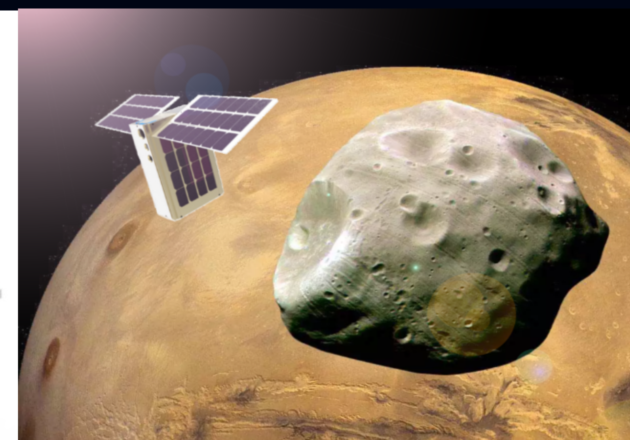
Use of Shape Memory Alloy Actuators for Precise Pointing on Interplanetary Small Satellites and CubeSats



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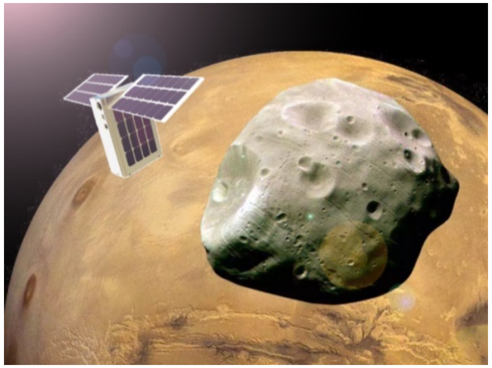
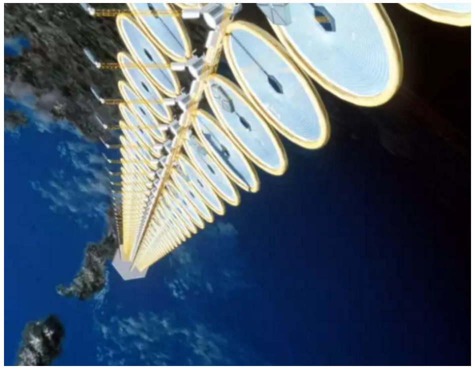
Outline

- Motivation
- Challenges
- Actuator Design
- Prototype Experiments
- Discussion
- Conclusions

Motivation

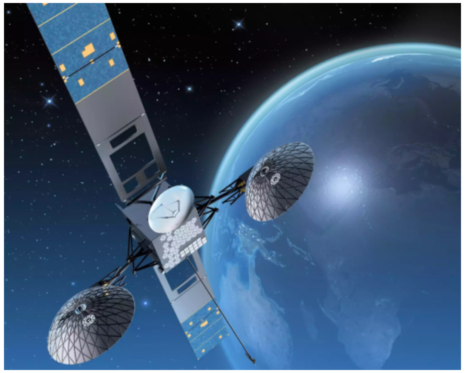


Low-cost Exploration



Space Power

Exo-planet Observation



Interplanetary Communications

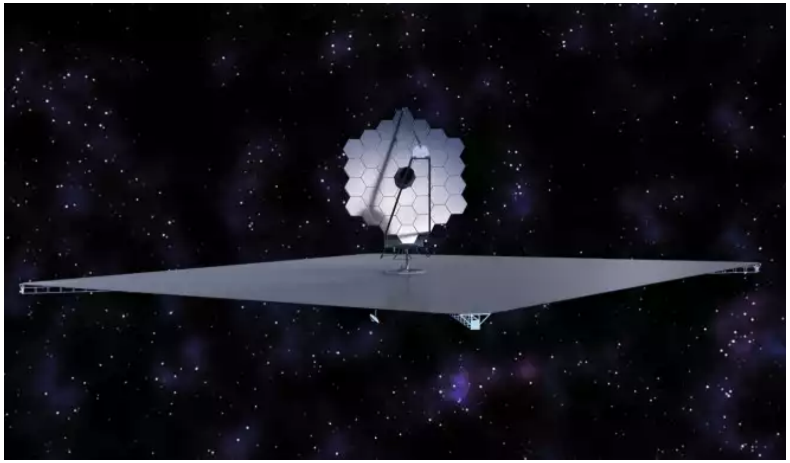
- New and emerging technology areas that may have transformative impact

Precise pointing critical/enabling for these applications

Next Generation Space Telescopes

- Exoplanet search, finding Earth 2.0s
- To see further into our past
- Planetary science, asteroid observation

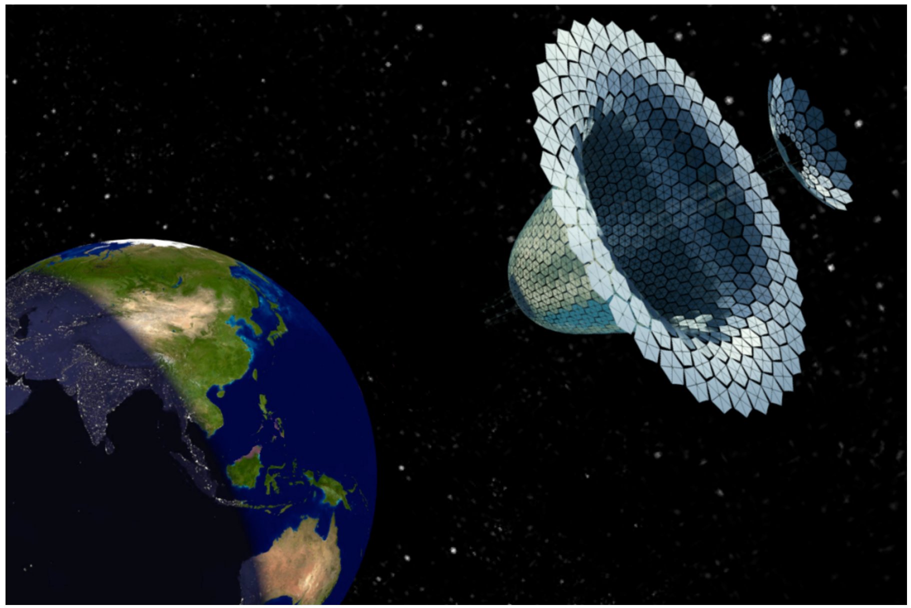
Alma Observatory



NASA Goddard LUVOIR

Rise of telescope arrays.

Massive Arrays



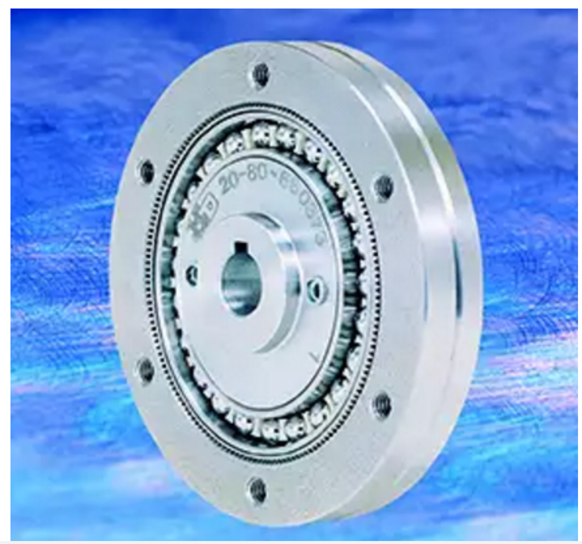
(NRL Concept, 2014)

- Applications spanning space power to astronomy, planetary science, earth observation, communications.

A big leap in capabilities, but with big challenges.

Reaction Wheels & Harmonic Drives

- The standard for precision pointing of spacecraft
- Proven track-record from space telescopes to outer-planetary missions.



Important challenges in using on them massive array.

The Challenges with Reaction Wheels

- Use of propellant for desaturation in deep space
- Major loss in functionality due to component failures
- Dry lubrication
- Relatively hard to manufacture
- Lacks scalability, extensibility
- Precision pointing and large → limited life

Piezo-electric Actuators

- Apply electrical current to excite piezo-electric crystal resulting in contraction.
- Proposed for corrective pointing of CubeSat exo-planet telescopes, JPL/MIT Asteria.

