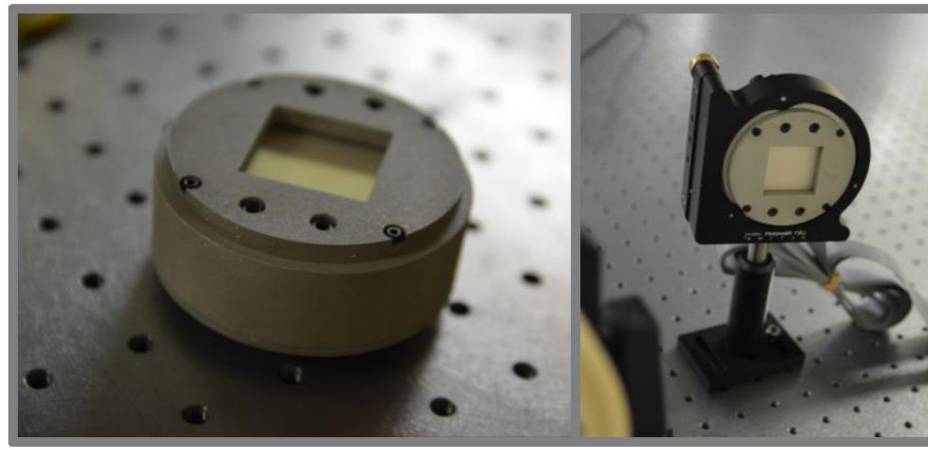
# Wavefront control with a Multi-actuator Adaptive Lens in imaging applications

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CNR IFN
Istituto di Fotonica e Nanotecnologie

# Multi actuator - Adaptive Lens

18 pzt actuators outside the clear aperture
Optical power: 1D

Clear aperture: 10mm – 25mm
Transmission:  visible NIR >94%

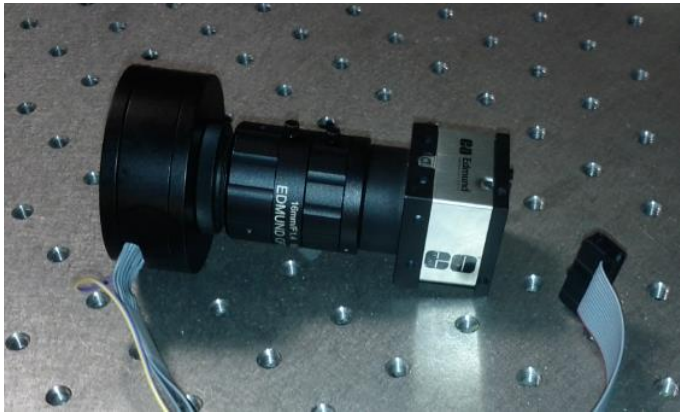
Initial aberration: 0.1waves rms
Corrected with about 10% rms voltage range

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

**Generates aberrations up to the 4th order**

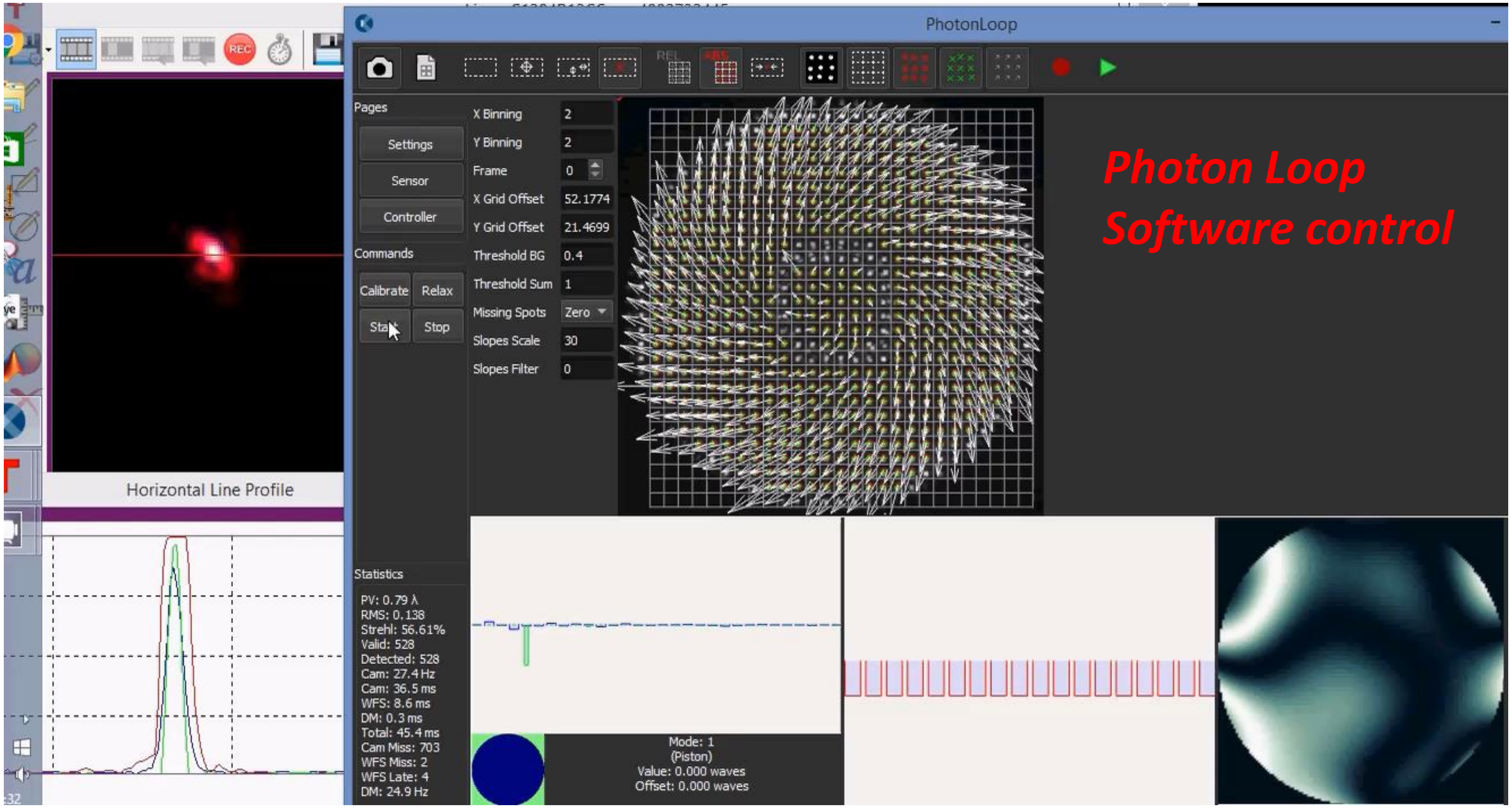
**Response time: about 10ms**

**Stefano Bonora, et al, Opt. Express 23, 21931-21941 (2015)**

**Adaptive lens mounted on a camera objective**

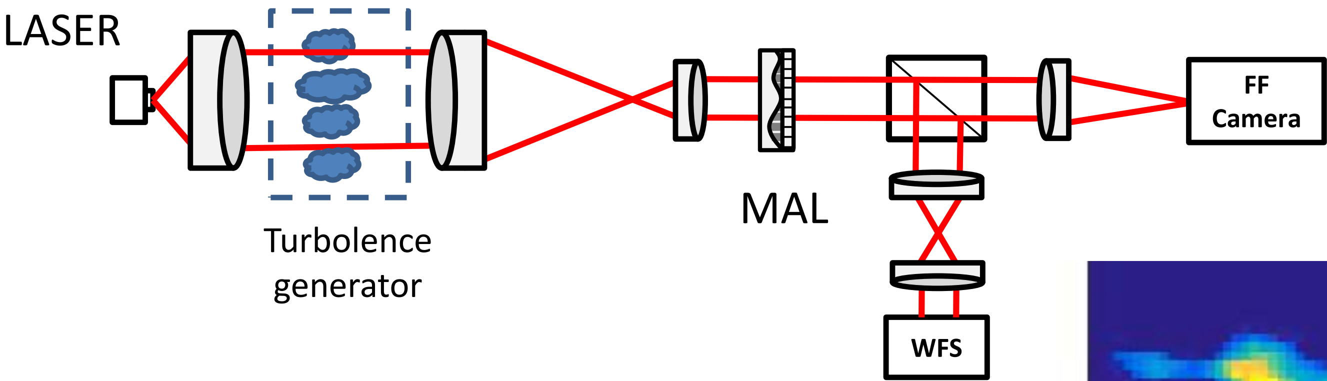
# Closed loop control with Shack Hartmann wavefront sensor

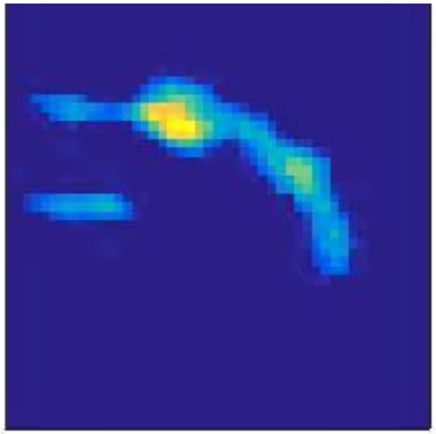



Frame rate: 500fps with 100 centroids
Lenslet: Pitch 150um/300um
Focal length: 5mm/15mm

