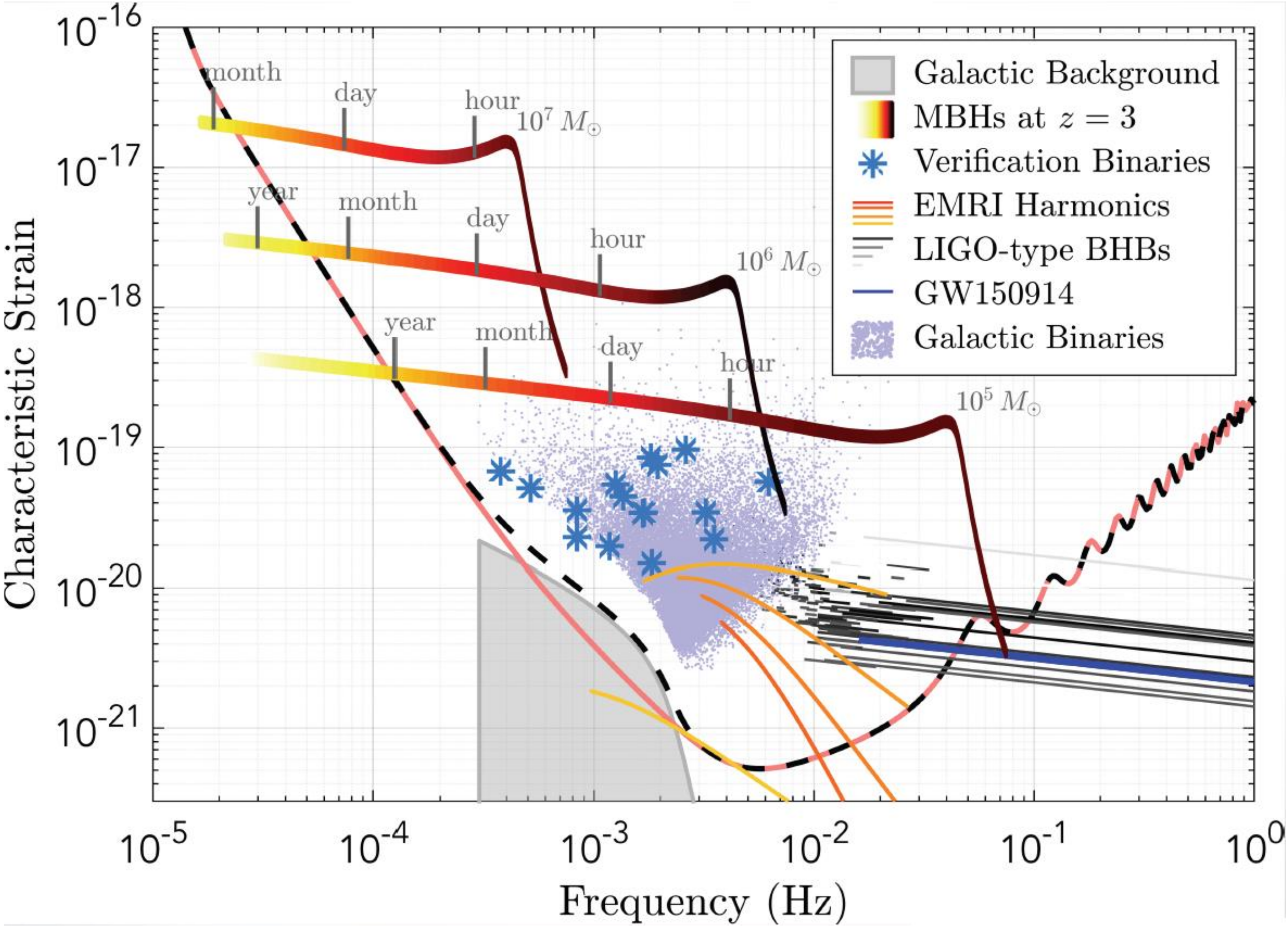
Laser Interferometer Space Antenna
Technology Development and Other Efforts in the U.S.

John W. Conklin
jwconklin@ufl.edu

Thanks to Ira Thorpe, GSFC

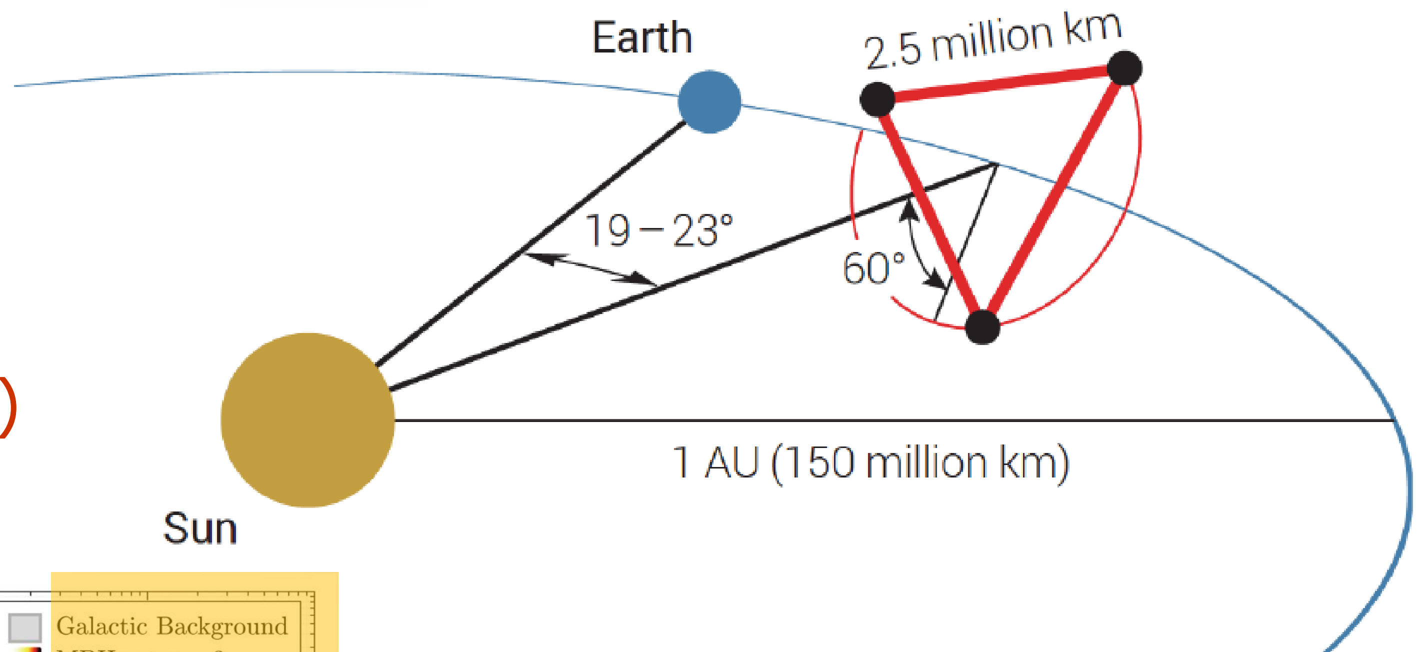
UNIVERSITY of FLORIDA | PSSL | PCOS Physics of the Cosmos | NASA | COR Cosmic Origins

