

THE INGOT-WFS PROJECT

WHERE WE ARE (AND ARE GOING)



Elisa Portaluri

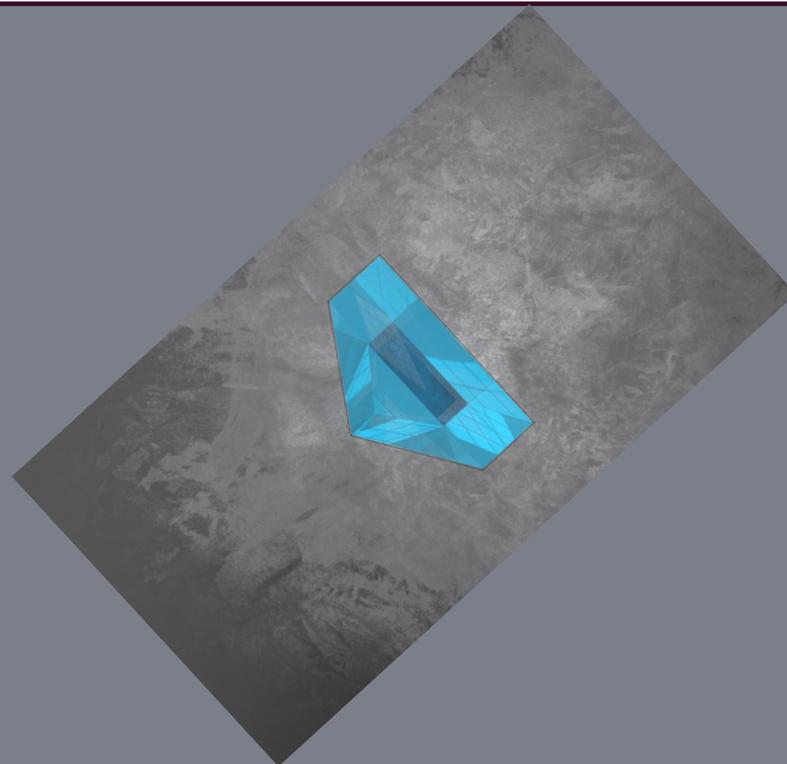
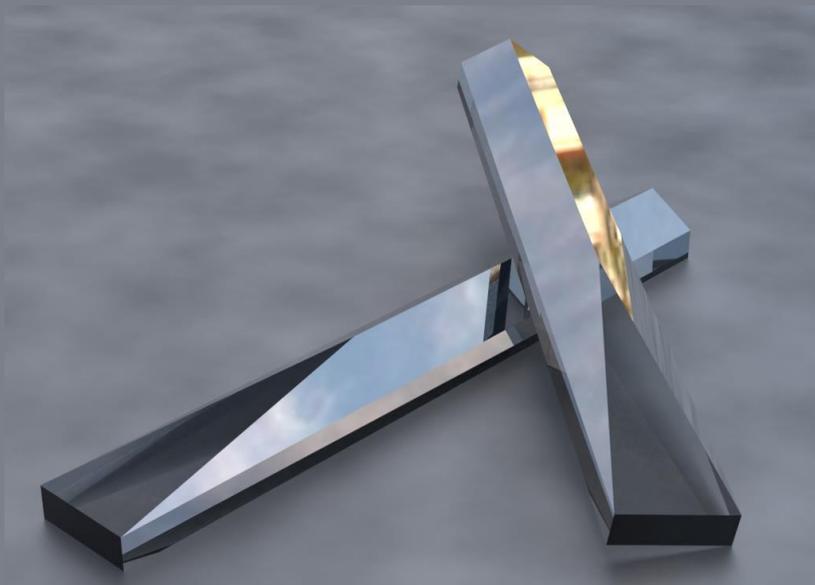


Full team:

Ragazzoni R., Bergomi M, Di Filippo S., Viotto V., Arcidiacono C., Greggio D., Radhakrishnan Santhakumari K. K., Marafatto L., Dima M., Farinato J., Magrin D., Di Rico G., Centrone M., and Bonaccini D.

ABSTRACT & OVERVIEW

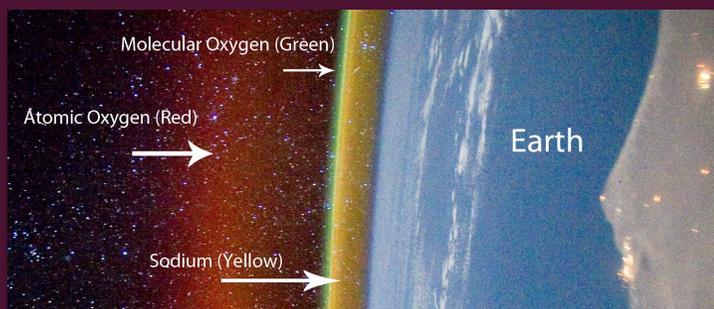
- ❑ Aimed at the feasibility study of an innovative and indispensable wavefront sensor (Ingot-WFS) to be used in combination of laser guide stars.



Ragazzoni et al. 2017

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Sodium layer height (Mesosphere) at 92 km

Sodium layer thickness of 10–20 km

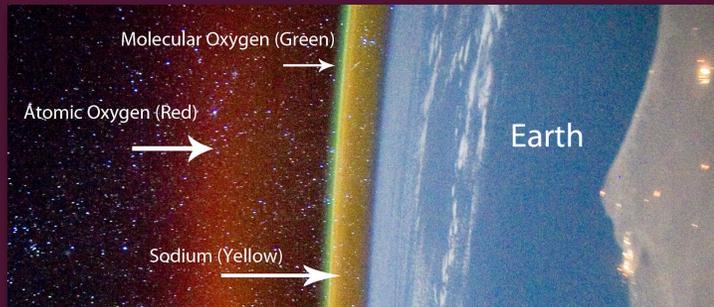
LGSs are NOT point-like sources,
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located at a FINITE distance

**GEOMETRY IS
IMPORTANT!!
They focus on a
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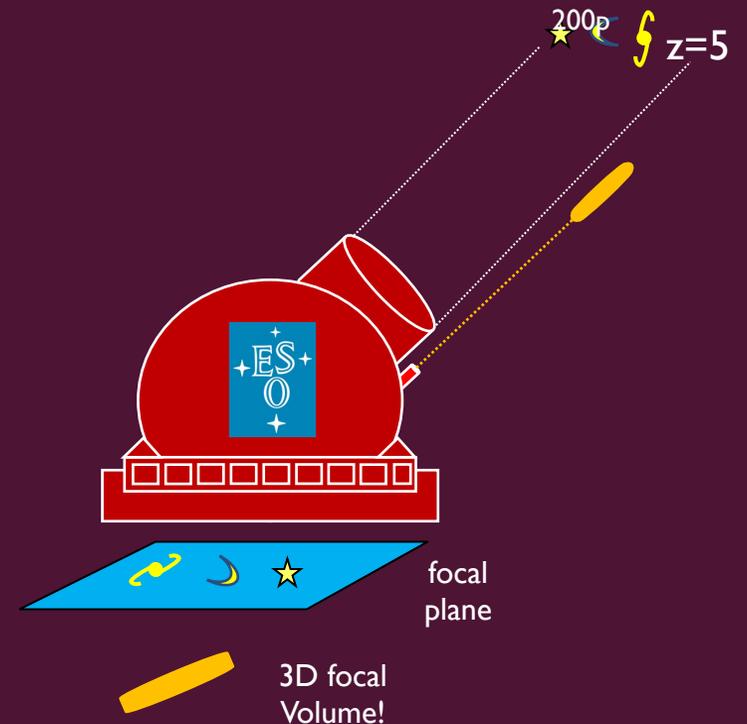


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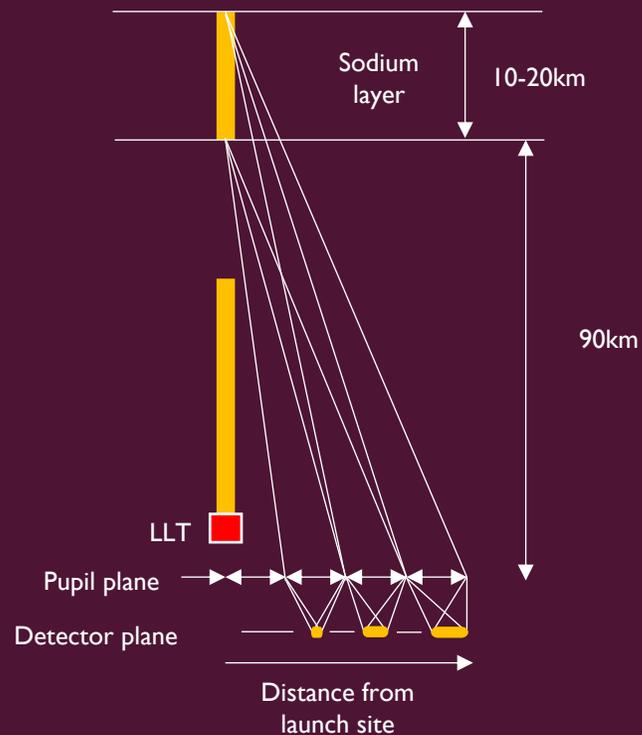
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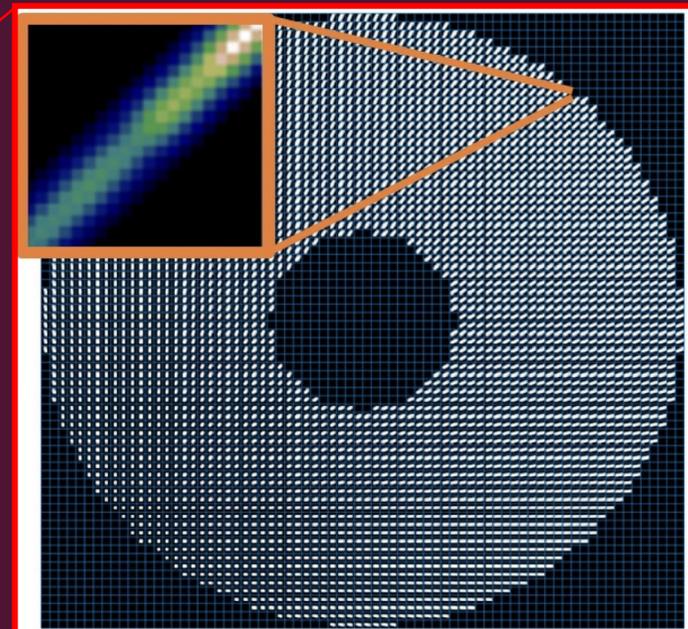


