

# Laser Interferometer Space Antenna

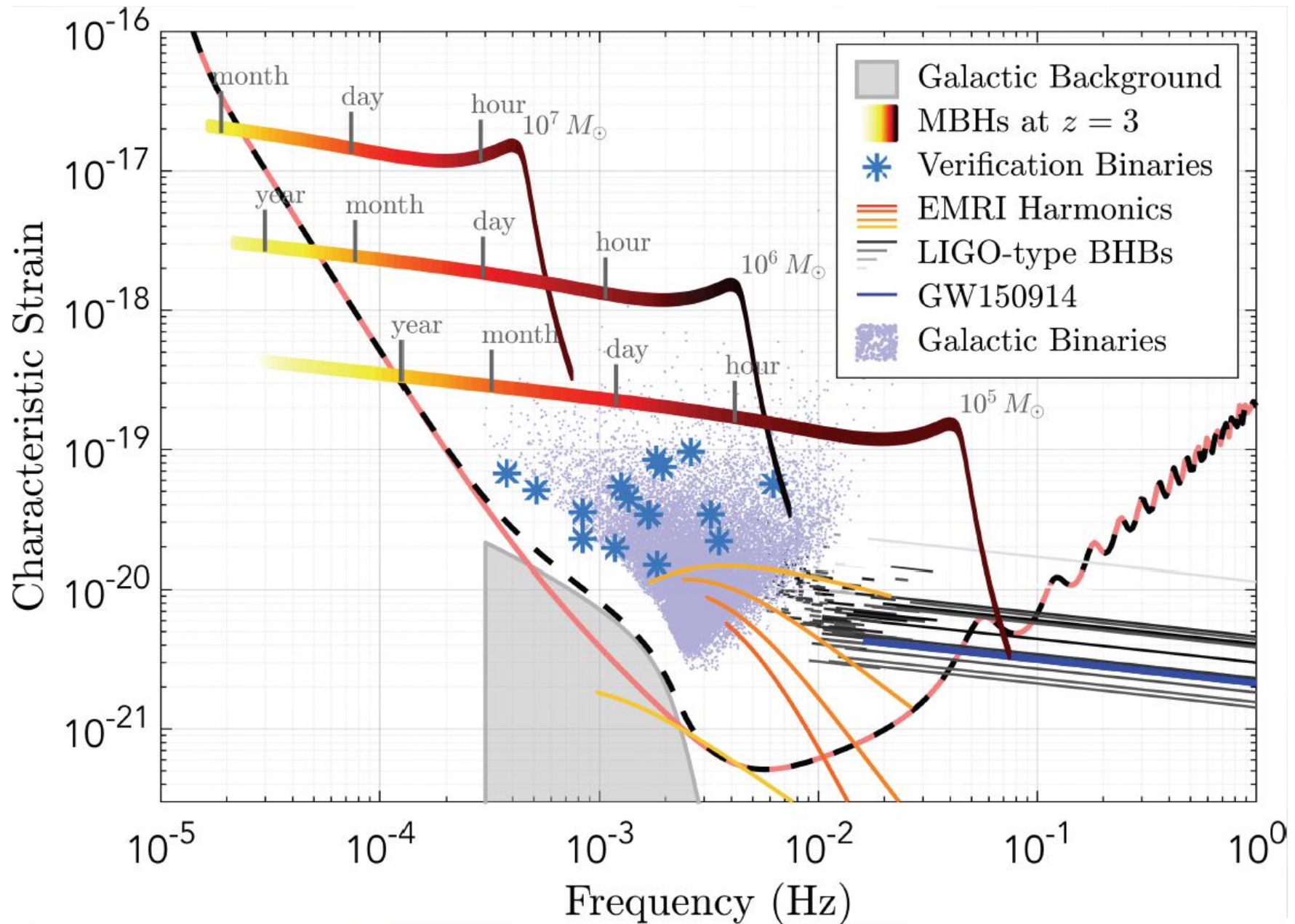
## Technology Development and Other Efforts in the U.S.

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Thanks to Ira Thorpe, GSFC



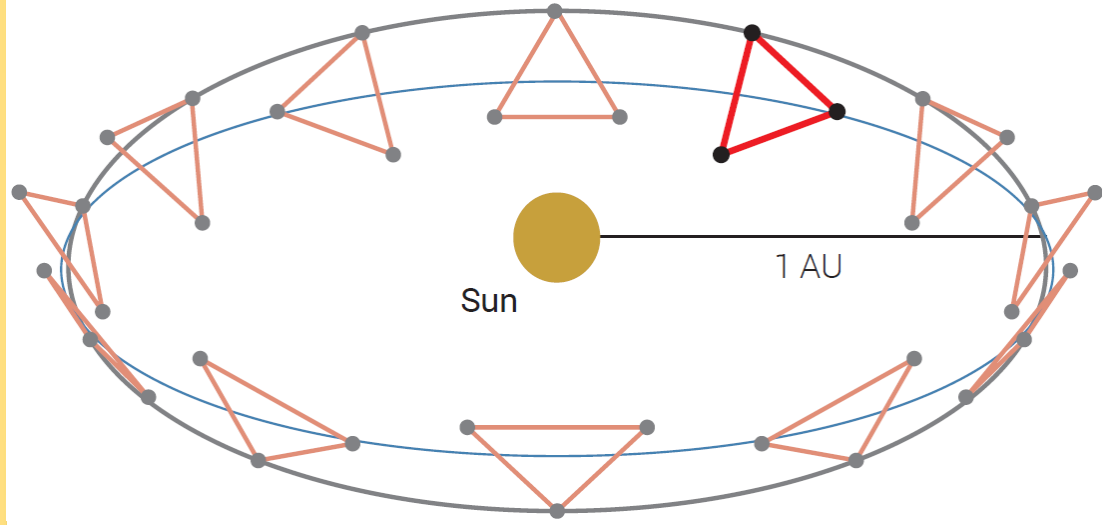
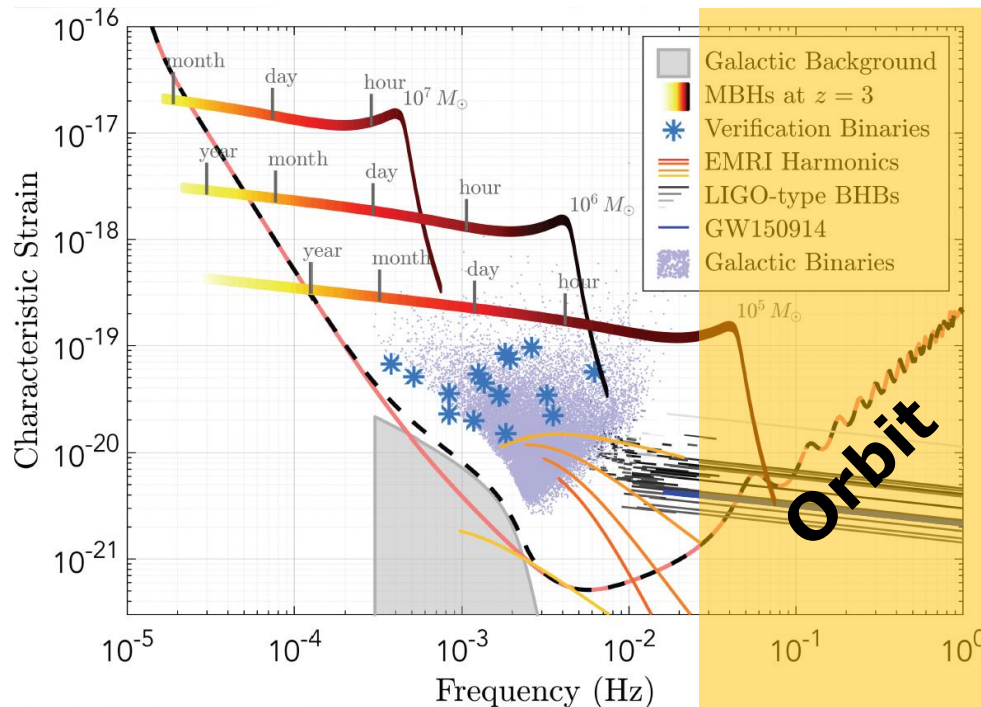
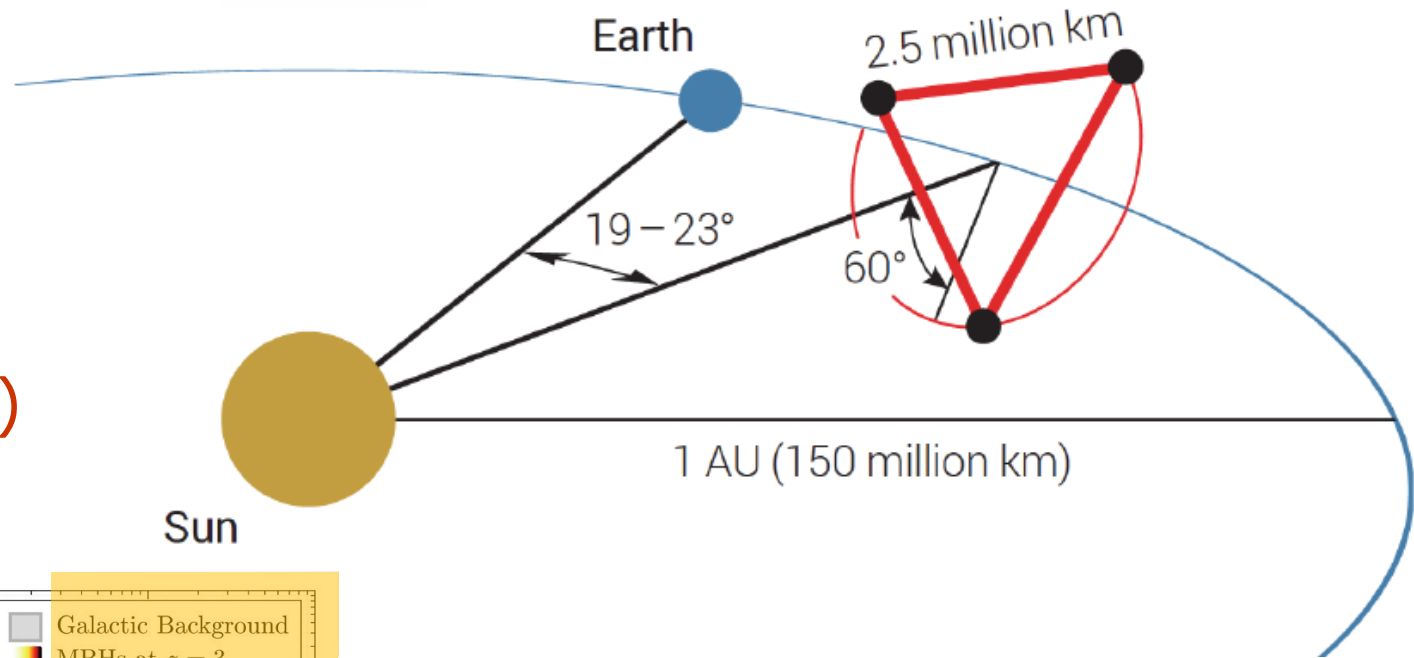
# LISA Sensitivity Curve



