Telescope Development for LISA

For the US Telescope Team
Presented by Jeff Livas/GSFC

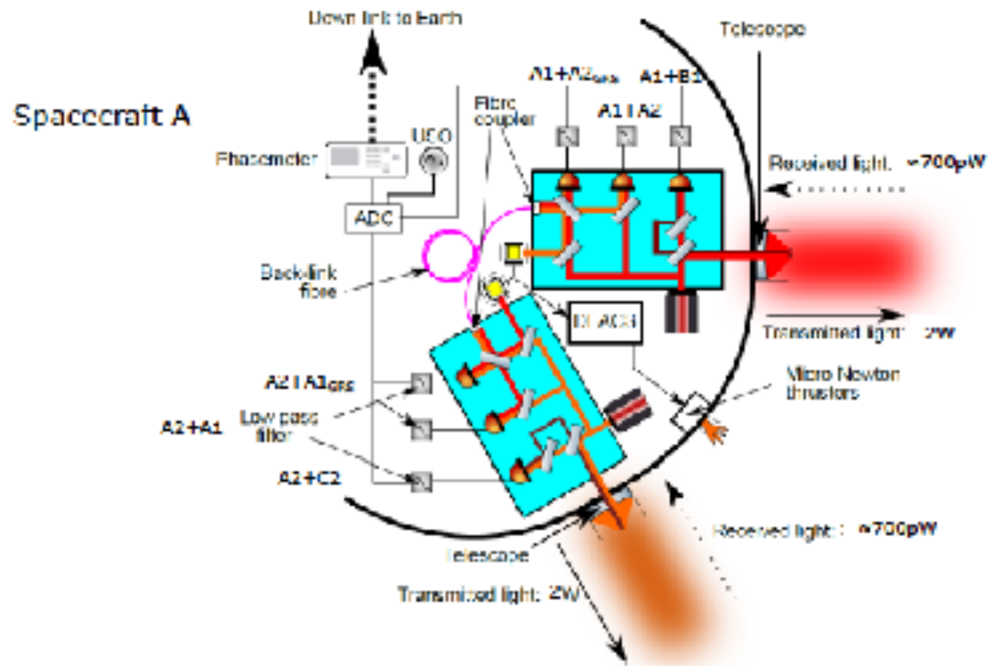
LISA Consortium Meeting
11 April 2018

Telescope Team

- Product design lead (PDL): Ritva Keski-Kuha
- Optics: Hui Li with help from Garrett West, Joe Howard
- Scattered light: Shannon Sankar, Len Seals
- Mechanical: Michael Hersch, Alex Miller, Andrew Weaver, Joe Ivanov
- Thermal: Angel Davis
- Instrument scientists: Ryan DeRosa, Shannon Sankar
- UF: Guido Mueller, Paul Fulda, Joe Gleason, new postdoc, Alex Weaver

Telescope Functional Description

- Efficiently deliver power on-axis to the far spacecraft
- Simultaneous transmit and receive
- Afocal beam expander
  - 300 mm dia primary
  - 2.24 mm dia on bench
  - 134X magnification
- Conjugate pupils to minimize tilt to length coupling
  - Map angular motion of the spacecraft jitter to angular motion on the optical bench with minimum lateral beam walk or piston



- Application is precision length measurement NOT image formation
  - Keep optical pathlength stable to ~ 1 pm/√Hz
  - Minimize coherent transmitter backscattered light

Telescope Design Drivers

- Robust optical design
  - Adequate build tolerances
  - Adequate environmental sensitivity
    - Thermal
      - Steady state
      - Response to fluctuations
    - Vibration, shock
  - Adequate interface tolerances
- Acceptable scattered light performance
  - Reasonable particulate contamination requirements
- Robust mechanical design
  - Materials choice can handle loads and be thermally and mechanically stable
  - Can be manufactured on a small scale
- Acceptable cost, risk

Telescope Design

Designed with support for the baseline trades

- to be revisited mid-Phase A (MCR/Feb 2019)

- Breathing angle compensation scheme
  - Baseline is telescope pointing
  - Confirmation pending fibre reliability tests
  - Expectation is that the backlink fibre with full balanced detection can be made to work
    - Already demonstrated in the lab
- Optical truss
  - Baseline is not to include it
  - Plan is to build telescope with required level of stability
    - Previous testing at UF and GSFC show this should be possible
- PAAM (Point Ahead Adjustment Mechanism) metrology
  - Adopt a step-and-stare scheme
  - PAAM is fixed most of the time so no metrology needed

Key Telescope Milestones

- NASA plans to supply a telescope that meets LISA mission requirements
  - Not necessarily a specific design: ideally, pick the best one
  - Schedule is tight for adoption, so the 4-mirror design is baselined
- Baseline design to Phase A Industrial contractors April 2018
  - They study it
- Meanwhile, NASA develops the baseline design/prepares for procurement
- Procurement initiated Feb 2019 (pending confirmation of baseline trades and design at the Mission Consolidation Review (MCR))
  - 12 months for a mechanical model (Feb 2020)
  - 18 months for first optical model (Aug 2020)
  - 24 months for second optical model (Feb 2021)
- ISO TRL 5 (breadboard) delivery (Nov 2021)
- ISO TRL 6 (elegant breadboard) (Nov 2023)
- In parallel, UF will
  - Develop a facility for testing the dimensional stability
  - Develop a concept for an optical truss
  - Perform auxiliary scattered measurements

Not much time for testing!

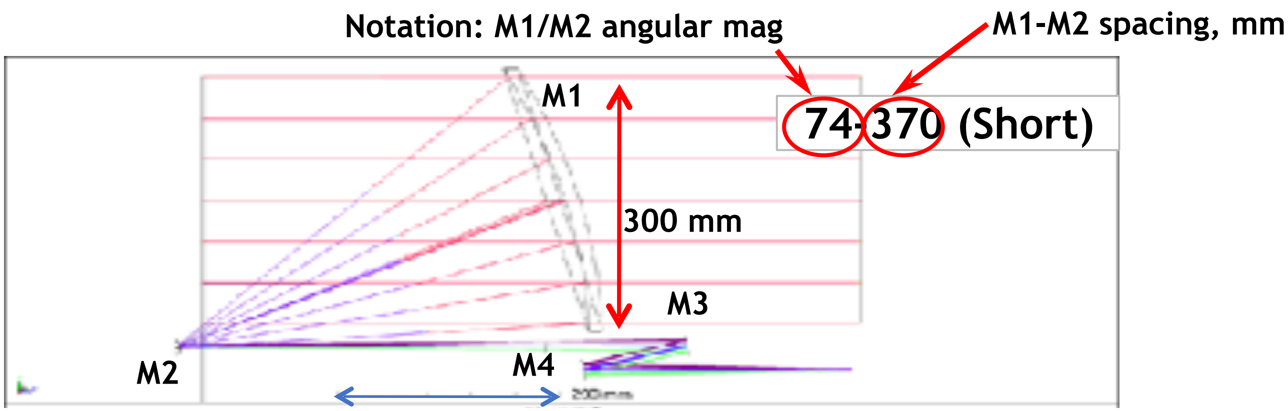
Note that if a different design is selected at the MCR, NASA will still build it but there will be a schedule delay