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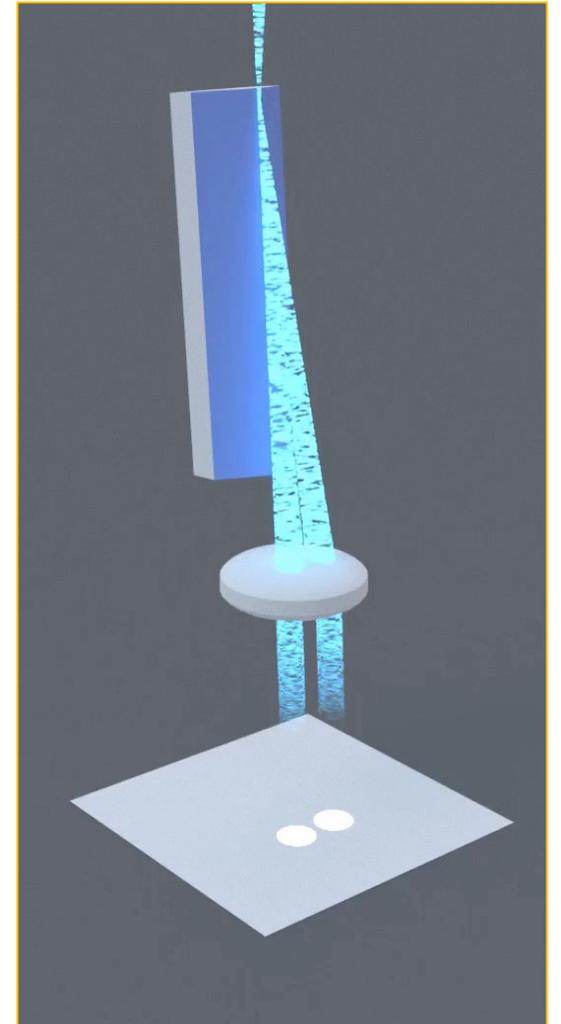
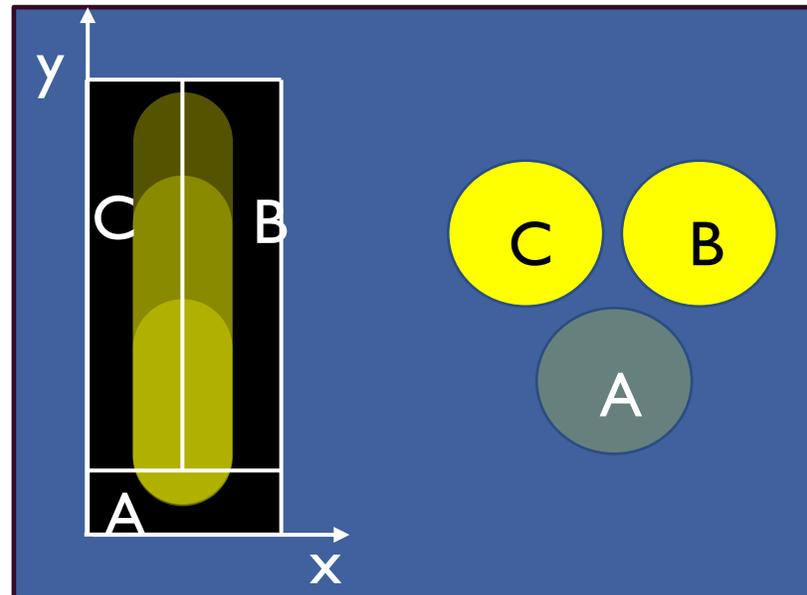
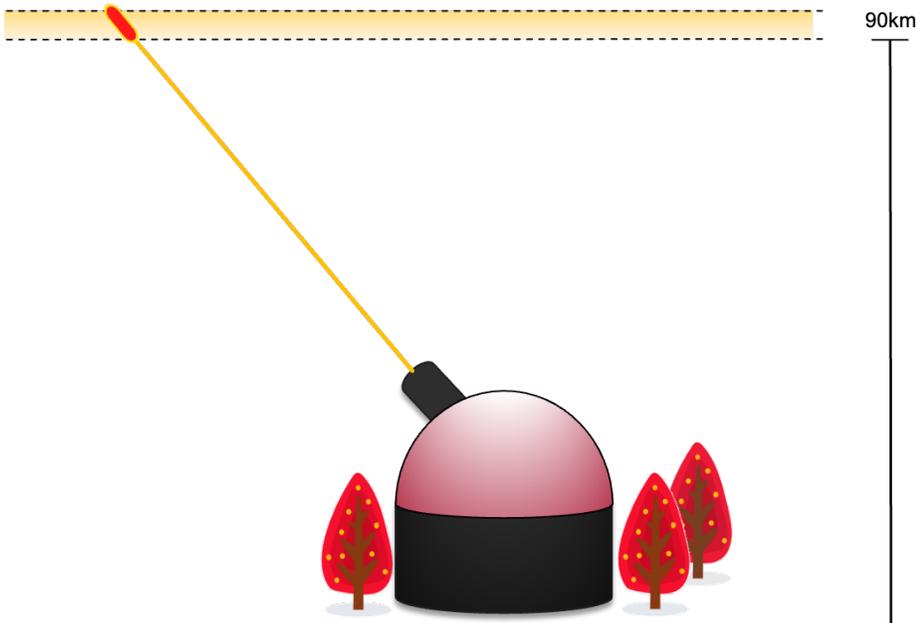


Oberti et al 2019



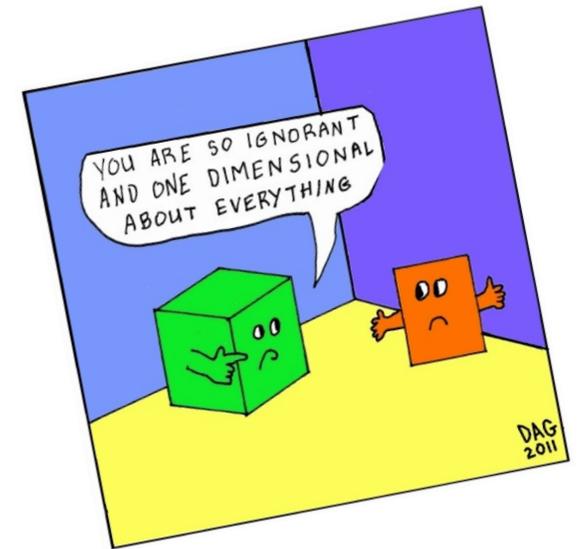
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- ❑ Aimed at the feasibility study of an innovative and indispensable wavefront sensor (Ingot-WFS) to be used in combination of laser guide stars.
- ❑ It is based on the idea of optimizing the match between the elongated source, which can be considered like "a cigar in the sky", and the optical surface used to sense it, shaped like an ingot prism.



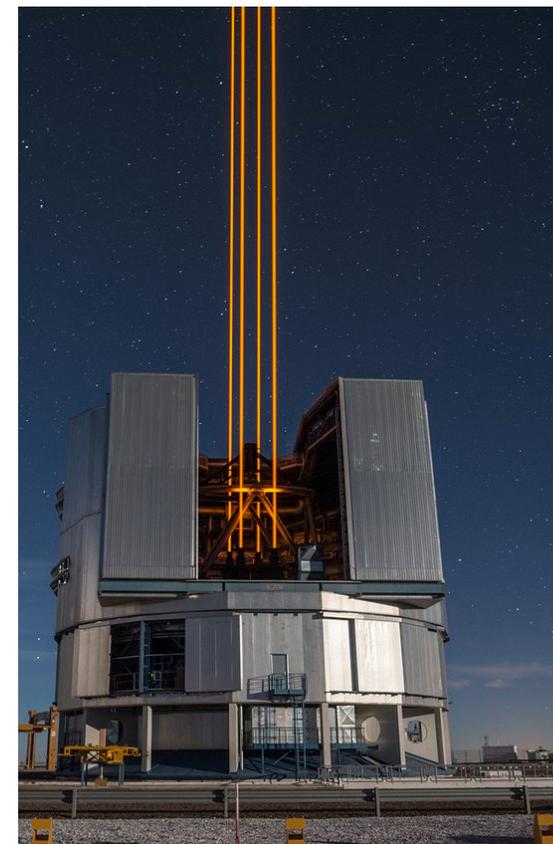
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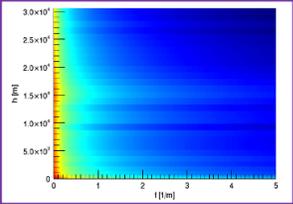
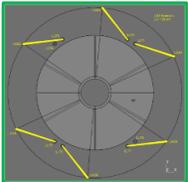
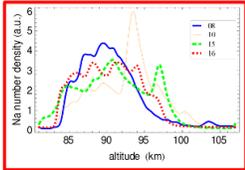
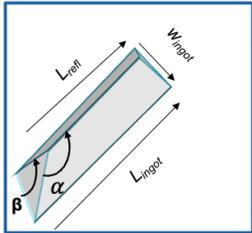
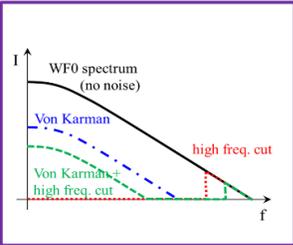
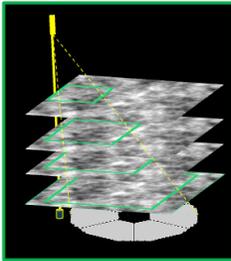
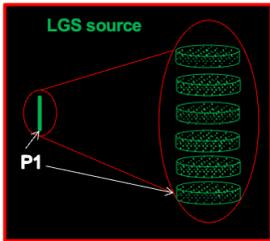
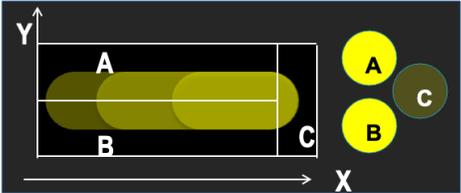


