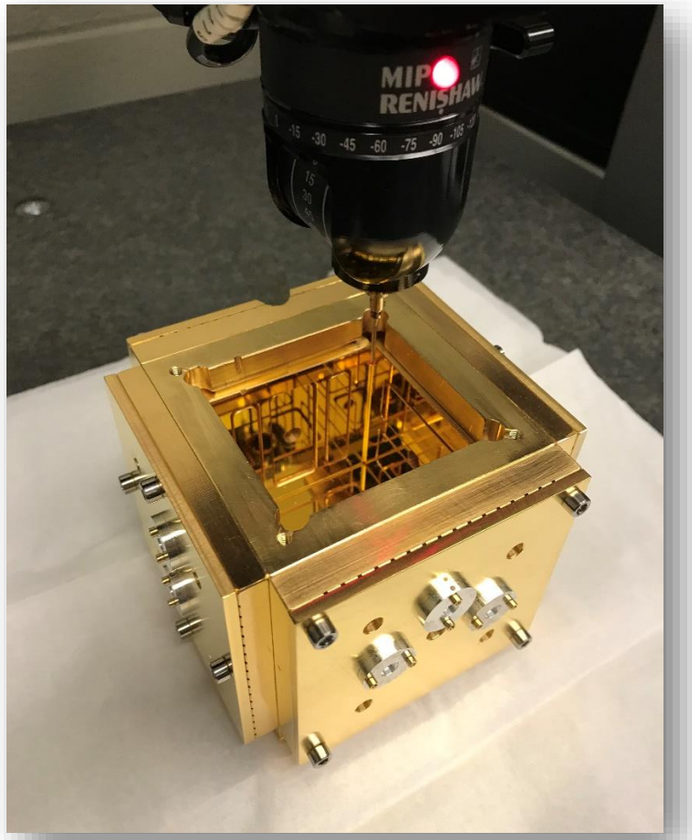
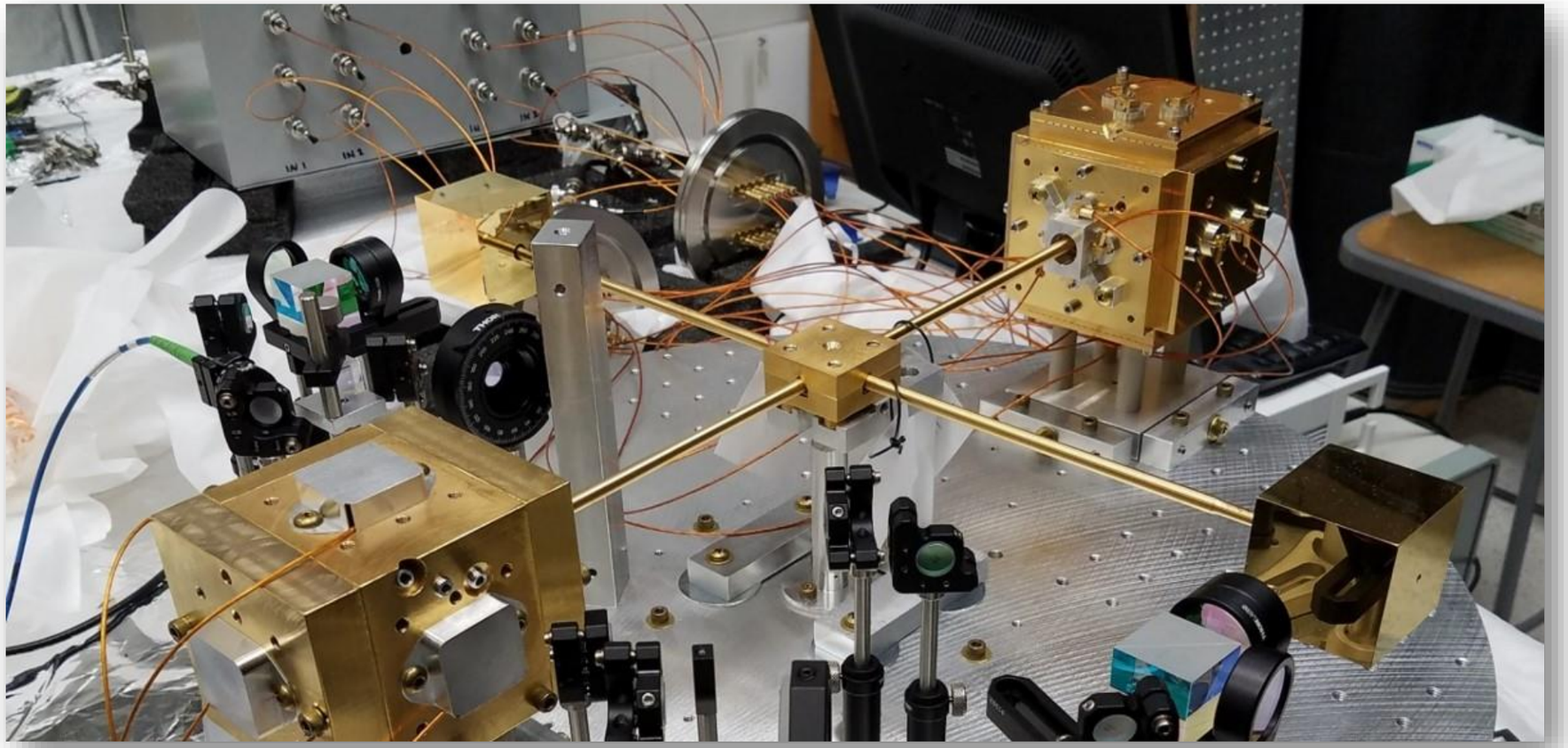
Simplified Gravitational Reference Sensors for Future Earth Geodesy Missions





