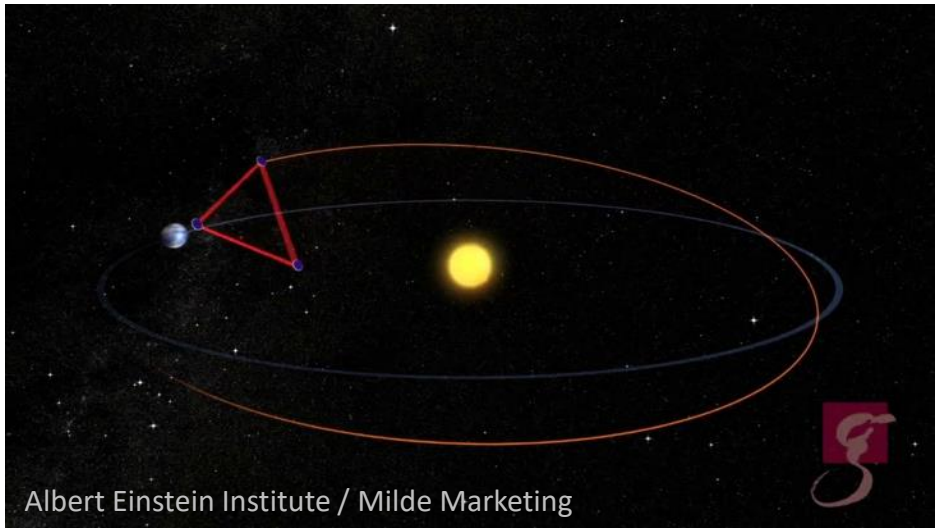
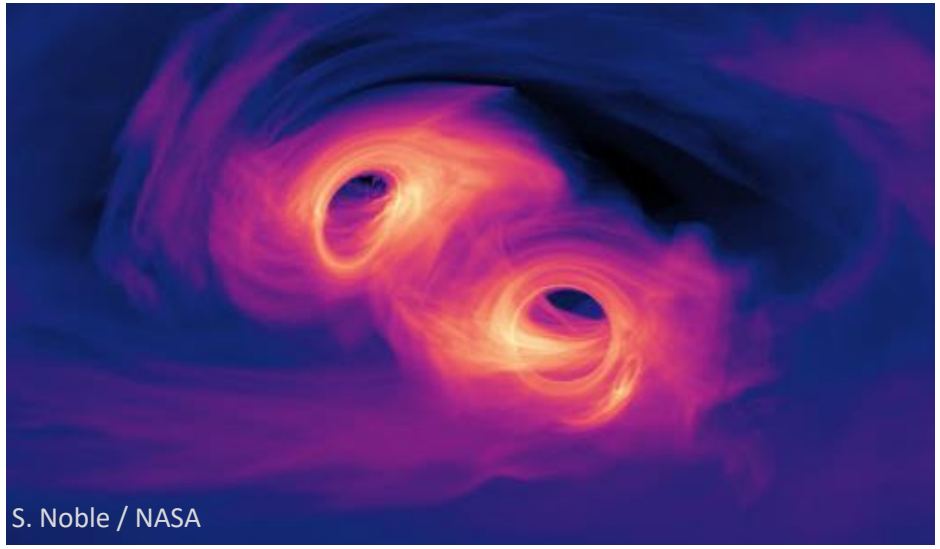
Update on LISA and NASA's Activities

Ira Thorpe, NASA/GSFC
NASA LISA Study Scientist
Astrophysics Advisory Council (APAC)
NASA HQ / Washington, DC
March 6th, 2020


Albert Einstein Institute / Milde Marketing


S. Noble / NASA

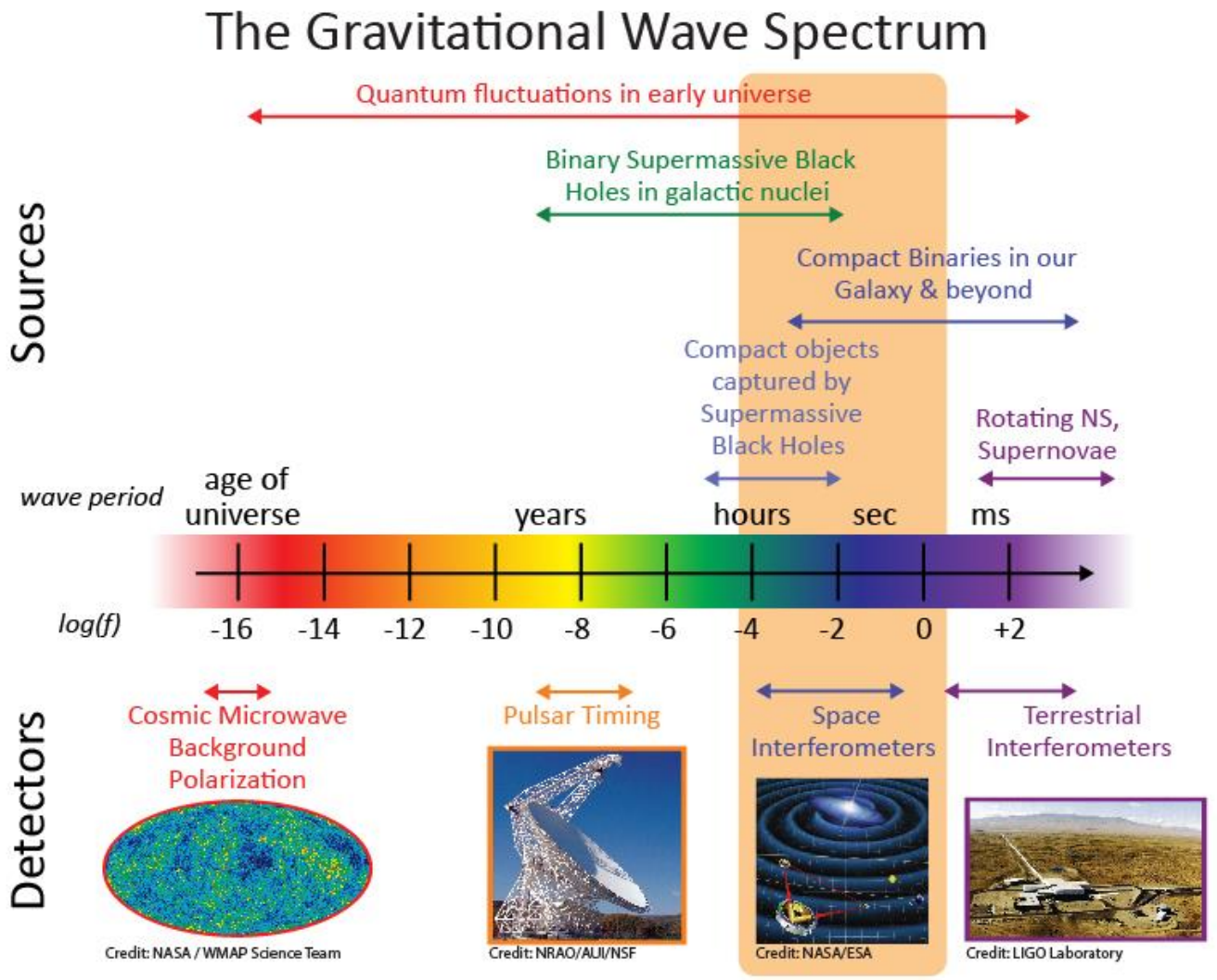
Talk Outline

- LISA Mission Overview
- NASA LISA Study Office (NLSO) Overview
- NLSO Systems Engineering & Technology Activities
- NLSO Science Activities
- Summary

LISA MISSION OVERVIEW

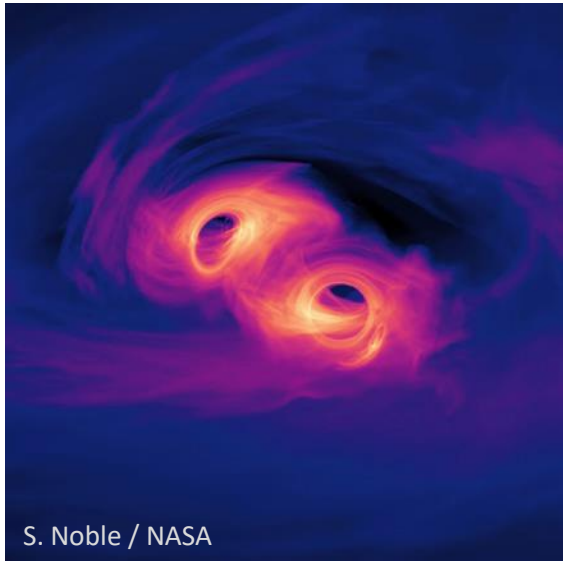
LISA Science Goals

- First GW observatory in the milliHertz band
- Tens of thousands of sources of many varieties
- Wide applications in astrophysics, cosmology, fundamental physics, etc.