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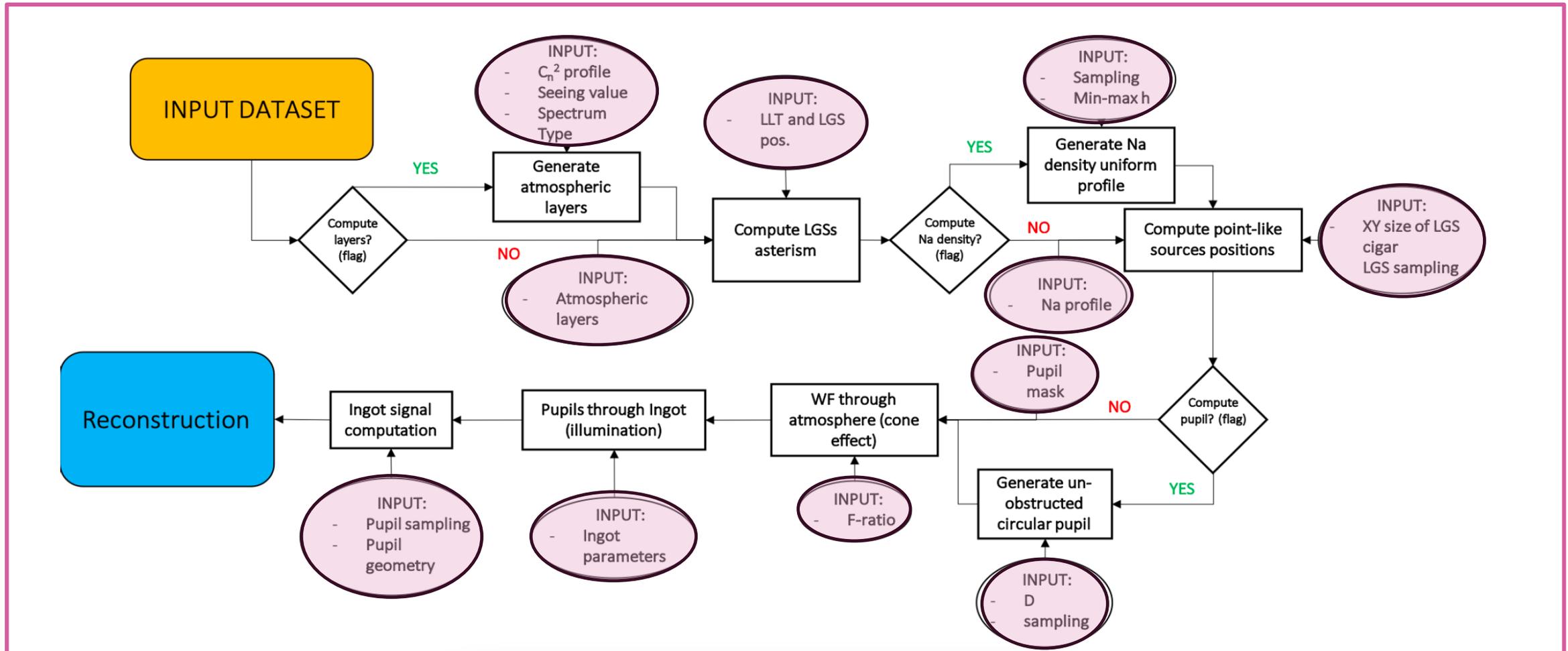
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- ❑ Accounts for **numerical simulations, lab experiments**, the prototype and, finally the **verification on sky** at the CANARY facility of the William Herschel Telescope in La Palma
- ❑ Developed by a passionate group of young researchers (~15, belonging to INAF institutes of Padova, Teramo and Rome)



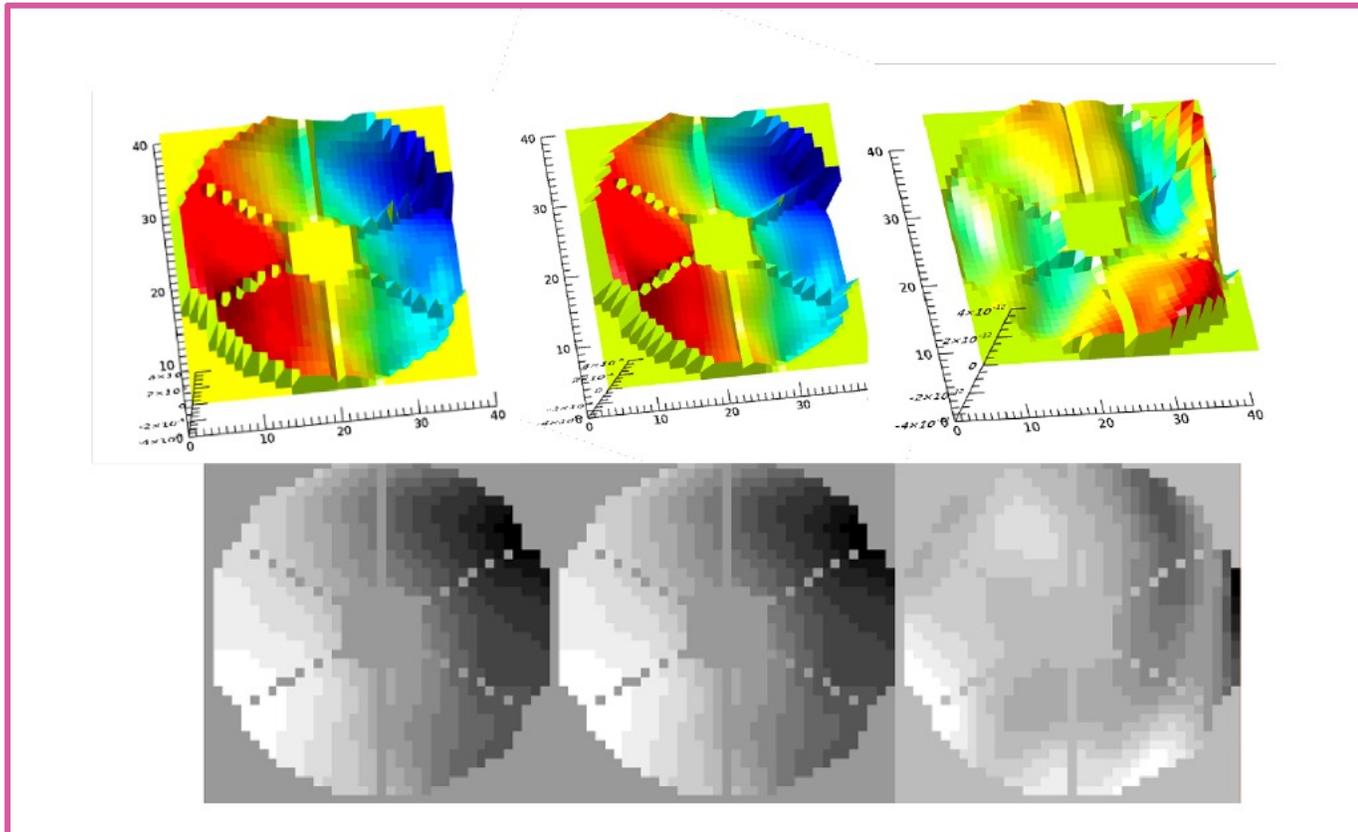
We developed a simulation tool to evaluate the impact of the ingot WFS and test its performance. The code accepts a list of input parameters, which describe the configuration whose final performance the user wants to estimate.