4-mirror Design Optimization

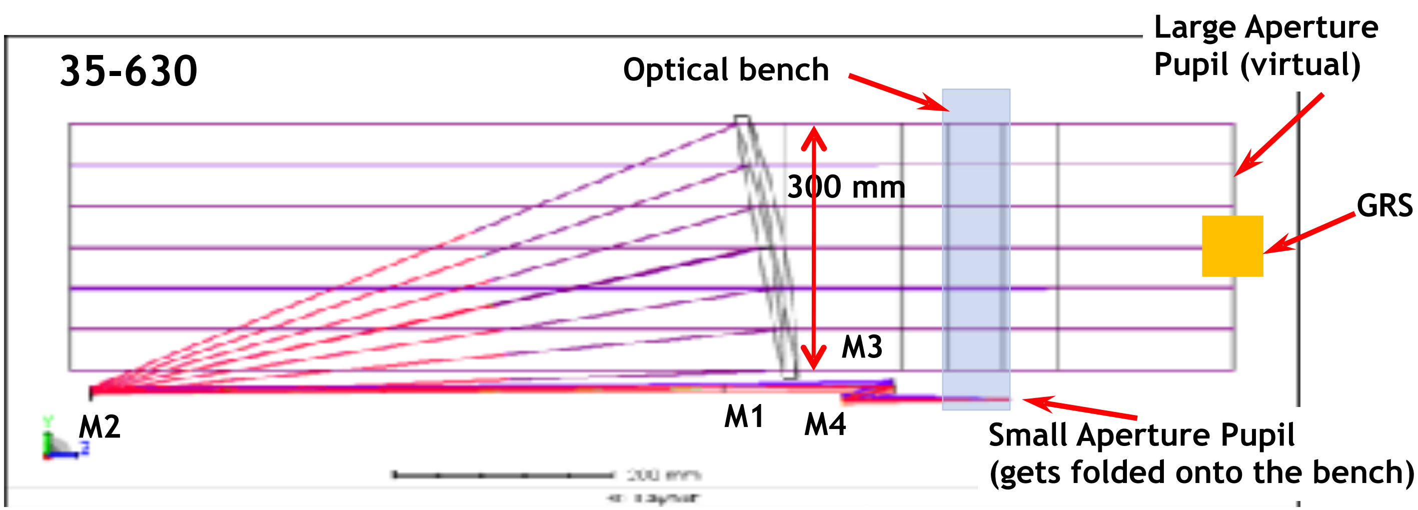
- 4-Mirror Design is the baseline
- Have been evaluating/optimizing the design
  - **No change in requirements/specifications**
  - **Just easier to build**
- Explored mirror positioning sensitivities and scattered light performance
- Parameters that were varied
  - M1-M2 separation
  - M1/M2 Magnification
  - optical surface shapes/figures
- Considering actuator for focus adjustment with M3/M4 grouping

Baseline vs Optimized Design

Same scale



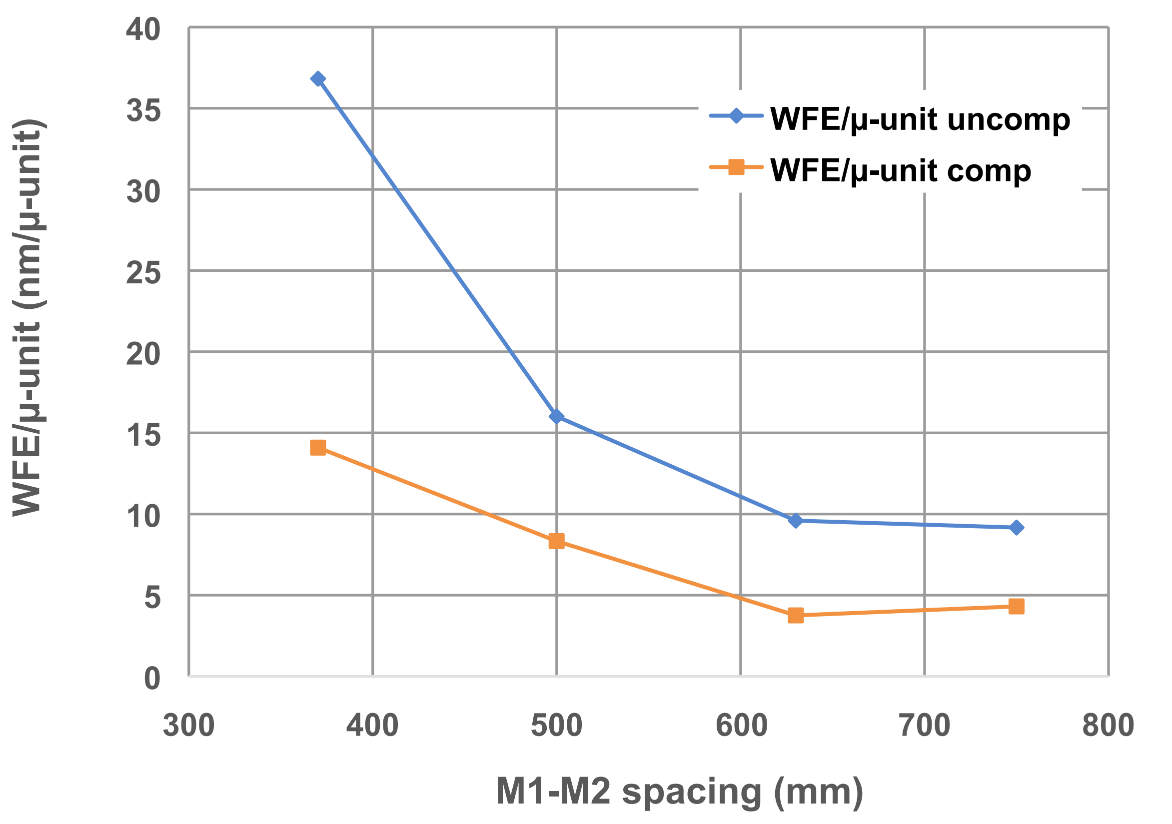
No change to requirements/specifications: just optimized to be easier to build