***It can work with a WFs as it was a deformable mirror!***

# Correction of dynamics aberrations with wavefront sensor

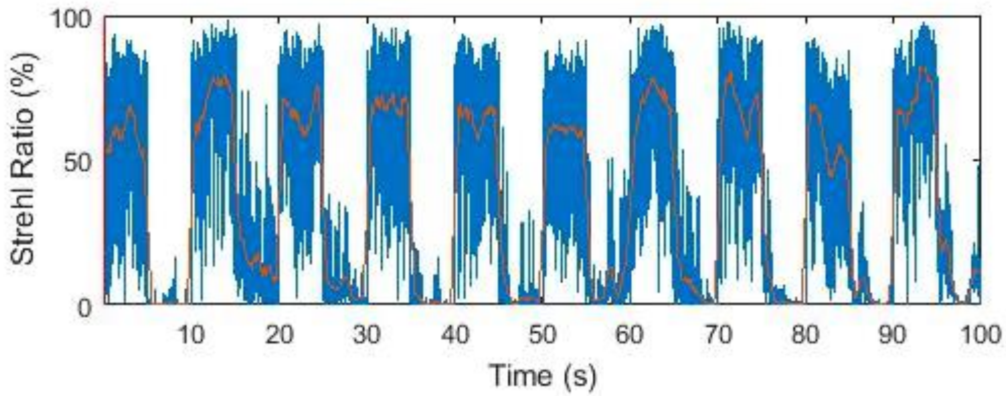


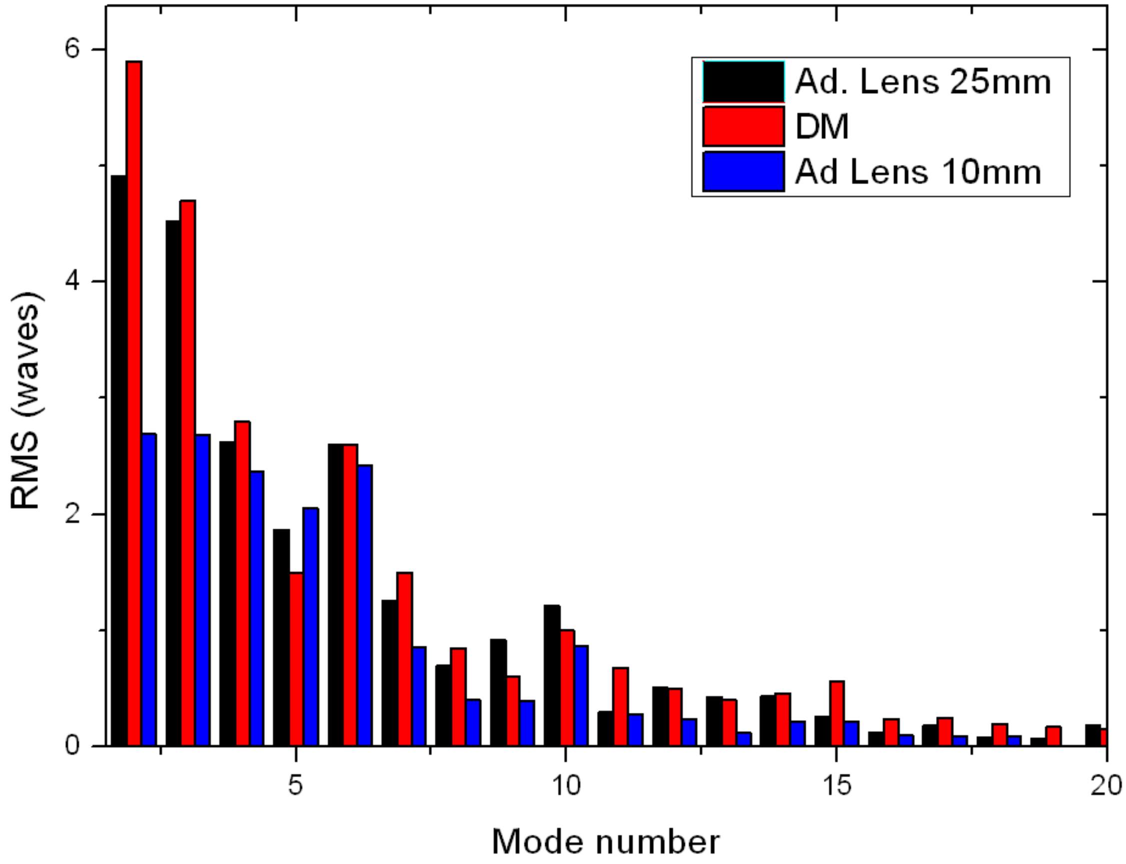
**TEST SETUP**

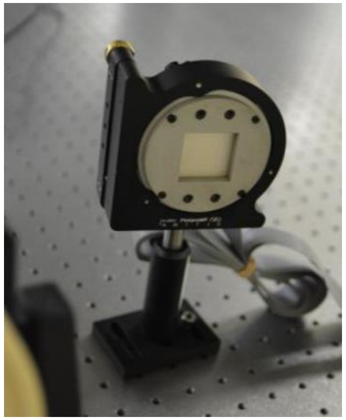
Aberration generated by a heat source with some air flow

