Bidirectional membrane deformable mirror

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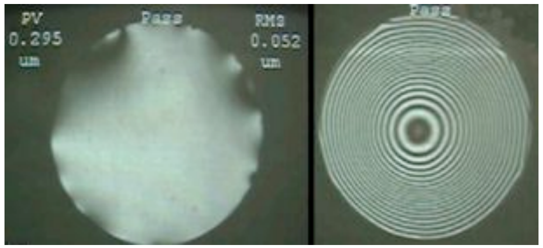
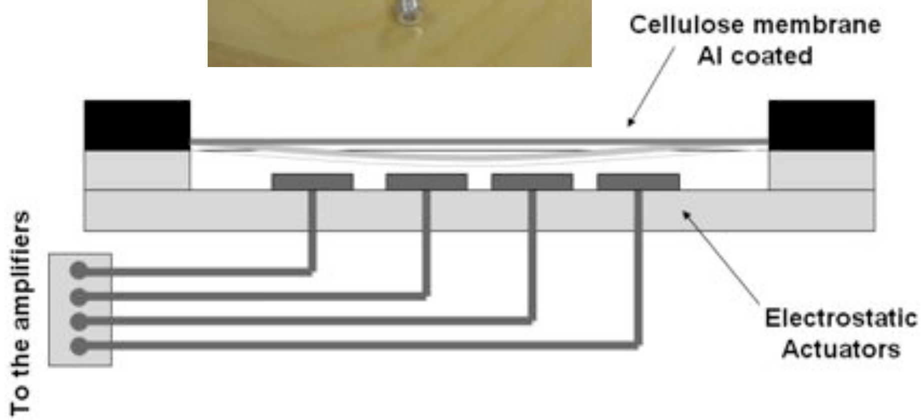
Summary

- Deformable mirror developed in Padova
- Behavior
- Electrostatic push-pull mirror with single transparent electrode
- Electrostatic push-pull mirror with patterned electrodes
- Electrodes managing
- P-P vs. P. only
- Application to ultra-fast optics

DM developed in Padova: mirror technology

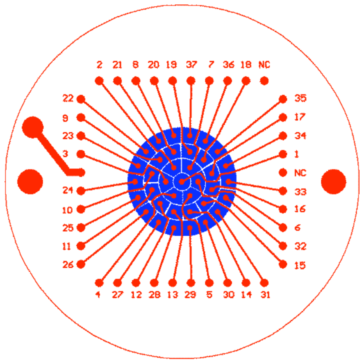
- Technology
  - Thin cellulose membrane (5 µm)
  - Mirrors diameters: 12 mm, 18 mm, 25 mm
  - 37 electrodes (up to 64), any pattern
  - Initial RMS deviation from plane <50 nm
  - Maximum deflection of 10 µm (min f=2m)
- Advantages
  - Compact device,
  - low cost, low power
  - New designs easy accessible



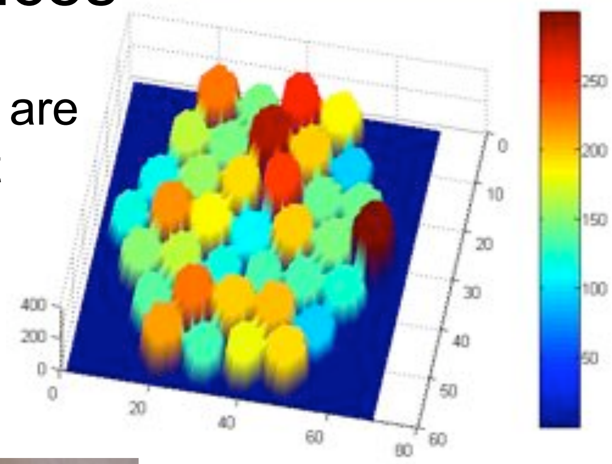


DM developed in Padova: electronic devices

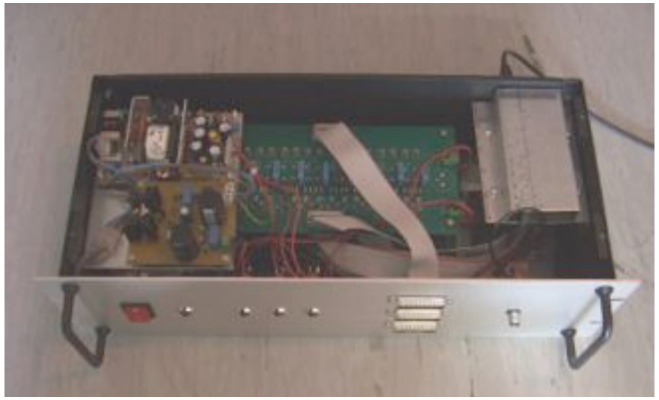
- PCB pattern example



- Actuators are independent

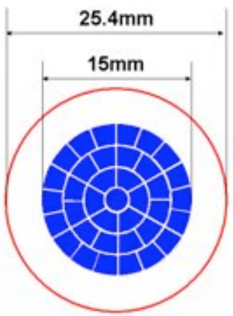


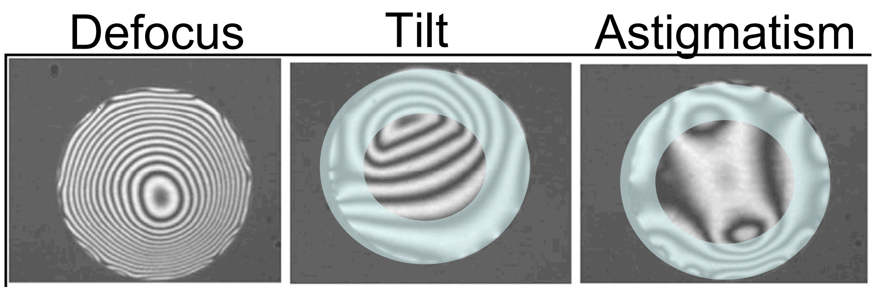
- High voltage, high frequency electrodes driver
  - Up to 64 channels
  - DSP technology
  - Stand alone
  - USB connection
  - C++ environment



S.Bonora, I.Capraro, L.Poletto, M.Romanin, C.Trestino,P.Villoresi. *A DSP Control System of Membrane Deformable Mirror using TMS320 C5502* Eders – Munich 2006
S. Bonora, I. Capraro, L. Poletto, M. Romanin, C. Trestino, P. Villoresi *Fast wavefront active control by a simple DSP-Driven deformable mirror* Review of Scientific Instruments 2006, September, 77

Examples of controlled deformations:





Optimal
Active region
0.6Radius

- Without biasing the membrane:

Tilt

Astigmatism

- With membrane biased to half voltage:

Tilt

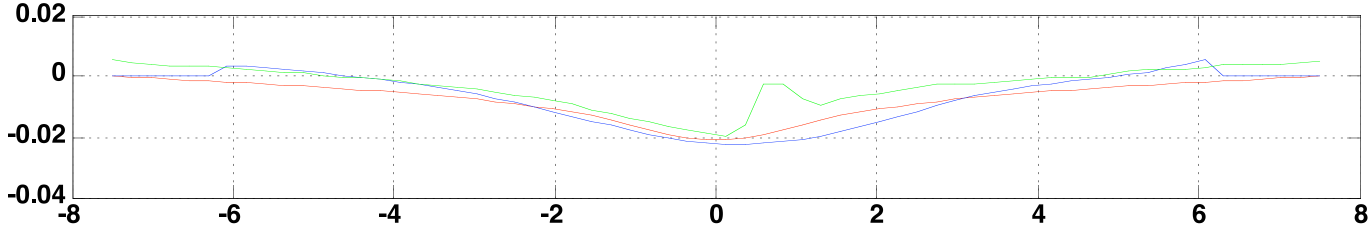
Astigmatism

Coma

Trefoil

Mathematical model

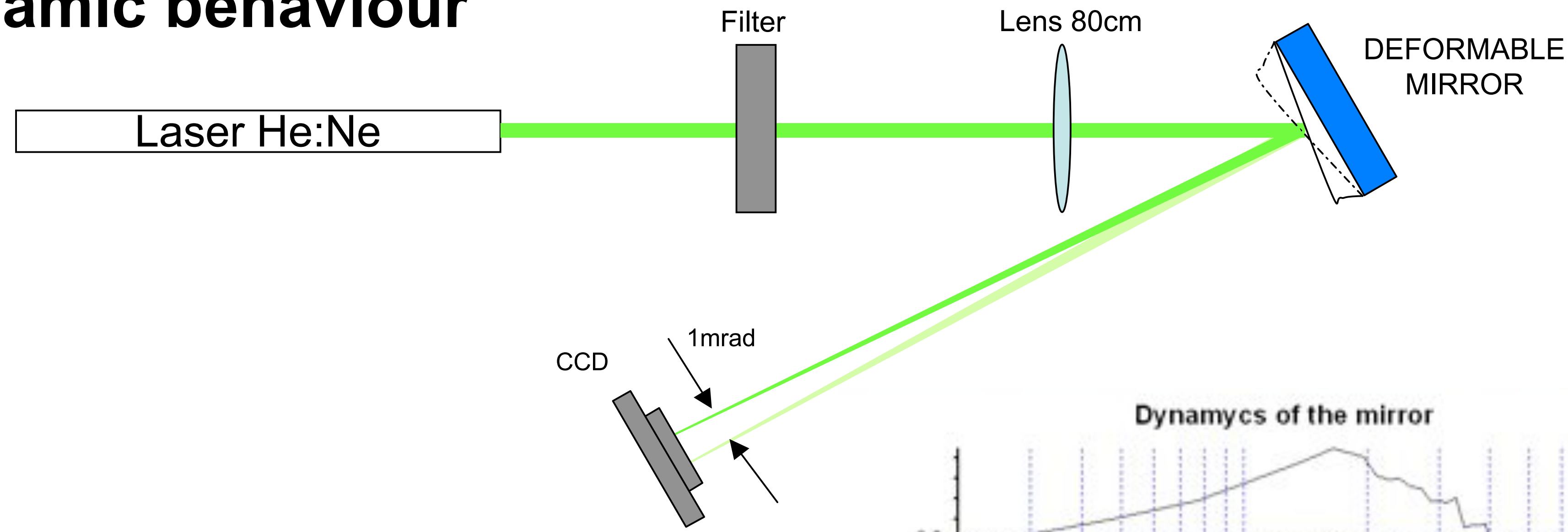
- Solution of the Poisson equation by some approximations
- Finite element model



Comparisons between: theoretical model, Zygo measures and Hartmann wavefront sensor measures

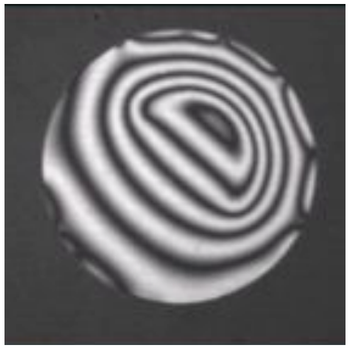
E. Clafin, N. Bareket, Configuring an electrostatic membrane mirror by least-squares fitting with analytically derived influence functions. J. Opt. Soc. Am. A Vol. 3, No. 11/Novembre 1986

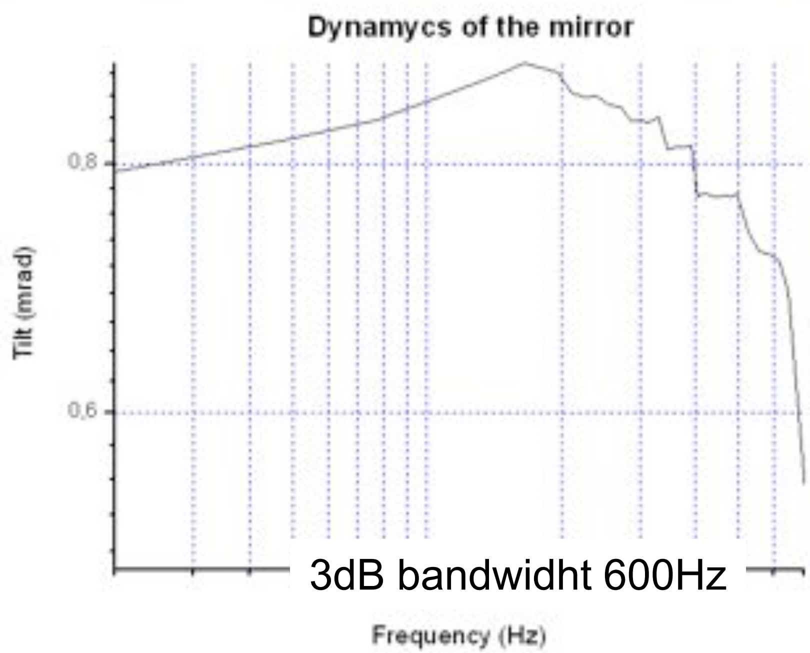
Dynamic behaviour



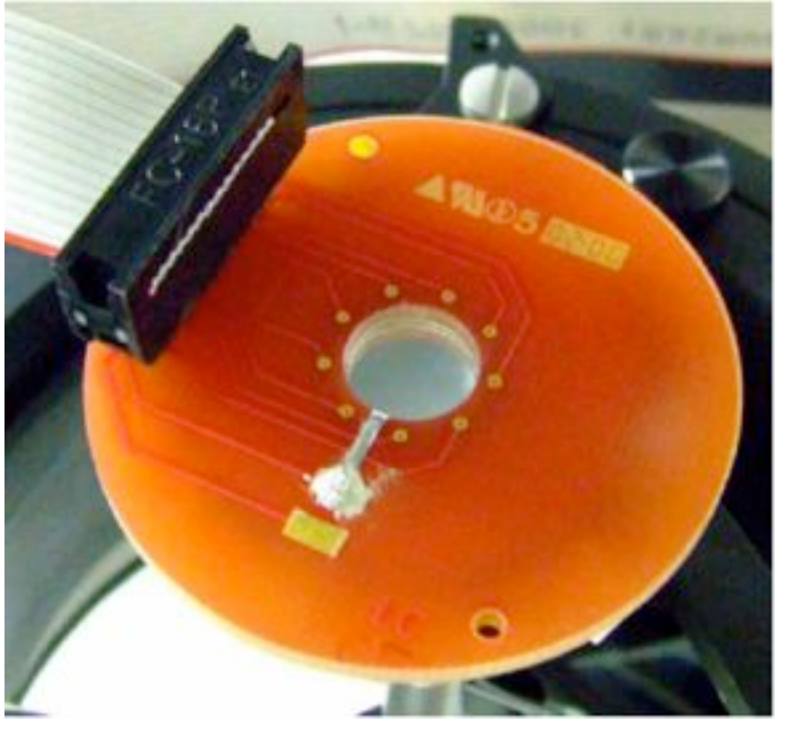
Measured by asynchronous sampling of the displacement by CCD camera

