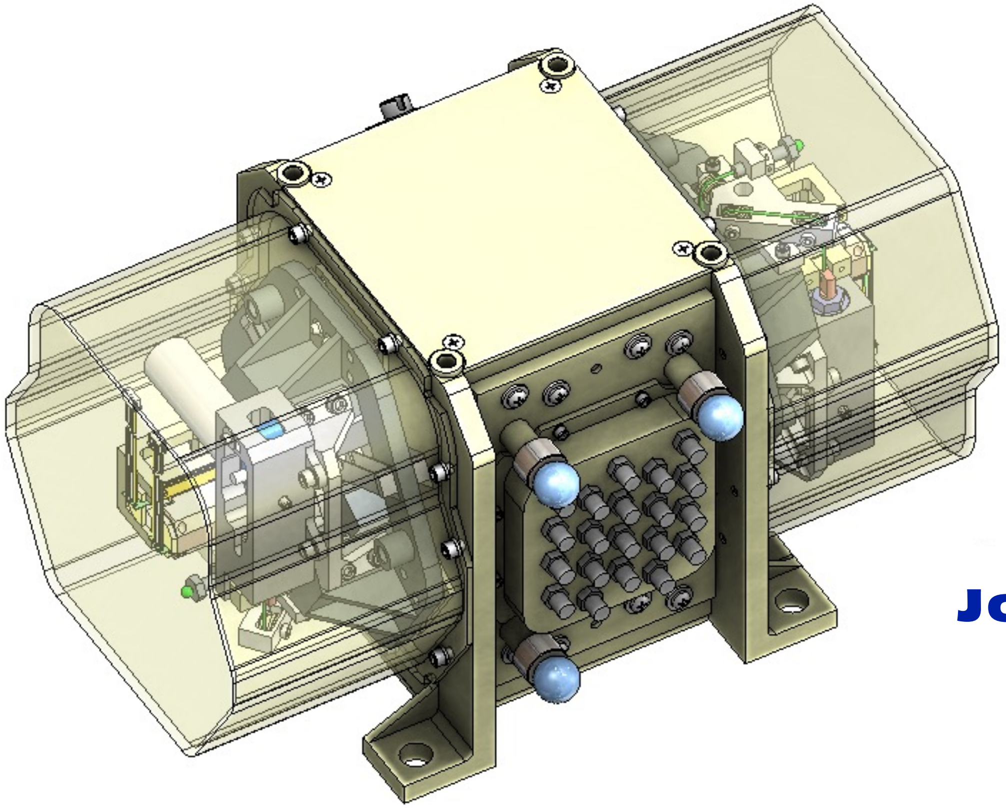
Simplified Gravitational Reference Sensors for Future Earth Geodesy Missions



John W. Conklin

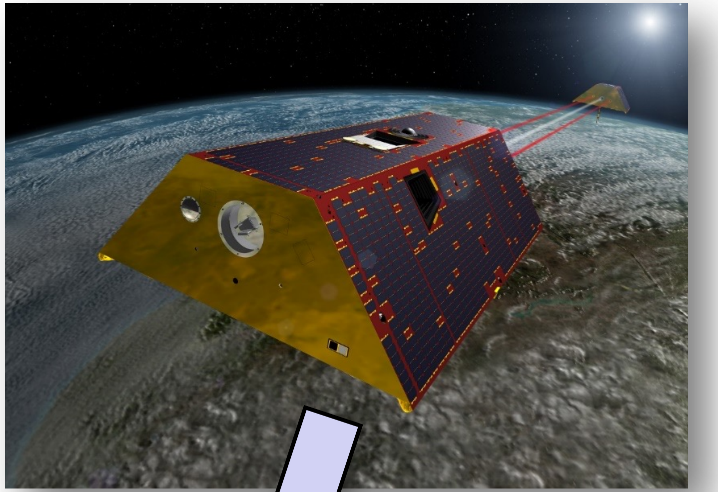
21 June 2023

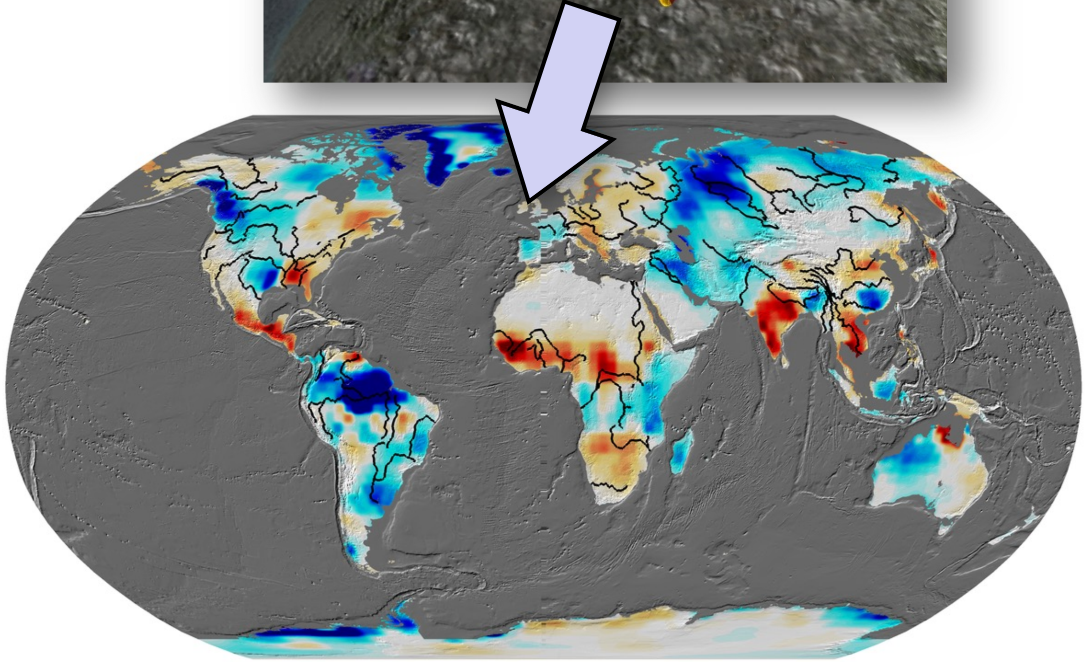
Science Motivation

PSSL

- Low-Low Sat-to-Sat Tracking missions, like GRACE & GRACE-FO, are vital for measuring mass transport over the surface of the Earth
  - Ice sheets, glaciers, underground water storage, large lakes & rivers, sea level
- LL-SST missions like GRACE-FO that use laser interferometry are technologically limited by accelerometer accuracy
  - Laser ranging measures variations in intersatellite distance due to gravity
  - Accelerometers account for non-gravitational motion of the two spacecraft
  - GPS receivers used for orbit determination