Photon Loop
(Shack Hartman WFs)
Operating at 400Hz in closed loop



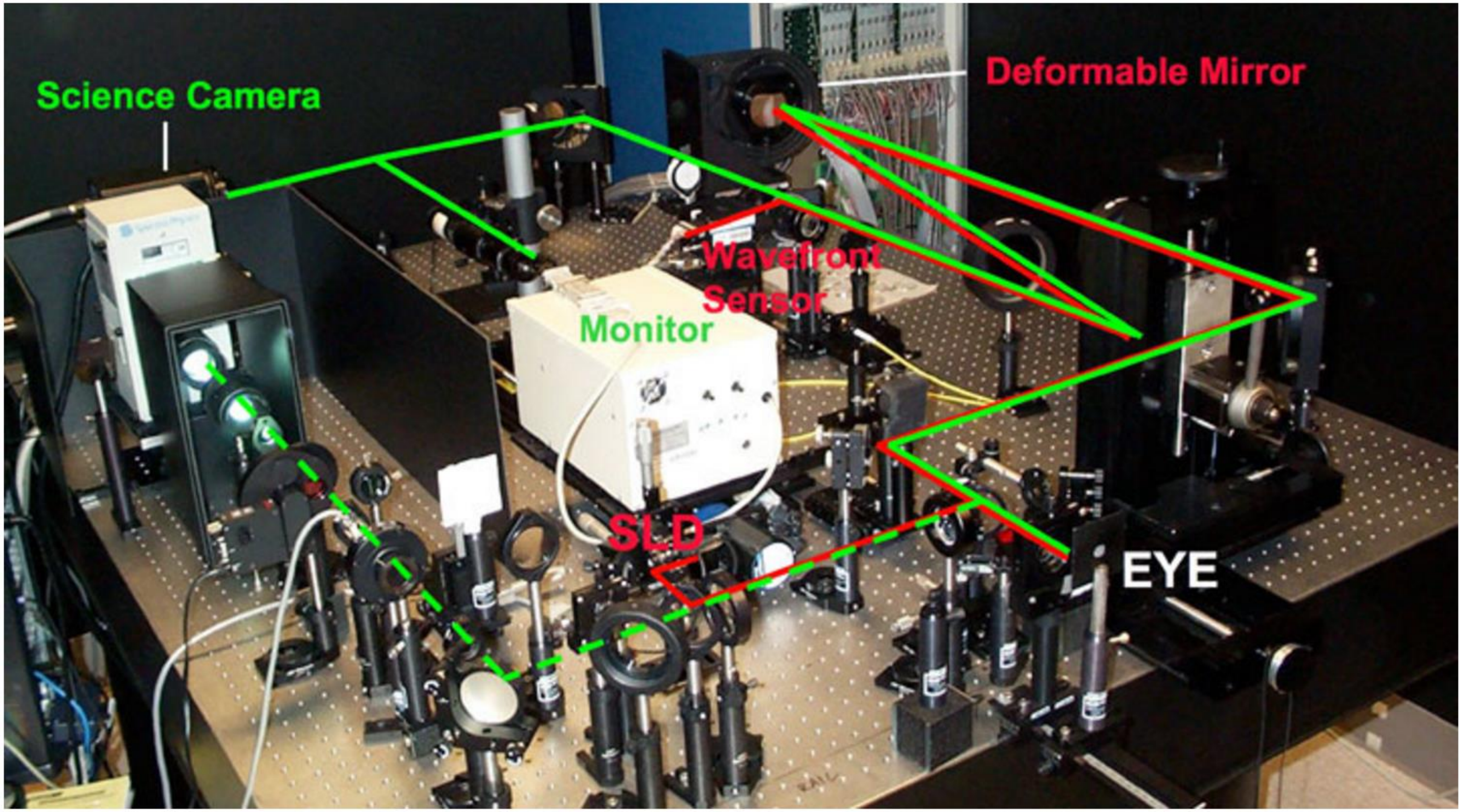
# Comparison DM – Adaptive Lens



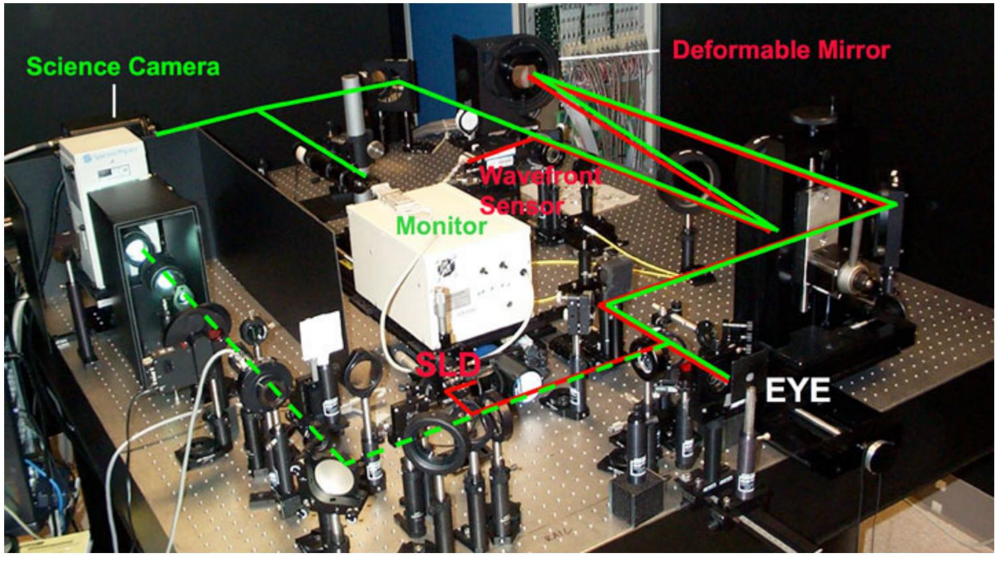
**Bimorph Deformable Mirror**: 22.5mm aperture, 32 actuators, designed for high power laser

