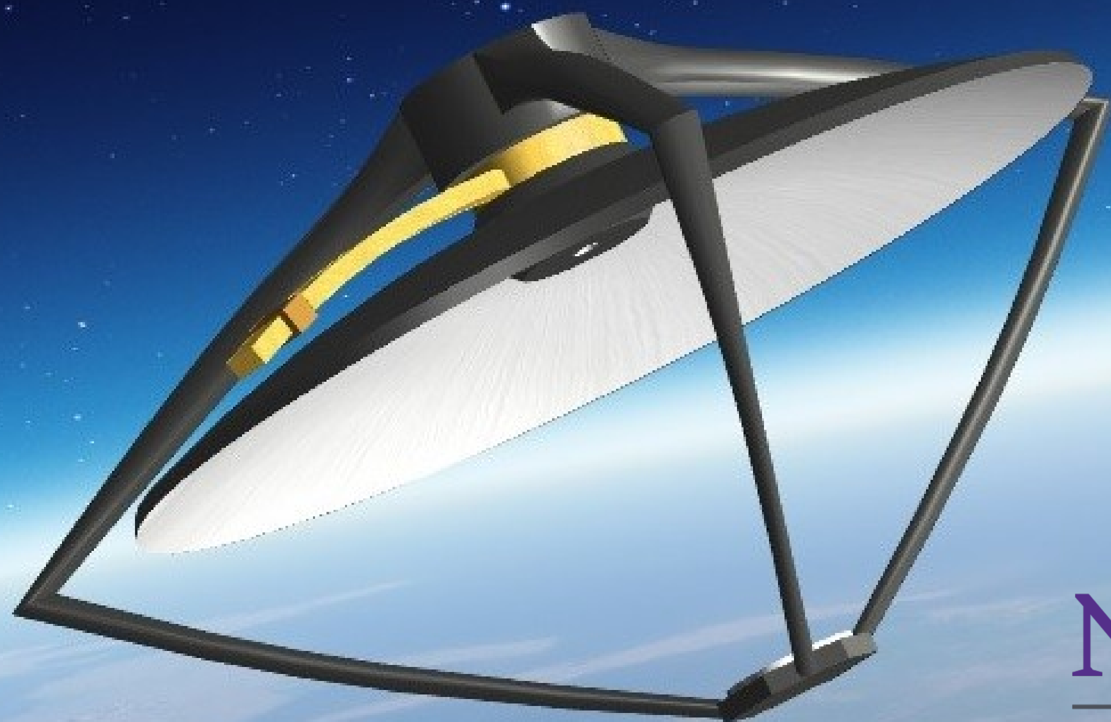
DOMinATE a Deployable Optical MembrAne TElescope



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CENTER FOR INTERDISCIPLINARY EXPLORATION AND RESEARCH IN ASTROPHYSICS

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Bigger is Better

Angular resolution: $\theta = 1.22\ \lambda/D$

Spatial resolution is proportional to the angular resolution

Sensitivity is proportional to the collecting area, which is proportional to the radius squared

Time resolution is proportional to the sensitivity

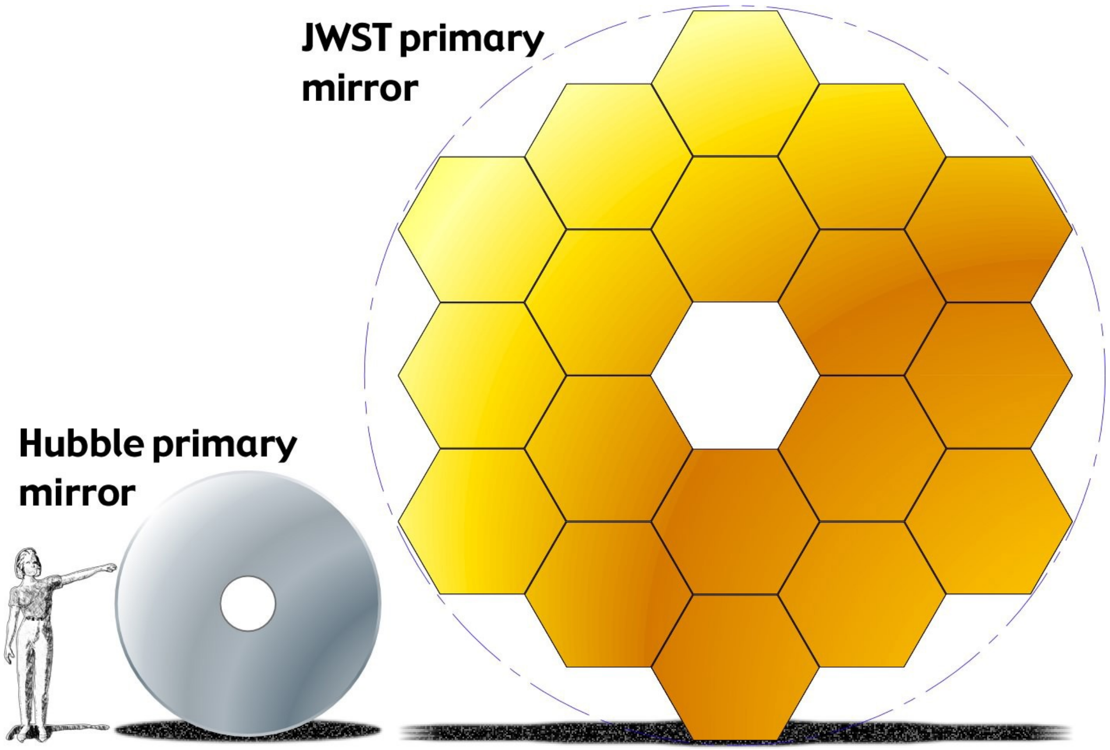
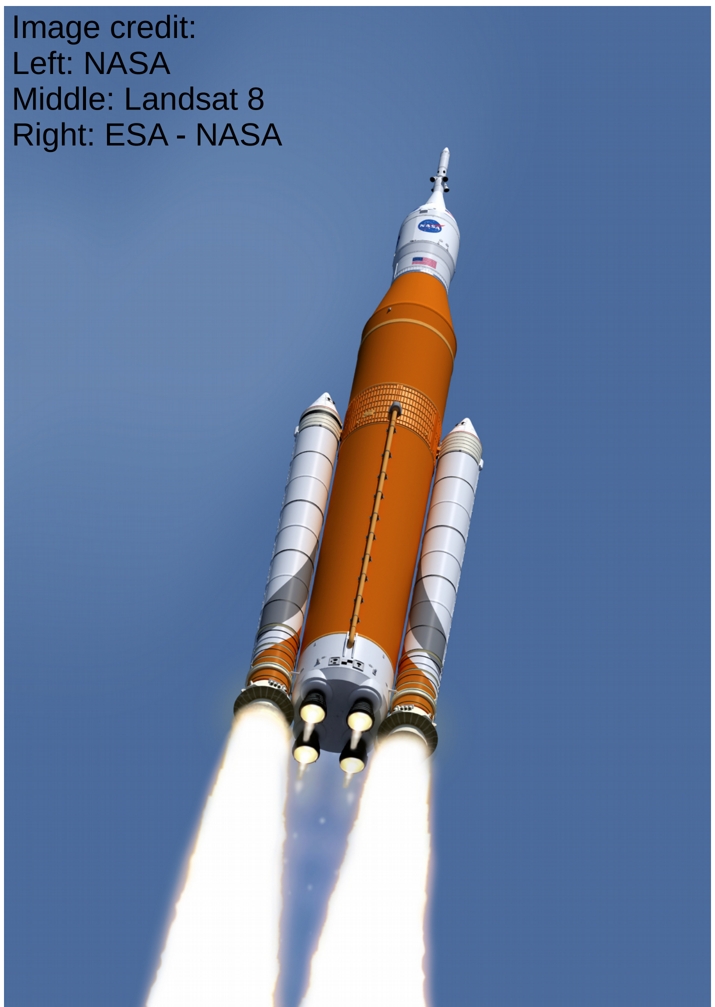