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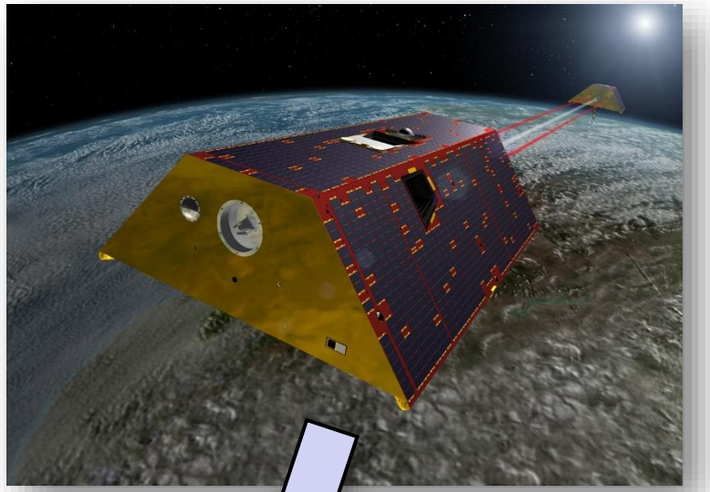
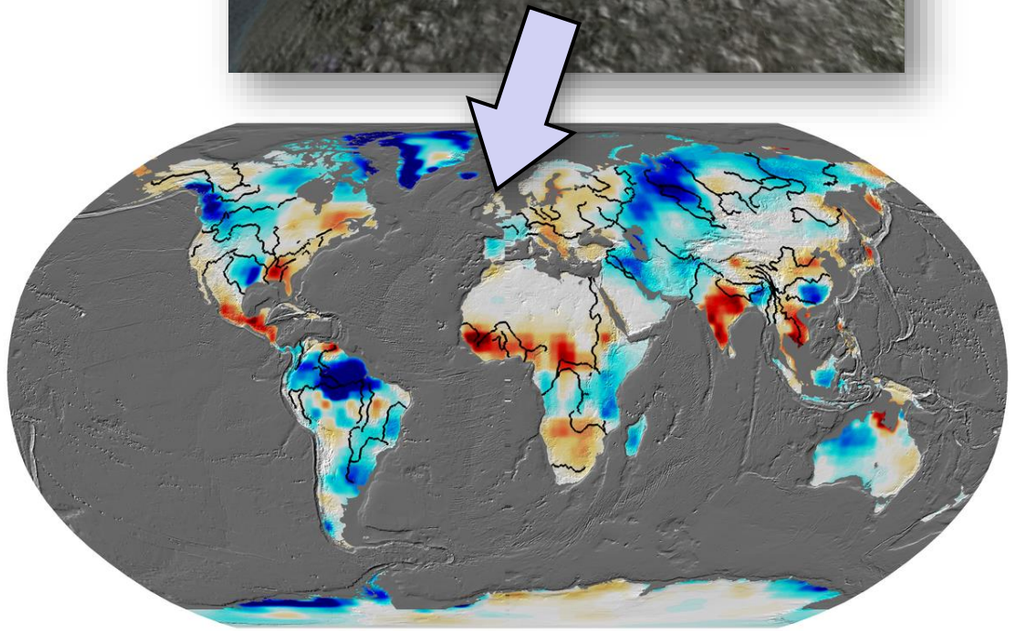
UF PSSL JPL Ball Aerospace & Technologies Corp. ESTO EARTH SCIENCE TECHNOLOGY OFFICE

