space structures laboratory

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A Robotically Assembled 100 m Space Telescope

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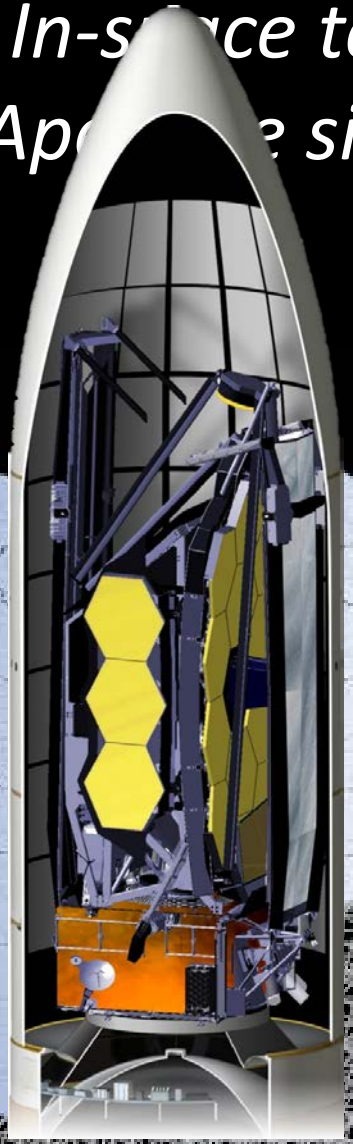
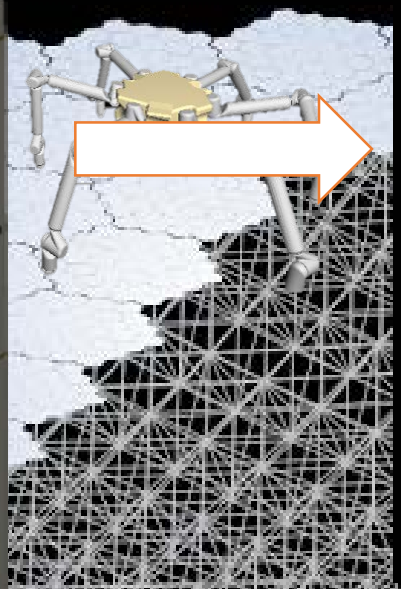
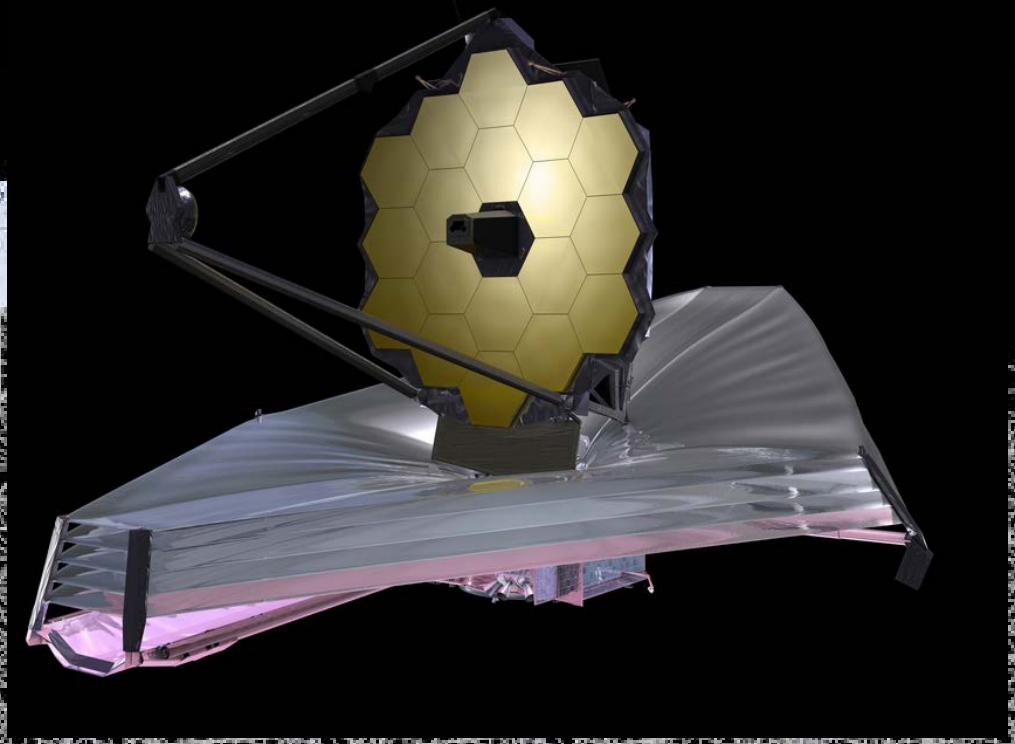
Ground-based assembly → Aperture size limited by launch vehicle

