space structures laboratory
Professor Sergio Pellegrino
California Insititute of Technology

Building Space Telescopes

Sergio Pellegrino

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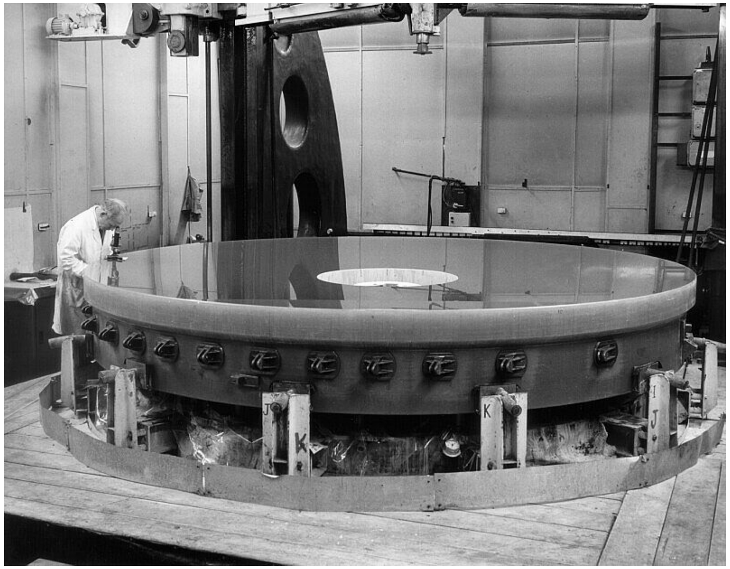
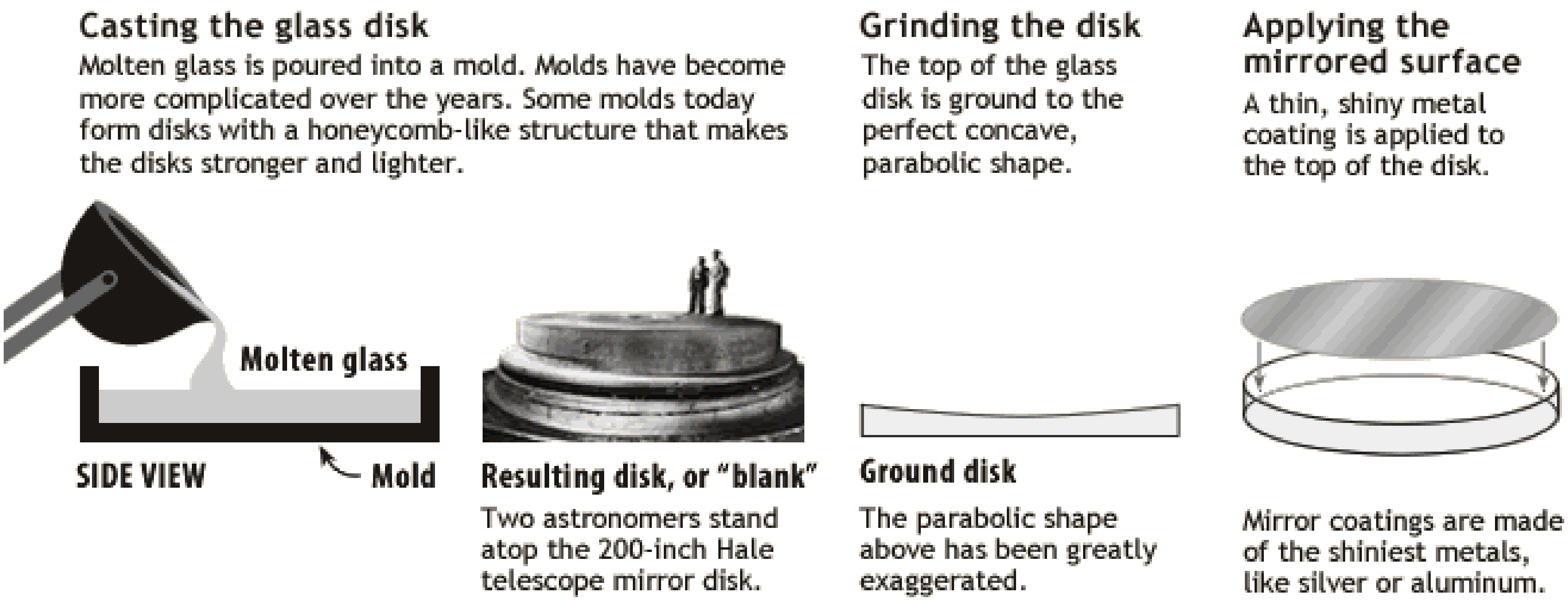
How I became interested in the telescopes of the future…

William Herschel Telescope

Its paraboloidal primary mirror is made of a glass-ceramic material. It has a clear aperture of 4.2 m and a focal length of 10.5 m. The mirror is a solid piece, with no empty cells.

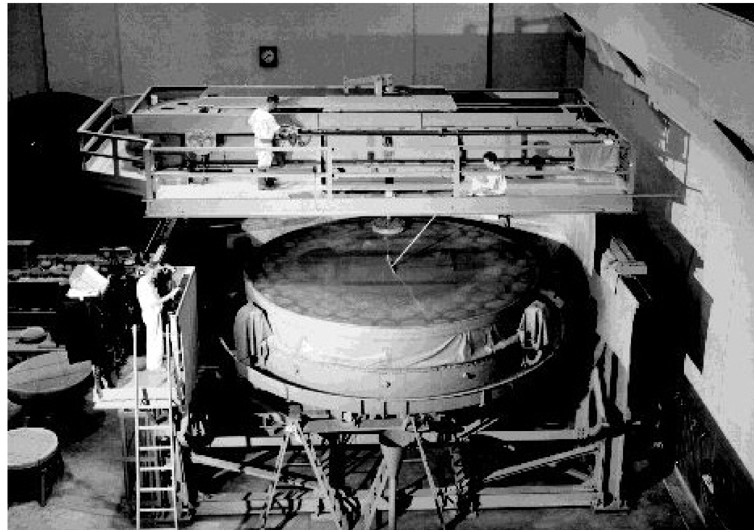


Making a glass mirror



From: http://amazing-space.stsci.edu/resources/explorations/groundup/lesson/basics/g40/

200-inch Hale Telescope



Northumberland Equatorial Telescope

ACCOUNT

OF THE

NORTHUMBERLAND EQUATOREAL

AND DOME,

ATTACHED TO

THE CAMBRIDGE OBSERVATORY.

BY G. B. AIRY, ESQ. M.A.

ASTRONOMER ROYAL,

LATE PLUMIAN PROFESSOR IN THE UNIVERSITY OF CAMBRIDGE.

CAMBRIDGE:

PRINTED AT THE UNIVERSITY PRESS.

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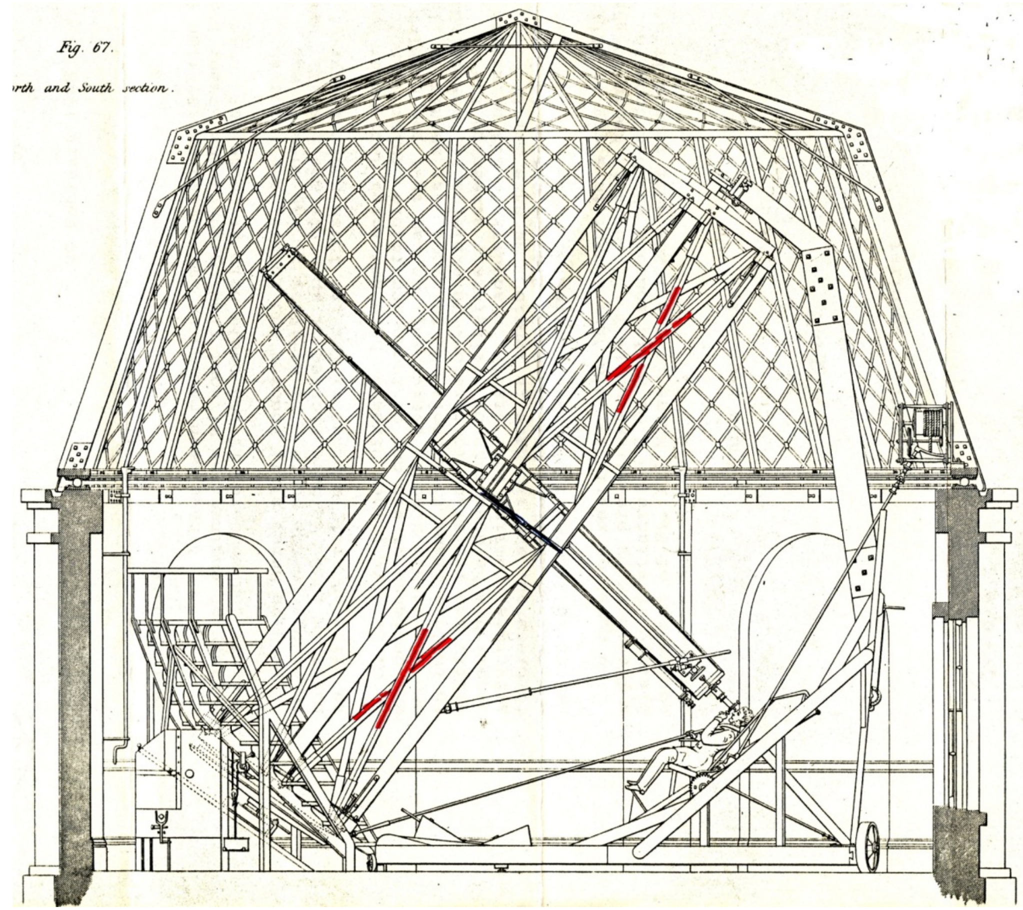


Keck Institute for Space Studies workshop on Large Space Apertures November 2008

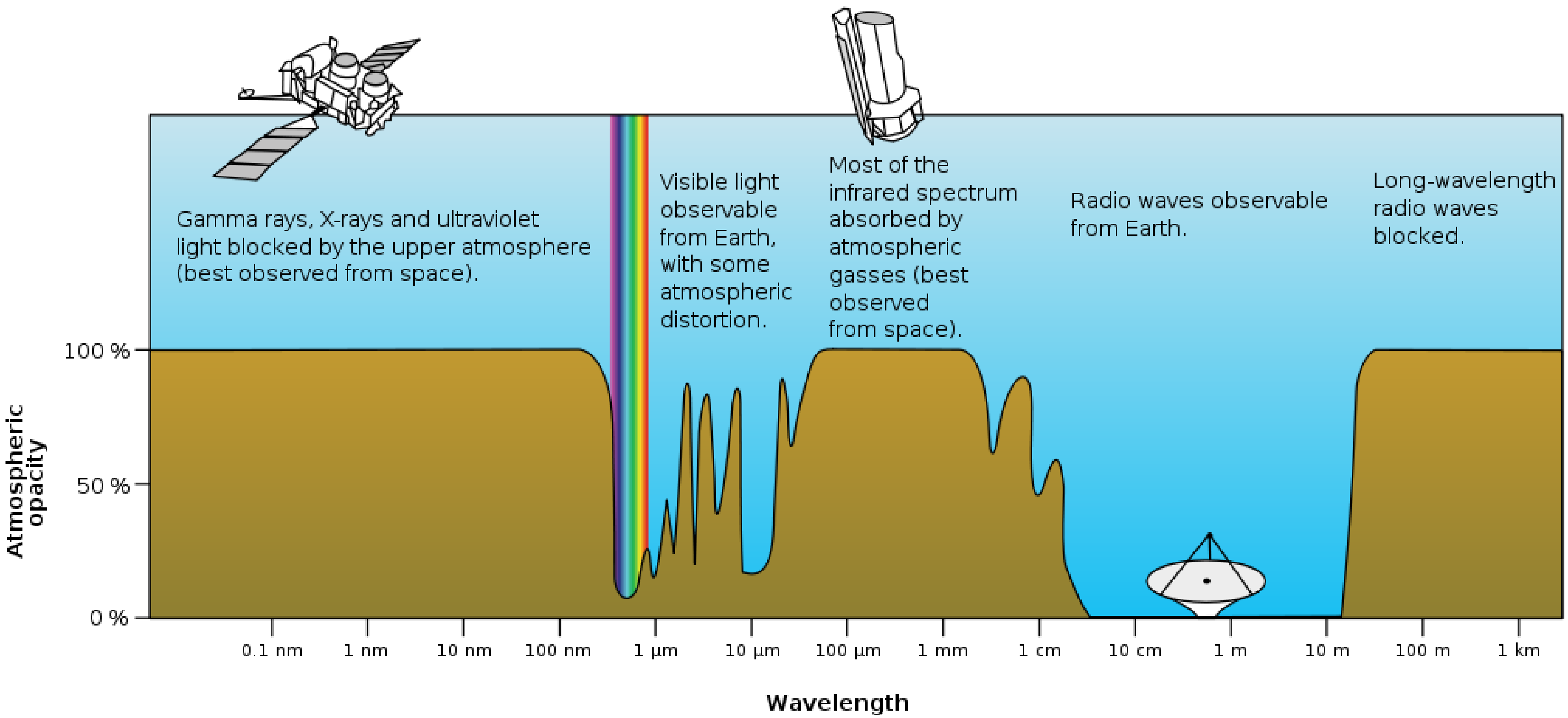
Four key questions:

1. What are the community's needs for (a) optical apertures or (b) RF apertures in the next 10-20 years?
2. What is the state of the art in optical and RF apertures?
3. What are the roadblocks that prevent us from meeting the community's needs, given the state of the art?
4. What approaches could be followed to address these roadblocks?

