LISA Telescope Challenges

For the Telescope Team

Presented by Ritva Keski-Kuha/GSFC

Mirror Tech Days

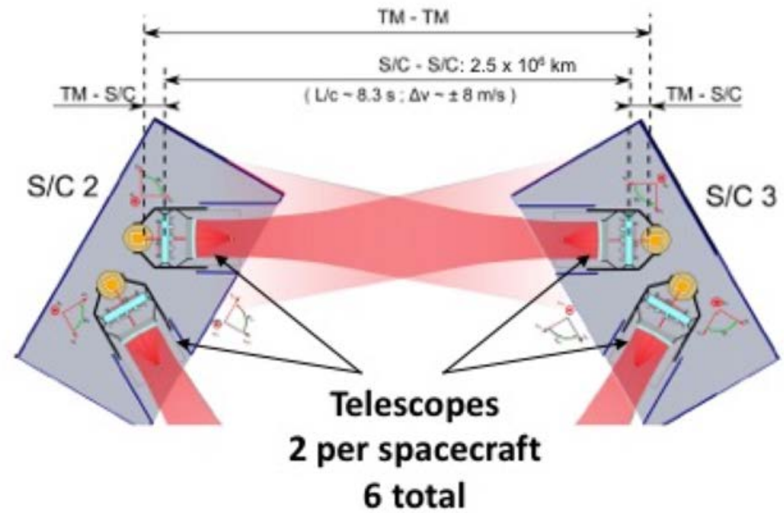
Nov 5, 2018

Telescope Team

- **PI: Jeff Livas**
- **Product design lead (PDL): Ritva Keski-Kuha**
- **Optics: Hui Li with help from Garrett West, Joe Howard, Mark Wilson**
- **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**

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**

Key Telescope Requirements

Parameter	Driven by	Required Value	
Primary diameter	Shot noise (power trans-mission and collection, $P_{\text{received}} \propto D^4_{\text{primary}}$)	300 mm	
Optical throughput (power effi-ciency)	Shot noise ($SNR_{\text{shot}} \propto 1/\sqrt{P_{\text{received}}}$)	$\eta > 0.85$	
Entrance pupil (large aperture) diameter	Shot noise	300 mm	
Entrance pupil (large aperture) location	Tilt to length coupling	In the plane of the COM of the PM (virtual)	
Exit pupil (small aperture) diam-eter	Optical bench design	2.24 mm	
Exit pupil (small aperture) loca-tion	Optical bench design	200-250 mm behind primary	
Afocal magnification	Optical bench design	$300/2.24 \simeq 134$x	
Field of regard (acquisition detec-tor)	Link acquisition	$\pm$ 500 µrad (approx. 0.03° or [illegible]	
Field of regard (science detector)	Spacecraft orbits	+/- 225 microradians	
Field of view (science detector)	Stray light	$\pm$ 8 µrad (approx. 1.7″)	
Exit pupil (small aperture) distor-tion	Heterodyne efficiency (SNR)	$< 10\,\%$	
Optical path length stability	Phase noise in series with main science measurement	$< 1\,\mathrm{pm}/\sqrt{\mathrm{Hz}}\ \sqrt{\left(1+\left(\frac{3\,\mathrm{mHz}}{f}\right)^4\right)}$, for $1 \times 10^{-4} < f < 1$ Hz	challenging
Back-scattered light from trans-mit beam	Phase noise in series with main science measurement	$< 1 \times 10^{-10}$ into Science field of view	challenging
Wavefront error	Pointing errors couple wavefront aberration into phase noise in se-ries with the main science mea-surement	$\lambda/30$ rms in the Science field of regard	

Telescope Design Drivers

- **Robust optical design**
  - **Adequate build tolerances**
  - **Adequate environmental sensitivity → low CTE glass**
    - **Thermal**
      - **Steady state**
      - **Response to fluctuations**
    - **Vibration, shock**
  - **Adequate interface tolerances**
- **Acceptable scattered light performance → off-axis design**
  - **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**

