LISA Telescope Spacer Design Issues

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Presentation Mode: Talk

The 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 afocal Cassegrain style design with a magnification of 80x. 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.

We describe the mechanical 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. Plans for fabrication and testing will be outlined.

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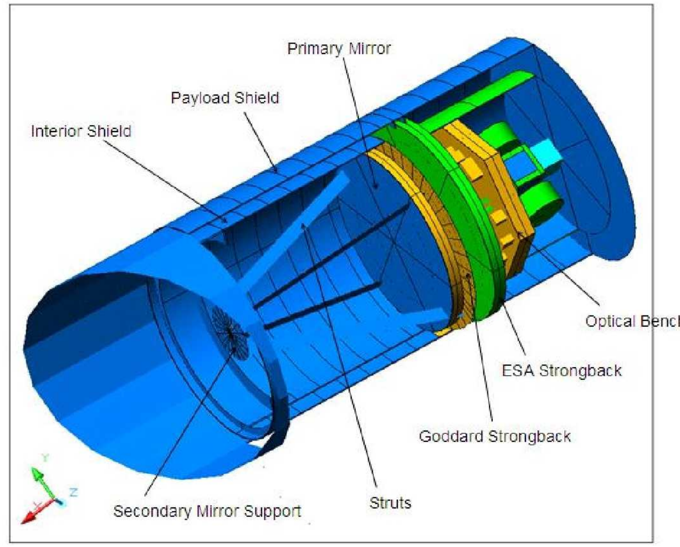
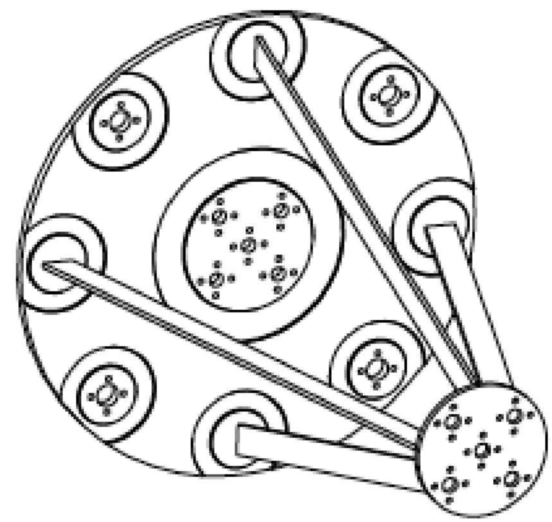
- Work done between Goddard Space Flight Center and the University of Florida
- **Objective**: develop and test a mechanical design for the main spacer element between primary and secondary mirrors
- Models of telescope spacer designs have been done, but not tested
- Material needs to be strong, stiff, lightweight
  - Most likely materials are SiC and CFRP
- Dimensionally stable
  - <1 pm/√Hz noise at 3 mHz
  - Distance between primary and secondary can't change by more than 1.2 μm over lifetime of mission

