Numerical Optimization of Electroactive Actuator Position for Optical Mirror Applications

CRAL
CENTRE DE RECHERCHE ASTROPHYSIQUE DE LYON

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INSA INSTITUT NATIONAL DES SCIENCES APPLIQUÉES LYON

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Project #ANR-18-CE42-0007-01 (Live-Mirror project)

Outline

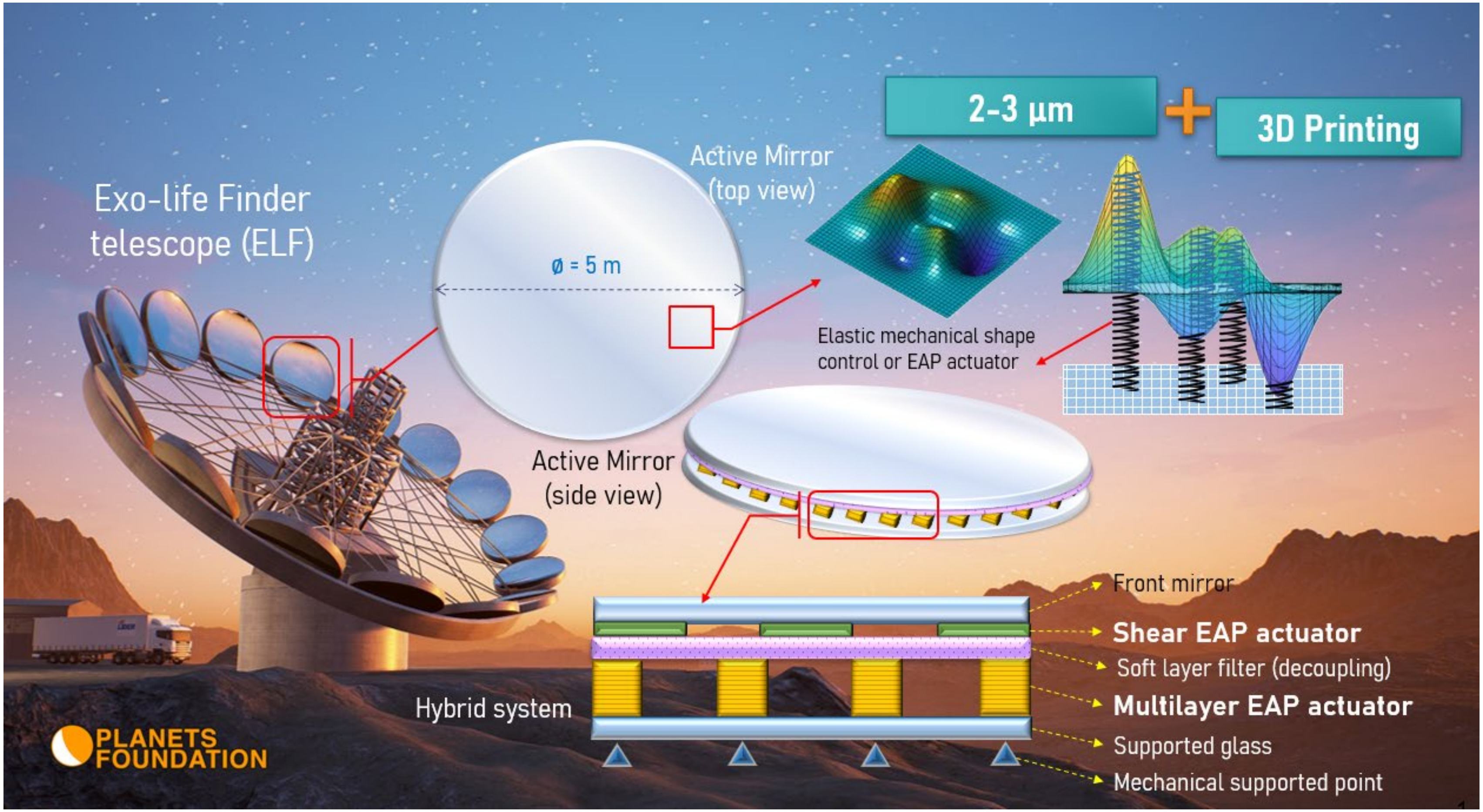
Before starting, who we are… www.simtecsolution.fr

SIMTEC : Fundamentals

- French Numerical modelling consultancy
- Leader in France of the COMSOL Certified Consultants, key partner worldwide
- 7 members Eng.D. + Ph.D.
- Main partners:
  - big international companies
  - laboratories
- Involved in the Research projects like EU FP (SHARK, SisAl)/ PhD supervision