- Volume envelope (mm) is 520 x 520 x 1160

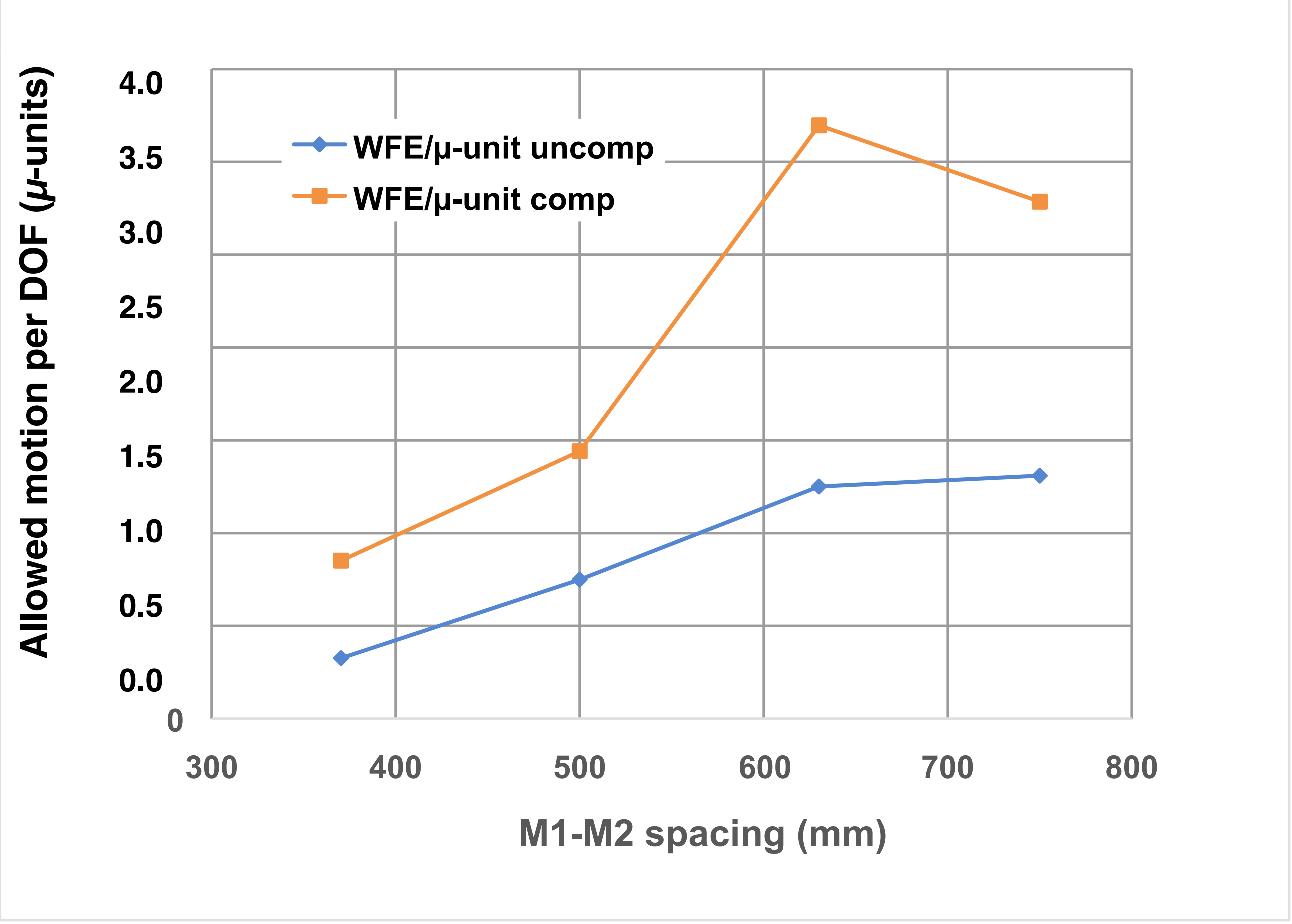
WFE Sensitivity vs micro-unit motion

- All degrees of freedom are RSS-ed together
- Lower number is better

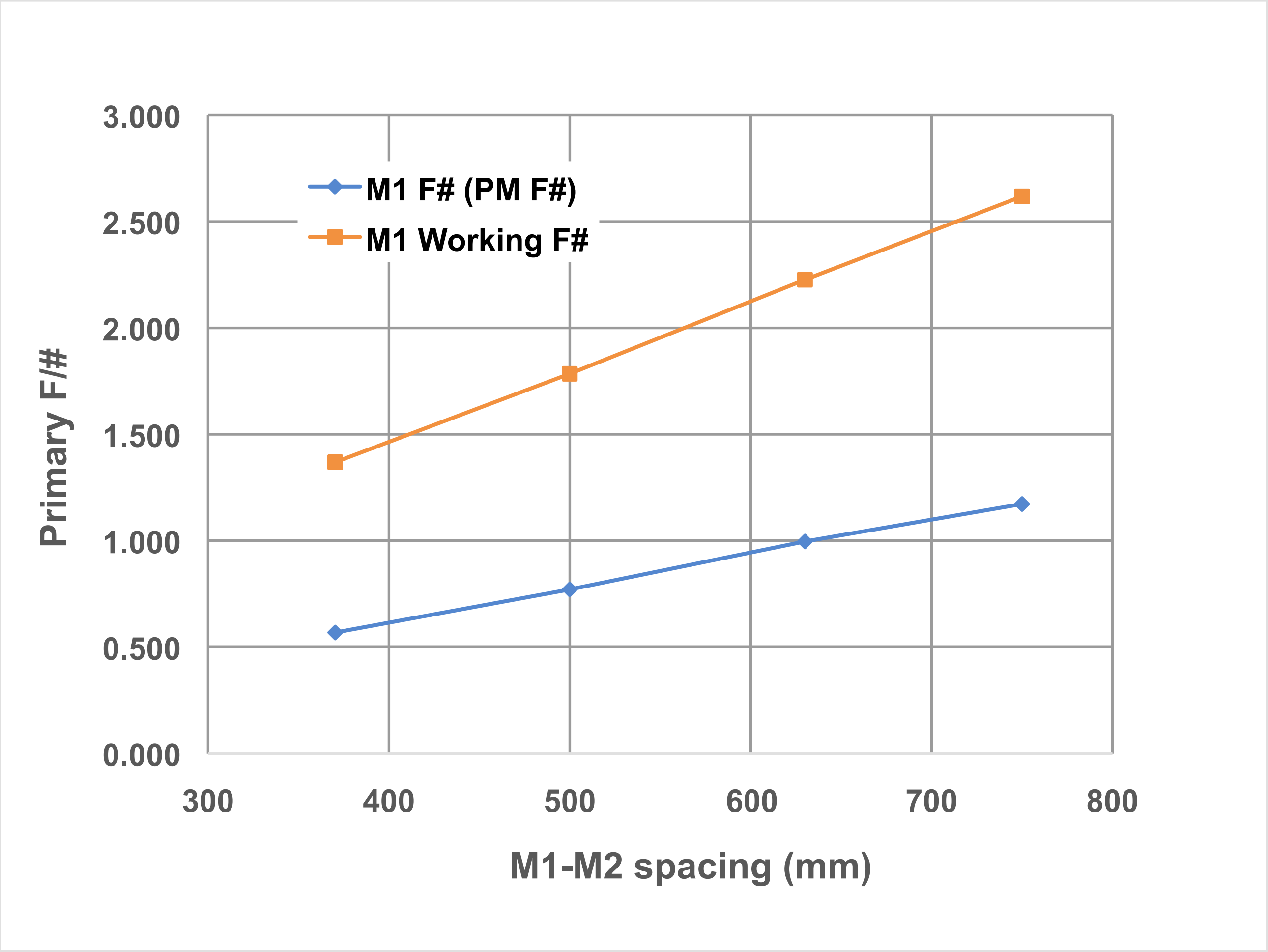


Allowed motions per Degree of Freedom

- Total WFE per budget allocation
- Higher number is better

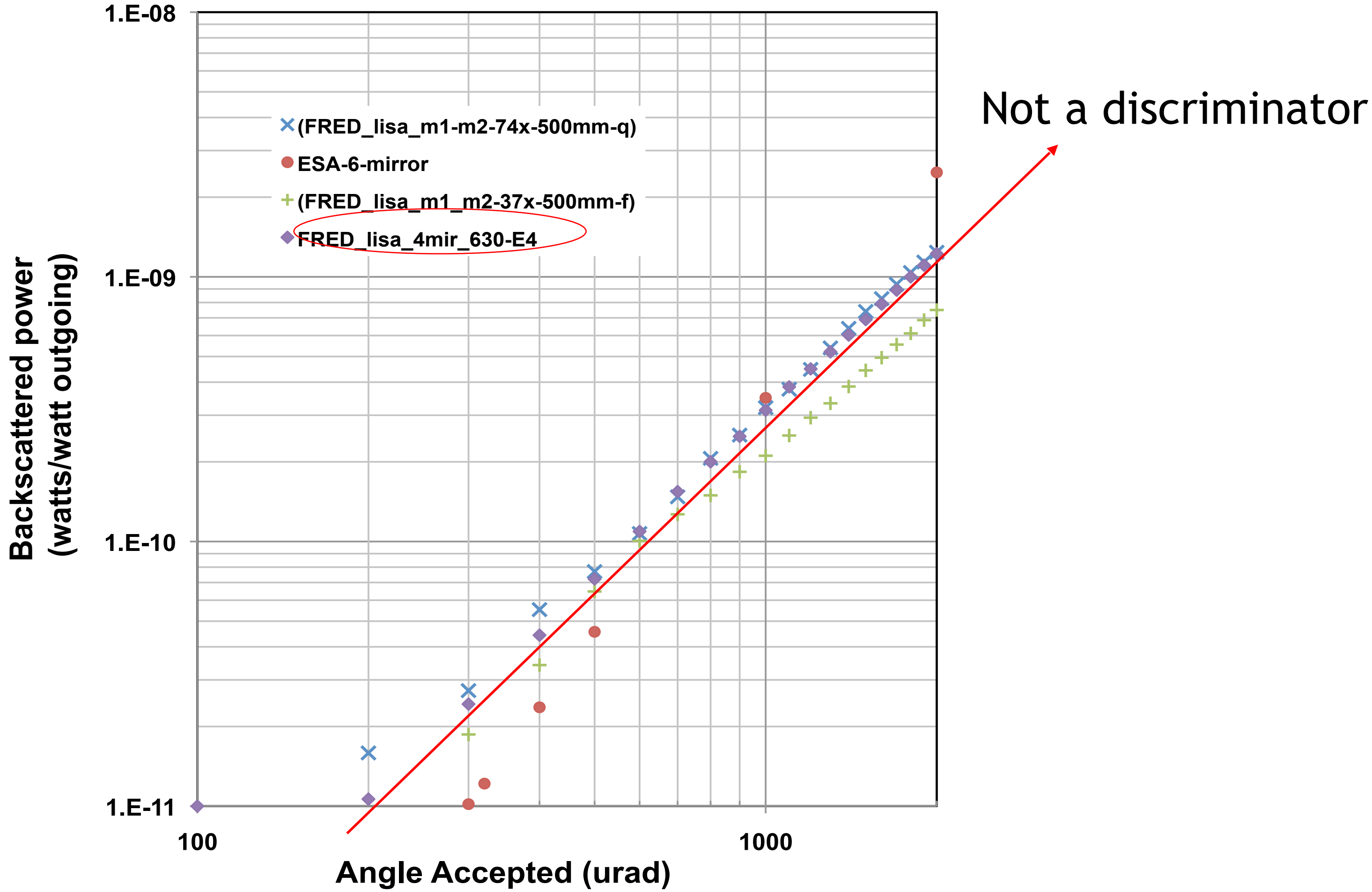


Primary Mirror F/#

