In-flight measurements system of Millimetron main mirror

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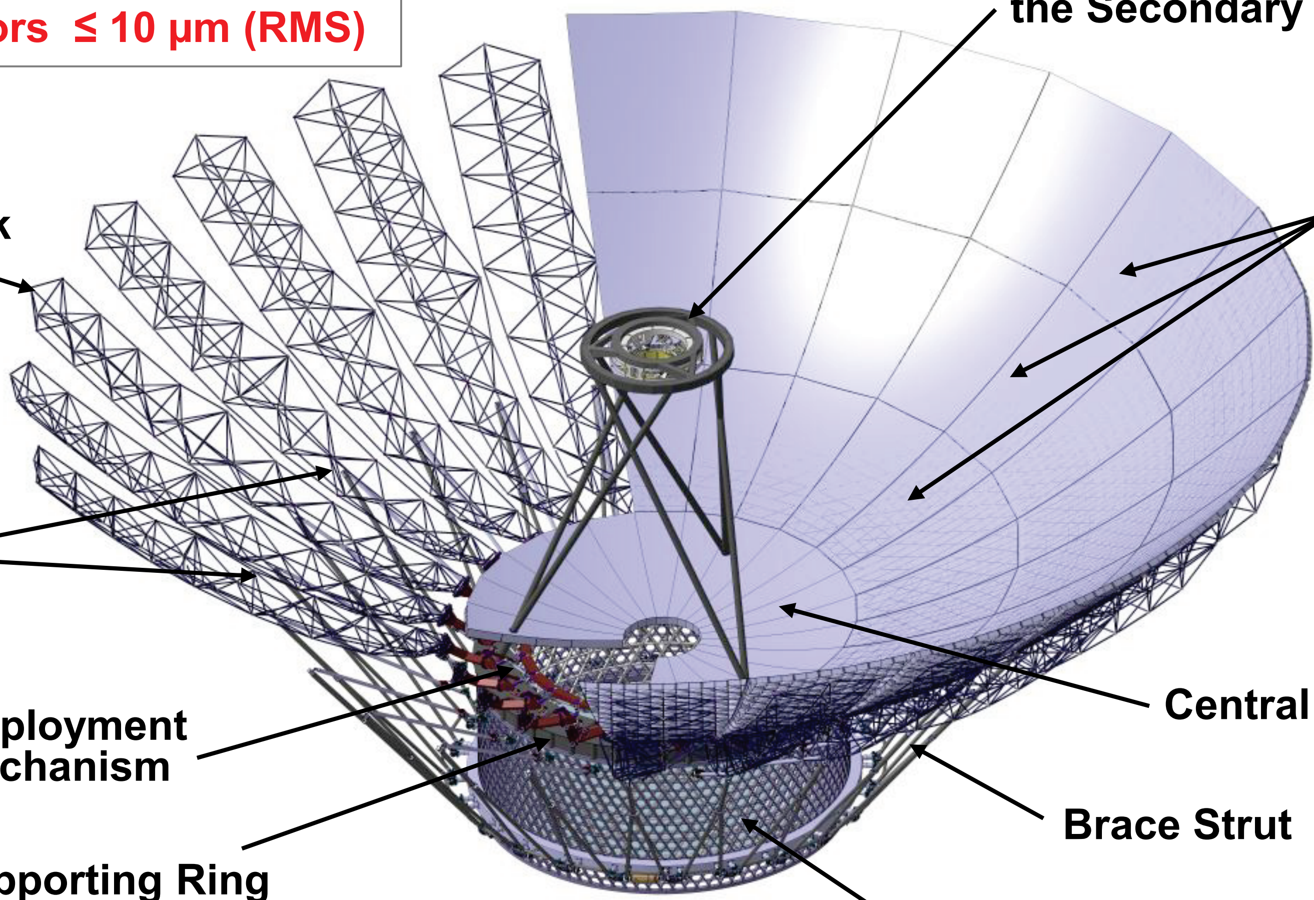
Primary mirror design

Primary Mirror requirements:

- aperture 10 m
- wave front errors ≤ 10 μm (RMS)



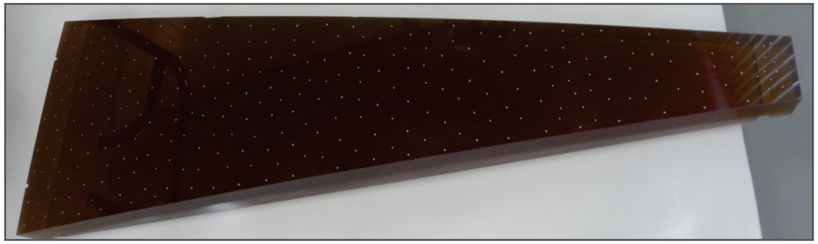
Technology of the Panels development

Material: CFRP (M55j + cyanate ester resin)

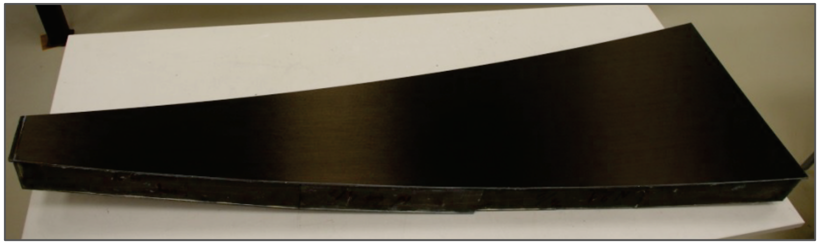
- ✓ Lightweight
- ✓ Extremely low thermal expansion coefficient
- ✓ Very low moisture absorption
- ✓ Developed for high stability space structure

Method: replica technique

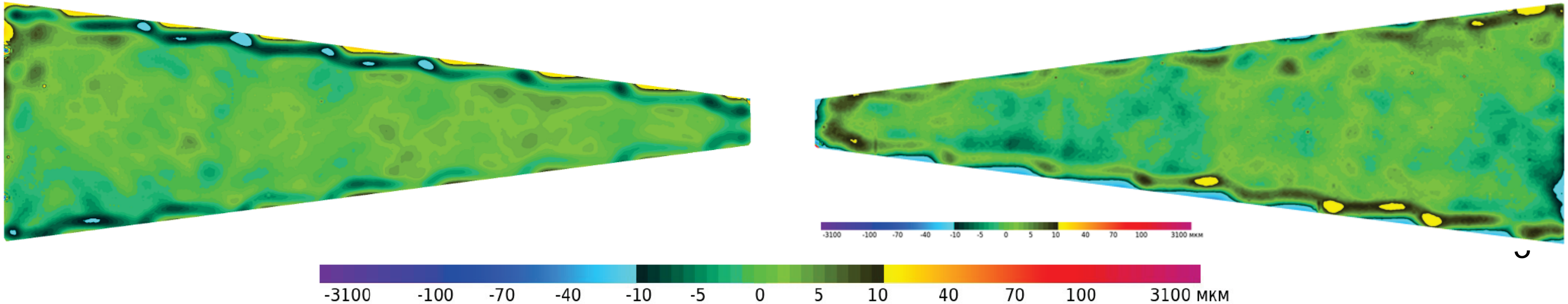
Take into account Planck telescope technology experience



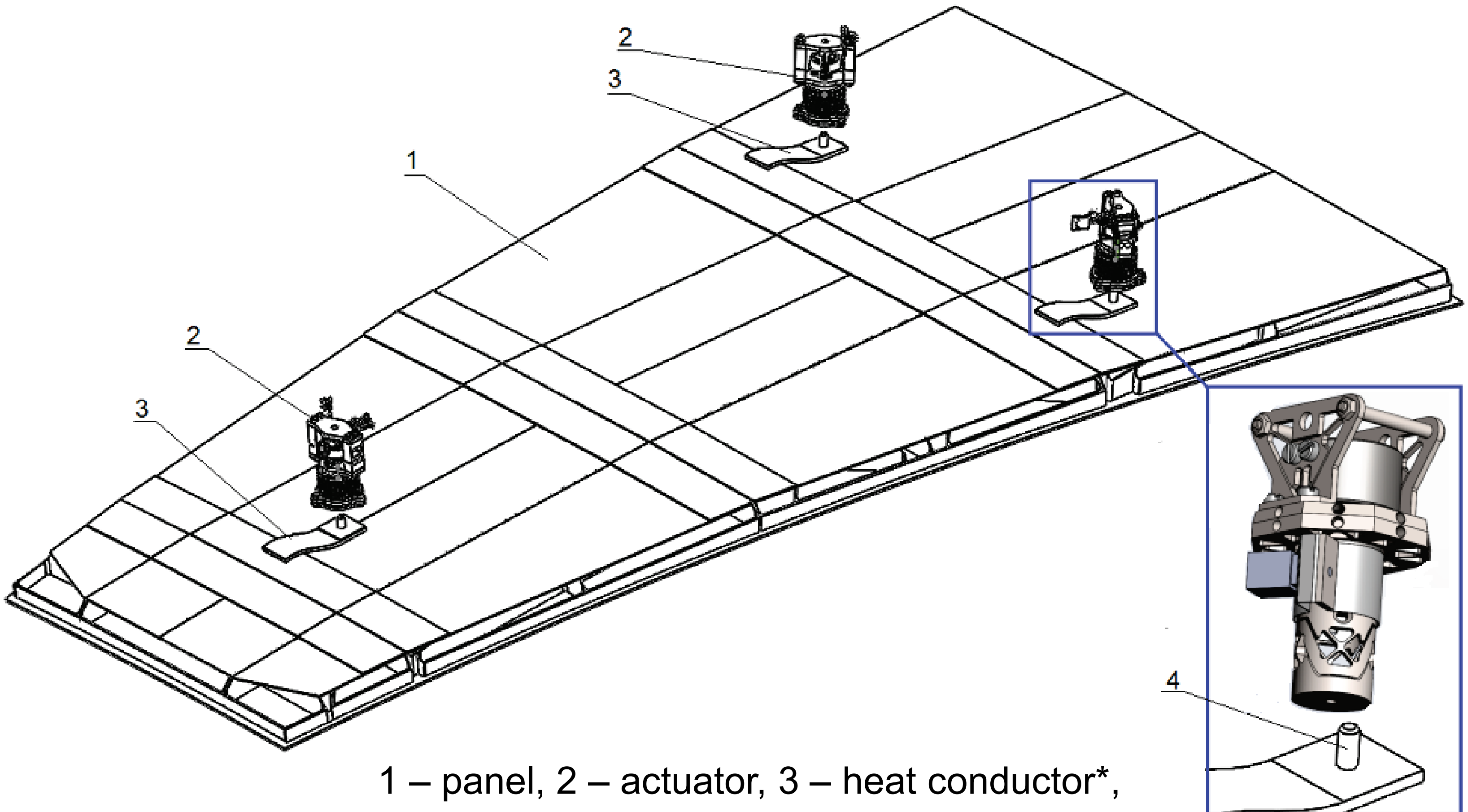
Parabolic mold (trial)
Focus= **2407,5 мм**
SFE ≈ 4.1 µm (RMS)



