space structures laboratory

Professor Sergio Pellegrino
California Institute of Technology

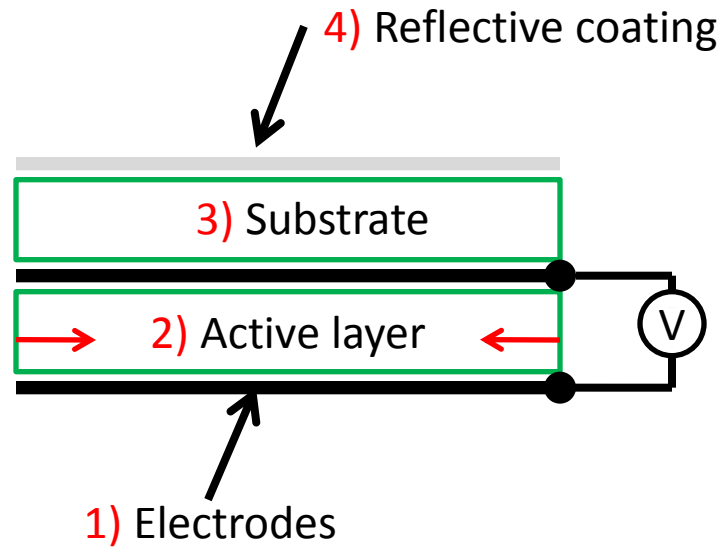
Optimization of Actuator Topology for Lightweight Deformable Mirrors

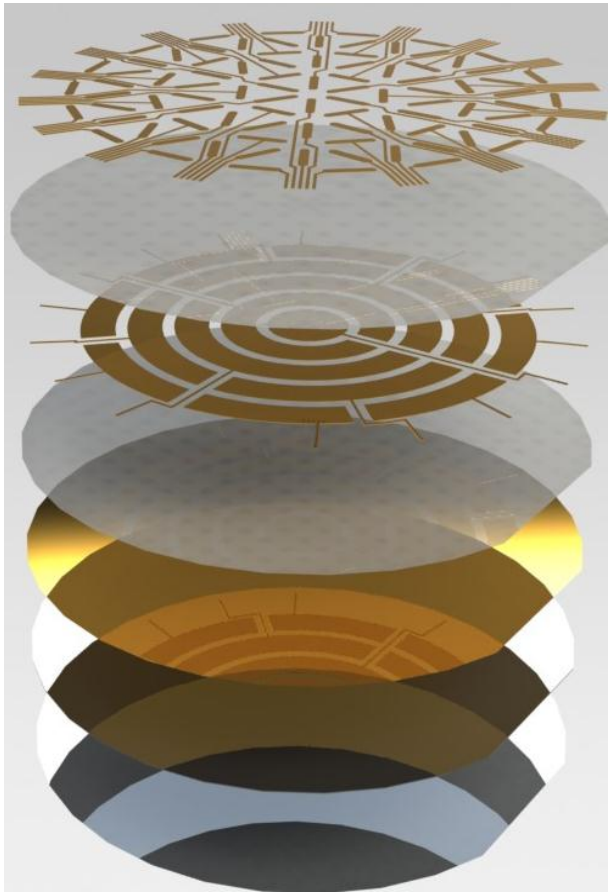
Marie Laslandes

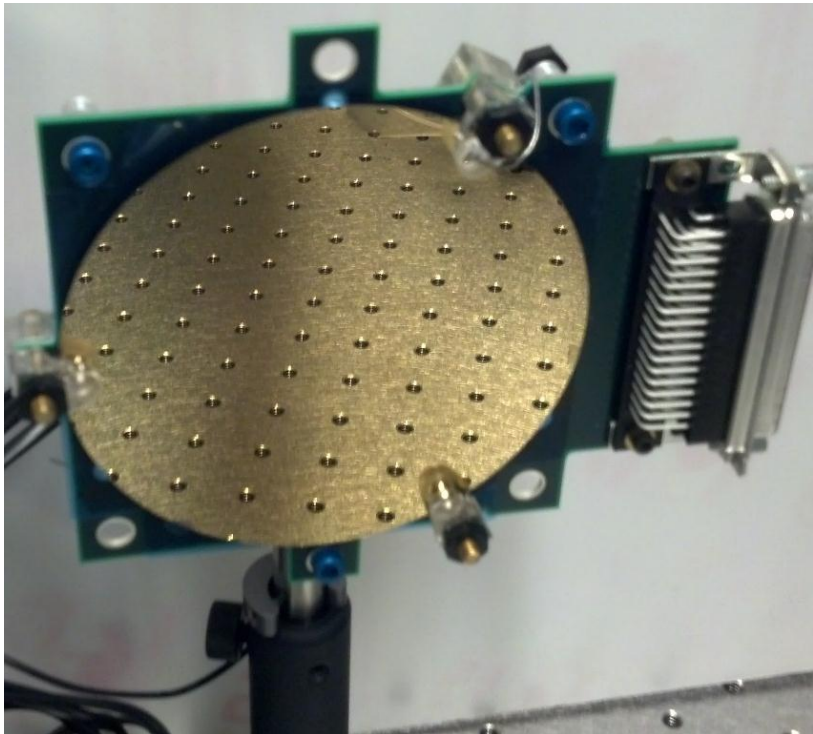
Mirror Tech Days – October 2013

Thin lightweight Deformable Mirror

- Thin shell laminated bimorph
  1) Electrode coatings to apply voltages
  2) Active layer for shape adjustment
  3) Lightweight, stiff, polished substrate to hold shape
  4) Reflective coating





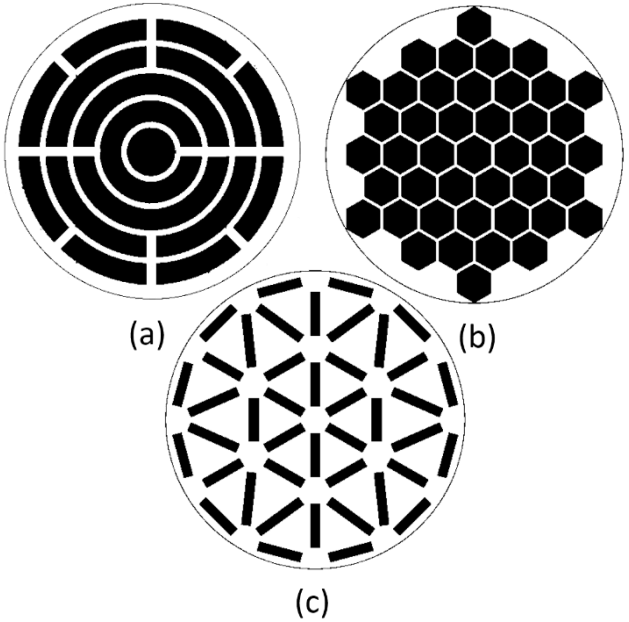


Actuator pattern

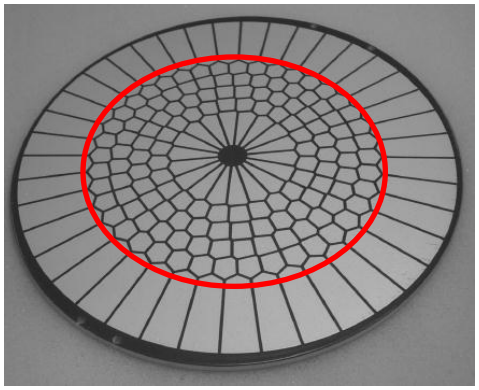
- Classical arrangement
  - mirror diameter > pupil
  - Not suitable for segmented applications