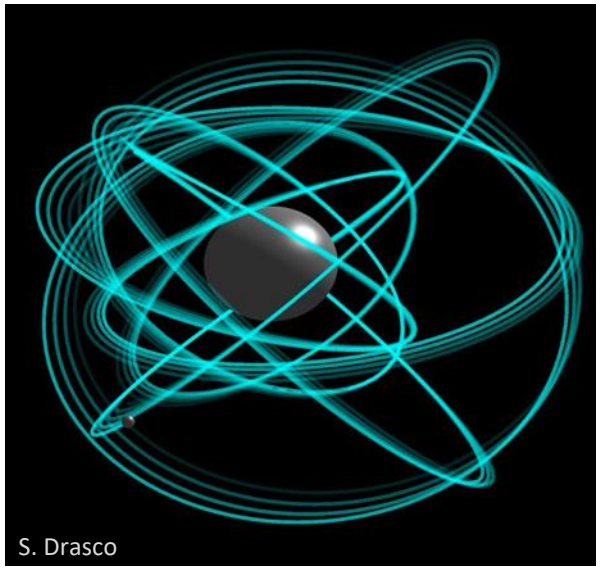
Science Highlights

Mergers of Massive BHs



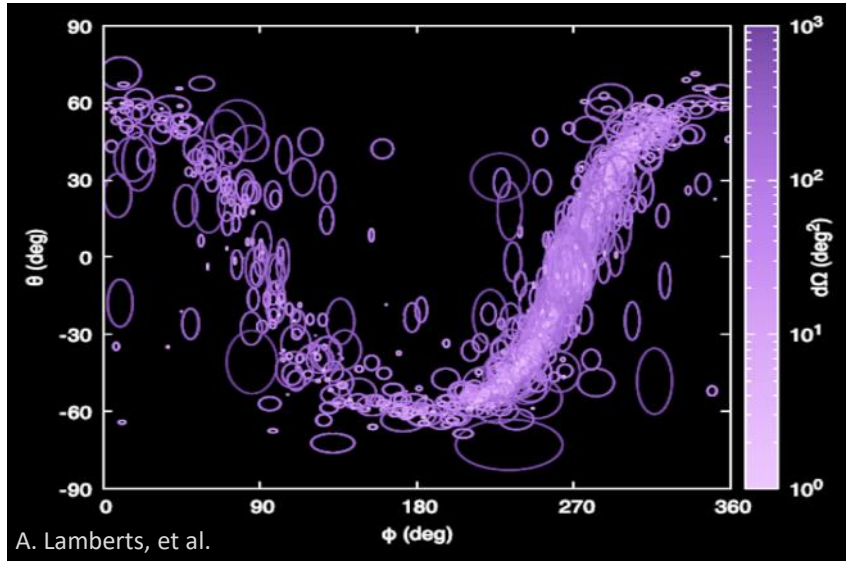
- $10^3 M_\odot \sim 10^8 M_\odot$
- $1 \lesssim z \lesssim 20+$
- D, M, m, χ, etc. at % level
- MBH formation and co-evolution with galaxies
- Potential EM counterparts?

Extreme Mass-ratio Inspirals



- BH analog of a TDE
- Extreme probe of strong gravity
- Probe high-mass demographics and dynamics of nuclear clusters

Ultra-compact binaries



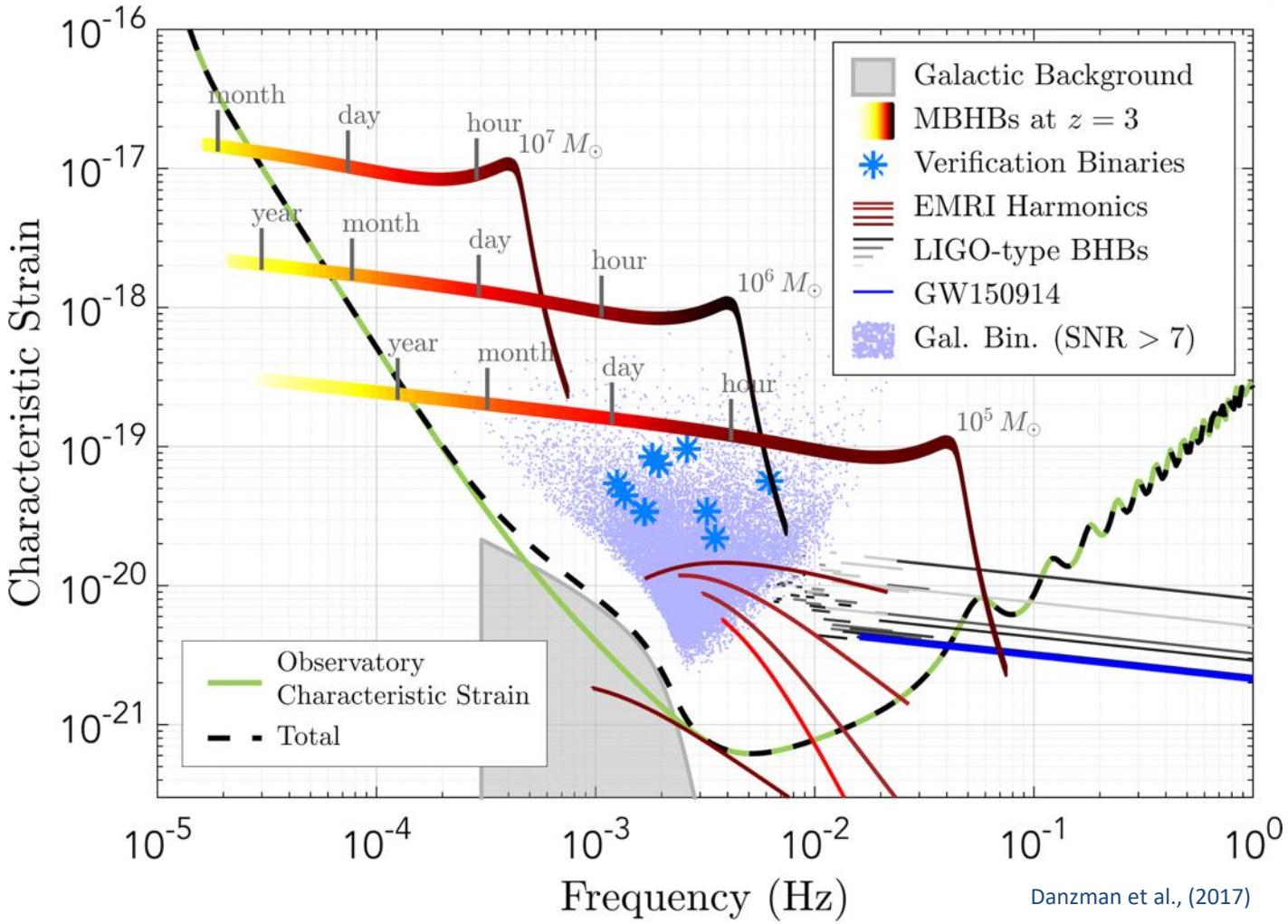
- ~10^4 resolved binaries (WD-WD, WD-NS, etc.)
- Unresolved galactic foreground
- Guaranteed multi-messenger sources
- End states of stellar + binary evolution, tracer of Milky Way formation history, binary astrophysics, etc.

