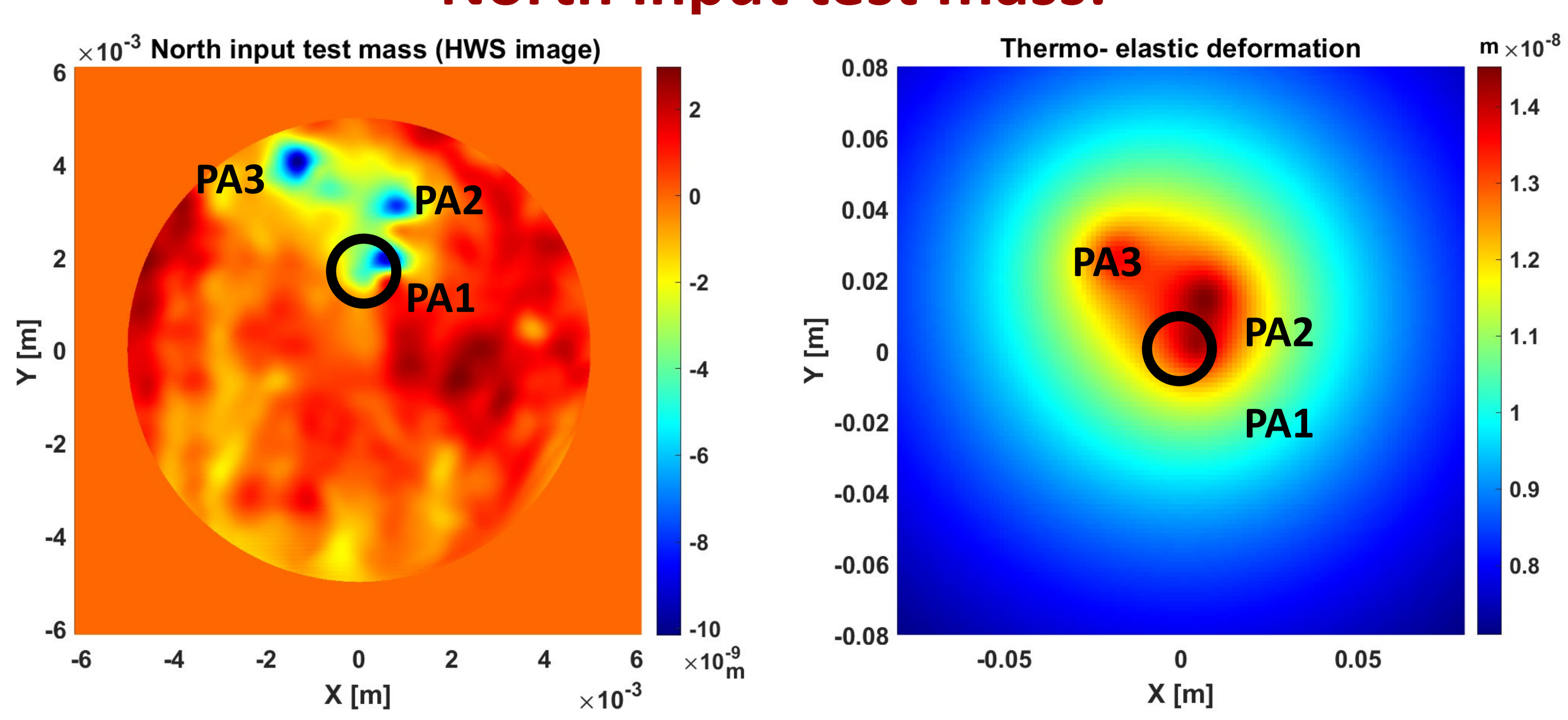
Investigation and mitigation of anomalous power absorptions in the Advanced Virgo Plus core optics

M. Cifaldi [1,2*], V. Fafone[1,2], C. Gasbarra[1], M. Lorenzini[1,2], I. Nardecchia[2], A. Rocchi[2]

[1] University of Rome Tor Vergata, Department of Physics, Rome, Italy
[2] INFN, Section of Rome Tor Vergata, Rome, Italy
*maria.cifaldi@roma2.infn.it

Introduction: During O3, highly absorbing areas on the surfaces of the main interferometer optics of Advanced Virgo have been observed. These anomalous micron-scale absorbers produce distortions as additional thermo-elastic deformation of the high reflectivity mirrors surfaces and thermal lensing in the optics substrate. With the aim to understand and mitigate their effects in the interferometer, a detailed and quantitative study of their characteristics has been carried out. The information about their position and fraction of absorbed power allows to put the basis for the development of an adaptive actuator, able to correct these aberrations in the Advanced Virgo Plus (AdV+) test masses.