- Astigmatism is everywhere
  - Off-Axis Parabola shape component
  - Misalignment effect
  - Initial shape error

- Design goals
  - Pattern allowing precise deformation up to the edges
  - Limit the number of actuators



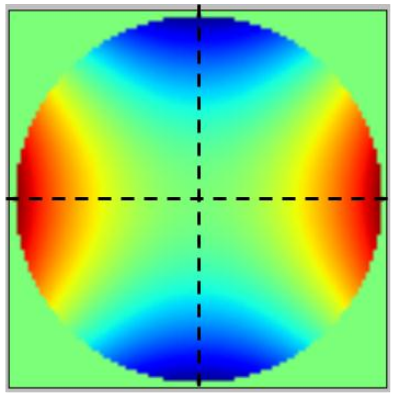
Classical electrodes patterns for bimorph mirrors



Cilas 188 actuator DM (AO system @ Subaru)

Generating Astm with one actuator

- Optimize electrode shape
  - Coupling FEA and optimization algorithm (CMAES)



Required deformation

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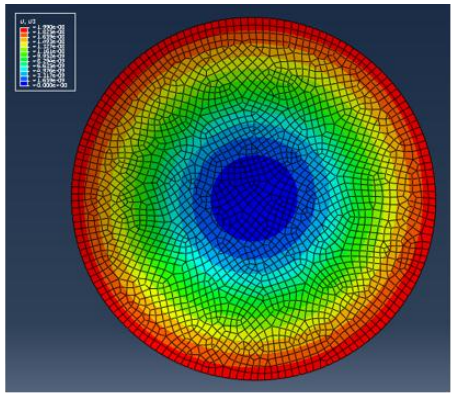
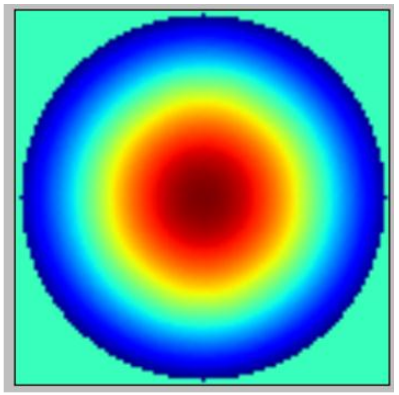
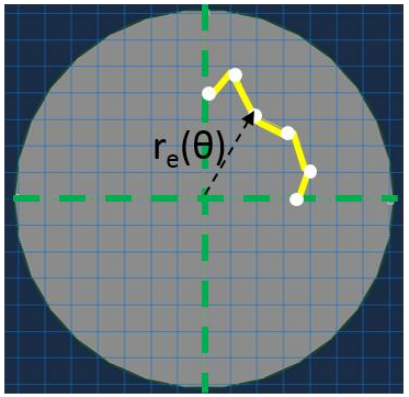


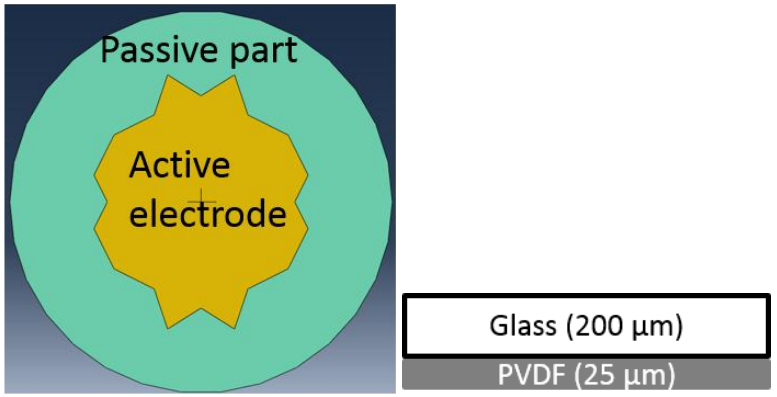
3. Resulting deformation



4. Residues



1. Contour definition



2. FEM creation

Minimize residual deformation
Maximize generated amplitude

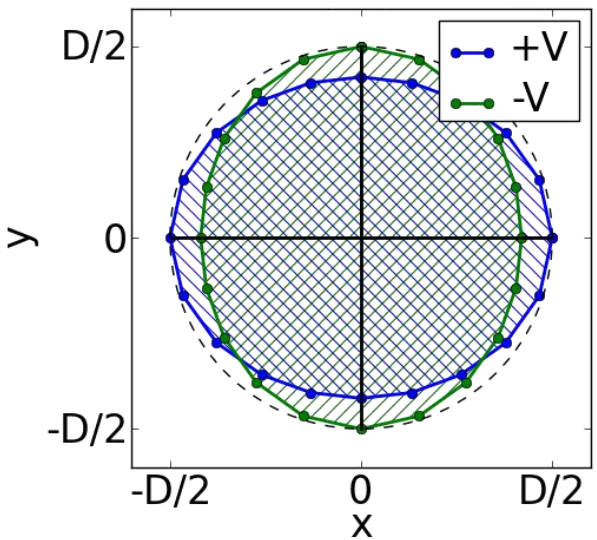
Method for electrode shape optimization

Two actuators system

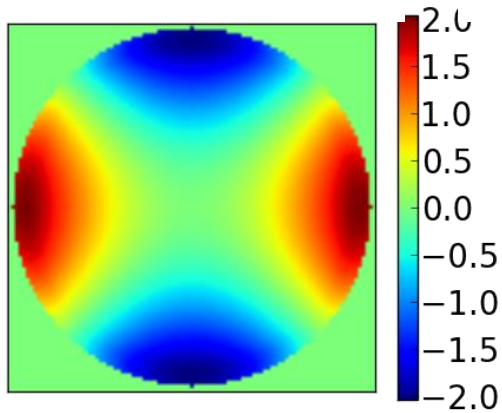
- One electrode result: deformation dominated by focus
- 2nd electrode to compensate focus, identical to the 1st one
  - Orthogonal, with opposite voltage
    - Suppress focus
    - Double astigmatism amplitude