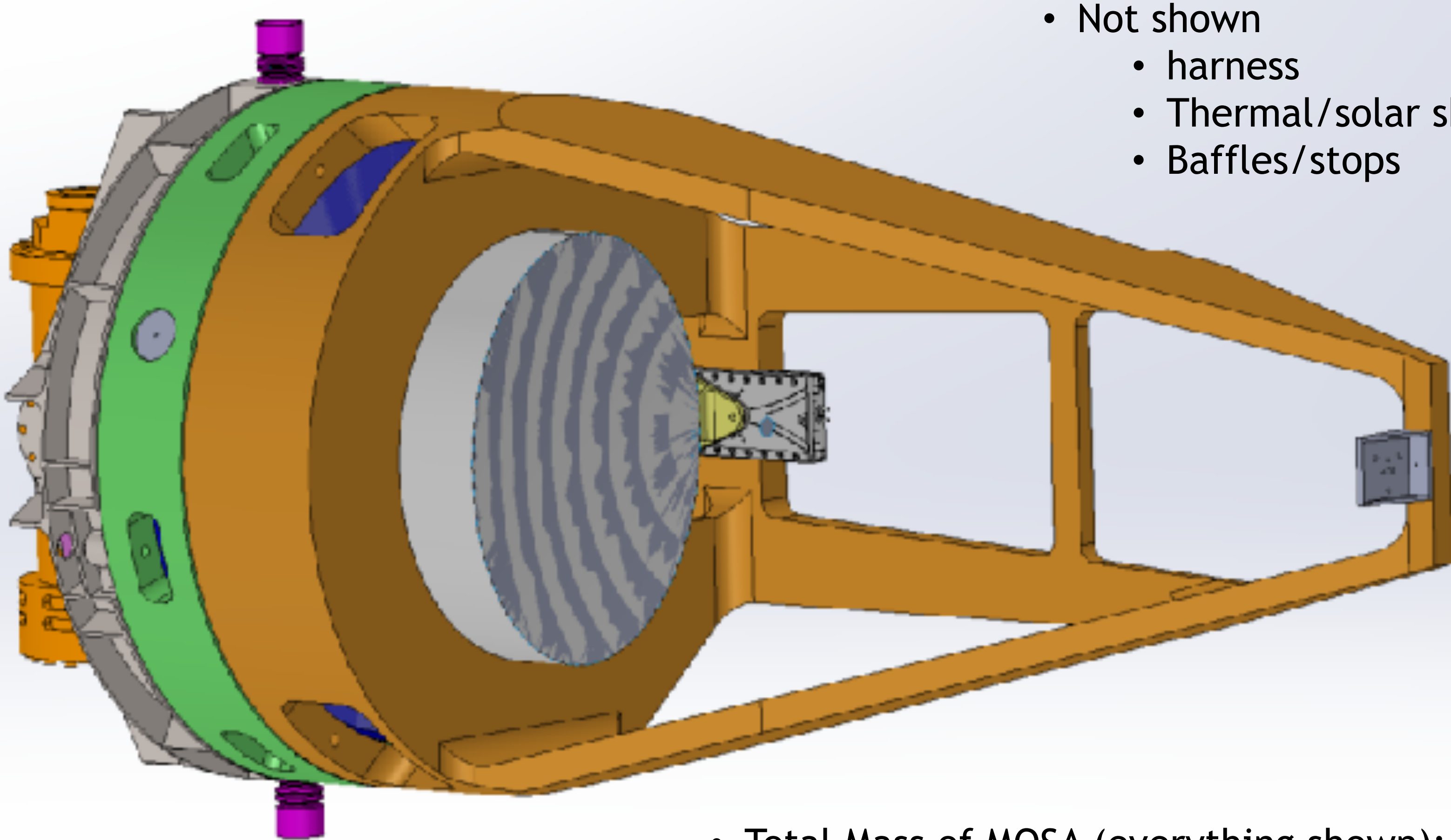


Scattered Light Performance: little difference

Modeled with FRED under similar surface roughness and contamination



Moveable Optical Sub Assembly (MOSA) Notional CAD Model

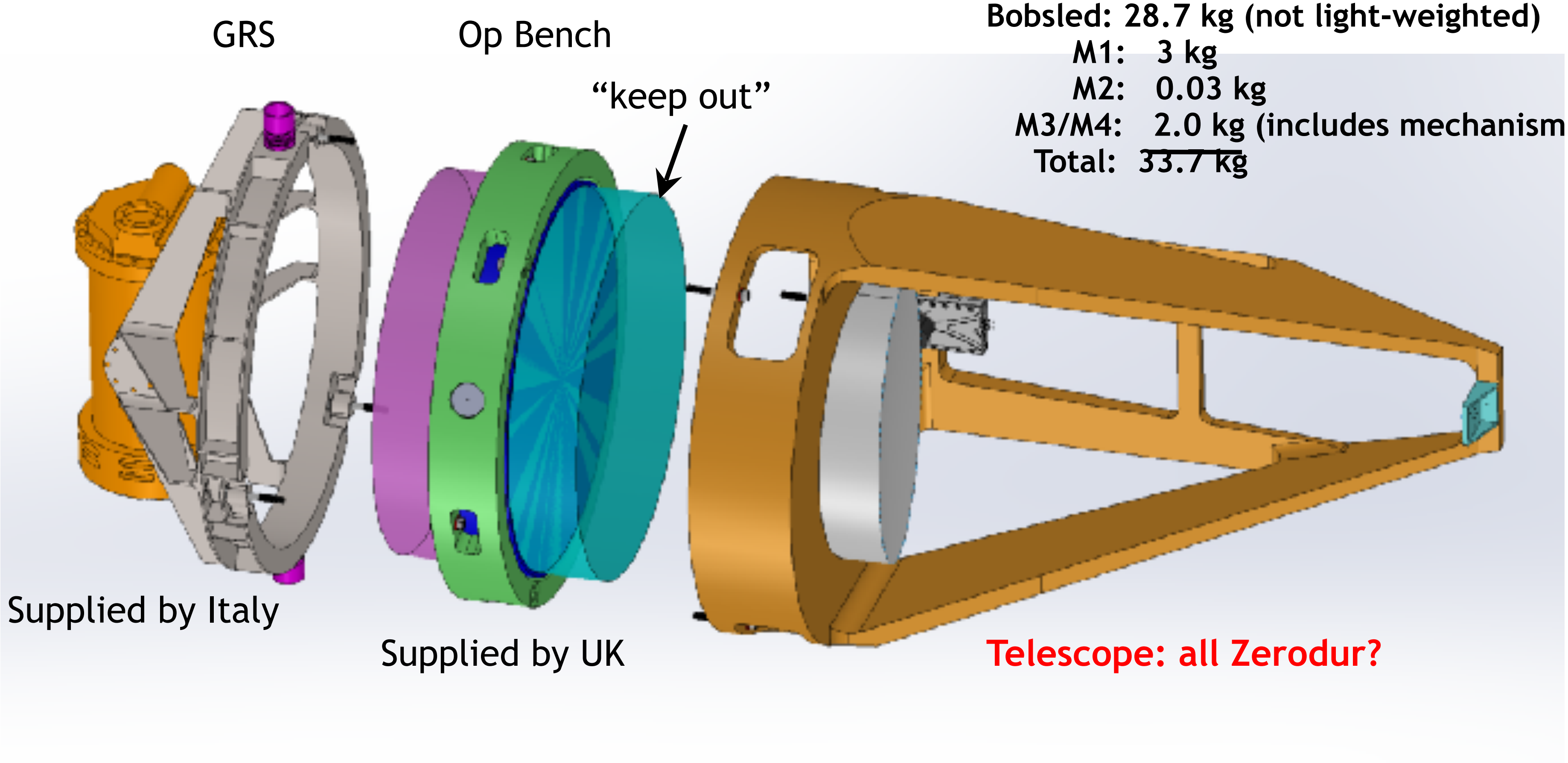


- Not shown
  - harness
  - Thermal/solar shields
  - Baffles/stops

- Total Mass of MOSA (everything shown): **84.5 kg**
  - **GRS = 17.7 kg**