Measured tilt
By Zygo interferometer



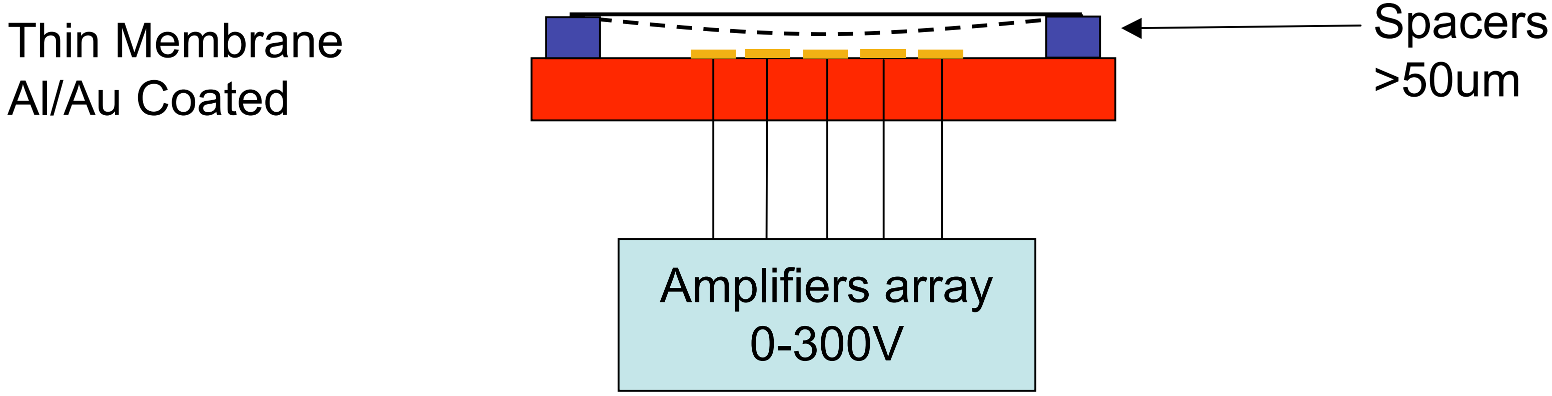


Electrostatic Push Pull mirror



S. Bonora, L.Poletto, *Push-pull membrane mirrors for adaptive optics,* Optics Express 2006, Vol. 14 No. 25

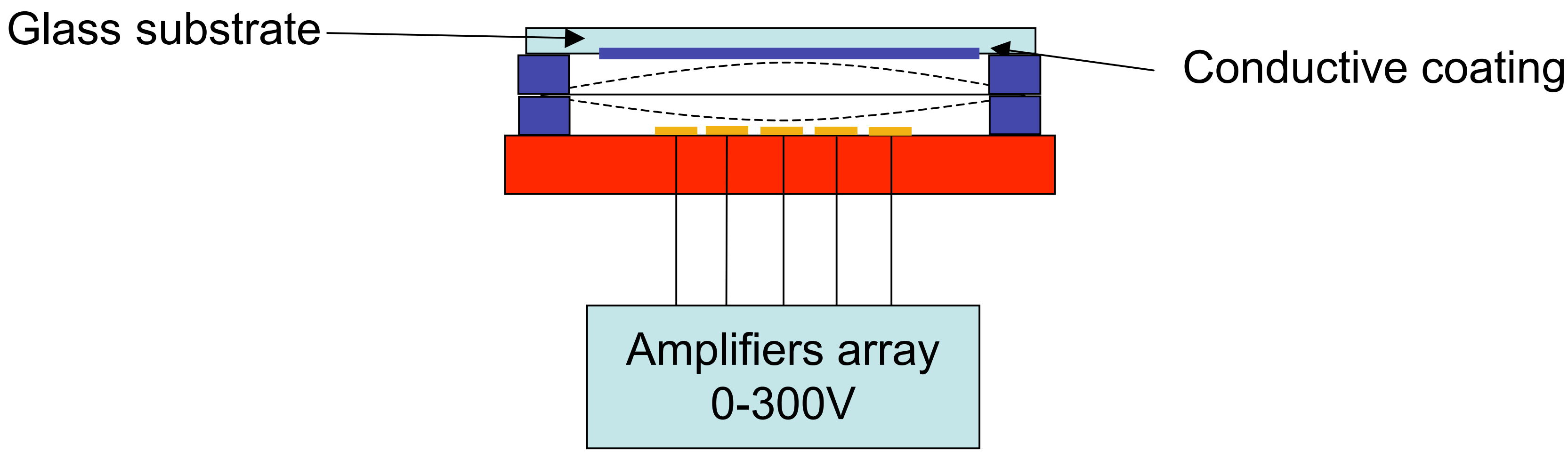
Principle



- ❑ Electrostatic attraction between PCB and thin membrane
  - ❑ Voltage 300V
  - ❑ Low power
  - ❑ Low cost

- ❑ Fragile ☹
- ❑ Not possible to clean ☹
- ❑ Only attraction is possible ☹

Push Pull mirror with single transparent electrode



- Electrostatic actraction between PCB and thin membrane

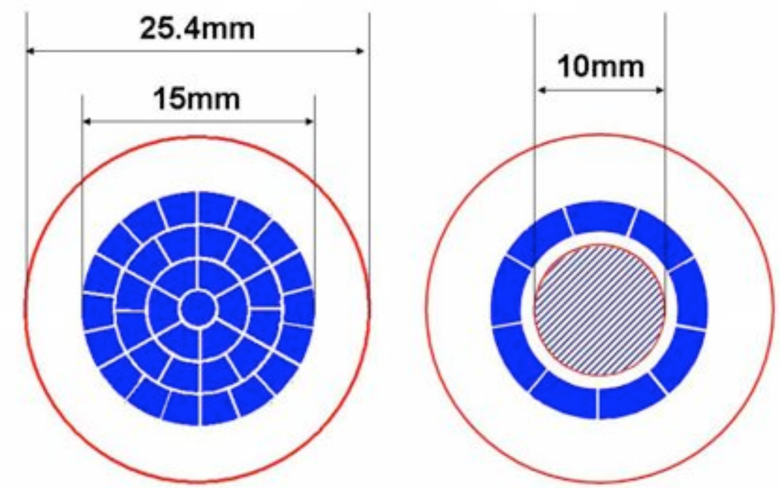
Transparent conductive coating (Indium Tin Oxide)

- Low cost

- ~~Fragile~~ ☺
- ~~Not possible to clean~~ ☺
- ~~Only actraction is possible~~ ☺