Edge actuation: 4 small electrodes

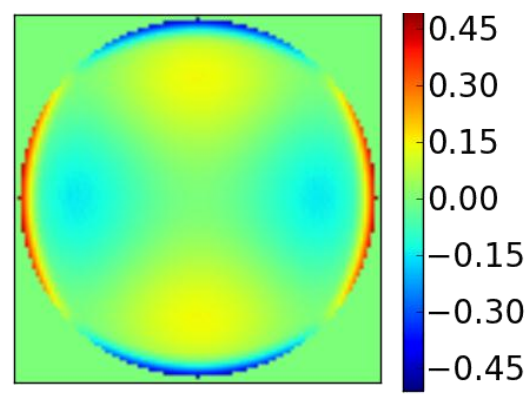
Electrodes shape



Induced deformation
1 um rms



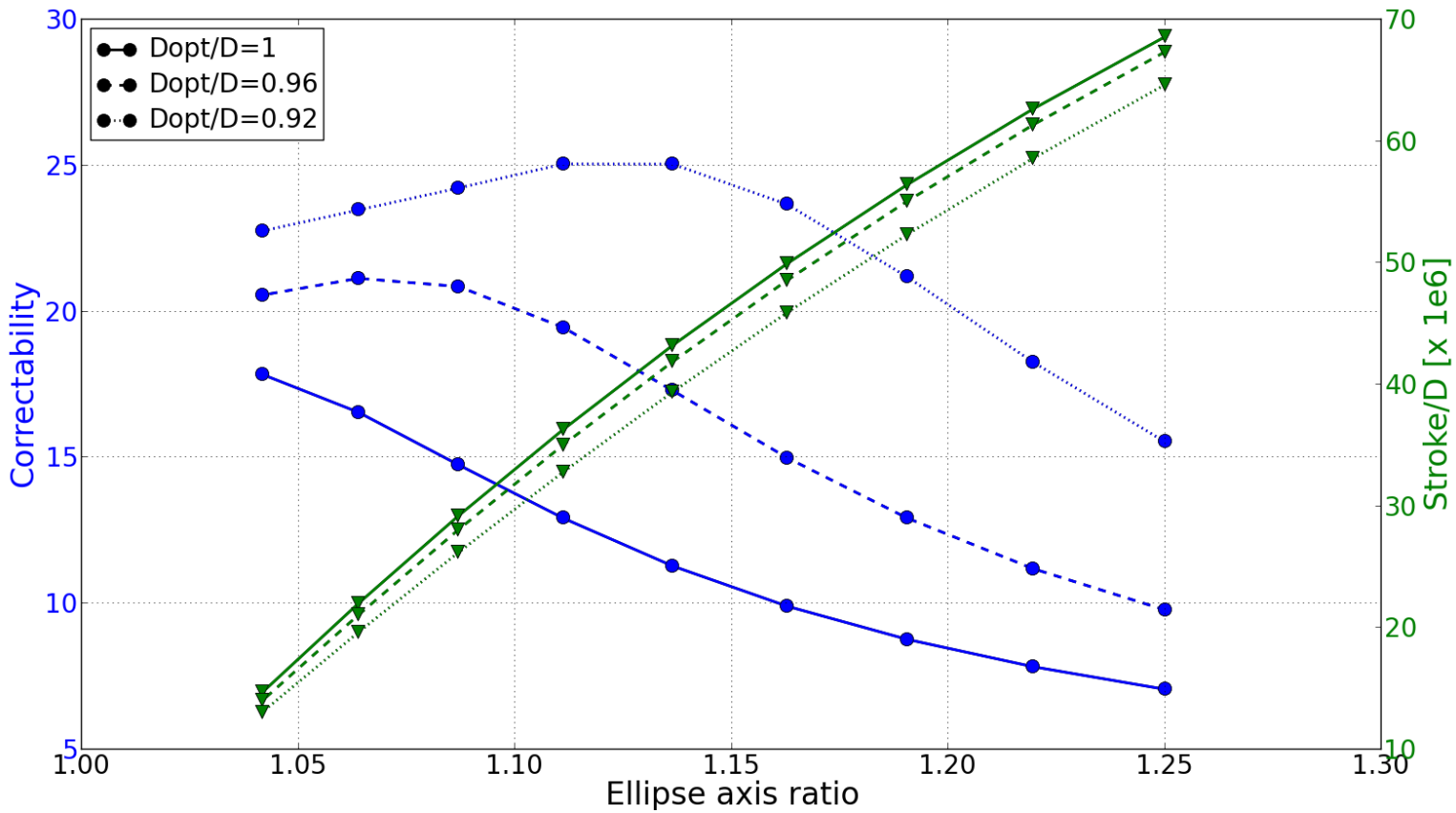
Residues
(compare to 1um rms of Astm)
0.1 um rms



Correctability vs stroke

- The smaller the actuator, the better the correctability
- The bigger the actuator, the better the stroke
- Electrodes shape: ellipses => easy parameterization

Trade-off, depending on application

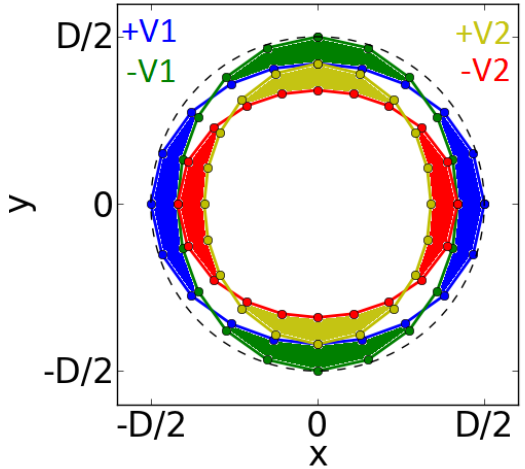


Correctability: *RMS before correction/ RMS after correction*
Stroke: *Amplitude corrigible without actuator saturation*

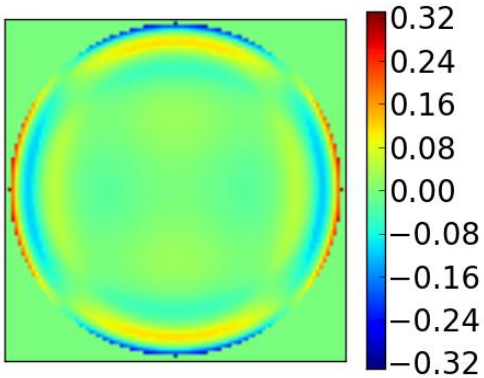
Adding actuators

- Internal actuators to reduce residuals
  - Same optimization method, give same pattern
  - Tune number of actuators and ellipses dimension for correctability and stroke