Key Telescope Milestones

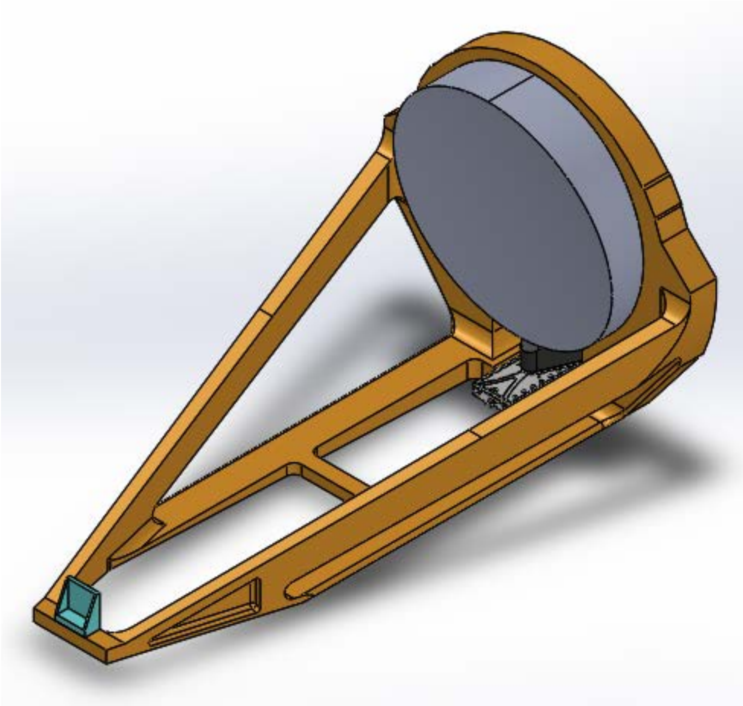
- **Nominal Launch Date is 2034**
- **2022 is Adoption (Implementation Phase gate)**
- **NASA plans to supply a telescope that meets LISA mission requirements**
- **Procurement initiated Feb 2019 (pending confirmation of baseline trades and design at the Mission Consolidation Review (MCR))**
  - **12 months for a mechanical model (Feb 2020)**
  - **18 months for first optical model (Aug 2020)**
  - **24 months for second optical model (Feb 2021)**
- **Elegant breadboard delivery (Nov 2021)**
- **Adoption June 2022**

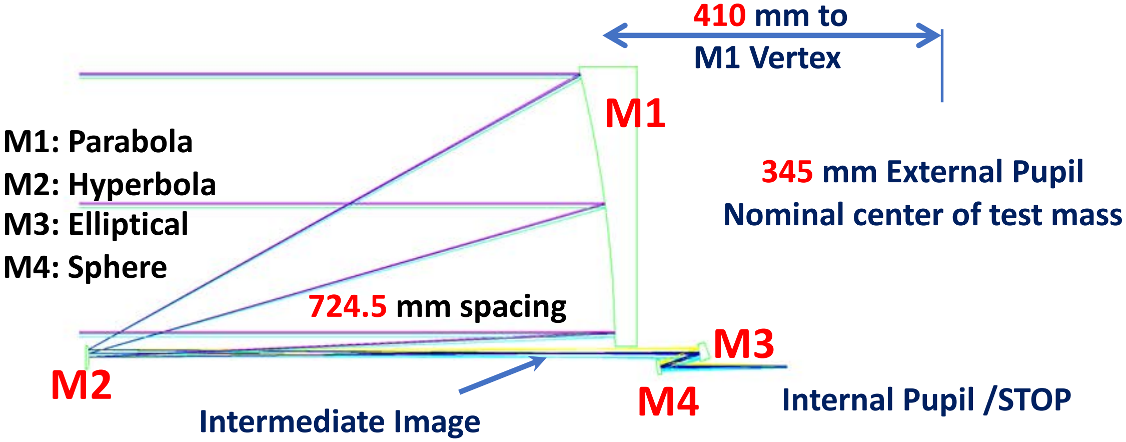
Not much time for testing!