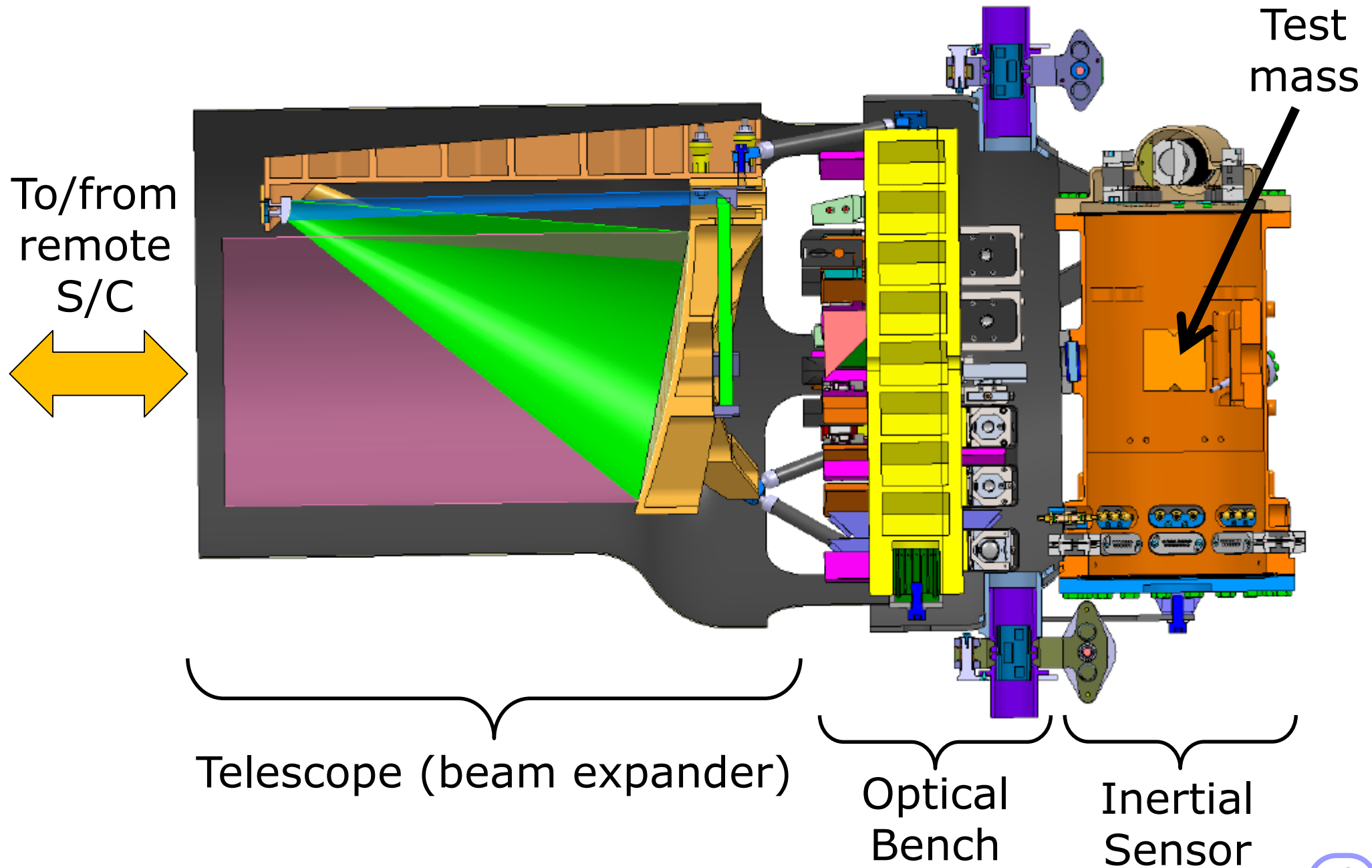


# Strain Curve → Orbit

- 4 yr mission
  - +6 yr extension
- 3 arms
  - (6 one-way links)