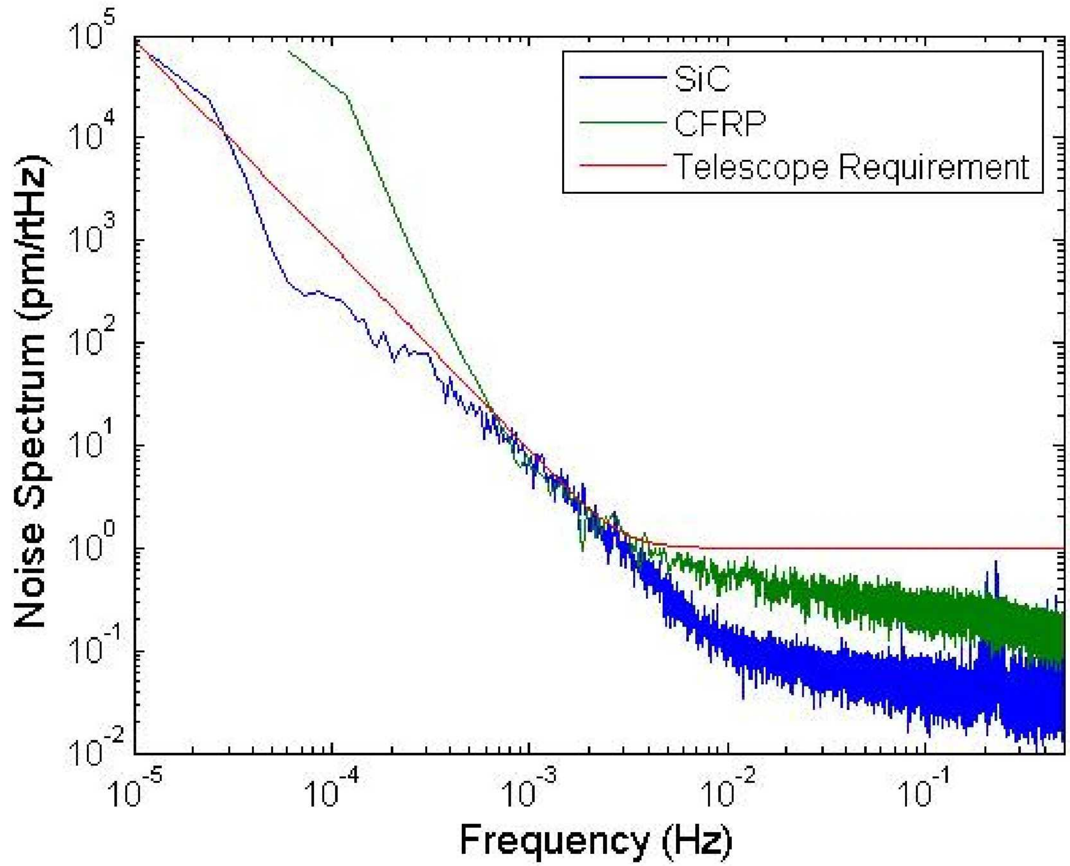
- Significant amount of discussion about design, materials, fabrication
  - See poster for details
- Decided on a SiC "Quad-Pod" design
  - Quadrant-PD for alignment sensing
- Several holes to place Michelson interferometers and Fabry-Perot cavities
  - Determine tilts and stability of the structure