Parabolic panel of central part of the PM
Focus= **2406,1 мм**
SFE ≈ 4.2 µm (RMS), Roughness: ≤ 0.2µm



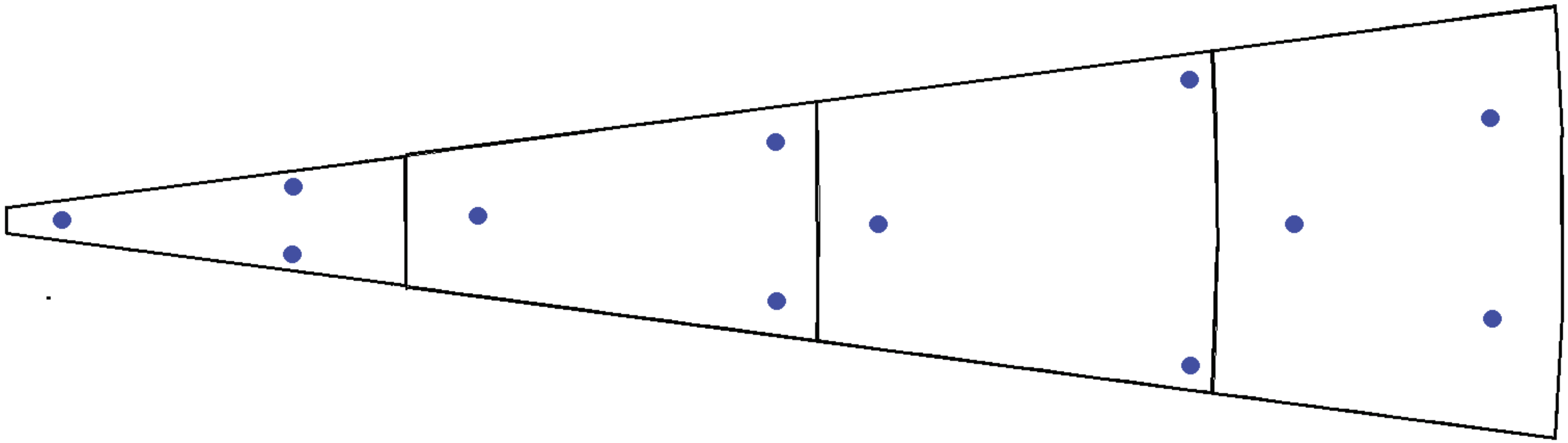
Panel Mounting Scheme



1 – panel, 2 – actuator, 3 – heat conductor*,
4 – mounting thread

Static determined support provides 3 degrees of freedom – 2 rotations and 1 linear translation («tip, tilt, piston»)

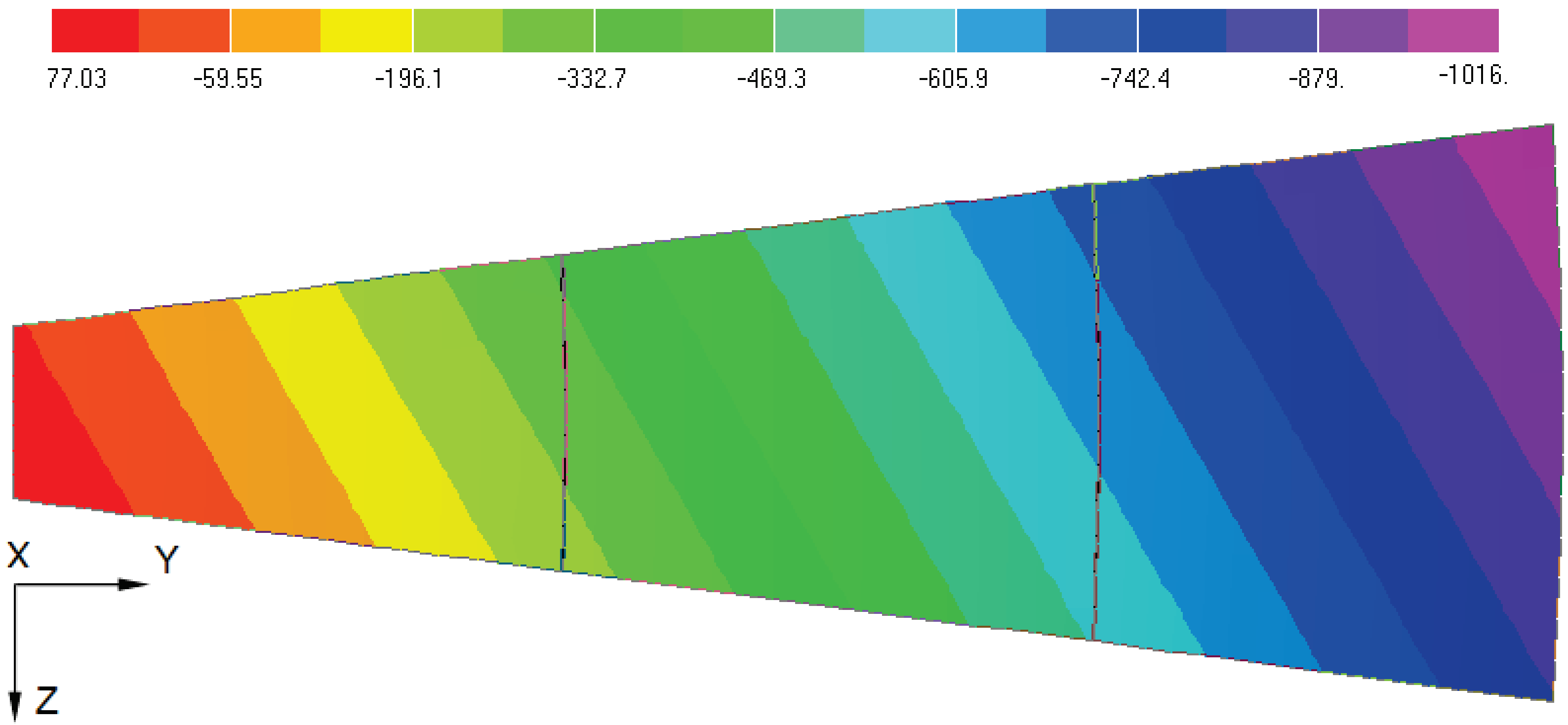
Placement of attachment points for one sector of the main mirror