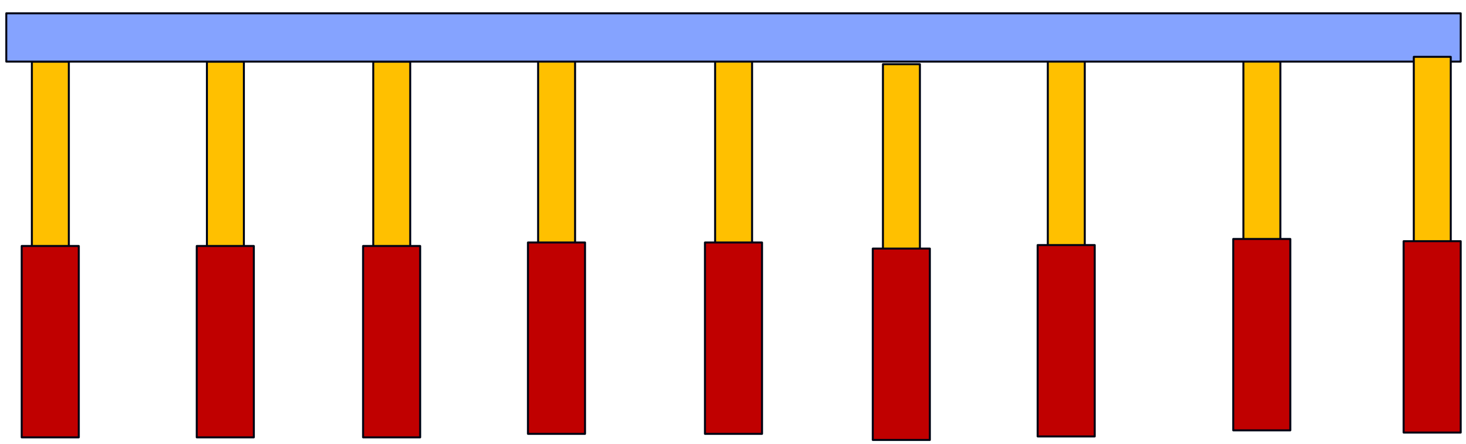
(Smith et al., 2016), (Seager et al., 2012)

Our Approach: Hyper-redundant Methods for Pointing

(Bilton & Dubowsky, 2012), (Sonawane & Thangavelautham, 2016)

- **Arrays of linear actuators used to 'shape' telescope mirror in space.**

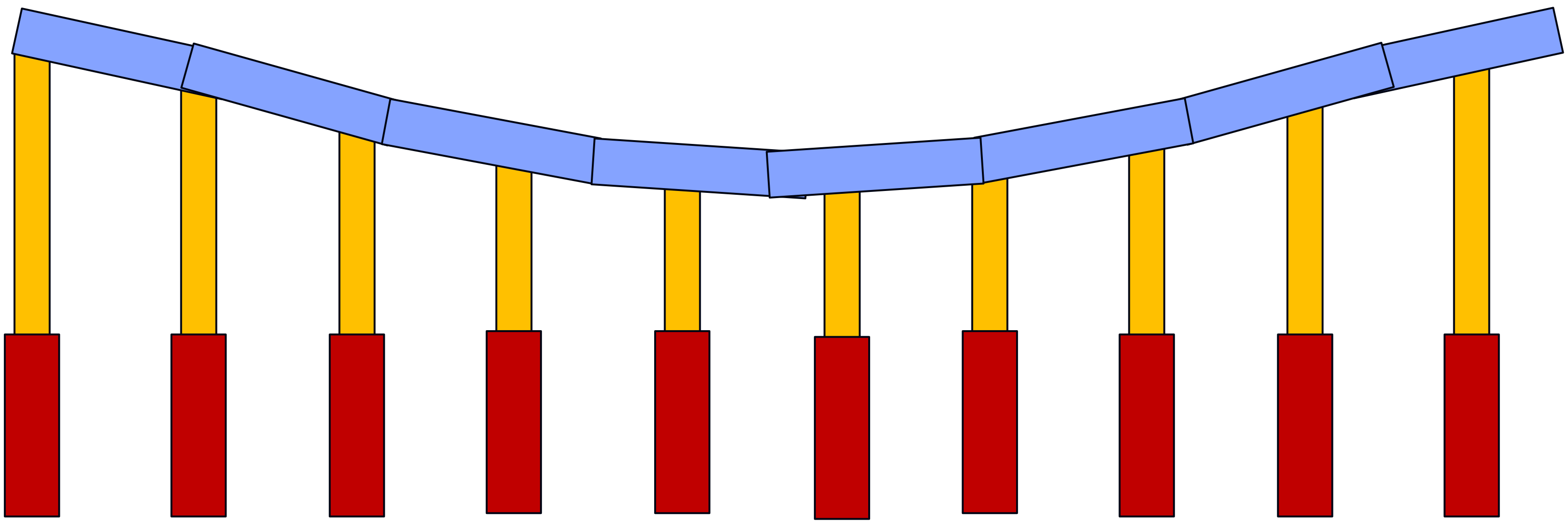
Mirror Module



Our Approach: Hyper-redundant Methods for Pointing

(Bilton & Dubowsky, 2012), (Sonawane & Thangavelautham, 2016)

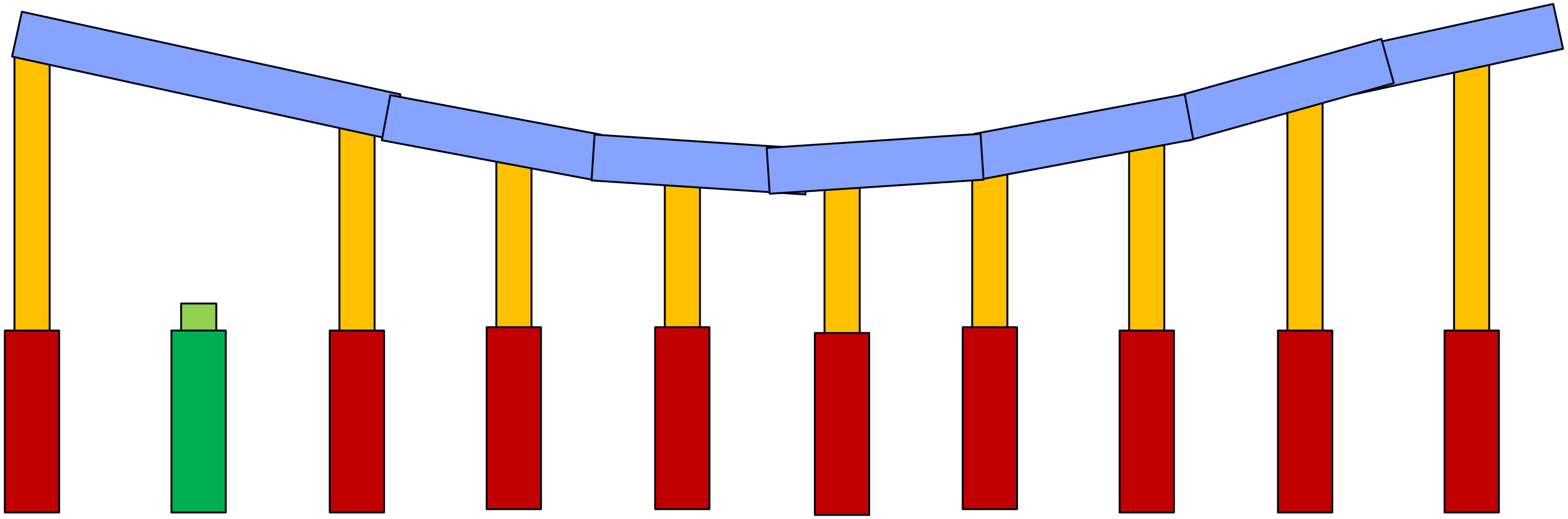
- Enables both redundancy and precision. One can be traded with the other.



