Mirao 52D electromagnetic deformable mirror:

experimental assessment and first ophthalmic applications

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1 Clinical applications

Adaptive optics … into clinics ?

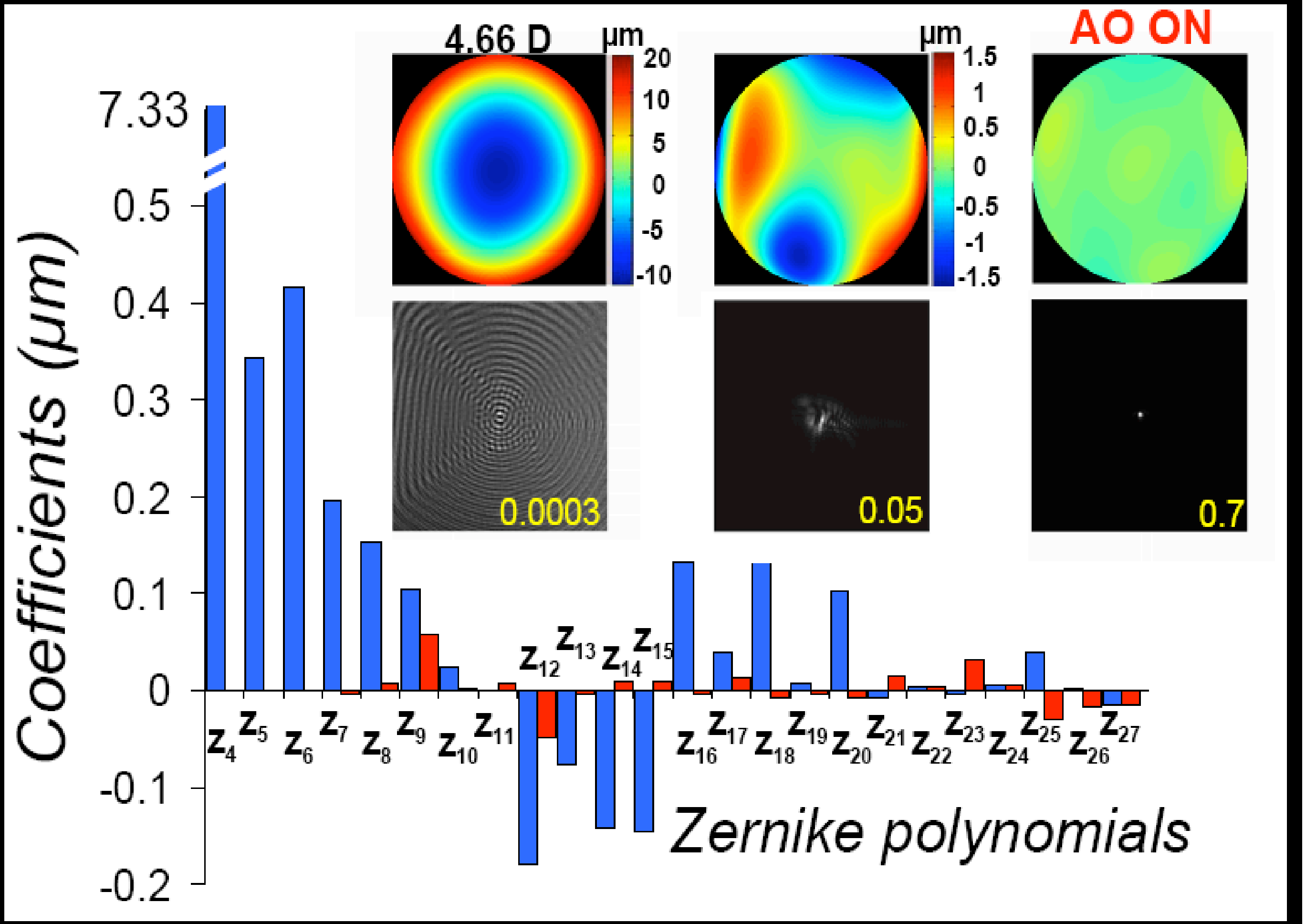
- many optical setups are now able to image the retina or manipulate aberrations using AO

- dynamic range of correction devices is sometimes a limitation to these AO applications on an extensive range of patients, limiting the potential clinical studies

➡ Development of a deformable mirror with characteristics consistent with ophthalmic clinical requirements

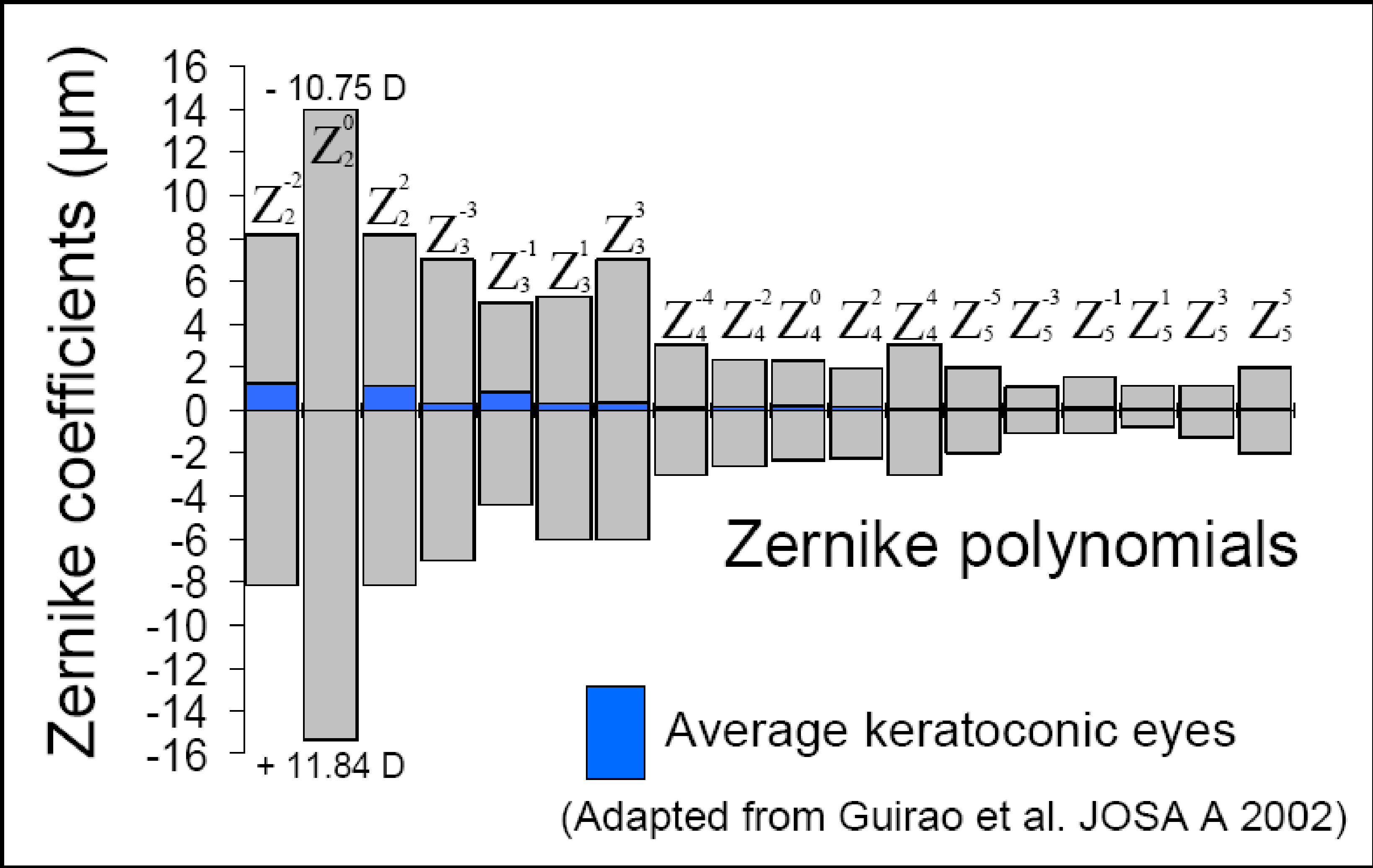
Aberration correction

- Closed-loop correction 8 Hz
- 6 iterations
- Myopic eye, irregular cornea
- Pupil diameter 6.6 mm