Main Findings of Workshop

- RF antennas for space is an important and relatively mature field of technology
- Observational astrophysics remains photon-limited and there is a compelling case for large aperture UV, Optical and Near-Infrared space telescopes with diameters of 10-20 m.

Opacity of Earth's Atmosphere



Most of the electromagnetic spectrum is blocked by the atmosphere

A Primer to Astronomical Observations

- Key is ratio of Signal to Noise (S/N); typically, $S/N > 3$ is required.

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- $S/N \propto \mu t \propto D^4$ where $\mu =$no. photons received from source per unit time, $t =$integration time.
- Observations with a telescope that has 10 times larger D are 10,000 times *faster.*

Some of the charts presented by Matt Mountain

Matt Mountain
Director, Space Telescope Science Institute
Going from HST to JSWT and Beyond: The Science Drivers for Large Apertures in Space

Video and charts available from:
http://kiss.caltech.edu/workshops/apertures2008/schedule.html

The James Webb & Hubble to same scale

JWST is 7 tons and fits inside an Ariane V shroud

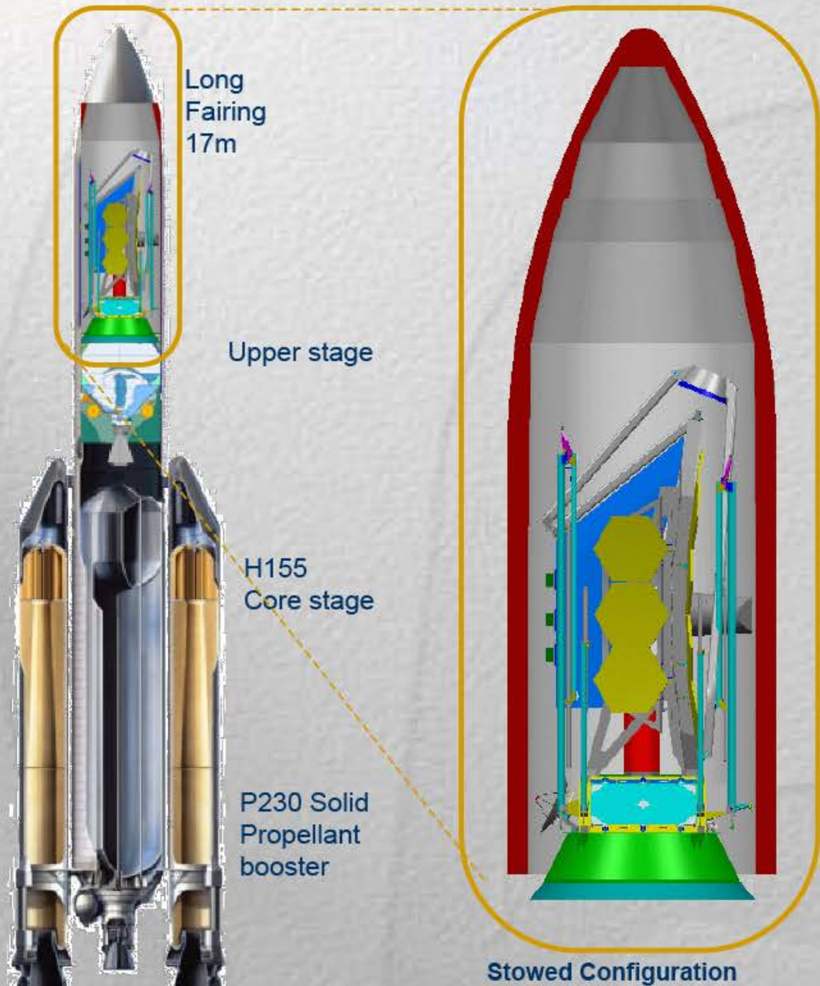
This remarkable feat is enabled by:

- Ultra-lightweight optics (~25 kg/m^2)
- Deployed, segmented, actively controlled primary
- Multi-layered, deployed sunshade
- *L2 Orbit allowing open design/passive cooling*

Courtesy Peter Stockman, STScI

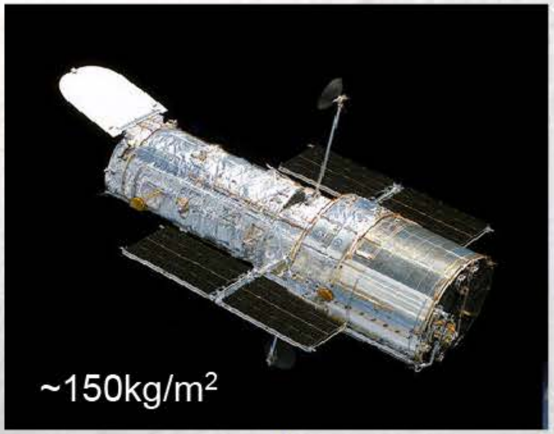
JWST Launch Configuration

- JWST is folded into stowed position to fit into the payload fairing of the Ariane V launch vehicle

