Real-time measurement of the Na layer profile for tomographic reconstruction: experimental results and its application to the E-ELT case

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Multi-conjugate AO and the need of LGSs

Some of the most important science goals of any Extremely Large Telescope are high-redshift galaxies and the re-ionization of the early universe.

In both cases, high performance wide-field Adaptive Optics is a critical requirement.

For this reason Multi-Conjugated AO systems will be built on those telescopes, but they need several Guide Stars for the real-time compensation of the atmospheric distortions over a wide field.

There are not enough bright Natural Guide Stars to cover the whole sky. Therefore, Laser Guide Stars are needed to operate such systems.

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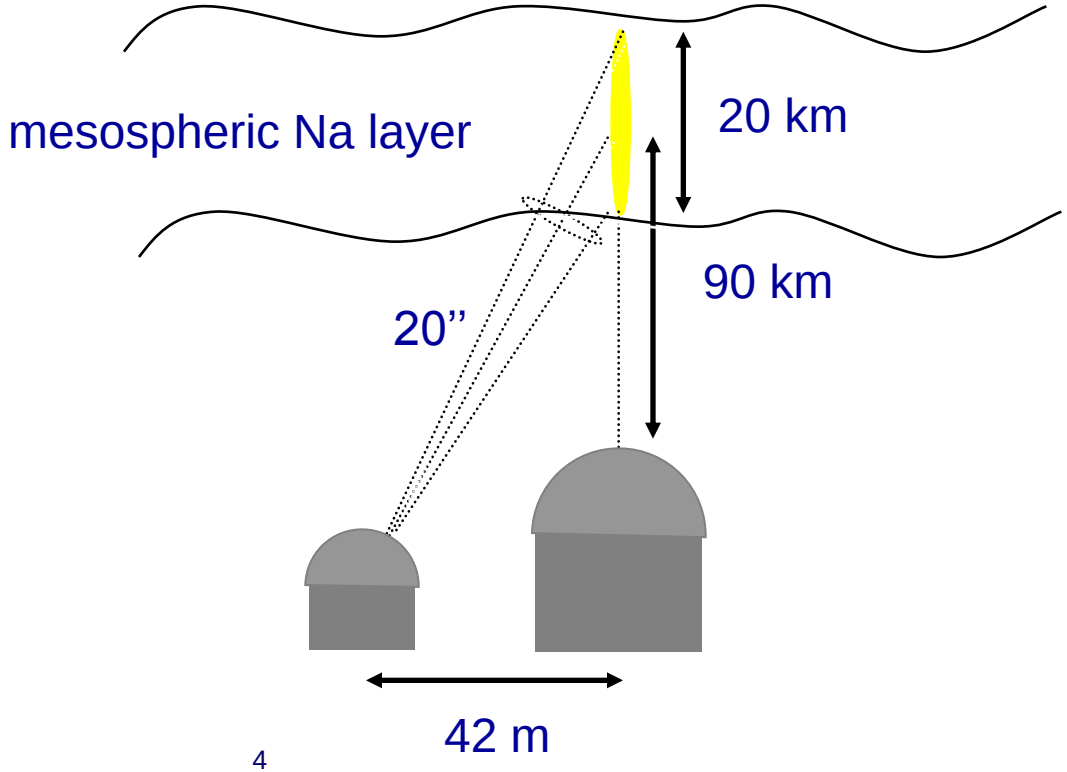
Among them, Sodium LGSs are widely used. They are generated by the back-scattered light from the sodium layer in the mesosphere.

Due to the vertical extension of the layer, the LGS is seen as an elongated source from the Wave Front Sensor subapertures located far from the launching point of the laser.

This elongation affects the calculation of the centroid in the WFS and the SNR, and therefore it has to be estimated.



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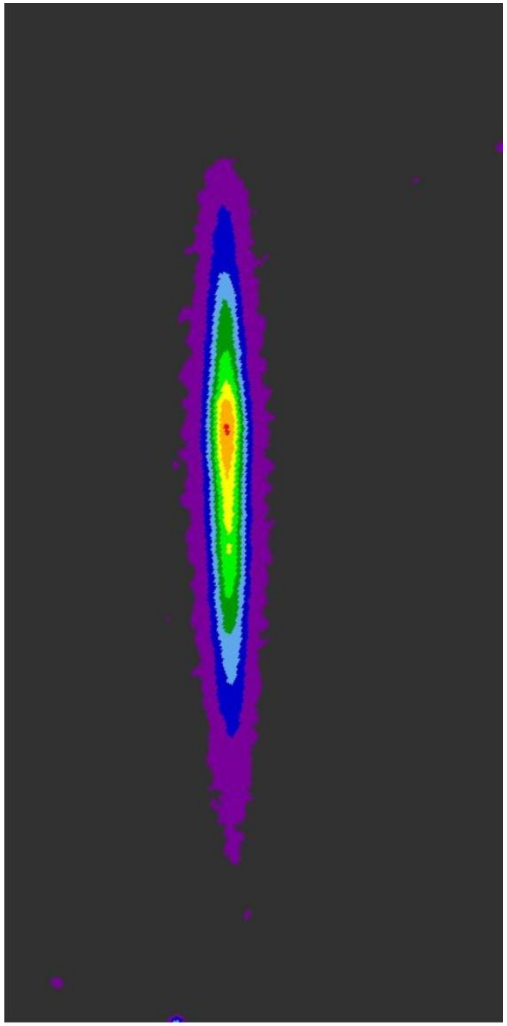

Mesospheric Sodium LGS
OGS-IAC80 telescopes
(Teide Observatory)
IAC - Grupo de Alta Resolución Espacial
2011-09-12

The altitude and linear vertical size of the Na LGS are usually assumed to 90 and 5-10km respectively, adopting the standard mesospheric sodium levels.