Courtesy E.J. Fernandez

Aberration correction



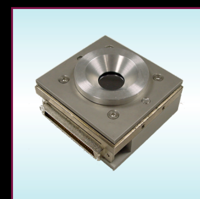
Courtesy E.J. Fernandez

Adaptive Optics Visual Simulator

Irx3 aberrometer

+

Mirao52d deformable mirror



+

OLED microdisplay

=

Crx1 AO
Visual Simulator

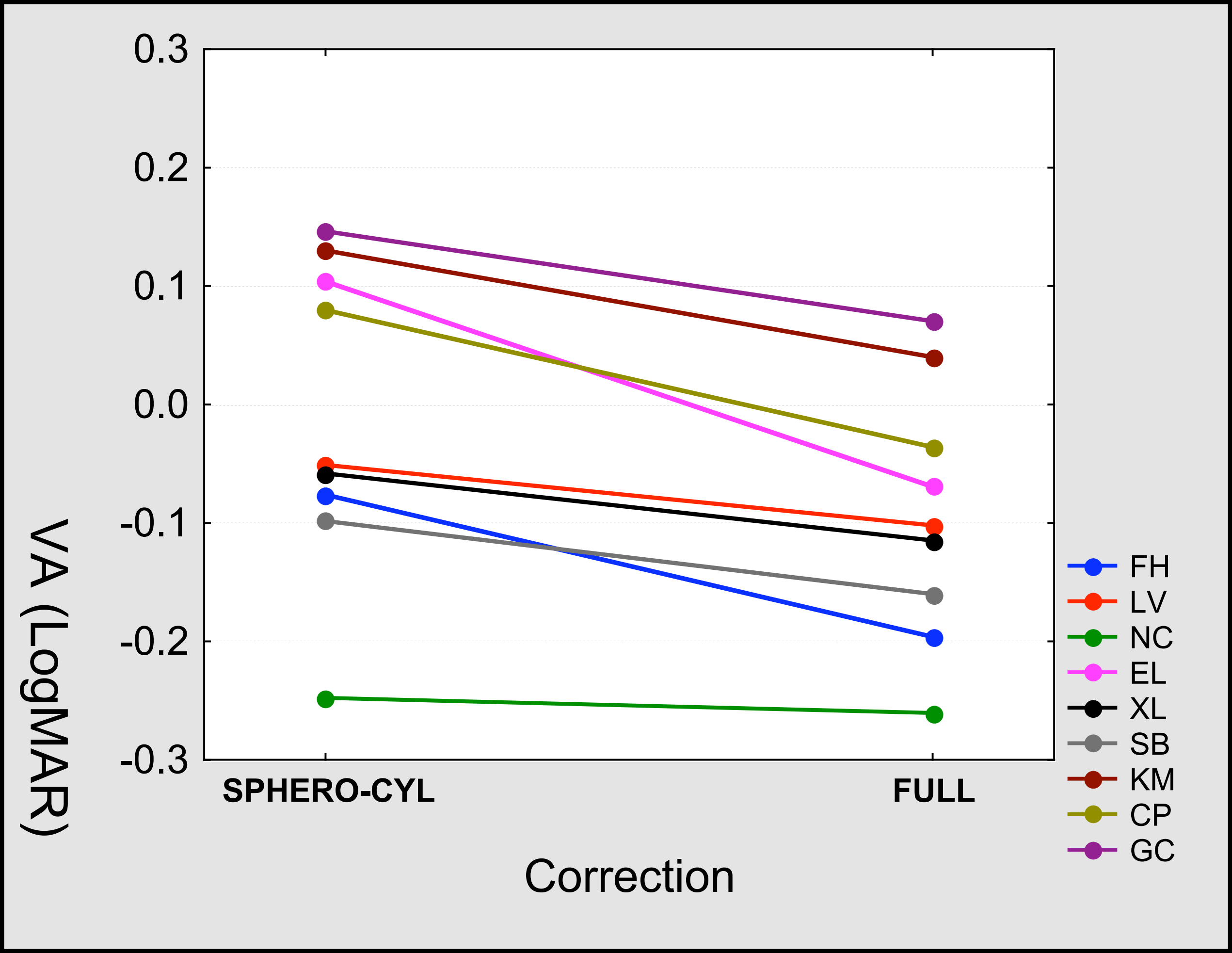
AO visual simulator

= AO phoropter

= an ophthalmic instrument able to:

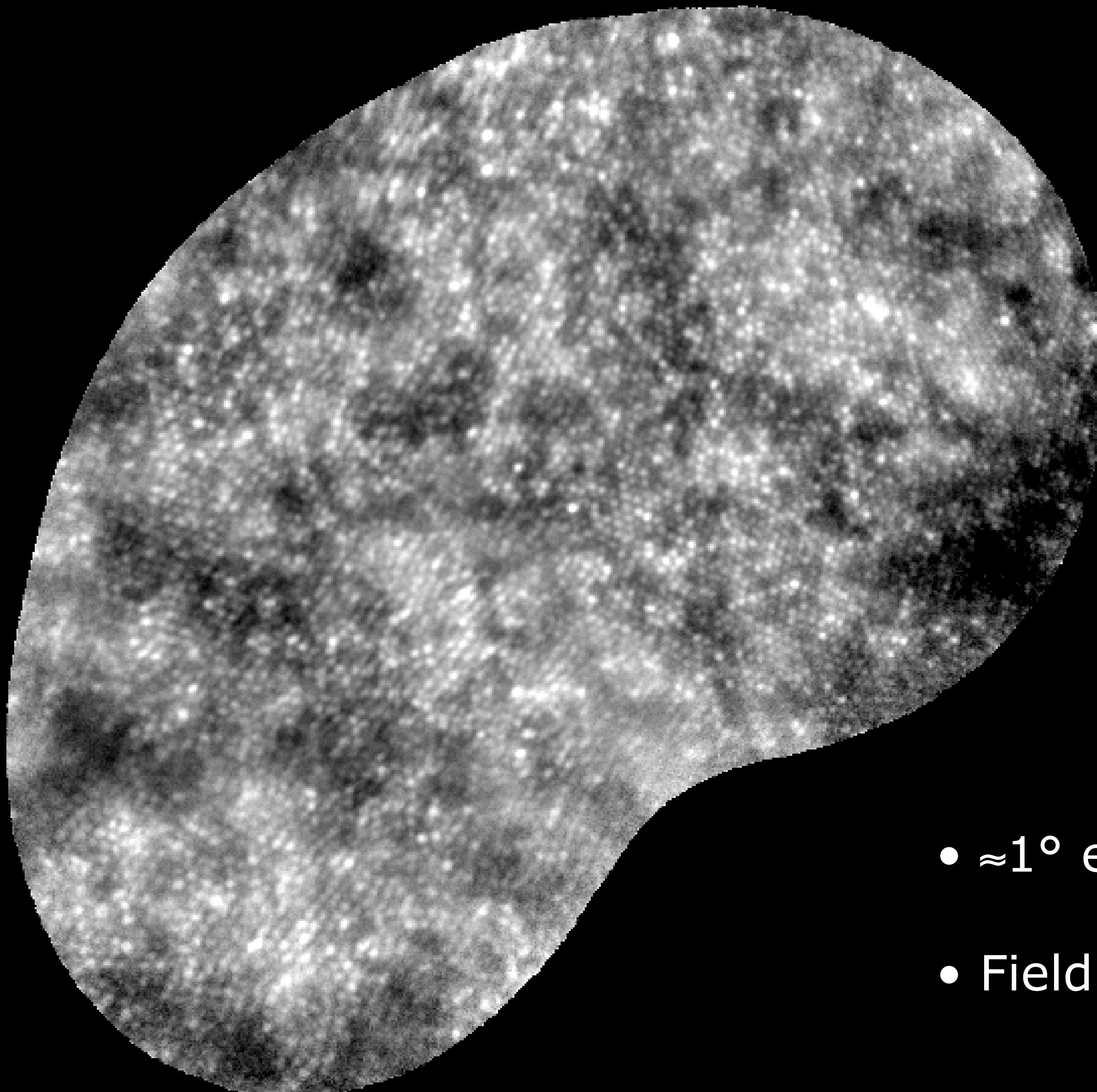
- Manipulate and control ocular wavefront aberrations
- Subjectively assess visual performance in the presence of user-defined aberration

