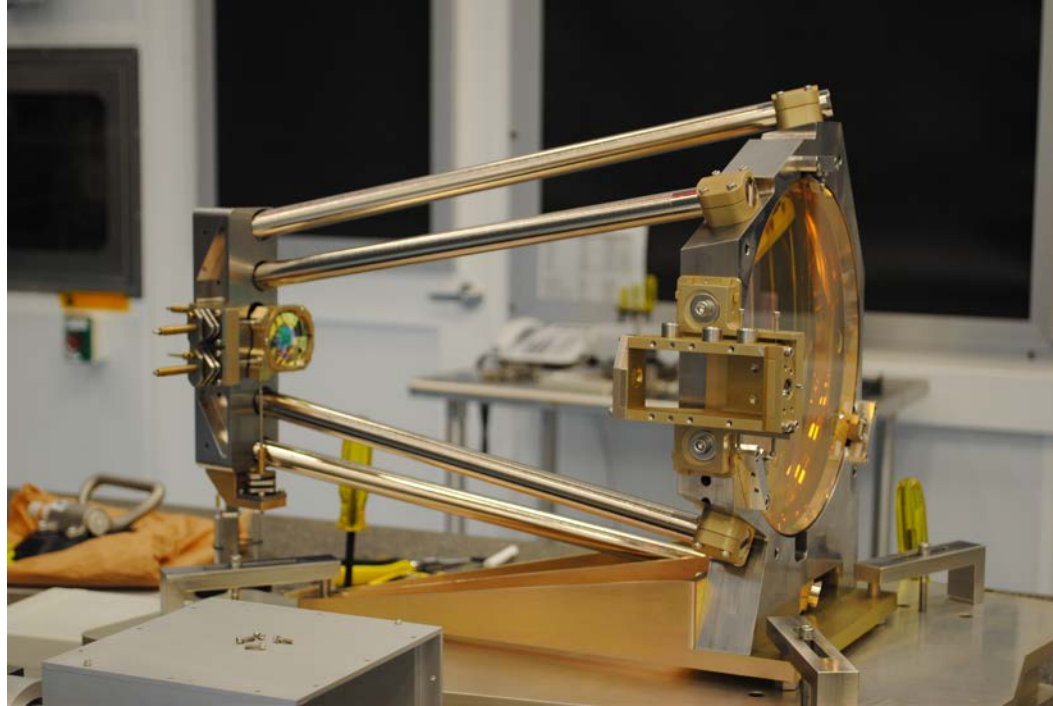




Telescope Design for LISA



**Jeff Livas, NASA Goddard Space Flight Center,
Ewan Fitzsimons, UK Astronomy Technology Centre
Isabel Escudero Sanz, ESTEC
LISA Symposium Meeting
11 July 2018**



US 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, **Ada Uminska**, Alex Weaver, **Simon Barke**

(Here at the Symposium)



Related Talks and Posters

Monday

- Ewan Fitzsimons (UK ATC): Optical Metrology for LISA: Optical Bench Design and Metrology Performance

Tuesday

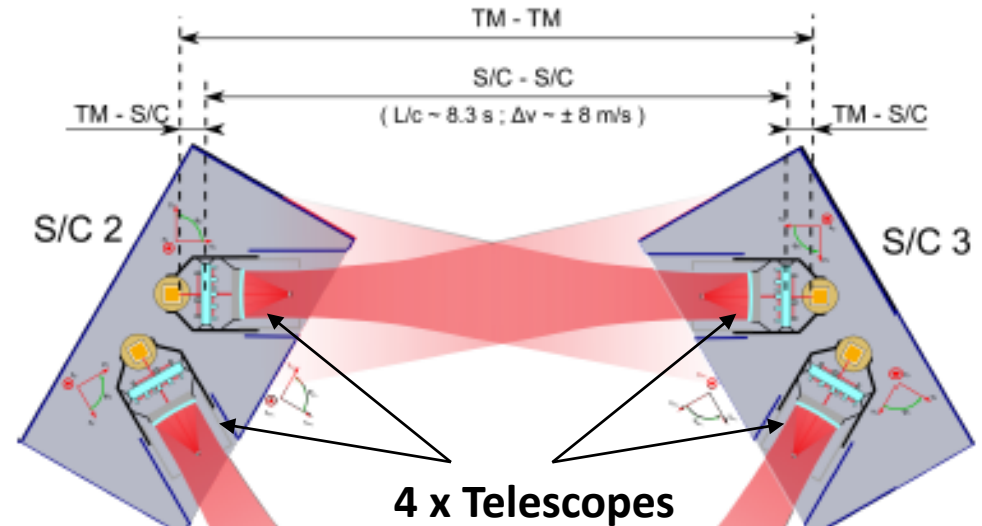
- Gudrun Wanner (AEI Hannover): Angular and Lateral Jitter Cross Coupling in LISA Pathfinder and LISA

