A sharp future for the 3.6m DOT? the power of adaptive optics for medium size telescopes

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STAR/PSILab

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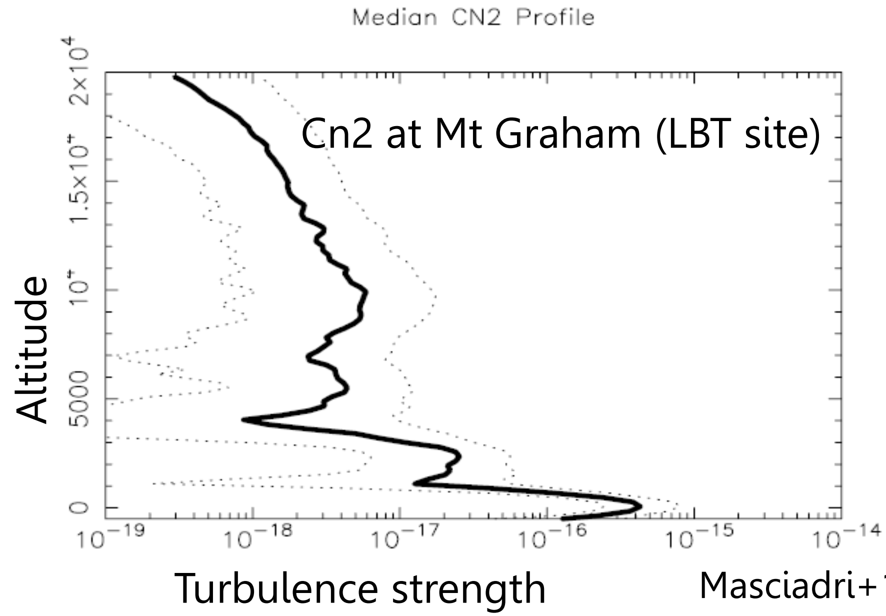
Atmospheric turbulence

C_N^2 is the refractive index structure constant

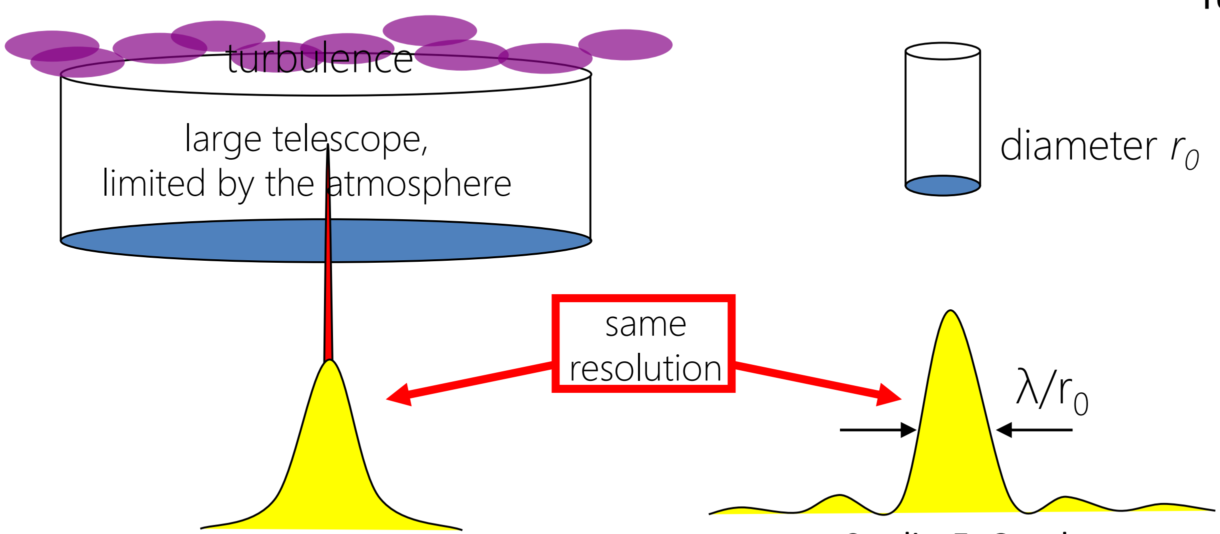
The integral of C_N^2 is Fried's parameter :

$$r_0 \propto \left[\lambda^{-2}(\cos\gamma)^{-1}\int C_n^2(z)dz\right]^{-3/5}$$



Masciadri+**10**

Telescope resolution is λ/r_0 instead of λ/D



Credit: E. Gendron

Order of magnitude of r_0 :

<u>In the visible</u>

Exceptionally :	25 cm
Astronomical site :	10 cm
Sart-Tilman:	3 cm (?)
Horizontal propag :	~ mm

AO motivation

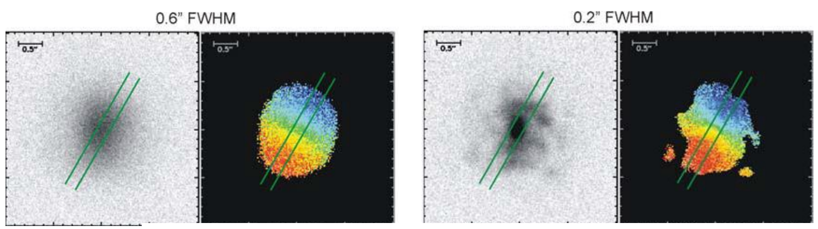
Resolution

$$\lambda/r_0 \rightarrow \lambda/D$$

seeing = 0.8arcsec in H-band => ~0.08arcsec

Sensitivity (point-like sources)

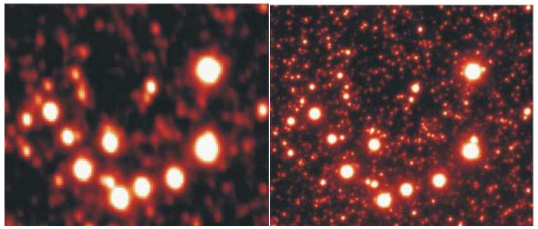
$$t_{int} \propto 1/D^2 \rightarrow t_{int} \propto 1/D^4$$



Simulation of a galaxy, slit of 0.25". ARGOS PDR

But also

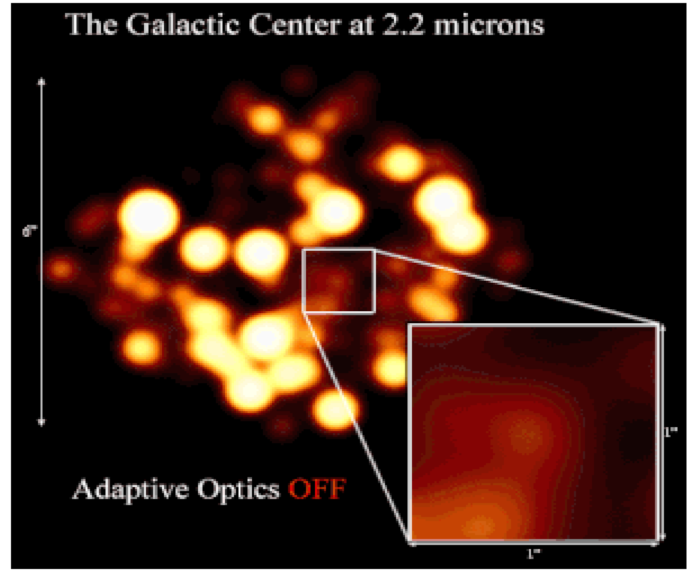
- Better slit couping efficiency
- Reduced crowding noise
- Better astrometry