Comparison between best sphero-cyl and full AO correction



Courtesy K. Rocha

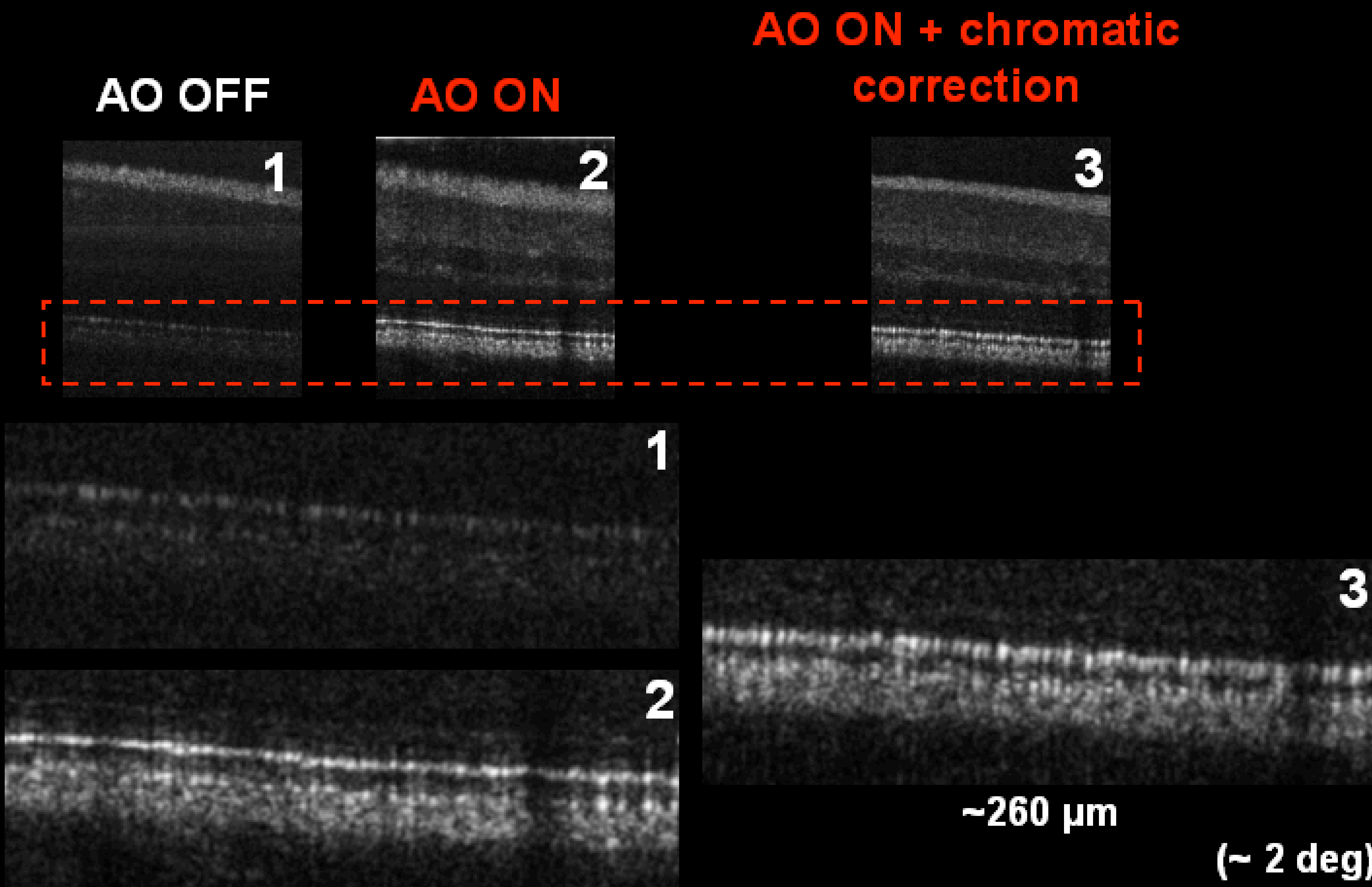
Flood illumination retinal imaging



- ≈1° eccentricity
- Field ≈2x2°

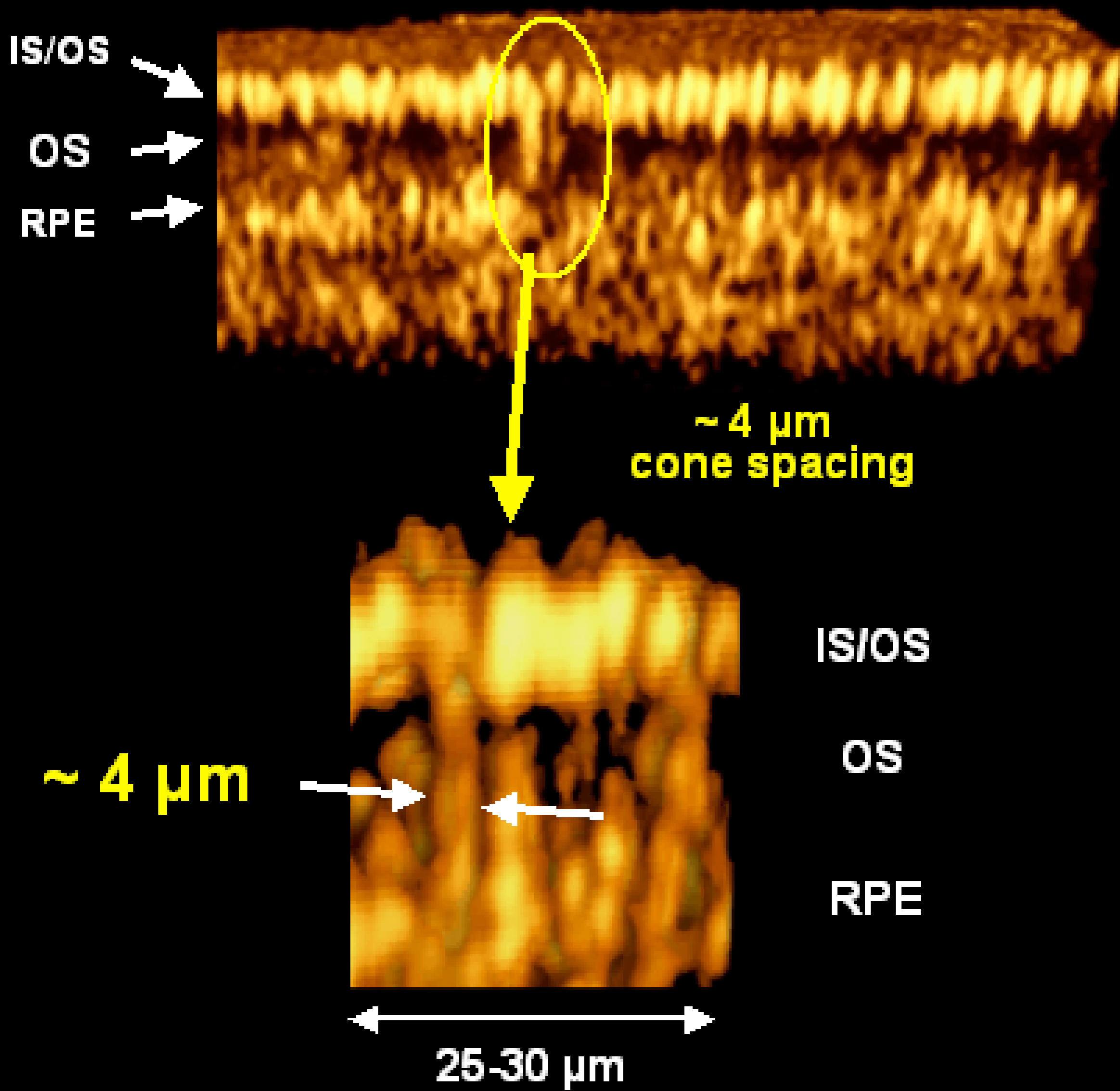
Courtesy M. Glanc, F. Lacombe

UHR Spectral Domain OCT



Courtesy E.J. Fernandez , W. Drexler

