3D PRINTING FOR ASTRONOMICAL MIRRORS

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Summary

THE MISSING PIECE

ASTROPHYSICS

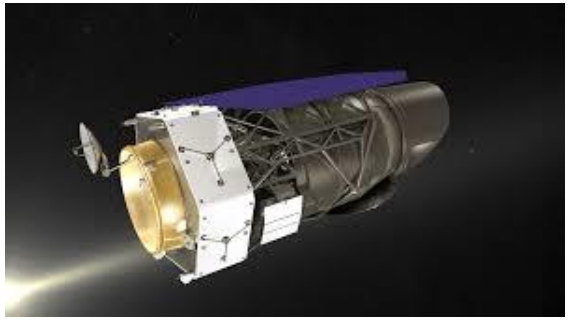
Decadal Survey Missions

-Thirty Meter Telescope will have 144 times the collecting area of Hubble and more than a factor of 10 better spatial resolution at near-infrared and longer wavelengths

-European Extremely Large Telescope (Visible, images 16x sharper than Hubble)

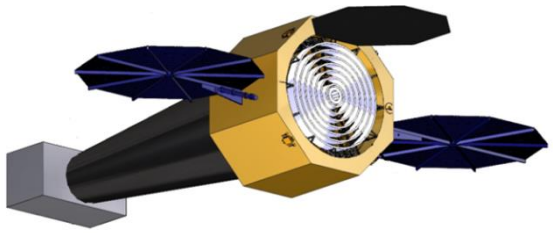
Context

WFIRST 2024



- Infrared telescope
  - Ice & gas giant exoplanet
  - Galaxies near Big Bang
- Size : D=2.4m

LYNX x-ray surveyor 2040?



- X-ray telescope
  - Invisible drivers of galaxies
  - Dawn of black holes
- Size : L=12m, D=4.5m

50x more sensitive than Chandra launched in 1999

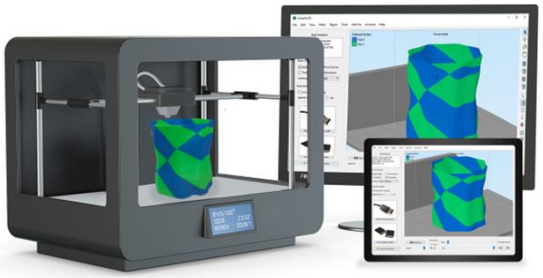
Objectives

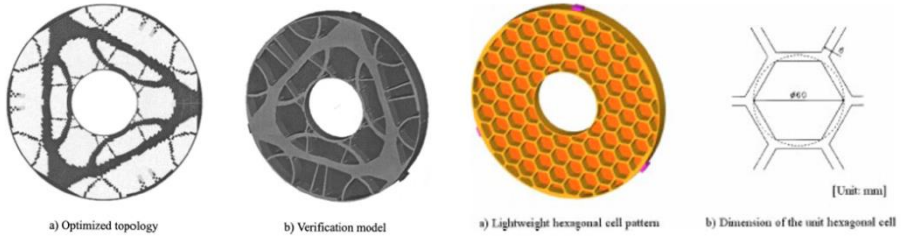
1. **WFIRST telescope** (LAM)**:**
   Stress polishing of mirrors for exoplanet imaging
   - Off axis parabolas FEA Simulation & optimization
   - Warping harness design

2. **LYNX x-ray surveyor** (UK ATC)**:**
   3D printing and lightweight / high precision structures
   - Comparison of the 3D printing process and material
   - Properties of lightweight structure in 3D printing
   - Study the feasibility of substrates polishing

Context

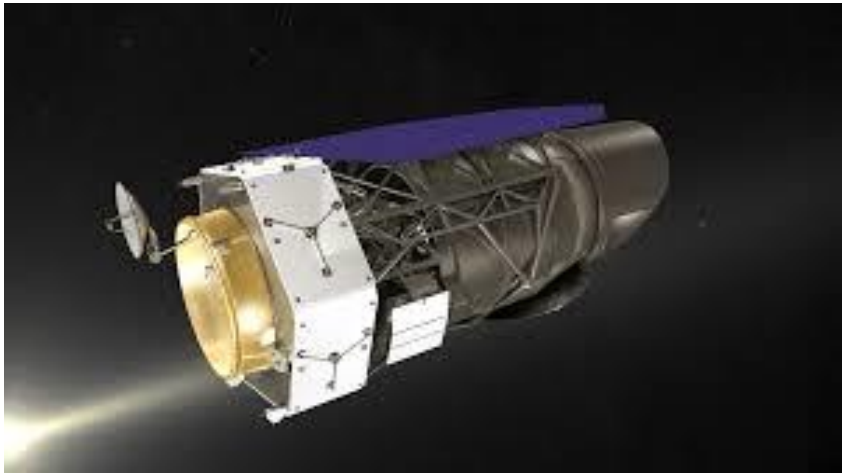
- **Requirements**
  - Large collecting area
  - High resolution
  - Low weight
- **Tools**
  - Active optics
  - 3D printing
  - Topological optimisation
  - Polishing process





CHAPTER 1: OFF AXIS PARABOLAS

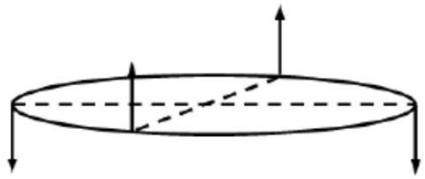
Stress polishing of off axis parabolas



Stress polishing principle

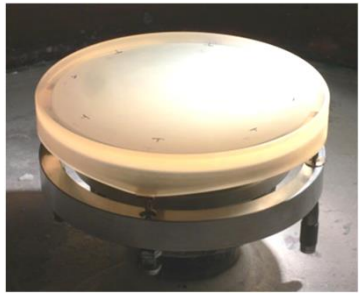
Step I: Substrate warping

- Into the inverse form you want to reach



Step II: Spherical grinding/polishing

- Using full size tools and Imprint the warping function

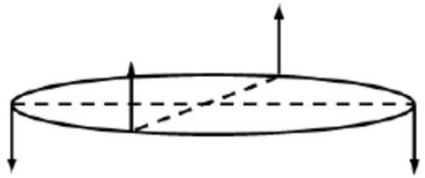


Step III: Removal of the loads

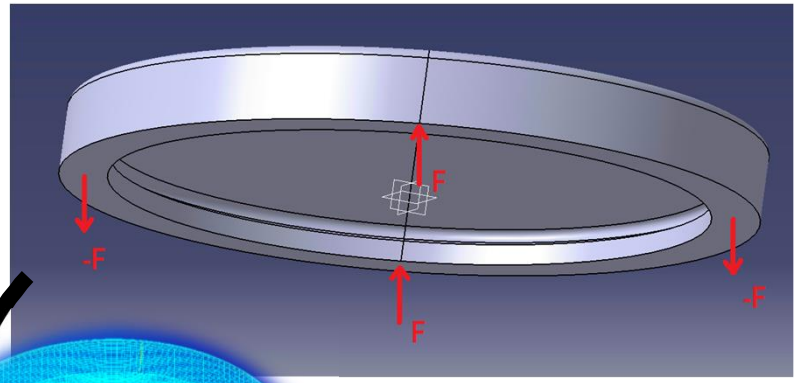
- Get your aspherical surface at rest

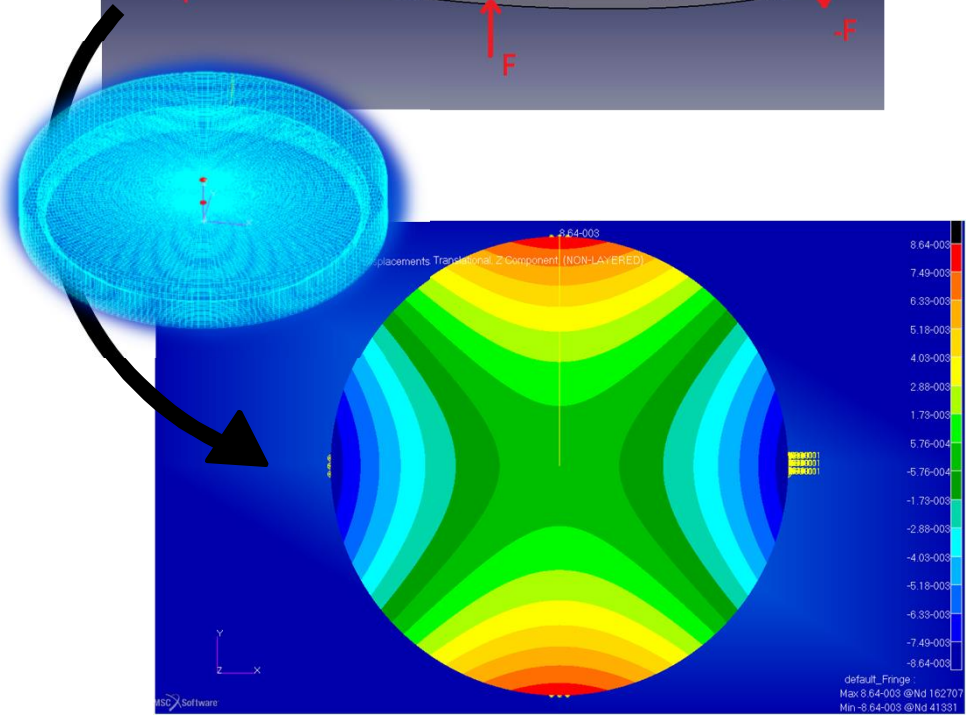
Gain:
High quality surfaces
Easy manufacturing
→ *Perfectly suited for High contrast imaging*

