Preliminary LISA Telescope Spacer Design

J. Livas, P. Arsenovic, K. Castelliucci, J. Generie, J. Howard, R.T. Stebbins
NASA/Goddard Space Flight Center, USA
J. Sanjuan, A. Preston, L. Williams, G. Mueller
University of Florida, Gainesville, USA

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 ~10 picometers. The separations are measured interferometrically. The telescope is an all-sky Cassegrain style design with a magnification of 800. The entrance pupil has a 40 cm diameter and will either be centered on-axis or de-centered off-axis to avoid obscurations. Its 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 paper 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
- Concept and build a mechanical design for the main spacer element between primary and secondary mirrors
- Tolerance analysis identifies the M1-M2 spacing as critical
- Mirrors and telescope are not part of the scope; just the spacer

Overview of the Mission
The LISA mission studies gravitational waves by detecting the strain they produce with a laser interferometer that measures the distance between pairs of freely floating proof masses arranged in a 5 x 10^6 km equilateral triangle constellation that orients the sun 30° behind Earth's orbit. The plane of the triangle is tilted at 60° with respect to the ecliptic. Each of the three spacecraft are in independent orbit around the sun so no station-keeping is required to keep the constellation together. The proof masses are isolated from disturbances by using drag-free satellite technology that keeps a spacer spacecraft centered around the proof masses to ~1 mm.

Telescope Stability Requirements
- The LISA telescope is for metrology not imaging; pathlength stability is key
- Two main requirements:
  1) Wavefront error < 0.04λ driven by the systematic stray light requirement of 0.05
  2) length stability \( \frac{\Delta L}{L} \times 10^{-6} \) driven by the need to keep the distance between proof masses on each spacecraft

- On-axis design used initially because a tolerance analysis was available; off-axis design has tighter requirements
- Main emphasis in this work is on a demonstration of the length stability requirement

Materials and Design
- Basic spacer design is 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 off-mirror detector

Conceptual Design: side view

Thermal Modeling

Comparison of Cylinder and Quadpod

Results
(See J. Sanjuan, poster H03-091-10 for more details)
- Observed Michelson Fringe displacements agree with expected values
- Fringe moves slowly, so stability is acceptable
- Visibility is ~93.6%
- Coefficient of Thermal Expansion (CTE) slightly less than vendor's reported numbers
- Encouraging; no unusual effects from junction 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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