SCHEDULE IS TIGHT

Telescope Design Summary: ”Bobsled”

- 4-mirror Cassegrain design plus Schwarzshild pupil extender
- 345 mm clear aperture F/1 primary
- M1- M2 spacing 725 mm
- External (virtual) pupil located over proof mass
- 134X magnification
- All low-CTE material construction
    - ULE or Zerodur

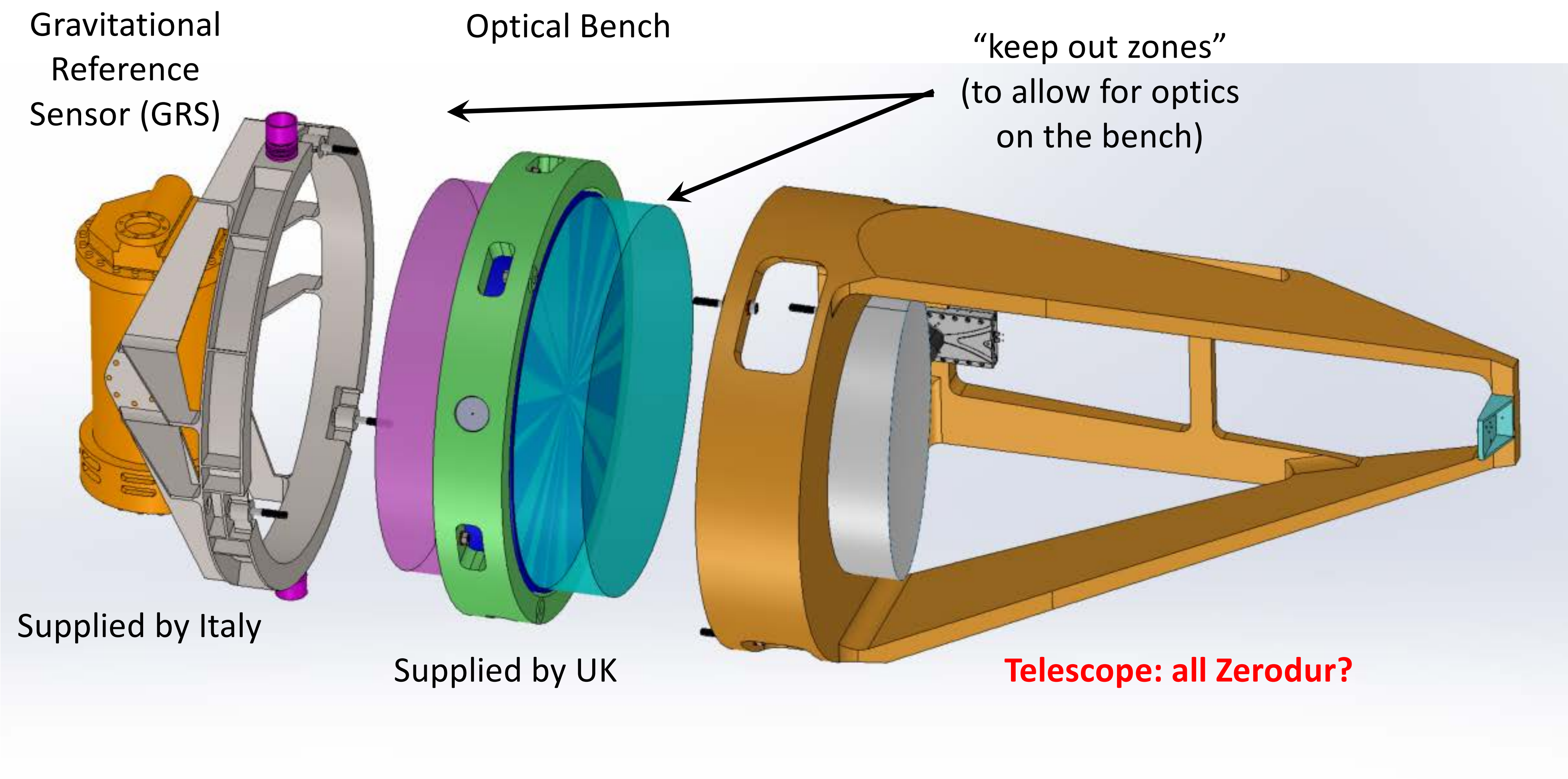




Component	Mass (kg)
Bobsled	14.32
M1 (50% Lightweight)	6.63
M2 with Mount	0.10
M3,M4, mechanism	1.16
Total	22.21

