Overview of LISA Science Implementation Data Center Study

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NASA Astrophysics Advisory Committee Meeting

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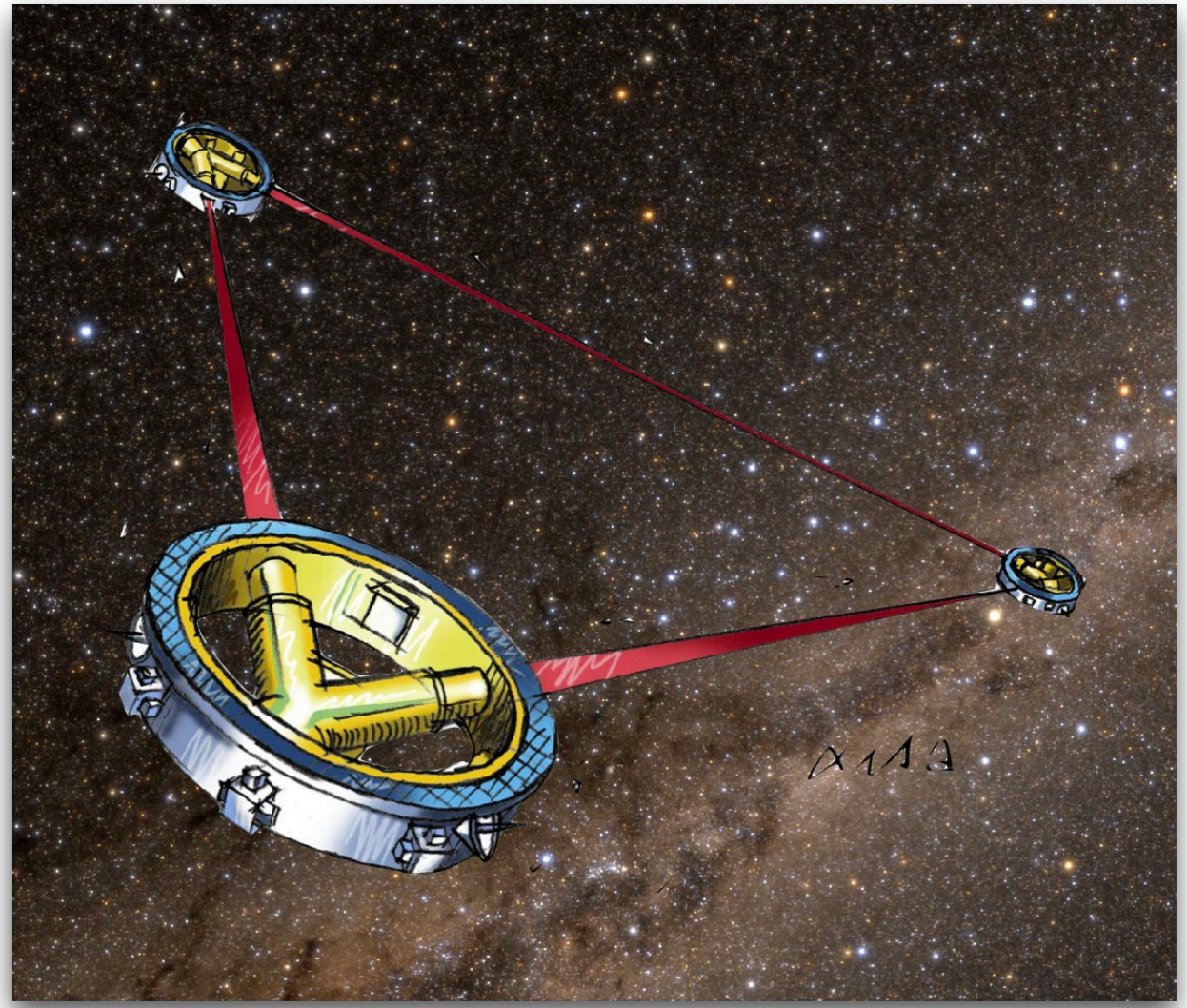