But the Na layer is **strongly affected by global and local effects**, either seasonal or very short time scaled.

Extracted from "Clemesha et al.", 1997, Rev. Bras. Geof. v.15 no.3.

site: São José dos Campos (Brasil)

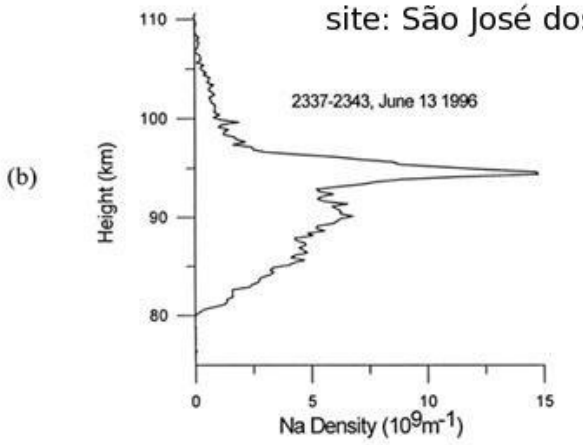

Figure 7 - (a) Time history of vertical distribution of Na for June 13-14, 1996; (b) Na_S layer observed at 2340 LT.

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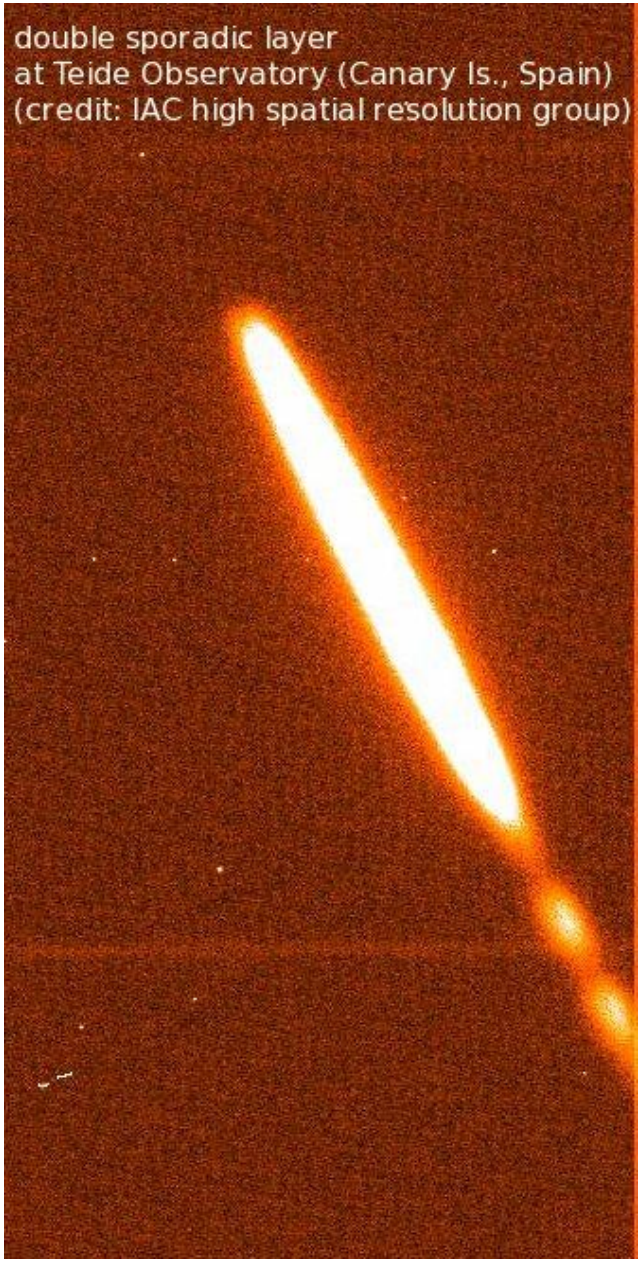
Sporadic bright layers can appear at different heights with an extension down to 500 meters.

These variations **may change the Na centroid** in a range of cents to thousands meters even **in a few minutes interval** affecting the centroid algorithm performance.

Therefore, it is required to measure on real-time its distribution vs. height. **This 3D distribution can be measured with a plenoptic camera**.



