Possible LISA Technology Applications for Other Missions

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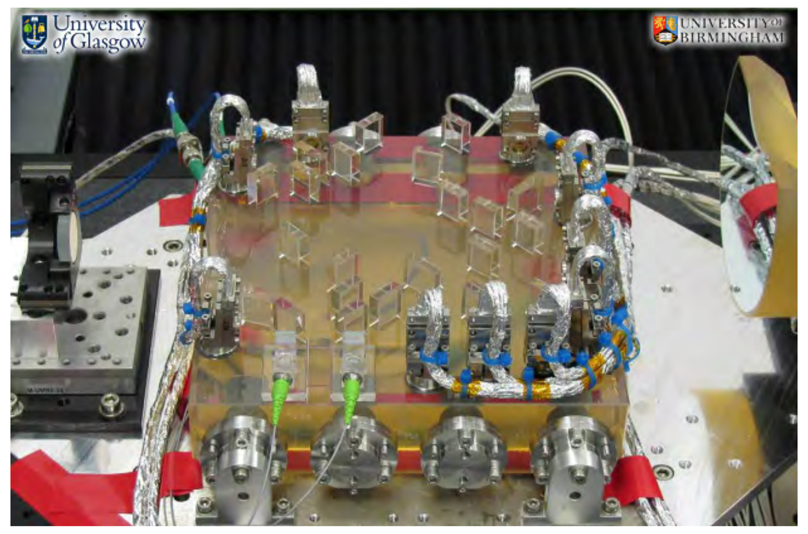
Abstract: The Laser Interferometer Space Antenna (LISA) has been selected as the third large class mission launch opportunity of the Cosmic Visions Program by the European Space Agency (ESA). LISA science will explore a rich spectrum of astrophysical gravitational-wave sources expected at frequencies between 0.0001 and 0.1 Hz and complement the work of other observatories and missions, both space and ground-based, electromagnetic and non-electromagnetic. Similarly, LISA technology may find applications for other missions. This paper will describe the capabilities of some of the key technologies and discuss possible contributions to other missions

Ultra-stable Structures: Optical Bench

LISA Pathfinder Optical Bench

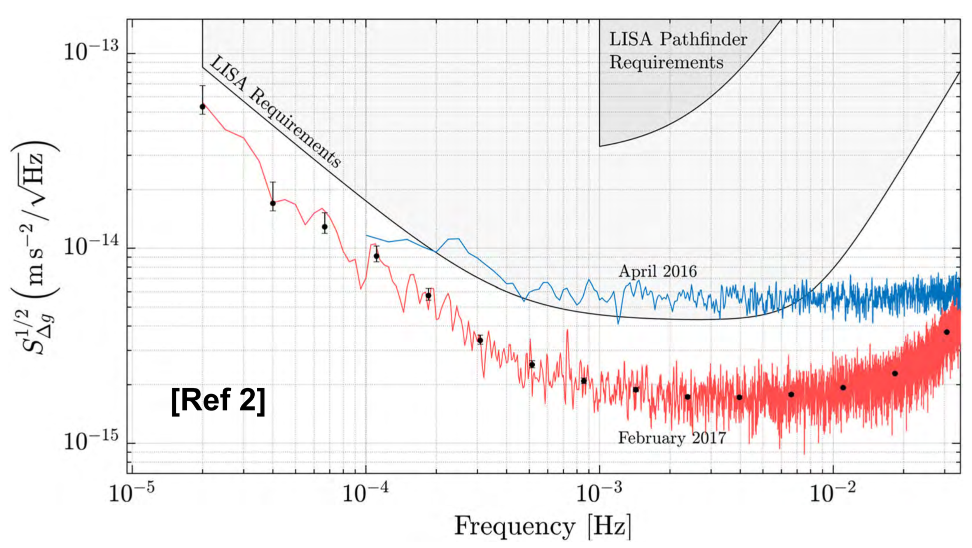


[http://sci.esa.int/lisa-pathfinder/51920-lisa-pathfinder-flight-optical-bench/]

Using hydroxy-catalysis bonding techniques, we can build complex optical structures with picometer-level dimensional stability and high mechanical strength. The optical bench [1] for LISA Pathfinder enabled stable precision laser interferometry that enabled the spectacular results show below. The LISA optical bench will use the same construction methods, and they may be applied to other instruments (see below) and missions that require large stable telescopes.

