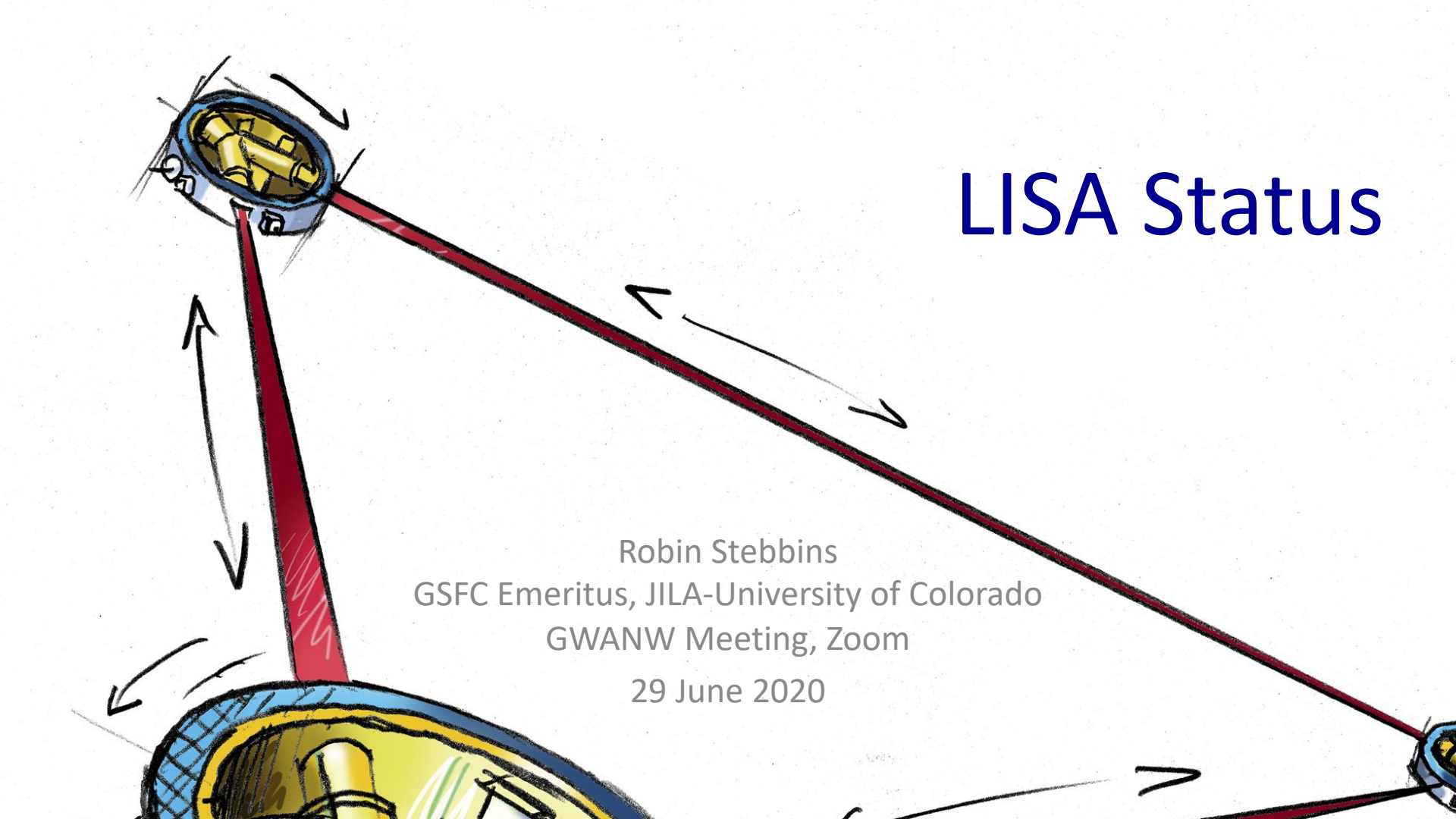


LISA Status

Robin Stebbins
GSFC Emeritus, JILA-University of Colorado
GWANW Meeting, Zoom
29 June 2020