Tomographic inputs: e.g. 35 layers atmosphere	System's inputs: e.g. ELT characteristics	LGS inputs: e.g. cylinder approximation	Ingot inputs: e.g. computing signals
<ul style="list-style-type: none"> - C_n^2 profile - Seeing value - Spectrum Type 	<ul style="list-style-type: none"> - LLT pos. - LGS pos. - Telescope characteristics 	<ul style="list-style-type: none"> - Na profile - XY size of LGS cigar - LGS sampling 	<ul style="list-style-type: none"> - Ingot size - Pupil sampling - Pupil geometry
			
			$S_x = \frac{B - C}{B + C}$ $S_y = \frac{(B + C) - A}{A + B + C}$
			

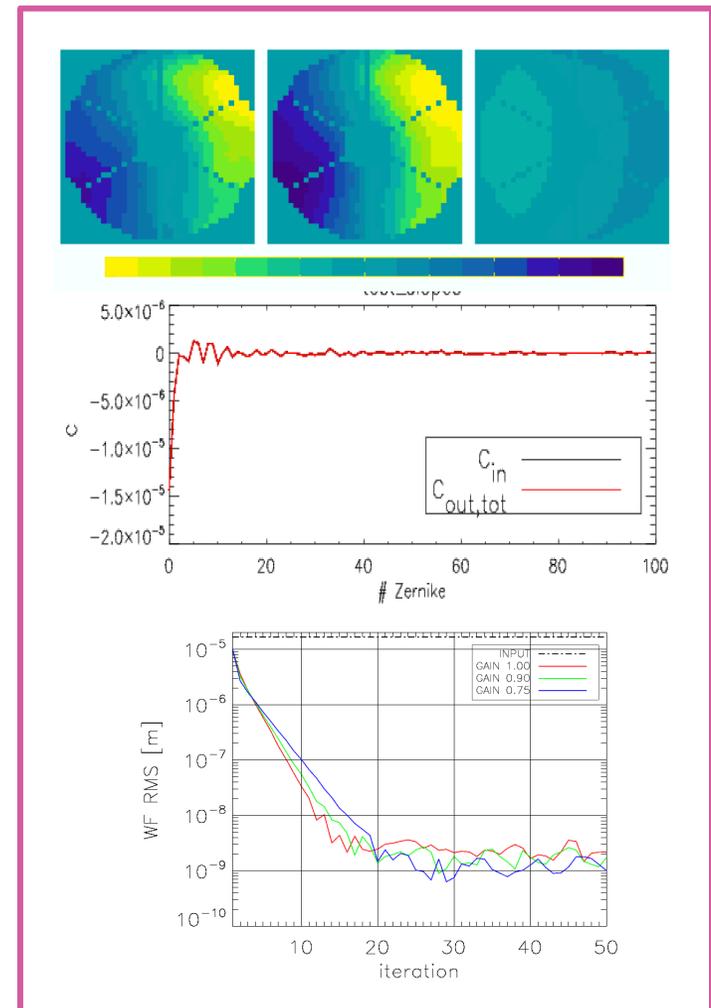
The outcome is the achievable SR, which can be compared with the one expected for the next generation of instruments in the same conditions and used to quantify the gain reachable in many cases, also considering the science applications.



We used a Zernike basis with 100 modes to produce the reconstruction matrix and build an input wavefront weighting with Noll coefficients. We were able to close the loop with different conditions, varying gain, resolution, sampling...

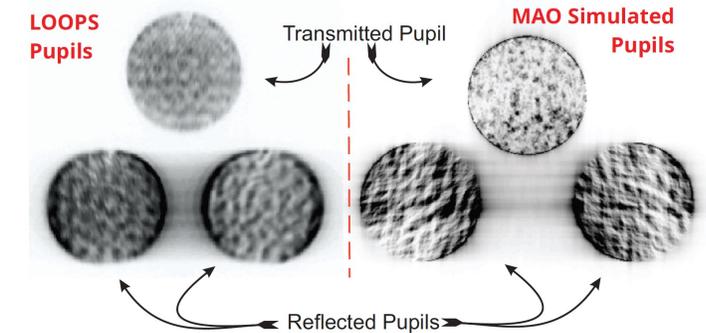


Portaluri et al. 2020, 2022

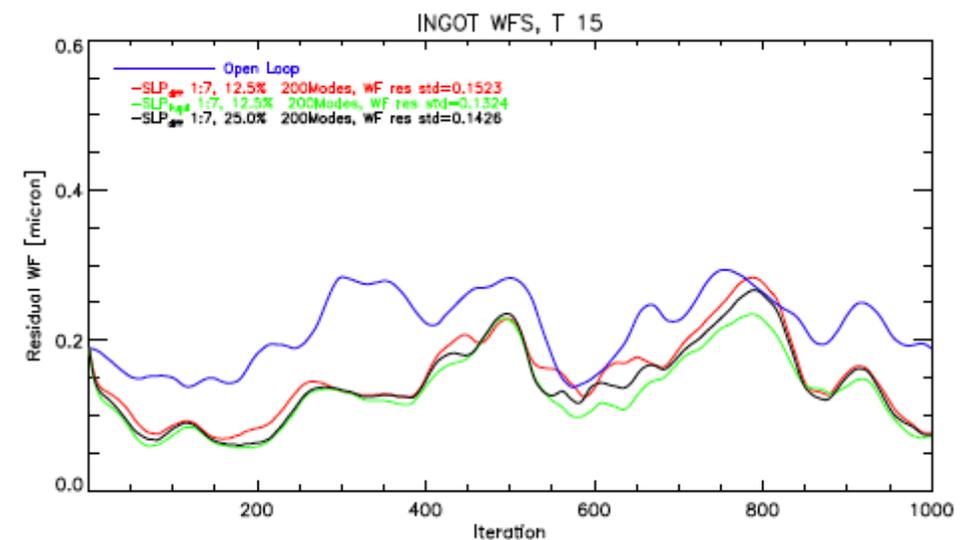


Two setups dedicated to investigate different features of the ingot-WFS: first tests @ LAM

1. Test in a quasi-real Adaptive Optics Closed Loop scenario at the LOOPS bench:
 - Ingot WFS is approximated with a set of 2D phase masks
 - Close the loop with an ingot-like WFS and compare it with the pyramid
 - Test different formulas for calculation of signals



Arcidiacono, Di Filippo et al. 2020



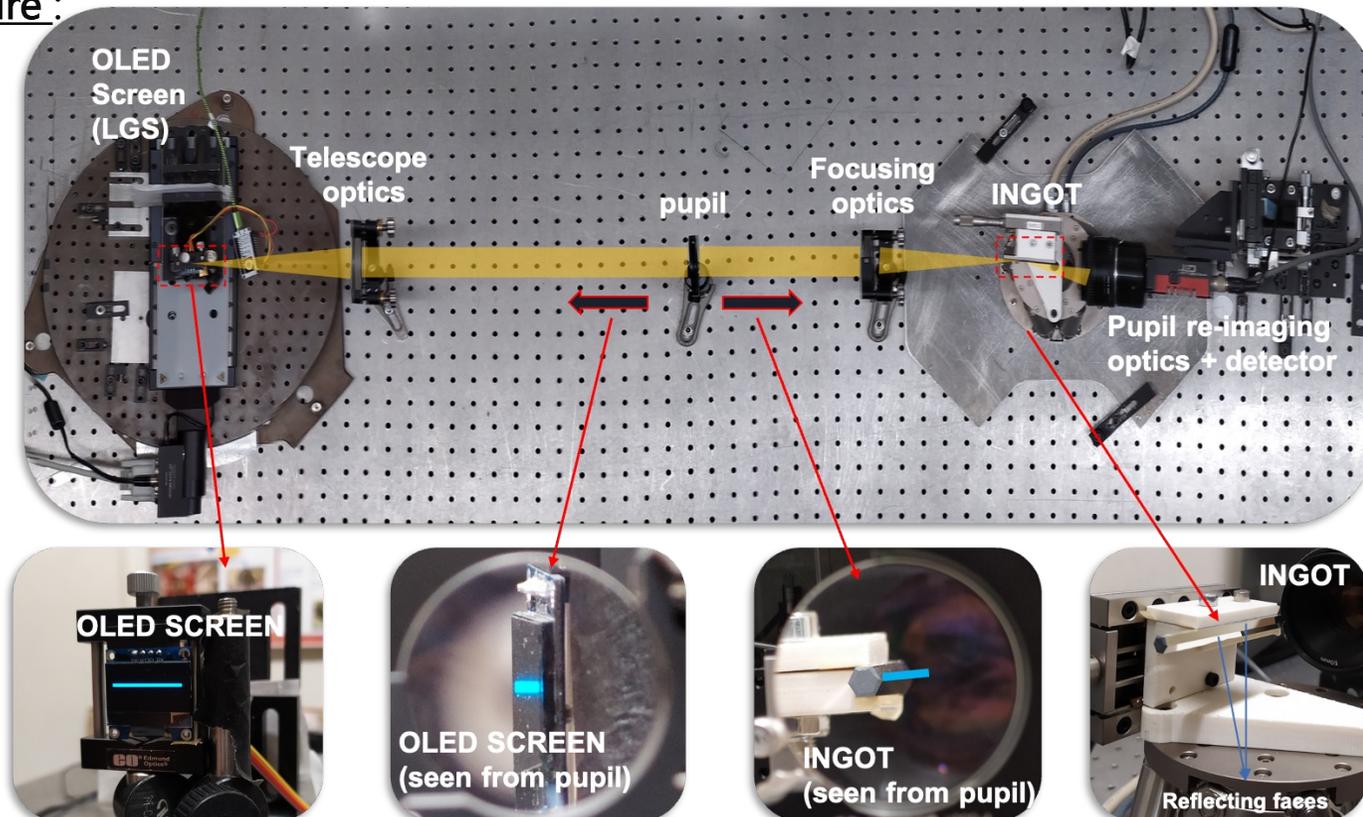
Two setups dedicated to investigate different features of the ingot-WFS: the Padova test-bench

2. Test-bench dedicated to investigate different features of the ingot-WFS.

Radhakrishnan, Greggio, Bergomi et al. 2020

Test of alignment and measurements of low-order static aberration in an Open Loop scenario and of an automatized alignment procedure :

- LGS source elongated along the optical axis
- Ingot prism
- Setup recreating ELT characteristics