# *Advantages of Adaptive lenses*

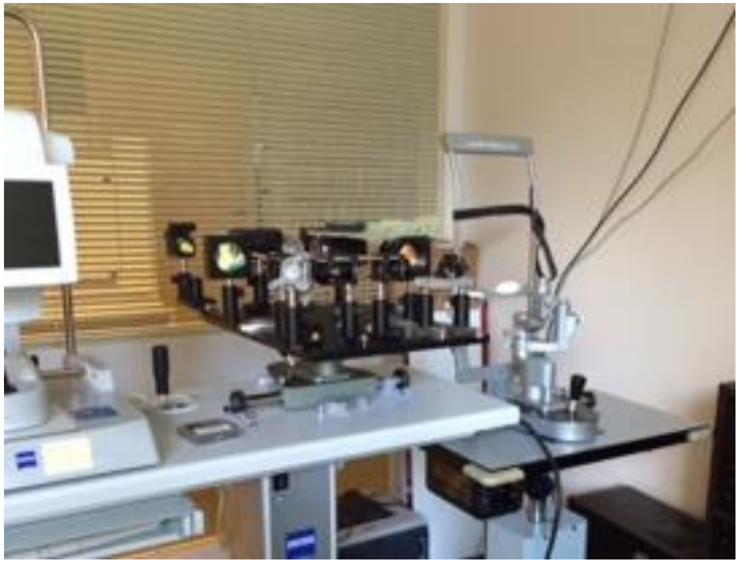



Courtesy of J.Werner

# *Advantages of Adaptive lenses*

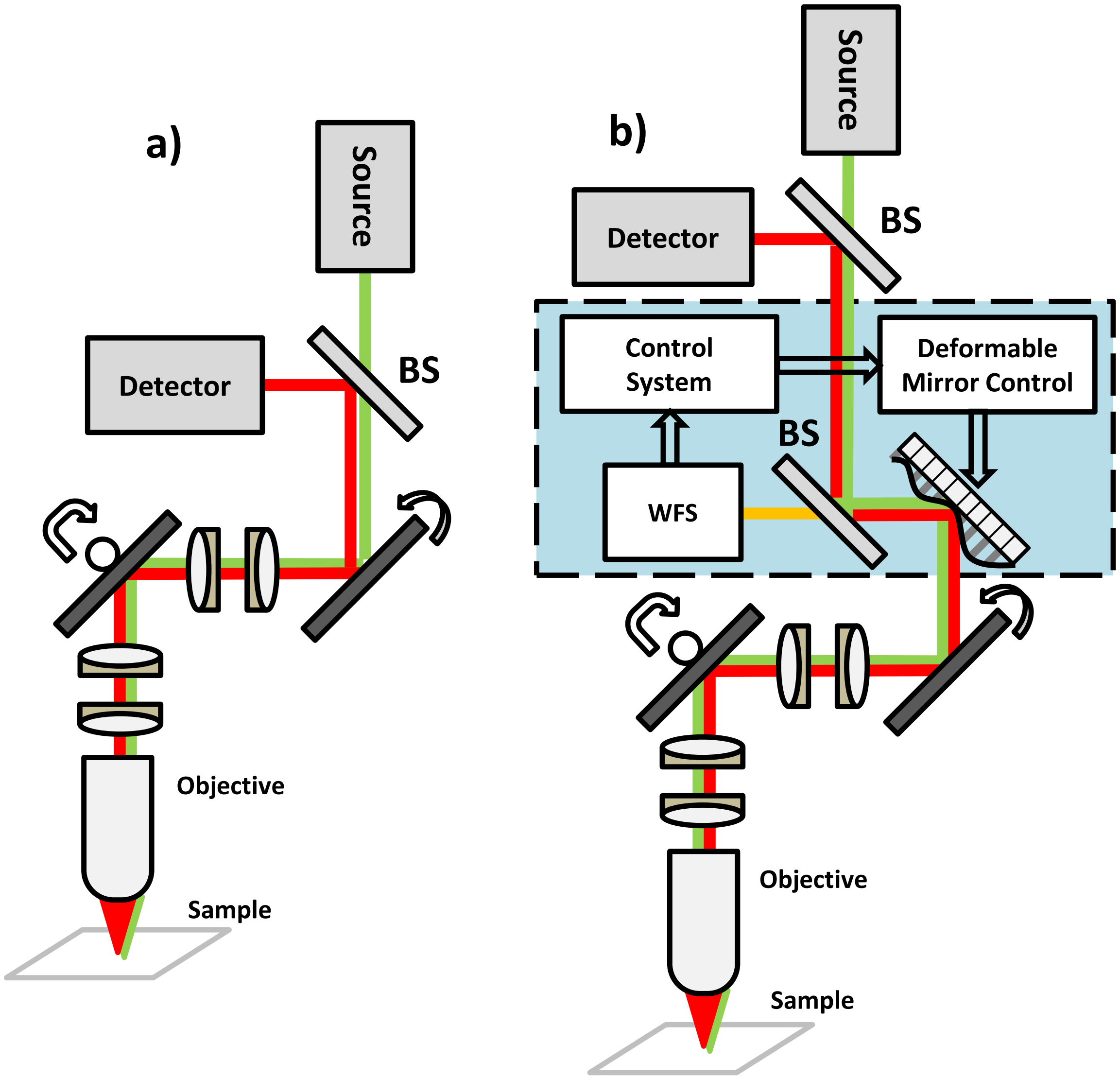



**Deformable mirror and Wavefront sensor based Ophthalmic system**

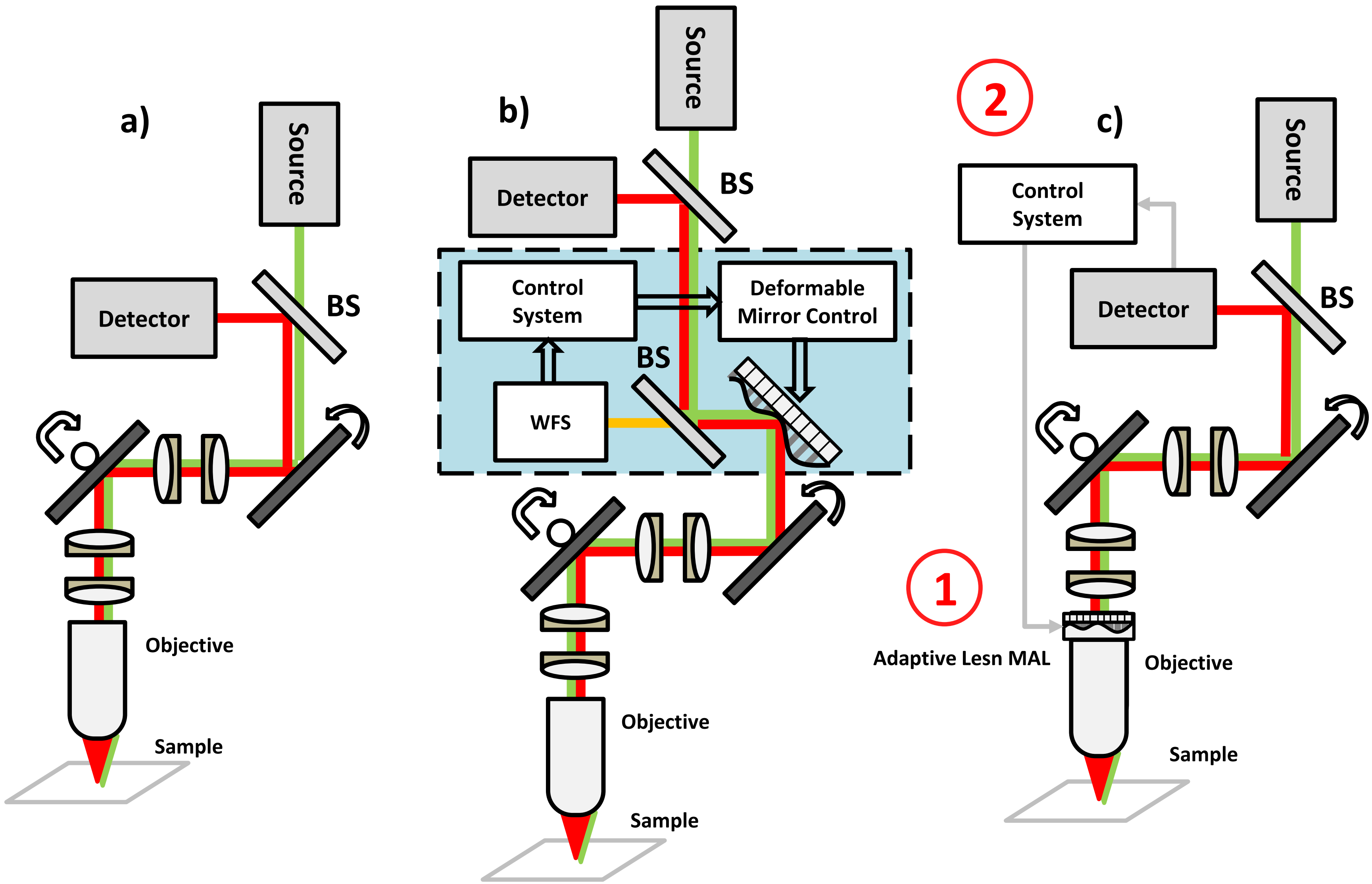


**Adaptive Lens based Ophthalmic system**
M.Sarunics, BORG Lab
SFU Vancouver

# Use of the Adaptive Lens in in-vivo imaging



# Use of the Adaptive Lens in in-vivo imaging

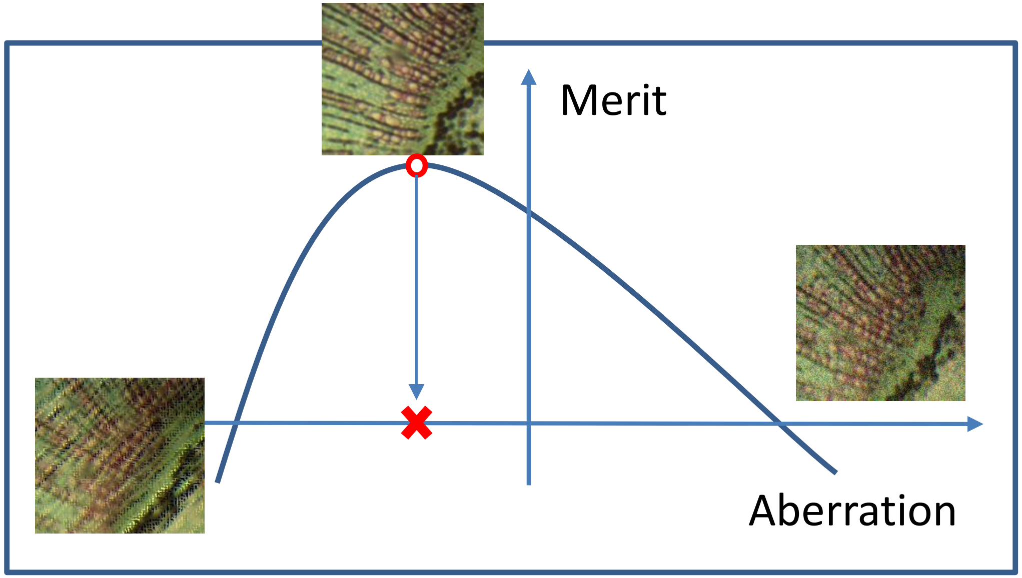


# Sensorless optimization: COORDINATE SEARCH

Definition of a merit function: $S = \int I^2(x,y)dxdy$

Muller-Buffington **image sharpening** function:

S is maximized when the wavefront distortions are zero*.



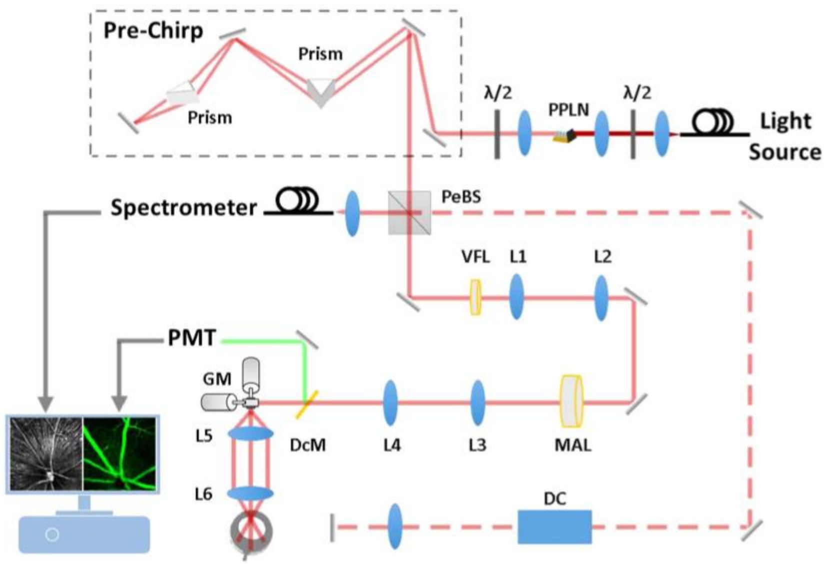

*R. A. Muller and A. Buffington, "*Real-time correction of atmospherically degraded telescope images through image sharpening*", J. Opt. Soc. Am., 67, 1200-1210 (1974).

***Debarre D., Booth M.J. and Wilson T., Image based adaptive optics through optimisation of low spatial frequencies, Optics Express, Vol. 15, No. 13, pp. 8176-8190, (2007).

# 2-photon microscopy in-vivo retina imaging with sensorless Adaptive Optics

Michelle Cua, Yifan Jian, Daniel J. Wahl, Yuan Zhao, Sujin Lee,
Stefano Bonora, Robert J.Zawadzki, Marinko V. Sarunic

*BORG Lab, SFU Vancouver*




- **Minimizing the exposure energy is paramount for non-invasive imaging**, for the delicate tissues of the retina.
- Combined 2P and OCT on the same system with the same laser source.