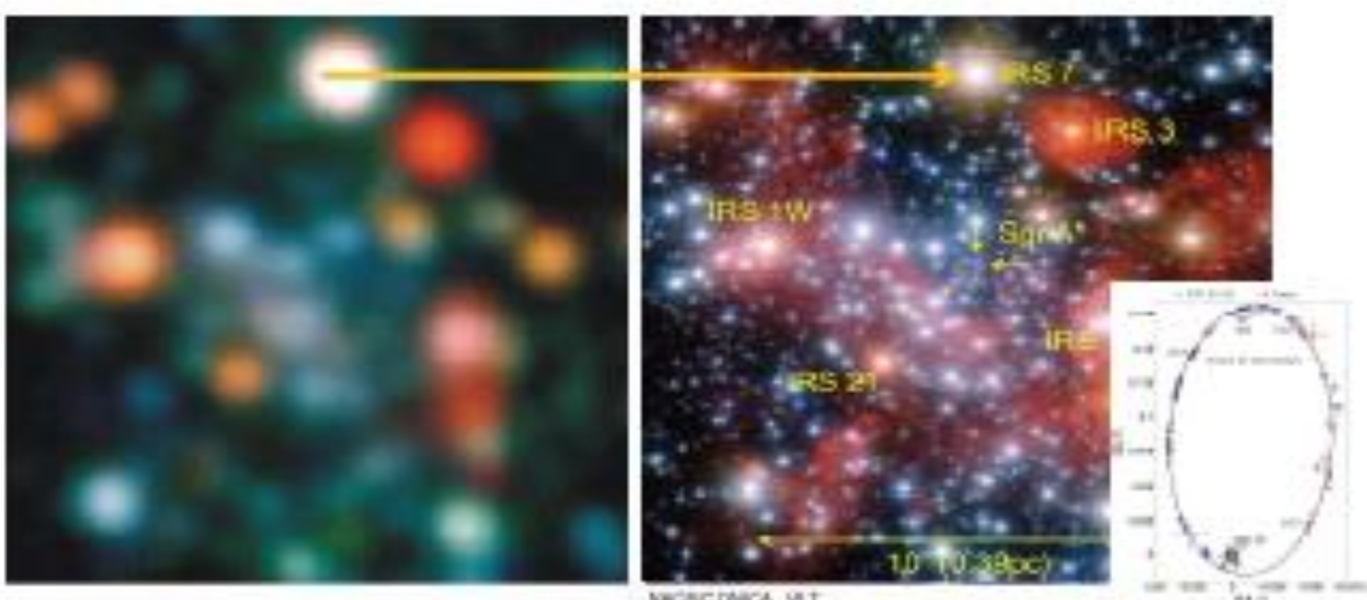


20" region (Left) with ISAAC. (Right) with MAD-GLAO.

Galactic center

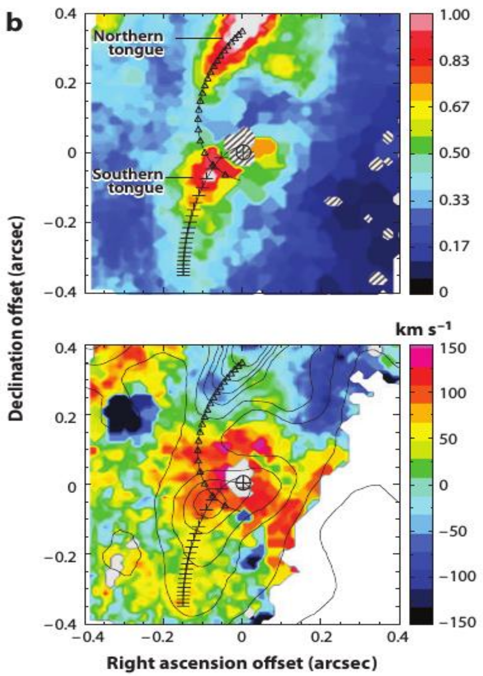
- Allowing to probe star orbits in the MW galactic center
- Has allowed to prove the presence of a supermassive black hole (>10^6 M_sun)
- A unique ‘laboratory’ for testing general relativity





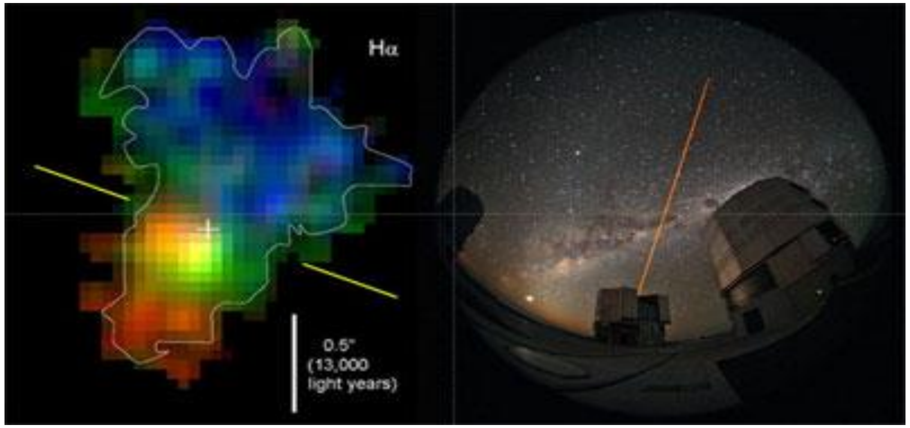
High-redshift universe

- Adaptive optics can also help the study of the high-redshift universe, galaxy evolution.
- Can help reveal the structure and dynamic of those early galaxies



