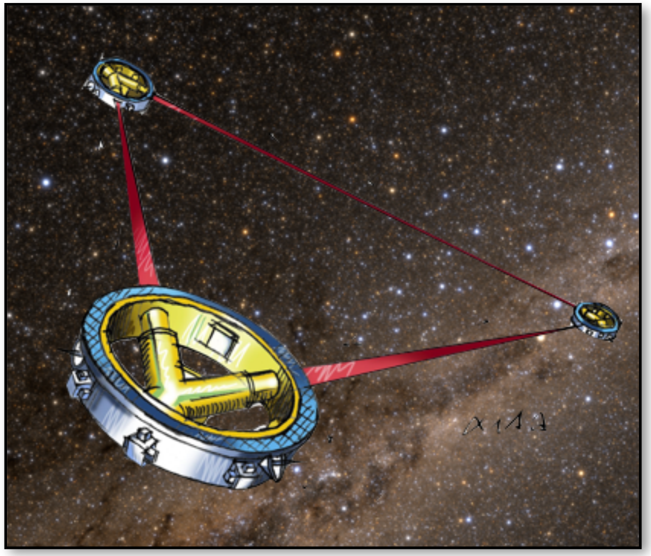
LISA and the roles for the US and NASA



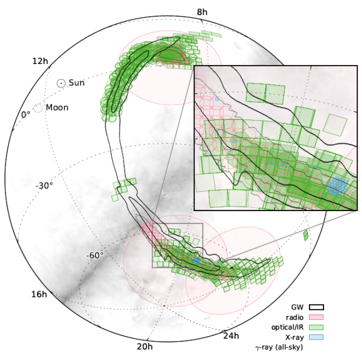
Ira Thorpe

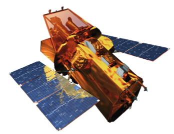
Gravitational Astrophysics Lab (663)

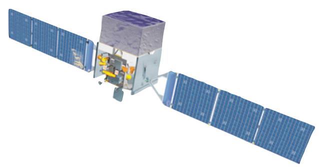
NASA/GSFC

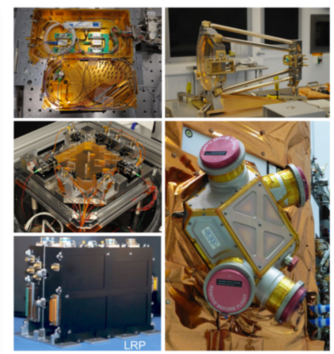
January 27th, 2017

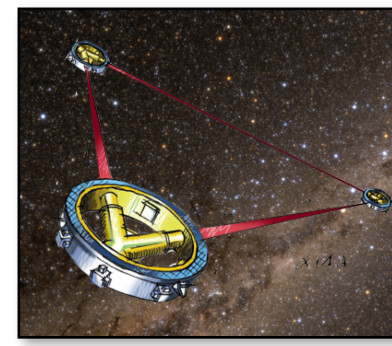
NASA’s role in the New Astronomy











Ira Thorpe

Gravitational Astrophysics Lab (663)

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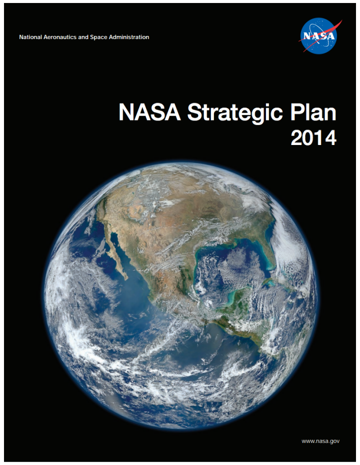
Why is NASA interested in GWs?

- **From the NASA SMD Strategic Plan**
  - Objective 1.6: "Discover how the Universe works, explore how it began and evolved, and search for life on planets around other stars."