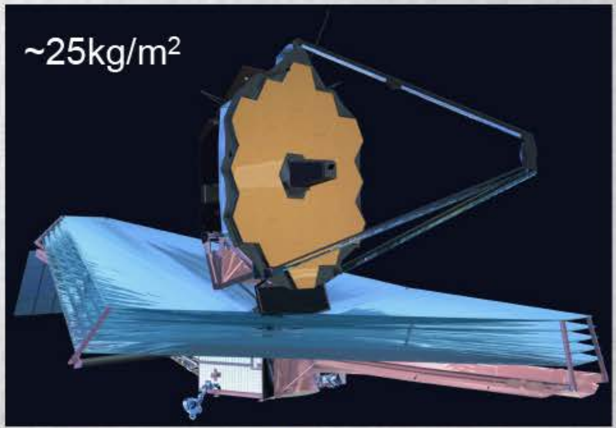


Space Telescope design and control philosophies

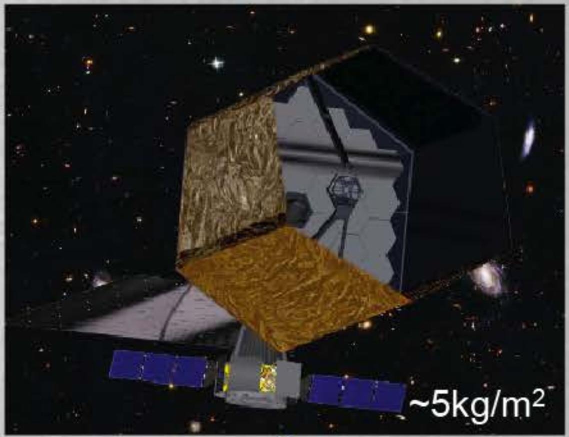
HST 2.4m



JWST 6m



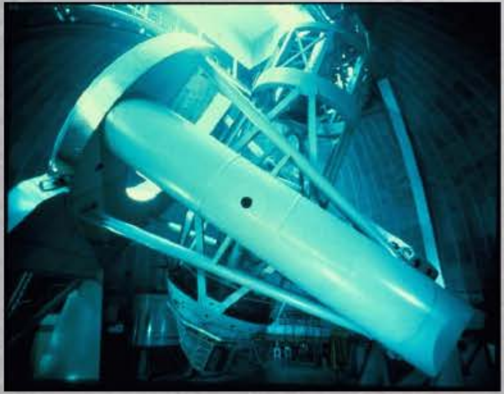
8m~16m LST



Passive control

Active control

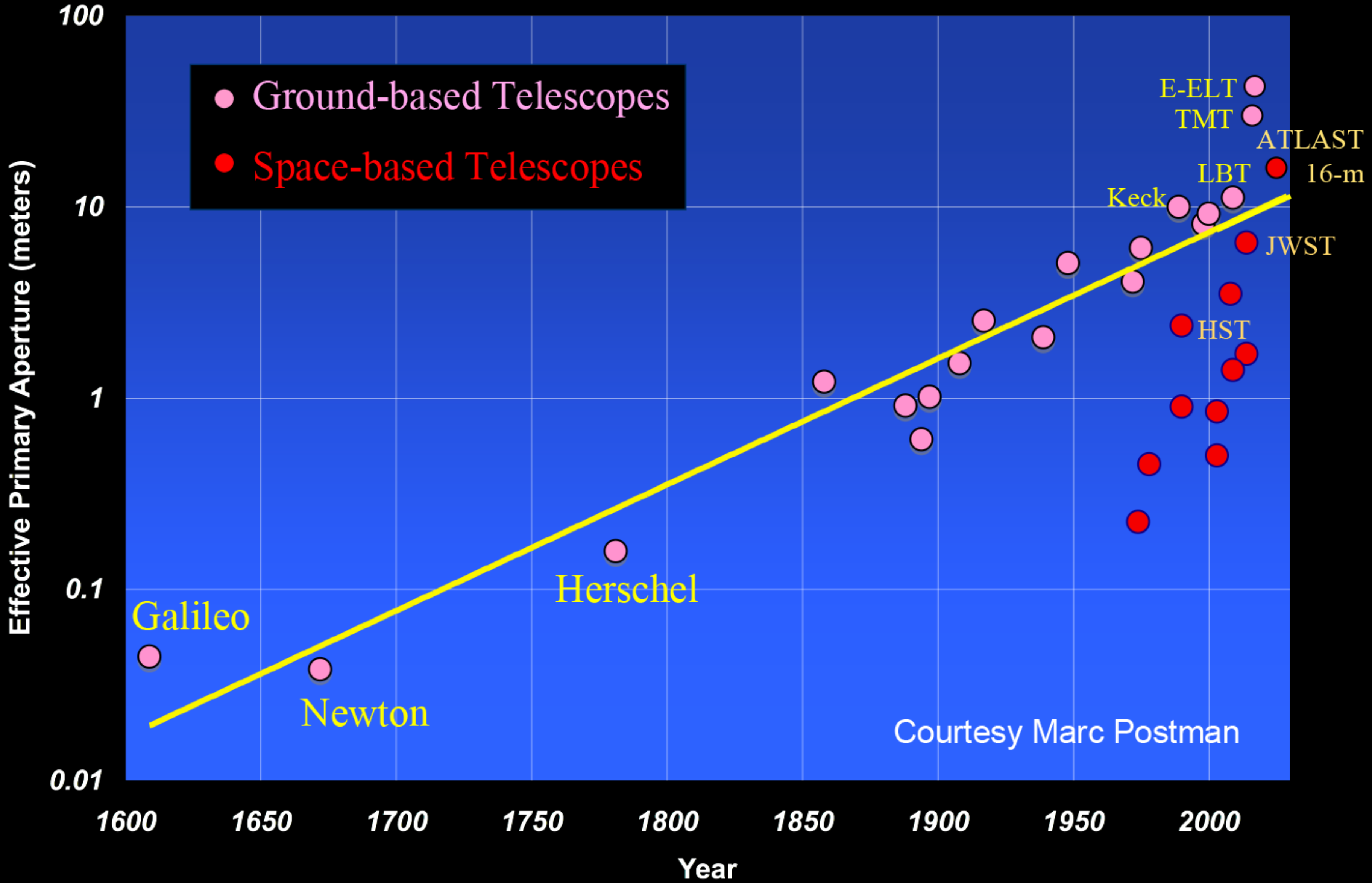
Fully active and adaptive control



Palomar 5m

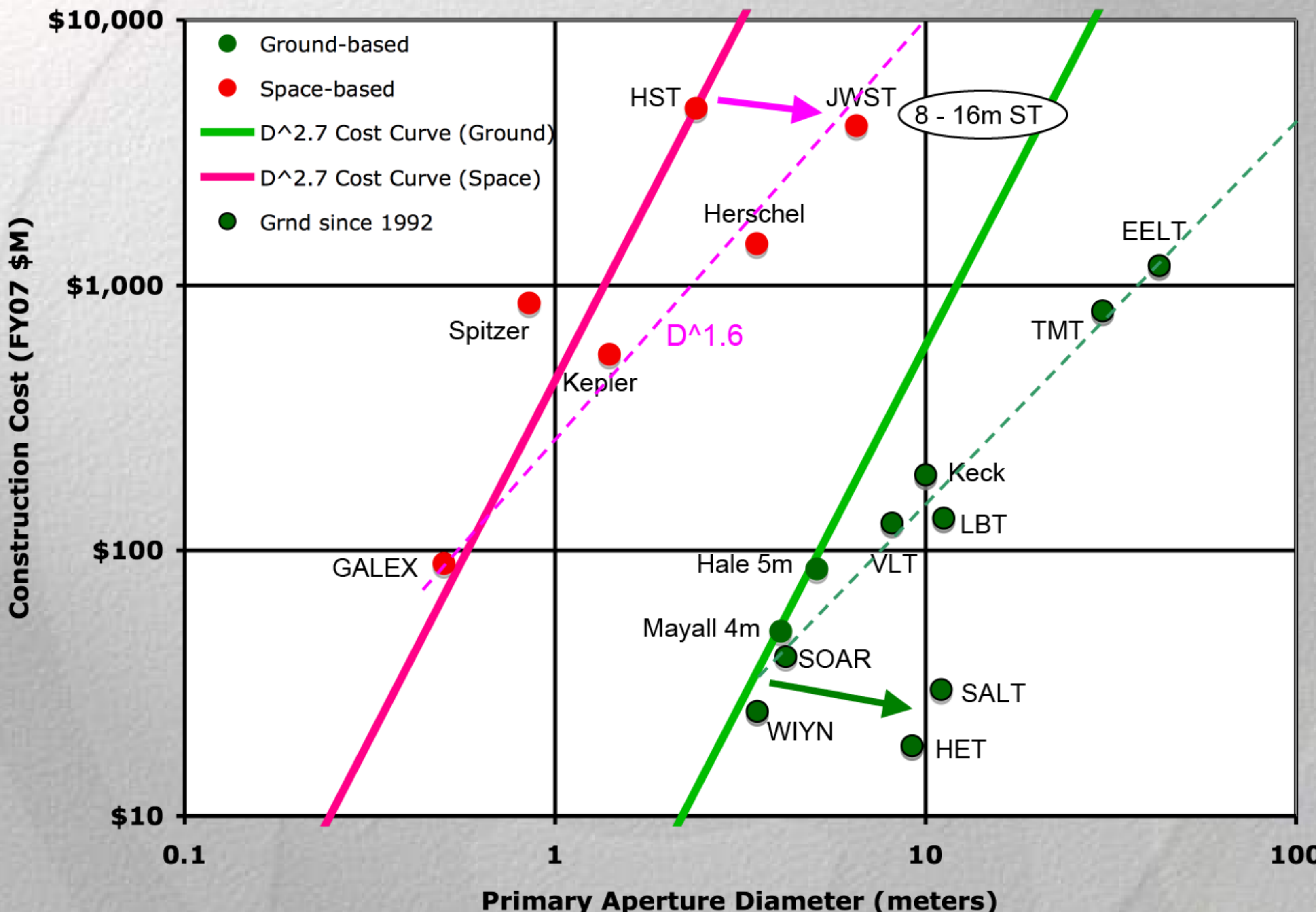
Keck 10m

Growth in aperture driven by science *and* technology

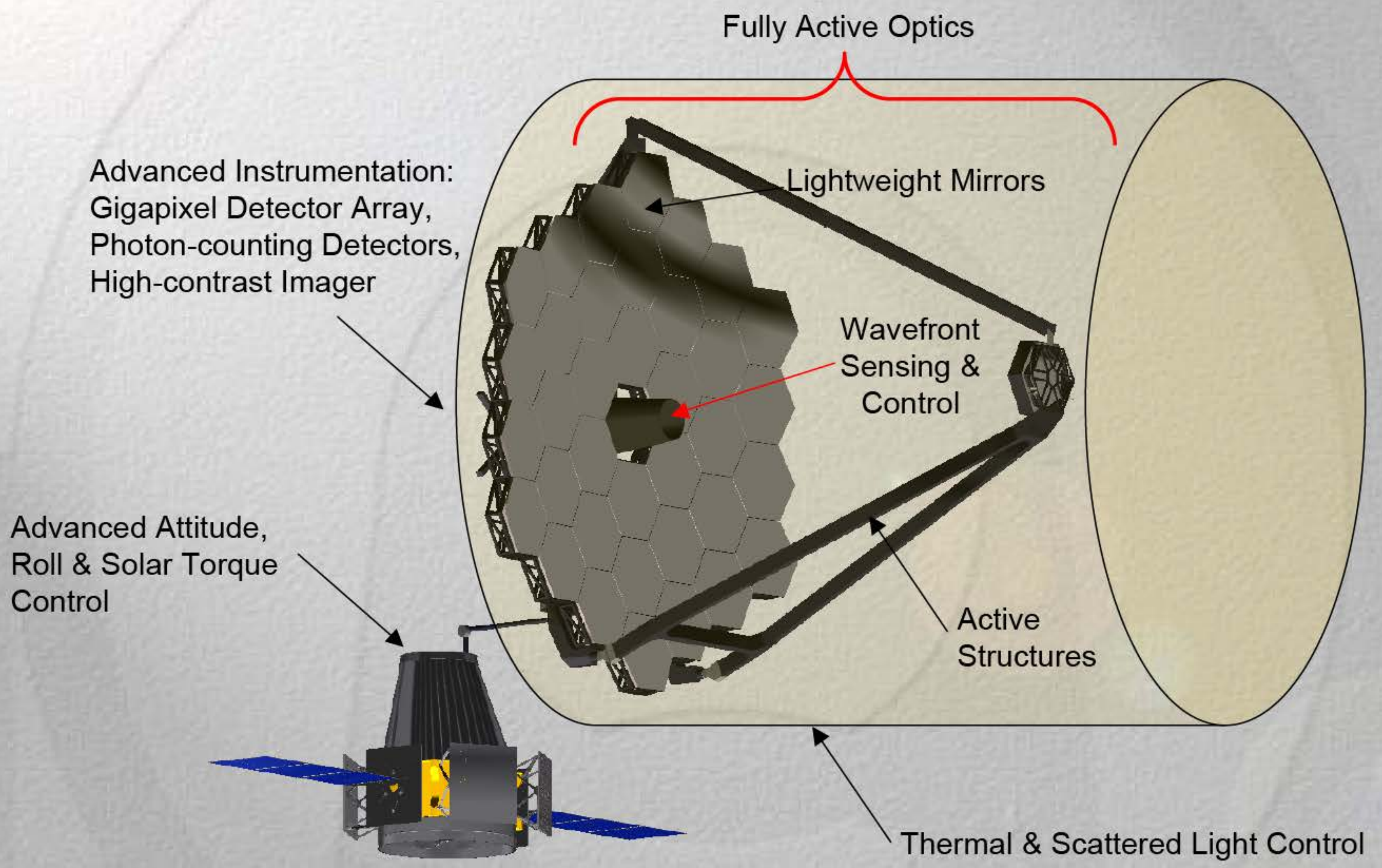


Primary Telescope Aperture vs. Time

Cost does NOT follow a fixed scaling relation with aperture as technology or architecture advance

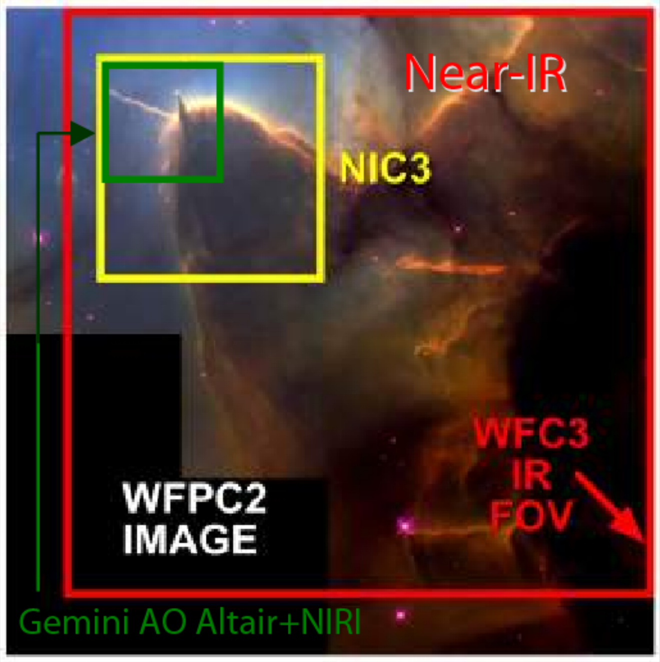


Key Technologies Needed for Large UVOIR Space Telescopes



Complementarity with Adaptive Optics

- Ground-based 30-m telescopes will achieve higher resolution in the NIR
- Space has much lower background
  - Exposure times for faint objects for a space 2-m are comparable to an AO-corrected 30-m shortward of 2 µm.
- Starlight suppression much better from space
  - 2-m space telescope outperforms a 30-m with AO
- Space provides a wider corrected field than AO, or even MCAO
- At optical wavelengths, AO fields on a 30-m will subtend just a few arcseconds .