For future Earth gravity field mapping missions beyond GRACE-FO

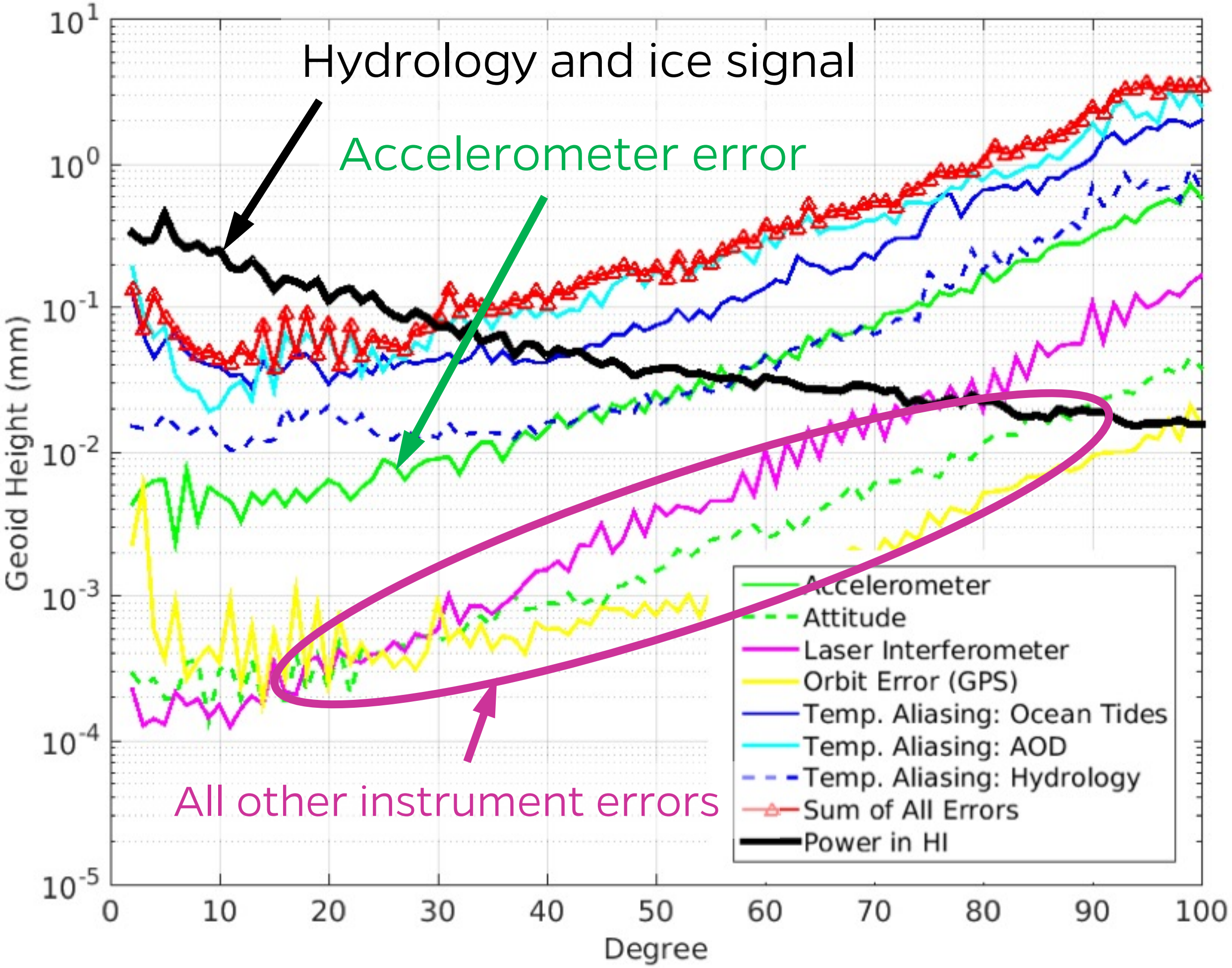




Example Earth Science outcome: Mapping changes in land water storage

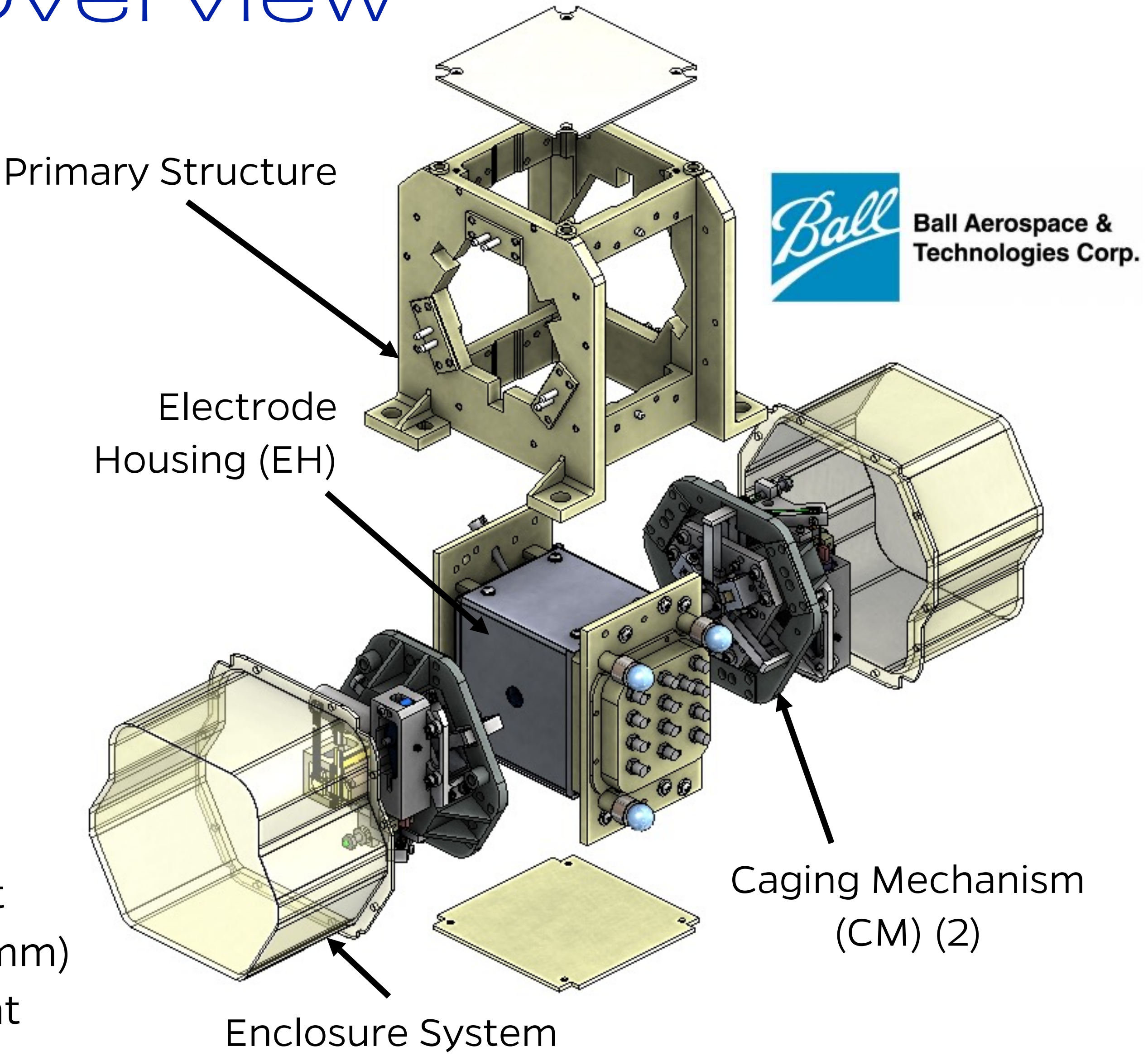
Current Measurement Systems Limited by Accelerometers