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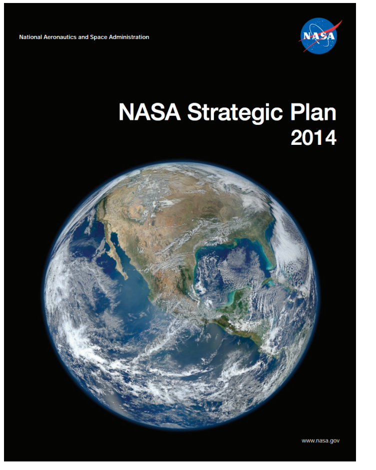
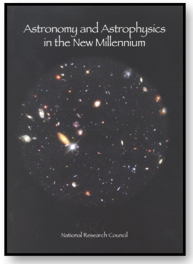


- **Jeremy Schnittmann (663)**
  - "Life on Miller's Planet: The Habitability Zone Around Supermassive Black Holes"

Community Demand for GW Science



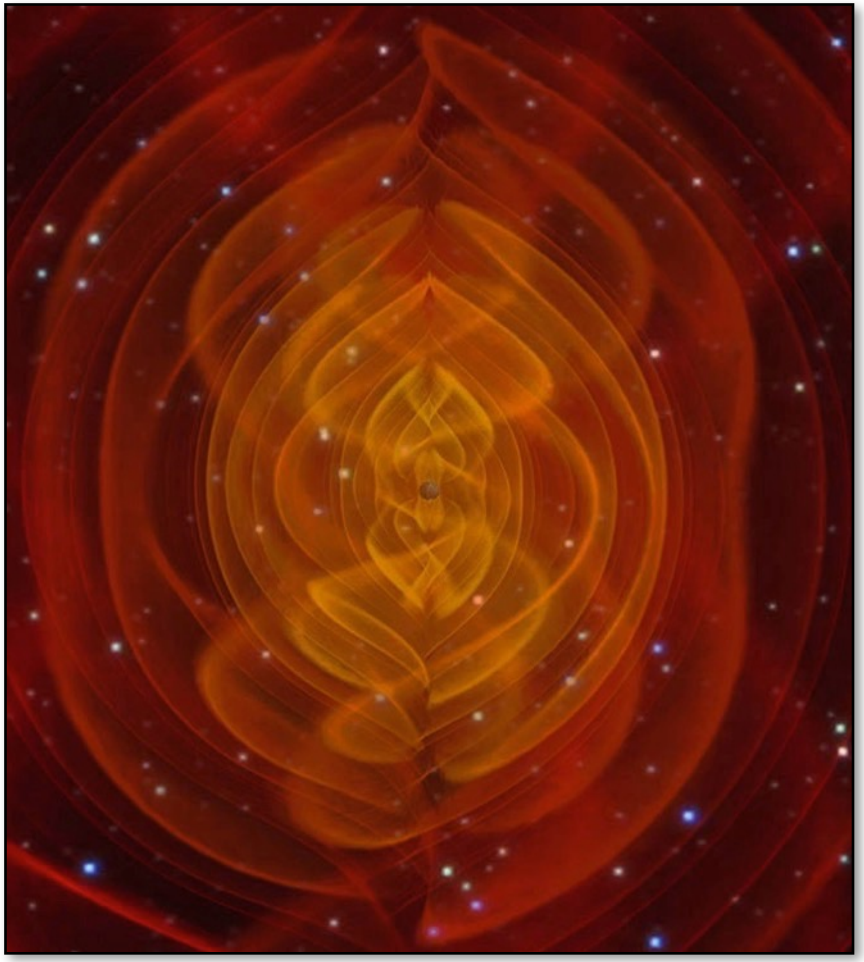
Astrophysics "Decadal Surveys" from National Research Council

- **Astronomy & Astrophysics in the New Millennium (2001)**
  - Endorses medium-scale NASA/ESA mission for GWs
- **New Worlds, New Horizons (2010)**
  - Endorses large-scale NASA/ESA LISA mission for GWs
- **National Academies Midterm Assessment (2016)**
  - Highlights successes of LIGO and LPF
  - Recommends renewing US efforts in LISA-like mission
  - Strong endorsement for US participation in ESA-led mission

The Promise of GW Science

- **Listening vs. Seeing**
- **Observing the Dark Sector**
- **Multi-*messenger* Astronomy**
- **Potential for discovery**