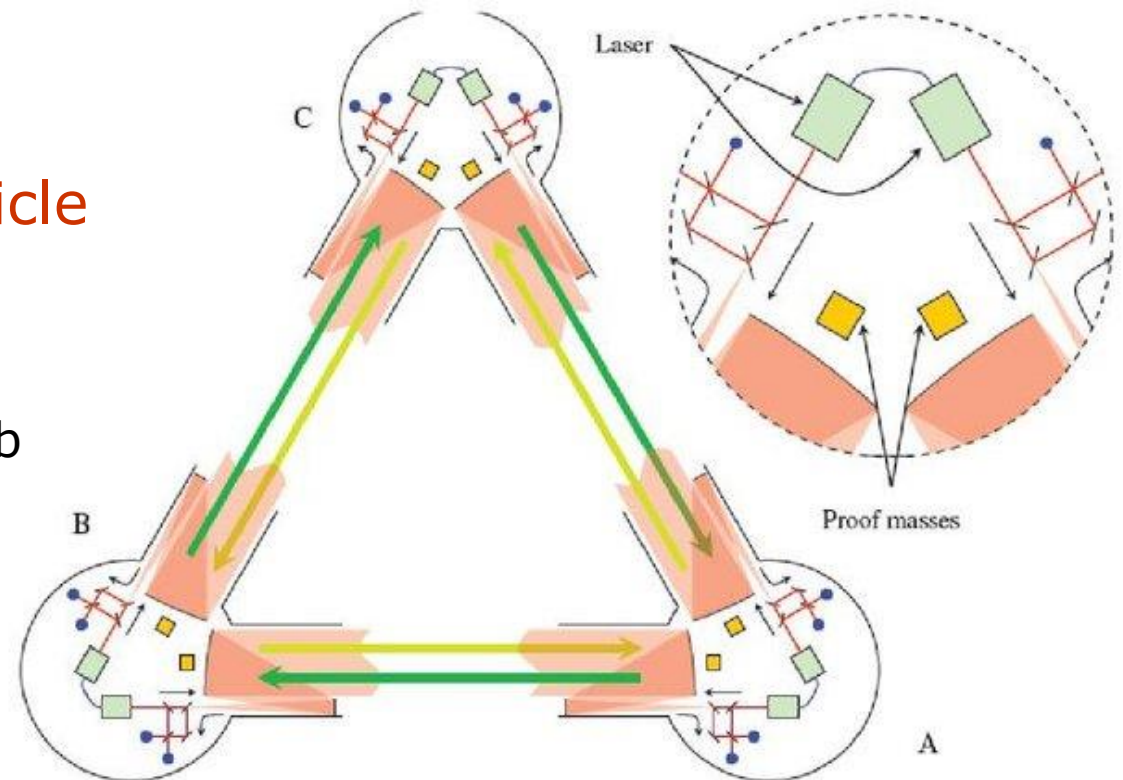
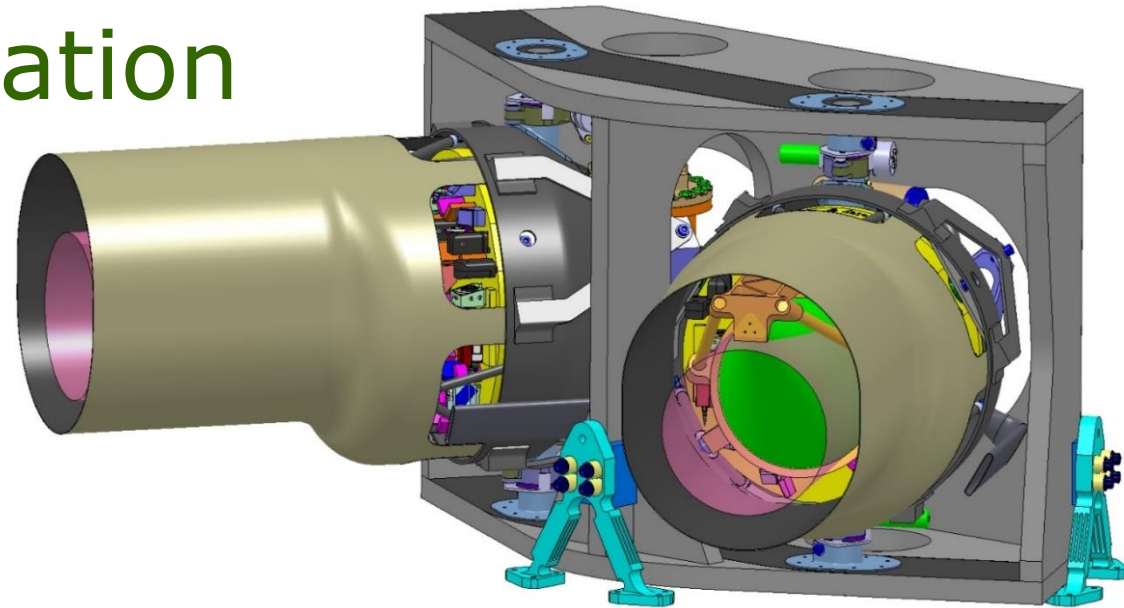


# LISA Core Instrument



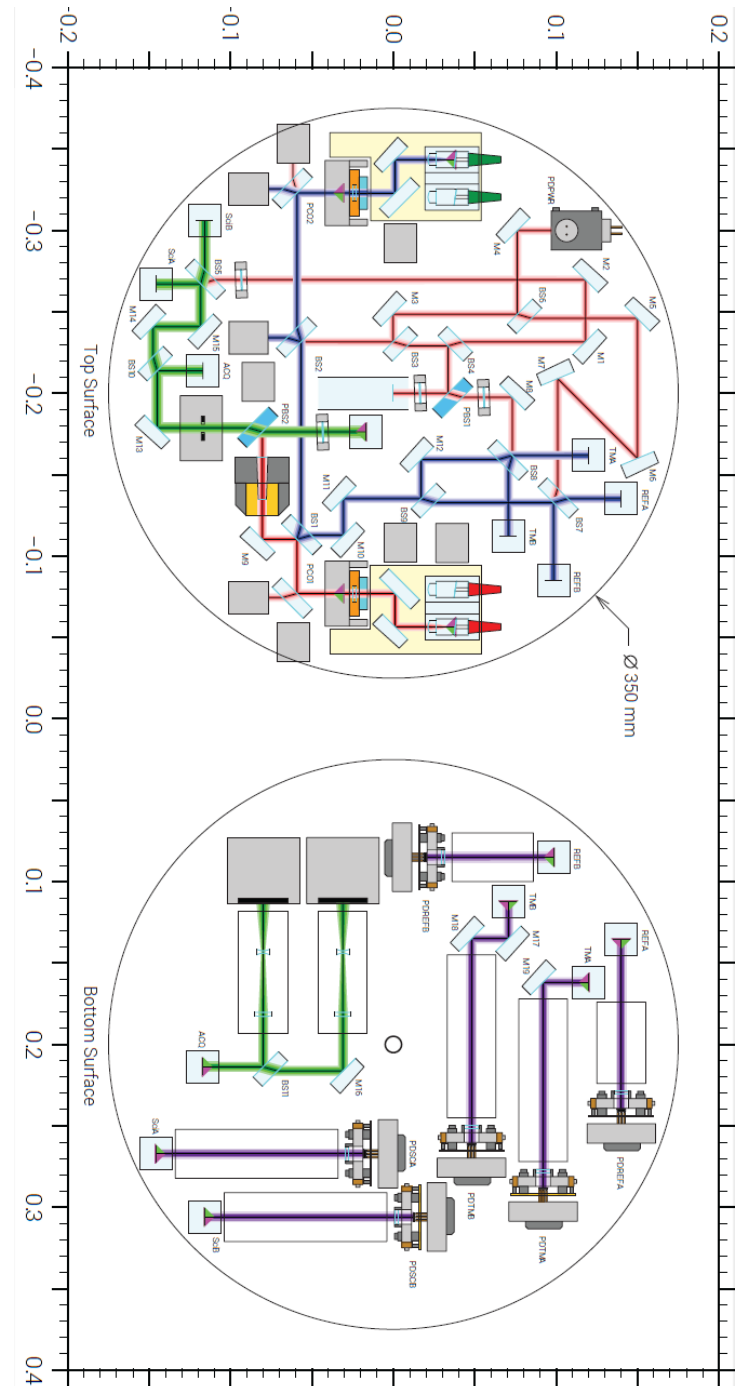
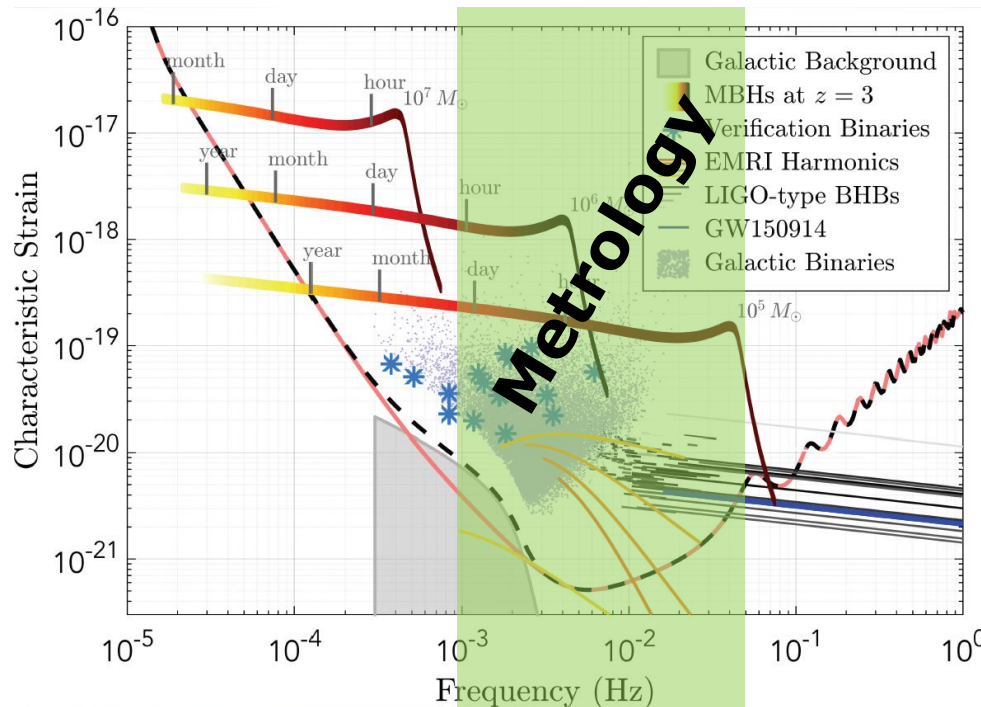
# The LISA Constellation