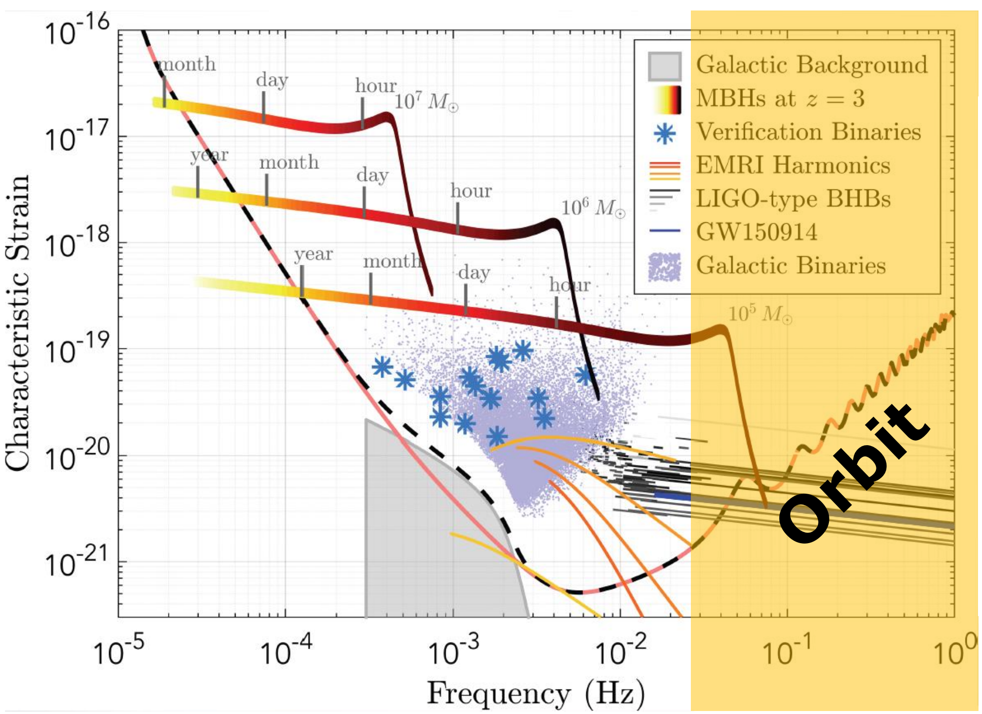
LISA Sensitivity Curve

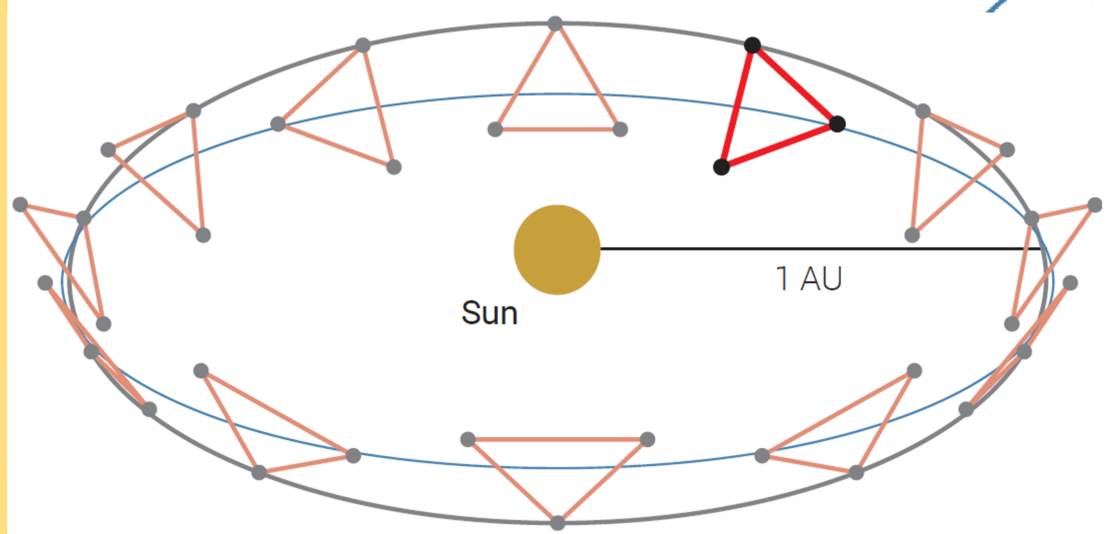


Strain Curve → Orbit

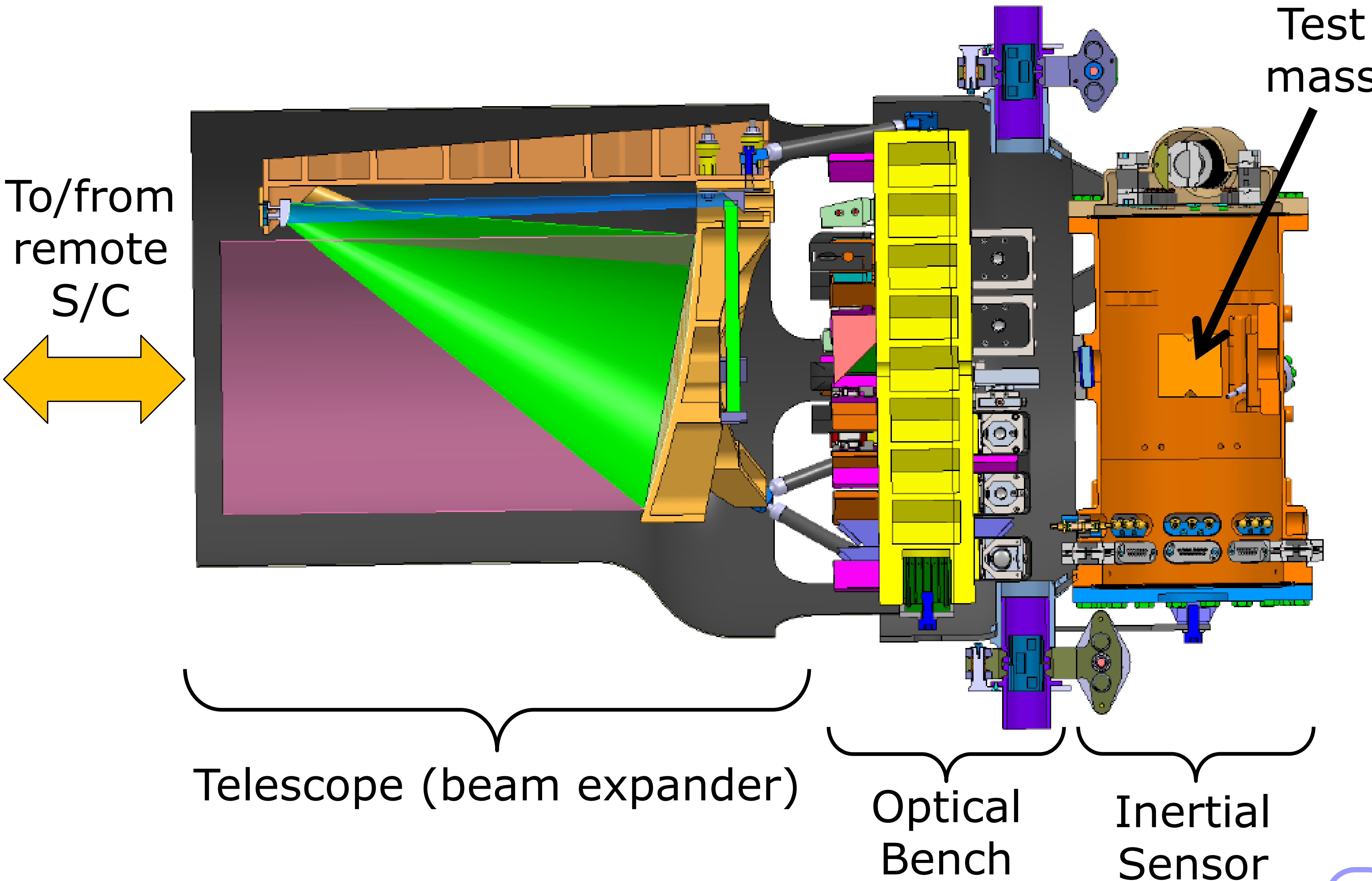
- 4 yr mission
  - +6 yr extension
- 3 arms
  (6 one-way links)