How NASA is participating in GW science



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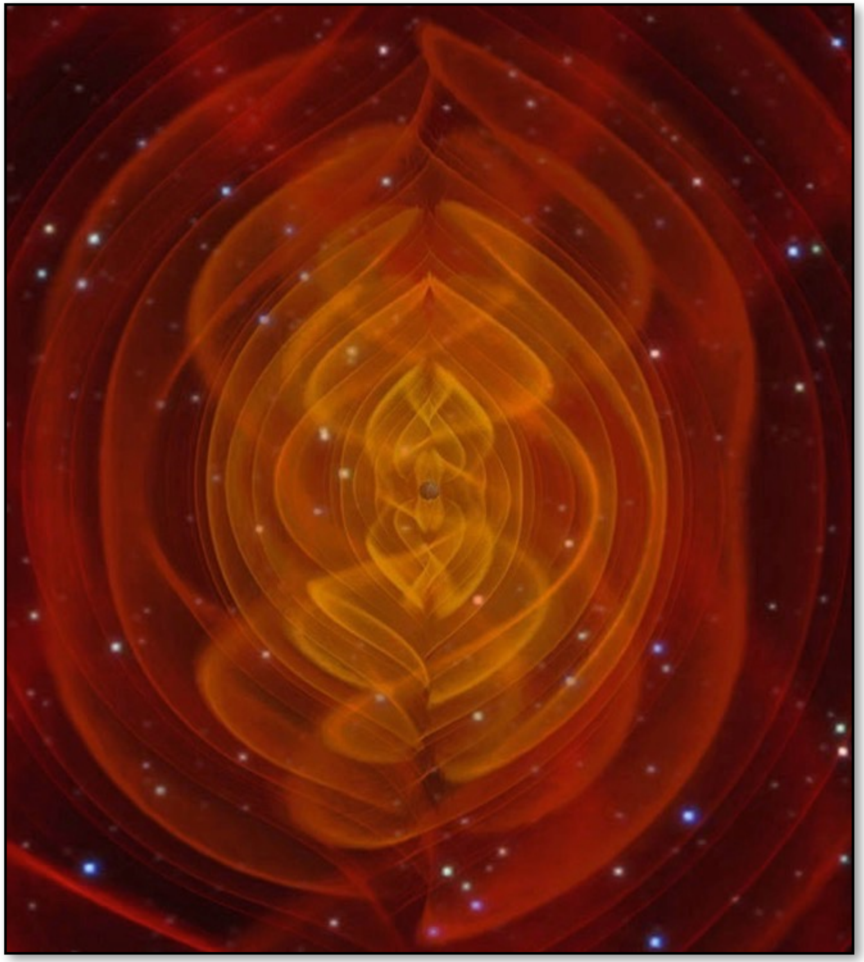
- **Participating in ground-based GW astronomy, esp. EM counterparts**