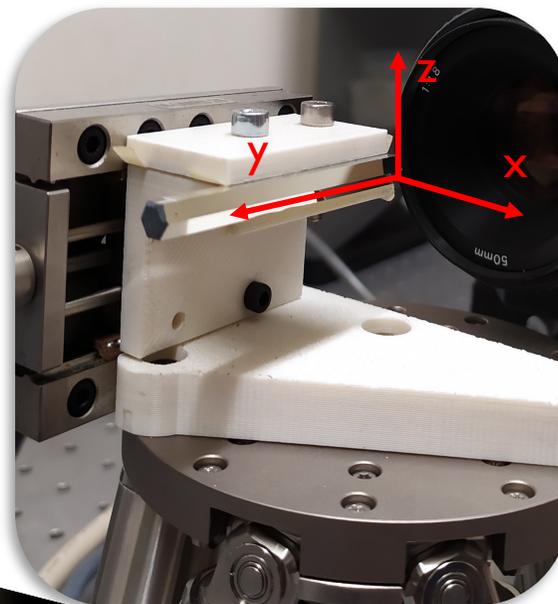


Two setups dedicated to investigate different features of the ingot-WFS: the Padova test-bench

We performed:

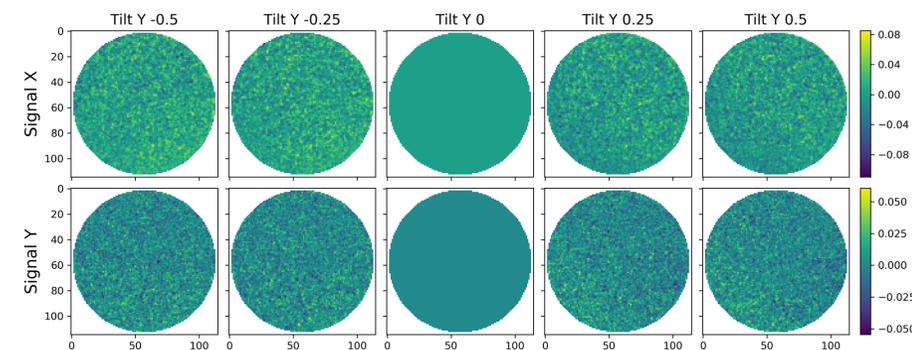
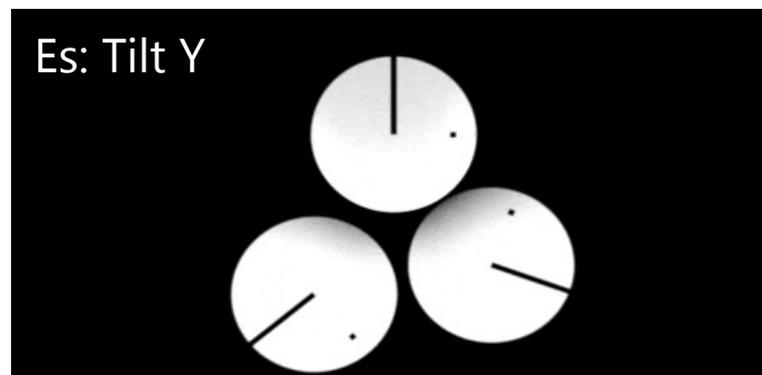
- **Movements** simulation analysis
- **Sensitivity** analysis
- Definition and automatization of the alignment procedures

Di Filippo et al. 2022

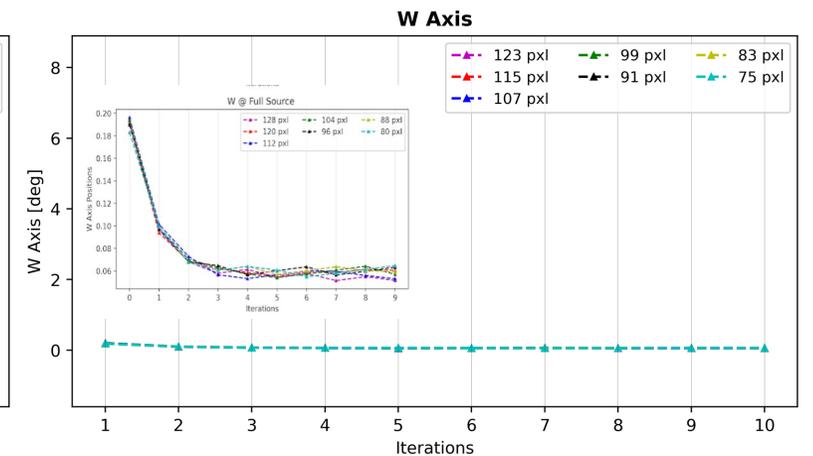
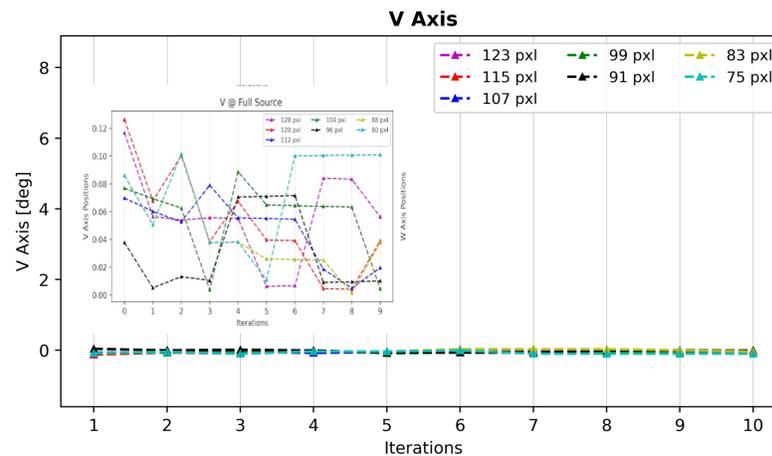
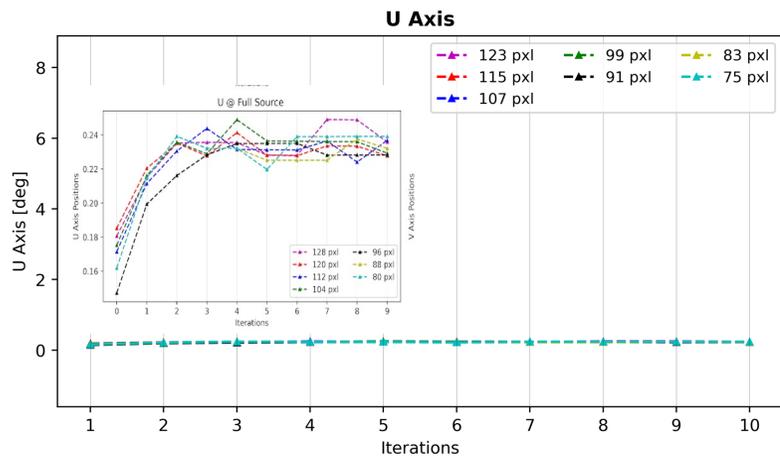
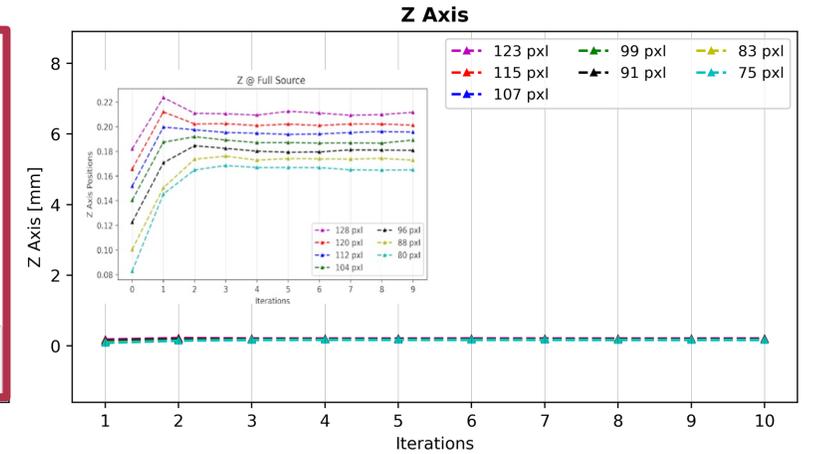
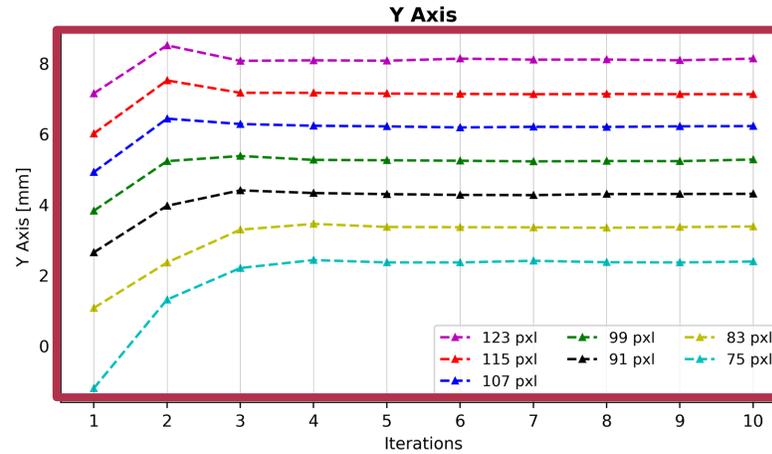
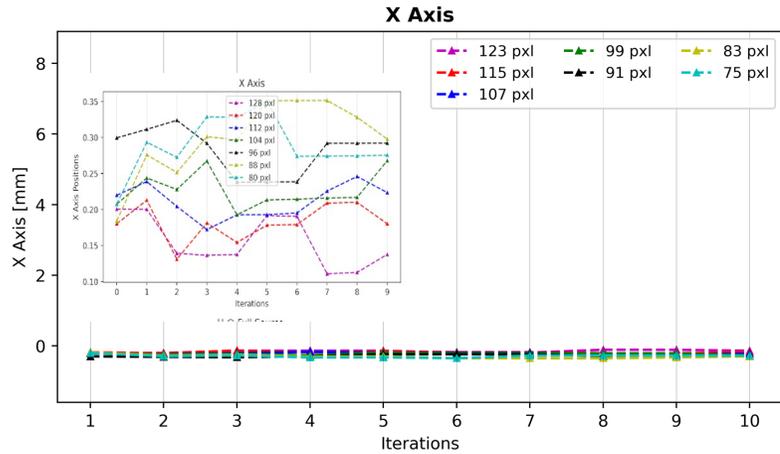