Final Drag-Free Results from LISA Pathfinder

Final results from LISA Pathfinder [2] showing the residual acceleration of a proof mass freely falling in orbit. These results demonstrate drag-free flight of a 2 kg proof mass isolated from all fluctuations within the LISA measurement band from 0.02 to 30 mHz.



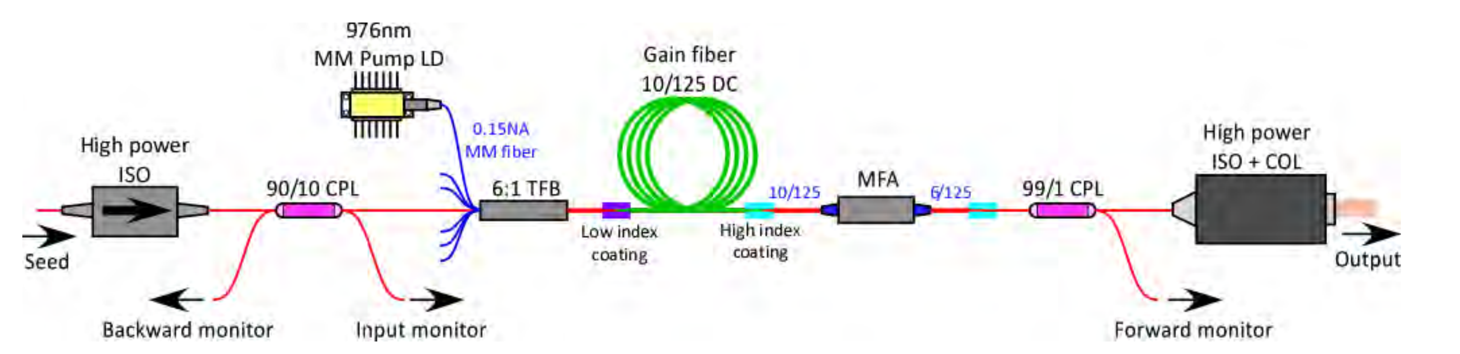
Reference

1. D.I. Robertson, E.D. Fitzsimons, C.J Killow, M. Perreur-Lloyd, H. Ward, J. Bryant, A. M. Cruise, G. Dixon, D. Hoyland, D. Smith, and J. Rogenstahl. "Construction and tesing the optical bench for LISA Pathfinder, Class. Quantum Grav. 30 (2013) 085006. doi: 10.1088/0264-9381/30/8/095006
2. M. Armano et al. Beyond the Required LISA Free-Fall Performance: New LISA Pathfinder Results down to 20 μHz, *Physical Review Letters* (2018). DOI: 10.1103/PhysRevLett.120.061101

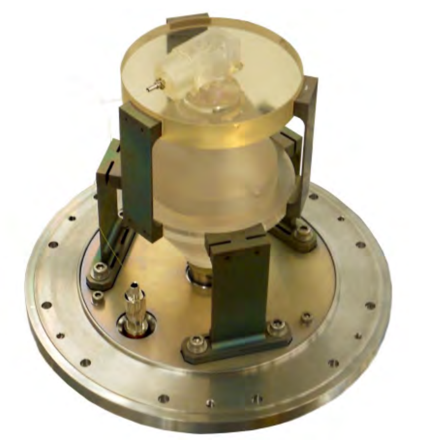
High Output Power Frequency Stabilized Lasers

Frequency-stabilized lasers enable high-precision metrology for gravitational wave detectors and other applications, including GRACE-Follow On, and laser communications.

