Deformable Mirrors Technologies at CILAS

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Topics

- Deformable Mirrors for Astronomy

- Deformable Mirrors for Laser Applications

Deformable Mirrors for Astronomy

- Piezo array
  - SAM (Stack Array Mirror) technology
  - Large DM technology
  - Mini DM technology
- Piezo Bimorph
- Tip/Tilt Mount

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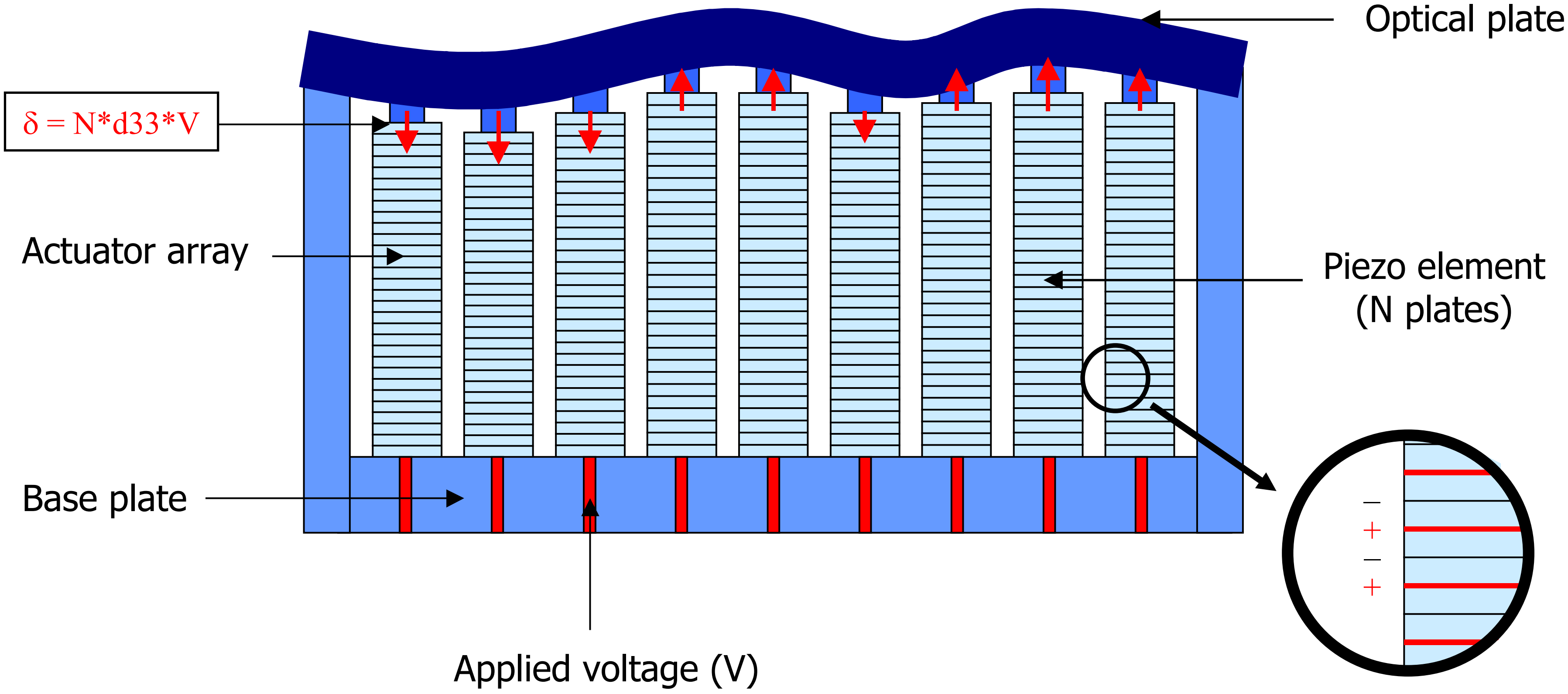
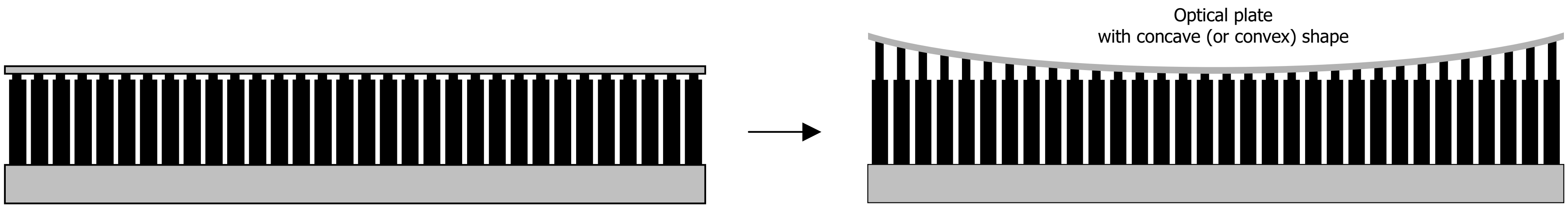
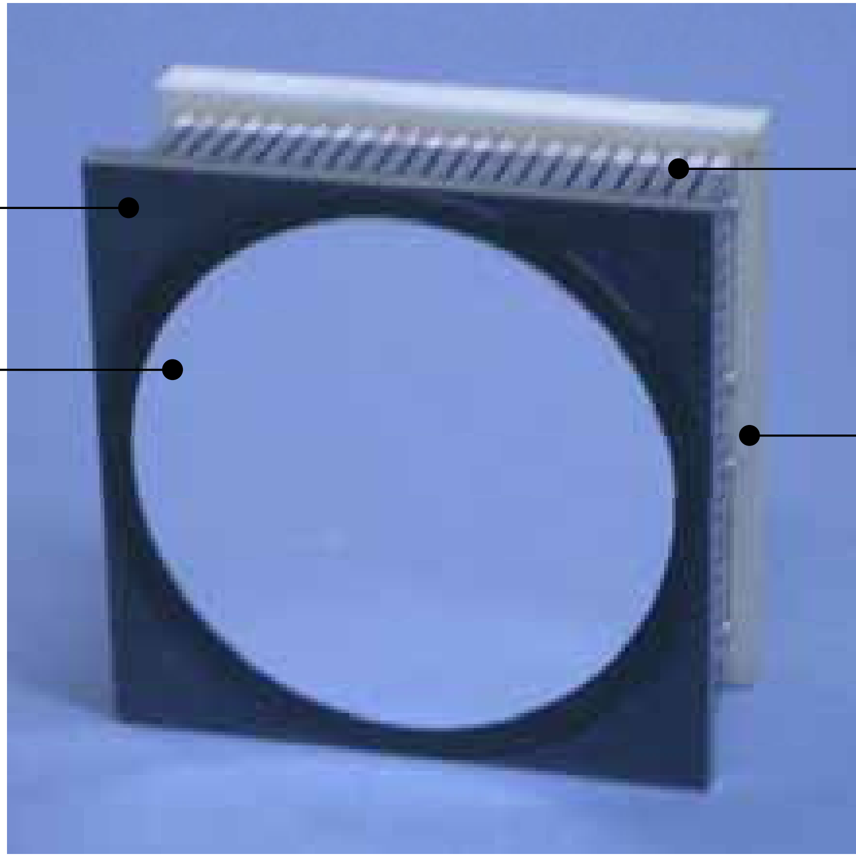
SAM concept (direct effect)





SAM for Gemini MCAO: DM4.5

Delivered
in April 2006



Goes with DM0:
293 actuators 5 mm spacing
& DM9:
208 actuators 10 mm spacing

106 mm dia. - 22x22 array - 416 actuators - Spacing: 5 mm x 5 mm

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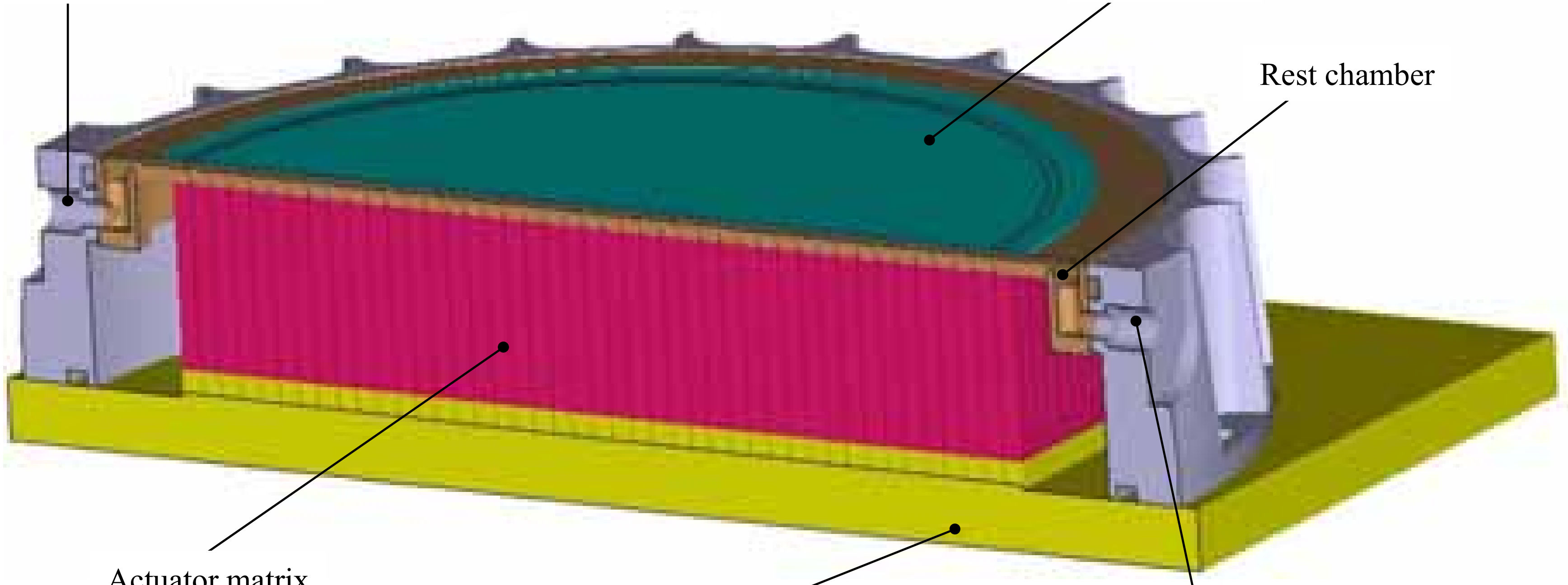
SAM for ESO VLT: HODM SPHERE