Electrodes configuration

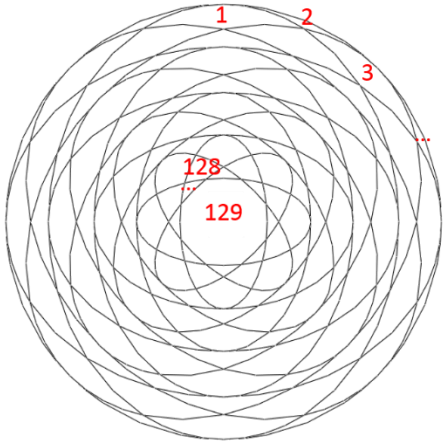


Residues:
0.05 um rms

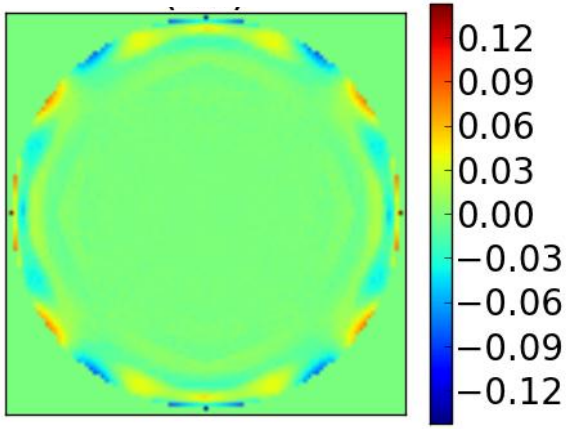


- Astigmatism x&y: rotate pattern of 45˚
  - Actuators defined by ellipses intersection

Electrodes configuration



Residues
0.01 um rms

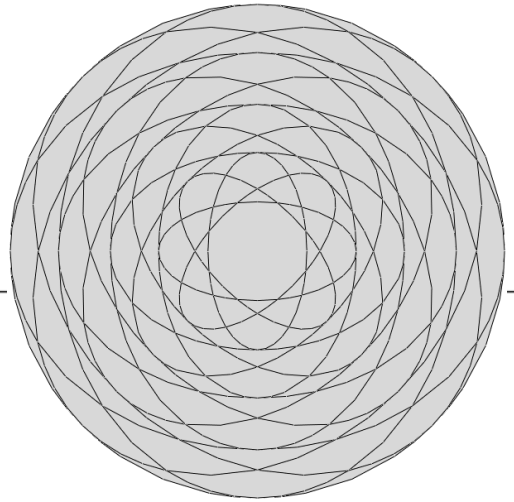


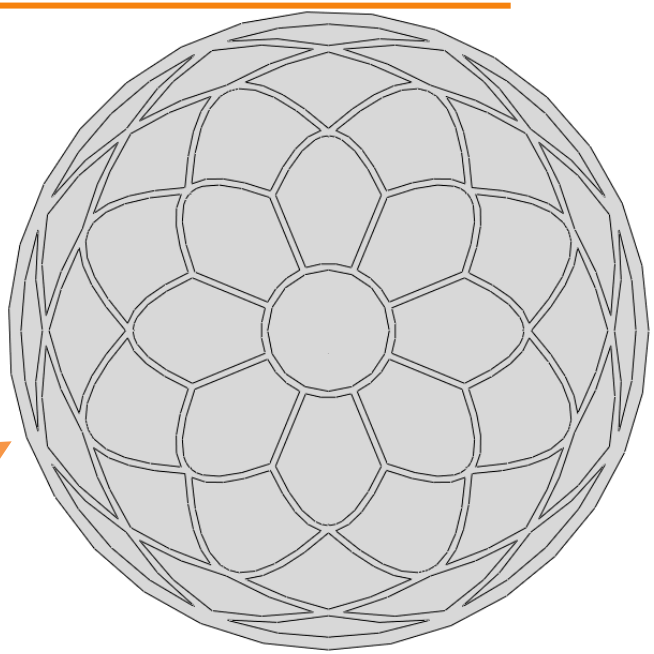
A lot of actuators,
can correct many modes

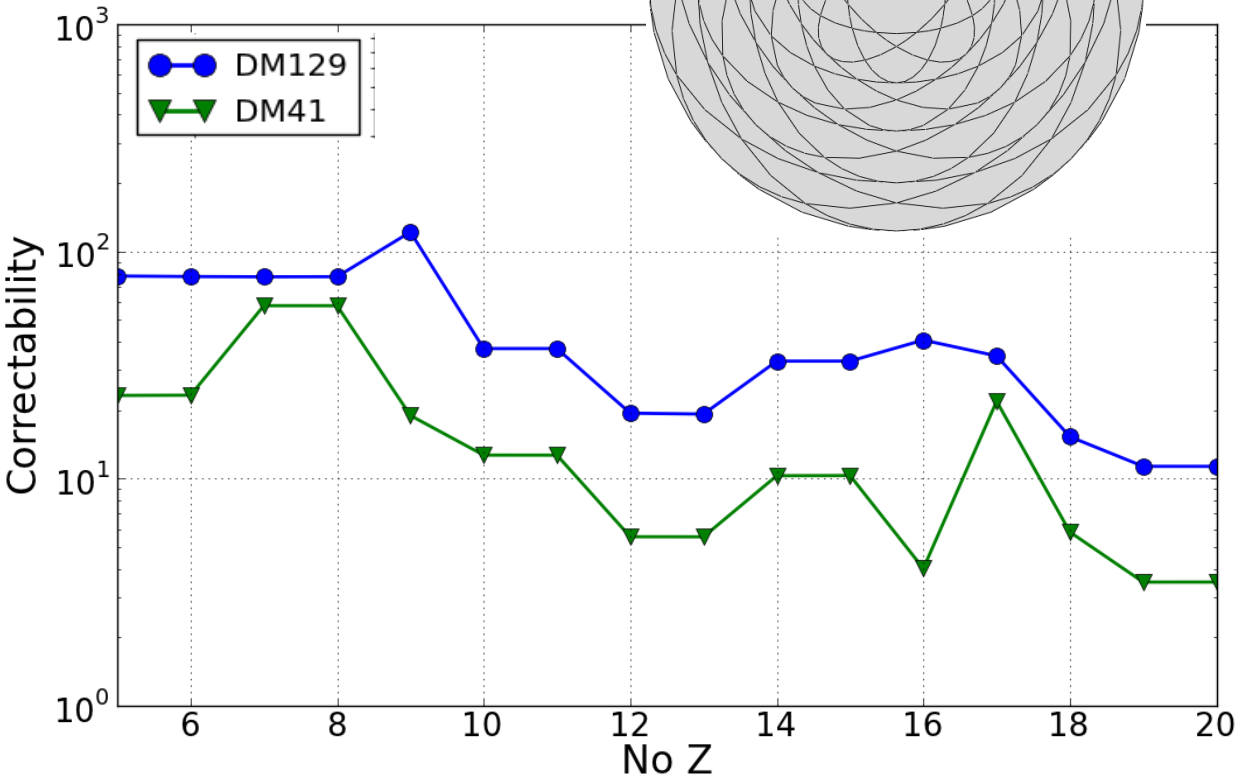
Manufacturing constraints

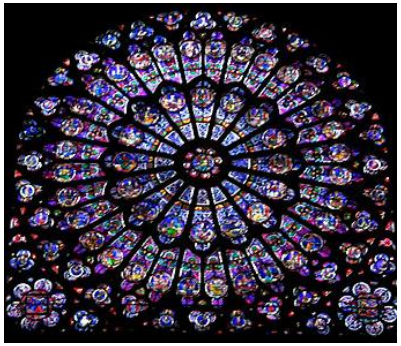
- Gaps between actuators and clear edge
- Size limit and number of actuators
  => Simplification from 129 to 41 actuators
  (Notre Dame pattern)