Science Motivation

- 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

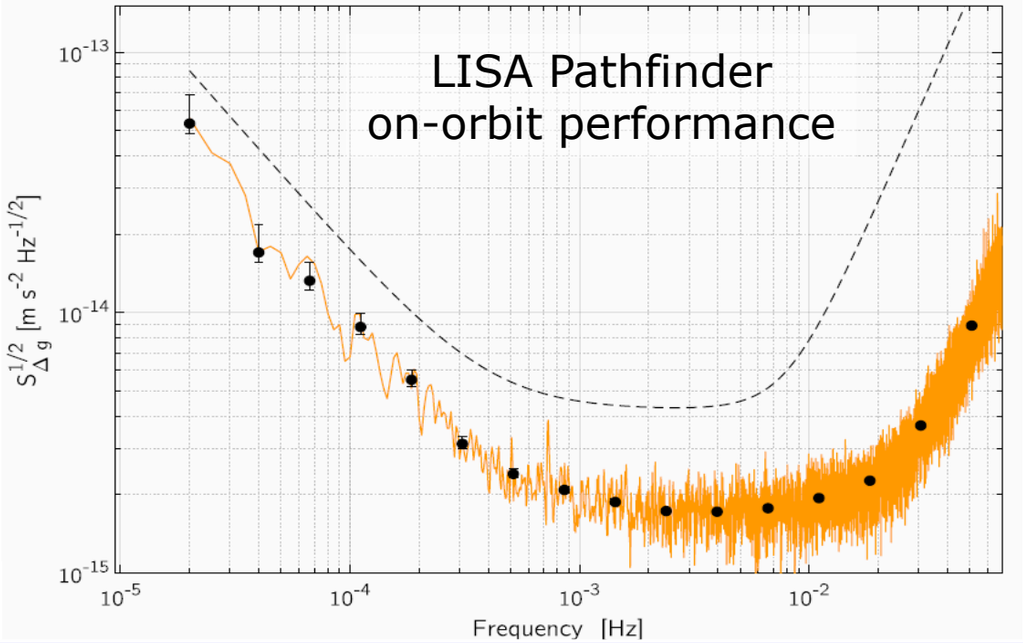


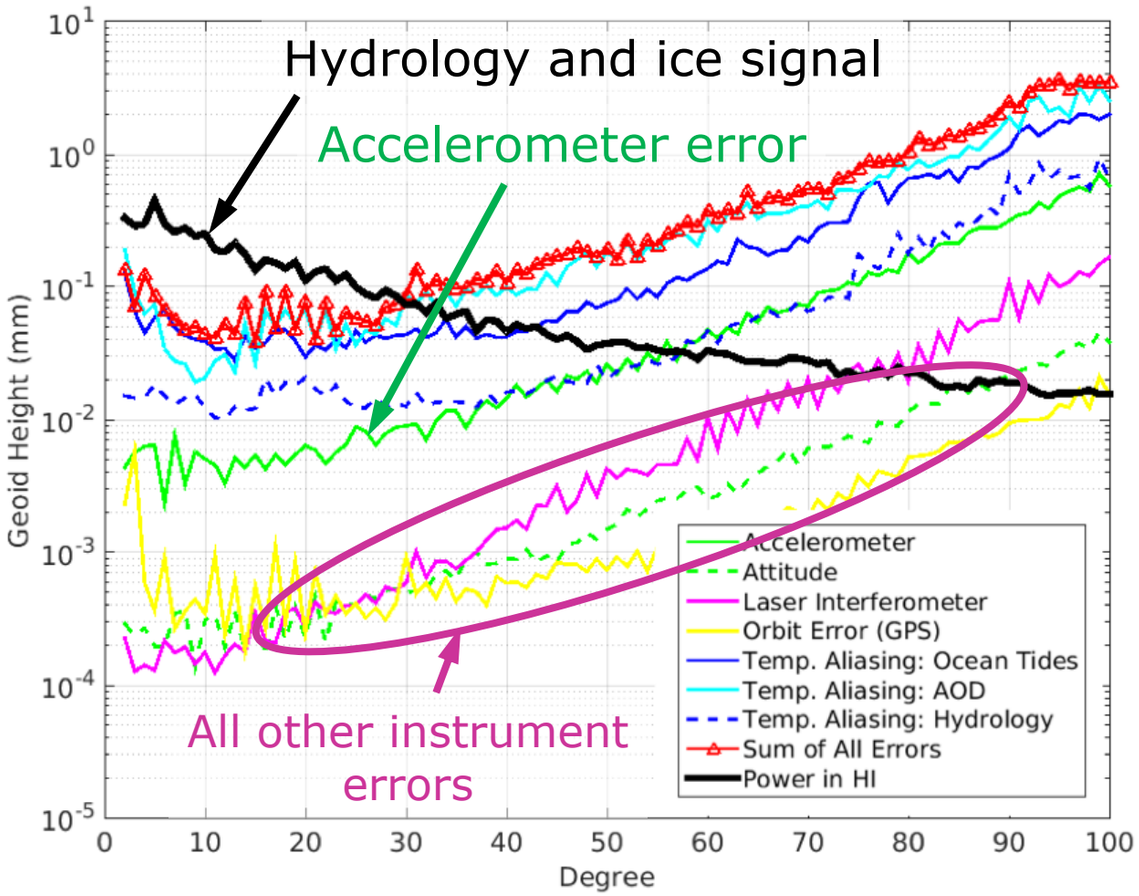


Example Earth Science outcome: Mapping changes in land water storage

Current Measurement Systems Limited by Accelerometers

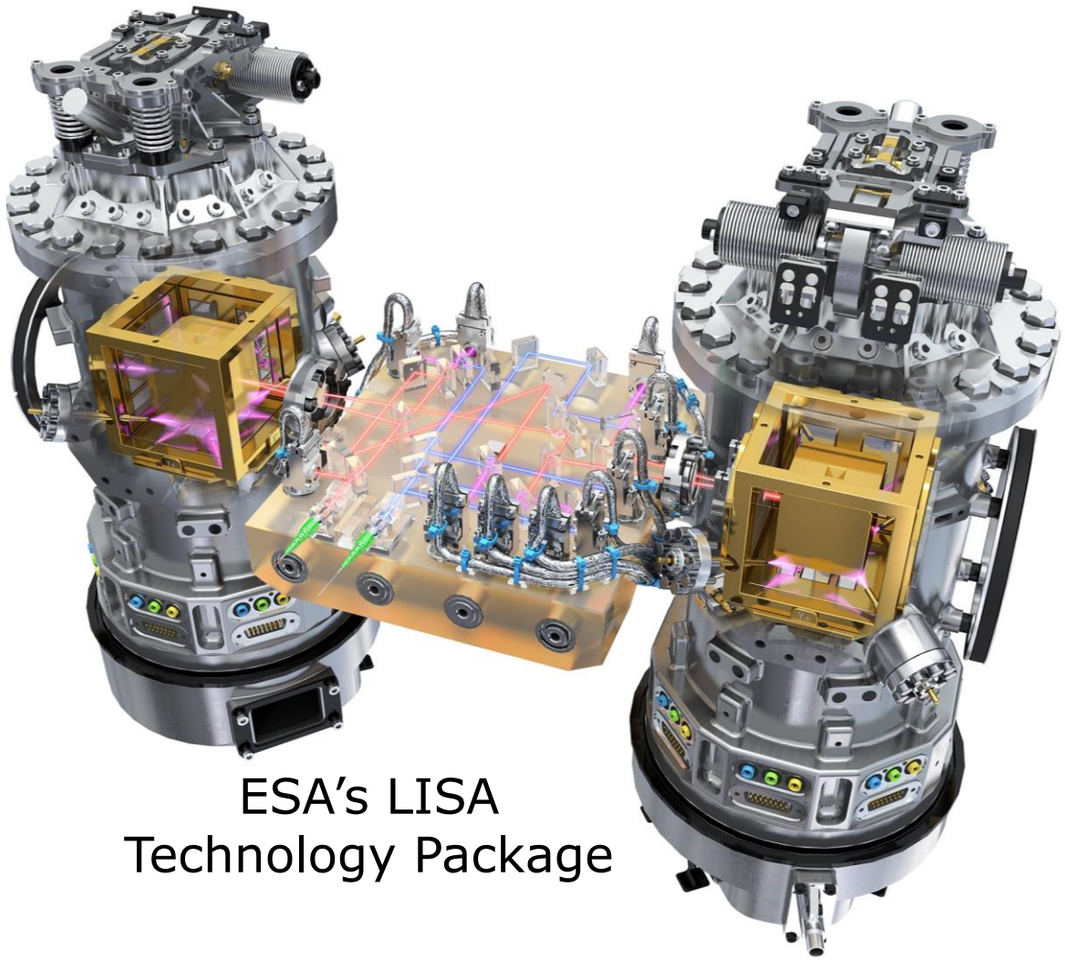
- Improved inertial sensing would allow future missions to take advantage of improvements made by laser ranging interferometry
- Temporal aliasing models continue to improve; eventually down to instrument noise limit
- Mass Change DO Study Team identified improved accelerometers as most important technology need for future missions
- ESA-NASA LISA Pathfinder (2015/16) demonstrated >10^4 improvement over GRACE-FO