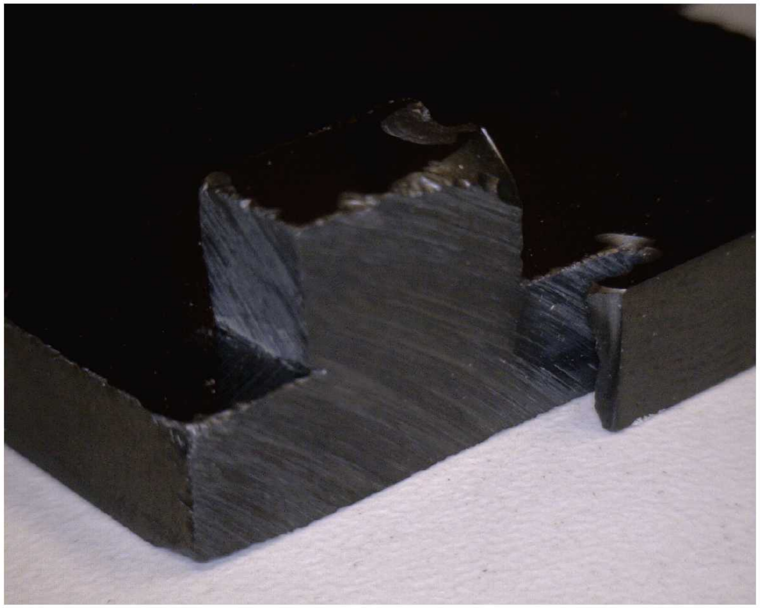


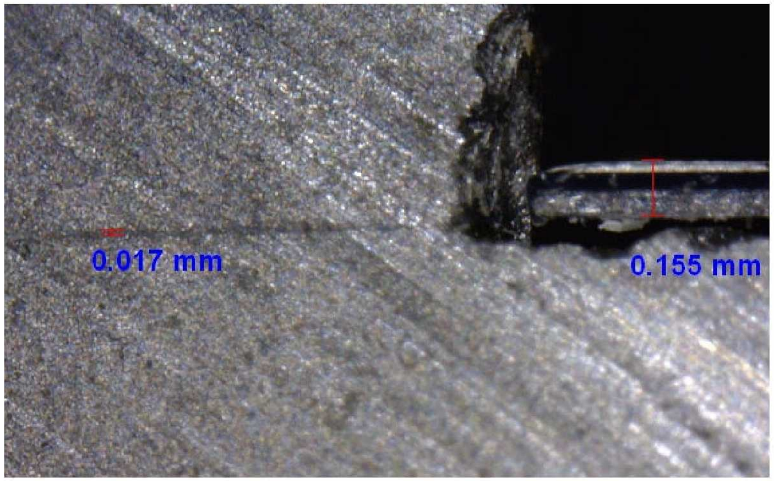
ISOMETRIC VIEW

- Why SiC?
  - High stiffness/thermal conductivity => reduced temperature gradients
  - Familiar with the material
  - Had dimensional stability results
  - Can use a variety of bonding techniques
- CFRP spacer provided by University of Birmingham, UK
- Many SiC vendors to choose from
  - Chose CoorsTek