+ Exotica (cosmic string cusps, cosmological GW background, exoplanets!)

Unique Data Set

- All-sky monitor
- No “pointing”
- Both transient and persistent sources
- Gradual buildup of information
- Global fit required to extract individual signals

- Junior partner will have an opportunity to participate in *all* science.
- Data policies are tricky



Danzman et al., (2017)

Organization

- Lead agency
- Spacecraft, LV, operations, payload elements
- Science Operations Center

lisa.esa.int

- Hardware contribution: payload-focused, ~$400M (Phase A-D LCC) including project management, systems eng., S&MA, etc.
- Science contribution TBD: participation in science ground segment, guest investigator program, archive functions, etc.

lisa.nasa.gov

- Major payload contributions
- Lead for science ground segment
- Lead for science applications

lisascience.org

The LISA Consortium

- **Grassroots organization working to organize contributions to LISA external to ESA**
  - Payload contributions (systems engineering, subsystems, I&T, etc.)
  - Science ground segment contributions (analysis pipelines, data centers, etc.)
  - Science investigations
- **Governed by bylaws and implemented through management structure**
  - LISA Instrument Group (LIG)
  - LISA Data Processing Group (LDPG)
  - LISA Science Group (LSG)
  - …
- **Individuals and/or research groups apply and commit FTEs**
  - Expectation is that individuals will secure funding to support their commitments (e.g. from ESA Member States)
  - Option for “affiliate” members w/o commitment
  - US participants but no direct connection to NASA funding
- **Interfaces between LISA Consortium and ESA / NASA / US Community / etc. still TBD**
  - Technical authority
  - Intellectual property and publication policies
  - Data policies
  - …

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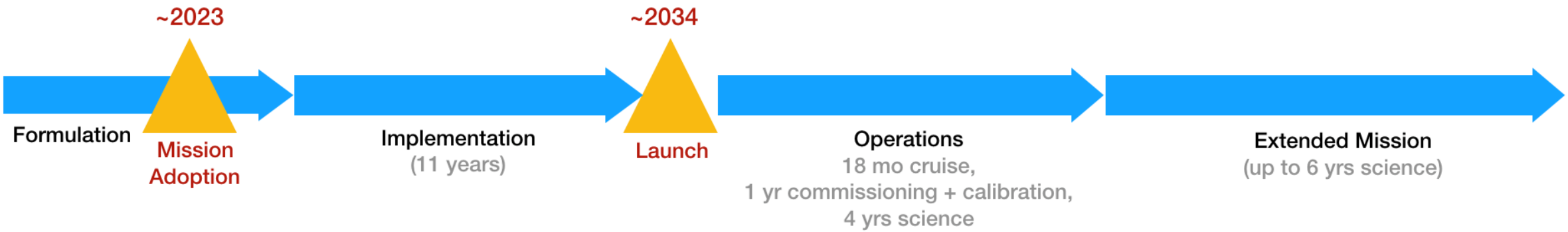
Status and Outlook

- **Currently in "formulation" (ESA Phase A)**
  - Mission design
  - Requirements development
  - Demonstration of key technologies
  - Negotiation of roles and responsibilities
- **Recent progress**
  - ESA Mid-Phase A review (Mission Consolidation Review) completed successfully Oct. 2019
  - Increase to ESA science budget motivated in part by LISA/Athena synergies

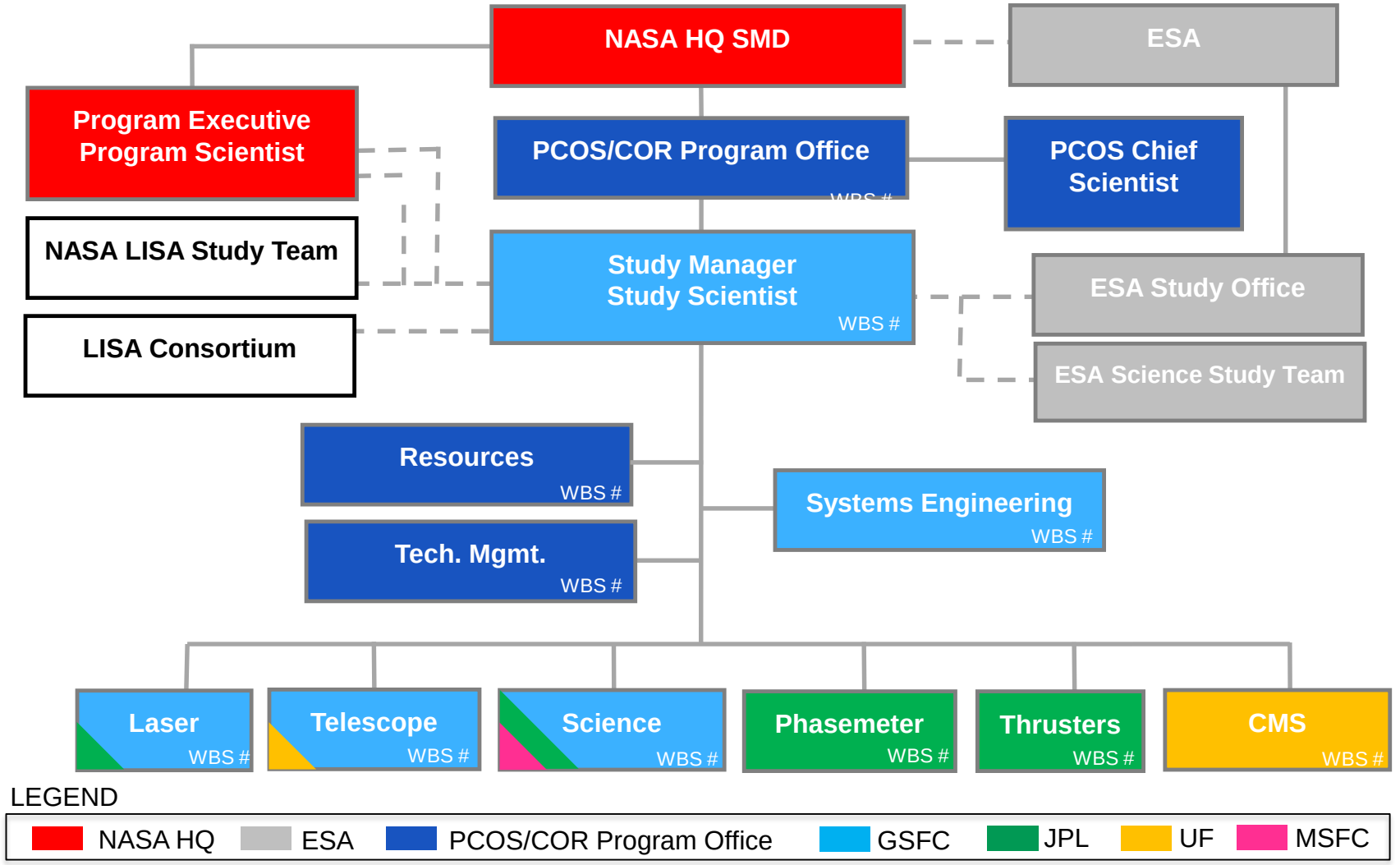


NASA LISA STUDY OFFICE (NLSO) OVERVIEW

NASA LISA Study Office

- **“proto-project”**
  - Conducts pre-formulation activities (NASA is pre-phase A)
  - Will evolve into formal NASA Project Office (~2021 TBD)
- **Hosted by Physics of the Cosmos Program at NASA/HQ**
  - Program responsible for managing science themes including gravitational waves
- **Executed by NASA field centers & partners**
  - GSFC: project management, science, and system engineering lead; telescope and laser development
  - JPL: science and systems engineering support; interferometry expertise and supporting technologies in micropropulsion and phase measurement
  - MSFC: science and science ground segment support
  - UF: charge management, telescope testing support