UHR Spectral Domain OCT



Courtesy W. Drexler , E.J. Fernandez

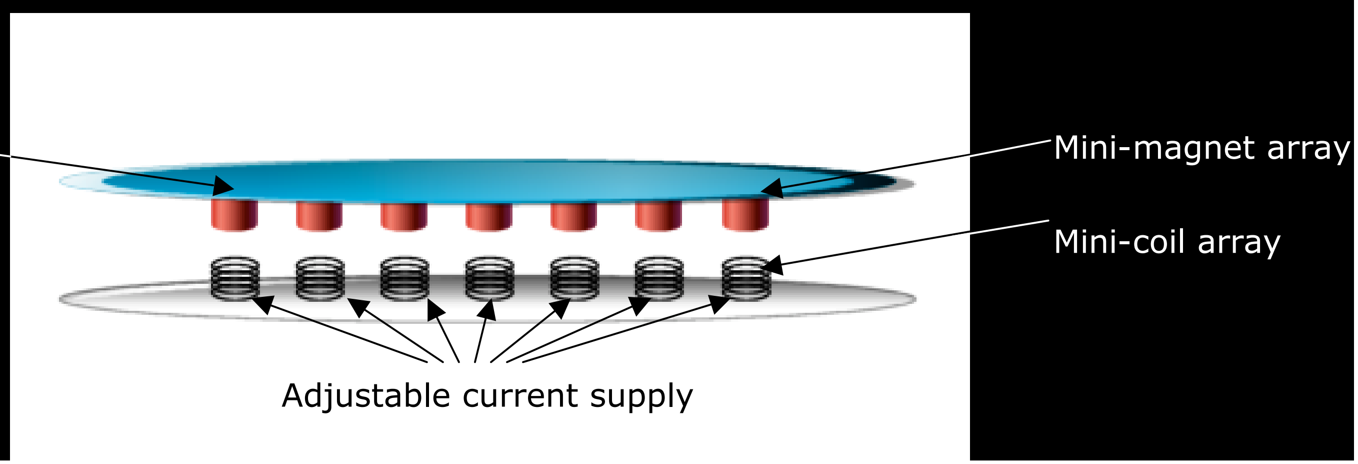
2 Experimental assessment

Mirao 52d: electromagnetic deformable mirror

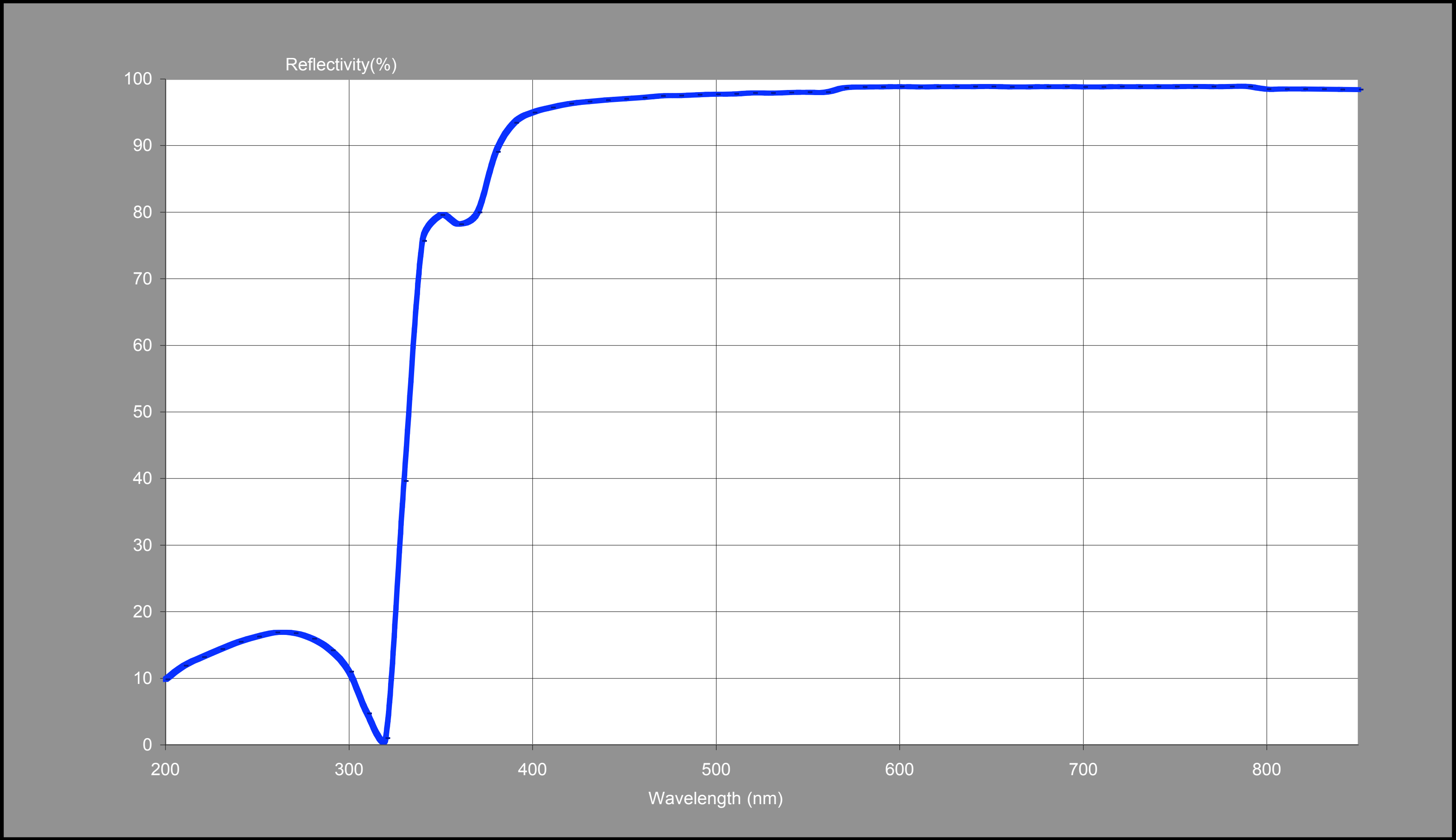
- 52 actuators
- Effective diameter 15 mm
- Overall size 66 x 66 mm
- Voltage range –1 V to +1V

- Electromagnetic technology:

Current I → Magnetic field $\vec{B} = \frac{\mu_0 . N}{L} . I$ → Force

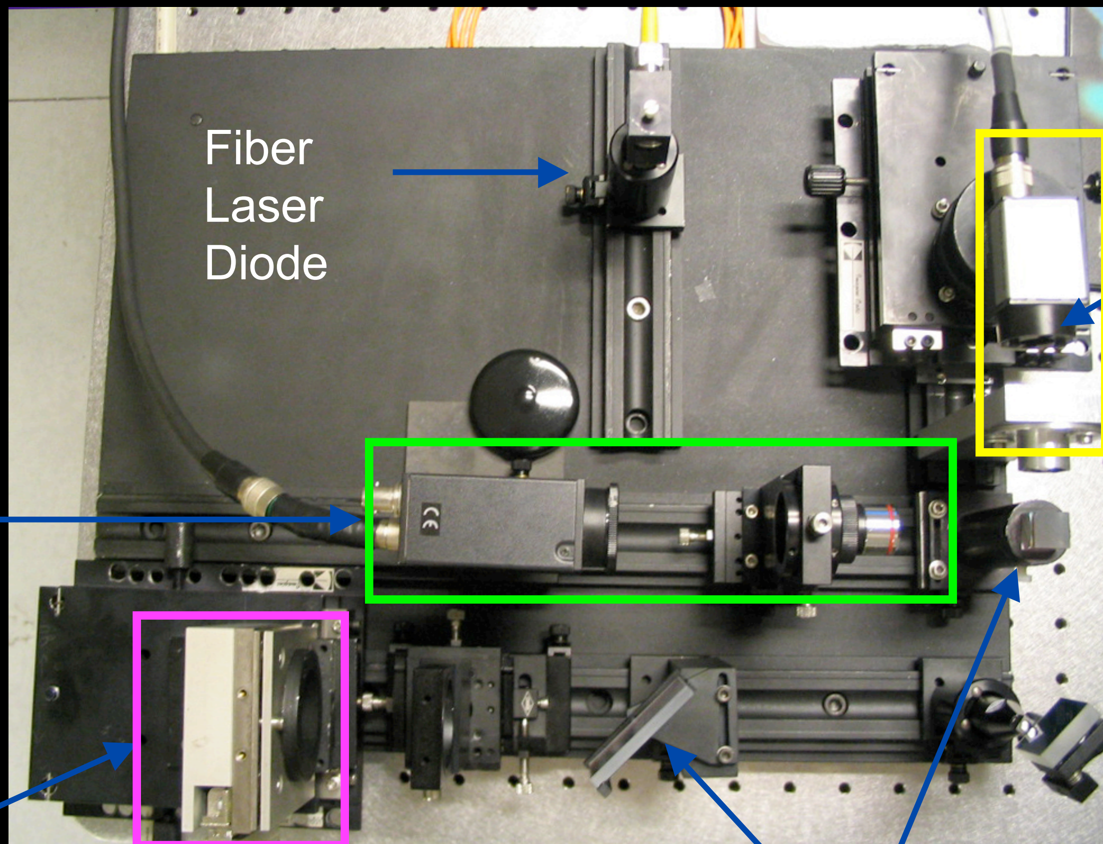


Membrane reflectivity



Visible > 95%
Infrared > 98%

Experimental setup



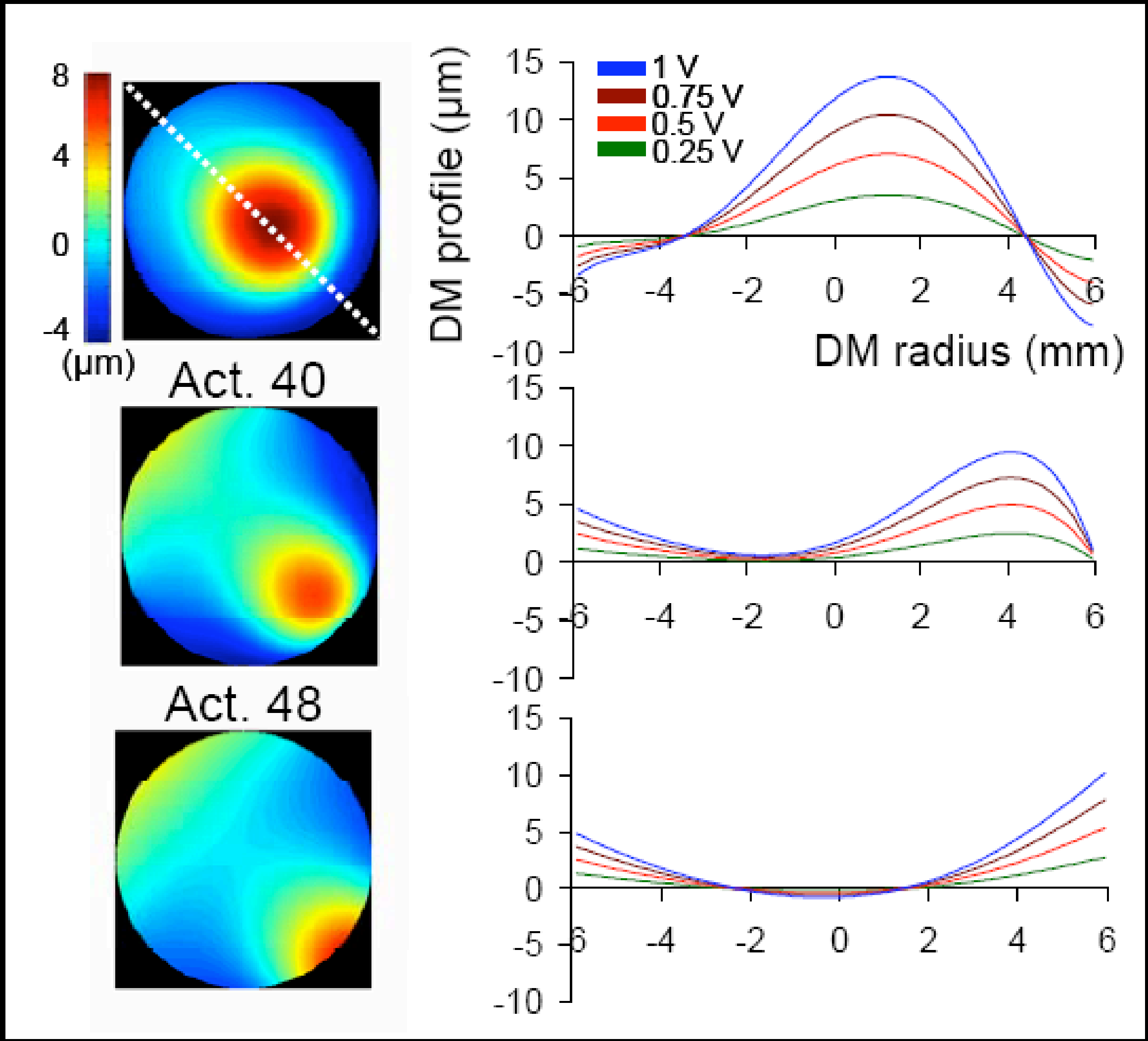
Hartmann-Shack wavefront sensor HASO32

PSF image

Deformable mirror mirao52d

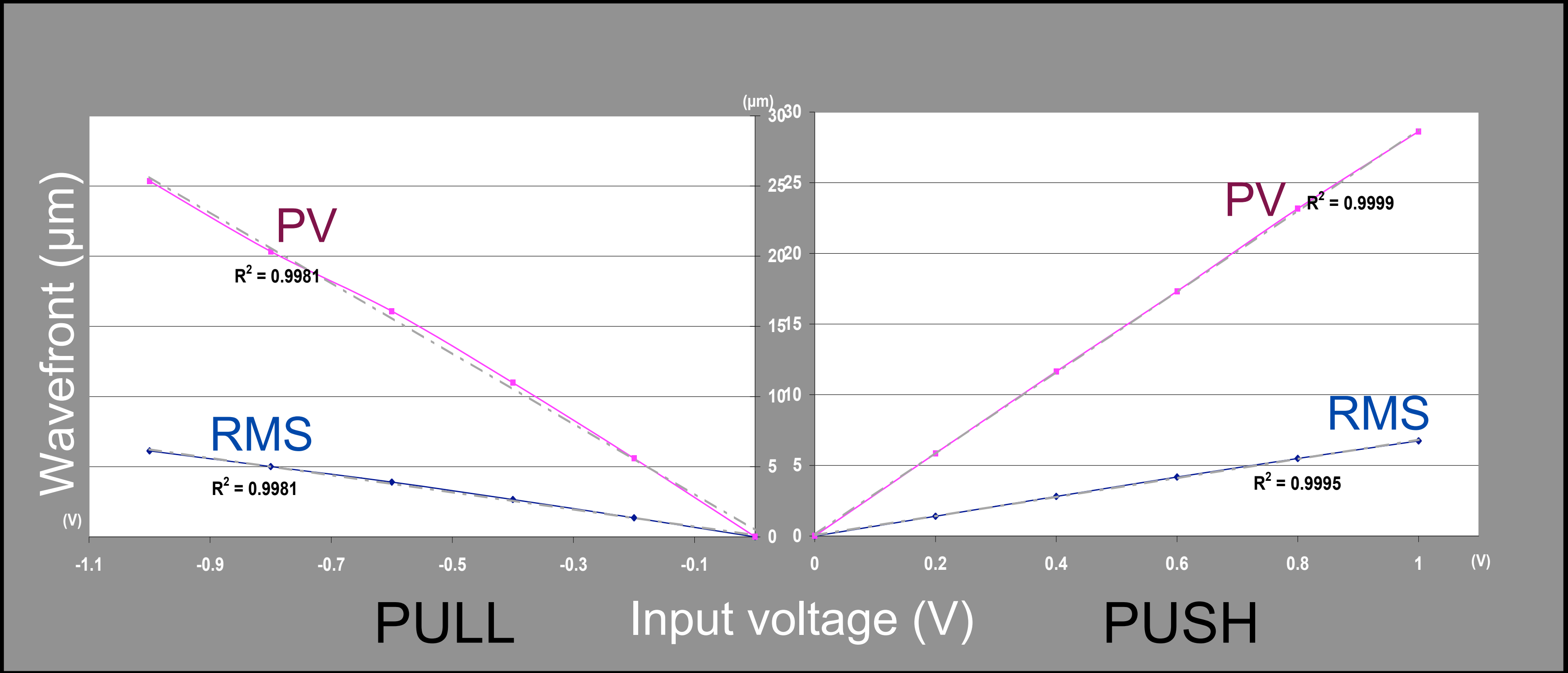
Beam splitters

Single actuator surface response



