The UF Torsion Pendulum, a LISA Technology Testbed: Sensing System and Initial Results

Andrew Chilton, Ryan Shelley, Taiwo Olatunde, Giacomo Ciani, John W. Conklin , Guido Mueller

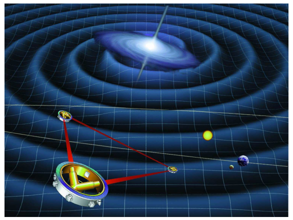
University of Florida

Abstract

The upcoming LISA Pathfinder (LPF) mission will test the gravitational reference sensor (GRS) and the disturbance reduction system (DRS) for a future LISA-like space mission. While LPF will show that the technology for LISA exists and meets the LISA requirements, it is likely that LPF will also reveal areas where future improvements can be made and might be necessary. Some of these are already well known (such as the discharging system). After all, the technology for LISA pathfinder was frozen about 10 years ago or about 30 years before a LISA-like mission will be launched. The need for continued testing and development of the technology is obvious. The University of Florida is currently building a torsion pendulum-based test facility to explore new techniques and also to develop a base in the US for state-of-the-art GRS technologies.

Space-Based Gravitational Wave Detectors

Space-based gravitational-wave missions such as LISA or eLISA will be sensitive in the signal-rich 30 μHz to 100 mHz frequency range. Massive black hole binaries out to redshifts beyond 20 emit in this range before and during their merger process. Detecting these waves allows us to characterize the progenitors and learn about the growth history of the super-massive black holes which form the center of most galaxies.



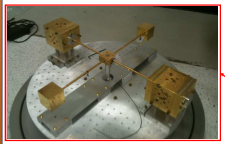
LISA will also enable precision tests of general relativity in the extreme relativistic case by observing the radiation from compact objects which trace out the space-time curvature of massive black holes while falling into them. These are just two of the many exciting science goals of a LISA-like mission.

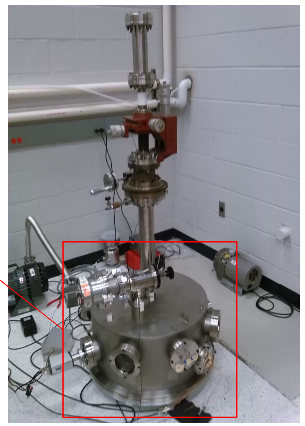
Pendulum Facility

The UF Torsion Pendulum is a LISA technology development facility aimed at exploring new technologies for a gravitational reference sensor. It currently consists of:

-Crossbar structure suspended from 1 m tungsten fiber

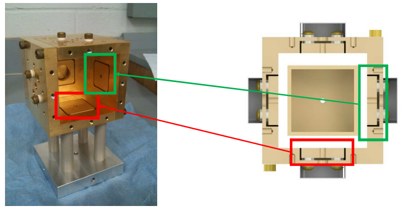
-Includes two GRS prototypes: each reads out position of TM





For a detailed description of the facility, see Ryan Shelley's poster.

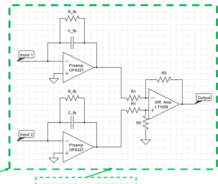
Capacitive Sensing Scheme for the GRS

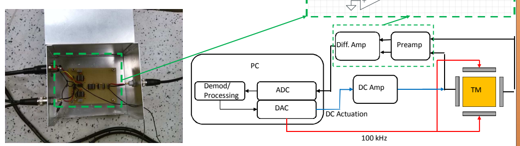


- 100 kHz signal "injected" through the red electrodes
- Pickup in green electrodes depends on TM position
- Differential sensing scheme, similar to LTP/Trento
  - Fewer electrodes
- Expansion planned later

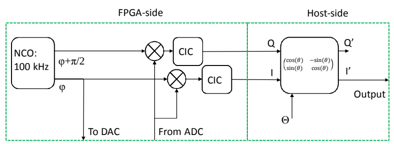
Analog Readout Electronics

- Simplified version of LPF flight electronics
  - No resonant bridge
- Actuation applied directly to electrodes at DC: filtered out of readout
- Expected ~nm/√Hz performance





Digital Readout Electronics



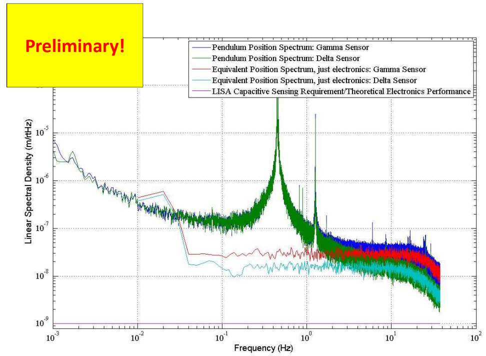
-Simple I-Q demodulation scheme

-CIC filters downsample/LPF data

-Acquisition handled by NI DAQ card

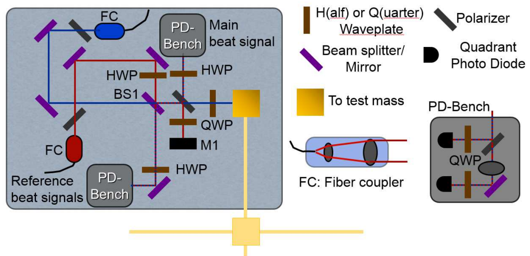
-Demodulation phase varied until entirety of the signal in I

Current Status and Preliminary Results



- Pendulum suspended and in vacuum, with two GRS prototype sensors ("Delta" and "Gamma") active.
- Measurement made with pendulum roughly centered inside GRS prototypes
- Fiber unwinding limits continuous observation time
  - Relieves stress which adds noise
  - Takes time to lower noise level
- Electronics only limit pendulum above measurement band…but perform ~10x worse than expected
- Could limit performance at lower frequencies eventually. Requires more investigation!

Future Work: Interferometric Readout Scheme



- Polarization-multiplexed heterodyne interferometer
  - Blue and red laser signals oppositely polarized, offset by heterodyne frequency.
  - Blue laser gathers phase information from TM
  - Red laser provides reference
  - Beat signal acquired on PD-benches
- Expected 10 pm/√Hz sensitivity
- Expansion to alignment sensing via wavefront sensing planned