Astigmatism mirror

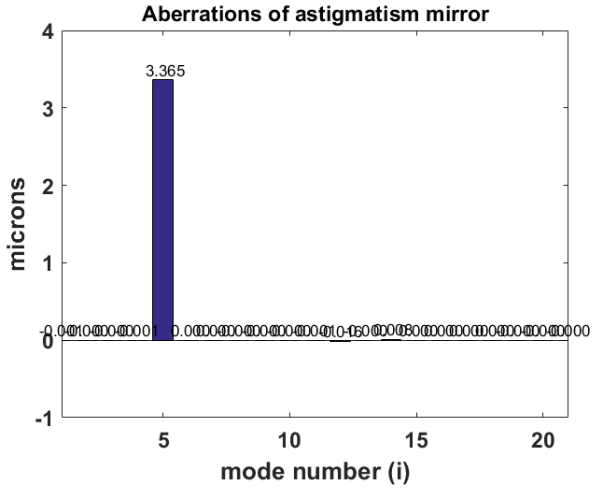


- Method

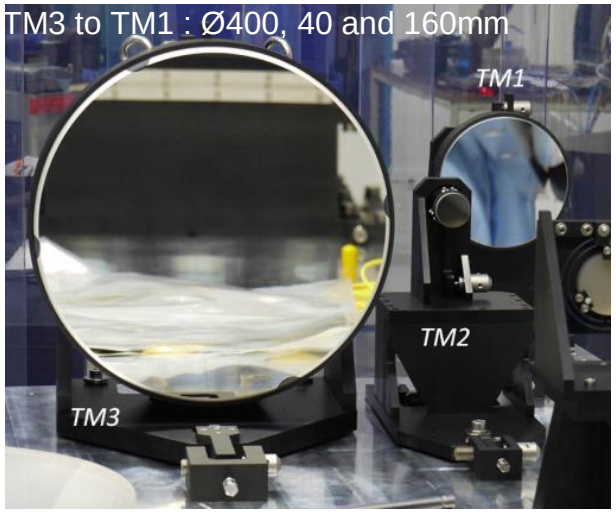


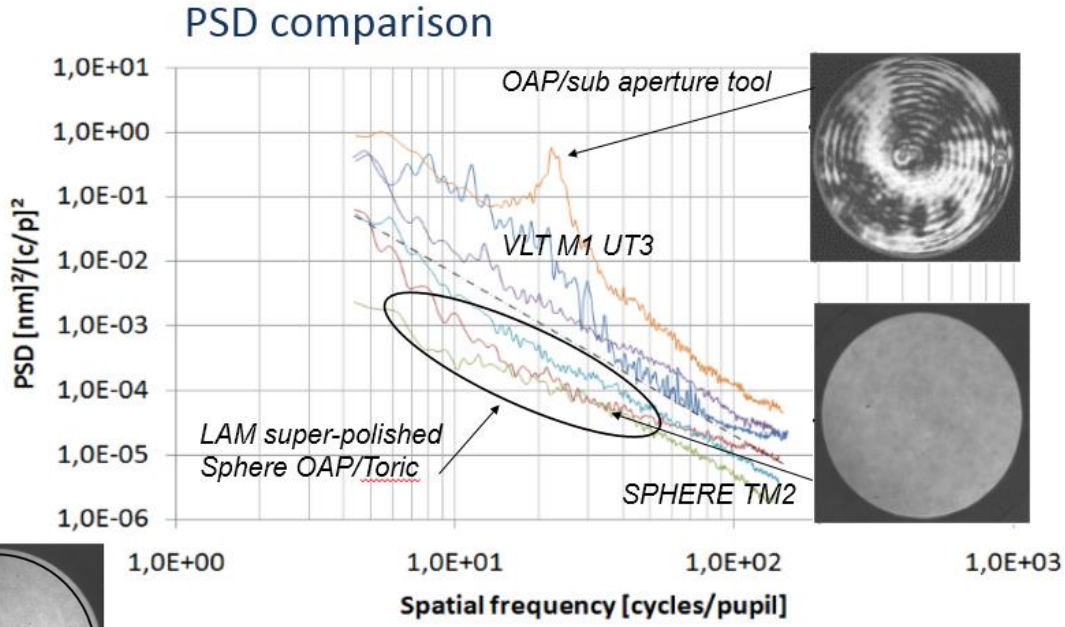


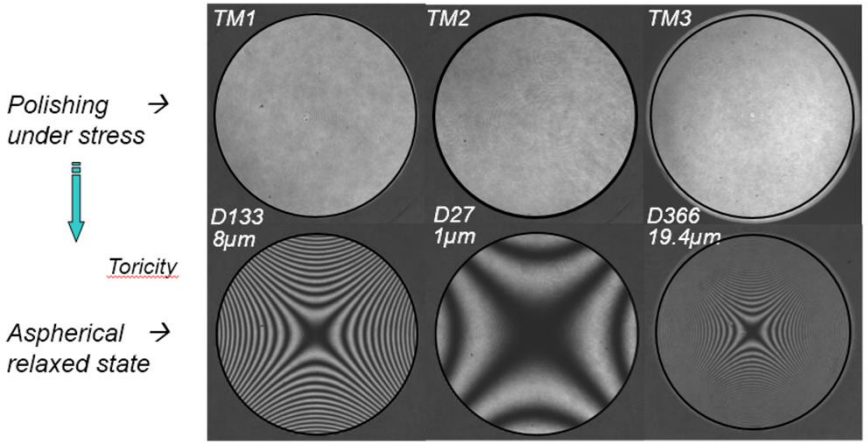
- Boundary conditions
  - Two pairs of opposite forces
  - Center attachement
- Material : Zerodur
  - E= 90600MPa



Super polished surfaces







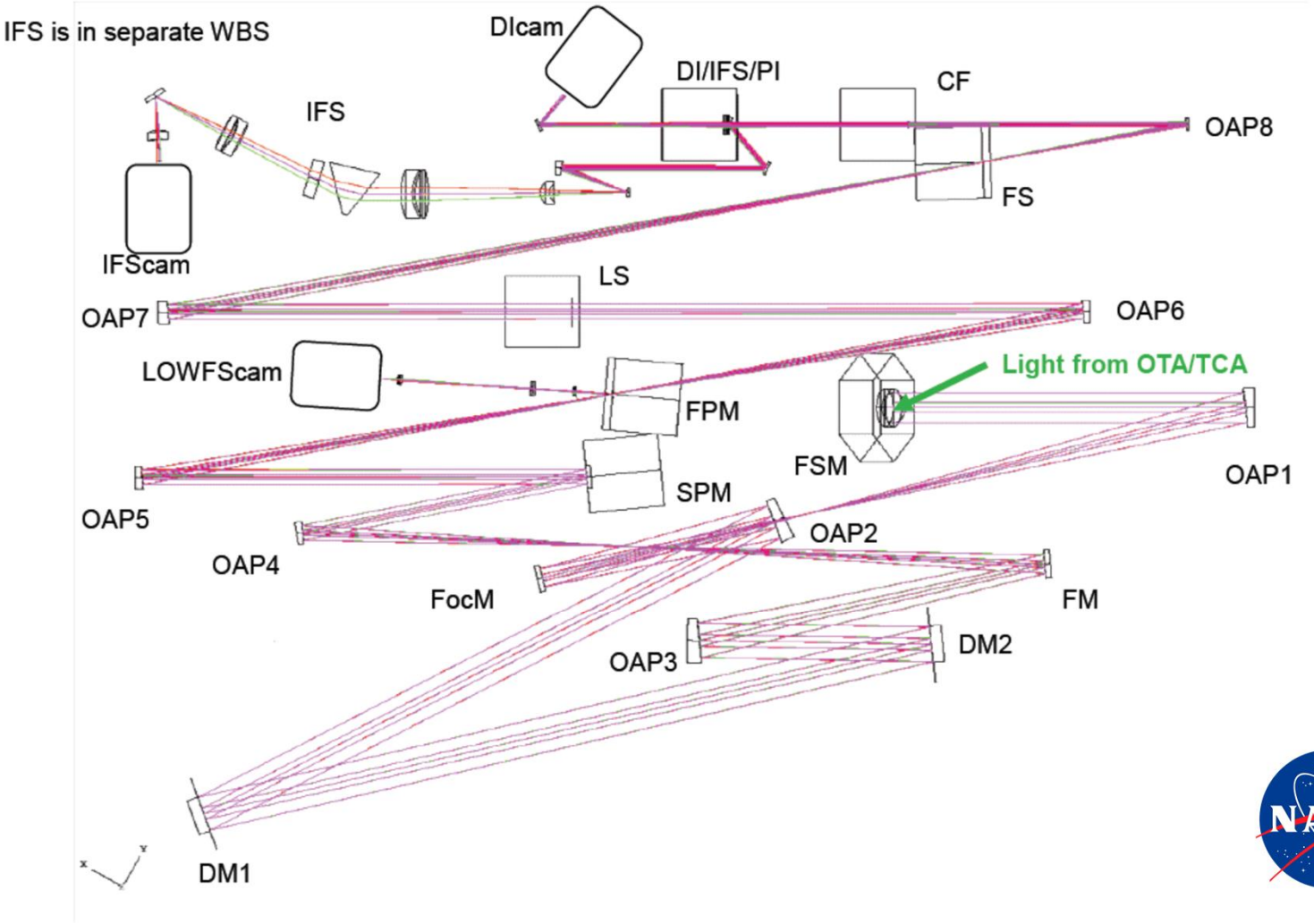
		TM1	TM2	TM3
Optical quality	LF	9.0nm	7.5nm	22.0 nm
	MF	1.3nm	1.1nm	2.5nm
	HF	1.1nm	--	1.6nm
Roughness		**5 Å**	**2 Å**	**9 Å**

VLT SPHERE toric mirrors

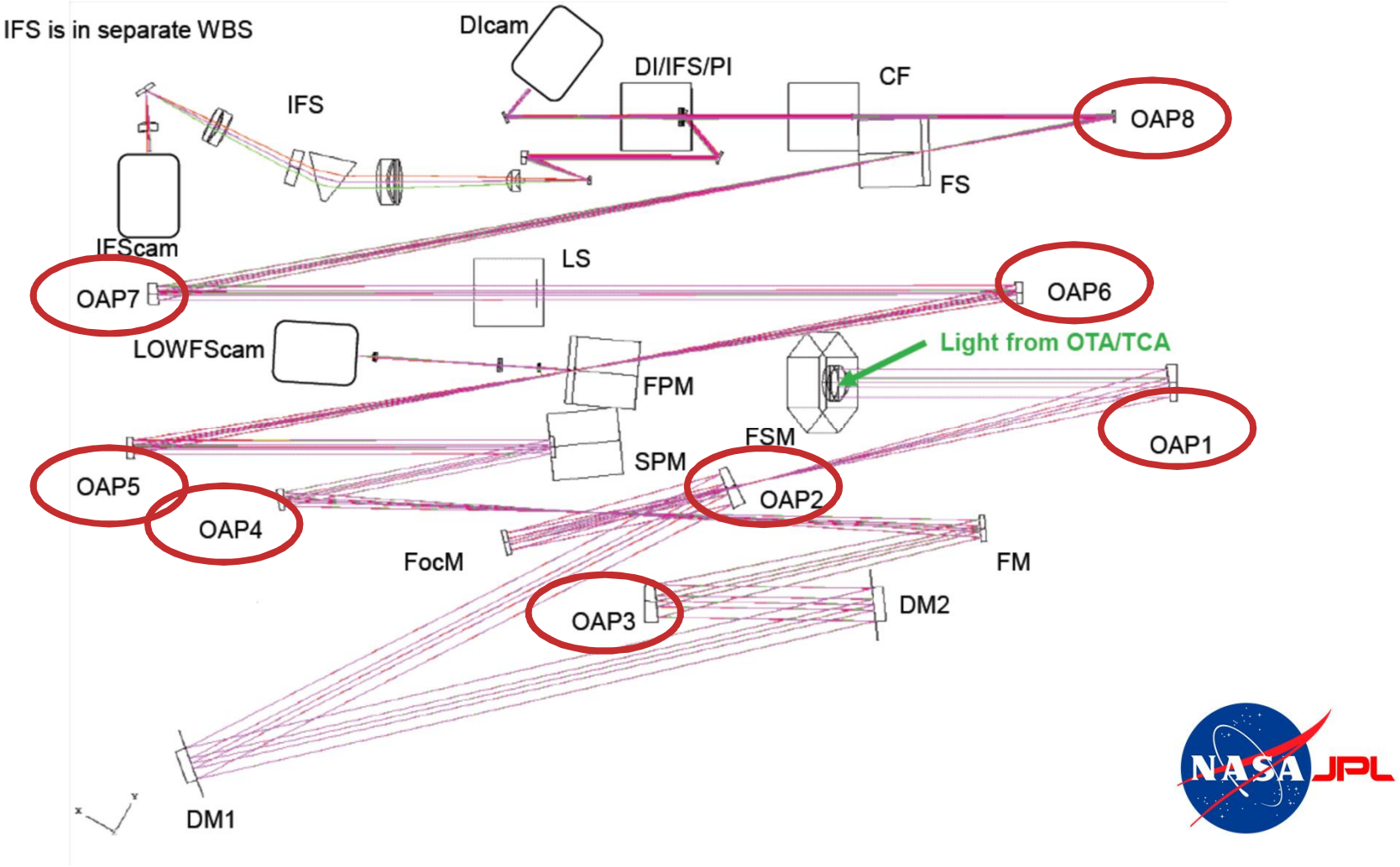
Delivered to SPHERE in 2011
+ one spare in 2013