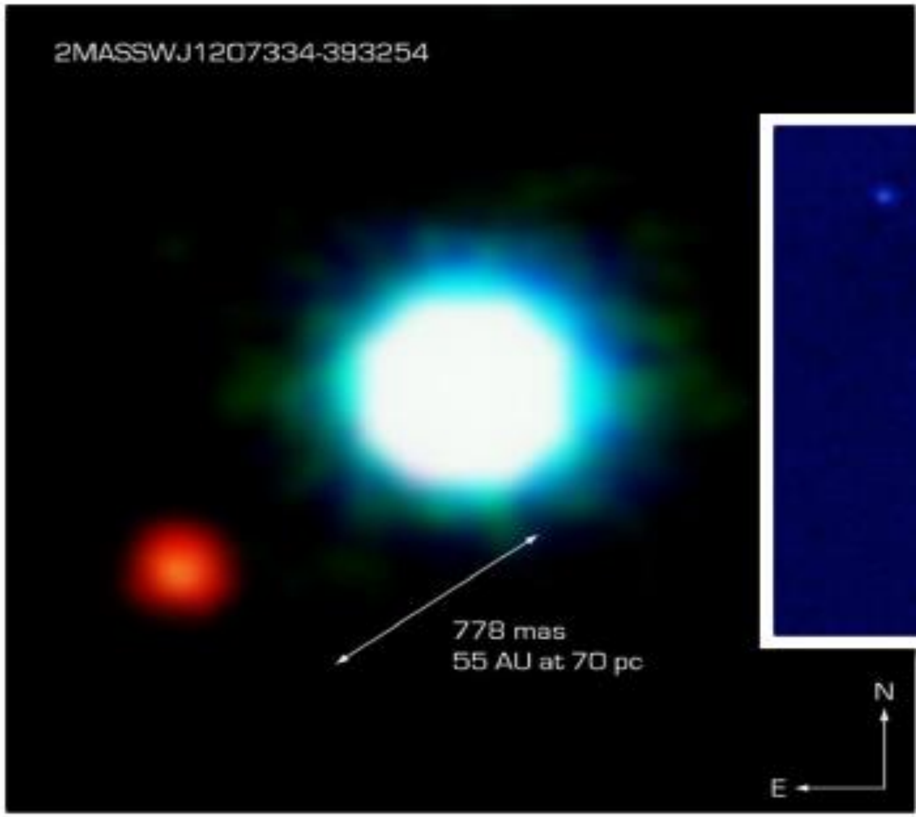
Muller-Sanchez et al 2009

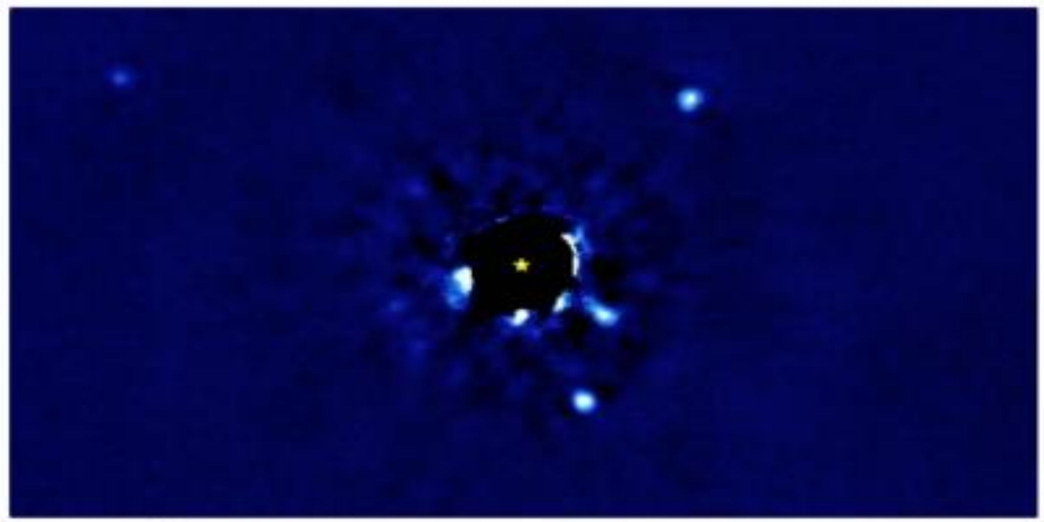
Gas inflow in the center of NGC1068



- Integral field spectroscopy with LGS single conjugated adaptive optics
- Here reveals a massive rotating disk in a z=2.38 galaxy

AO makes it possible to image exoplanets



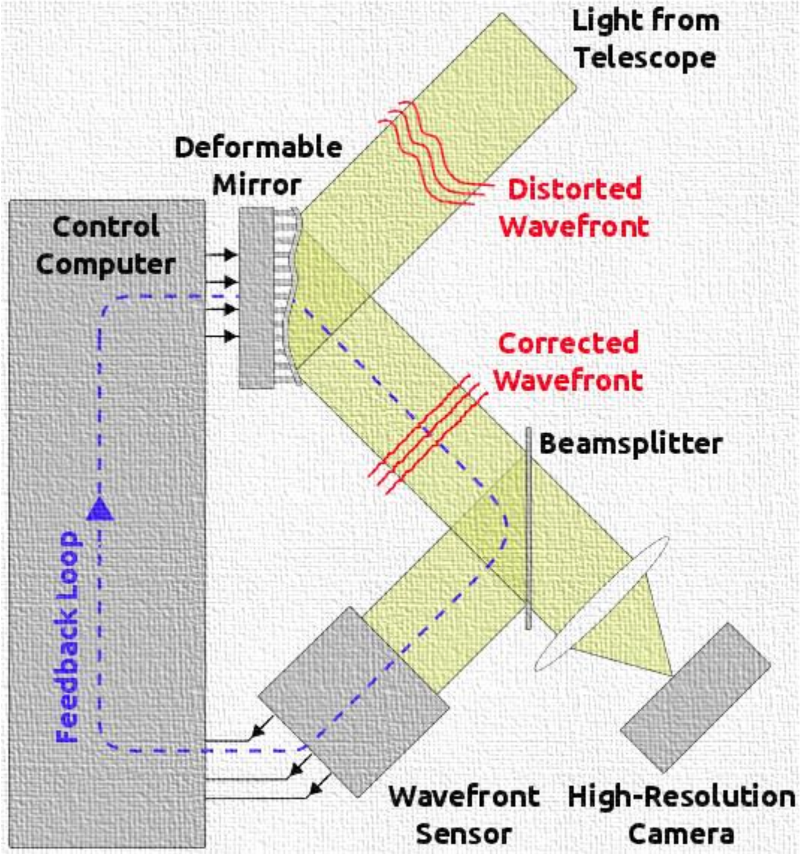


HR 8799

Main applications of adaptive optics

- Solar system: asteroids, planets
- Star formation: multiplicity, disks, exoplanets
- Resolved stellar populations: galactic clusters, nearby galaxies
- Galactic center: 3D orbits, flares, …
- AGNs: black hole mass, gas inflow/outflow, quasar host galaxies & mergers
- High redshift universe

Taxonomy of AO concepts



Single conjugated adaptive optics

- 1 deformable mirror
- 1 wavefront sensor
- Provides ~50% Strehl at 2µm

Typical numbers :

R (limit.)~15 mag,

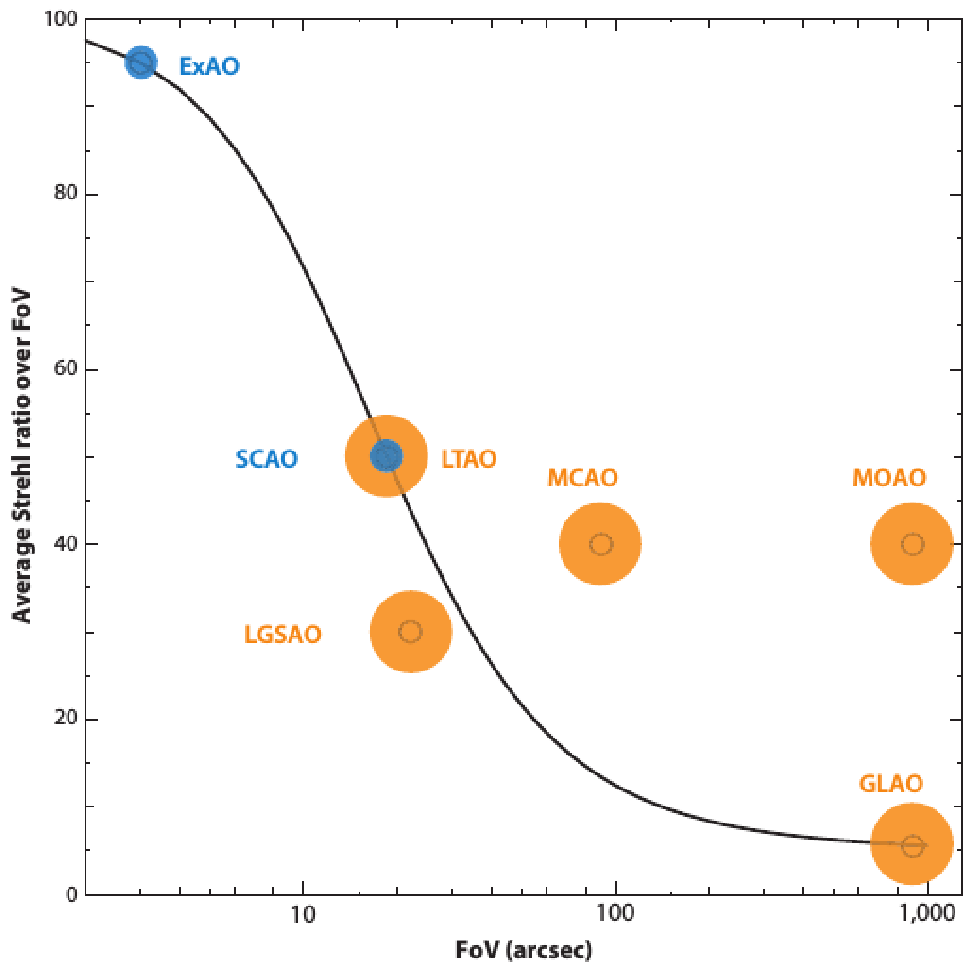
θ ~ 30arcsec at 2µm

➢ *Sky coverage: ~1%*

Use **laser guide star** to extend the sky coverage to 10-50%

Taxonomy of AO species

SCAO : single conjugated
LGSAO : SCAO with laser
ExAO : SCAO on steroids
GLAO : ground-layer
LTAO : laser tomography
MCAO : multi-conjugated
MOAO : multi-object