All-fiber Master Oscillator Power Amplifier Architecture

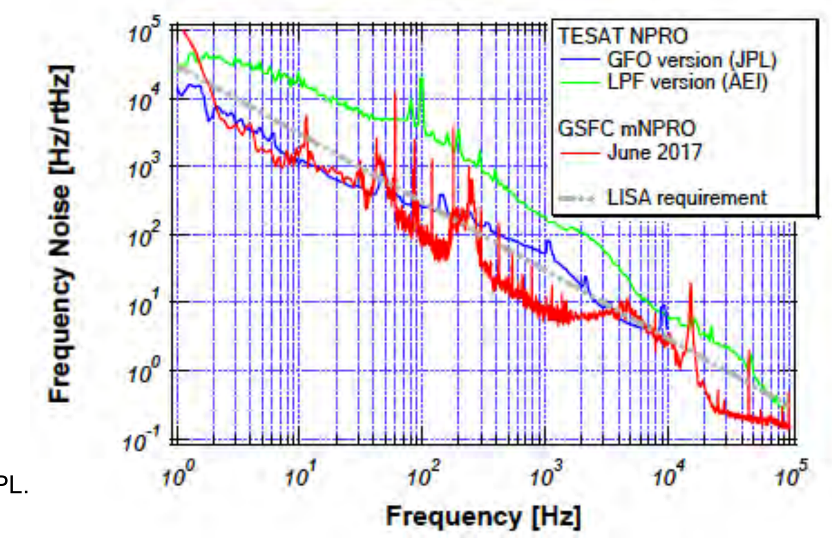


TRL6 Fabry –Perot Reference Cavity



Developed for Grace Follow-on by Ball Aerospace and JPL. See also below right panel.

Seed Frequency Noise Performance



Reference

Kenji Numata, Anthony W. Yu, Jordan B. Camp, Michael A. Krainak, "Laser system development for gravitational-wave interferometry in space," Proc. SPIE 10511, Solid State Lasers XXVII: Technology and Devices, 105111D (15 February 2018);

Colloid Micro-Newton Thrusters for LISA Pathfinder

Very low noise thrusters enabled the high precision drag free operation in LISA Pathfinder and may find application in other mission that require precision position of structures, such as starshades

- Colloid Thrusters emit charged droplets that are electrostatically accelerated to produce thrust
- Current and voltage are controlled independently by adjusting the flow rate and beam voltage
- Precise control of IB(~ μA) and VB (~ kV) facilitates the delivery of micronewton level thrust with better than 0.1 μN precision
- The exhaust beam is positively charged, well-defined (all charged particles), and neutralized by a cathode/electron source if needed