Hugot, Ferrari et al
Applied Optics 2009
A&A 2012

WFIRST Coronagraphic instrument



WFIRST Coronagraphic instrument

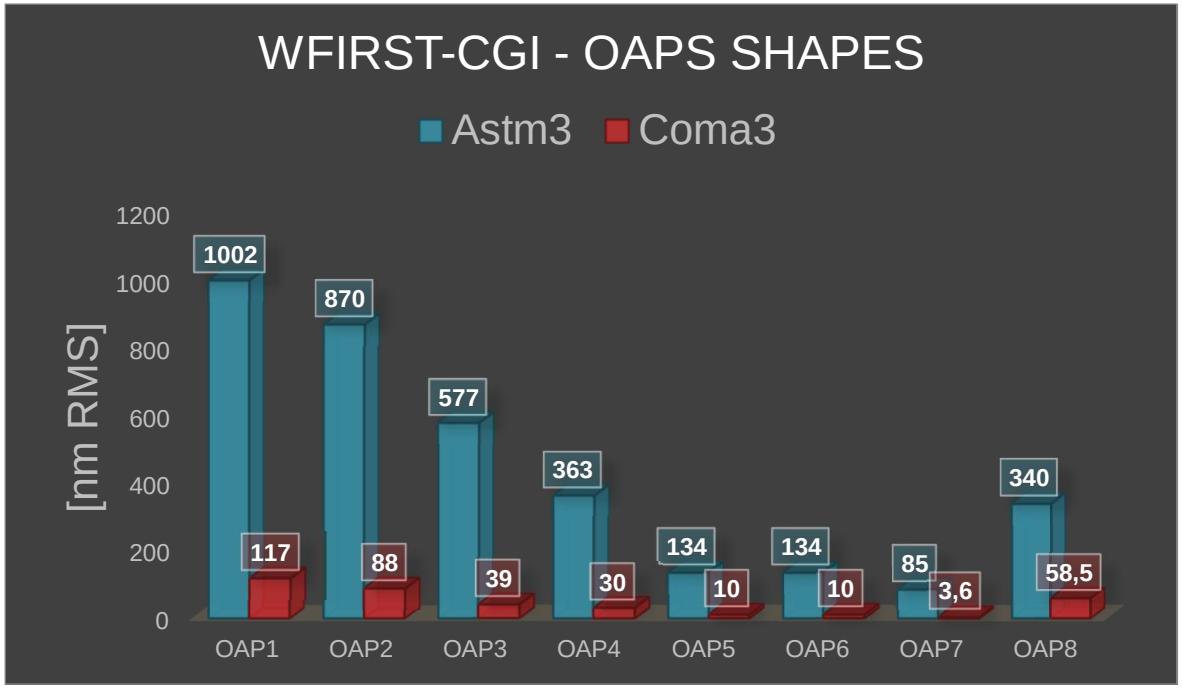


WFIRST-CGI OAPs

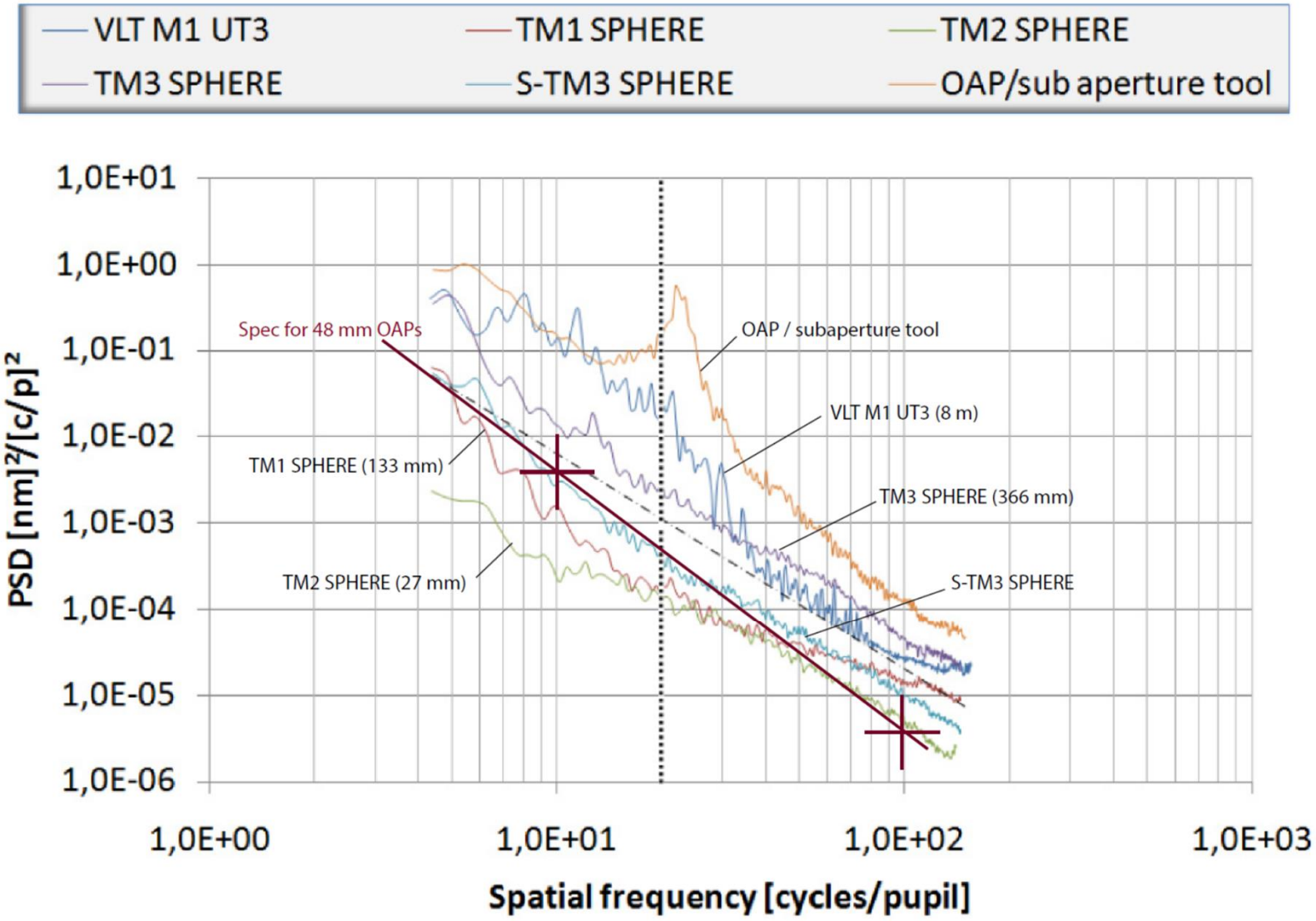
WFIRST CGI Optics	Diameter	Roc (BFS)	OAD	Astm3	Coma3
OAP1	58	1180 (1188,3)	140	-1002	-117
OAP2	58	1360 (1369,5)	161,36	-870	-88
OAP3	58	2032 (2046)	240	-577	-39
OAP4	30	864 (870,7)	102	-363	-30
OAP5	30	1270 (1274,7)	110	-134	-10
OAP6	30	1270 (1274,7)	110	-134	-10
OAP7	30	2200 (2209)	200	-85	-3,6
OAP8	30	550 (552,3)	50	-340	-58,5

Roc: Radius of curvature
BFS: Best Fit Sphere
OAD = Off Axis Distance
Astm3 : amount of Astigmatism in nm RMS
Coma 3: Amount of Coma in nm RMS

- Challenges in terms of surface quality
- Most difficult are OAP1&8



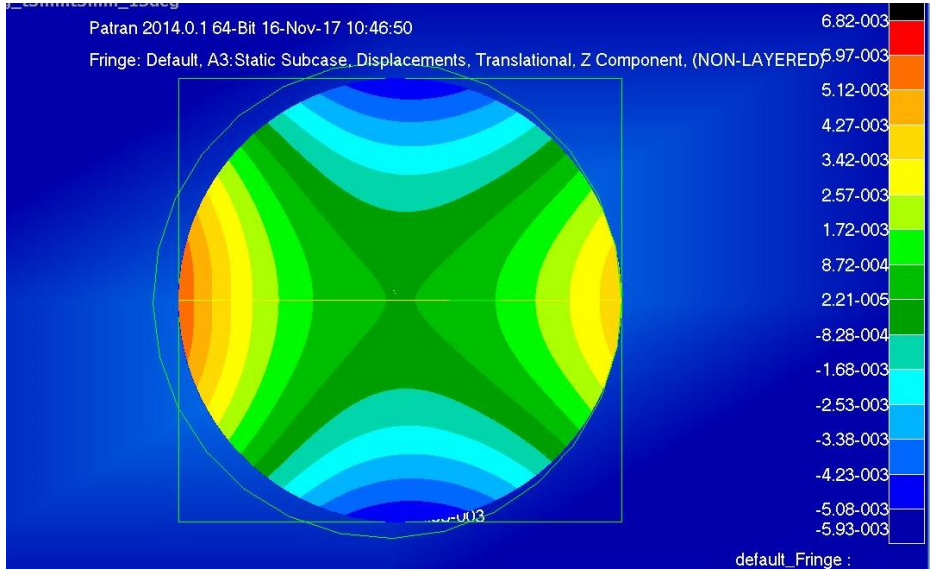
Comparison to WFIRST Specifications



Astigmatism + Coma mirror

- Requirement
  - Shape of WFIRST mirrors: Astigmatism and Coma
    → Break the symmetry

- Result with FEA



- Boundary condition
  - Two pairs of opposite forces
  - Clamped center

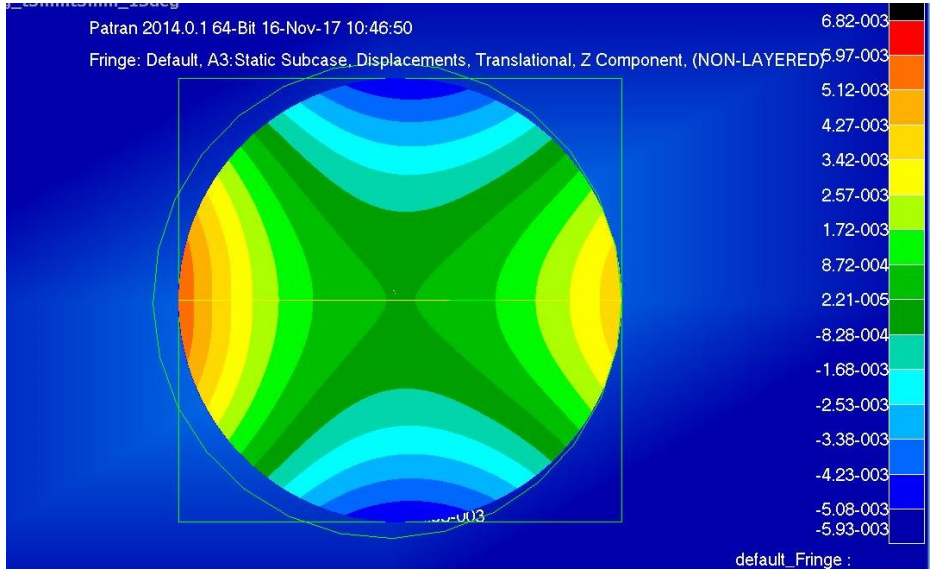
- Parametric study
  - Cannot be disclosed ☺

Astigmatism + Coma mirror

- Requirement
  - Shape of WFIRST mirrors: Astigmatism and Coma

→ **Design under patent**

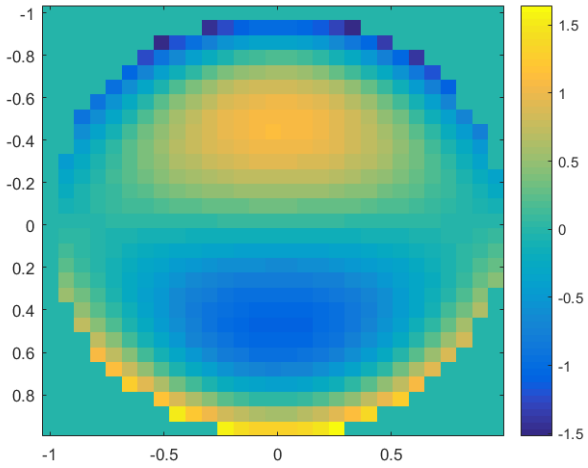
- Result with FEA

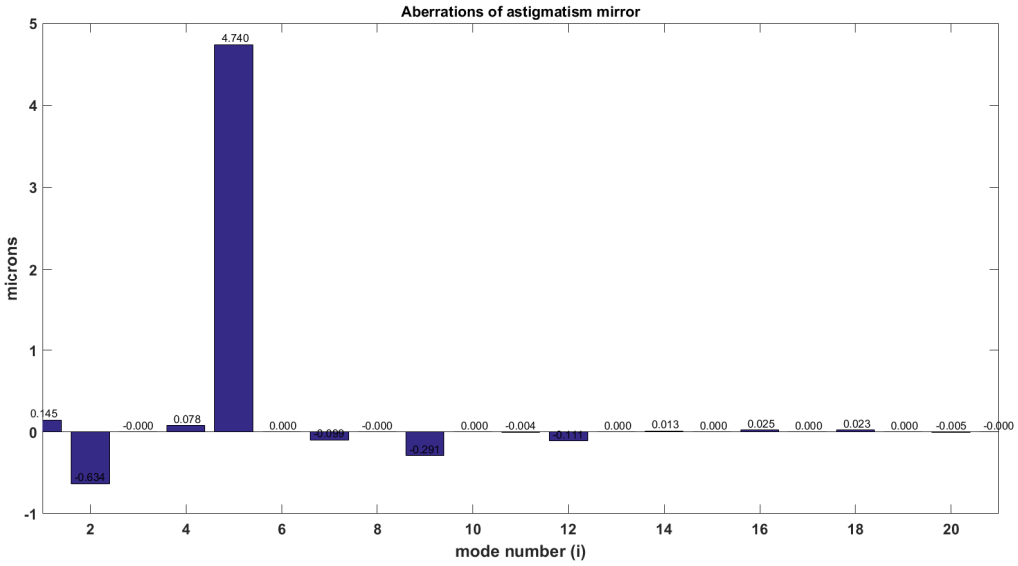


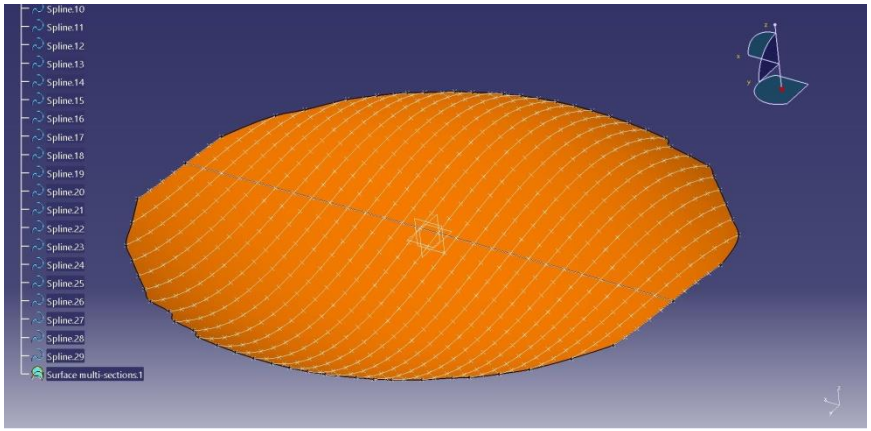
- Boundary condition
  - Two pairs of opposite forces
  - Clamped center
- Parametric study
  - Cannot be disclosed ☺