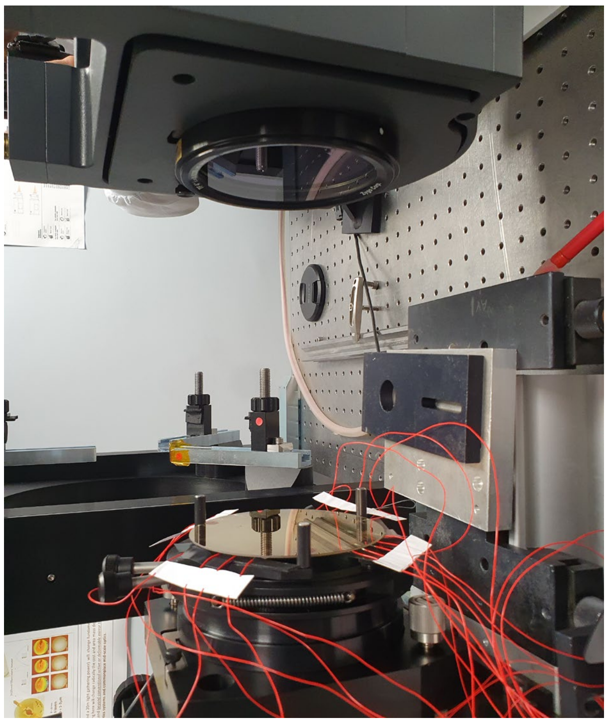
COMSOL Certified Consultant

I. Background – Objectives



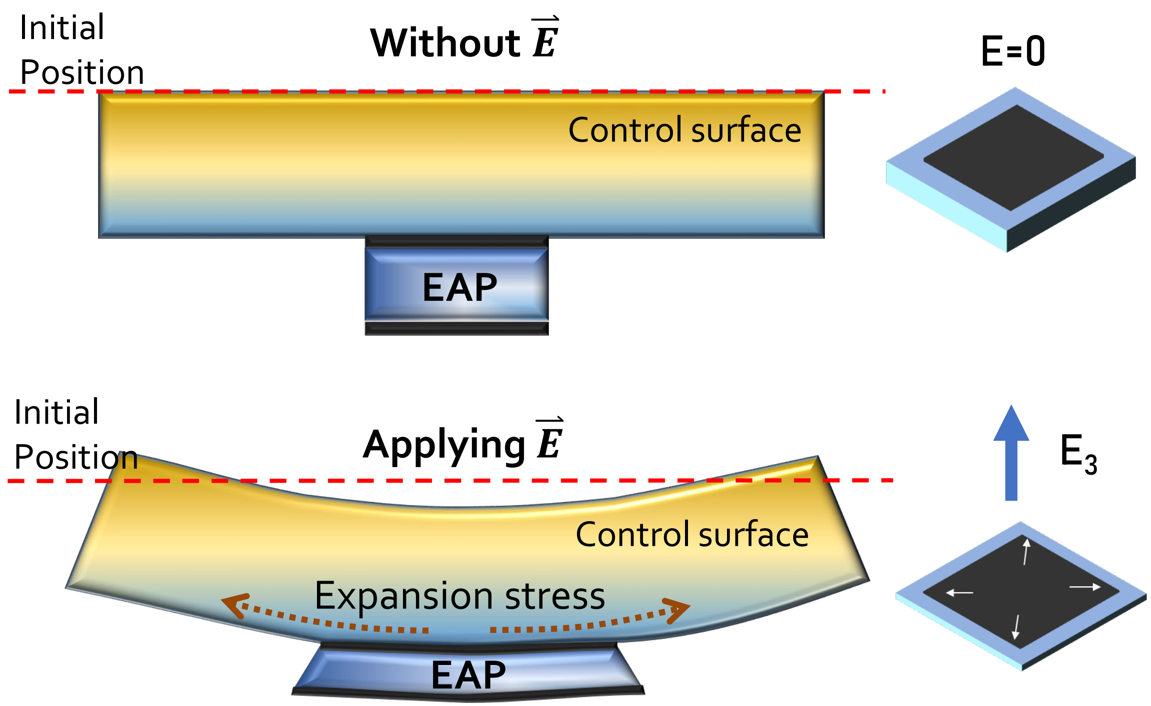
EAP = Electro Active Polymer

I. Background – Objectives



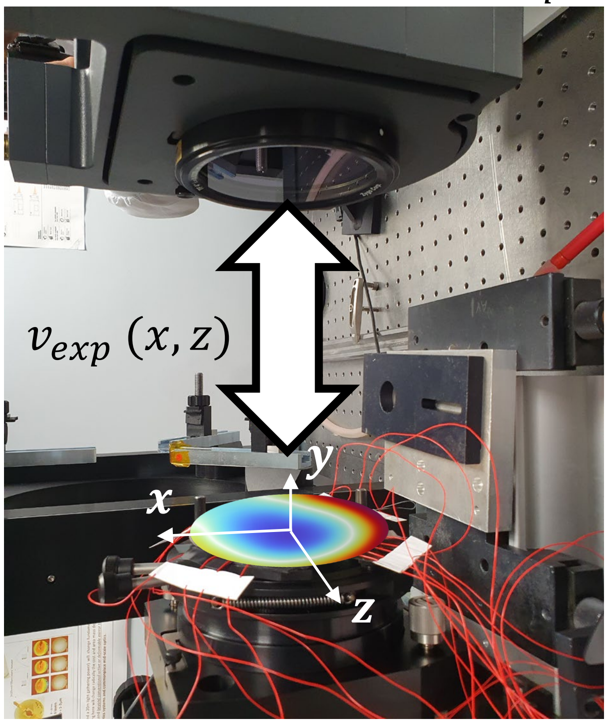
ZYGO measurements

Mirror surface deformed by an active EAP actuator



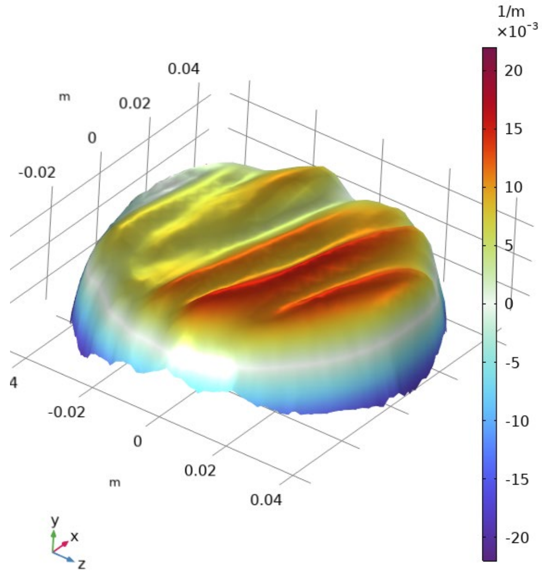
I. Background – Objectives

Imported data in Comsol : $v_{exp}\ (x, z)$

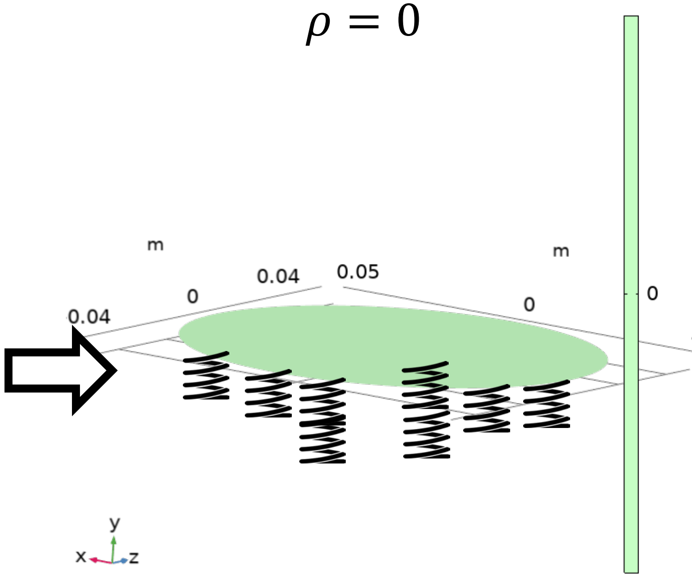


Real Local Curvature

$$\rho = \frac{\partial^2 v_{exp}}{\partial x^2} + \frac{\partial^2 v_{exp}}{\partial z^2}$$



$$\rho = 0$$



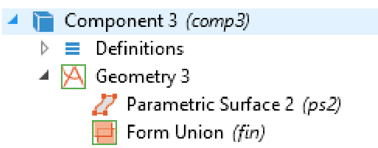
Objective :