Delivered
in November 2007

180 mm dia. - 41x41 array - 1377 actuators - Spacing: 4.5 mm x 4.514 mm

SAM for NSO ATST: Cooled M9 DM

Preliminary design done in April 2007



200 mm dia. - 41x41 array - 1385 actuators - Spacing: 5 mm x 5 mm

SAM for TMT NFIRAOS: DM0

Preliminary design done in June 2007

Will be mounted on a Tip/Tilt Stage

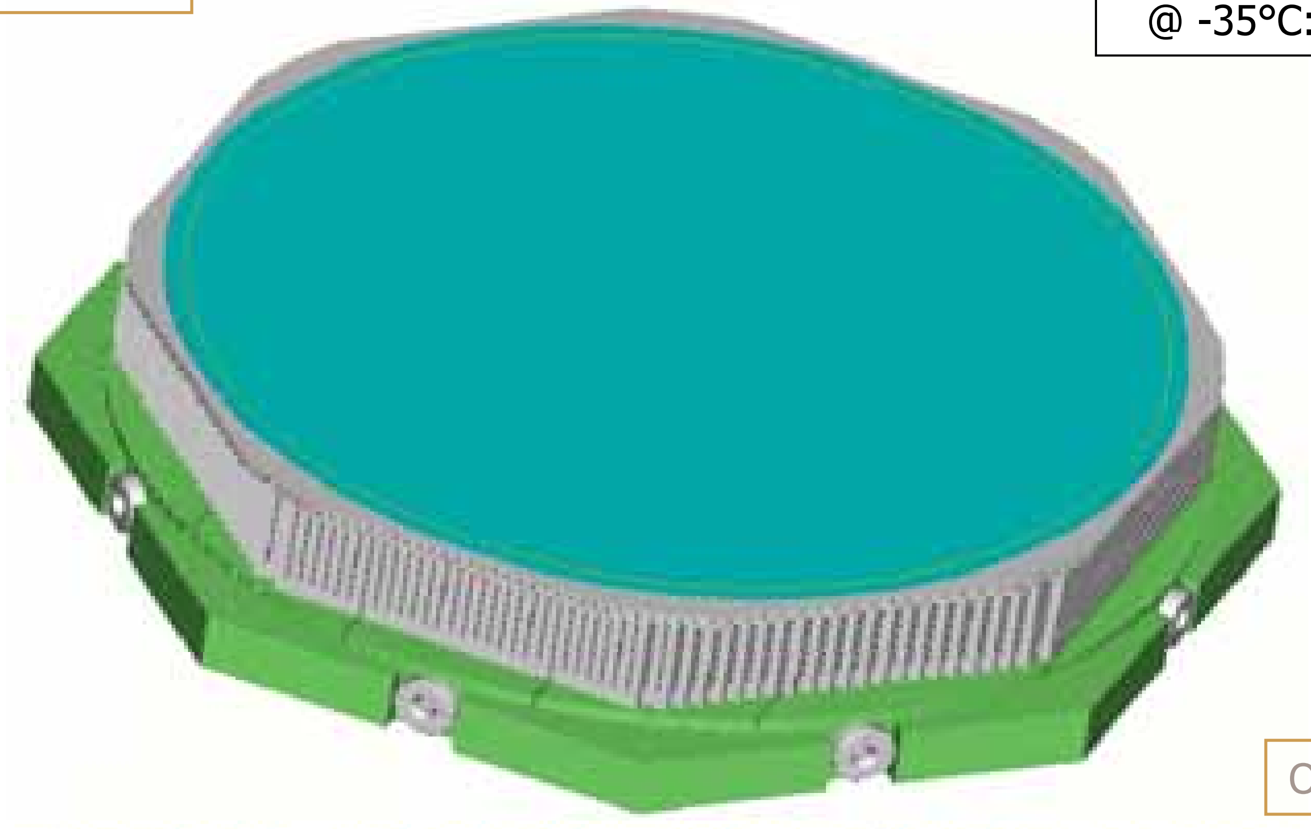
Operating temp.: -35°C

300 mm dia. - 63x63 array - 3125 actuators - Spacing: 5 mm x 5.127 mm

SAM for TMT NFIRAOS: DM1

Conceptual design done in 2006

Flattened subscale mirror @ -35°C: < 15 nm rms



Operating temp.: -35°C

360 mm dia. - 73x73 array - ≈ 4200 actuators - Spacing: 5 mm x 5 mm

SAM main common characteristics

Pupil diameter: up to 500 mm diameter

Actuator spacing: from ≈ 4 to some tens of mm

Stroke: see hereafter

Interactuator stroke: large, thanks to actuator strength - around 30 to 40% of the stroke PV according to the mechanical coupling

Actuator bandwidth: well within usual correction needs, thanks to parts stiffness - see hereafter

Optical quality: high since the polishing is done at the end of the manufacturing process
20 nm rms wavefront error obtained once the mirror is flattened

Hysteresis: ≈ 5% (for full stroke)

Dissipated power: negligible at mirror level, thanks to capacitive principle

Temperature dependence: very low, thanks to materials choice - tested quasi-constant behavior from -35C to 30C

Mechanical compatibility: very good since the structure is very stiff and the optical plate thick (> 1 mm for 5 mm spacing)

SAM temporal behavior

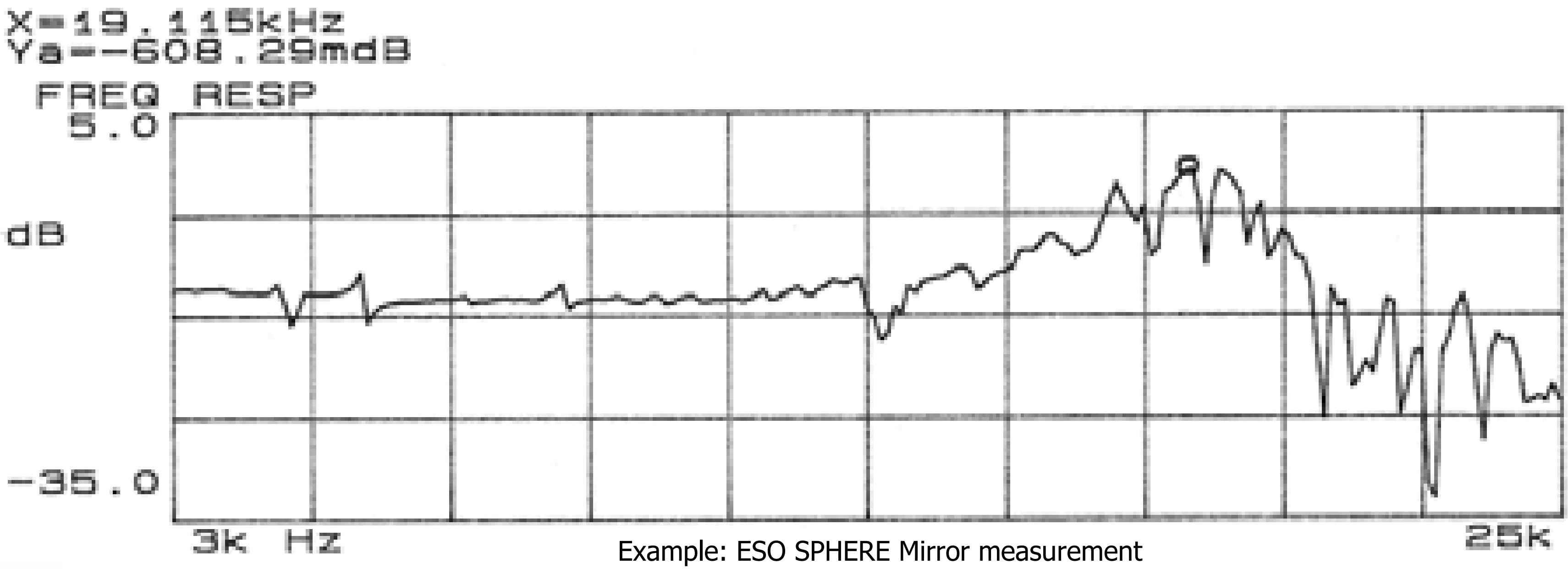
Actuator behavior

First natural frequency of an actuator:

$$fr = 0.25\ l^{-1}\ (E/\rho)^{1/2}$$

l: actuator length (mm)
E: Young modulus of the piezo material (N/m2)
ρ: density of the piezo material (kg/m3)

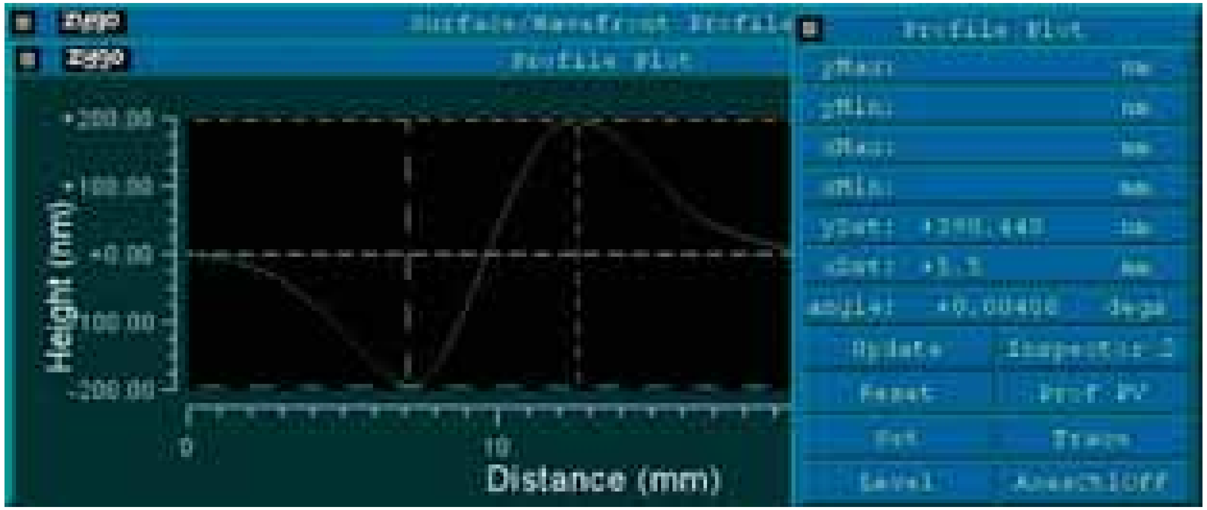
For SAM this frequency is situated in the 15-20 kHz region, which is consistent with usual temporal needs.



Example: ESO SPHERE Mirror measurement

SAM spatial behavior

100 V on 3x3 actuators



± 50 V on 2 actuators

Maximum stroke

± 5.0 µm for ± 400 V

-> ± 4.5 µm (after flattening)