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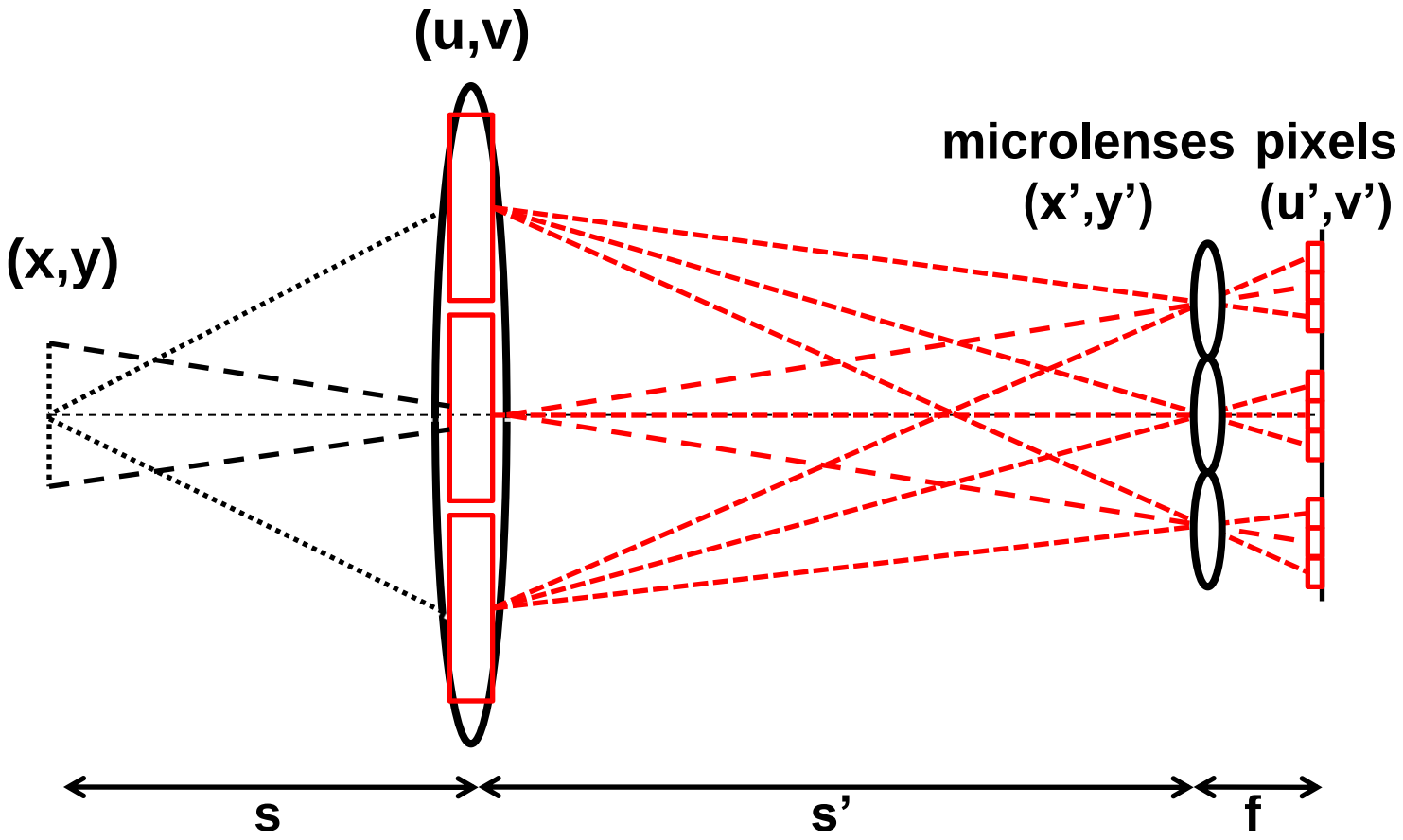
The plenoptic camera – how it works



The plenoptic camera captures the Light Field, a four-variable (x,y,u,v) volume representation of all rays and their directions.

The microlenses sample the spatial coordinates (x,y) and the pixels sample the angular coordinates (u,v).

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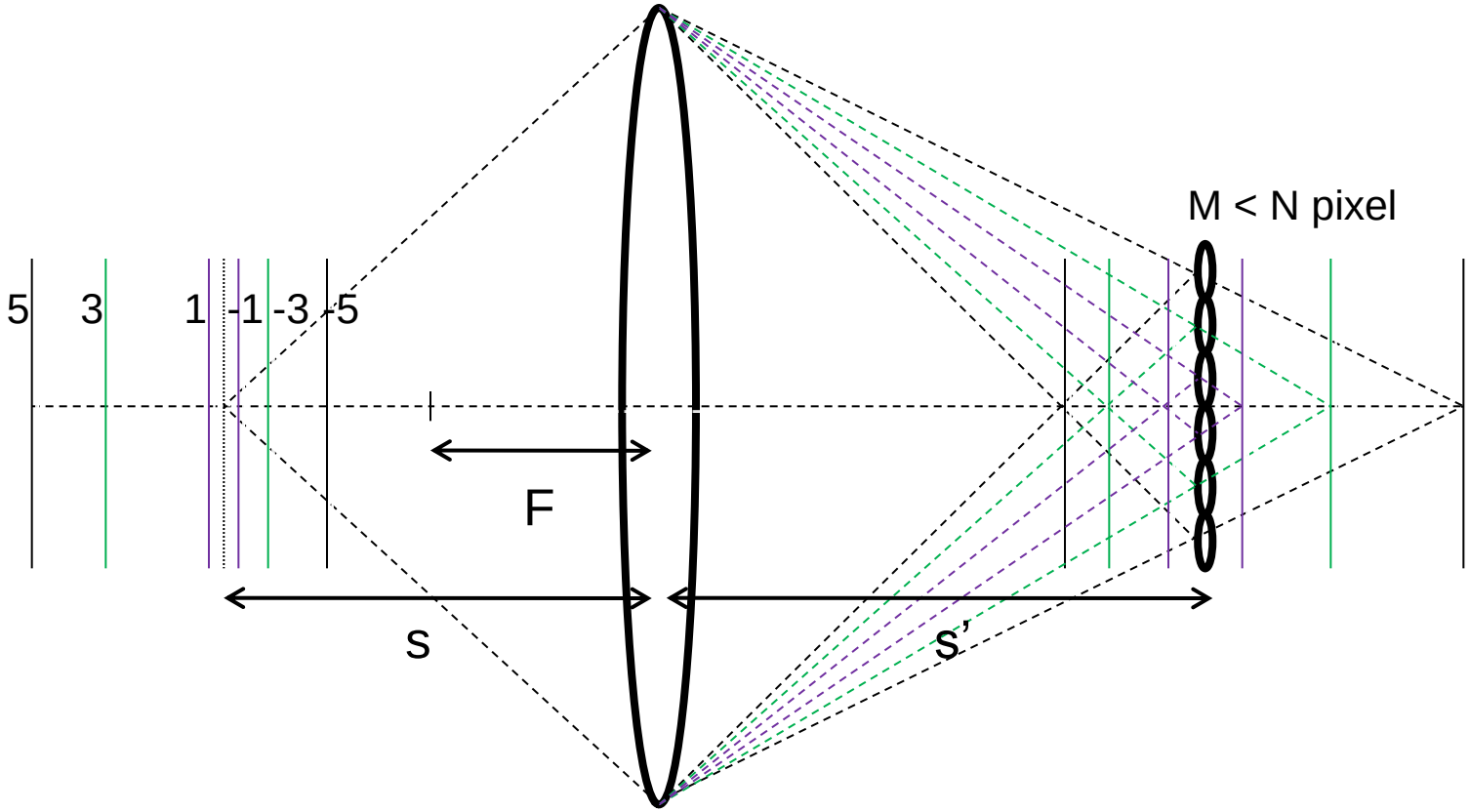

