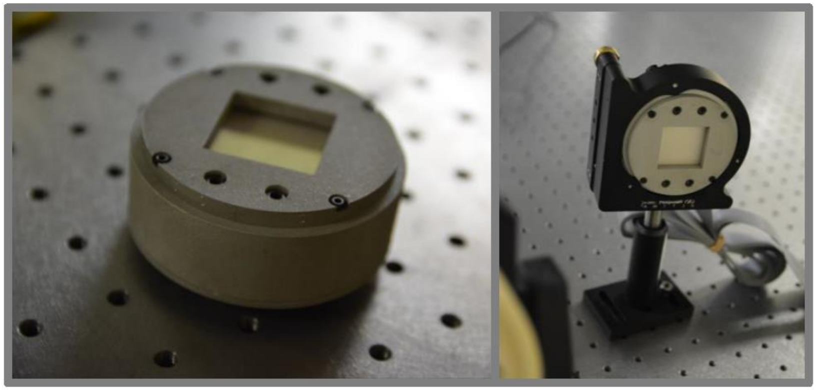
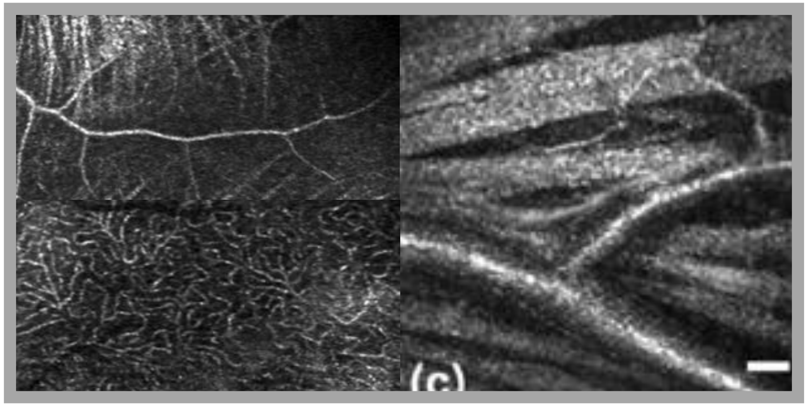
Development of devices and systems for adaptive optics

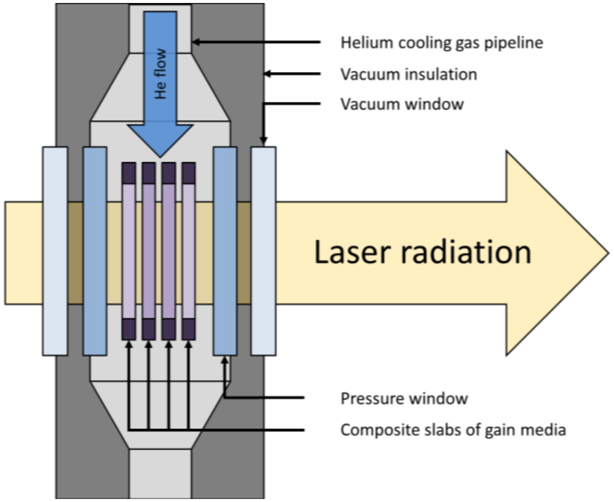




J.Mocci, R.Muradore, F.Mousavi, P.Vallone, P.Villoresi, S.Bonora
CNR-Institute of Photonics and Nanotechnology, via Trasea 7, 35131, Padova, Italy
Università degli Studi di Verona
Università degli Studi di Padova

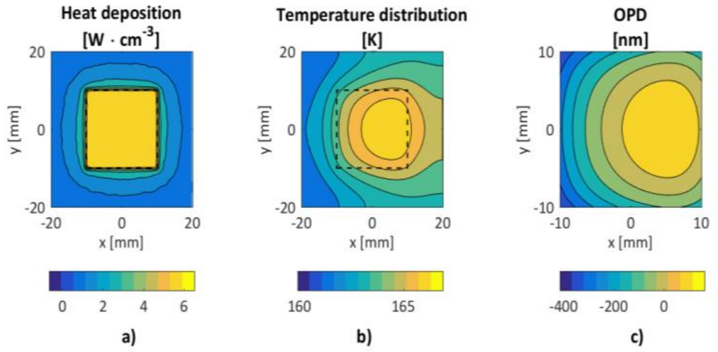
CNRIFN
Istituto di Fotonica e Nanotecnologie

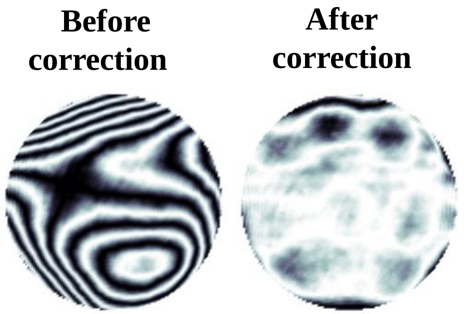
Aberrations in lasers

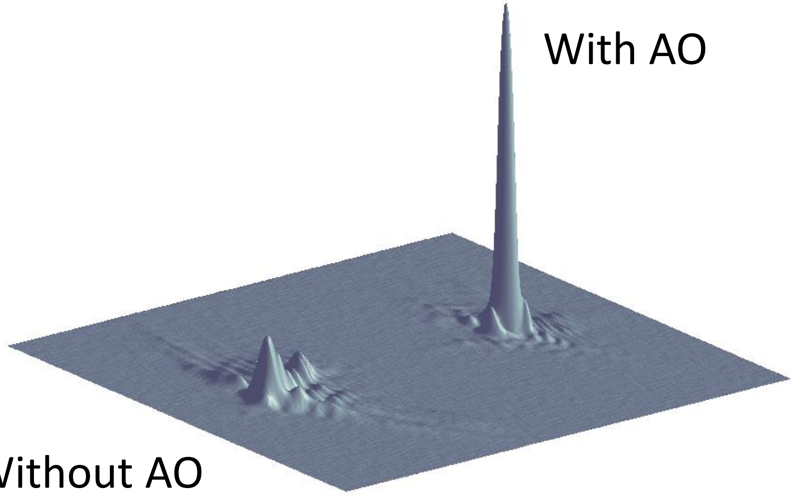


Aberrations from:

Thermally induced phase aberrations



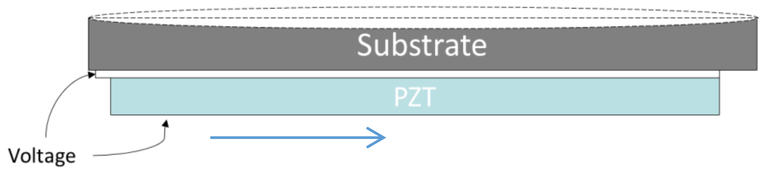




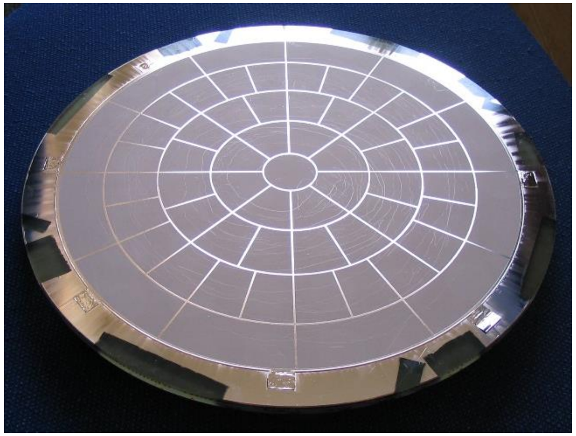
In lasers aberrations reduce the intensity

