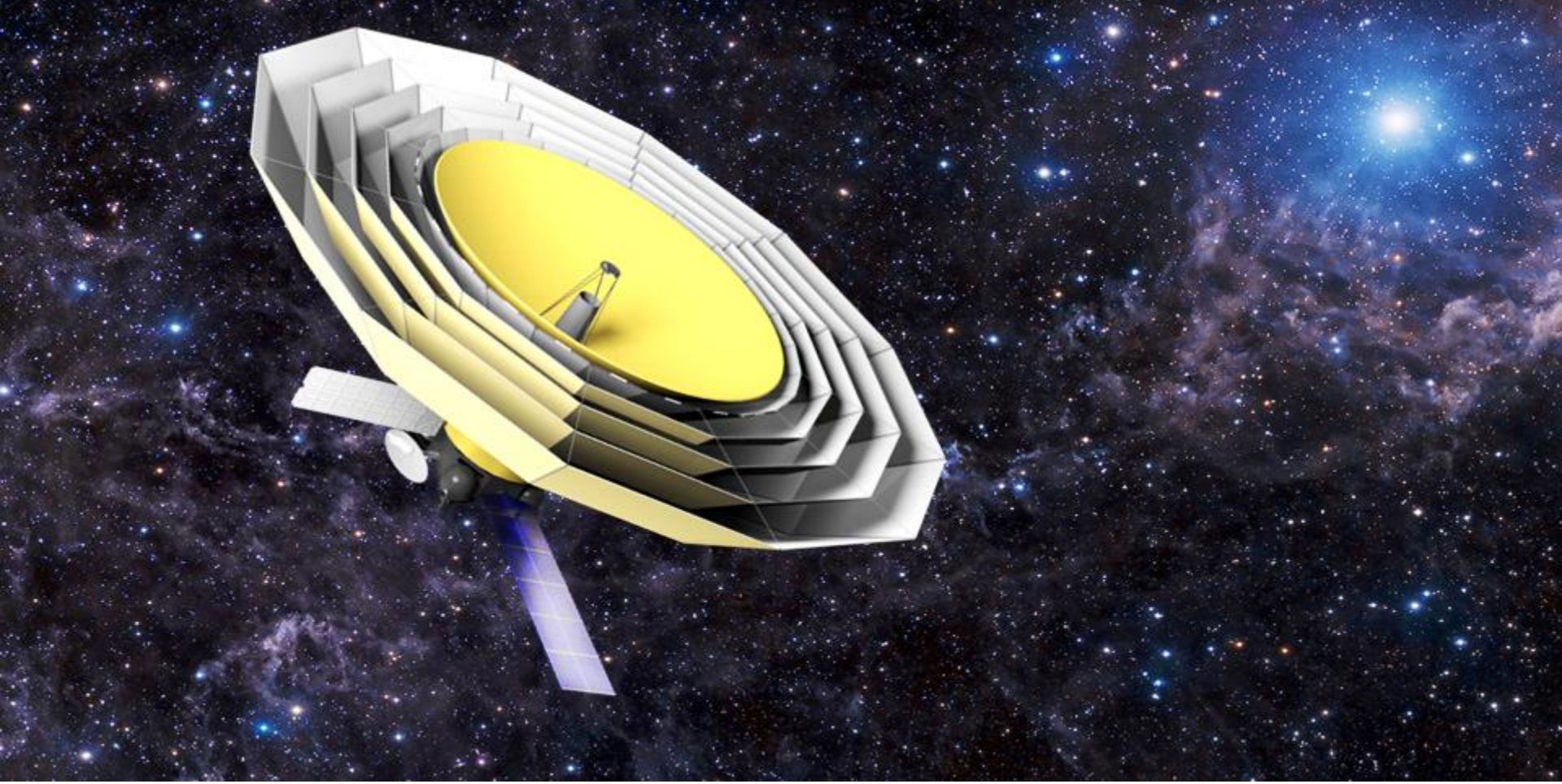

The Millimetron antenna

ASC LPI

RESHETNEV COMPANY

E. Golubev on behalf of the Millimetron team

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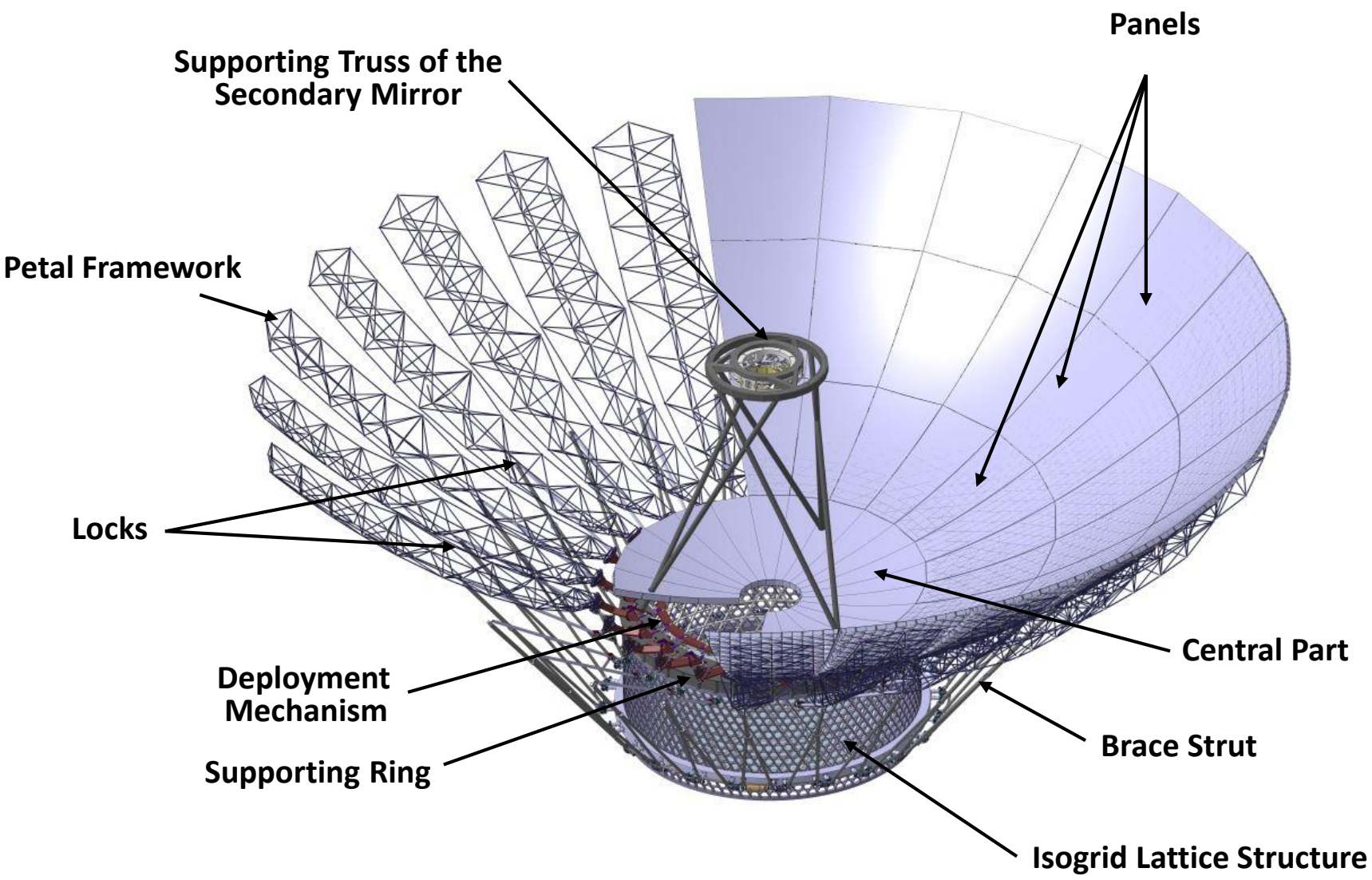
Design of the Millimetron Antenna