Ideal 129 actuators system and feasible 41 actuators system: design and performance



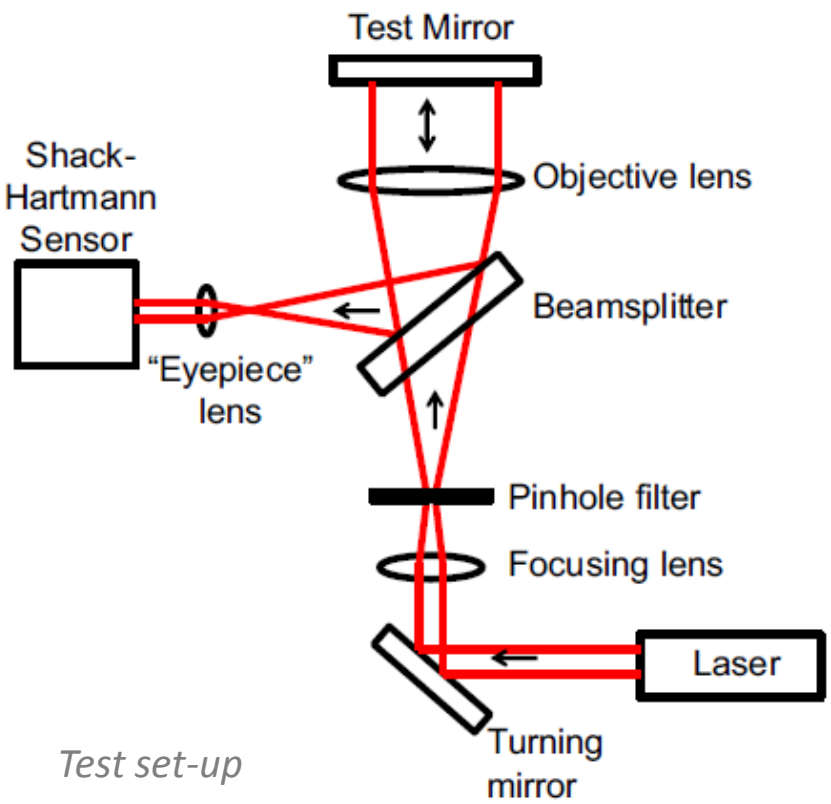




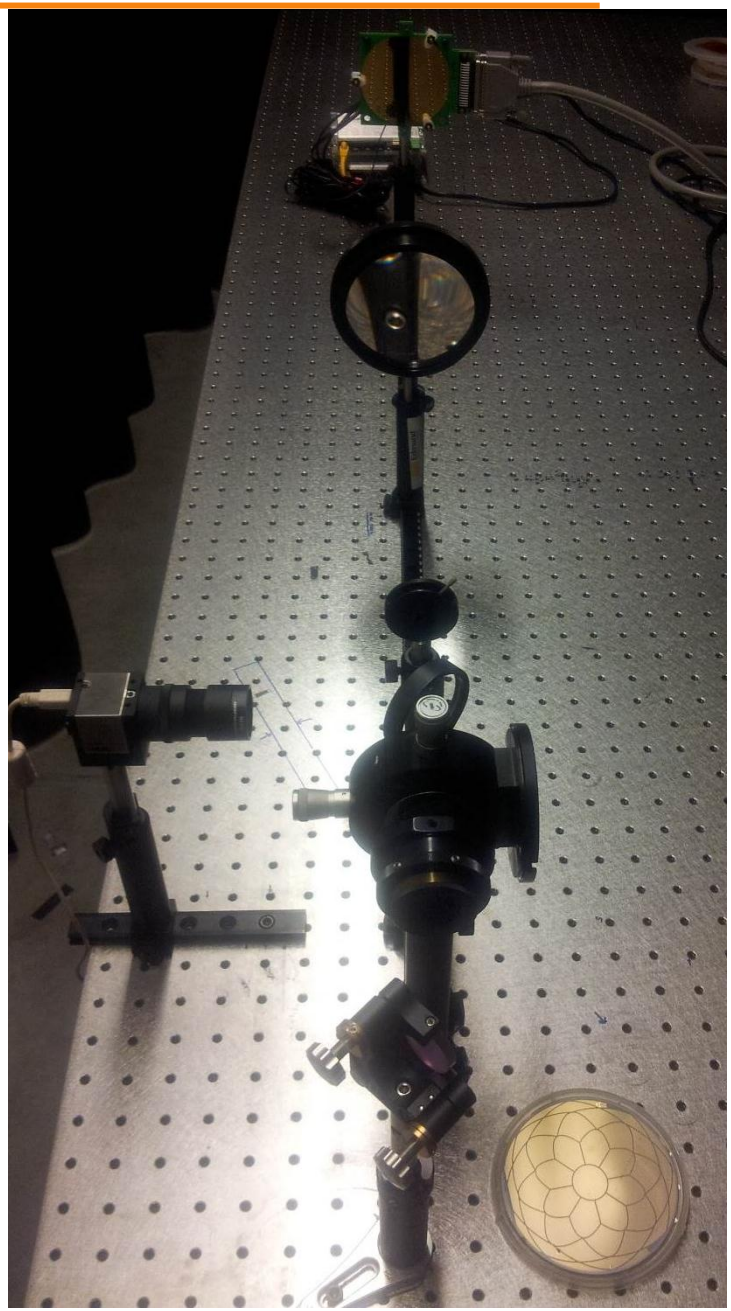


Testing Notre Dame pattern

- 100 mm flat mirror
- Optical surface deformation measured with Shack Hartmann Wave-Front Sensor