Wed

- David Robertson (Glasgow): Building LISA Optical Benches – Speed and Precision through Automation, 9:20 AM
- Catherine Nguyen (APC/CNRS): LISA Telescopes -- Scattered Light Issues, 9:40 AM
- Shannon Sankar (Maryland): Analysis of the LISA Telescope Optical Design, 10:20 AM
- Lea Bischof (AEI Hannover): Investigating an Optimal Backlink Candidate for LISA, 11:50 AM
- Simon Barke (UF): Ultra-stable Mechanical Interfaces for Optical Bench and Telescope Testing poster 309.28

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
 - From Gudrun Wanner's talk: "relay"



From the LISA Payload Description Document

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



Key Requirements

Parameter	Driven by	Required value
wavelength	laser frequency noise	1064 nm
Large aperture diameter	shot noise	300 mm
large aperture (external) pupil location	tilt to length coupling	in the plane of the center of mass of the Proof Mass (virtual)
small aperture diameter	optical bench design	2.24 mm clipped gaussian with $\omega = 1.0$ mm
small aperture (internal) pupil location	optical bench design	200-250 mm behind the primary vertex
Afocal magnification	optical bench design	$300/2.24 = 135X$
optical throughput power efficiency	shot noise	> 0.85 (mirror reflectivity and internal clipping)
net wavefront quality departure from a collimated beam over the science field of view	pointing	$< \text{or} = \lambda/30$ RMS (35 nm)
science field of view	stray light	± 8 microradians
Science field of regard	orbits	± 20 microradians
Acquisition Field of Regard	link acquisition	± 225 microradians
small aperture (internal) pupil distortion	heterodyne efficiency (SNR)	$< 10\%$
optical path length stability	displacement noise budget	$< 1 \text{ pm}/\sqrt{\text{Hz}} \times (1+(3 \text{ MHz}/f)^4)^{1/2}$
coherent backscatter	phase noise	$< 1 \times 10^{-10}$ into the science field of view at the detector

From the LISA Payload Description Document



Telescope Design Drivers

- **Robust optical design**
 - Adequate build tolerances
 - Adequate environmental (in-)sensitivity
 - Thermal
 - Steady state
 - Response to fluctuations
 - Vibration, shock
 - Adequate interface tolerances
- **Robust mechanical design**
 - Materials choice can handle loads and be thermally and mechanically stable
 - Can be manufactured on a small scale (need ~ 10 units)
- **Acceptable scattered light performance**
 - Reasonable particulate contamination requirements
- **Acceptable cost, risk**