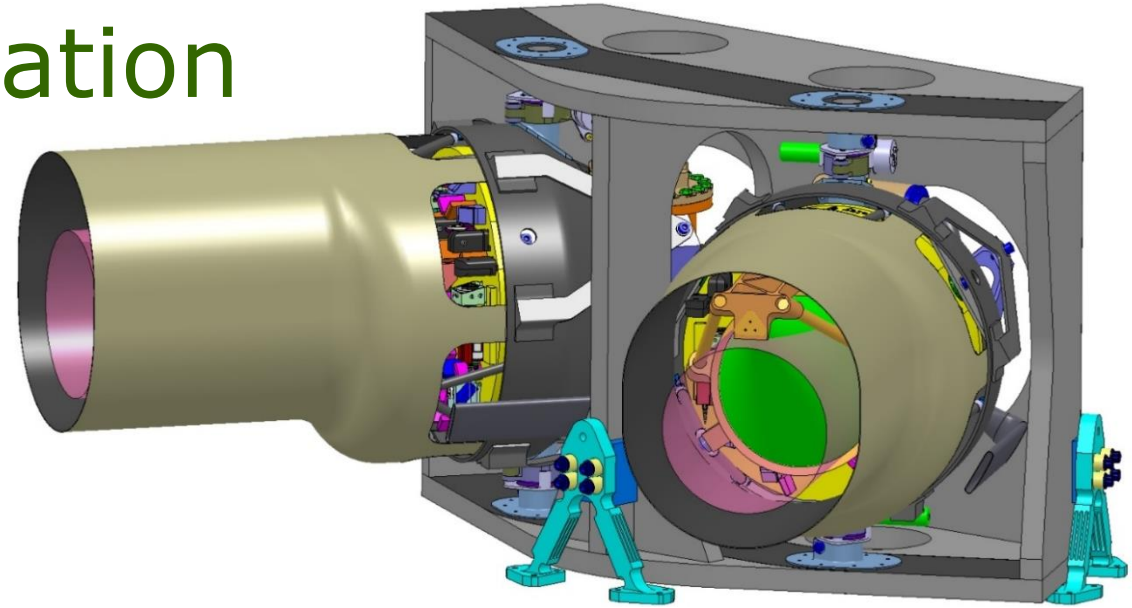




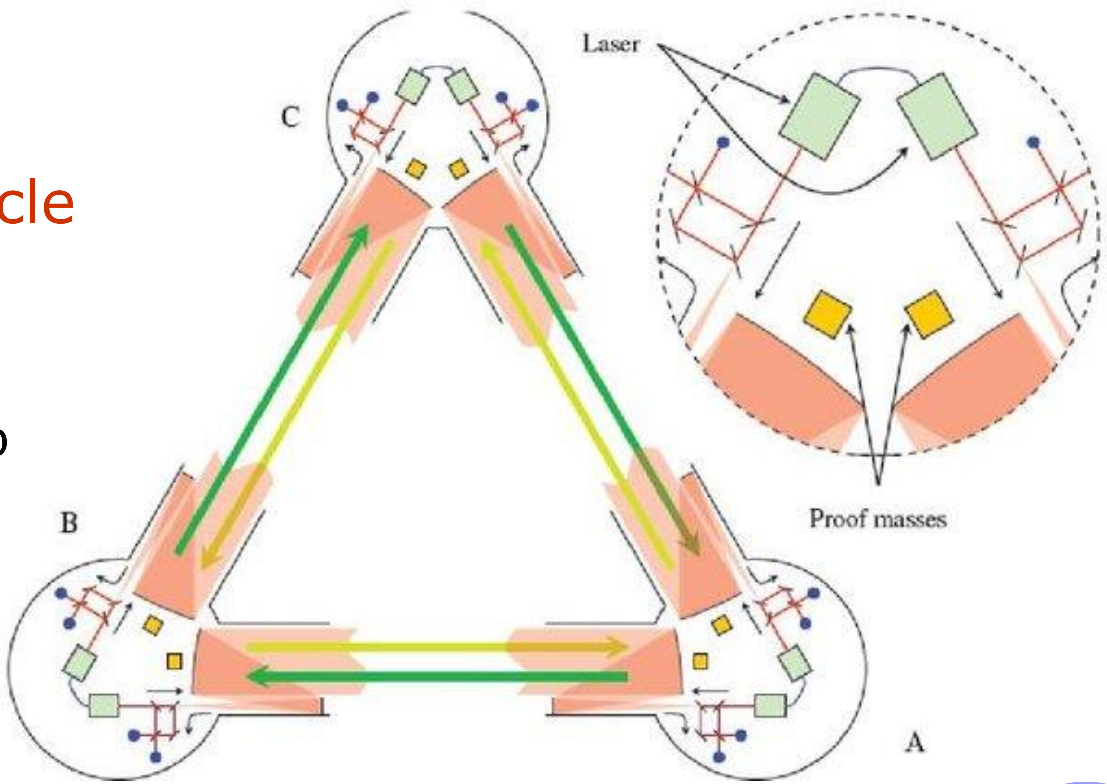
LISA Core Instrument



The LISA Constellation

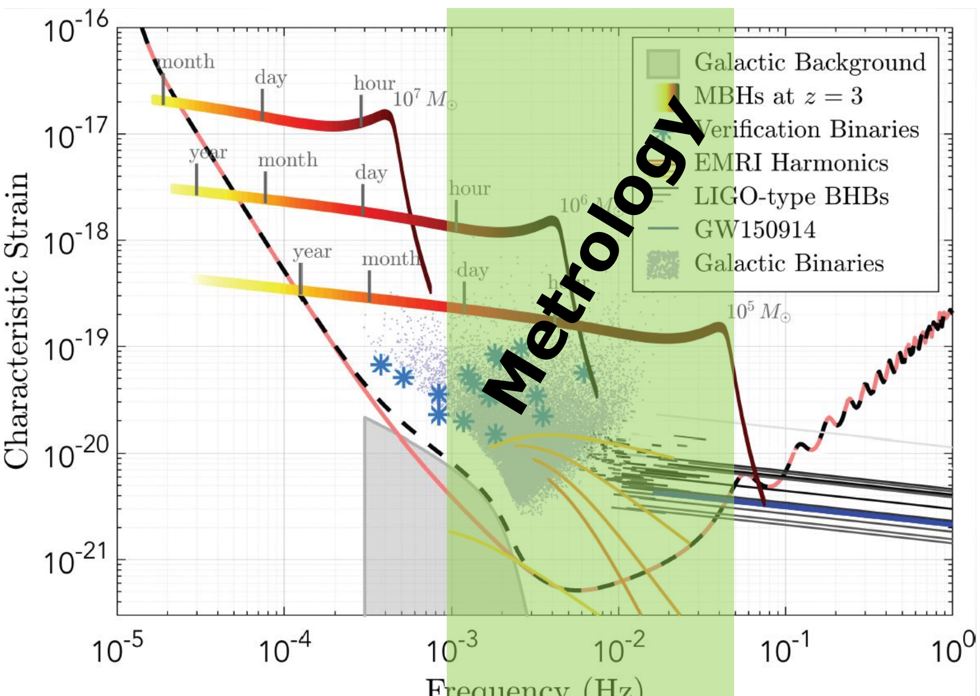


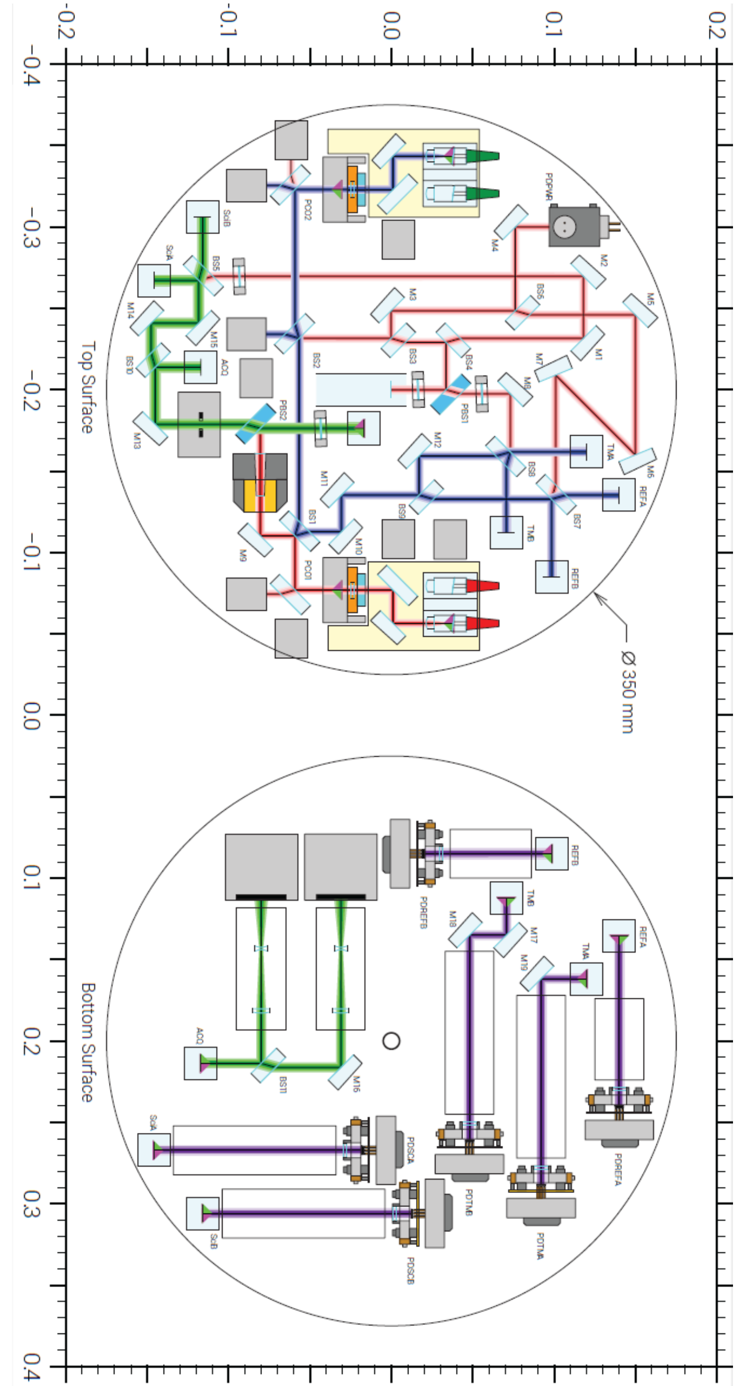
- 3 Identical spacecraft
  - 6 Test masses
  - 6 Telescopes
  - 6 lasers (+ redundancy)
  - 6 optical benches
- Electric propulsion to get to final orbits (tentative)
- Launched on a single vehicle (Ariane 6.4)
  - French Guiana
  - Launch mass ~ James Webb Space Telescope