Position of actuators

Main error along deployment rotation axis

Deployment error: ± 1000 um

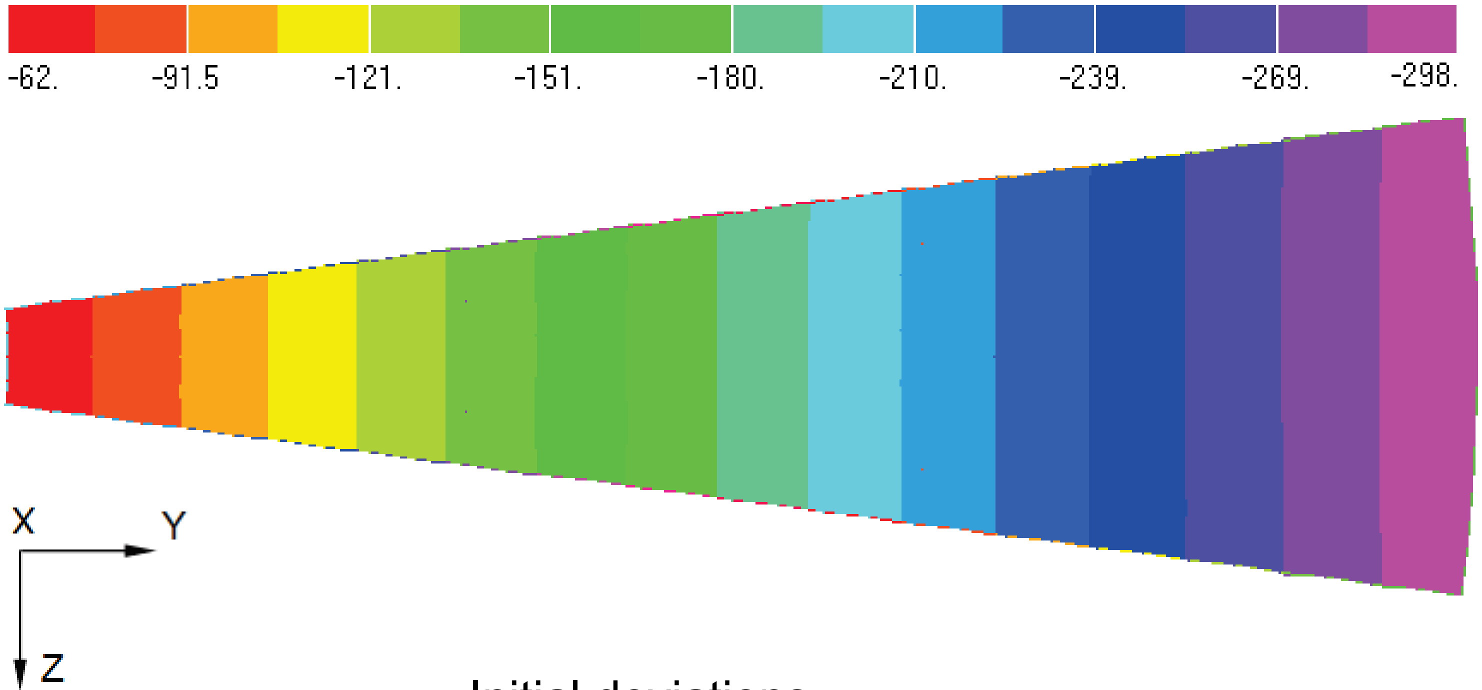


After adjustment:
RMS ≤ 1 um
Actuator movement:
34, 342, 246 um

After adjustments:
RMS ≤ 1 um
Actuator movement:
789, 356, 634 um

После юстировки:
RMS ≤ 1 um
Actuator movement:
785, 979, 1094 um

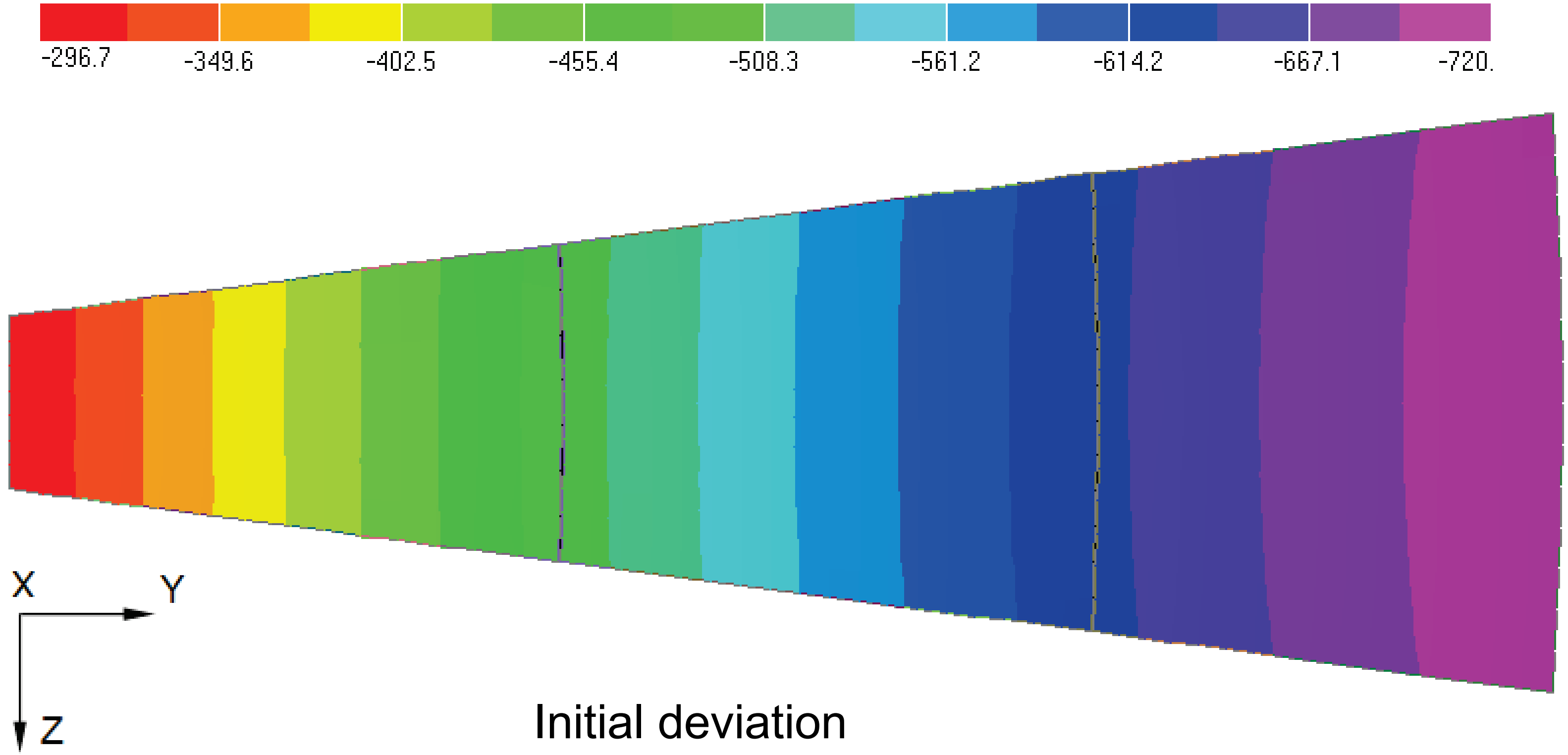
Deployment error 1 mm along Y axis (central mirror)



Initial deviations

After adjustment:
RMS = 1.3 um
Actuator movement:
95, 241, 241 um

Deployment error 1 мм along Y axis (petal)



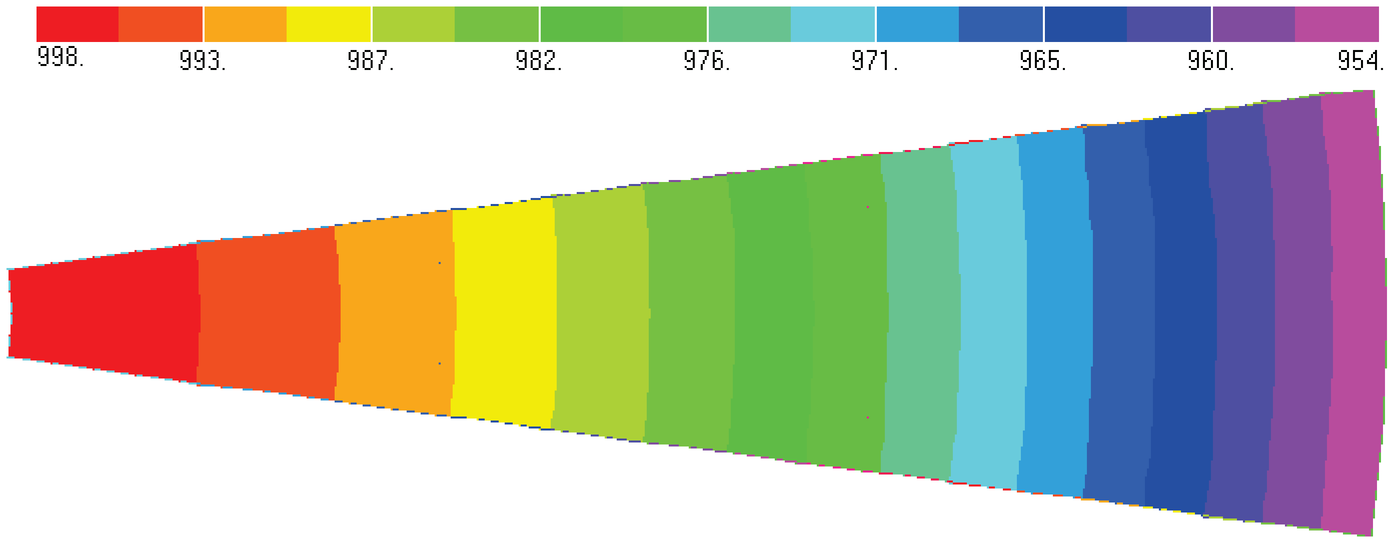
Initial deviation

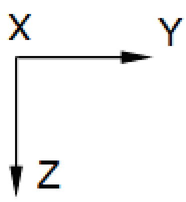
After adjustment:
RMS = 2.4 um
Actuator range:
343, 482, 482 um

After adjustment:
RMS = 2.0 um
Actuator range:
509, 632, 632 um

After adjustment:
RMS = 1.2 um
Actuator range:
648, 705, 705 um

Deployment error 1 mm along X axis (central mirror)

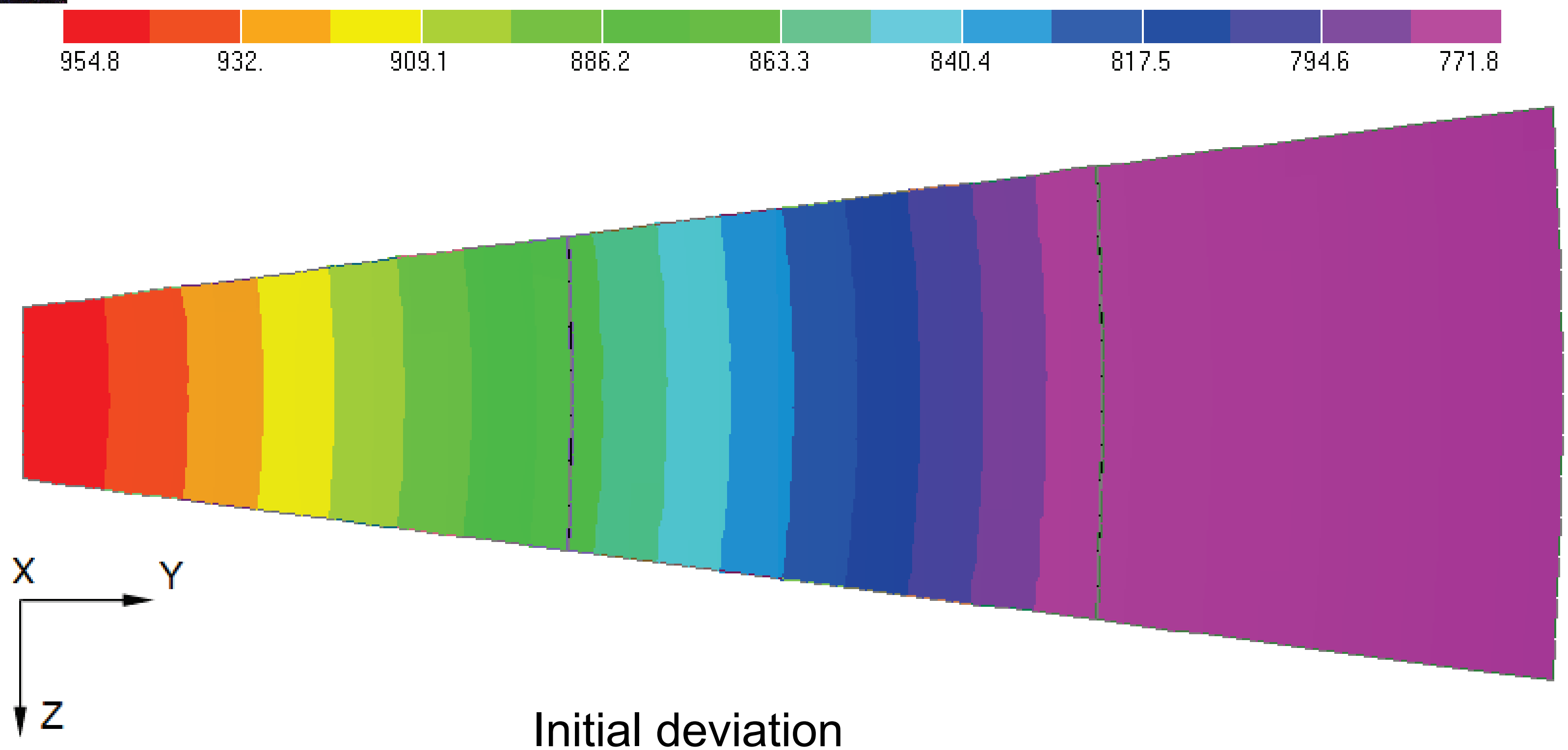




Initial deviations

After adjustment:
СКО = 0.2 um
Actuator movement:
999, 972, 972 um

Deployment error 1 mm along X axis (petal.)