Image from NASA

Bigger is Bigger, Heavier, More Expensive and Takes Longer

	Payload fairing (m)	Cost (M$)
Ariane 5:	4.57 x 16.19	~165-220
Falcon 9:	5.2 x 13.1	~62
Falcon Heavy:	5.2 x 13.1	~90
SLS:	~8.4 x 31	~500

	HST	JWST
Mirror diameter (m):	2.4	6.5
Launch weight (kg):	11,110	6,500
Cost (billion $):	~4.7	~8.8
Development (years):	~20	~20



Advantages of Membrane Mirrors

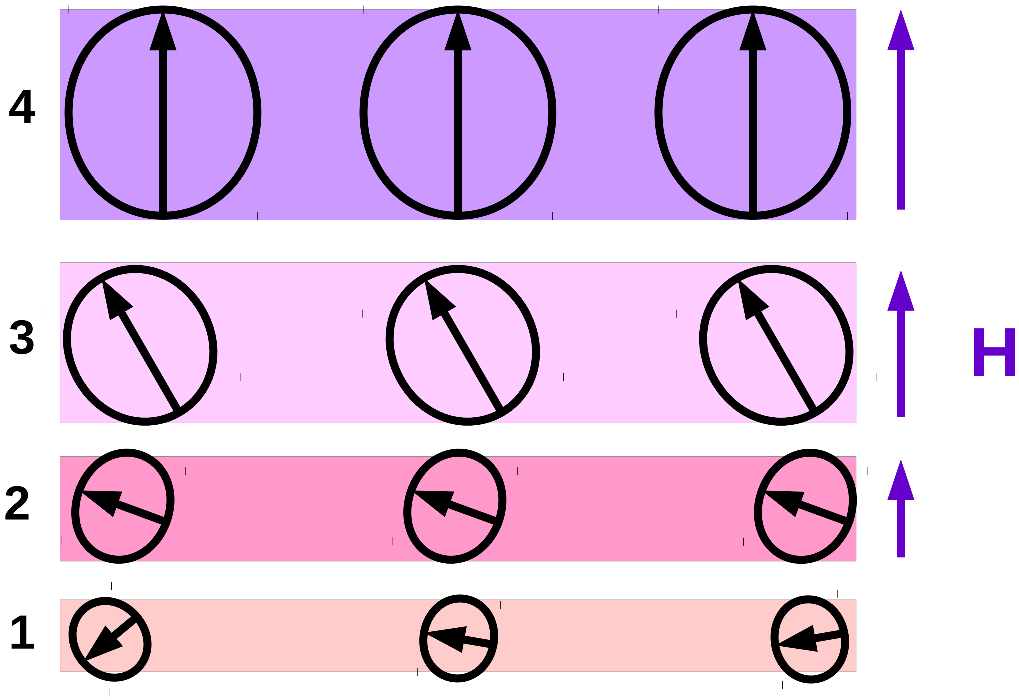
	Payload Weight (kg)
Ariane 5:	6,100 – 20,000
Falcon 9:	4,850 – 23,800
Falcon Heavy:	~26,700 – 63,800
SLS:	~70,000 – 130,000

Image credit:
Top and bottom: NASA

Membrane Mirrors

- Limited success at microwave frequencies (Hz)
- For optical a RMS figure error of 10s of nm is required
- RMS figure error ~100s of μm

Magnetostriction & Magnetic Smart Materials (MSMs)



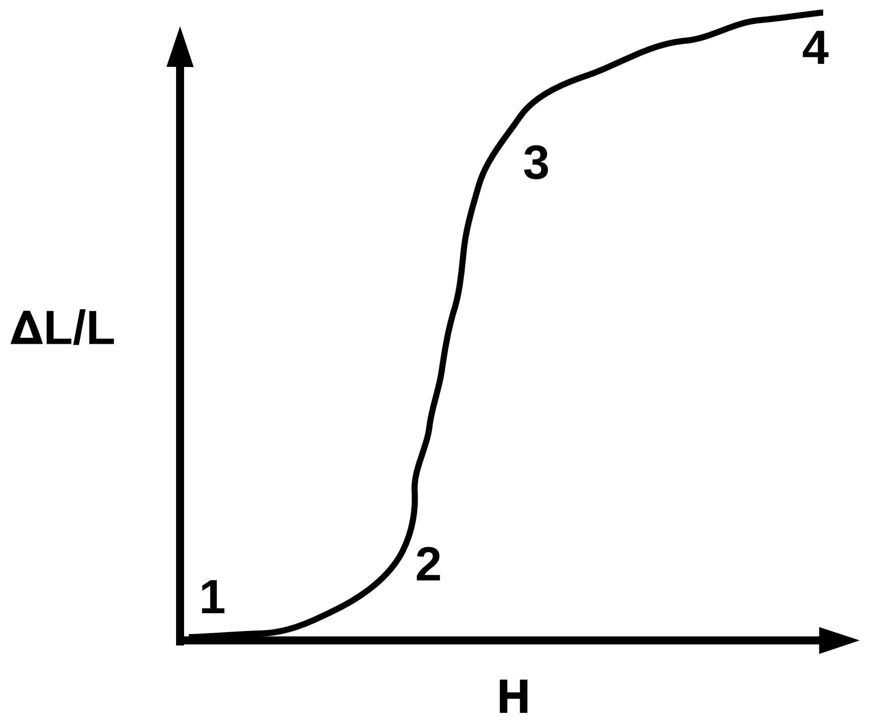
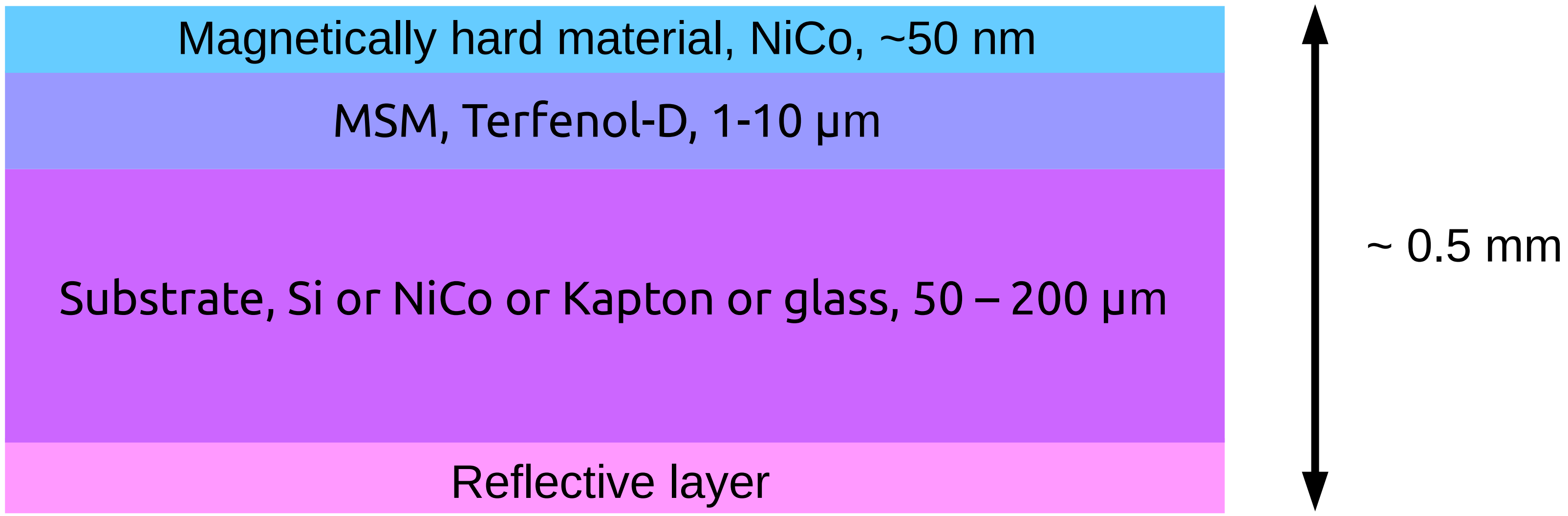