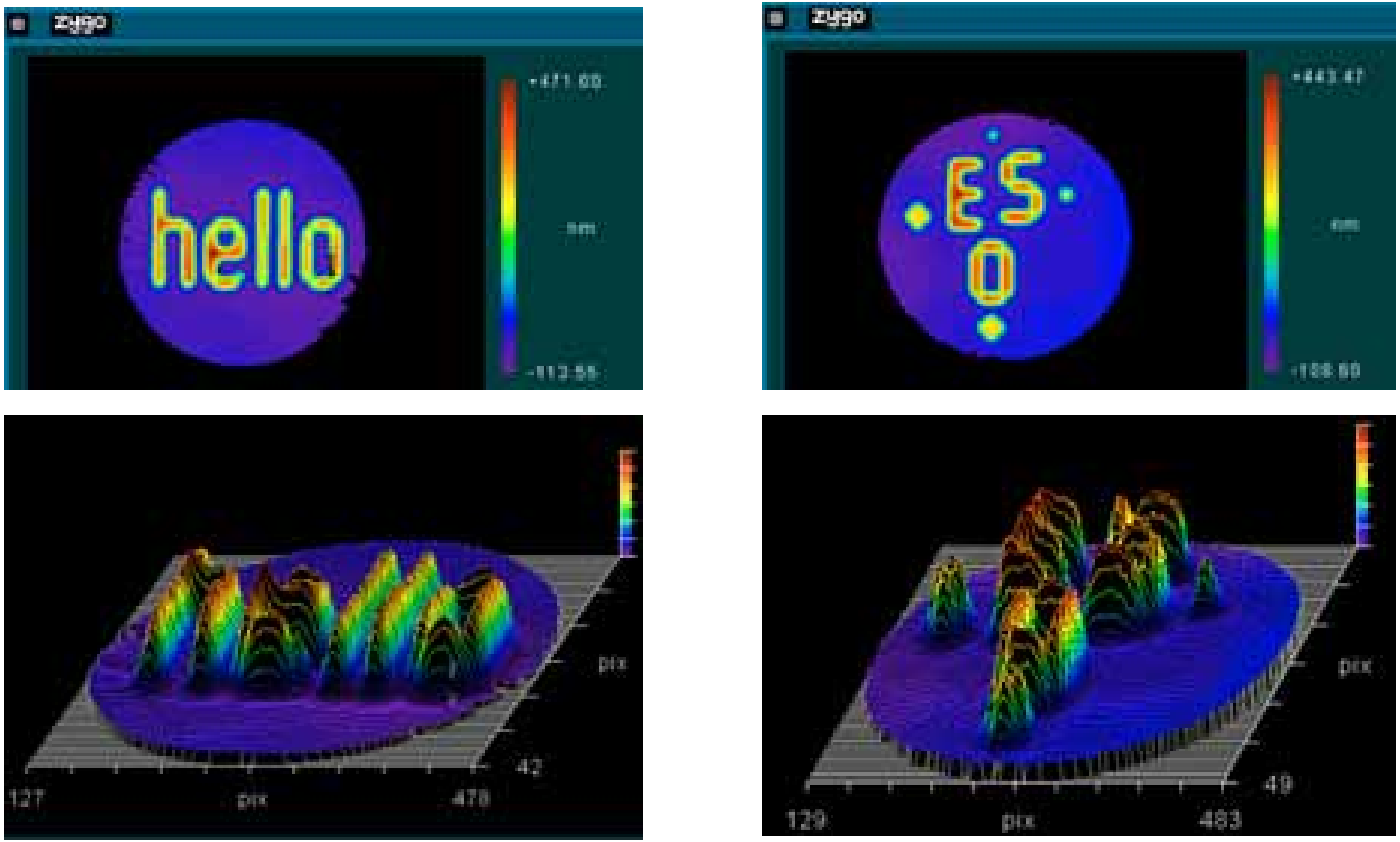
Interactuator stroke

3.0 µm for ± 400 V

Example: ESO SPHERE Mirror measurements

SAM spatial behavior

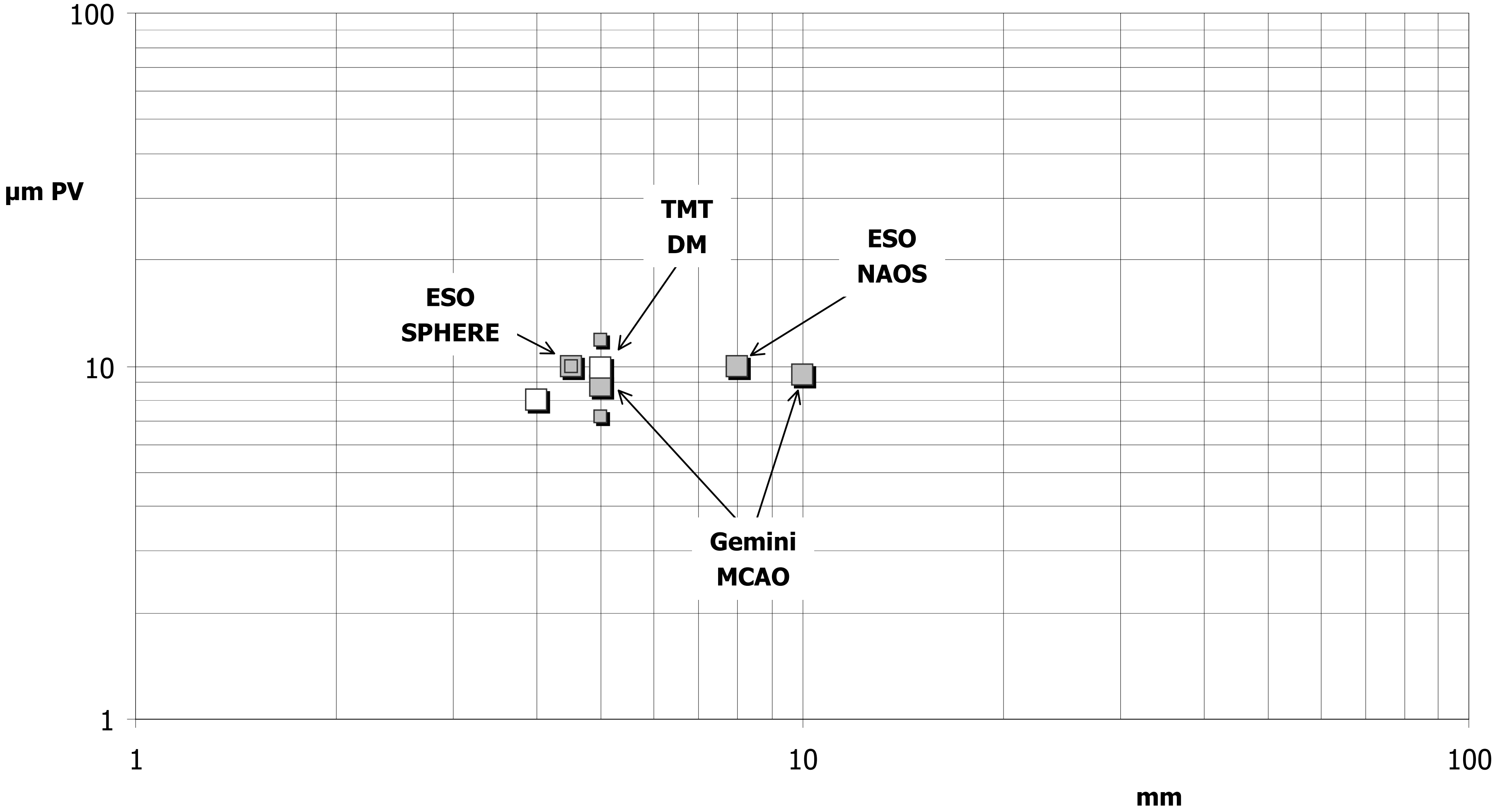
High order correction



Example: ESO SPHERE Mirror measurements on a ϕ 150 mm pupil

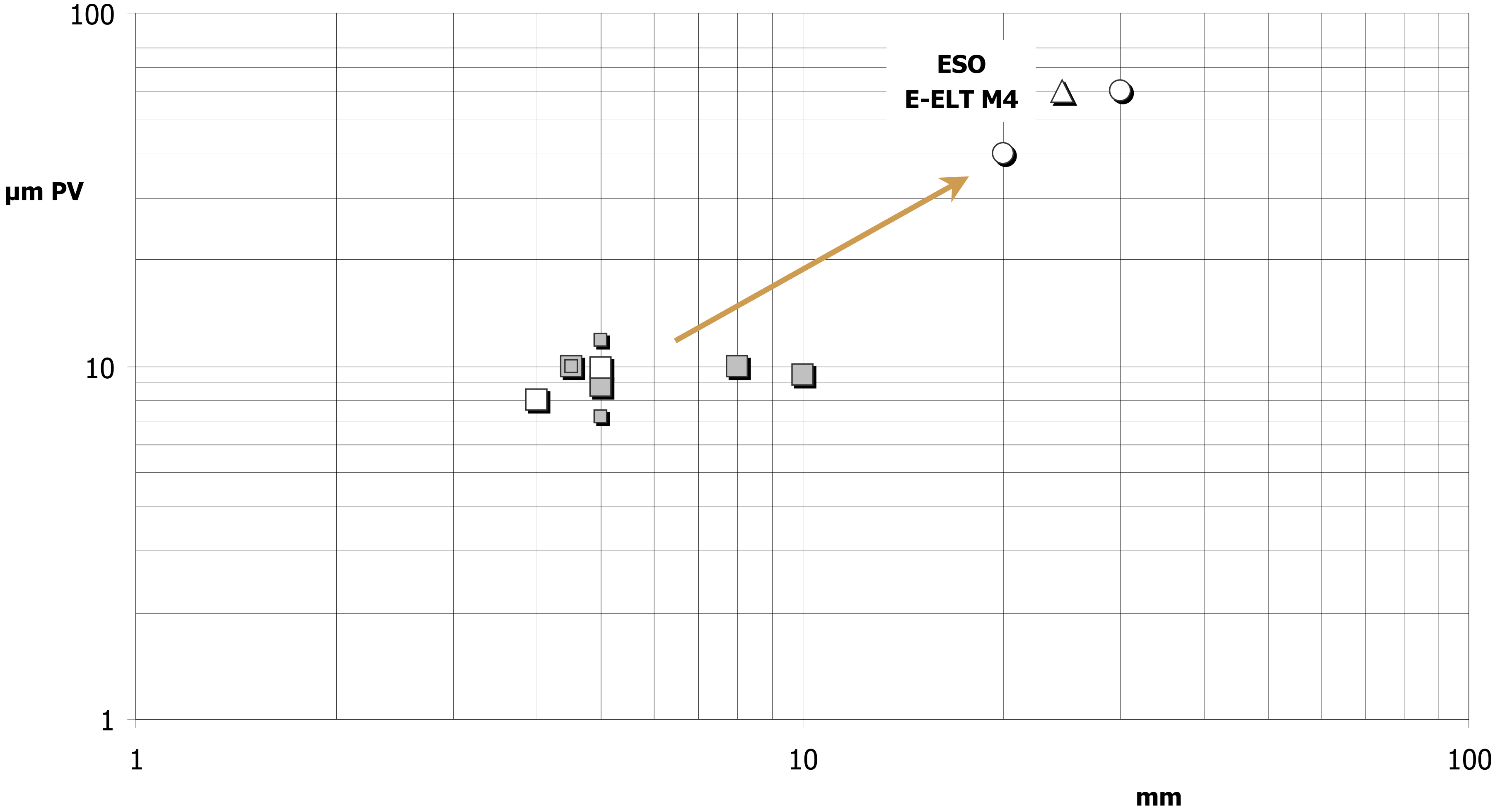
SAM spatial behavior

Stroke vs. spacing

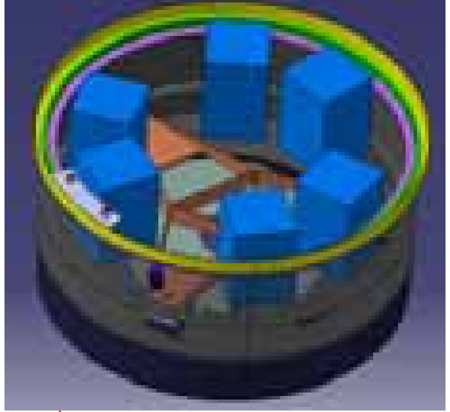


Toward Large DMs (ASMs)

Stroke vs. spacing

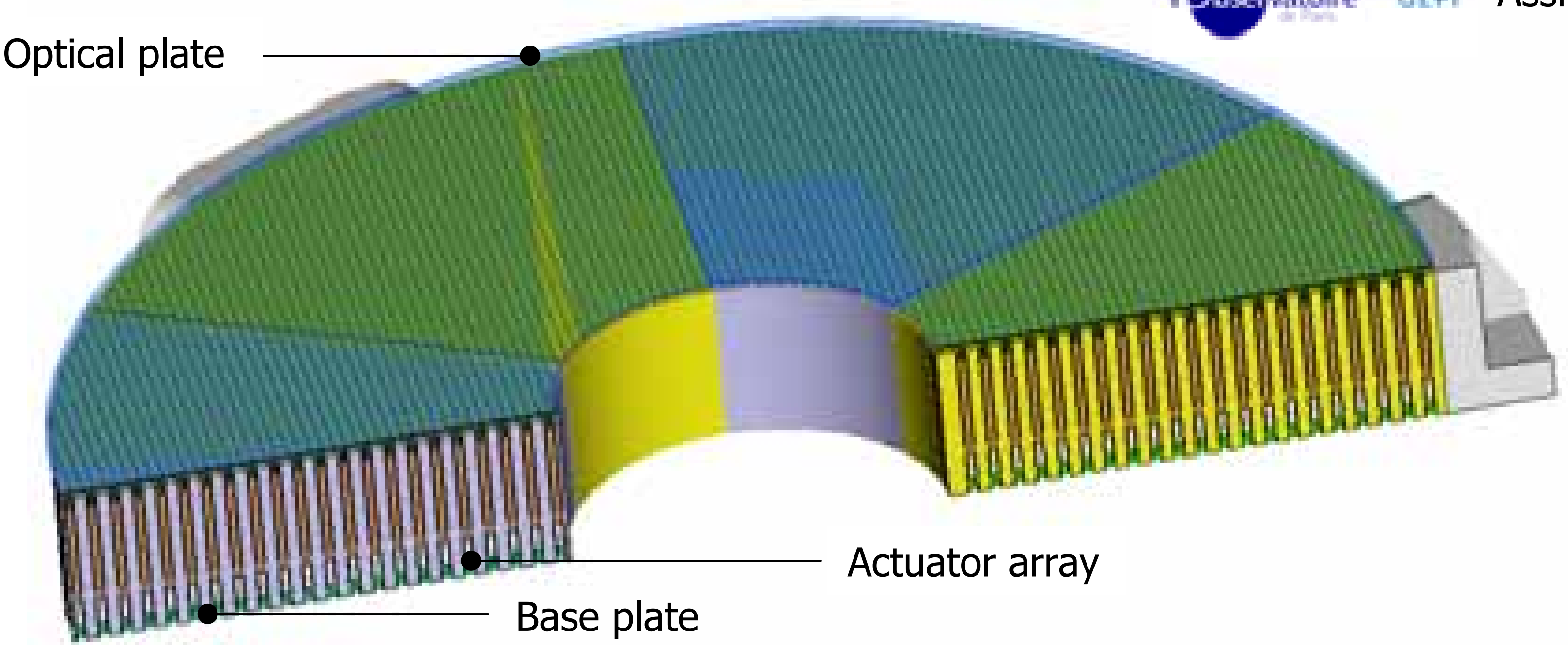


Large DM for E-ELT: M4AM



AMOS	Mechanical positioning
BOOSTEC	SiC base plate
EADS astrium	Using SiC for optics
ONERA	High level spec. analysis
l'Observatoire de Paris, GEPI	Assistance for concept