- **3 Identical spacecraft**
  - 6 Test masses
  - 6 Telescopes
  - 6 lasers (+ redundancy)
  - 6 optical benches
- **Electric propulsion to get to final orbits (tentative)**
- **Launched on a single vehicle (Ariane 6.4)**
  - French Guiana
  - Launch mass ~ James Webb Space Telescope



# Strain Curve → Metrology

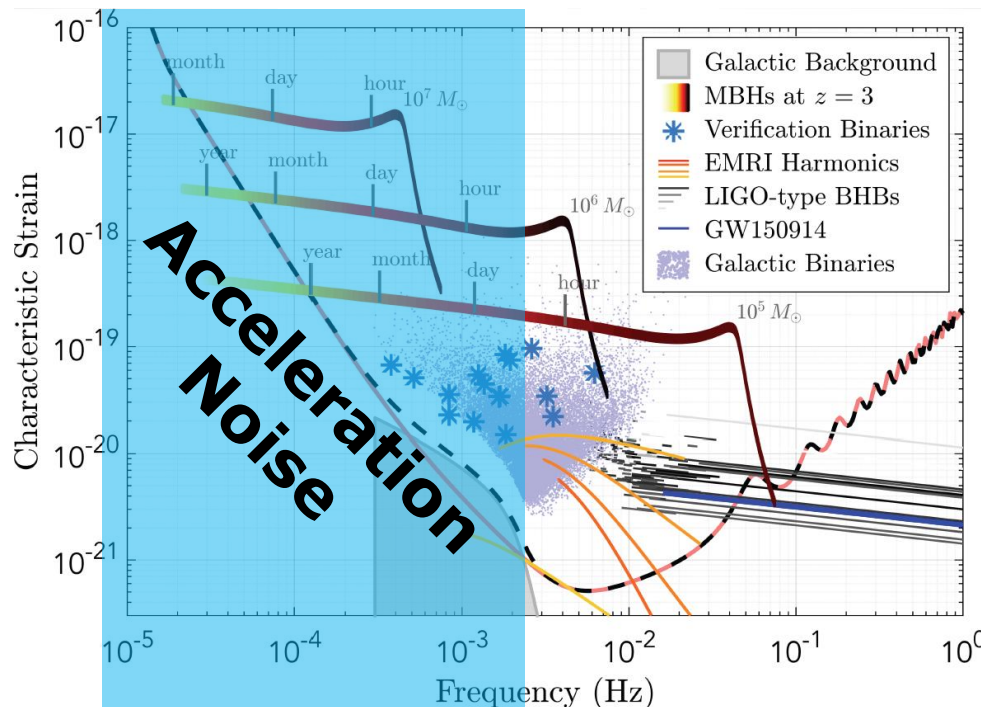
- 10 pm/Hz<sup>1/2</sup> one-way
  - 2 W, 1064 nm lasers with frequency stabilization
  - Low CTE optical benches with 4 interferometers
  - $\mu$ cycle over MHz phasemeter
  - 30 cm telescopes





# Strain Curve → Acceleration Noise

- **Disturbance Reduction System**
  - Inertial sensor with test masses, electrode housings, electronics, charge control, caging mechanism
  - Drag-free control using microthrusters
  - Quiet thermal, EM, gravitational environment with monitoring



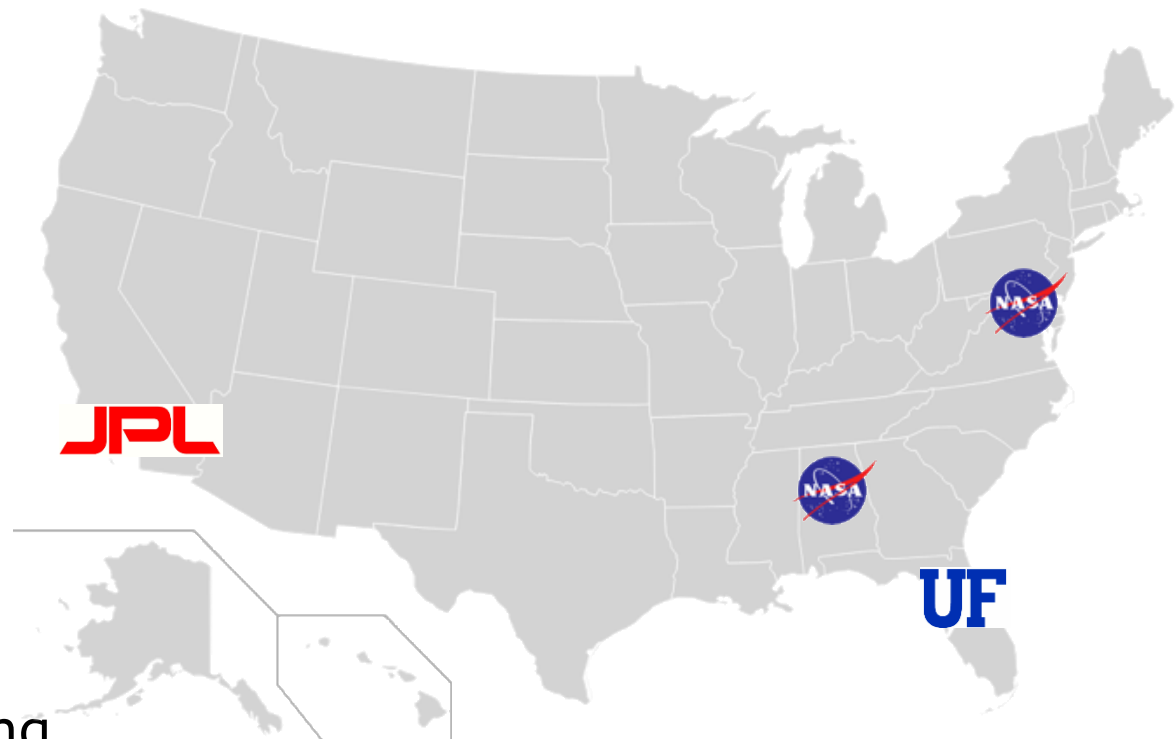
# Top-level LISA Mission Organization

- Mission lead – European Space Agency
- “NASA is a **major junior partner**” in LISA – P. Hertz
- Mission Industrial Prime
  - Competitive in Phase A (now); Down-select before Phase B (2020)
    - Airbus D & S, Germany
    - Thales Alenia Space, Italy
  - Possible NASA Contributions to LISA platform
- Science Instrument
  - LISA Consortium: Instrument lead
  - Airbus D & S: Instrument architect
  - European member state instrument contributions
  - NASA instrument contributions
- Science
  - LISA Consortium consisting of European and U.S. members