Organization Chart



Study Office Near-Term Goals

- **Collaborate with partners (ESA, LISA Consortium) on formulation activities**
  - Mission development
  - Instrument design
  - Science ground segment preparations
- **Develop and assess potential NASA contributions**
  - Payload systems and subelements (req. tech development)
  - Spacecraft components
  - Ground segment contributions
  - Operations contributions
  - Science support
  - …
- **Assess each contribution**
  - Compatibility with partners / ease of interfaces
  - US interest
  - NASA capabilities
  - Cost & Budget availability
- **Work with NASA HQ, ESA, Consortium to consolidate final roles and responsibilities**
  - MoU drafted prior to adoption (~2023)

NLSO SYSTEMS AND TECHNOLOGY ACTIVITIES

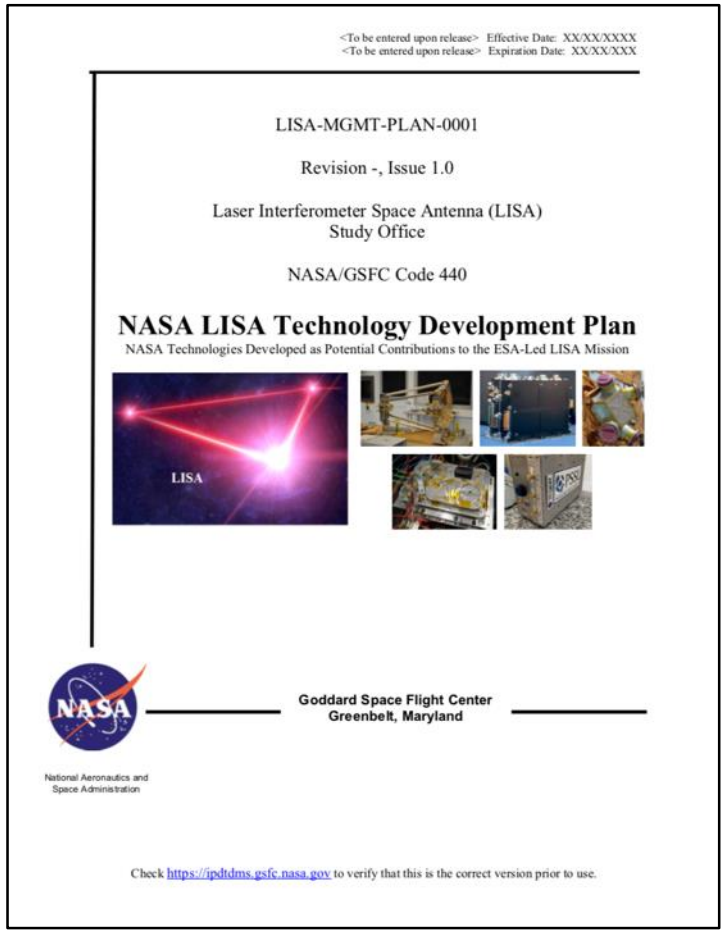
Systems Engineering Activities

LISA is a single instrument distributed across a constellation of spacecraft.
Systems engineering is paramount to mission success!

- **Support ESA-led activities**
  - Systems Engineering Office (SEO)
  - SEO WGs (laser, Tel/OB, contamination, propulsion, …)
  - Industrial System Study progress meetings
  - Support ESA reviews (e.g. MCR)
- **Support Consortium-led activities**
  - LISA Instrument Group (LIG) meetings & payload documentation (e.g. MCR)
  - Payload Assembly, Integration, Verification & Test (AIVT) planning and activities
  - Simulation working group
  - Performance modeling group
- **Conduct internal NASA reviews (w/ ESA + LIG participation)**
  - Telescope design review (Jan ‘19)
  - Microthruster peer reviews (Sept. ’18 & Feb ‘20)
  - Charge Management peer review (Nov ‘19)
  - Laser TRL5 brassboard pre-ship review (March ’20)
  - …

NASA Study Office Technology Development

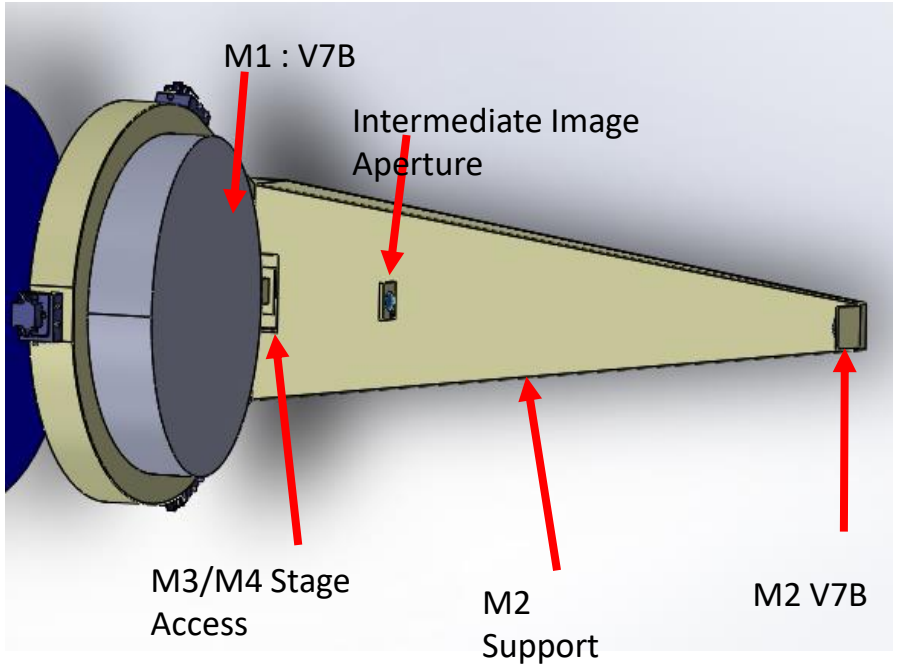
- **Investment in five enabling technologies:**
  - Telescope (Goddard Space Flight Center + U. Florida)
  - Laser System (Goddard Space Flight Center + JPL)
  - Charge Management System (U. Florida)
  - Phasemeters (Jet Propulsion Laboratory)
  - Microthrusters (Jet Propulsion Laboratory)
- **Goals**
  - Demonstrate technology readiness prior to mission adoption
  - Demonstrate key driving requirements to reduce mission risk
- **Study Office Role**
  - Coordinate across individual development efforts (cf. Technology Plan)
  - Harmonize requirements between ESA/Consortium development and NASA developments (ensure participation with SEO and LIG groups)
  - Develop contribution scenarios (work with ESA, LIG, and NASA/HQ)
  - Manage cost, schedule and technical risk



NASA LISA Tech. Dev. Plan issue 1.0
(released Feb. 2020)

NASA Technology Development Progress - Telescope

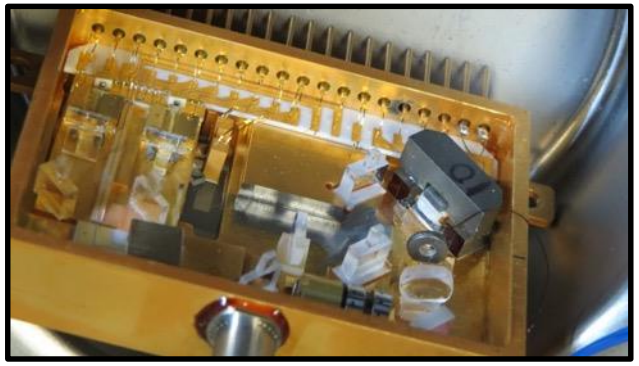
- **Procurement process for prototype models (1 structural + 2 optical performance) underway**
  - RFP released Sept. 16
  - Proposals received Oct. 23
  - Contract target early 2020
- **Internally developed reference design as proof of concept (right) and for interface discussions with ESA/Consortium partners**
- **Preparing facilities for optical tests at GSFC and UF**
- **Supporting SEO Tel/OB WG and LIG activities**

