Deformable Mirrors for Mitigation of Non-axisymmetric Optical defects for the Future Generation of Gravitational Wave Detectors

L.A. Corubolo[1,2*], L. Aiello[1,2], E. Cesarini[2], M. Cifaldi[2], V. Fafone[1,2], M. Ianni[1,2,3], M. Lorenzini[1,2], D. Lumaca[2], Y. Minenkov[2], I. Nardecchia[2], A. Rocchi[2], V. Scacco[1,2], C. Taranto[1,2v]

[1] University of Rome Tor Vergata, Department of Physics, Rome, Italy
[2] INFN, Section of Rome Tor Vergata, Rome, Italy
[3] University of Rome La Sapienza, Department of Physics, Rome, Italy
*lucianoantonio.corubolo@roma2.infn.it

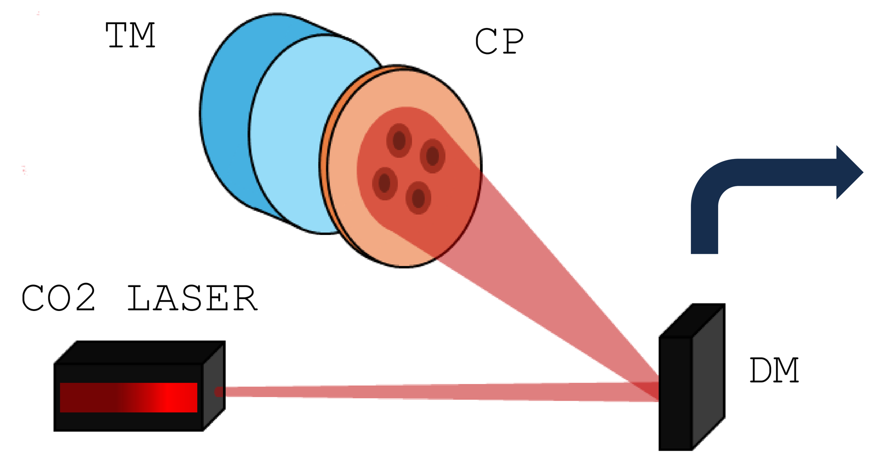
Optical aberrations can significantly deviate the gravitational wave detector from its optimal working point, making it ***unmanageable and drastically reducing its sensitivity***. Therefore, the Thermal Compensation System (TCS) [1], designed to detect and compensate for these optical aberrations, primarily exploits the thermo-optic effect to correct wavefront deformations by illuminating on-path optics with a shaped CO_2 laser beam. Future generations of gravitational wave detectors, such as ET-HF, are expected to achieve ***unprecedented levels of intracavity optical power***, which will amplify the effects of optical aberrations, including non-axisymmetric ones. We are currently investigating Deformable Mirrors (DMs) as a versatile solution to mitigate these ***non-axisymmetric optical defects***. Indeed, DMs can adapt the reflective surface to match a selected phase pattern and reproduce a desired intensity profile. We employed a ***Modified Gerchberg-Saxton*** (MoG-S) algorithm to determine the phase corrections required for intensity compensation.

WHY DEFORMABLE MIRRORS?

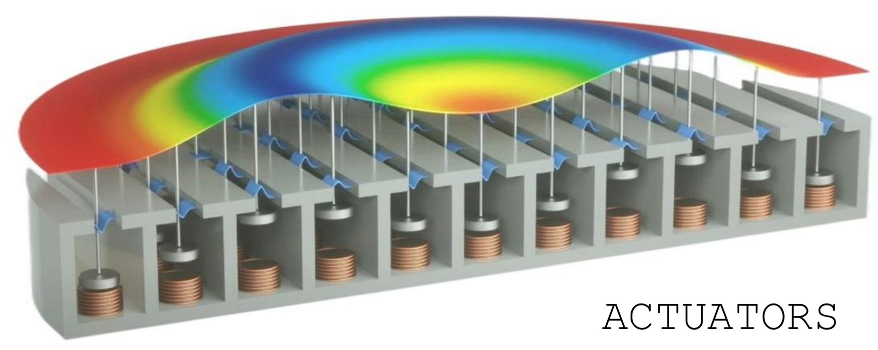
Problem: variations in optical path due to temperature gradients and mechanical strains of the test mass (TM).