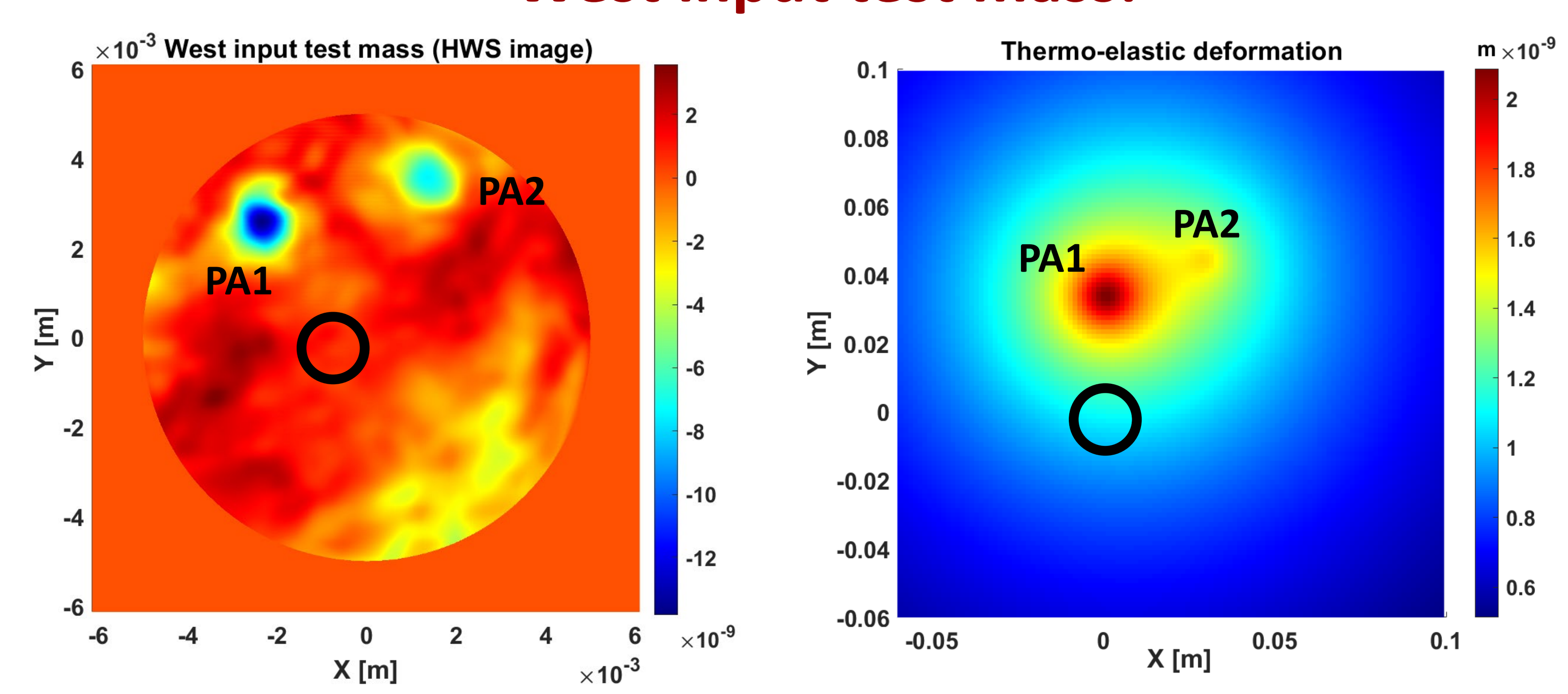
North input test mass:



On the left: Wavefront map measured by the HWS-DET probing the NI test mass. WF has been acquired two minutes after the ITF is locked at dark fringe. This is the first in which it is possible to see the three point absorbers. On the right: The simulated thermo-elastic deformation due to the points, based on the analysis of the HWS image. The Gaussian weighted RMS value of the thermo-elastic map is $1.50 \cdot 10^{-9} m$. The center of the mirrors is in the regions inside the black circles.