Our Approach: Hyper-redundant Methods for Pointing

(Bilton & Dubowsky, 2012), (Sonawane & Thangavelautham, 2016)

- Even if one or a few actuators are damaged, the shape degrades gradually.



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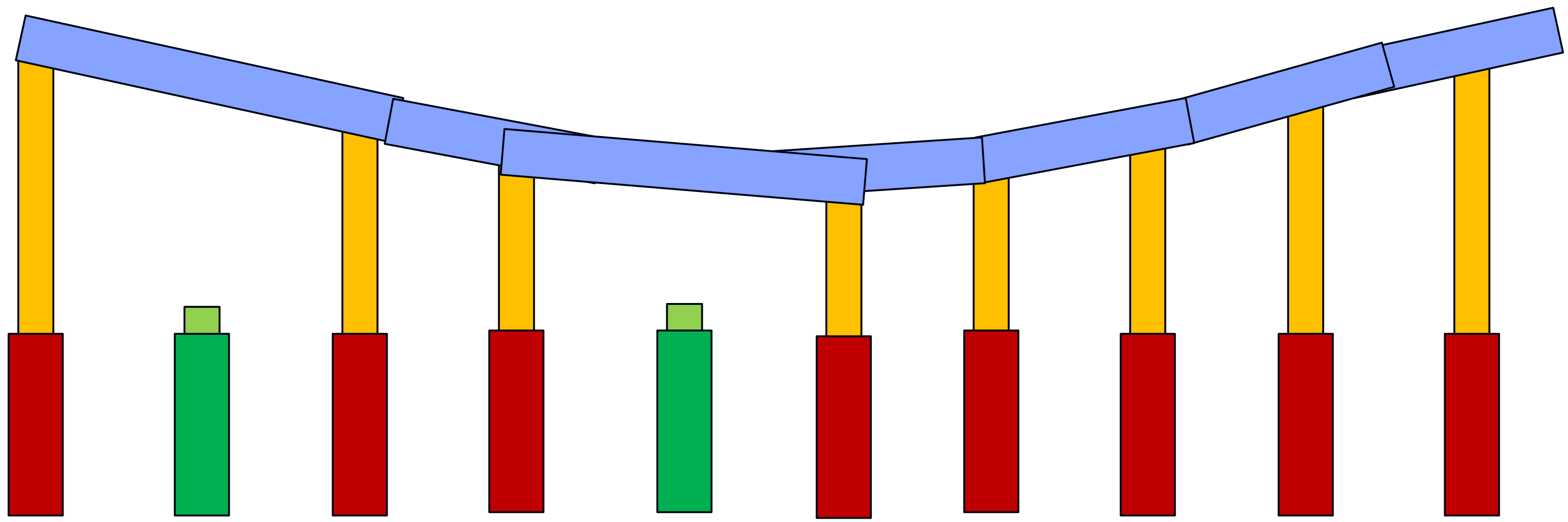
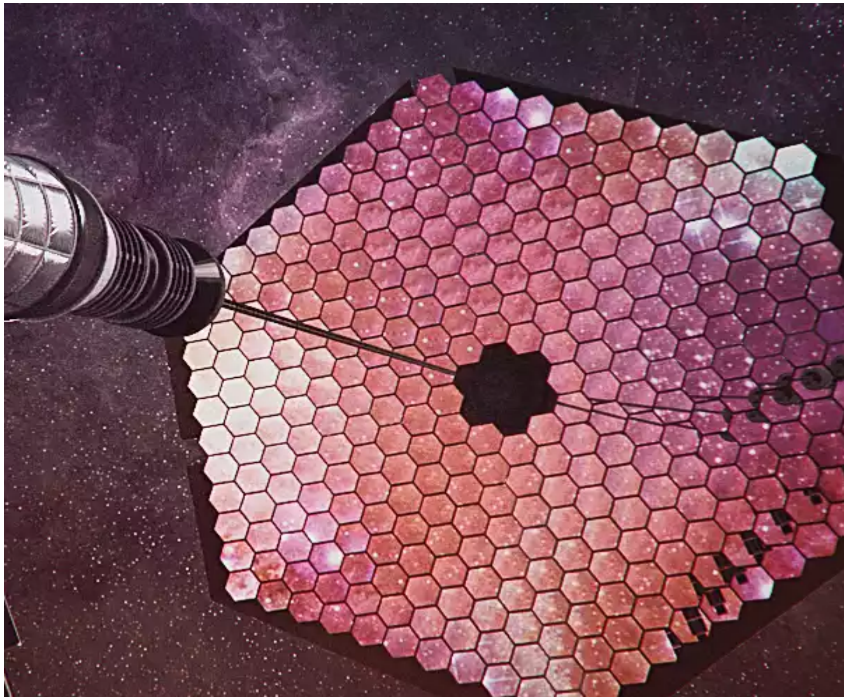


Our Approach: Hyper-redundant Methods for Pointing

(Bilton & Dubowsky, 2012), (Sonawane & Thangavelautham, 2016)

- Modular and scalable
- Decentralized control
- Extensible
- Resized on demand
- Graceful degradation



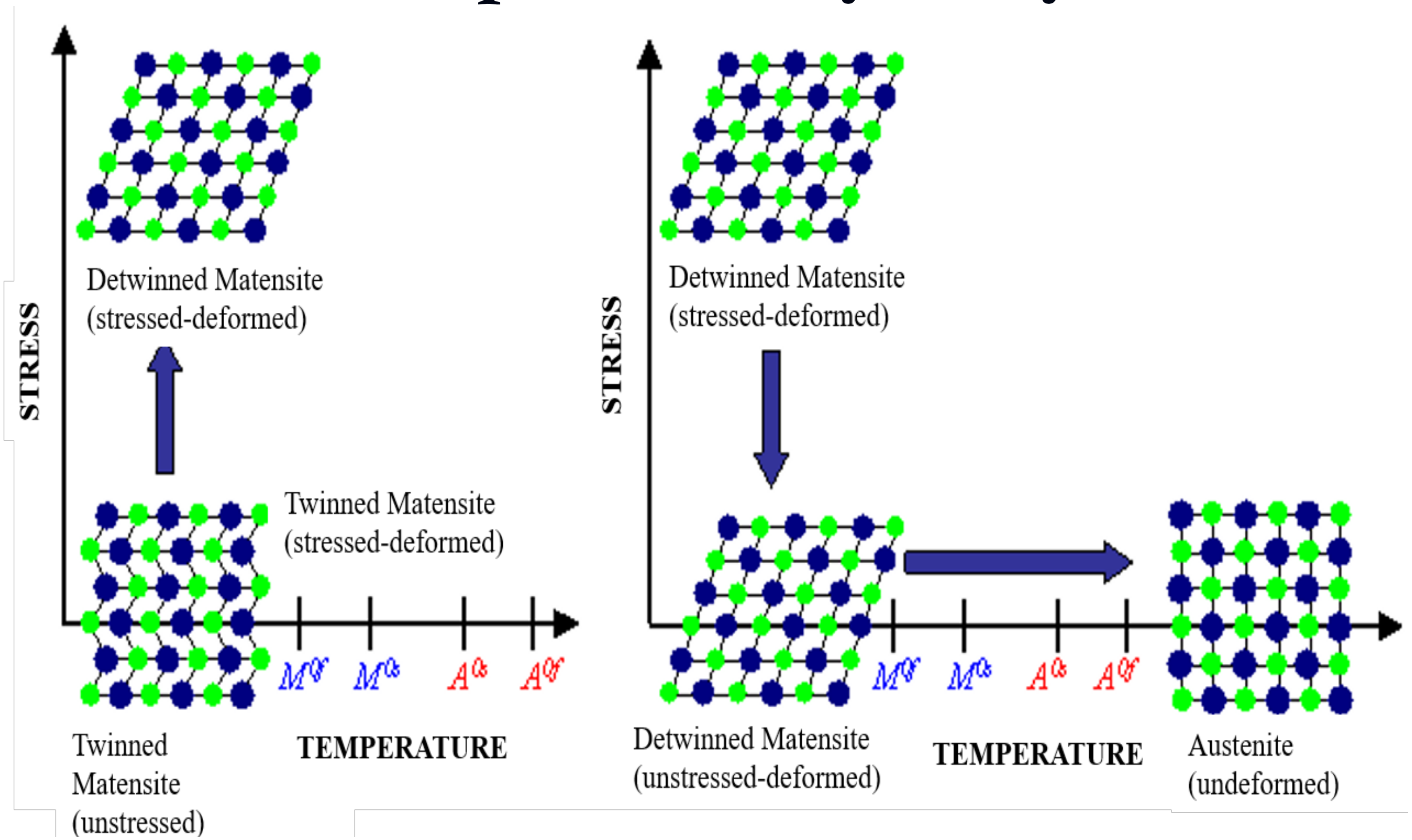
Actuator Needs

- Metal, solid-state
- Few components
- Reduced jitter or provide compensation
- Avoids lubrication, minimizes wear and tear
- Handle millions of cycles
- Achieve 1 arcsecond or less.
- Simple to assemble, low-cost
- Can be mass-produced