In-space telescope assembly robotics (ISTAR) → Aperture size limited by structural capability and budget

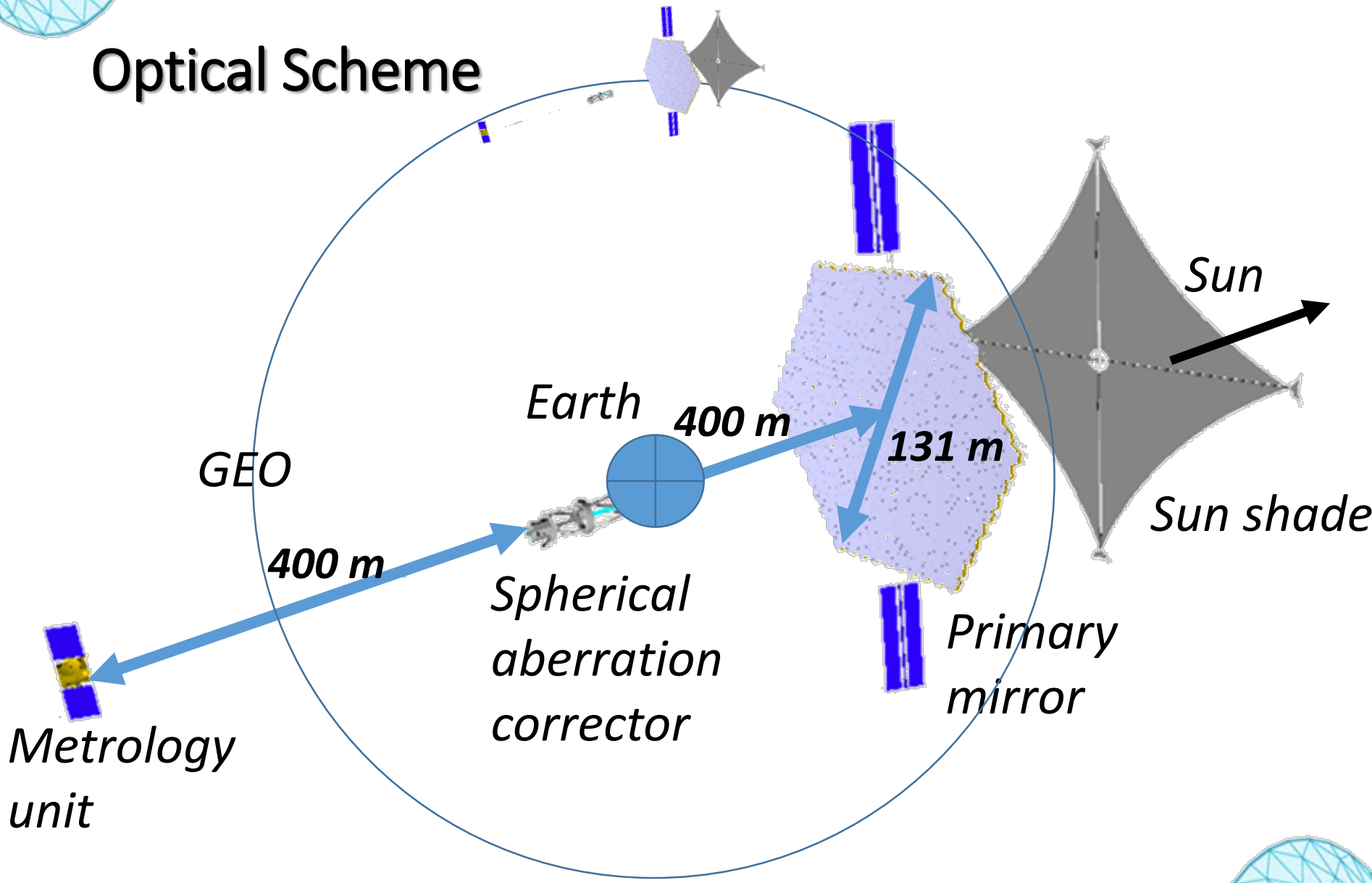






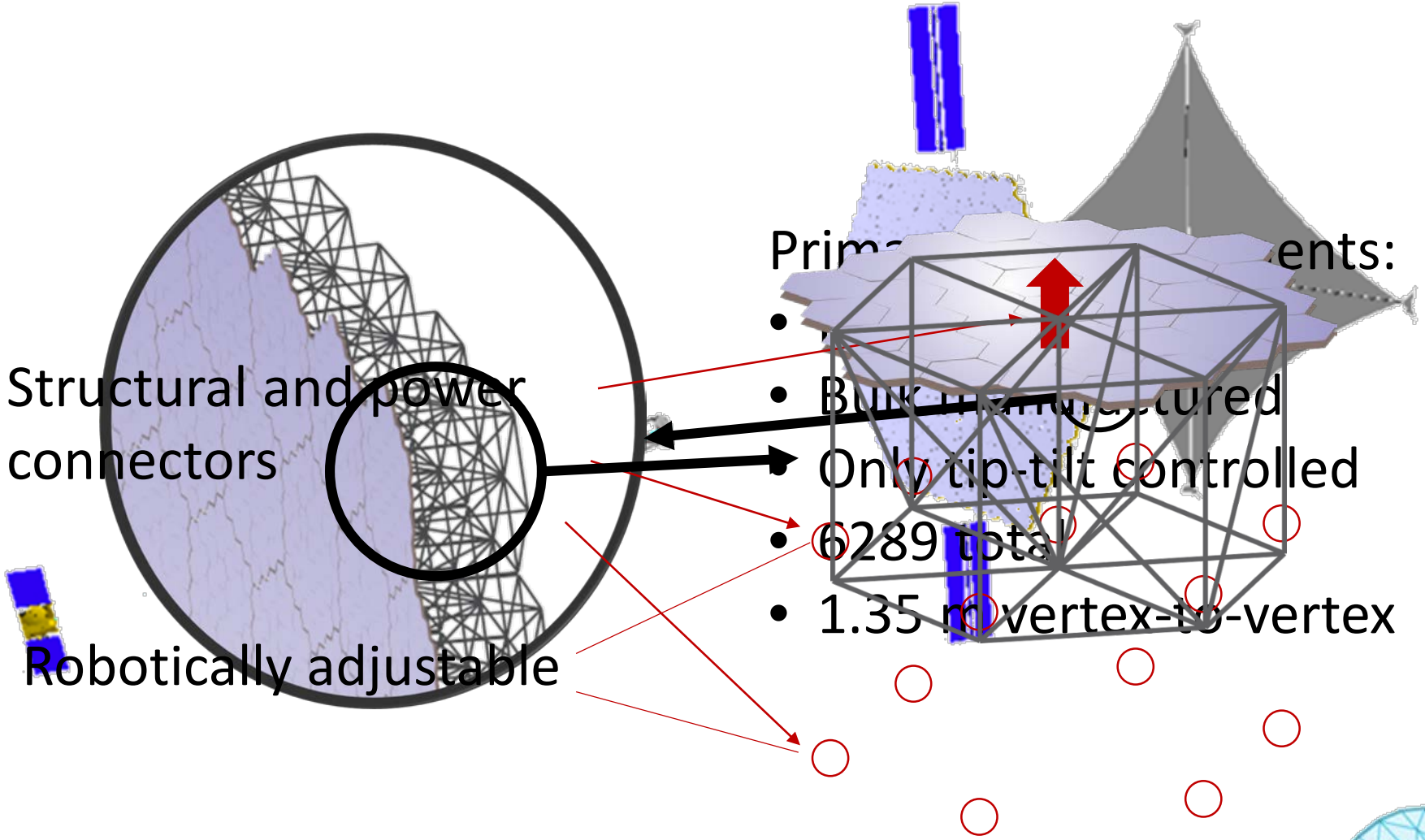
Images courtesy of NASA

Optical Scheme



Primary Mirror

Mirror module



Prim ents:

- Bulk manufactured
- Only tip-tilt controlled
- 6289 total
- 1.35 m vertex-to-vertex