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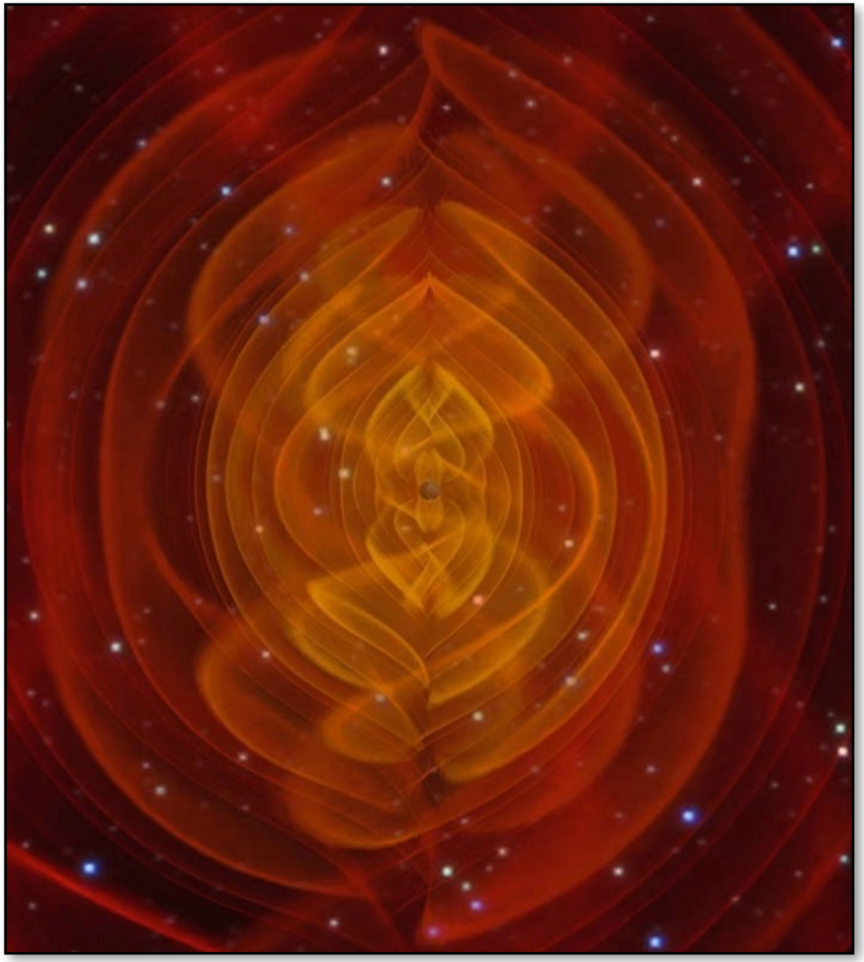

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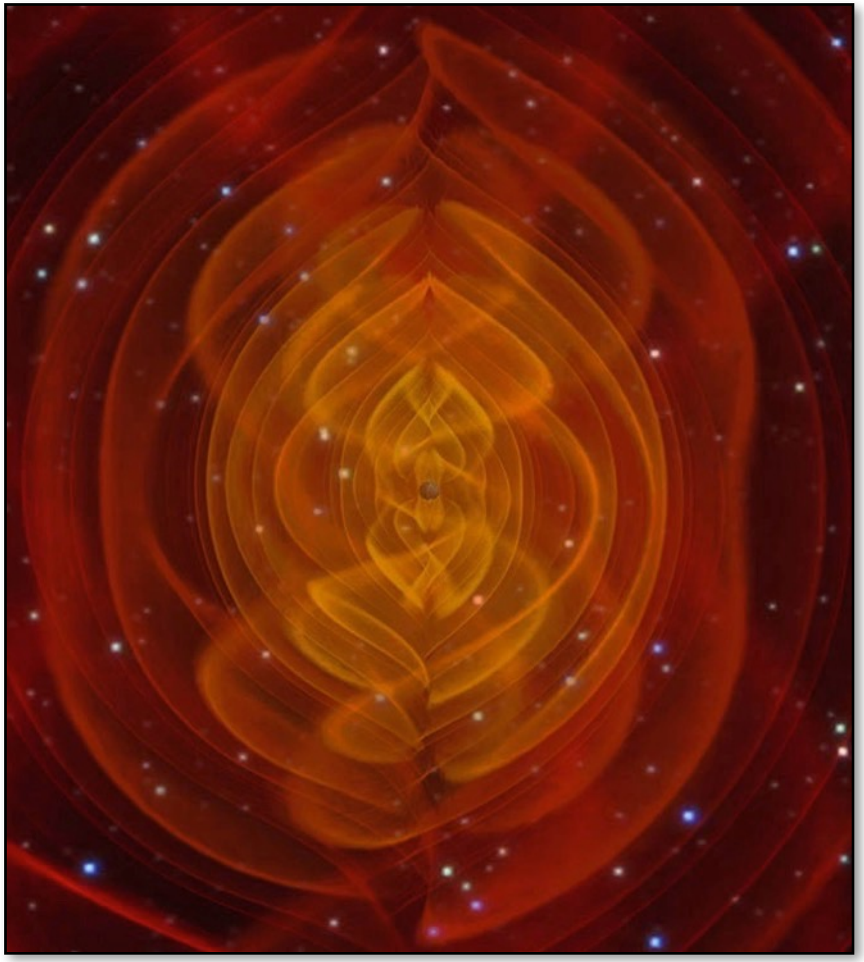