Early concept proposed to ESO in June 2007 → Conceptual design, prototyping & preliminary design November 2007 - April 2010



≈ 2.5 m dia. - ≈ 8600 actuators - Spacing: 24.5 mm

Large DM spatial behavior

Maximum mechanical stroke:

$\delta = N*d33*V$

N: number of piezo plates constituting the stack

d33: direct piezo coefficient (m/V)

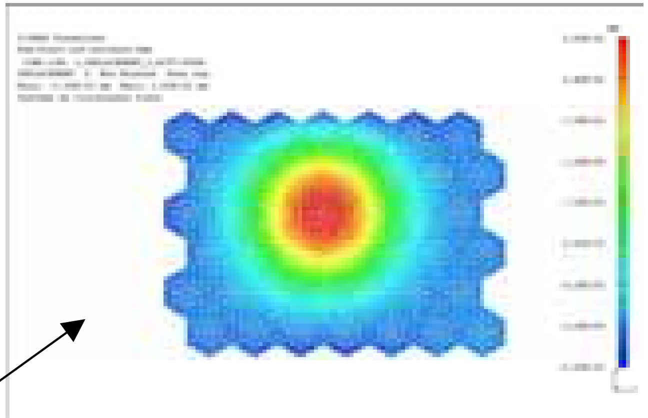
V: applied voltage (V)

For:

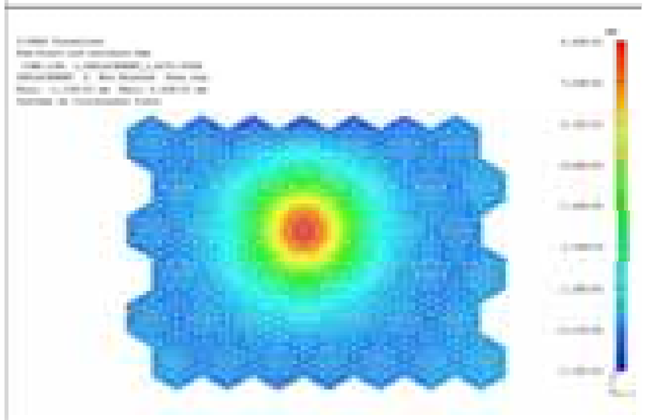
N = 250

d33 = 300E-12m/V

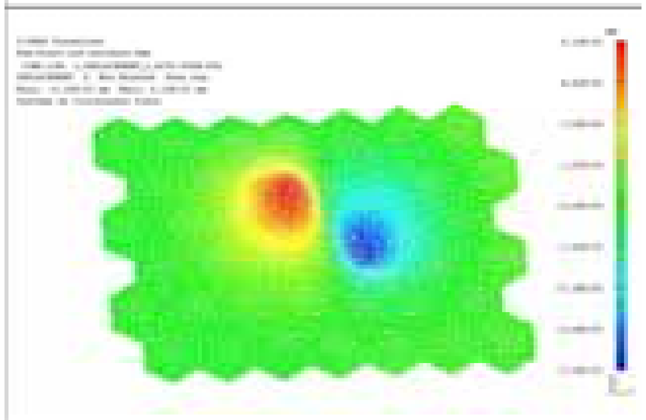
-> δmax = ± 30 µm (60 µm PV) for ± 400 V



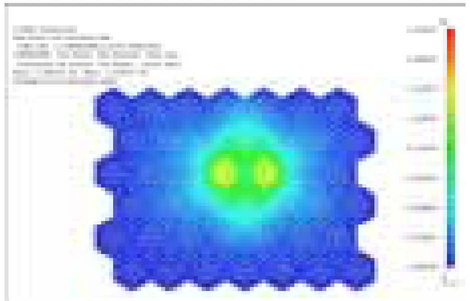
(1 + 6) actuators stroke



1 actuator stroke

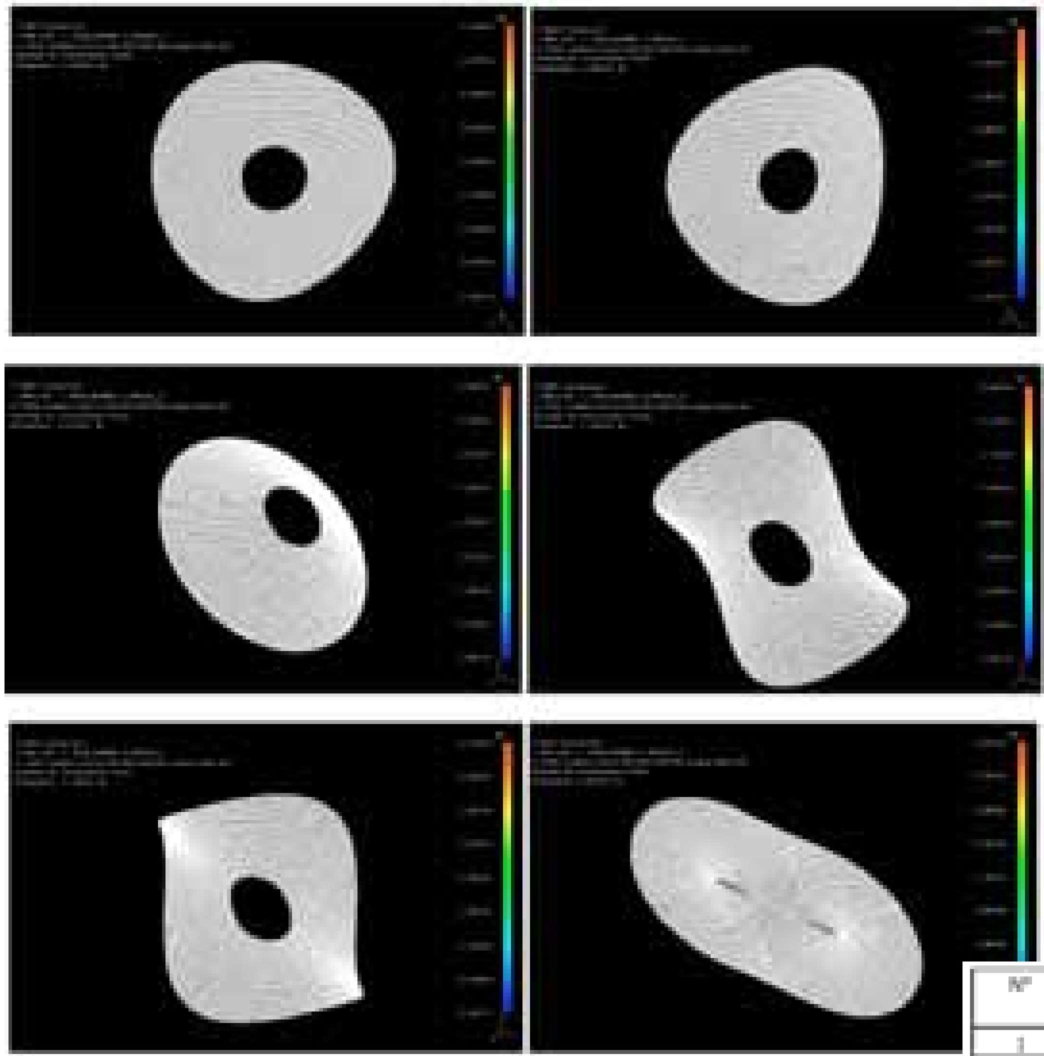


Interactuator stroke and stresses



Tradeoffs between:
- needed strokes
- needed mechanical coupling
- stresses in the plate

Large DM dynamical behavior



Mirror first natural frequencies

N°	Frequency (Hz)	Type
1	296	Trefoil 1
2	296	Trefoil 2
3	487	Defocus
4	712	
5	713	
6	890	

Actuator natural frequency

$fr = 0.25*l^{-1}*(E/\rho)^{1/2}$

l: actuator length,

E: Young modulus of the PZT material

ρ: density of the PZT material

For:

$l \approx 250$ mm

E = 6.0E10 N/m2

ρ = 7550 kg/m3

-> $fr \approx 2.8$ kHz

Goal: natural frequencies of M4AM high enough to avoid effect on the closed-loop correction features of M4AU