Truss module

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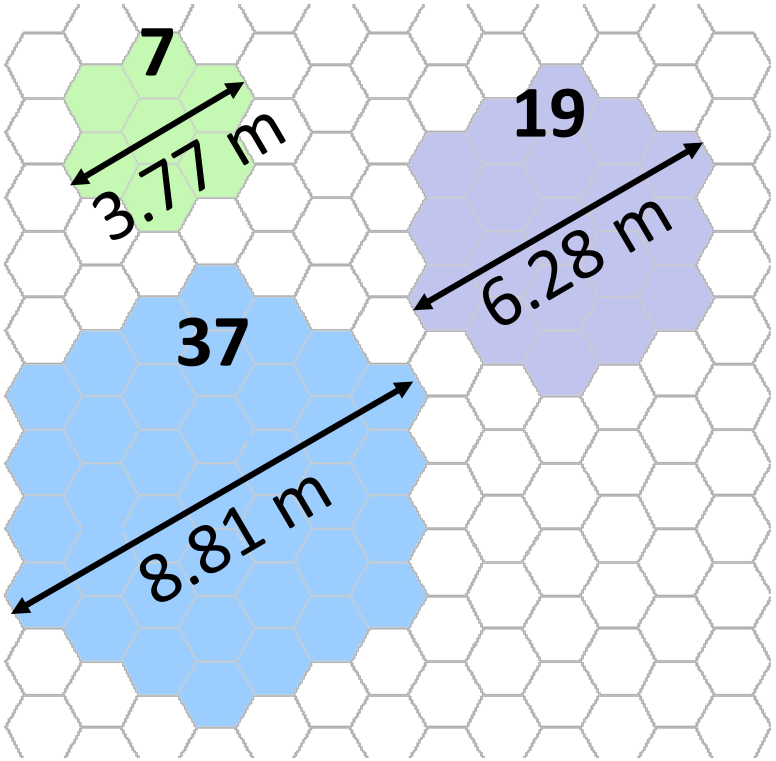
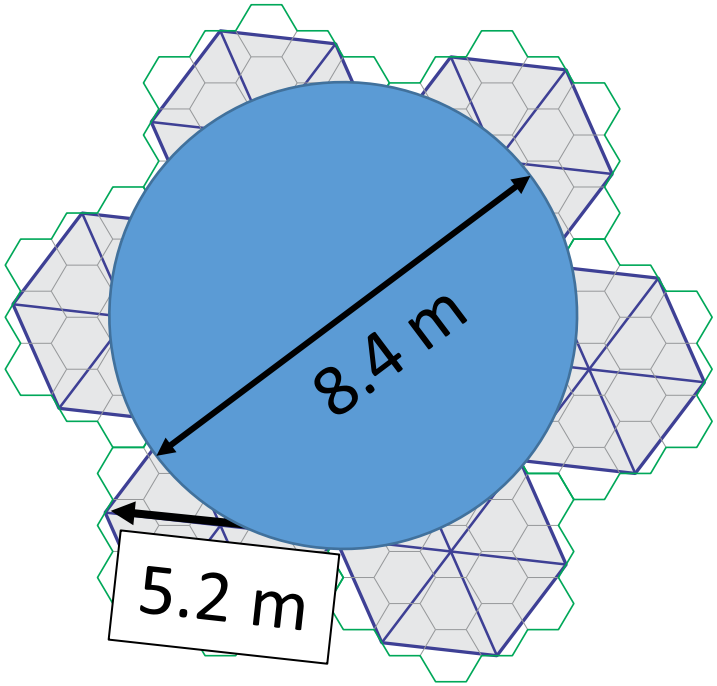
Module Sizing