Stowed Configuration of the Primary Mirror

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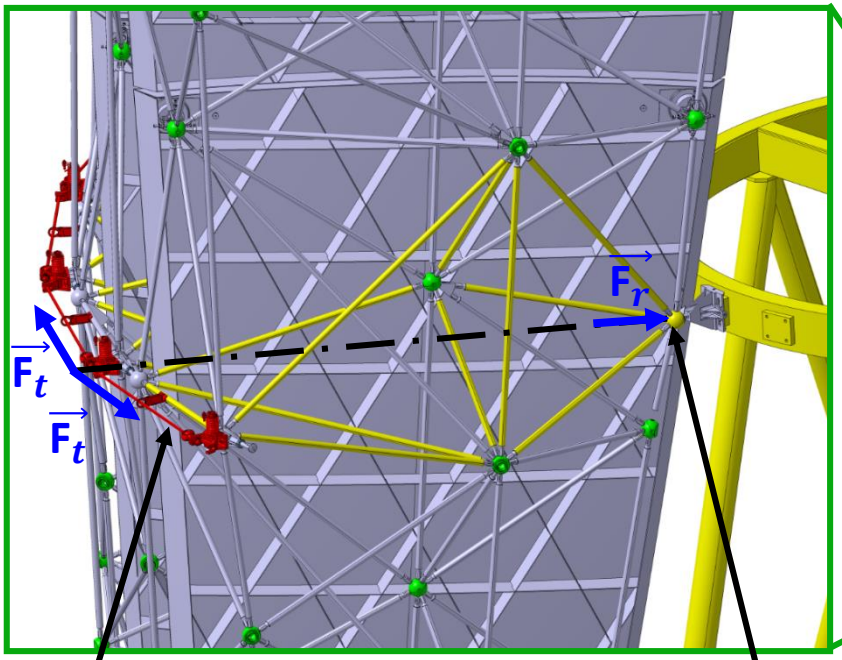
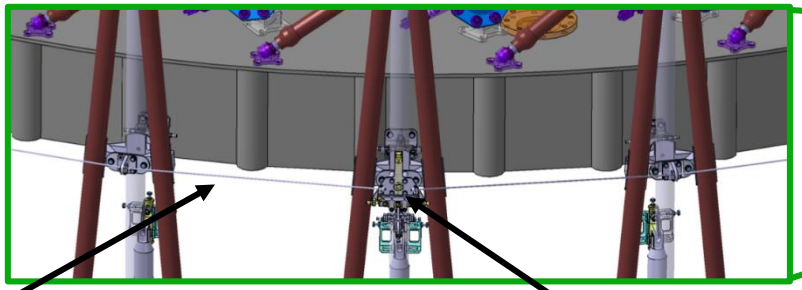
Petal fixation



External lock ring with pretensioned segmented truss

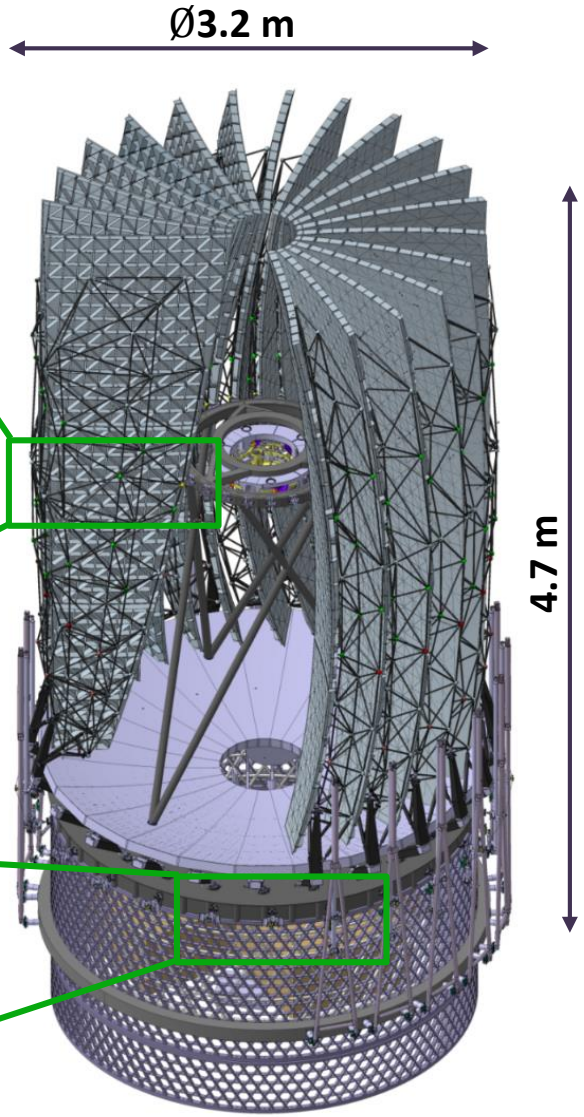
Internal lock ring
"conical socket – spherical tips"

Brace struts fixation



Pretensioned truss

Brace strut lock



The Secondary Mirror

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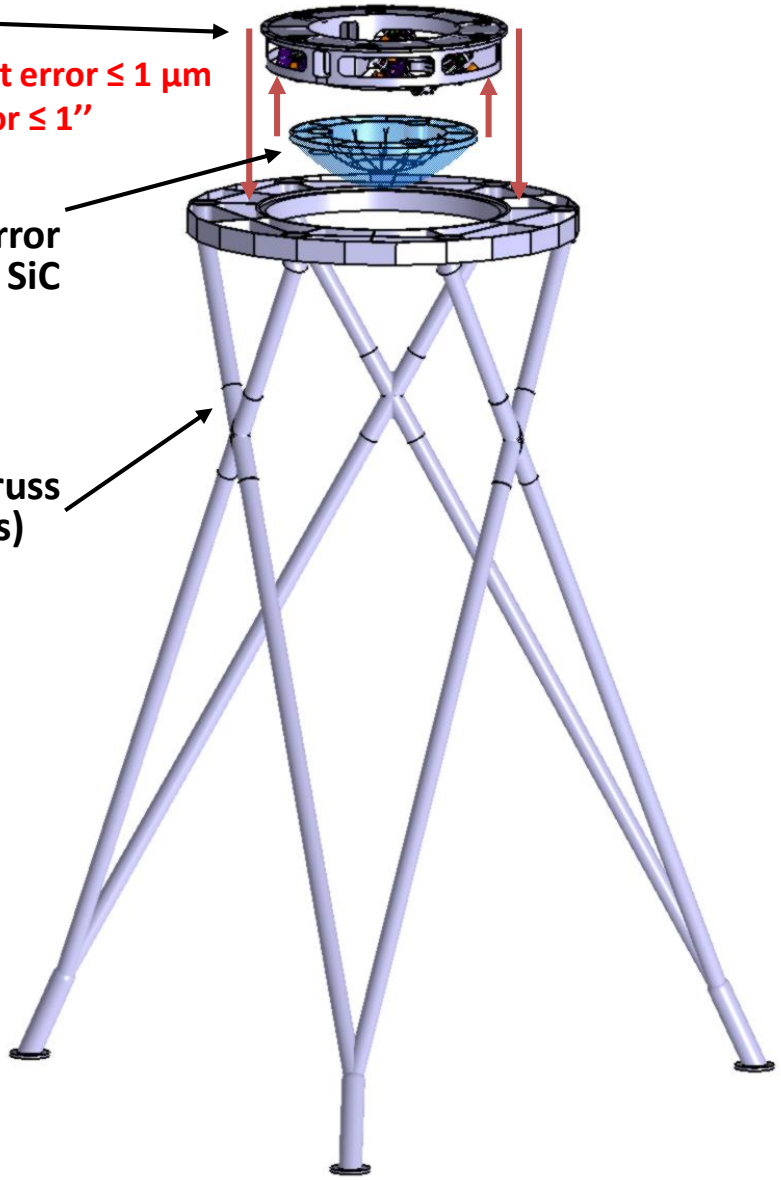
Hexapod

- ❑ **Displacement error ≤ 1 µm**
- ❑ **Rotation error ≤ 1''**

Secondary Mirror (hyperbolic) - SiC

Supporting Truss (CFRP tubes)

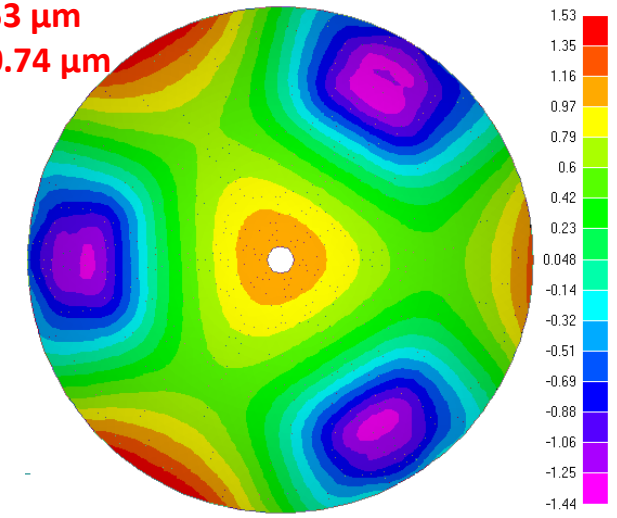


✓ **Surf. Errors ≤ 1µm (measured)**
limited by CMM measurement

Scale model (1:3)