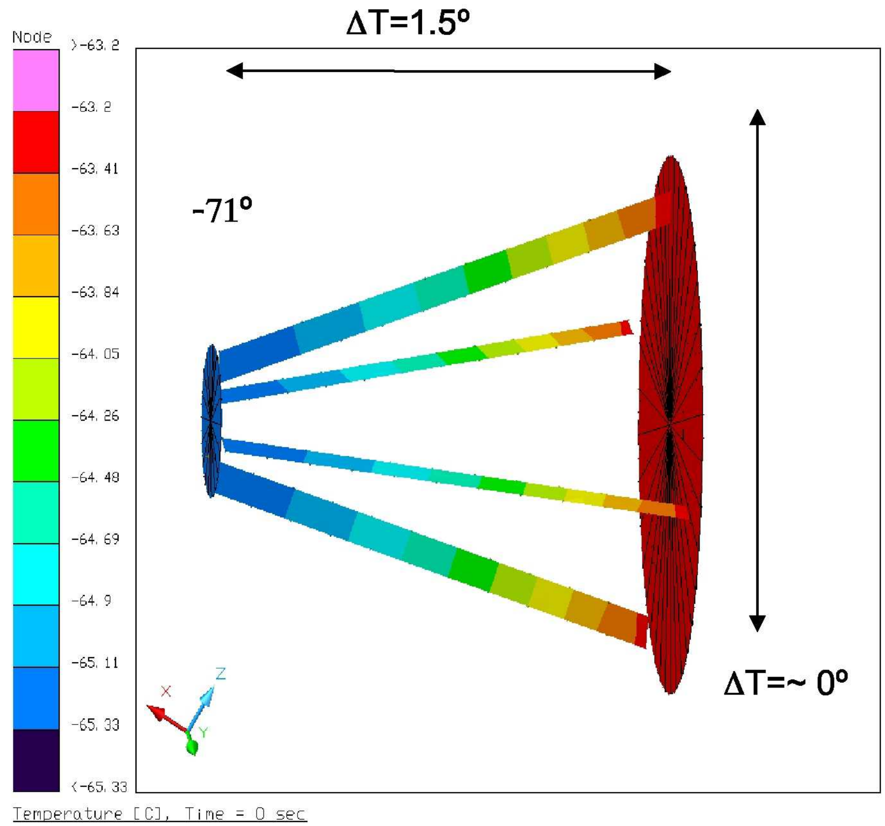


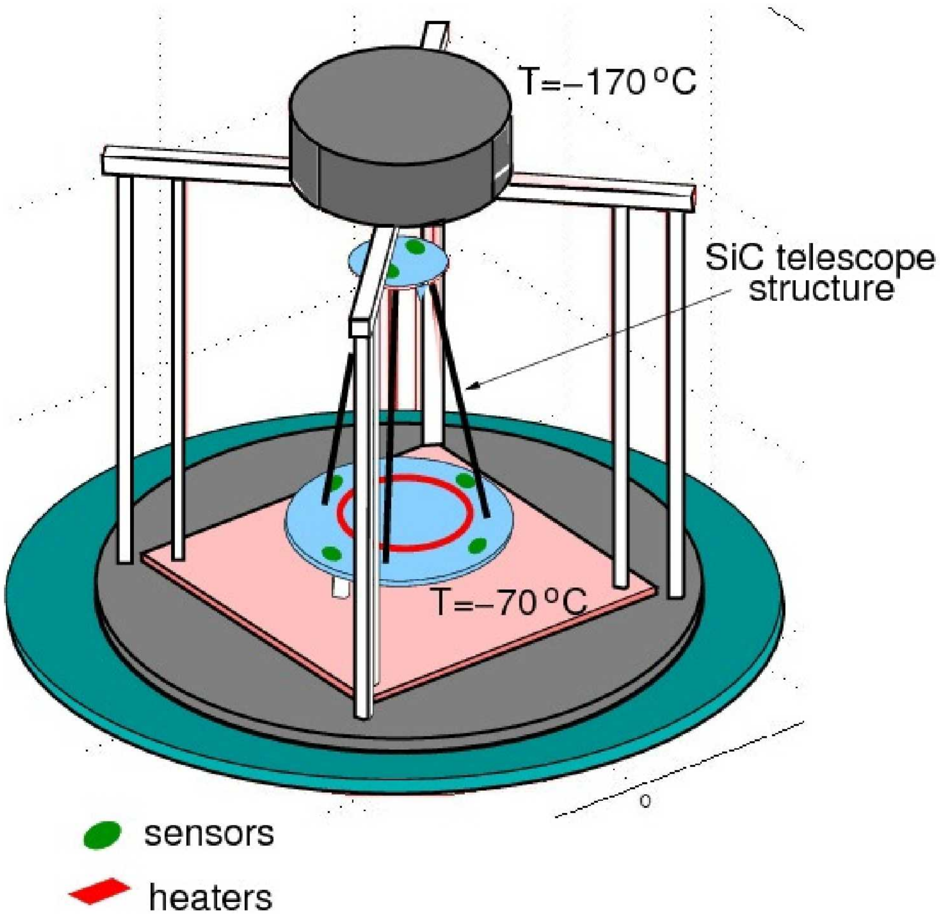
- Needed a way to bond pieces together in a strong, stable, and precise manner
- Used hydroxide-catalysis bonding
  - Use small amount (a few µL) of sodium silicate solution
  - Allows for precision alignment and can fill gaps
  - ~3 MPa shear strength
  - Durable -> cut with tile saw
  - Heat to 373 K and cool to 77 K, still retains strength
  - Works on many surface profiles (<24 λ surface flatness)





- Thermal analysis was done on the spacer design
- Spacer temperature close to -70º C
- Small axial gradient
- Negligible radial gradient
- Low gradients due to high thermal conductivity