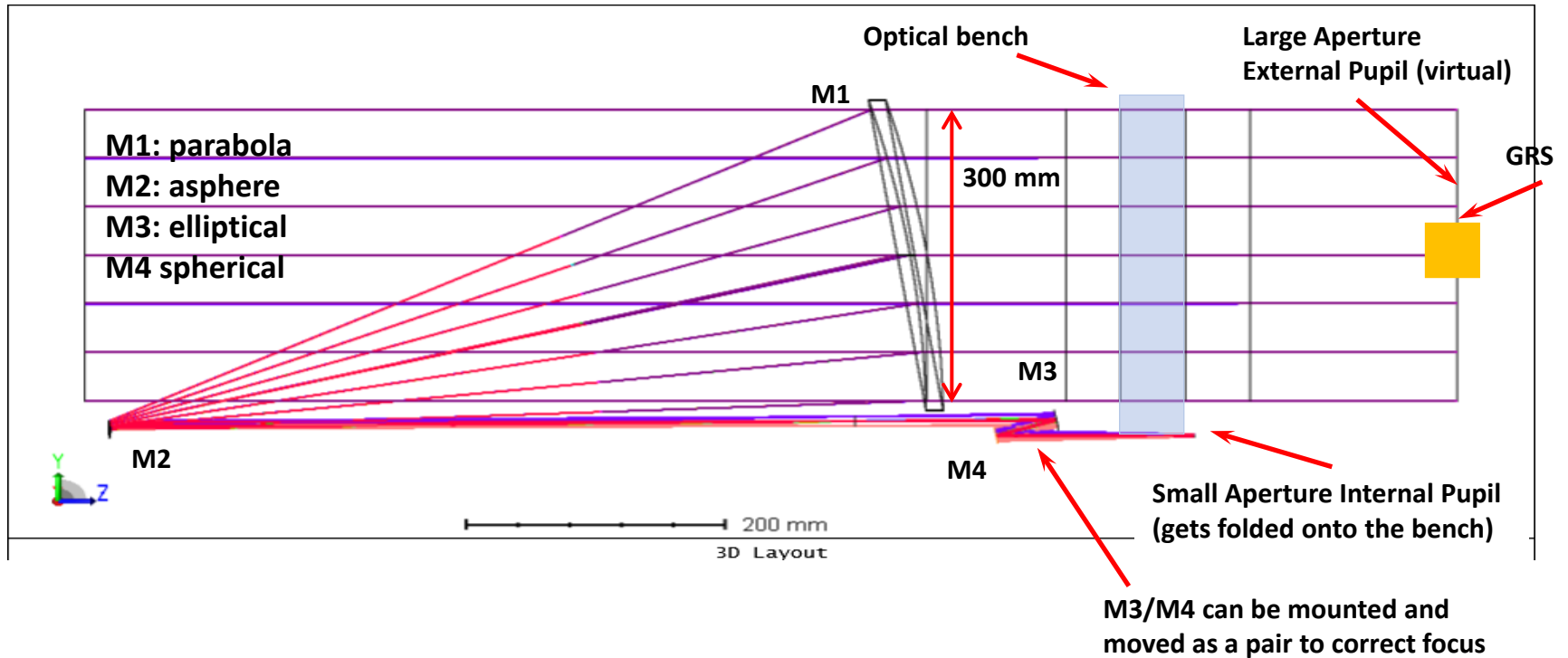


Telescope Design

Designed with support for the baseline trades

- **to be revisited mid-Phase A (MCR/~Mar 2019)**
- **Breathing angle compensation scheme**
 - **Baseline is telescope pointing**
 - **Confirmation pending fiber reliability tests**
 - **Expectation is that the backlink fiber with full balanced detection can be made to work**
 - **Already demonstrated in the lab**
- **Optical truss**
 - **Baseline is to not include it**
 - **Plan is to build telescope with required level of stability**
 - **Previous testing at UF and GSFC show this should be possible**