Shape Memory Alloys (SMAs)

- Alloys that can take on one of several crystalline states.
- State transition through change in temperature.
- States can be programmed/reprogrammed.
- Popularized as memory metal eye glasses

Shape Memory Alloys

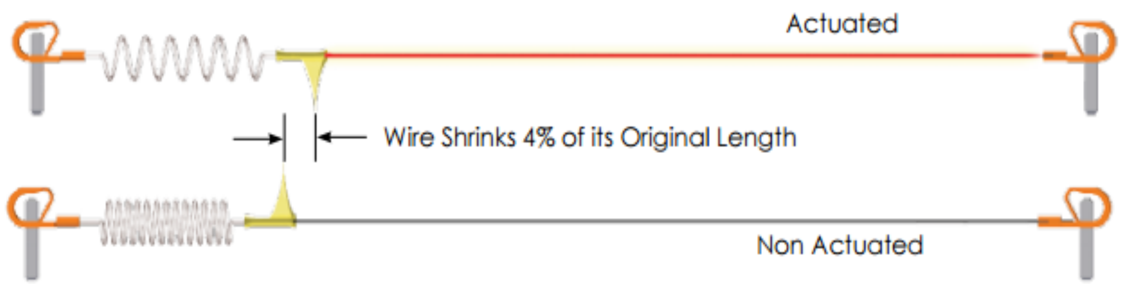


Shape Memory Effect

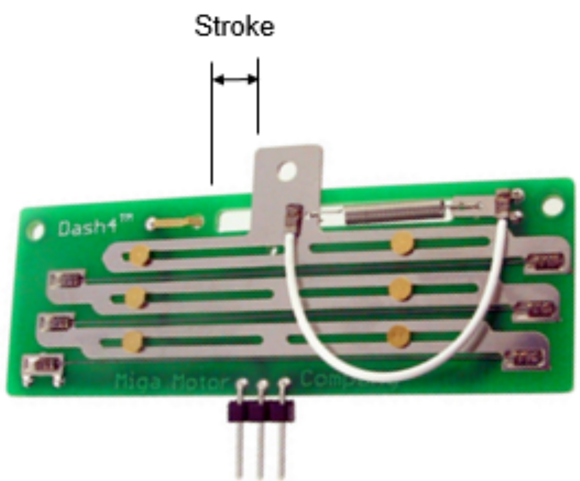
Current and Proposed Technology

	APM technology	Power	Mass	Cost	Specific work ratio	Operating temperature
Gimbal based 2 axis	Stepper motor	3.9 W	2.7 kg	high	low	-40 to 60 °C
Gimbal based 1 axis	Stepper motor	27.4 W	1.8 kg	high	low	-50 to 105 °C
KARMA5	stepper motor	25 W	10 kg	high	low	-75 to 170 °C
SADM	stepper motor	5 W	5 kg	high	low	-45 to 75 °C
Proposed APM	**SMA**	**4 W**	**0.5 kg**	**low**	**high**	**-100 to 200 °C**