Normal distortion of the SM made from SiC due to cool-down to 4K (calculated)

PV = 1.53 µm
RMS = 0.74 µm



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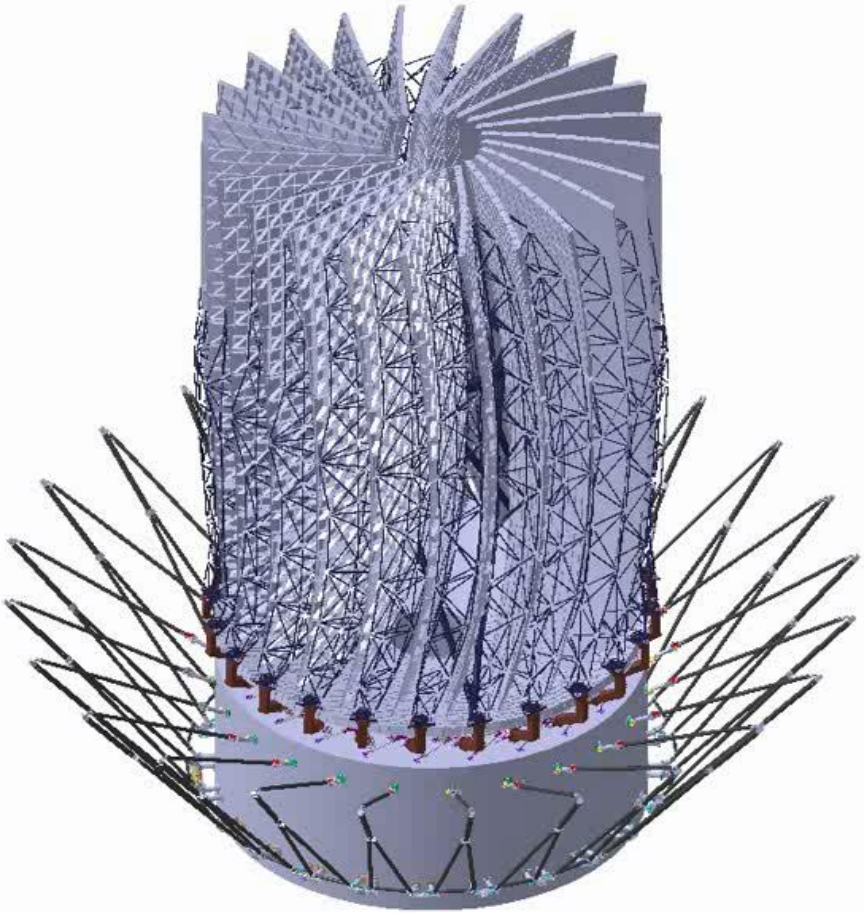
Deployment Strategy

- required deployment accuracy ≤ 1 mm (PV)



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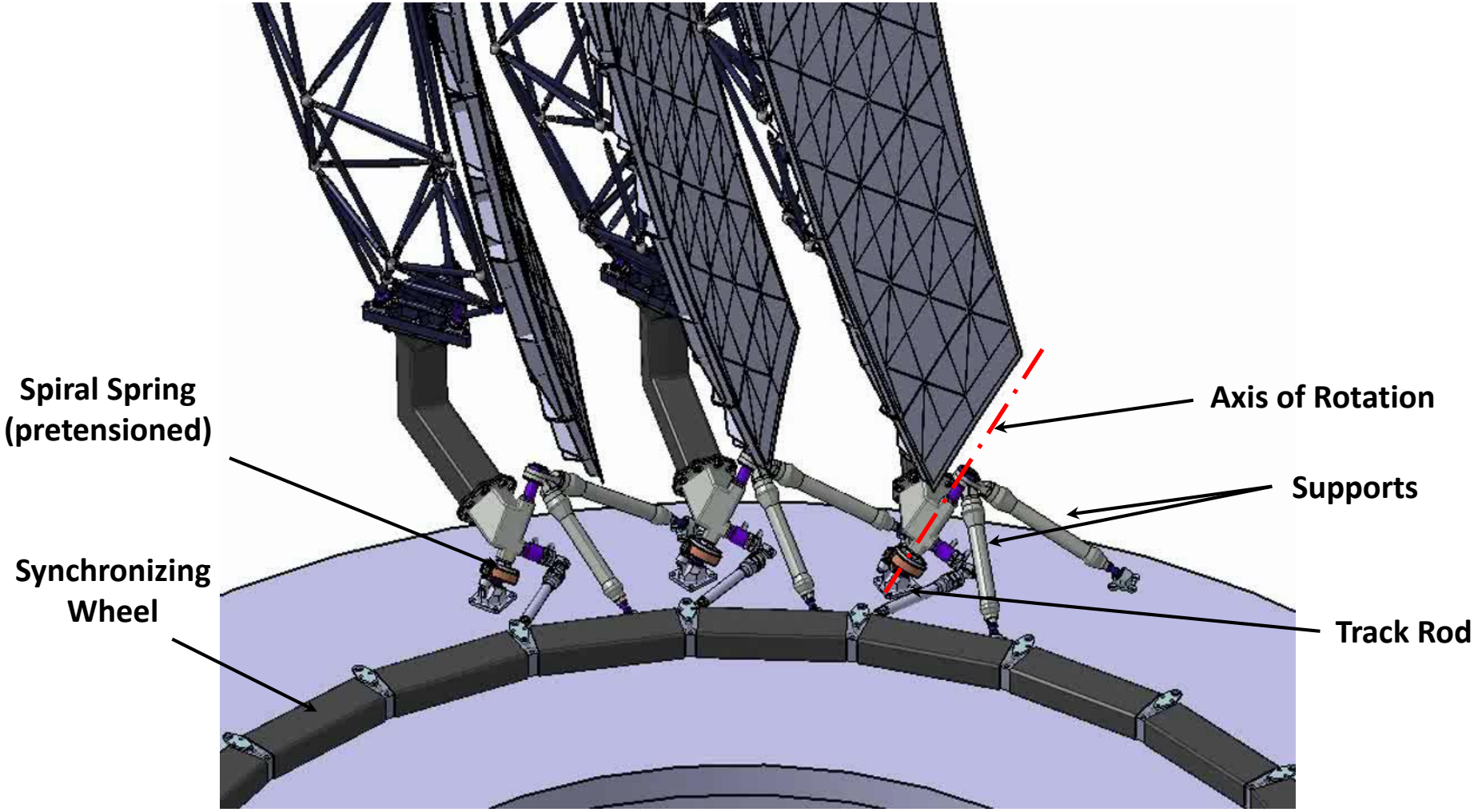
Deployment Mechanism