***The OCT images constitute a coherence-gated, depth-resolved signal for image-guided aberration correction***

# 2P Retinal Imaging in mouse eye

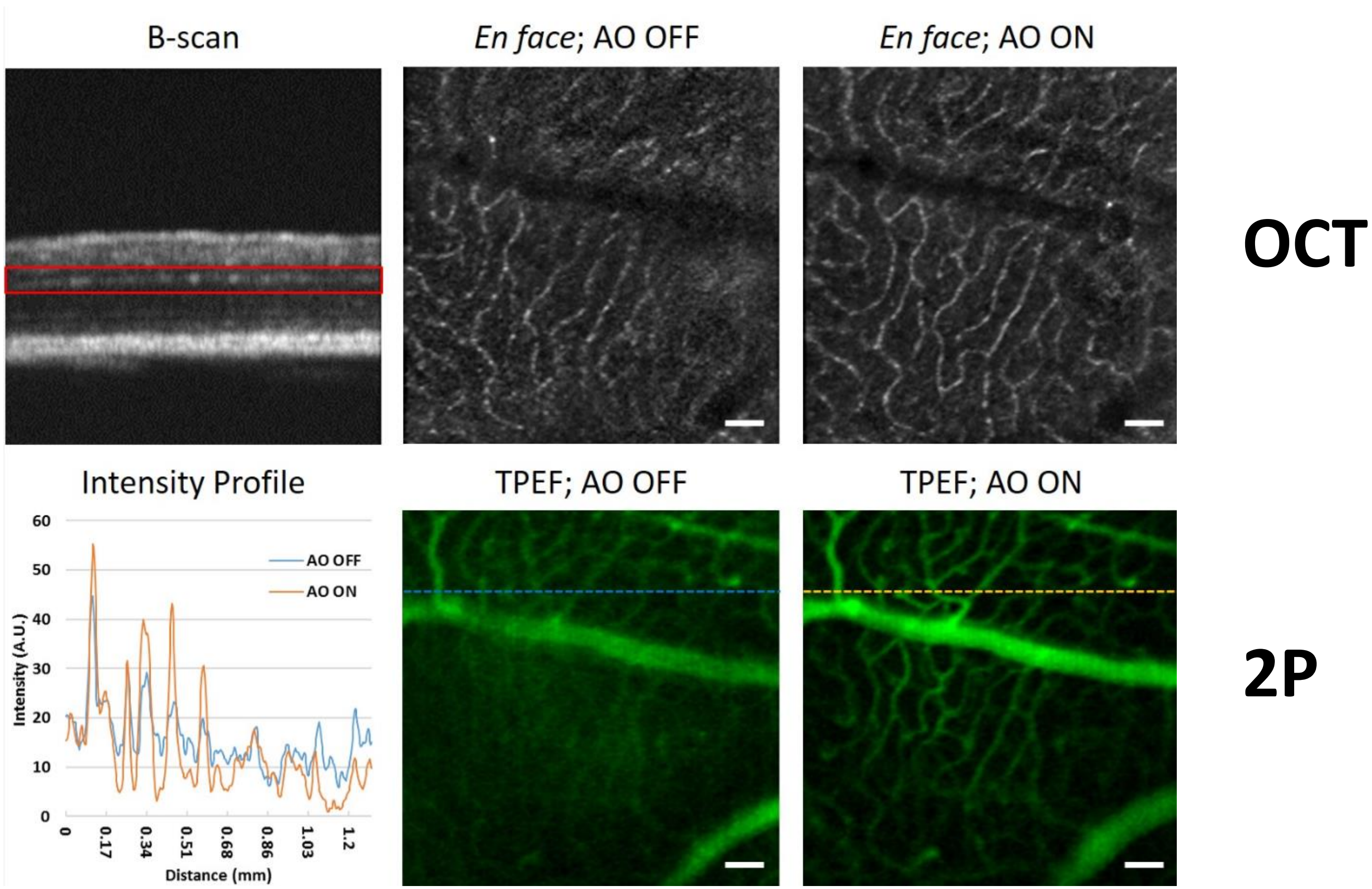



**Figure 3 OCT and TPEF images of the mouse retina before and after aberration correction. White arrowheads highlight improvement in visibility of vasculature with optimization. Scale bars denote 100 μm.**

Myeong Jin Ju, *Clinical-grade Adaptive Optics Swept Source Optical Coherence Tomograph*, **Scientific Reports** 6, Article number: 32223

# Results: Z-scan

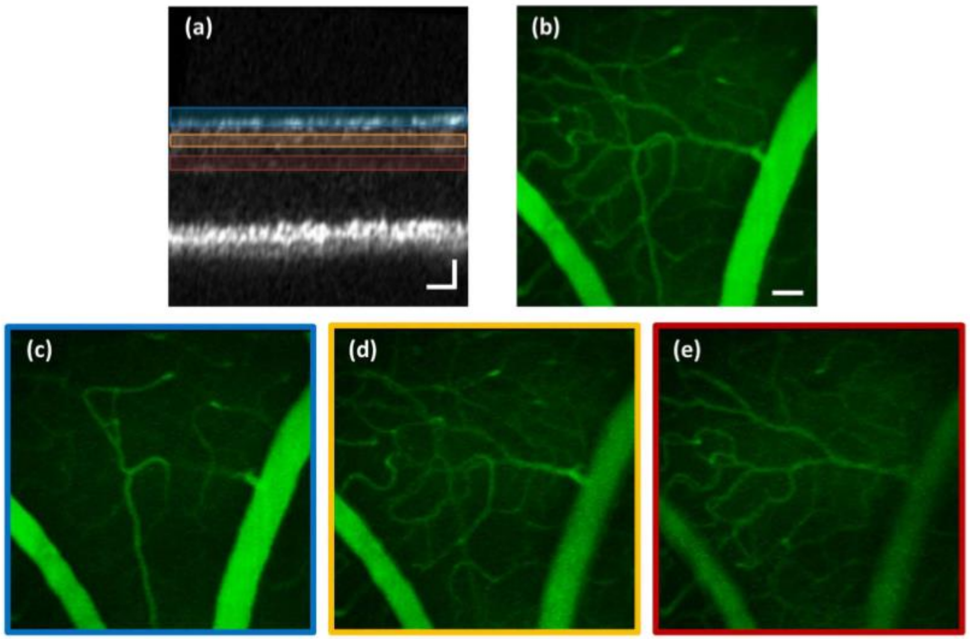
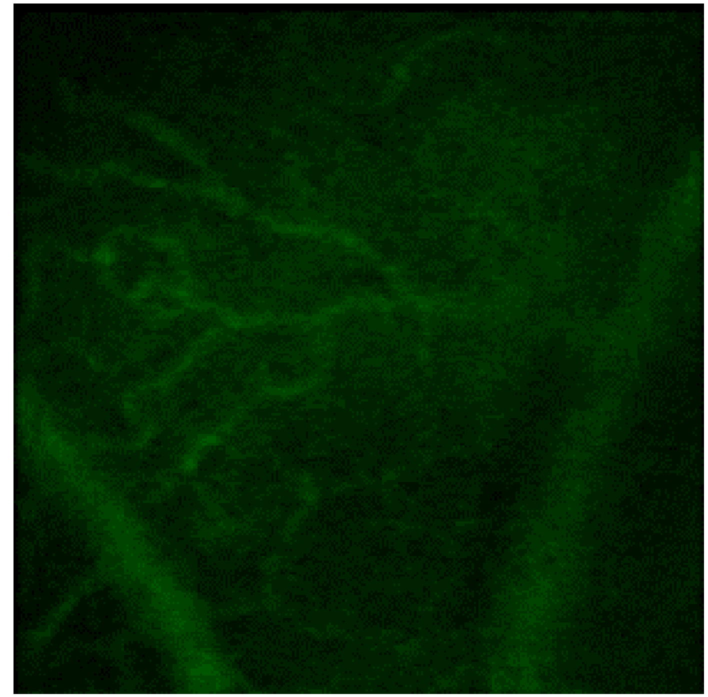



**Figure 6.** (**a**) OCT B-scan of mouse retina indicating the axial focus position by the blue, yellow and red boxes. (**b**) Maximum intensity projection of TPEF images of mouse retinal vasculatures after OCT-guided SAO optimization from the video frames in Video 1. (**c–e**) Mouse vasculature at different retinal layers after SAO aberration correction. The TPEF images in this figure are the average of 50 rigidly registered TPEF frames. Scale bar: 90 µm. Vertical Scale bar for B-scan: 40 µm.



Myeong Jin Ju, *Clinical-grade Adaptive Optics Swept Source Optical Coherence Tomograph*, **Scientific Reports** 6, Article number: 32223

# 2P in-vivo mouse brain imaging

## In collaboration with: P.Pozzi, H.Verstraete and M.Verhaegen

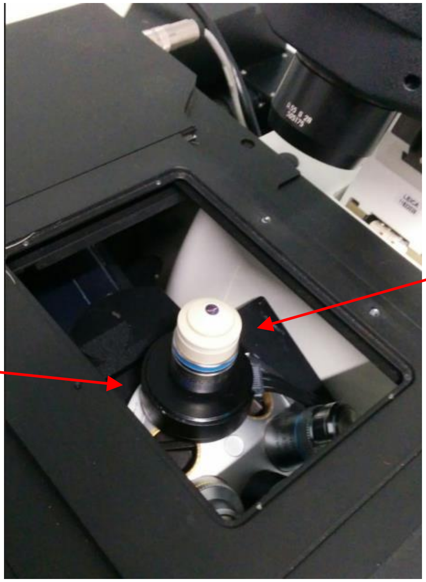
## TU Delt and Rotterdam Erasmus Medical Center

**GOAL**: demonstate that the versatile use of the adaptive lens and wavefront sensorless approach optimization

**IDEA**:

1_application of the adaptive lens on the back aperture of the objective
2_optimize the acquired image by the microscope by a “screen capture”

**Test**:
1_ confocal microscope for training
2_ 2P microscope in vivo brain imaging



# 2P in-vivo mouse brain imaging

## In collaboration with: P.Pozzi, H.Verstraete and M.Verhaegen
## TU Delt and Rotterdam Erasmus Medical Center

**Location**: inferior colliculus of GCamp in sugically opened transcranial window protected by a coverslip glass.

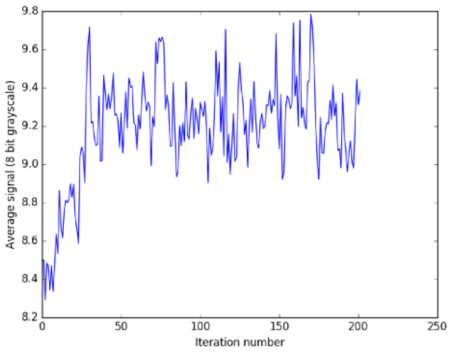
**Objective**: water dipping 40X, 1.0 N.A. from Zeiss, with a back aperture pupil of approximately 9 mm.

**Adaptive lens**: 18-actuators adaptive lens, with an aperture of approximately 10 mm was installed between the objective and the microscope through two adapters.

**Measurements**: performed at an excitation wavelength of 920 nm. The field of view was approximately 120 $\mu m$ x120 $\mu m$.