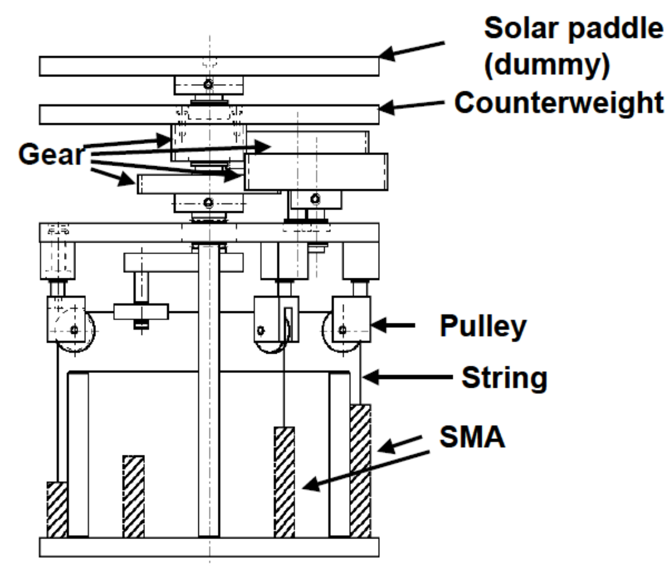
SMA based Linear actuators



Actuation of SMA wire

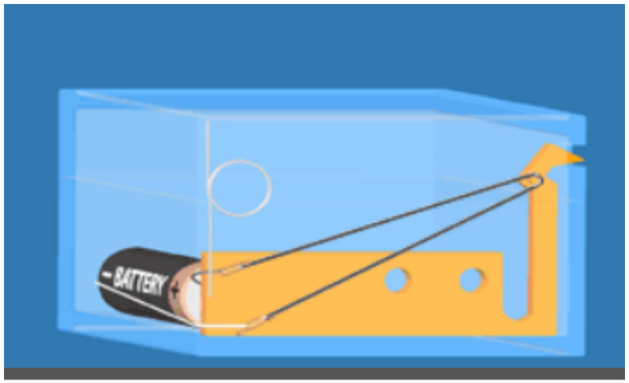


. MigaOneTM Linear actuator

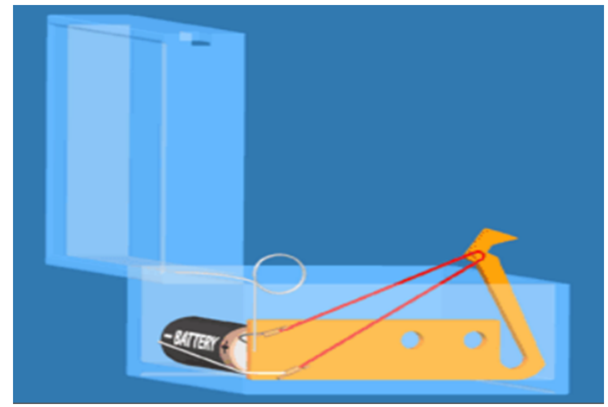


Solar Paddle Actuator

Latching Mechanism

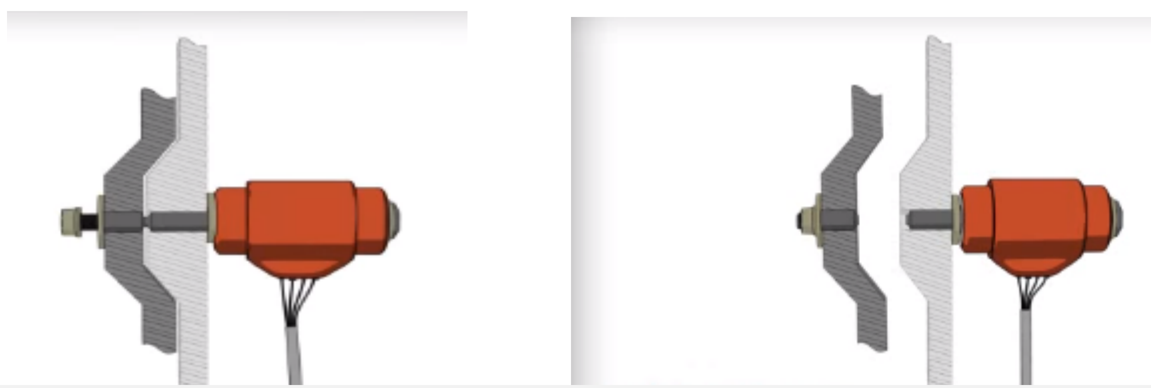


Extended position



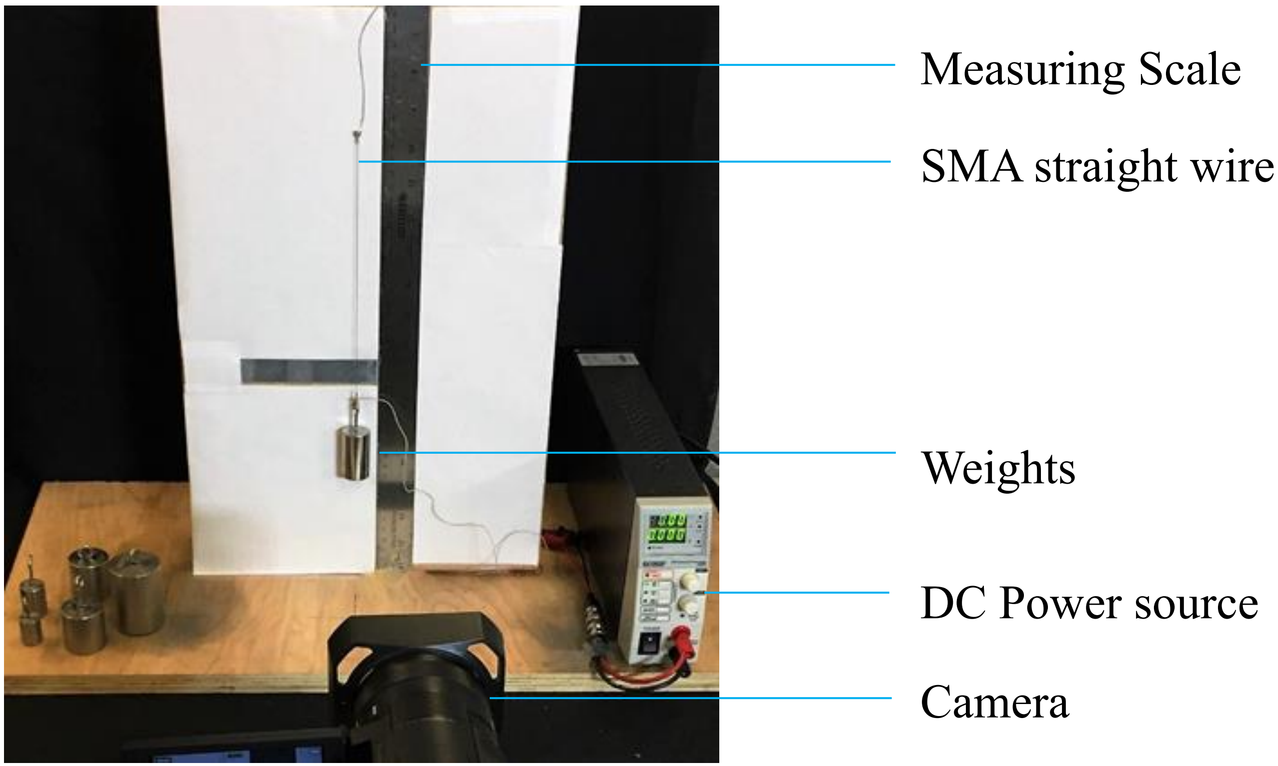
Contracted position)

Latching Bolt



SMAs already being used in space.

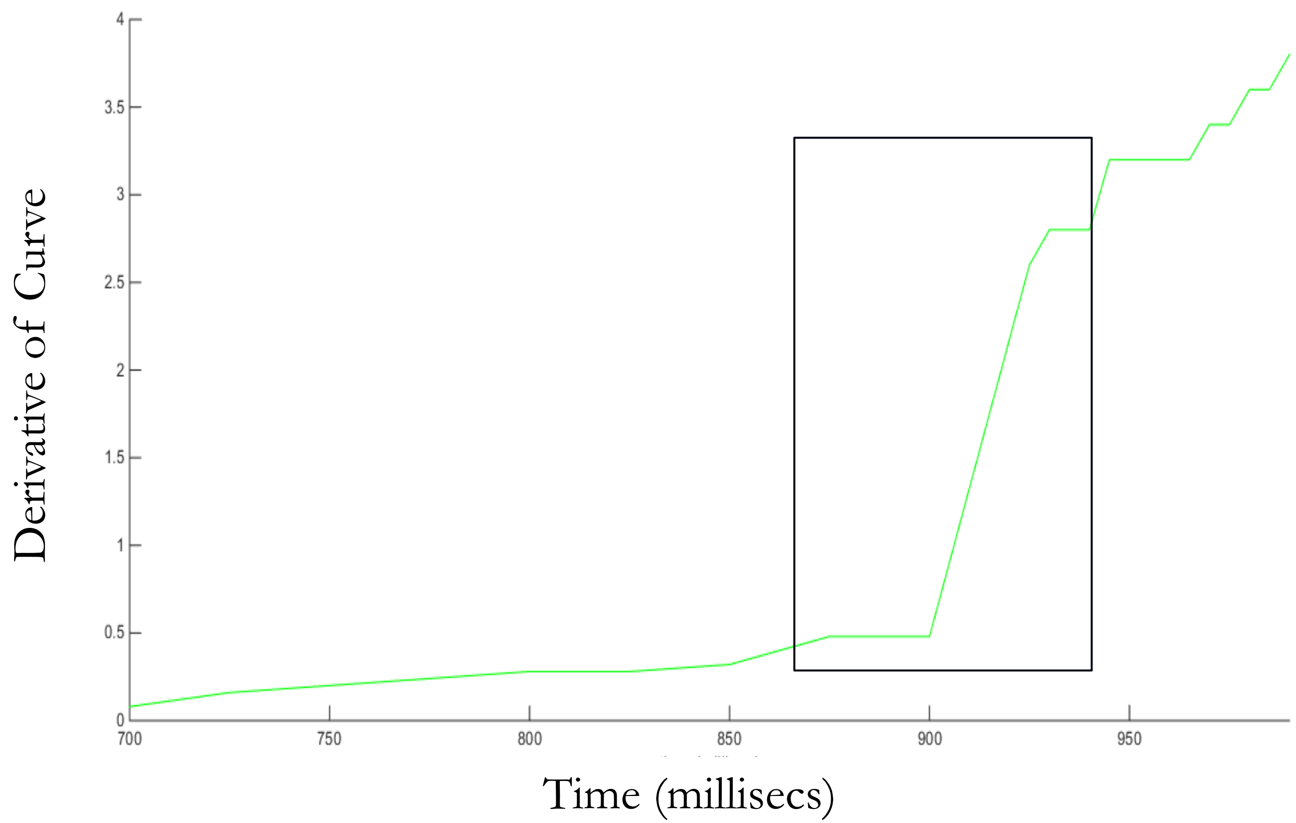
SMA Characterization



DC power source connected to resistor controls SMA

Performance Analysis

- **Heat from resistor, $I^2R(\Delta t)$ drives SMA expansion due to phase transition. Some stochasticity.**