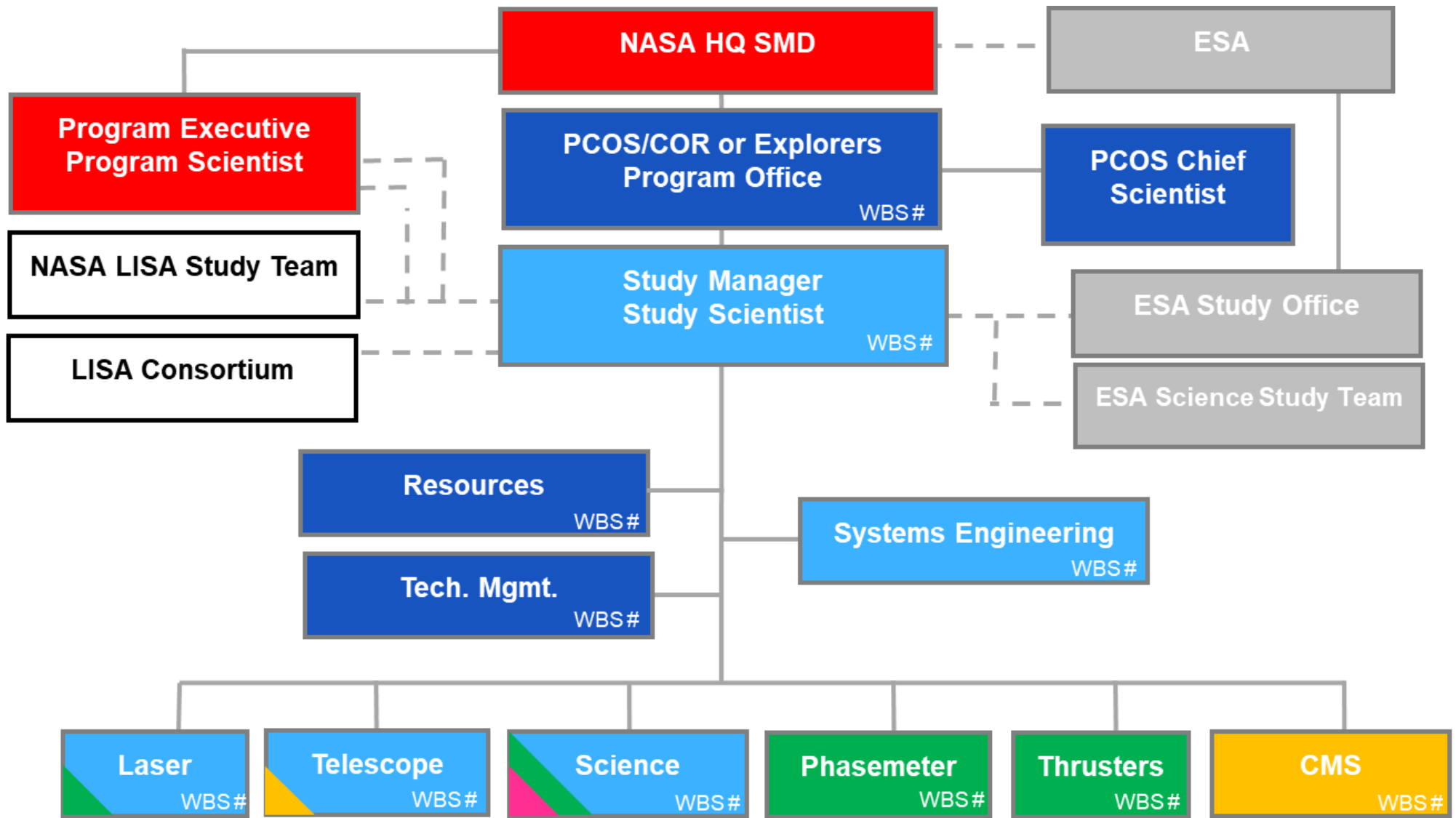


# NASA LISA Study Office

- “proto-project”
  - Conducts pre-formulation activities w/o formal project structure
  - Will evolve into formal NASA Project Office
- Hosted by Physics of the Cosmos (PCOS) Program
  - Program responsible for science themes including GW
- Executed by NASA field centers, academia
  - GSFC: management, science, sys. eng; telescope, laser
  - JPL: science, sys. eng. support; interferometry, micropropulsion
  - MSFC: science support
  - UF: CMS, telescope testing



# Organization Chart

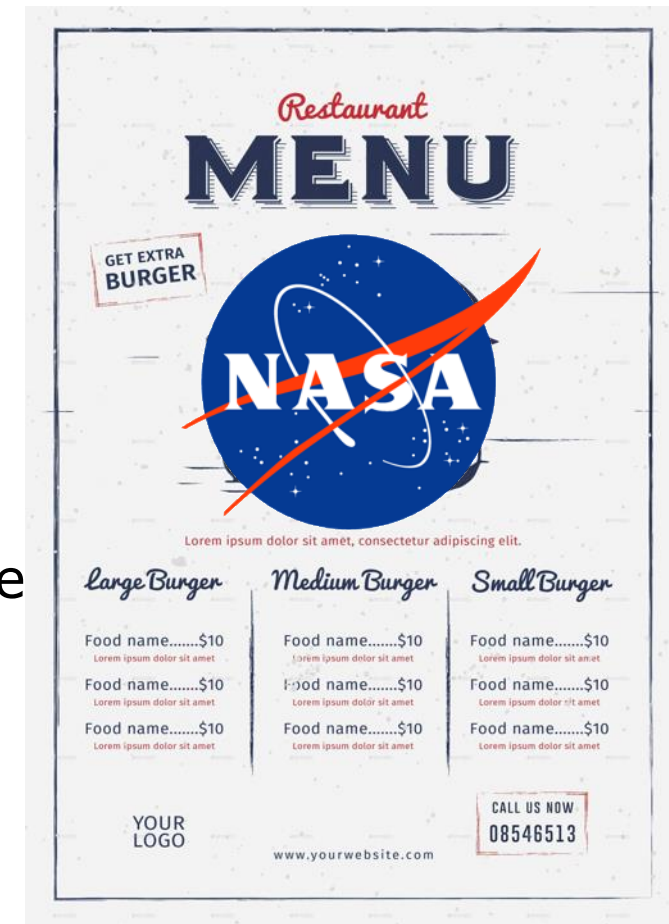


**LEGEND**

<span style="color: red;">■</span> NASA HQ	<span style="color: grey;">■</span> ESA	<span style="color: blue;">■</span> PCOS/COR Program Office	<span style="color: lightblue;">■</span> GSFC	<span style="color: green;">■</span> JPL	<span style="color: yellow;">■</span> UF	<span style="color: magenta;">■</span> MSFC
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# Study Office Near-term Goals

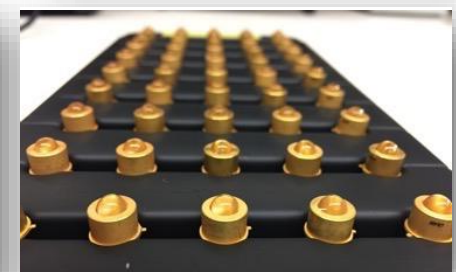
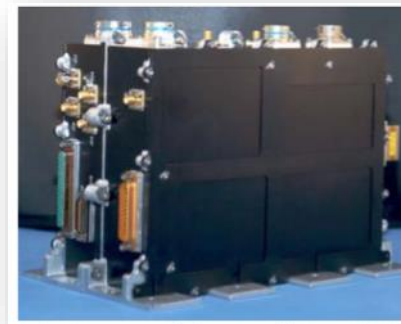
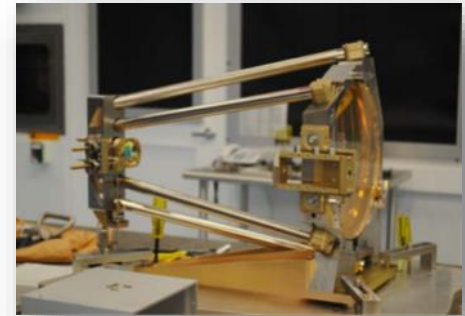
- Develop “menu” of possible NASA contributions
  - Payload systems and subelements (req. tech development)
  - Spacecraft components
  - Ground segment contributions
  - Operations contributions
  - Science support
  - ...
- Assess each contribution
  - Compatibility with partners/ease of interface
  - US interest
  - NASA capabilities
  - Cost
- Work with NASA HQ, ESA, Consortium to consolidate final roles and responsibilities





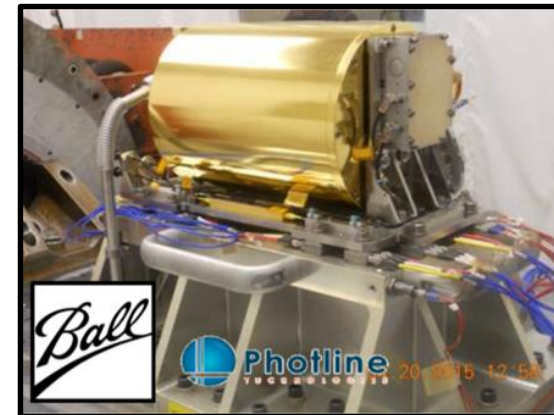
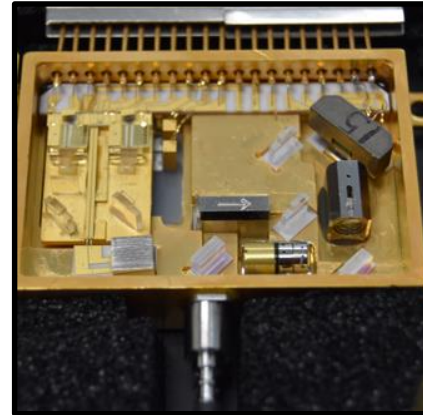
# U.S. Technology Development