Baseline Design

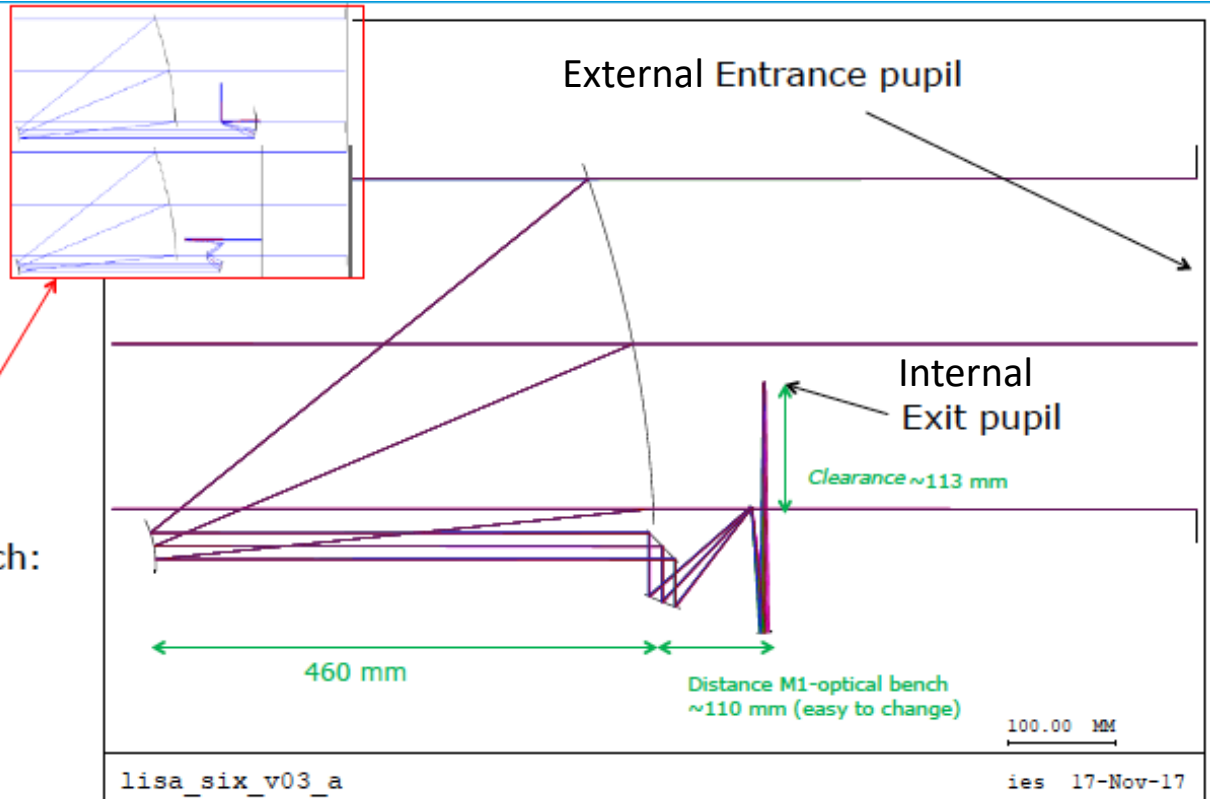


Shannon Sankar: Analysis of the LISA Telescope Optical Design, 10:20 AM

6 mirror design alternative

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

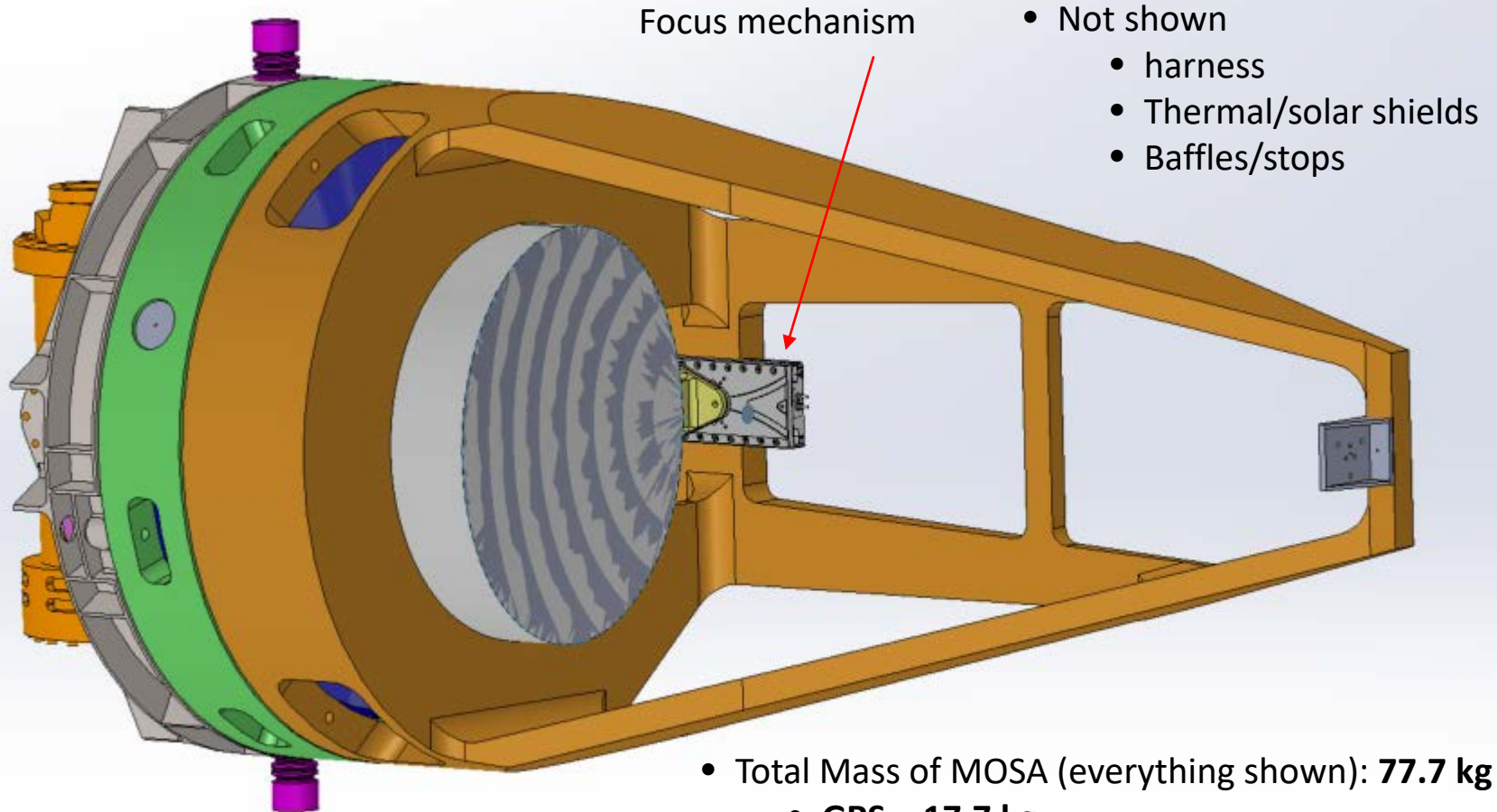
- Entrance/exit pupils:
300/2.24 mm
- Six mirrors:
2 parabolas
1 flat (folding)
1 ellipses
2 hyperbolas
- Exit pupil clearance:
~ 113 mm
- Distance M1-optical bench:
~110 mm, can be changed
easily without a major
impact on pupil clearance:
folding flexibility.