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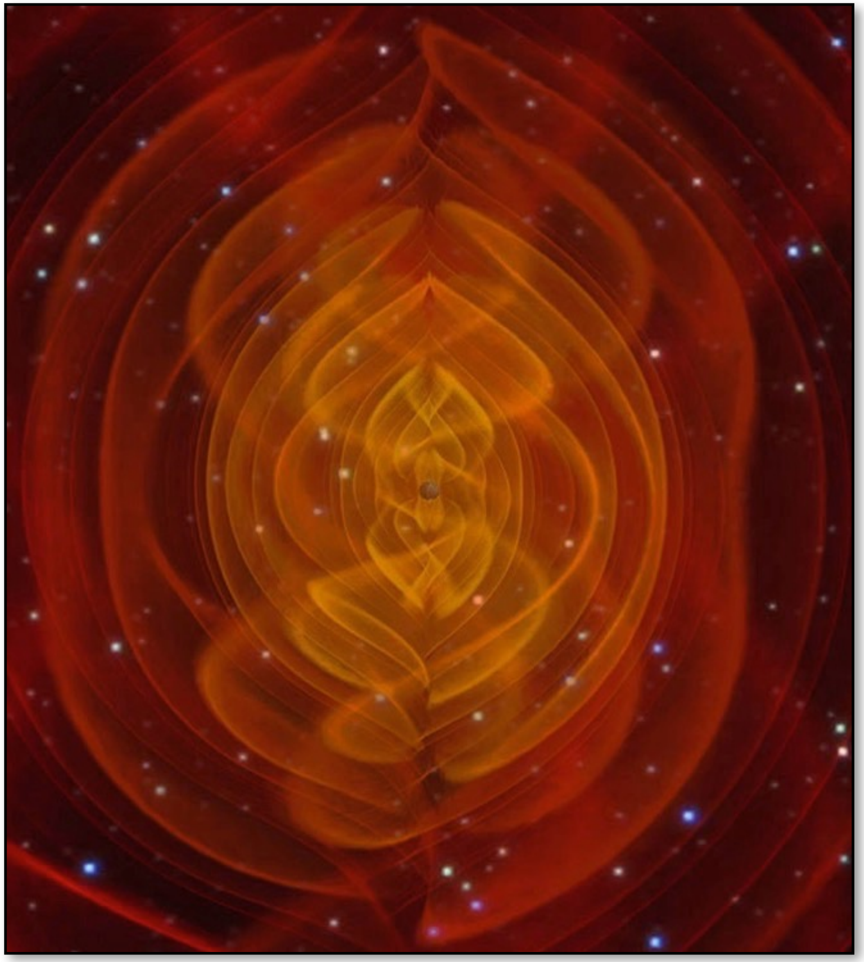