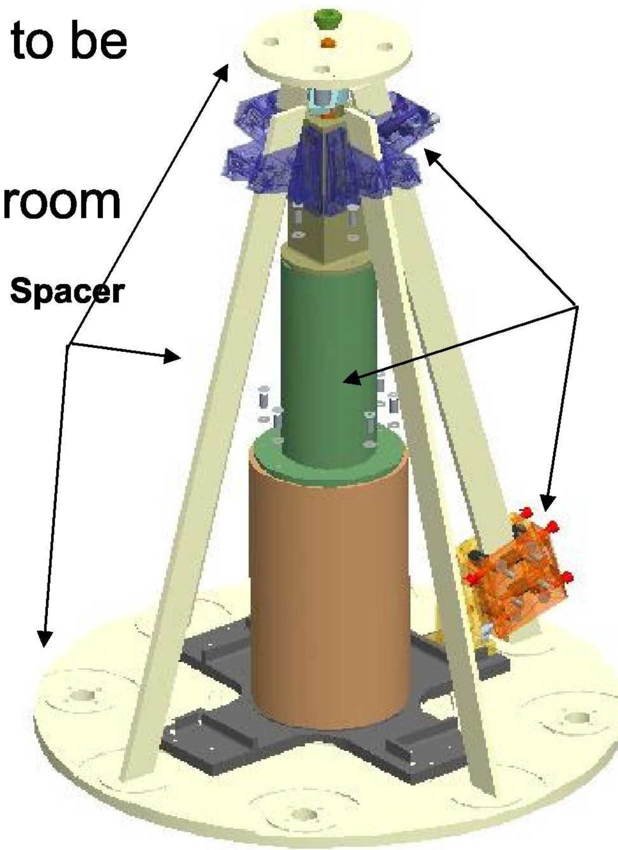




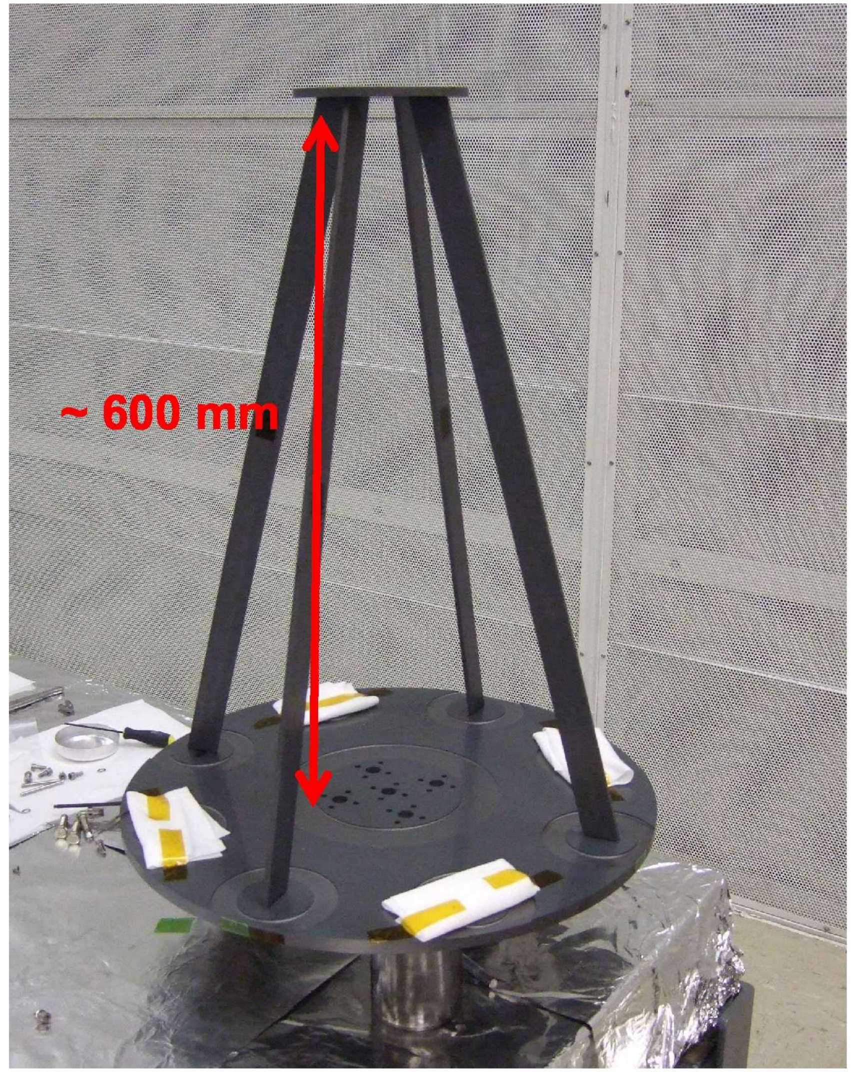
- Vacuum tank was modified and passive thermal shields designed to provide right temperature
- Liquid nitrogen is used to cool the structure
- Heaters will be used to keep telescope at the right temperature
  - Can change the operating temperature of the SiC
- Secondary faces “open space”