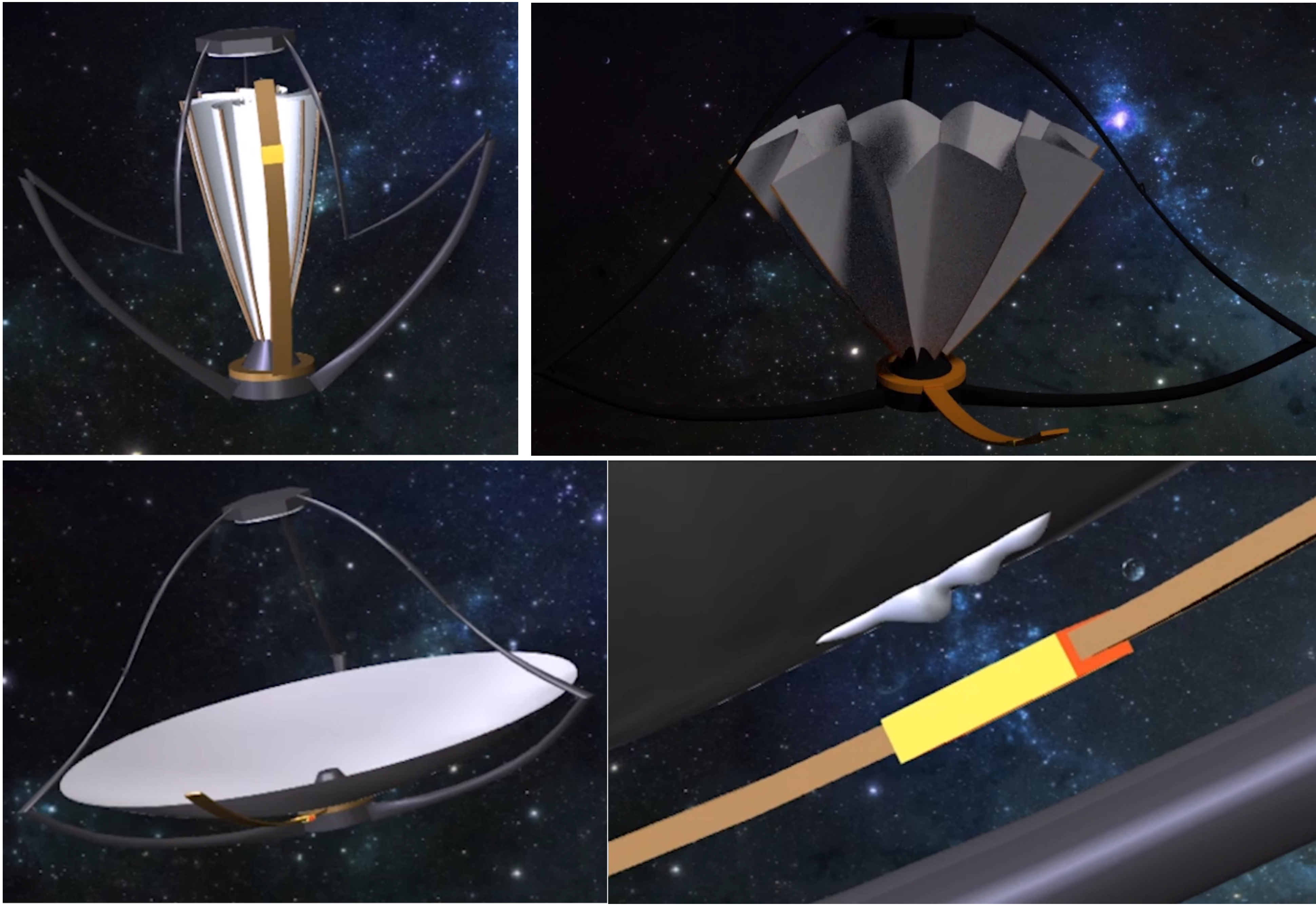
Image adapted form Olabi, A.G., and Grunwald, A., 2008, Materials & Design, 29, 469

Our Concept



1) Fold the mirror for launch
2) Mechanically deployed the mirror
3) Mobile electromagnets apply an external magnetic field
4) The MSM layer expands or contracts
5) A controlled shape change in the reflecting surface
6) The deformation is maintained by the magnetically hard material