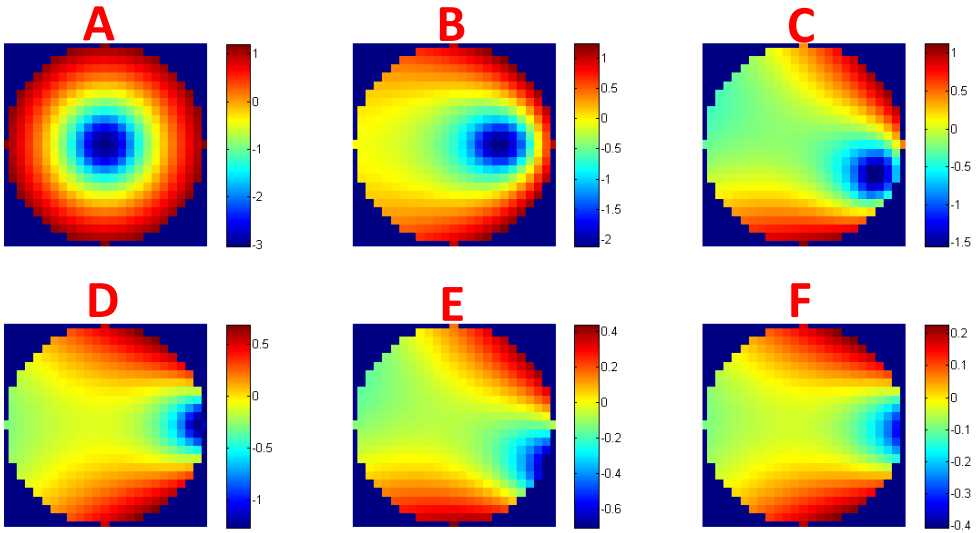
Test set-up



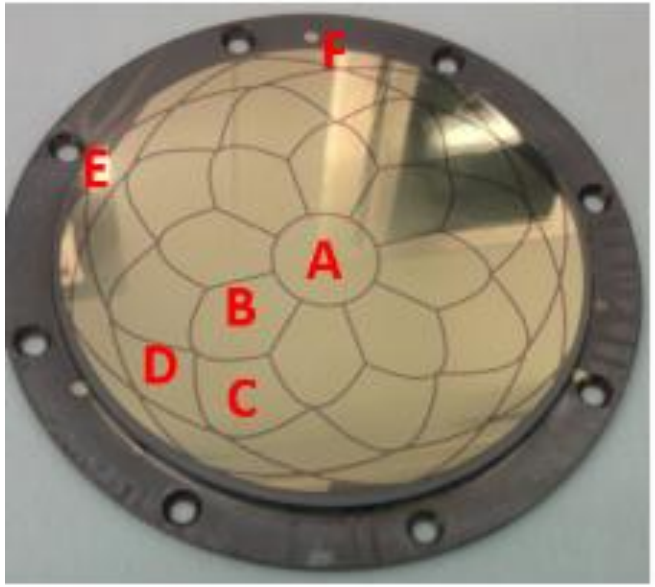
Notre Dame pattern – first results

- Influence Functions measurement: Amplitudes and shapes match simulations

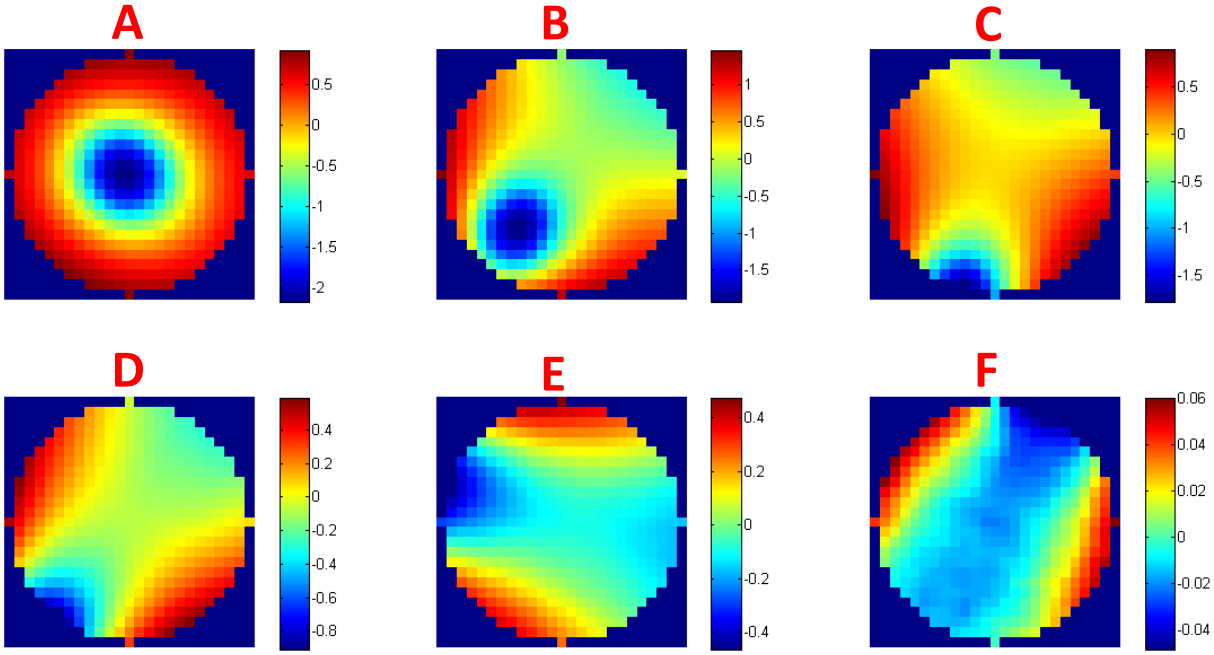
Expected performance should be recovered



Simulated Influence Functions



Tested electrode pattern



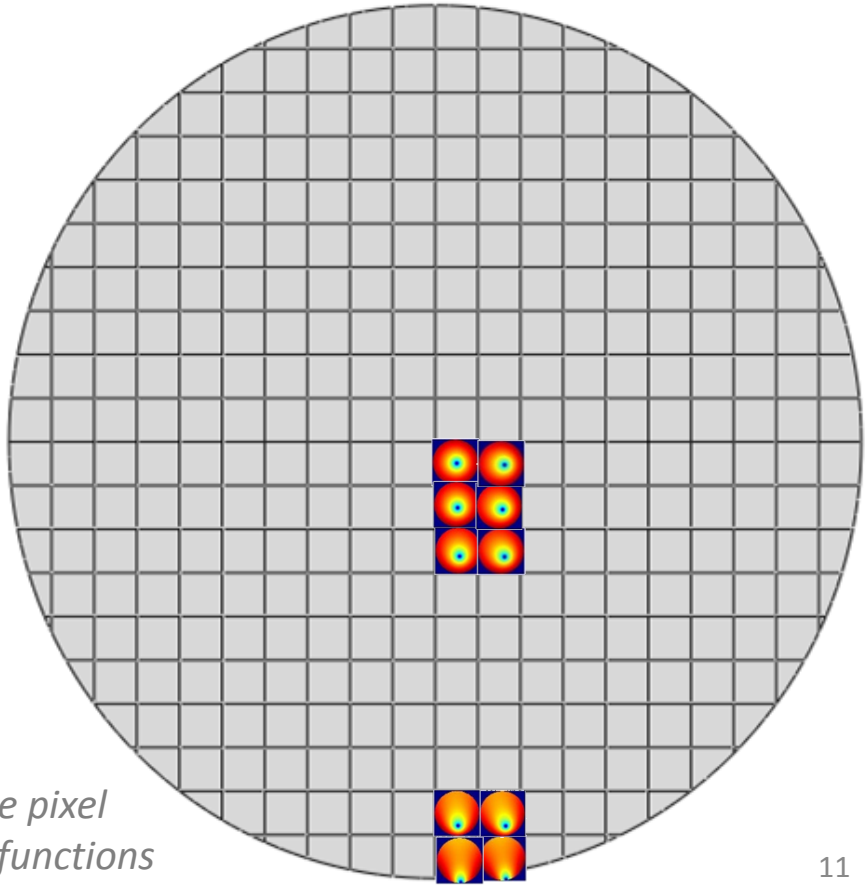
Measured Influence Functions

Toward a more general method

- Previous method
  - Pattern optimized for one given mode
  - Generation of other modes is possible but not optimized