The Simplified Gravitational Reference Sensor

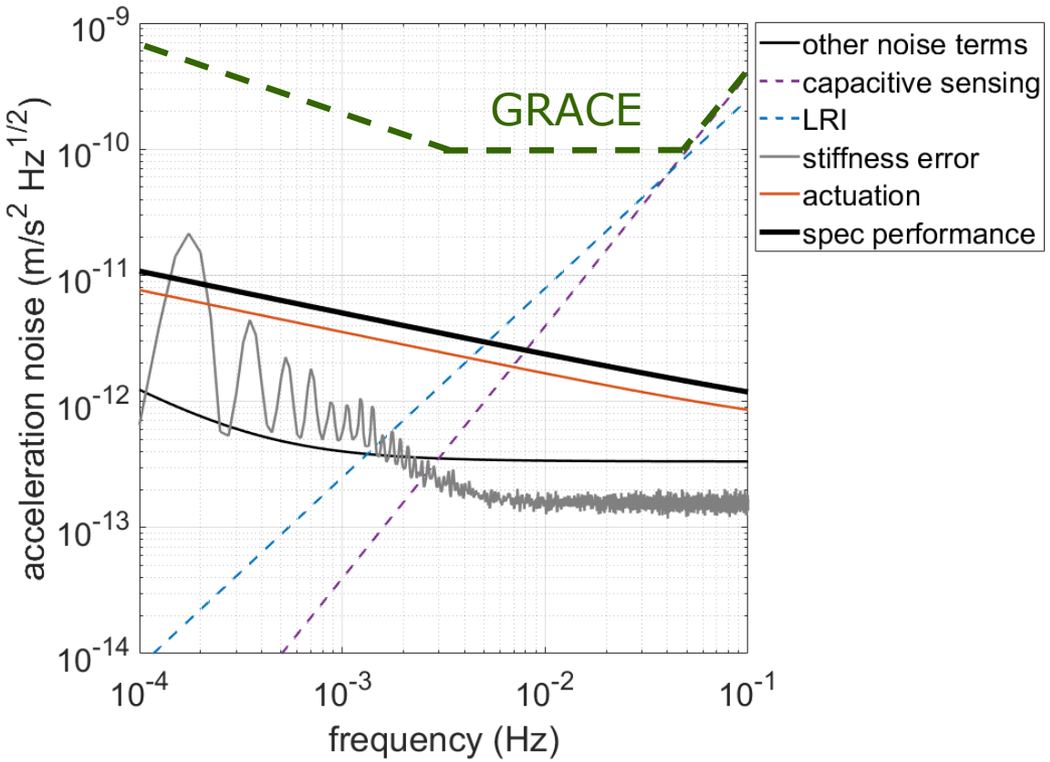
- High-TRL LISA Pathfinder GRS includes:
  - Test mass and electrode housing contained within a vacuum enclosure
  - Test mass caging (launch lock) mechanism
  - Charge management system (developed by UF for LISA)
  - Front End Electronics
- Requires quiet thermal, EM, gravitational environment
- Goal: Use Pathfinder heritage to improve performance compared to electrostatic accelerometers by:
  - Replacing test mass grounding wire with a non-contact UV photoemission-based charge management system
  - Allows large TM (0.5 kg) and TM-housing gap (~mm)
  - Venting to space lowers residual pressure and improves thermal isolation
  - Tightly integrate S-GRS and laser interferometer, eliminating microwave ranging instrument
  - Drag-compensation improves performance further by reducing test actuation noise