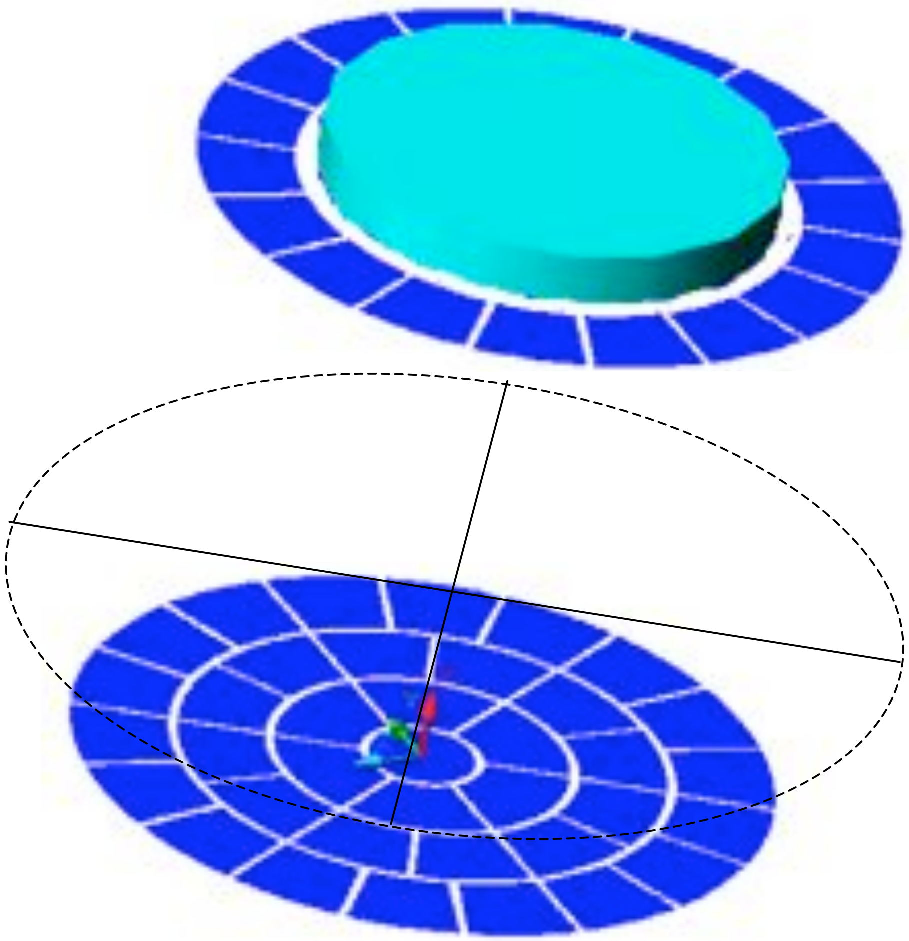
Electrodes configuration

Extenal electrodes for higher order aberrations

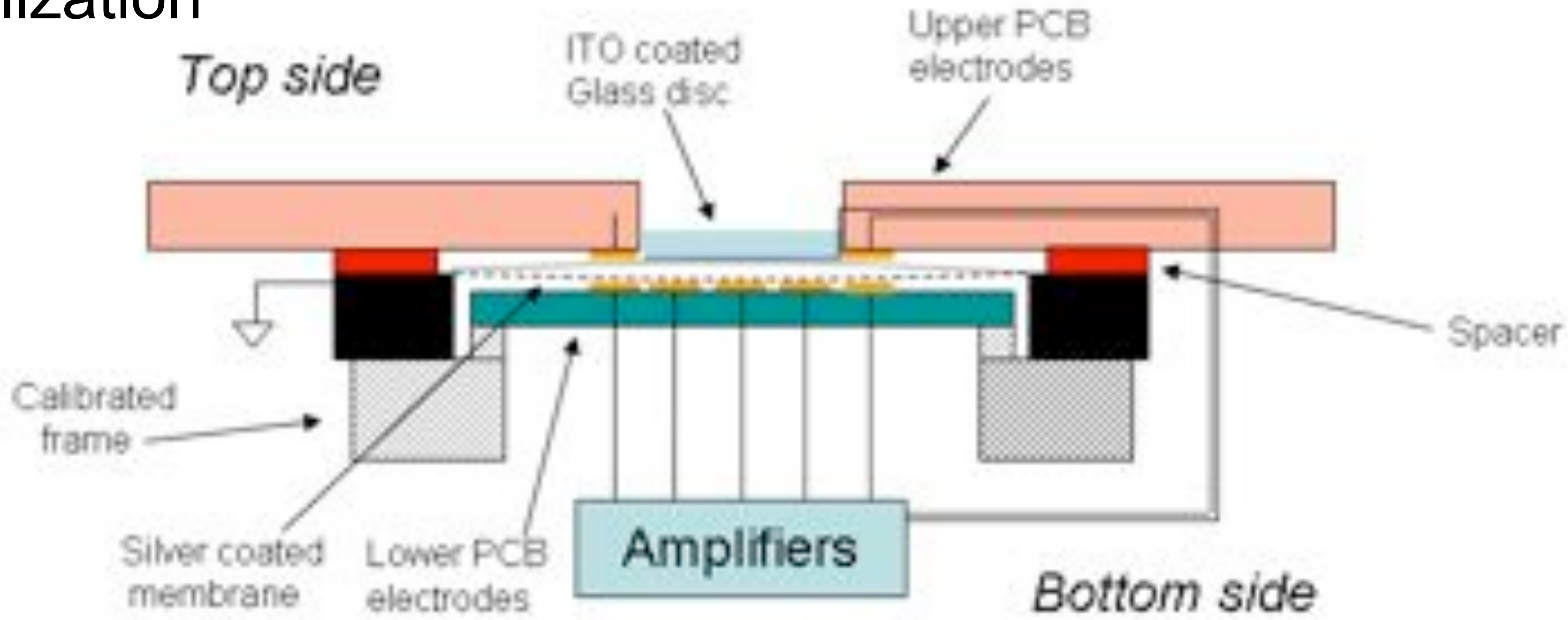


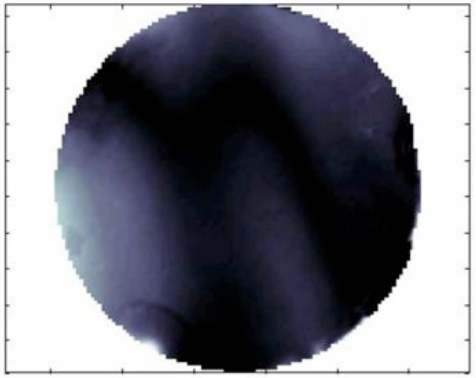
Bottom electrodes

Top electrodes

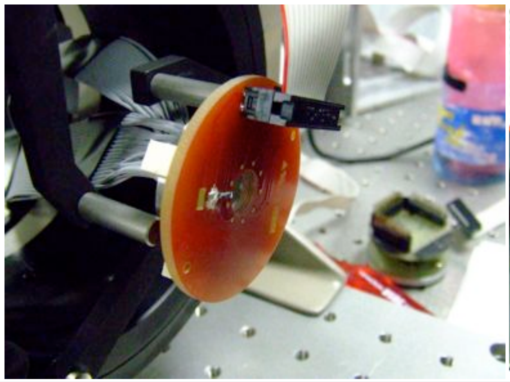


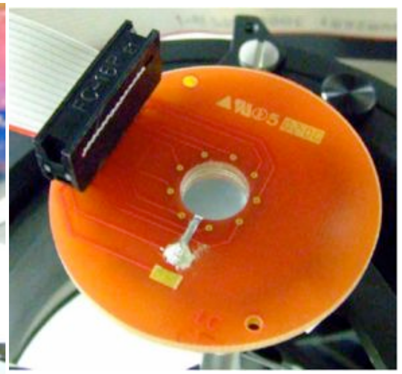
Realization





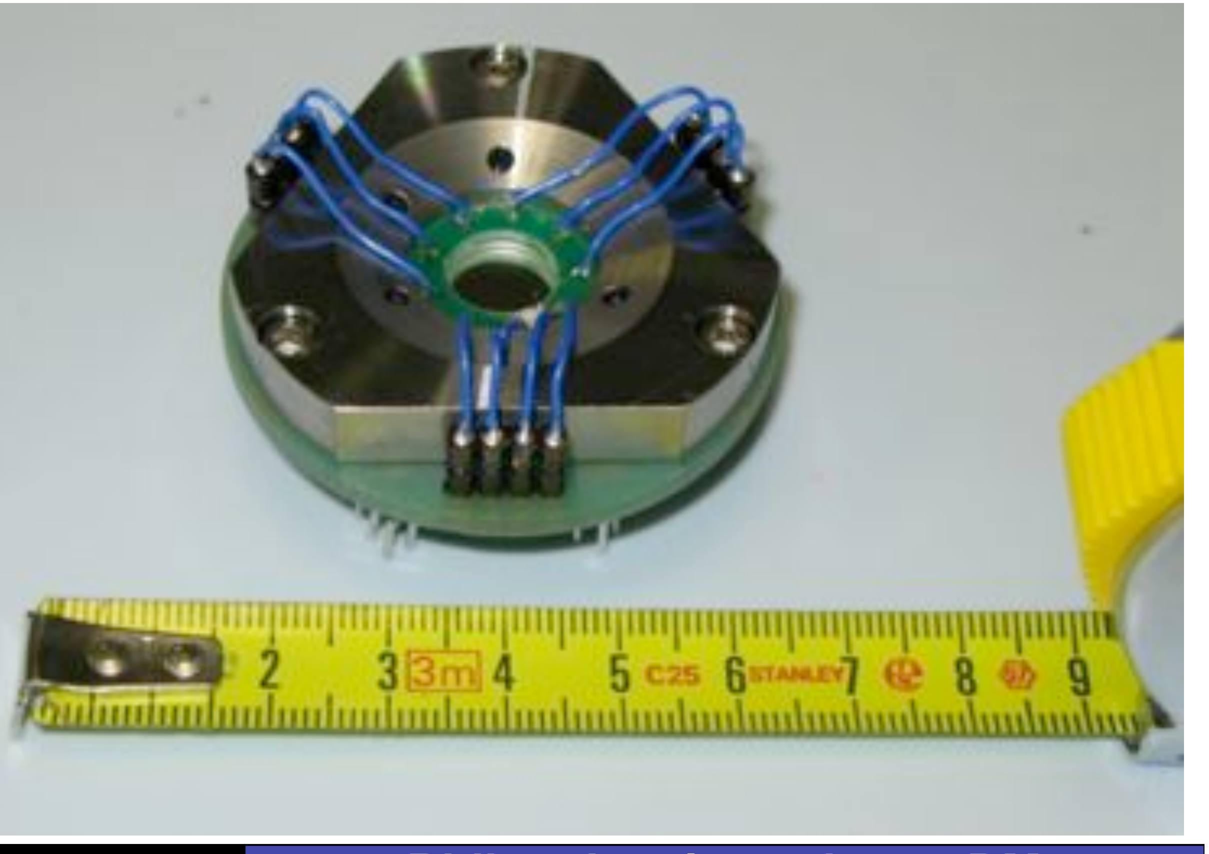
Initial RMS less than 30nm



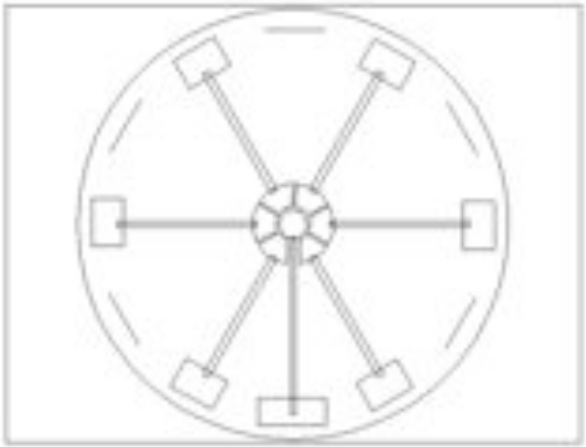


Realization

Push pull deformable mirrors with only a central transparent electrode



Push Pull mirror with patterned transparent electrodes



CAD drawing of the patterned transparent conductive electrodes

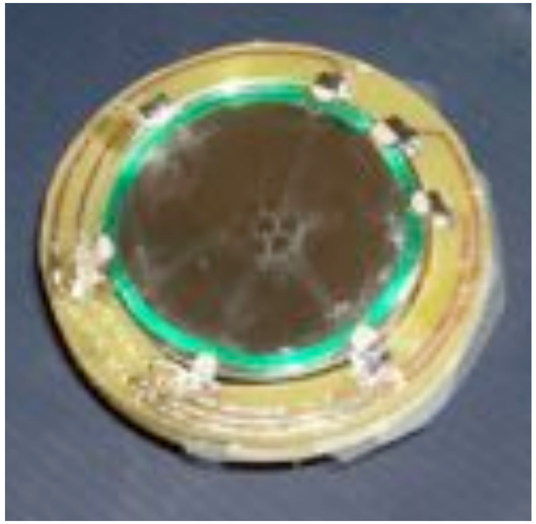
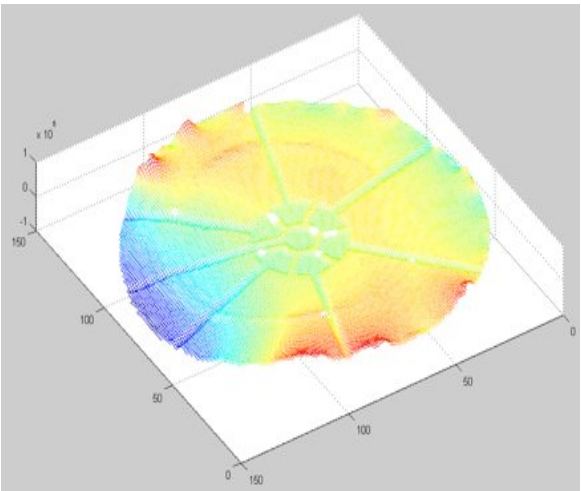
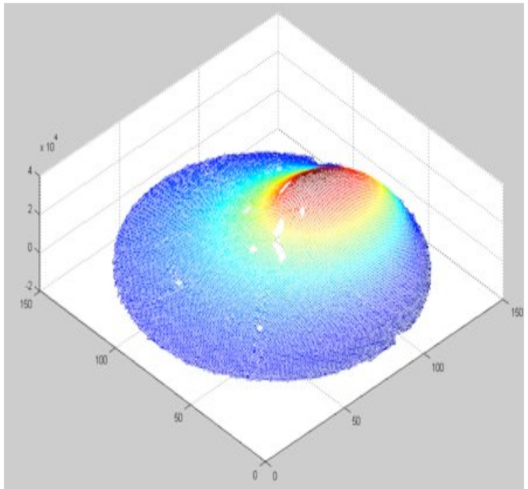


Image of the device



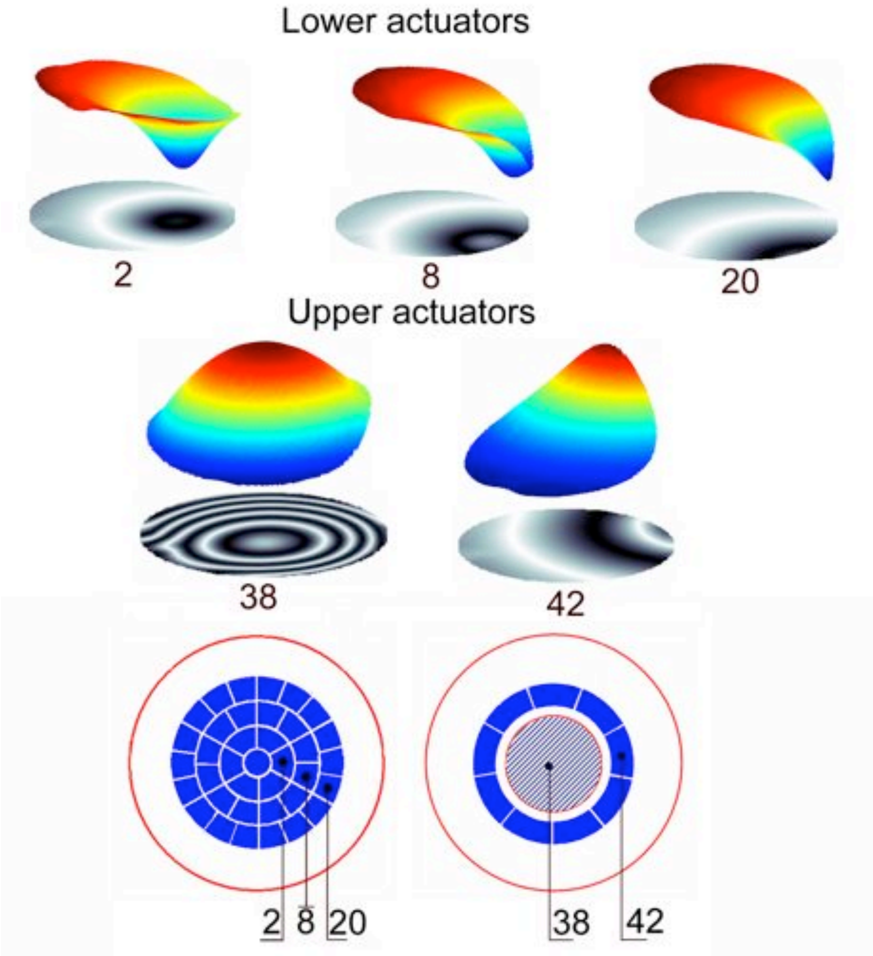
Flat membrane measurement using Zygo interferometer



An influence function

Experimental results

Influence function Matrix measured by Zygo interferometer