Millimetron antenna / Error budget

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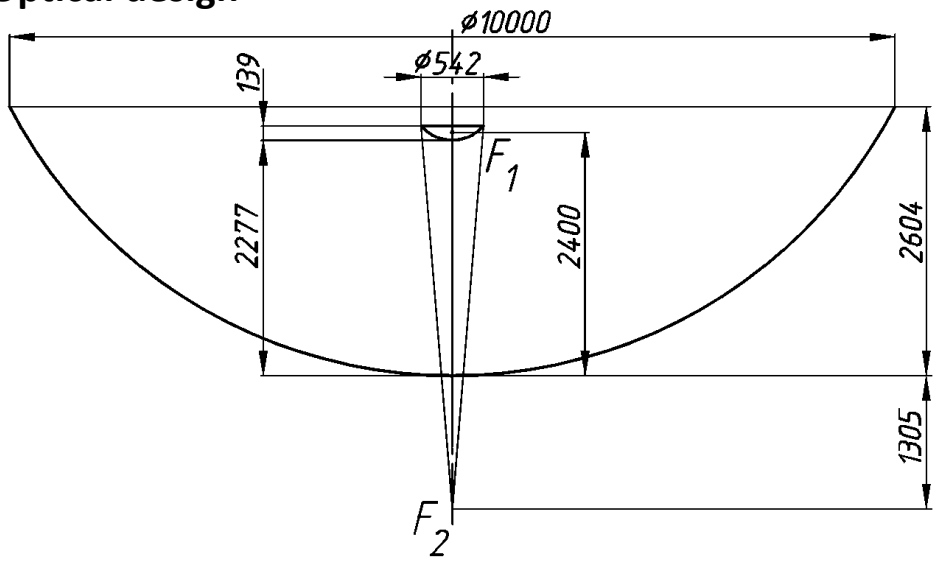
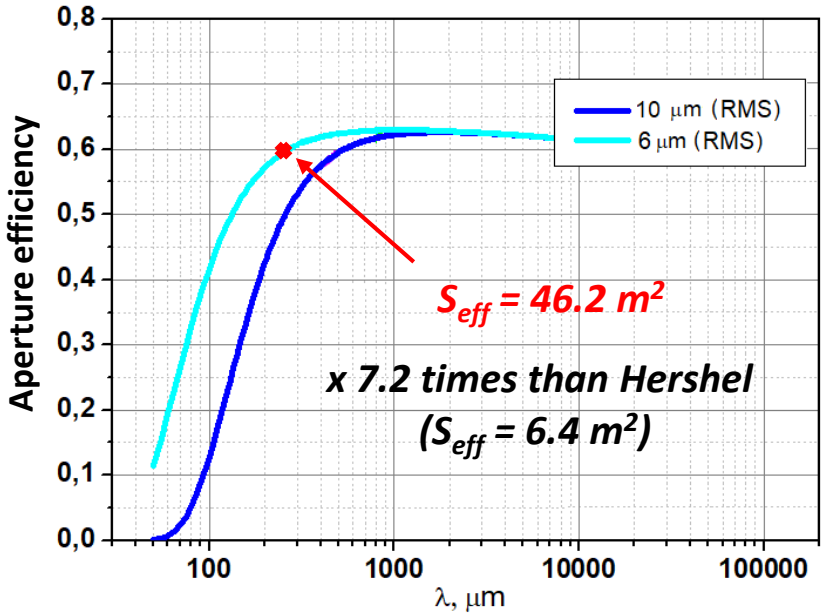
Optical design





Telescope		6 μm (RMS)
1	**Primary mirror**	**5,8**
1.1	Panels	3,6
1.2	Assembly*	0,3
1.3	Deployment*	0,7
1.4	Thermal and moisture distortions of framework*	2,8
1.5	1g offload*	0,8
1.6	Panel distortions due to adaptation	0,2
1.7	Panel curvature correction**	2,2
1.8	Adaptation	0,5
1.9	Alignment	1,0
1.10	Non-static image quality	0,2
	Total	**5,3**
	Margin	0,5
2	**Secondary mirror**	
2.1	Manufacturing	1,0
2.2	Thermal distortions	0,8
2.3	Alignment	1,0
2.4	Non-static image quality	0,2
	Total	**1,6**

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Risks mitigation in the Primary Mirror development

Technical challenges	Critical items	Development steps
10-m aperture deployable space mirror	Accurate and reliable deployment	▪ Verification of petals and brace struts deployment accuracy; ▪ Development of the zero-gravity system
	Mechanical performance under the launch loads	▪ Verification of the latching systems; ▪ Vibration testing in the launch configuration;
SFE ≤ **9.8 µm** RMS (goal 5.8 µm) at *T* up to **4.5K**	High-precision lightweight panels from CFRP	▪ Validation of the replica technique accuracy and repeatability;
	Thermal dimensional stability of PM structures	▪ The measurement of thermal distortions of a panel and a petal framework in cryovacuum conditions;
	Panels position and curvature adjustment	▪ Mock-up for a panel adaptation via 3 "tip&tilt" actuators; ▪ Mock-up for a panel curvature correction via a center self-contained actuator.

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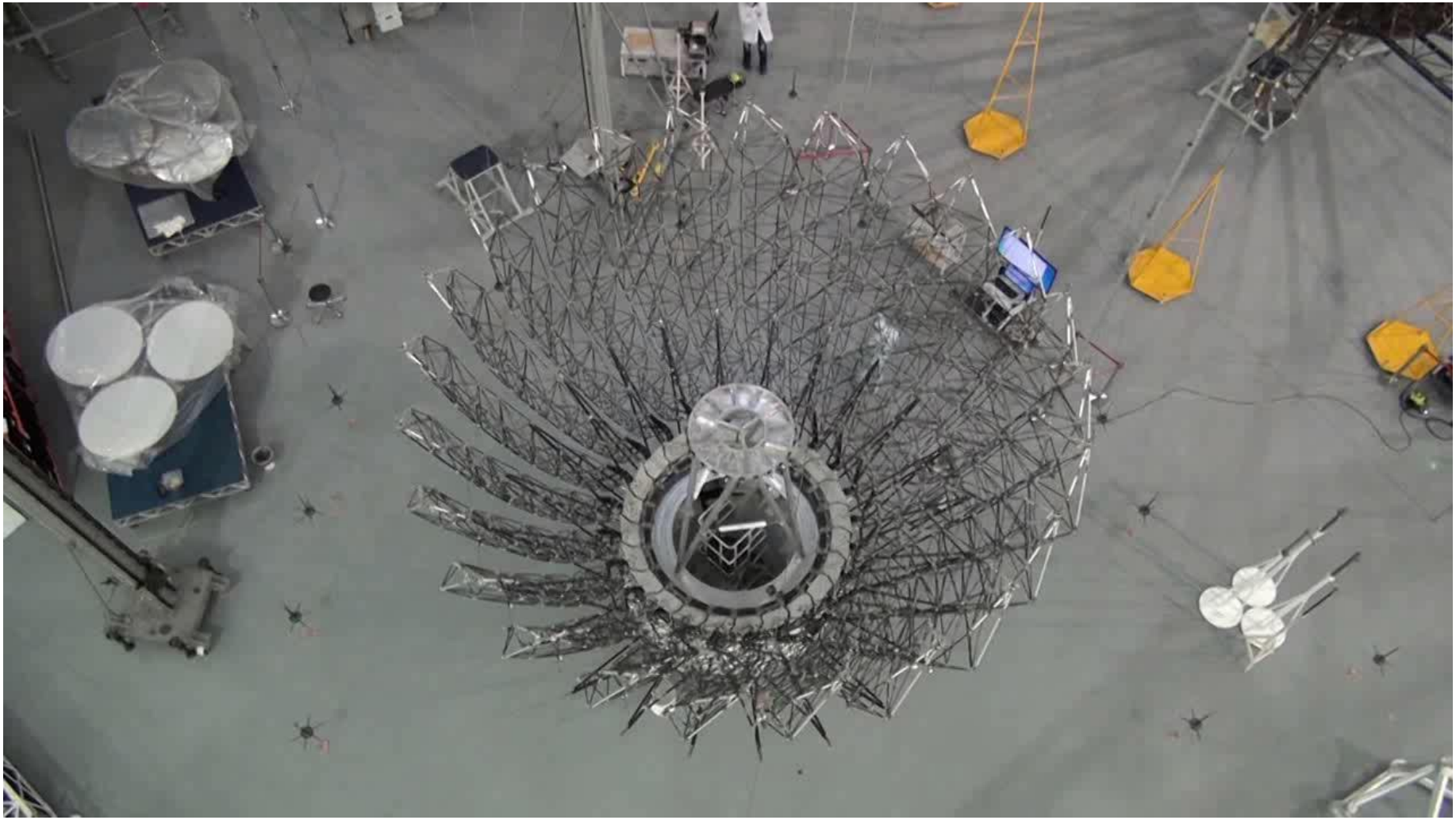
Primary Mirror mock-up at November 11, 2016



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Development and testing of full-scale Primary Mirror mock-up

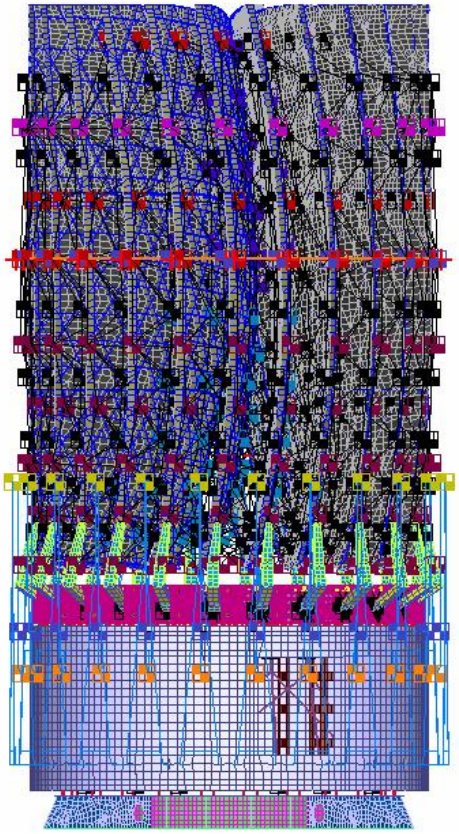
4

Phases of the test program:

1. Verification of deployment system performances in terms deployment accuracy and repeatability;
2. Development and verification of a zero-gravity system;
3. Verification of the latching system of petals in operational and folded positions;
4. Verification of deployment system of brace struts;
5. Vibration testing in the stowed configuration.