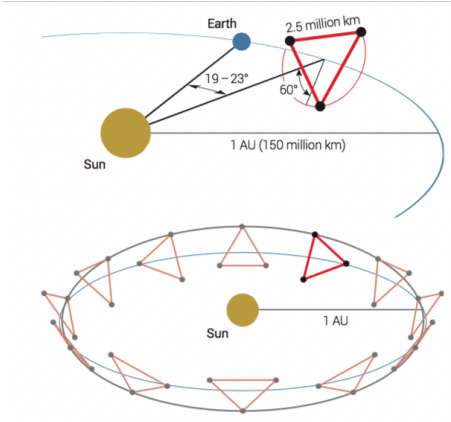
LISA Status

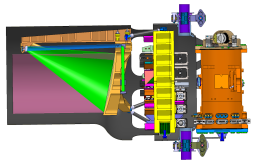
- Review
  - Mission concept
  - Sources
  - Science
- Programmatics
  - ESA and NASA
  - LISA Consortium
  - Science Study Team (SST)
  - NASA LISA Study Team (NLST)
  - Budget and schedule

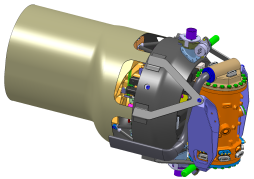
- Events of the past year
  - Formulation continues
  - Technology development
  - Mission Consolidation Review (MCR)
  - Phase A extended
  - Science ground segment
  - Science equirements
  - Astro2020 decadal

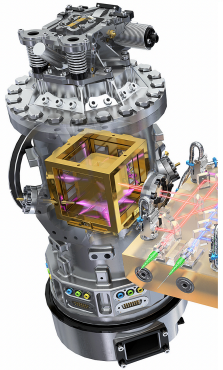
Critical elements of the mission concept

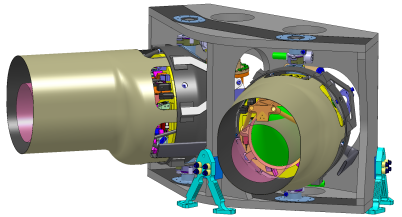
- Laser interferometer using triangular constellation of spacecraft in heliocentric orbits
- Continuous laser interferometric ranging with picometer sensitivity
- Arms millions of kilometers long
- Drag-free masses with femto-g disturbances
- Time delay interferometry (TDI)