Find an optimized EAP layout that minimize the local curvature $\rho = \frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial z^2}$

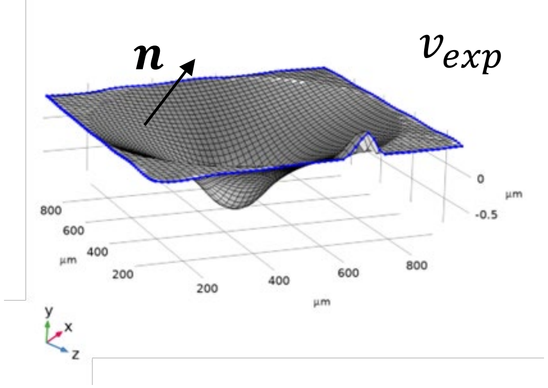
II. Modelling and Numerical Model

1st step: Curvature Computation

2 methods tested in COMSOL



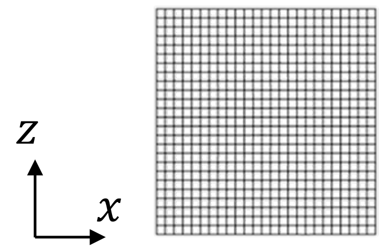
Parametric Curved Surface



$$u_{geom} = y$$

$$\rho_{geom} = \Delta_T u = (I - \boldsymbol{n}\boldsymbol{n}^T)\Delta u_{geom}$$

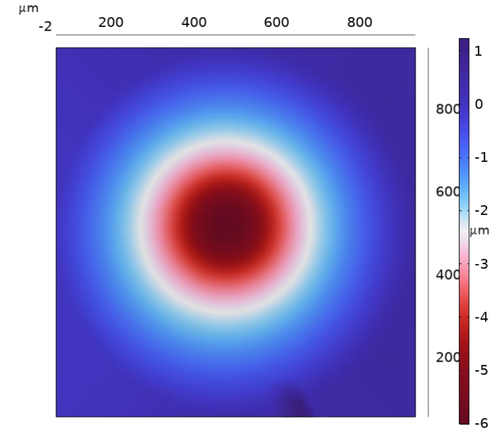
Mapped Geometry



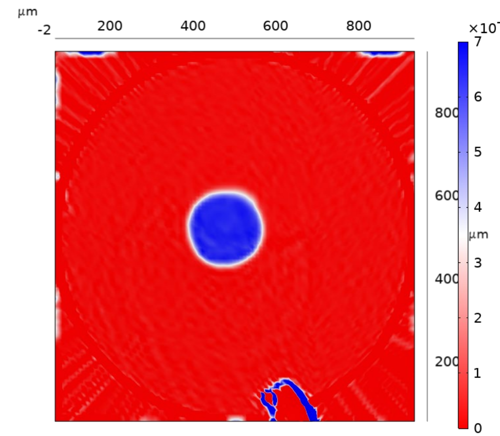
$$\lambda \Delta u + u = v_{exp}$$

$$\rho_\lambda = \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial z^2}$$