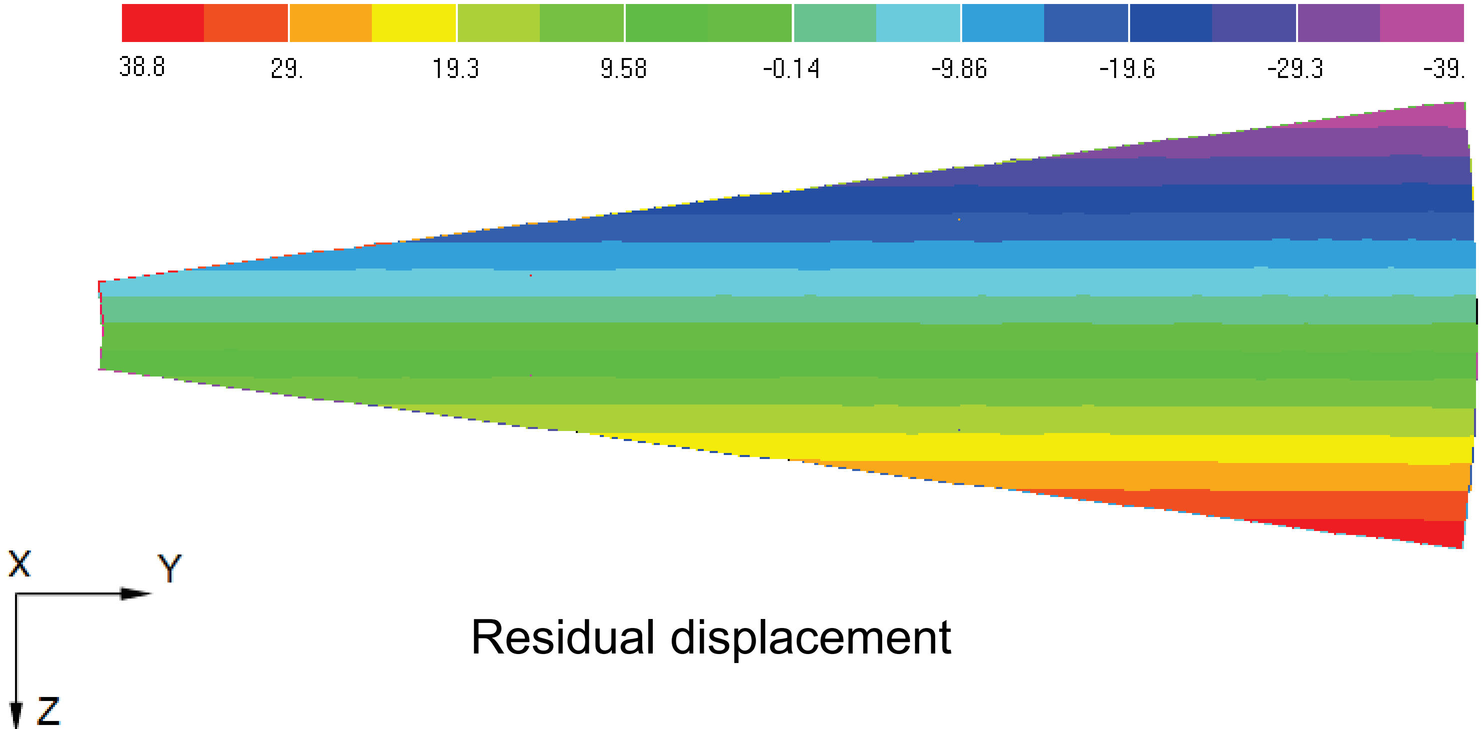
Initial deviation

After adjustment:
RMS = 1.1 um
Actuator movement:
941, 880, 880 um

After adjustment :
RMS = 1.4 um
Actuator movement:
864, 779, 779 um

After adjustment :
RMS = 1.2 um
Actuator movement:
762, 709, 709 um

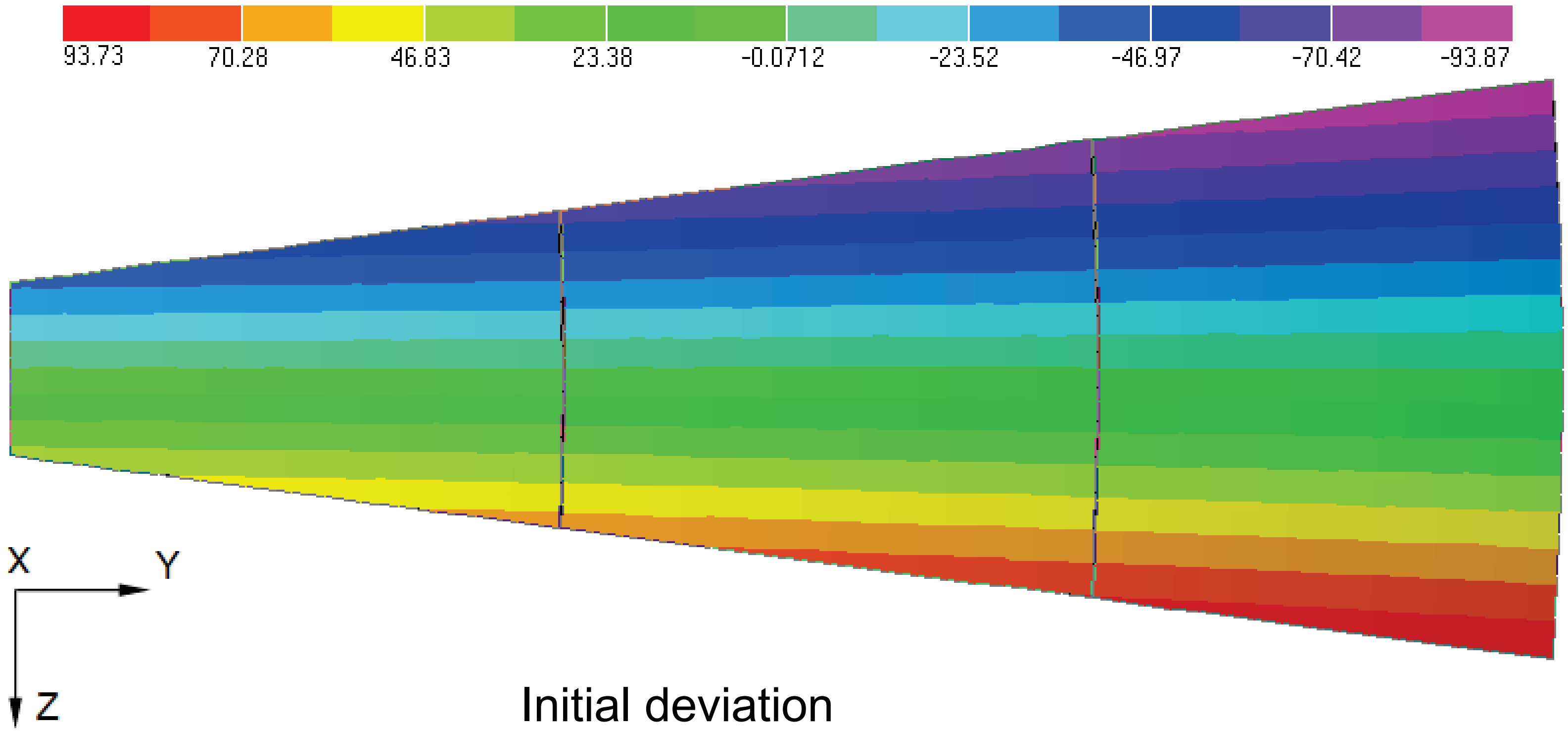
Deployment error 1 mm along Z axis (central mirror)



Residual displacement

After adjustment:
RMS = 0.2 um
Actuator movement:
0, 24, 24 um

Deployment error 1 mm Z axis (petal)



Initial deviation

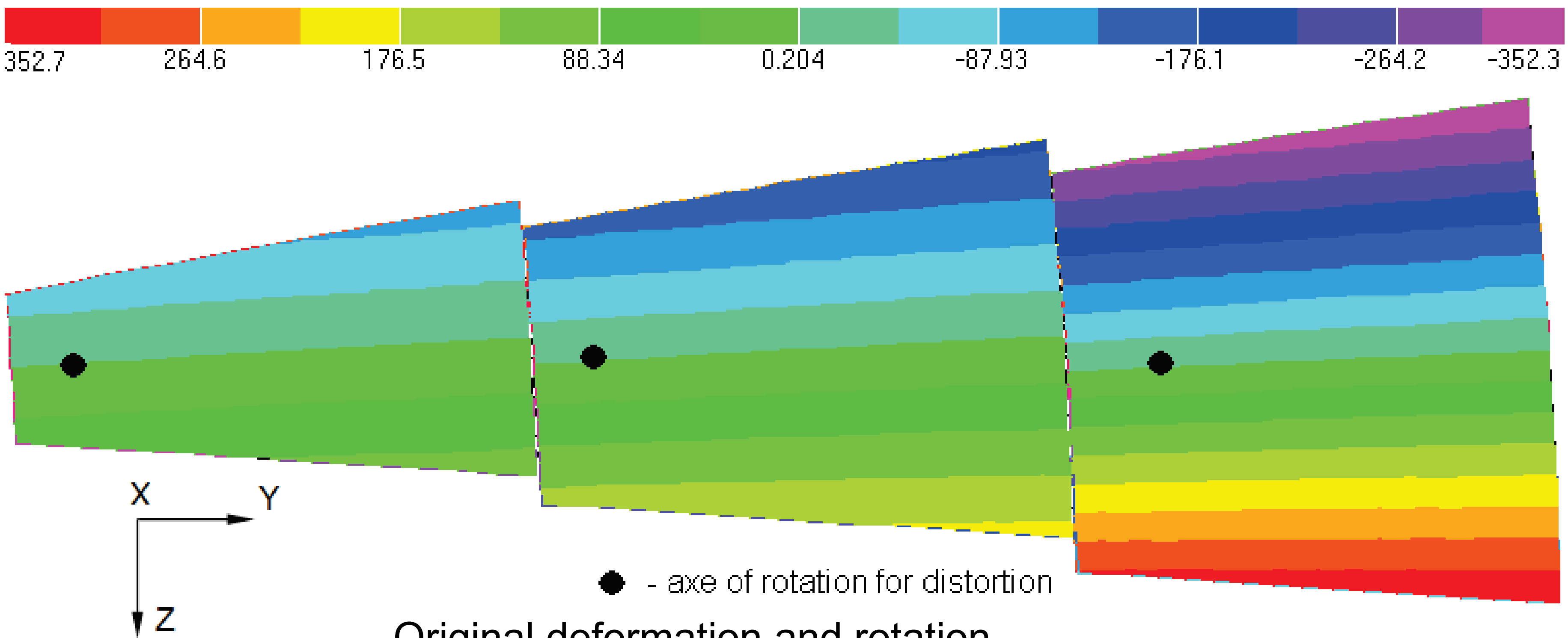
After adjustments:
RMS = 1.0 um
Actuator movement:
0, 52, 52 um