- **Goal**
  - Bring a handful of critical technologies to sufficient readiness prior to mission adoption (goal: TRL6 by 2022)
  - Demonstrate key driving requirements, reduce risk
- **Investment strategy**
  - US heritage/expertise
  - insight into the GW instrument
  - known and tractable interfaces
- **Technologies**
  - Stable Laser system (GSFC+JPL)
  - Telescope (GSFC+UF)
  - Phase measurement, interferometry processing (JPL)
  - Micropropulsion (JPL)
  - Charge management (U. Florida)

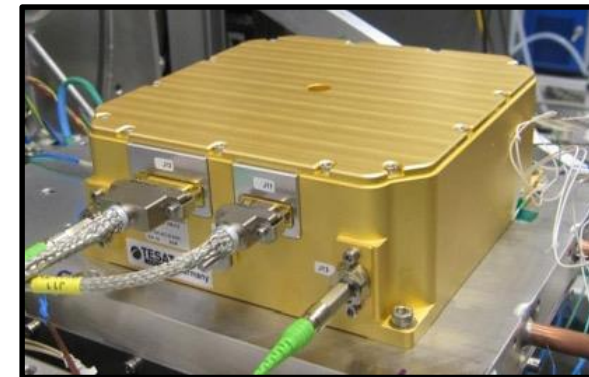
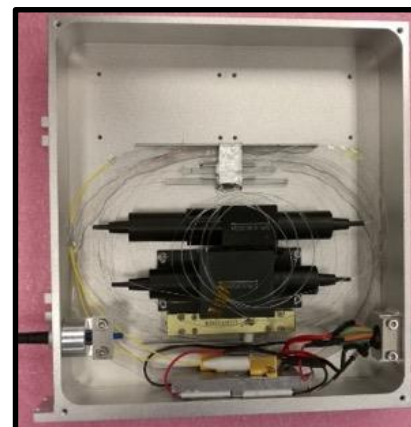


# Laser System (GSFC + JPL)

- Role in flight system: Provide light for primary IFO measurement
- Challenging Requirements
  - Lifetime / Reliability
  - Frequency & intensity stability
- Development strategy
  - Master Oscillator, Power Amplifier (MOPA) architecture
  - Evaluating in-house and commercial options for MO & PA
  - Leverage GRACE-FO LRI heritage for frequency stabilization

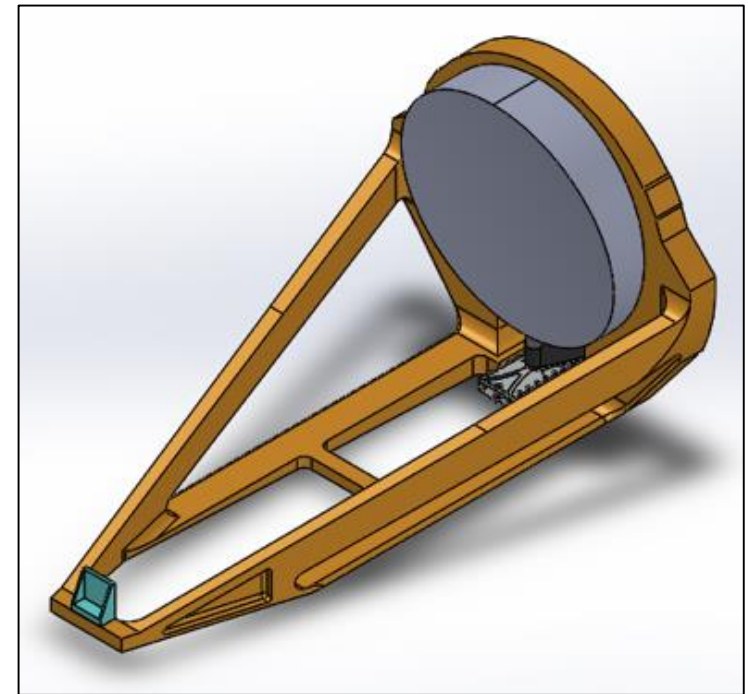


Clockwise from top left: mNPRO package (GSFC/AVO photonics), frequency reference cavity for GRACE-FO (Ball), GRACE-FO master oscillator (TESAT) , Fiber amplifier prototype (GSFC/Fibertek)

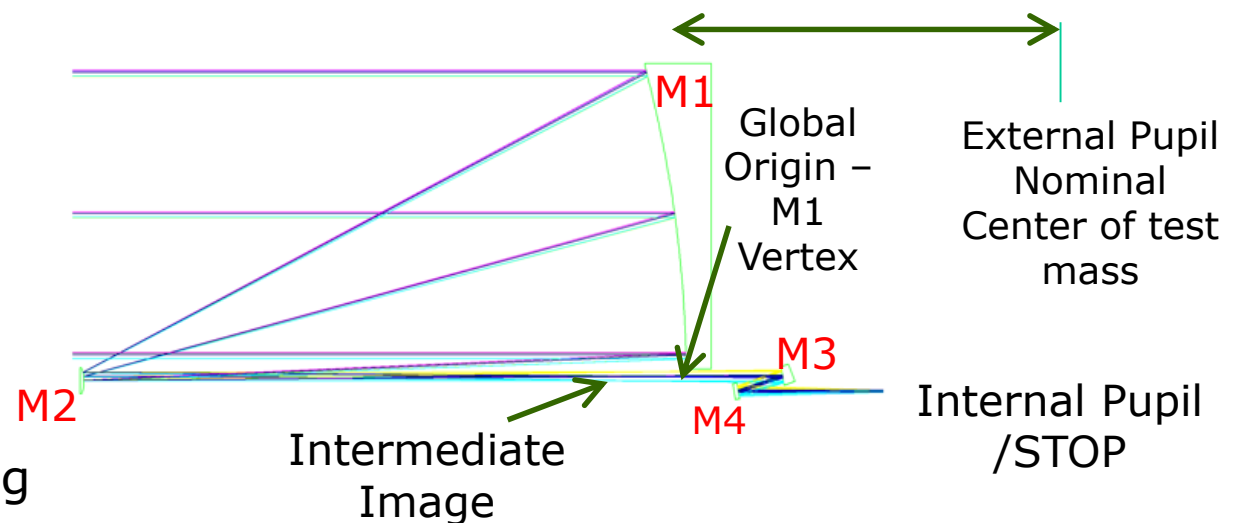


# Telescope system (GSFC + UF)

- Role in flight system: Mitigate diffraction losses over long baseline.
- Challenging requirements
  - Dimensional stability (in interferometric path)
  - Scattered light (simultaneous Tx/Rx)
  - Manufacturability (6 flight units + spares)
- Development strategy
  - 4 mirror, off-axis design to mitigate scattered light
  - Low-CTE material (e.g. Zerodur/ULE) for dimensional stability
  - Early engagement with industry to design for manufacture, integration
  - Partner with UF for dimensional stability testing



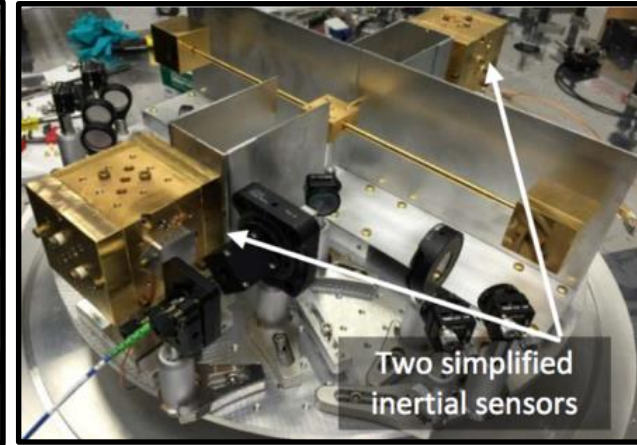
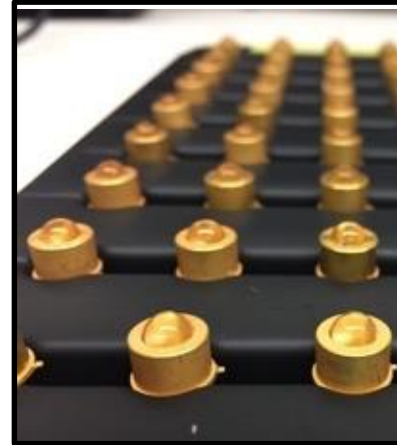
CAD model of 'bobsled'  
design concept.  
Aperture is  $\sim 30\text{cm}$