Moveable Optical Sub Assembly (MOSA)

Notional CAD Model

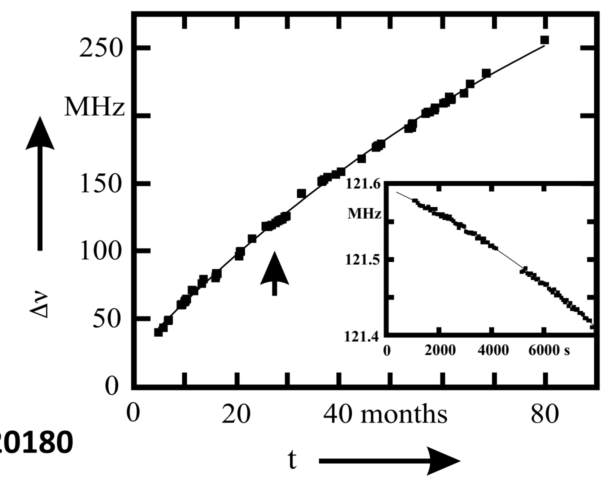


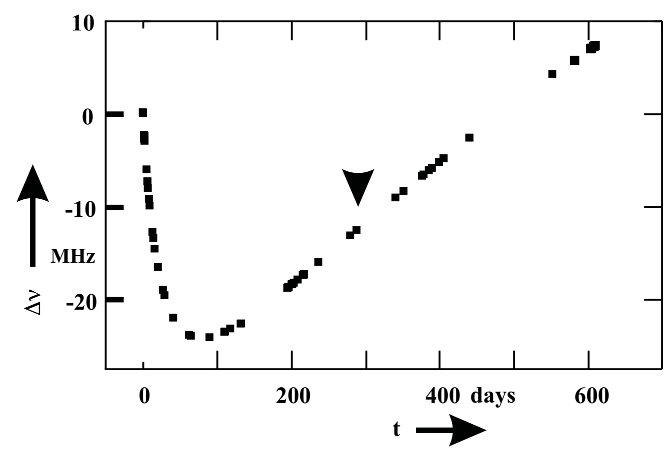
- Notional: need to agree on interfaces, etc
- Modular to allow for alignment and integration of OB with telescope or GRS
- Lightweighting and structural analysis in progress

Materials Challenges: dimensional stability

- Concept: ultra-low expansion (CTE) glass construction plus thermally stable environment provides dimensional stability
- CTEs of Zerodur and ULE are both acceptable
  - Zerodur also exhibits long term contraction
    - ~ Exponential with ~ 11 year time constant (out of measurement band)
    - Does not appear to be a direct displacement noise problem
    - Over mission lifetime may degrade the WFE (defocus?)
  - ULE production may require expensive stack seal or multiple-piece construction

