Which AO technologies ELT needs to study the deep universe?

The case of the Ingot WFS

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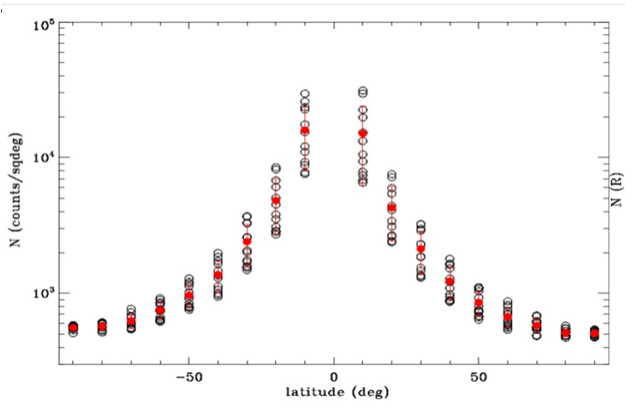
Adaptive Optics at the ELT

Scientific motivation - Thanks to their optimal angular resolution and a high light-collecting power, the next generation of telescopes will investigate how galaxies form and evolve in a cosmological context, likely looking at the **deep field observations**.

However, to make the AO systems work properly, the ELTs need bright reference stars close to the scientific target. This is one of the main limitation factor for the AO correction, which reduces the investigation to small and specific areas and it is linked to the so-called **sky coverage** (SC). Therefore, they will necessarily make use of Laser Guide Stars (LGS)

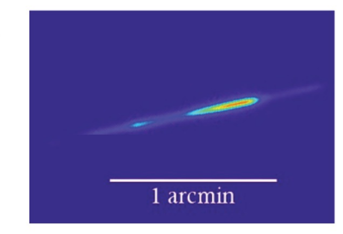
Focus - Due to the limiting magnitude (14-17 mag, V-band) that makes stars potential natural guide stars, the SC can vary a lot, reaching the lowest values at the galactic poles (0.5%, K band).



Using LGSs to create artificial reference stars in the direction of the observed object, it is possible to increase the SC and obtain high Strehl Ratios (reaching SR~30% over a 1′ FoV with up to 50% SC in the South Galactic Pole with MORFEO[1] and 50% SC with HARMONI[2] on axis).

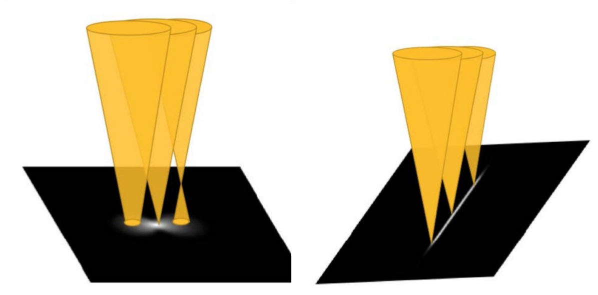
Why a new WFS ?

Technological problem - The planned **WaveFront Sensors** (WFSs) for ELTs will be used in a sub-optimal mode. Therefore, they will not exploit the full capabilities of the AO systems, affecting the final performance.

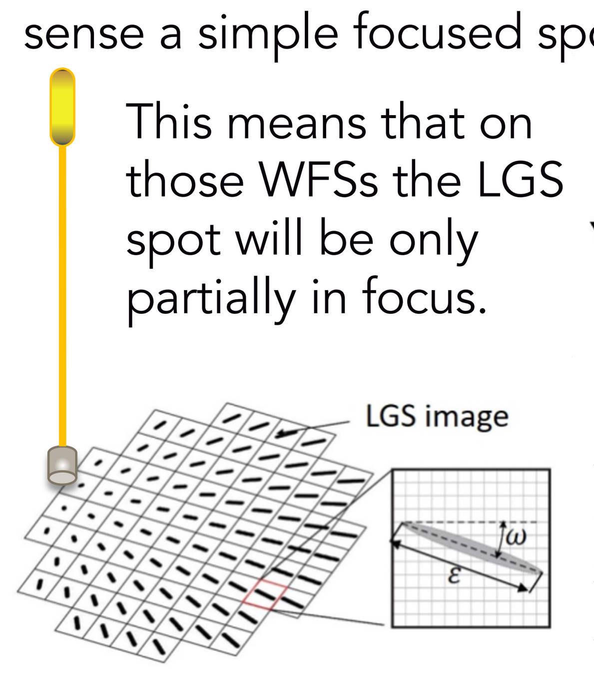


Focus - Due to their intrinsic geometry, LGSs are NOT point sources, but extended elongated objects with a given orientation in the sky. However, classical WFS, like the Shack-Hartmann and the Pyramid WFS are prepared to sense a simple focused spot of the GS.