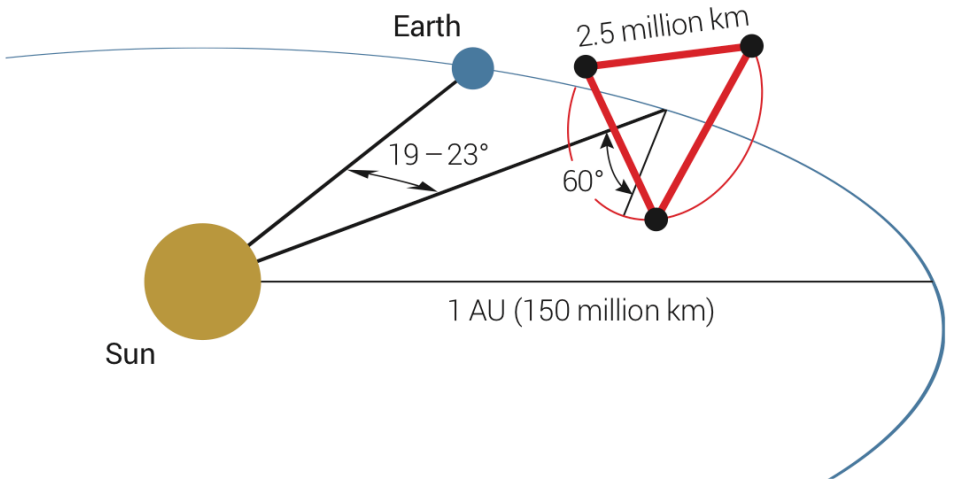
C. Viroux / ESA

Presentation Outline

- Background & Context
- Summary of Study Process
- Summary of Study Findings
- Response & Current Activities

The LISA Mission

- **Space-based gravitational wave observatory targeting *milliHertz* wavelengths**
- **2.5Mkm triangular constellation in Earth-trailing heliocentric orbit**
- **Drag-free inertial references (LPF heritage) and long-baseline laser interferometry (GRACE LRI – like)**
- **Supported in Astro2000, Astro2010 and Astro2020**



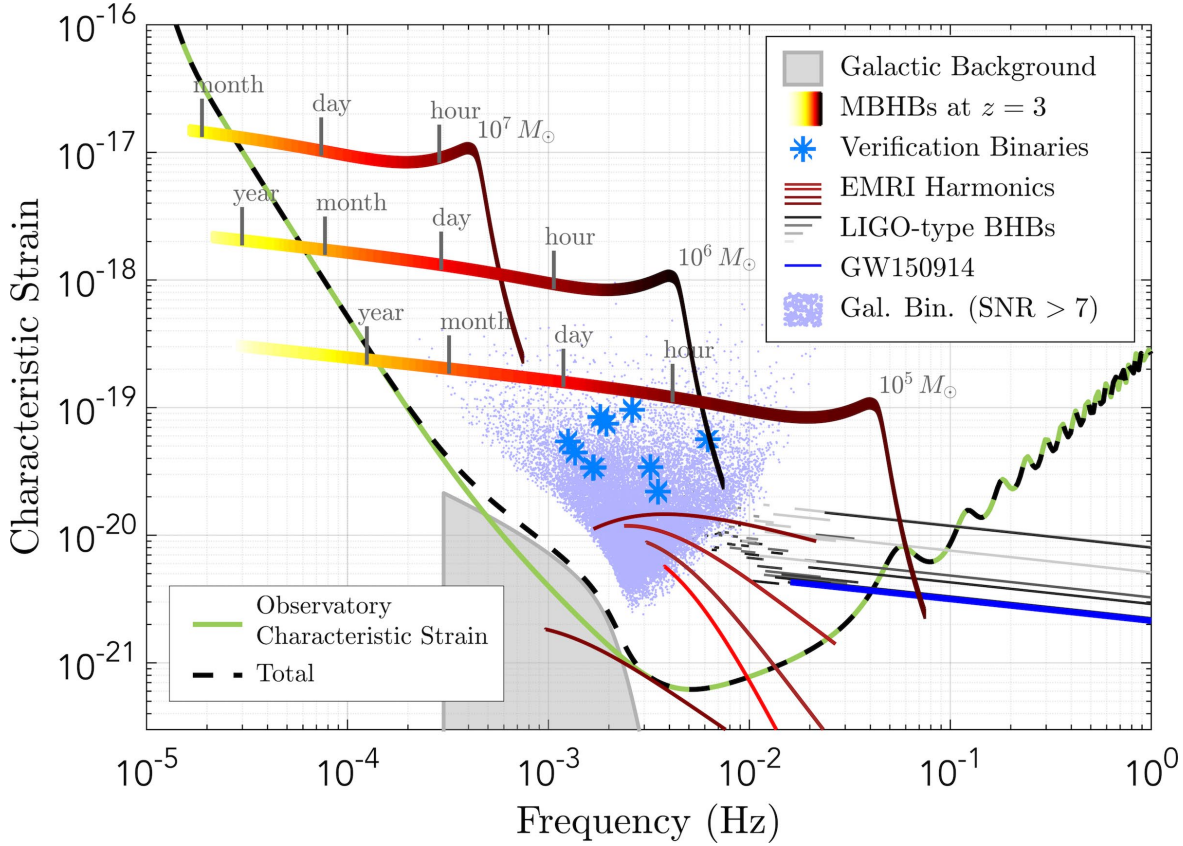
Danzmann, et al.