F. Riehle 1998 *Meas. Sci. Tech.*





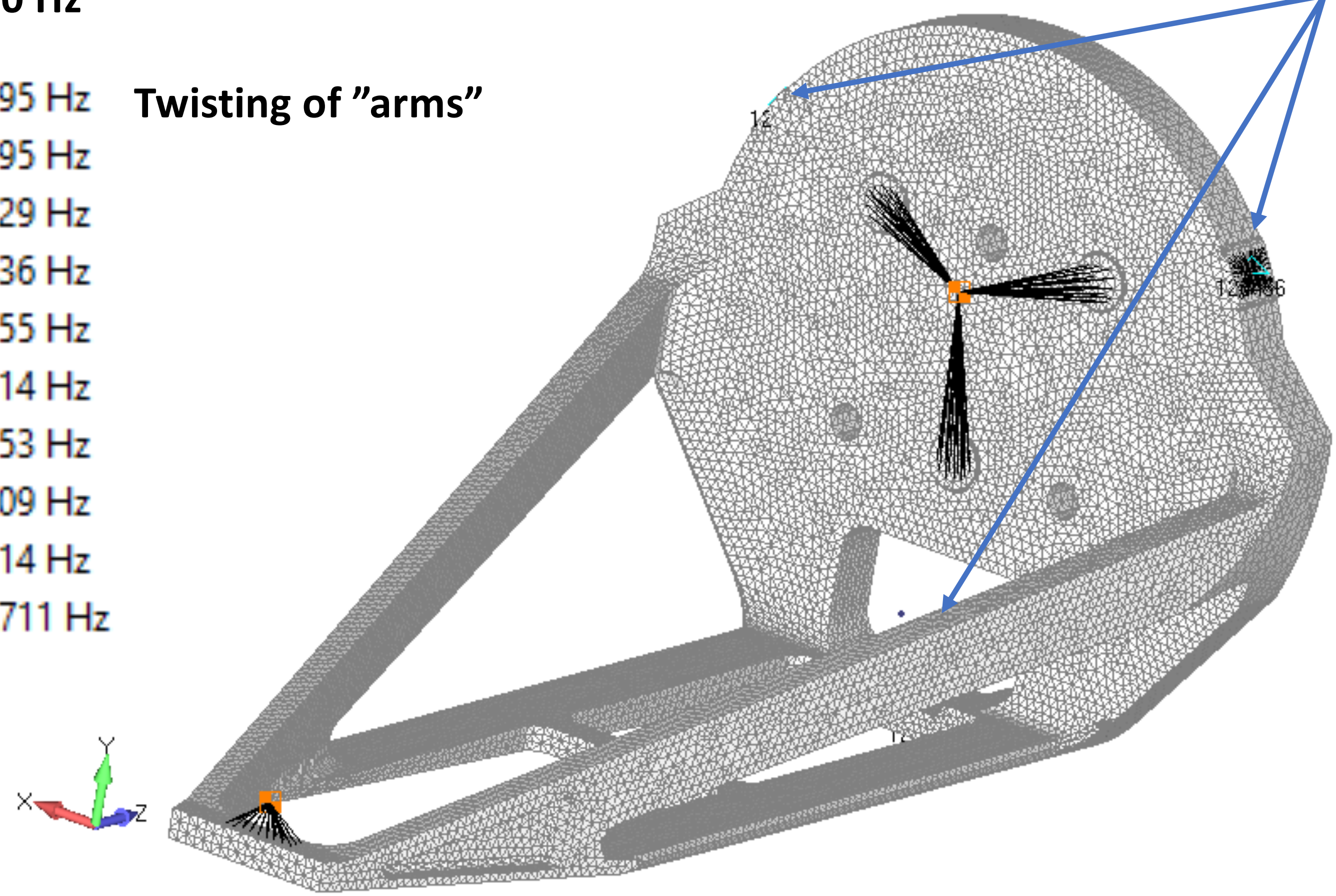
Materials Challenges: Stiffness

Preliminary Modal Analysis

Lowest frequency mode is well over 40 Hz

Mode 1, 128.4695 Hz **Twisting of "arms"**
Mode 2, 204.8195 Hz
Mode 3, 249.3729 Hz
Mode 4, 273.5336 Hz
Mode 5, 325.8255 Hz
Mode 6, 342.5614 Hz
Mode 7, 381.2853 Hz
Mode 8, 438.2209 Hz
Mode 9, 465.8114 Hz
Mode 10, 520.0711 Hz

Constraints



Summary

- **Robust 4 mirror design has been developed**
  - **Meets LISA requirements**
  - **Buildable**
- **Schedule is tight to build and test for 2022 adoption**
- **Challenges still to be addressed**
  - **All glass construction: joints, yields**
  - **High magnification design requires tight tolerances and careful alignment**
  - **Structural/thermal analysis and materials and joints testing as needed**
  - **Interface definition: Telescope-OB requires precision alignment**
  - **Testing definition: what can realistically be accomplished/needed for Adoption**