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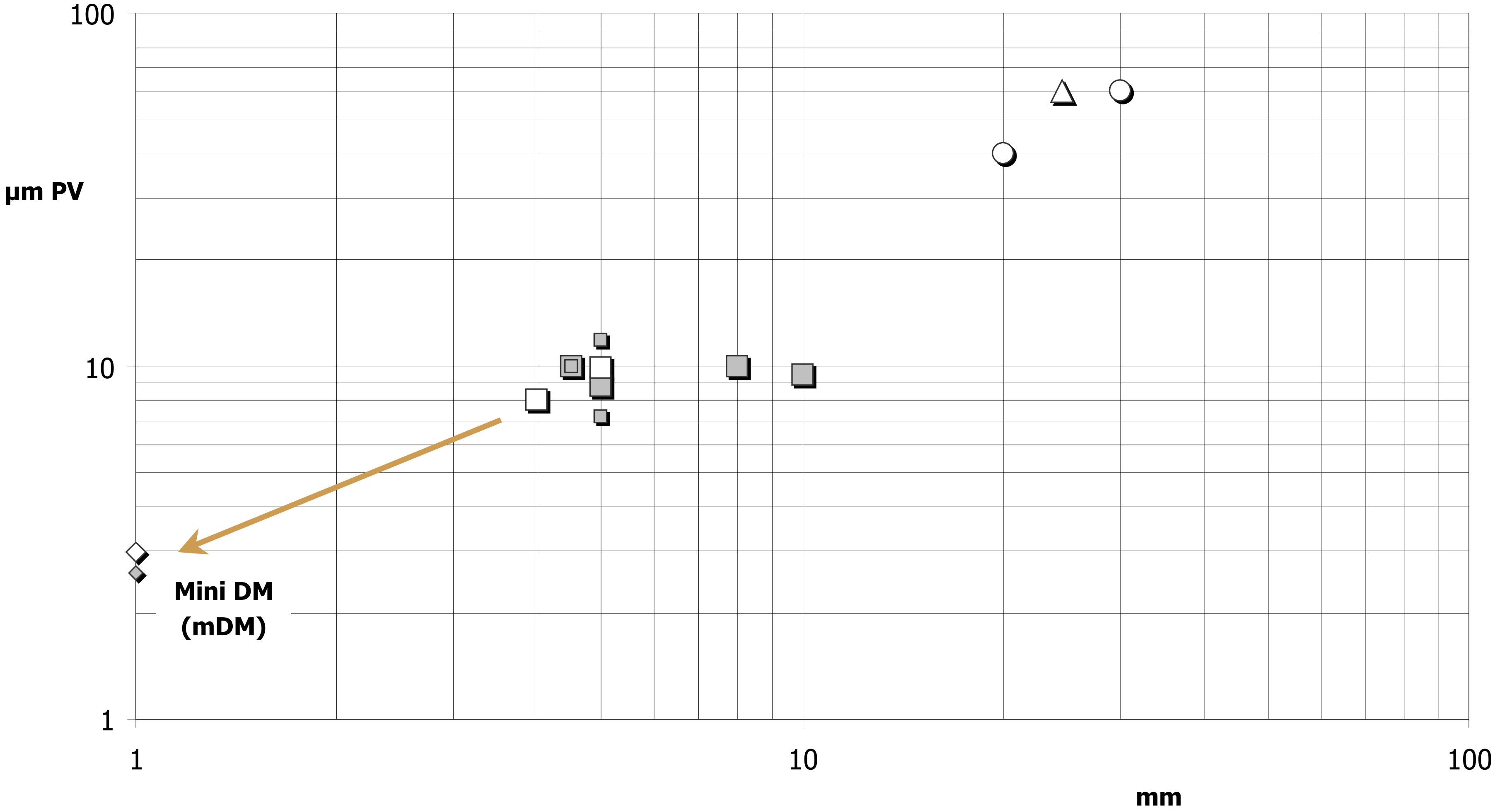
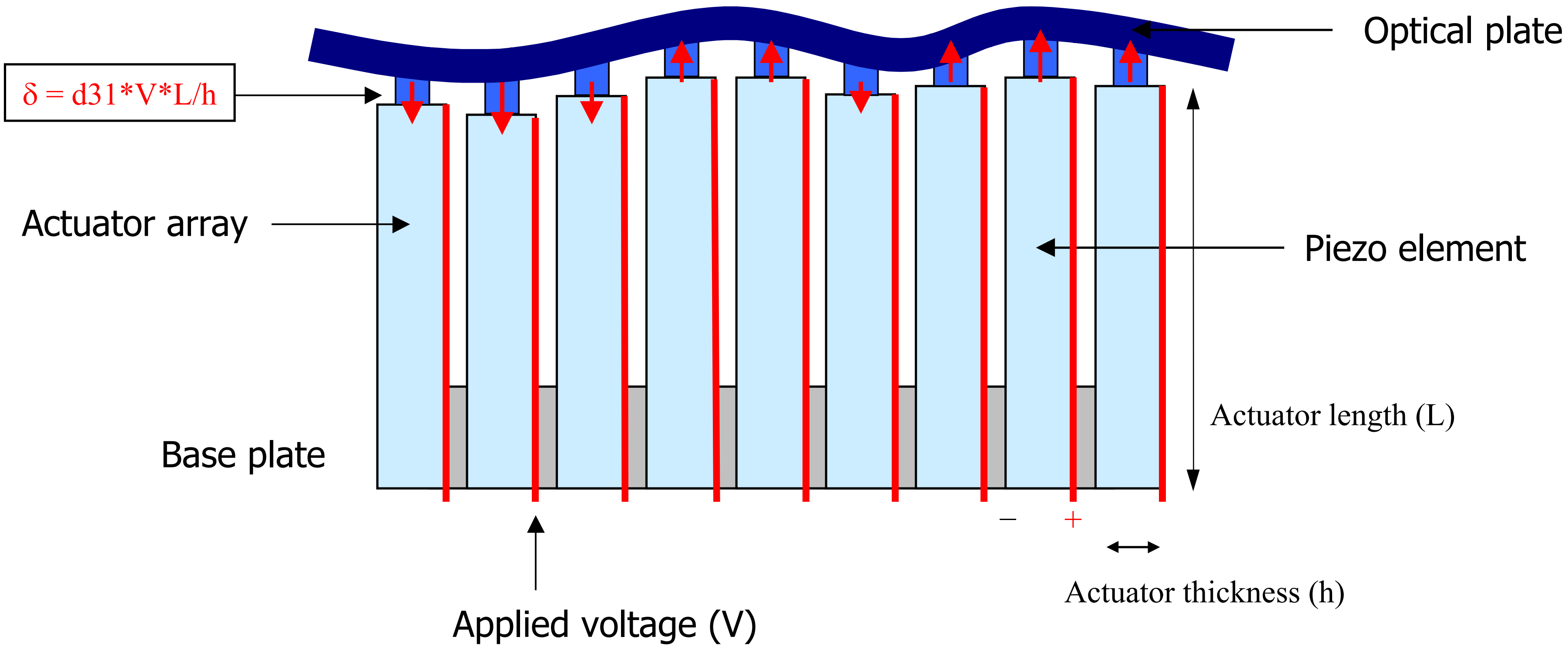
Toward Mini DMs

Stroke vs. spacing

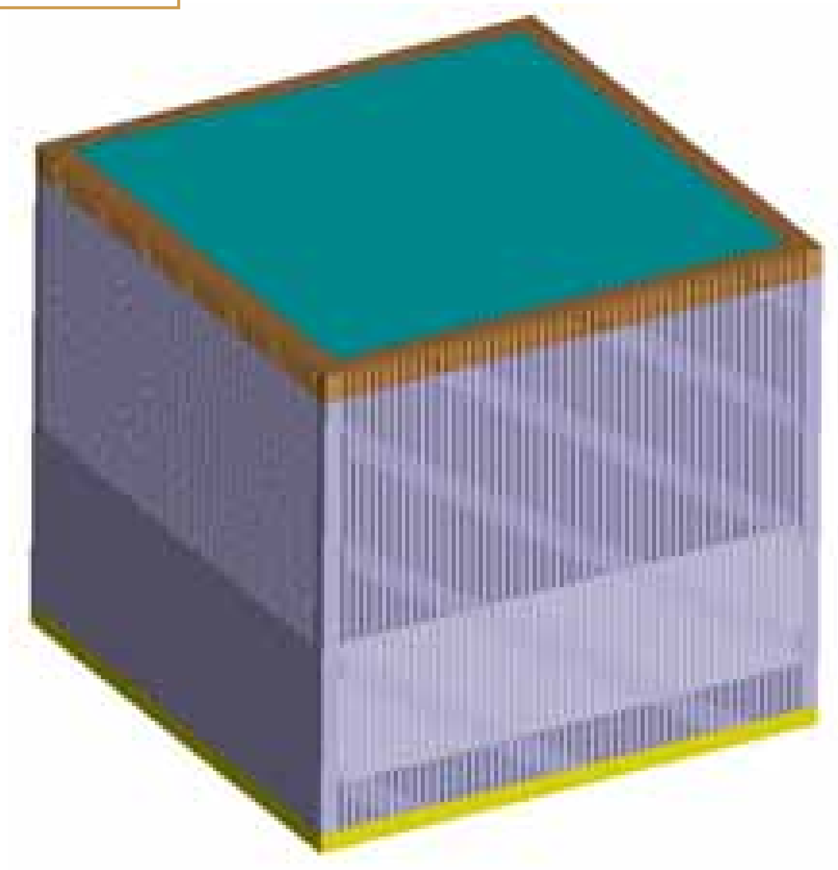


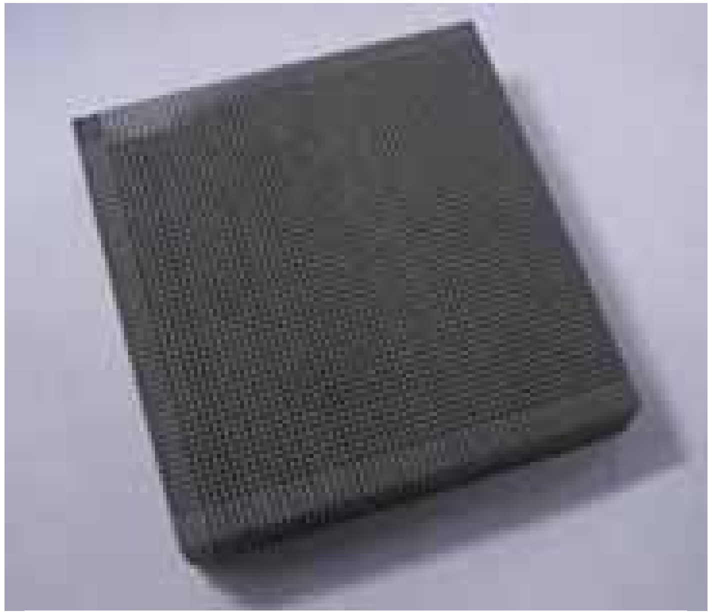
mDM concept (transverse effect)