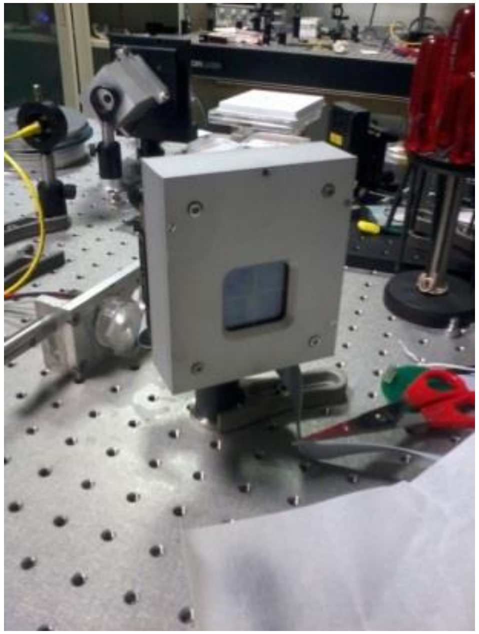
Deformable mirror technology

Piezoelectric bimorph DM



Converse piezoelectric effect
PZT expands and bends the glas substrate

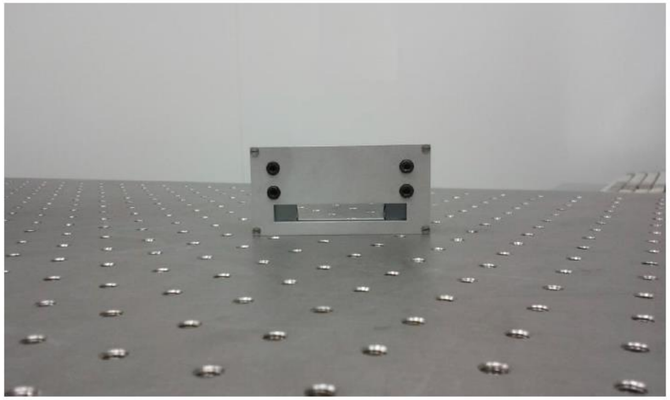




40mm x 40mm
Hilase

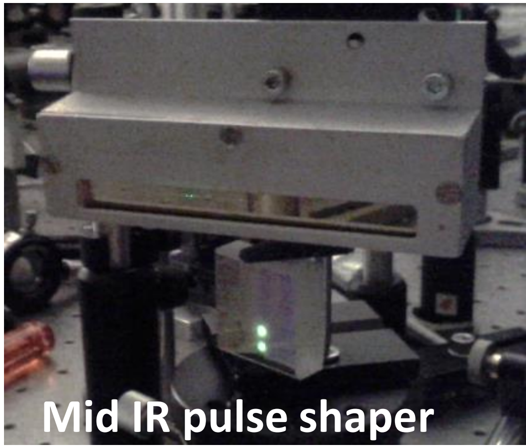
Advantages:

Possible to scale up the size, robust, any coating (metallic or dielectric)



Pulse shaping

Adaptive optics activity



Our deformable mirrors:

Bimorph (metallic or dielectric)

Applications:

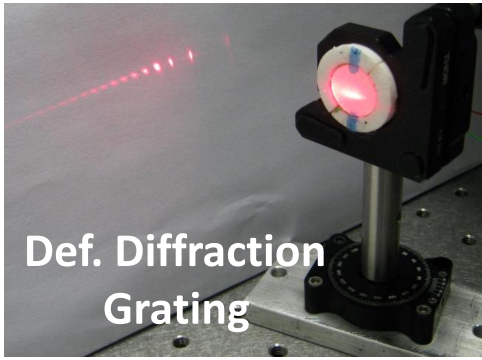
Application of DMs to pulse compression and shaping ultrashort lasers UV, Vis, NIR and Mid-IR, High peak /High avg power lasers

S.Wall et al, Quantum interference between charge excitation paths in a solid-state Mott insulator, ***Nature Physics****, 114-118, Vol. 7, 2011*

REVIEW: D.Brida et al, Few-optical-cycle pulses tunable from the visible to the mid-infrared by optical parametric amplifiers ***J. Opt.*** *12 (2010) 013001*

DMs and Deformable diffraction grating for XUV ultrashort pulses

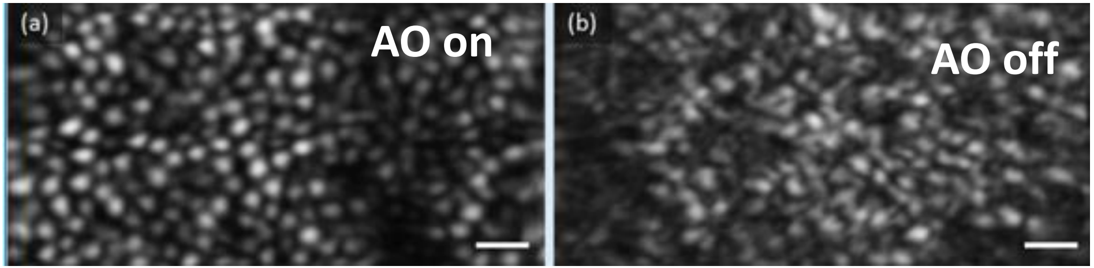
S. Bonora, et al. *Active diffraction gratings: Development and tests*, **Rev. Sci. Instrum**. 83, 123106 (2012);



Medical/microscopy imaging (2 Photons, OCT, confocal)

S. Bonora,et all "*Wavefront correction and high-resolution in vivo OCT imaging with an objective integrated multi-actuator* adaptive lens," Opt. Express 23, 21931-21941 (2015)

K.S.K. Wong, et al , "I*n vivo imaging of human photoreceptor mosaic with wavefront sensorless adaptive optics o*ptical coherence tomography", Biomed. Opt. Express 6, 580-590 (2015)



OCT
In vivo retinal cones image
In human eye

High power lasers
Femtosecond lasers – Pulse shaping
Medical Imaging

What we are asked for:

- **High performance:**
  - Technical requirements:
    - Dimensioni 25mm – 100mm (we are looking into 20cm DM)
    - Stroke >20um
    - Damage Threshold > 20J/cm^2 (ns), > 5J/cm^2 (fs)
    - Broad bandwidth and Low GDD (fs)
    - Actuators 32 – 144
    - Response time 10Hz (DM response time about 1ms)
    - Vacuum compatible (10^{-4}mbar)

- **Quality**
  - Preliminary simulations -> DM desing
  - Collaboration for installation/Participate to experiments
  - Spares
  - Quality ISO certification, Warranty
  - Reliable electronics

} involve industrial partners

PHASICS
The phase control company

OPTO ENGINEERING
THE TELECENTRIC COMPANY

Design example:
Deformable mirrors for Hilase

J.Pilar, A.Lucianetti, S.Bonora
HiLASE project, Institute of Physics AS CR, Na Slovance 2, 18221, Prague, Czech Republic
CNR-Institute for Photonics and Nanotechnology, Via Trasea 7, 35131, Padova, Italy

POWER OF LIGHT

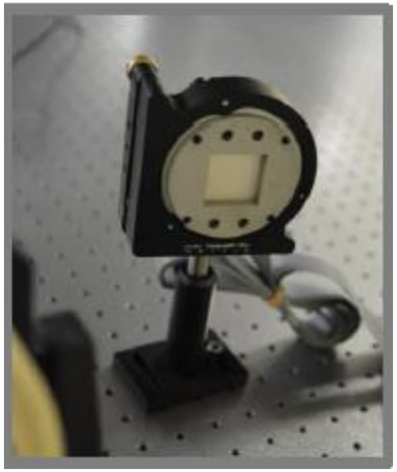
HILASE

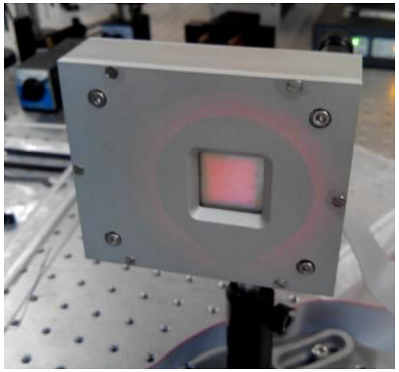
High average power cryogenically-cooled diode-pumped solid-state laser system

Developed deformable mirrors for:

Hilase (Czech republic) and Dipole (UK)