How NASA is participating in GW science

- Participating in ground-based GW astronomy, esp. EM counterparts
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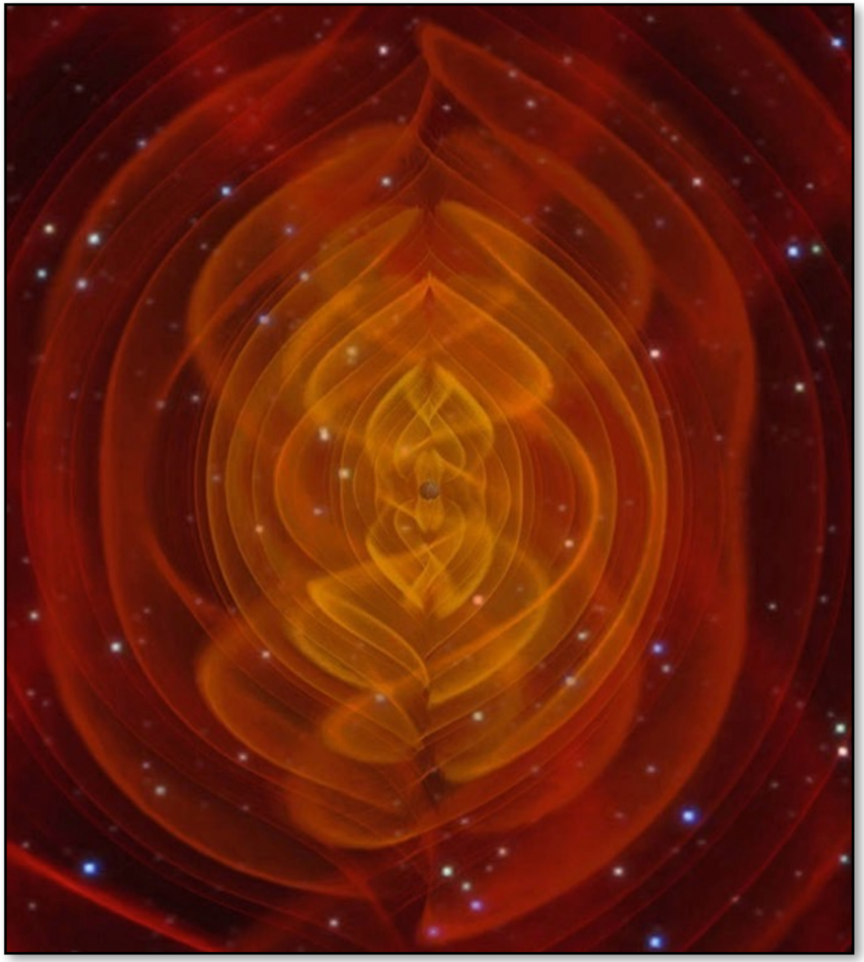
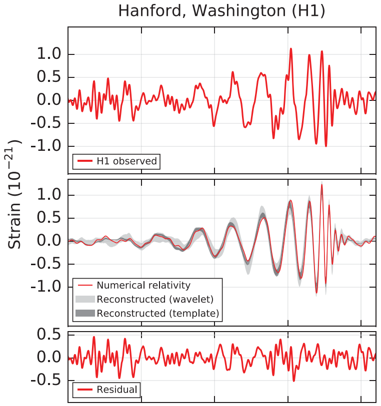
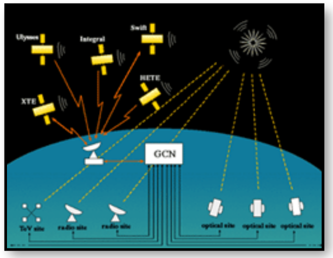
- Participating in LISA Pathfinder operations and data analysis
- Developing technologies for space-based observatory
- Partnering with ESA on LISA-like mission

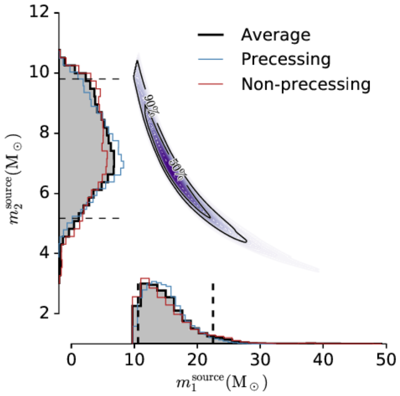


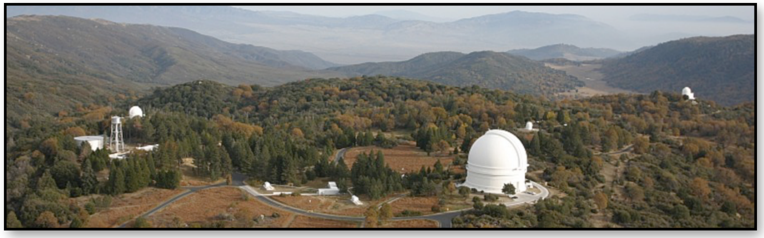
NASA Participation in LIGO

- **LSC Members @ NASA Centers**
  - GSFC (6 members)
  - MSFC (4 members)
  - JPL/Caltech (several)
- **Activities**
  - GW detection pipelines
  - rapid source localization
  - event circulars
  - targeted follow-ups
- **Additional participation through EM follow-up**
  - Swift
  - Fermi
  - Ground-based telescopes