Due to the finite sampling of the (u,v) plane the object space is also finitely sampled.

Depending on how the pixels are combined, we retrieve the focused image of the object placed at one distance or another.

There are different algorithms that refocus more or less planes at different distances.

The plenoptic camera – how can it measure the Na profile

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This 3D reconstruction makes possible to retrieve the distances at which the objects are.

For this reason it is especially adequate to measure the height variations and vertical distribution of the LGS beacons.

This novel approach provides **real-time information on the Na layer profile** that can be introduced in the reconstruction algorithm to solve the problems derived by the spot elongation, giving a more complete alternative to other methods.

Measuring the Na profile – laboratory results

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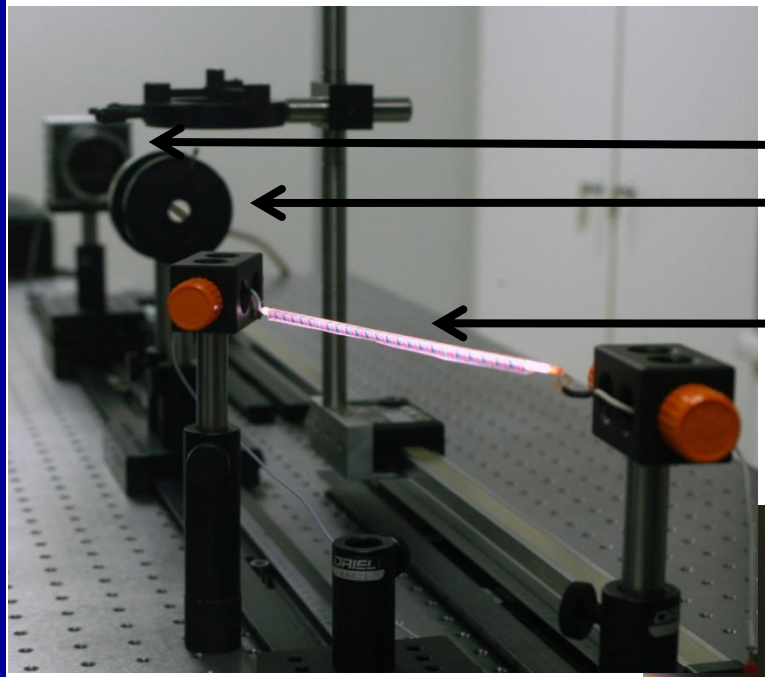
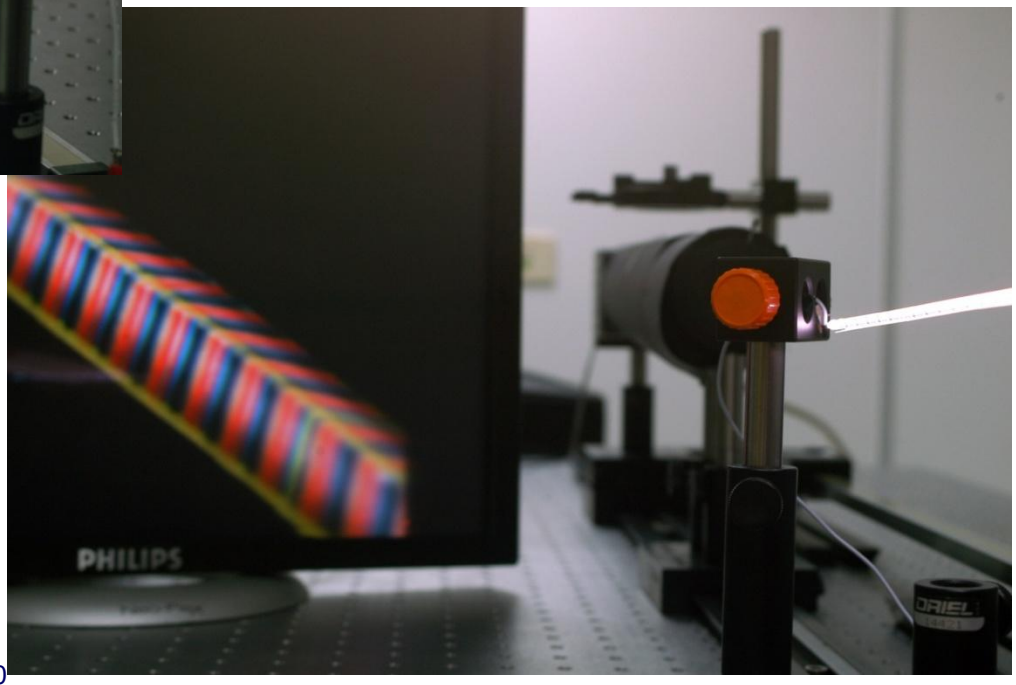