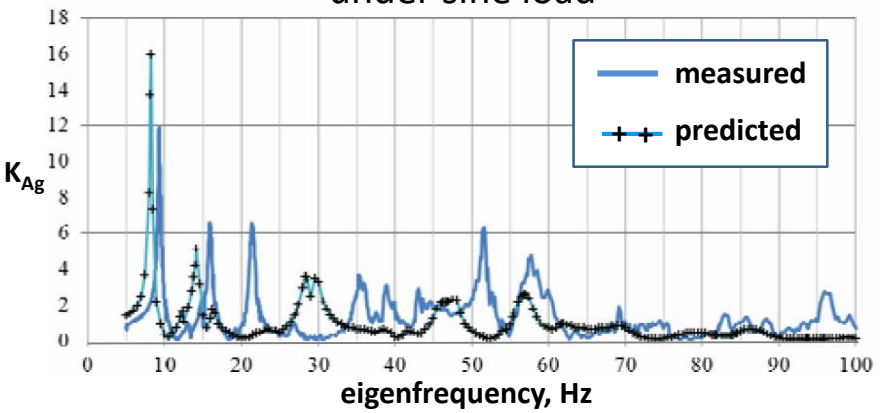
Vibration testing in the stowed configuration

Foto PM mock-up on a shaker



FEM of mock-up

Frequency response in the transverse direction under sine load



1st bending mode = 8.5 Hz (predicted), 9.3 Hz (measured)

✓ **acceptable for launch vehicle**

✓ **No structural degradation and visible damage after test;**

✓ **No unexplained frequency shifts more than 5% between pre and post test;**

✓ **Latching system of PM for the stowed configuration verified.**

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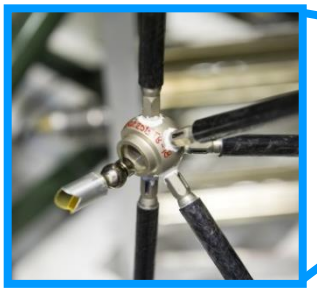
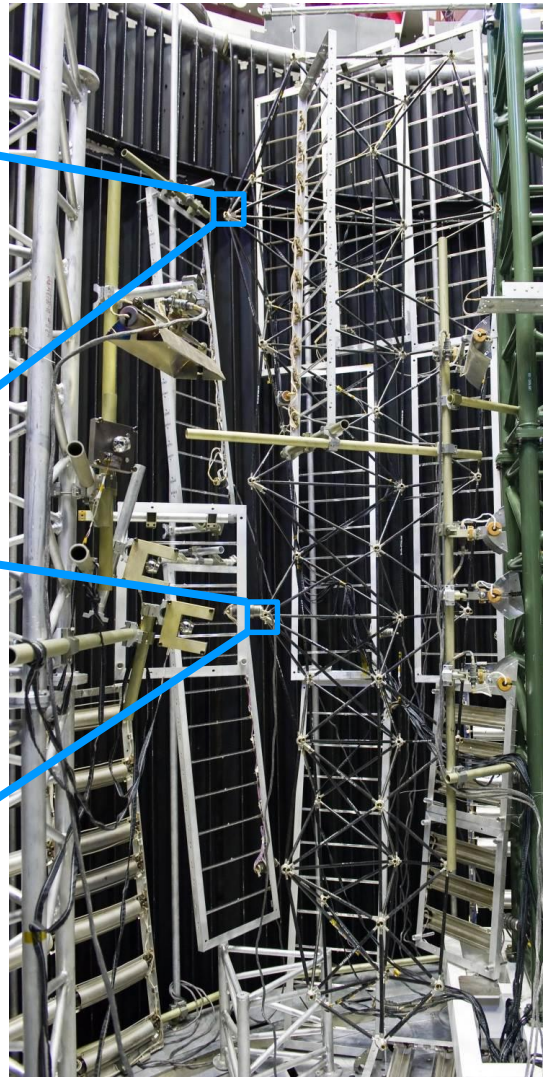
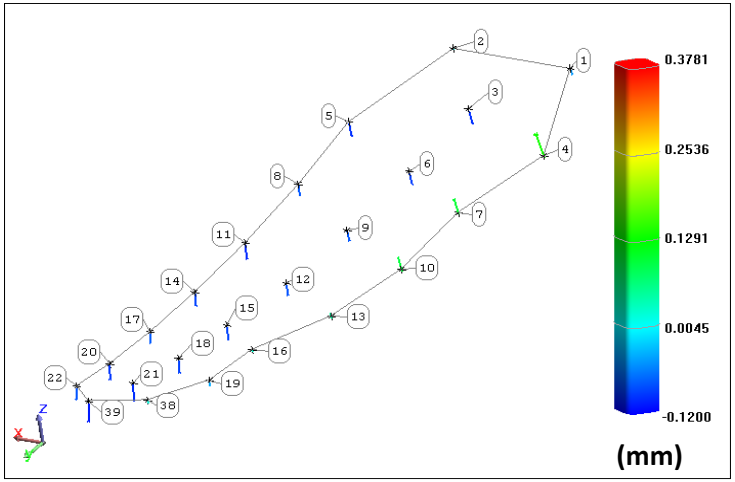
Thermal distortions measurement of petal framework



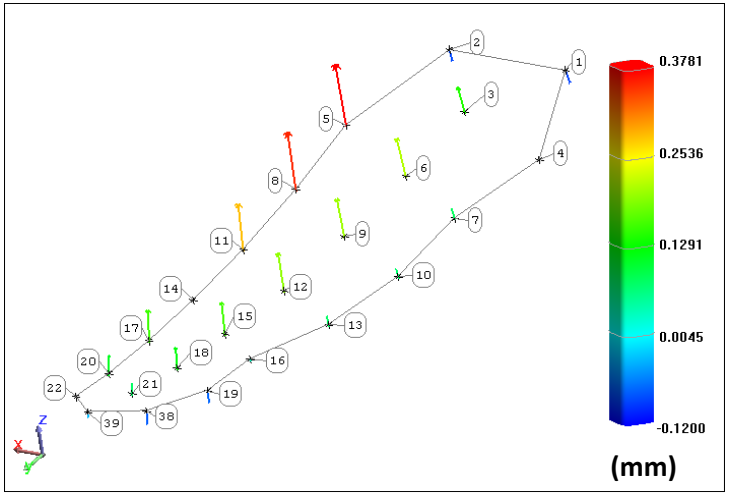
34 Optical targets



Petal framework in a thermal vacuum chamber (Max thermal gradient <10°C)