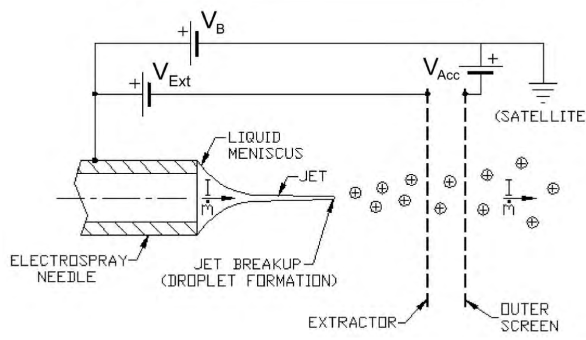
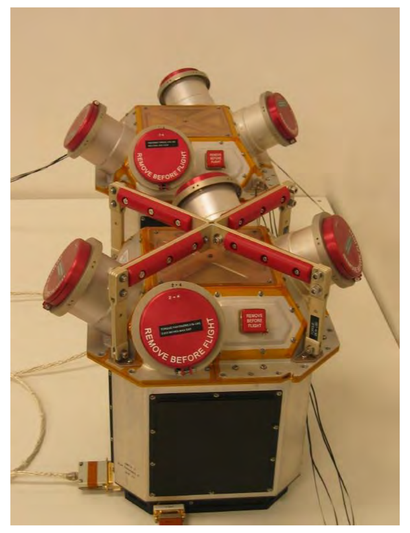
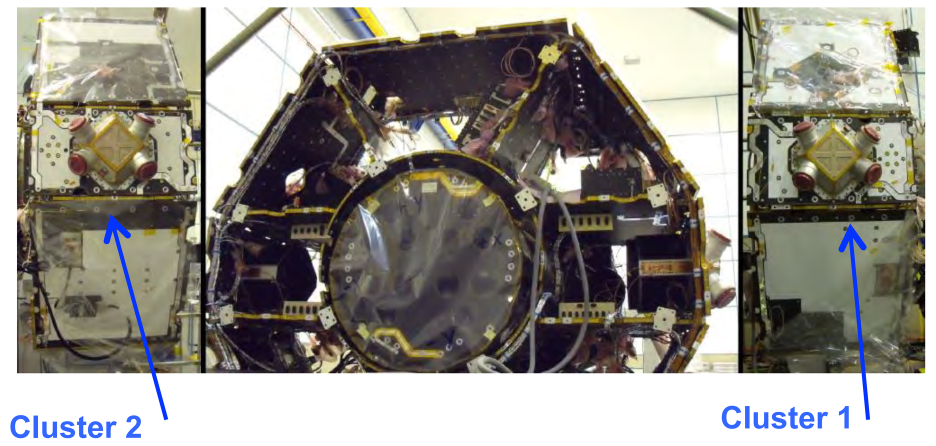


Image courtesy of Busek Co.

Cluster 1 and 2



LISA Pathfinder Spacecraft



Reference

J. K. Ziemer, T. M. Randolph, G. W. Franklin, V. Hruby, D. Spence, N. Demmons, T. Roy, E. Ehrbar, J. Zwahlen, R. Martin et al., "Colloid Micro-Newton Thrusters for the Space Technology 7 mission", *Aerospace Conference 2010 IEEE. IEEE*, pp. 1-19, 2010.

Ultra Stable Structures: Telescopes

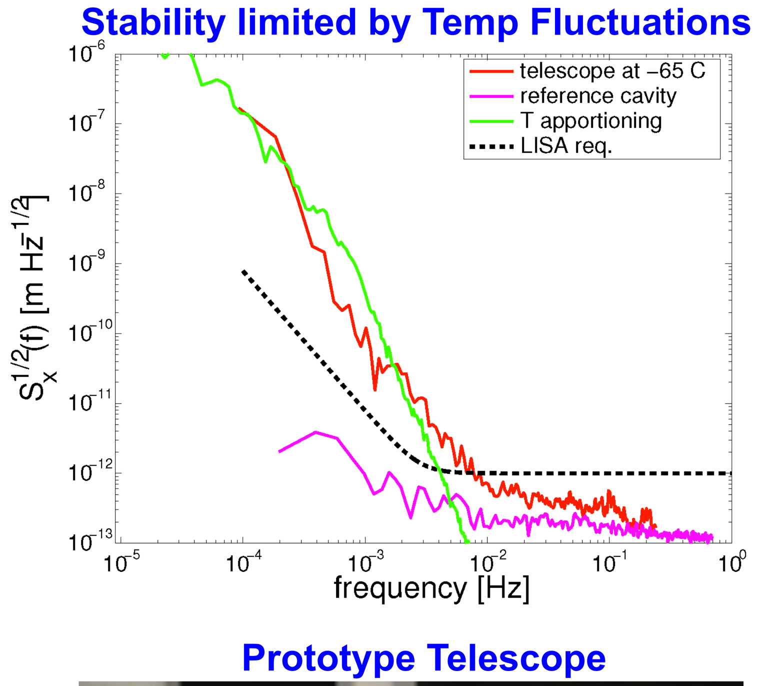
The basic requirements are similar to those for any good quality imaging telescope, but are supplemented by two additional requirements that are specific to the displacement measurement application: picometer-level dimensional stability and low scattered light.