- Improved inertial sensing would allow future missions to take advantage of improvements made by laser ranging interferometry
- Temporal aliasing models continue to improve; eventually down to instrument noise limit
- The S-GRS is based on the ESA-NASA LISA Pathfinder (2015/16) design with demonstrated >10^4 improvement over GRACE-FO
- S-GRS team funded through ESTO IIP to reach TRL 6 by January 2025



S-GRS Design Overview

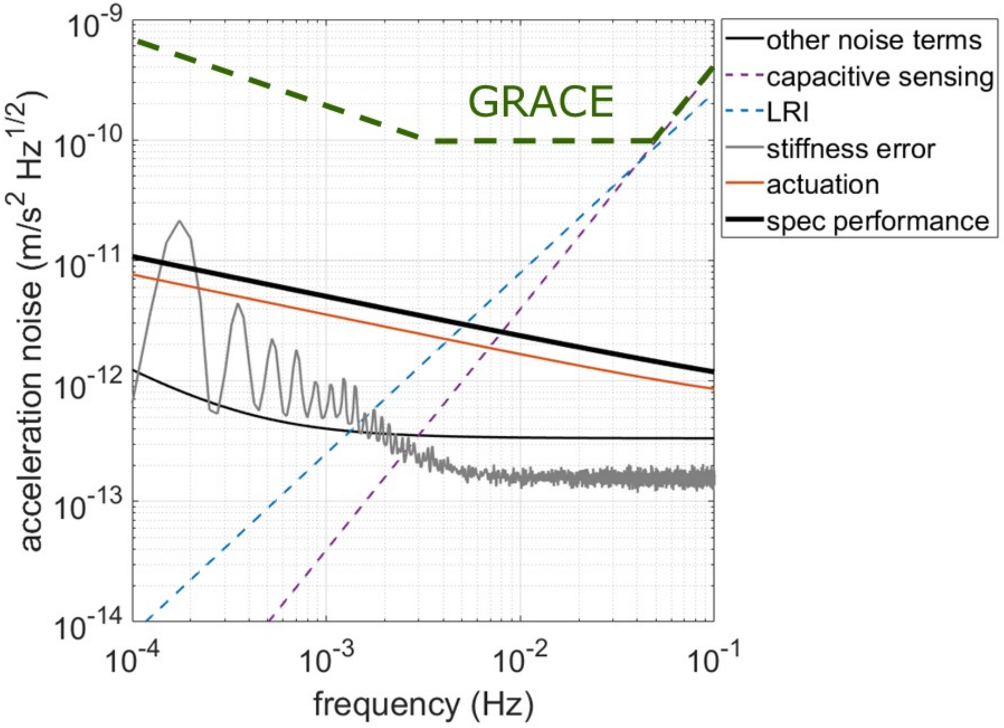
- S-GRS Head (Ball Aerospace)
  - Test mass and electrode housing
  - Test mass caging mechanism (launch lock)
  - Support structure
- Electronics units (Fibertek)
  - Charge management system (developed by UF for LISA)
  - TM sensing and actuation electronics
  - Control electronics & software
  - Power and Caging Unit
- Control software (CrossTrac Eng.)
- Improvements relative to GRACE
  - Replace TM grounding wire with UV photoemission-based charge management
  - Larger TM (0.5 kg) and TM-housing gap (~mm)
  - Venting to space improves TM environment
  - Drag-compensation improves performance further by reducing test mass actuation noise



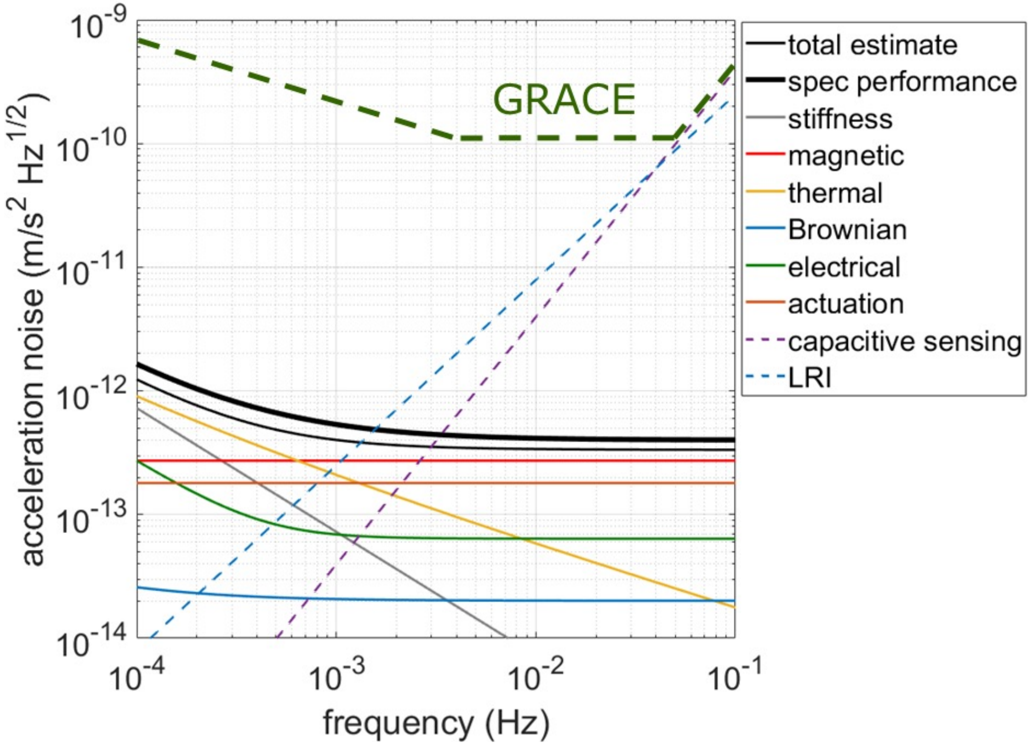
S-GRS Head

S-GRS Performance Modeling

- Two operational scenarios selected:
  - Non-drag-compensated at 500 km altitude (e.g. GRACE-FO)
  - Drag-compensated spacecraft at 350 km