After adjustments:
RMS = 1.6 um
Actuator movement:
0, 75, 75 um

After adjustments:
RMS = 1.8 um
Ходы актюаторов:
0, 48, 48 um

Deployment error with rotation

Rotation over vertical axis through actuator 1, amplitude 1000 um



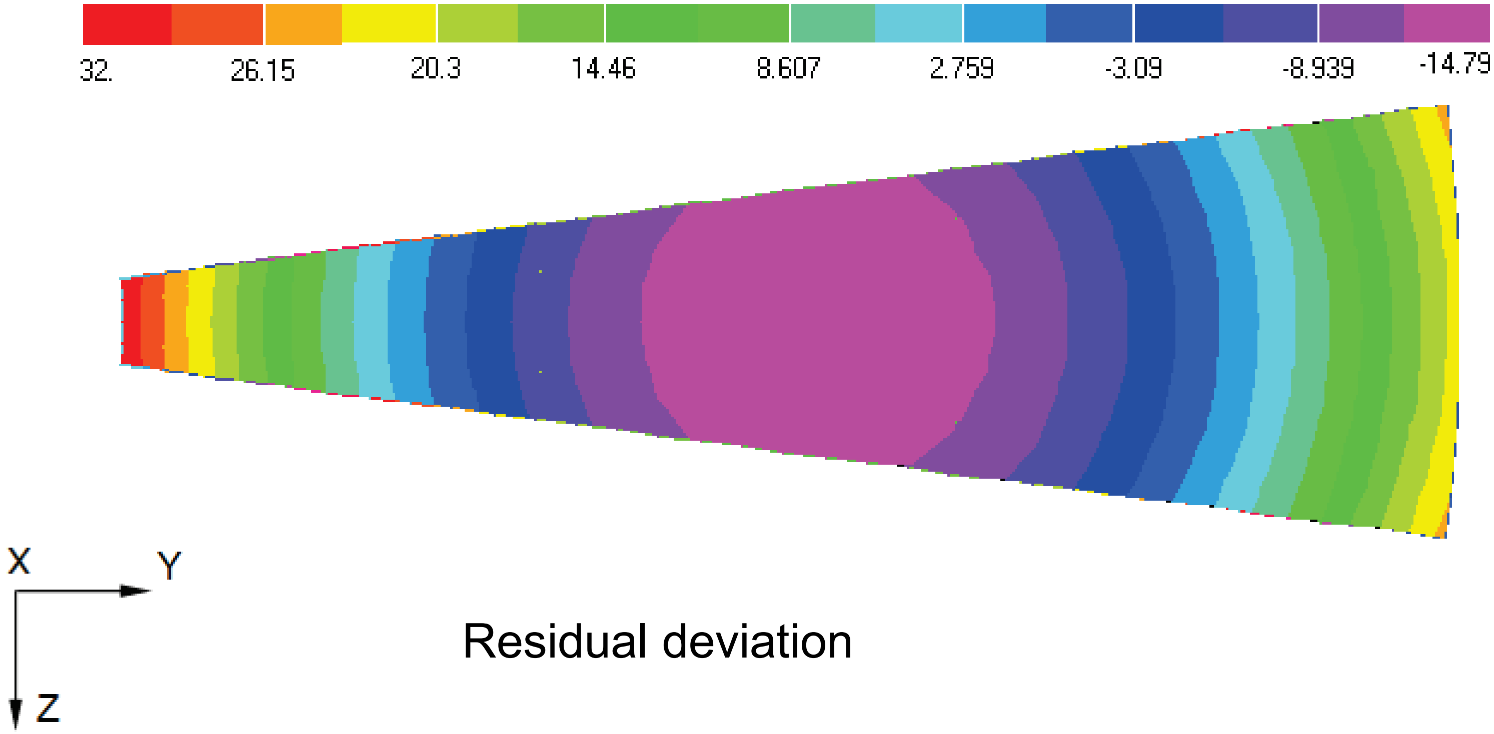
Original deformation and rotation

After adjustments:
RMS = 1.7 um
Actuator movement:
0, 89, 89 um

After adjustments:
RMS = 3.7 um
Actuator movement :
0, 173, 173 um

After adjustments:
RMS = 6.7 um
Actuator movement :
0, 184, 184 um

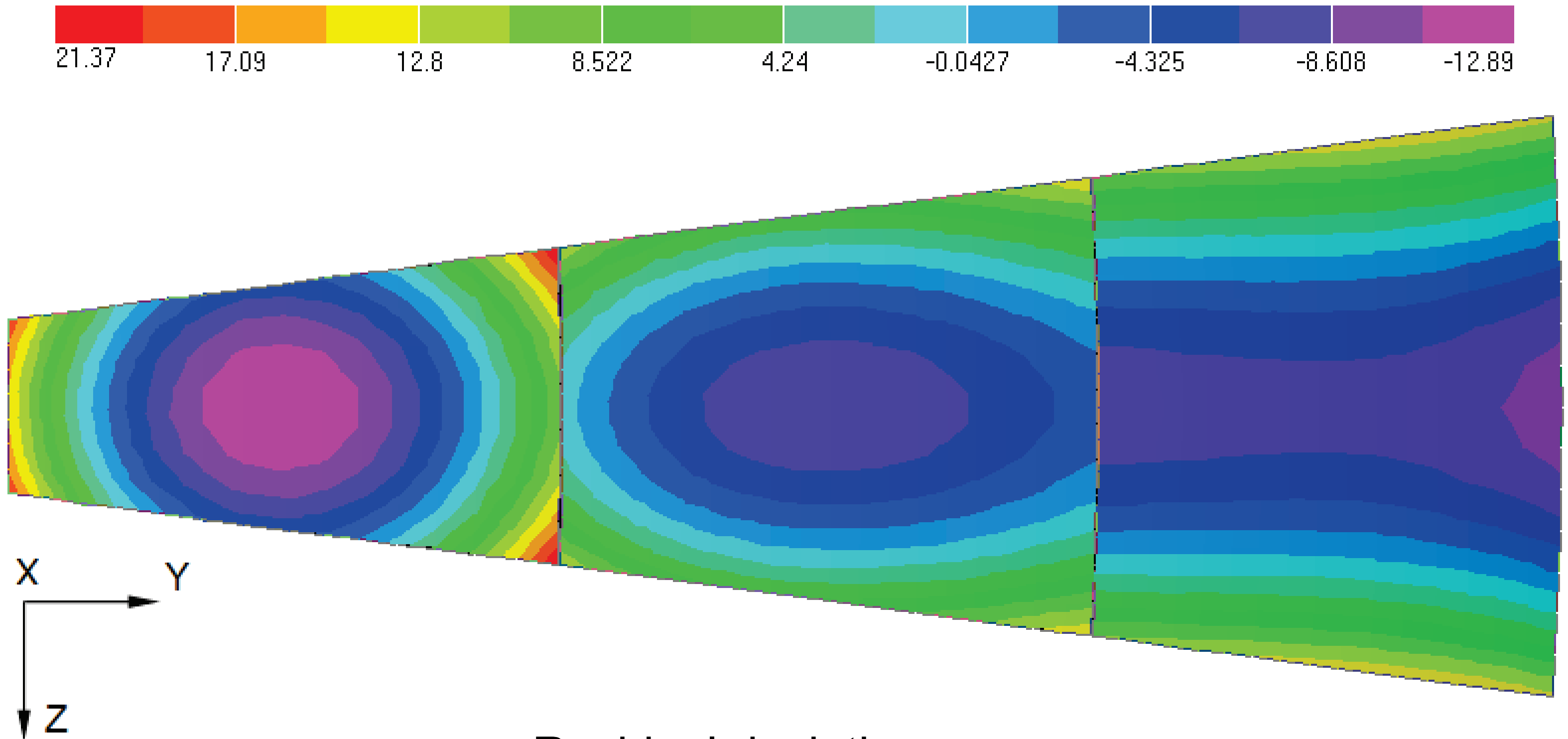
Focus difference 3 mm (central mirror)



Residual deviation

After djustments:
RMS = 12.6 um
Actuator range:
15, 187, 187 um

Different focus 3 mm (petal)