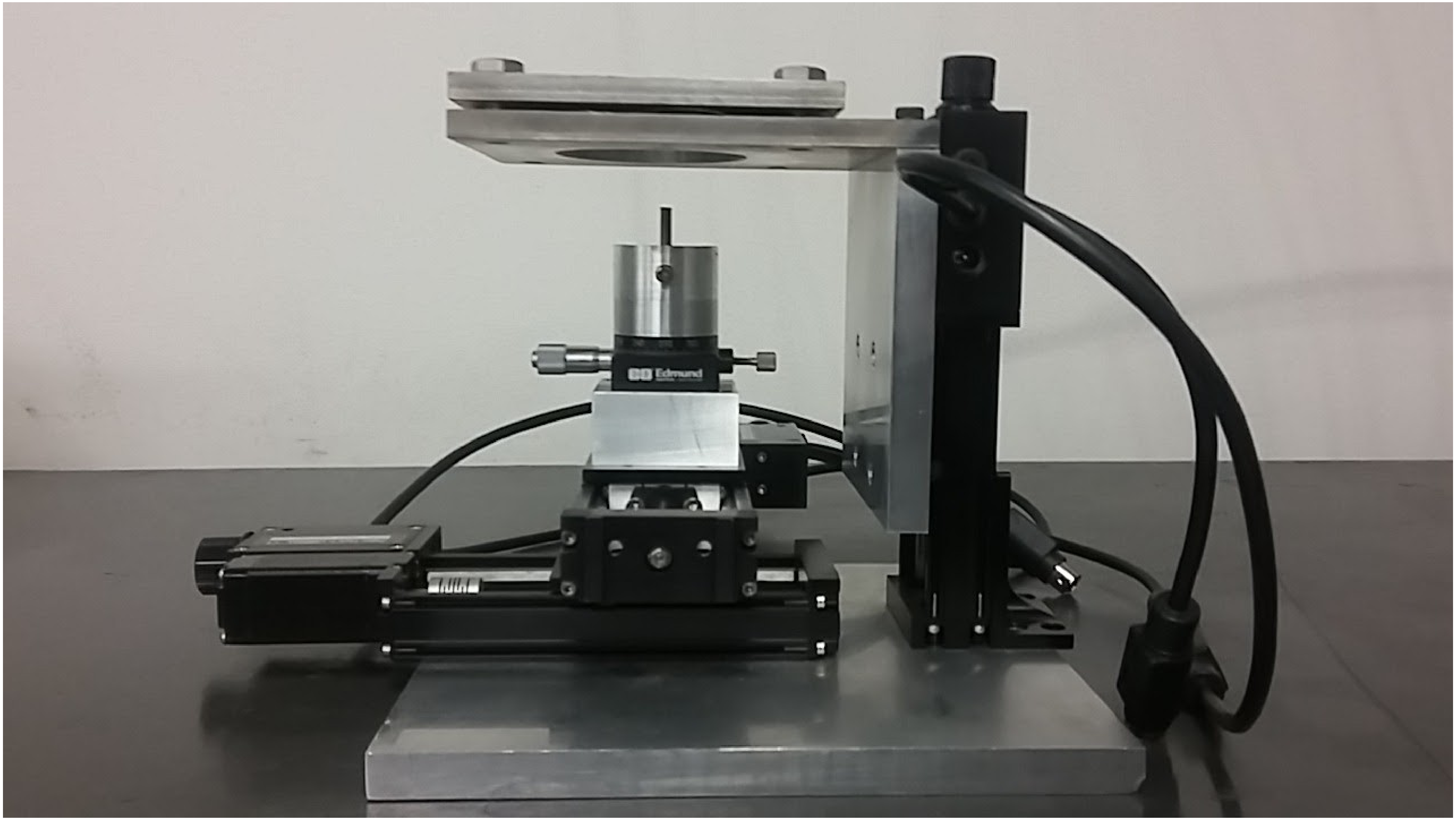
Our Concept



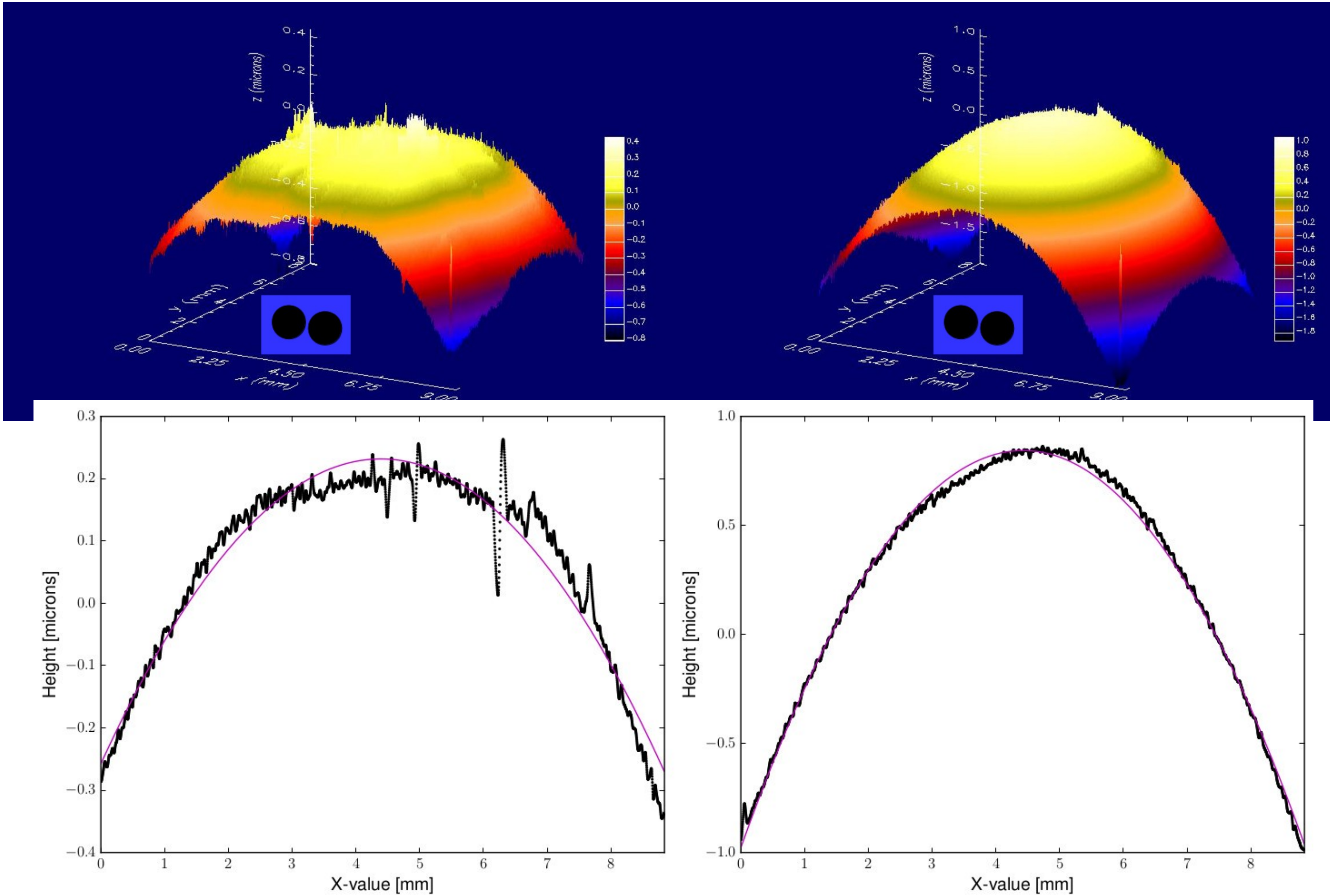
Comparison with Current Technology

Piezo-electric and Electrostatic Actuators	MSM + Electromagnets
Actuators are deposited on the backside of the mirror	Non-contact application of an external magnetic field
The number of actuators becomes unfeasibly large	A few electromagnets
Active control, fixed wires and constant power are required	Does not require active control
A deformation can only be generated at the location of an actuator	A deformation can be generated at any position