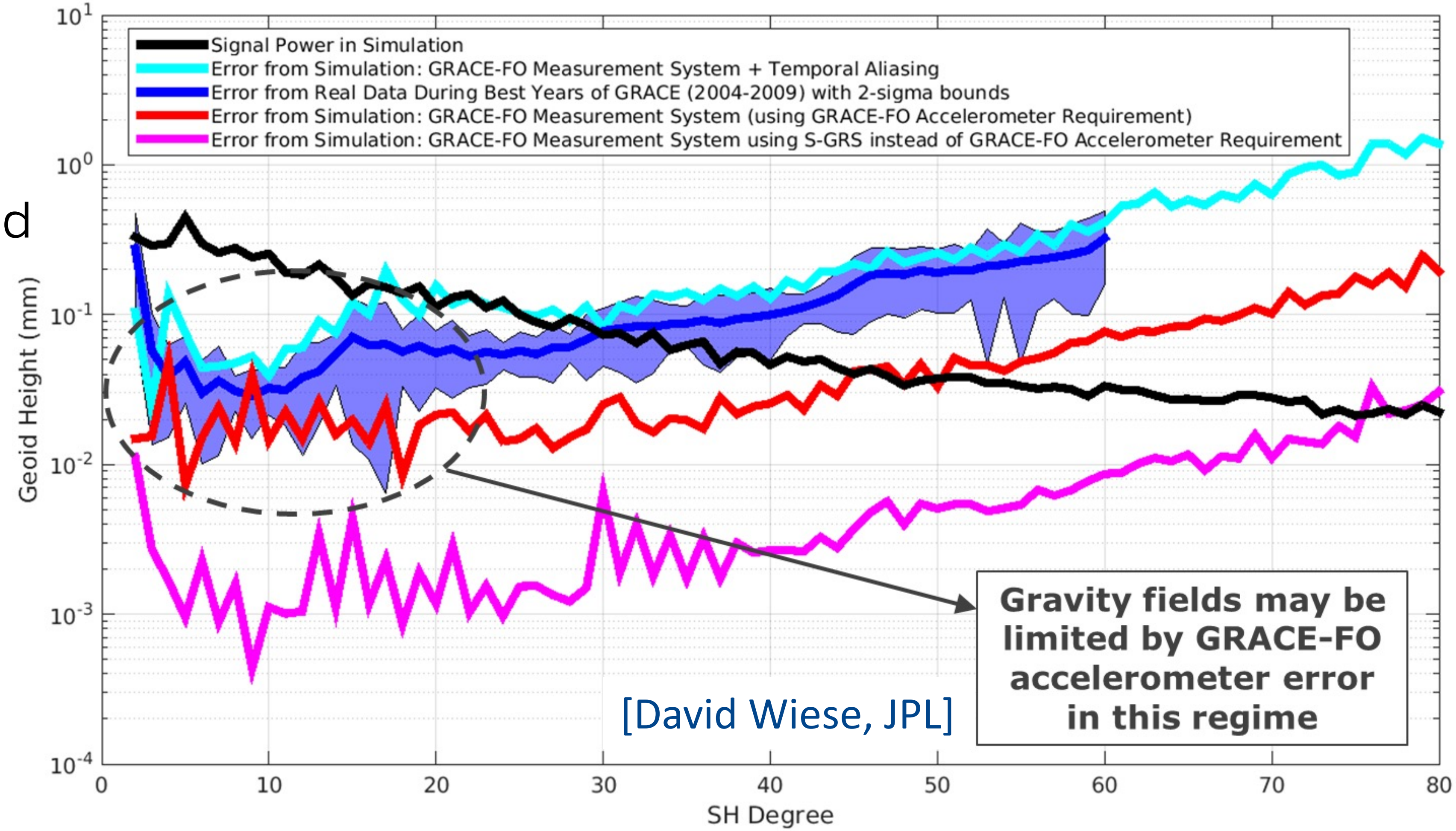
Operated as an accelerometer based on GRACE-FO flight environment



Operated on a drag-compensated spacecraft

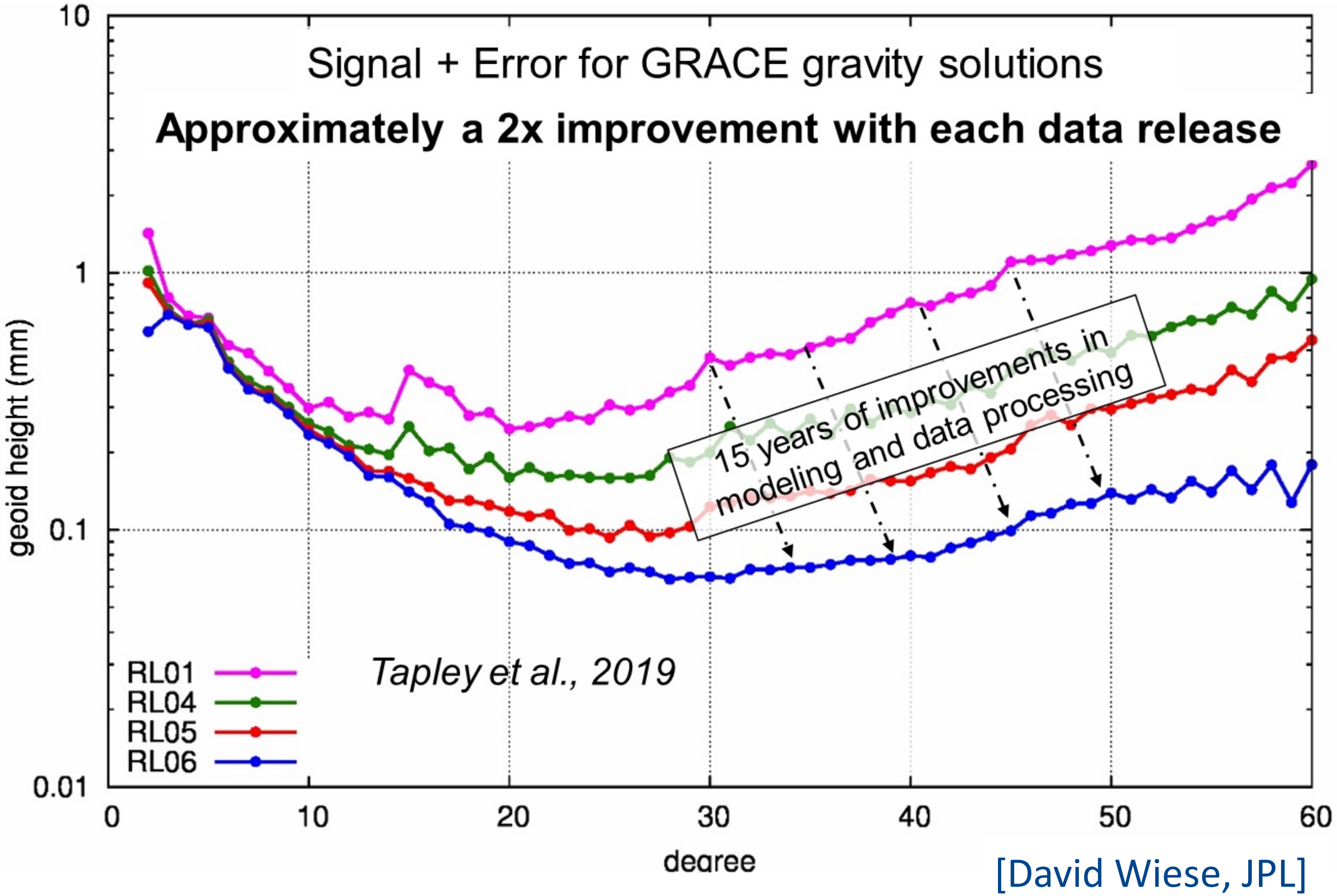
S-GRS Could Improve Science from GRACE-like Missions Immediately