Strain Curve → Metrology

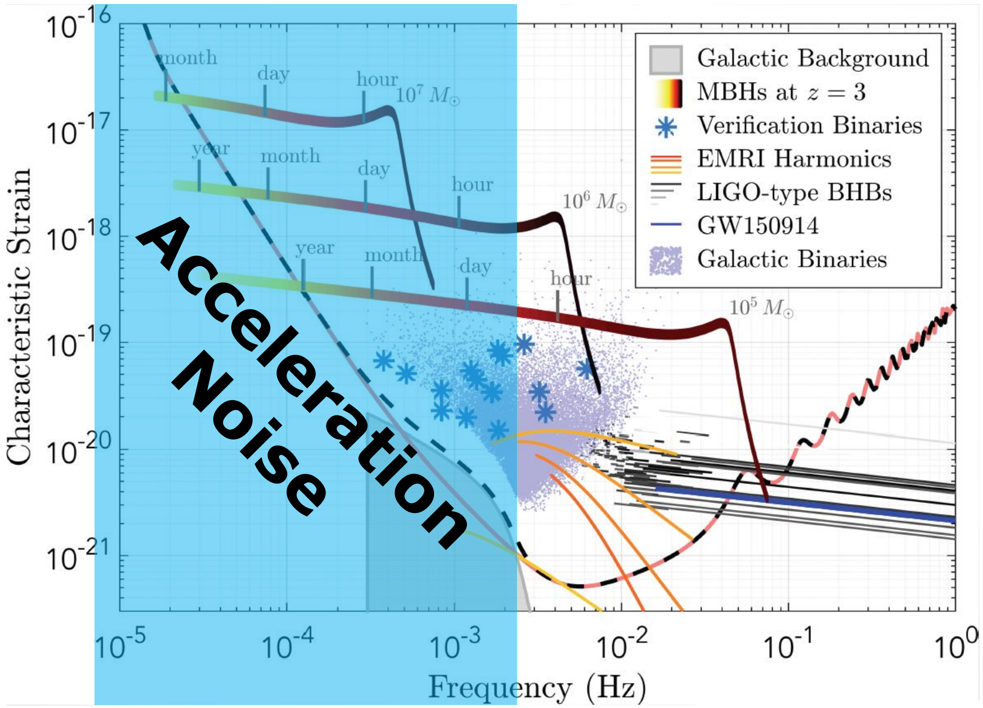
- 10 pm/Hz$^{1/2}$ one-way
  - 2 W, 1064 nm lasers with frequency stabilization
  - Low CTE optical benches with 4 interferometers
  - μcycle over MHz phasemeter
  - 30 cm telescopes





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

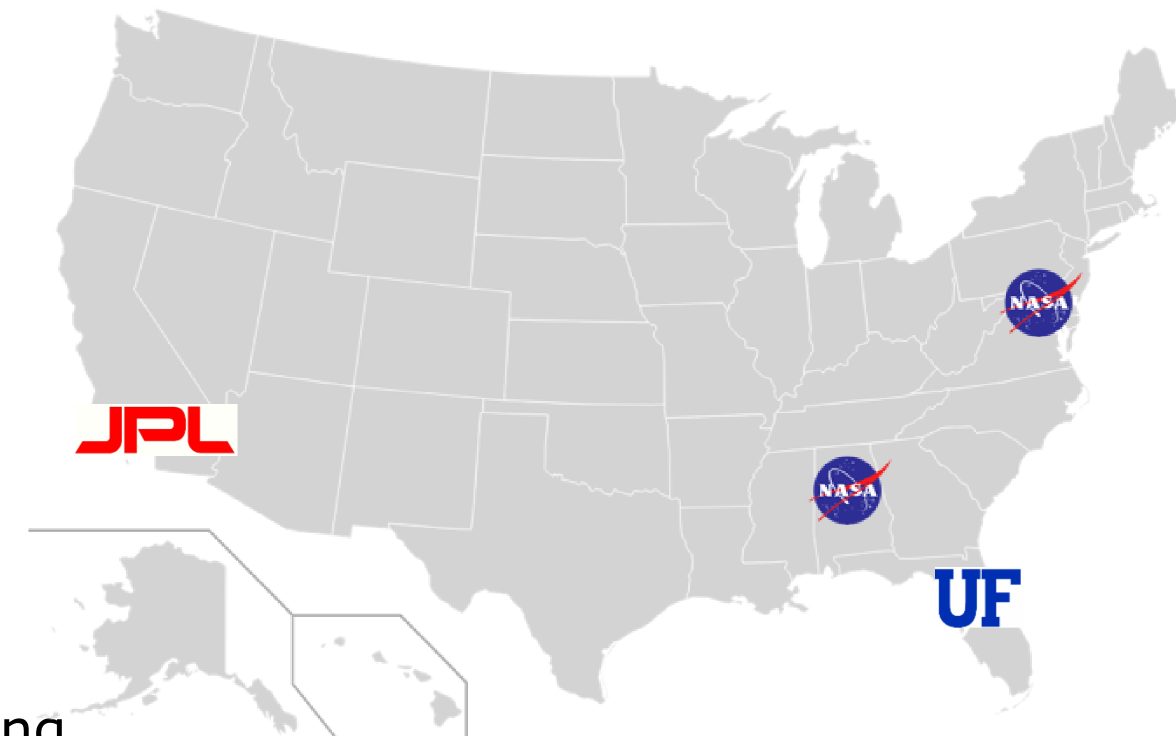


Top-level LISA Mission Organization

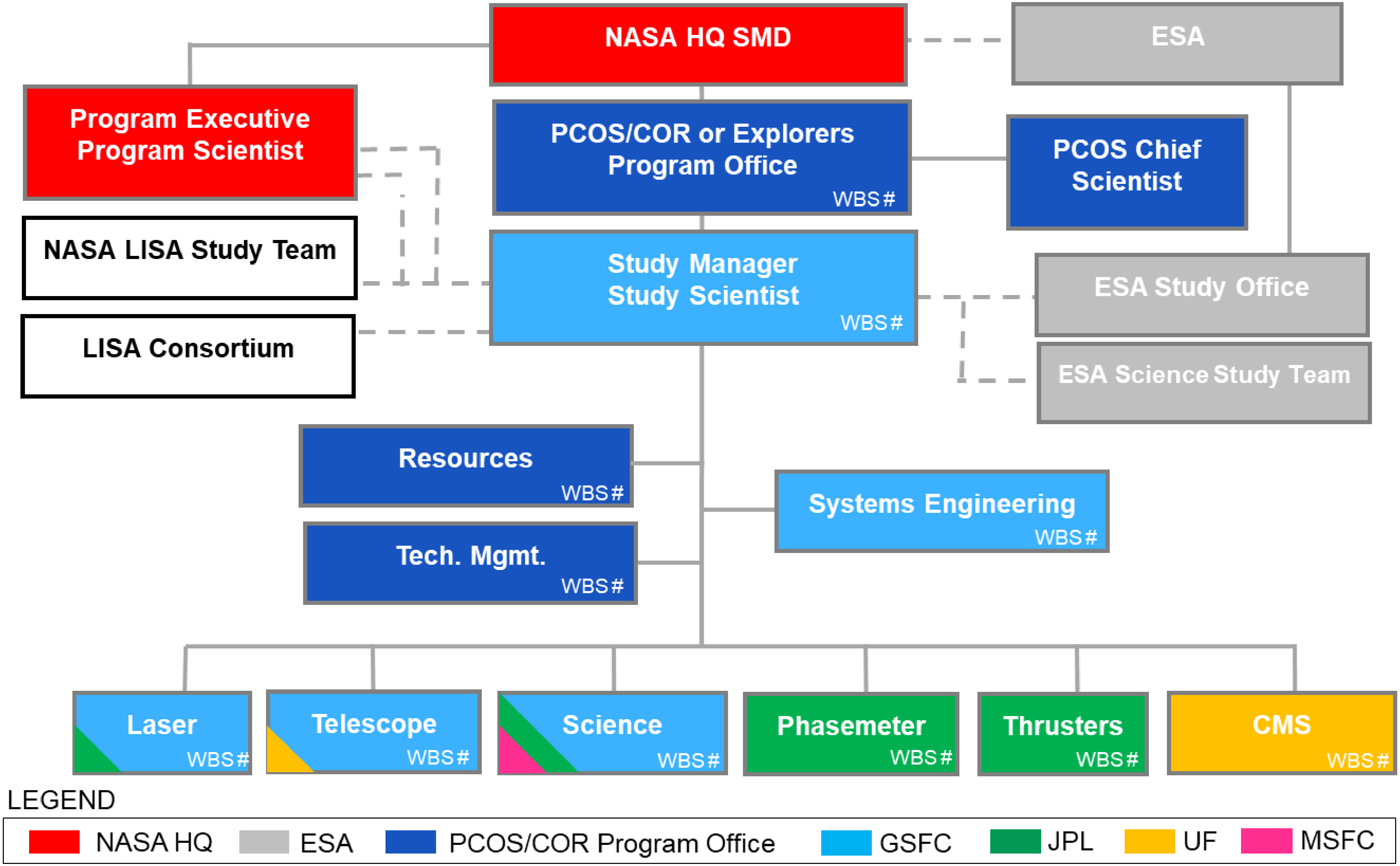
- Mission lead – European Space Agency
- "*NASA is a **major** junior partner*" in LISA – P. Hertz
- Mission Industrial Prime
  - Competitive in Phase A (now); Down-select before Phase B (2020)
    - Airbus D & S, Germany
    - Thales Alenia Space, Italy
  - Possible NASA Contributions to LISA platform
- 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