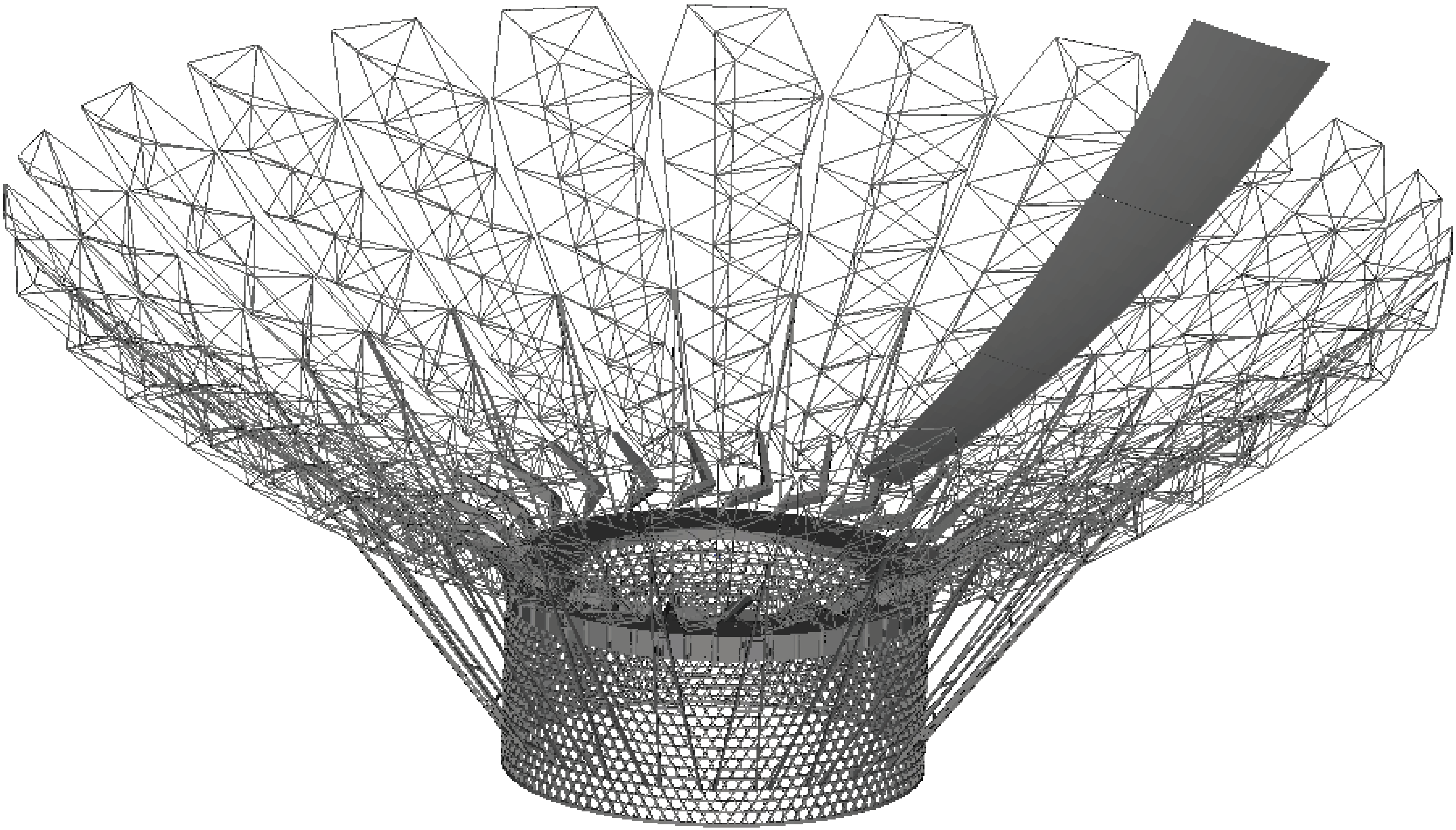
Residual deviations

After adjustment:
RMS = 9.1 um
Actuator range:
380, 781, 781 um

After adjustment :
RMS = 5.6 um
Actuator range:
890, 1527, 1527 um

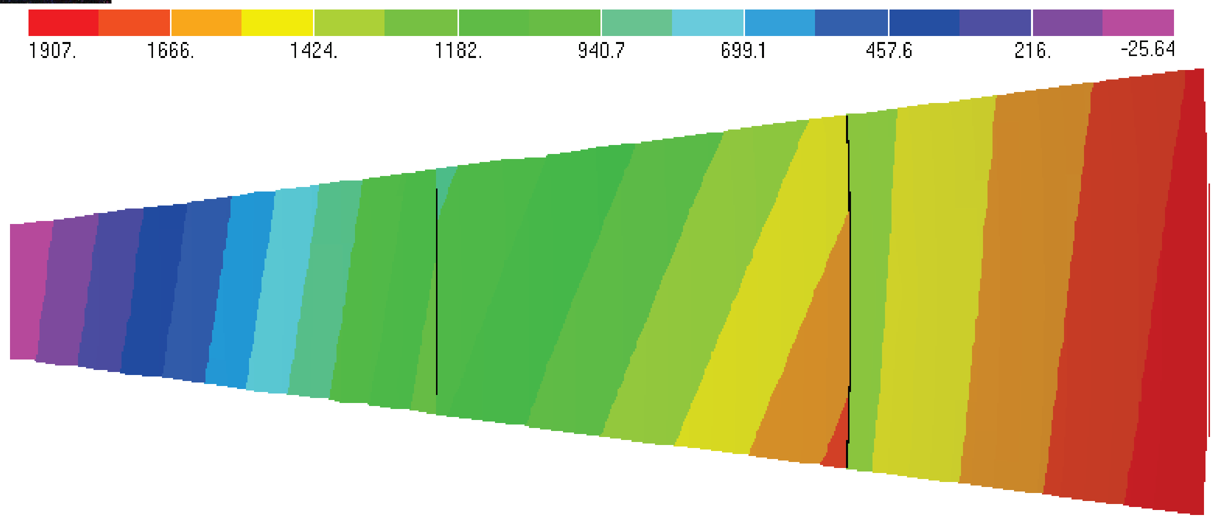
After adjustment :
RMS = 7.1 um
Actuator range:
1663, 2114, 2114 um

Compensation of temperature change

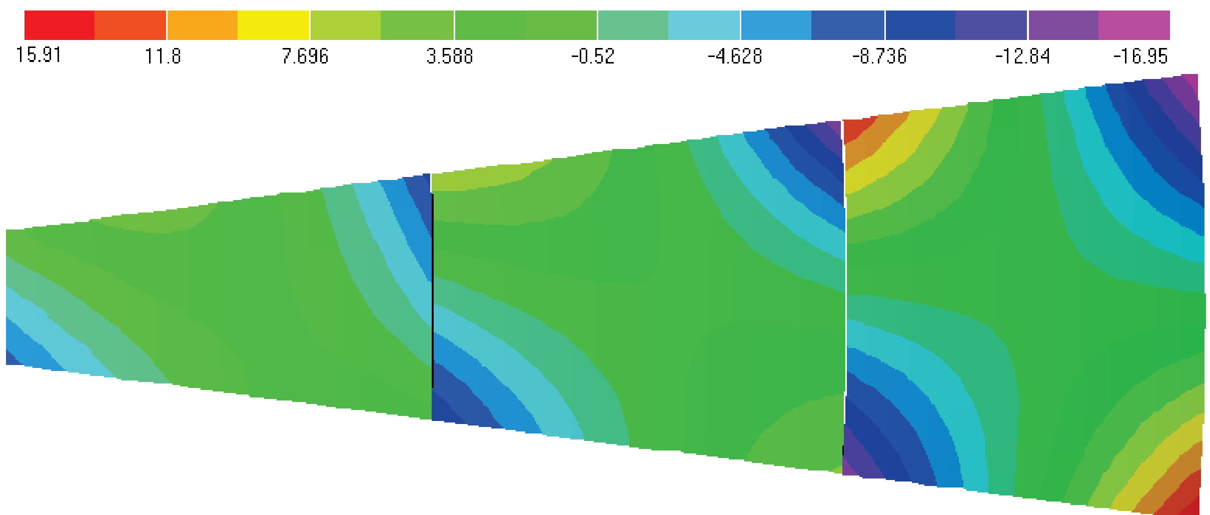


Visualization FEM model used for calculations

Thermo deformation compensation for 4K



Initial RMS after cooling down 534 um relative to paraboloid of F=2399.8 мм (optimized for panel thermal deformation)



Residual deformations

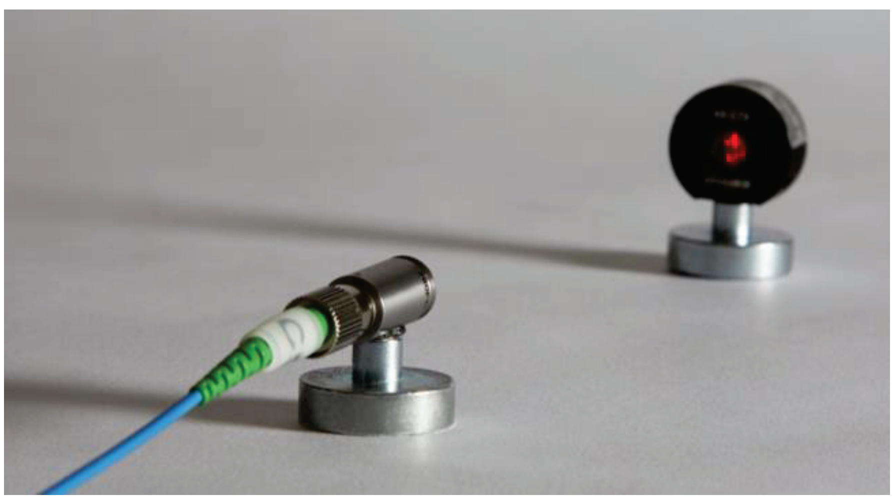
RMS = 2.9 um
Actuator displacement:
1177, 258, 176 um