- Designed a jig to align and hold parts to be able to hydroxide bond
- Structure was put together in a clean room

Alix Preston, Joe Generie, Kyle Norman, Kevin Castellucci

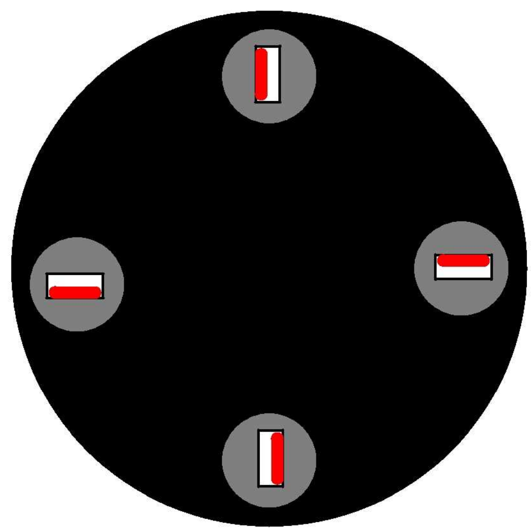


Transported by car back to UF and kept in low-traffic “clean” room

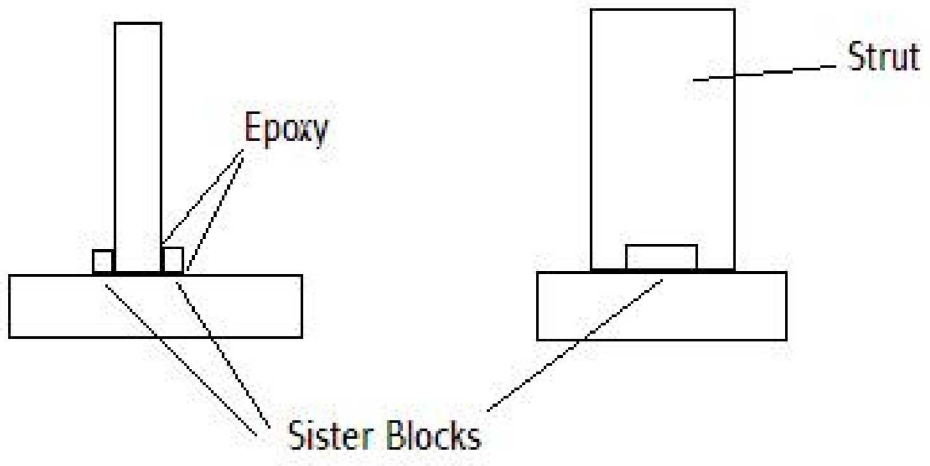


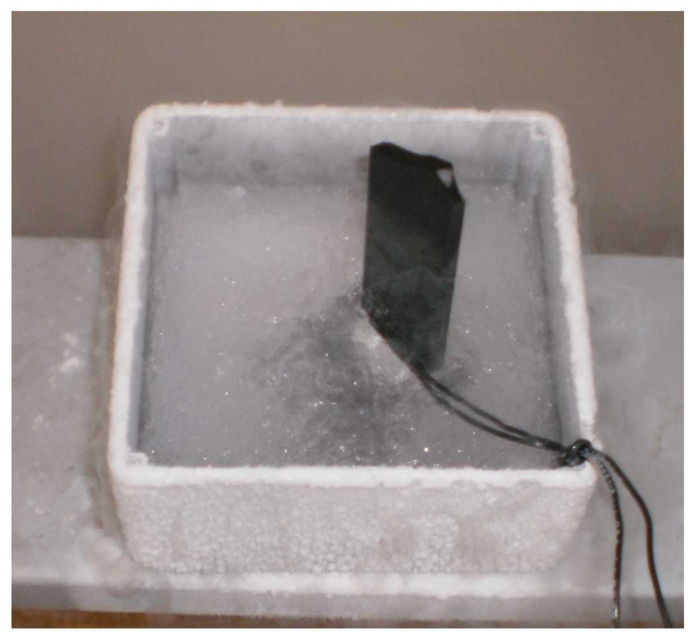
- Structure was left in clean room for about 1 month
- Noticed one day one of the struts was not attached in a rather peculiar manner
- Did some inspection of bonds, seemed OK
- Decided to cool it down in vacuum tank
- Once it was warmed up, small amount of force was applied to secondary
- Structure fell apart, 1 strut broke