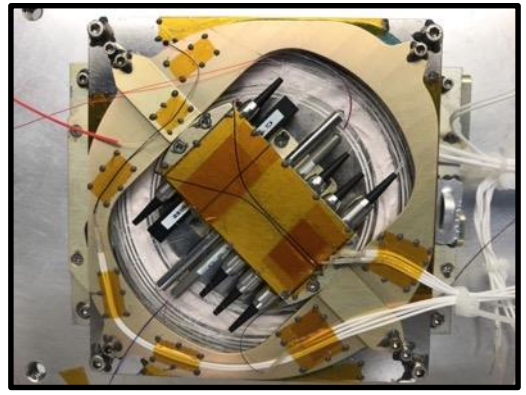


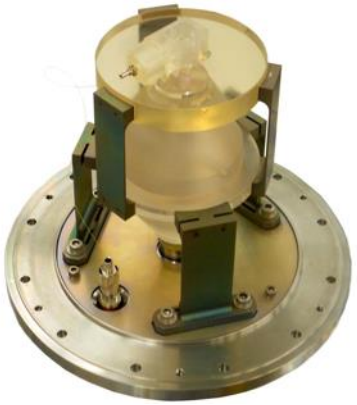
CAD model of NASA proof-of-concept design

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 to arrived GSFC Nov.
- **Frequency reference (JPL lead)**
  - Contract initiated with Ball aerospace 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
  - Preparing to deliver prototype lasers to ESA partners for test in May/June 2020



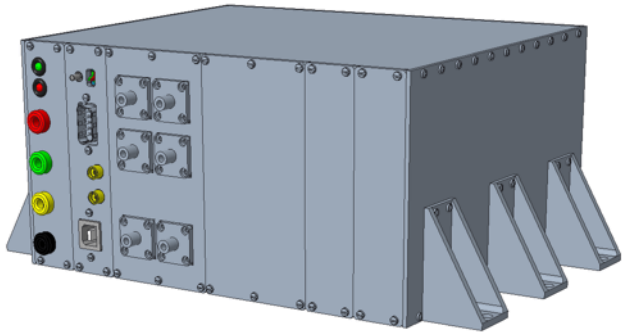


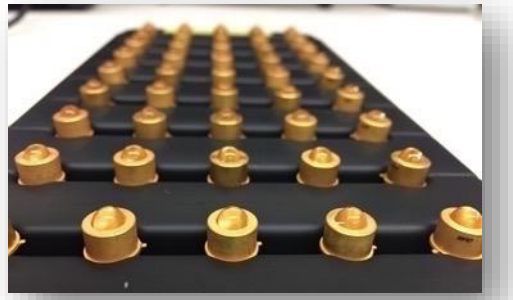


(top) mNPRO master oscillator under test at GSFC. (bottom left) Fiber amplifier. (bottom right) frequency reference cavity for GRACE-FO.

NASA Technology Development Progress – Charge Management

- **TRL4 Charge Management Device delivered to U. Trento for testing**
  - 1st delivery of LISA (prototype) hardware to Europe
  - Integratedwith U. Trento torsion pendulum for system-level testing of charge control
  - TRL4 milestone review passed on Nov. 19
- **TRL5 Unit design underway**
  - Mid-TRL 5 peer review held on Nov. 18 (ESA + LIG participation)
  - TRL 5 scheduled completion Sept. 2020
- **Working with GSFC photoincs group to evaluate options for fiber harness and conduct radiation testing**
- **Supporting SEO Charge Management WG and LIG activities**

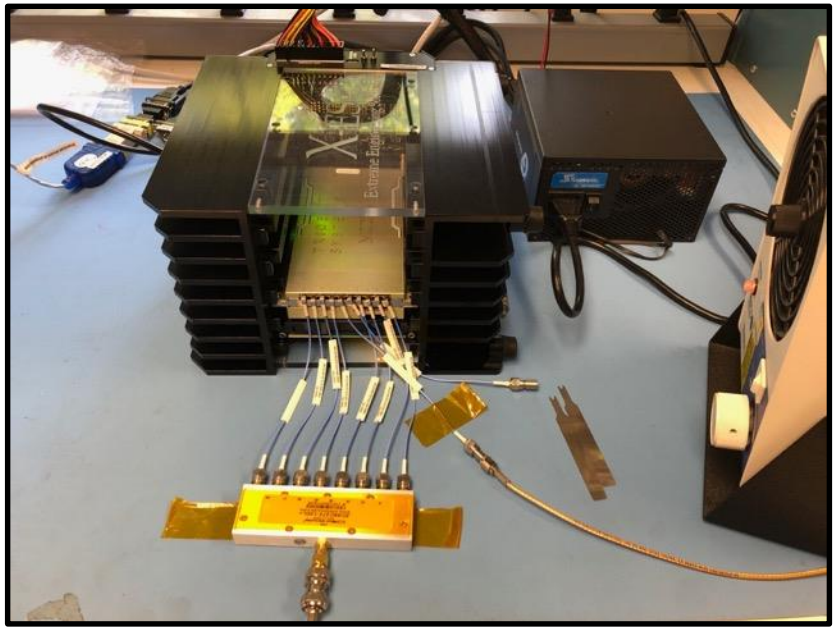




(top left) TRL 5 design. (bottom left) UV LEDs used for performance/lifetime testing. (right) TRL4 charge management unit in place at U. Trento torsion pendulum facility.

NASA Technology Development Progress – Phasemeter

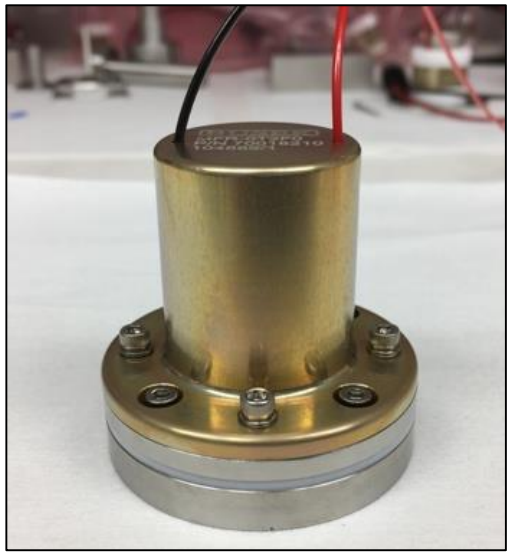
- **In-flight results from LRI instrument published**
  - includes LISA-like phasemeter (LRP)
  - Outperforms noise requirements
  - limited by frequency stability of laser (only one arm)
- **Working with Industry to produce scalable LISA prototype**
  - Marriage of existing flight-heritage hardware 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**

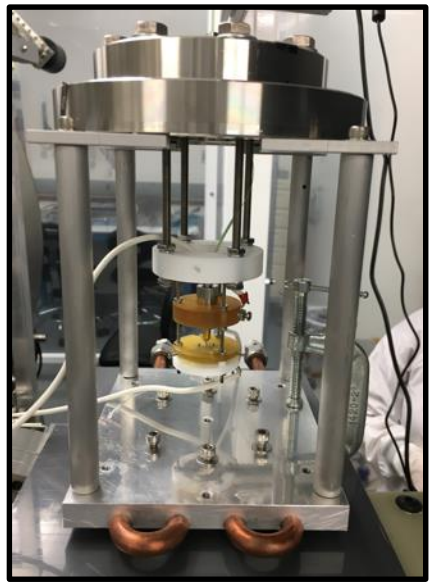


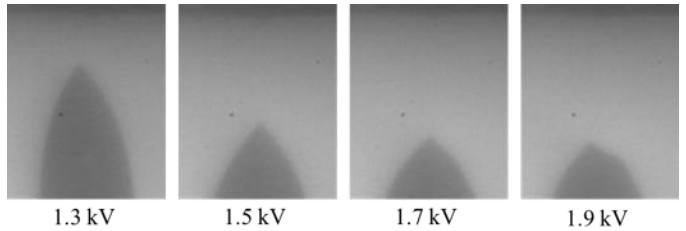
8-channel phasemeter prototype card (Trident Systems) under test at JPL.