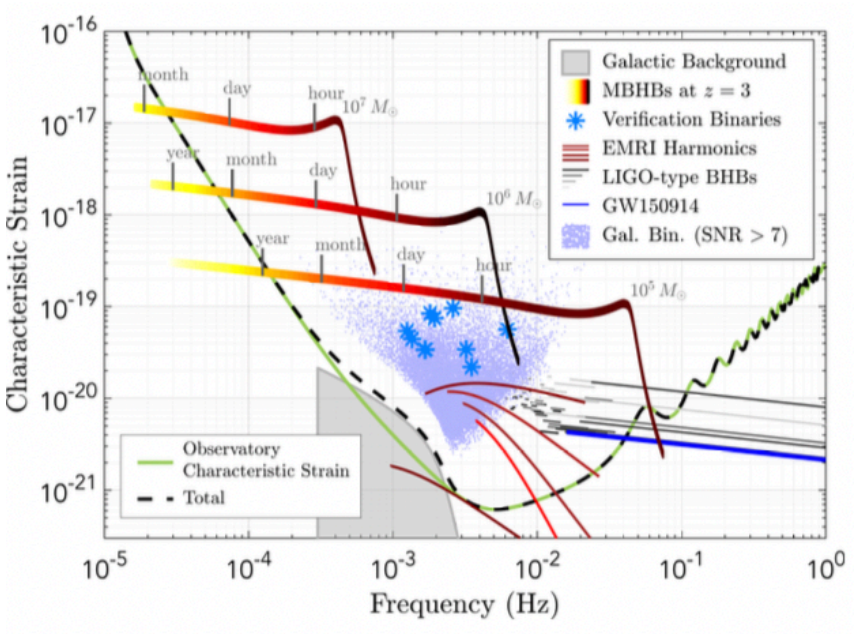


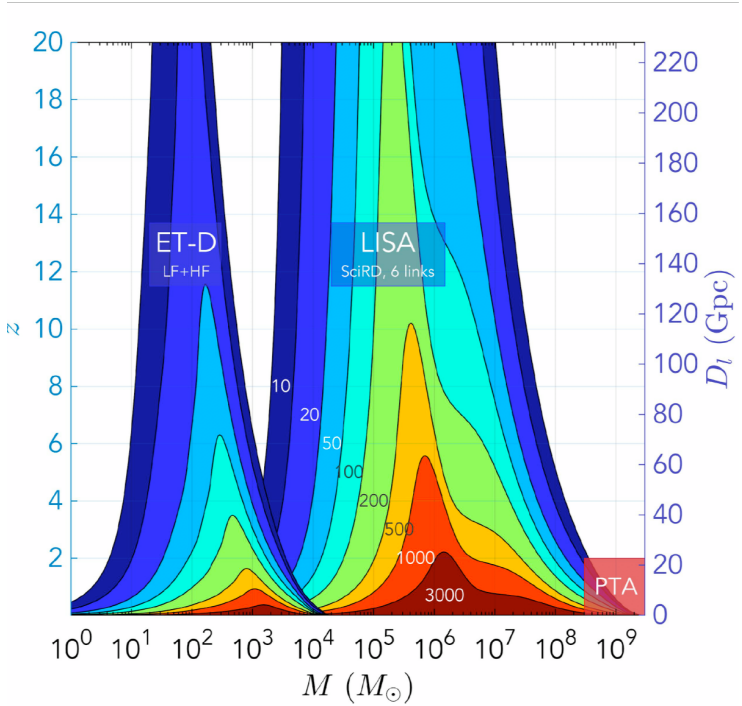


Instrument

Characteristic	LISA
Operating band	0.1mHz – 1 Hz goal (changed)
Armlength	2.5 Mkm, could be 1-10 Mkm, set by orbit choices and evolution, and system design choices.
Limiting noises	Spurious low-frequency forces: thermal effects, residual gas, stray electrostatics, shot noise, cross-couplings
Directional information	Orbital motion gives amplitude modulation, frequency modulation and phase modulation
Polarization information	Instantaneous from 2 interferometers, evolves with time.
Instrument lifetime	Fixed, up to 10 yrs. No repairs. Lifetime limited by consumables and orbital evolution. (Under review)
Outstanding technology challenges	Reliability of lasers and microthrusters, system robustness, stray light

LISA Science





Credit: N. Cornish, M. Hewitson, and the LISA and ET Teams. Created for the Gravitational Wave International Committee (GWIC).

LISA Sources

- MBHBs: ~100 10^3 - 10^8 M_{sun} inspirals/mergers/ringdowns out to z~20
- Stellar-mass compact objects: ~3x10^4 quasi-stationary WD/NS/BH binaries in the galaxy, confusion foreground, optical counterparts
- EMRIs & IMRIs: ~100s/yr EMRIs, rate uncertain
- IMBHs (10^2 - 10^4 M_{sun}): Detection to high z, rate unknown
- Massive stellar BHs (<10^2 M_{sun}): ~100 BH early inspirals out to z~0.1, crossing into the 3G band to merge
- Bursts and backgrounds: Possibly cosmic strings, bursts, discoveries.