- Science data products limited in lowest SH degrees by a combination of temporal aliasing and accelerometer error
- S-GRS lowers measurement system error to ensure science data products are limited by temporal aliasing in all SH degrees
- S-GRS has the potential to improve quality of monthly gravity fields relative to GRACE and GRACE-FO data record



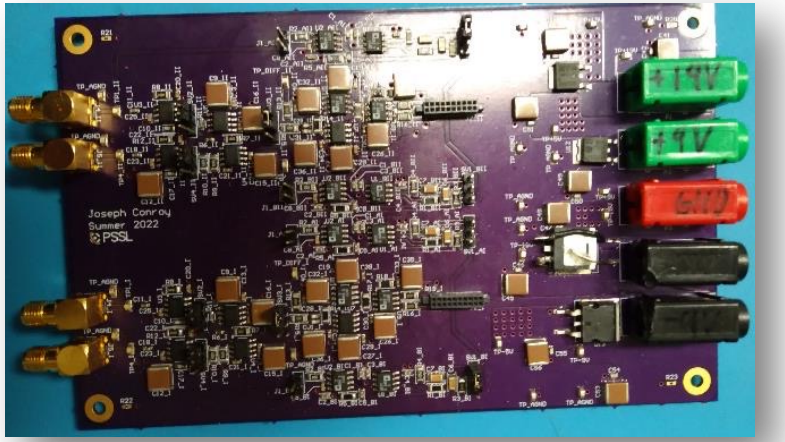
S-GRS can Improve Gravity Fields 10x

- Community constantly improving quality of science through improved modeling of mass variations and data processing methods
- As this trend continues, error can be driven down to performance of measurement system
- S-GRS allows for a potential 10x improvement in quality of gravity fields as data processing and modeling improve

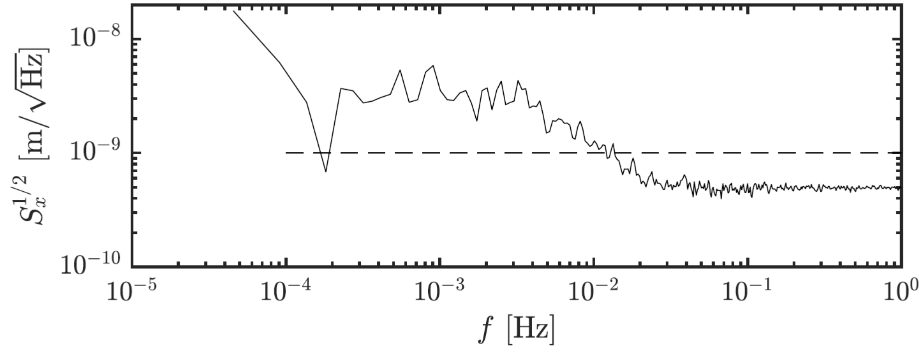


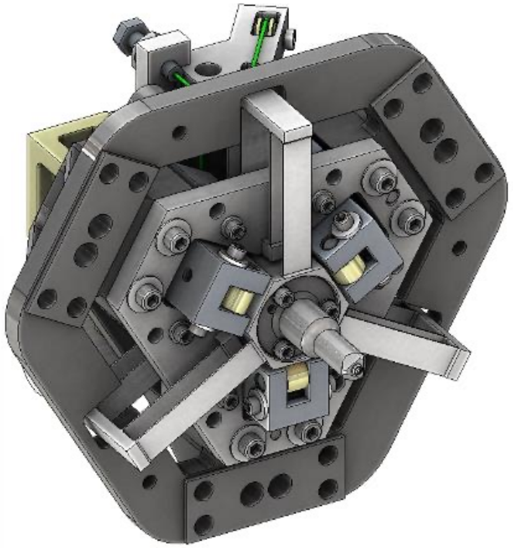
[David Wiese, JPL]