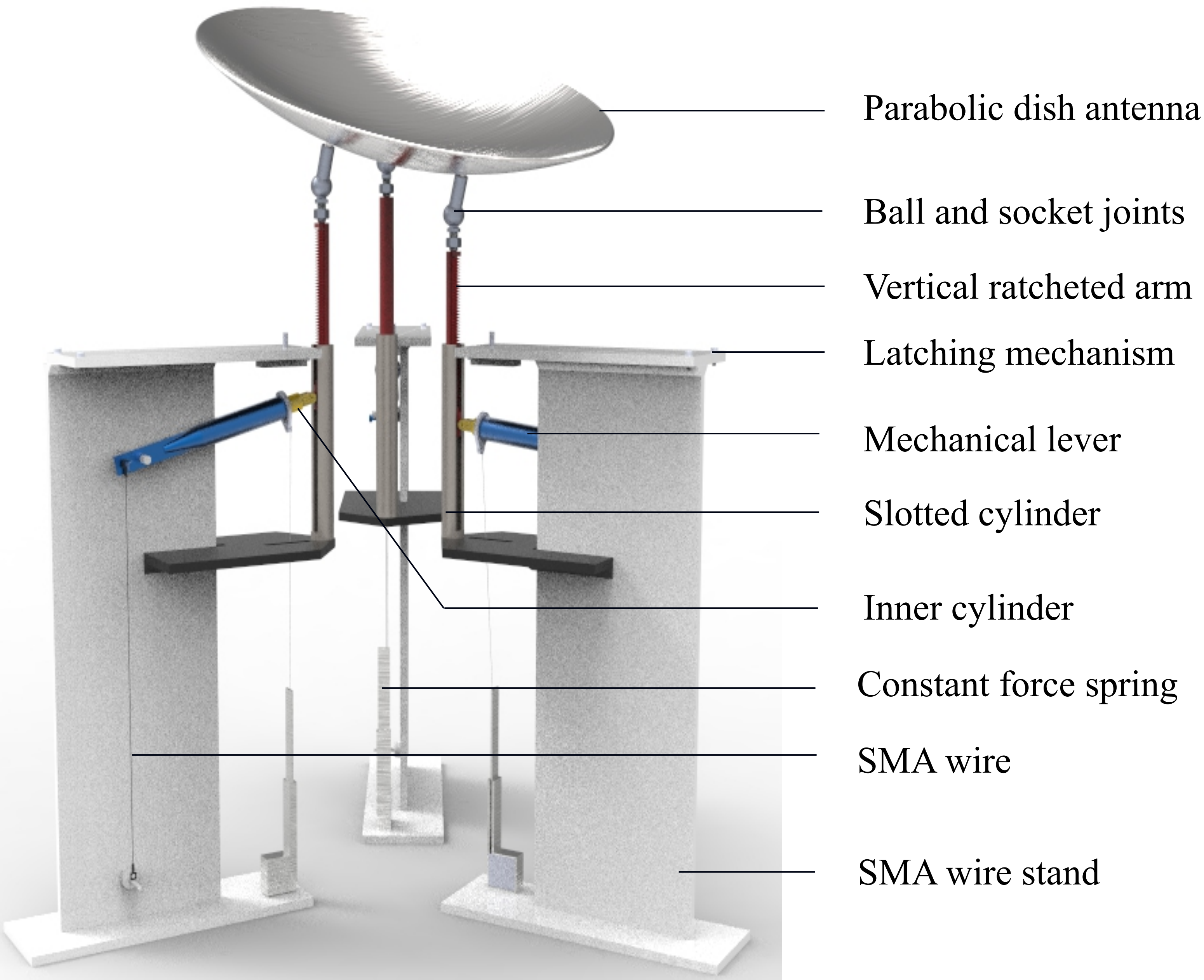


SMA Design Pathway

- Wire instead of springs – handles higher loads for less input power
- SMA wire extensions capped at 4% enabling a million cycle repeatability.
  - Greater extension, 5-8 % results in 1,000 cycles or less.
- Lever used to increase effective extension length
- Latching used to conserve power

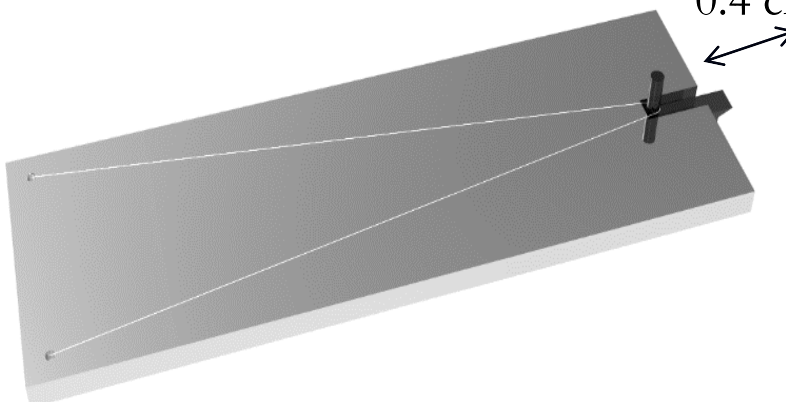
Design decisions to maximize life and reliability.

Prototype Design



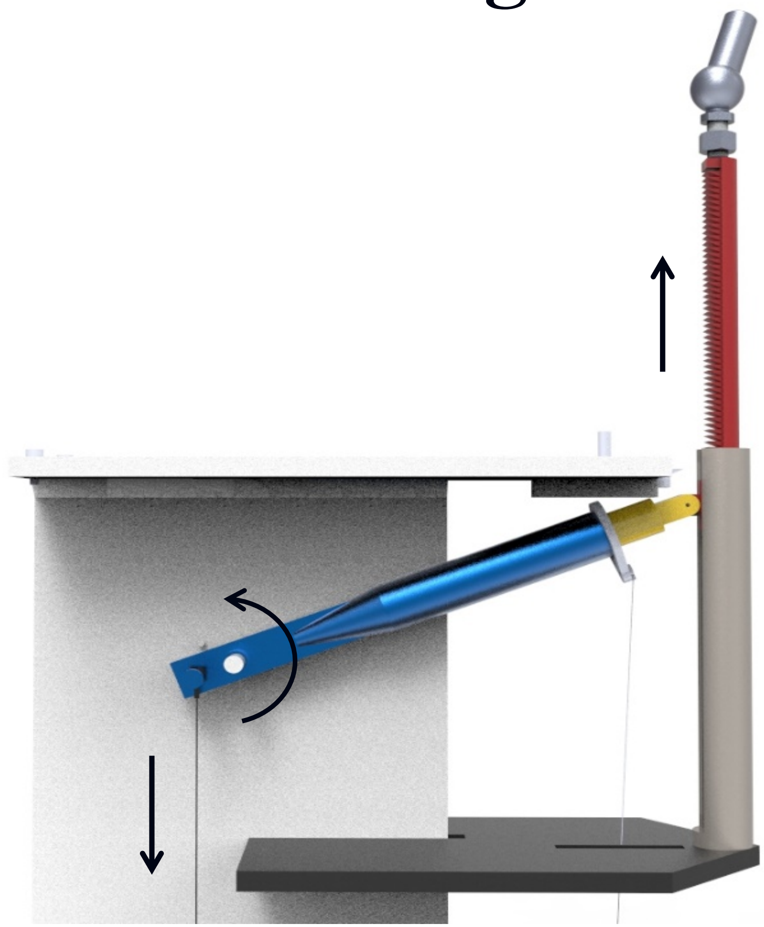
SMA Latching Mechanism

- **SMA contracts and unlatches from lock-teeth**
- **Linear actuator free to move.**



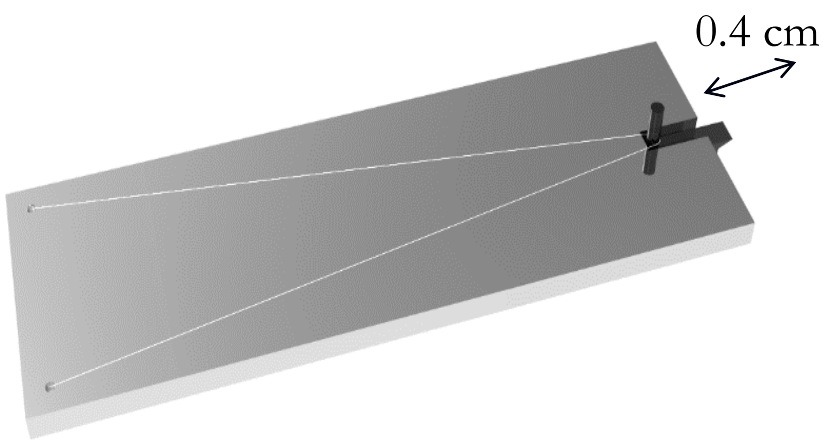
SMA Linear Lever Actuator Design

- SMA contracts
- Mechanical lever multiplies extension
- Rail linearizes extension