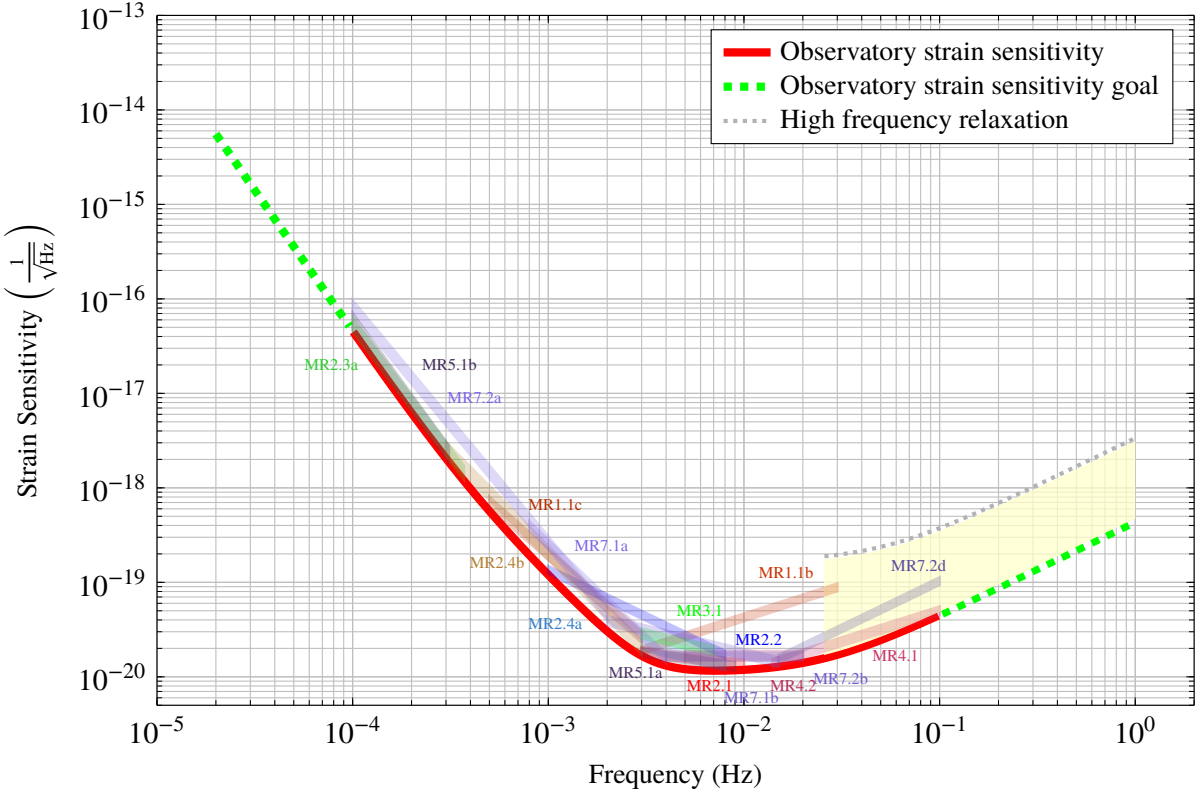
LISA signals and data analysis

- Tens of thousands of superimposed sources, requiring simultaneous fitting
- SNRs up to 10^4 enable high precision measurement of source parameters, like mass, spin vectors, orbital parameters, distance, sky location
- All sky instrument with sky location encoded in the waveforms through amplitude, frequency and phase modulation
- Merger events weekly, sources emerging and disappearing constantly
- Most galactic binaries and EMRIs are detectable for the duration of the mission
- MBH mergers predicted days to weeks in advance. Prediction alerts will be sent out, with progressively improving information.
- Source information improves with catalog updates
- Sagnac mode allows monitoring the instrument noise constantly.