Mini DM prototyping

Under manufacturing
for LAOG/ESO
Design review passed
in November 2007



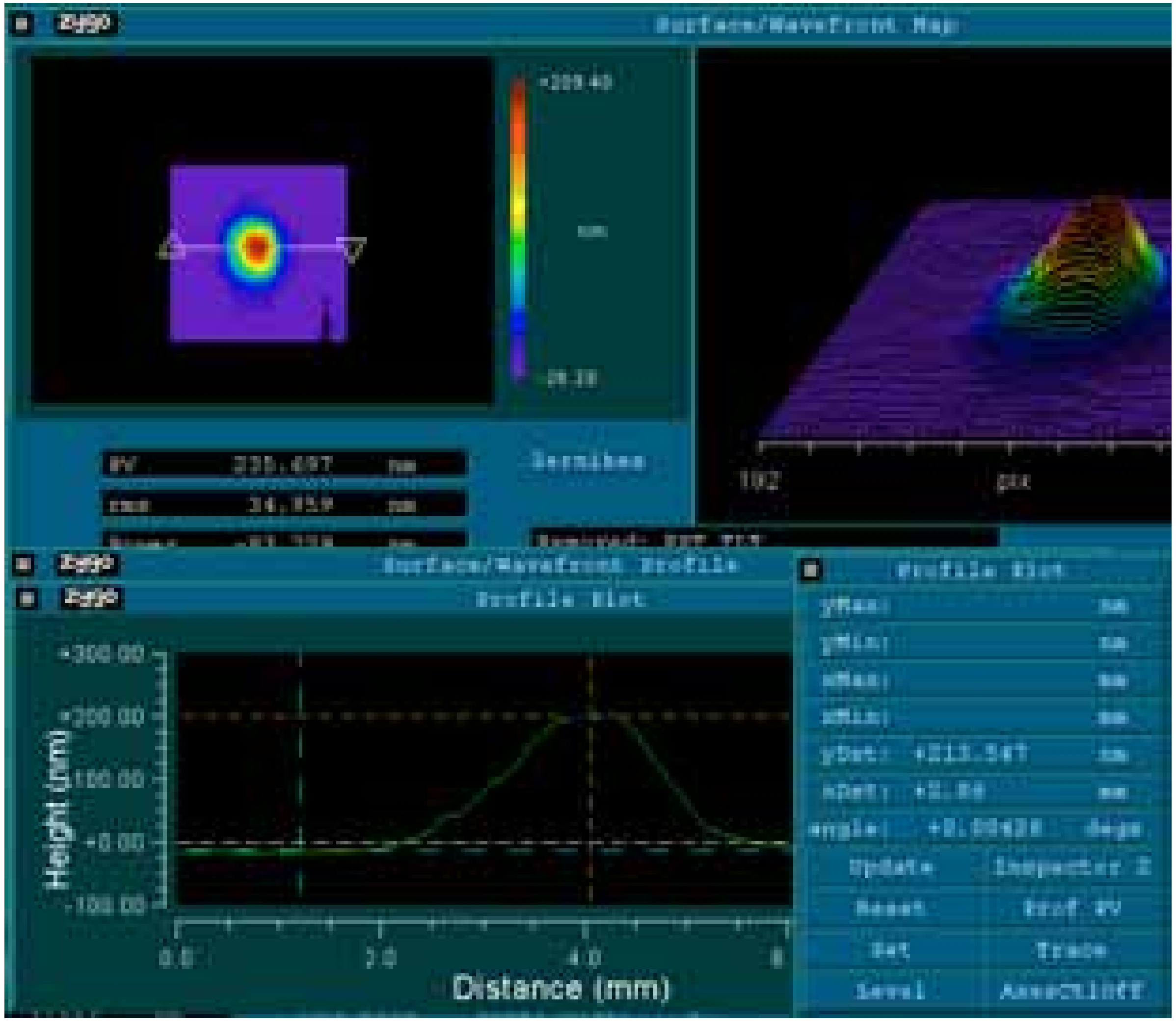


50x50 actuator array sawing test

49 mm dia. - 50x50 array - ≈ 1900 actuators - Spacing: 1 mm x 1 mm

CILAS

Mini DM spatial behavior



100 V on 1 actuator

Maximum stroke

± 1.3 (goal 1.5) µm for ± 400 V

Interactuator stroke

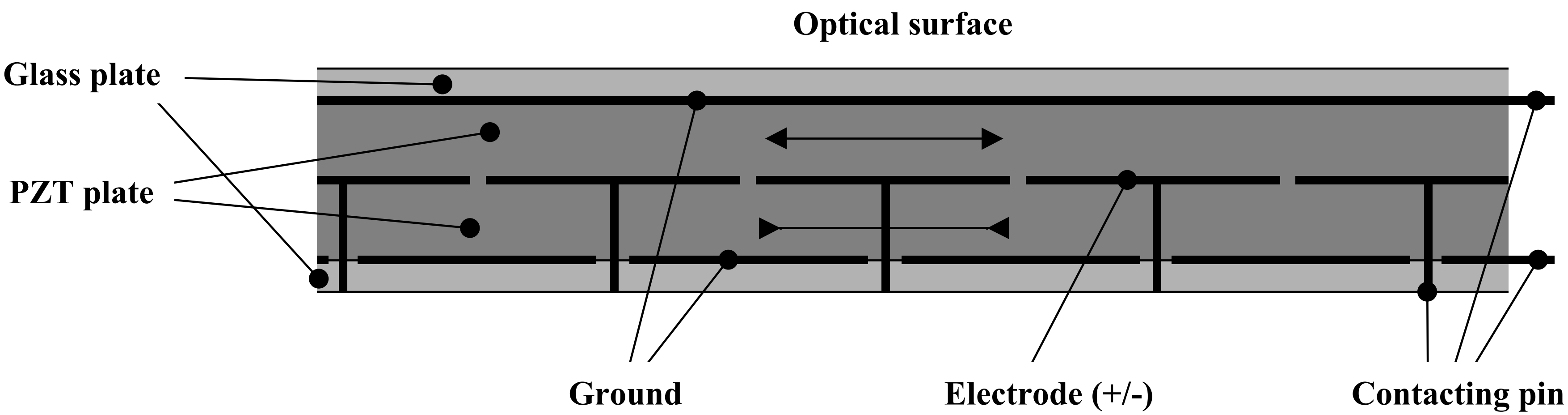
1.0 (goal 1.2) µm for ± 400 V

Example: early result on a mockup

“Mini”! DM goal characteristics

Pupil diameter:	**200 mm diameter**
Actuator spacing:	**1 mm**
Number of actuators:	**≈ 30,000**
Stroke:	**3 µm**
Interactuator stroke:	**1.2 µm**
Actuator resonance freq.:	**> 30 kHz**
High order WFE:	**20 nm rms**
Hysteresis:	**≈ 5% (for full stroke)**

BIMorph concept (transverse effect)



Pupil diameter: up to 100 mm diameter

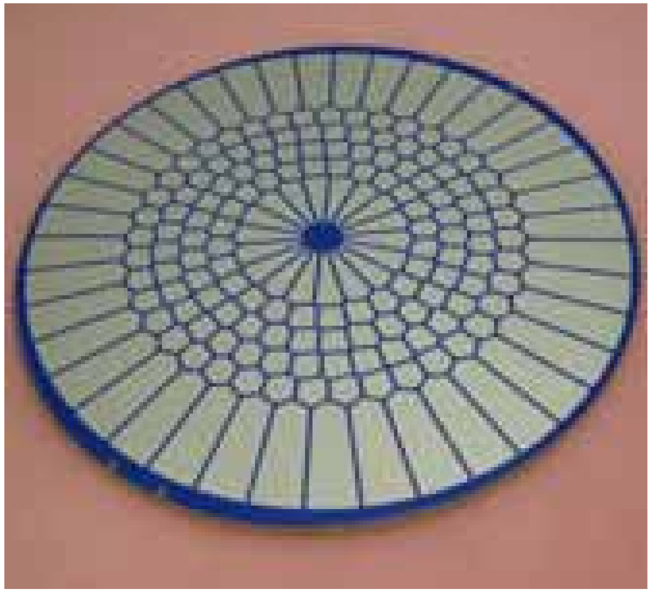
Optical quality: 20 nm rms wavefront error obtained once the mirror is flattened

Temperature dependence: very low, thanks to symmetrical architecture

Temporal behavior: curvature resonance frequency > 700 Hz

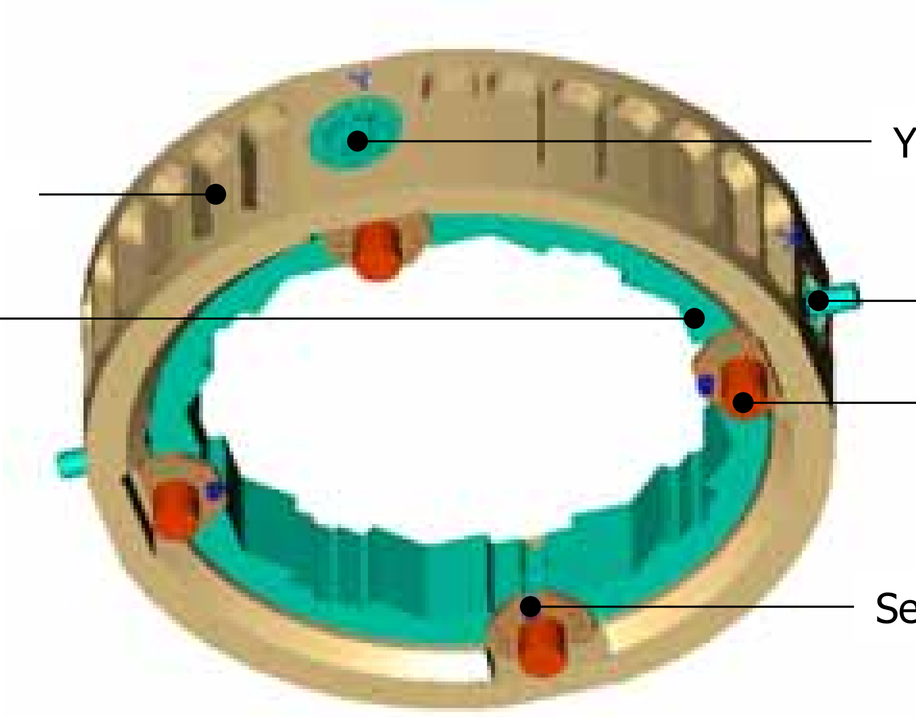
BIM188 for Subaru Telescope

Delivered in July 2005



130 mm dia. - 94 mm aperture - 188 electrodes - ± 12 m curv. radius (± 90 µm stroke)

Tip/Tilt Mount (Gimbals concept)



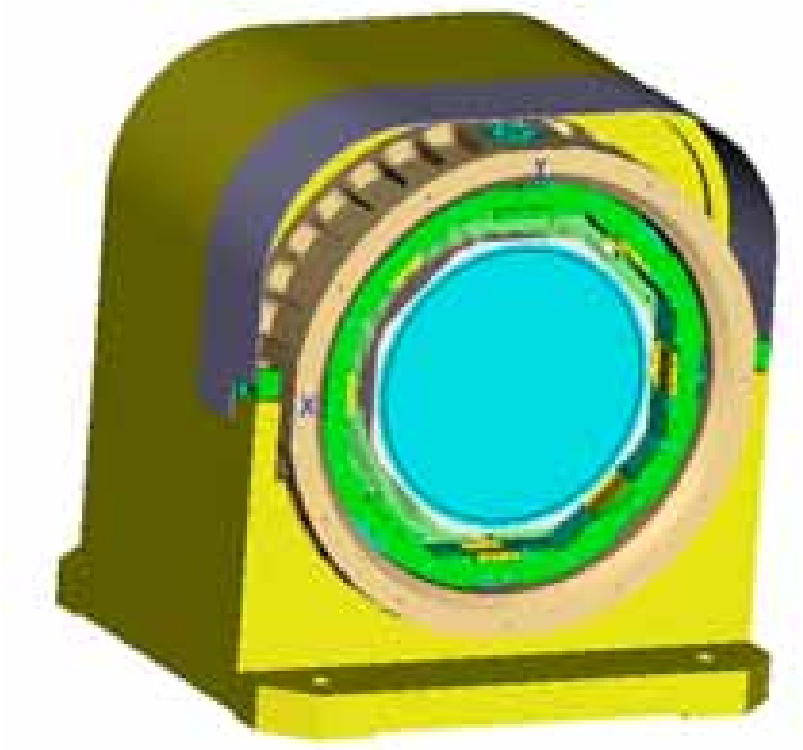
Concept coming from Observatoire de Paris

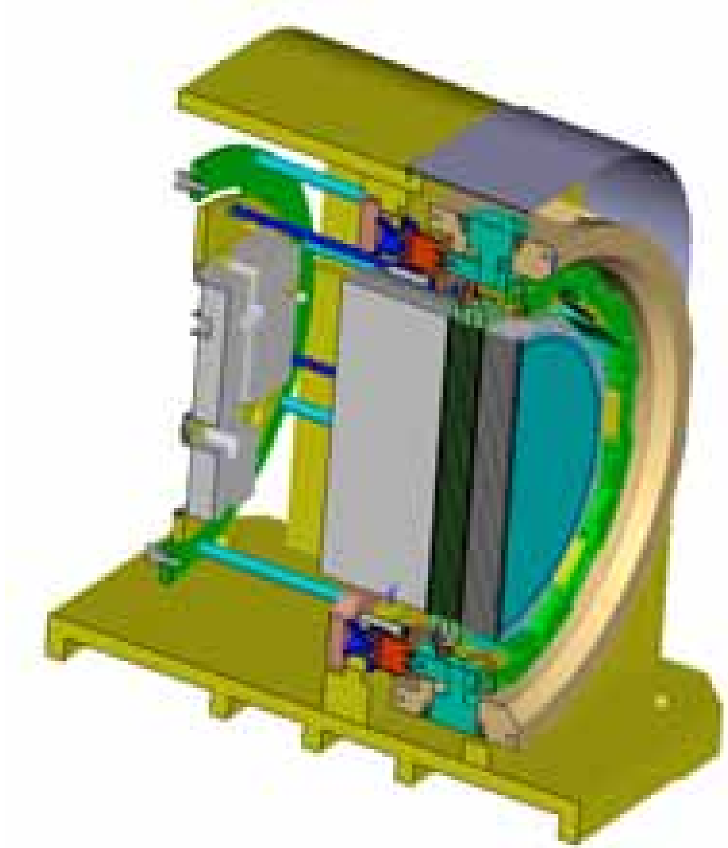
Architecture:	**simple**
Stroke:	**large**
Resolution:	**high**
Mechanical spec.:	**two independent and perpendicular axes with very low cross-talk** **rotation axes well defined** **soft interaction with chassis** **weak spurious modes**

Tip/Tilt Stage Proto for TMT

TMT

Design review passed
in October 2007





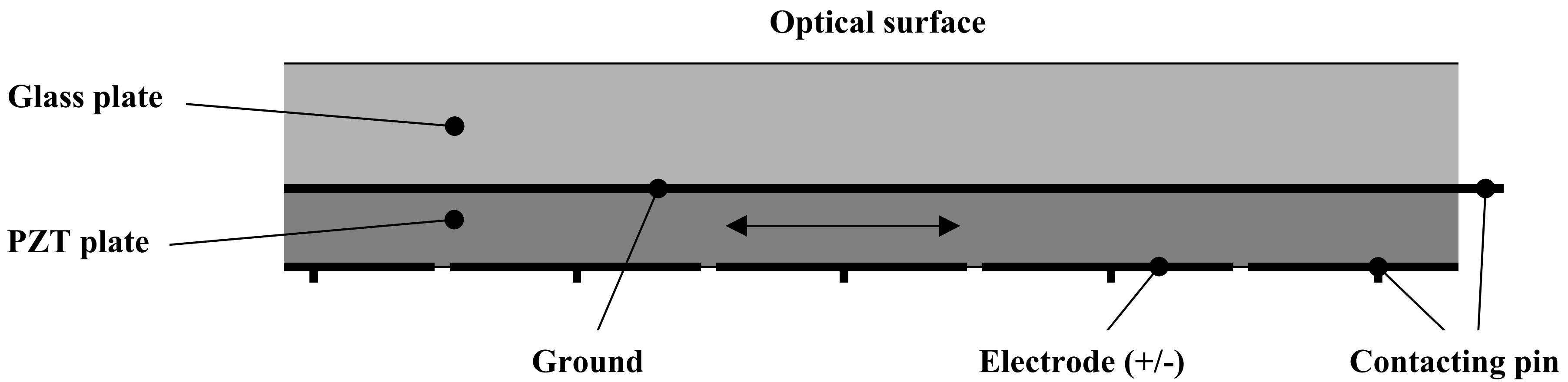
32 kg DM mass - 40 Hz bandwidth @ -3dB - 500 µrad PV stroke