Pathways to Discovery in Astronomy & Astrophysics for the 2020s, §1.6:

NASA's Program of Record. NASA's upcoming Roman Space Telescope, and ESA's Athena X-ray Observatory and LISA mission, in which NASA is a significant partner, are essential to the survey's science program. Advice on how to optimize the science return includes: holding a non-advocate review of Roman Space Telescope's science program to set the appropriate mix of survey time to guest investigator-led observing programs; and at the appropriate time, establishing funding for LISA science at a level that ensures U.S. scientists can fully participate in LISA analysis, interpretation, and theory.

The LISA Data Products

- **Both a *survey* and a *time-domain* mission**
  - >10^4 persistent galactic sources, number and precision improve with time
  - 10s-1000s of transient extragalactic sources, some with possible EM counterparts
  - Possible cosmological and other stochastic or exotic sources
- **All-sky, high duty cycle instrument**
  - Single instrumental data stream containing all sources + instrument noise
  - "Global Fit" needed to identify & extract sources



Millihertz gravitational wave spectrum comparing LISA sensitivity (green line) against expected galactic & extra-galactic sources (colored points and curves)

The LISA Partnership

- **ESA-led mission**
  - Large mission in Cosmic Visions Programme
  - Currently in ESA Phase B1
  - Mission Adoption (gateway to Phase B2/C/D) targeted for Nov. 2023
  - Launch mid-2030s TBC
- **NASA Partnership**
  - Study Office Established 2017 (ESA mission selection)
  - Major payload elements (telescopes, lasers, charge management)
  - Systems engineering & other TBD mission support
  - Science ground segment & science participation
- **ESA Member States**
  - Major payload elements (inertial reference, optical bench, phase meter)
  - Instrument science expertise
  - Science ground segment & science participation

SIDC Study Timeline

- **2020 LISA Independent Review**
  - Comprehensive cost & technical review of NASA LISA program initiated by HQ APD (chair: F. Martin)
  - Primary focus on hardware, brief look at science and ground segment
  - Recommended dedicated ground segment & science study as follow-on
- **SIDC Study proposed by PhysCOS in FY22 budget request**
  - PhysCOS to host & manage
  - NLSO to provide logistic support & technical expertise
  - Findings available in Spring 2022
- **SIDC study conducted as planned**
  - Chair/panel selected August-Sept. 2021
  - Kickoff October 2021
  - Core work period December 2021 – February 2022
  - Outbrief to PCOS March 2022
  - Outbrief to APD (Hertz) June 2022

Study Charge (paraphrased)

Conduct an analysis of the LISA science ground segment and science activities with the aim of identifying potential NASA contributions.

- What should NASA's role(s) in the LISA science ground segment look like, in terms of architecture, concept of operations, top-level requirements, and interfaces?

- How do the suggested NASA roles fit into existing NASA organizations or entities (e.g. future LISA project, multi-mission archive and data facilities, etc.)? Which components of a NASA contribution may need to be created or competed?

- What is the recommended approach to develop the NASA contributions, including high level schedule and (parametric) budget?

- Are there alternative approaches that should be considered as well? If so, what are their architectures, concept of operations, requirements, and interfaces? How do they differ and what are the pros and cons of each?

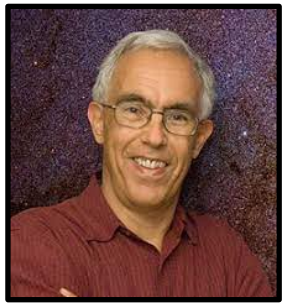
https://pcos.gsfc.nasa.gov/lisa/documents/LISA_Science_implementation_study_charter_rev_2.pdf

SIDC Panel

- **Panel Membership**
  - Feryal Özel (chair, University of Arizona)
  - Jeanne Behnke (GSFC)
  - Will Farr (Stony Brook U, Flatiron Inst)
  - Kathy Flanagan (STScI)
  - Tom Prince (Caltech)
  - Xavi Siemens (University of Oregon)
  - Nick White (Space Science Solutions)
  - Stanley McCaulley (MSFC, costing specialist)
- **Observers**
  - Charles Lawerence (JPL)
  - Rita Sambruna (GSFC)
  - Debra Wallace (MSFC)
- **Support**
  - Ira Thorpe (ex. Secretary)