Design by Isabel Escudero Sanz/ESTEC

Moveable Optical Sub Assembly (MOSA) Notional

CAD Model



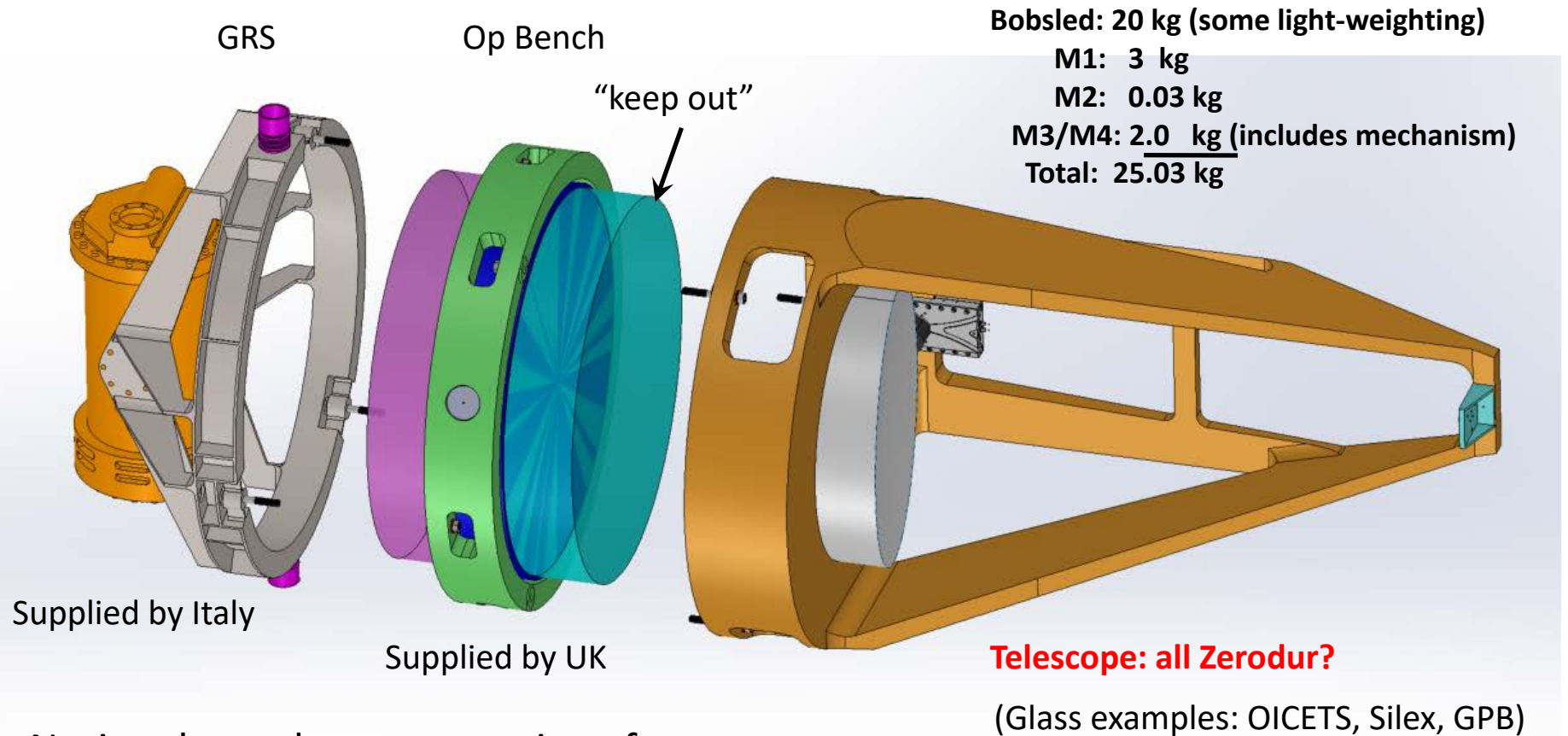
Focus mechanism

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

- Total Mass of MOSA (everything shown): **77.7 kg**
 - GRS = 17.7 kg
 - OB = 25 kg, ring = 8.1 kg if Zerodur
 - Telescope = 25 kg
- Volume envelope (mm) is 520 x 520 x 1160