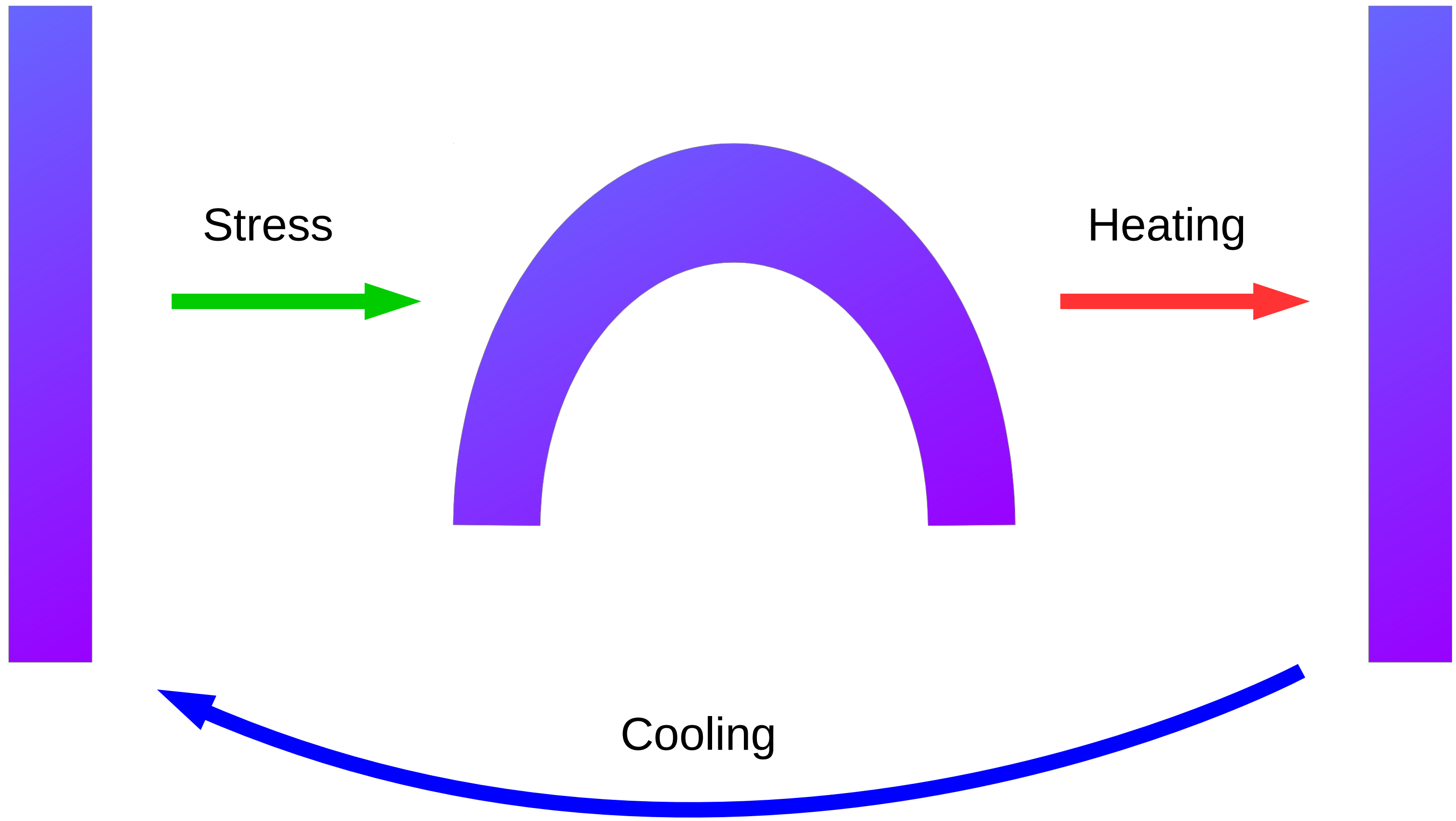
Generating a Deformation



Generating a Deformation



Shape Memory Alloys (SMAs)



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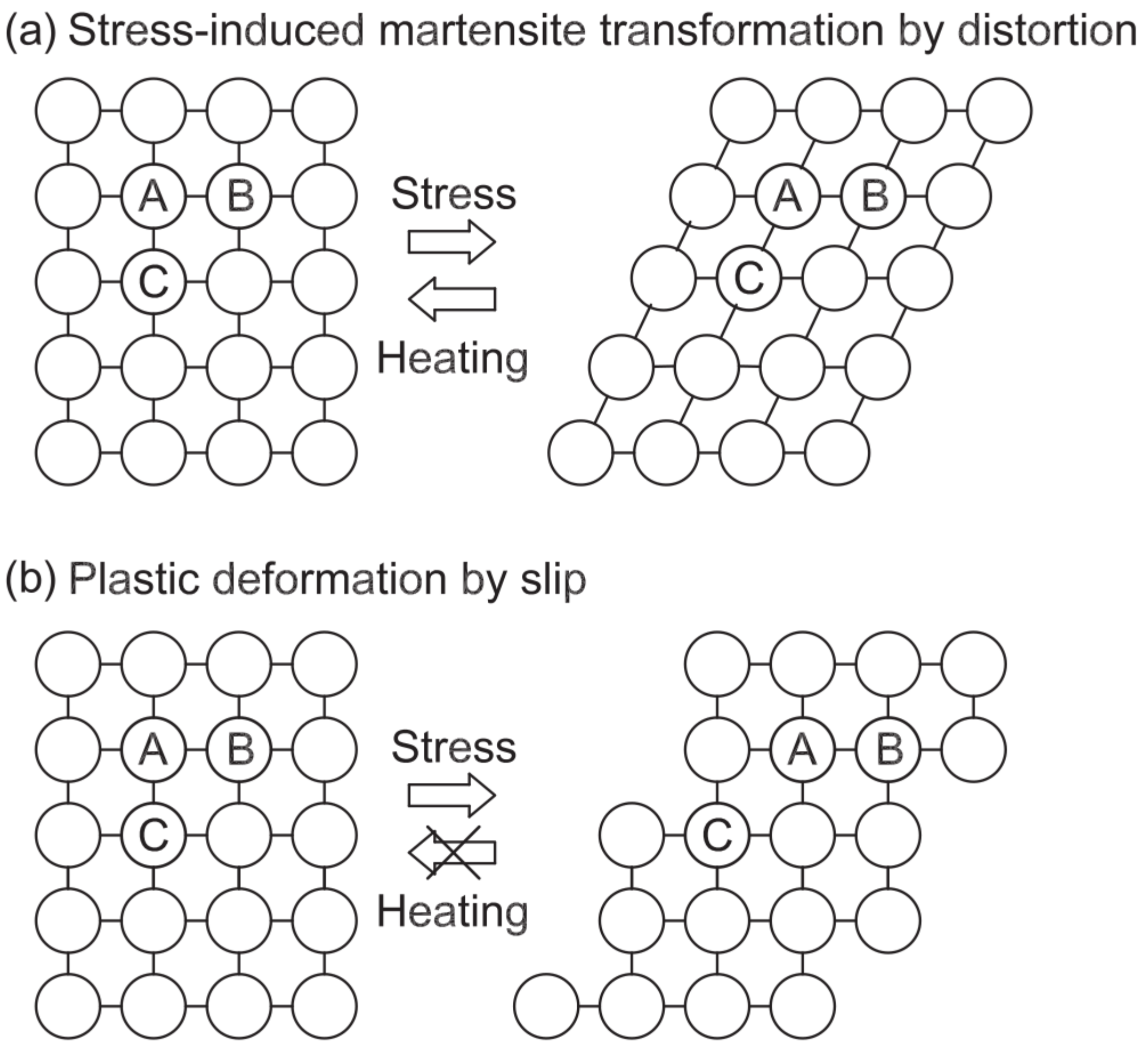


Image from Cladera, A., et. al., 2014, construction and Building Materials, 63, 281