$v_{exp}(x,z)[\mu m]$



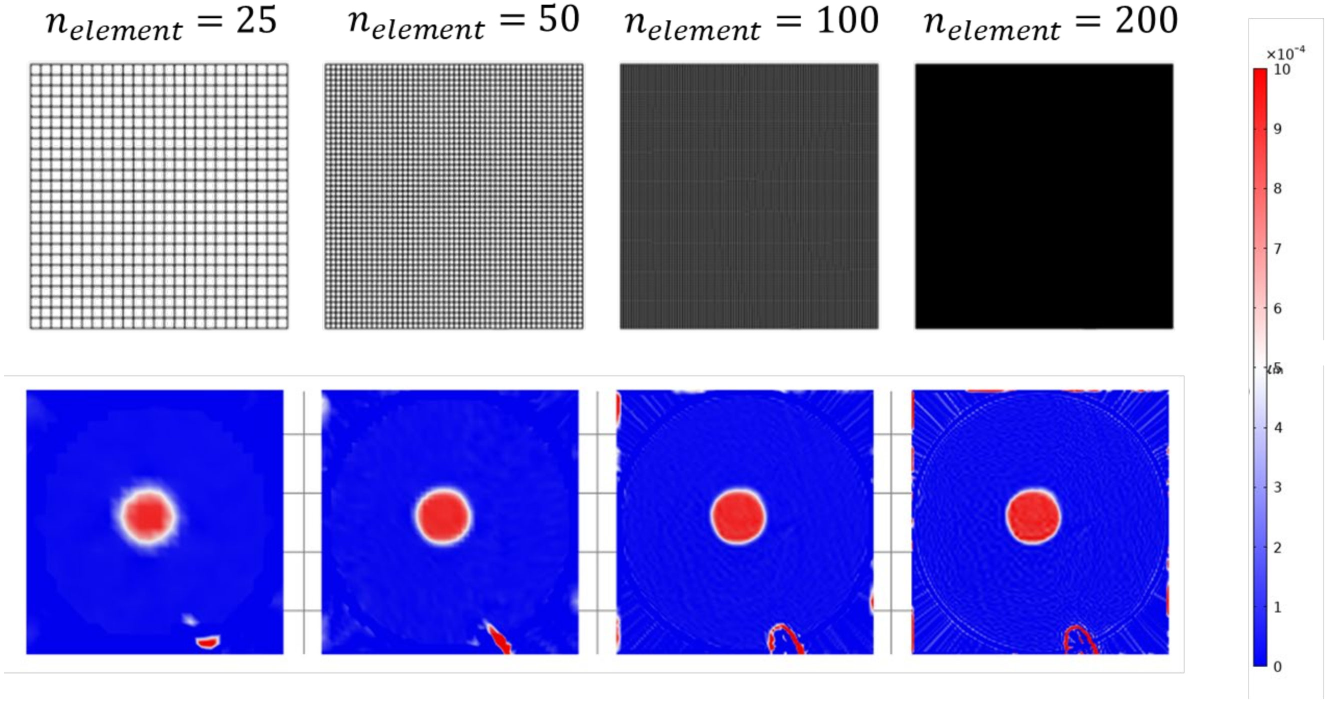
$\rho_\lambda\ [1/m]$



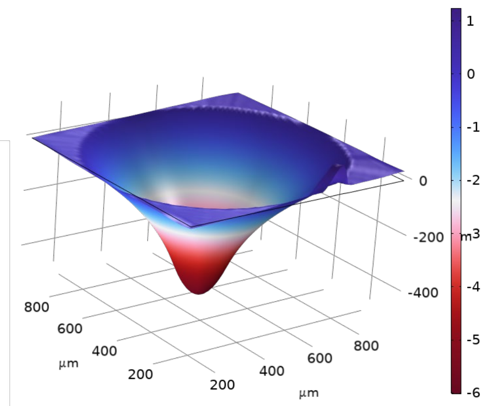
II. Modelling and Numerical Model

1st step: Curvature Computation – Mesh Validation

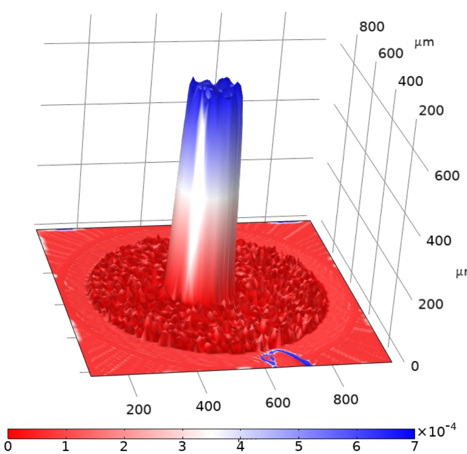
$n_{element} = 25$ $n_{element} = 50$ $n_{element} = 100$ $n_{element} = 200$