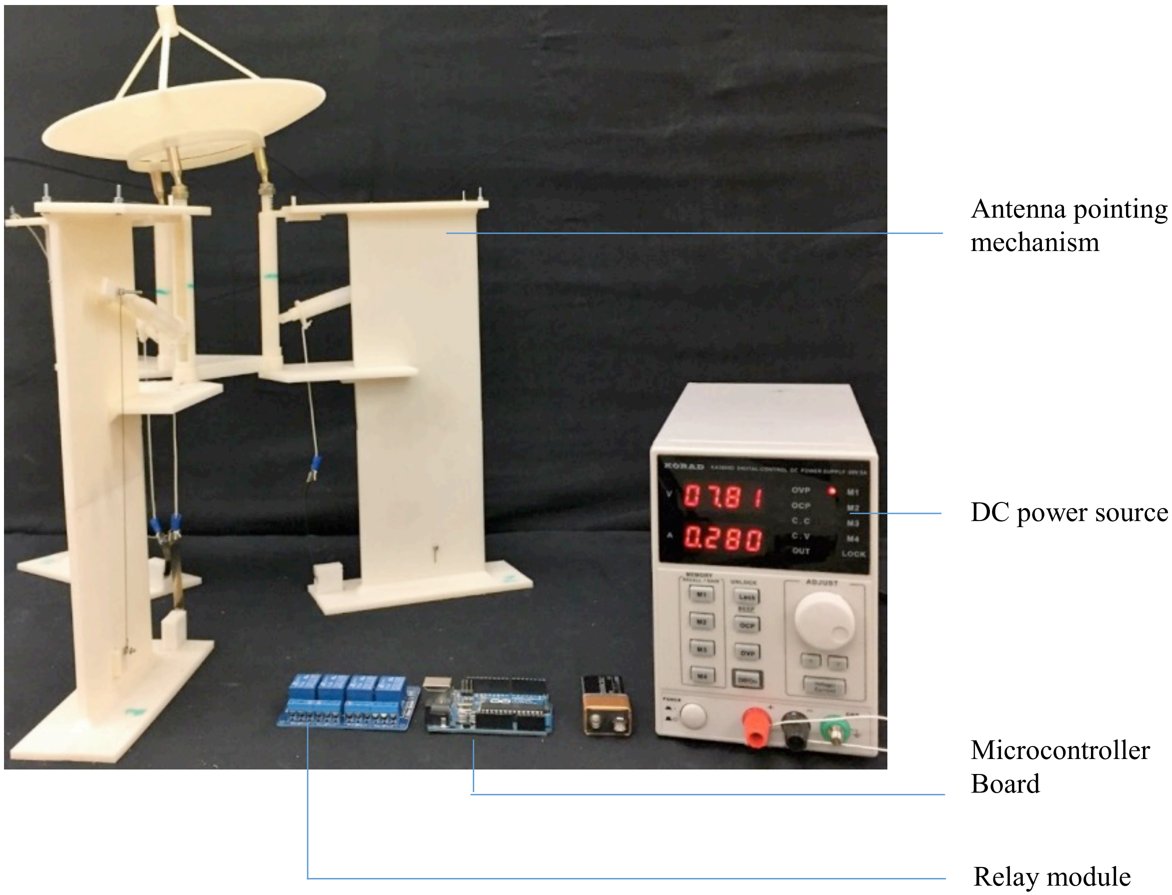


SMA Latching Mechanism

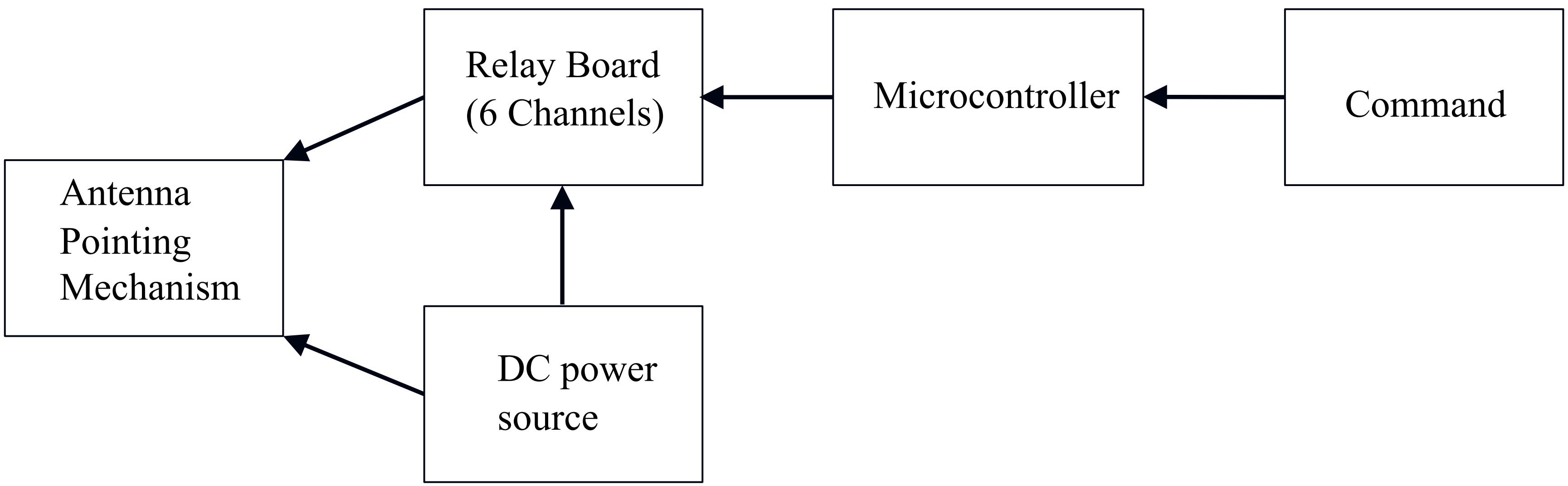
- **SMA expands and latches linear actuator extension.**



Experimental Setup



Experiment System



Actuator Operation

(a) Latched

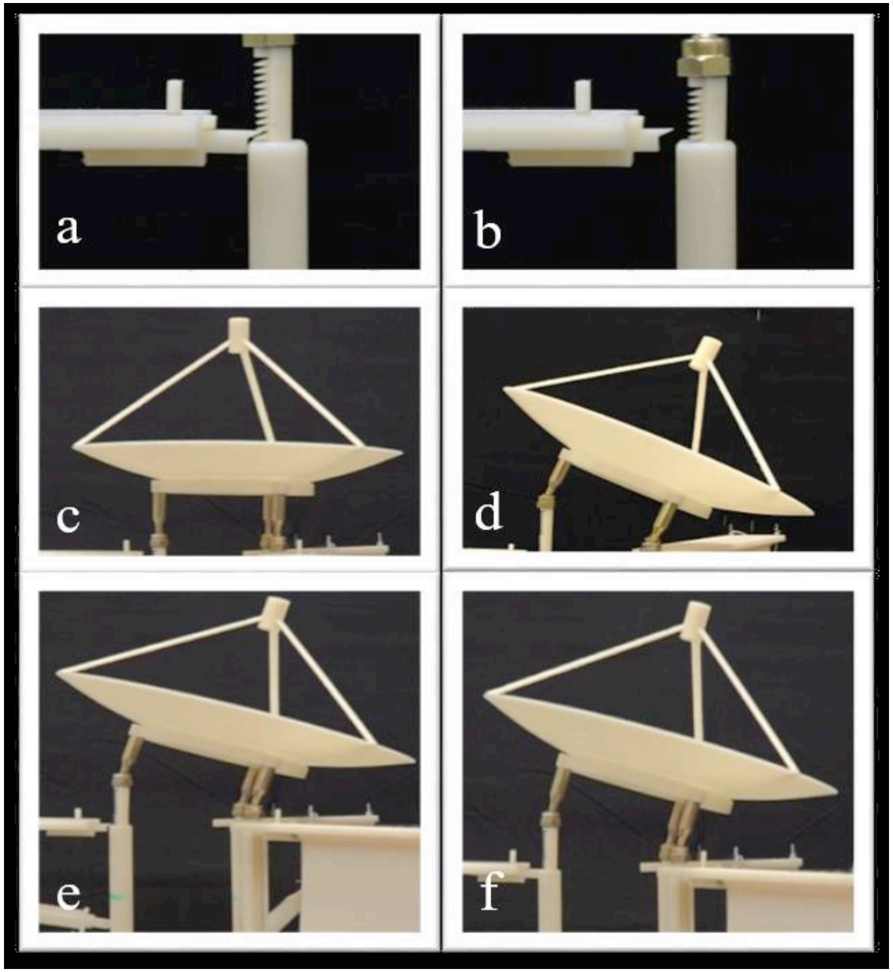
(b) Unlatched

(c) Zeroing of antenna,

(d) Stroke set (with overshoot)