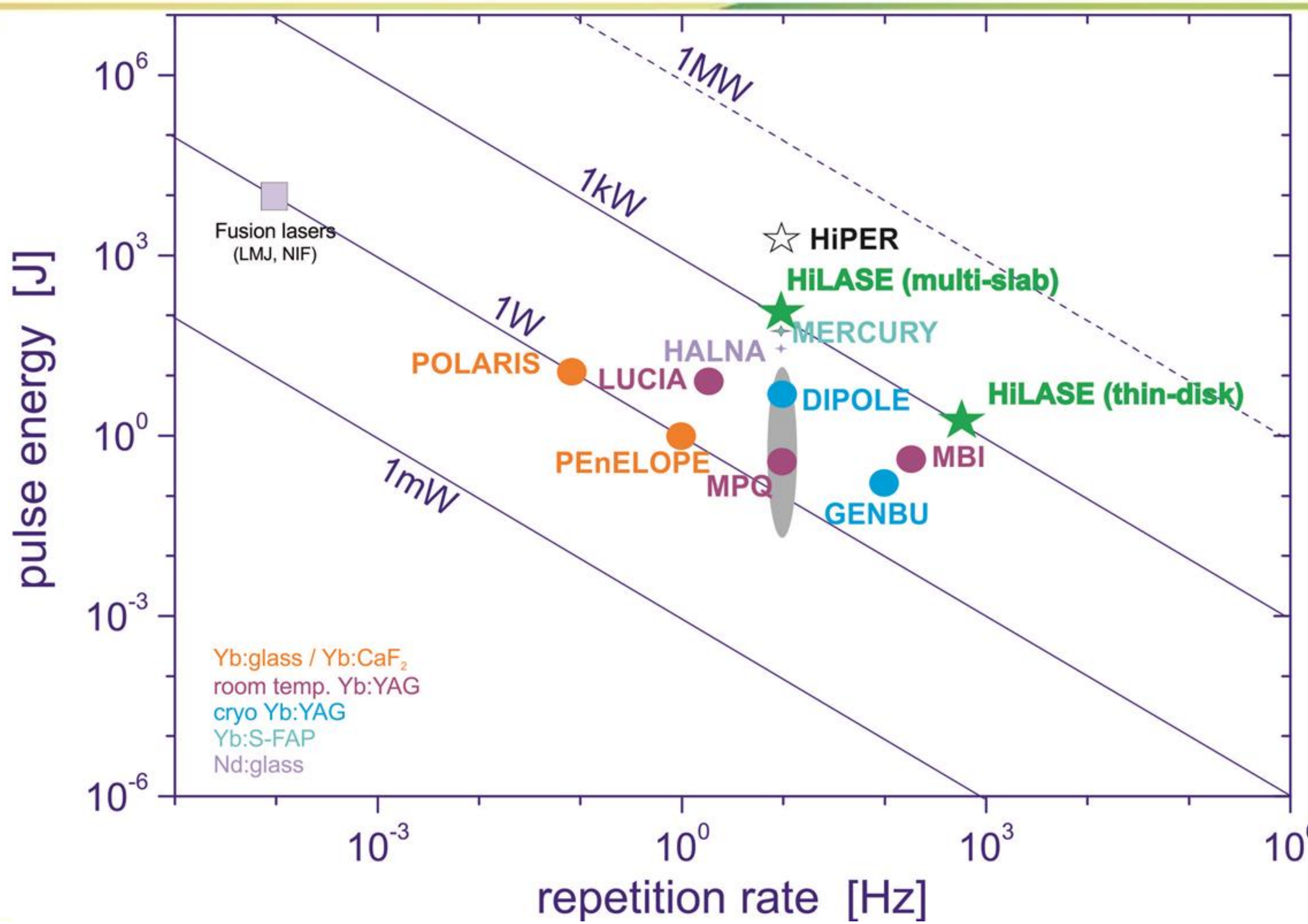
Energy: 10J
Duration: 10ns
Rep rate: 10Hz
Size: 27mm x 27mm,
Wavelength: 1030nm
7x7 actuators





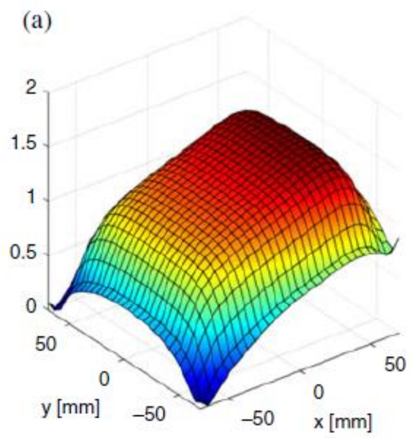
HiLASE & ELI Beamlines

Current and future high-energy laser facilities

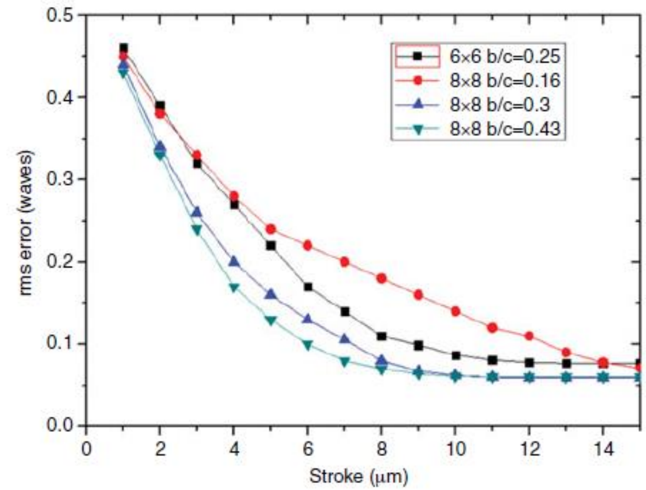


Simulations and DM design

Laser
Themo-Optical
Model



DM model
FEM
others



Example of
Actuator
layout

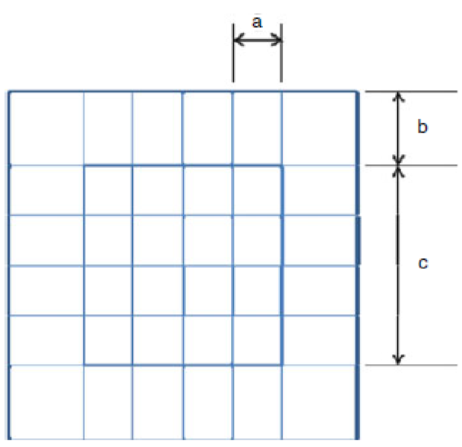
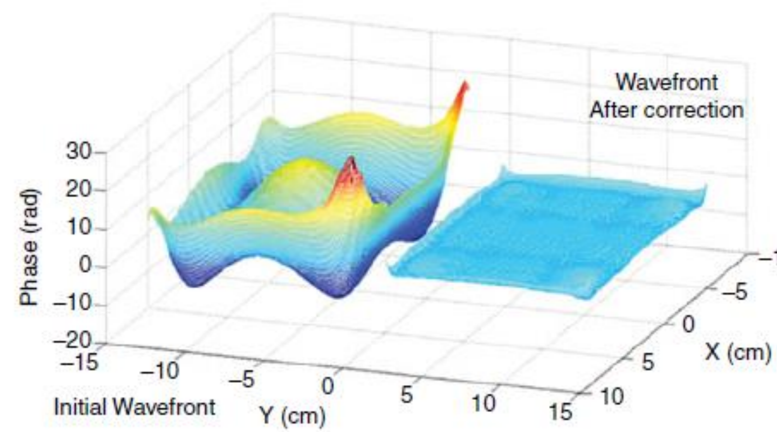
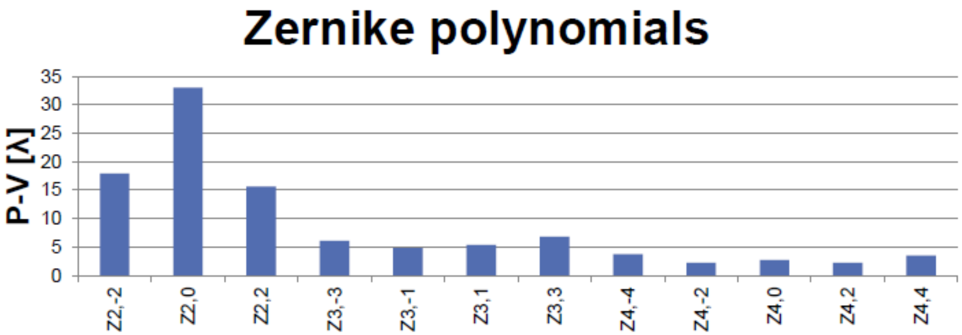


Figure 20. The actuator layout of the DM.