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.

Prioritization of technologies

- **NASA has slowed development of the microthruster and phasemeter technologies starting in FY20**
  - Telescope, Laser, and charge management device are highest priority for NASA based on ESA input and internal NASA assessments
- **Impacts**
  - At HQ direction, NASA Study Office, in consultation with JPL managers, has developed strategy for mitigating impacts by funding highest priority activities.
  - Design study for stabilization cavity (part of laser system) will continue on pace at JPL
  - Key JPL team members are contributing to NASA systems engineering team
- **Summary**
  - Phasemeter and Microthruster technologies remain viable candidates for NASA contributions

NLSO SCIENCE ACTIVITIES

NLSO Science Activities Summary

- **Support ESA-led activities**
  - Science Study Team meetings and task groups
  - Planning and prototyping of potential ground-segment contributions
- **Support Consortium-led activities**
  - LDPG, LSG calls and meetings
  - Contribute to Science and data analysis WPs and WGs (RGs?)
  - Participate in Consortium face-to-face meetings
- **US community activities**
  - NLST logistical support (NLST reports directly to NASA/HQ APD)
  - Support GWSIG / PhysPAG / PCOS activities (NASA's broader interface to community)
- **Science Core Team Activities**
  - Prototyping LISA analysis infrastructure
  - Study science impacts of trades
  - Provide LISA expertise to support NLST activities
  - Support response to Astro2020

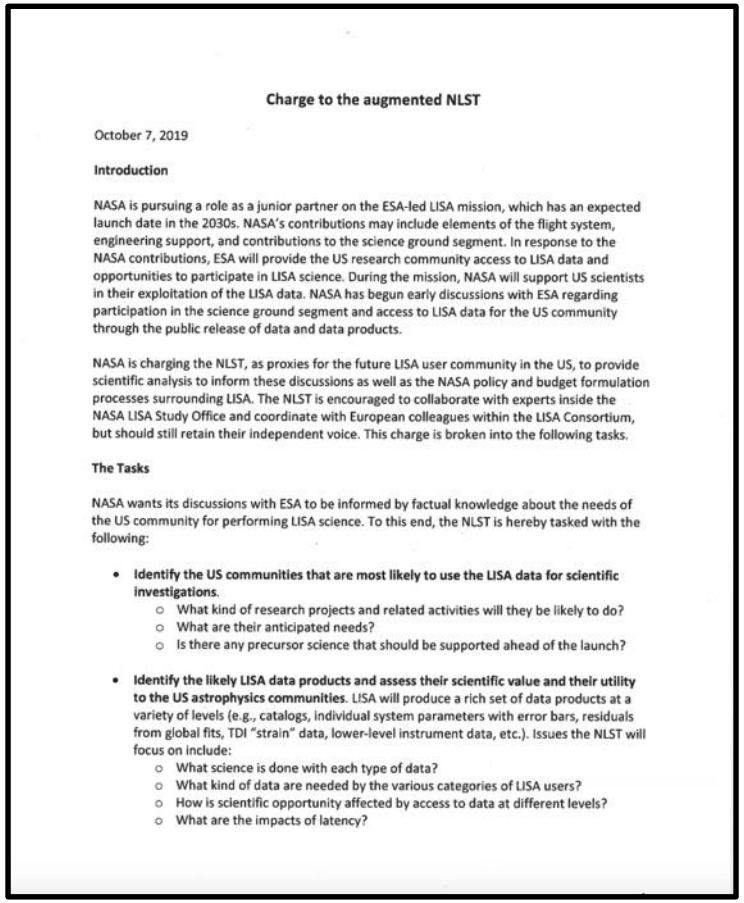
NASA LISA Study Team

- **Independent group of scientists representing the future US LISA user community**
  - Provide input to NASA HQ and NASA Study Office on LISA science questions
  - Represent LISA science to Astro2020
  - Interface with broader US research community
  - Interface with LISA Consortium (communication only, no expectation or funds to perform Consortium work)
- **Membership**
  - Members appointed for 3-year terms
  - Second cohort appointed in October 2019
  - Kelly Holley-Bockelman serves as Chair

Name	Institution	Member Since
Jillian Bellovary	CUNY-Queensborough	2017
Peter Bender	University of Colorado	2017
Emanuele Berti	Johns Hopkins University	2017
Warren Brown	Harvard-Smithsonian Astrophysical Observatory	2017
Robert Caldwell	Dartmouth College	2017
Neil Cornish	Montana State University	2017
Jeremy Darling	CASA, University of Colorado Boulder	2019
Matthew Digman	Ohio State University	2019
Mike Eracleous	Pennsylvania State University	2017
Kayhan Gultekin	University of Michigan	2019
Zoltan Haiman	Columbia University	2019
Kelly Holley-Bockelman (Chair)	Vanderbilt	2017
Joey Key	University of Washington, Bothell	2017
Shane Larson	Northwestern University	2017
Xin Liu	University of Illinois Urbana-Champaign	2019
Sean McWilliams	West Virginia University	2017
Priyamvada Natarajan	Yale University	2017
David Shoemaker	Massachusetts Institute of Technology	2017
Deirdre Shoemaker	Georgia Institute of Technology	2017
Krista Lynne Smith	Stanford / Southern Methodist University	2019
Marcelle Soares-Santos	Brandeis University	2019
Robin (Tuck) Stebbins	University of Colorado	2017

New NLST Tasks from NASA HQ

- **Describe "science value" of data products**
  - inform data policy discussions
- **Outline science return for various models of US participation and community support**
  - inform SGS budgeting and negotiation for SGS roles with partners
- **Preliminary report delivered Feb. 3**
  - Under review by HQ
  - Final report expected ~ Mar. 1



Charge to the augmented NLST

October 7, 2019

Introduction

NASA is pursuing a role as a junior partner on the ESA-led LISA mission, which has an expected launch date in the 2030s. NASA's contributions may include elements of the flight system, engineering support, and contributions to the science ground segment. In response to the NASA contributions, ESA will provide the US research community access to LISA data and opportunities to participate in LISA science. During the mission, NASA will support US scientists in their exploitation of the LISA data. NASA has begun early discussions with ESA regarding participation in the science ground segment and access to LISA data for the US community through the public release of data and data products.

NASA is charging the NLST, as proxies for the future LISA user community in the US, to provide scientific analysis to inform these discussions as well as the NASA policy and budget formulation processes surrounding LISA. The NLST is encouraged to collaborate with experts inside the NASA LISA Study Office and coordinate with European colleagues within the LISA Consortium, but should still retain their independent voice. This charge is broken into the following tasks.