Silicon Carbide Meets Dimensional Stability Requirement

A silicon-carbide metering structure has demonstrated it is limited by laboratory temperature fluctuations. On orbit temperature fluctuations are a factor of 100X lower, so it will meet requirements.

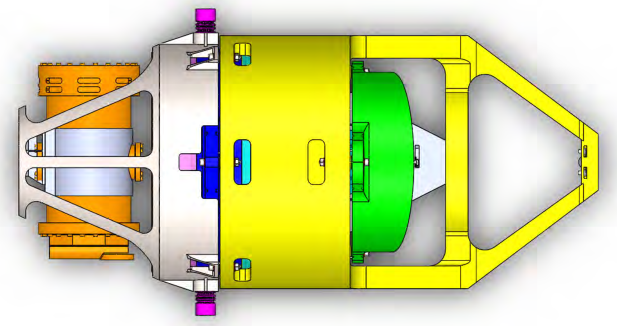
Top to bottom plate distance is 600 mm

Stability limited by Temp Fluctuations

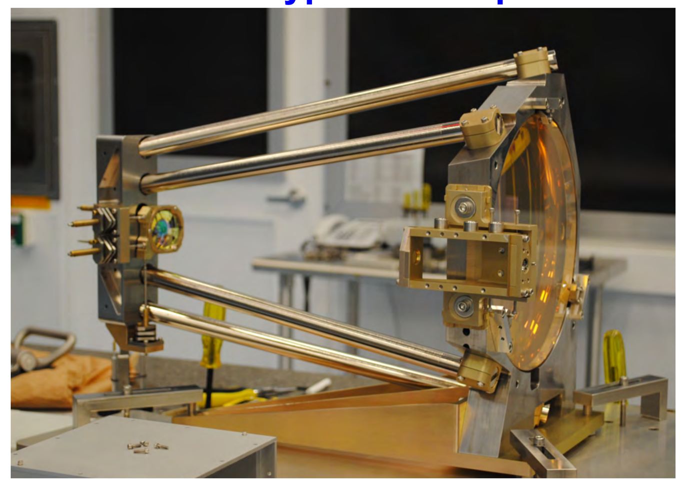


All-Zerodur Design

Low CTE material plus passive thermal isolation yields picometer-level stability.



Prototype Telescope



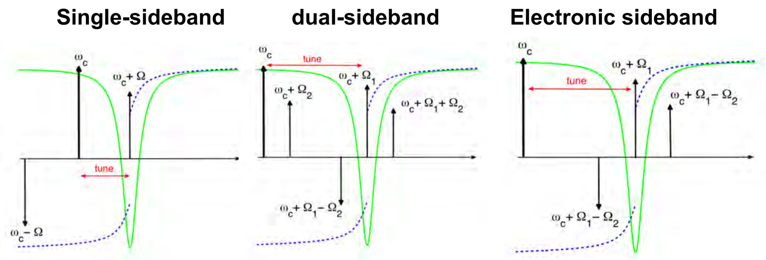
Reference

Livas, J. et al; "Telescopes for space-based gravitational wave missions". *Opt. Eng.* 52 (9), 091811 31 July 2013; doi: 10.1117/1.OE.52.9.091811