This means that on those WFSs the LGS spot will be only partially in focus.



LGSs focus on a 3D volume, not on a plane. They have a cigar-shape on sky!



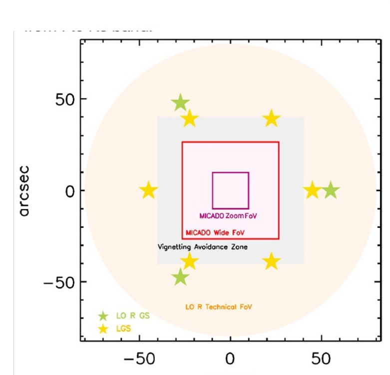
Moreover, the LGS spots appear elongated when seen far from the laser launcher position. This elongation translates into a decrease in the sensitivity of the wavefront error measurements and sometimes the excess of light should be truncated to avoid cross-talk between adjacent pixels.

To optimise the wavefront sensing capabilities, the WFS should be tailored to the LGS geometry.

Sodium LGSs at ELT

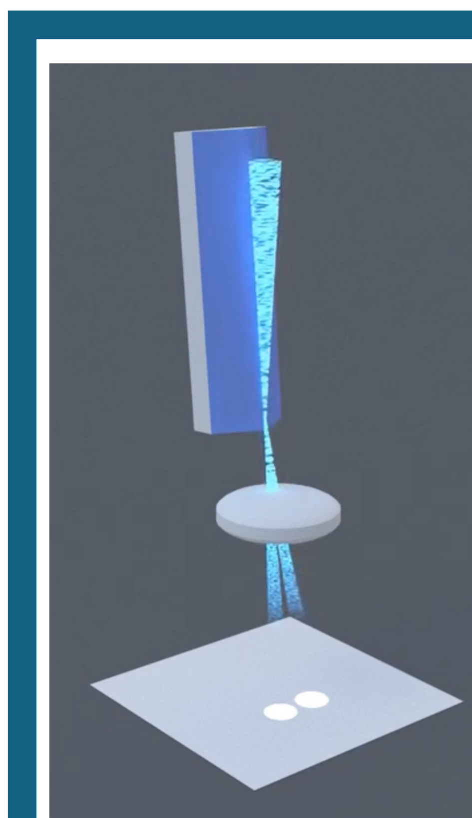
Created by excitation and de-excitation of sodium atoms using powerful lasers fired from the side of the telescope.

Atomic sodium resultant of meteoric disintegration remains at an altitude between 89 km and 92 km,. It is concentrated on a layer with a thickness of 10–20 km, with highly variable characteristics.



Lasers tuned at **λ** ≈ 589.2 nm, producing an artificial monochromatic source. The ELT foresees 4 Laser Launcher Telescopes with up to 8 LGSs!!

The Ingot WFS

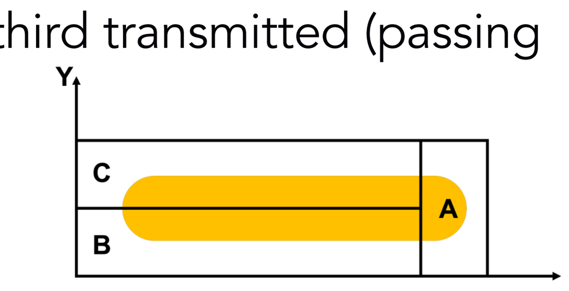


A new concept of a WFS[3,4] involves a combination of refractive and reflective surfaces configured in a complex prismatic shape ("Ingot"). This design utilises the 3D shape of the beacon and ensures a 1:1 correspondence between the beacon and the WFS.

The spot is fully focused along the prism and can be split to select light from various parts of it. Each portion is directed onto a pupil image, potentially onto a common location for detection.

Current design splits the incoming LGS light into three beams as shown below, two reflected off the prism and the third transmitted (passing unperturbed).