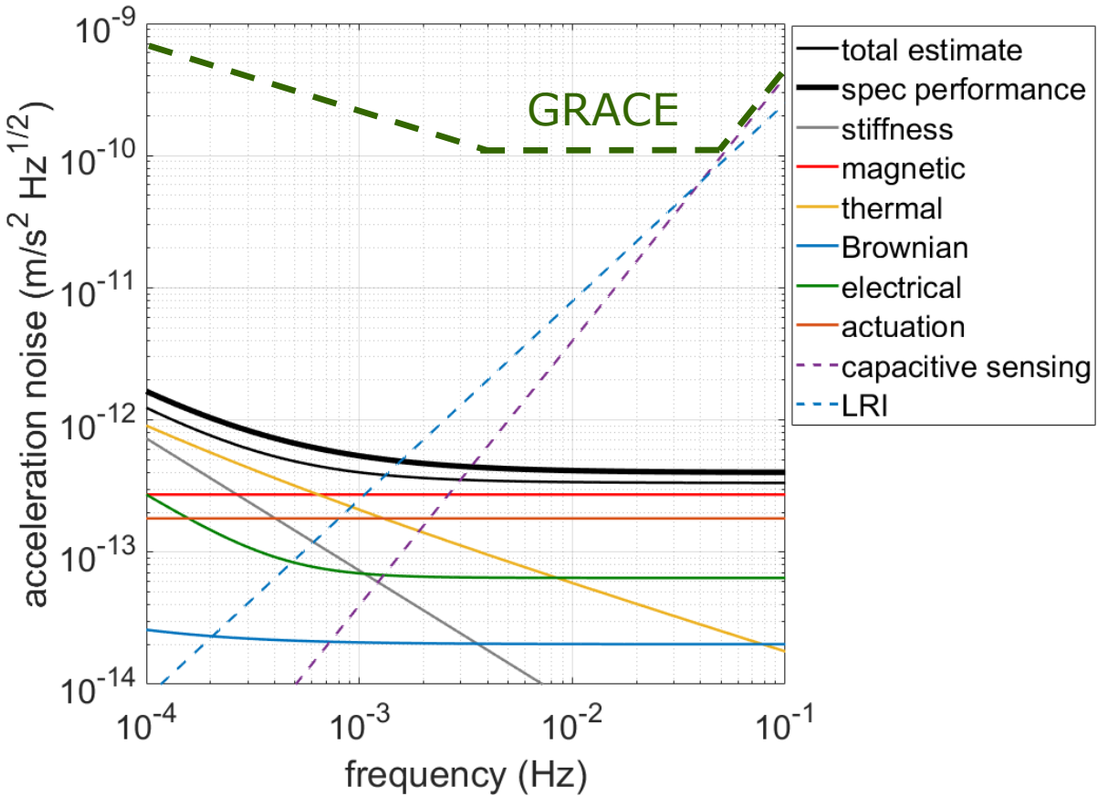
ESA's LISA Technology Package

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



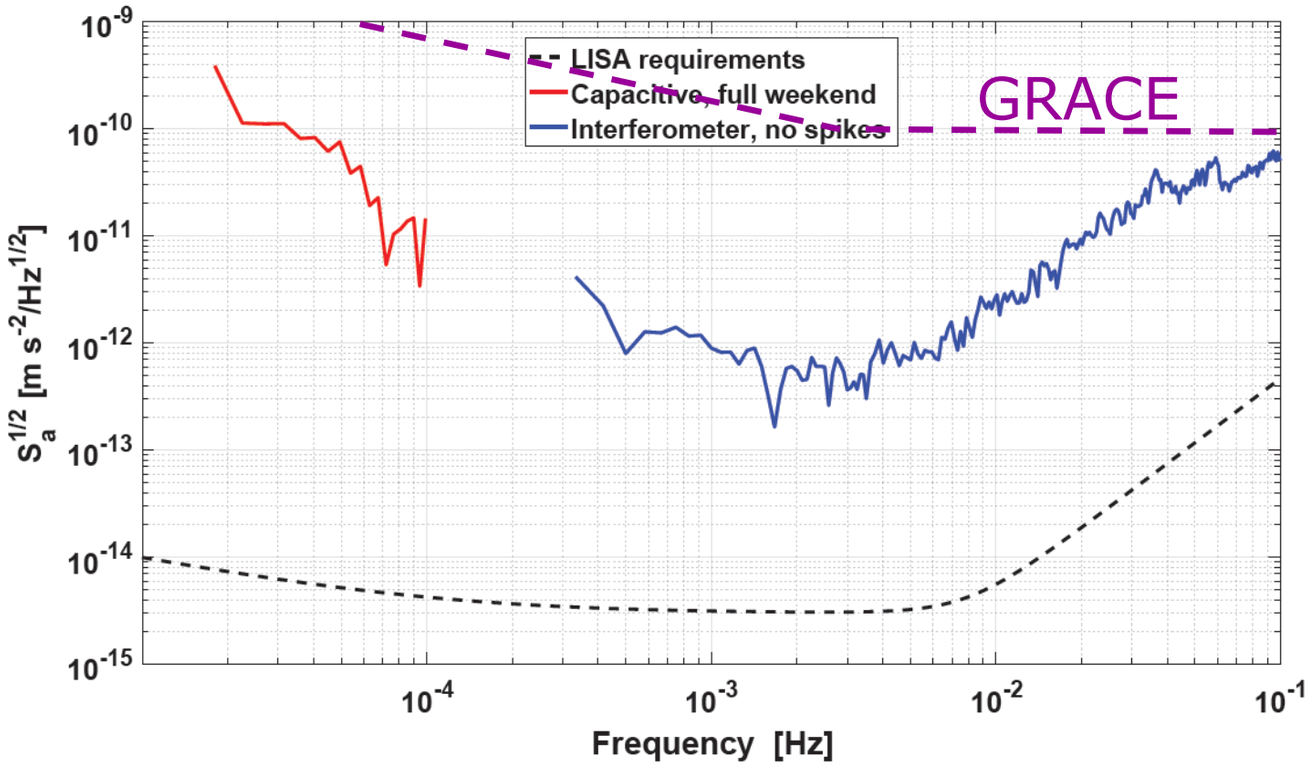
Operated as an accelerometer based on GRACE-FO flight environment

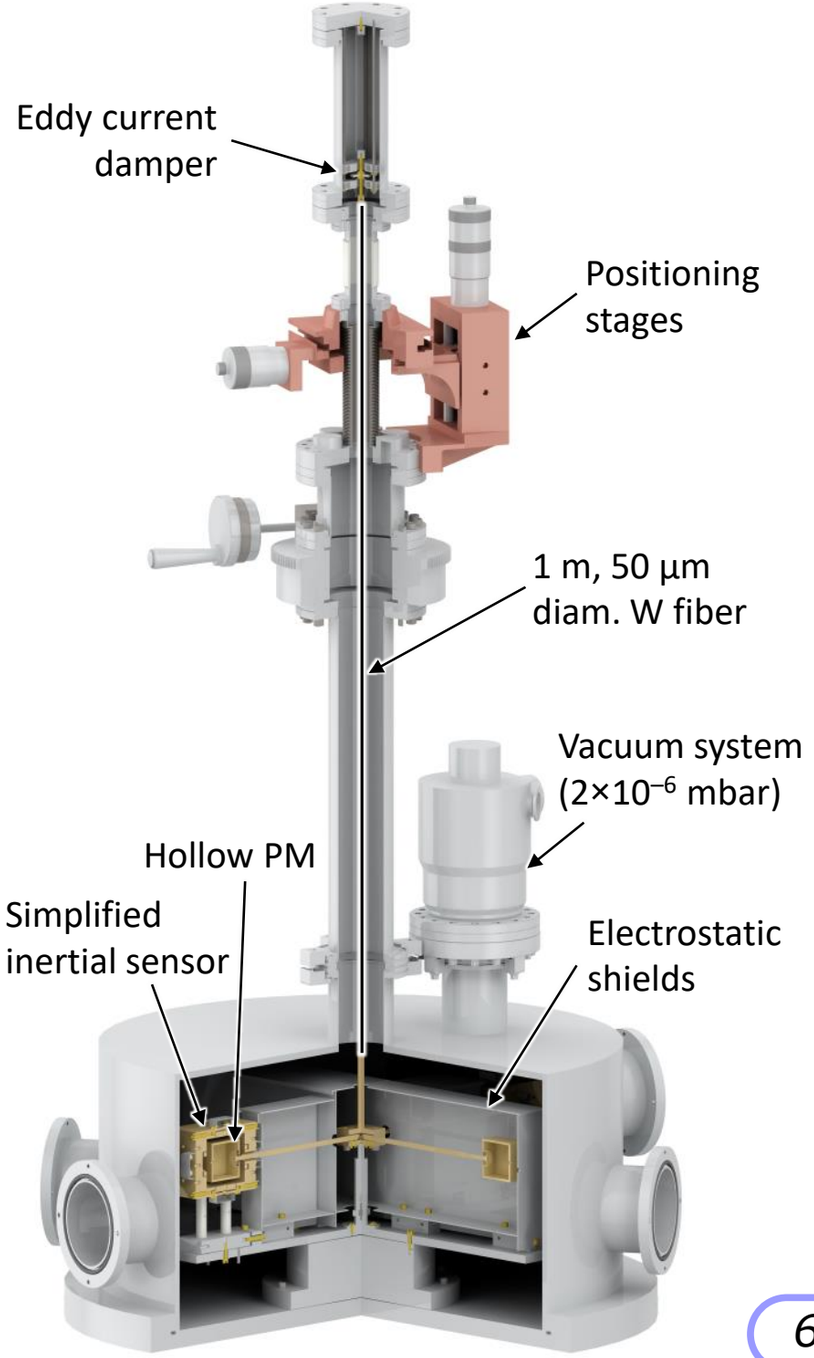


Operated on a drag-compensated spacecraft

UF Torsion Pendulum

- Test-bed for precision inertial sensors
- 1 m, 50 µm diameter fiber supports cross bar with 4 hollow TMs (rotation → translation)
- Light (0.46 kg) Al structure reduces needed fiber diameter
- Capacitive (15 nm/Hz$^{1/2}$) + IFO (0.2 nm/Hz$^{1/2}$) readouts