plenoptic camera CAFADIS

telescope

Na layer

3D screen



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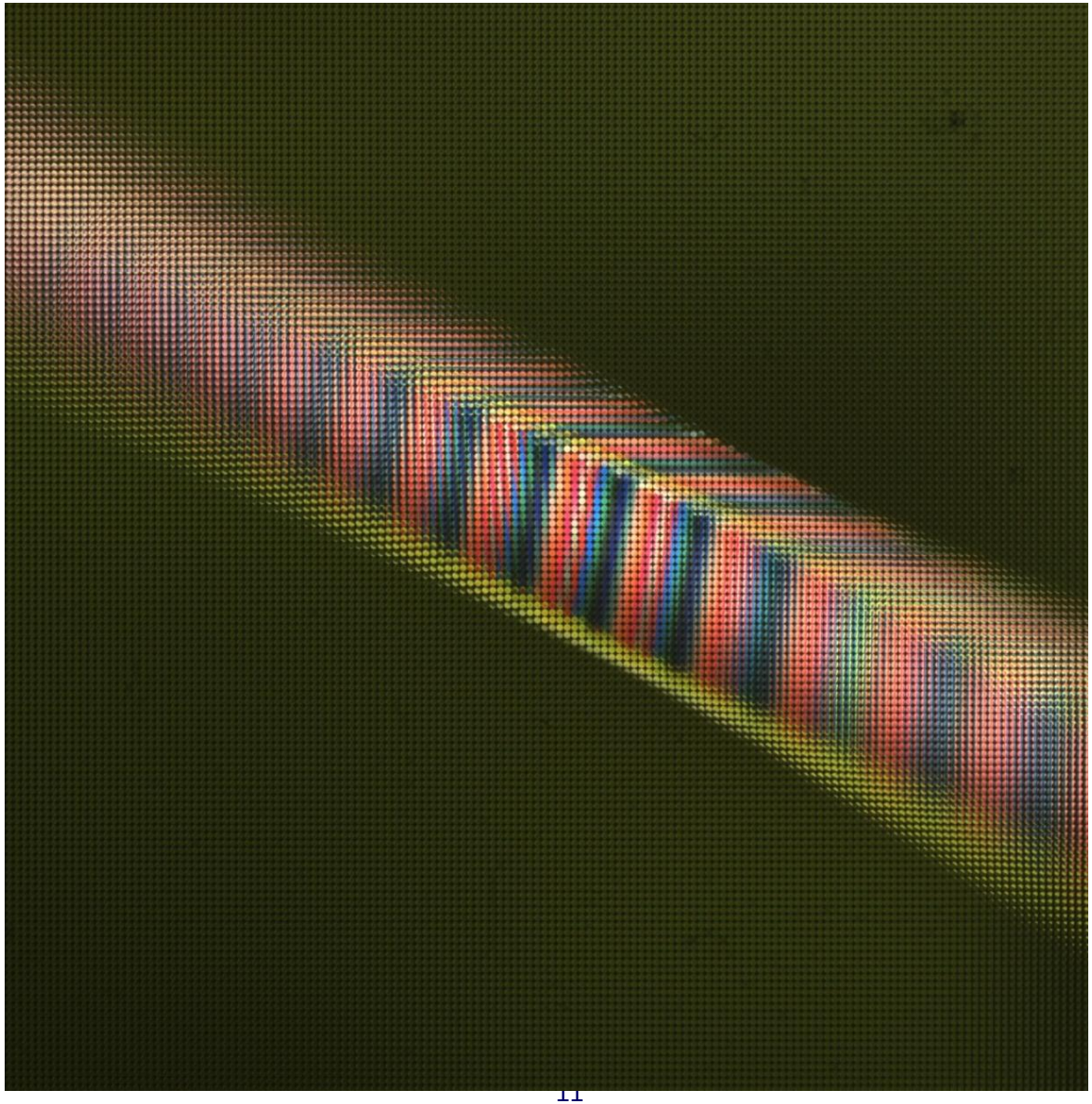

Plenoptic image captured by CAFADIS

NxN microlenses

MxM pixels/ml

create a N^2xM^2 pixels image

This image is processed with the plenoptic software programmed for GPUs, allowing reconstruction times of ~ms. The fastest variations of the Na profile have been found to be ~1Hz (Chun et al, 2008).