**Merit function**: total intensity of the detected fluorescence.

**Algorithm**: Extremum seeker: DONE optimization

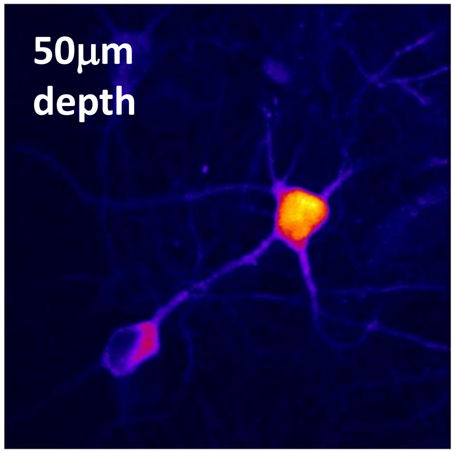


# 2P in-vivo mouse brain imaging

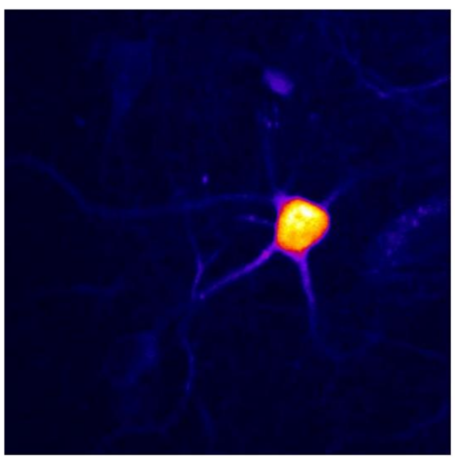
## In collaboration with: P.Pozzi, H.Verstraete and M.Verhaegen

## TU Delt and Rotterdam Erasmus Medical Center

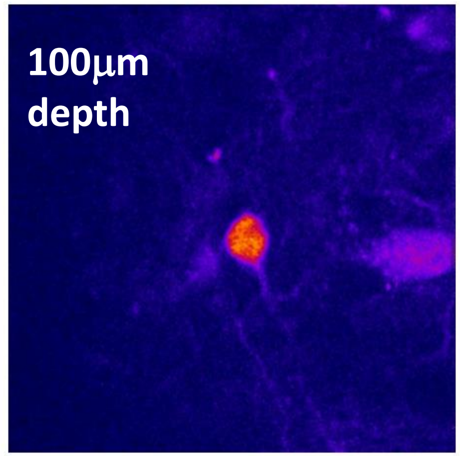
Flat lens:



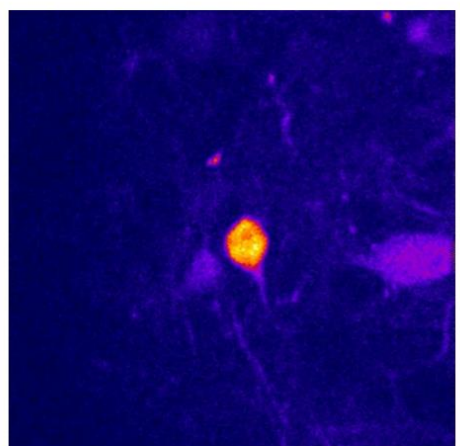

After optimization:



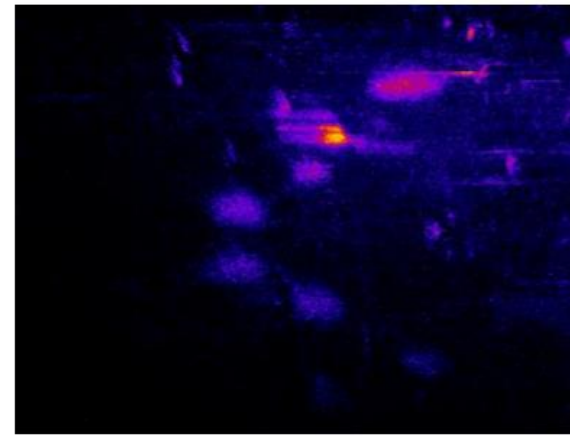
Flat lens:



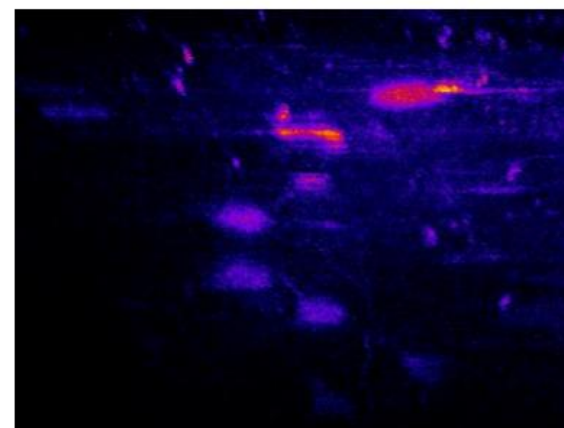

After optimization:



Flat lens:

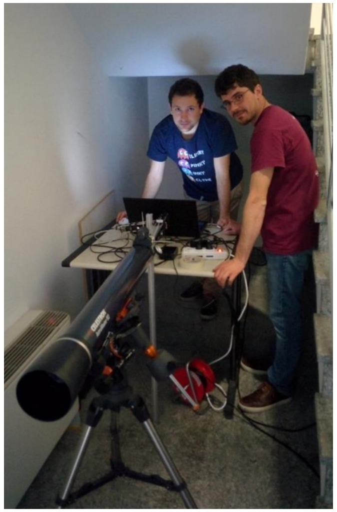


After optimization:

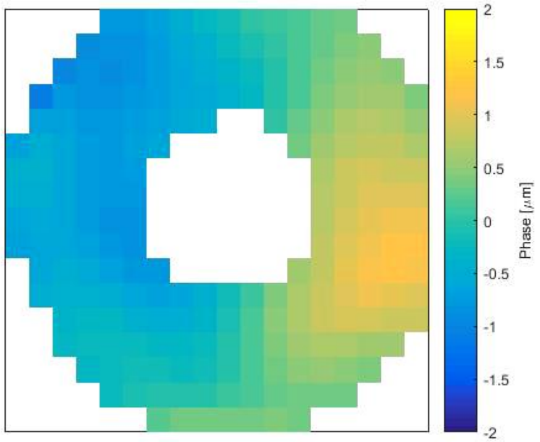


# Long distance wavefront propagation (3km)
## Collaboration with MBDA Italy, spa

GOAL: realize a wavefront simulator for **horizontal** laser propagation



Preliminary
Lab Test




Frame rate 250Hz
Test su 3km
Telescope: 30cm

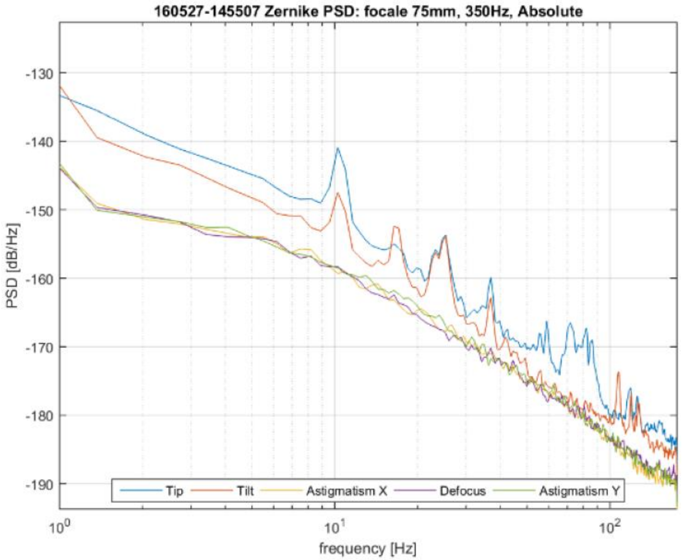
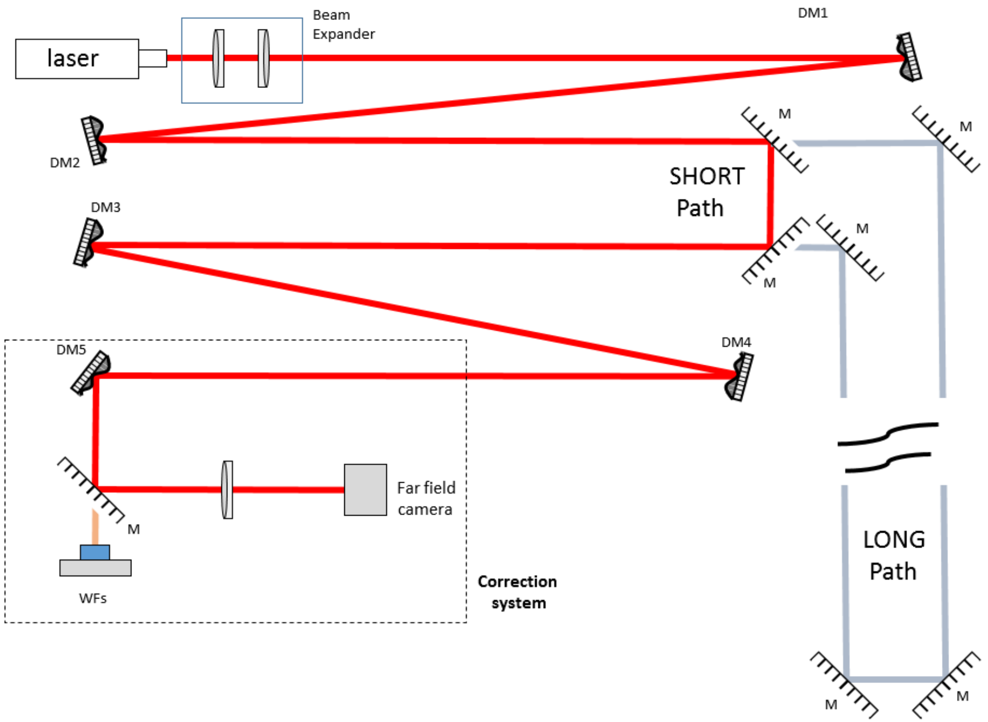