External ring 0.8 um 1.3 um
Positive displacement
2.5 um PTV

Upper actuators 3 μm

Zernike polynomials generation

- Problems
  - Avoid electrodes Saturation
  - Exploit the mirror capabilities

Compute **p**

$$\mathbf{p} = \mathbf{A}^{-1} Z(x, y)$$

Some definitions

$$\mathbf{p}' = \{ p_i \in p, p_i > p_{\max} \}$$
$$p'_i = p_{\max} \forall p'_i \in \mathbf{p}'$$
$$\mathbf{A}' = \{ A_i \mid p_i > p_{\max} \}$$
$$\mathbf{p}'' = \{ p_i \in \mathbf{p}, p_i \le p_{\max} \},$$
$$\mathbf{A}'' = \{ A_i \mid p_i \le p_{\max} \}.$$

Compute **p”**

$$\mathbf{p}'' = \mathbf{A}''^{-1} \left[Z(x, y) - \mathbf{A}'\mathbf{p}' \right]$$

Update **p**

$$\mathbf{p} = \mathbf{p}' \cup \mathbf{p}''$$

p” saturated ?

Yes

Geometry: How to choose the optimal parameters

$$P_i = \frac{D_i}{\sqrt{D_1^2 + \dots + D_n^2}}$$ Purity

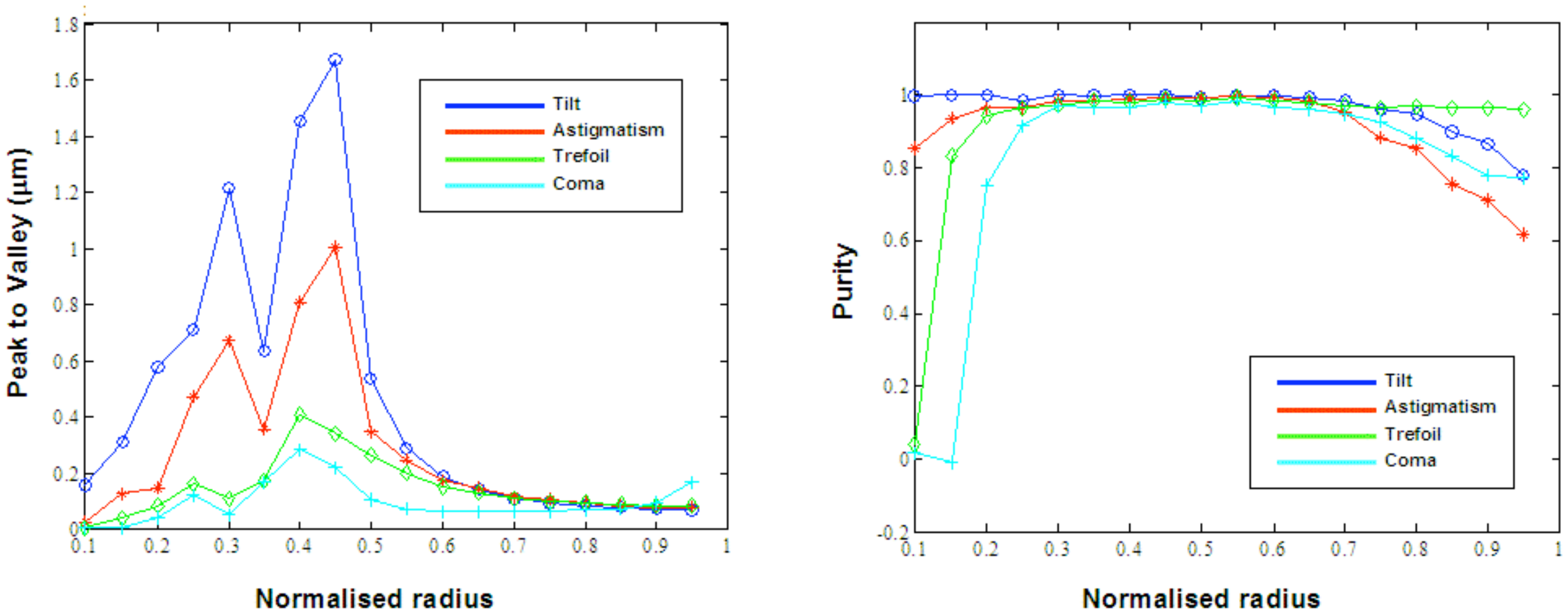
$$Di = < M(x,y) \bullet \hat{\mathbf{z}}_i(x,y) >$$ D_i=1 if the M(x,y) is parallel to $\hat{\mathbf{z}}_i$