- Low symmetry martensite phase

- High symmetry austenite phase

- Martensite ↔ austenite = cooling ↔ heating

- Austenite: single variant crystal structure

- NiTi martensite: 24 crystal structures

- Martensite takes on the variant structure that allows the maximum strain (ΔL/L) for the given stress

- Strains of 6-8%

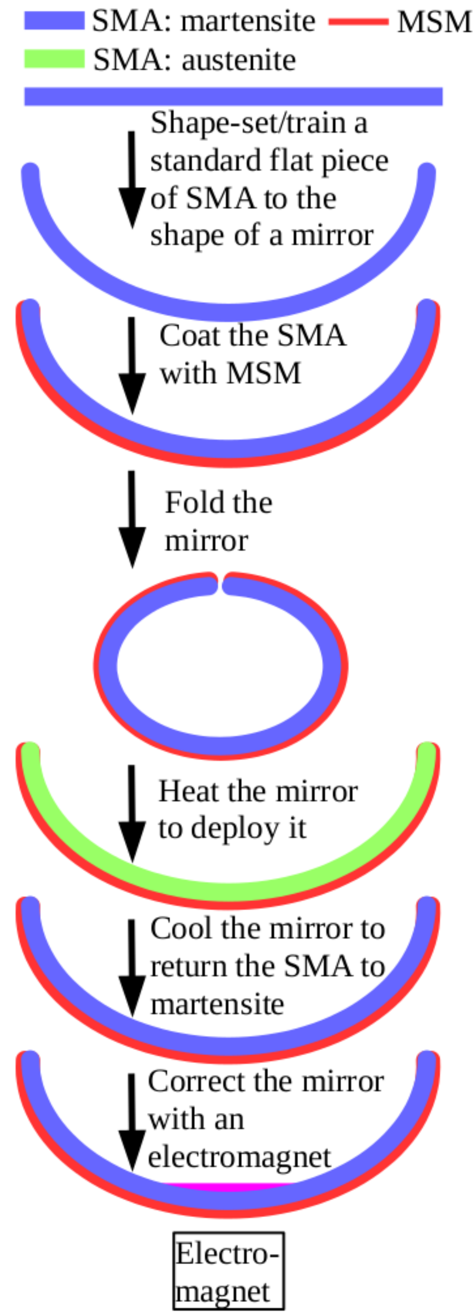
The Advantages/Disadvantages of SMAs

Advantages

- No magnetically hard material → larger deformations
- A deformation can be erased by local heating
- Membranes are floppy SMAs are not
- Austenite can be shape-set

Disadvantages

- Accuracy to which austenite can be shape-set
- Shape-set austenite cannot be heated beyond ~300℃
- RMS surface roughness of SMAs



Conclusion

Aim

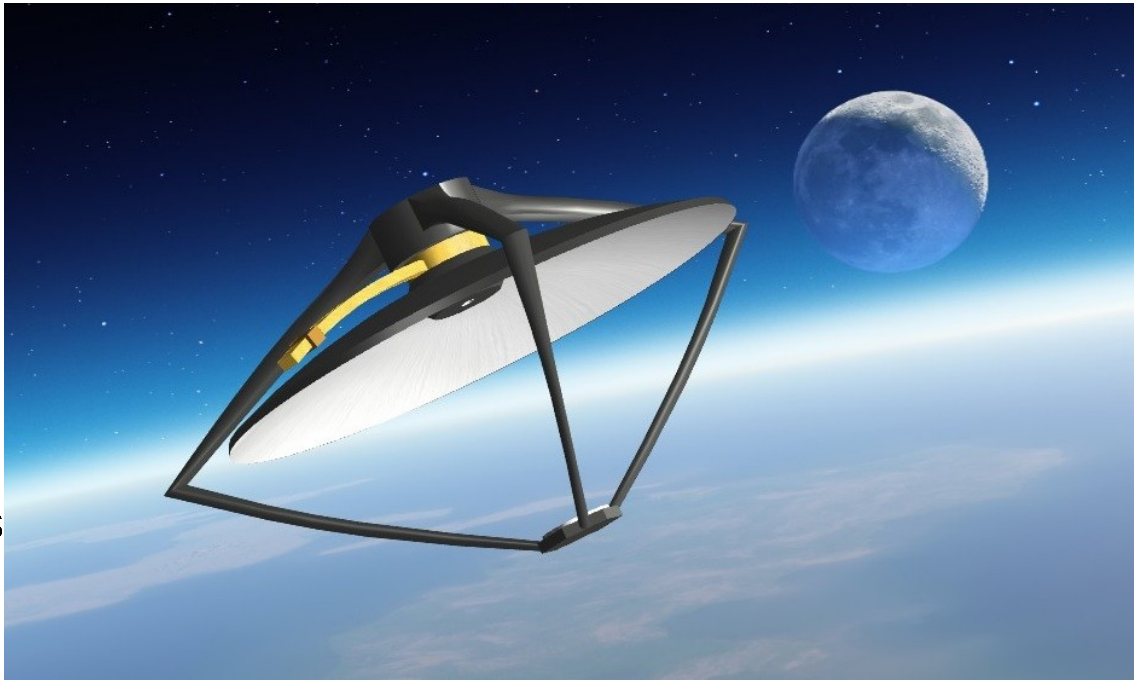
- Foldable membrane mirrors
- Increase satellite apertures
- Increase satellite resolution and sensitivity

Status

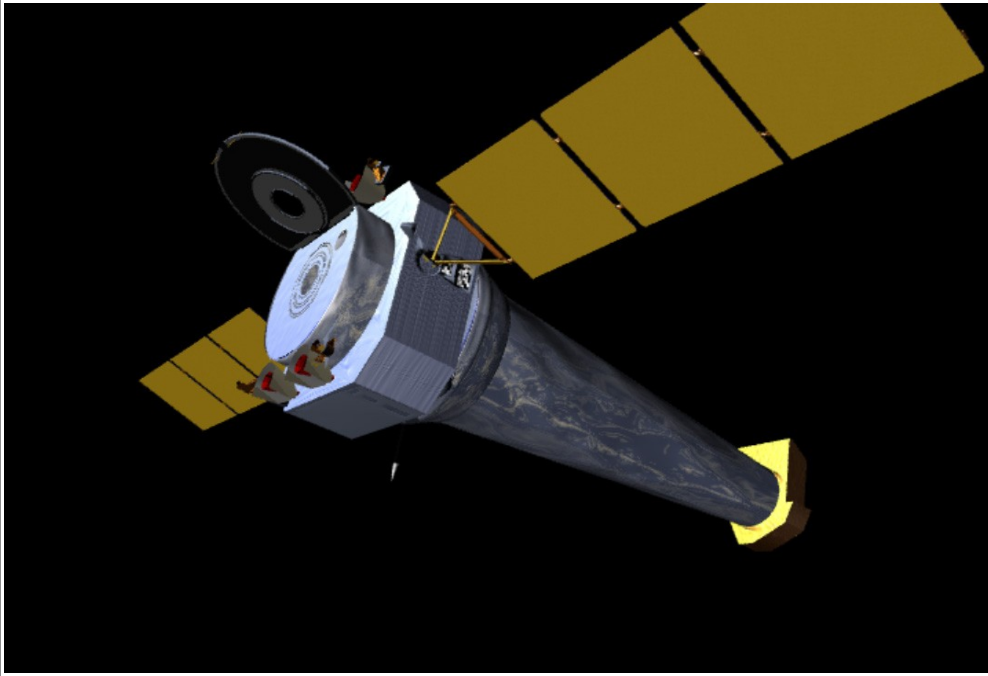
- Deformations in four substrates
- Deformations up to 1.5 μm
- Deformation that is stable for 71h