- Analysis was done on bonds and struts
- Bonds appeared to have formed
- Determined the telescope twisted in the alignment jig
- Still no evidence of faulty bonds causing the strut to fall off

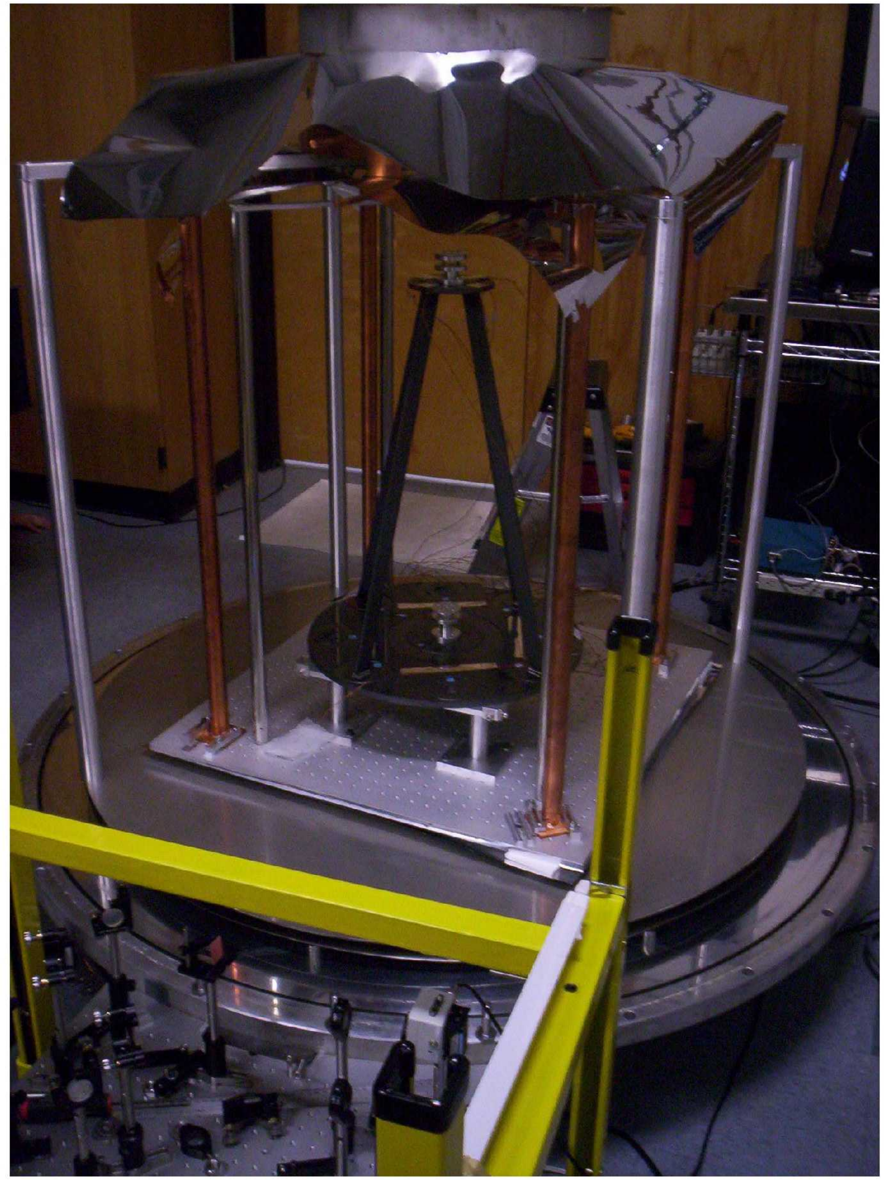


- Jig was redesigned, telescope parts were repolished
- Use hydroxide bonding to provide precision bonding
- Use “sister blocks” to provide added strength
  - 3 mm x 4 mm x 20 mm
  - 8 MPa shear strength
  - Cooled SiC and sister blocks to 77K