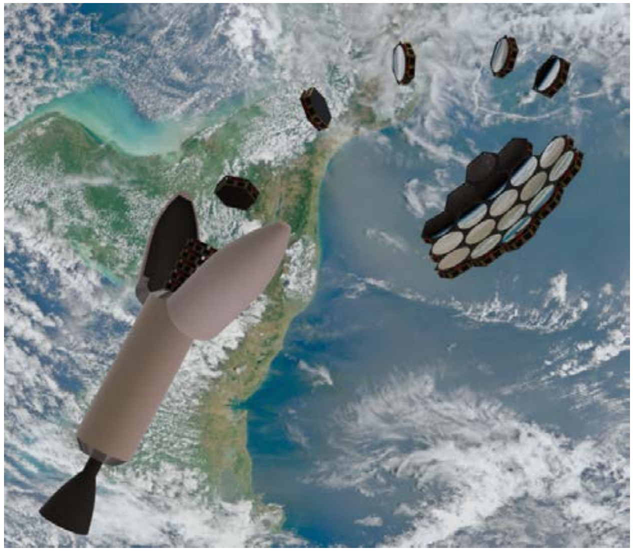
Exposure times for S/N=5 point source AO in typical conditions:

	J=25.2	H=24.5	K=23.2
Instrument	1.2 µm	1.6 µm	2.1 µm
HST+WFC3	8 min	20 min	-
8-m VLT NAOS+Conica	640 min	730 min	260 min
30-m + MCAO	6 min	6 min	0.06min

Even a 2.4m space telescope can be competitive with a 30m groundbased telescope

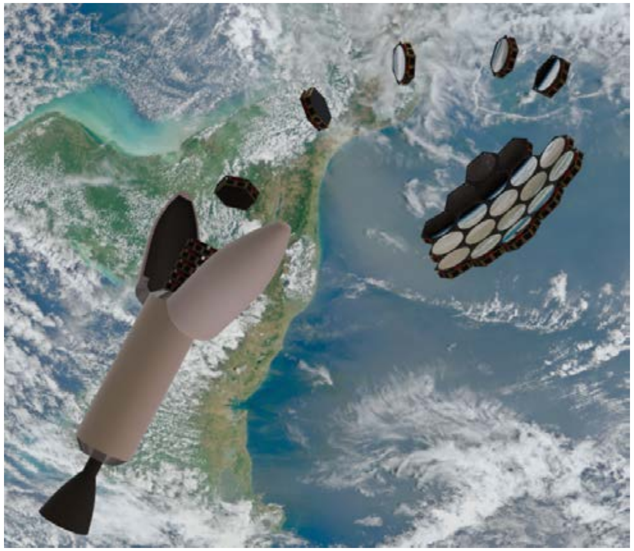
Our Vision for Future Large Space Telescopes

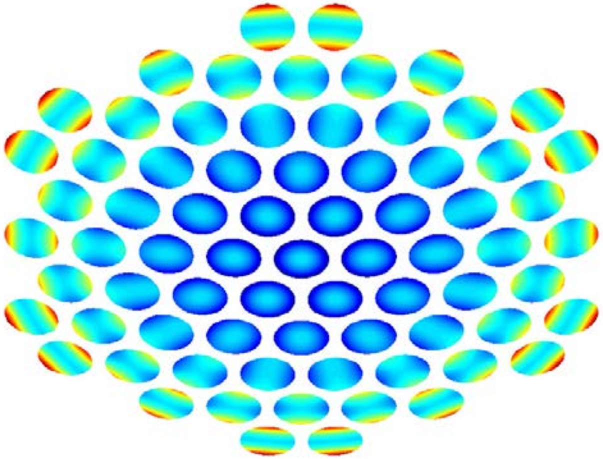
- Aperture:
  - Segmented primary mirror
  - Many segments
  - Multiple launches
  - On-orbit autonomous assembly



Our Vision for Future Large Space Telescopes

- Aperture:
  - Segmented primary mirror
  - Many segments
  - Multiple launches
  - On-orbit autonomous assembly
- Mirror segments:
  - Lightweight
  - Identical (nominally spherical)
    - Lower cost
    - Redundancy
    - Ease of manufacture and test
    - BUT: Curvature errors across array
  - Adjustment capability






Keck
INSTITUTE FOR SPACE STUDIES
CALIFORNIA INSTITUTE OF TECHNOLOGY
JET PROPULSION LABORATORY

Demonstration of Key Technologies

Small telescope mission:

- Lightweight adaptive mirrors
  - Each 10 cm diameter
  - Mounted on Cubesats
- Prime focus design
  - Deployable detector package
- Autonomous assembly and docking
  - Segments detach, reconfigure and reattach

Autonomous Assembly of a Reconfigurable Space Telescope (AAReST)

- Accomplish two key experiments in LEO by demonstrating new technologies for
  - Autonomous rendezvous and docking with small spacecraft for telescope re-configuration
  - A low-cost active deformable mirror
- Operate as long as necessary to accomplish the objectives (1 month+)
- Gather engineering data that enables the next system development
- Accomplish the mission inexpensively for a 2015 launch

AAReST Team

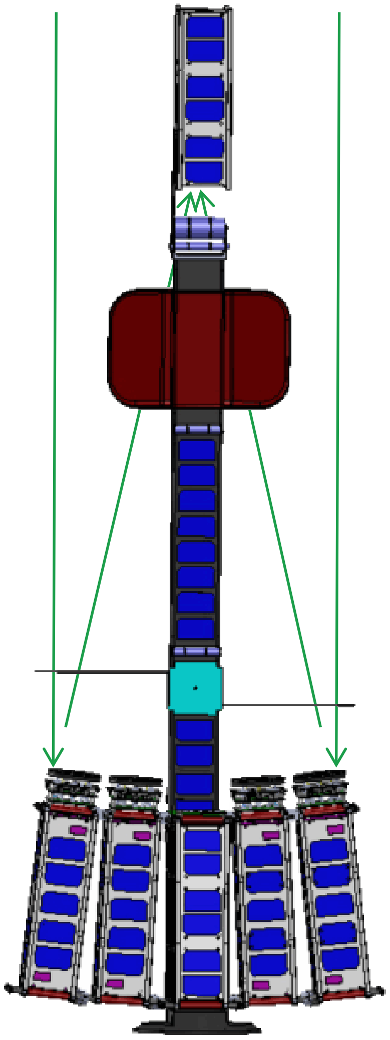
- Spacecraft
- Docking system
- Spacecraft integration & mission operations

- Deformable mirrors
- Telescope system
- Reconfiguration algorithm
- Optical focus algorithm

- Electronics and mirror fabrication support
- Project management

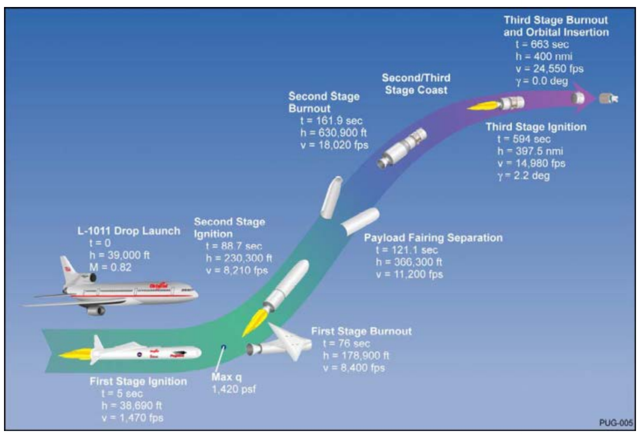
Telescope Details

- Prime focus design, FoV 1 deg
- Reconfigurable through the use of deformable mirror technology
- Key Parameters:
  - F_{eff} = 1.2 m
  - $D_{wide\ (compact)}$ = 0.58 m (0.34 m)
  - $F/D_{wide\ (compact)}$ = 2 (3)
- Instrumentation package
  - Corrective lenses
  - Scientific instruments

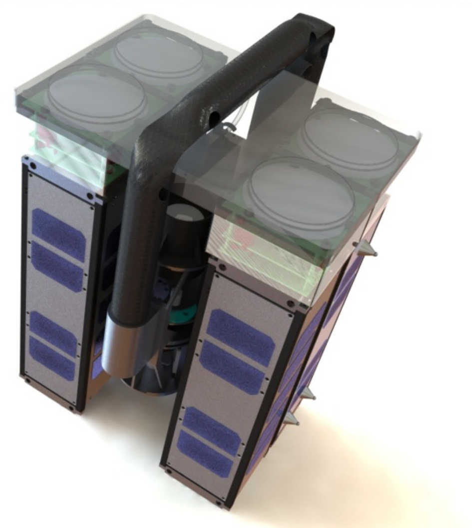


Concept of Operations

Deploy Telescope/ Solar Arrays → Spacecraft Check-out → Telescope Calibration → Re-configuration → Extended Mission Ops