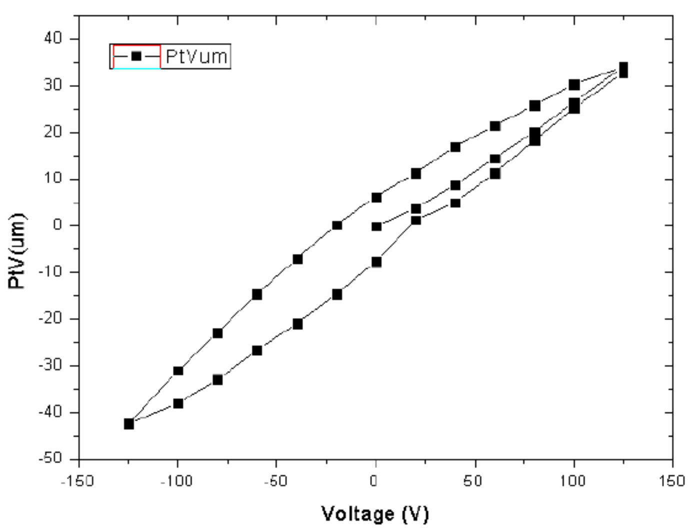
1) Jan Pilar, et al, Design and optimization of an adaptive optics system for a high-average-power multi-slab laser (HiLASE), Applied Optics, Vol. 53, Issue 15, pp. 3255-3261 (2014) * **selected by the Editors, for publication in the Virtual Journal for Biomedical Optics (VJBO), Vol. 9, Iss. 7 — Jul. 9, 2014**
2) A.Lucianetti, et al, Design of a kJ-class HiLASE laser as a driver for inertial fusion energy, High Power Laser Science and Engineering, (2014), Vol. 2, e13

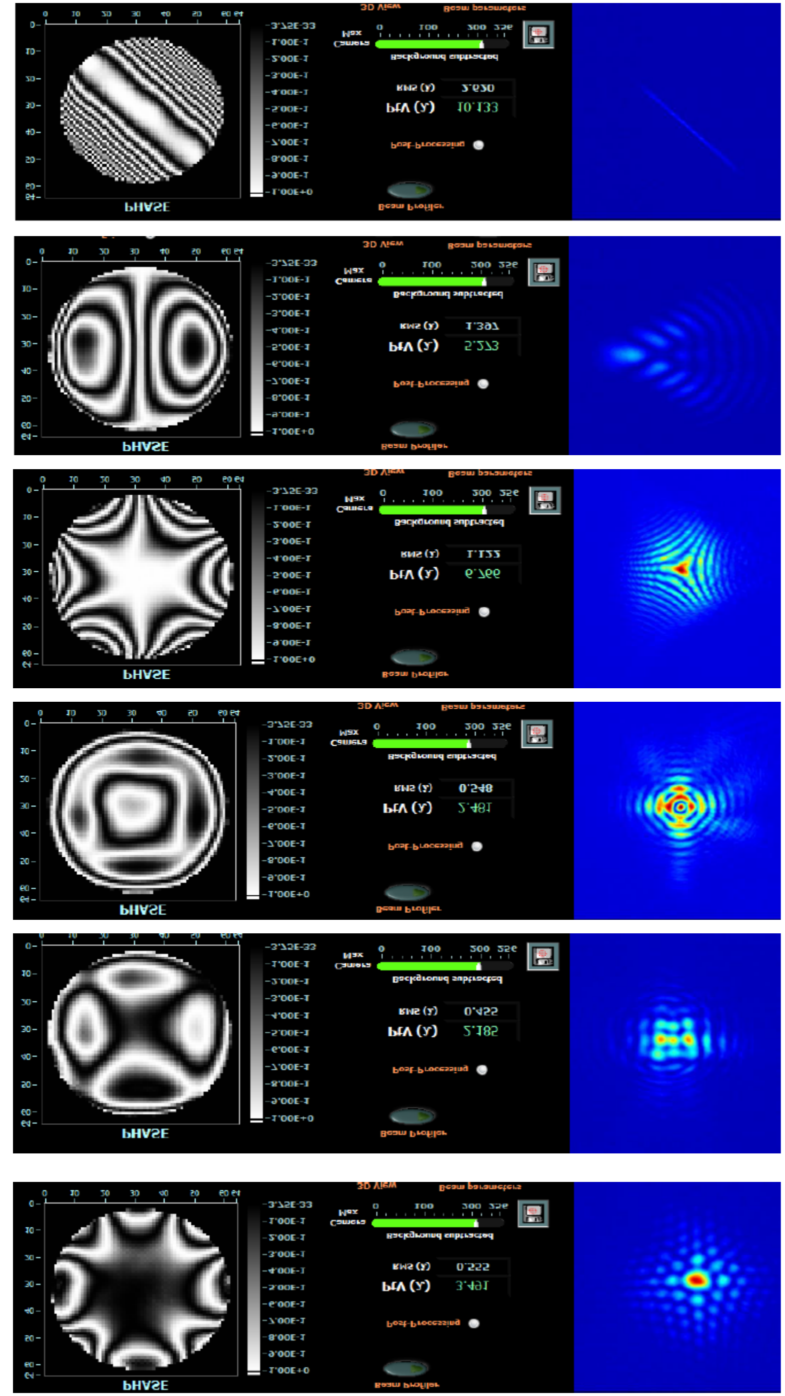
DM characterization



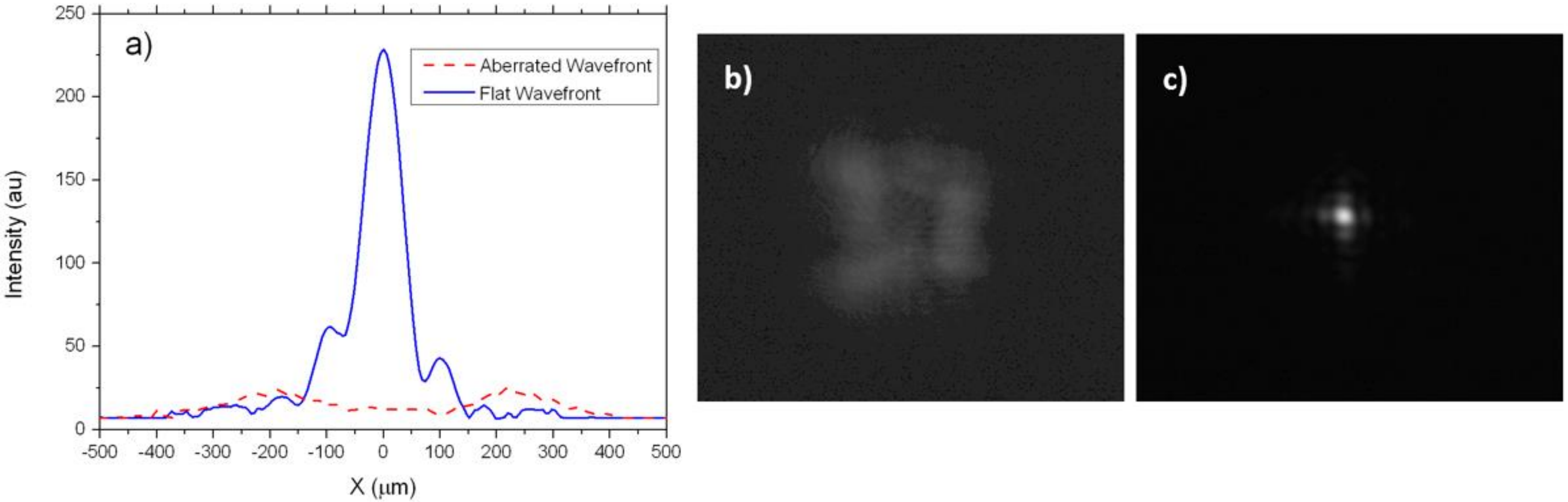
MAX STROKE AND HYSTERESIS

- Material used for active layer of DM: PZT
- PZT exhibit hysteresis cca 20%
- The maximal DM surface deflection: ~ -42µm – +32µm