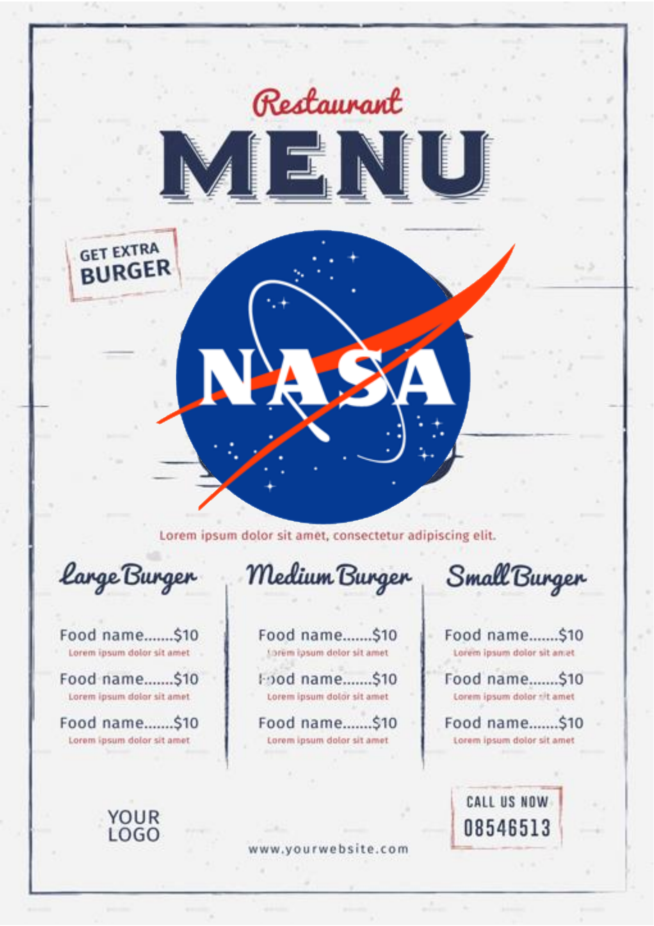


Organization Chart



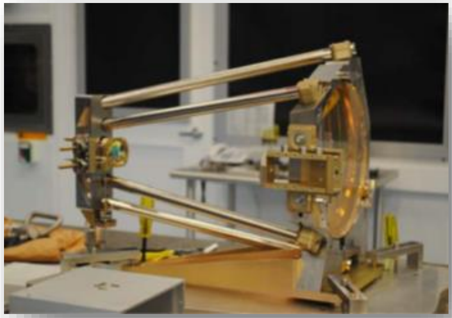
Study Office Near-term Goals

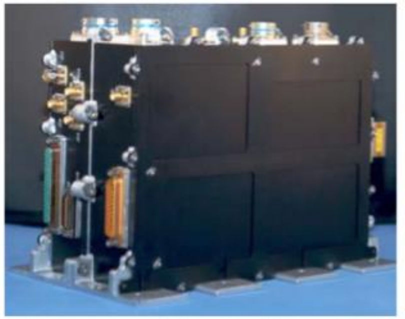
- Develop "menu" of possible NASA contributions
  - Payload systems and subelements (req. tech development)
  - Spacecraft components
  - Ground segment contributions
  - Operations contributions
  - Science support
  - …
- Assess each contribution
  - Compatibility with partners/ease of interface
 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

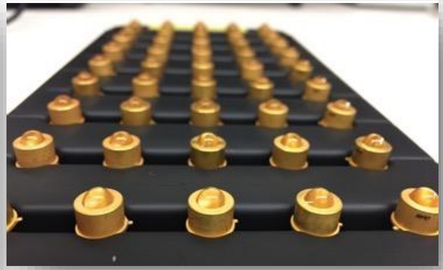


U.S. Technology Development

- 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)

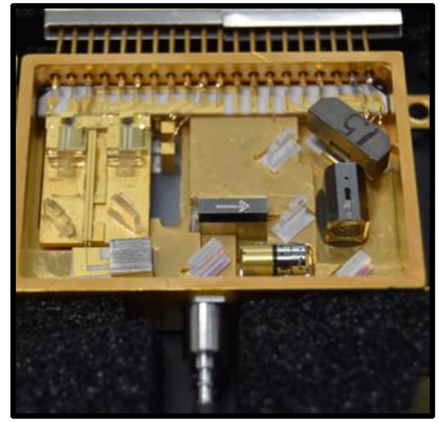


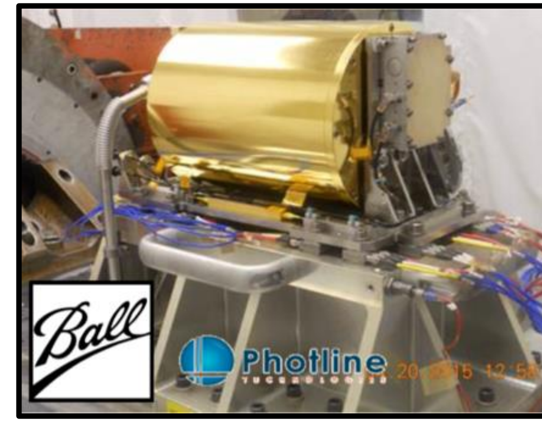




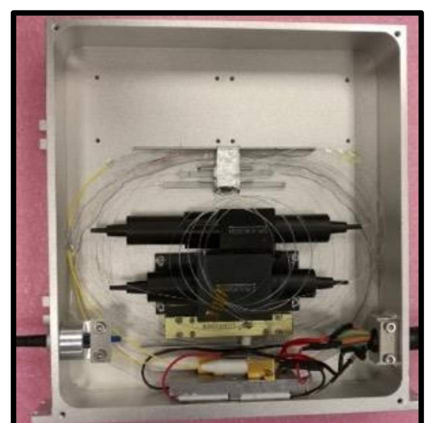
Laser System (GSFC + JPL)