Solution: produce a suitable intensity pattern on the compensation plate (CP) to introduce a complementary correction in TM's optical path.

Method: DM alters the phase of the probe beam to reproduce the required intensity pattern on the CP.



DM's actuation in intensity

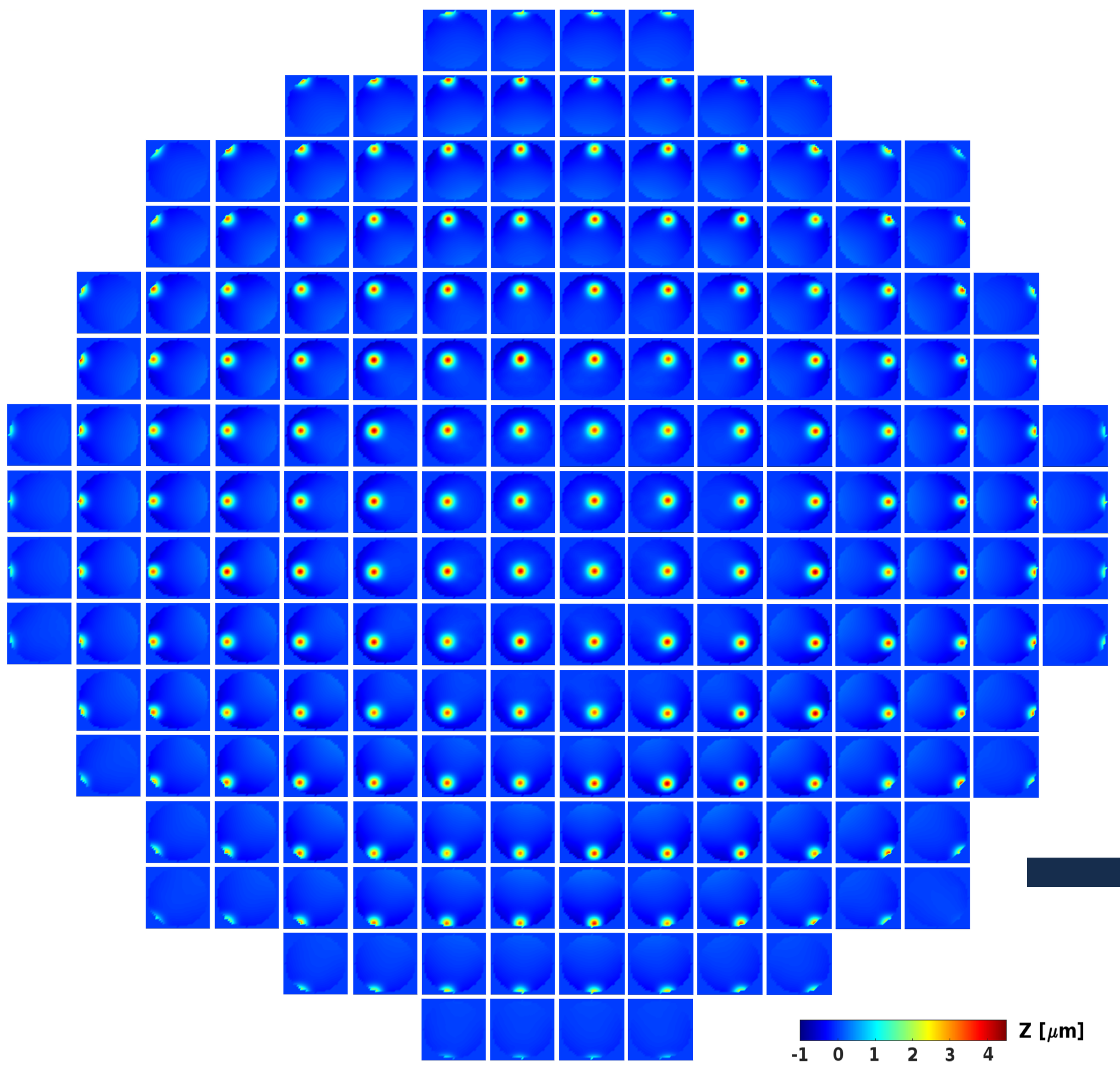


Internal structure of a DM with magnetic actuators

DM ACCURACY IN PHASE

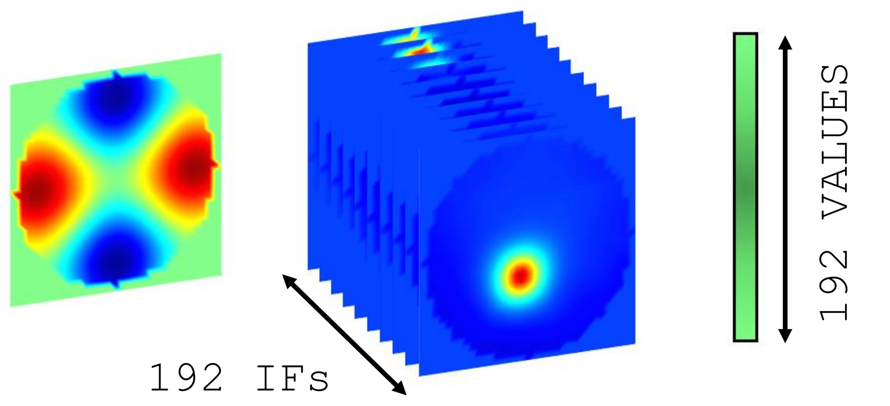
We selected the DM model equipped with 192 magnetic actuators provided by ®ALPAO.

The ***Influence Functions*** (IFs) are the building blocks to reproduce a complex phase target. A Shack-Hartmann (SH) sensor was employed to measure the wavefront variation induced by each single actuator on an incident laser beam (λ = 532nm).