S-GRS Development Highlights

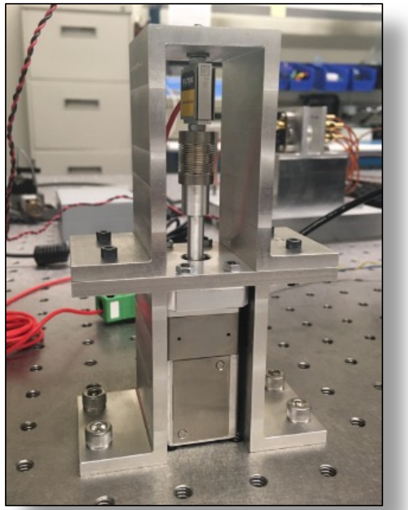


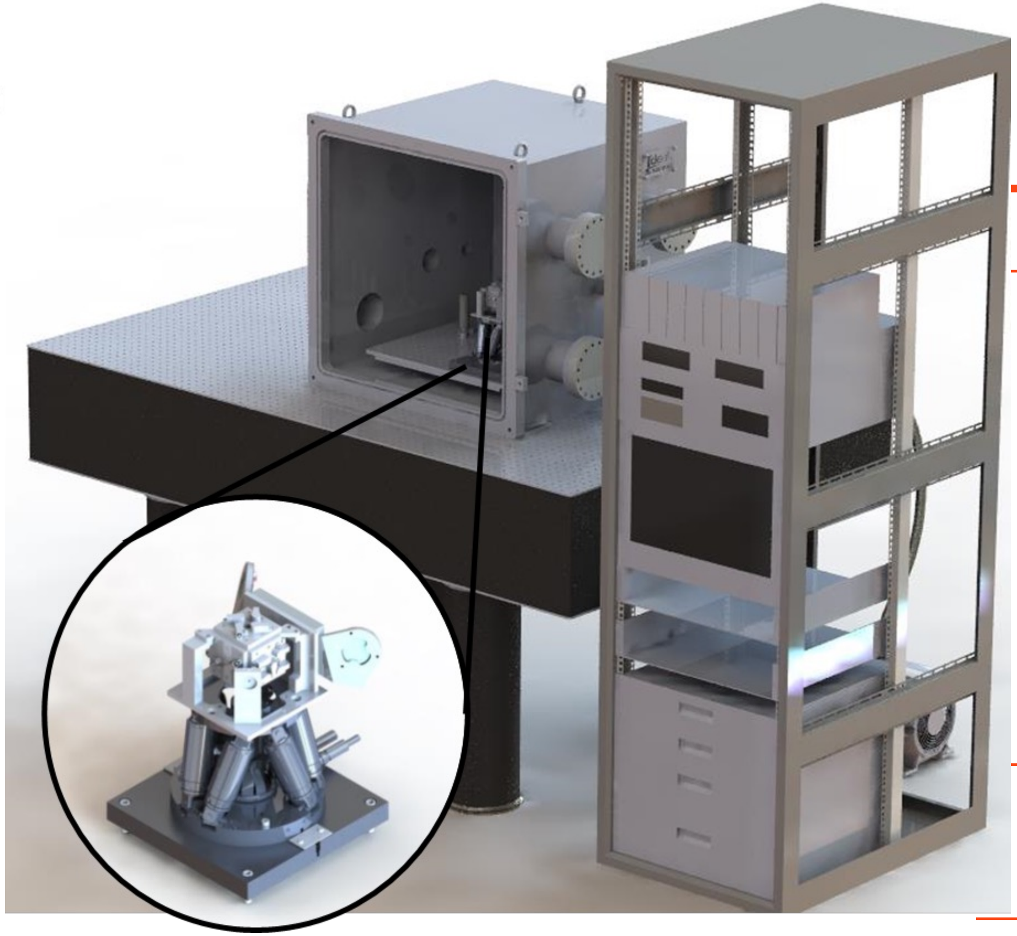
Prototype sensing electronics meets performance requirements