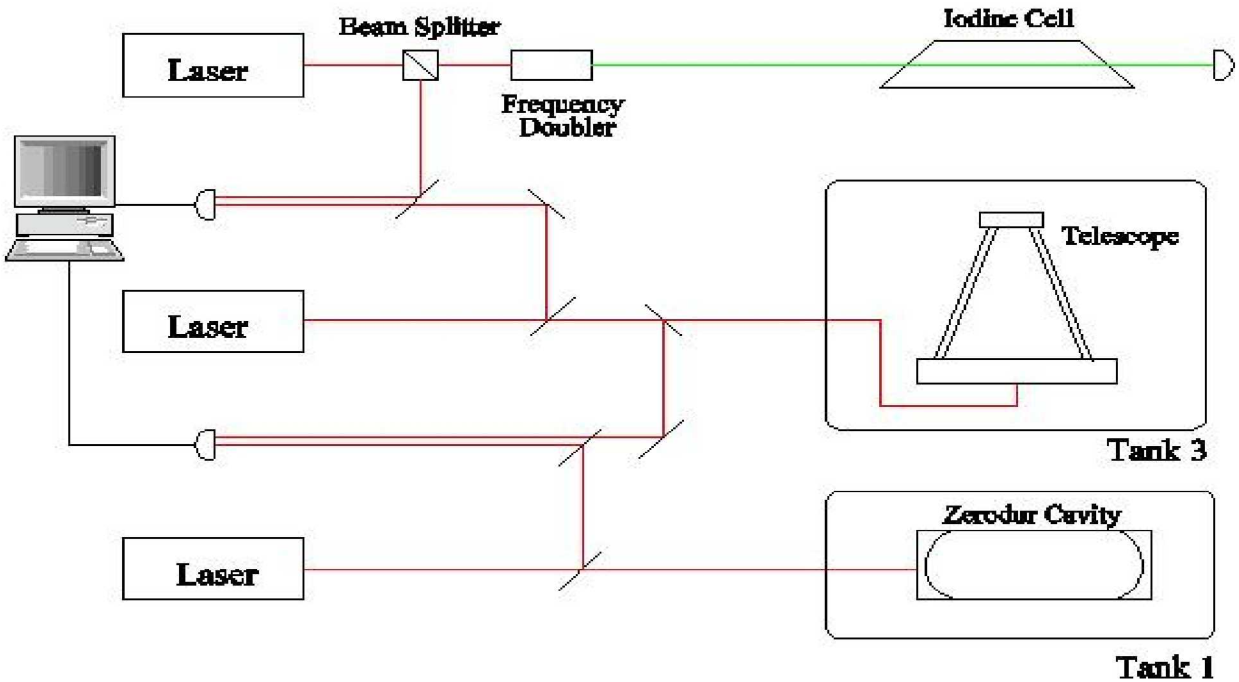


- Tested out using an aluminum mock-up
- Thermally cycled mock-up
- Tested heaters/temp sensors
- Re-bonded the SiC structure



- Used a Michelson interferometer while cooling down
  - Should see large breaks, strut(s) unbonding
  - CTE measurement
  - More results on the poster
- Survived thermal cycling

- What's next?
  - Use iodine stabilized laser to determine absolute stability -> absolute stability
  - Place cavity in center -> relative stability
  - Michelson interferometers off center -> tilting
  - More stability measurements soon



Thank You

•Many thanks to the University of Birmingham Center for Space and Gravity Research group for providing the CFRP cavity

•Research supported by NASA contract 00069955