  - **OB = 25 kg, ring = 8.1 kg if Zerodur**
  - **Telescope = 33 kg**
- Volume envelope (mm) is 520 x 520 x 1160

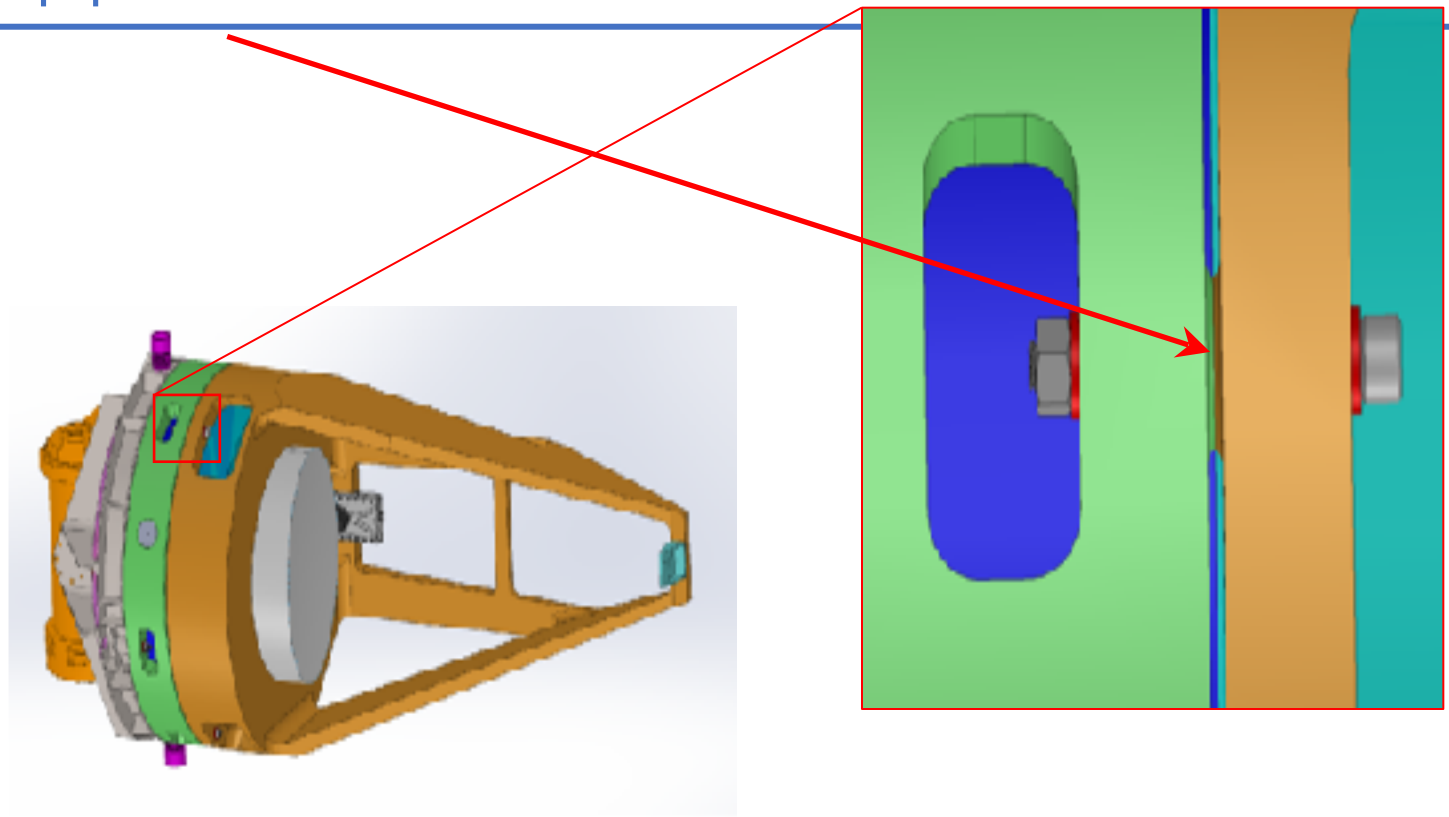
Moveable Optical Sub Assembly (MOSA)

Notional CAD Model



- Notional: need to agree on interfaces, etc including for testing at UF
- Modular to allow for alignment and integration of OB with telescope or GRS
- Lightweighting and structural analysis in progress