Measured distortions at *t* = -140 °C



Measured distortions at *t* = +140 °C

✓ **Max measured distortions ≤ 0.4 mm (PV)**

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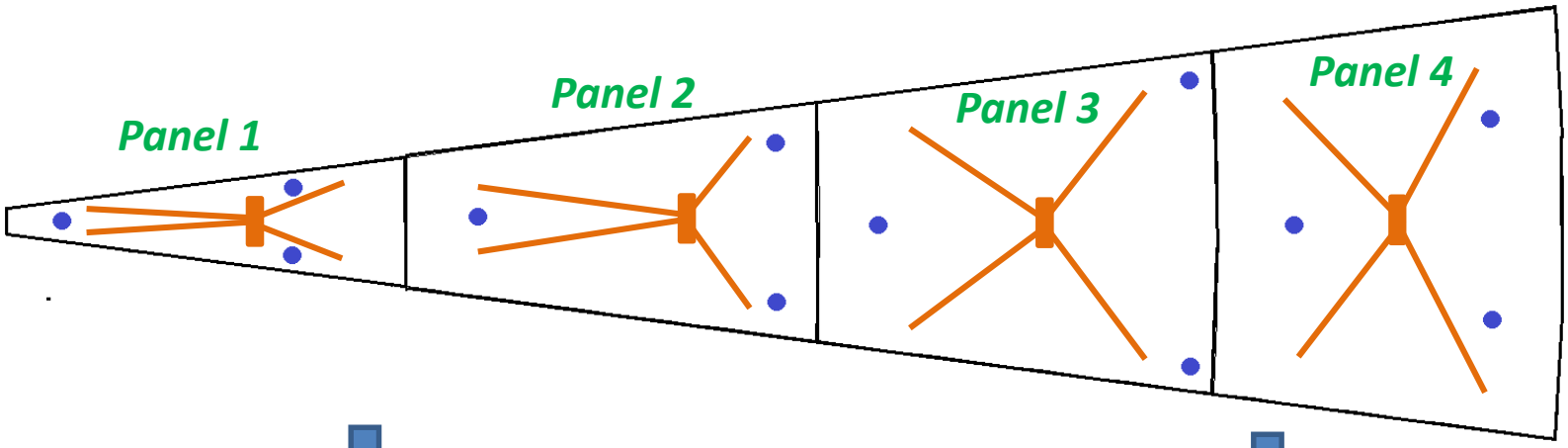
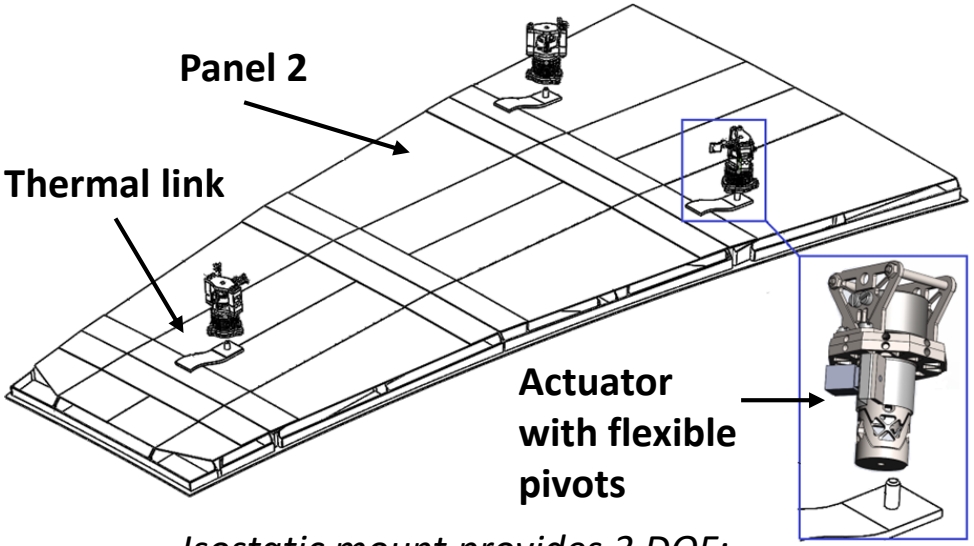
Panels position and curvature adjustment