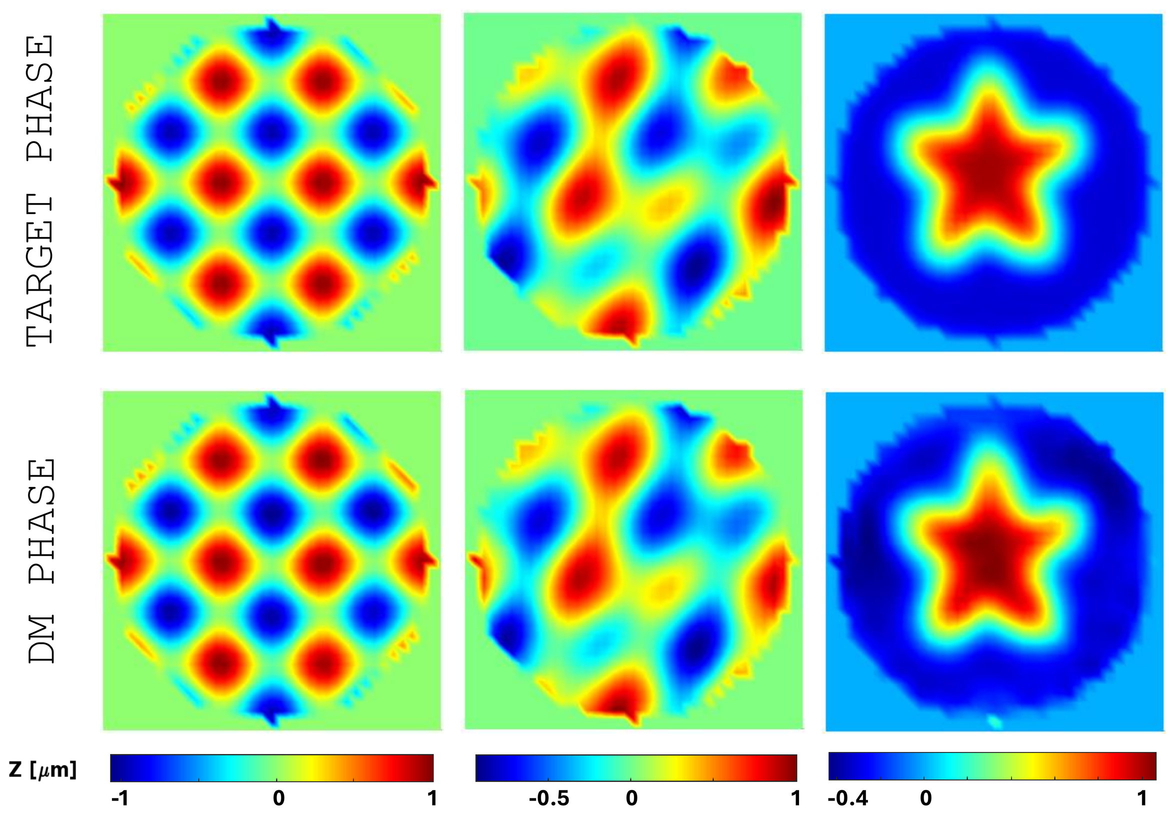


Experimental influence functions of DM192-BAX730

TARGET = INFLUENCE MATRIX × ACTUATION COEFFICIENTS



Influence matrix formalism to derive the actuation weights

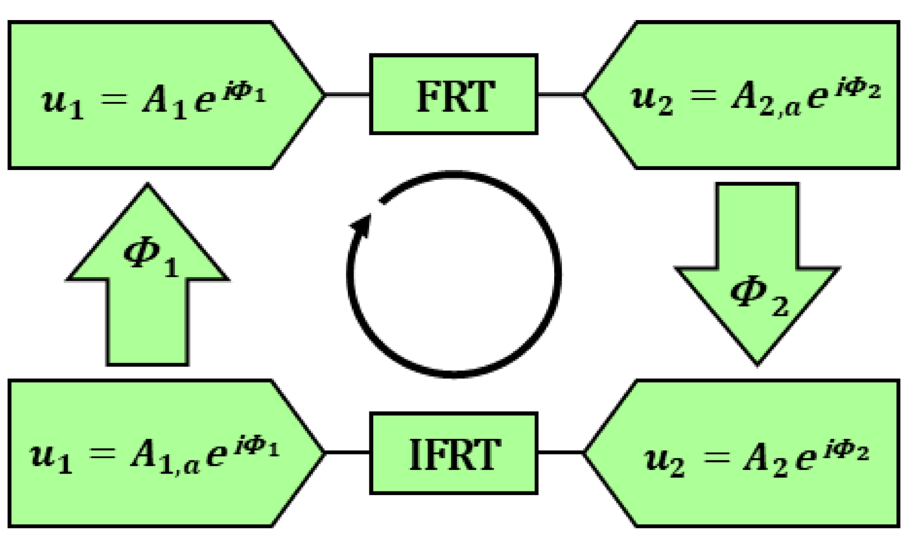


Comparison between target and experimental phases

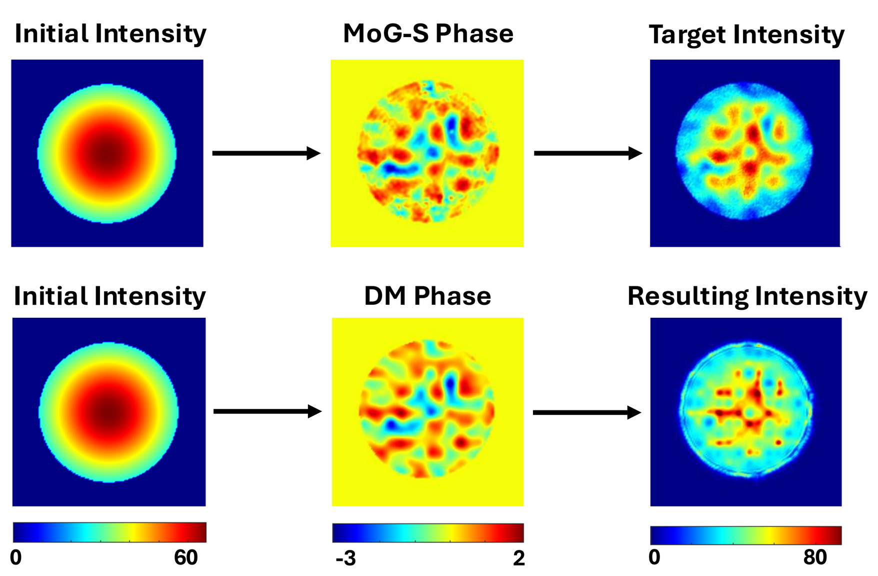
DM ACCURACY IN INTENSITY

Phase retrieval problem: recover the unknown phase starting from two measurements of intensity (initial and target) at distance z from DM. We implemented the ***MoG-S algorithm*** [2] to derive the DM phase and obtain the target intensity. The simulated results will be experimentally verified.