Tunable Frequency Stabilized Lasers

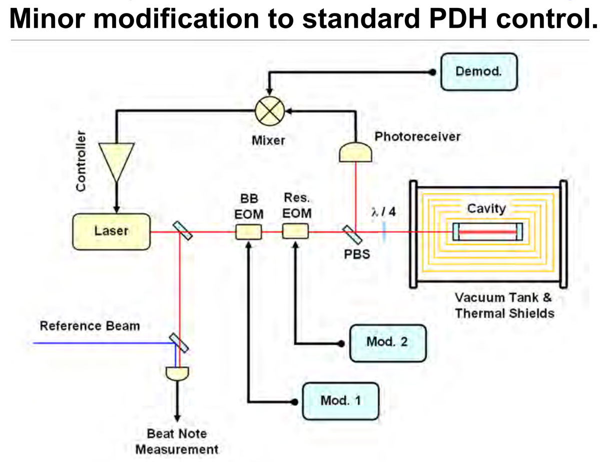
We have demonstrated that the carrier frequency of the main laser source can be made to tune in frequency without sacrificing the noise performance.

Frequency Tuning Alternatives.



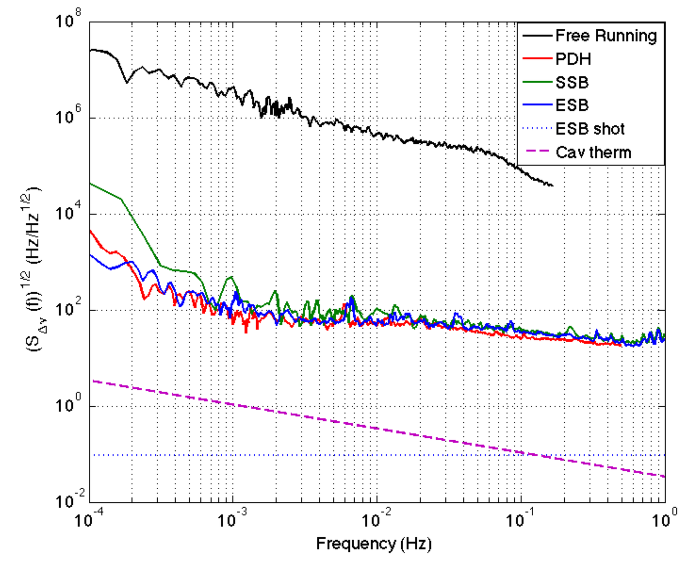
Frequency Stabilization Block Diagram

Minor modification to standard PDH control.



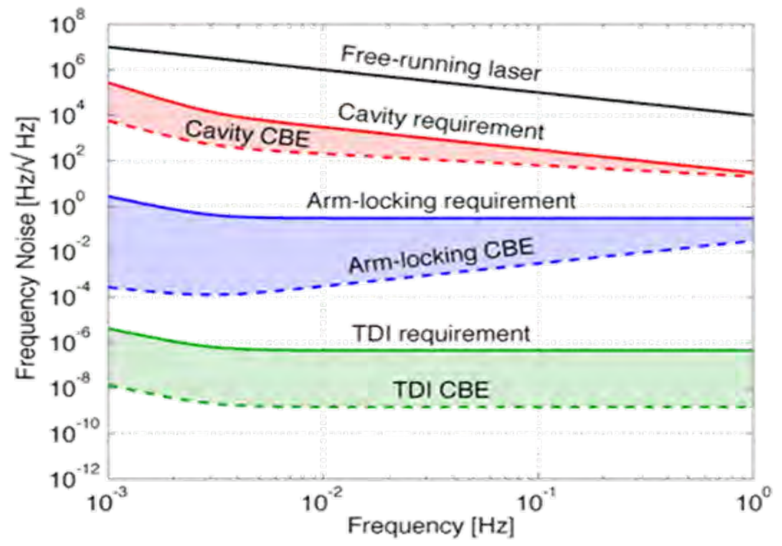
Measured Frequency Noise Performance

Same noise with and without tuning.