RMS = 3.8 um
Actuator displacement:
377, 255, 562 um

RMS = 5.8 um
Actuator displacement:
381, 795, 828 um

Main panel metrology

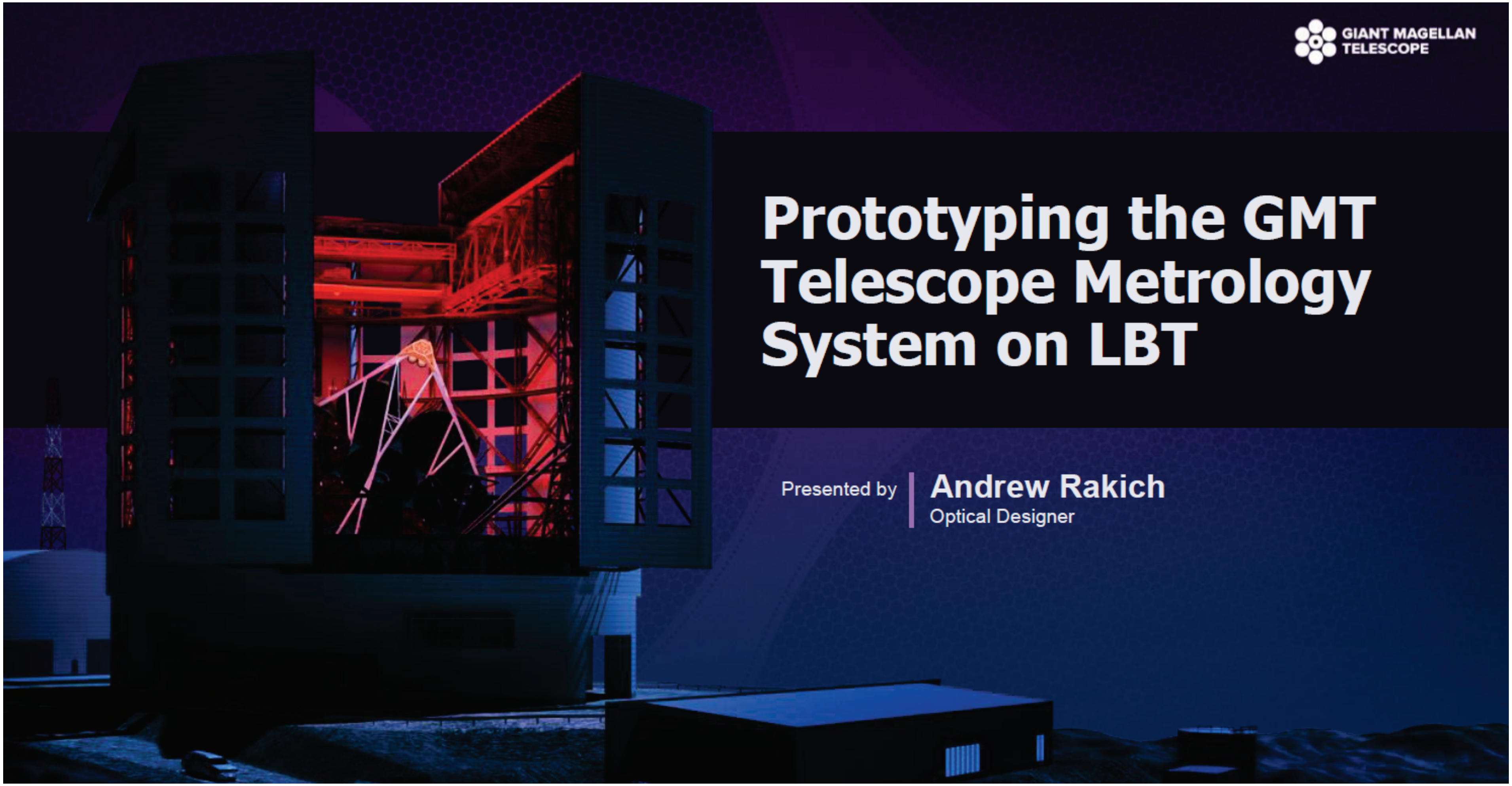
- **Laser trilateration** with absolute laser metrology – main method (1-2 um accuracy)



Etalon AG -> Hexagon

Laser trilateration

Demonstrated on the ground



Laser trilateration

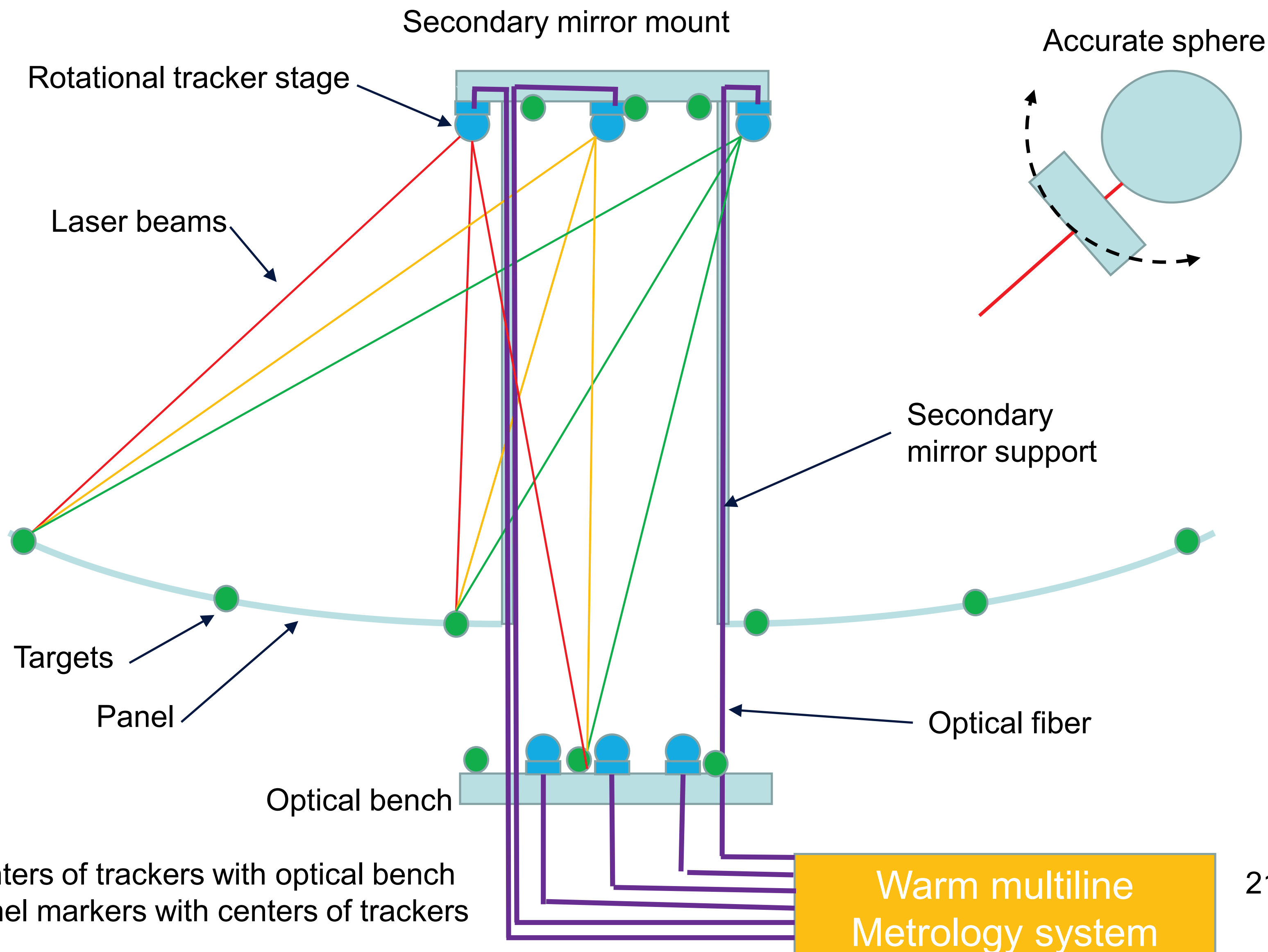
Estimates for GMT (Andrew Rakich)

GIANT MAGELLAN TELESCOPE

The GMT Telescope Metrology System

Degree of Freedom	Requirement (1σ)	Design Estimate (1σ)
M1 x,y	≤ 75 μm	1.4 μm
M1 z	≤ 75 μm	0.87 μm
M1 Rx, Ry	≤ 0.375 arcsec	0.068 arcsec
M1 Rz	≤ 0.375 arcsec	0.054 arcsec
M2 x,y	≤ 75 μm	8.2 μm
M2 z	≤ 75 μm	1.5 μm
M2 Rx, Ry	≤ 3 arcsec	0.64 arcsec
M2 Rz	≤ 3 arcsec	3.0 arcsec