Mirror module size choices

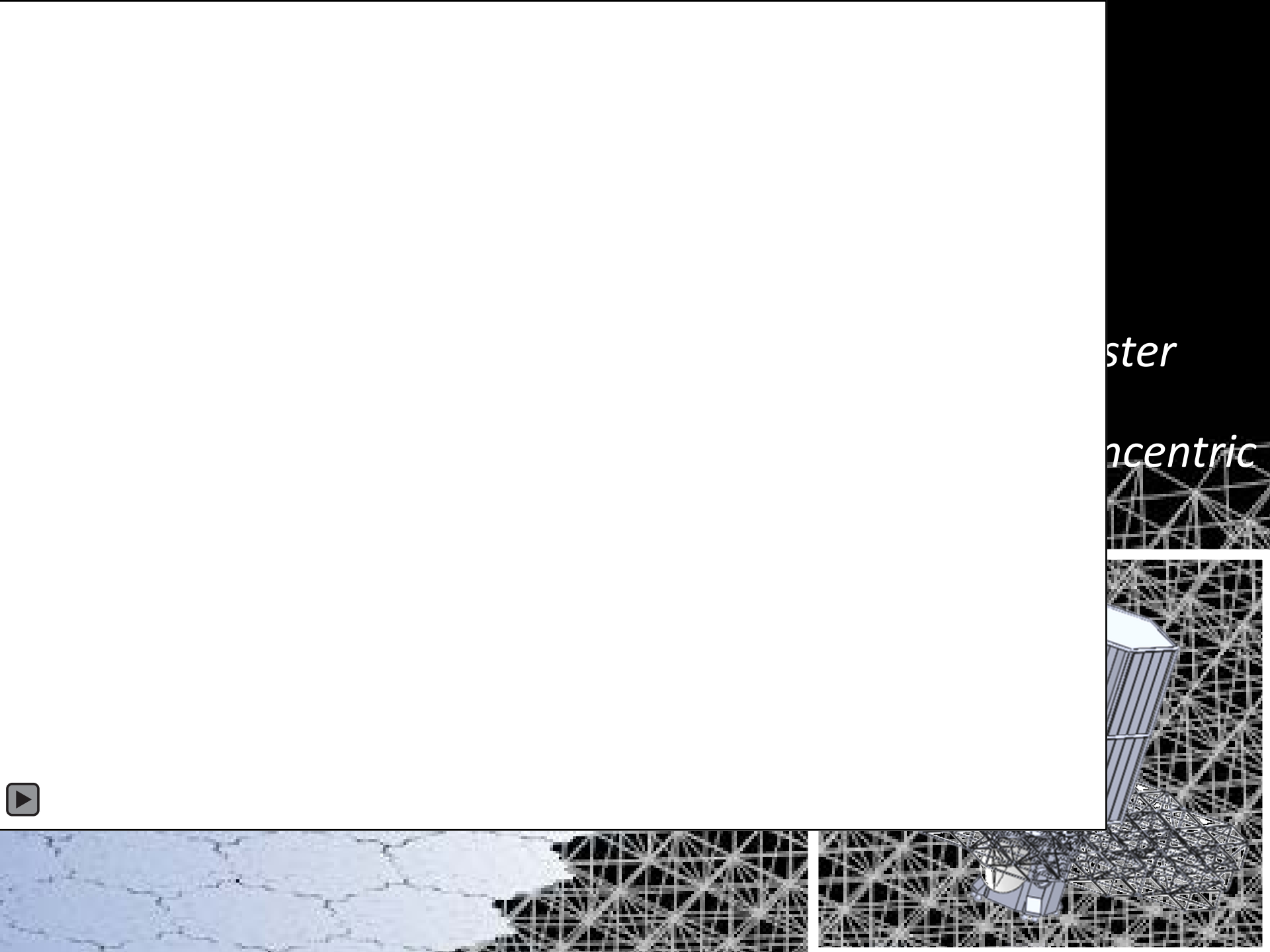


STS payload fairing size



6289 segments → 331 modules

Truss Module Deployment Scheme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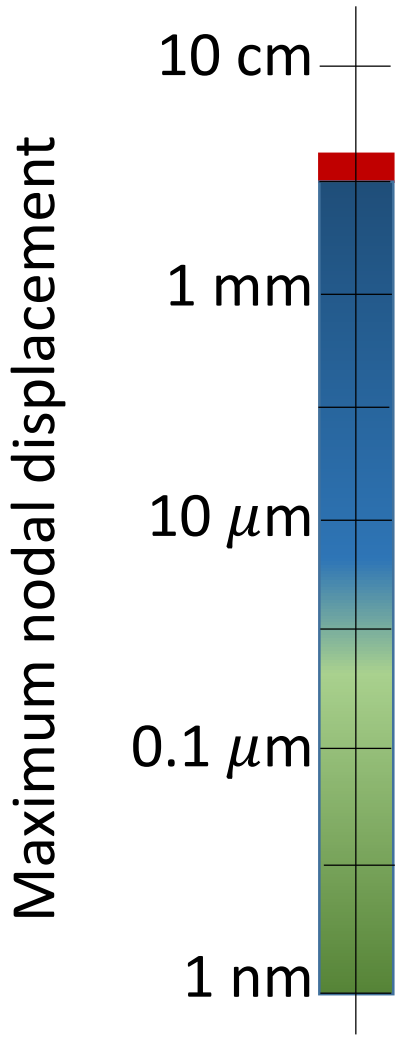
Precision Requirements



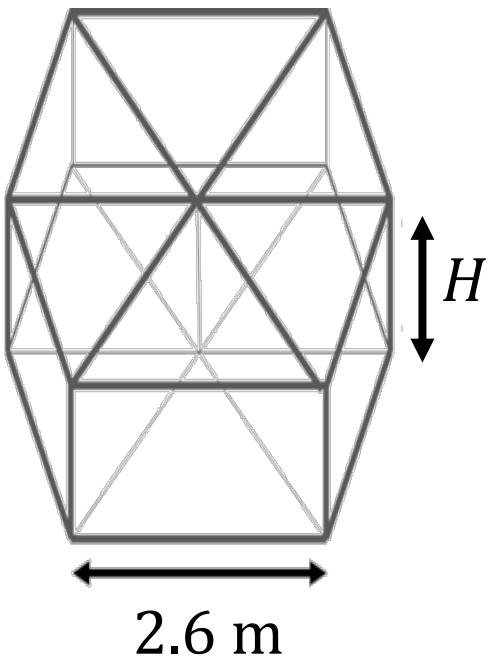
Robotic truss adjustment
30 mm → 10 mm
Corrects fabrication and assembly errors