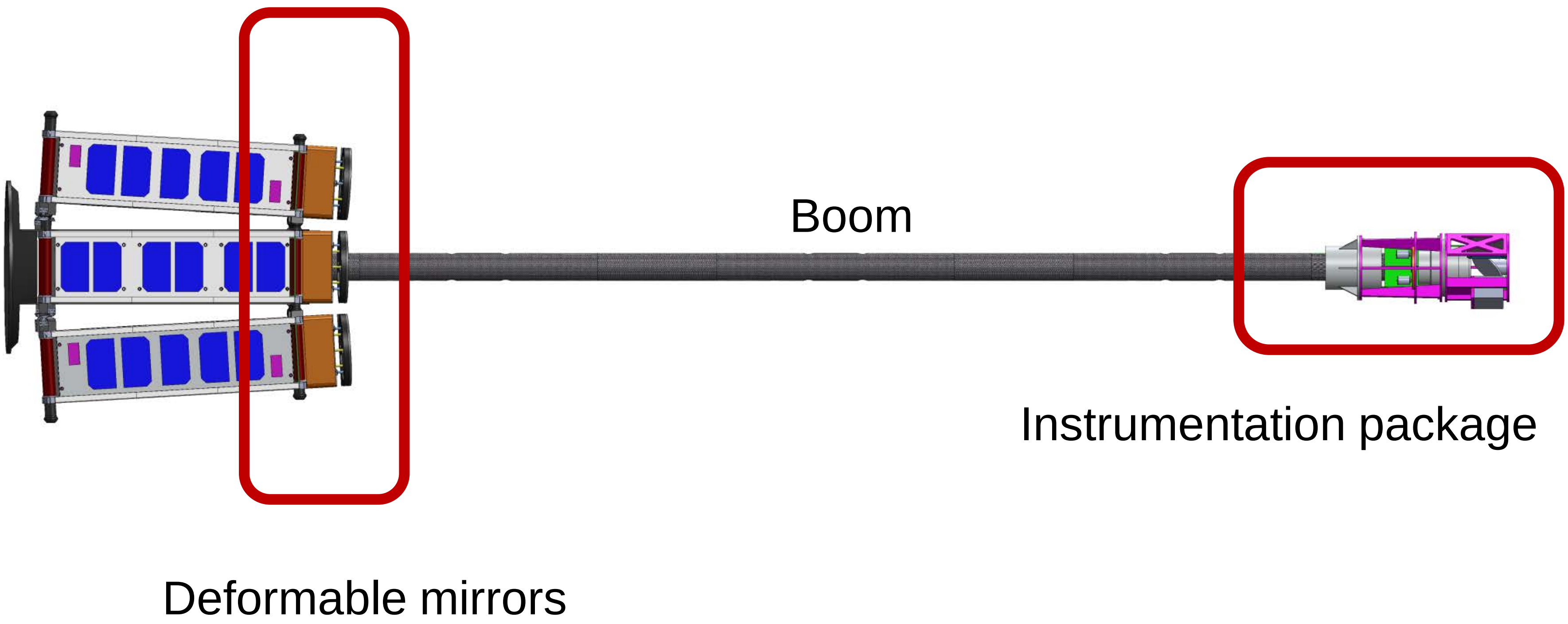
Piggy-back launch on Pegasus vehicle



Launch

De-Orbit

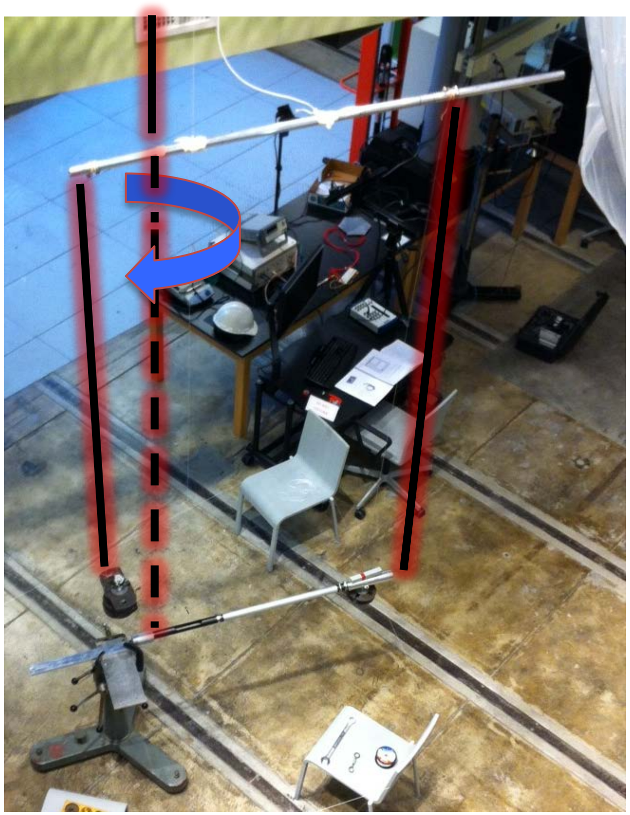
Telescope and Boom



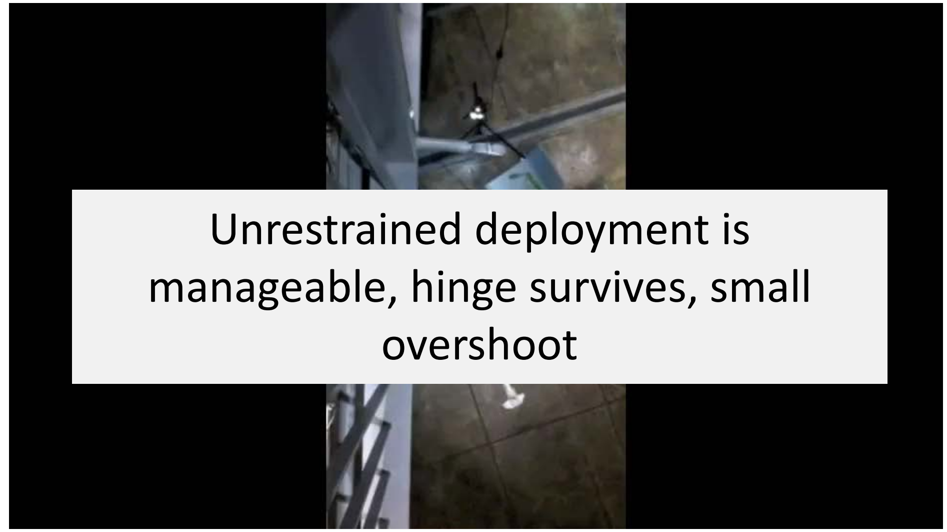
Deployment of Carbon-Fiber Boom

Boom weight 50 g

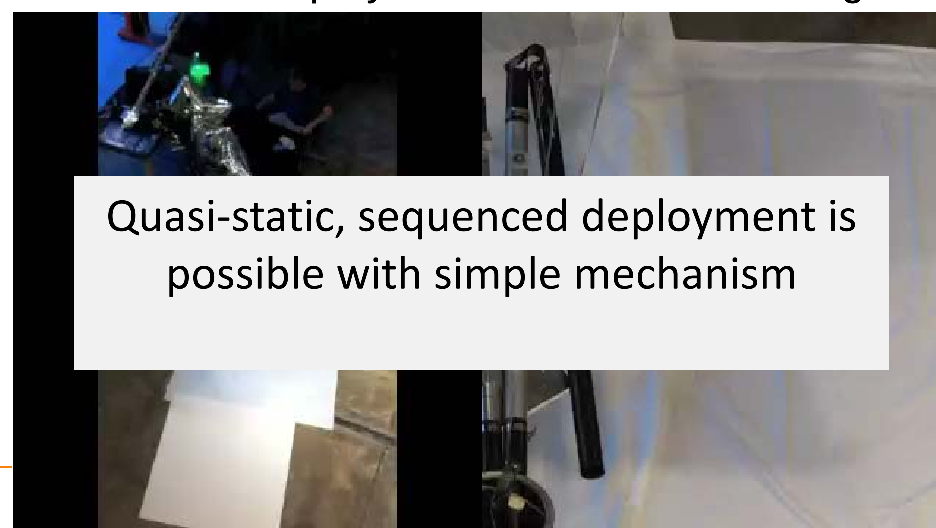
Whiffle tree gravity off-load



Unrestrained deployment of boom with single hinge

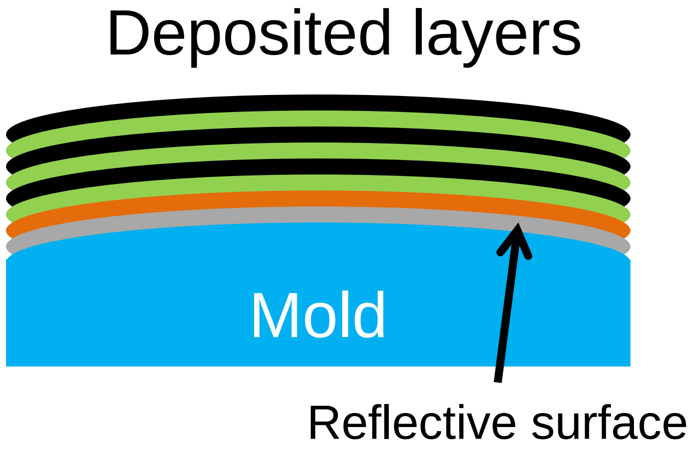


Restrained deployment of boom with 2 hinges



Deformable Mirror Concept

- Thin shell laminate
  - Built up on polished mold
    - Replication
  - Lightweight, stiff substrate
  - Active materials
    - Piezoceramics (e.g. PZT)
    - Electrostrictives (e.g. PMN-PT)
    - Electro-active polymers (e.g. PVDF)



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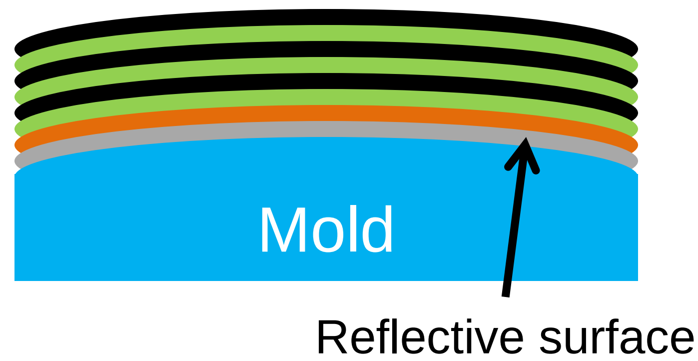
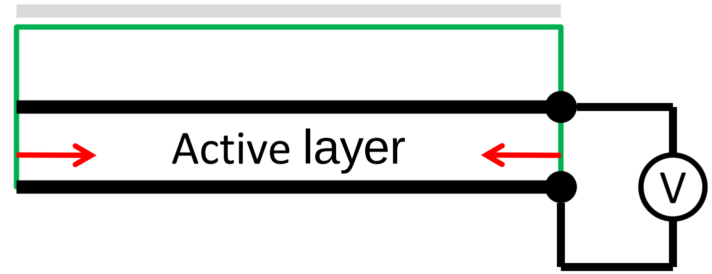
    - Electro-active polymers (e.g. PVDF)
- Surface parallel actuation
  - In-plane strains create mirror curvature
  - Thin, low areal density