$\hat{\mathbf{z}}_i$ Zernike terms

$$\mathbf{A} = [\mathbf{A}_1 \dots \mathbf{A}_{47}]$$ Influence functions matrix

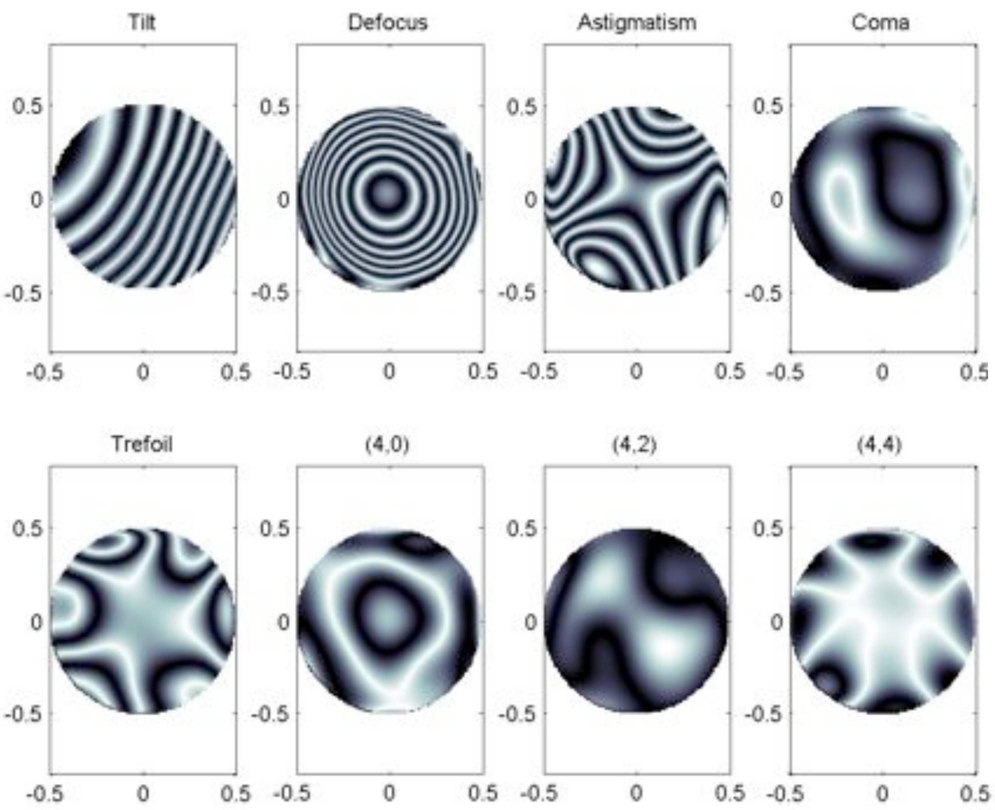
$$\mathbf{p} = \mathbf{A}^{-1} Z(x,y)$$

Active region



Optimal active region 0.4 x Radius = 10mm

Results



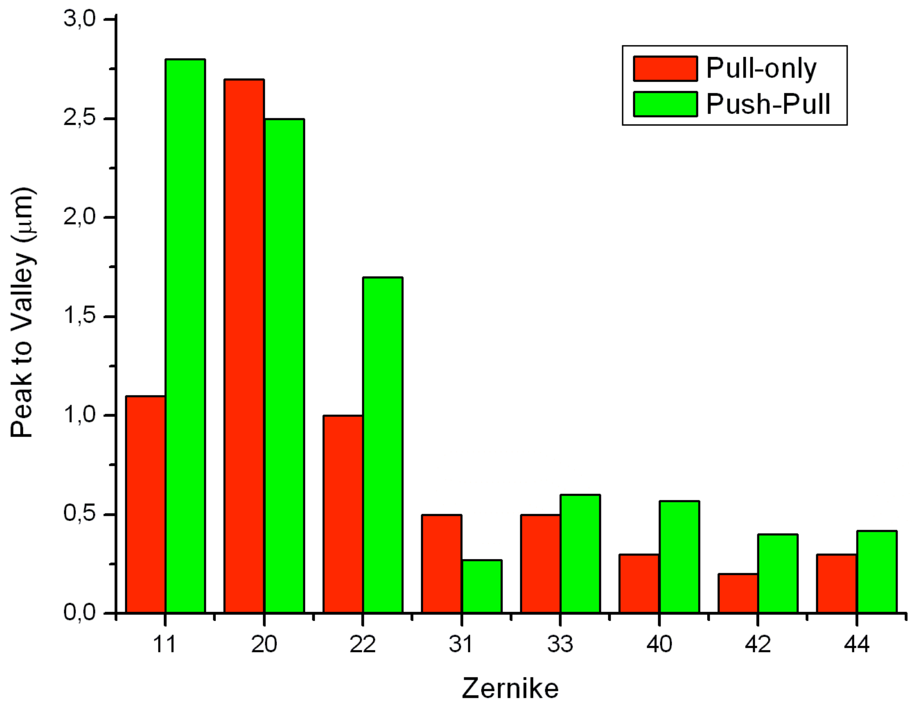
Aberration	Peak to Valley (μm)	RMS deviation (μm)	Purity
Tilt	1.6	0.14	0.93
Defocus	2.6	0.20	0.97
Astigmatism	2.1	0.12	0.96
Coma	0.3	0.05	0.83
Trefoil	0.9	0.10	0.92
(4,0)	0.6	0.11	0.41
(4,2)	0.2	0.03	0.61
(4,4)	0.4	0.09	0.80

Peak to valley/RMS < 18% (4,0)

Measurements by Zygo interferometer

Performance comparison

- Methods
  - comparison of the peak to peak amplitude of aberrations with a pull mirror
  - correction of a statistical distribution (human eye aberrations)



Results compared with a Membrane mirror
D=18mm
Active region 10mm
Membrane biased at 140V