# Charge Management System (UF)

- Role in flight system: Control electric charge on test masses, mitigate electrostatic forces
- Challenging Requirements
  - Reliability / lifetime (COTS devices)
  - Multiple subsystem interfaces
- Development strategy
  - UV LEDs to replace Hg lamps flown on LPF
  - Extensive UV test campaign for performance + lifetime
  - Investigate pulsed charge control technique enabled by LEDs, while remaining compatible with LPF's DC technique
  - Support system-level testing with torsion pendula at UF & Trento
  - Partner with Industry (Fibertek) to advance TRL

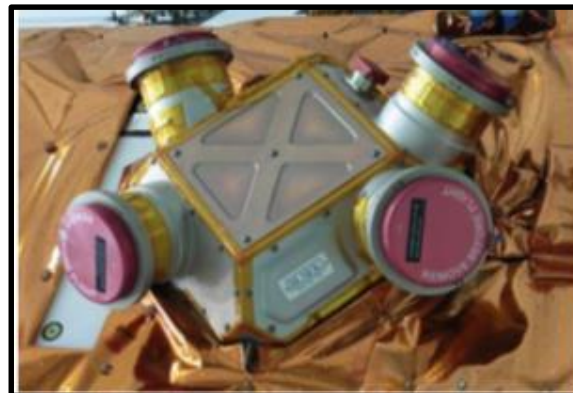
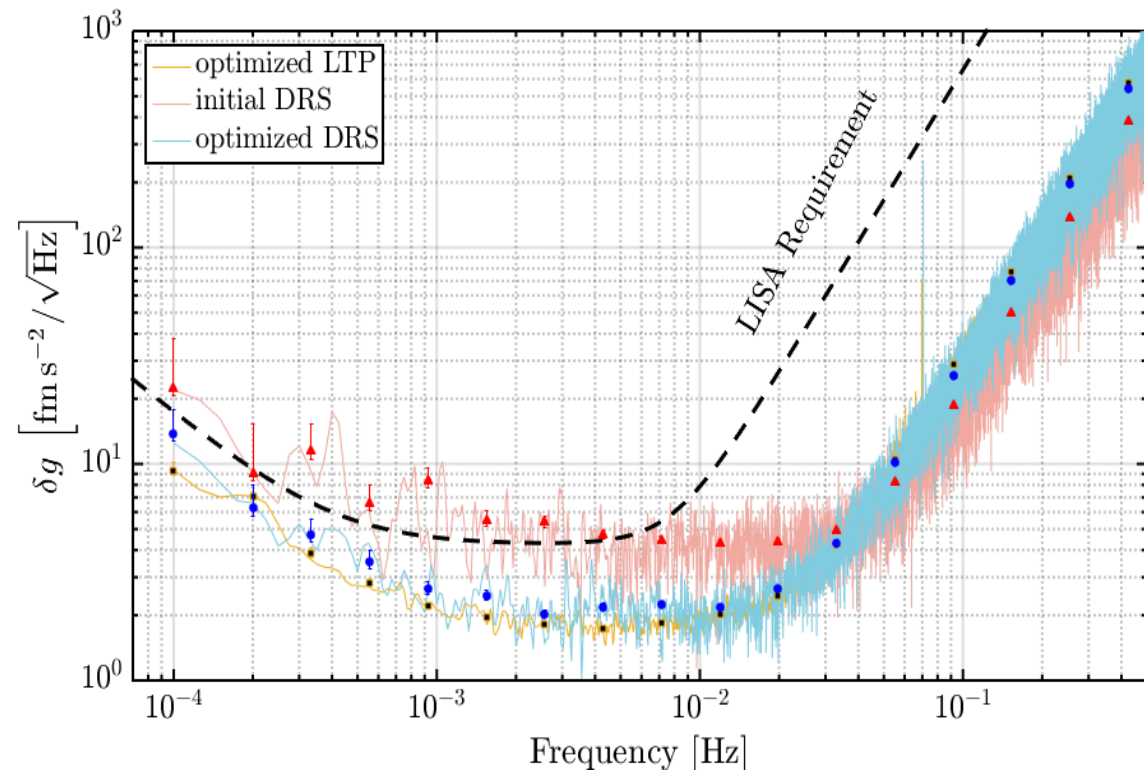


Clockwise from top left: UV LEDs for test, UF torsion pendulum, TRL 4 pulsed current source board, TRL 4 charge management device,



# Colloidal Micronewton Thrusters (JPL)

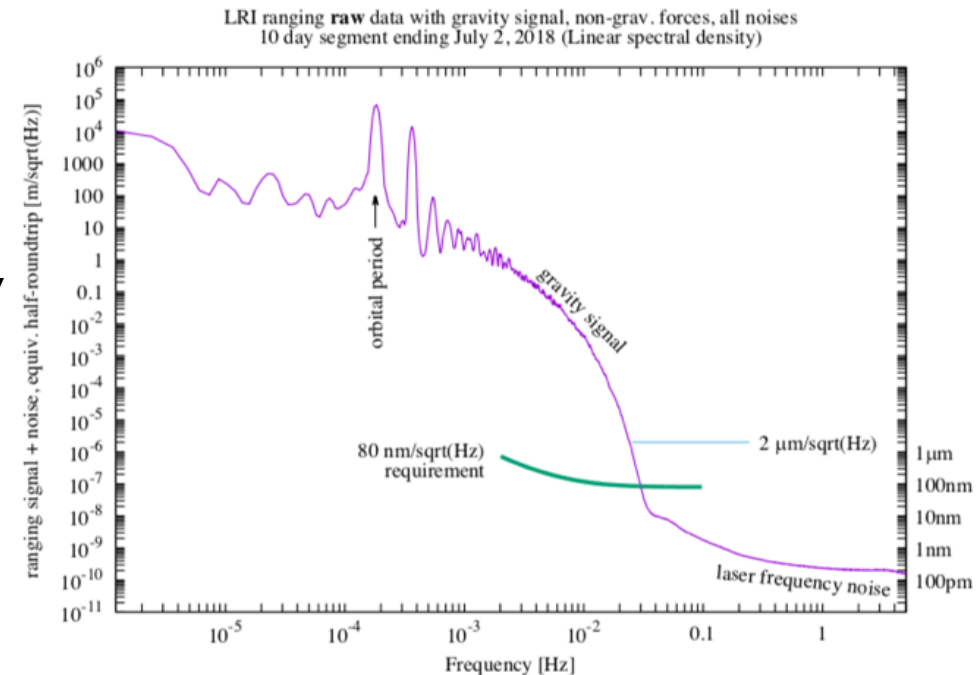
- Role in flight system:  
Precision attitude, position control of S/C during science
- CMNTs offer reduced system mass compared to cold gas = longer mission life
- Challenging Requirements
  - Low thrust  $\sim 10$   $\mu\text{N}$
  - Precision thrust  $\sim 0.1$   $\mu\text{N}$
  - Low noise  $\sim 1 \mu\text{N}/\text{rtHz}$
  - lifetime
- Development strategy
  - Build off of ST7 results (excellent performance, some reliability issues)
  - Understand and model failure mechanisms
  - Taylor design to LISA requirements



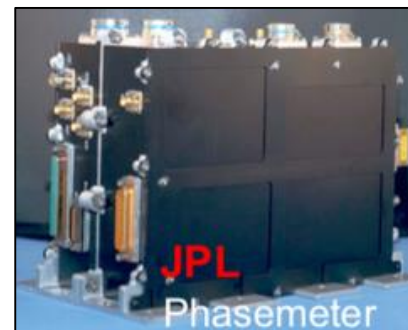
Top: residual differential acceleration noise for LPF in different thruster configurations (LTP = cold gas, DRS = CMNTs) Right, CMNT thruster cluster on LPF.