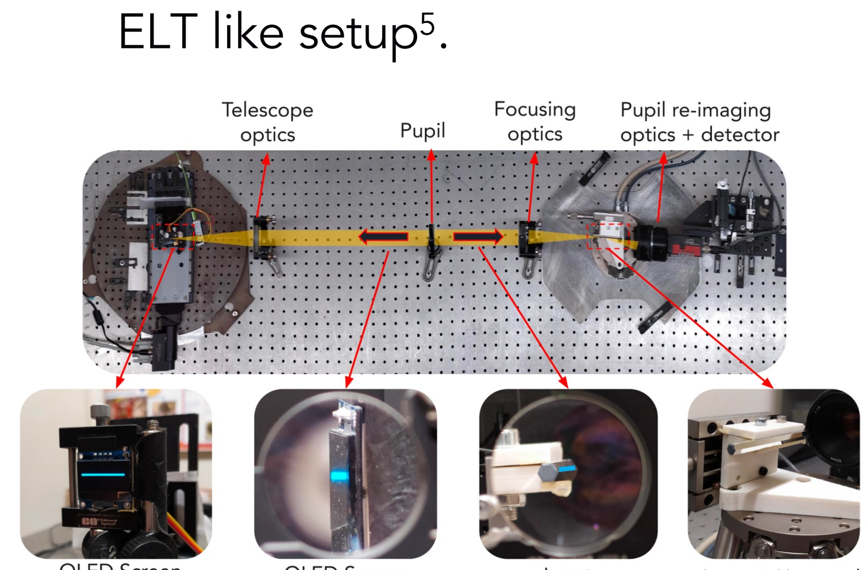
Scan the QR code to see the Ingot working!



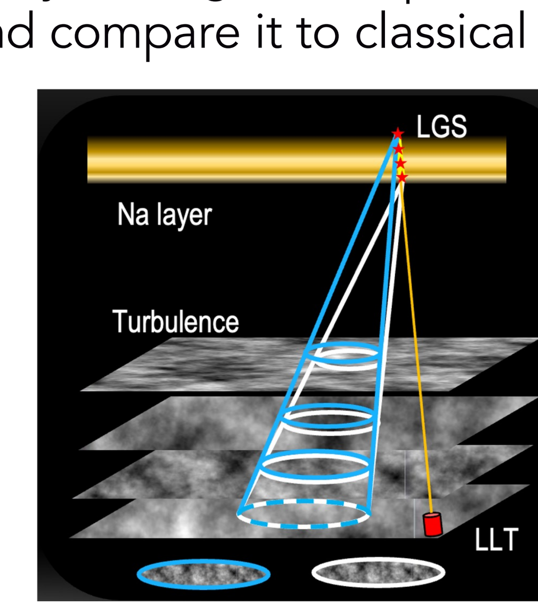
The project is multiphase

1. At INAF laboratories we have assembled a **test bench** to simulate the LGS source on an ELT like setup[5].

Scan the QR code to see our LGS changing!



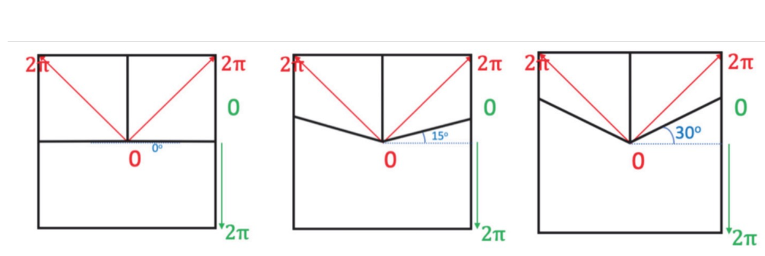
2. We are developing simulations to study the Ingot WFS performance and compare it to classical WFS[6].



The team!!

We plan to test the Ingot on sky in the near future!

3. Quasi-real closed loop scenario was tested at the LOOPS bench at LAM[7] with a spatial light modulator.



References

1) Busoni et al., 2022, SPIE, 12185, 121854R
2) Thatte et al., 2022, SPIE, 12184, 1218420
3) Ragazzoni et al., 2017, AO4ELT5, 0096
4) Ragazzoni et al., 2024, A&A, in press
5) Di Filippo et al., 2022, SPIE, 12185, 121854V
6) Portaluri et al., 2020, SPIE, 11448, 114483I
7) Arcidiacono et al., 2022, SPIE, 11448, 1144868.