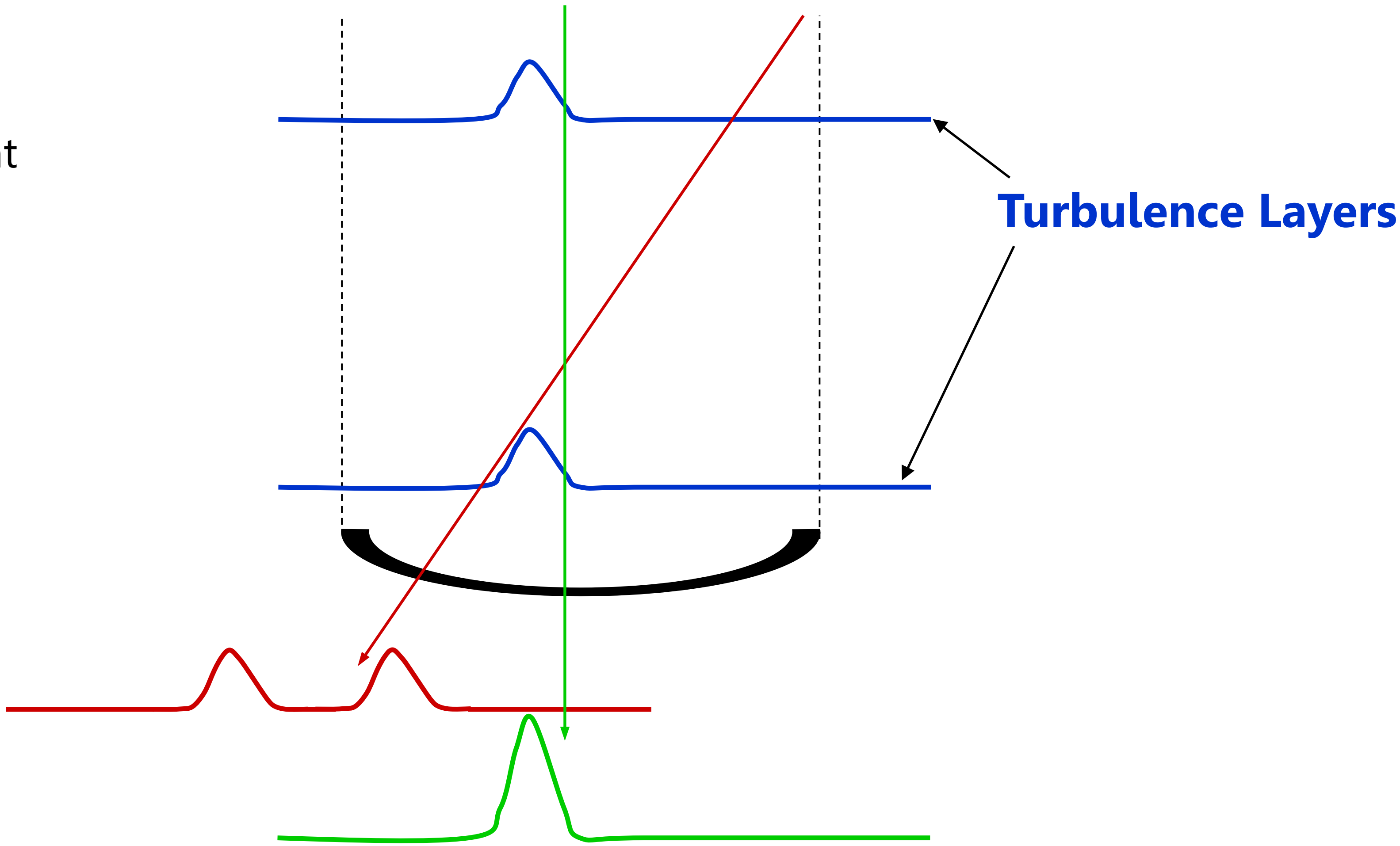


Rigaut & Neichel 2018

Taxonomy of AO species

MCAO & GLAO PRINCIPLE

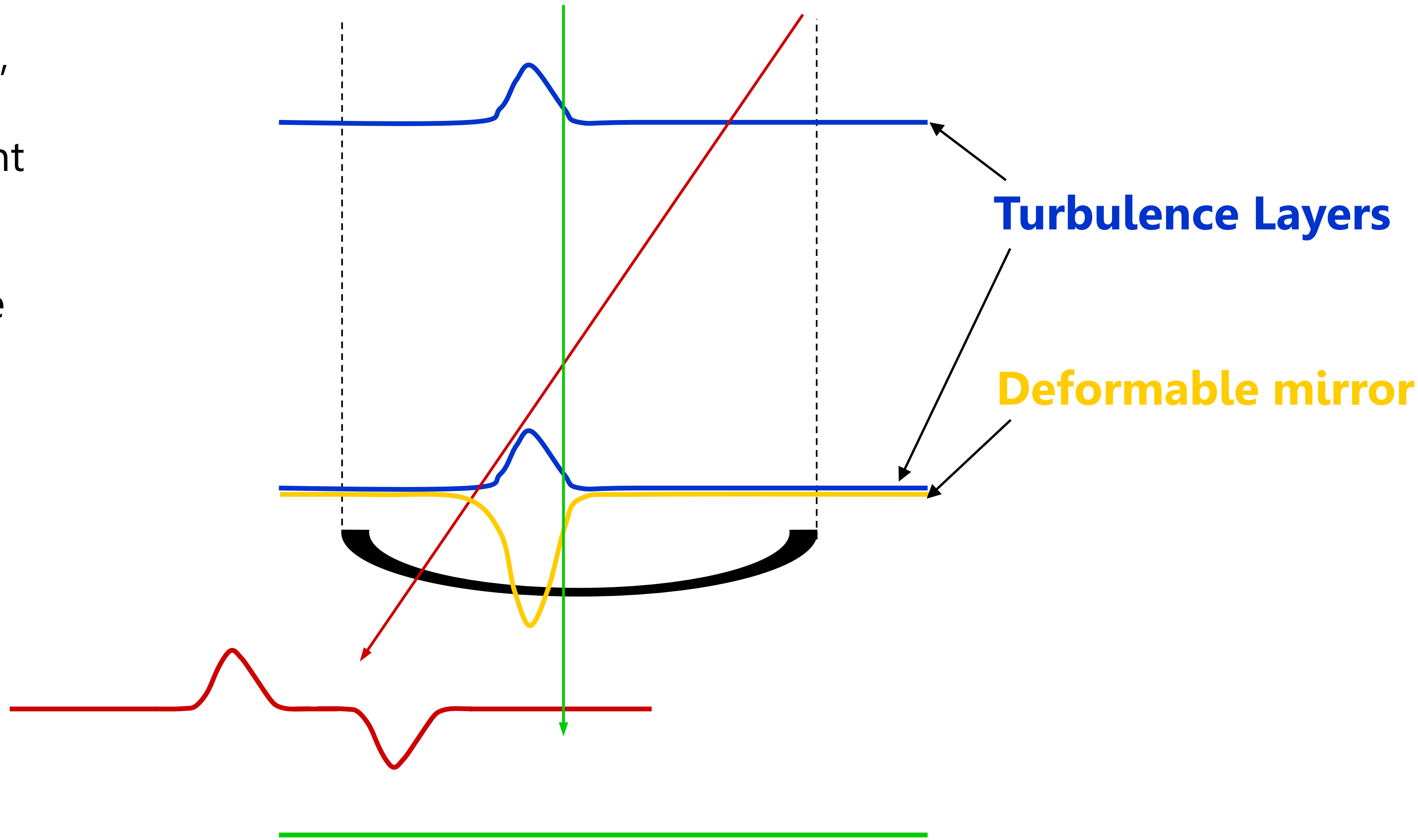
with 2 turbulent layers,
on- and off-axis
wavefronts are different



