Marco

System Eng.

Valentina, Jacopo

Numerical Simulations

Davide

Data Processing

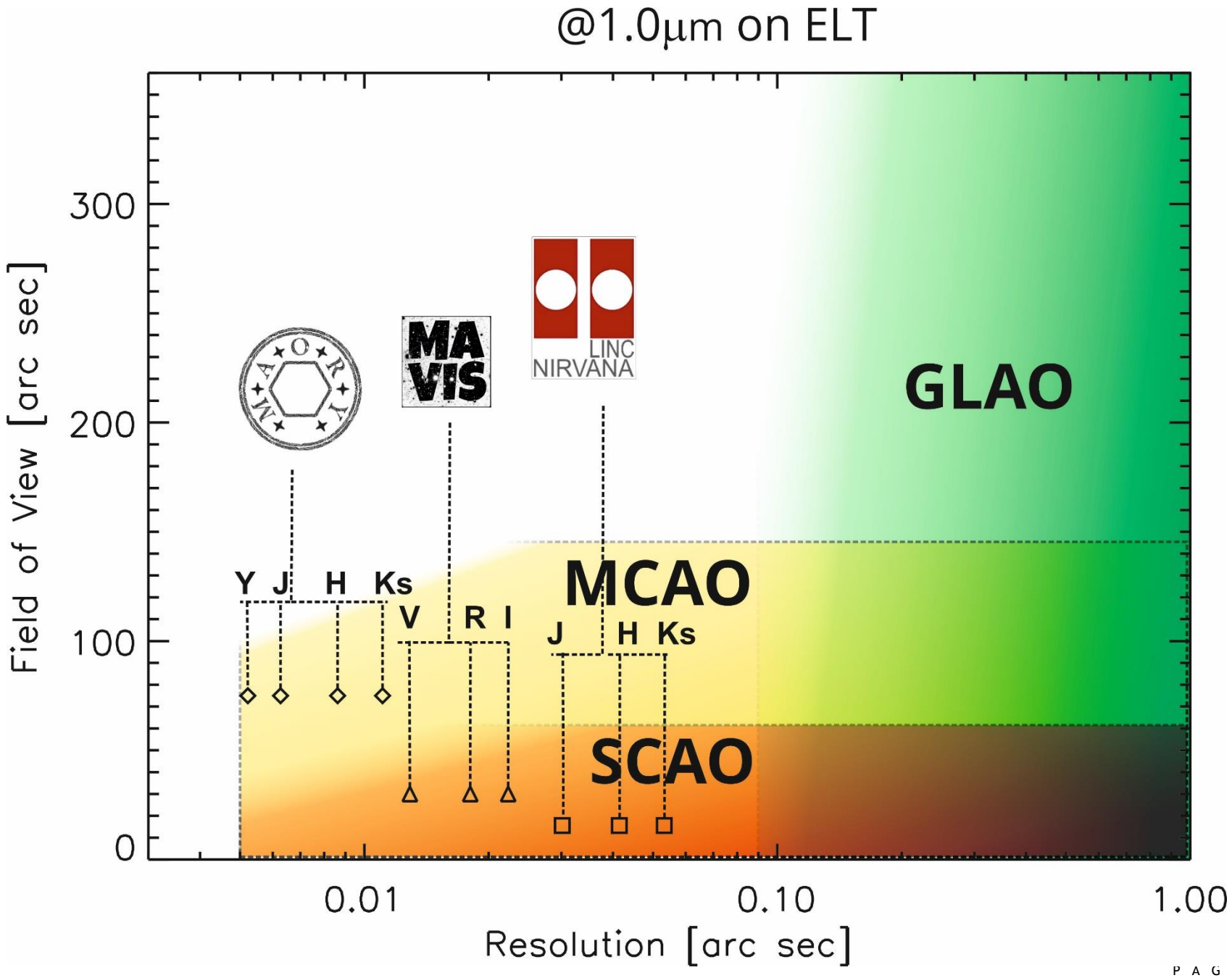
Elena

OPTICAL Design

Davide, Simone e Demetrio

Better performance on larger FoV require:
more actuators per DM;
more DM;
Brighter References;
More References.

And in general, the higher the correction the lower the realization tolerances.



THANKS FOR YOUR ATTENTON