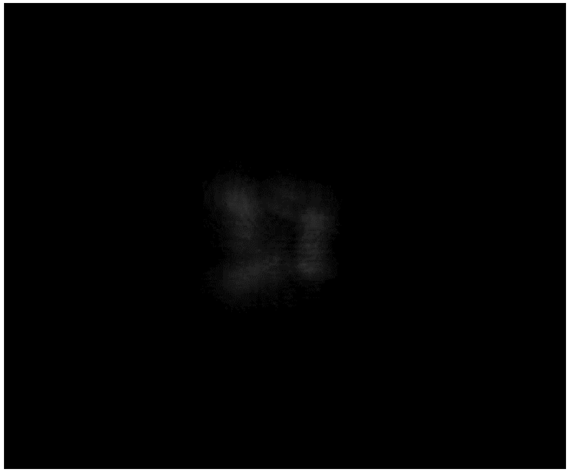




Closed loop working



Comparison of the laser spot before and after the closed loop activation

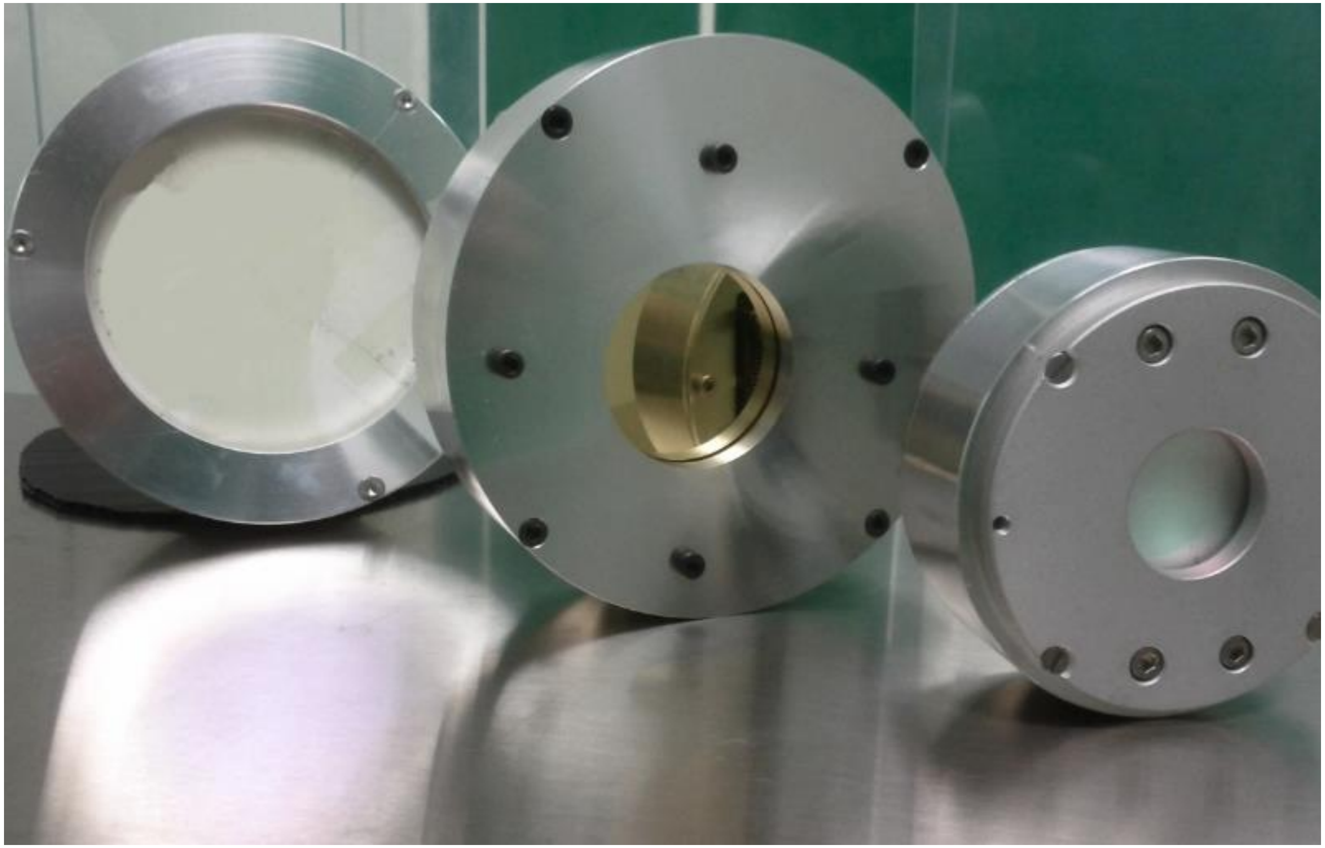


Our recent DMs for High Power laser

Pisa (ITA) ILIL lab
5J, 800nm, 100fs
75mm aperture

Virgo (ITA)
2W, 10.6um, CW
144 actuators

Livermore
0.85ns, 740-900nm, 0.5J
Low GDD <100fs^2
5J/cm^2



Adaptive lens and application in sensorless microscopy

Adaptive lens: properties

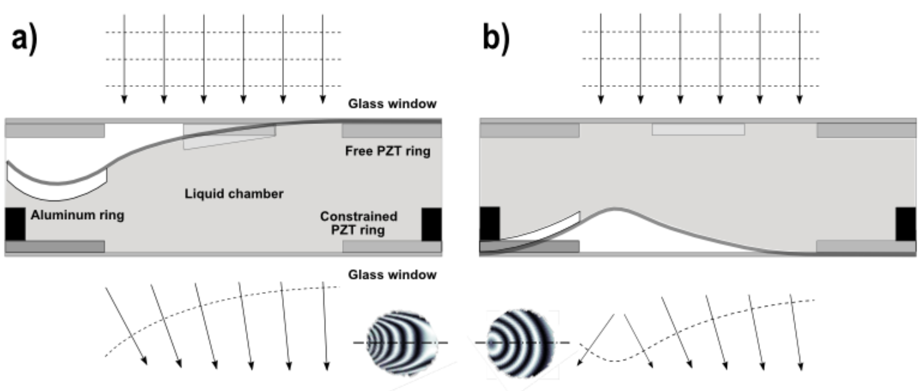
18 pzt actuators outside the clear aperture
Optical power: 1.4D

Clear aperture: 10mm
Transmission: visible NIR (TBM)

Initial aberration: 0.22waves rms
Corrected with about 25% rms voltage range

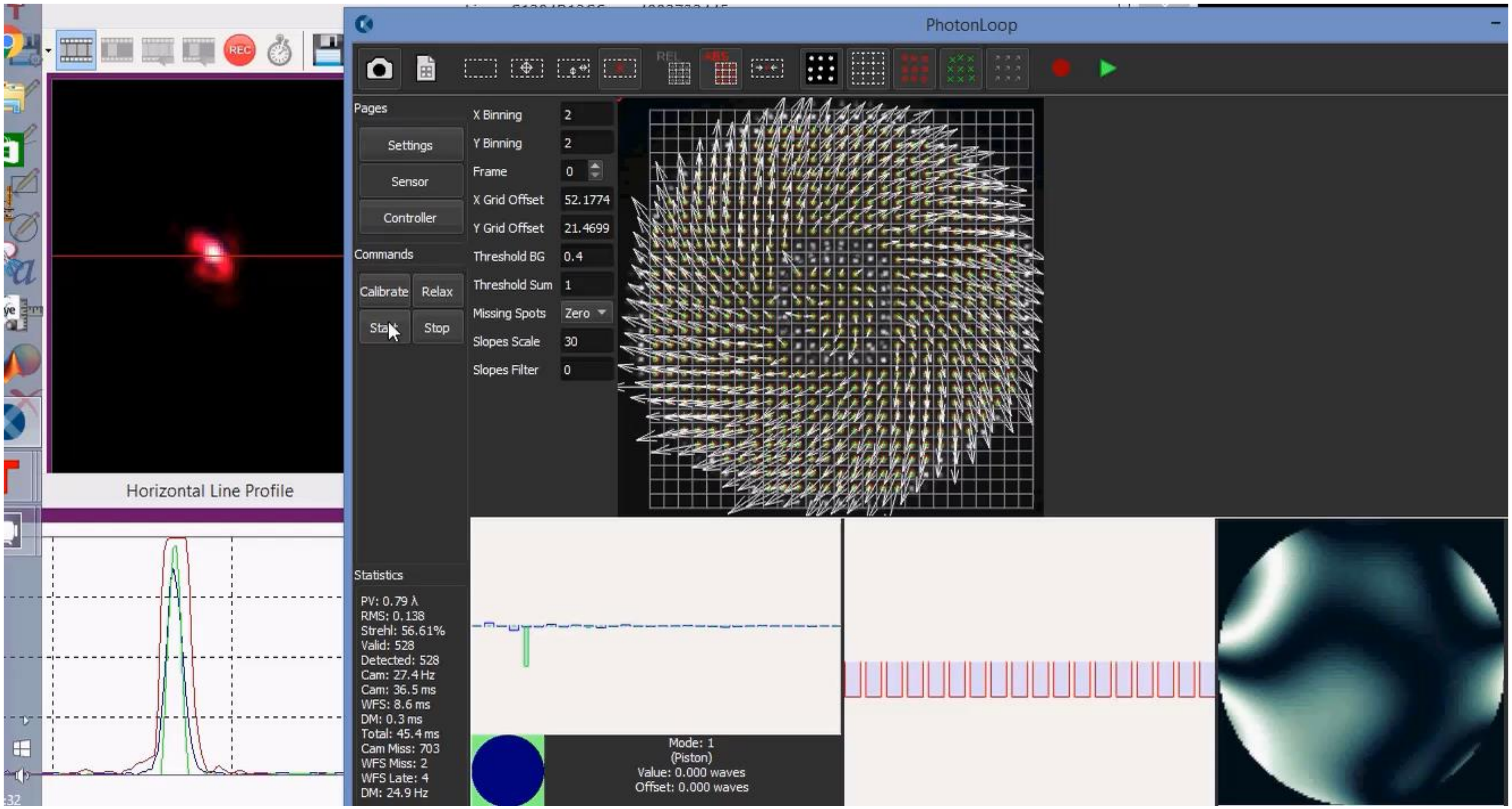
Technology: PZT bimorph
Voltage range: -125V/+125V