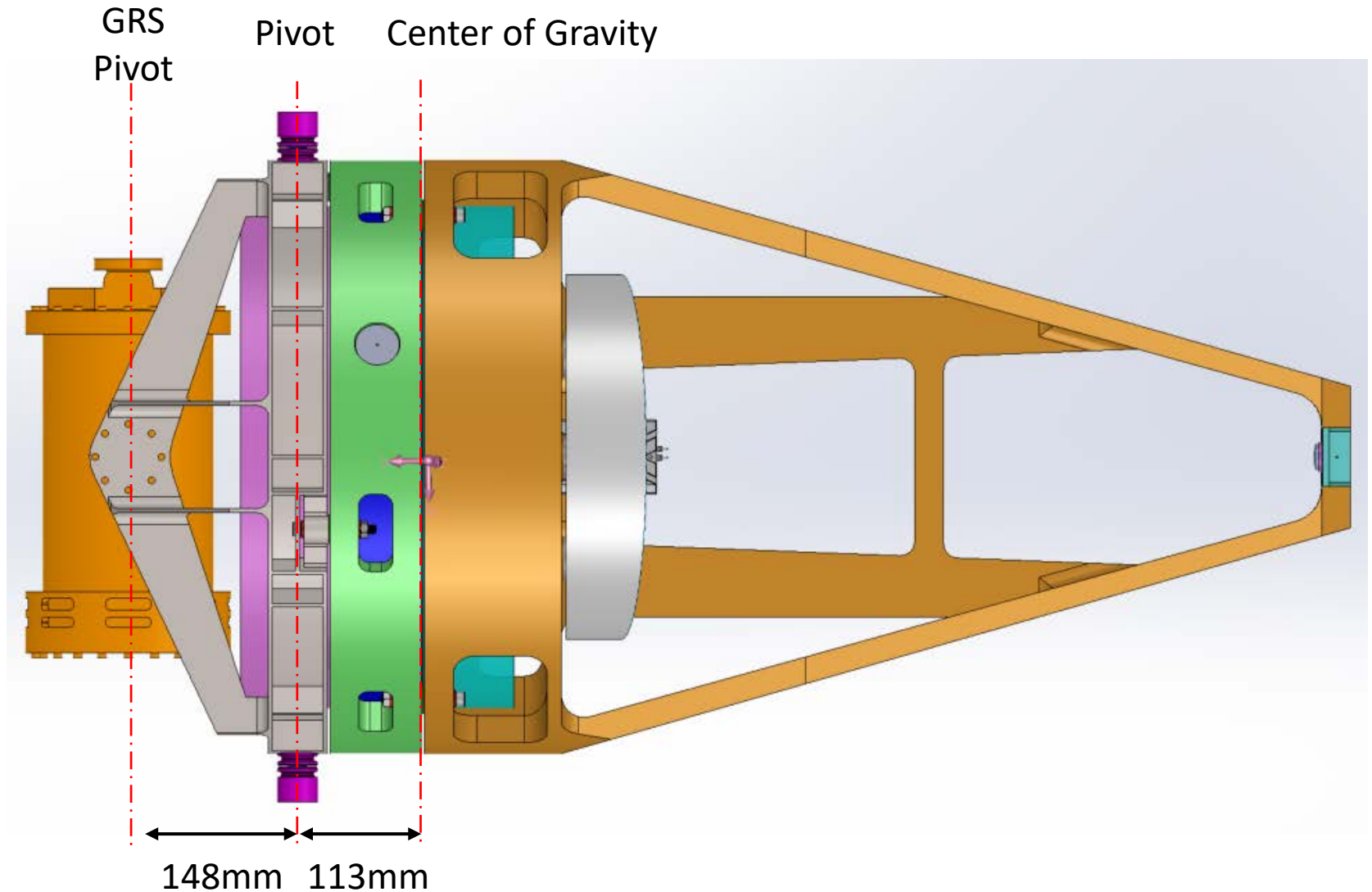
Moveable Optical Sub Assembly (MOSA)