Experimental setup: the laser (λ = 532nm) impinges on DM, a SH wavefront sensor is positioned in the DM image plane to control the DM-induced phase variation while a CCD (fixed on a translation stage) measures the correspondent intensity after propagating at distance z from DM.



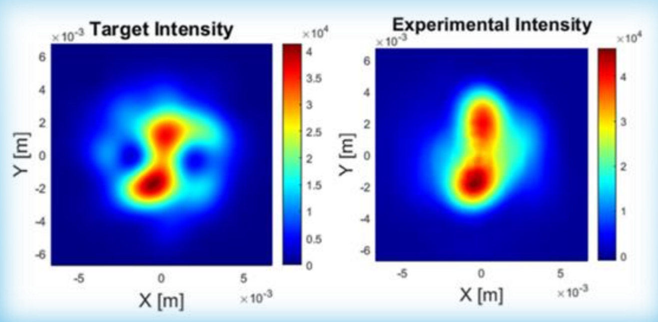
MoG-S algorithm



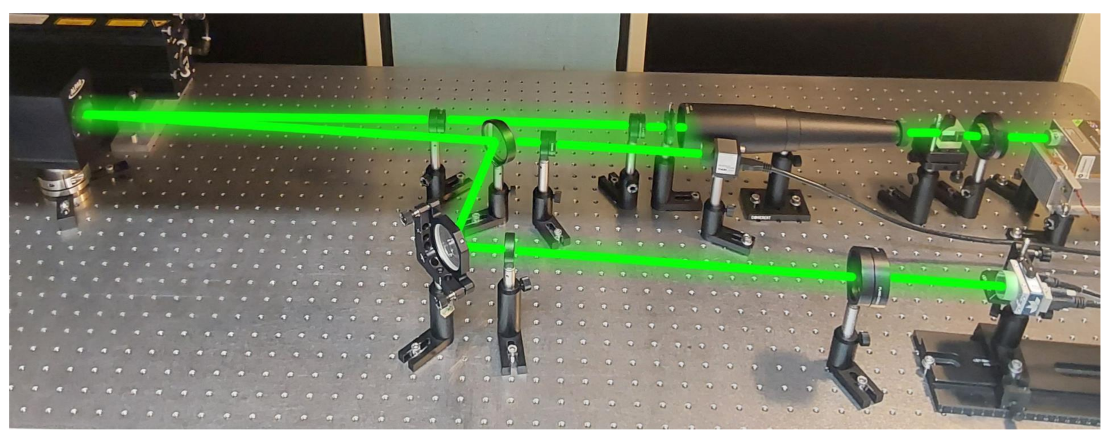
Simulated intensity produced by the DM-induce phase variation

PREVIOUS RESULTS WITH CO_2 LASER

We already know CO2 laser can reproduce simple intensity patterns [3], now the green laser allows to control the phase and test the DM performance with more complex patterns.



Target and experimental intensities with CO_2 laser



Optical layout to control the DM phase and measure the resulting intensity

CONCLUSIONS AND NEXT STEPS

DMs can reproduce a selected intensity on CP to compensate for existing optical aberrations caused by non-axisymmetric residuals.

- Produce more realistic intensity patterns and look at the optical path length variation induced by the resulting intensity
- Apply the analysis introducing a CO_2 laser
- Define a closed-loop algorithm to control the resulting intensity

REFERENCES

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