Study Process

- **Information Gathering**
  - Live briefings w/ Q&A
  - Background Reports
- **Work Sessions**
  - Rotate through topics identified in charter, panel members assigned to lead
  - Findings drafted early and refined along the way
- **Report writing**

Live Briefings

Shahid Habib: NASA HQ perspective
Ira Thorpe: LISA Mission and NASA LISA Study Office Overview
Kelly Holley-Bockelmann: NASA LISA Study Team Report
Tuck Stebbins: NLST Ground Segment Study
Neil Cornish: GW Data Analysis and Algorithms
Tyson Littenberg: Current NASA ground segment activities
Oliver Jennrich: LISA Data Analysis and Science – ESA Perspective
Antoine Petiteau: LISA Data Analysis and Science – LISA Consortium Perspective
Harry Teplitz: Lessons from Euclid Ground Segment
Stanley McCauley: Costing Models

Background Report and Documents:

NLST Science Support Taskforce Report
NLST Ground Segment Study
LISA Astro2020 White Paper
ESA LISA Science Operations Assumptions Document
SMD Data Policy
NASA-ESA Euclid MoU
Other technical documents on LISA science

Findings – Data Analysis

Finding: **LISA analysis requires a "global fit" to the L1 data to deliver and refine science results. This analysis is currently at a low readiness level. Adopting multiple independent approaches for this pipeline will help with science trade offs, increase confidence in the products, and maximize the science returns from LISA.**

Recommendation: **The NASA LISA science ground segment should develop the capability for end-to-end analysis of LISA data, starting with minimally calibrated data (i.e., data that are at the lowest scientifically useful level). The NASA global fit pipeline should be one of several independent pipelines within the LISA Consortium. To optimize the scientific productivity of LISA, these pipelines should contribute to the final delivery of L2 and L3 products by the ESA Science Operations Center.**

Recommendation: **NASA should invest early in the development of global fit algorithms and analysis as a necessary step in developing a NASA global fit pipeline.**

Findings – Community Investment

Finding: **The development of the science capability and the community requires a similar timescale to the mission itself. Furthermore, early development of analysis capabilities by an engaged community can help optimize mission operations and reduce mission risk. Support for different types of involvement need to be provided to grow the community.**

Recommendation: **NASA should provide as soon as possible opportunities and funding to groups and individuals within the scientific community to become engaged with LISA software development, theoretical studies, and mock data analysis with "on-ramps" for new investigators and new ideas.**

Findings – Community Investment

Finding: The gravitational wave astrophysics is a new field that is growing through the successful NSF funded LIGO and NanoGrav efforts, and NASA LISA precursor funding. This nascent NASA community does not benefit from the legacy of past/current NASA missions in the same discipline such as occurred prior to the launch of the NASA Great Observatories.

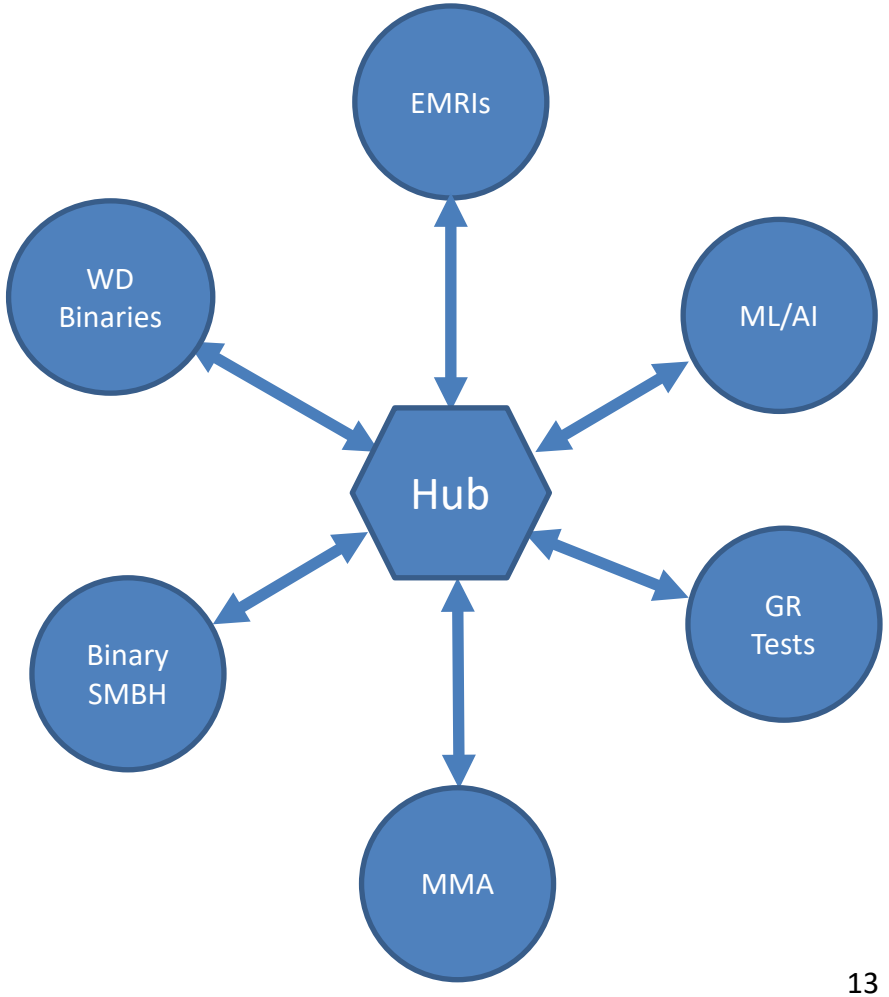
Finding: There are overlaps in gravitational wave science and research areas that multiple agencies could benefit from. Any programmatic or interagency barriers could artificially prevent fruitful progress in such areas.