Generates aberrations up to the 4th order



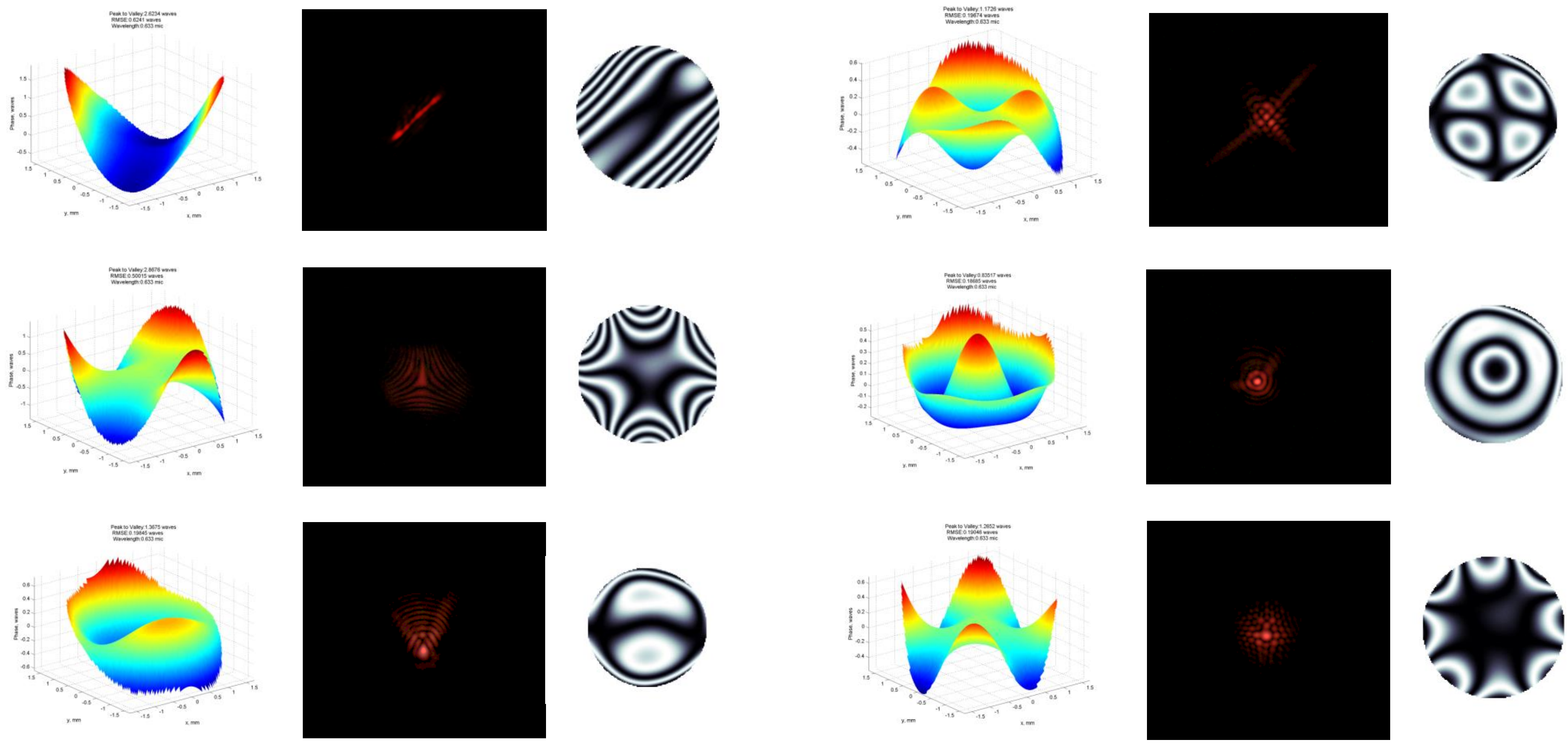
Adaptive lens mounted on a camera objective

Closed loop control with wavefront sensor

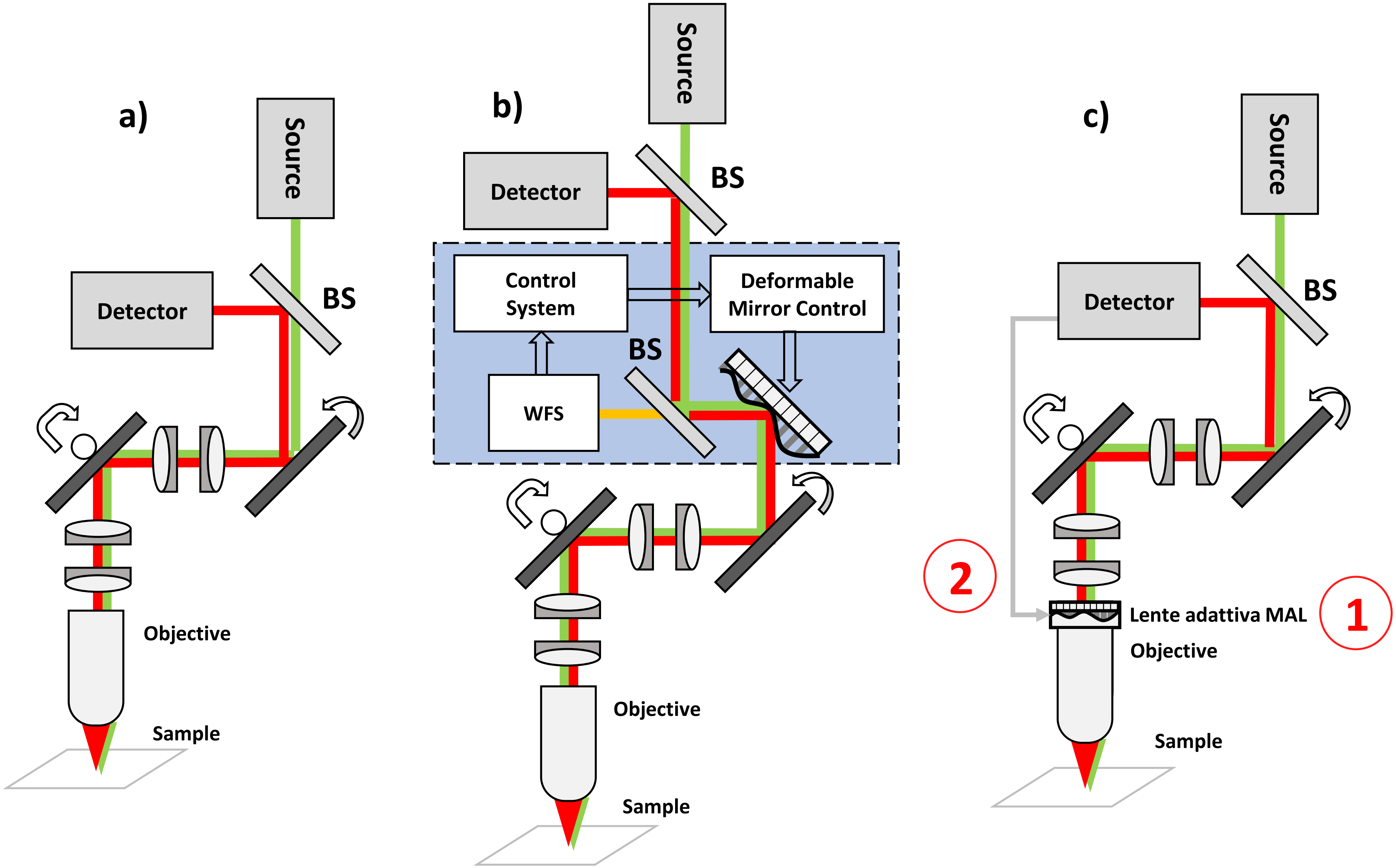


Closed loop and Far Field

It is then possible to generate any aberration up to the 4th Zernike order



Use of the Adaptive Lens in in-vivo imaging



Key elements:

- Wavefront sensorless algorithm ①
- An adaptive lens that can replace a deformable mirror ②

Key properties of the adaptive lens:

- **Open loop control**: *we need to operate the Adaptive Lens without the wavefront sensor!*

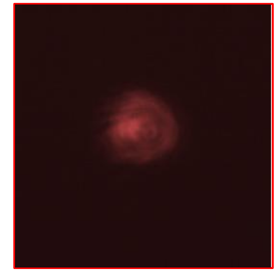
- **In Vivo**: *fast response time!*

Scan sequence

Relaxation time: 5 oscillations +/- about 300ms

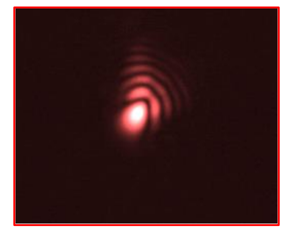
11 points per aberrations

About 0.5 sec for each aberration

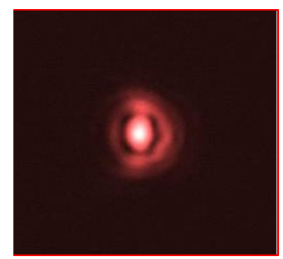


Defocus

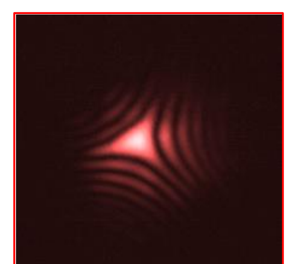
«Astigmatism»



Coma



Spherical Ab.



Trefoil

Adaptive Lens: Compact OCT Opthalmoscope

System realized at the Simon Fraser University (Vancouver)

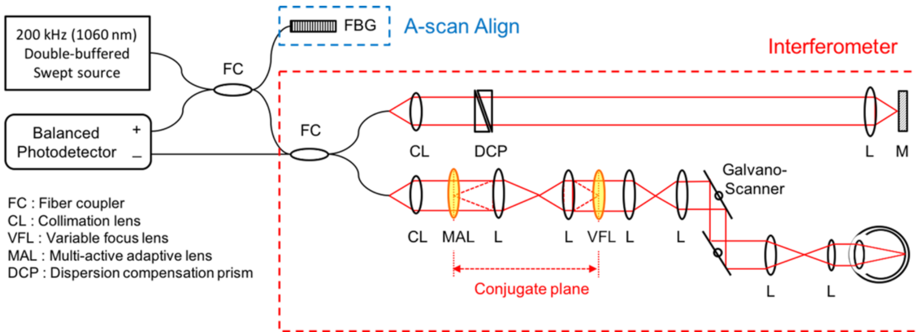
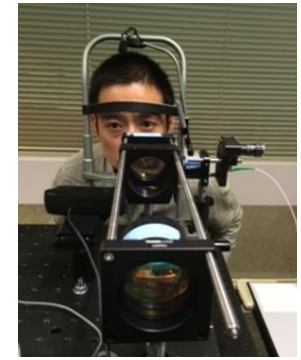
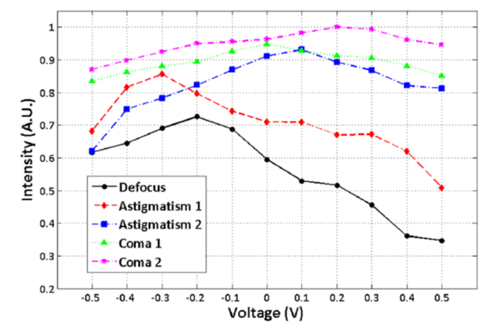
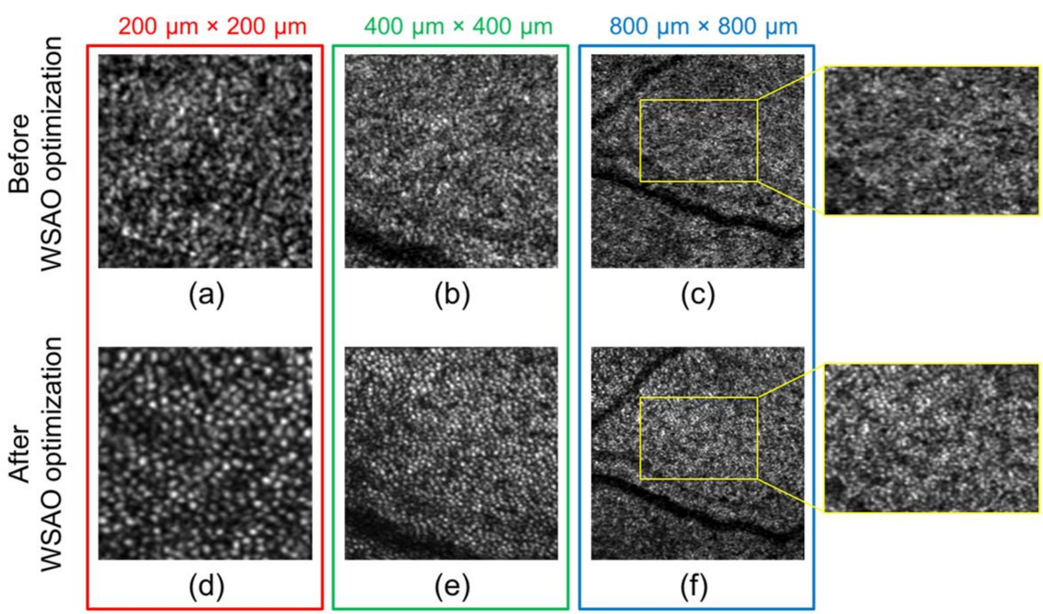
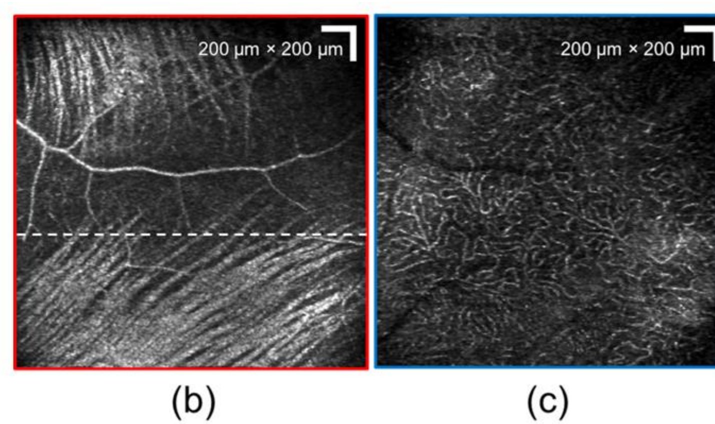


Figure 1 Schematic diagram of MAL-WSAO-SS-OCT system









Electronic driver

Electronics MUST BE: reliable, easy to use, compact

Integrate the electronic inside the DM

Orbital Angular Momentum (OAM) of light

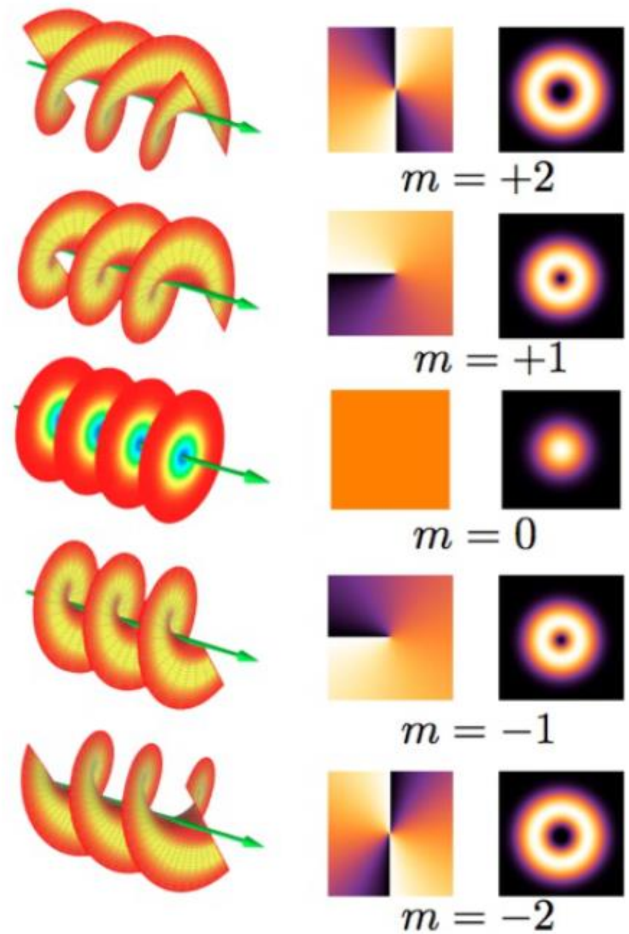
F.Mousavi,P.Villoresi, G.Vallone

Total angular momentum of light beam in the paraxial approximation is split into SPIN (polarization) and Orbital Angular Momentum (OAM)