Astigmatism + Coma mirror

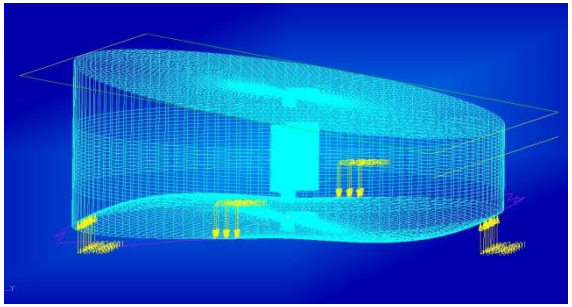
- New design approach



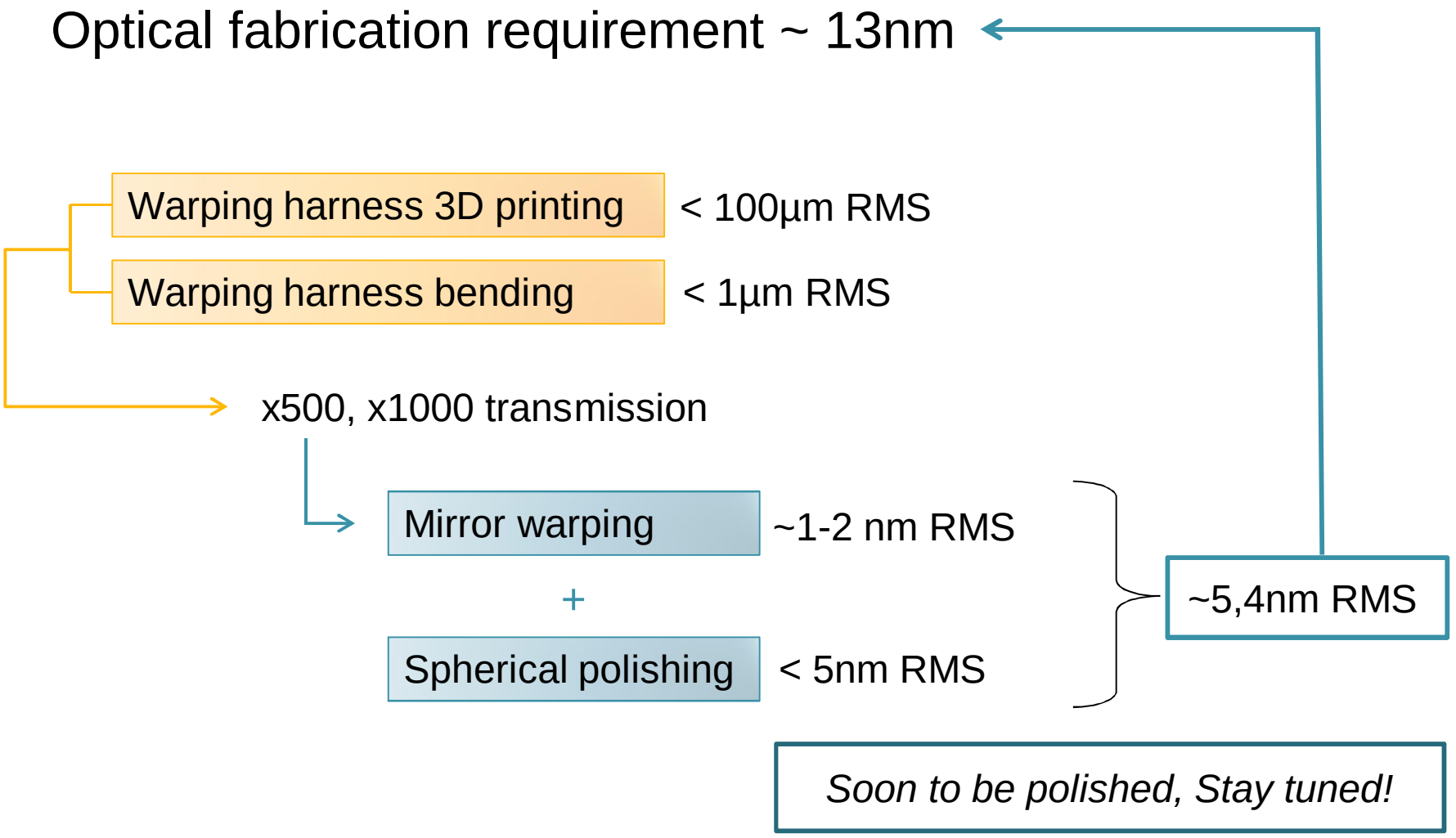


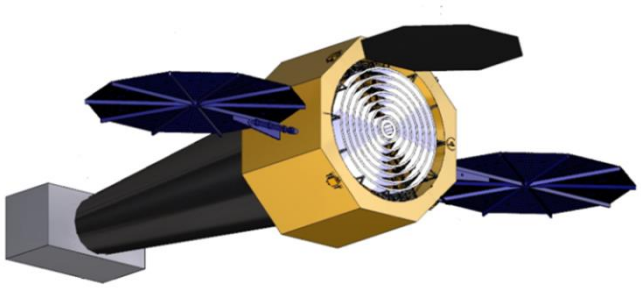


- Add wedge to avoid Trefoil y
- Decrease the thickness



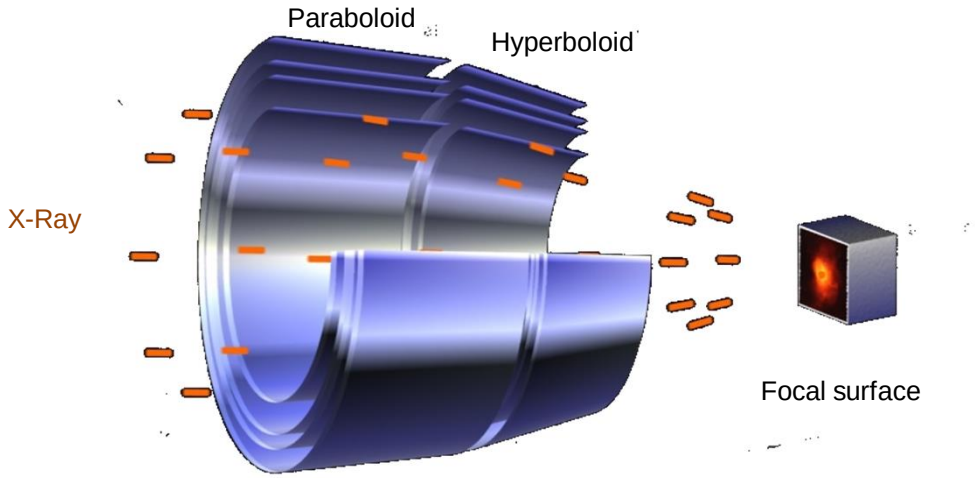
3D printing application





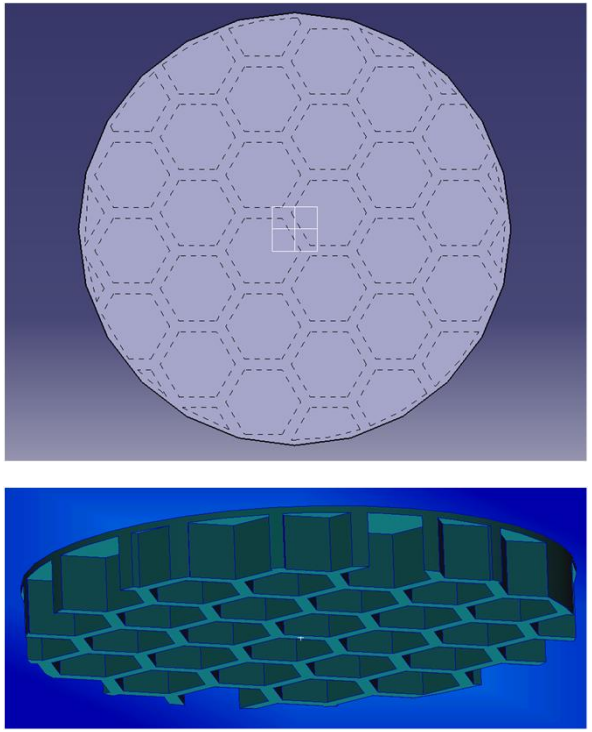
CHAPTER 2: LIGHTWEIGHT MIRRORS

3D printing of lightweighted structures & mirrors

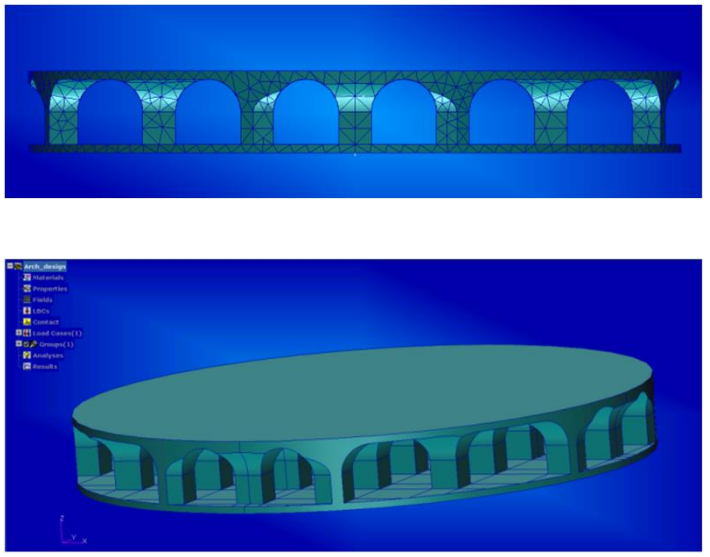


Honeycomb and Arch design

- Honeycomb design
  - Usual in lightweight structure
  - Mechanical manufacturing

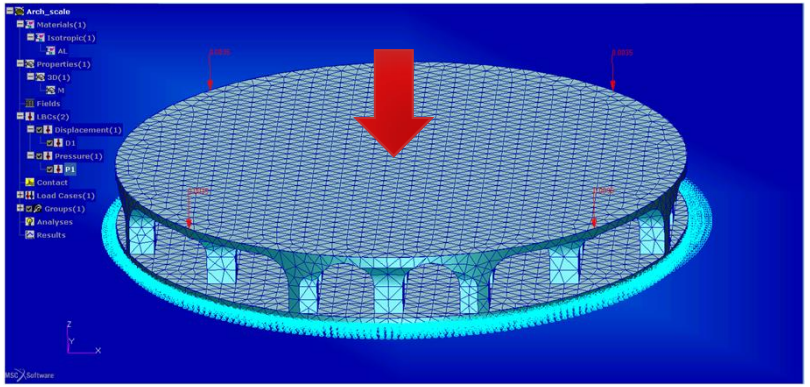


- Arch design
  - New lightweight structure
  - Manufacture by 3D printing



Honeycomb and arch design

- FEA simulations
  - Boundary conditions
    - Pressure on one face 3500Pa
    - Base attachment
  - Material : Aluminium
    - E= 70000 MPa