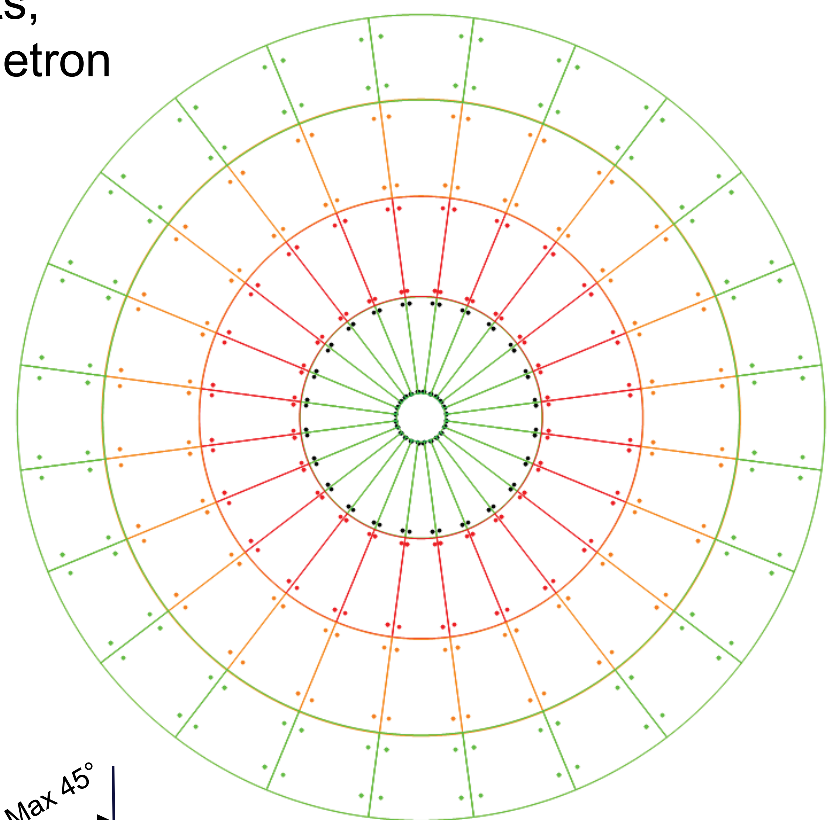
Laser trilateration main principle

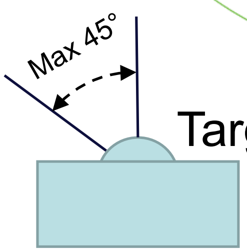


1. Relate centers of trackers with optical bench
2. Relate panel markers with centers of trackers

Laser trilateration targets

Example of laser targets, Millimetron

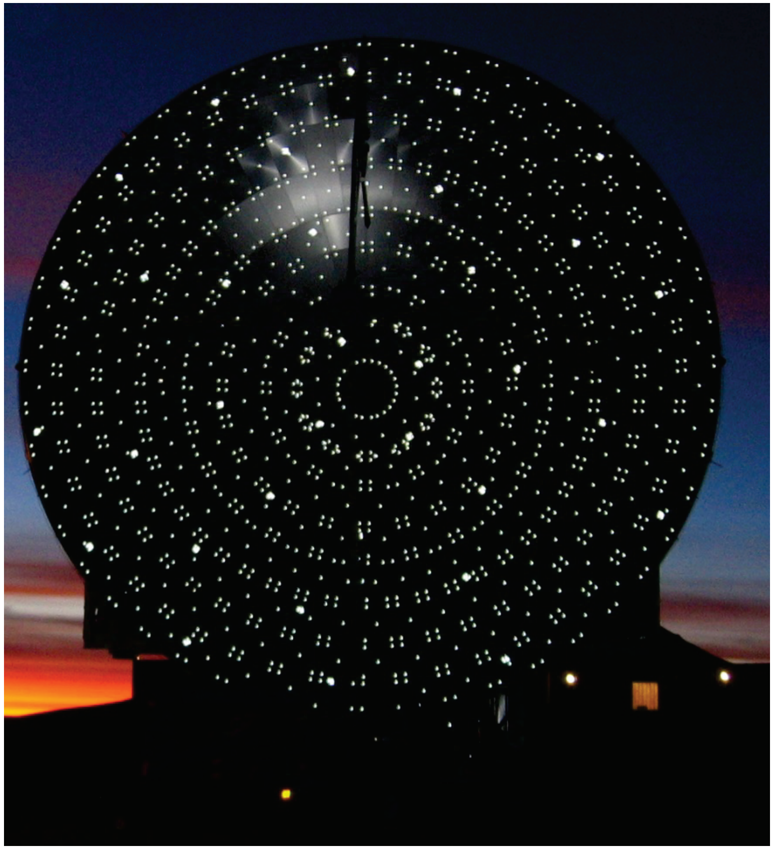




Target, part of sphere

Panel

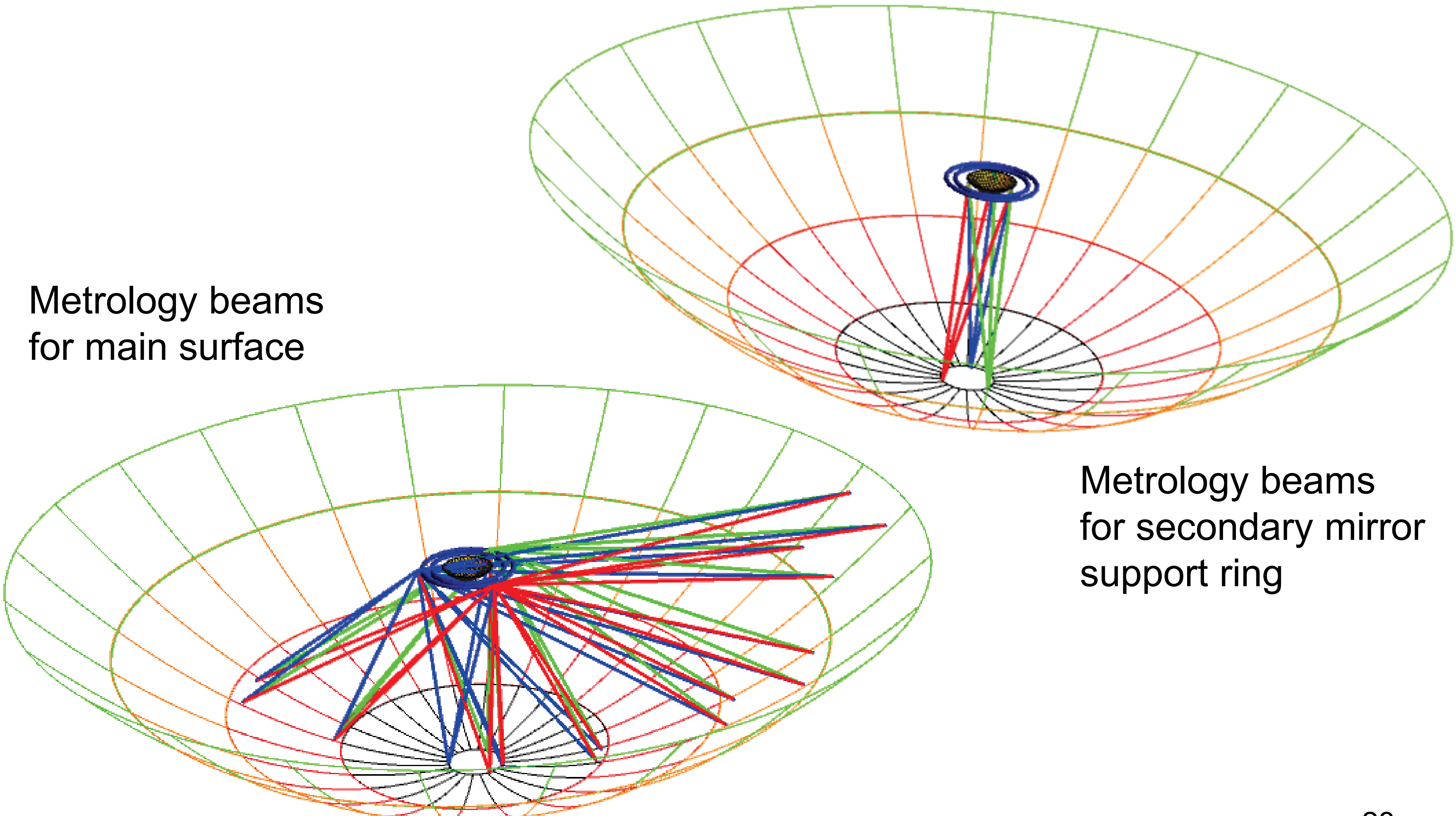
Photogrammetry targets



APEX telescope, © MPIfR

Targets related to the surface during manufacturing/measurements

Laser trilateration metrology beams



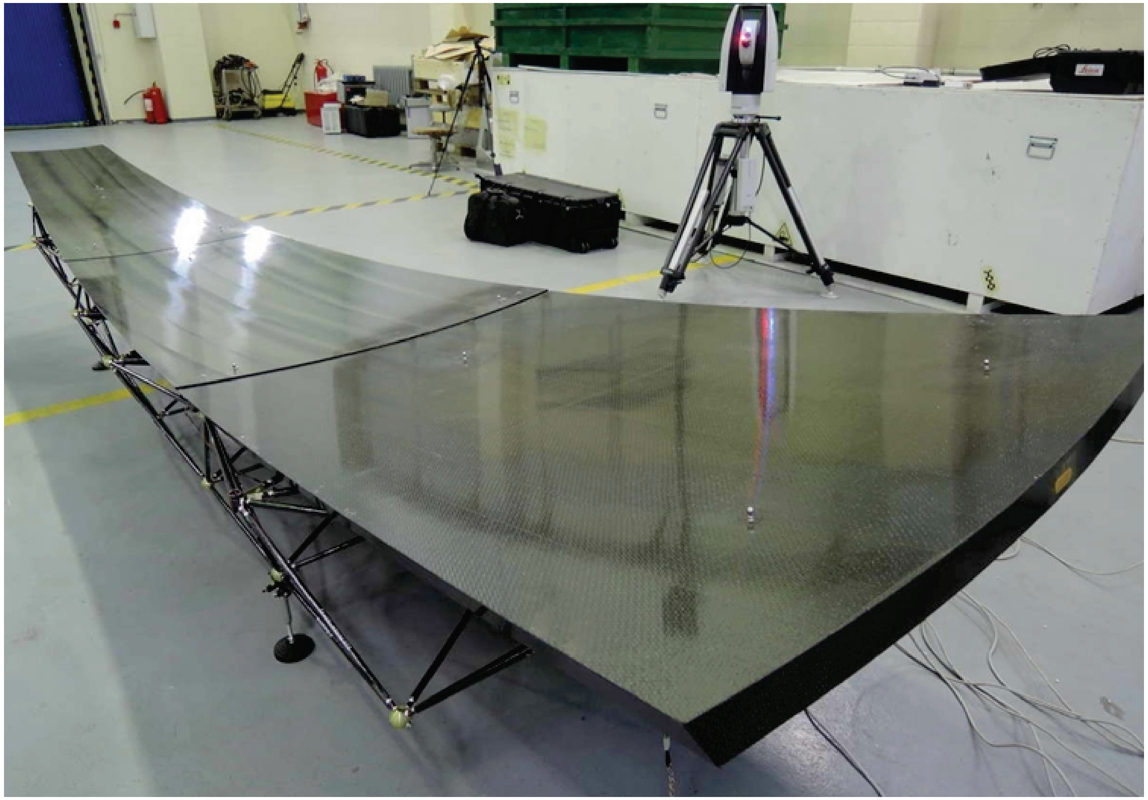
System parameters

- System parameters
  - Measurement accuracy <1μm (Vacuum)
  - Access to all panels
  - Initial panel positions within 1cm from nominal
  - 4 trackers on secondary mirror mount
  - 4 trackers on optical bench
  - Multiline measurement module in room temperature container
  - Fiber optics signal transport to trackers

System deployment steps

- Measure panel surface and relate it with installed markers
- Ranging system works in air and 300K
  - Demonstrate system on panel level
  - Demonstrate system at petal level
  - Demonstrate system at 2 petal model
  - Demonstrate system with full mock-up (TBC)

Development status



- Development status
  - Actuators feed back tested on prototype using Leika tracker
  - Ground based principle demonstrated, also vibration
  - System design development in Novosobirsk
  - Multiline metrology system has been acquired

Planned metrology systems backup

- **Photogrammetry** with targets on panels and set of cameras on rim of secondary mirror (100um accuracy)
- **Astronomical instrument** on bright point like sky source (planet, or mazer).
  - Pre-alignment by photogrammetry
  - Total power observation has enough S/N to distinguish single panel response
  - Sequential panel signal tuning lateral and Z displacement
  - Increasing frequency of instrument, sequential improvement of panel shape
  - Takes long time, depends on pointing jitter, used as backup

Conclusions

Proposed three actuators adaptation scheme has been studied
Three ways of panel measurement in space are under study

- Laser trilateration (main method)
- Photogrammetry
- Sky source signal iteration on receiver beam