$$S_x = \frac{B - C}{A + B + C} - \frac{B_{ref} - C_{ref}}{A_{ref} + B_{ref} + C_{ref}},$$

$$S_y = \frac{A}{A + B + C} - \frac{A_{ref}}{A_{ref} + B_{ref} + C_{ref}}.$$

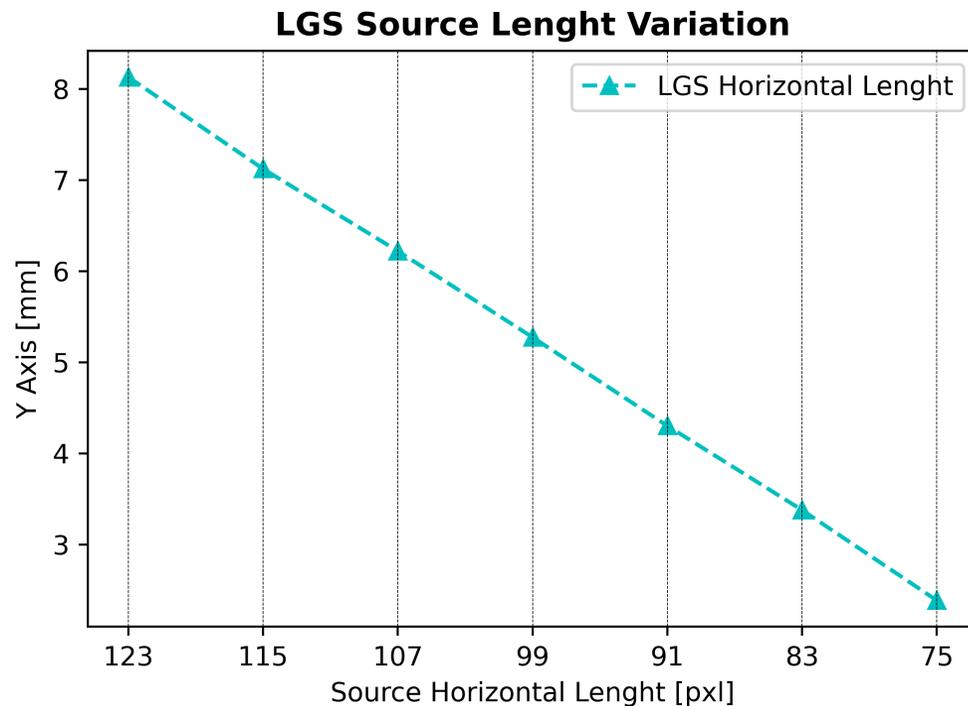
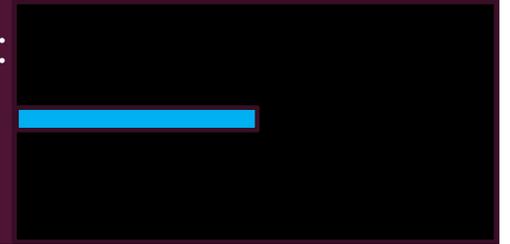


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 - Length of LGS source



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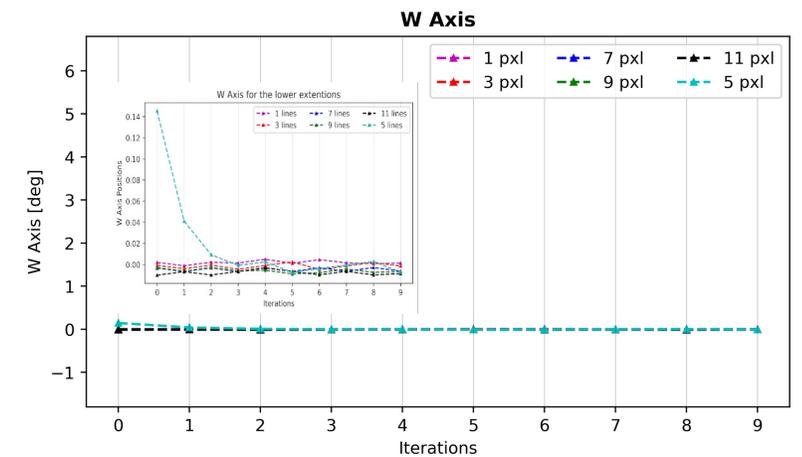
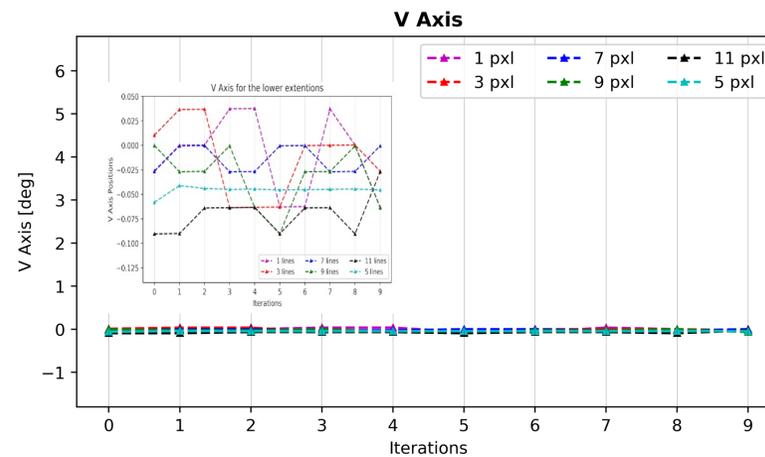
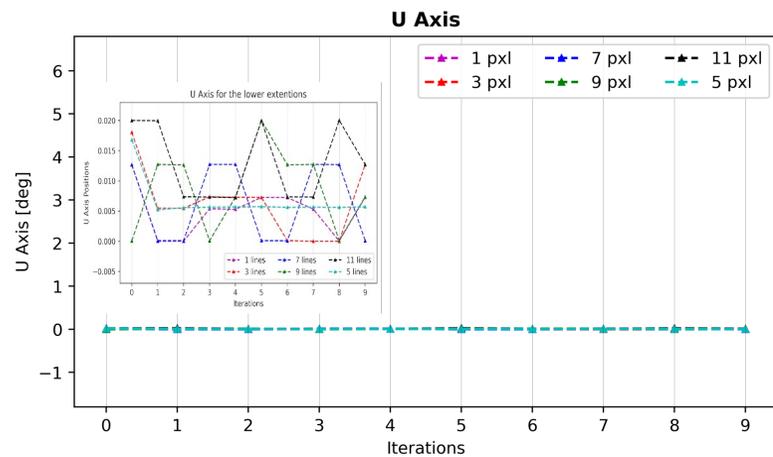
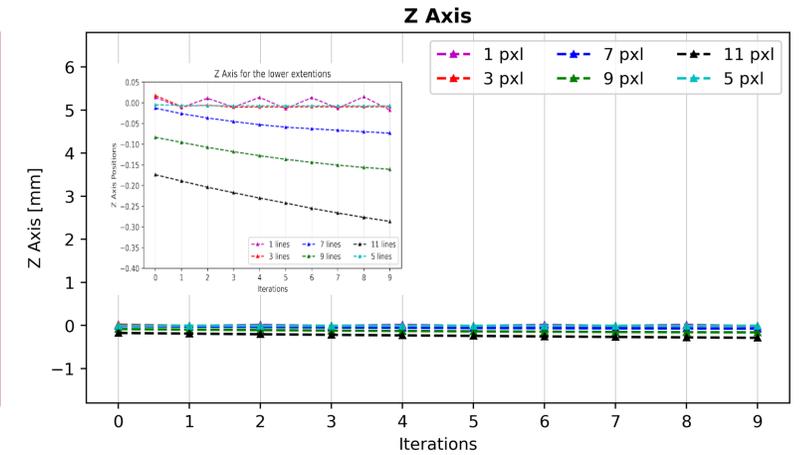
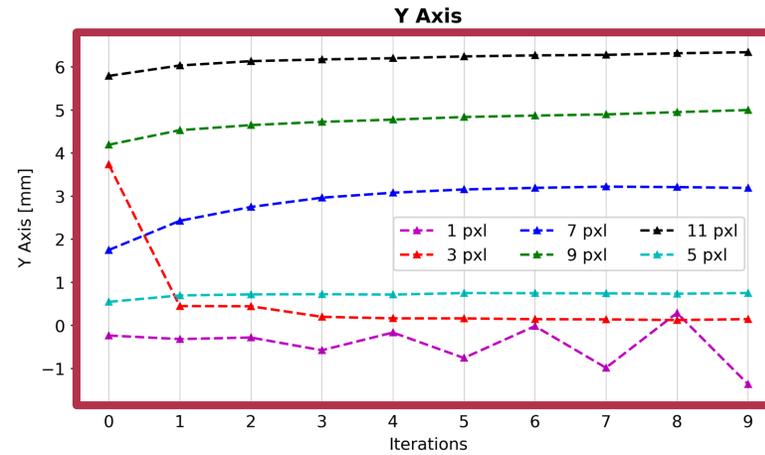
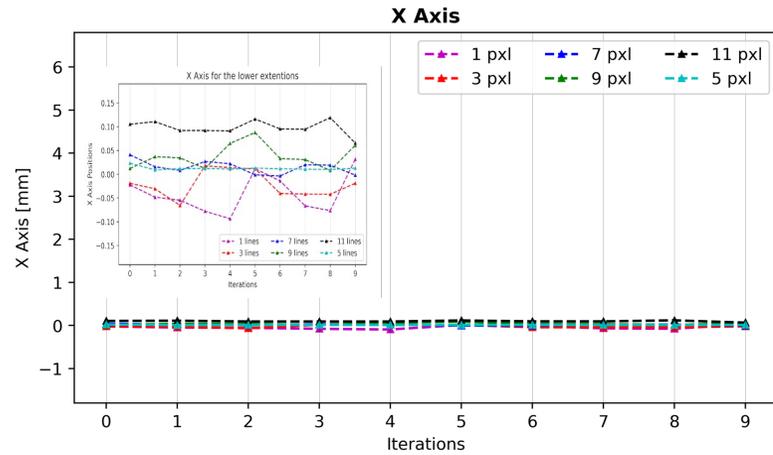
Source Length [pxl]	Y coord	Delta
123	8,13	
115	7,12	1,01
107	6,22	0,90
99	5,28	0,94
91	4,30	0,98
83	3,38	0,92
75	2,39	0,99