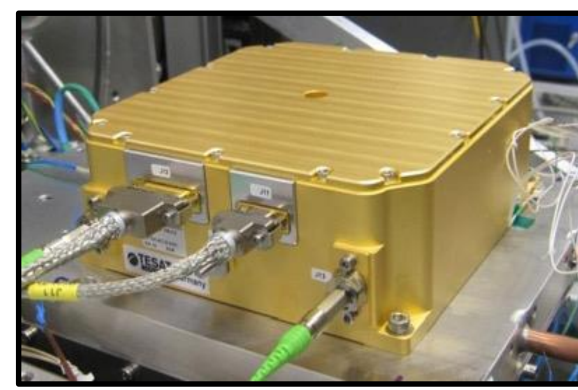
- Role in flight system: Provide light for primary IFO measurement
- Challenging Requirements
  - Lifetime / Reliability
  - Frequency & intensity stability
- Development strategy
  - Master Oscillator, Power Amplifier (MOPA) architecture
  - Evaluating in-house and commercial options for MO & PA
  -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





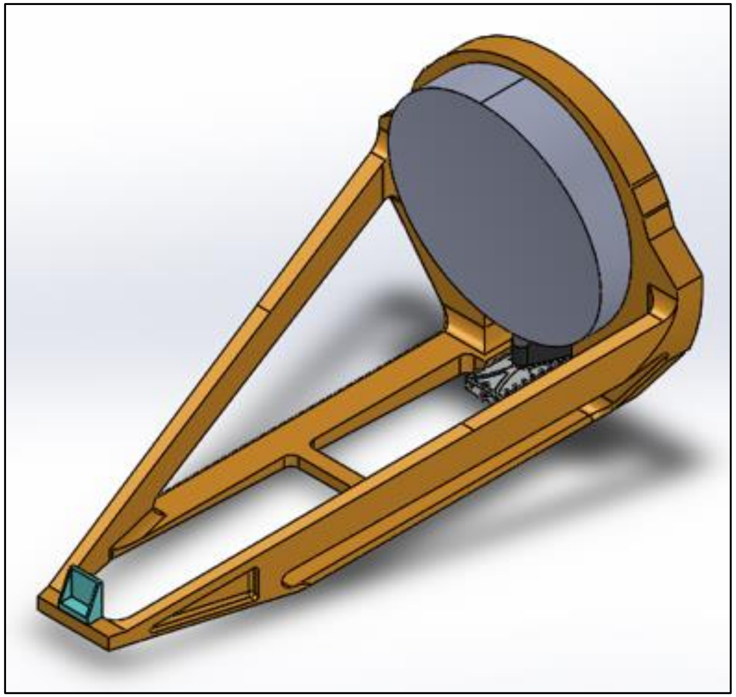
Clockwise from top left: mNPRO package (GSFC/AVO photonics), frequency reference cavity for GRACE-FO (Ball), GRACE-FO master oscillator (TESAT) , Fiber amplifier prototype (GSFC/Fibertek)



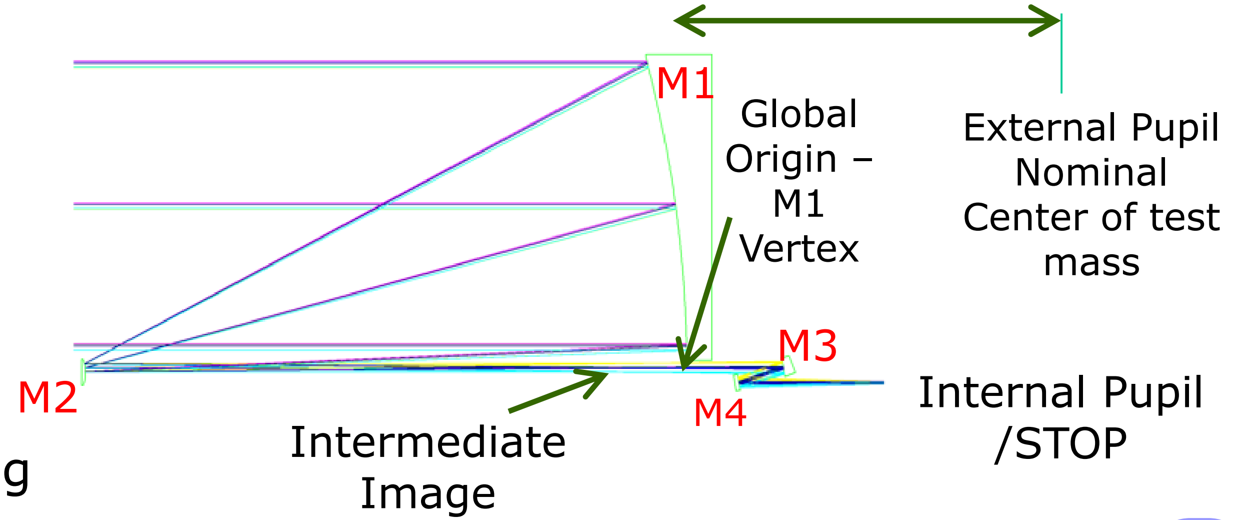


Telescope system (GSFC + UF)

- 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

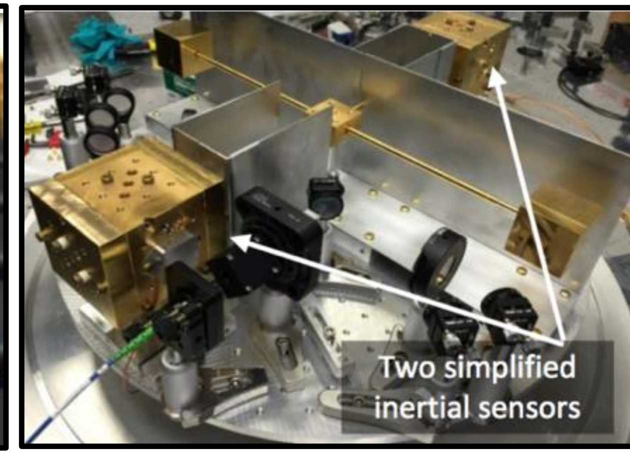


CAD model of 'bobsled' design concept. Aperture is ~30cm



Charge Management System (UF)