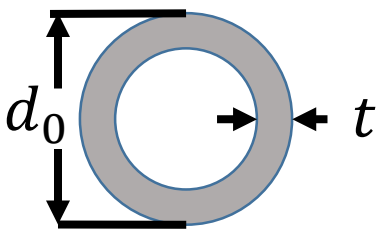
Rigid body actuators under primary mirror segments
10 mm → $\mathcal{O}(\mu\mathrm{m})$
Corrects quasi-static errors

Active mirrors in SAC
$\mathcal{O}(\mu\mathrm{m})$ → $\mathcal{O}(\mathrm{nm})$
Corrects quasi-static errors

Truss Module Design

Truss module dimensions





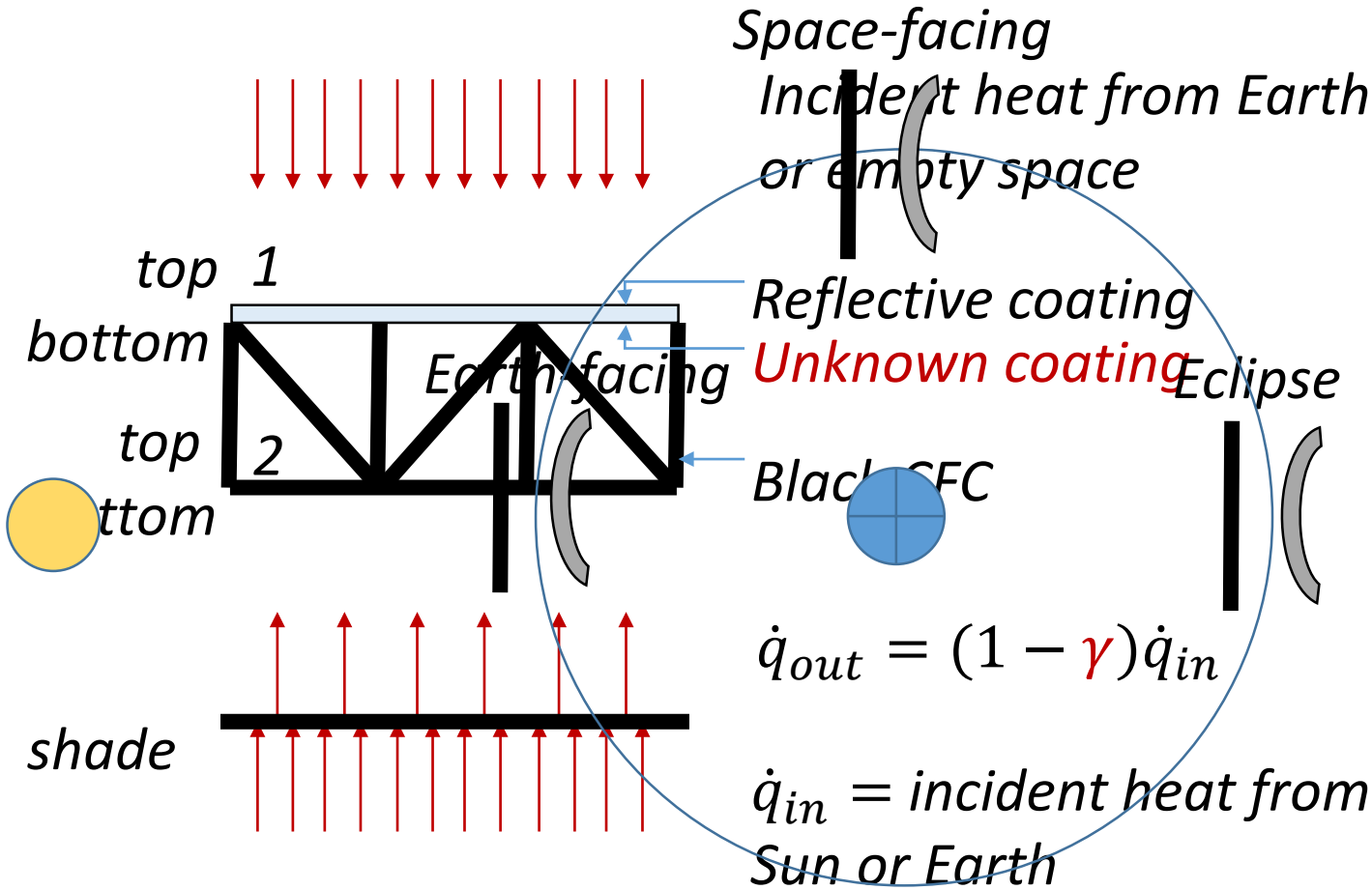
Material = M55J carbon fiber composite

Choose design parameters to maintain required precision in the presence of:

- Gravity gradient loads
- Fabrication and assembly errors
- Dynamic disturbances
- **Thermal environment**
  - Change in curvature most detrimental effect

$$\Delta T_{max} = \frac{\Delta K_{max} H}{CTE(truss)}$$

Thermal Analysis



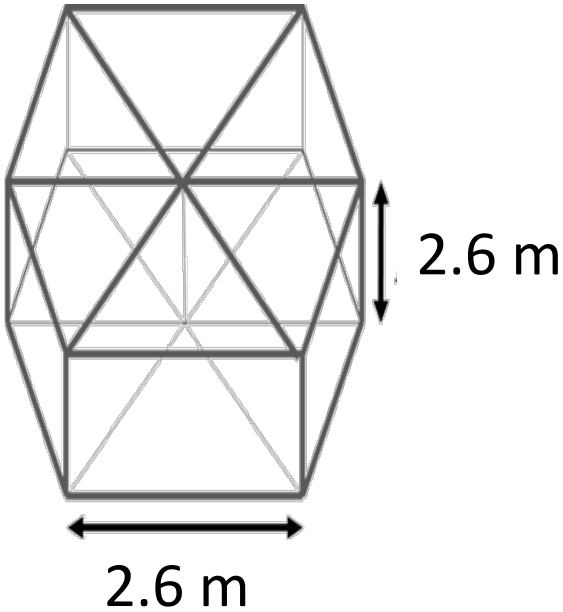
Thermal Analysis

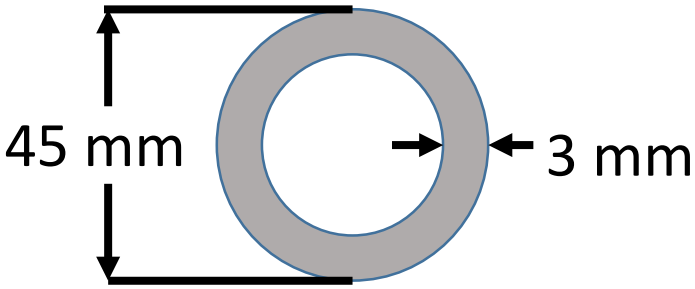
$$\Delta T_{max} = \frac{\Delta K_{max} H}{\alpha_{TRUSS}} = \mathbf{13.59\ K}$$

Coating = colored paint ($\alpha = 0.6$)

$$\boldsymbol{\gamma} = 0.6$$

Case 1	278	273	5
Case 2	278	273	5
Case 3	89	87	2





Summary

Primary mirror vertex-to-vertex dimension	131 m
Primary mirror radius of curvature	800 m
Number of primary mirror segments	6289
Number of mirror modules	331
Maximum mirror module dimension	6.28 m
Maximum truss module dimension	5.2 m
Truss depth	2.6 m
Truss areal density	4.01
Primary mirror mass	kg
Fundamental Frequency	1.0 Hz
Maximum gravity gradient distortion	45 nm
Maximum allowable assembly error	5 mm

Conclusions

- 100 m robotically assembled space telescope is feasible
- Future work
  - Better characterization of metrology, SAC, and sun shade
  - Structural components
    - Truss module connectors
    - Truss module hinges
  - Robotic Assembly

Acknowledgements

The research was carried out in part at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

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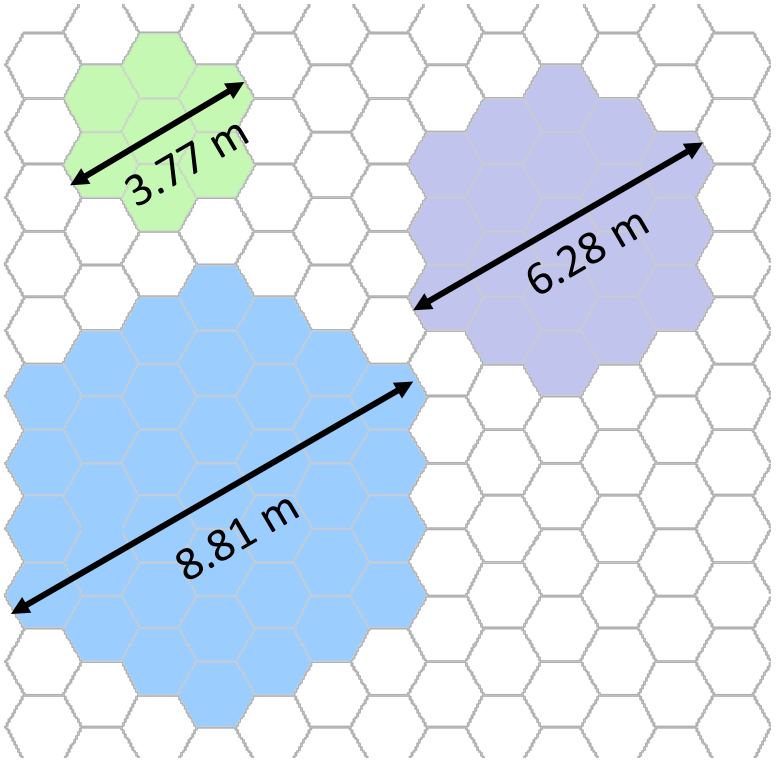
BACKUP