Reducing line length by 8 pixel at a time (1.68 mm)

As expected, shift in aligned position is linear along the optical axis (Y axis, approx 0.96 mm).

Testing the robustness of automatized alignment procedure in varying conditions. So far:

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- Thickness of LGS source

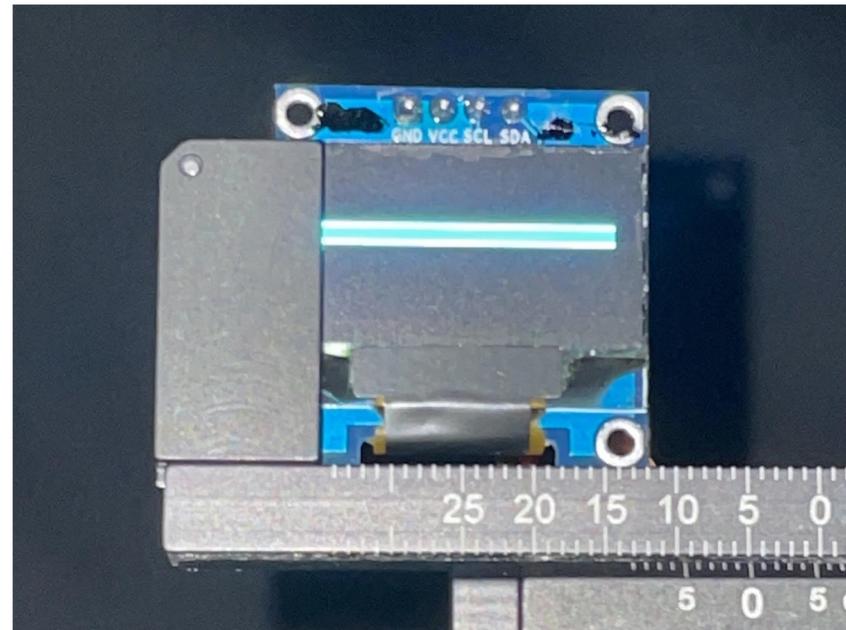
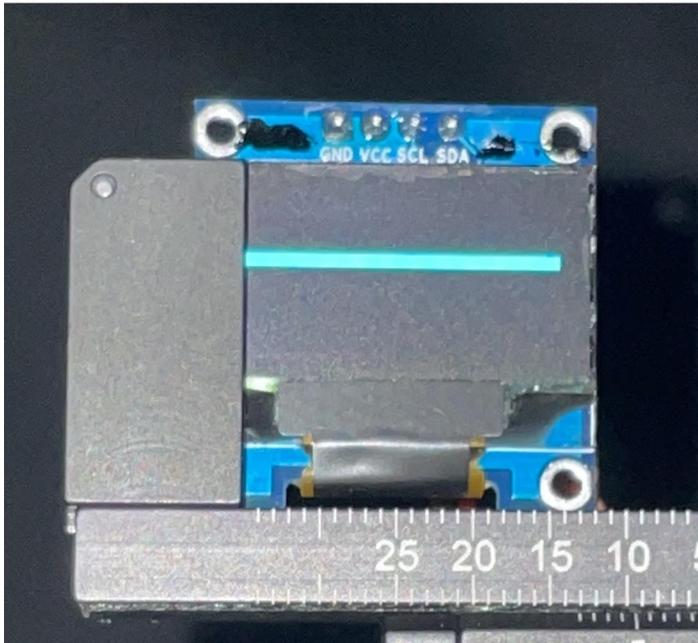


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The source thickness has been increased/decreased symmetrically wrt to the original one → no variation in the final hexapod position expected.

Y axis discrepancy → a feature in the flux of the source?



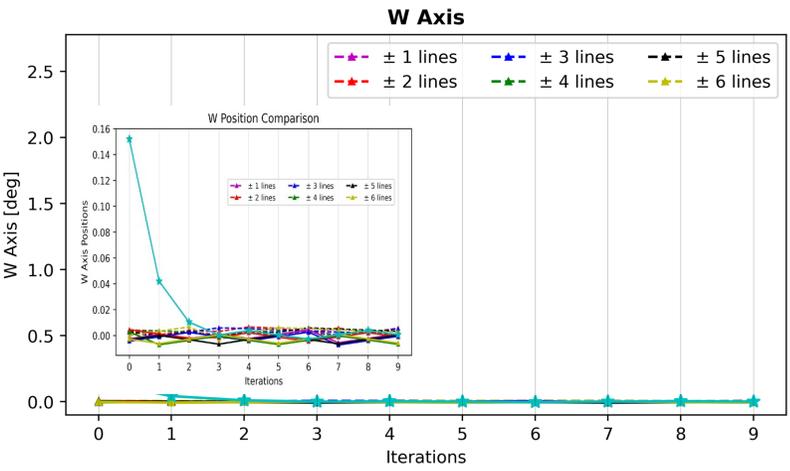
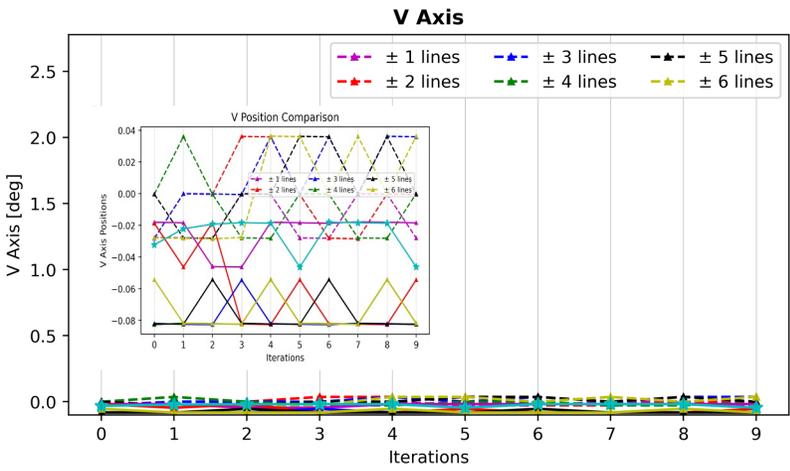
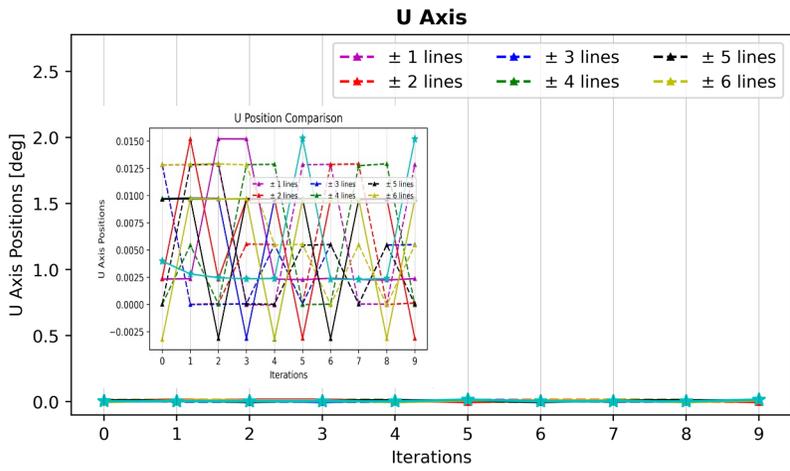
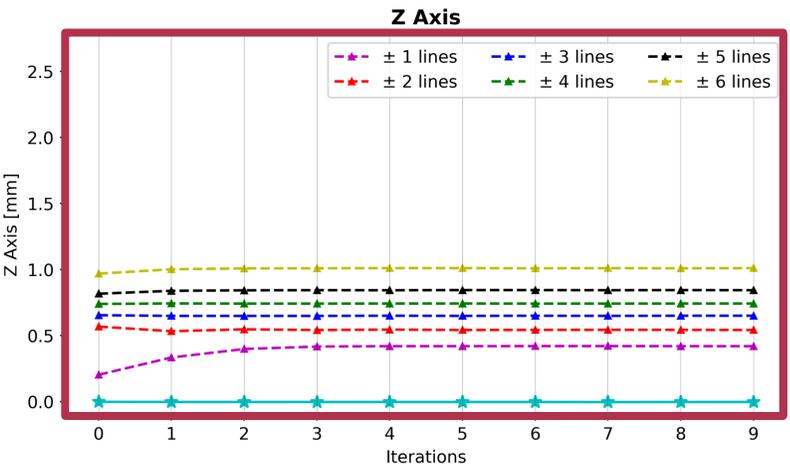
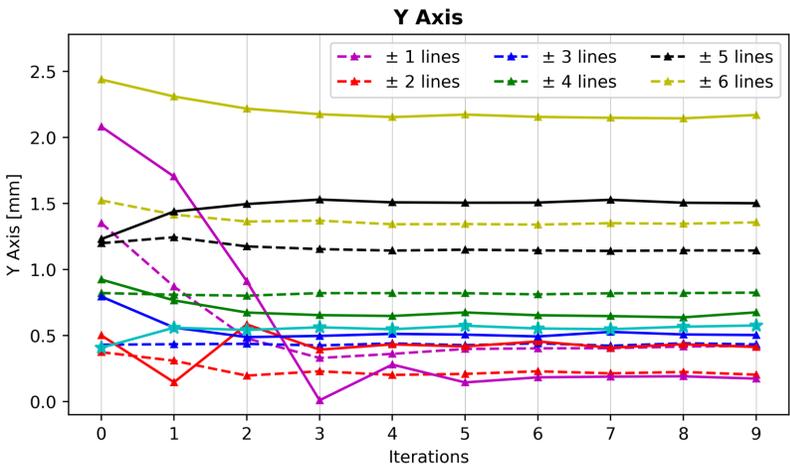
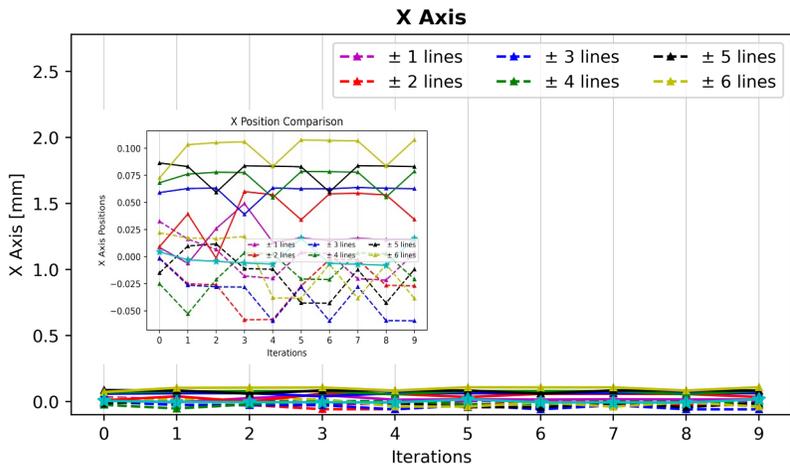
numerical simulations