LISA Science

- Study the formation and evolution of compact binary stars in the Milky Way Galaxy
- Trace the origin, growth and merger history of massive black holes across cosmic ages
- Probe the dynamics of dense nuclear clusters using extreme mass-ratio inspirals (EMRIs)
- Understand the astrophysics of stellar origin black holes
- Explore the fundamental nature of gravity and black holes
- Probe the rate of expansion of the Universe
- Understand stochastic GW backgrounds and their implications for the early Universe and TeV-scale particle physics
- Search for GW bursts and unforeseen sources

Noise Requirements, derived from Science Requirements



Programmatics (1/2)

- ESA-led mission. NASA is a junior partner. JAXA may join. Roles and responsibilities not finalized.
- ESA Study Office, System Engineering Office functioning. Project scientist change.
- ESA provides the spacecraft, the launch and the ground operations.
- NASA provides telescope, lasers and charge management system.
- LISA Consortium provides remainder of the instrument and science ground processing. LISA Instrument, Data Processing, and Science Groups
- Phase A (Conceptual Design) in third year (one year extension)
  - Competing prime contractors: Airbus Defence and Space GmbH and Thales Alenia Space S.p.A.
  - Instrument contract to AEI/Hannover, and DLR contract to Airbus/Freidrichshafen
  - Activities: Contractors completed initial studies, Mission Consolidation Review (MCR) passed, recommendations being implemented, Mission Formulation Review started.
- Science Study Team (SST): provides scientific advice to ESA Study Office.
- ESA Study Scientist transition: Paul McNamara moved to the international coordination office; Oliver Jennrich and Nora Luetzgendorf assumed responsibilities

Programmatics (2/2)

- NASA Study Office: study manager, study scientist, system engineering
  - Collaborate with ESA and Consortium on mission formulation
  - Develop and assess NASA contributions
  - Work to consolidate final roles and responsibilities, MOU ~2023
- NASA LISA Study Team (NLST, 18 researchers) provides “analysis” to NASA HQ and the Study Office, promote mission to research community, represent LISA to Astro2020 decadal, participate in Consortium
- LISA Core Team: GSFC, JPL, MSFC and U Florida technologists and scientists

Schedule and Budget

Schedule

- June 2017 – LISA selected as L3
- May 2018 – Phase A started
- 2018-2021 – Phase A
- July 2021 – Mission Formulation Review
- 2021 – Phase B1 start
- 2024 – Adoption
- 2025 – Phase B2, C and D
- 2034 – Launch
- +6.5 yrs – Ferry, commissioning, baseline science operations
- +4 yrs – Extended operations

Budget (very rough)

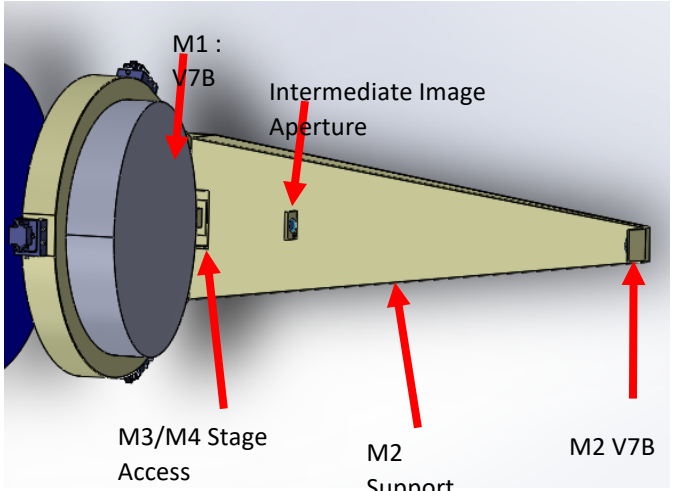
- ESA L-class cap – 1.04 Beuro
- Member states - ~200 Meuro, TBC
- NASA - $400M for flight system + $100M for science analysis

Progress over the last 12 months

- Formulation
  - Initial system design completed
  - Requirements development and flowdown
  - Technology development/demonstrations
  - Establish roles and responsibilities
- MCR passed in Oct. ’19
  - Design adequately defined
  - Eliminate ‘goals’ from science requirements
  - Restructure technical oversight
- MFR started Jun. ‘20
- Increase in ESA science budget
- SST
  - High and low frequency performance goals studied and re-stated
  - Review of lifetime requirement in progress
  - Continuing discussions of science ground segment and data policy
- NLST
  - Science support study completed
  - Astro2020 decadal input complete: science and mission white papers, RFIs, response to questions