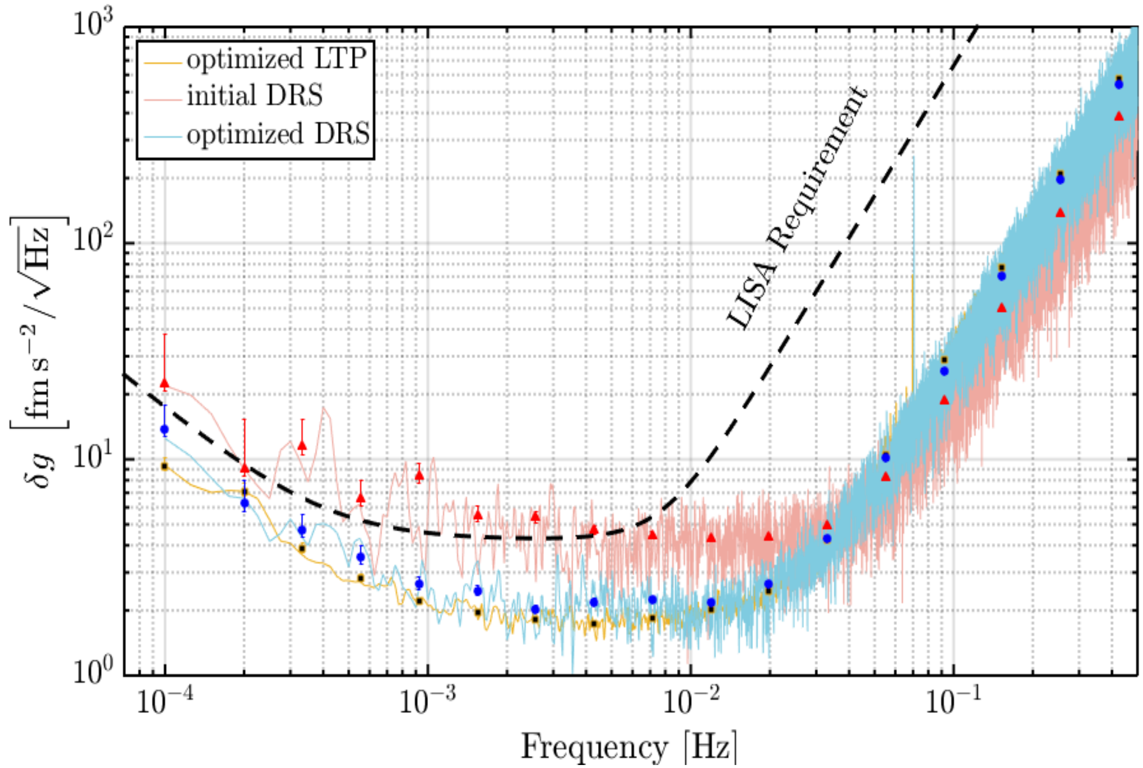
- Role in flight system: Control electric charge on test masses, mitigate electrostatic forces
- Challenging Requirements
  - Reliability / lifetime (COTS devices)
  - Multiple subsystem interfaces
- Development strategy
  - UV LEDs to replace Hg lamps flown on LPF
  - Extensive UV test campaign for 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)

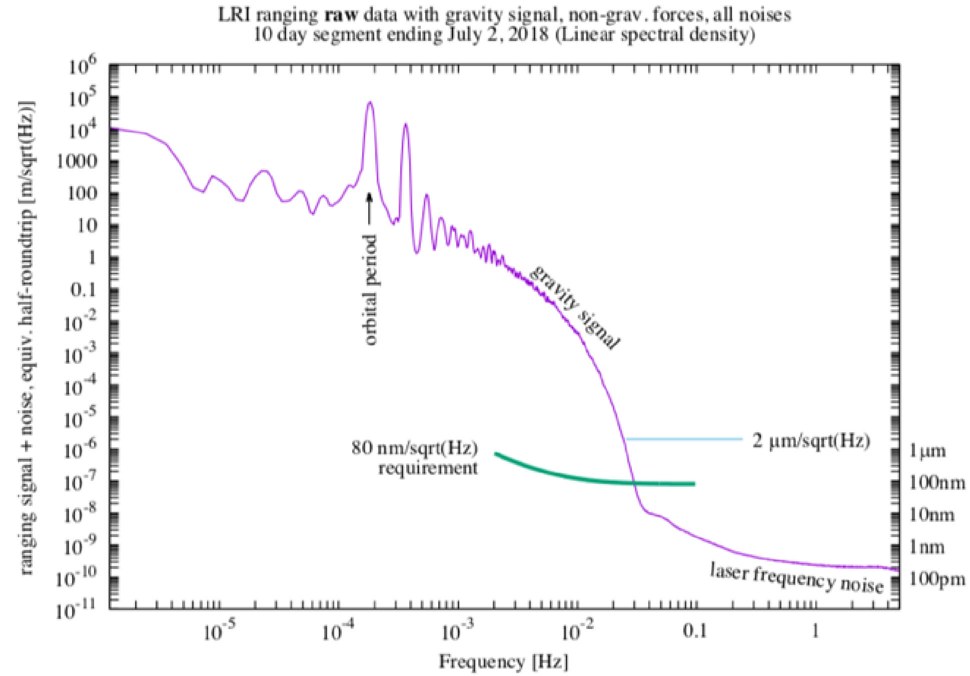
- Role in flight system: Precision attitude, position control of S/C during science
- CMNTs offer reduced system mass compared to cold gas = longer mission life
- Challenging Requirements
  - Low thrust ~10 uN
  - Precision thrust ~0.1 uN
  - Low noise ~1uN/rtHz
  - lifetime
- Development strategy
 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



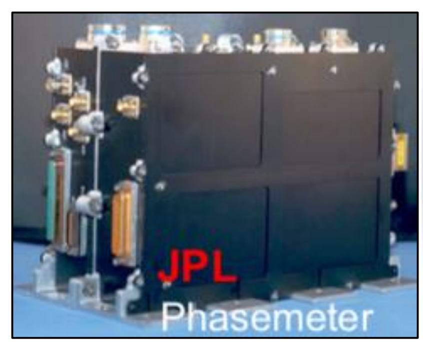
Top: residual differential acceleration noise for LPF in different thruster configurations (LTP = cold gas, DRS = CMNTs) Right, CMNT thruster cluster on LPF.

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: ~10 MHz signals
  - Low noise: ~1 ucycle/rtHz phase noise
  - High channel count: ~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)
  - 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 upscopes

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

- Astro2020 WPs
- FAQ
- More coming soon!