Future Work

- Optimize parameters e.g. thickness of the MSM
- Noise and thermal effects
- Control (deformation & figure)
- Substrates: shape memory alloys



Additional Slides: Other Applications



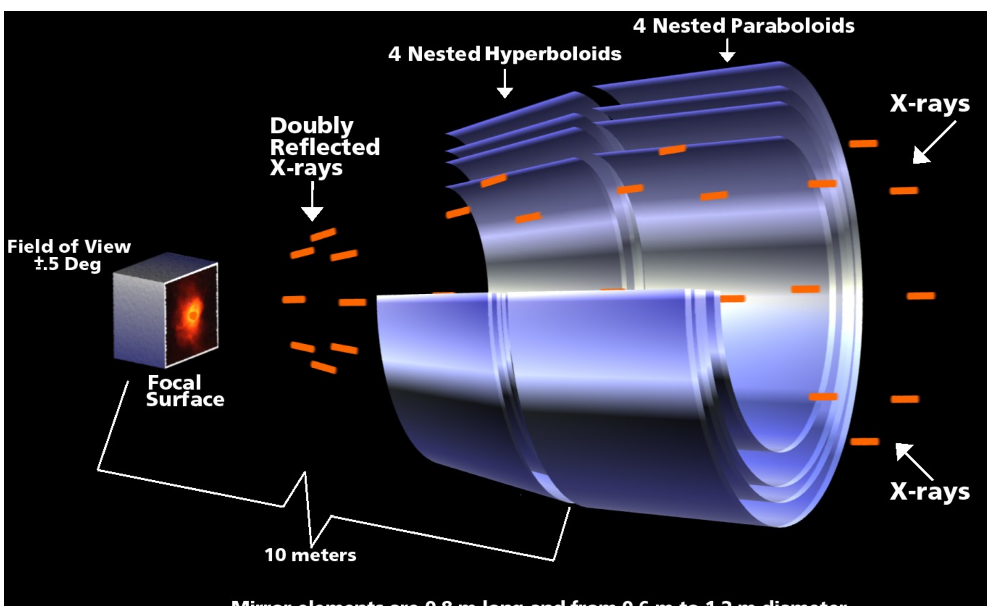


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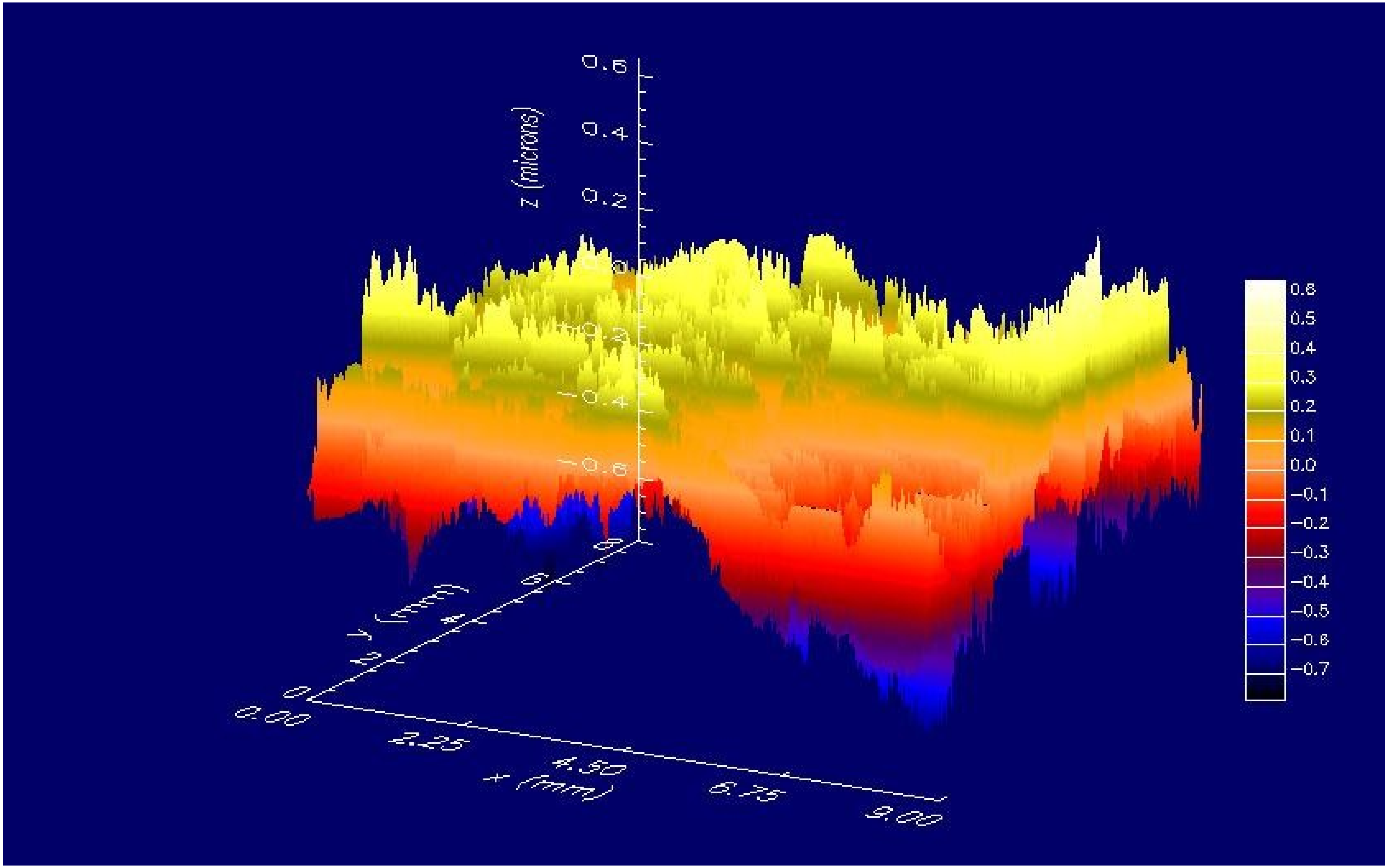
Image credit:
Top and bottom left: NASA
Right: Argonne National Laboratory