*Figura 6: Focale 75mm, 350Hz, pomeriggio*

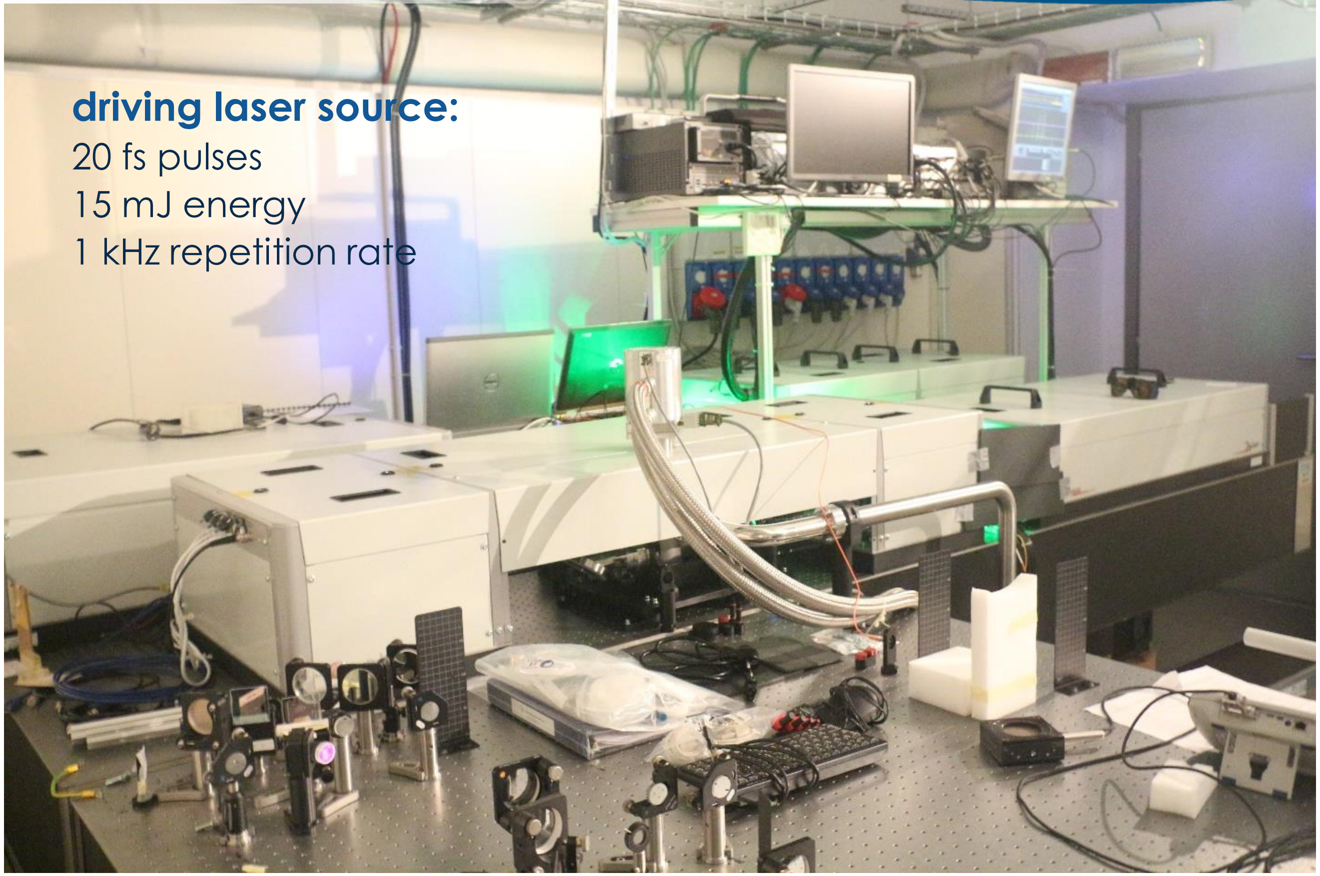
# Table top turbulence simulator (with 3 deformable mirrors ☺) MBDA - CNR




**The system will be used to study the laser propagation over long distances and correction techniques**

# Closed loop systems for CEP stabilization

## the laser source

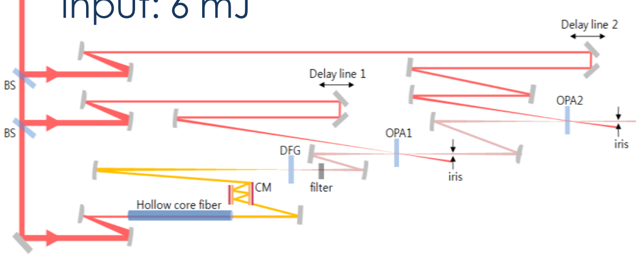


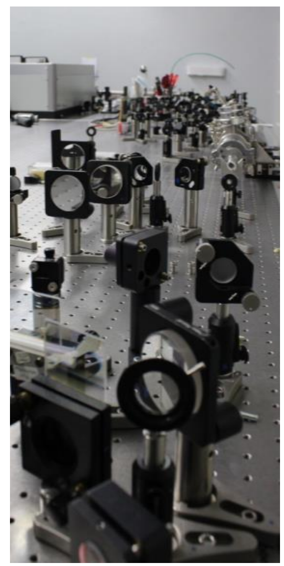
**driving laser source:**
20 fs pulses
15 mJ energy
1 kHz repetition rate

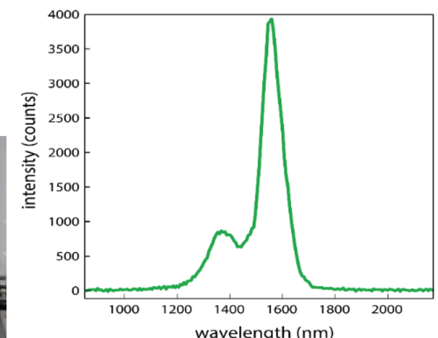
# developing 1kHz intense tunable OPA

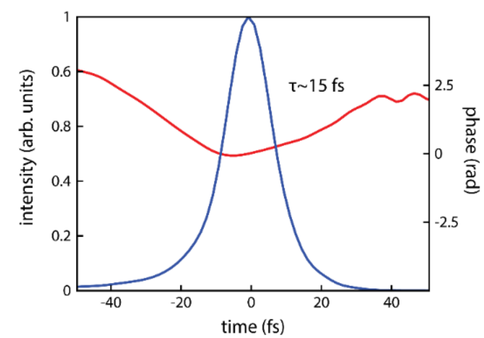
scheme and characterization of the source

input: 6 mJ






1 mJ, 15 fs, 1 kHz

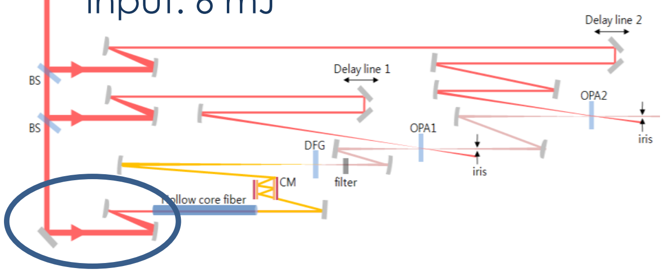
1300 - 2000 nm

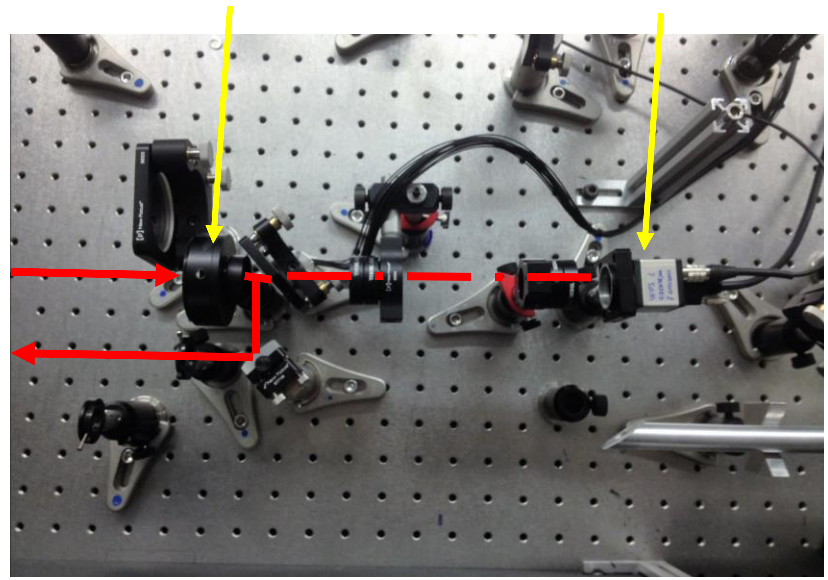
www.mi.ifn.cnr.it/research/ultrafast/molecularimaging