MCAO & GLAO PRINCIPLE

with 2 turbulent layers,
on- and off-axis
wavefronts are different

and cannot be
corrected with a single
DM



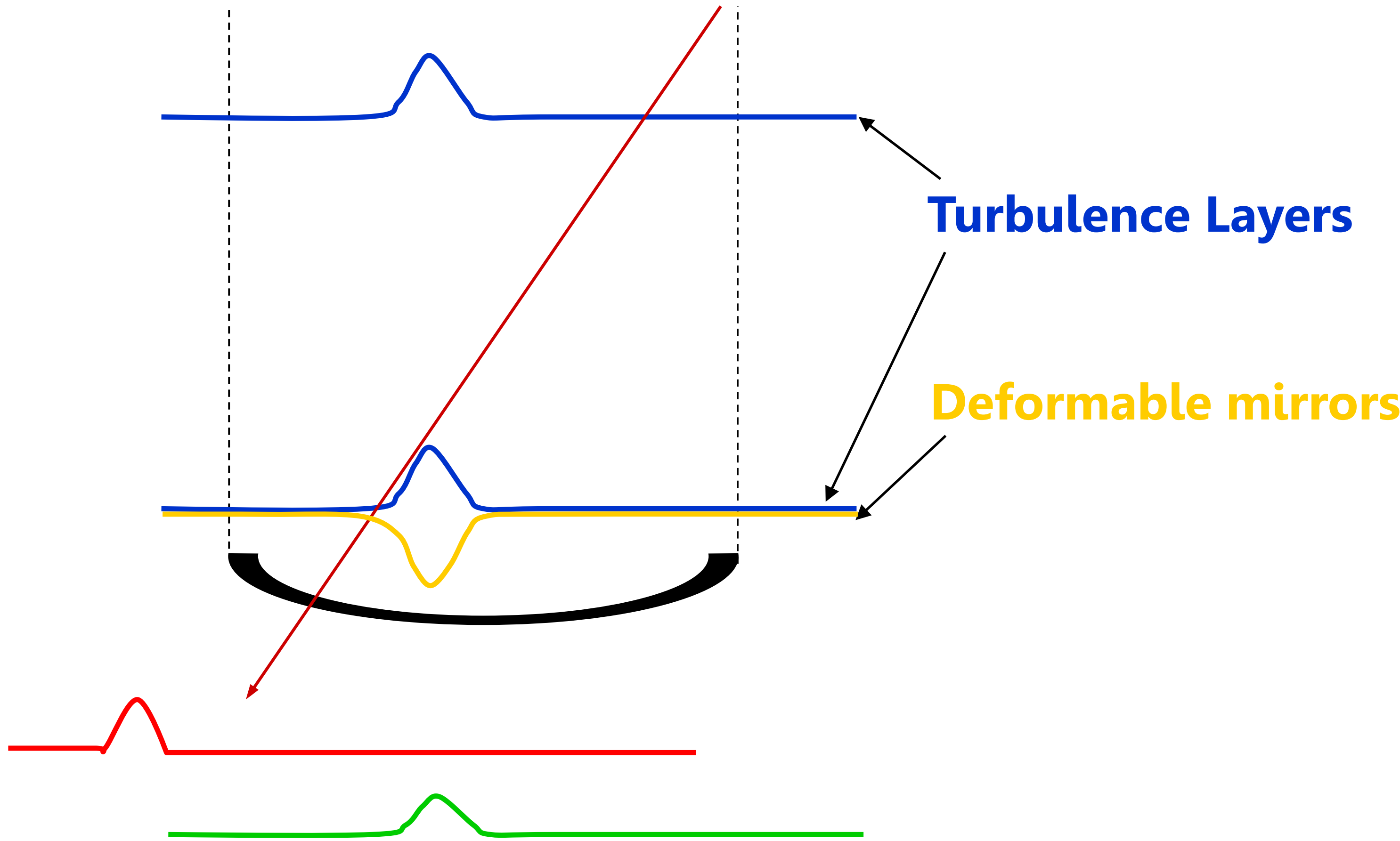
Taxonomy of AO species

MCAO & GLAO PRINCIPLE

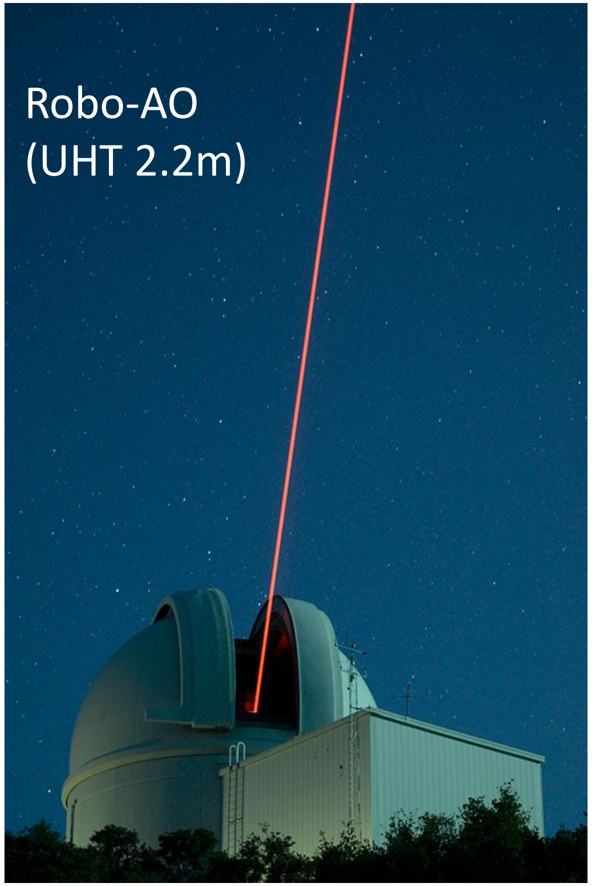
with 2 turbulent layers, on- and off-axis wavefronts are different

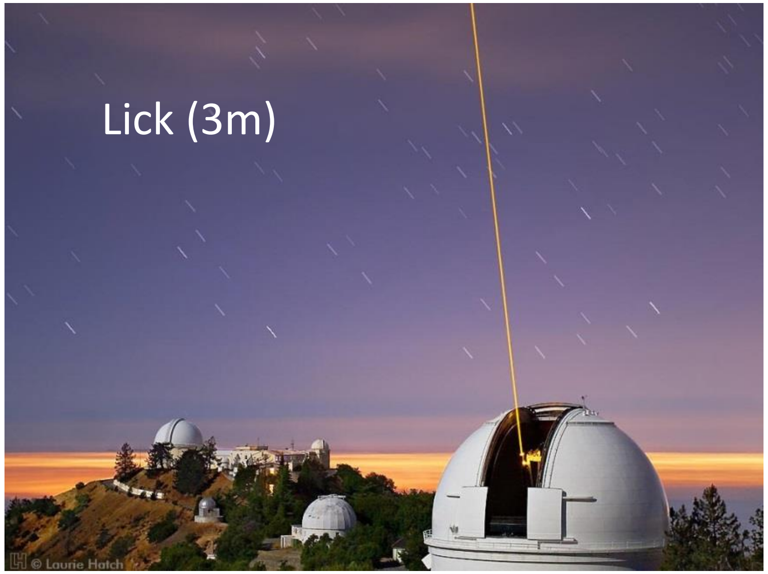
and cannot be corrected with a single DM