Deformable Mirrors for Laser Applications

- Piezo Monomorph

- Force actuators DM

MONOmorph concept (transverse effect)



Pupil diameter: up to 200 mm diameter

Optical quality: < 10 nm rms wavefront error obtained once the mirror is flattened (see hereafter)

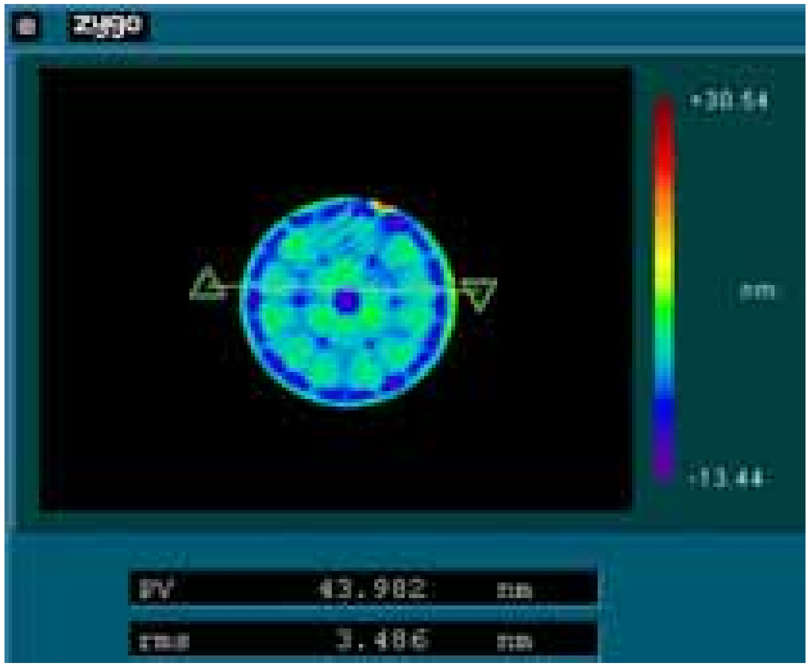
Temperature dependence: compensated by DM stroke

Temporal behavior: curvature resonance frequency > 700 Hz

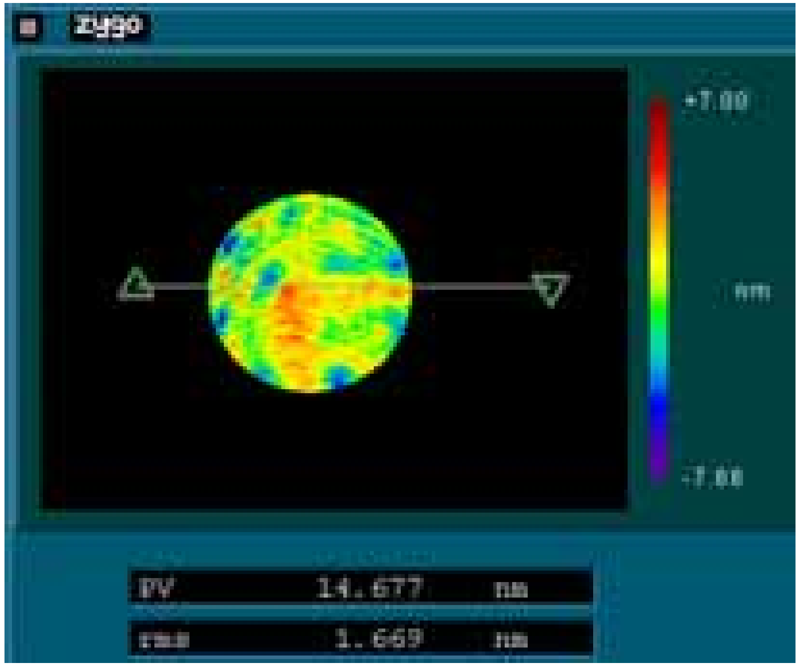
MONO36 for LOA

MONO36 under test @ Imagine Optics

Former Bimorph architecture



New Monomorph architecture



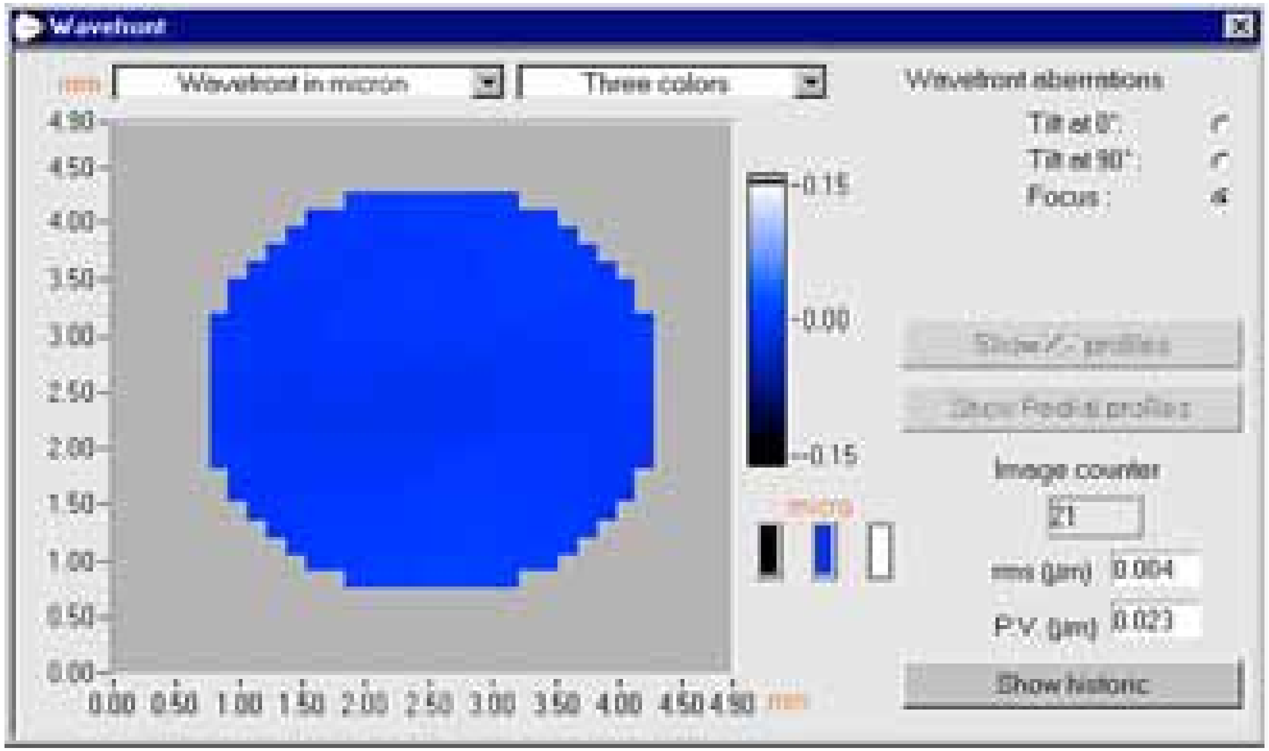
Filtered shape at rest

110 mm dia. - 60 mm aperture - 36 electrodes - 3.4 nm rms wavefront once filtered

MONO61 for University of Osaka

OSAKA UNIVERSITY

FAT
in November 2007



110 mm dia. - 75 mm aperture - 61 electrodes - 4 nm rms wavefront once flattened

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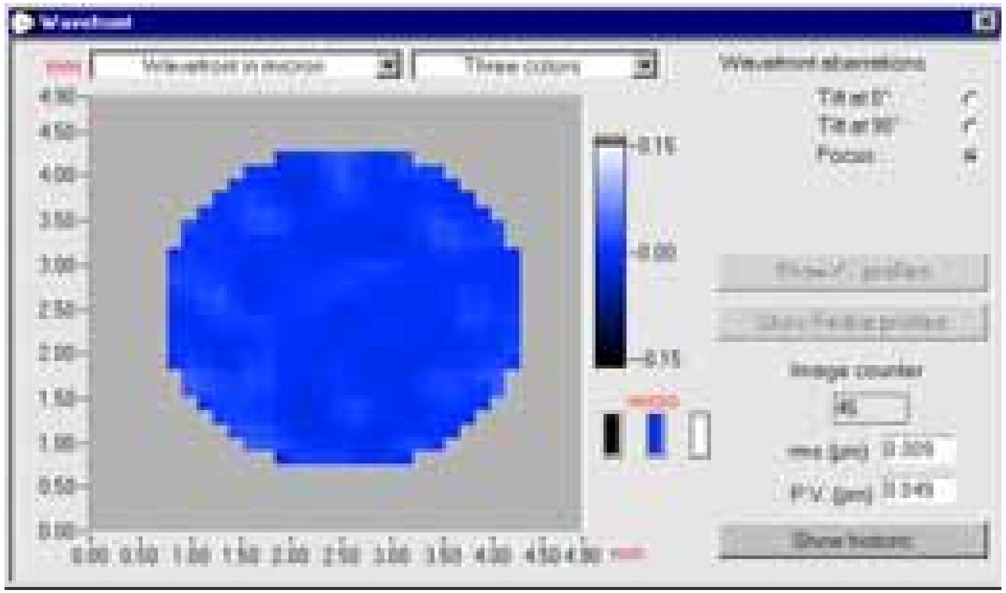
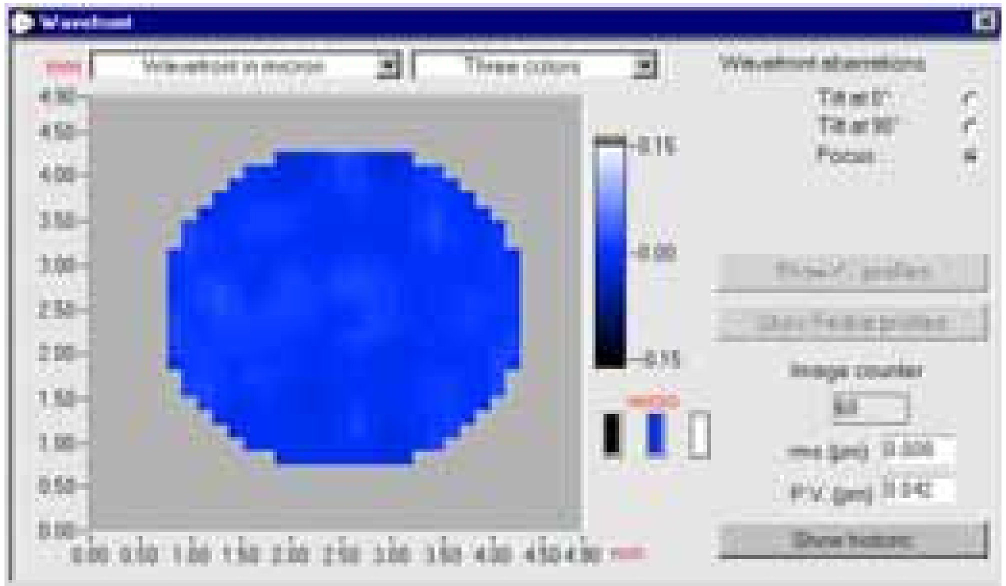
MONOmorph spatial behavior