$v_{exp}(x, z)[\mu m]$



$\rho_\lambda\ [1/m]$

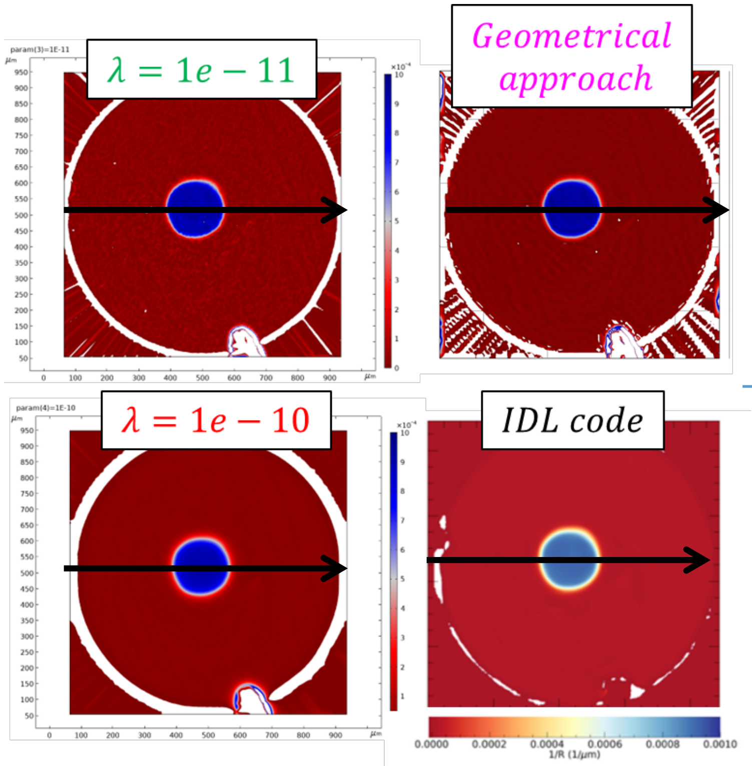


- Mesh convergence OK

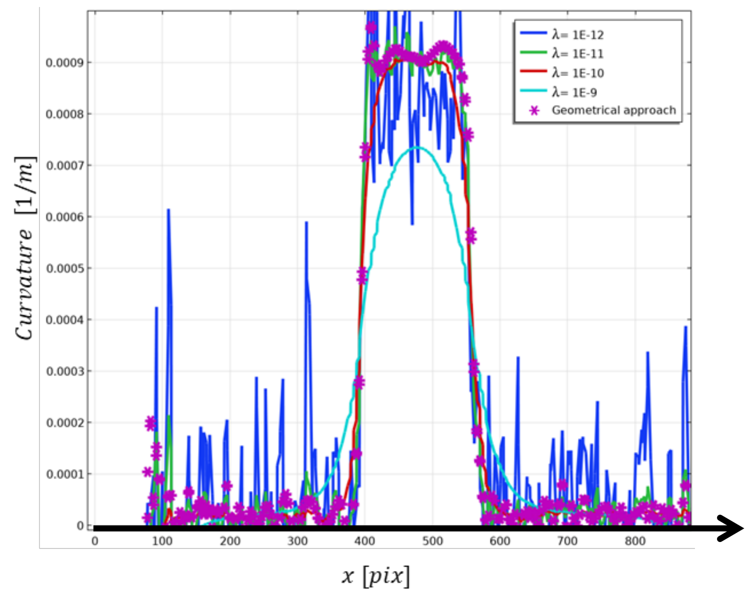
II. Modelling and Numerical Model

1st step: Curvature Computation – Numerical Validation

$$\lambda \Delta u + u = v_{exp}$$



$\longrightarrow$ $x\ [pix]$



- Validation of both approaches
- Choice of the parameter of tunning $\lambda = 1e - 11$

II. Modelling and Numerical Model

2nd step: Mechanical Problem – Equations & Boundary Conditions

Solid Mechanics

$$\nabla \cdot S = 0$$

$$\varepsilon_{el} = \frac{1}{2}(\nabla \boldsymbol{u} + \nabla \boldsymbol{u}^T)$$

Electrostatics

$$\nabla \cdot D = 0$$

$$\boldsymbol{E} = -\nabla V$$

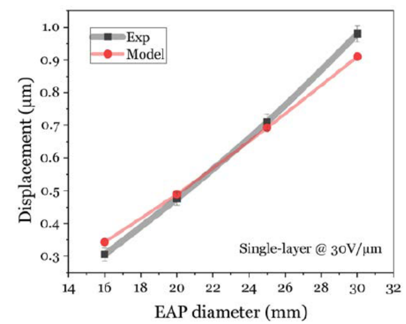
ε_0: Vacuum permittivity
ε_R: Reference permittivity
e : Coupling matrix
C: Elasticity matrix

$$\boldsymbol{D} = e{:}\,\varepsilon_{el} + \varepsilon_0 \varepsilon_r \boldsymbol{E}$$

$$S = C{:}\,\varepsilon_{el} - e^T \boldsymbol{E}$$

$$\Rightarrow \quad S_{yy} \sim \varepsilon_0 \varepsilon_r E_y^2 \sim \varepsilon_0 \varepsilon_r \left(\frac{\Delta V}{Thickness}\right)^2$$

Previous Work



K. Thetpraphi, *Development of electroactive polymer actuators for next generation mirror : Live-Mirror*, PhD Thesis, 2021.

- ElectroMechanical Model validated with experimental results

II. Modelling and Numerical Model

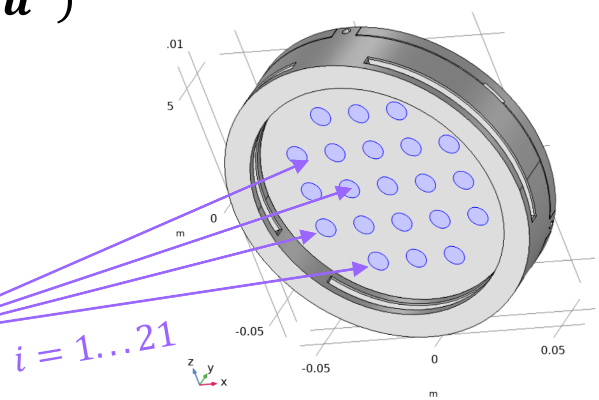
2nd step: Mechanical Problem – Equations & Boundary Conditions

Solid Mechanics

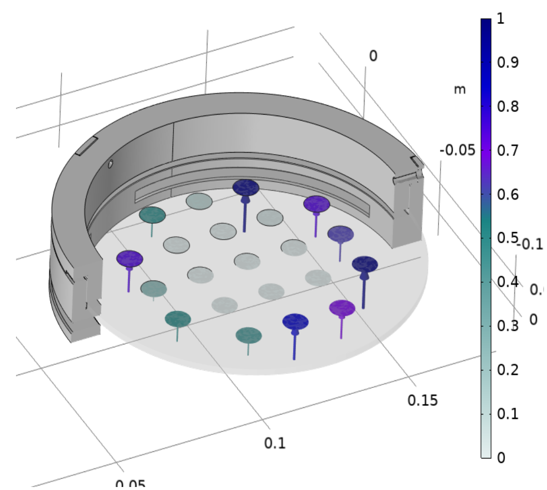
$$\boxed{\nabla \cdot S = 0}$$

$$\varepsilon_{el} = \frac{1}{2}(\nabla \boldsymbol{u} + \nabla \boldsymbol{u}^T)$$

- $\boldsymbol{u}|_{R=R_{disk}} = \boldsymbol{0}$
- $S \cdot \boldsymbol{n} = \boldsymbol{F_i}$



$F_i = K_i * p_{piezo}$ K_i



- Mechanical problem solved

II. Modelling and Numerical Model

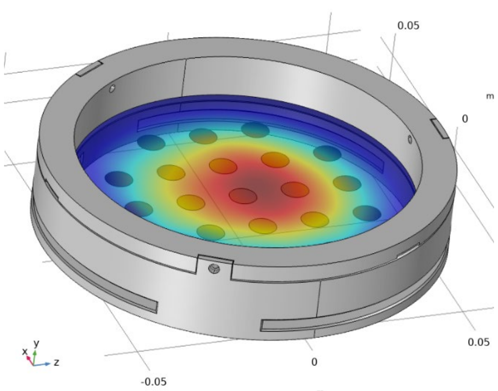
3rd step: Optimization Procedure

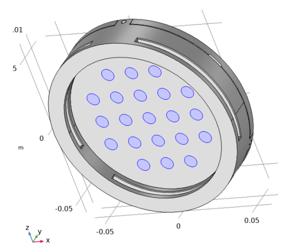
Optimization procedure to find K_{f_i} that minimizes :