But a single DM can correct a given layer



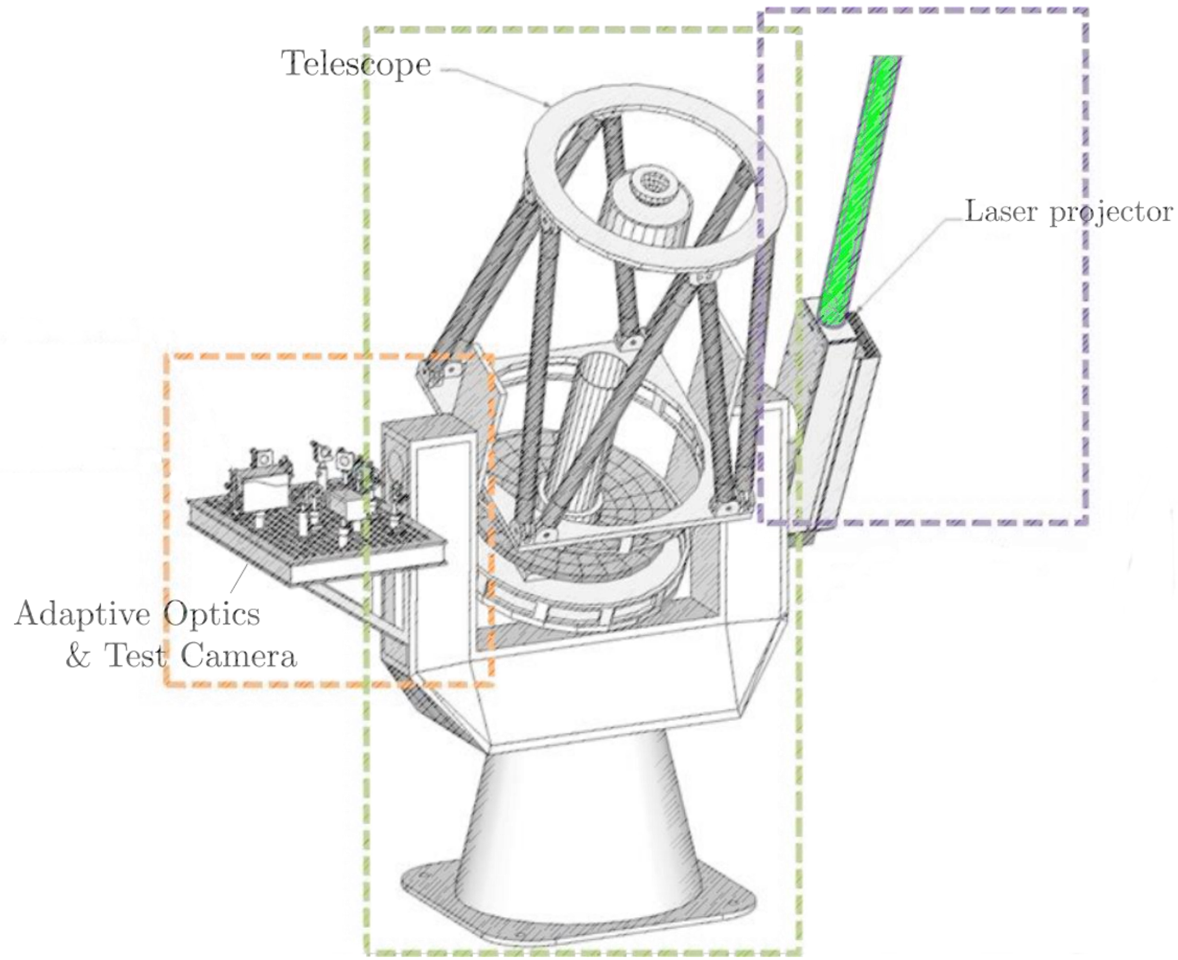
Current LGS systems on 2-4m telescopes





+ SAM at SOAR (4.1m telescope) with UV laser

SALTO: new adaptive optics project at ULiege

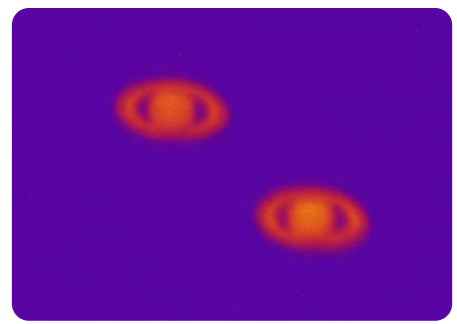


- Aim: robust and autonomous AO system on medium-sized telescope with laser guide star
- Partnership: AMOS + ULiege
- Project funded
- Demonstrator building 2019-2020
- To be installed in Belgian countryside

SALTO: new adaptive optics project at ULiege

Development within the project includes:

- Error budget and end-to-end simulations for AO systems
- Telescope design
- Laser launch design
- Adaptive optics design
- Real time control
- DIMM and weather forecast