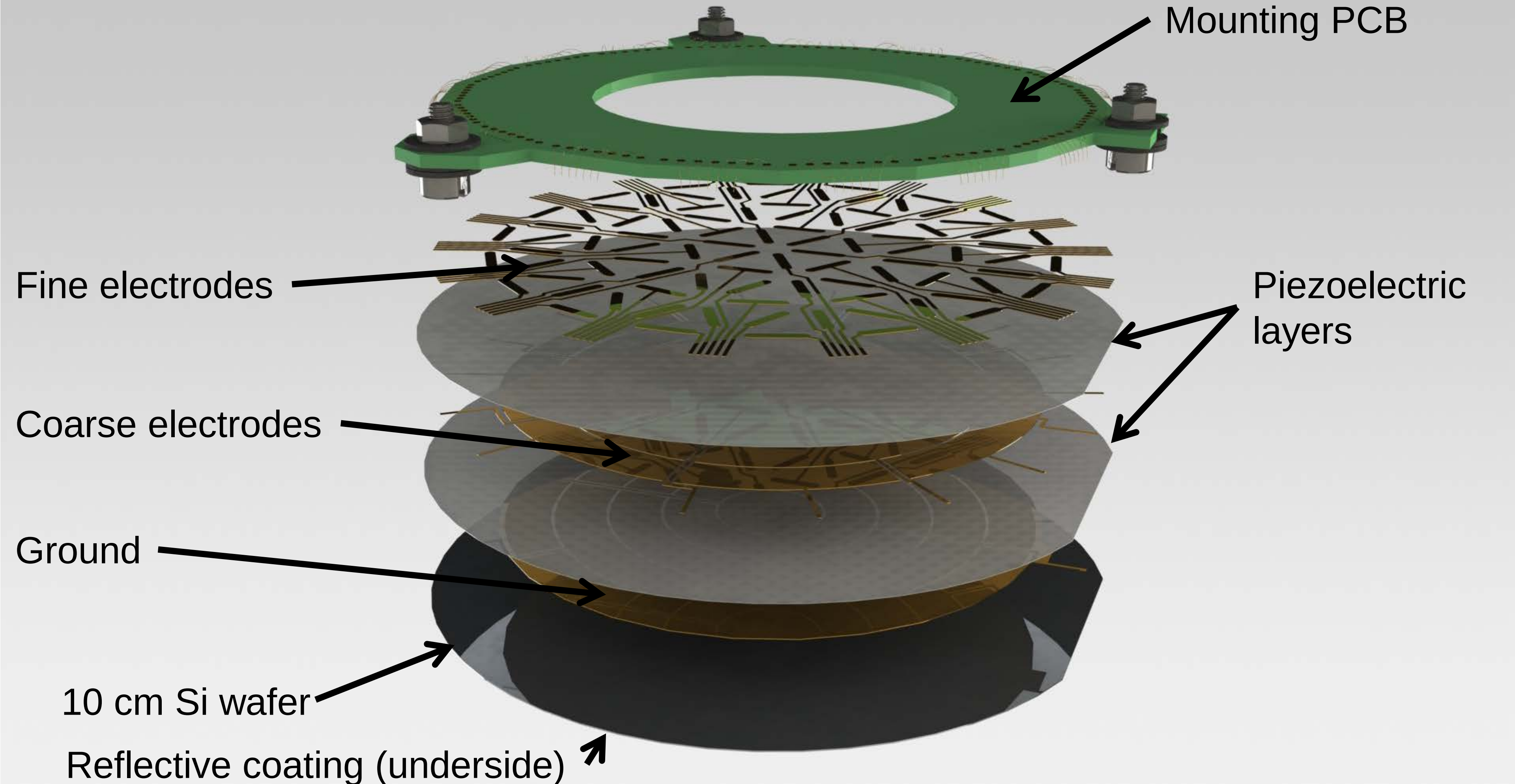
Deposited layers



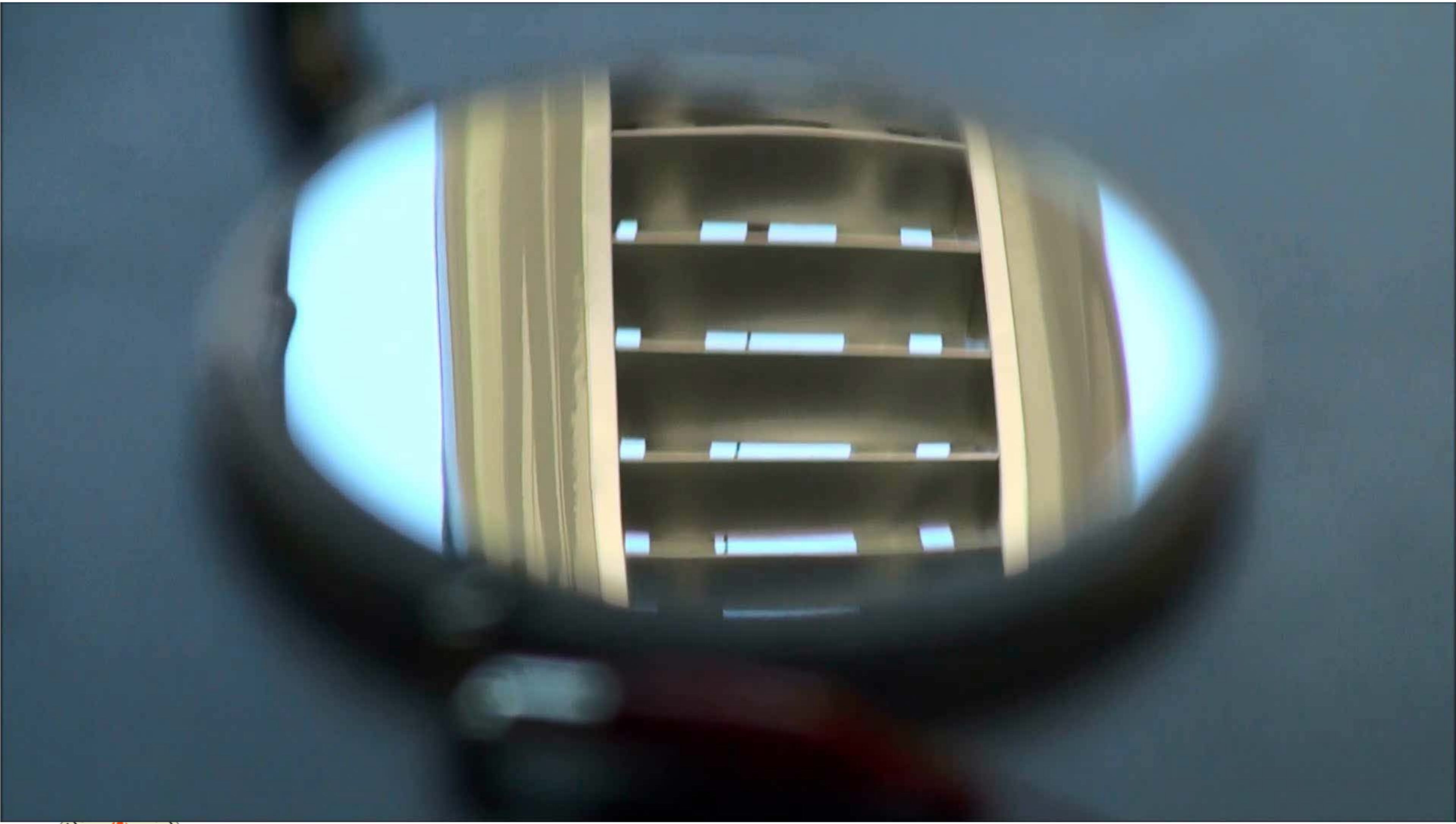


Deformable Mirror Design

- Alternating layers of electrodes and active material
- 90 (fine pattern) + 16 (coarse pattern) channels
- Mass < 5 grams (0.6 kg/m^2)



Demonstration of a Working Mirror

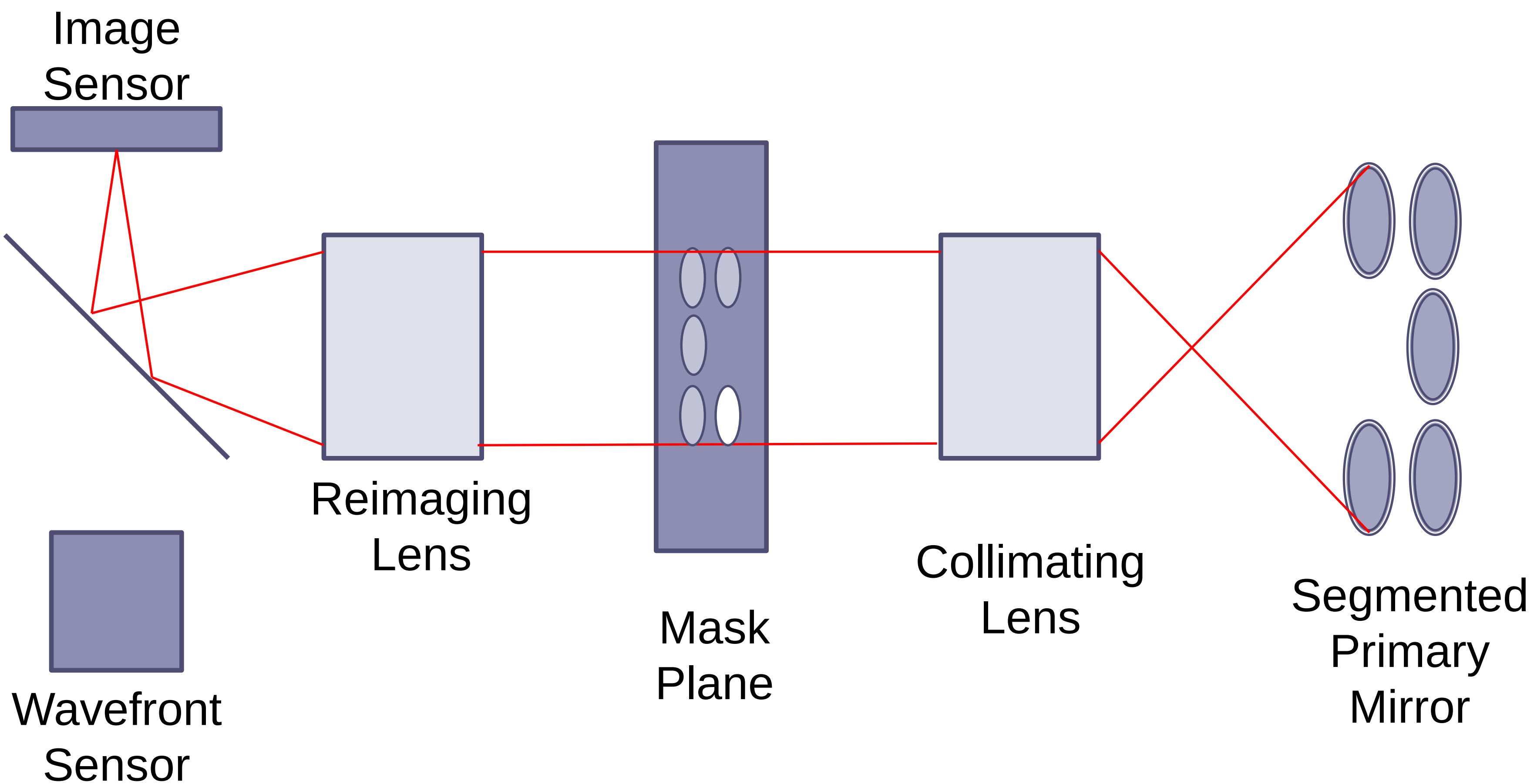


What about larger apertures?

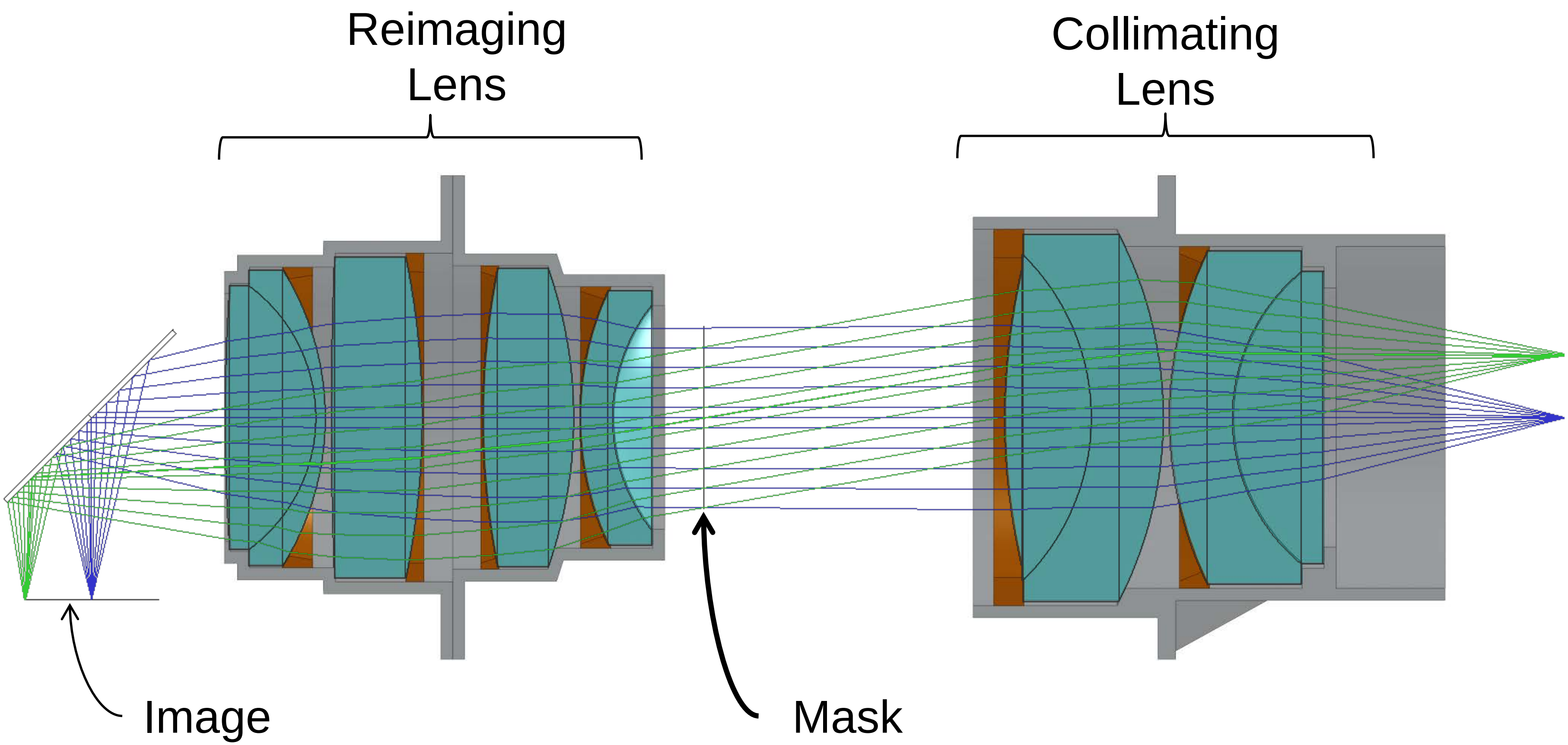
- Concept still valid, but…
- Silicon wafers constrained to 12” diameters
- Alternative substrates
  - Carbon fiber?
  - How to achieve lasting polished surface with acceptable roughness?