Enables Multi-stage stability loops

Adds options and/or margin



Reference

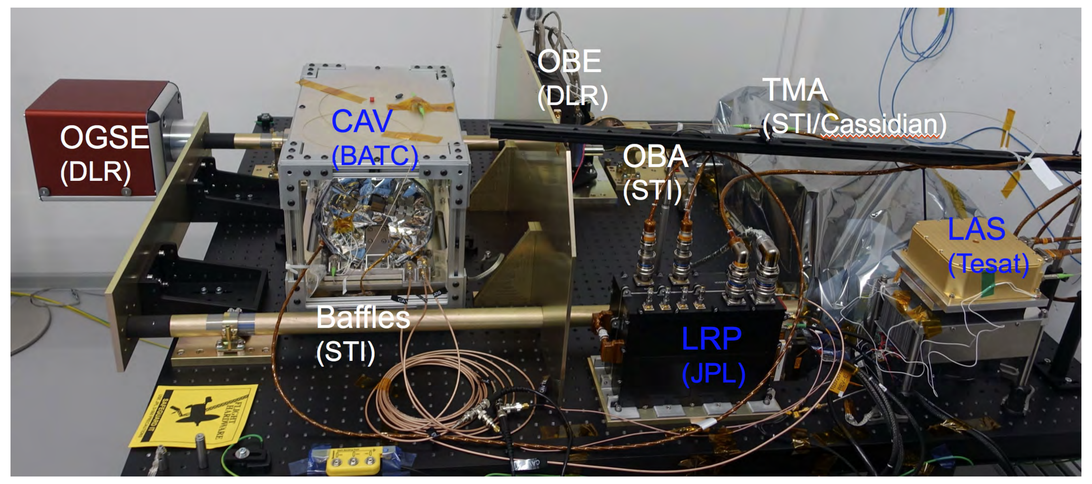
U.S. Patent 7,970,025, "System and method for Tuning the Central Frequency of a Laser while Maintaining Frequency Stabilization to an External Reference", issued 28 Jun 2011

Flight-Ready Phasemeter: GRACE-Follow-On

A phasemeter originally developed for the LISA Mission is ready to fly on the Gravity Recovery and Climate Experiment (GRACE) Follow On Mission.

Flight Hardware Ready for Spaceraft Integration

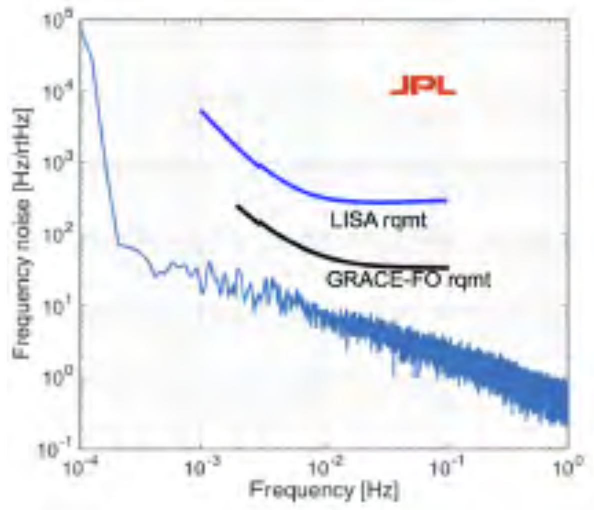
CAV, LRP, and LAS are all elements developed for LISA.



Elements of the technology originally developed for LISA are ready to fly on the Gravity Recover and Climate Experiment Mission. These elements include a cavity (labeled CAV in the picture above) frequency stabilized seed laser (LAS) and a Laser Ranging Procesor (LPR) based on a phasemeter that meets LISA requirements.

Measured Frequency Stabilization

Exceeds both LISA and GRACE FO requirements



Reference

B Bachman, G de Vine, J Dickson, S Dubovitsky, J Liu, W Klipstein, K McKenzie, R Spero, A Sutton, B Ware and C Woodruff, "Flight phasemeter on the Laser Ranging Interferometer on the GRACE Follow-On Mission, 11th International LISA Symp,, *J. of Physics: Conf. Ser.*, Vol. 840, 012011 (2017).