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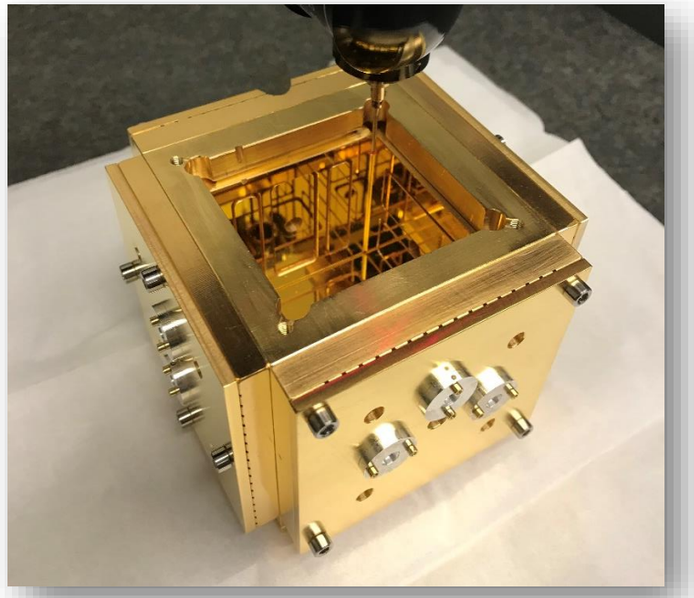
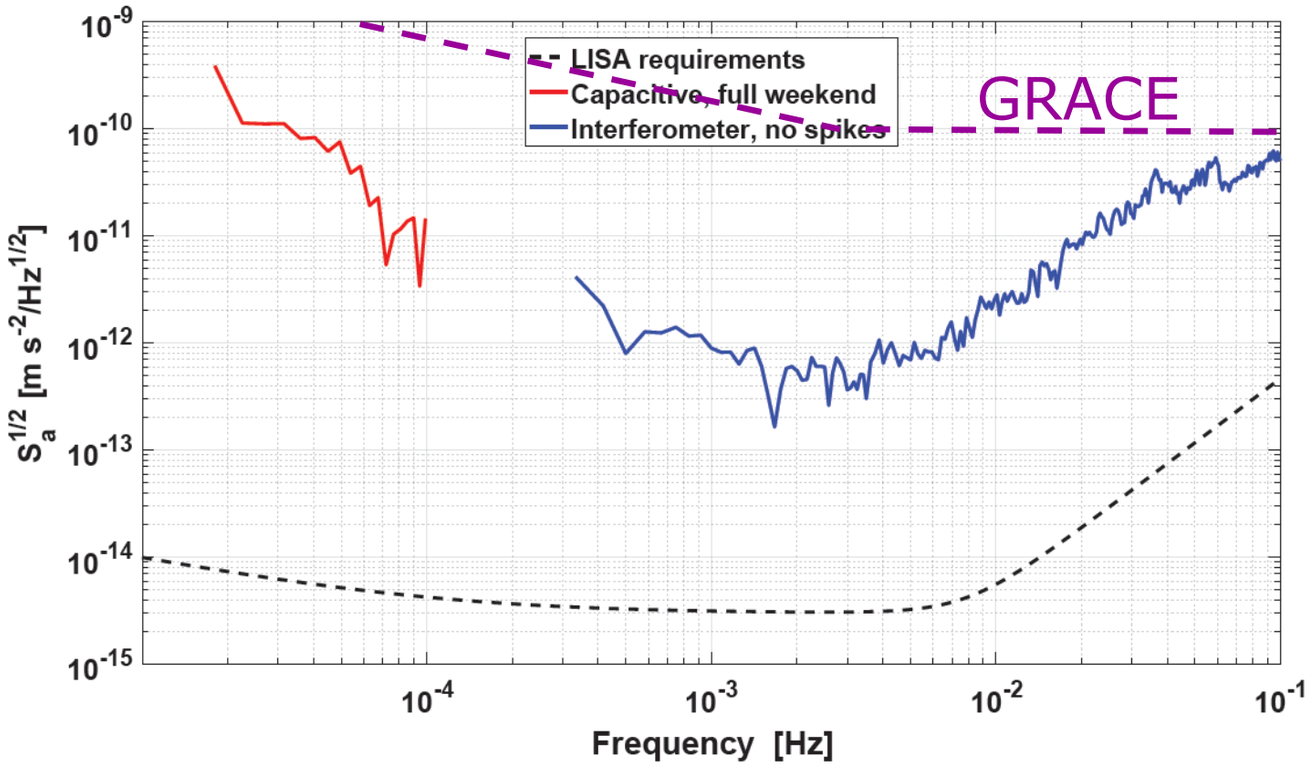
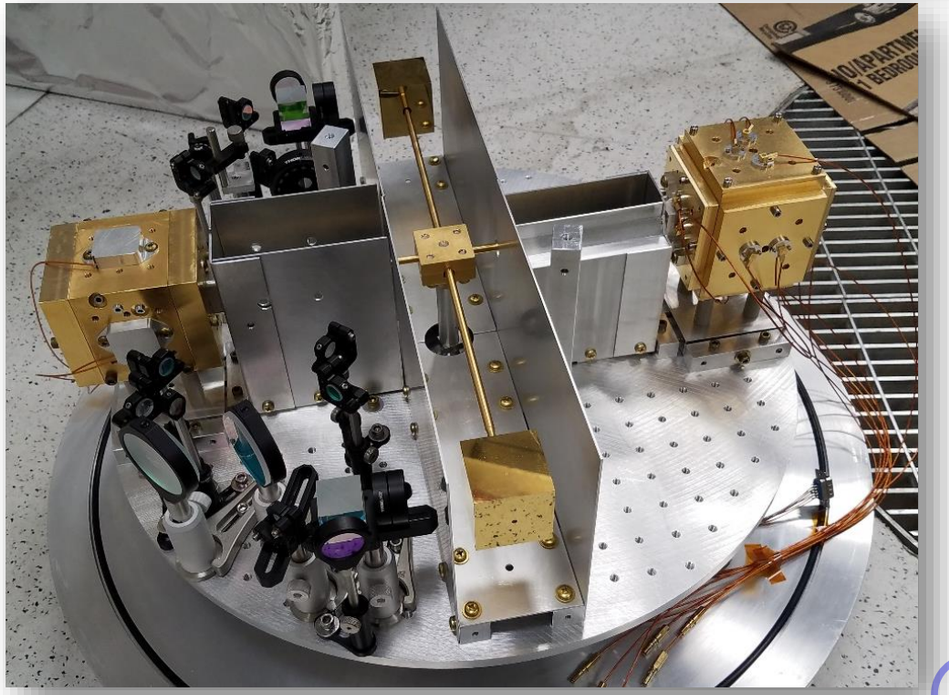