TM Caging Mechanism design and testing

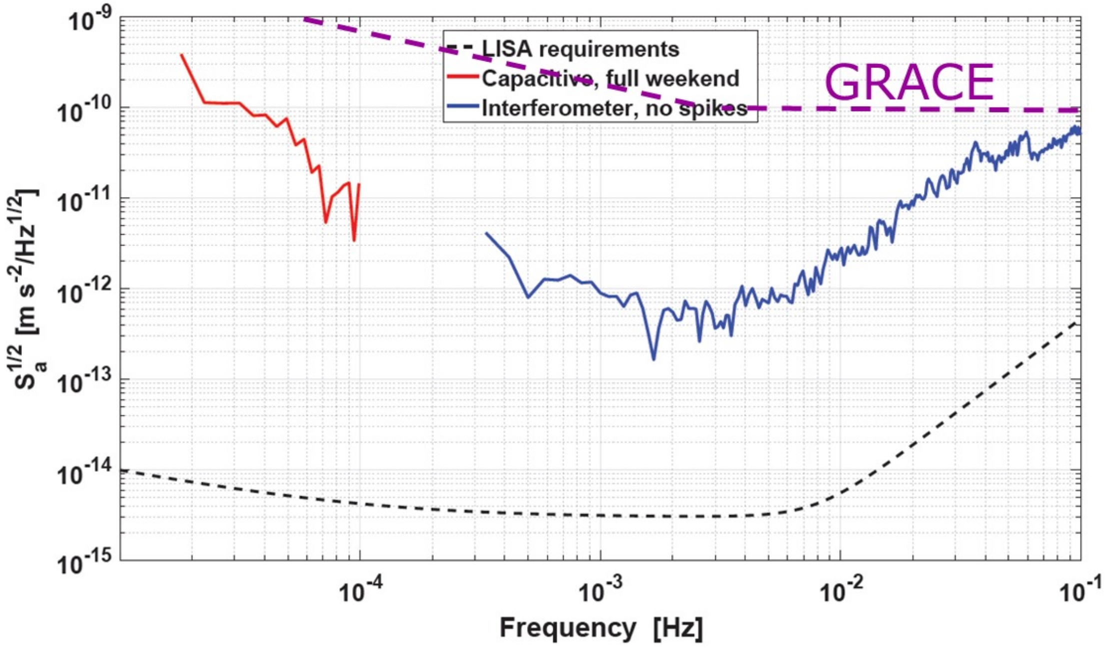


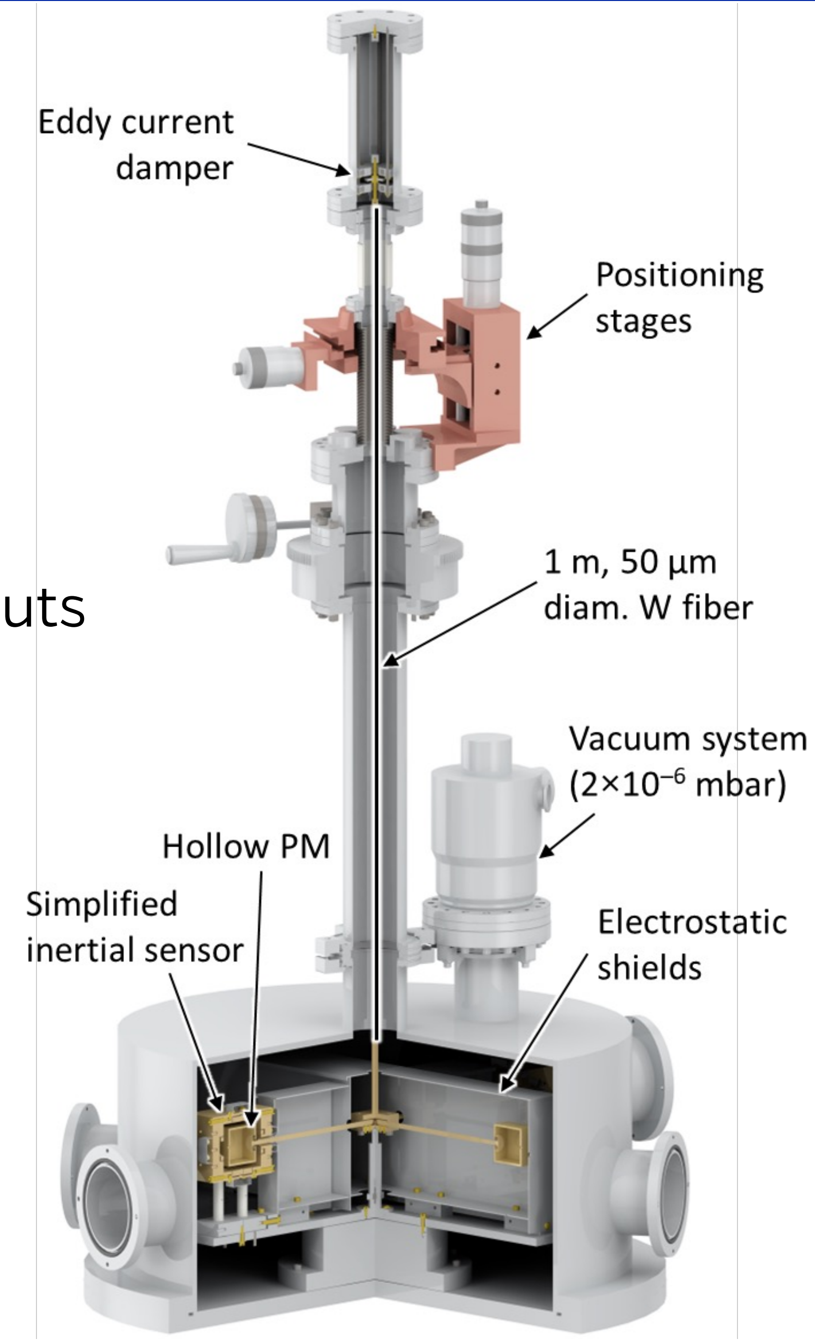


Charge Management and Metrology Testbed

UF Torsion Pendulum

- Testbed for precision inertial sensors
- 1 m, 50 μm diameter fiber supports cross bar with 4 hollow TMs (rotation → translation)
- Light Al structure reduces needed fiber diameter
- Capacitive (15 nm/Hz$^{1/2}$) + IFO (0.2 nm/Hz$^{1/2}$) readouts





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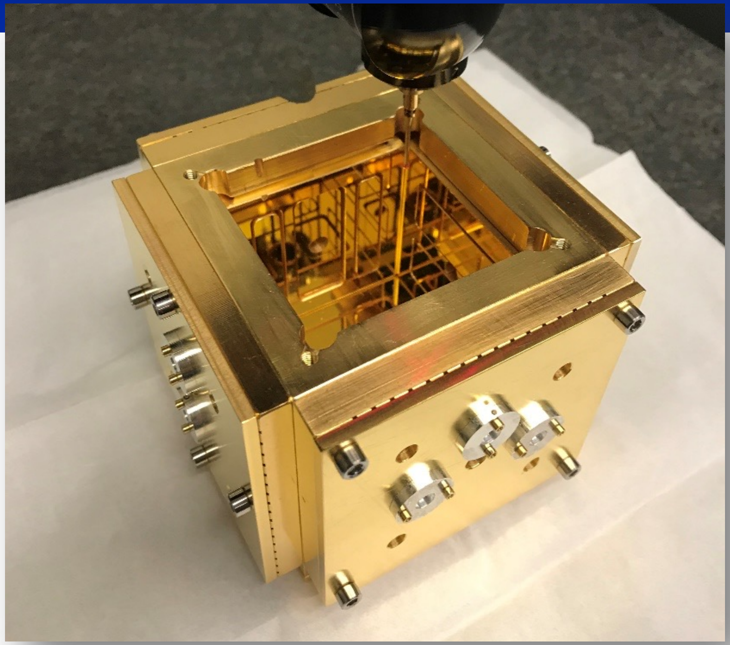