Courtesy E.J. Fernandez

Linearity

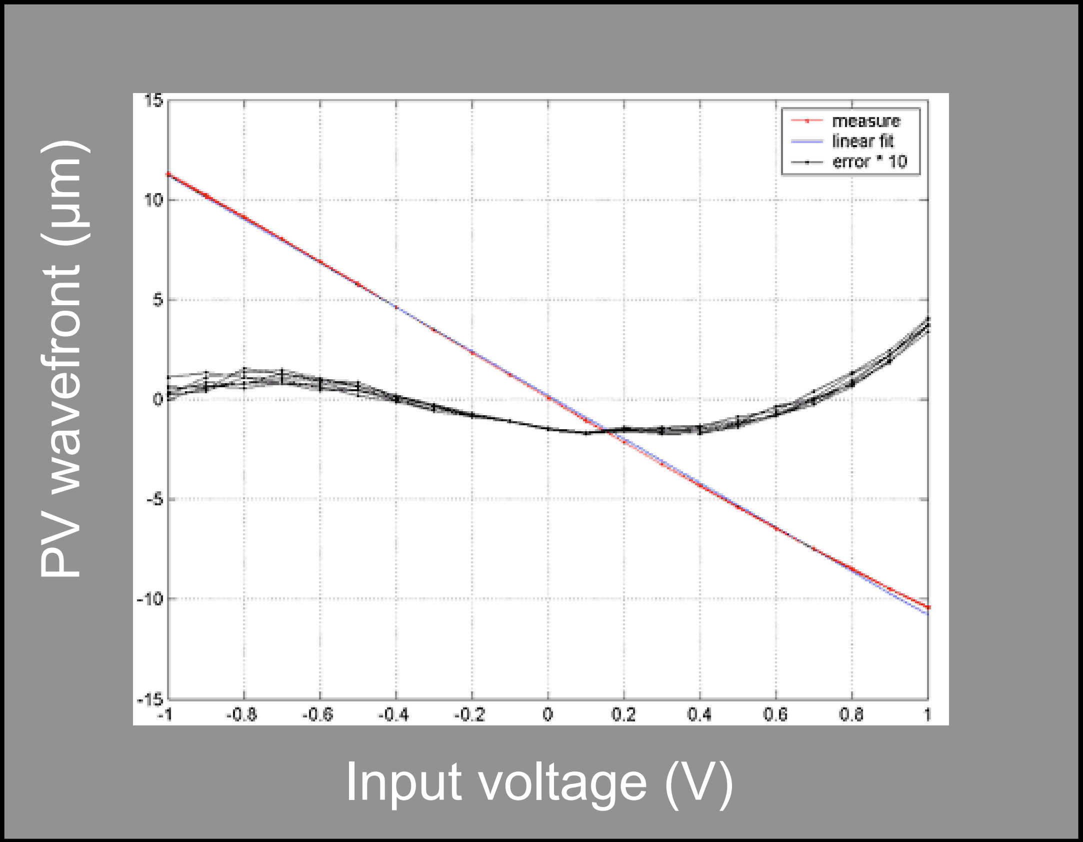


➡ Linearity > 98%

Predictible behaviour

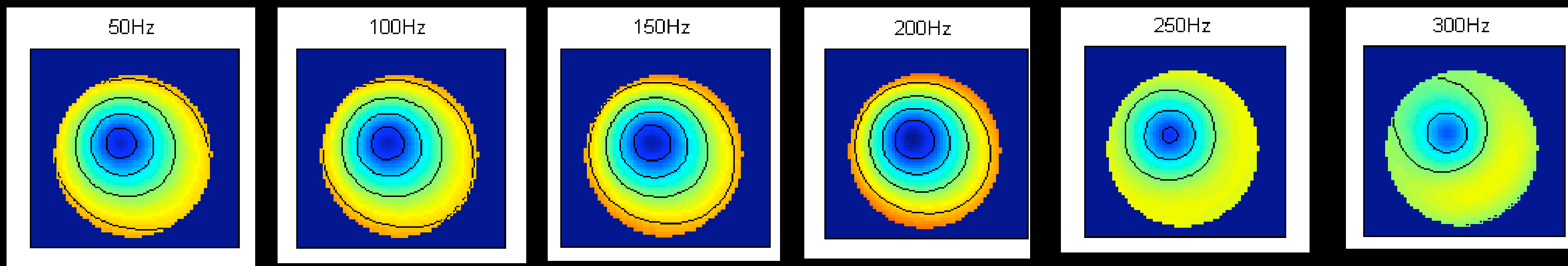
Hysteresis

Single actuator response in 8 up-down cycles (open loop)



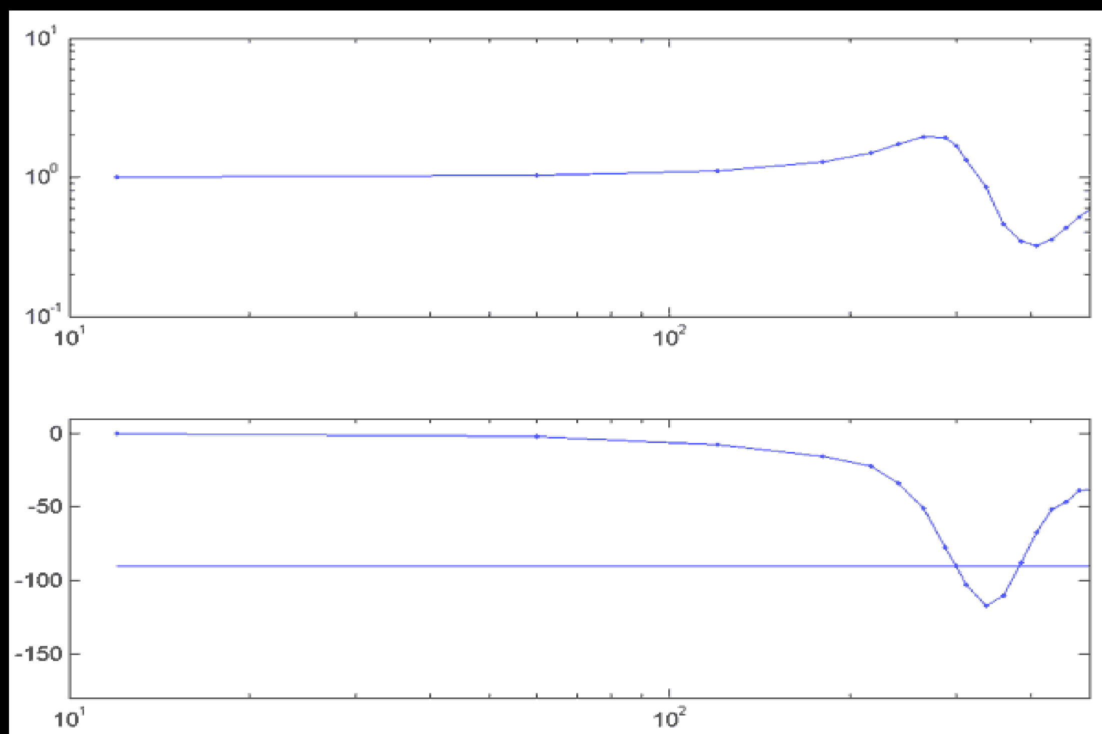
➡ Hysteresis < 1%

Temporal characteristics



Gain

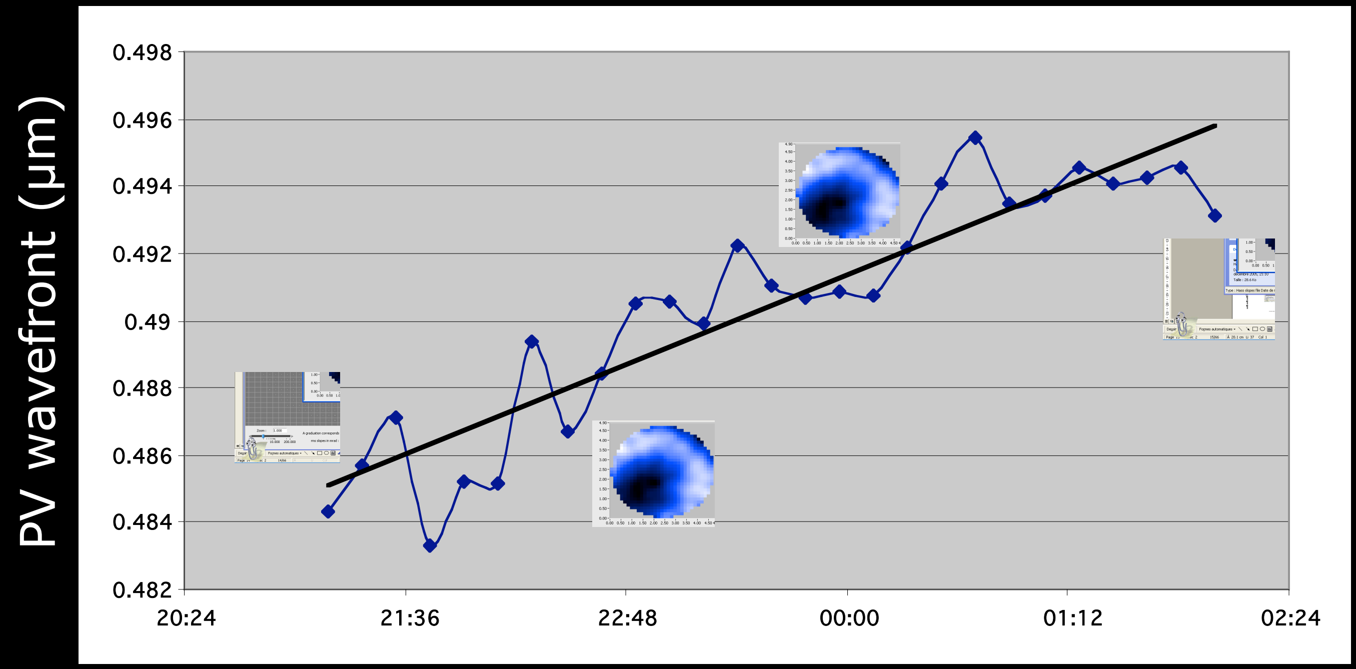
Phase (d°)