lab experiments

verification on sky

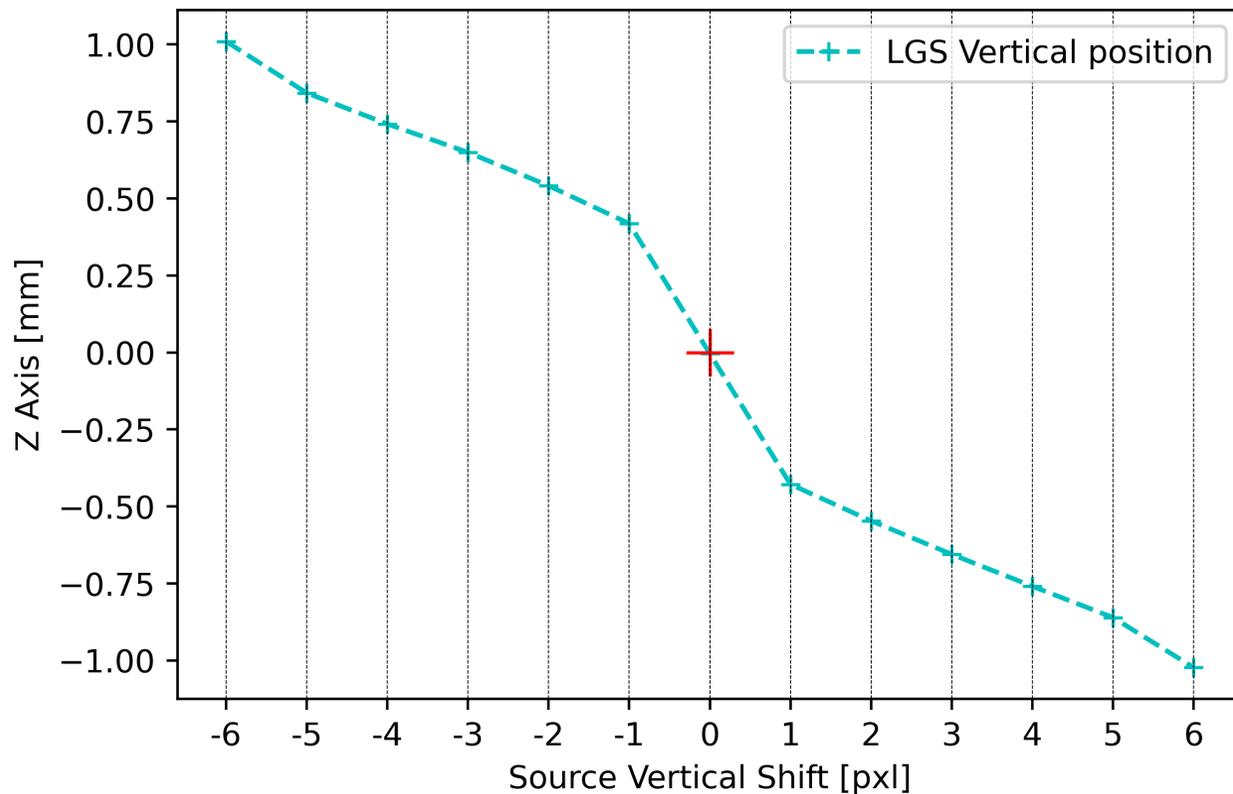
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- Shift of LGS source perpendicularly to the optical axis



Testing the robustness of automatized alignment procedure in varying conditions. So far:

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- Shift of LGS source perpendicularly to the optical axis



Shift by one line (0.21 mm) up or down, maintaining the overall thickness of 5 lines.

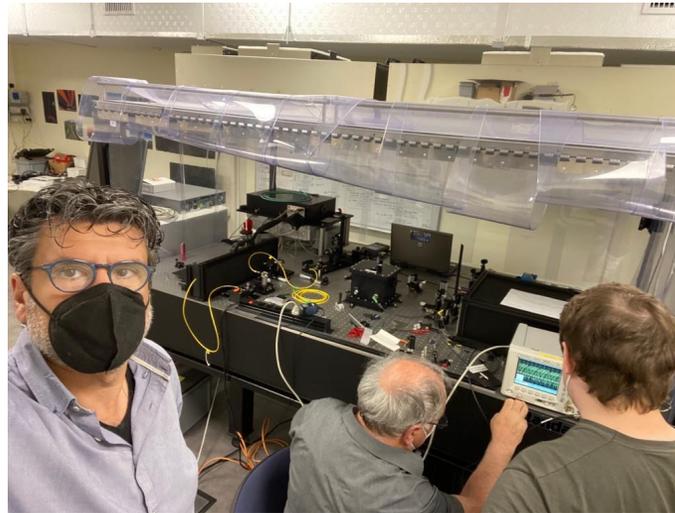
Source Shift [lines]	Z coord	Delta	Source Shift [lines]	Z coord	Delta
0	-0.003	0,425	0	0.003	-0.422
+1	-0.428	0.119	-1	0.419	-0.123
+2	-0.547	0.109	-2	0.541	-0.108
+3	-0.665	0.104	-3	0.650	-0.092
+4	-0.759	0.101	-4	0.742	-0.101
+5	-0.86	0.163	-5	0.843	-0.167
+6	-1.023		-6	-0.003	

The Ingot WFS can be considered in the strategy of risk mitigation for the next generation of ELTs equipped with LGS launchers (located at the side of the telescope)...

...we have to go in the direction of prototyping!!!



First, we will test it and verify the performance on a stand-alone opto-mechanic system in the Laser Laboratory at INAF-OAR, provided by a LGS simulator and possible a turbulence generator.



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Then we plan to study the feasibility and participate to the next year call at ESO Wendelstein Laser Guide Star Unit (WLGSU) @ William Herschel Telescope (WHT), adapting interfaces and organizing the on-sky verification.



A sodium laser beam is launched from the WLGSU as part of laser guide star field tests for validating ELT laser guide star baseline performance.

The WLGSU is located 40 m from the WHT, and is used together with CANARY adaptive optics system on the WHT.



CONCLUSIONS

This R&D project has an **ambitious goal**: to develop a sensor that allows to optimize the performance of the AO systems of the new generation telescopes, **overcoming some well-known limits**, related to the use of LGS.

To achieve this goal, several phases of experimentation and testing are required (in laboratory and through simulations), all well defined, of **considerable technological and theoretical effort**.

In fact, the peculiarity of the study lies precisely in the **different approach to face an old problem**: for the first time we have to carry out **3D tests in the laboratory** (to couple the geometric characteristics of the LGS to the sensor itself), and managing how **to deal with the E2E simulations** as the Fourier method (2D), commonly used, would not enhance its advantages.

The various stages that have to be faced are linear and their succession goes hand in hand with the knowledge of the sensor response and with the skills that the whole team acquires in a trade-off training process.

We hope to have a prototype soon and some exciting news once we will test on sky.



THANKS



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