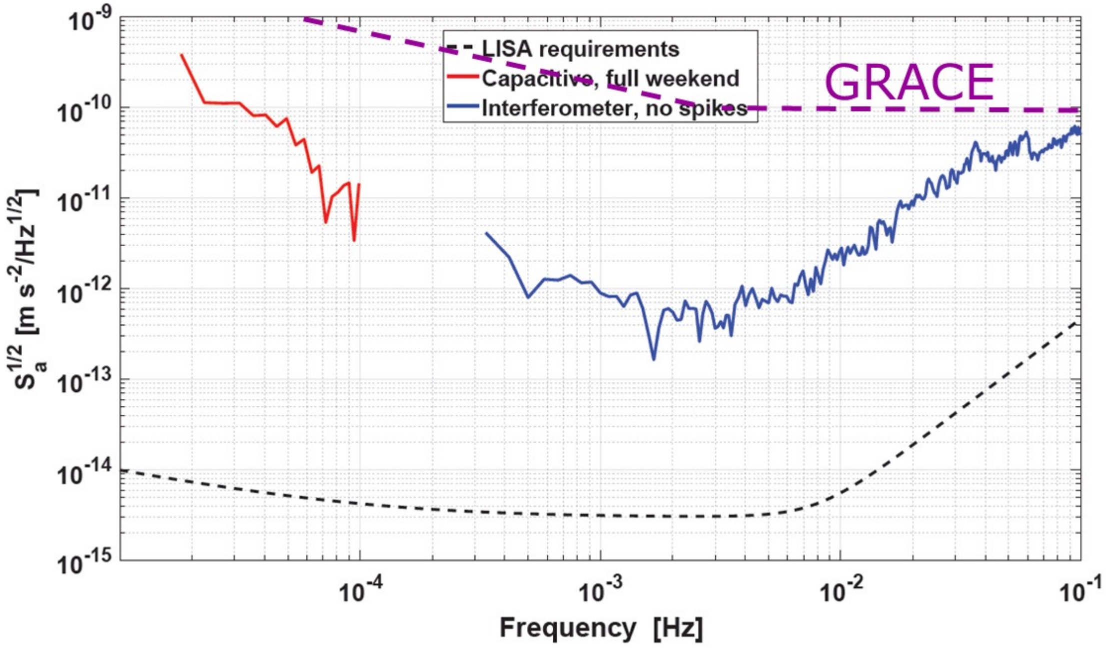

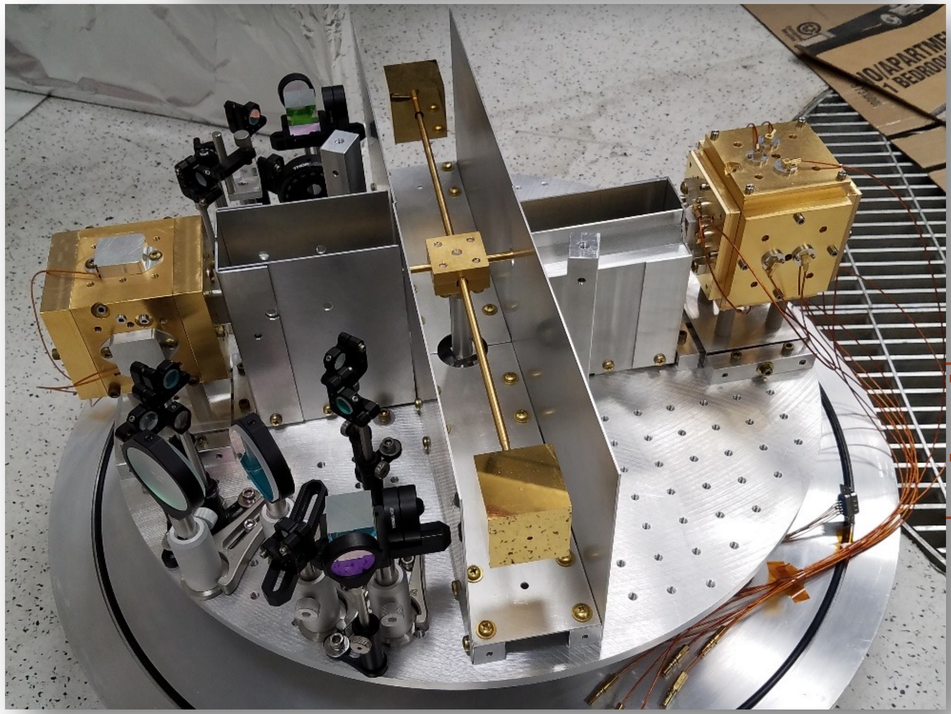

UF Torsion Pendulum

UF UNIVERSITY of FLORIDA

PSSL

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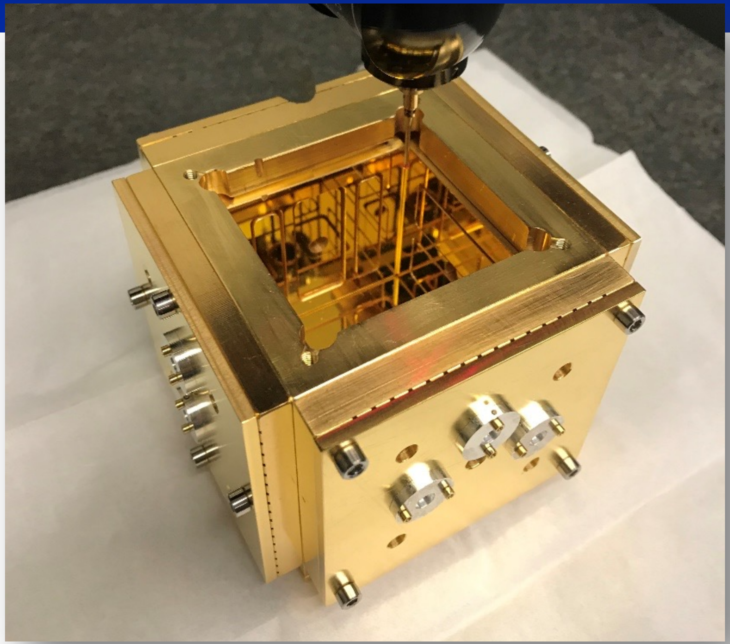
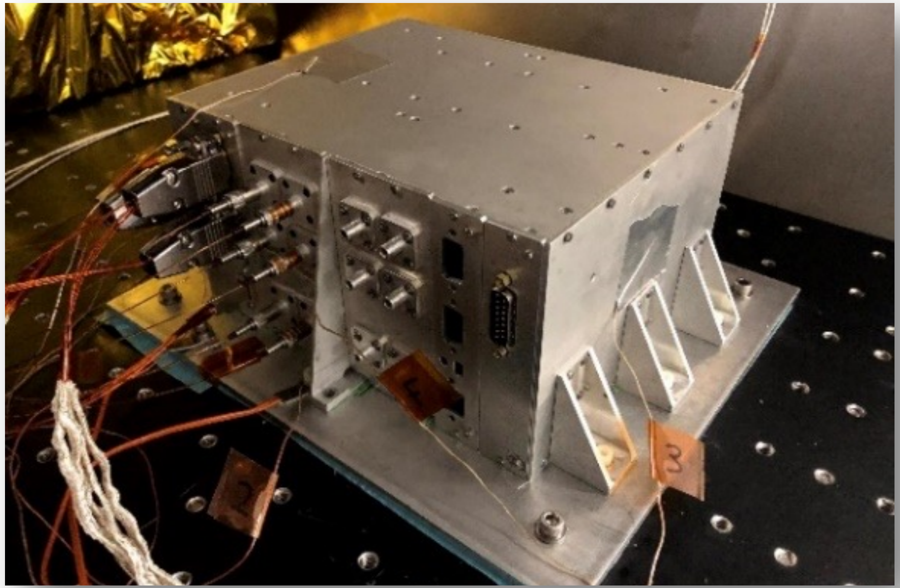
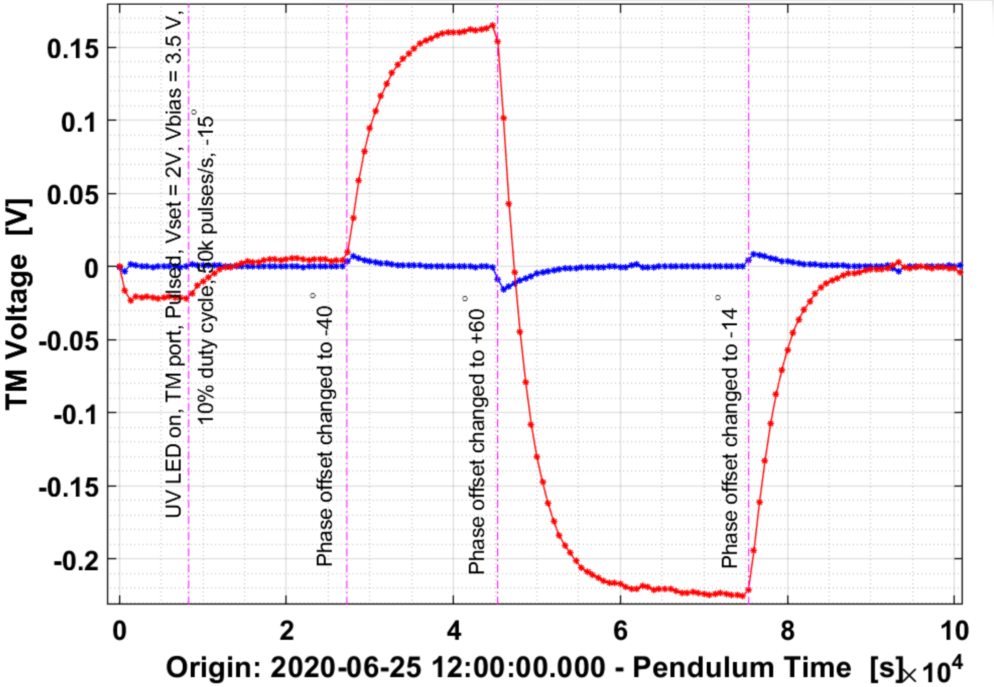




TRL 5 LISA CMS in UF TVAC chamber



S-GRS IIP Task Milestones and Outlook

- Key Milestones
  - TRL 6 Caging Mechanism delivered from Ball to UF for testing — Aug 2023
  - TRL 6 S-GRS Head delivered from Ball to UF for testing — Jan 2024
  - TRL 6 S-GRS Head achieves TRL 6 — May 2024
  - TRL 6 software delivered from CrossTrac to Fibertek — July 2024
  - TRL 6 S-GRS Electronics Unit delivered from Fibertek to UF for testing — Nov 2024
  - TRL 6 S-GRS Electronics Unit achieves TRL 6 — Jan 2025

- Charge Management Device reaches TRL 6 by Dec 2023 for Class A/B LISA mission

- Seeking opportunities for an S-GRS flight technology demonstration this decade
  - Looking for partners and a host spacecraft platform
  - First opportunity is InVEST 2023

UF PSSL

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