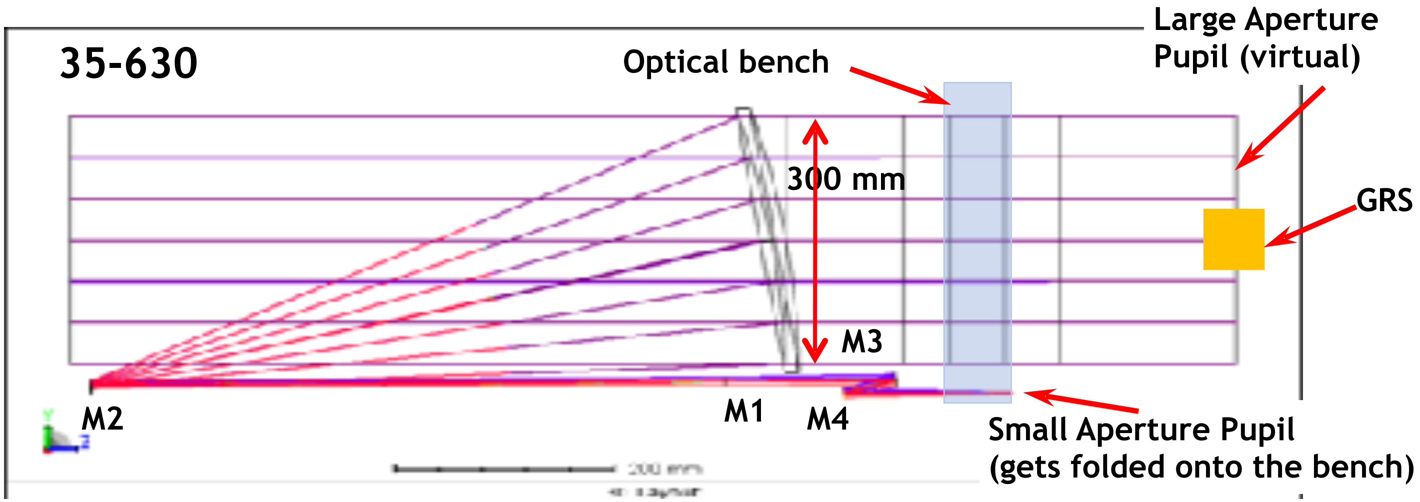
Lapped Interfaces

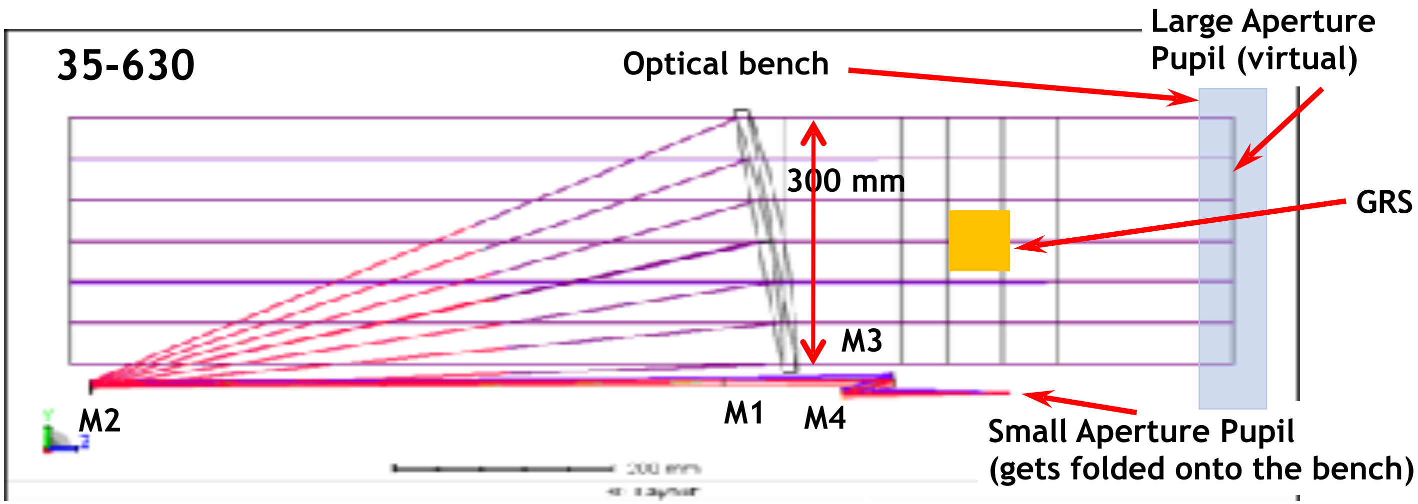


- Key is all-zerodur metering between telescope and OB
- Three lapped pads between telescope (orange) and OB Ring (green)
- Three lapped pads between GRS mount (grey) and OB Ring (green)
- Fastened with an athermalized bolt stackup (high CTE red washers). Bolts will be stretched and fastened; no torqueing at these interfaces.