# developing 1kHz intense tunable OPA

scheme and characterization of the source

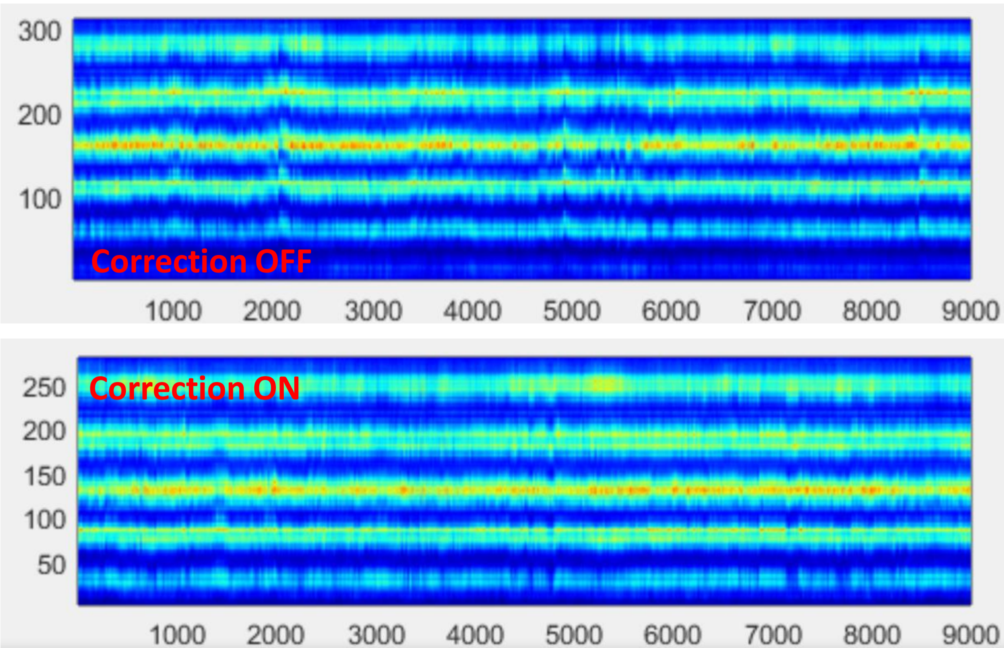
input: 6 mJ



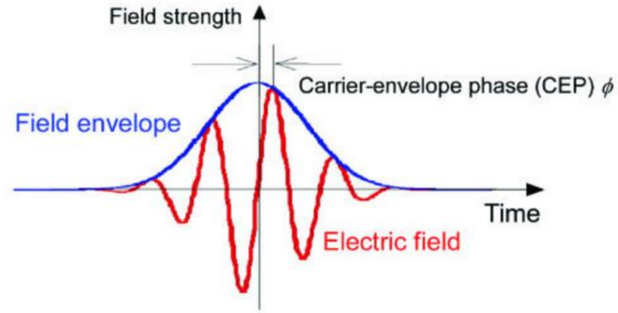




www.mi.ifn.cnr.it/research/ultrafast/molecularimaging

# Carrier envelope phase stabilization




Std non corrected 0.26rad
Corrected 0.079rad



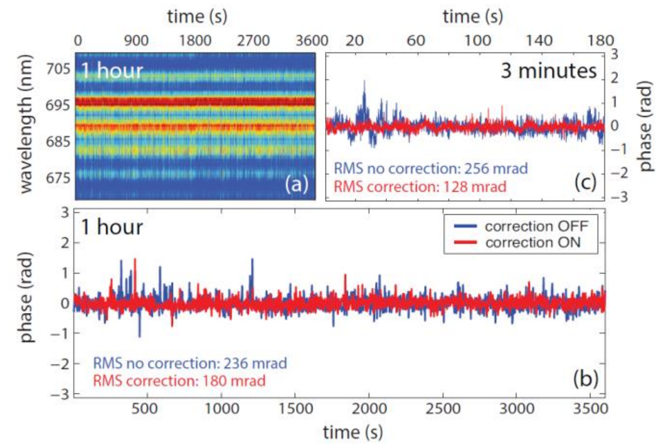
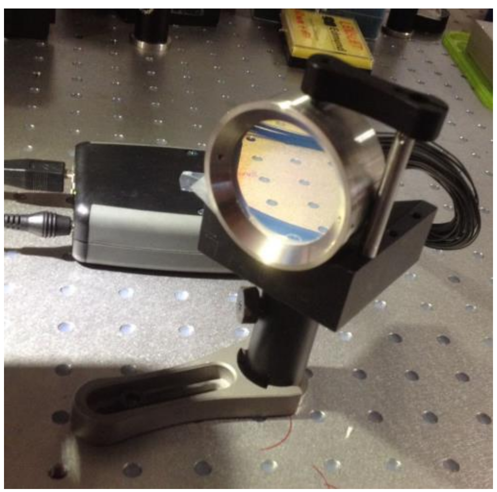




**Fig. 6.** Characterization of the CEP fluctuations at the IR-OPA output: (a) scan of the spectral interference pattern acquired by the f-2f interferometer over 1 hour when the AO systems were operating. (b- c) Retrieved CEP evolution without (blue curve) and with correction operated by the AO1 and AO2 systems (red curve) over a period of 3 minutes (b) and over 1 hour (c).

# Laser cutting of 25mm steel sheets with 4kW CW laser, Salvagnini Spa

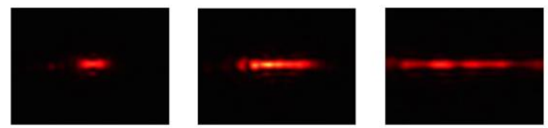
**GOAL:**
Increase the cut **speed**

And cut **quality**



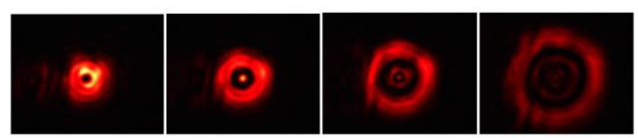
salvagnini

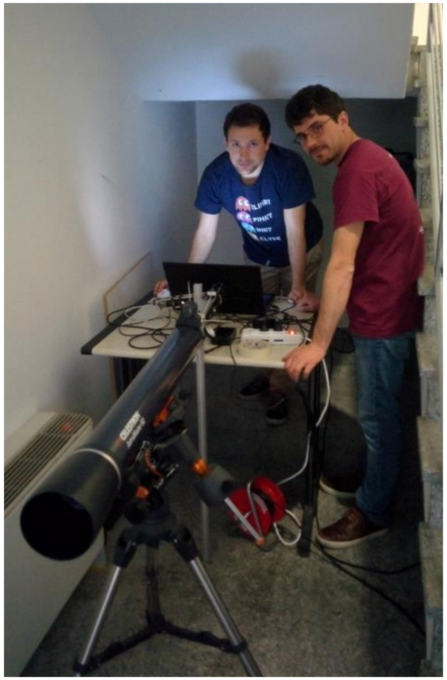
PSF allungata direzione x diversi rapporti L/d

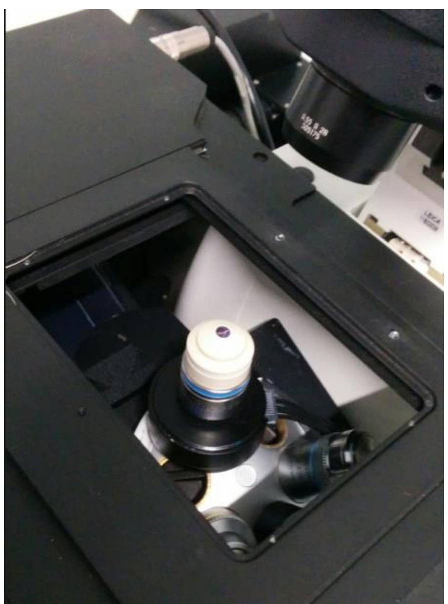


PSF allungata direzioni generiche

PSF ad anello con diversi rapporti d/D








## *Special thanks to:*

***BORG* group in SFU Vancouver**, **Dr Marinko Sarunic**

**Yifan Jian, Sujeen Lee, Michelle Cua, Daniel Wahl, Myeong Jin Ju, Morgan Heisler**

**Robert Zawadzki, UC Davis**

**Paolo Pozzi, Hans Verstraete, M.Verhaegen, TU Delft**

**and**

***Martino Quintavalla and Jacopo Mocci***


# Thanks!


*Email: stefano.bonora@pd.ifn.cnr.it*