- General method: goal
  - Optimize generation of a set of modes
  - Introduce actuator saturation in the optimization process

- Based on "pixel influence functions"
  - Finite Element Model with numerous small actuators
  - Algorithm: group pixel actuators



Finite Element Model showing the pixel actuators and some of its influence functions

Optimization method

Inputs

- N_1 "Pixel" actuators: Position (x_p, y_p) & Influence Functions M_p
- Correction requirements: N Zernike modes with amplitude: $\{a_i Z_i\}$
- Number of final actuators: N_2
- Limit voltage: V_l

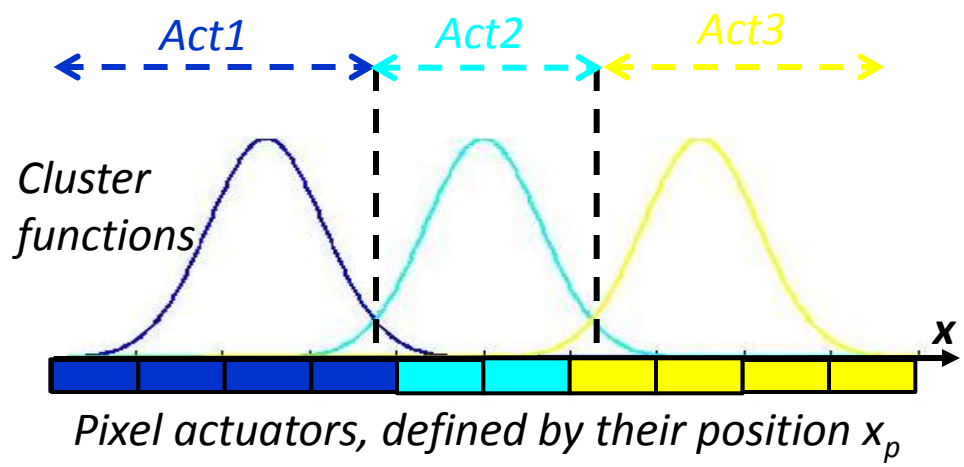
Grouping

- Through N_2 "cluster" functions

$$C_k = exp\left\{\frac{-1}{2w^2}\left[(x - x_{o,k})^2 + (y - y_{o,k})^2\right]\right\}$$

- Each pixel actuator is allocated to a group depending on the cluster functions values

=> N2 new influence functions: sum pixel influence functions M_p of a same group



Compute performance with new IF

- Residual deformation R_i for each $a_i Z_i$ (constrain voltages to V_l)

=> Objective function: $\sqrt{\sum R_i^2}$

Minimize objective function: Optimize $(x_{o,k}, y_{o,k})$

($2xN_2$ variables)

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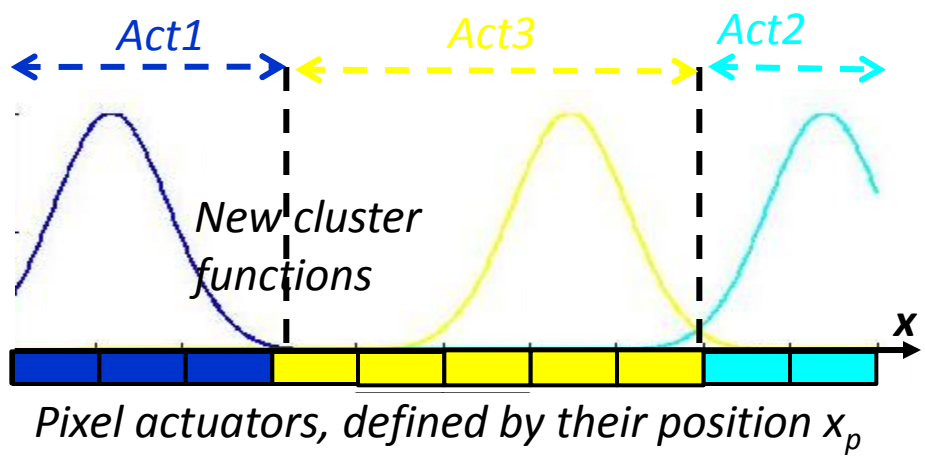

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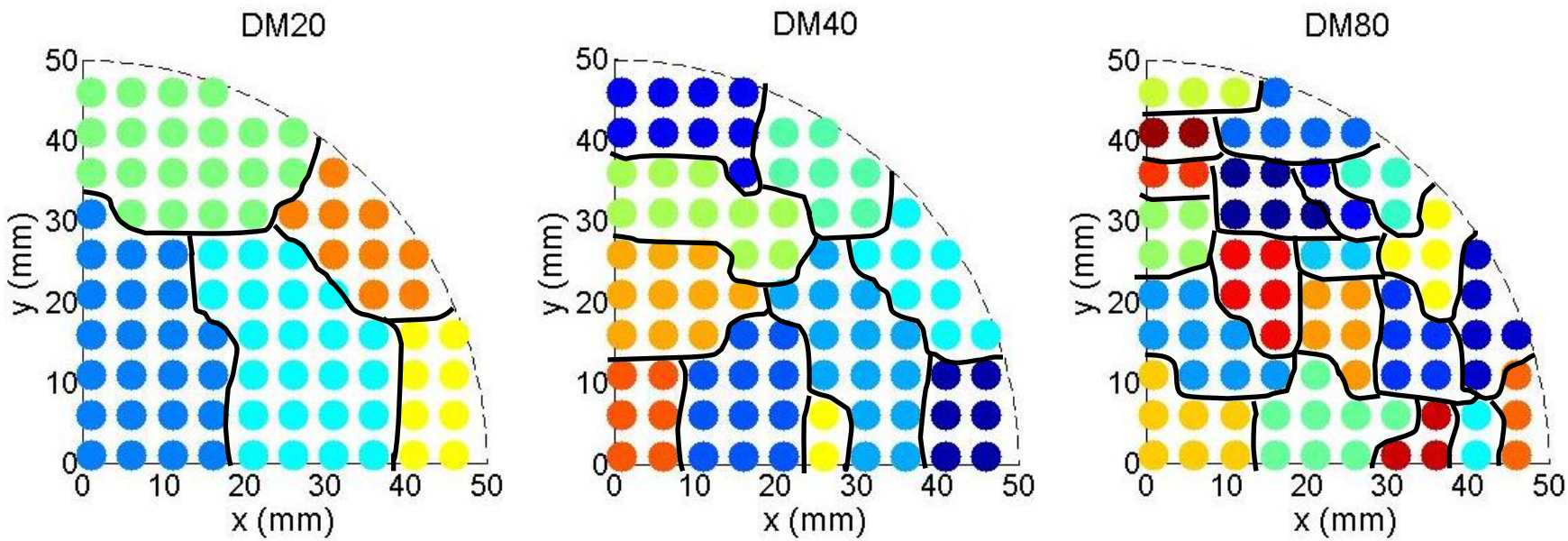
($2xN_2$ variables)