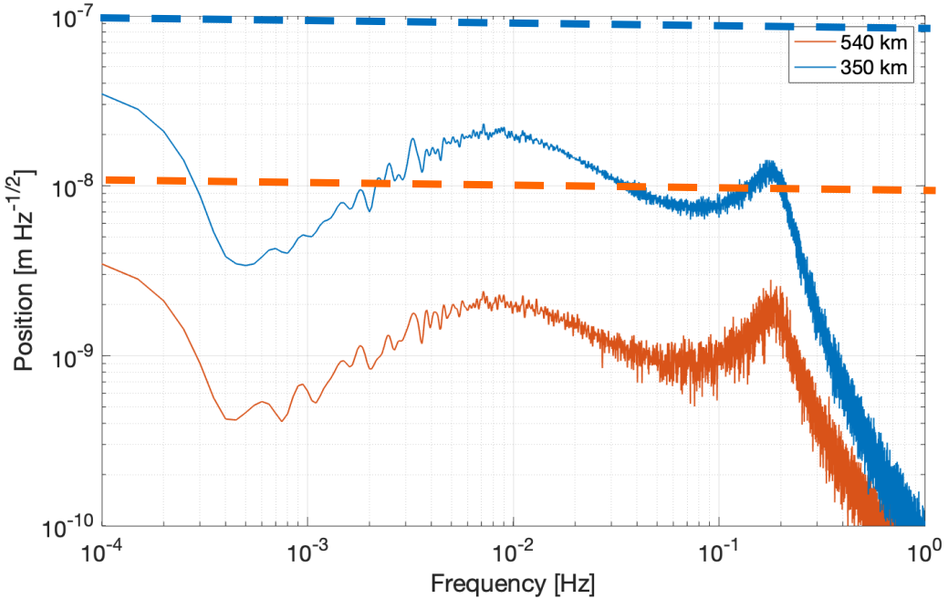


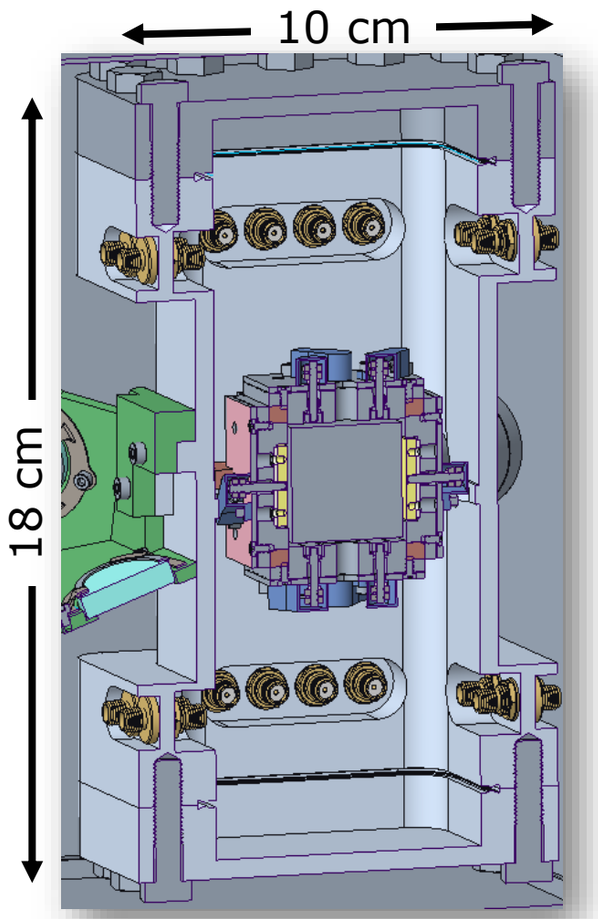
S-GRS Development Highlights

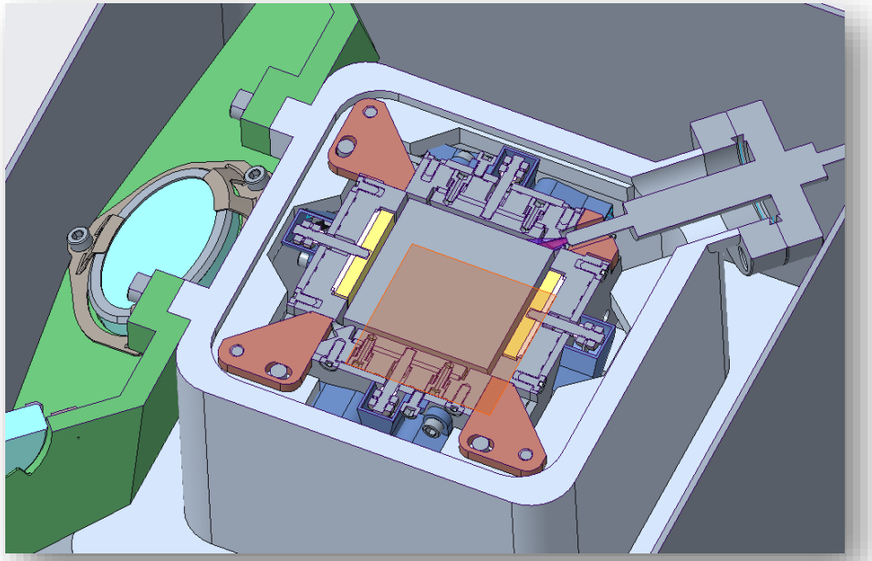
- S-GRS electronics enclosure based on LISA
  - ~15 W power consumption; TRL 6 by 2022
- Low mass mechanical design
  - <10 kg sensor head, <5 kg electronics
- Numerical dynamics models
  - TM release, test mass control, drag-compensation