(e) Settling time

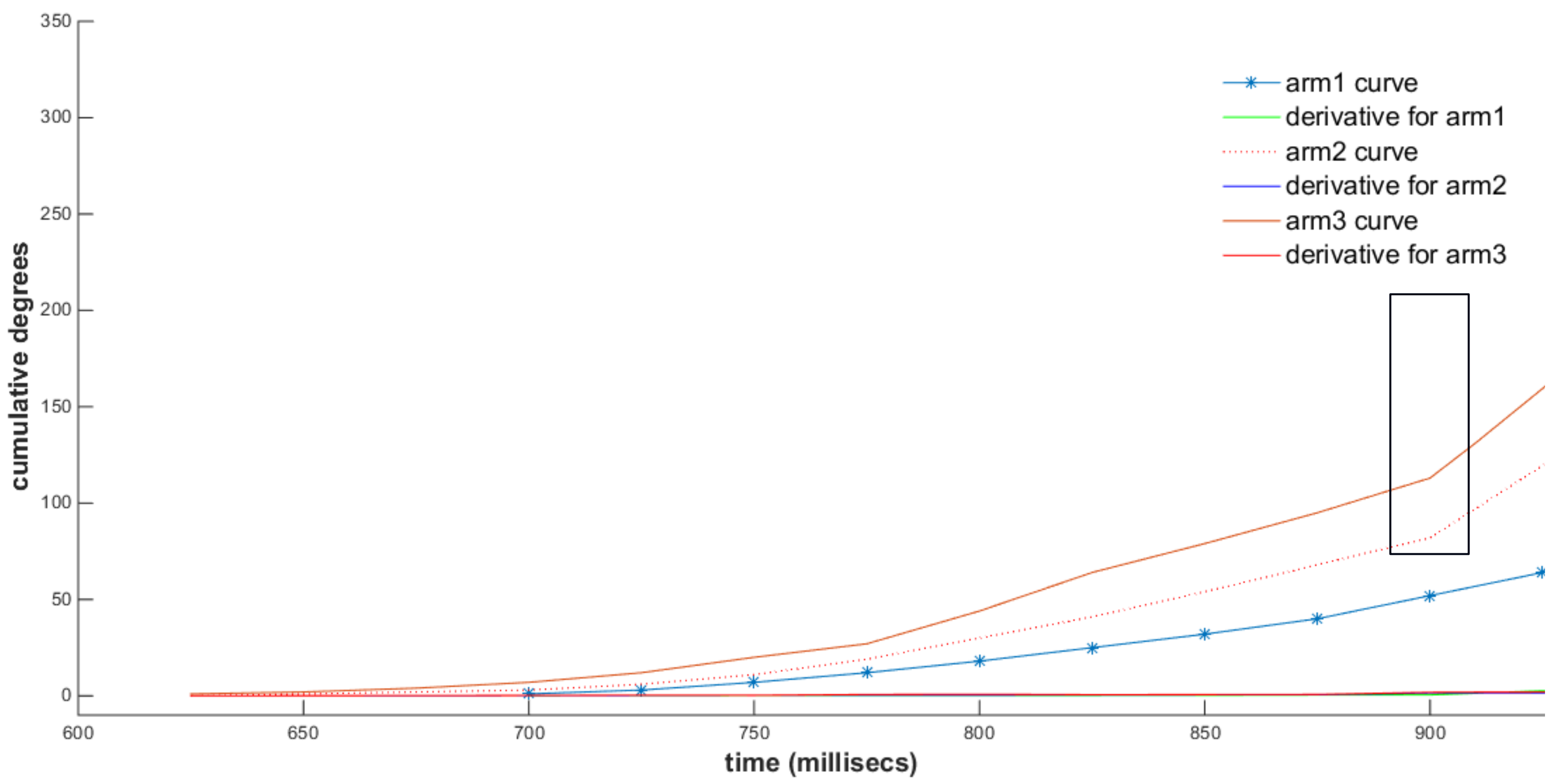
(f) Lock



Video Demonstration

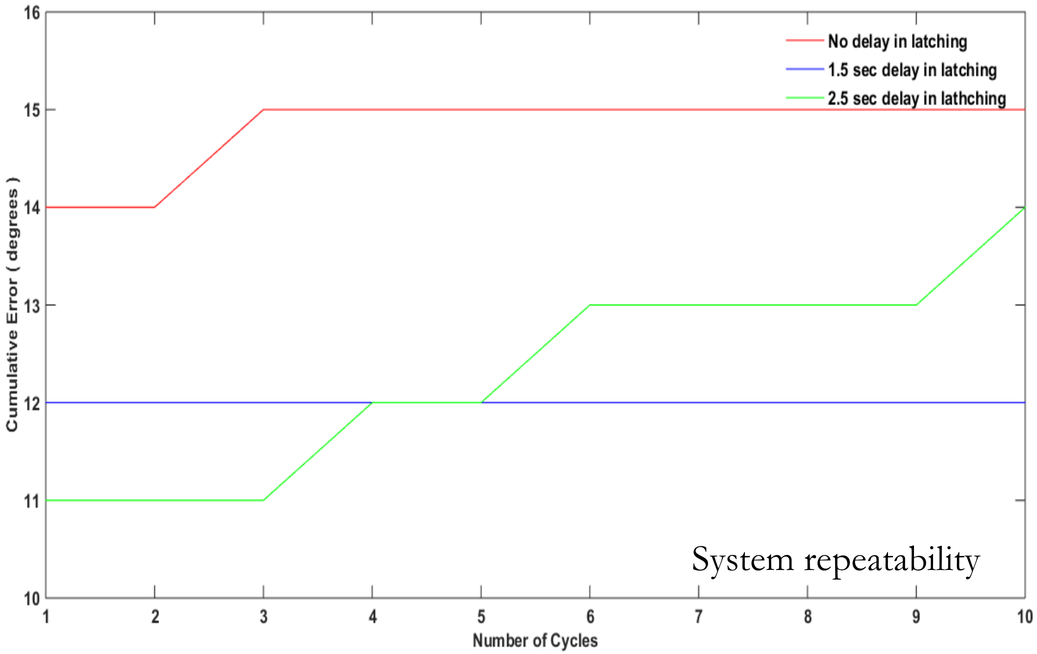
Calibration

- Takes 1 sec to position an actuator. Parallel ops.
- Further analysis need to speed-up performance.



Experiment Repeatability

- Optimal latching delay time found – show no build up in angular error over 10 cycles.
- Extended experiments being performed to 100 and 1000 cycles.



System repeatability

Conclusions

- A prototype SMA linear actuation based pointing mechanism developed
  - Solid-state
  - Low-cost, built entirely of commercial, easy to obtain components.
  - Simple design – potential for assembly in space.
- Laboratory prototype achieves 1 degree precision We have designs to achieve 0.1 arcsecond
- Excellent repeatability – 1 million cycles (theory)

Future Work

- Demonstrate 1 arcsecond prototype
- Further simplify design for in-space assembly
- Thermal-vac test prototype
- Plans for balloon followed by CubeSat demonstrator mission

Thank you !

Questions ?