Frequency (Hz)

Stability in open loop

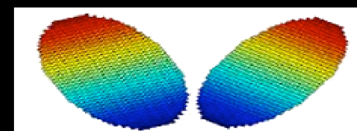
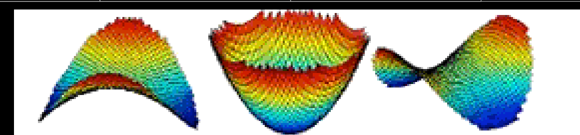
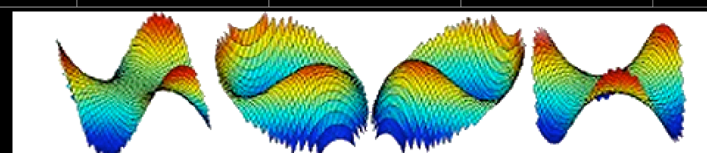
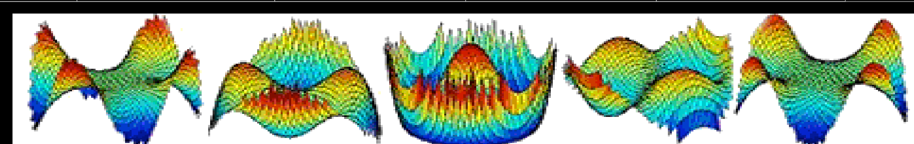
Wavefront changes over time
Open loop, open setup, standard room conditions (A.C.)



0.015 µm in 5 hours

Zernike mode generation / correction

Wavefront range (PV)

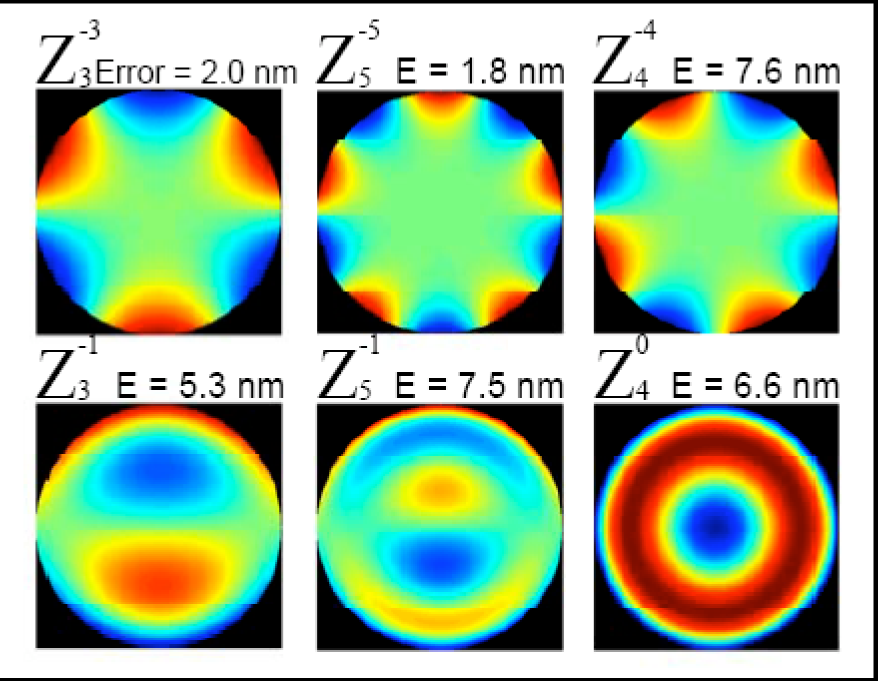
1		±50 µm	±50 µm			
2		±30 µm	±35 µm	±30 µm		
3		±25 µm	±10 µm	±10 µm	±25 µm	
4		±15 µm	±8 µm	±8 µm	±8 µm	±15 µm

Zernike mode generation / correction

Precision:

- Difference between expected and measured Zernike coefficients
- Expected Zernike coefficient:

  1 µm RMS



Courtesy E.J. Fernandez

➡ Error < 0.010 µm RMS
Negligible cross-talk

Conclusions

- Magnetic deformable mirror:
  - high stroke (max. 50 µm)
  - generates / compensates large wavefront aberrations
  - tilt capability
  - linear (predictable behaviour)
  - safety (low voltage)

- Suitable for many ophthalmic applications:
  - ability to create / compensate both low and high-order aberrations (ex. keratoconus)
  - good candidate for integration on clinical systems

Thanks !