NASA Technology Development Progress - Telescope

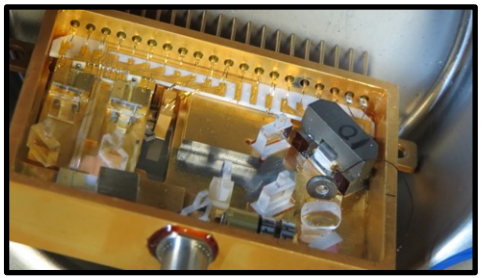
- Contract for prototype models (1 structural + 2 optical performance) awarded
- Internally developed reference design as proof of concept (right) and for interface discussions with ESA/Consortium partners
- Preparing facilities for optical tests at GSFC and UF
- Supporting SEO Tel/OB WG and LIG activities

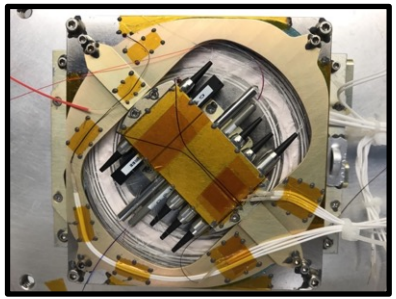


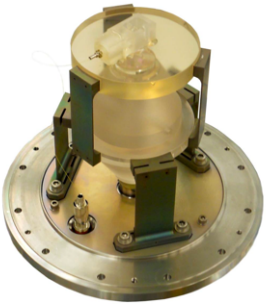
CAD model of NASA proof-of-concept design

NASA Technology Development Progress - Laser

- Master Oscillator: (mNPRO)
  - First set of prototypes performing well
  - Design for next set of prototypes underway
- Fiber Amplifier
  - Vendor selected (FiberTek)
  - First units delivered to GSFC in Nov.
- Frequency reference
  - Contract initiated to capture lessons learned from GRACE-FO cavity
- Reliability
  - Initiated reliability study of pump diodes w/ LGS
- Interfaces & Systems
  - Participating in SEO Laser WG & LIG activities
  - Ready to deliver prototype lasers to ESA partners for test in May



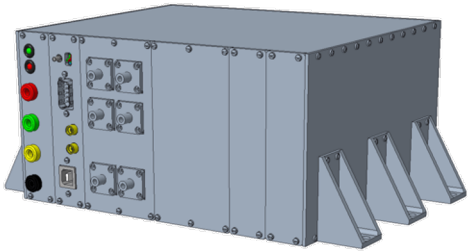


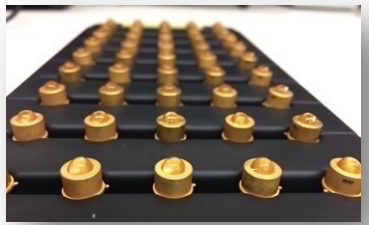


(top) mNPRO master oscillator under test at GSFC. (bottom left) Fiber amplifier. (bottom right) frequency reference cavity for GRACE-FO.

NASA Technology Development Progress – Charge Management

- TRL4 Charge Management Device delivered to U. Trento for testing
  - 1st delivery of LISA (prototype) hardware to Europe
  - Integrated with U. Trento torsion pendulum for system-level testing of charge control
  - TRL4 milestone review passed Nov. ‘19
- TRL5 Unit design underway
  - Mid-TRL 5 peer review completed Nov. ‘19
  - TRL 5 scheduled completion Sept. 2020
- Working with GSFC photoncs group to evaluate options for fiber harness and conduct radiation testing
- Supporting SEO Charge Management WG and LIG activities