Movie is not linked

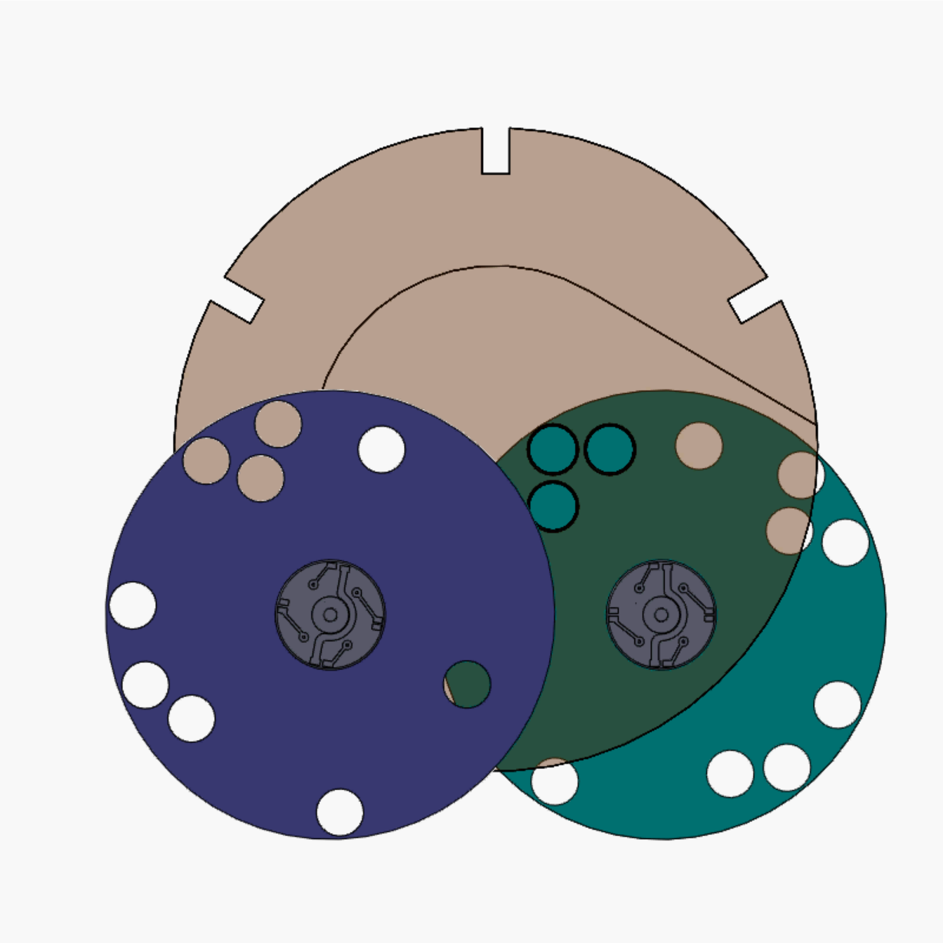
Concept of Instrumentation Package



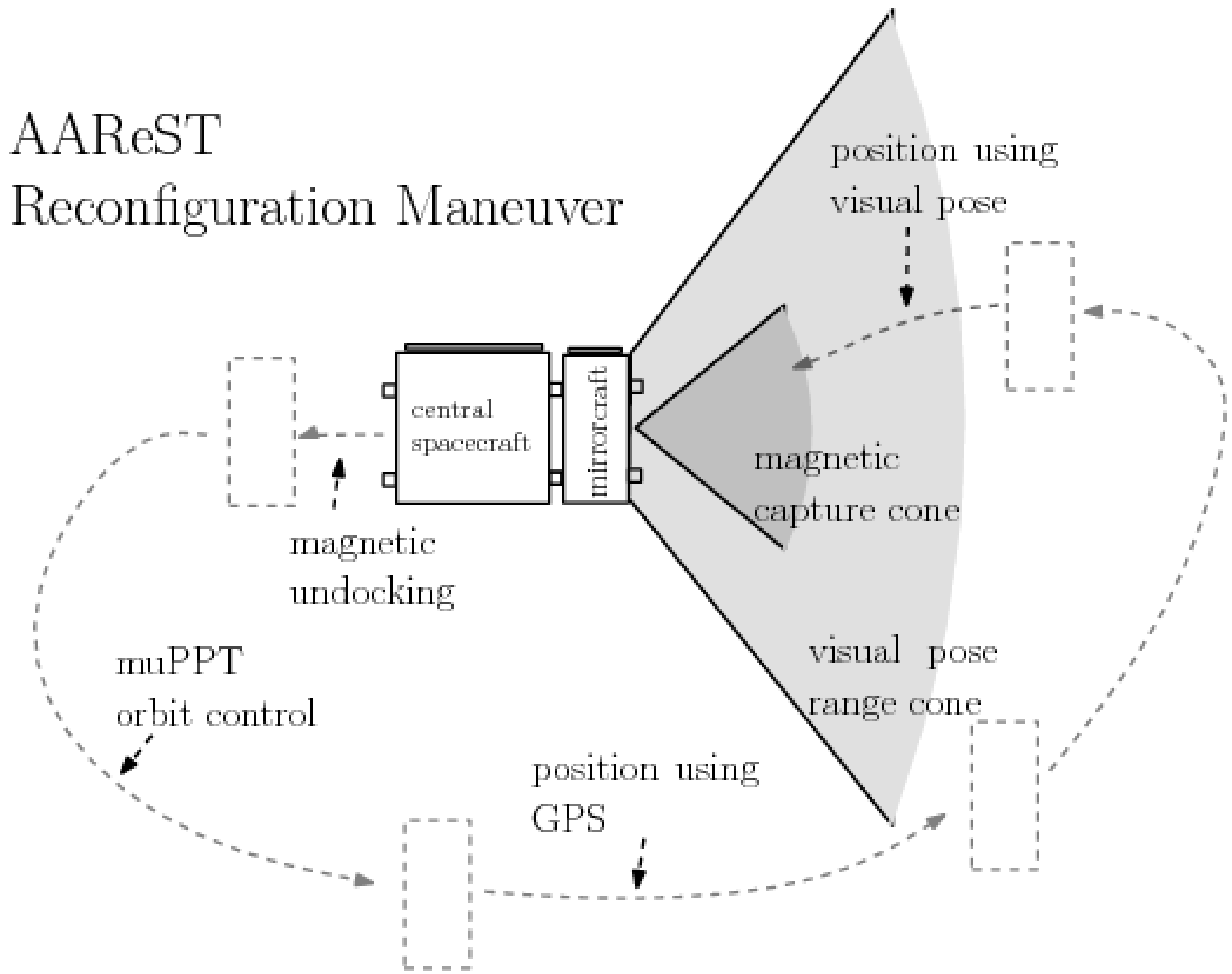
Optical Elements

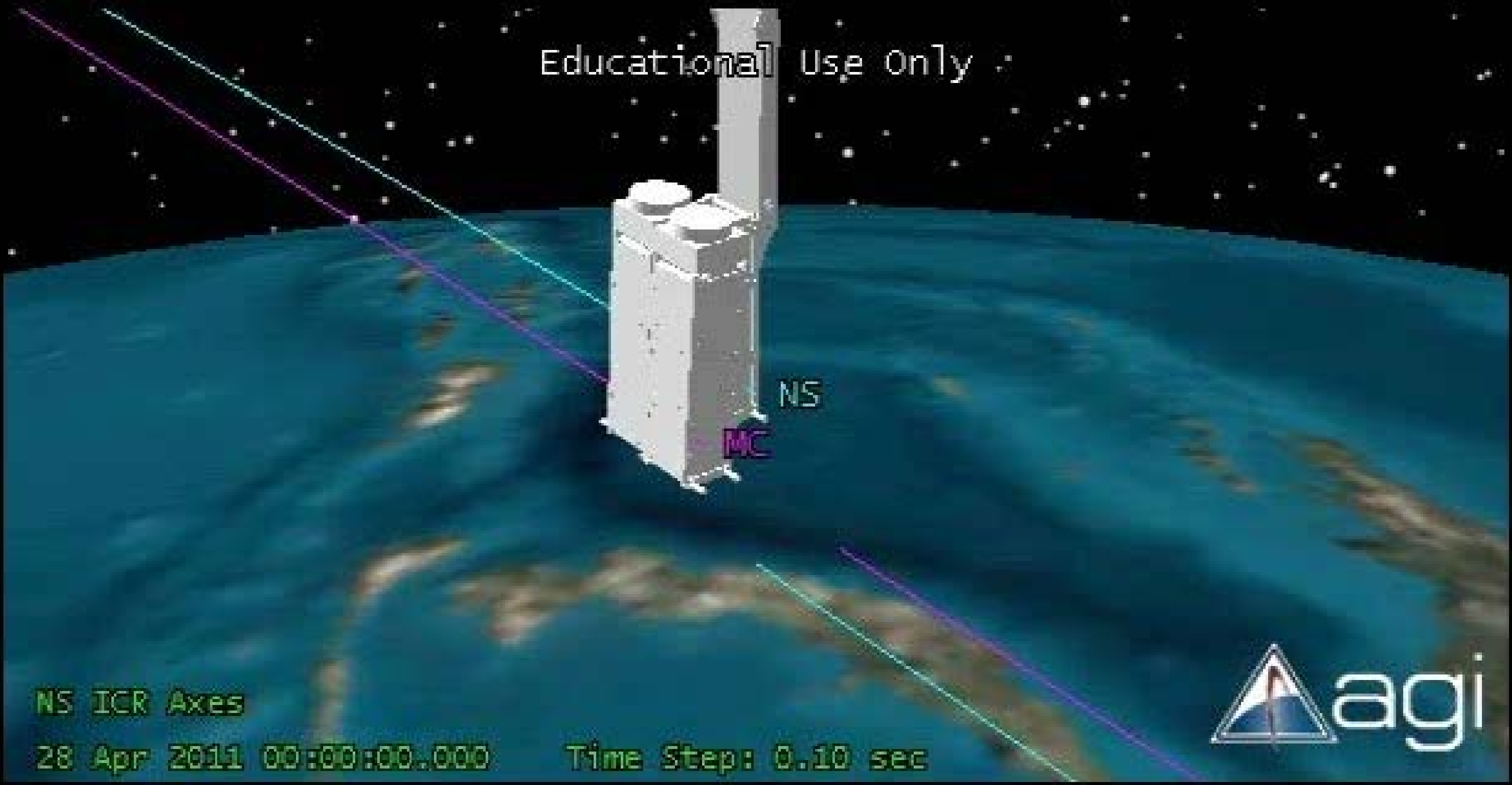


Mask Mechanism



Reconfiguration and Docking Concept

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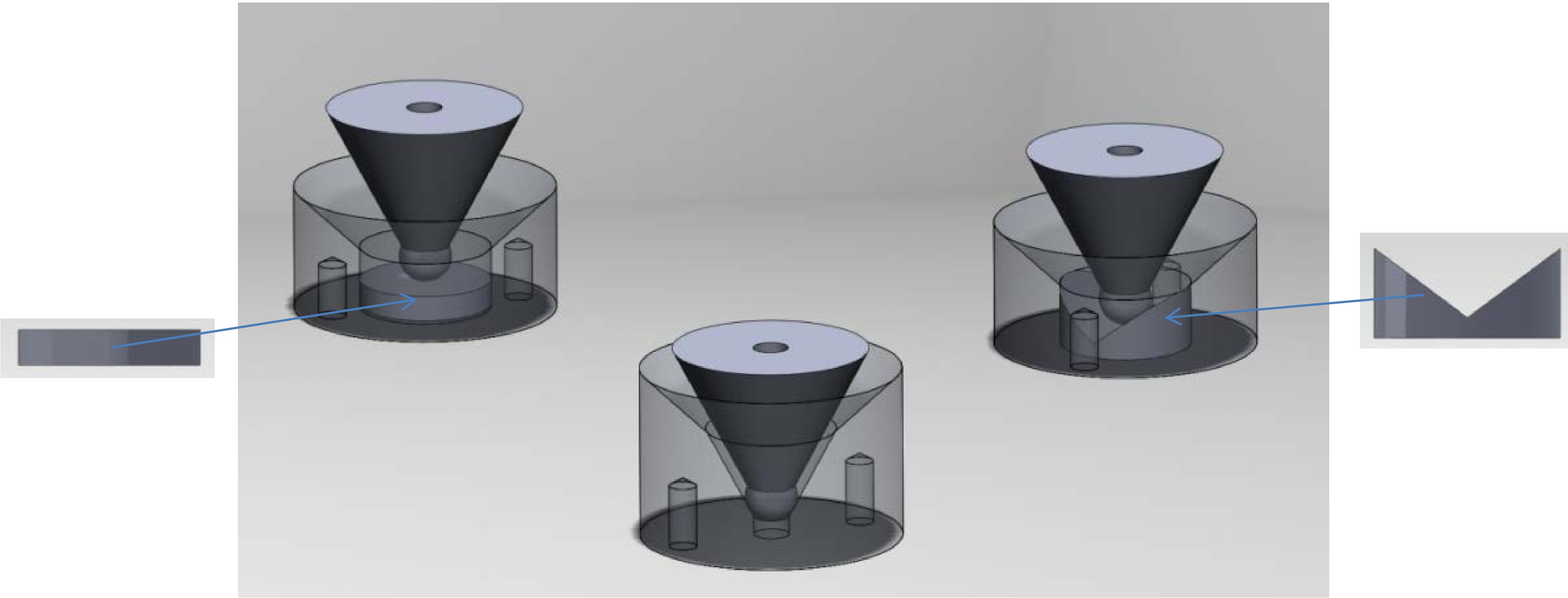
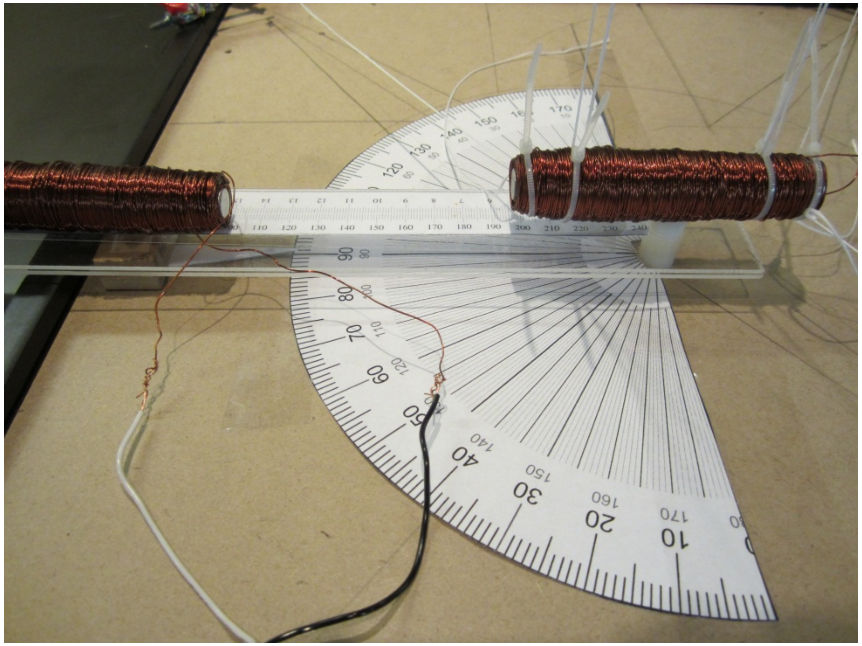
Docking Interface