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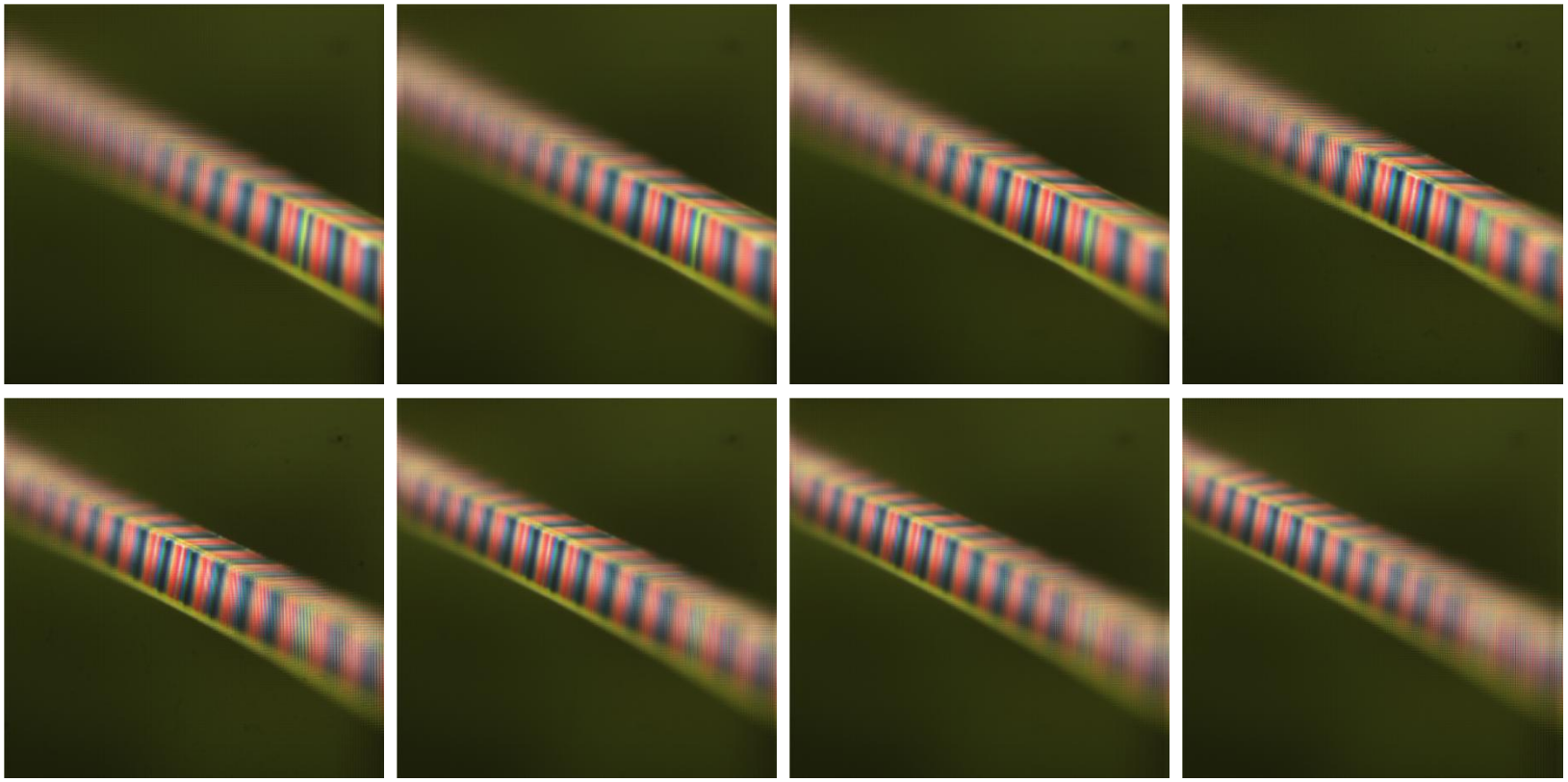
Super (spatial) resolution algorithm: (2*p*-2) refocused planes, with *p* equal to a prime number smaller than #pixels/2



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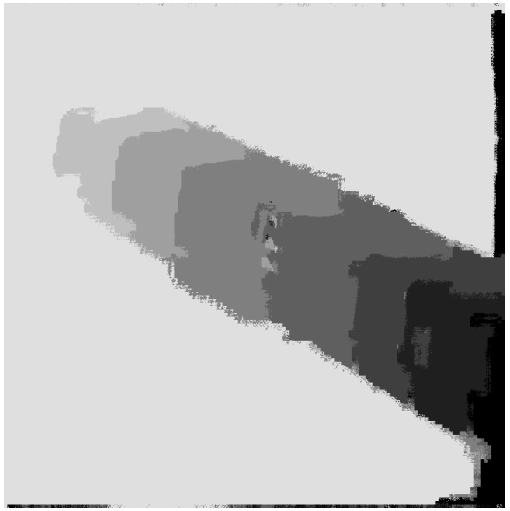
Not refocused

All-in-focus



Map of distances

A F/19 camera, with 12 pixels behind each microlens, processing the information with the super-resolution algorithm, gives 8 refocused planes. Each grey zone corresponds to the part of the image that is focused at each distance.

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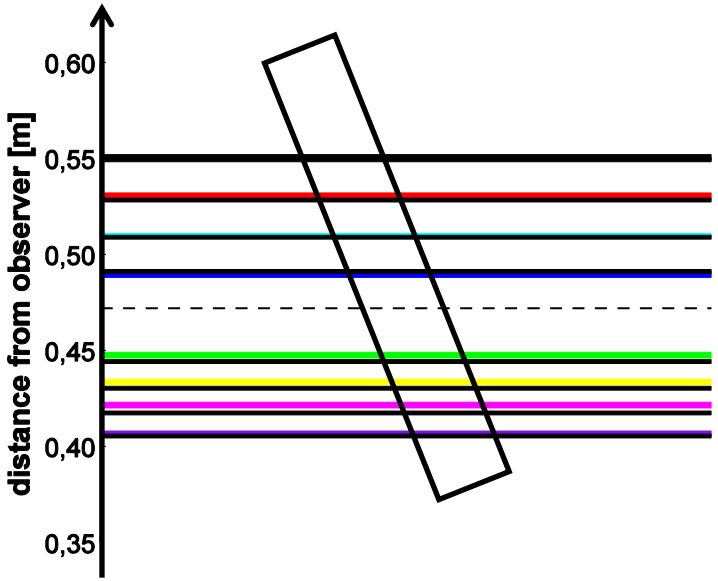
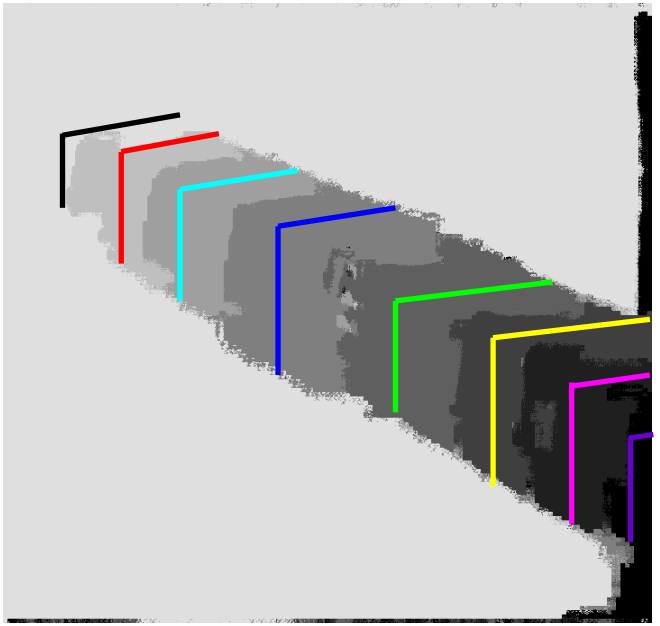