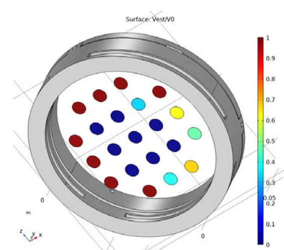
$$J = \iint \left(\rho_{exp} - \rho\left(K_{f_i}\right)\right)^2$$

SNOPT Algorithm

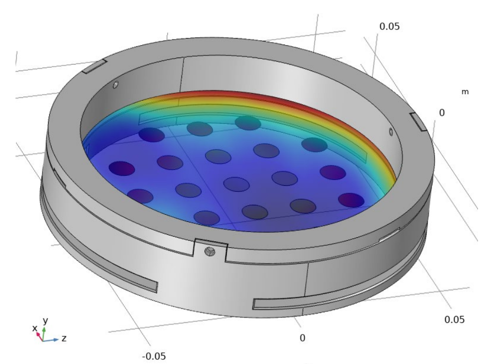
Initial Curvature





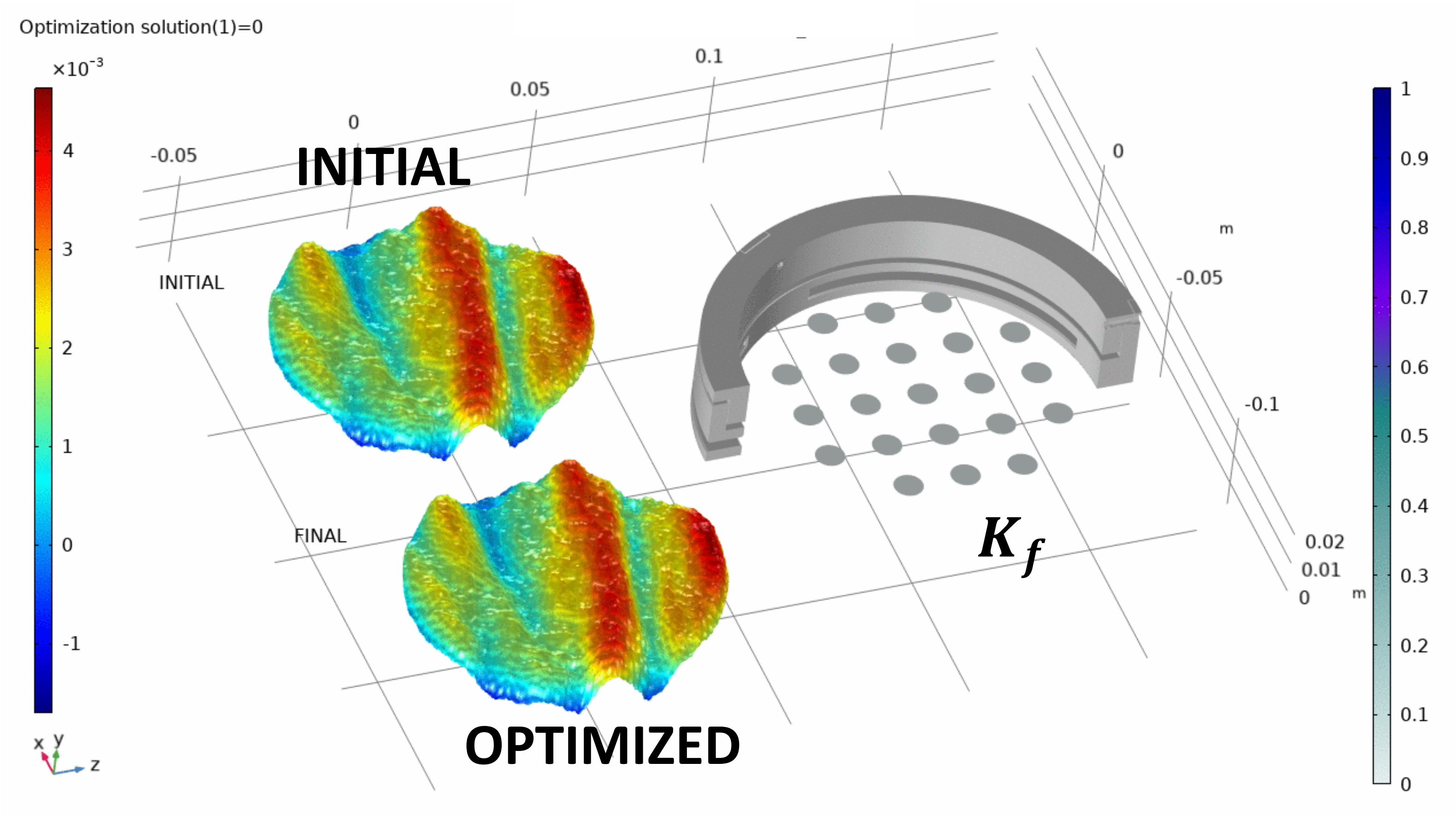


Final Curvature