Mirror Module Design



Gaps between segments in one module	100 mm 1.7
Gaps between segments of neighboring modules	98 mm to 101.3 mm

Mission Requirements

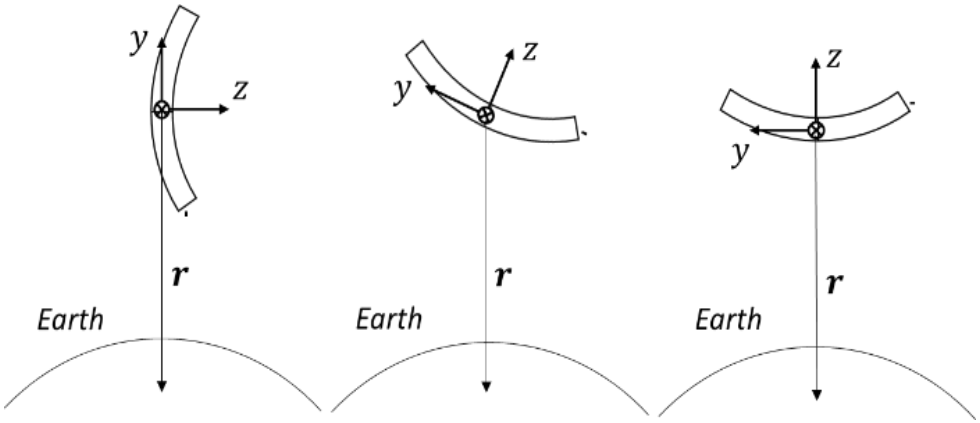
Maximum overhead between targets	3 min
Operating temperature	240-300 K
Maximum primary mirror areal density	25 for mirrors + for structure
Gap between mirror segments	100 10 mm
Nominal orbit	GEO

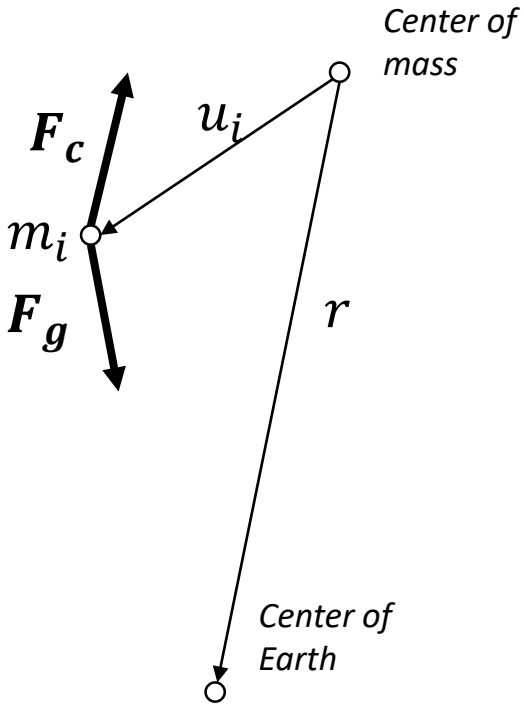
Assembly Error and Vibration Analysis

Disturbance	Minimum fundamental frequency [Hz]
Reaction wheels	0.1
Random disturbances with 0-100 Hz bandwidth and amplitude	0.459
Settling time < 3 min	0.69

Assembly Error level [mm]	10	1	0.1
RMS Total Distortion [mm]	9.73	0.96	0.12
Max Total Distortion [mm]	57.10	5.63	0.71

Gravity Gradient Analysis





$$\boldsymbol{F_c} = centrifugal\ force = \frac{\mu m_i \boldsymbol{r}}{||\boldsymbol{r}||^3}$$

$$\boldsymbol{F_g} = gravitational\ force = \frac{\mu m_i (\boldsymbol{r} - \boldsymbol{u_i})}{||\boldsymbol{r} - \boldsymbol{u_i}||^3}$$

$$\delta_{max} = 45\ \text{nm}$$