Swapping the order of the OB and GRS

Basically swaps the positions of the large and small aperture pupils

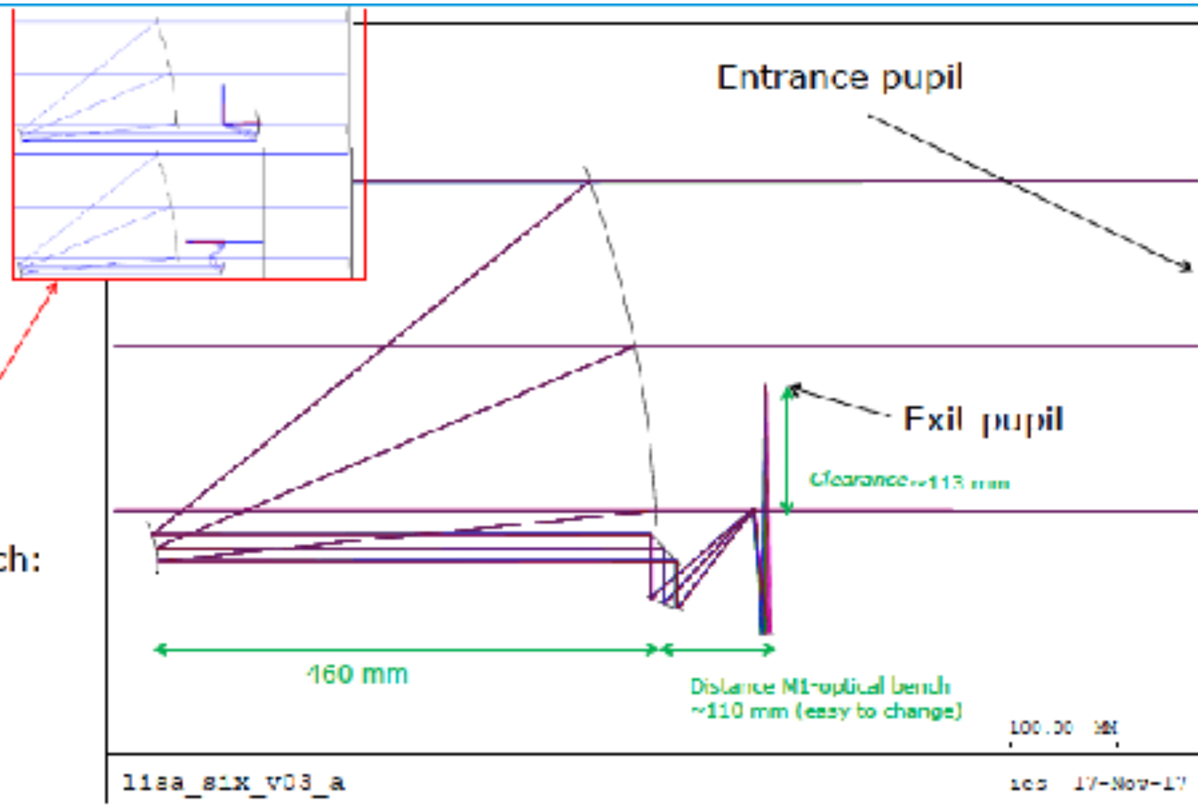




6 mirror design required

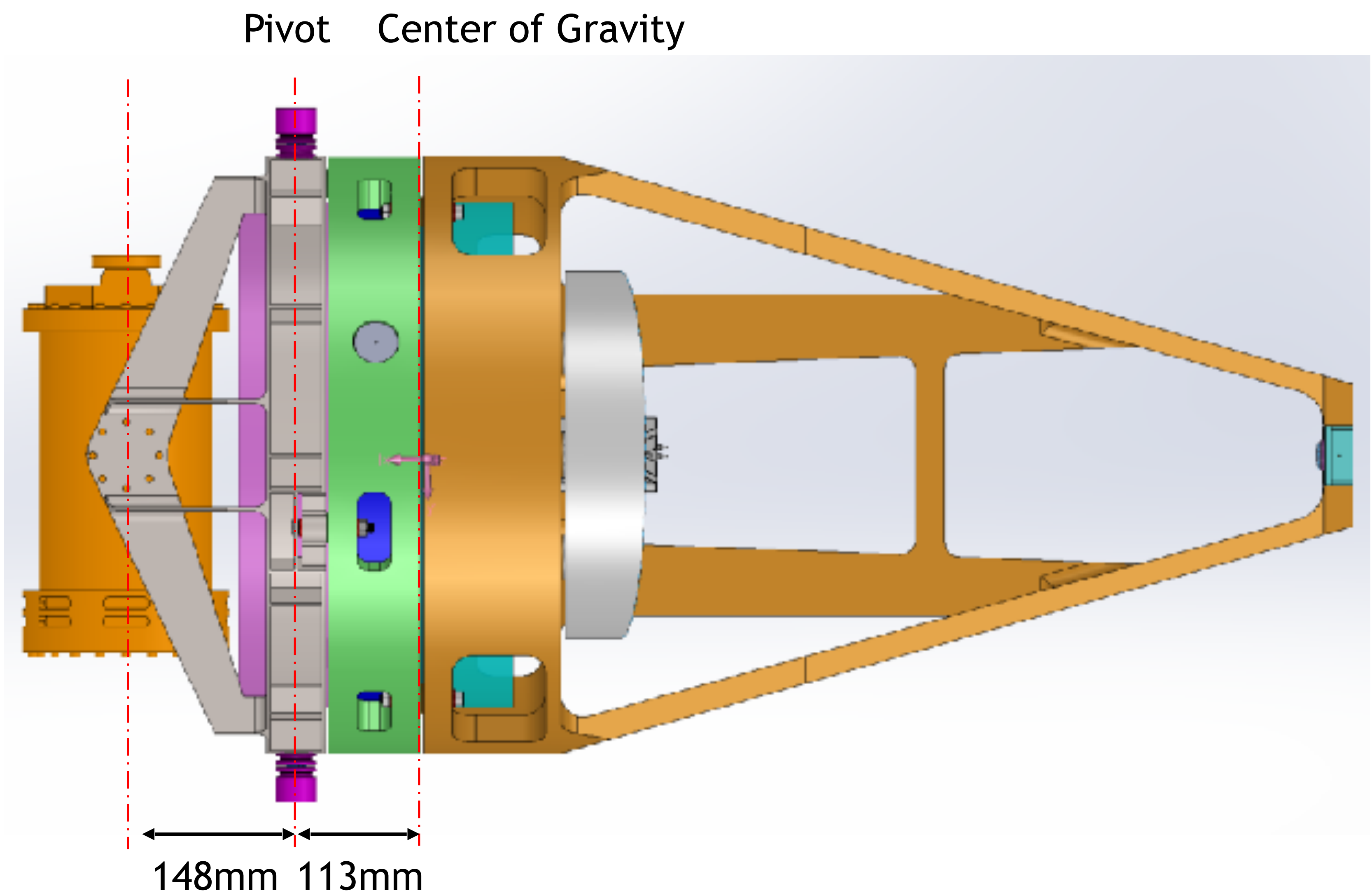
Distance from M1 to the optical bench can be extended more easily

- Entrance/exit pupils: 300/2.24 mm
- Six mirrors:
  2 parabolas
  1 flat (folding)
  1ellipses
  2 hyperbolas
- Exit pupil clearance: ~ 113 mm
- Distance M1-optical bench: ~110 mm, can be changed easily without a major Impact on pupil clearance: folding flexibility.



Design by Isabele Escudero Sanz/ESTECH

Pivot could be placed over GRS

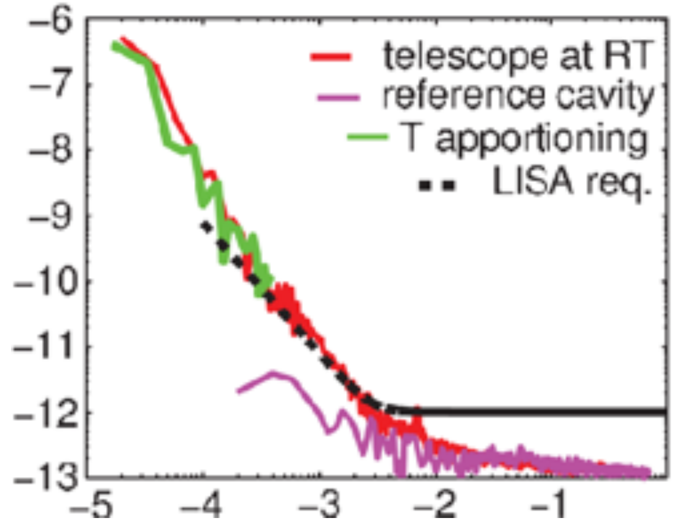


Previous Work:
SiC Spacer Dimensional Stability Demonstration

Spacer Activity Objective

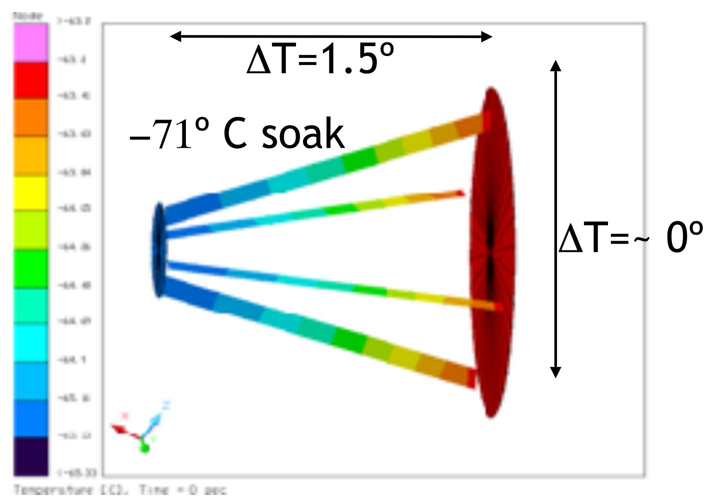
- Develop and test a design for the main spacer element between the primary and secondary mirrors
- M1 - M2 spacing identified as critical by tolerance analysis
- SiC meets stability requirement
- On-axis Quadpod would not meet scattered light requirement

SiC Spacer Design
Meets Requirements



SiC Spacer Design: QuadPod

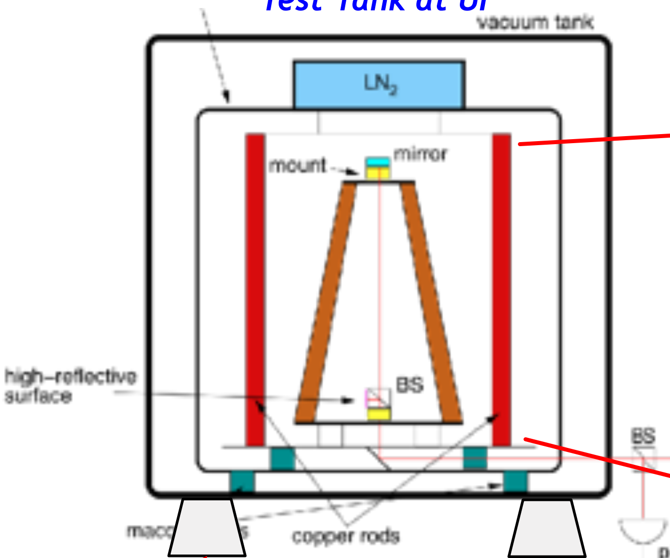
Thermal Model to Determine Test Conditions



Sanjuan, J., et al. *Rev Sci Instrum* **83**(11), 116107 (2012)