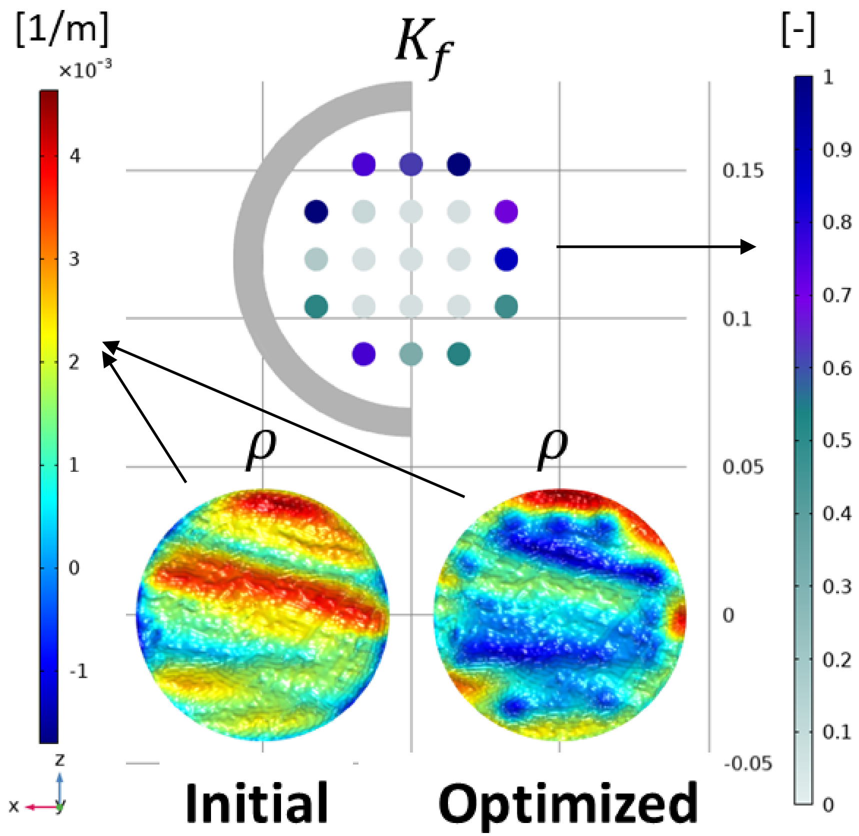
III. Main Results

Optimization Procedure



III. Main Results

Optimized Results



On this example:

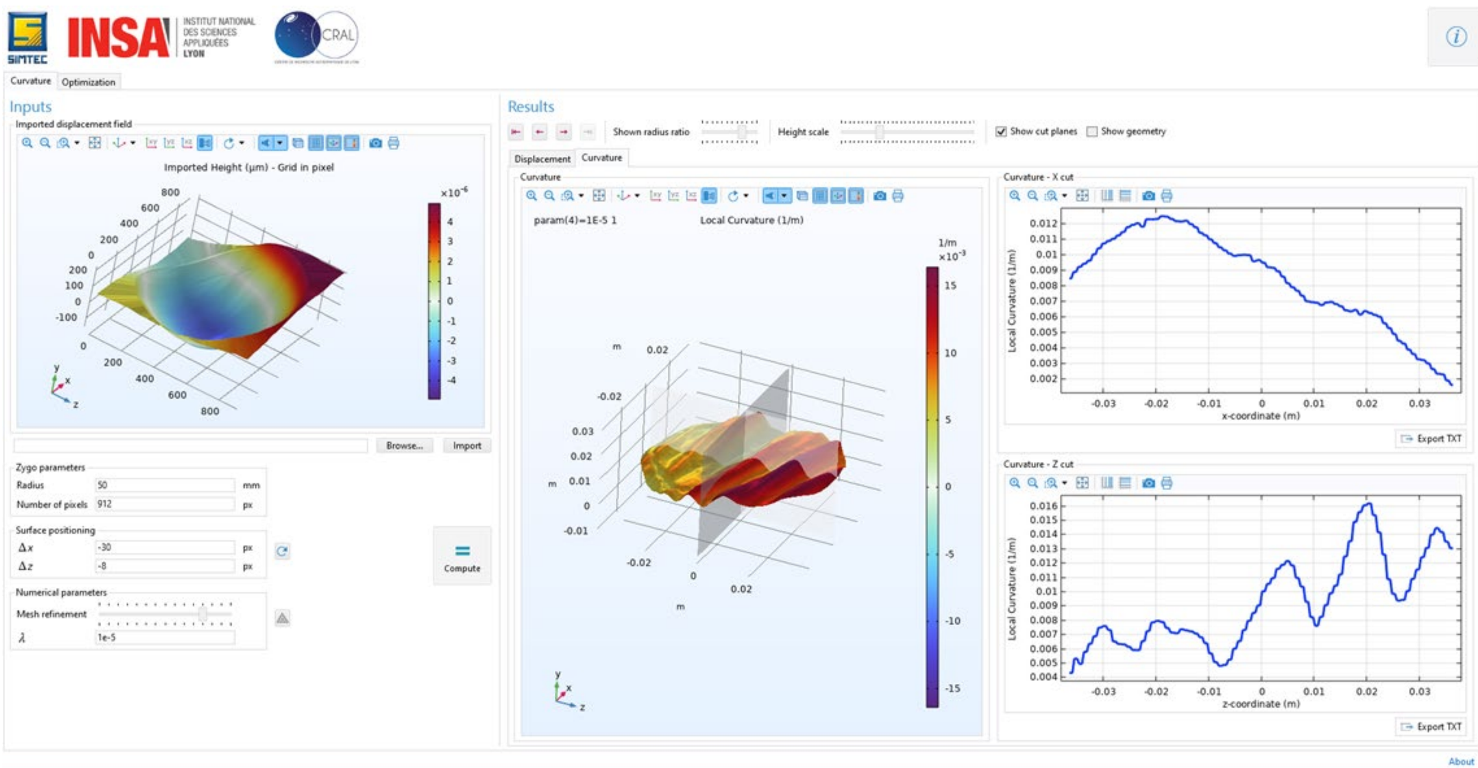
$$Gain = \frac{RMS(\rho_{initial})}{RMS(\rho_{optimized})} > 300\%$$