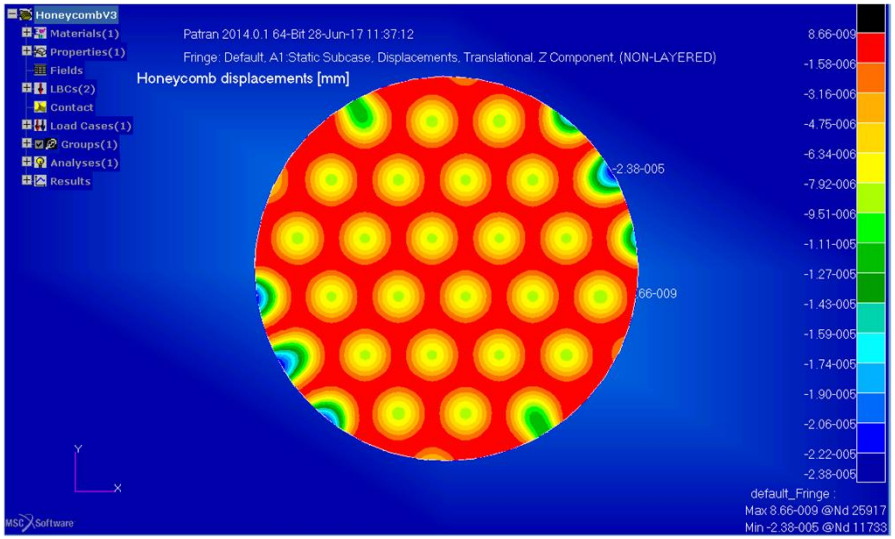
Boundary conditions

Compare the maximum displacement of the models

Honeycomb and arch design

Honeycomb design

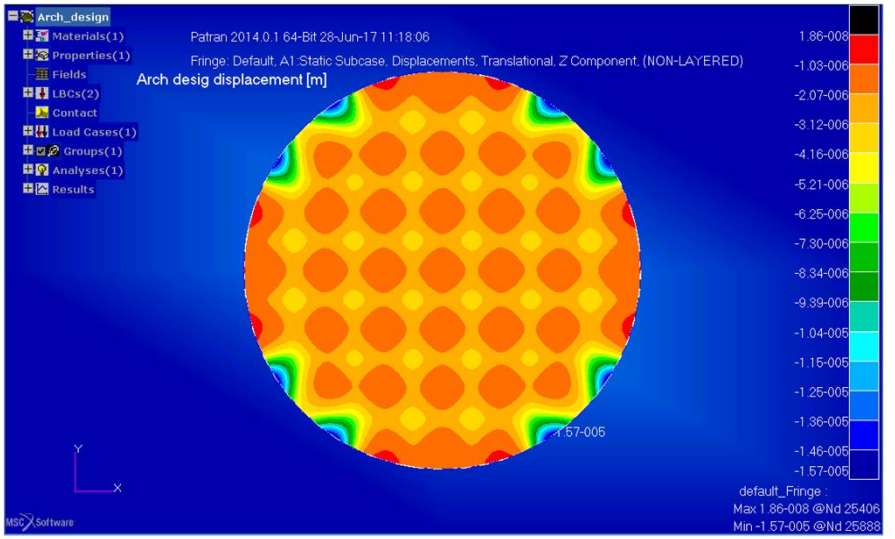
- Volume 35,0%



- Max displacement -23,8nm

Arch design

- Volume 34,8%

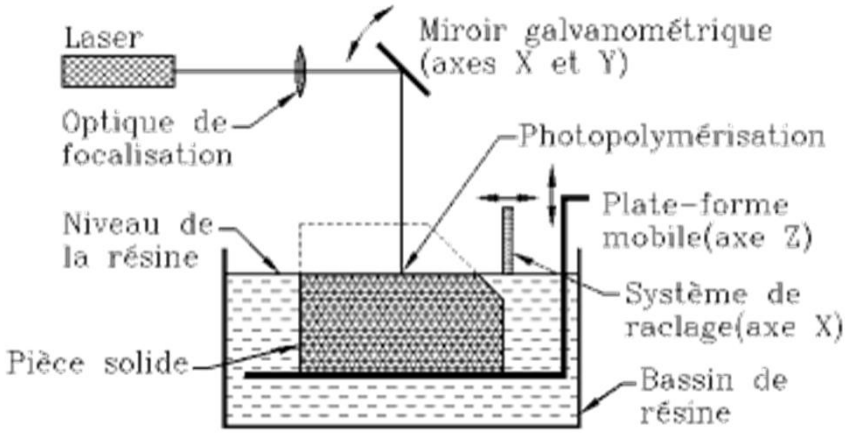


- Max displacement -15,7nm

→ Arch design is a better option in terms of displacement

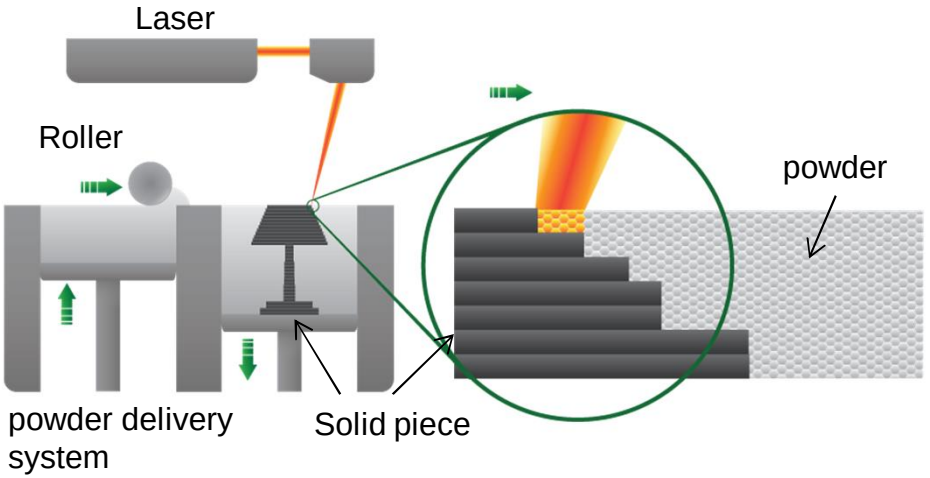
3D printing methods

Stereo-lithography



- Using photo-polymerization
  - Liquid resin (Plastics)

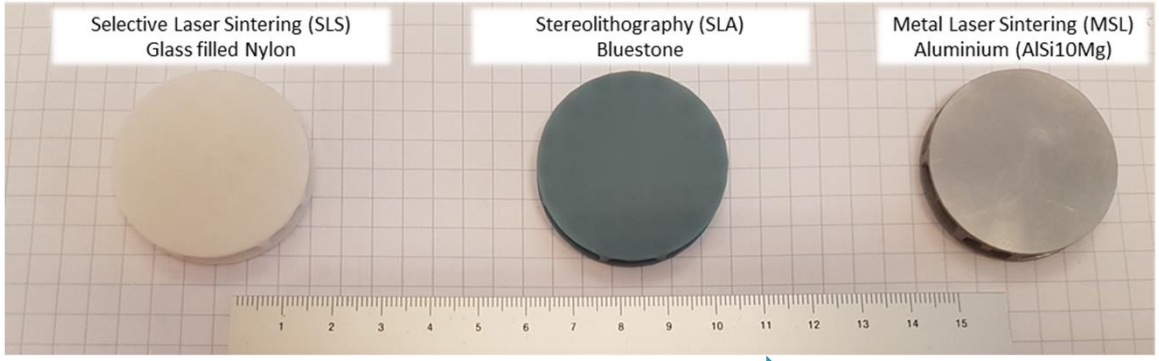
Selective Laser Sintering



- Using sintering method
  - Polymer (Nylon, polystyrene)
  - Metal (Steel, titanium, alloy mixture)
  - Composite

Material and post polishing process

Glass filled Nylon	Bluestone	AlSi10Mg
Composite material White and slightly porous E = 3,2 Gpa CTE = 68 $\times 10^{6}$/°C	Plastic with Ceramic qualities New composite material E = 7,6 GPa CTE = 33-44 $\times 10^{6}$/°C	Aluminum alloy Excellent machinability E = 64 Gpa CTE = 21 $\times 10^{6}$/°C

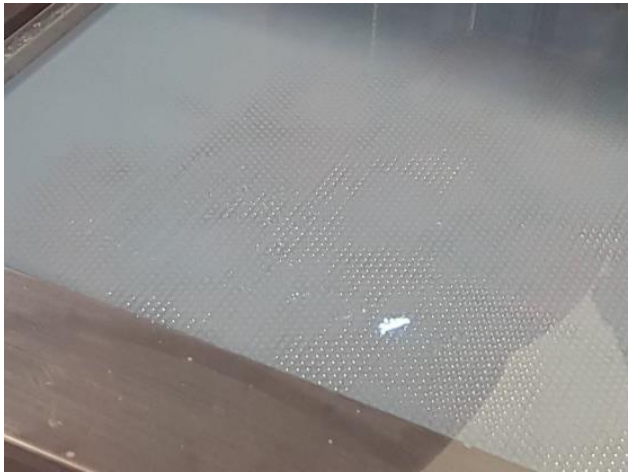


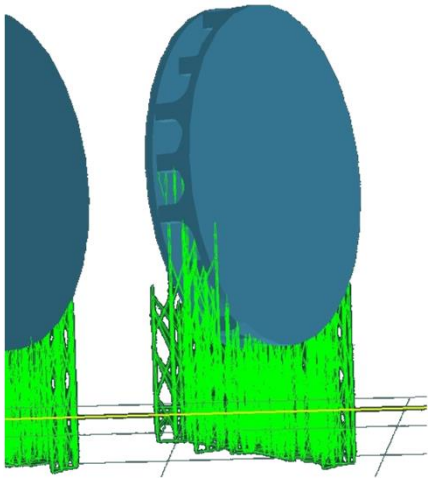
Increasing the polishing quality

Polishing state	Raw	Sanded	Skim	Blasted	Pure Ni coating	NiP coating
AlSi10Mg	X			X		X
Bluestone	X	X	X	X	X	
Glass filled Nylon	X				X	

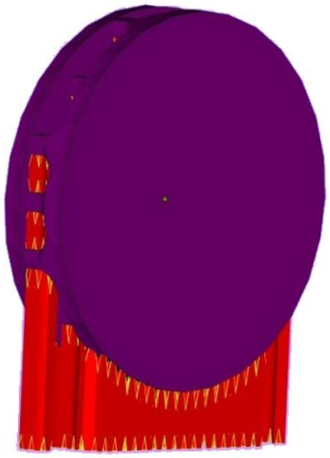
Manufacturing methods

- Bluestone
  - Stereo-lithography





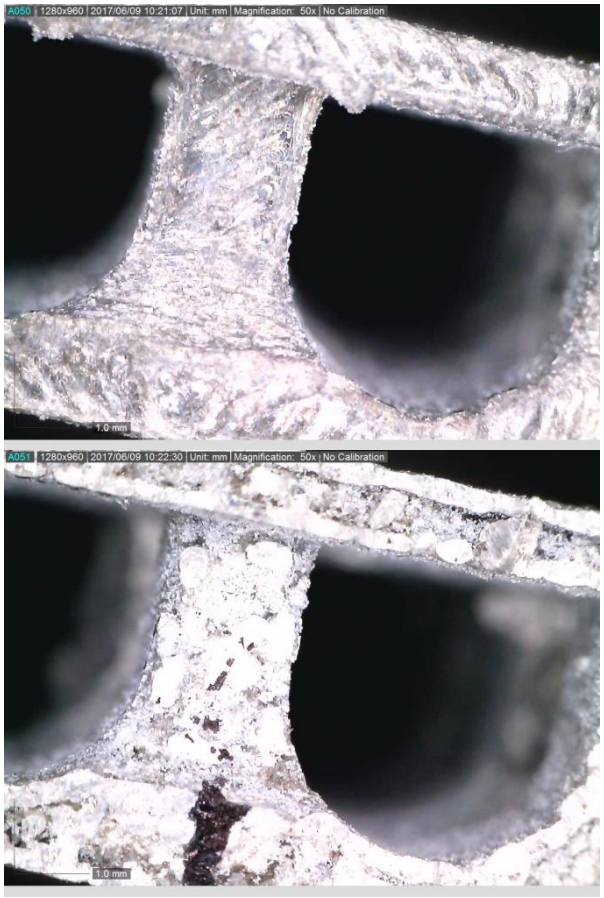
- AlSi10Mg
  - Metal Laser Sintering



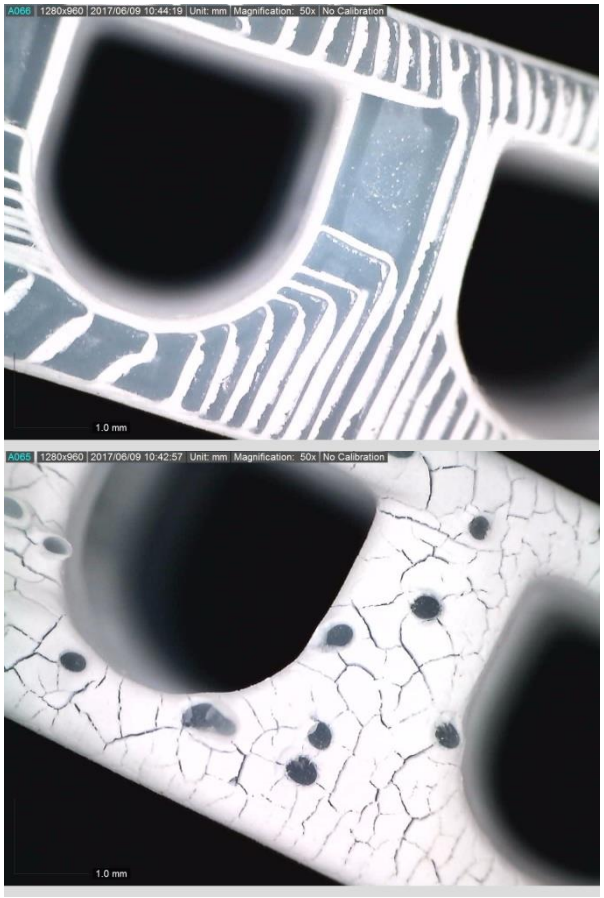
CA model UK

Microscope imaging

- Position of the samples during manufacturing impact the precision and the surface quality