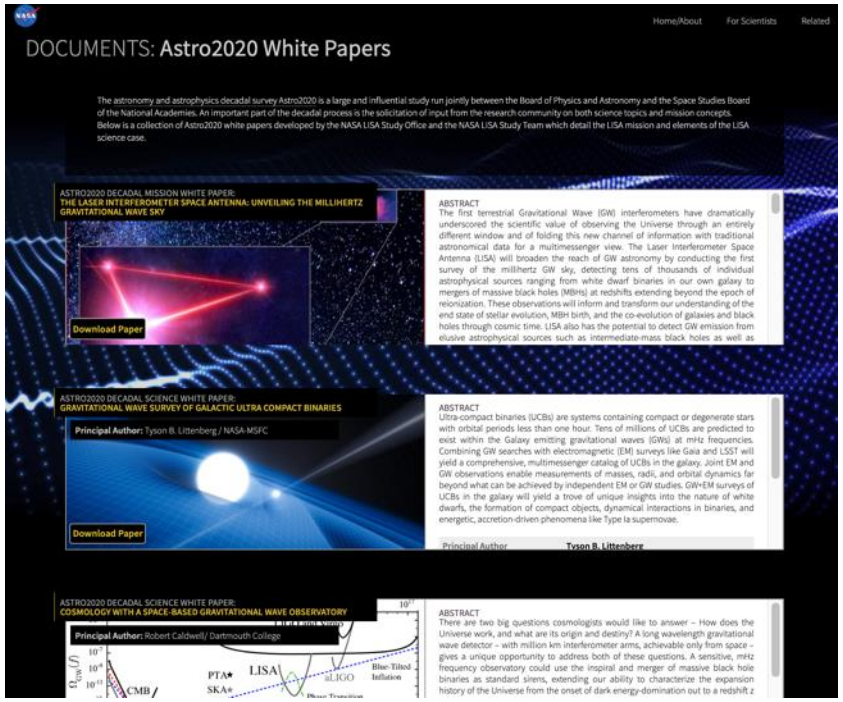
The Tasks

NASA wants its discussions with ESA to be informed by factual knowledge about the needs of the US community for performing LISA science. To this end, the NLST is hereby tasked with the following:

- **Identify the US communities that are most likely to use the LISA data for scientific investigations.**
  - What kind of research projects and related activities will they be likely to do?
  - What are their anticipated needs?
  - Is there any precursor science that should be supported ahead of the launch?
- **Identify the likely LISA data products and assess their scientific value and their utility to the US astrophysics communities.** LISA will produce a rich set of data products at a variety of levels (e.g., catalogs, individual system parameters with error bars, residuals from global fits, TDI "strain" data, lower-level instrument data, etc.). Issues the NLST will focus on include:
  - What science is done with each type of data?
  - What kind of data are needed by the various categories of LISA users?
  - How is scientific opportunity affected by access to data at different levels?
  - What are the impacts of latency?

Decadal Survey Activities

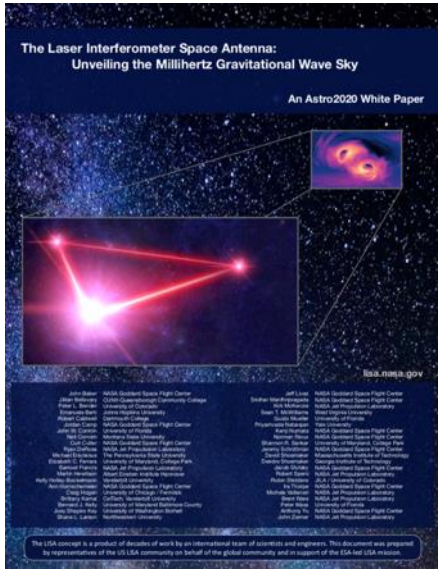
- **Science WPs**
  - Input organized by NLST
  - Participation from NASA Core Team, broader US community, European LISA community, etc.
  - 11 NLST-organized science WPs submitted
- **Mission WP submitted to APC call**
  - Summarized LISA science, mission concept, programmatics, and likely US role
- **RFI Responses**
  - Provided cost information in response to a request that came to NASA HQ
  - Responded to an RFI with specific questions from the from program panel on Particle Astrophysics and Gravitation on Jan 14th
- **Other information**
  - Supporting documentation (FAQs, detailed docs, etc.) on lisa.nasa.gov



Astro2020 whitepapers available at:
https://lisa.nasa.gov/documentsAstro2020.html

LISA "Mission" Whitepaper

- **Relevance**
  - Astro2020 guidance was that WFIRST/Athena/LISA WPs were "not necessary"
  - LISA community felt strongly that an APC WP gave an opportunity to clarify LISA's context in the science program and NASA's potential roles
- **Highlights**
  - Science case summary
  - Mission description
  - Summary of technical readiness incl. LPF and LRI heritage
  - Outlook for schedule and partnerships
- **Outlines potential "upscopes"**
  - Intended to support the Astro2020 charge to evaluate upscopes, descopes, and cancellation.
  - Broad-brush scenarios for additional contributions beyond nominal hardware contributions




The Laser Interferometer Space Antenna — An Astro2020 APC Whitepaper

1 Executive Summary

The first terrestrial Gravitational Wave (GW) interferometers [1, 2] have dramatically underscored the scientific value of observing the Universe through an entirely different window – and of folding this new channel of information with traditional astronomical data for a multimessenger view [3, 4, 5, 6]. **The Laser Interferometer Space Antenna (LISA) will broaden the reach of GW astronomy by conducting the first survey of the millihertz GW sky**, detecting tens of thousands of individual astrophysical sources ranging from white-dwarf binaries in our own galaxy to mergers of massive black holes (MBHs) at redshifts extending beyond the epoch of reionization. **These observations will inform – and transform – our understanding of the end state of stellar evolution, MBH birth, and the co-evolution of galaxies and black holes through cosmic time.** LISA also has the potential to detect GW emission from elusive astrophysical sources such as intermediate-mass black holes as well as exotic cosmological sources such as inflationary fields and cosmic string cusps[1].

LISA is now in Phase A as a European Space Agency (ESA) led mission with significant contributions anticipated from several ESA member states and NASA. **The mission concept retains all essential features of the NASA/ESA LISA mission that was ranked as the 3rd priority for Large-class missions in the 2010 Decadal Survey [7]**, including the full three-arm triangular configuration that measures GW polarization and improves robustness. Since that ranking, **LISA's technical readiness has been greatly advanced through two flight demonstrations**: the ESA-led LISA Pathfinder mission (2015-2017) and the Laser Ranging Instrument on board the US/German Gravity Recovery And Climate Explorer Follow-On mission (2018-). The Midterm Assessment of the 2010 Decadal Survey recommended that the US participate as a "strong technical and scientific partner" in an ESA-led LISA mission [8]. NASA is currently supporting preproject activities to support a range of potential contributions to LISA including instruments, spacecraft elements, and science analysis. The currently envisioned scale of these contributions is at the lower end of the medium-scale cost range identified by Astro2020 ($500M - $1.5B). **A recommendation for an upscope in US participation in LISA would provide opportunities to more fully exploit heritage from prior US investments, balance technical and programmatic risks across the partnership, and expand opportunities for future US leadership in this new field of astronomy.**

Box 1 - LISA Mission Overview

Science Objective: All-sky survey of millihertz gravitational waves

Measurement Concept: Long-baseline optical interferometry between drag-free test masses

Orbit: Heliocentric 2.5 Mkm triangular constellation, 20° Earth-trailing

Launch: Early/mid 2030s, Ariane 6.4

Lifetime: 1.5 yr transfer, 1 yr commissioning, 4 yrs science, ≤ 6 yrs extension

Cost: Total mission: Large (>$1.5B); US share: Medium ($500M - $1.5B)

Partners: European Space Agency (lead), ESA Member States, NASA

[1] LISA Astro2020 Science whitepapers available at: 2.lisa.nasa.gov/document/367.html

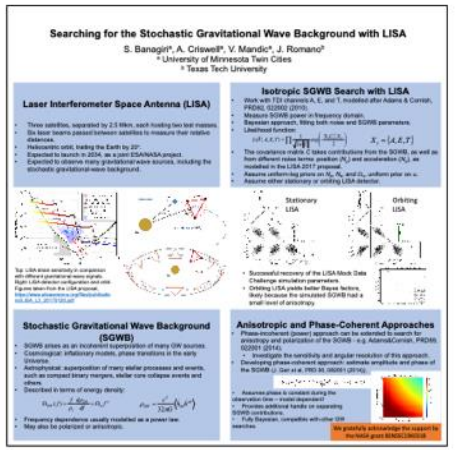
https://lisa.nasa.gov/downloads/forScientists/whitePapers/LISA_Astro2020_APC_final.pdf