# Phase Measurement + Interferometry (JPL)

- **Role in flight system:**
  - Track and record optical interference signals for science + auxiliary IFOs
  - Provide error and control signals to laser, and spacecraft
  - Implement clock transfer, ranging, and possibly communications across long-baseline link
- **Challenging Requirements**
  - High dynamic range:  $\sim 10$  MHz signals
  - Low noise:  $\sim 1$  ucycle/rHz phase noise
  - High channel count:  $\sim 100$  per S/C
- **Development strategy**
  - Build off of results from GRACE-FO LRI and earlier LISA work
  - Add LISA-specific functionality
  - Work with industrial partners to develop scaleable design



Clockwise from top: early ranging results from LRI on GRACE-FO, 40-channel LISA prototype (JPL/Trident), Laser Ranging Processor for GRACE-FO (JPL)





# Mission Development & Systems Engineering

- Support ESA & European National Agencies in mission development
  - Conduct/support technical analyses
- Participate in trade studies
- Identify potential US “non-payload” contributions to LISA, e.g.
  - Communications elements
  - Power system / propulsion elements
  - Operational support
- Coordinate US technology development
  - Harmonize requirements across programmatic boundaries
  - Support internal trades

# LISA & Astro2020

- LISA is part of the “program of record”
  - It is an ongoing activity with a baseline cost accounted for in NASA spending projections
- Astro2020 will still comment on LISA
  - From the Statement of task:

*“The study will **assess** whether **NASA’s plans of** WFIRST, Athena, and **LISA** play an appropriate role in the research strategy for the next decade. The study may include findings and **recommendations regarding these plans**, as appropriate, **including substantive changes** to NASA’s plans. Recommendations may include, but are not limited to, actions ranging from **increased investments (upscopes) to reduced investments (descopes) and termination**. It is **not necessary to rank** WFIRST, Athena, and **LISA** among other recommended activities for space”*

# How NASA/Community is Preparing

- **Science whitepapers**
  - 11 organized by the NLST
  - Many others relate to LISA
- **Develop Supporting Material**  
(not submitted, available as reference, e.g. [lisa.nasa.gov](http://lisa.nasa.gov))
  - Overall Science Case
  - Technical Readiness
  - Analysis/Theory Readiness
  - LISA for Observers
  - FAQ, observer tool, graphics, etc.
- **Response to queries from Astro2020**
  - Present baseline plan
  - Assessment of NASA's cost, risk, and science benefits
  - Comment on potential upscoopes

# LISA Mission Schedule

- **Currently in Phase A**
  - Competitive “System Prime” phase
  - Mission and instrument formulation
- **Next milestones**
  - Mission Consolidation Review – Summer 2019
  - Mission Formulation Review – Summer 2020 (Earliest possible Mission Prime down-select)
- **Major milestone: Mission Adoption – end of 2022**
  - Mission design is “frozen”
  - Who is doing what is finalized
- **Launch = Mission Adoption + ~10 years = early 2030’s**
  - Cruise = 2.5 years
  - Nominal mission = 4 years
  - Extended mission = 6 additional years



# “For Scientists” on [lisa.nasa.gov](http://lisa.nasa.gov)

- Astro2020 WPs
- FAQ
- More coming soon!

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## FAQ

Frequently Asked Questions

FAQ:

Click an individual question to see the answer or use these buttons to show/hide ALL answers.

Show All Hide All

- How does LISA differ from LIGO and other ground-based gravitational wave interferometers?
- How mature is LISA's technology?
- How can LISA observe so many sources simultaneously? Won't there be a source confusion problem?
- How does LISA localize sources and how well will it do so?
- LIGO has already found gravitational waves, why do we need LISA?
- How precisely does the distance between the LISA satellites need to be maintained?
- LIGO and other ground-based interferometers are enormously complex, isn't attempting this in space too difficult?
- How are the three LISA spacecraft able to point at one another?
- How long will the LISA mission last?
- What is NASA's role in LISA?
- How can I get involved with LISA?

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## DOCUMENTS: Community White Papers

The astronomy and astrophysics decadal survey Astro2020 is a large and influential study run jointly between the Board of Physics and Astronomy and the Space Studies Board of the National Academies. The U.S. scientific community shares information regarding various important astronomy and astrophysics topics with the members of the study team through the submission of White Papers on each topic. For Astro2020, the science-focused white paper deadline was March 11, 2019. Below you can find the white papers submitted by members of the NASA LISA Study Team in support of the science goals that will be addressed by LISA and other space-based gravitational wave observatories.

**ASTRO2020 DECADAL SCIENCE WHITE PAPER:  
GRAVITATIONAL WAVE SURVEY OF GALACTIC ULTRA COMPACT BINARIES**

Principal Author: Tyson B. Littenberg / NASA MSFC

Download Paper

**ABSTRACT**  
Ultra-compact binaries (UCBs) are systems containing compact or degenerate stars with orbital periods less than one hour. Tens of millions of UCBs are predicted to exist within the Galaxy emitting gravitational waves (GWs) at mHz frequencies. Combining GW searches with electromagnetic (EM) surveys like Gaia and LSST will yield a comprehensive, multimessenger catalog of UCBs in the galaxy. Joint EM and GW observations enable measurements of masses, radii, and orbital dynamics far beyond what can be achieved by independent EM or GW studies. GW+EM surveys of UCBs in the galaxy will yield a trove of unique insights into the nature of white dwarfs, the formation of compact objects, dynamical interactions in binaries, and energetic, accretion-driven phenomena like Type Ia supernovae.

Principal Author: **Tyson B. Littenberg**  
Co-Authors: **Kateřyn Břevík, Warren R. Brown, Michael Eracleous, J. J. Hermes,**

**ASTRO2020 DECADAL SCIENCE WHITE PAPER:  
COSMOLOGY WITH A SPACE-BASED GRAVITATIONAL WAVE OBSERVATORY**

Principal Author: Robert Caldwell / Dartmouth College

Download Paper

**ABSTRACT**  
There are two big questions cosmologists would like to answer - How does the Universe work, and what are its origin and destiny? A long wavelength gravitational wave detector - with million km interferometer arms, achievable only from space - gives a unique opportunity to address both of these questions. A sensitive, mHz frequency observatory could use the inspiral and merger of massive black hole binaries as standard sirens, extending our ability to characterize the expansion history of the Universe from the onset of dark energy domination out to a redshift  $z \sim 10$ . A low-frequency detector, furthermore, offers the best chance for discovery of exotic gravitational wave sources, including a primordial stochastic background, that could reveal clues to the origin of our Universe.

Principal Author: **Robert Caldwell**  
Co-Authors: **Mustafa Amin, Craig Hogan, Kelly Holley-Bockelmann, Daniel Holz,**

**ASTRO2020 DECADAL SCIENCE WHITE PAPER:  
THE GRAVITATIONAL WAVE VIEW OF MASSIVE BLACK HOLES**

Principal Author: M. Colpi

Download Paper

**ABSTRACT**  
Coalescing, massive black-hole (MBH) binaries are the most powerful sources of gravitational waves (GWs) in the Universe, which makes MBH science a prime focus for ongoing and upcoming GW observatories. The Laser Interferometer Space Antenna (LISA) - a gigameter scale spacebased GW observatory - will grant us access to an immense cosmological volume, revealing MBHs merging when the first cosmic structures assembled in the Dark Ages. LISA will unveil the yet unknown origin of the first quasars, and detect the swelling population of MBHs of  $10^7$  to  $10^9 M_{\odot}$  forming within protogalactic halos. The Pulsar Timing Array, a galactic-scale GW survey, can access the largest MBHs in the Universe, detecting the cosmic GW longground from inspiraling MBH binaries of  $\sim 10^6 M_{\odot}$ . LISA can measure MBH spins and masses with precision far exceeding that from electromagnetic (EM) probes, and together, both GW observatories will provide the first full census of binary MBHs, and their orbital dynamics, across cosmic time. Detecting the loud gravitational signal of these MBH binaries will also trigger alerts for EM counterpart searches, from decades (PTAs) to hours (LISA) prior to the final merger. By witnessing both the GW and EM signals of MBH mergers, precious information will be gathered about the rich and complex environments in the aftermath of a galaxy collision. The unique GW characterization of MBHs will shed light on the deep link between MBHs of  $10^6$