Preliminary LISA Telescope Spacer Design

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Abstract
The Laser Interferometric Space Antenna (LISA) mission observes gravitational waves by measuring the separations between freely floating proof masses located 5 million kilometers apart with an accuracy of \( \pm 10 \) picometers. The separations are measured interferometrically. The telescope is an all-sky Cassegrain style design with a magnification of 80×. The entrance pupil has a 40 cm diameter and will either be centered on-axis or off-centered for disturbance avoidance. The two main purposes are to transform the small diameter beam used on the optical bench to a diffraction limited collimated beam to efficiently transfer the metrology laser between spacecraft, and to receive the incoming light from the far spacecraft. It transmits and receives simultaneously. The basic optical design and requirements are well understood for a conventional telescope design for imaging applications, but the LISA design is complicated by the additional requirement that the total optical path through the telescope must remain stable at the picometer level over the measurement band during the mission to meet the measurement accuracy. This poster describes the requirements for the telescope and the preliminary work that has been done to understand the materials and mechanical issues associated with the design of a passive metering structure to support the telescope and to maintain the spacing between the primary and secondary mirrors in the LISA on-orbit environment. This includes the requirements flowdown from the science goals, thermal modeling of the spacecraft and telescope to determine the expected temperature distribution, layout options for the telescope including an on- and off-axis design, and plans for fabrication and testing.

Objective
- Develop and test a mechanical design for the main spacer element between primary and secondary mirrors
- Tolerance analysis identifies the M1-M2 spacing as critical
- Minor modifications
- No New Model

Overview of the Mission
The LISA mission studies gravitational waves by detecting the strain they produce with a laser interferometer. The scientific objective is to measure the distance between freely floating proof masses arranged in a 5 x 10^7 km equilateral triangle constellation that orbits the sun 30° behind Earth's orbit. The plane of the triangle is aligned at 90° with respect to the ecliptic. Each of the three spacecraft are in an independent orbit around the sun, so a station-keeping is required to keep the constellation together. The proof masses are isolated from disturbances by using drag-free satellites to maintain the spacing between the proof masses on (1)axis.

Telescope Stability Requirements
- The LISA telescope is for metrology not imaging; pathlength stability is key
- Two main requirements
  1) Wavefront error \( \leq 0.2 \) nm — driven by the system-based Strain ratio requirement of 0.78
  2) Length stability \( \Delta l / l = \Delta l / (l + l/2) = \Delta l / (2l) \approx 6 \times 10^{-10} \)

- Off-axis design used initially because a toler ance analysis was available; on-axis design has tighter requirements
- Main emphasis in this work is on the determination of the length stability requirement

Telescope Stability Results
- Two versions, same prescription
- Not a comparison between designs, but rather the same design implemented on- vs. off-axis

On-axis vs. Off-axis
In general, the compensated sensitivities of an off-axis system for SM6 motion are 4x greater than an equivalent on-axis one, but the axial SM6 motion is 1% greater due to the offaxis nature of the system and axial motion (only) of the compensator.

On-axis tolerance analysis
- In general, the compensated sensitivities of an off-axis system for SM6 motion are 4x greater than an equivalent on-axis one, but the axial SM6 motion is 1% greater due to the off-axis nature of the system and axial motion (only) of the compensator.

Comparison of Cylinder and Quadpod

Materials and Design
- Basic on-axis design is a cylinder for both on- and off-axis telescopes. Fabrication limitations forced a quadpod design, with the four-fold symmetry mechanically over-constrained, but matches the symmetry of the quad coil main detector

Conceptual Design: side view
- Telescope Strogback
- Thermal Coeduc0ivi0y	 W/m¥¡K	 r0	 (830l
- Frac0ure Tougheecc KIC	 MPa¥m
- Bulk Moduluc	 GPa (lb/ie
- Elac0ic Modu l u c	 GPa (lb/ie

Materials properties typically very vendor and process dependent
- Range on high as 4.1
- Depending can be in a %

Thermal Modeling
- Range 10 to 200 W/mK
- Range ~ 10 picometers.
- Normal 10 x 100 W/mK
- Normal 10 to 200 W/mK

Results
- Observations Michelson Fringe displacements agree with expected values
- Fringe more stable, so stability is acceptable
- Waveform analysis
- Coefficients of Thermal Expansion (CTE) slightly less than vendor's reported numbers
- Encouraging: no unusual effects from joints or bonding
- Next step is to construct a Fabry-Perot cavity and lock a laser for stability measurement by comparing to a conventional cavity-stabilized laser

Summary and Conclusions
- Silicon Carbide is a viable candidate for a LISA telescope metering structure
- Care must be taken when choosing a vendor

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