Additional Slides: The Road Ahead

1) Deformation stability: substrate/noise



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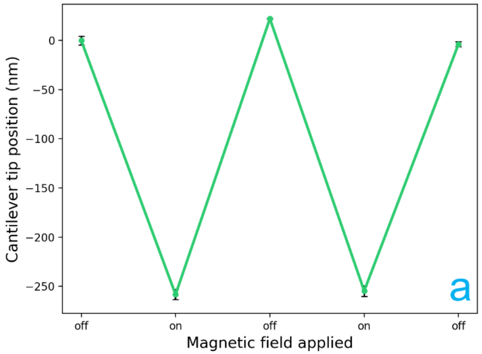
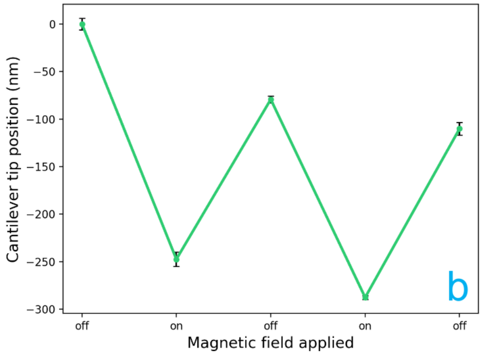
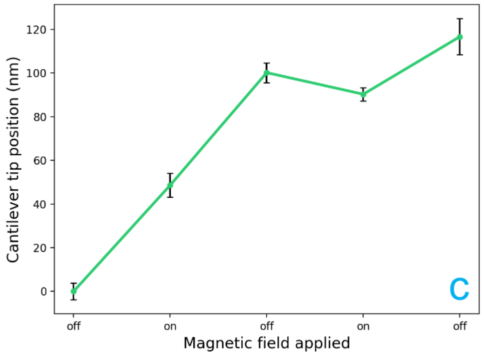
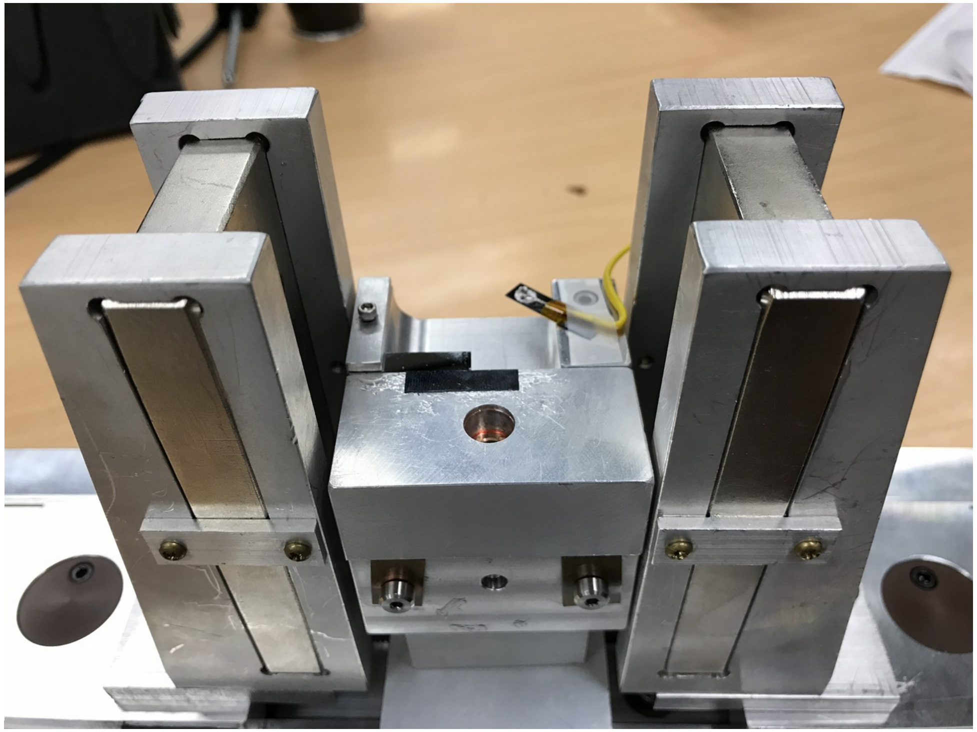
1) Deformation stability: substrate/noise

2) Not all samples show a response









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1) Deformation stability: substrate/noise

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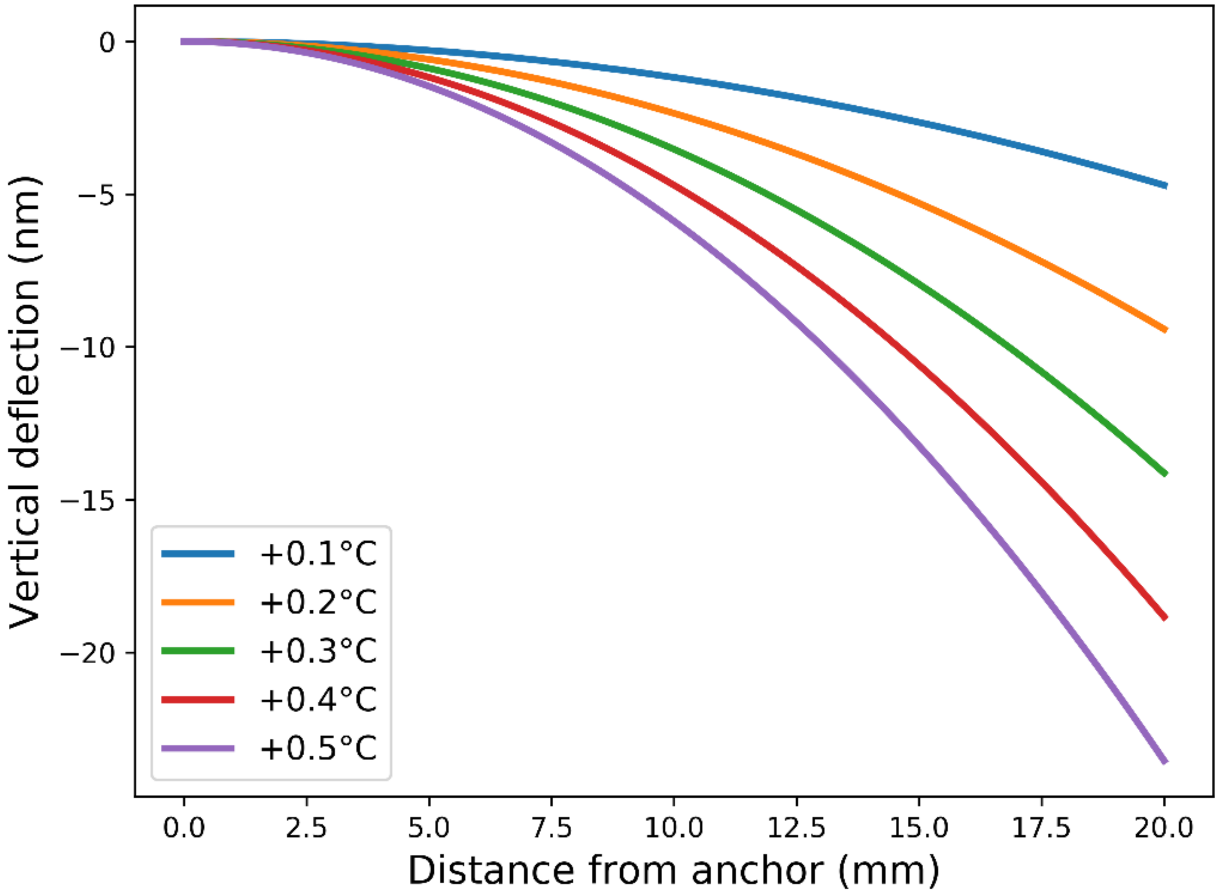
3) Understand and eliminate thermal effects



Additional Slides: The Road Ahead

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3) Understand and eliminate thermal effects

4) Optimize
   - Thickness of the MSM
   - Thickness of the magnetically hard material
   - Annealing: Terfenol-D crystal structure and response plane
   - Magnetic field strength

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7) Figure control