Notional CAD Model

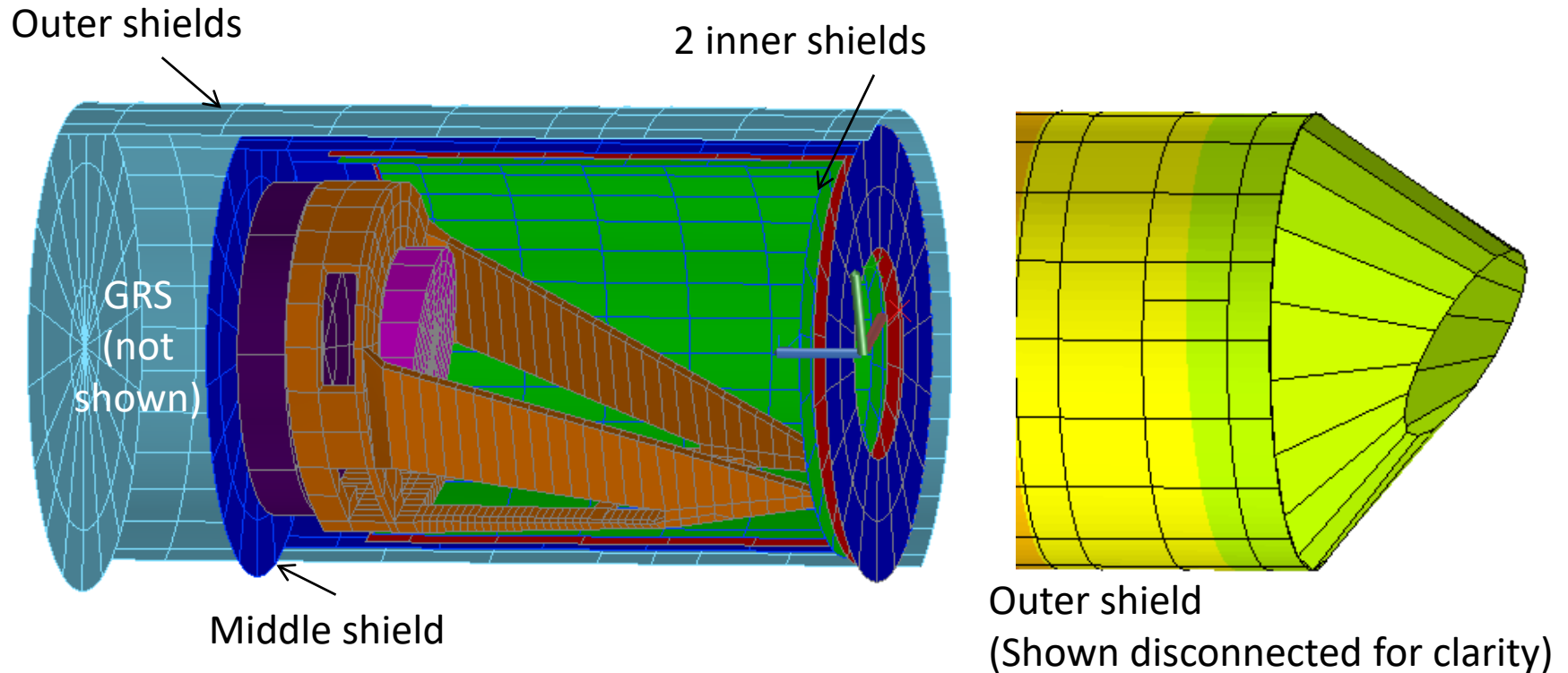


- Notional: need to agree on interfaces, etc
- Modular to allow for alignment and integration of OB with telescope or GRS
- Lightweighting and structural analysis in progress

Pivot could be placed over GRS (preferred)

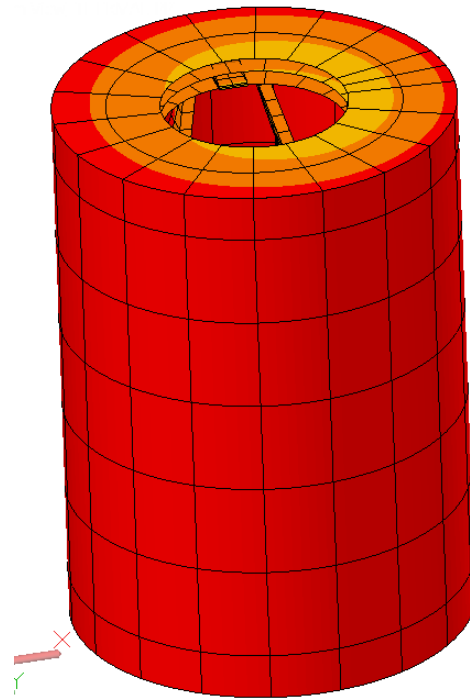
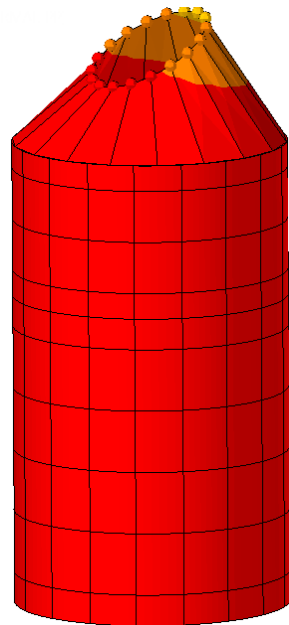


Notional Thermal Baffle Structure



- Thermal baffles could cause contamination during launch
 - Optical bench is well shielded
 - Telescope less so
- Telescope cover may not help if particulates come from the baffles

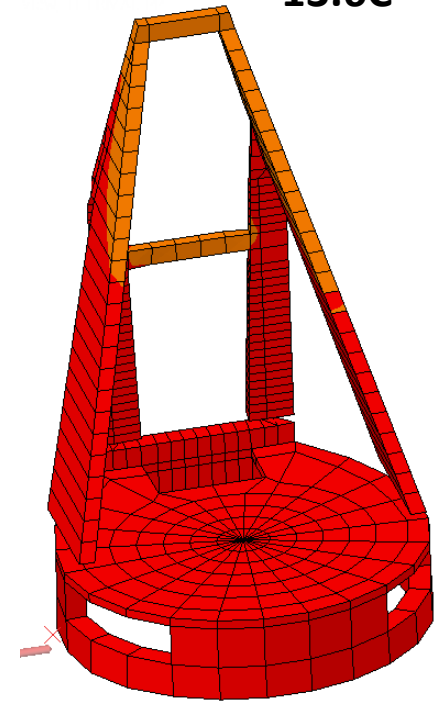
Light Weighted Bobsled with 20 C Outer Shell