E. Dalimier and C. Dainty
Opt. Express **13,** 4275-4285 (2005)

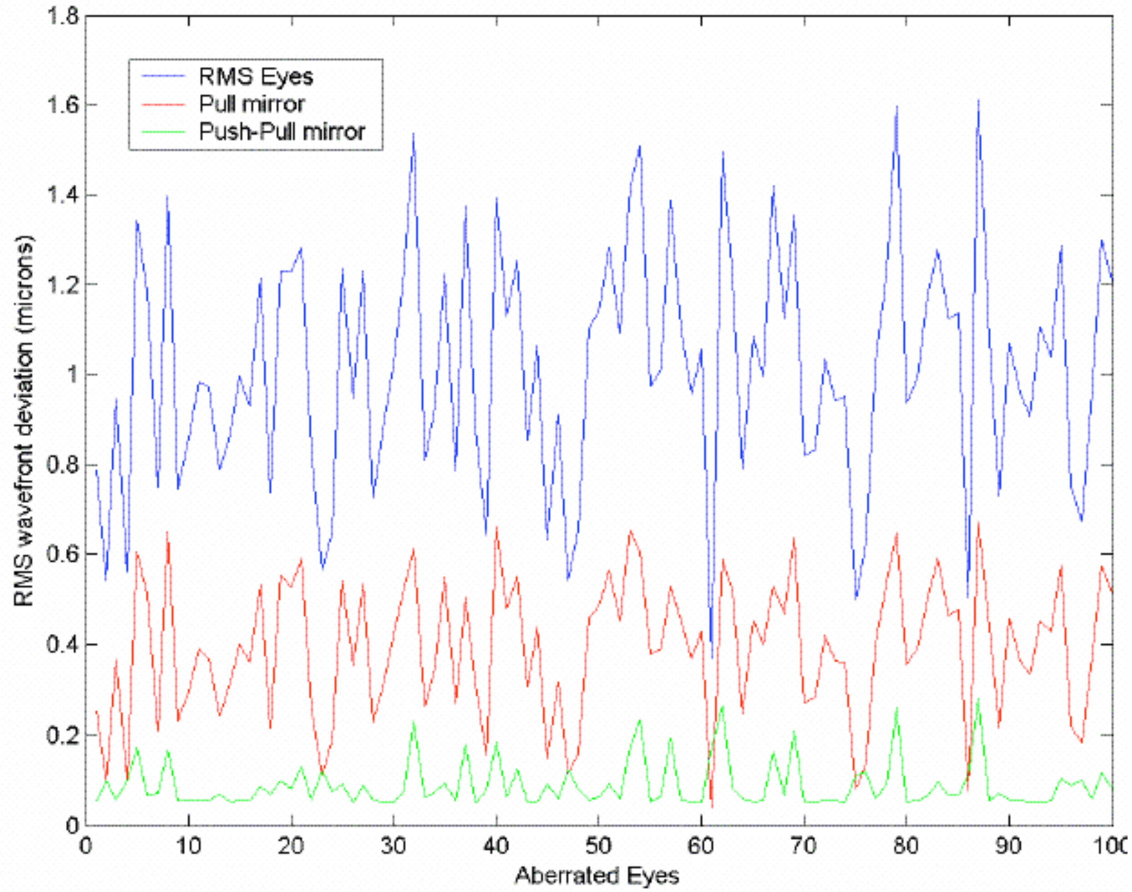
correction of a statistical distribution

Young population with no visual problems

Pull mirror biased at half voltage

Push pull mirror, optical bias at the value of the average defocus

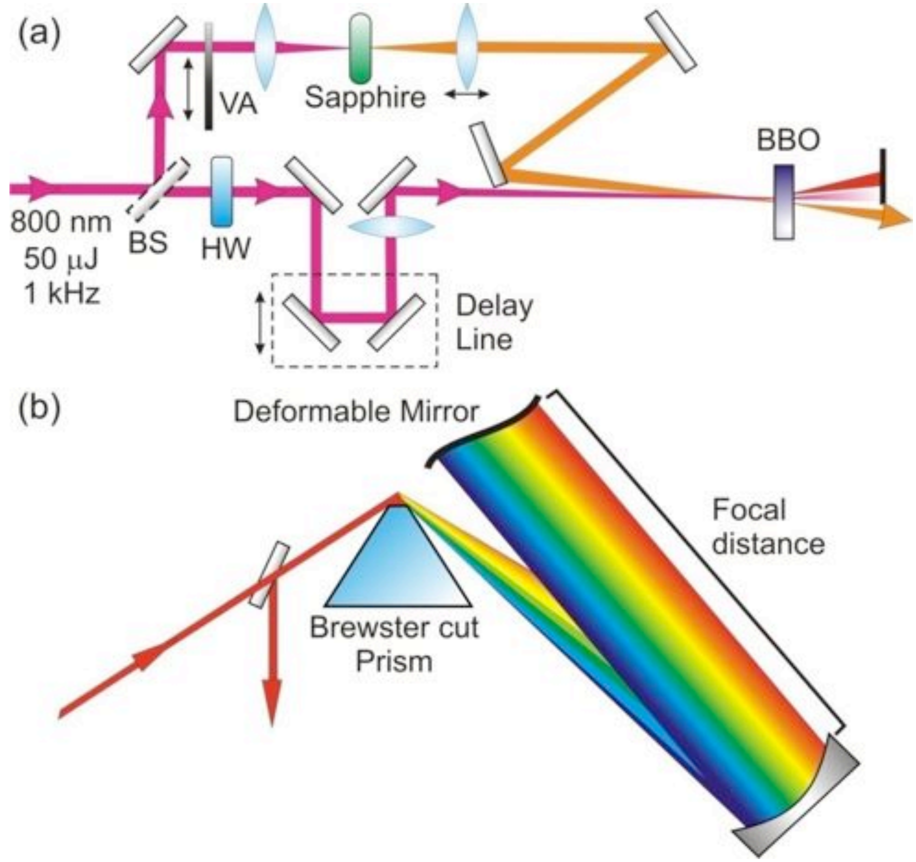
Push Pull mirror average error is 3 times smaller!!!



Human eye statistics: J.F. Castejon-Mochon, N.Lopez-Gil, A.Benito, P.Artal "Ocular wave-front aberration statistics in a normal young population", *Vision Research* **42**, 1611–1617, (2002)

Applications to ultrafast optics

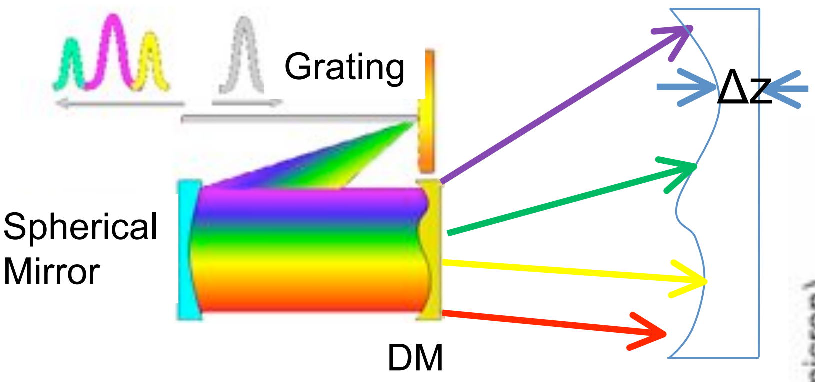
- Generation of IR transform limited fs pulses by OPA
- Observation of photo-induced phase transition in fs time scale
- DMs for petawatt lasers and relativistic regime



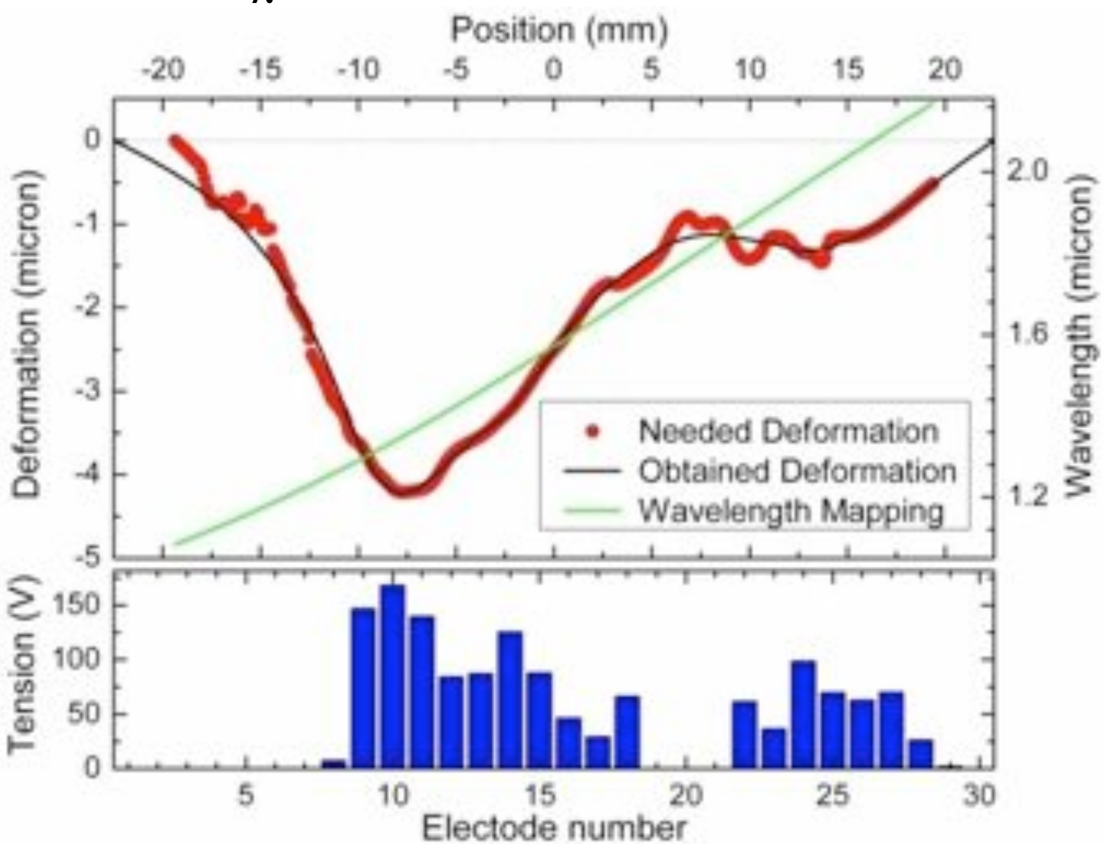
- Source
  - Laser source Ti:Sh 795nm 150fs, 80µJ 1kHz
  - OPA parametric process in BBO with NIR source and white light in Sapphire plate