Point Absorber	Distance from centre (cm)	Size (cm) of the OPL increase (FWHM)	Absorptions (lower limit) (ppm)
1	0.47	2.27	90
2	1.65	2.10	65
3	3.44	1.30	600

West input test mass:

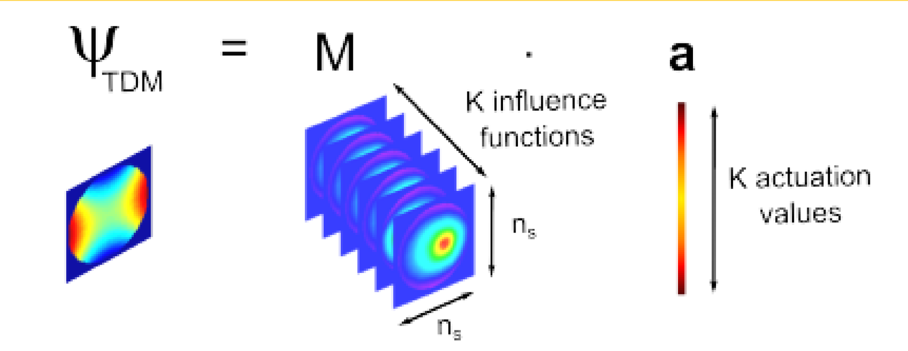


On the left: Wavefront map measured by the HWS-INJ probing the WI test mass. WF has been acquired one minute after the ITF is locked at dark fringe. This is the first in which it is possible to see the two point absorbers. On the right: The simulated thermo-elastic deformation due to the points, based on the analysis of the HWS image. The Gaussian weighted RMS value of the thermo-elastic map is $2.6 \cdot 10^{-10} m$. The center of the mirrors is in the regions inside the black circles.

Point Absorber	Distance from centre (cm)	Size (cm) of the OPL increase (FWHM)	Absorptions (lower limit) (ppm)
1	3.57	1.33	720
2	5.35	1.18	955

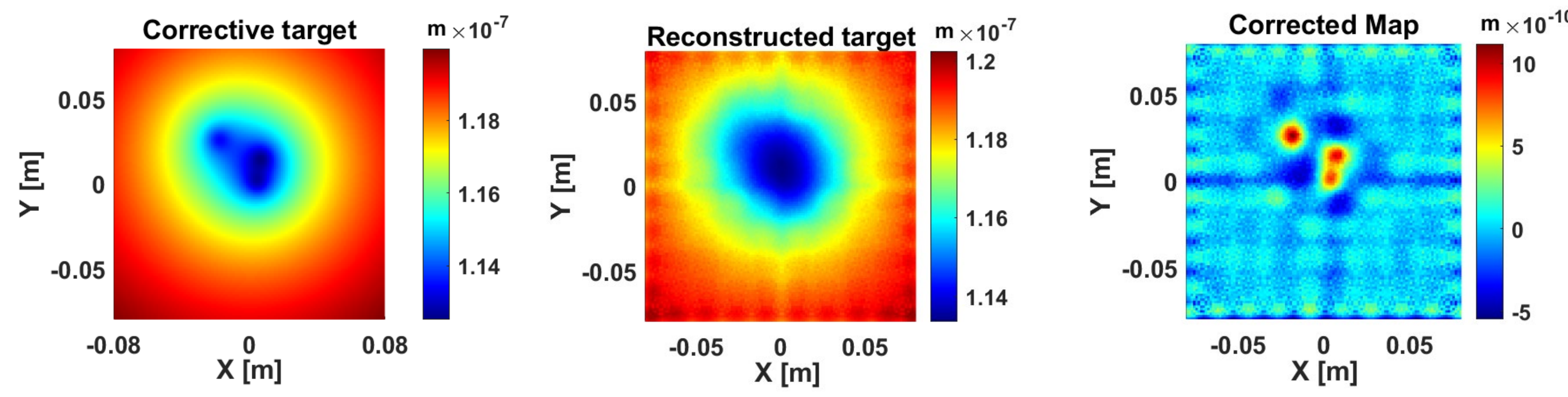
Influence matrix formalism:

With the aim to compensate the point absorbers, a corrective map has been computed. Considering a matrix of actuators as a suitable solution to reproduce the desired target, it is possible to evaluate the actuation coefficients using the influence matrix formalism.



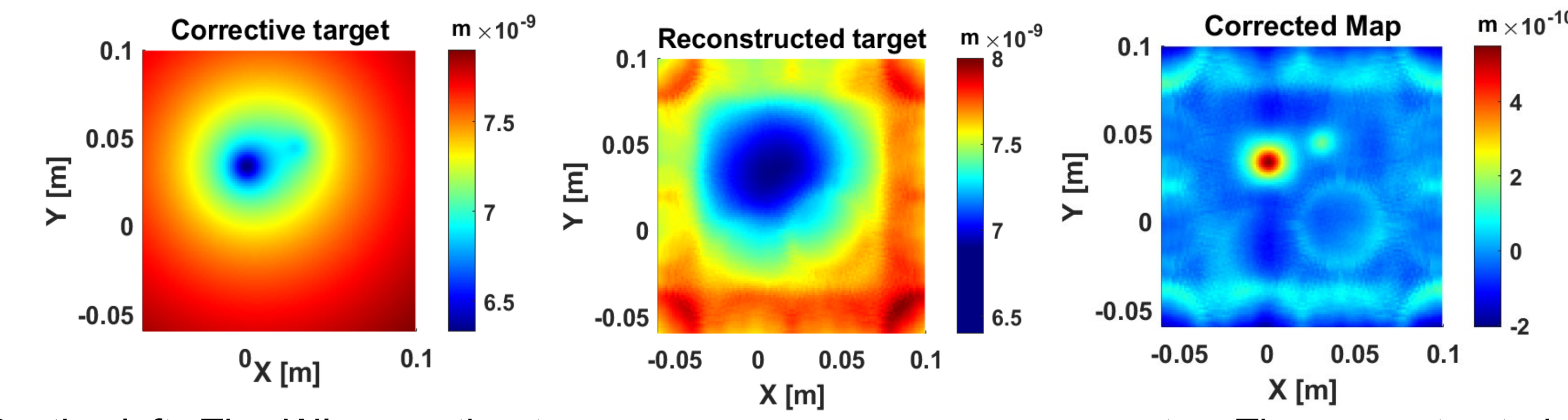
$$\psi = M \cdot \vec{a} = \sum_{i=1}^{N} I_i(x,y)\, a_i$$
$$\vec{a} = (a_1, \dots, a_i, \dots, a_N)$$
$$\min \| M \cdot \vec{a} - T \|_2^2$$

North input test mass:



On the left: The NI corrective target to be reproduced. In the center: The reconstructed target by 100 actuators. On the right: The corrected map obtained by the sum of the initial thermo-elastic deformation and the reconstructed target. The Gaussian weighted RMS before the correction is $\mathbf{1.50 \cdot 10^{-9} m}$, after the correction the value is $\mathbf{2.42 \cdot 10^{-10} m}$.

West input test mass:



On the left: The WI corrective target to be reproduced. In the center: The reconstructed target by 144 actuators. On the right: The corrected map obtained by the sum of the initial thermo-elastic deformation and the reconstructed target. The Gaussian weighted RMS before the correction is $\mathbf{2.6 \cdot 10^{-10} m}$, after the correction the value is $\mathbf{7.7 \cdot 10^{-11} m}$.

Conclusions and future plans:

Optical simulations have been run to test the effect of the corrected maps on the ITF performance.

Ongoing activities:

- Optimization of actuator configuration (# actuators, matrix typology)
- Evaluation of the impact on the ITF
- Definition of optical and executive design of the actuator

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