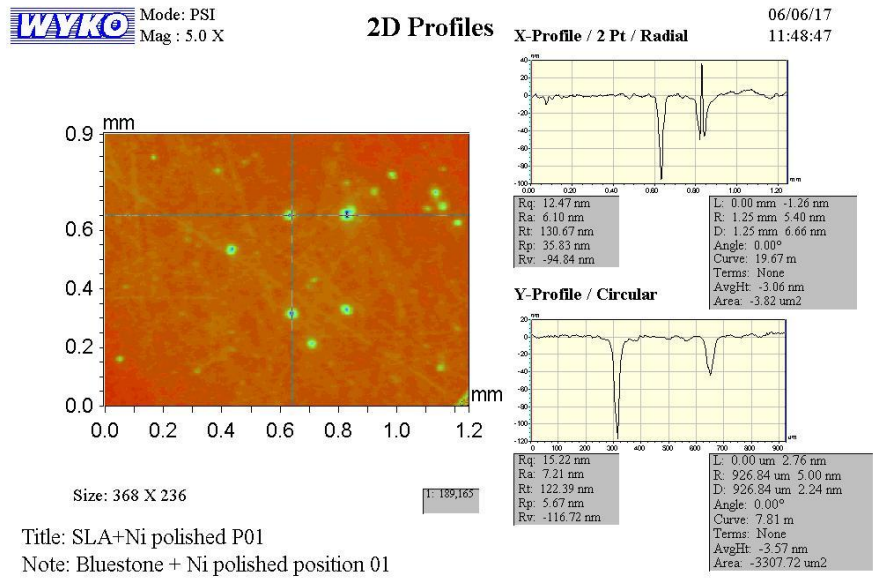
AlSi10Mg raw

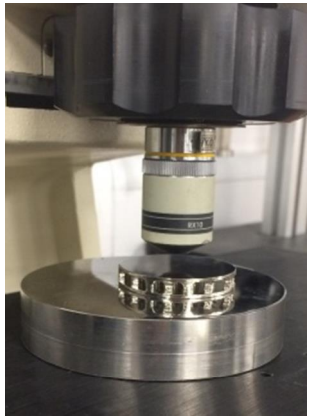


Bluestone raw

Arch measurement

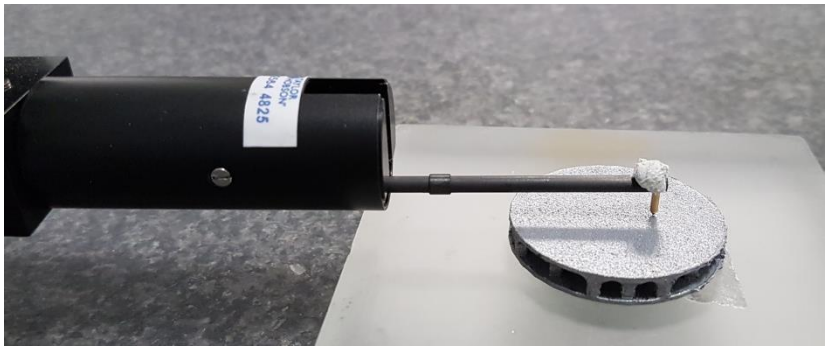
- Microscope interferometer

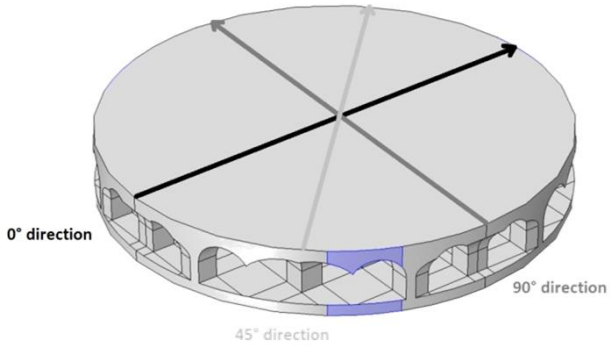




Microscope imaging

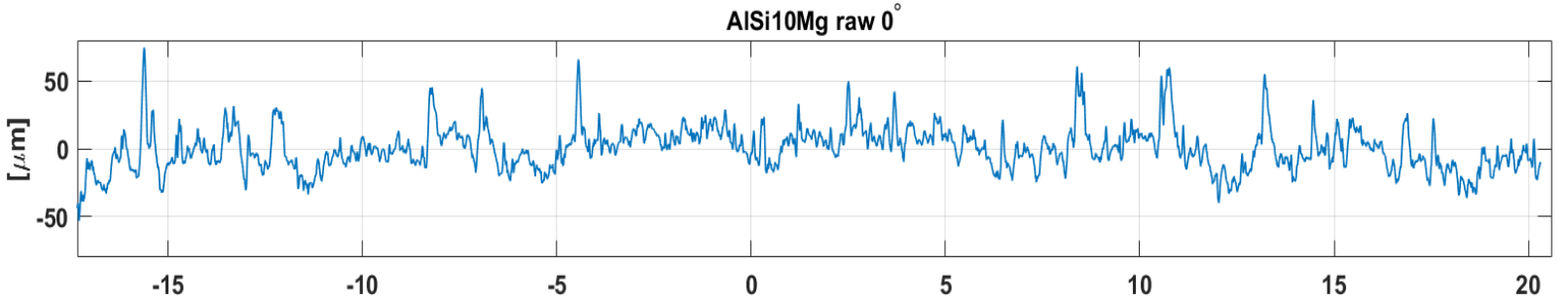
- Surface measurement

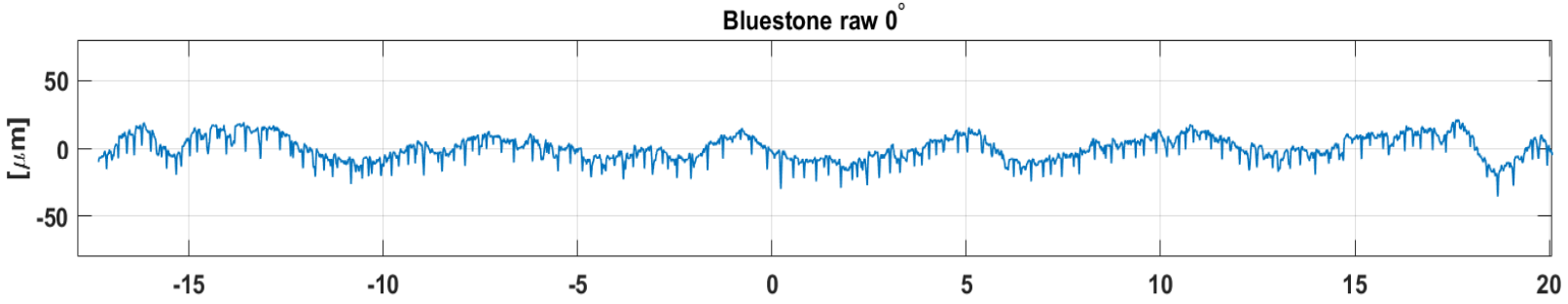


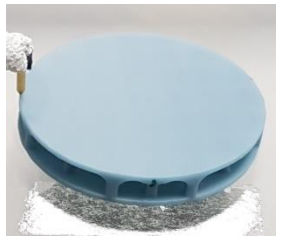


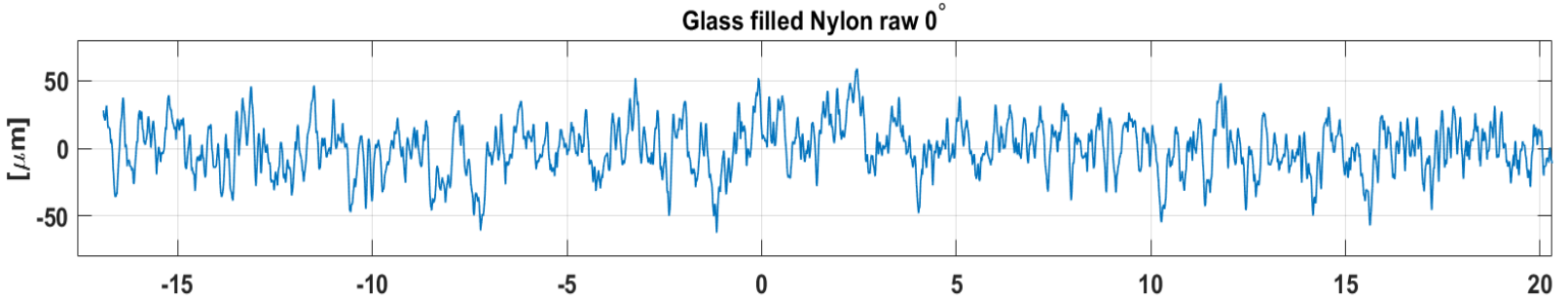
- 3 measurements per direction

Raw samples - surface profile

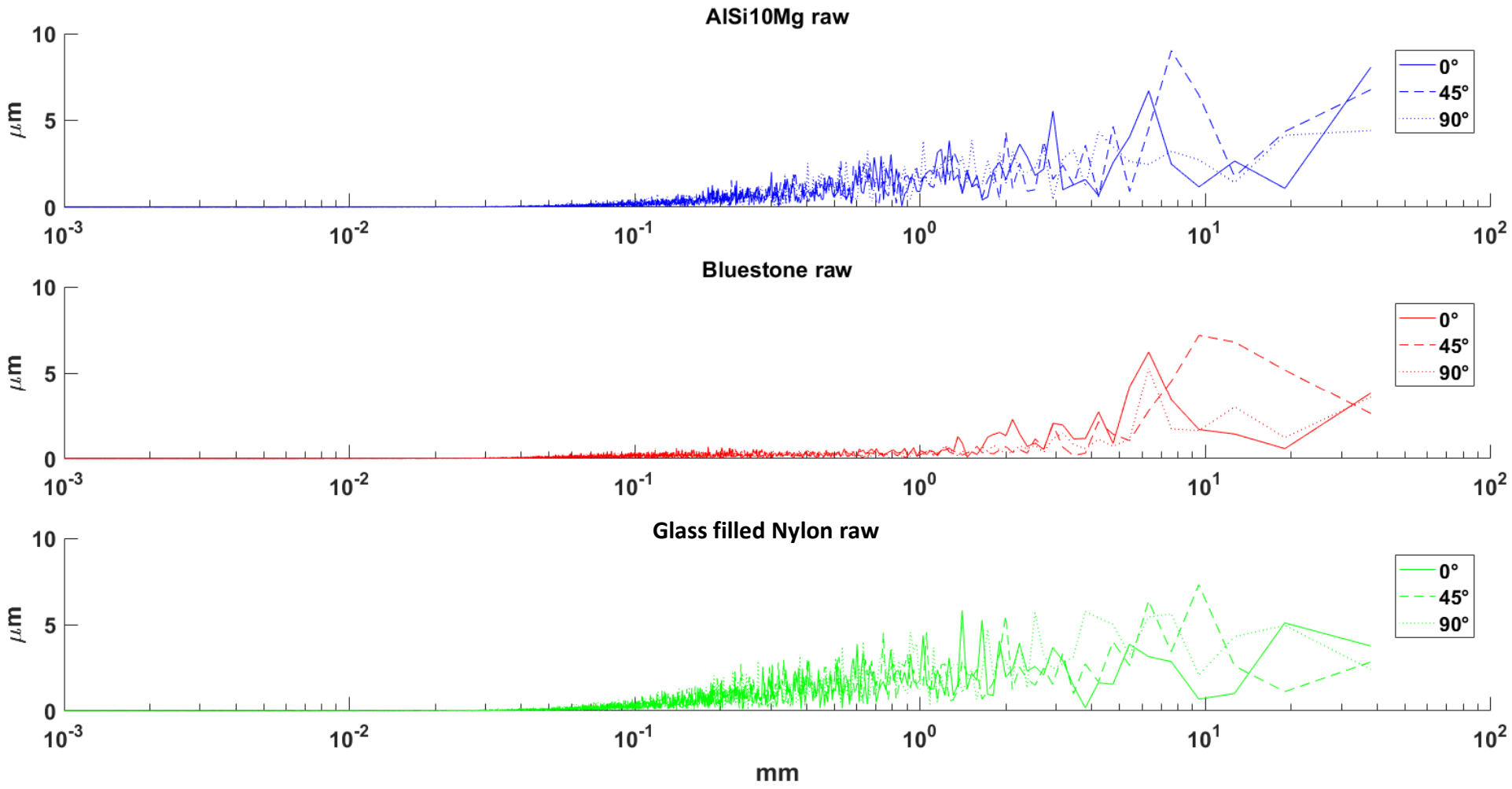




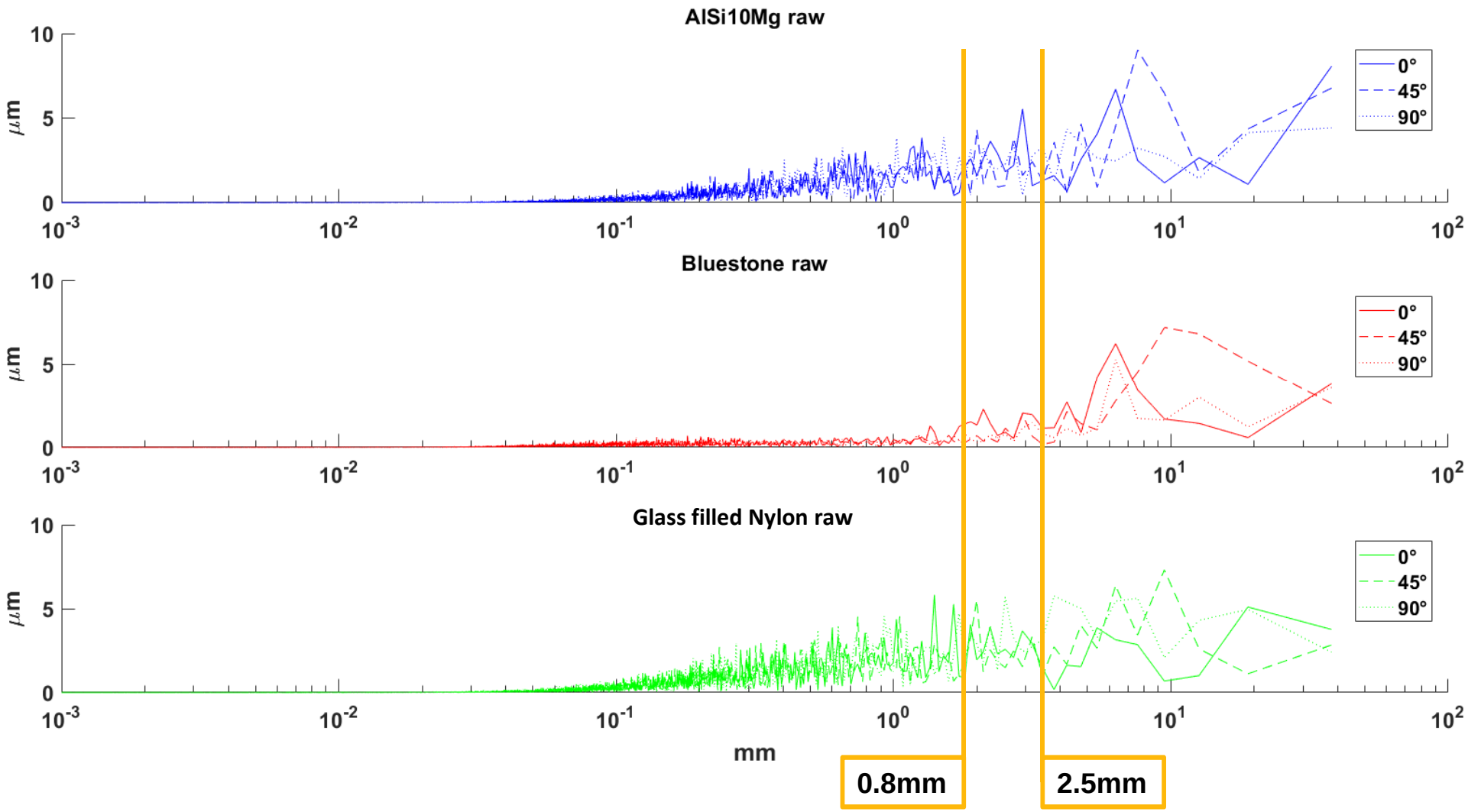




Fourier analysis - Spatial frequencies

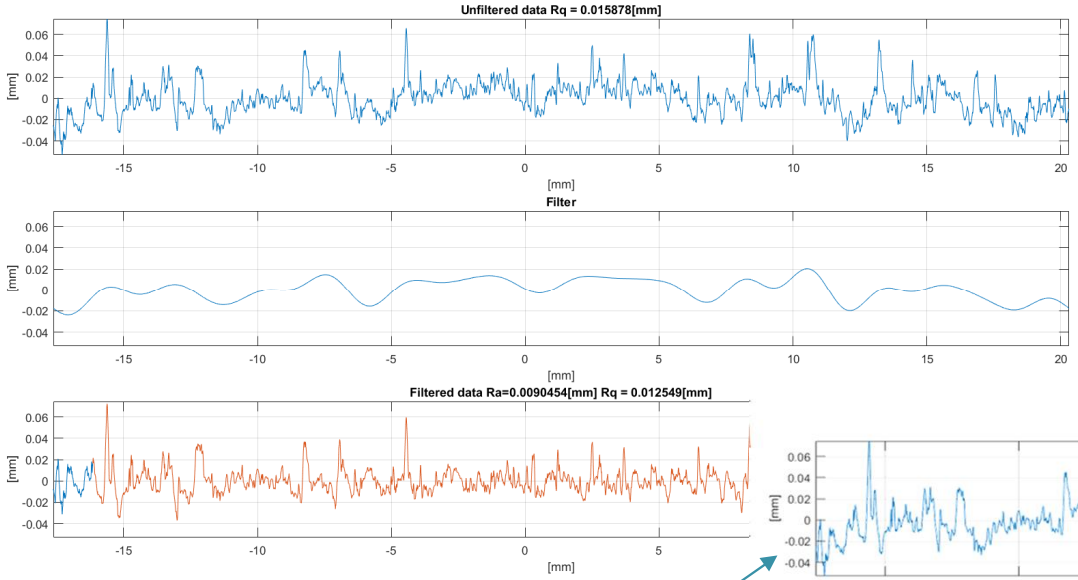