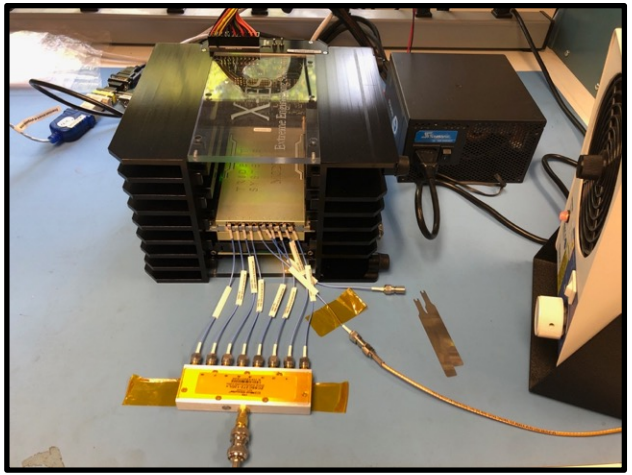




(top left) TRL 5 design. (bottom left) UV LEDs used for performance/lifetime testing. (right) TRL4 charge management unit in place at U. Trento torsion pendulum facility.

NASA Technology Development Progress – Phasemeter

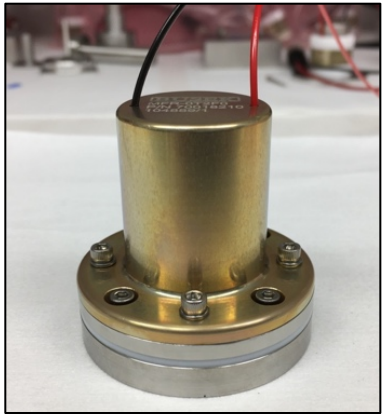
- In-flight results from LRI instrument published
  - includes LISA-like phasemeter (LRP)
  - Outperforms noise requirements
  - limited by frequency stability of laser (only one arm)
- Working with Industry to produce scalable LISA prototype
  - Marriage of existing flight-heritage hardware with JPL firmware
  - First boards now under test at JPL
- Supporting SEO and LIG activities
  - Phasemeter WG to define requirements/interfaces
- Pursuing potential partnerships with German-led Phasemeter group

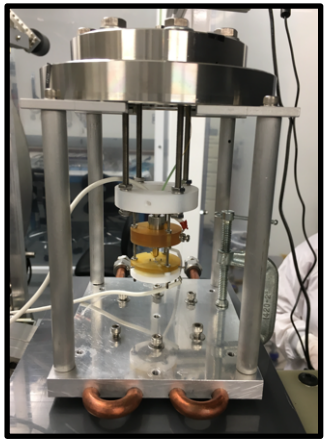


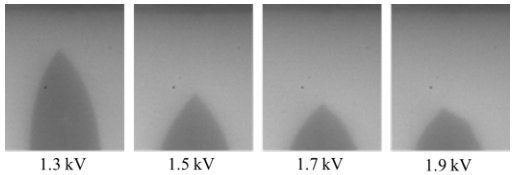
8-channel phasemeter prototype card (Trident Systems) under test at JPL.

NASA Technology Development Progress – Microthrusters

- Developed LISA design based on lessons learned from ST7
  - Preserve heritage of basic design
  - Increased lifetime through redundancy, improvements to microvalves, and tweaks of electrode geometry
- Fabricating prototype components for testing
- Performing in-situ beam profiling (UCLA) to inform new lifetime models
- Working with ESA and contractors to study configuration options
  - Opportunity for significant reductions in launch mass







(top left) Redundant microvalve at Busek (top right) single emitter thruster under test at JPL (bottom) in-situ microscopy of Taylor cones and electrospray at UCLA.

Summary

- LISA has passed the mid-Phase review (MCR) and proceeding to formulation review
- ESA, NASA, Member States and Consortium are re-examining their roles and responsibilities.
- Technology development on track for nominal schedule
- NLST
  - Completed science support report
  - Completed decadal input
  - Continuing outreach activities