$$J_z = J_z^{\text{spin}} + J_z^{\text{OAM}}$$

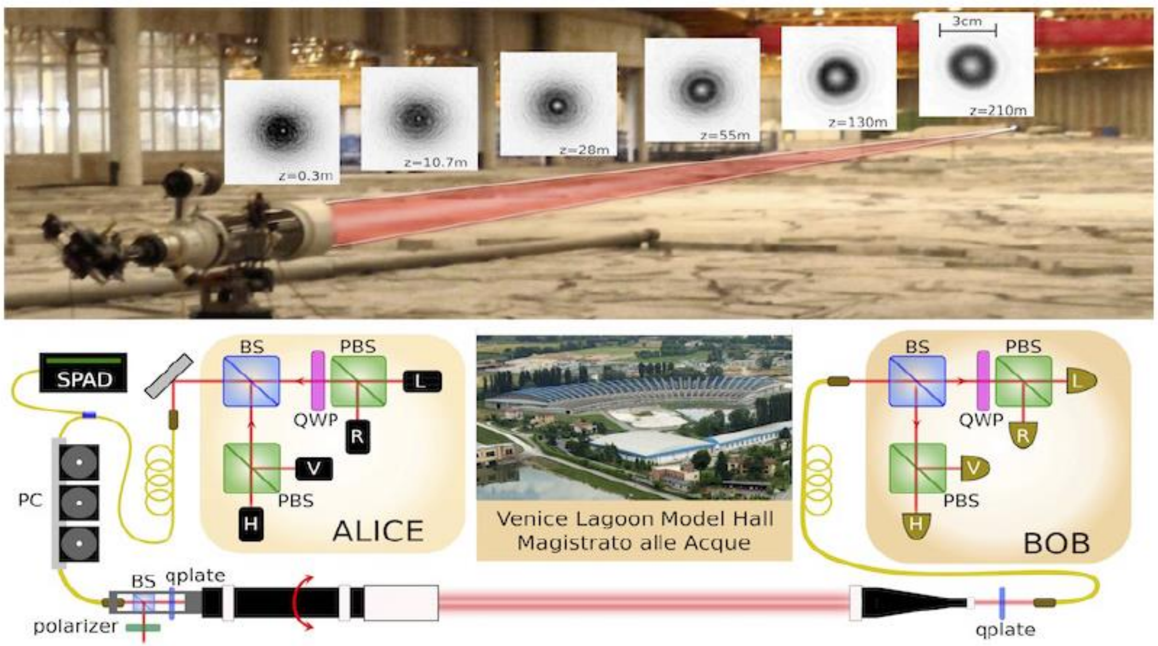
The OAM is related to the phase $eim\Phi$ (with integer m) in the transverse plane.

The wavefront becomes a spiral and the intensity has the typical "Donuts" shape



Adaptive optic for OAM

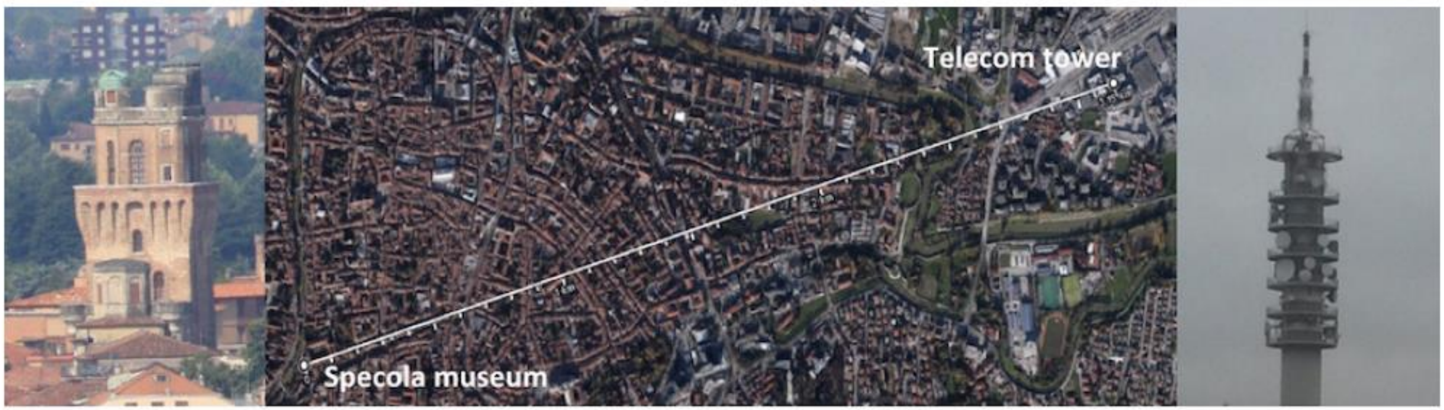
- Deformable mirrors can correct wavefront aberration induced by turbulence
- The information encoded in the different OAM states can be preserved in free-space as demonstrated by the recent quantum communication protocol realized with OAM at a distance of 210 m

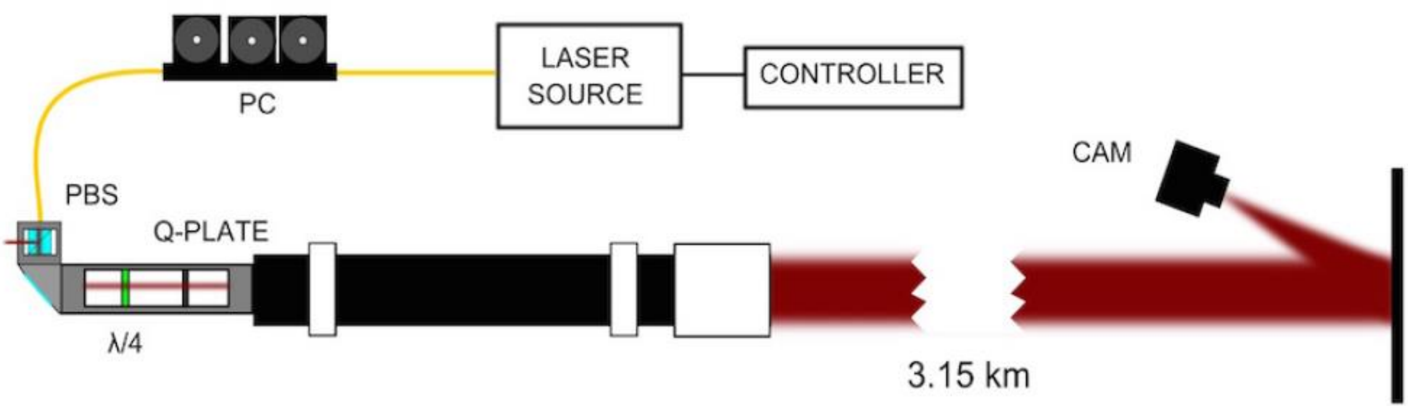


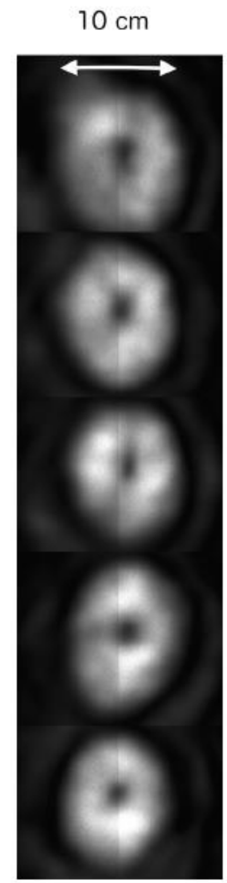
- Km scale distances require the use of adaptive optics

OAM in Free-space

- Since the OAM in related to the beam wavefront, turbulence may alter the OAM content (see right images)







Active projects

- DM for CW fiber lasers 2kW – Salvagnini Spa
  - Cutting and welding
- Adaptive Lenses – Ophtalmic and Vision
  - UC Davis, SFU
- Fast Wavefront sensor
  - University of Verona
- DM for XUV synchrotron radiation (13nm – 100nm)
  - Desy, Hamburg
- Integrate the electronic inside the DM
- Develop larger DMs: 20cm diameter

Thank you!

stefano.bonora@dei.unipd.it