- Compressor
  - IR pulse at 1.6µm compressed by 4-f closed by a linear deformable mirror

Mirror design for 4-f compression



$$\Delta\varphi(x) = 2\frac{2\pi}{\lambda}\Delta z(x)$$

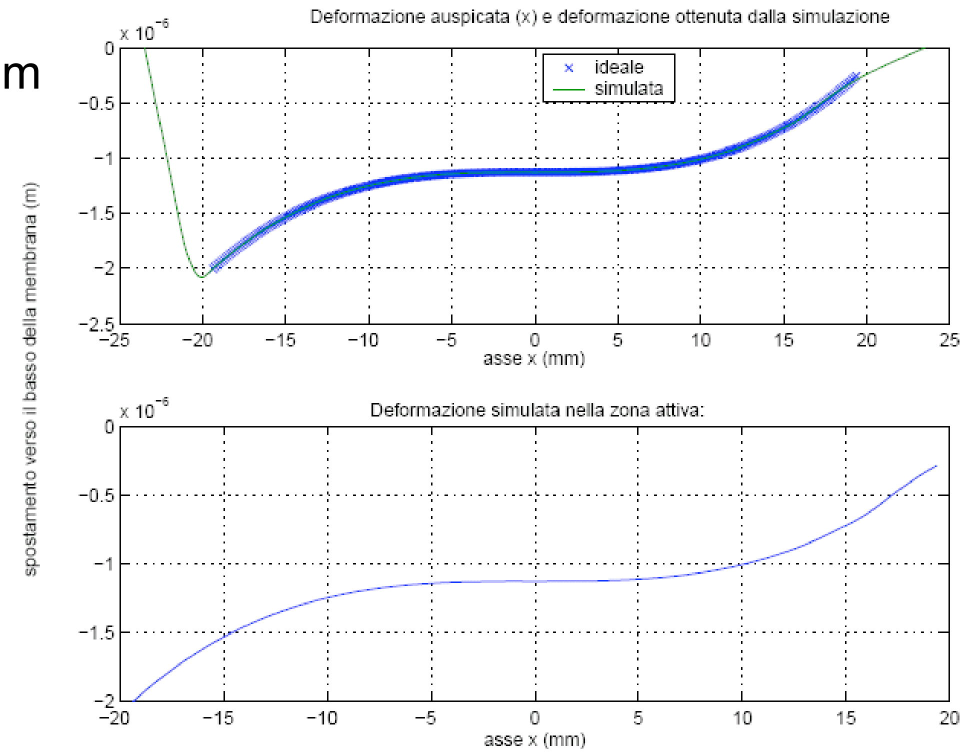


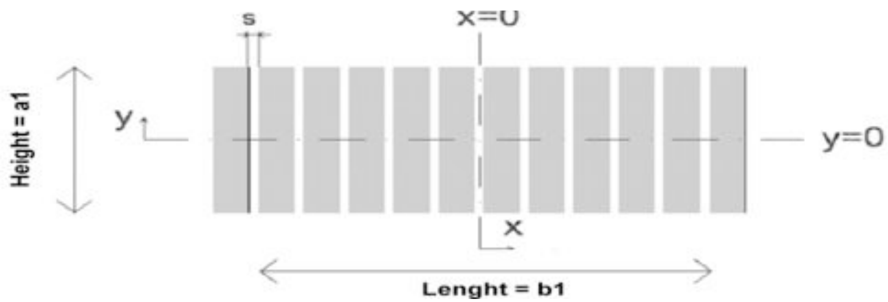
The mirror can fit the phase

Maximum voltage used 150V

Mirror design for 4-f compression

- Linear mirror
- Membrane electrostatic 15mm x 47mm
- Max deflection 10μm
- Ideal parameters: active region 0.95 length
- 30 actuators





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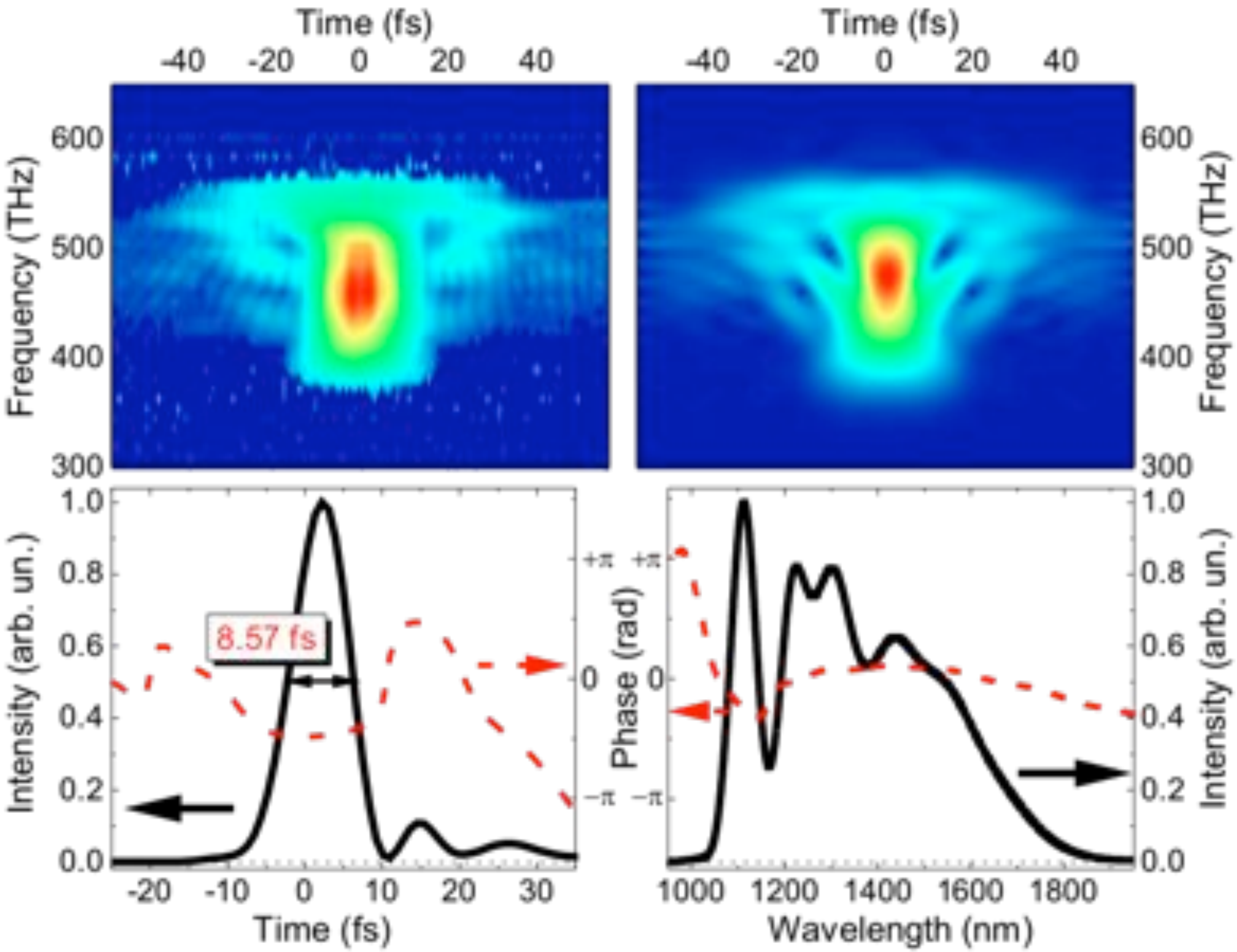

SHG- FROG Pulse Characterization

8.57 fs
Present world record!!
1.5 optical cycles
Useful for pump-probe Experiment

Next steps:
❑ Push-pull mirror capabilities for pulse shaping
❑ Extend the working principle to UV region.

Contacts

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