Fourier analysis - Spatial frequencies



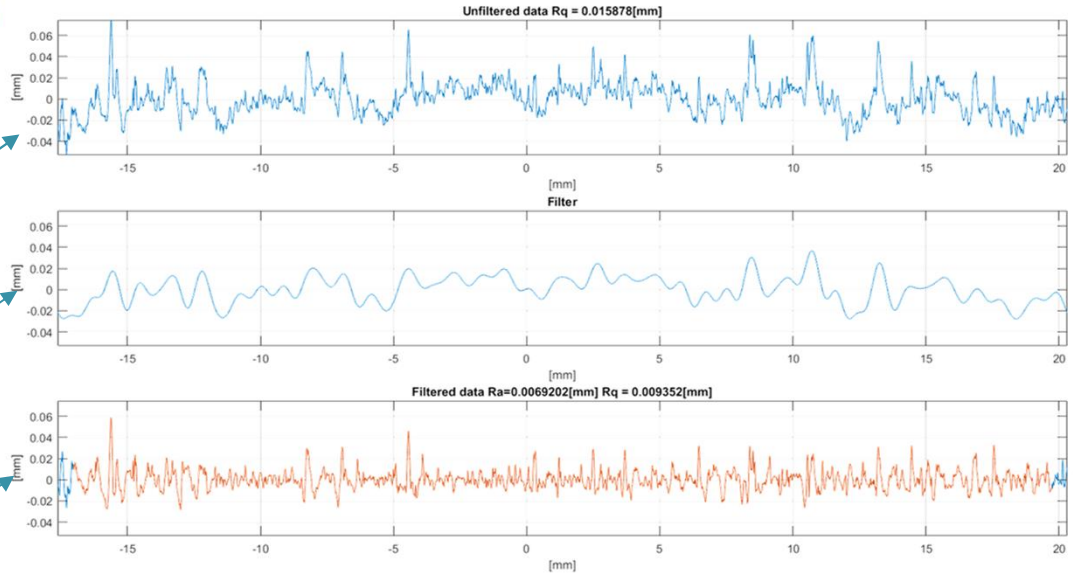
Fourier filtering result

AlSi10MG raw 0°



Cut off 2,5mm

Cut off 0,8mm

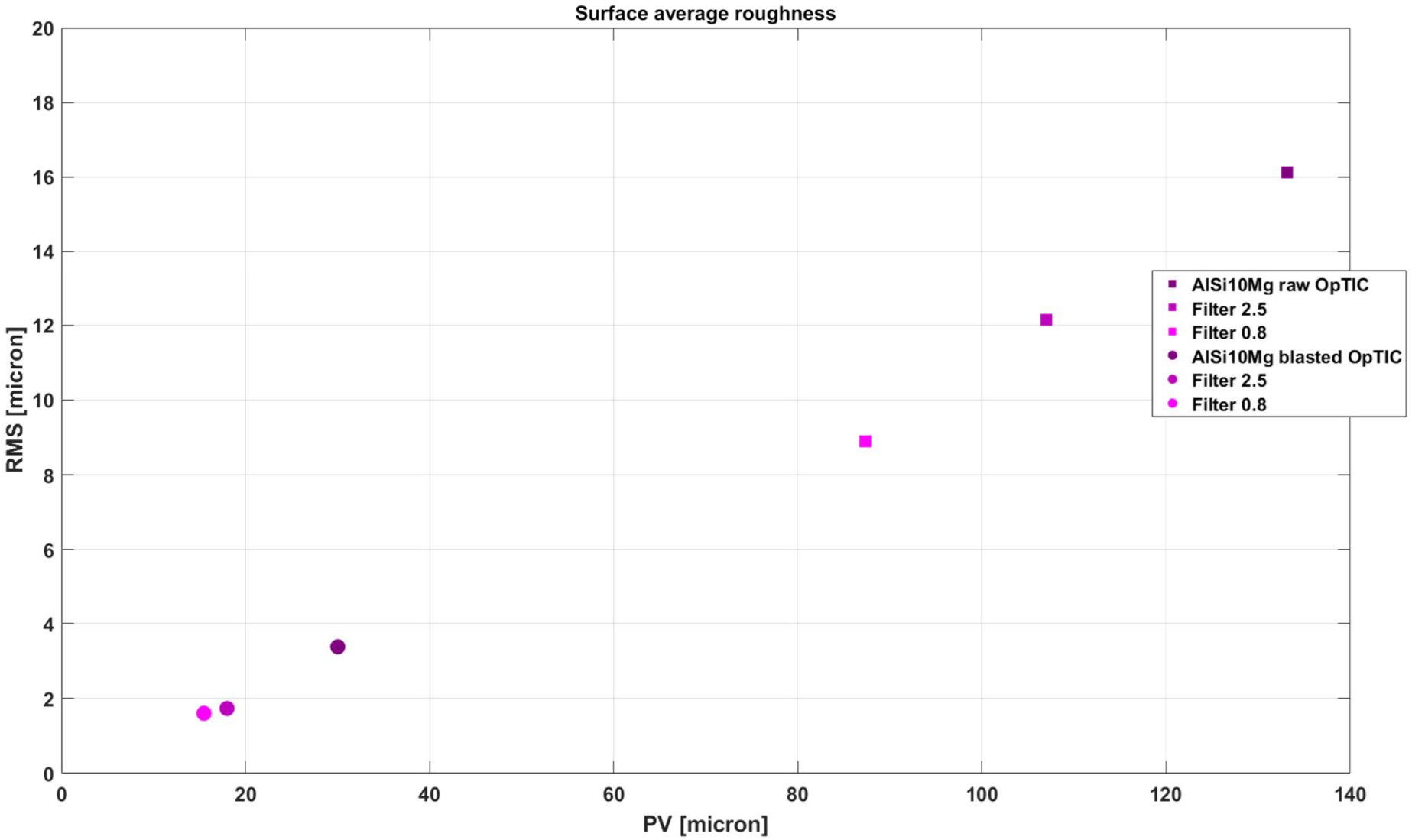


Non filtered

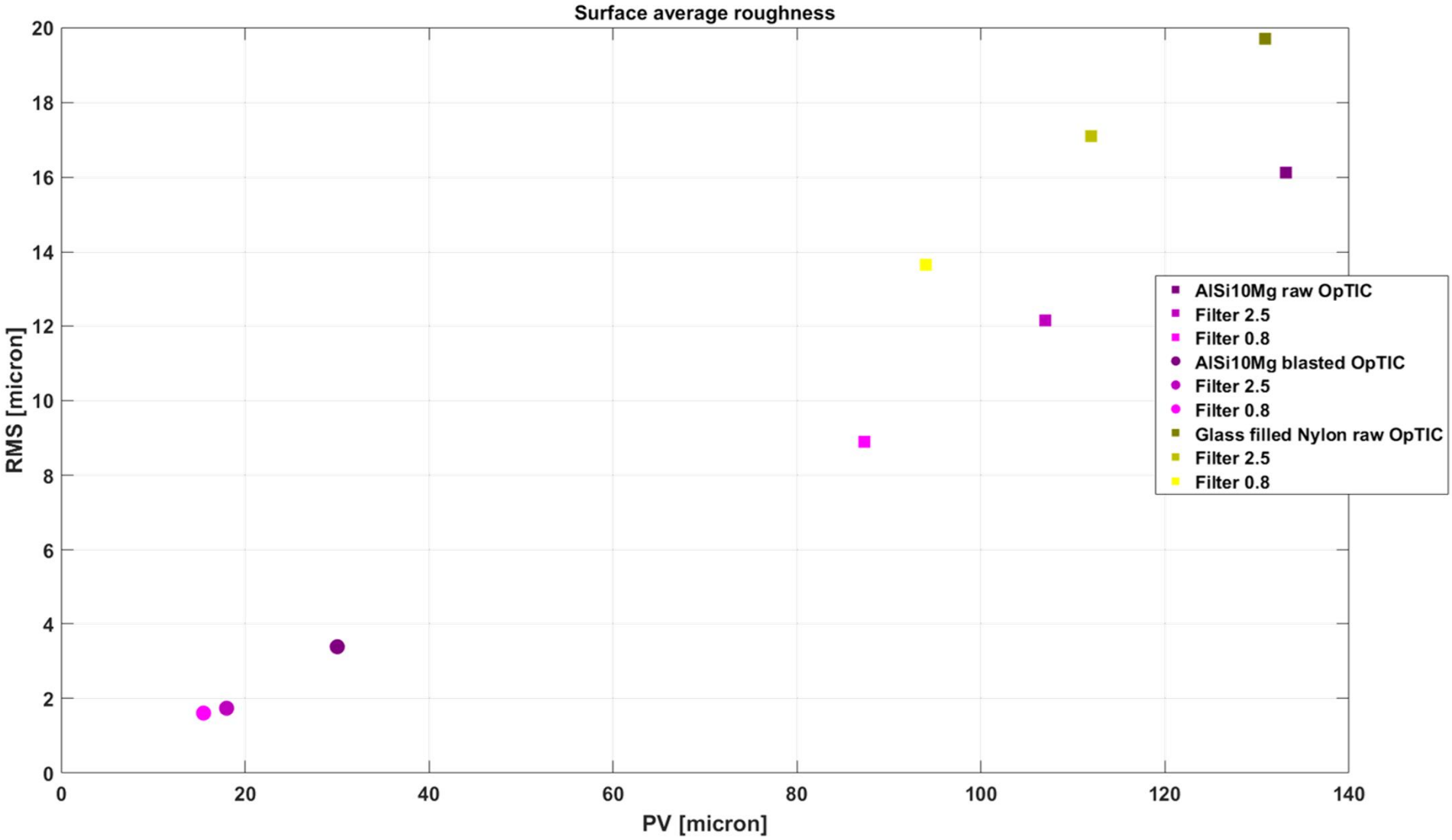
Waviness

HF residual

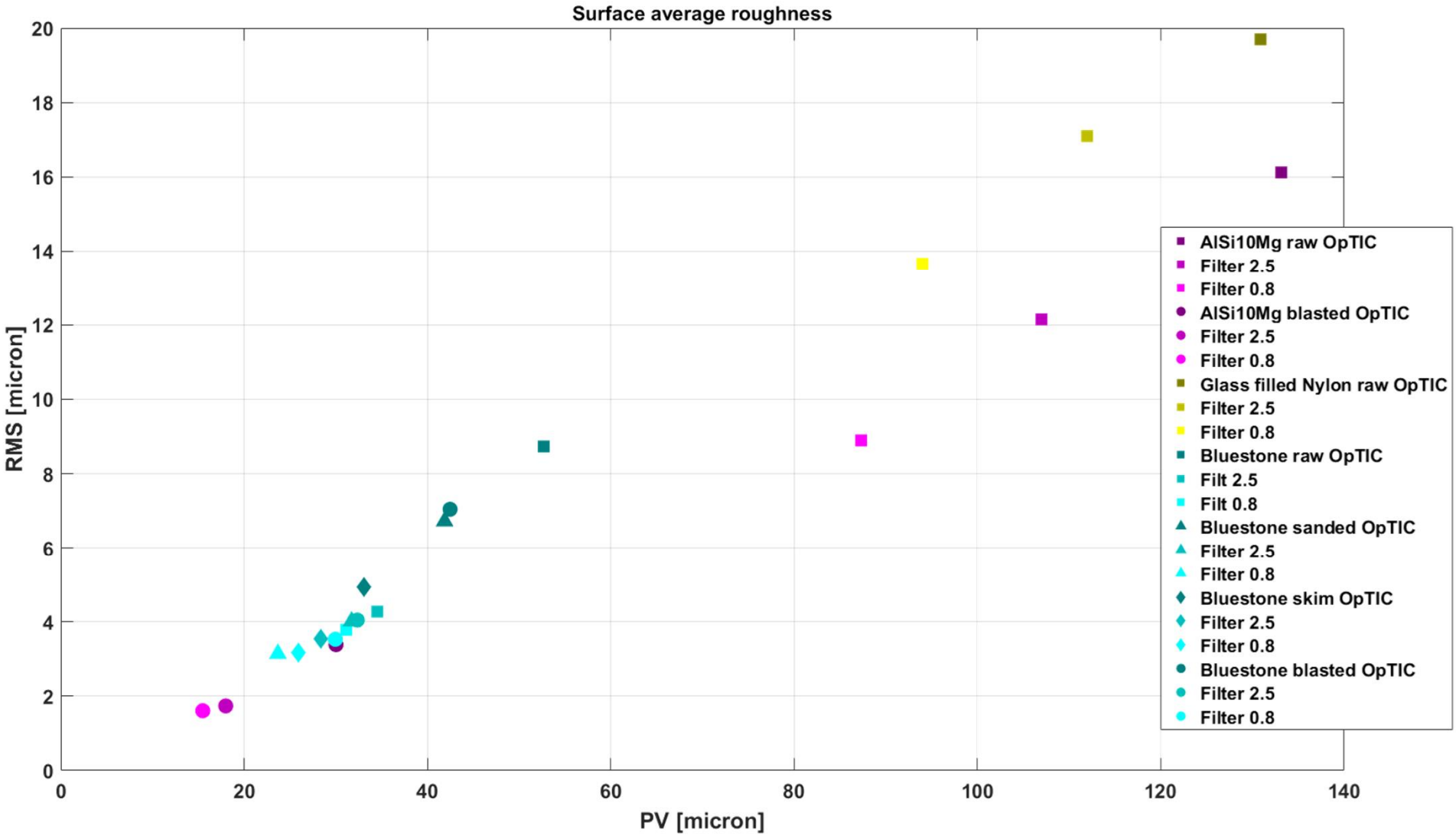
Comparison and impact of the filtering



Comparison and impact of the filtering



Comparison and impact of the filtering



Topology optimization

Step I: Design on CAD software

- Simplest design

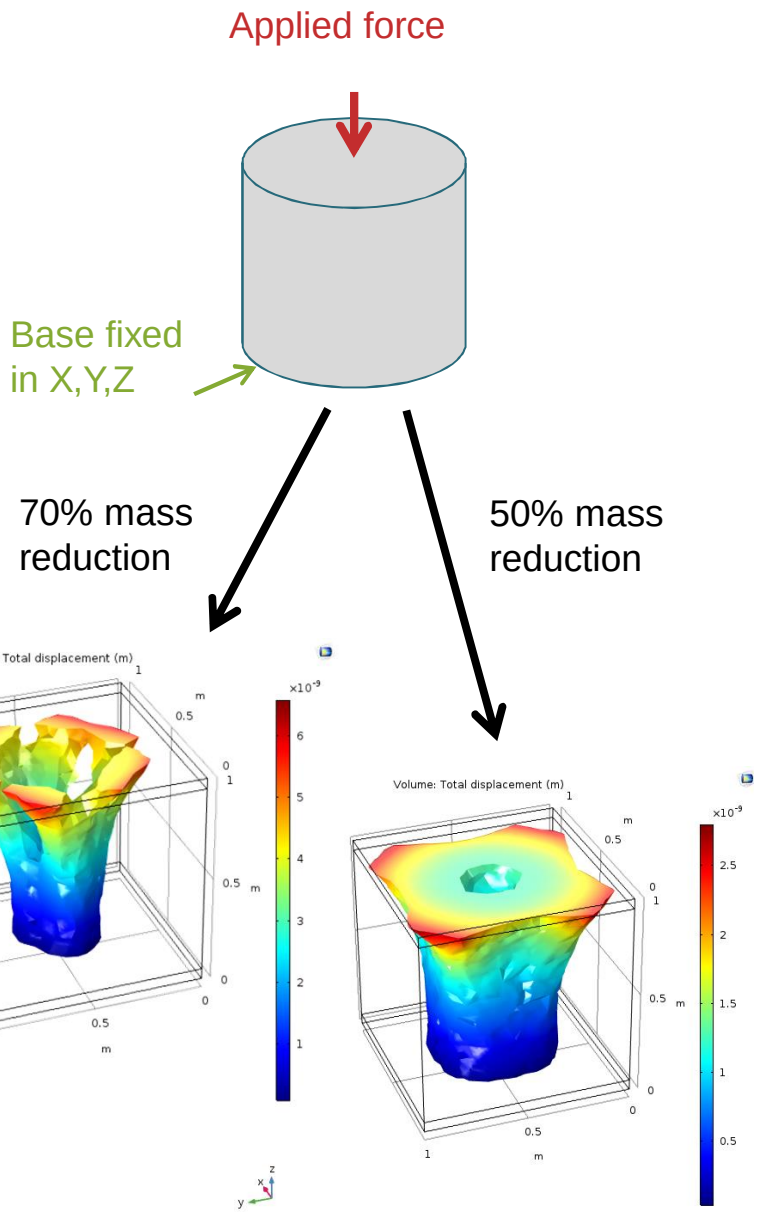
Step II: FEA simulation

- Placement of the boundary conditions

Step III: Choice of the properties

- Percentage of mass to keep

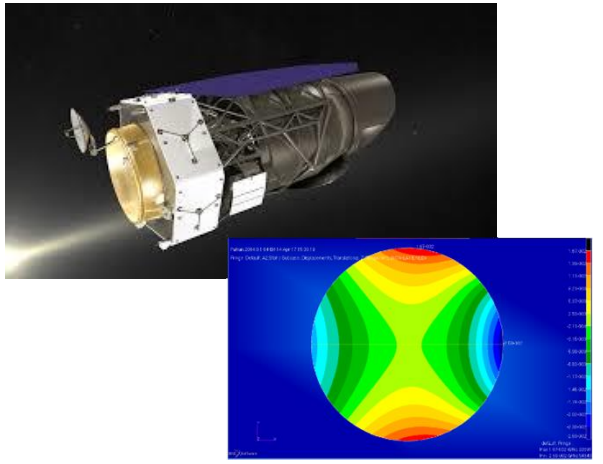