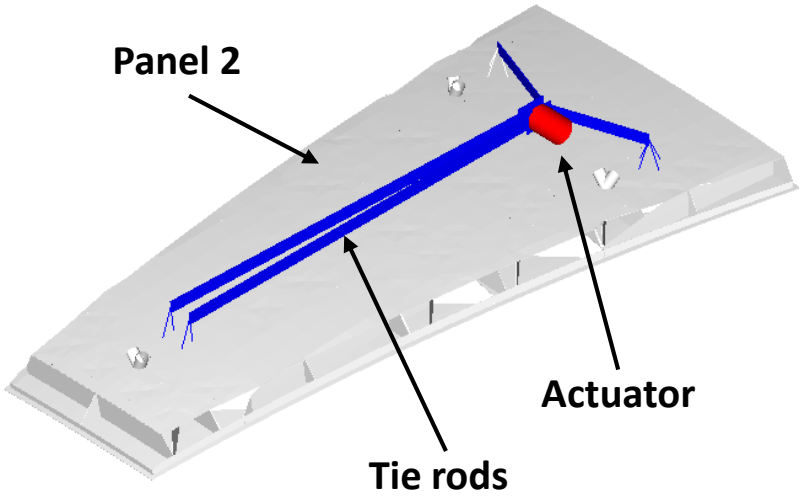


Concept of panel adaptation via 3 actuators

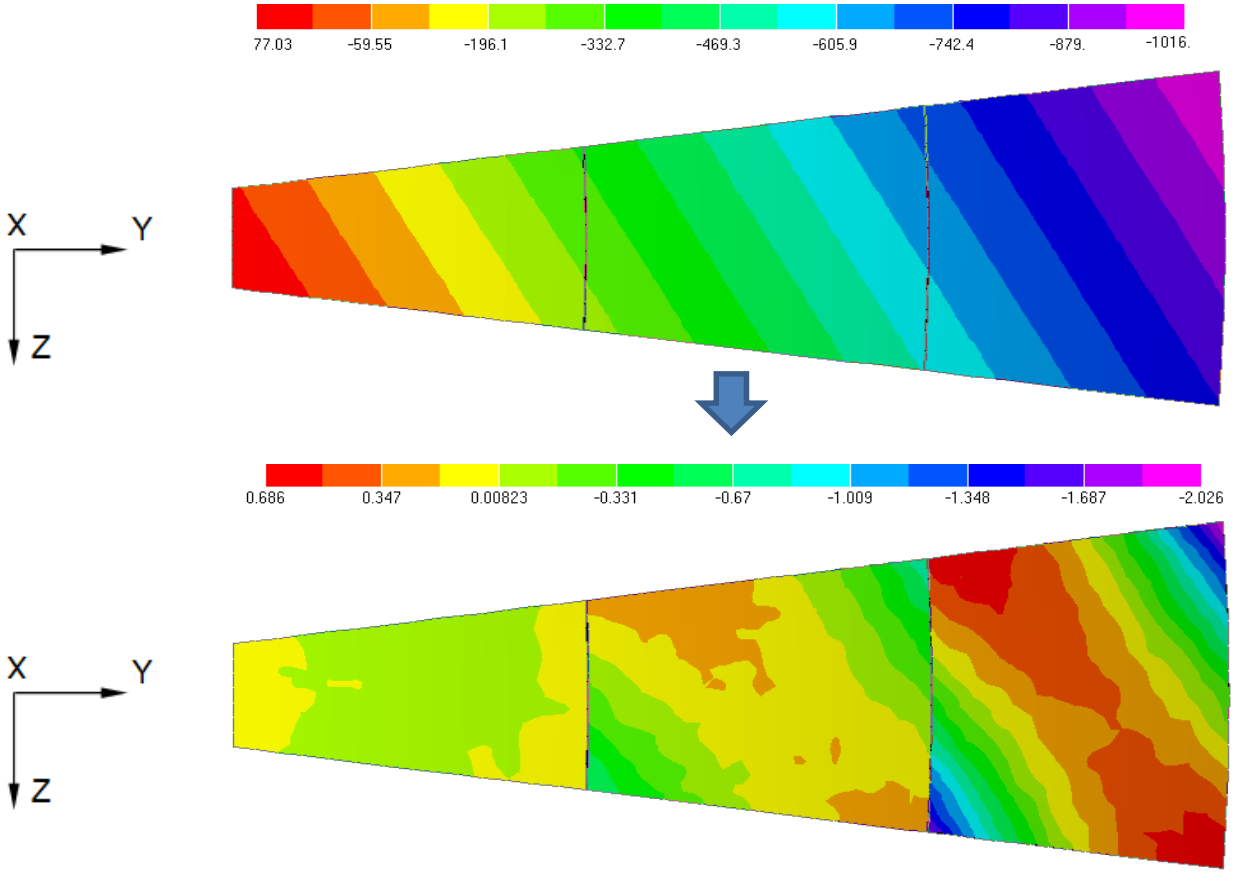


Isostatic mount provides 3 DOF:
2 rotation and 1 displacement

Concept of panel curvature correction



Deployment error alignment



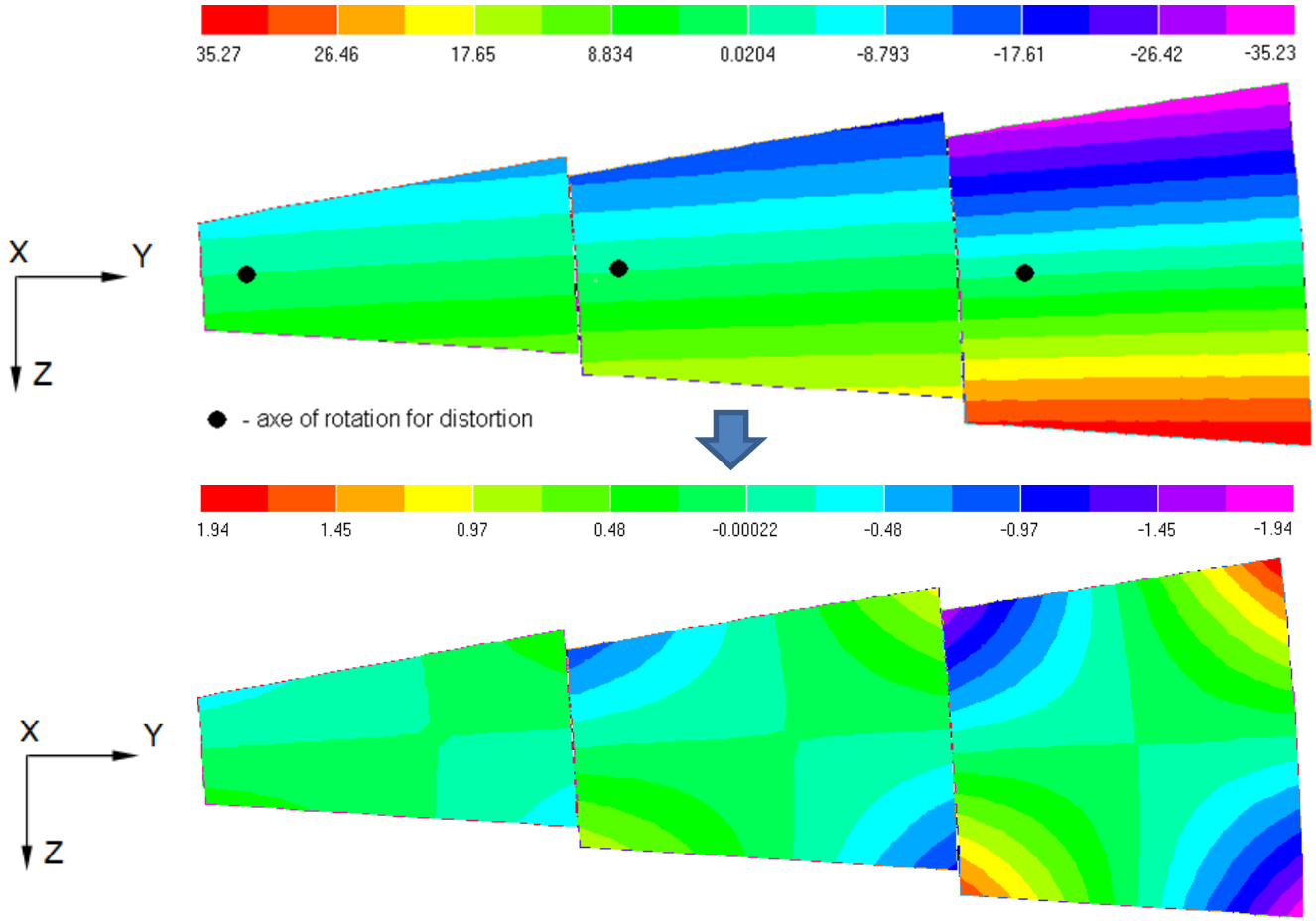
$A_\varepsilon = \pm 1$ mm*

*Errors are caused by deviation in the turning angle of a petal around deployment axis

Residual misalignments

	Panel 2	Panel 3	Panel 4
RMS before adjustment, µm	183	544	923
RMS after adjustment, µm	0.2	0.6	0.9
Actuator movements, µm	34/ 342/ 246	789/ 356/ 634	785/ 979/ 1094

Assembly error alignment



The worst case of assembly error:

Rotation over vertical axis of actuator 1 with **A_ε =±100 µm**

Residual misalignments

	Panel 2	Panel 3	Panel 4
RMS before adjustment, µm	5.6	10.6	20.4
RMS after adjustment, µm	0.2	0.4	0.7
Actuator movements, µm	4/ 34/ 25	79/ 36/ 64	78/ 98/ 109

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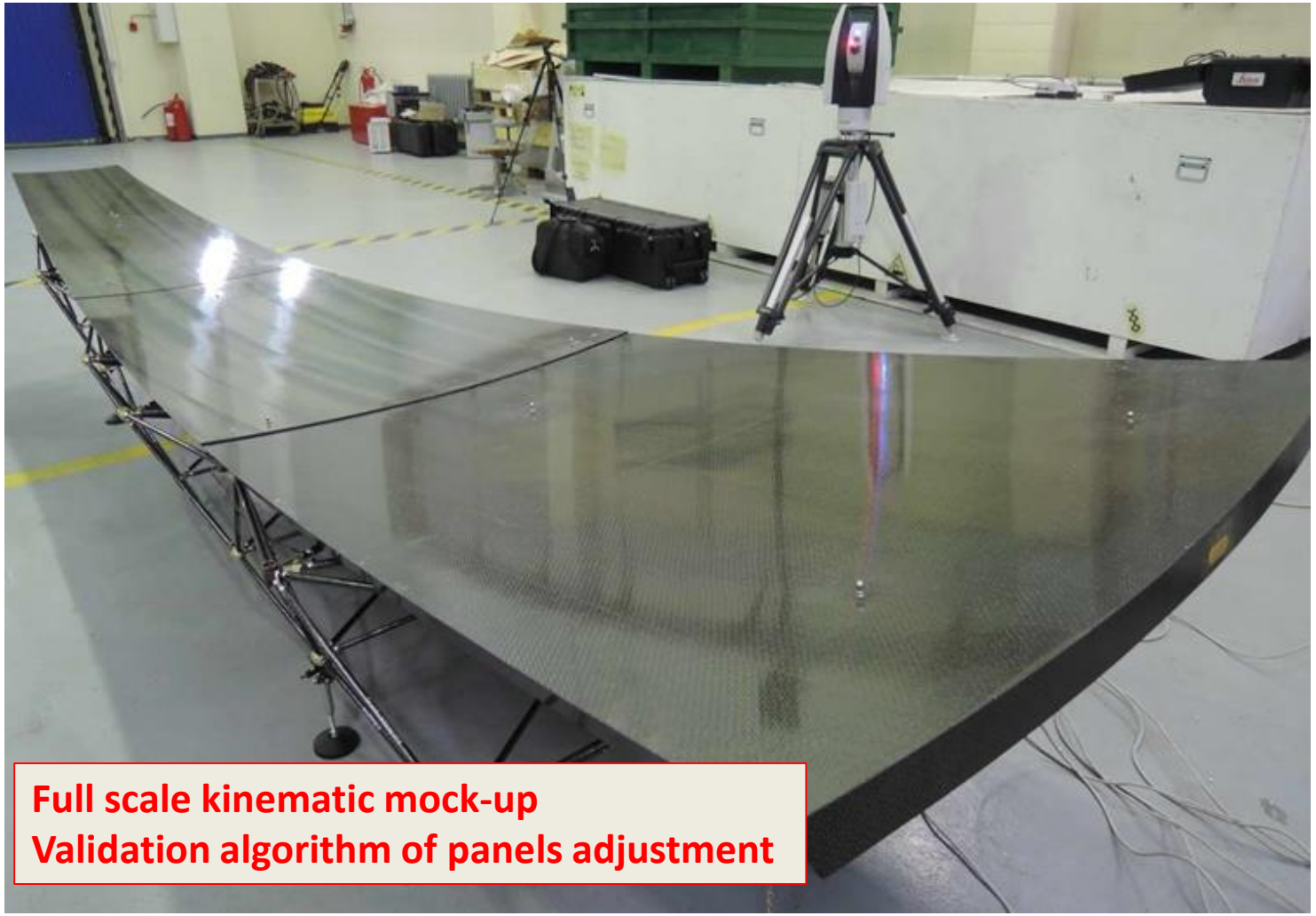
Mock-up of panel adaptation system