- Universidad de Murcia
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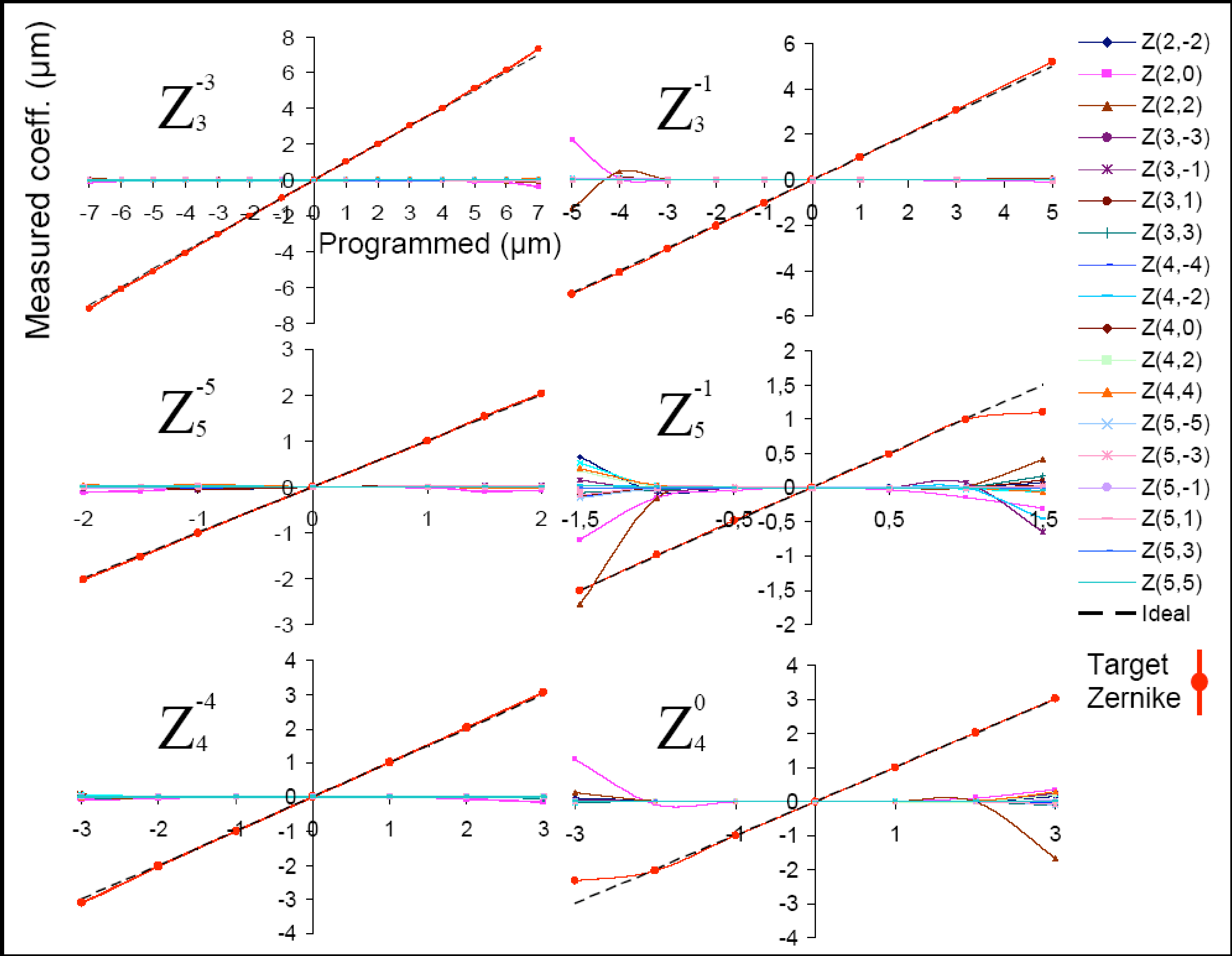
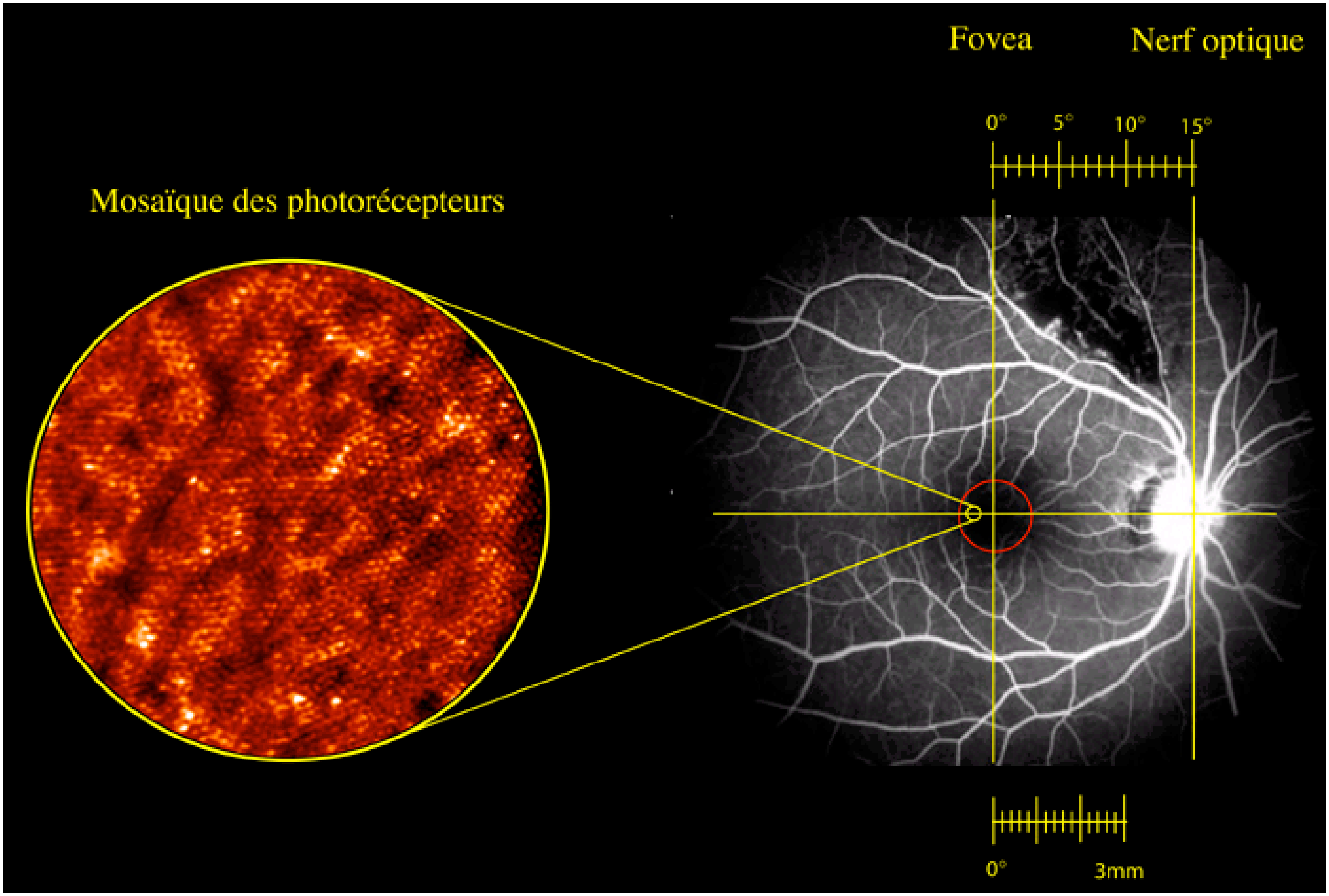
  - B. Hermann, A. Unterhuber, B. Pova_ay, W. Drexler
- CNRS LESIA - Observatoire de Paris
  - M. Glanc
- MaunaKea Technologies
  - F. Lacombe
- Imagine Eyes
  - N. Chateau, L.Vabre , X. Levecq, F. Martins

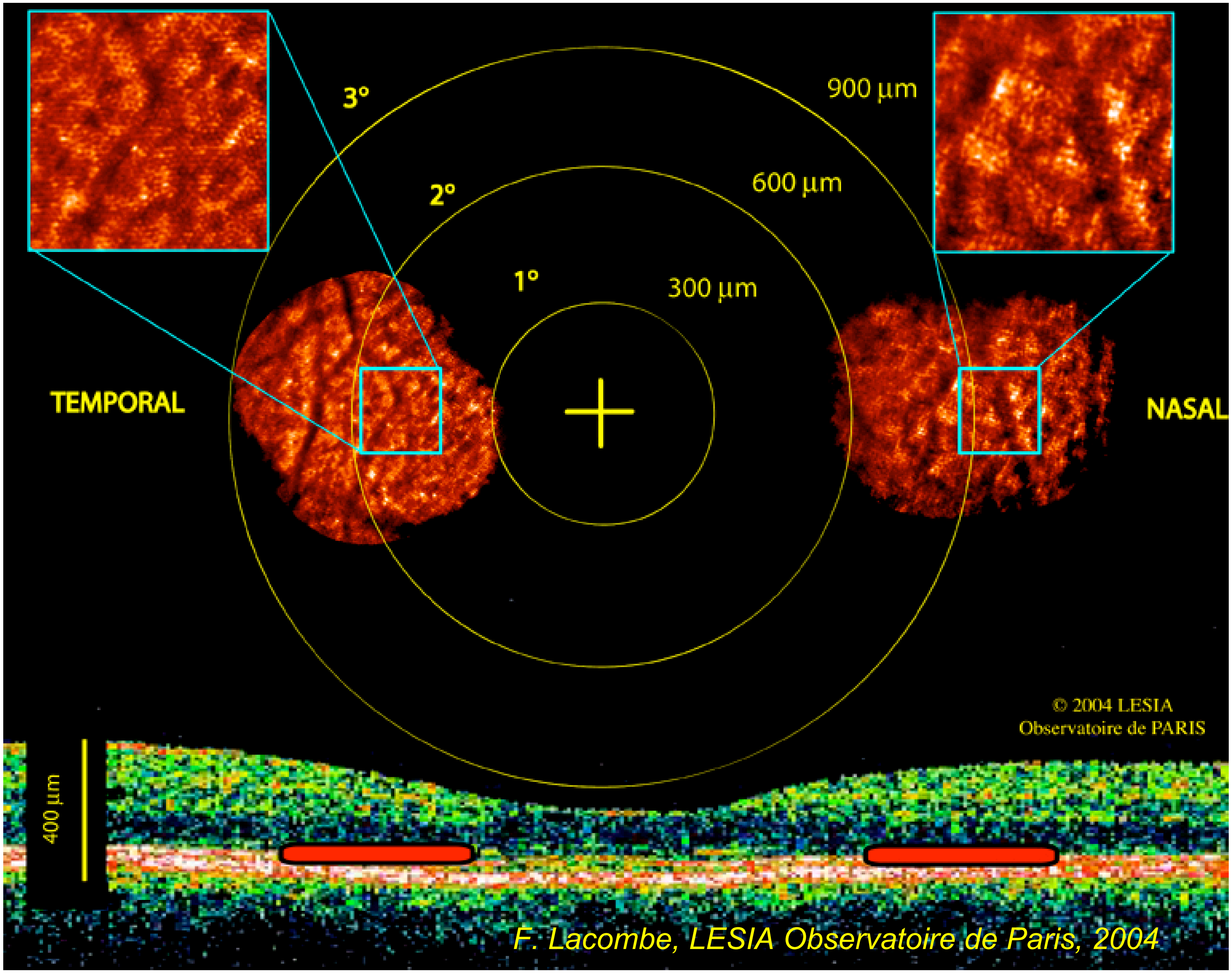
Mode coupling



Courtesy E.J. Fernandez



F. Lacombe, LESIA Observatoire de Paris, 2004


3°
2°
1°
900 µm
600 µm
300 µm
TEMPORAL
NASAL
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400 µm
F. Lacombe, LESIA Observatoire de Paris, 2004