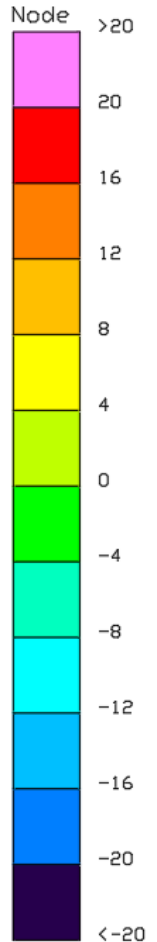
Bottom part of
outer shell at 20C

Gradient= 6.4C

13.6C

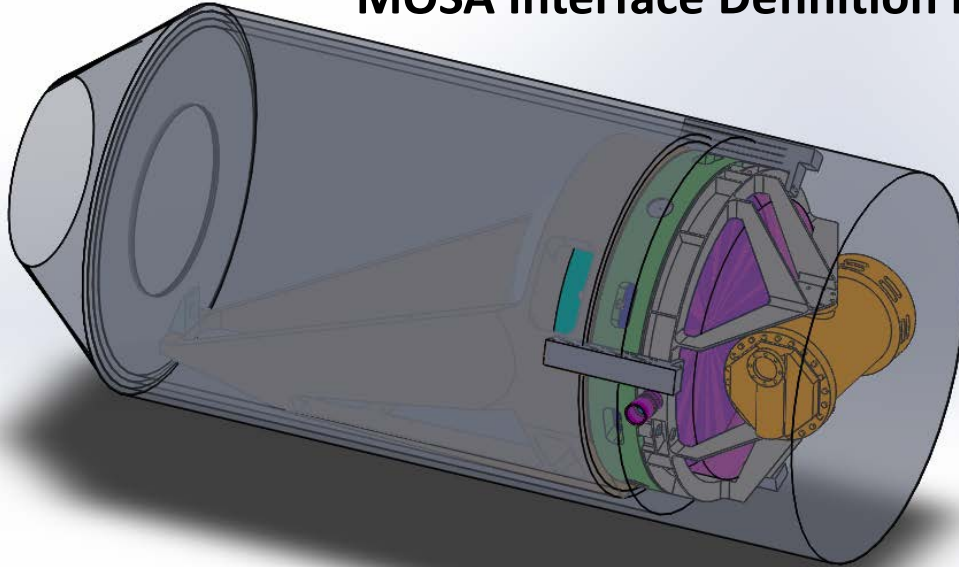


20C



Baffling: notional mounting concept

MOSA Interface Definition Required



1 mm thick Al baffle

Baffle 1: 4.2kg

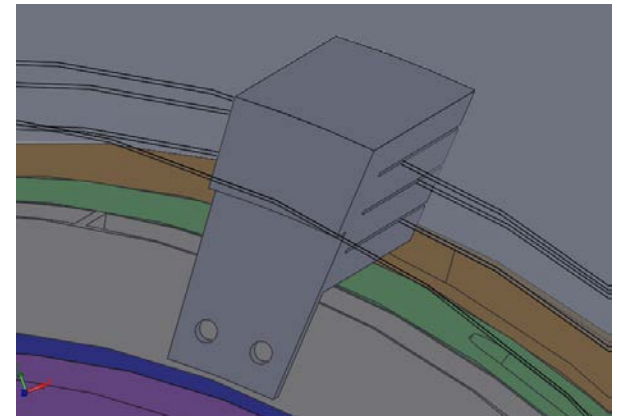
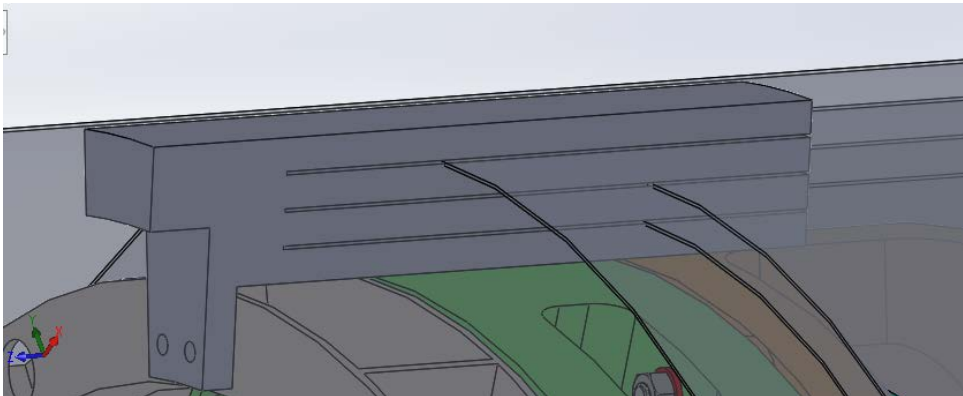
Baffle 2: 4.5kg

Baffle 3: 5.0kg

Baffle 4: 8.0kg

Interface part: 0.43kg * 3 parts =
1.3kg (material assumed PEEK
plastic)

Total : 23.0kg (this is heavy!)





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 ~ April 2019
(pending confirmation of baseline trades and design at the MCR)**
 - 12 months for a mechanical model (Apr 2020)
 - 18 months for first optical model (Oct 2020)
 - 24 months for second optical model (Apr 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



Summary

- **Robust 4 mirror optical design has been developed**
 - Meets LISA requirements
 - Flexible
 - Buildable from an alignment tolerance perspective
- **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
 - Optical
 - Structural/mechanical
 - Thermal
 - Harness/electrical
 - Testing definition: what can realistically be accomplished/needed for **Adoption**
 - Unit testing
 - Higher level of integration testing