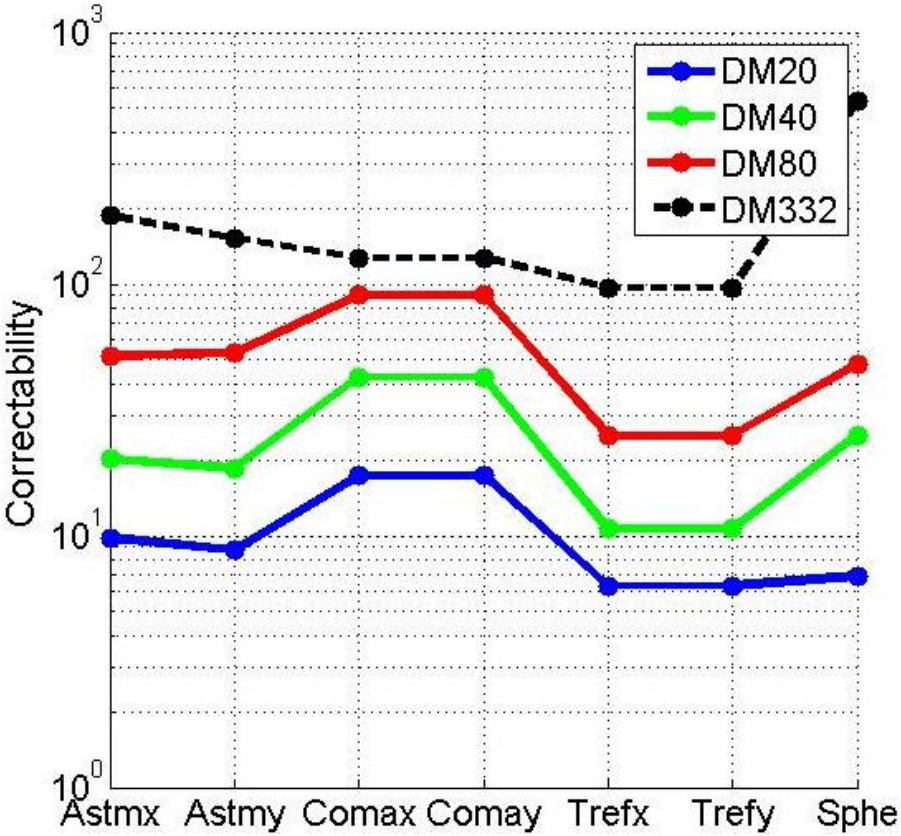
Example design

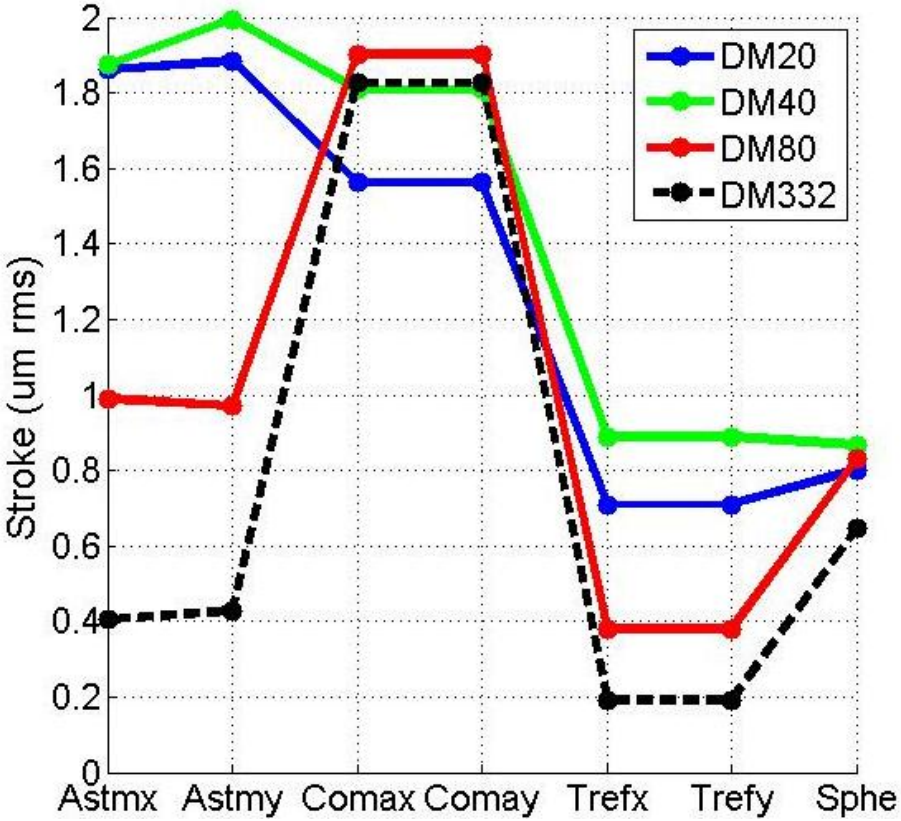
- Thin Deformable Mirror FEM
  - 100 mm diameter, Flat
  - 200 um glass and 25 um PVDF
  - 332 pixel actuator (5x5 mm)
  - Meshing: 25 elements per actuator
- Optimization for 20, 40 and 80 actuators
  - Optimized on one quarter + symmetry
  - Edge actuators are recovered
- Correction requirements, on a 96 mm pupil:
  - 2 um rms of Astm3x&y
  - 1 um rms of Coma3x&y, Sphe3
  - 0.5 um rms Tref5x&y
- Limit voltage: 500 V



Example design - performance

- Correctability
  - Increases with the number of actuators
- Stroke
  - Driven by the input mode amplitude
  - Decreases with the number of actuators





Conclusion

- Optimization of the actuator pattern for thin deformable mirror
  - 2 methods: ‘intuitive’ and general
  - Couple Finite Element Analysis and optimization algorithm
- Inputs: correction needs
  - Deformable mirror optimized for a given application
  - Correction specifications defined within a system study
- Method could be applied to other types of Deformable Mirrors