TRL 5 LISA Charge Management Device (University of Florida)

S-GRS Simulated Control Performance

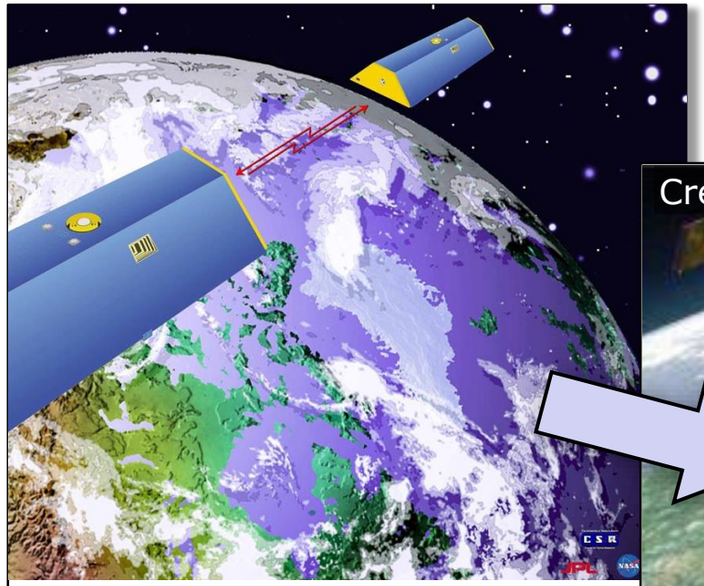




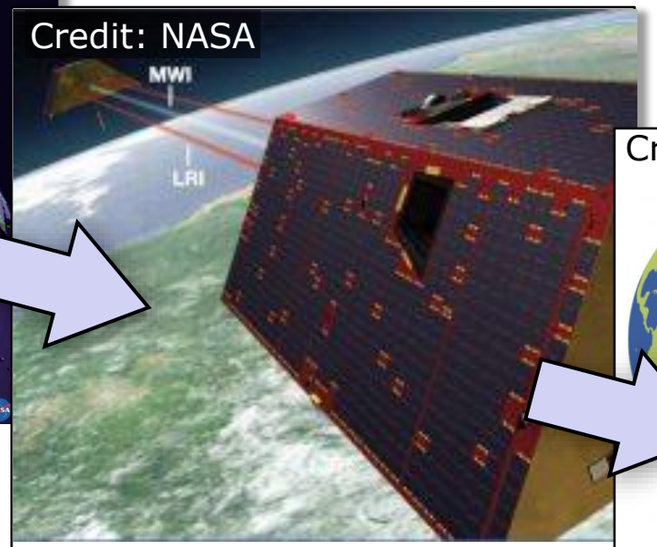


S-GRS Mechanical Design Concept

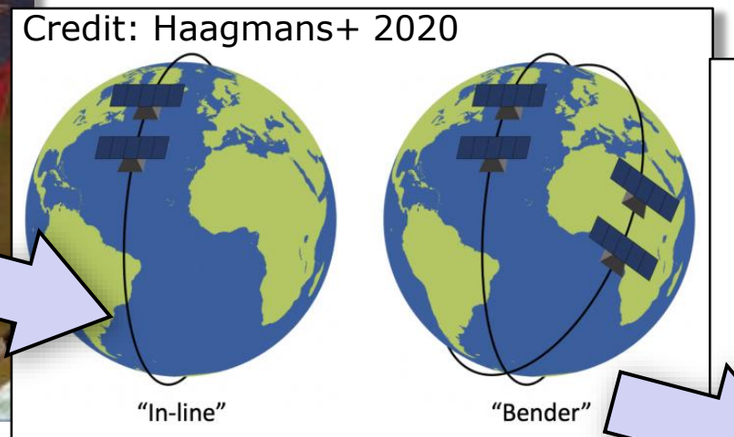
S-GRS Project Long-term Vision



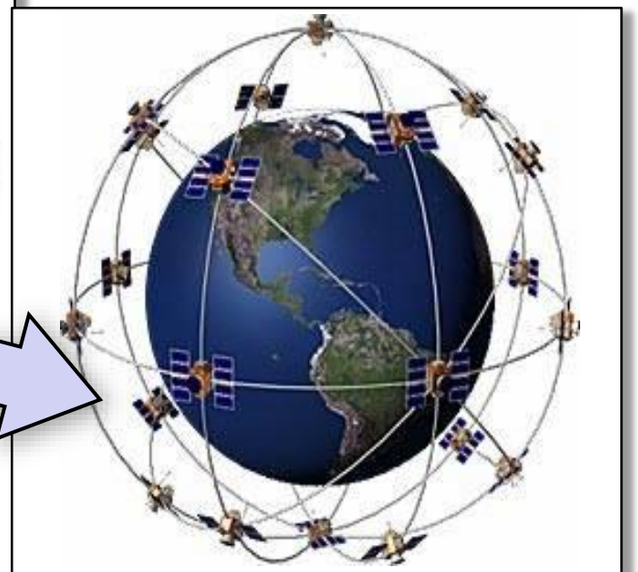
GRACE (2002)
First Low-Low Sat-to-Sat Tracking (LL-SST) mission, includes microwave ranging + + electrostatic accelerometers



GRACE-FO (2018)
Laser Ranging Interferometer (LRI) tech demo improves intersat range sensitivity



Next MC Mission (~2027)
S-GRS as tech demo would improve non-gravity acceleration measurement consistent with LRI sensitivity



Future (2030's)
Low-cost small satellite constellations improve spatio-temporal resolution

- Current IIP-IDC grant + LISA: TRL 3-5 by end of 2021
  - Follow-on IIP-IDD (planned proposal): TRL 5-6 by 2024

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