LISA Preparatory Science Grants

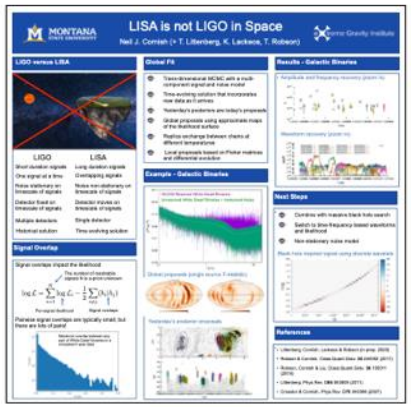
Not part of NLSO. Grants are managed directly by NASA/HQ as part of ROSES

- **NASA/HQ funded grants to support LISA-related science**
  - Refine the LISA science case
  - Develop the future LISA user community
- **Process**
  - ROSES element, selected through standard NASA peer-review process
  - Independent of NASA Study Office and NASA LISA Study Team
  - No obligation (or prohibition) to work with NASA Study Office or Consortium
- **First cohort awarded in 2018**
  - Progress presented at special session of January 2020 AAS meeting in Honolulu
- **Goal is to hold additional calls in the future**

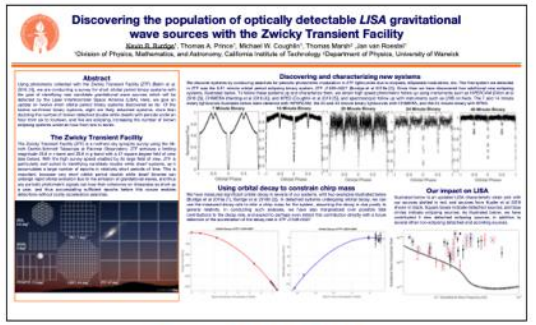
LPS Highlights from AAS Honolulu



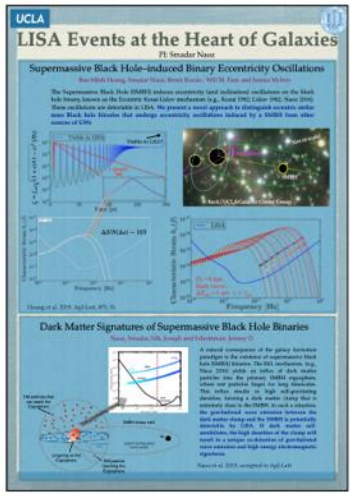
Mandic (U. Minn.)



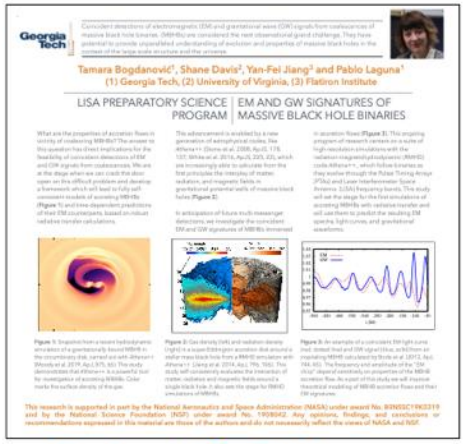
Cornish (Montana St.)



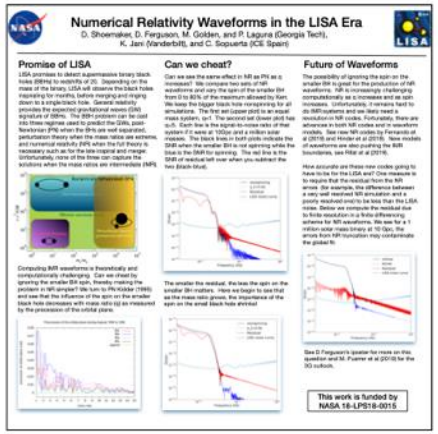
Prince (Cal. Tech)



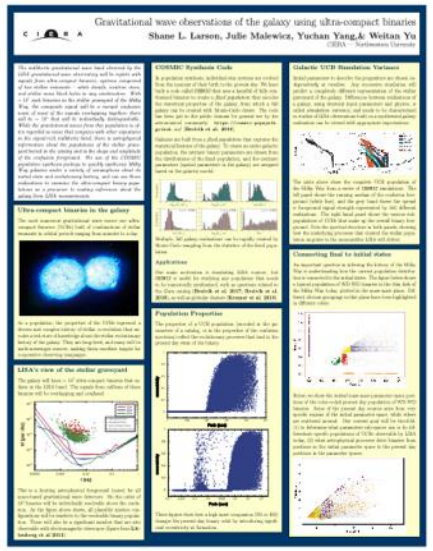
Naoz (UCLA)



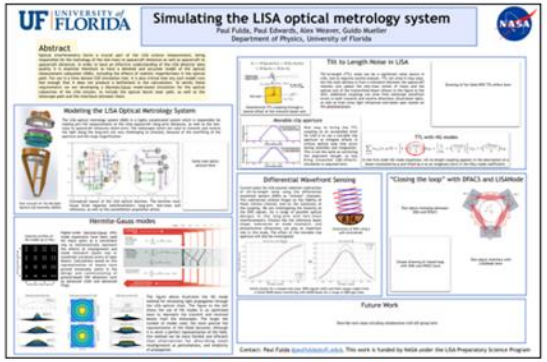
Bogdonavic (Ga. Tech)



Shoemaker (Ga. Tech)



Larson (CIERA – Northwestern)



Wass (U. Florida)

LISA Science Ground Segment and NASA's role

- **LISA's science ground segment (SGS) is *an essential part of the instrument***
  - The SGS consists of the algorithms, computing infrastructure, personnel, etc. required to deliver the mission science objectives from the telemetered data
  - This complex, integrated system will be composed of contributions coming from ESA, ESA Member States, and NASA
  - Many parallels with the hardware portion of the instrument with the exception that there are more opportunities for parallelisim.
- **NASA's role in SGS under development**
  - Expectation is that science support, including SGS contributions, will be in addition to ~$400M NASA hardware contribution.
  - Ongoing work within LISA Consortium and NLSO Science Core Team to define the SGS and potential contributions.
- **In addition to NASA's commitments to SGS elements, NASA will conduct activities to facilitate exploitation of LISA data & science by the broader US research community**
  - Examples: Guest Investigator grants, Data archives, tools, help desks, etc.
  - US and European communities have different models for science support which must be considered
  - Data access rights are a complex issue which will require continued conversation
- **Upcoming NLST report will help define science justification for various options**

SUMMARY

Summary

- **Steady Progress being made on multiple fronts**
  - Technology development proceeding on schedule, though microthruster and phasemeter technologies are now proceeding at a reduced pace
  - Good engagement with European-led systems engineering and design activities
  - Initial work to understand complexity of science ground segment and associated data flow
  - Input provided to Astro2020, prepared to respond to further inquiries
- **Much work ahead of us**
  - Continued development of technologies
  - Consolidation of spacecraft and payload designs as well as roles and responsibilities
  - Initial outlining of science ground segment and potential US contributions

lisa.nasa.gov

- **Revamped in 2017 to replace “old” NASA LISA site**
  - New programmatic (ESA lead)
  - New science context (LIGO, LPF, LRI, etc.)
  - Mobile-friendly
- **Entry points for various users**
  - Interested public
  - Science community
- **Highlights**
  - Reference Docs (Astro2020 & others)
  - FAQ
  - LISA-relevant announcements
  - Summary of activities & team members
  - Source calculators (coming soon)

BACKUP