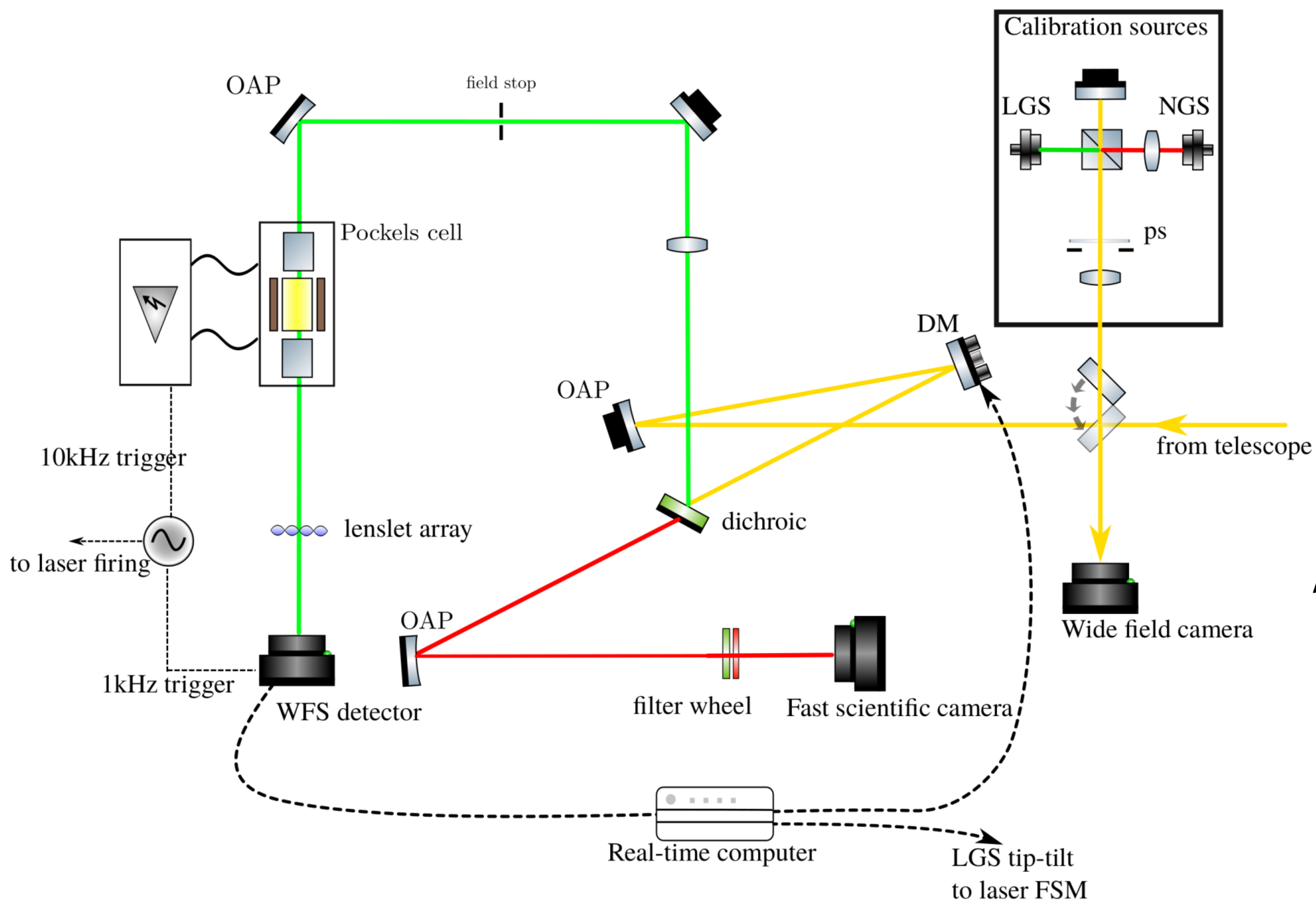


Adaptive Optics System

Using state-of-the-art off-the-shelves components

WFS detector

Nuvu Hnu128AO
- 128x128
- 1kHz framerate
- 1.8kHz in 64x64
- <1 e- ron
- Good QE @532nm



Deformable mirror

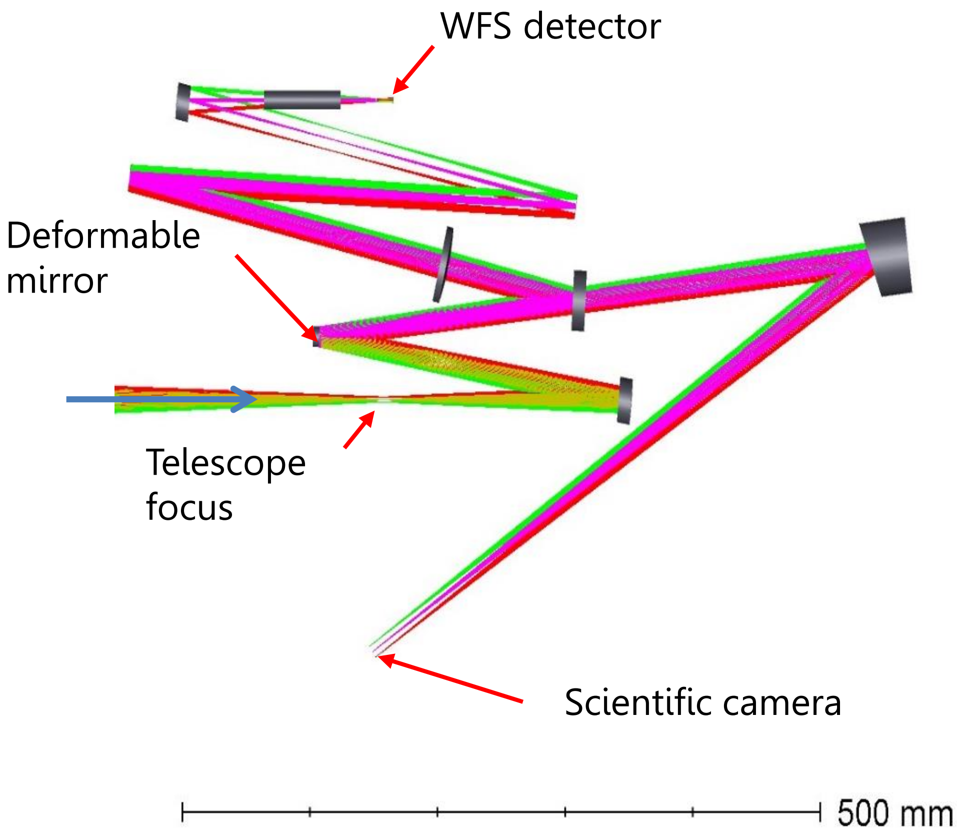
ALPAO DM Hi-97
- D=13.5mm
- 97 actuators
- Large stroke
  - Tt stroke PV wf 60um

Fast scientific camera

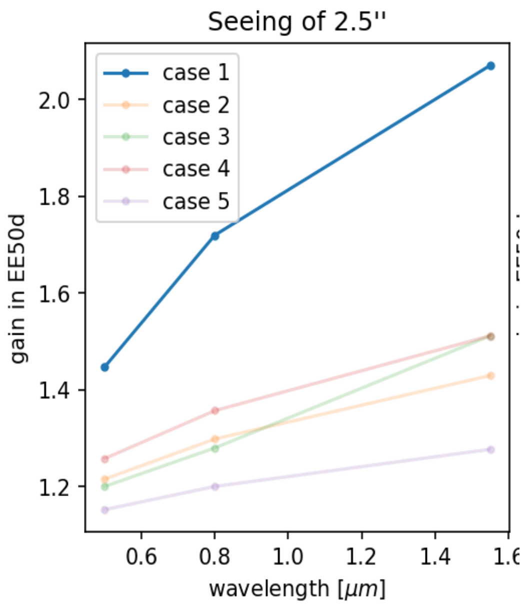
CRED-2
- 640x512
- 0.9-1.7um
- Up to 600fps
- low- noise

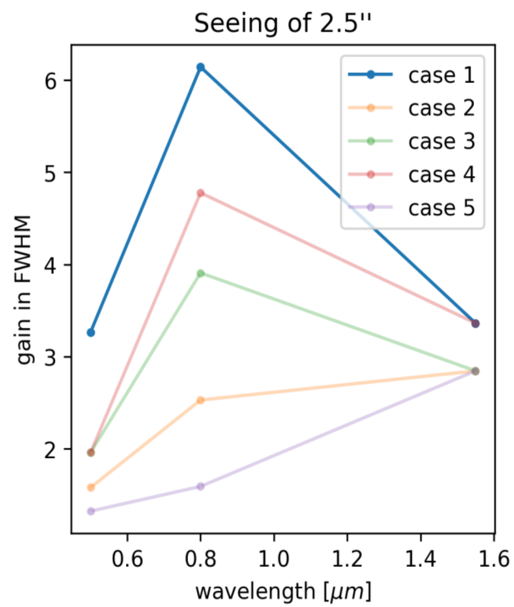
Adaptive Optics preliminary design

Parameter	Value
Diffraction limit @500nm	0.15″
Diffraction limit @ 1700nm	0.5″
Scientific camera	
Pixel scale	0.1″
Field-of-view	1′
WFS camera	
Number of subap on diameter	10
Number of pixels / subap	8
Subap FoV	8.5″
Pupil size at SH	1.92mm



System design: error budget & simulation





Numerical results at wavelengths of [500, 800, 1550]nm:

Simulation	Strehl [%]	EE50d ['']	FWHM ['']
No correction	[0, 0, 10]	[2.6, 2.5, 2.3]	[2.2, 1.9, 1.7]
Closed-loop	[0, 15, 60]	[1.8, 1.4, 1.]	[0.7, 0.3, 0.5]

Main system parameters

- LGS @ 10km
- Seeing: **2.5-3.5"**
- Framerate: 1kHz
- Number of corrected modes: 50-70
- 10 subapertures on telescope diameter

- Subaperture FoV: 6.5-8.5"
- Subaperture size: 6x6px

- Gating range up to 1.5km (up to 10μs)