110 micron pitch	s=472 mm
12 pixel/microlens	s'=342 mm
8 planes in 15 cm	D=17.8 mm

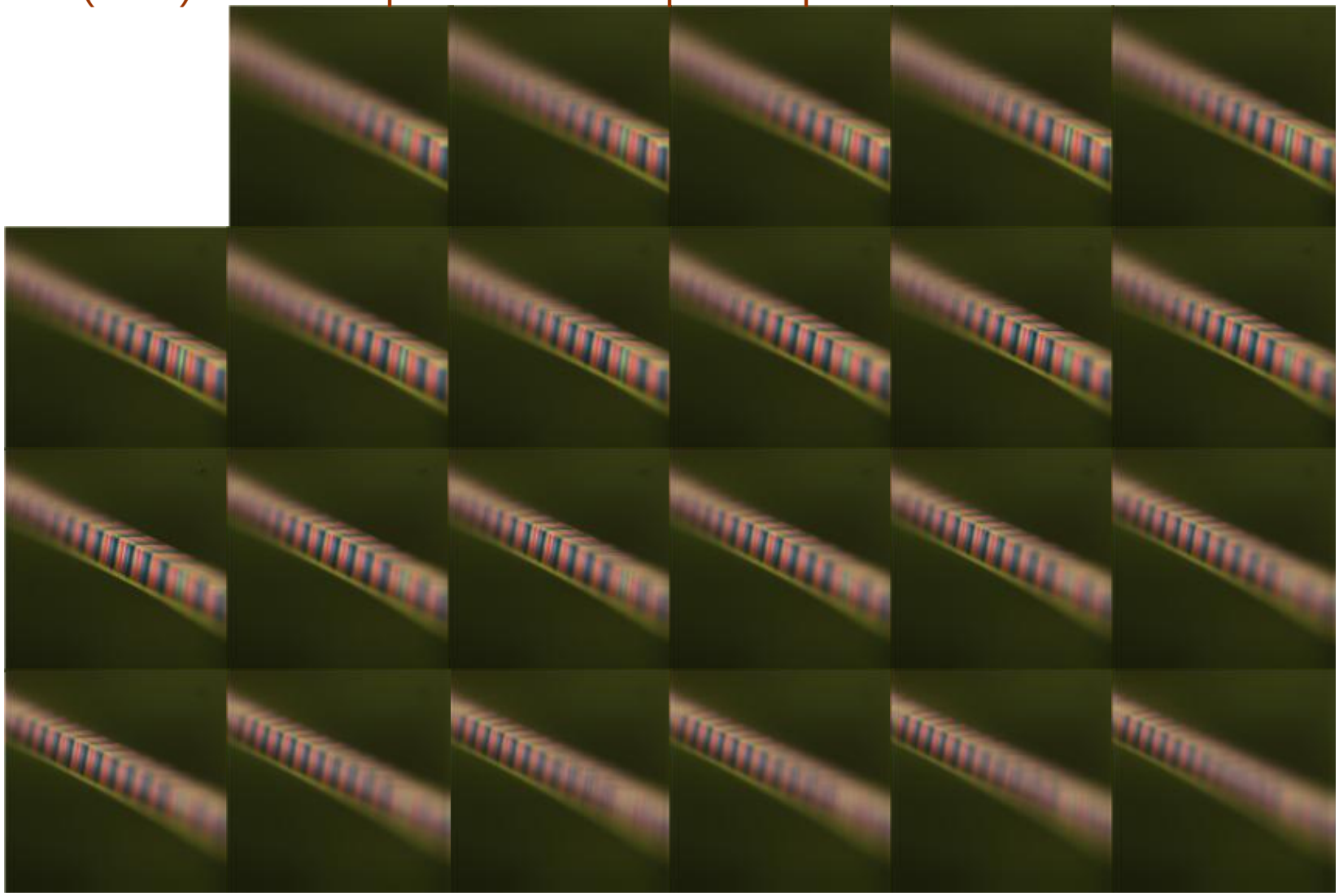
The predicted distances correspond to the distances measured in the lab, within 1 mm accuracy .

Extrapolating to the sky, that means a 200 m precision, covering 28 km.

In **real-time**.