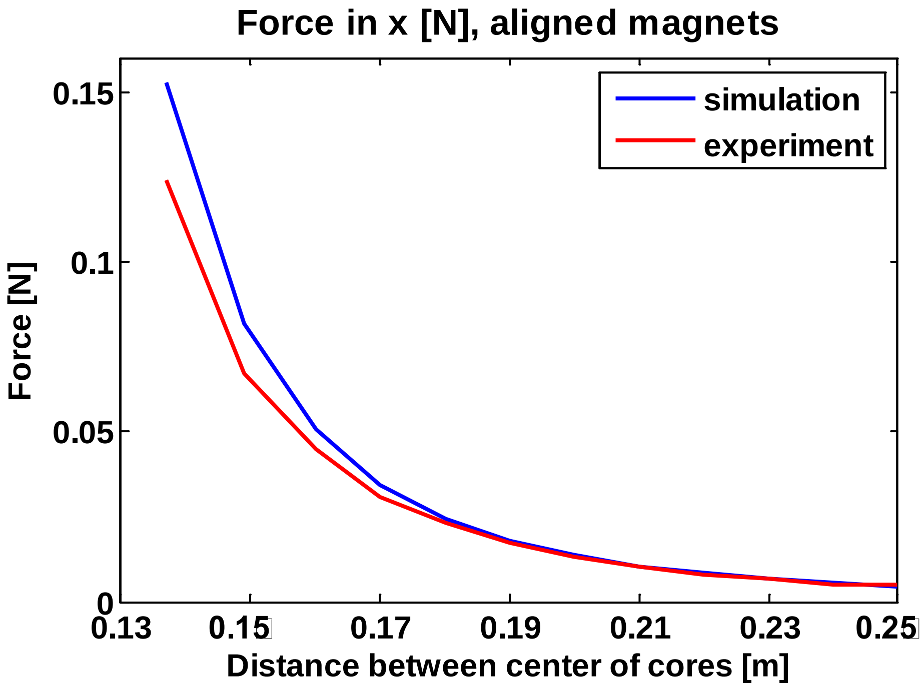


- Permanent magnet provides compressive preload
- Materials: steel cones and Teflon cups

Testing of Electromagnets

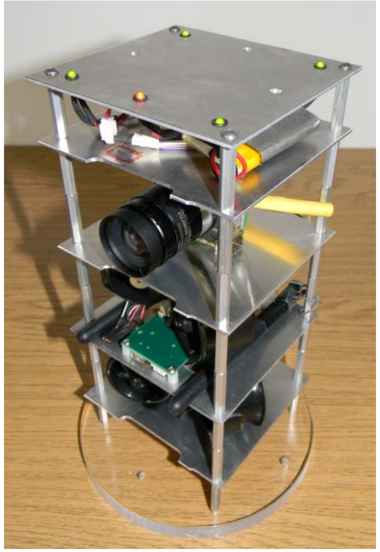
- Each cubesat prototype has two electromagnets
- Used for the final docking approach and undocking





Forces are quite small

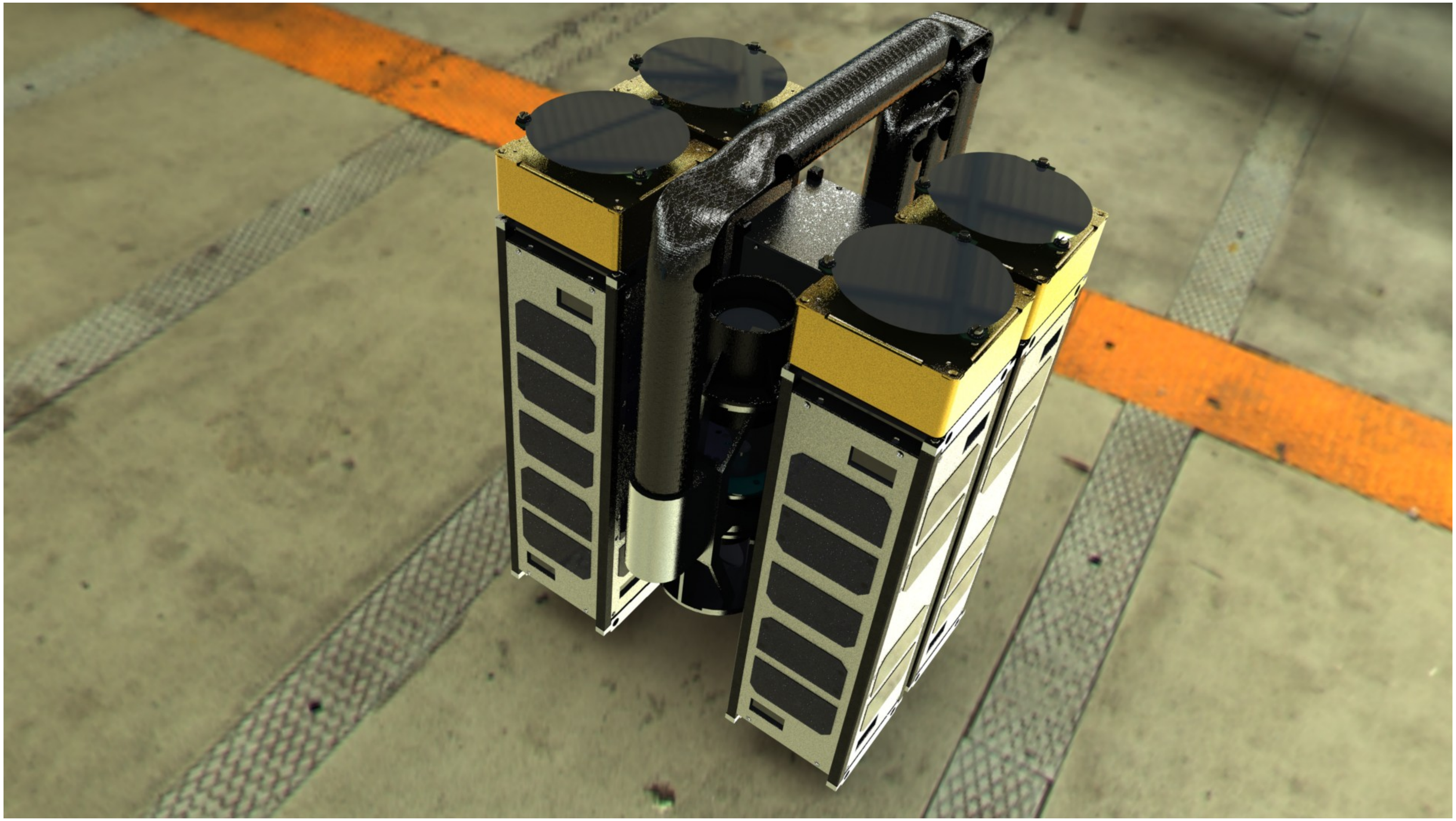
Testing of Docking Maneuver



Robotic Cubesat Surrogate

- Frictionless 2-D environment
- Propulsion mimicked by air jets
- Permanent magnets for latching
- Receding Horizon trajectory planning

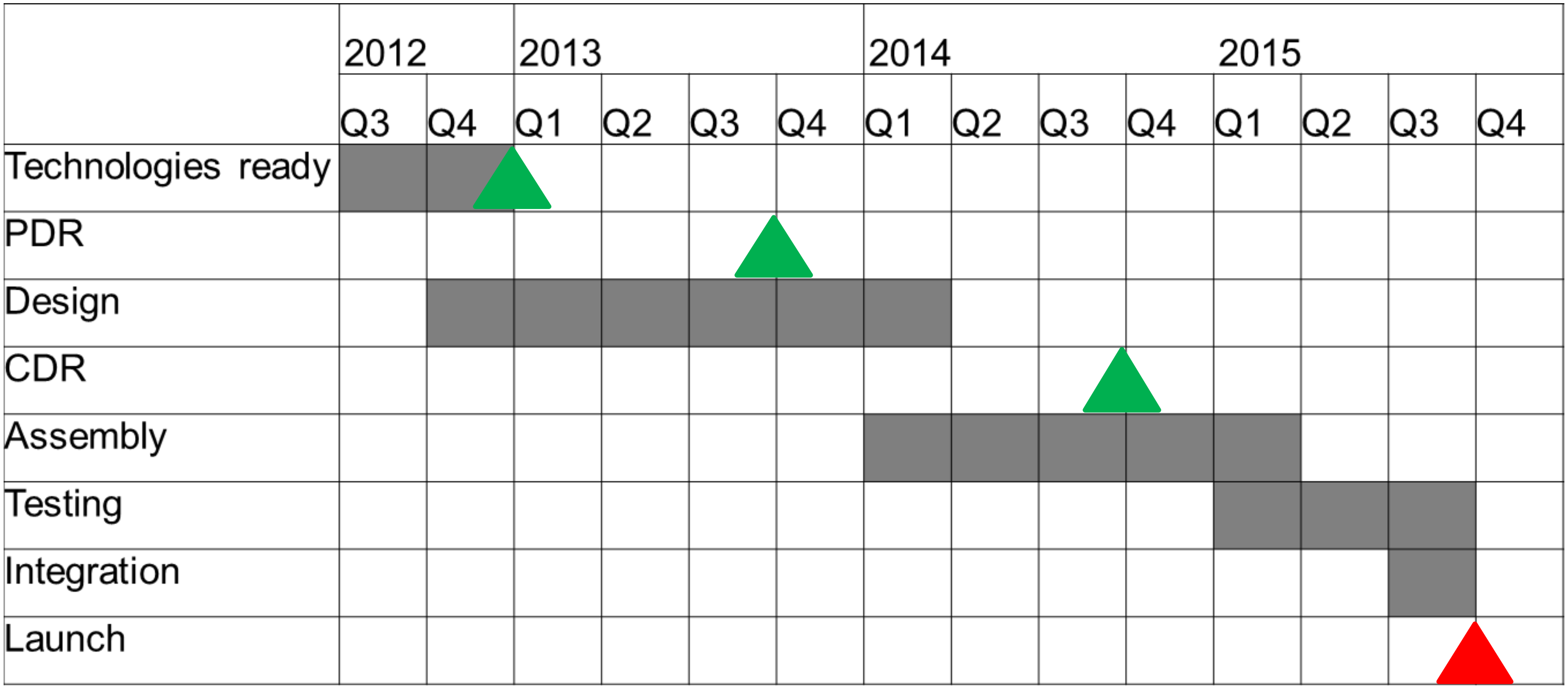
Current Status



Only Joking, it's a Computer Model!

http://pellegrino.caltech.edu/aarest.html

AAReST Schedule



Ae105 2012 Instructors

- **Behcet Acikmese** (Ae105 Instructor)
- **Greg Davis** (Ae105 Instructor)
- **Yunjin Kim** (Ae105 Instructor)

Special thanks to

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- **John Steeves**
- **Gwen Johnson**

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Kobie Boykins

Andrew Kennett

Mark Thomson

Eric Sunada

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