Seeing campaing is starting in near future

Possible applications at the 3.6m DOT

Improve synergies with V & ELTs and with space surveys

- NGS or LGS SCAO for TIRCAM-II (+ other small FoV instruments)
- LGS SCAO with a single NIR-IFU
- Visible AO – combined wih Lucky Imaging
- GLAO to feed an DOT IFS
- XAO with high resolution NIR spectrograph

Reminder:

AO works better at longer wavelength

- coherence length is greater and timescale is longer
- a phase change of 250nm is λ/2 at 500nm and only λ/10 at 2μm

SCAO for the DOT

High-resolution imaging PLATO follow-up

High-resolution imaging needed (PLATO pixel scale 15″/px):

- Discard false positive
- Search for secondary source diluting signal
- Statistics of planet occurrence vs host star multiplicity

~100,000 targets with Mv<=11

➢ very efficient AO system with good short wavelength correction

IFU with LGS-AO & follow-up of GAIA

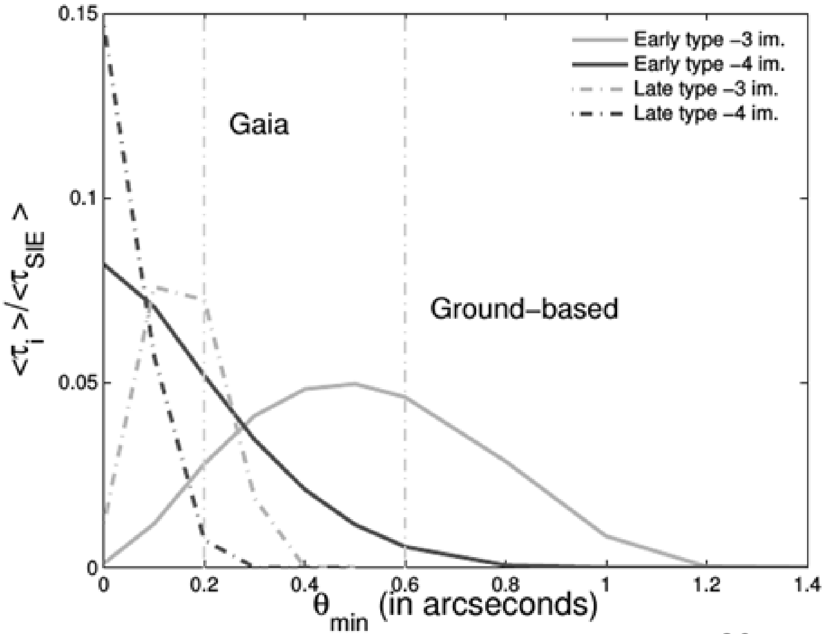
Follow-up needed for:

- Confirmation
- Redshifts determination for accurate modelling

3000 lensed quasars out of > 5 10^5 detected QSOs

➢ NIR IFU with R~2000, 3-4″ FoV

+ AO to match the resolution of Gaia



Finet & Surdej 2016

LGS-SCAO for the DOT

Possible system parameters:

- 532nm laser focussed at 16km, 10W
- 16x16 Shack-Hartmann
- Tip-tilt guide star: 17.5 R-mag at 30" away from target

- K-band ~25%
- Sky coverage is ~51%

Error budget		Values	Units
High-order errors	Focus anisoplanatism	197	nm
	Fitting error	89	nm
	Aliasing error	51	nm
	Temporal error	65	nm
	Wavefront measurement error	70	nm
	Multispectral error	0	nm
	Total	242	nm
Tilt errors	Tilt measurement error	49	mas
	Tilt temporal error	14	mas
	Tilt anisoplanatism	42	mas
	Total	66	mas

Performances	Strehl_noTilt	Strehl	FWHM	EE50
R 658nm	0.0 %	0.0 %	0.15 arcsec	0.57 arcsec
H 1630nm	42.0 %	12.0 %	0.18 arcsec	0.24 arcsec
K 2190nm	62.0 %	25.0 %	0.2 arcsec	0.17 arcsec

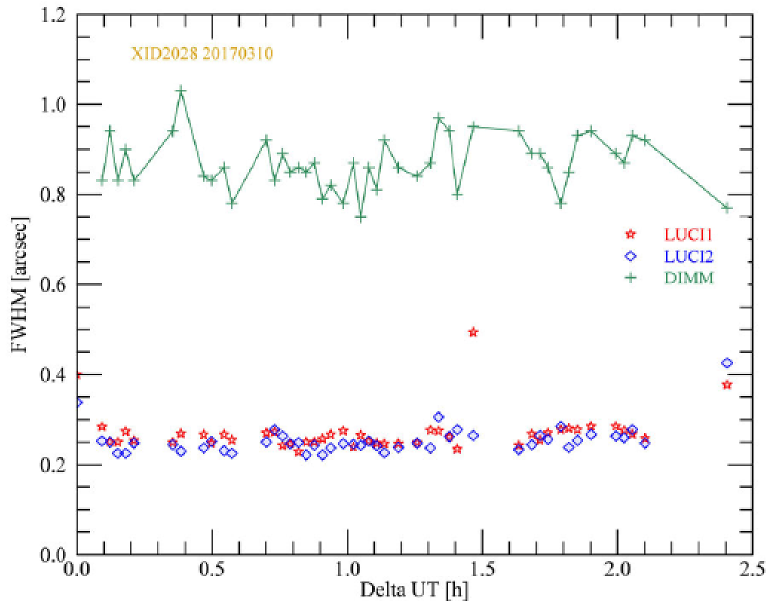
	avg	pole	gal. center	[30, 30]deg
Sky coverage < 6"	7.0 %	0.0 %	5.0 %	2.0 %
Sky coverage < 30"	51.0 %	5.0 %	75.0 %	34.0 %

Beyond conventional for the DOT

GLAO

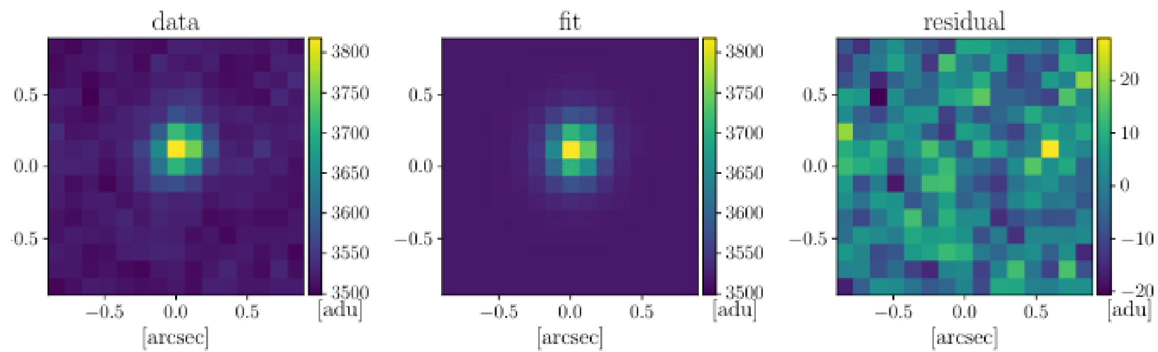
- Moderate additional risk
- Good and stable correction
- Gain for spectroscopy
- Well behave PSF
- Improve up to the visible

-> 'Imaka, SAM



GLAO PSF is well described by a Moffat

$$I(r) = I_0[1 + (r/R)^2]^{-\beta}$$



ARGOS – 3.8min exposure, K-band

Conclusions

- SALTO aims is to build a 1m class telescope demonstrator with LGS-AO.
  - targeting 1-4m class telescope
  - development features many different aspects
  - on-sky by end of 2020
  - opportunity to benchmark ideas with SALTO

- AO can benefit many applications at the DOT
- AO would improve the synergy possibilities of the DOT with V-, E- large telescopes and space mission (e.g. GAIA, PLATO, TESS, …)