Measuring the Na profile – laboratory results

It is possible to increase the depth resolution with the Radon algorithm:
(2N-1) refocused planes with N equal to #pixels



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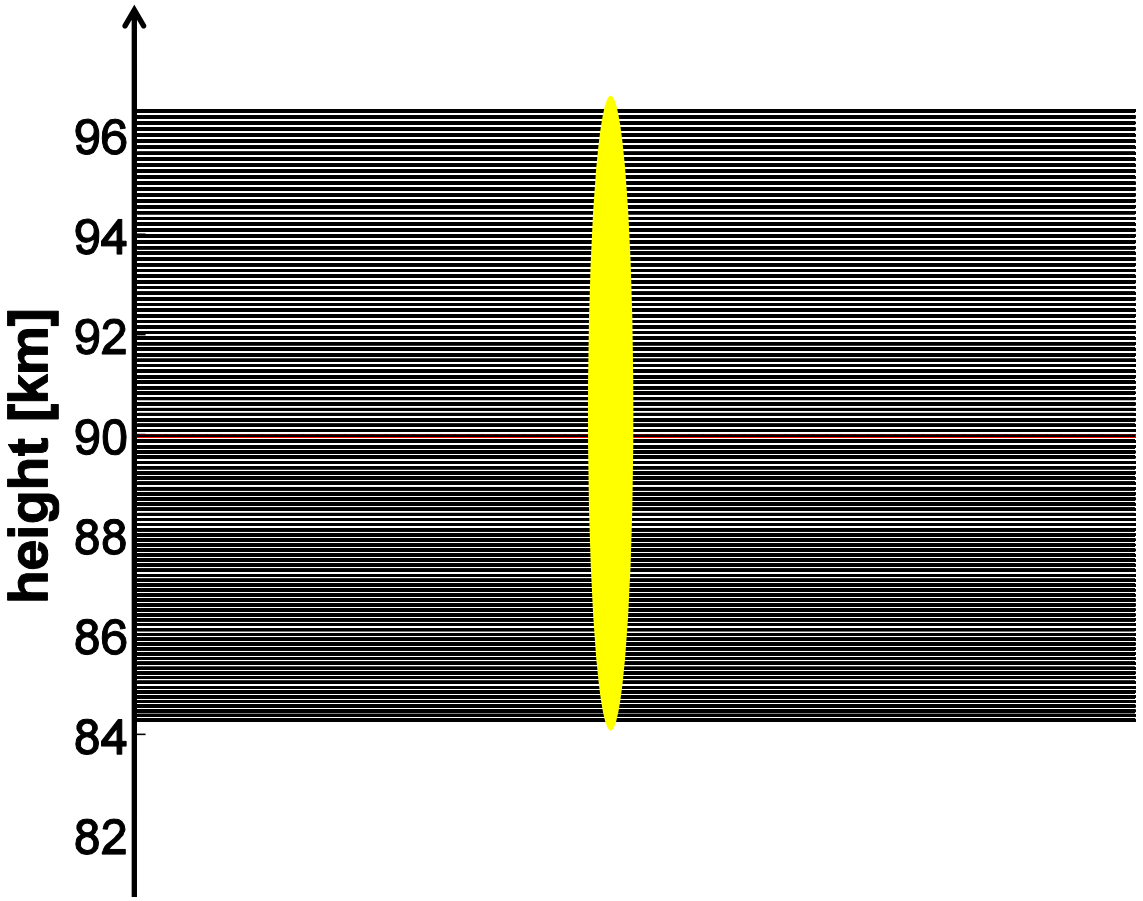

350 micron pitch

200x200 microlenses

F/15, D=42 m

58 pixel/microlens

114 planes

107 meters resolution in depth

Future work: on-sky tests

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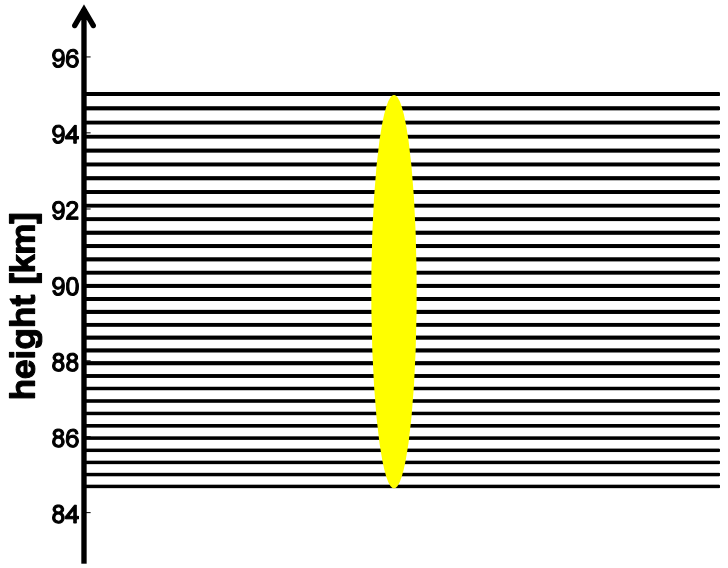
We plan to implement on-sky tests at Observatorio del Teide using the Na LGS facility placed at the Coudé focus of the ESA's Optical Ground Station and the nearby 1,5 m Telescopio Carlos Sánchez to place the plenoptic camera.

Images will be taken in parallel with the IAC80 telescope in order to validate the results.



130 micron pitch
230x150 microlenses
16 pixel/microlens
31 planes
f=220 micron
320 meters resolution in depth

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- **Plenoptic cameras can be used to take real-time measurements of the mesospheric Sodium layer profile, improving the quality of the wavefront reconstruction for MCAO**
- **Lab results prove the feasibility of the technique**
- **It can be applied to the E-ELT with off-the-shelf tools, no instrument development required**
- **The map of distances for the Radon algorithm will be implemented in the incoming months to increase depth resolution**
- **On-sky tests will be performed during spring 2012**

THANKS for listening!

... and other acknowledgements

We would like to thank Félix Gracia-Temich for making our lab "Na layer".

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For more information on the CAFADIS camera see:

www.cafadis.ull.es