Result:
Optimum shape for the given forces
Should be printable



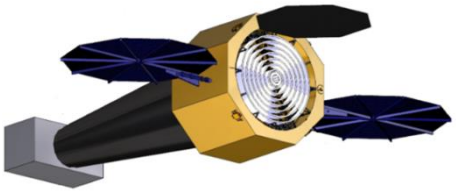
Conclusion

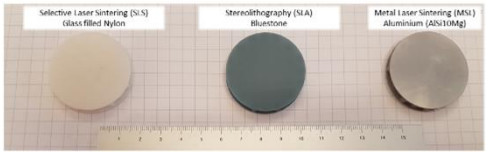
Future work

- Optimize the warping harness
  - *Find the solution by varying the parameters*
  - *Create the 3D printing prototype*
  - *Test and measure on the prototype*



- Improve the substrate surface quality
  - *Try new optimized lightweight structure*
  - *Measure the new samples*





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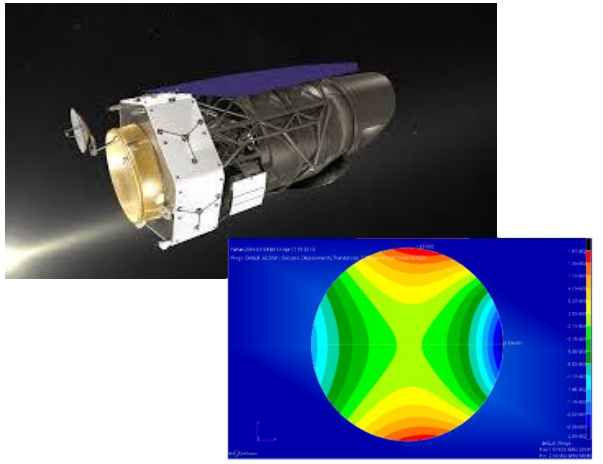

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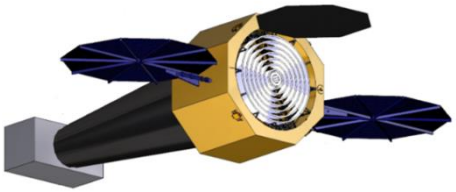

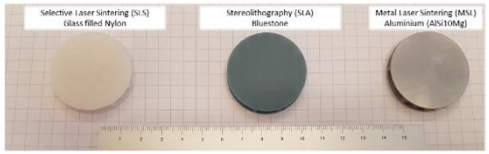

Questions?