⇩

Validation of the numerical approach

III. Main Results

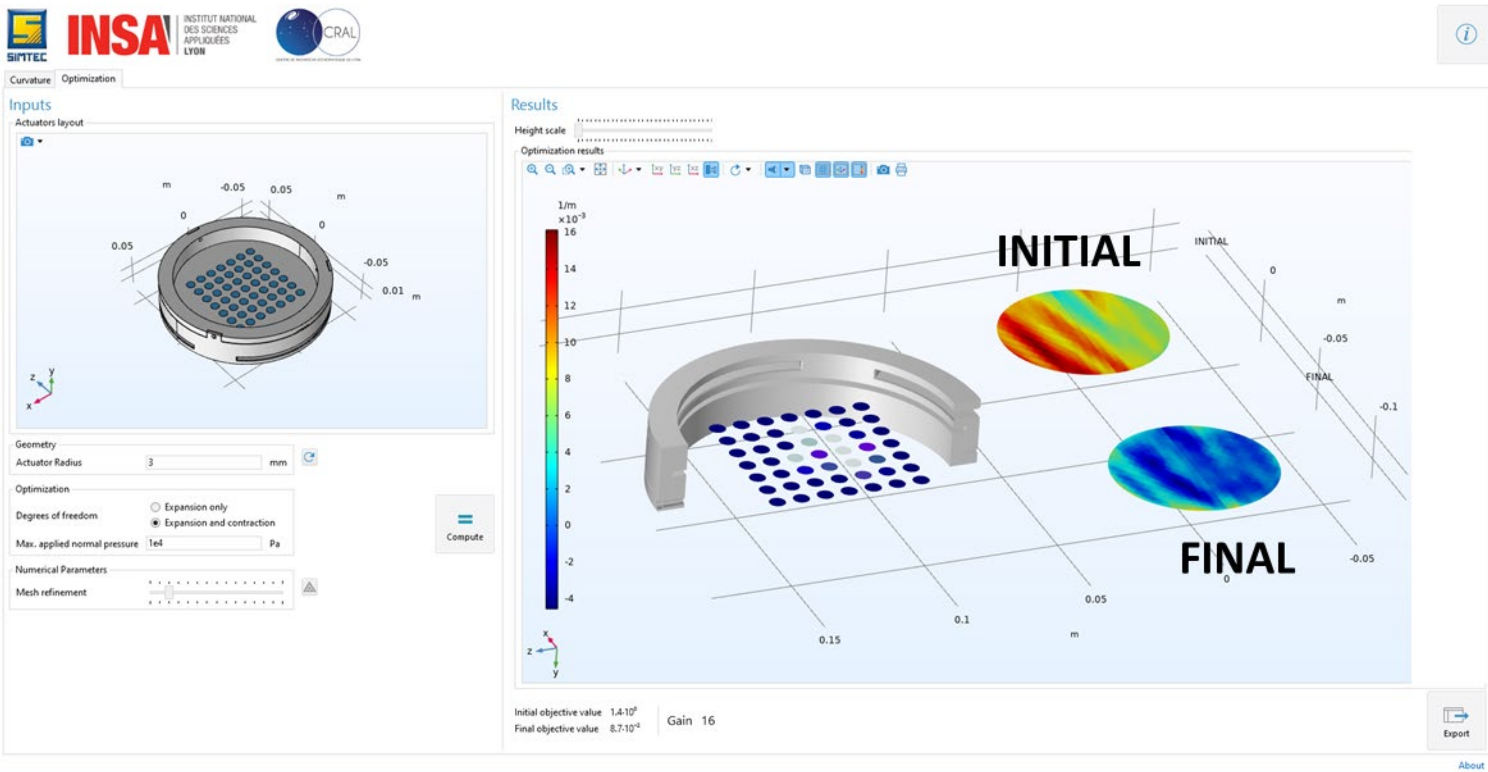
Application



- Import of experimental data & Pre-processing
- Local Curvature Computation and Post-processing

III. Main Results

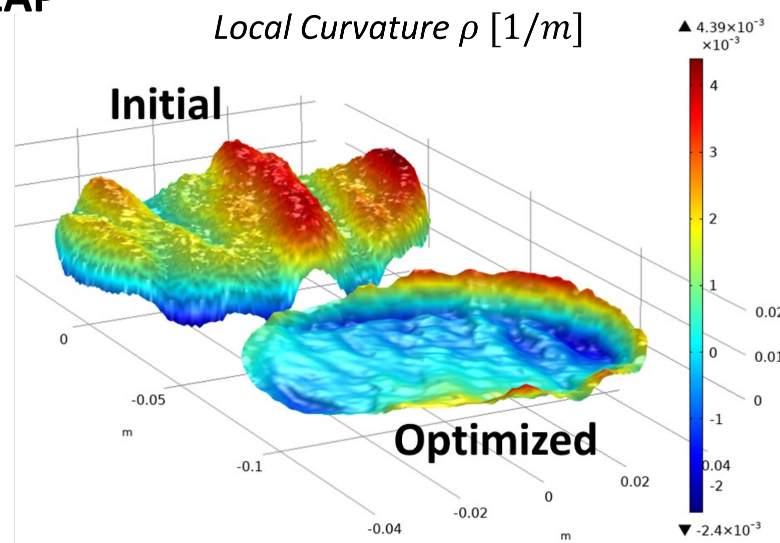
Application



- Parametrization of the EAP Geometry Pattern
- Full Parametrized Optimization Procedure
- Export of resulting K_{f_i} for each EAP

IV. Conclusions - Perspectives

- Development of an **optimization procedure** to predict the **optimum force (~ electrical potential)** to be applied to each actuator,
- Parametrization of the optimization procedure to study **the influence of the geometry pattern**
- **Validation of the curvature computation and optimization loop with a specified pattern of EAP**

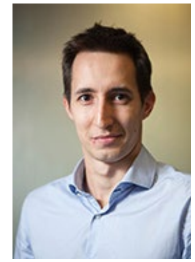


To finish…

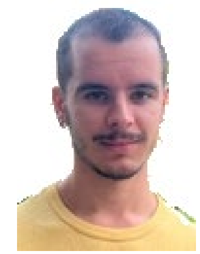
Thank you!

Q&A?

Our question: What about a coffee to discuss your topic? ☺



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