Recommendation: Where it is relevant to LISA source theoretical modeling or data analysis algorithm development, NASA funding for analysis utilizing LIGO, NanoGrav and other relevant datasets should be encouraged. NASA should also encourage coordination with NSF for mutual support for GW science and proposals.

Findings – Recommended Approach

- **Finding:** US LISA expertise resides in the community, and cannot be reproduced in a single centralized science data center.
- **Finding:** Coordination and financial management of a complex international project requires central leadership.
- **Recommendation:** A distributed hub and node model is recommended.
- **Recommendation:** LISA science center should start as soon as possible. The hub should be competed and established first and once, with the goal of ensuring long-term stability through the launch and prime mission. The nodes should be competed subsequently and funded through the prime mission of LISA.

Notional nodes shown



Findings – Community Investment

Finding: **Because of the very heterogeneous nature of the LISA Consortium, it is important for members of the U.S. community to be active participants in the LISA Consortium, to have ongoing opportunities to join the Consortium, and, where appropriate, take lead positions within the Consortium activities. Full participation by individuals from the U.S. in the LISA Consortium will be essential for the U.S. since the LISA Consortium will play a role in producing science products and publications.**

Recommendation: **NASA should fund the participation of individuals in the LISA Consortium, both from NASA Centers and from members of the broader U.S. scientific and technical community.**

Findings – International Coordination

Finding: **NASA's role in the LISA mission will be defined in a MOU with ESA. Particularly important in that MOU will be the definition of the NASA roles and responsibilities within the LISA Consortium, an organization whose structure is evolving within the European partners. This will critically determine US participation in LISA science.**

Recommendation: **NASA should agree with ESA on not only the relationship with the ESA Science Center, but also on the role of the US LISA community and the Science Center within the LISA consortium.**

ESA and NASA should define the interface between NASA deliverables (software, L2 and L3 data products) and other science products delivered by member states.

The US LISA community's participation in the Consortium must be funded appropriately by NASA, with flexibility (no caps) on US scientist participation. NASA's support should extend to participants from NASA Centers and to members of the broader U.S. scientific and technical community.

Response

- **Support Community Building**
  - Continue LISA Preparatory Science Program within ROSES
  - Continue technical engagement with ESA & Consortium
  - Work with NLST to reach & grow US LISA Community
- **Begun negotiations with ESA and European partners**
  - What management structures will work best?
  - What documents will govern NASA's SGS participation, responsibilities, and rights?
  - What data policy will best serve all stakeholders?

Open Questions

- **Interface with European Ground Segment**
  - Value in “clarity” that comes from a single unified top-level product (e.g. source catalog)
  - Generating such a product is a delicate process that requires careful technical and programmatic collaboration.
  - Lower-level products are scientifically valuable for expert users. How to document and support them?
- **Reconcile different philosophy on science investigations from some stakeholders**
  - “User Facility” model where data products are developed by the experts and released to the public who then conduct science investigations
  - “Collaboration” model where science investigation teams are integrated into the instrument and ground segment teams under a single organizational umbrella.
  - Partly tied to data policy

Summary

- **SIDC Study provided a valuable framework for developing an important contribution to LISA**
- **LISA Study Office and PhysCOS Program Office are supporting APD to develop specific implementation that is responsive to the SIDC report**
- **Timescale for planning is short**
  - Top-level agreements (e.g. ESA/NASA MoU) ready for ESA Adoption in < 12mo
- **Timescale for implementation is longer, but *lots* of work to do**
  - Need to ramp-up activities now