Curvature correction

20 µm wavefront for 200 V max
-> residual error: 9 nm rms wavefront

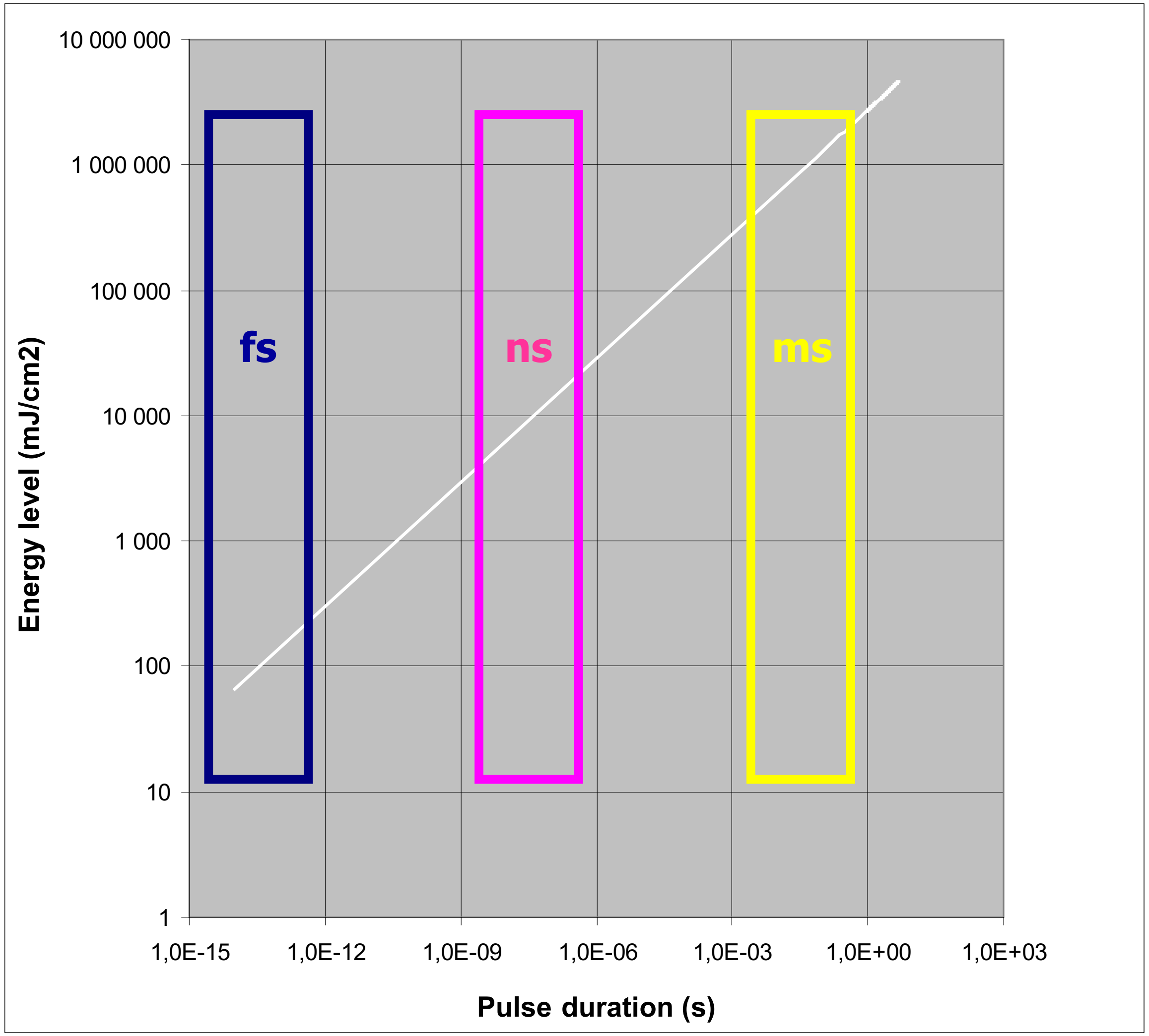


Astigmatism correction

20 µm wavefront for 200 V max
-> residual error: 8 nm rms wavefront

Example: MONO61 measurements

MONOmorph laser energy level



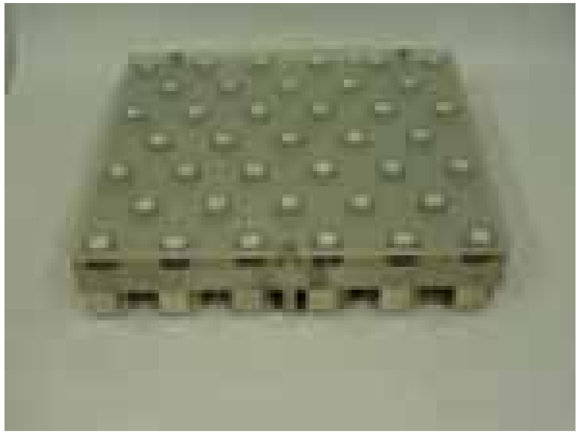
Estimation based upon test results

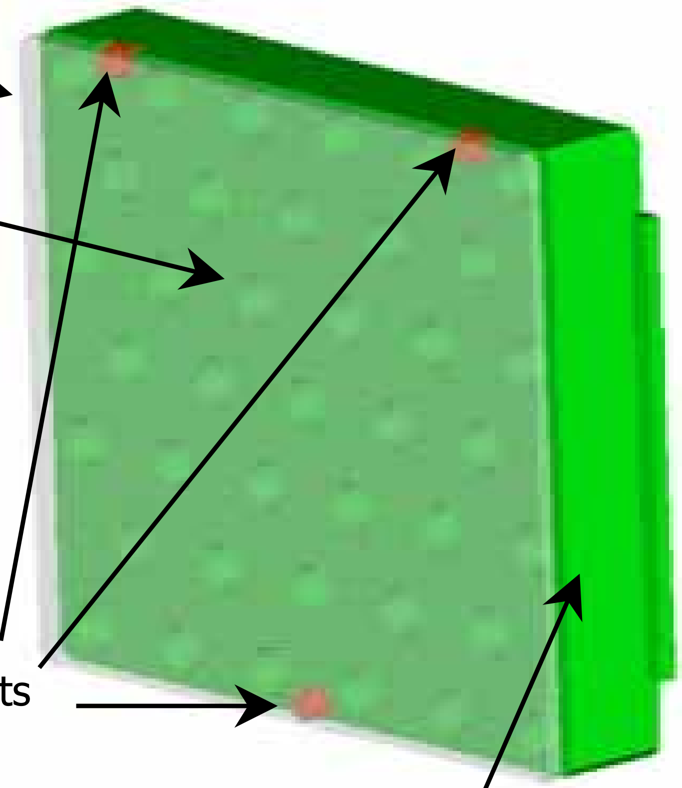
Enhanced protected silver coating

Dielectric coating

Under study

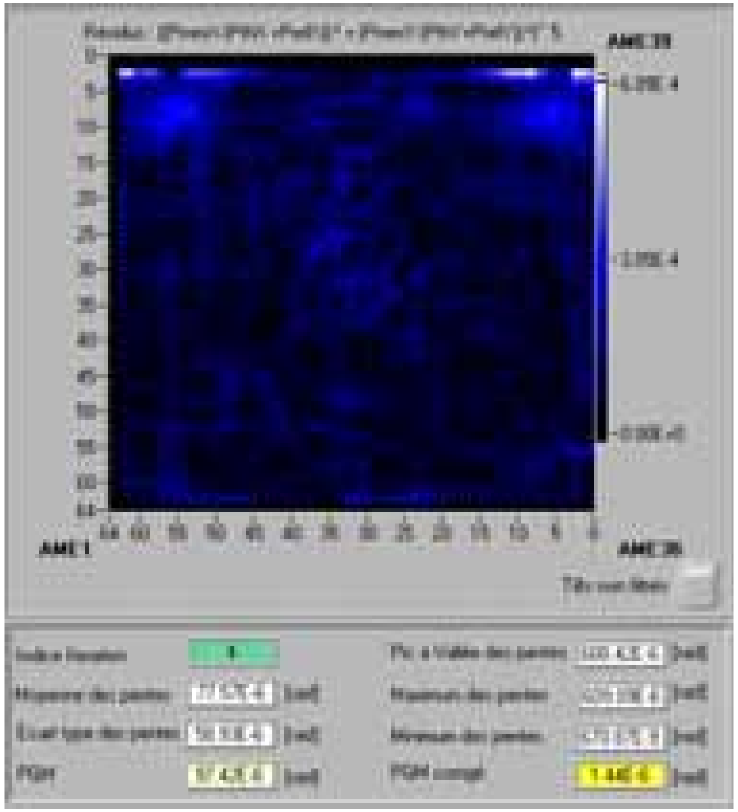
Force Actuators DM for LMJ





Actuator ISP System

Force Actuators DM main characteristics



Architecture: **Large size, scalability and simple design**

Correction: **Adapted correction stroke (10 µm range)**

Stability: **Excellent open loop stability (0.2 µrad rms/hour)**

Optical quality: **High quality optical surface (1.4 µrad rms mechanical)**

Energy level: **> 10 kJ/pulse @ 1053 nm (ns range)**

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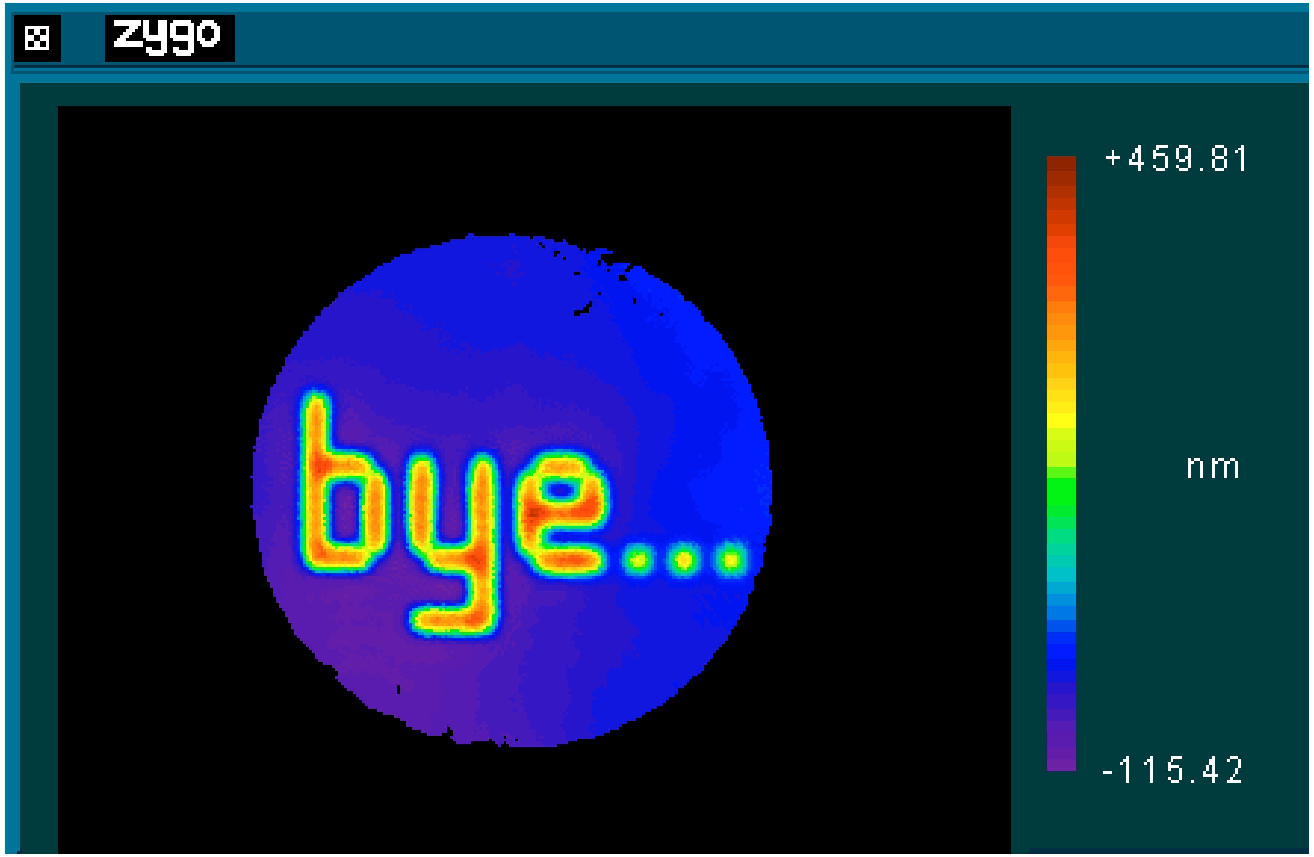

... and thank you