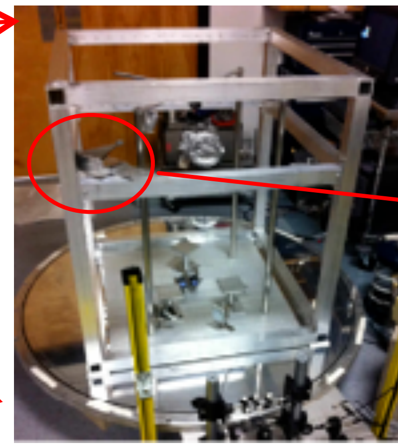
Previous Work: UF Test Facility

Test Tank at UF

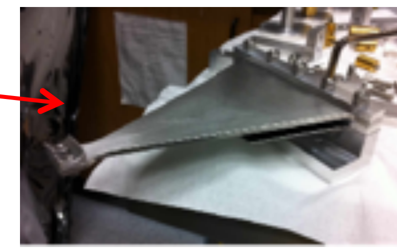


Second stage inside tank

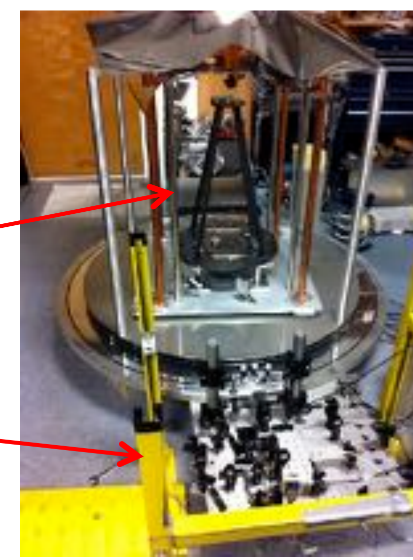
Interior frame supports spacer



Isolation provided by compact spring blades



Vibration isolation: first stage is damped spring feet

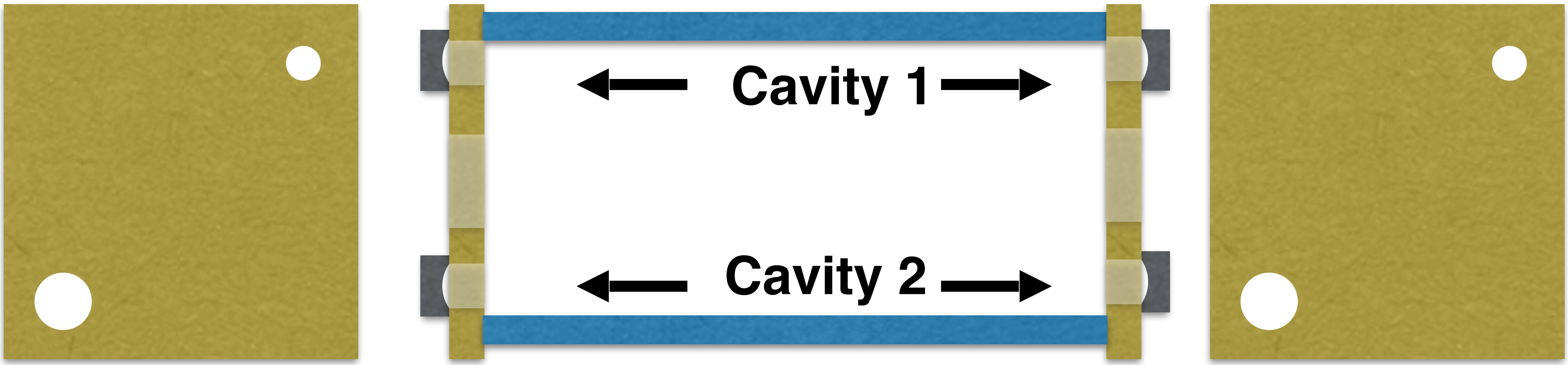


Spacer shown in place

External optics

University of Florida: Telescope Length Stability Testing

2 year development phase



Telescope testbed for pm-tests:

- ULE/Zerodur/Clearceram structure
- Three integrated optical cavities
  1. Reference Cavity
  2. Test cavity

- Place telescope inside structure
  - Use cavity 2 for telescope cavity (next slide)
  - Reduce input beam size to ~300um
    - Telescope output: 4.5cm waist
  - Open Questions: Losses/Finesse
  - Flip orientation to have > 30cm clear aperture

Step 1: Shorter/smaller testbed of testbed (Size: TBD, ~20cm long)

- Test techniques to assemble structure (avoid non-reversible bonding techniques)
- Design/testing of small optical bench/telescope/truss interface

Step 2: Design final testbed for final telescope based on lessons learned

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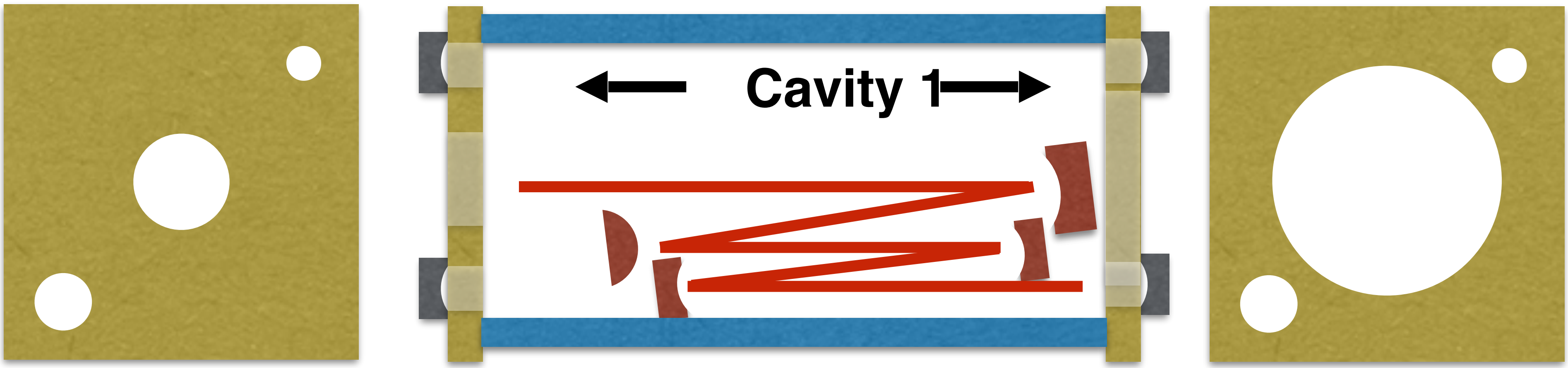

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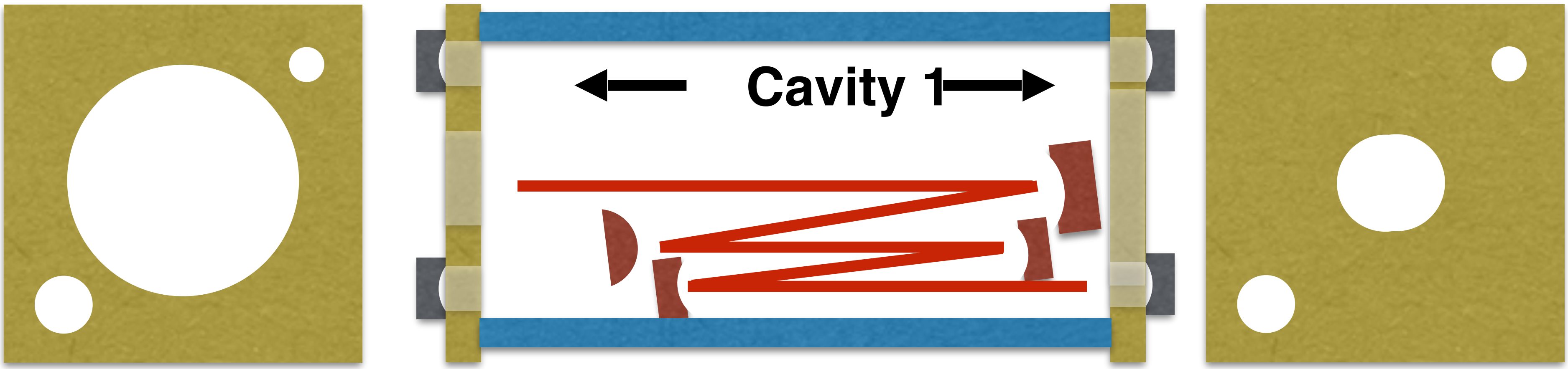

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Summary

- **Robust 4 mirror design has been developed**
  - Meets LISA requirements
  - Flexible
  - Buildable
- **Schedule is tight to build and test**
- **Much work still to be done**
  - Structural/thermal analysis and materials and joints testing as needed
  - Interface definition: Telescope-OB, but also complete MOSA
  - Testing definition: what can realistically be accomplished/needed for Adoption
  - Unit testing
    - WFE
    - Scattered light
    - Pathlength stability
    - Environmental testing
  - Higher level of integration testing
    - With optical bench
    - Far-field simulator
    - End-to-end simulator modeled on GRACE-FO test set-up?