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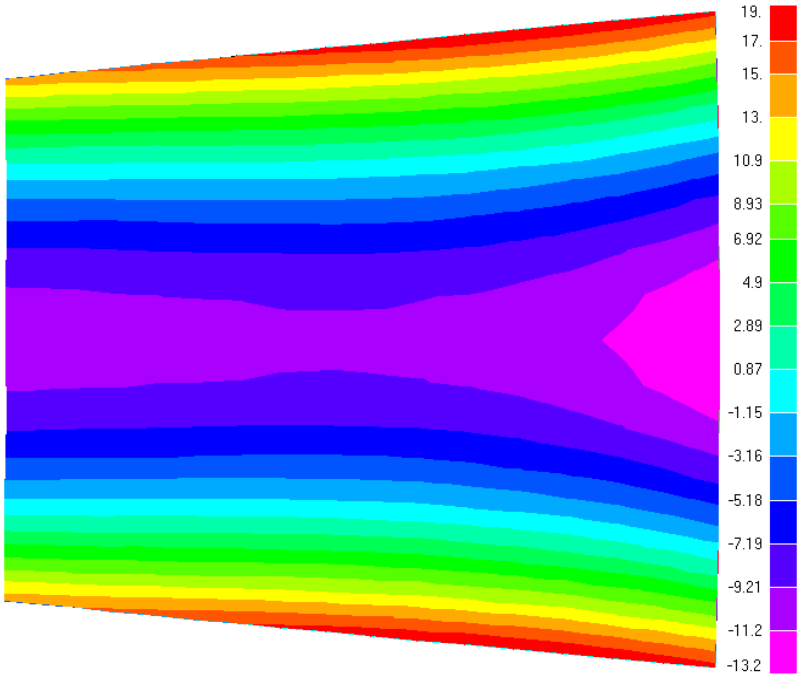
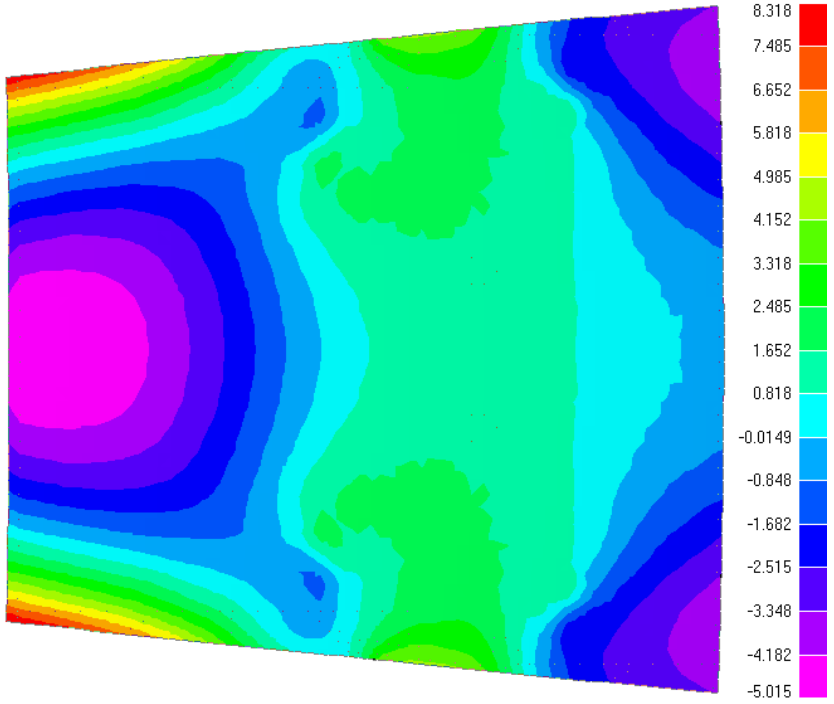
Panel curvature correction system

SFE for panel 4 with ΔF = 4 mm after adjusting by 3 actuators



RMS = 9.4 µm

Residual SFE for panel 4 after curvature correction



RMS = 2.3 µm

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Primary Mirror Error Budget

Panel type / external factor	Panel 1 (central)	Panel 2 (internal)	Panel 3 (middle)	Panel 4 (external)	Total, µm (RMS)
Assembly errors*	0,1	0,3	0,5	0,7	**0,3**
Inaccuracy of deployment and fixation*	0,0	0,2	0,6	0,9	**0,3**
Thermal and moisture distortions of framework*	1,5	2,9	3,8	5,8	**2,8**
Panel curvature correction **	2,4	3,0	2,1	2,3	**2,2**
1g offload*	0,5	1,0	1,0	1,0	**0,8**
Panel distortions due to adaptation	0,1	0,2	0,5	0,3	**0,2**
Adaptation	0,5	0,5	0,5	0,5	**0,4**
Alignment	1,0	1,0	1,0	1,0	**0,9**
Non-static image quality	0,2	0,2	0,2	0,2	**0,2**
Panels	3,0	4,4	4,6	4,6	**3,6**
Total	13,2	11,2	9,6	10,5	**5,3**

Note:

* residual RMS got after adaptation via 3 "tip&tilt" actuators per panel and SM

** residual RMS got after curvature correction ΔF = 4 mm

More details about panel adaptation in the presentation of A. Baryshev "In-flight Surface Error measurement system"

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Conclusions

1. Testing of the full-scale mock-up of the primary mirror is finished:

- ✓ Achieved deployment accuracy - 0.3 mm (PV)
- ✓ Locking systems for operational and stowed configurations have been verified
- ✓ Dynamic performances are acceptable for launch-vehicle

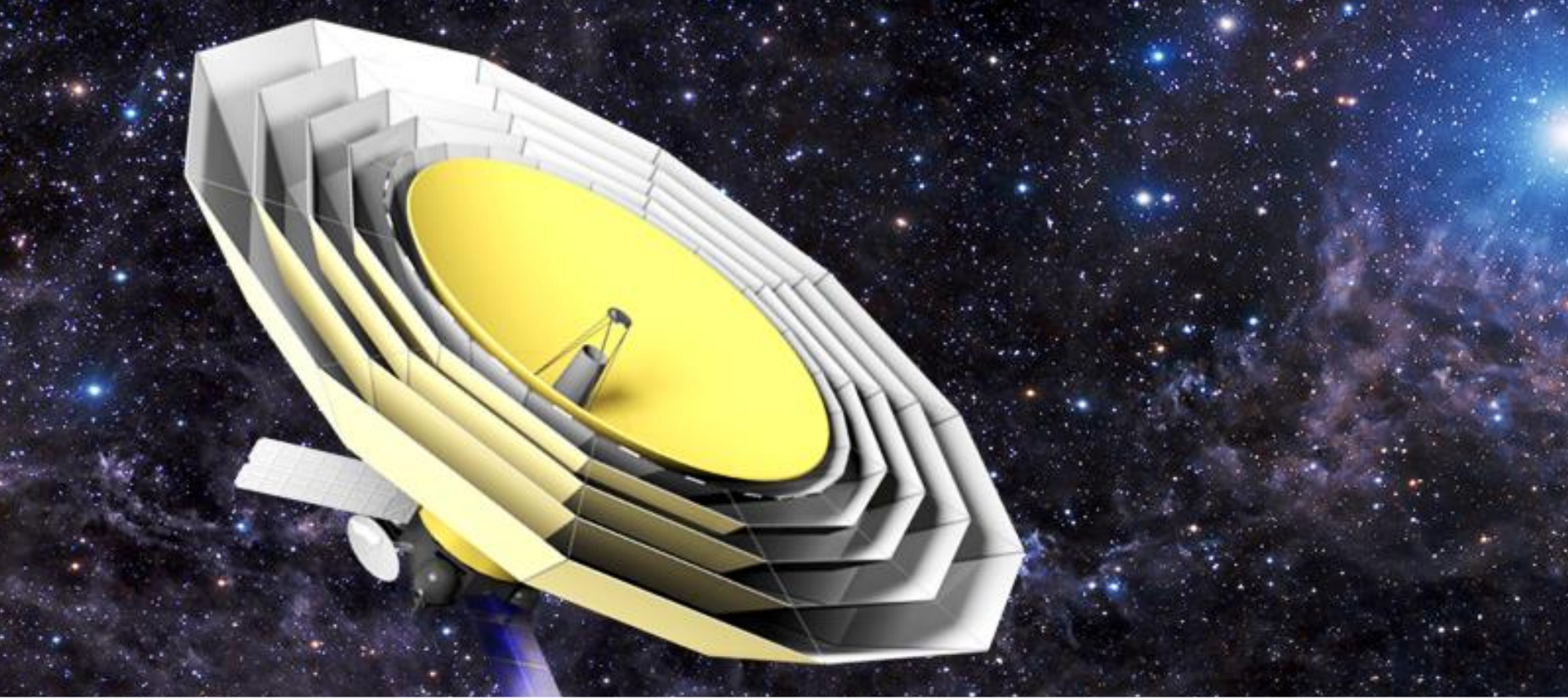
2. Thermal dimensional stability of the primary mirror components:

- ✓ Thermal distortions of the petal framework (cool down to 120K) ≤ 0.4 mm (PV)
- ✓ Thermal distortions of the panel by cooling to 120K not exceeded the 19 µm (PV)

More details in next presentation →

3. Panels position and curvature adjustment

- ✓ Kinematic scheme of the panel adjustment provides compensations of all misalignment factors and meet error budget requirements
- ✓ Algorithm of panels adjustment validated
- ✓ Curvature correction on-board system can handle with the focus length deviation in the range of ± 4 mm



Thank you for your attention