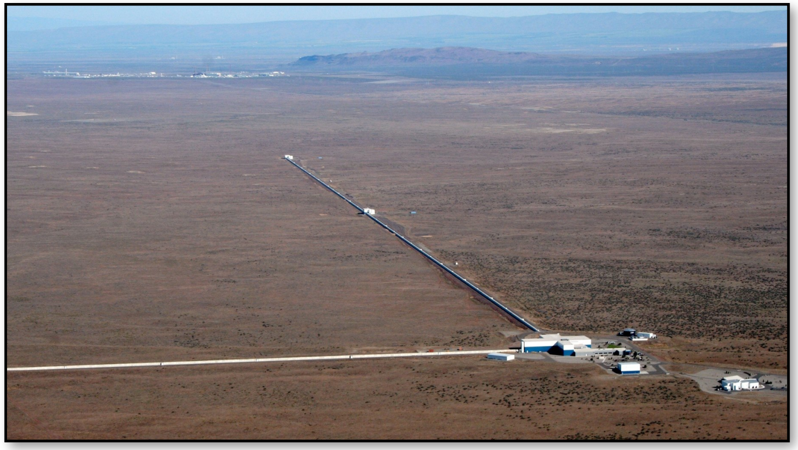






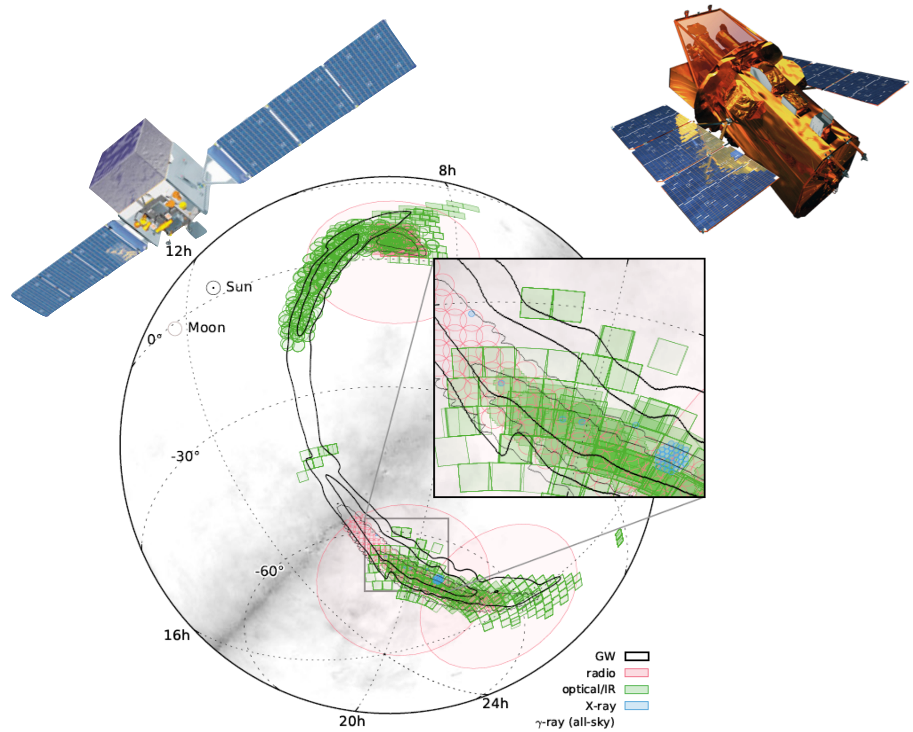
Why follow-up is important

- **GW & EM information are complimentary**
  - bulk masses vs. atoms
  - gravity vs. temperature
  - distance vs. redshift
- **GW & EM > GW or EM**
  - source astrophysics
  - host galaxy astrophysics
  - cosmological distance ladders
  - fundamental physics tests



NASA’s Unique Role for EM follow-up

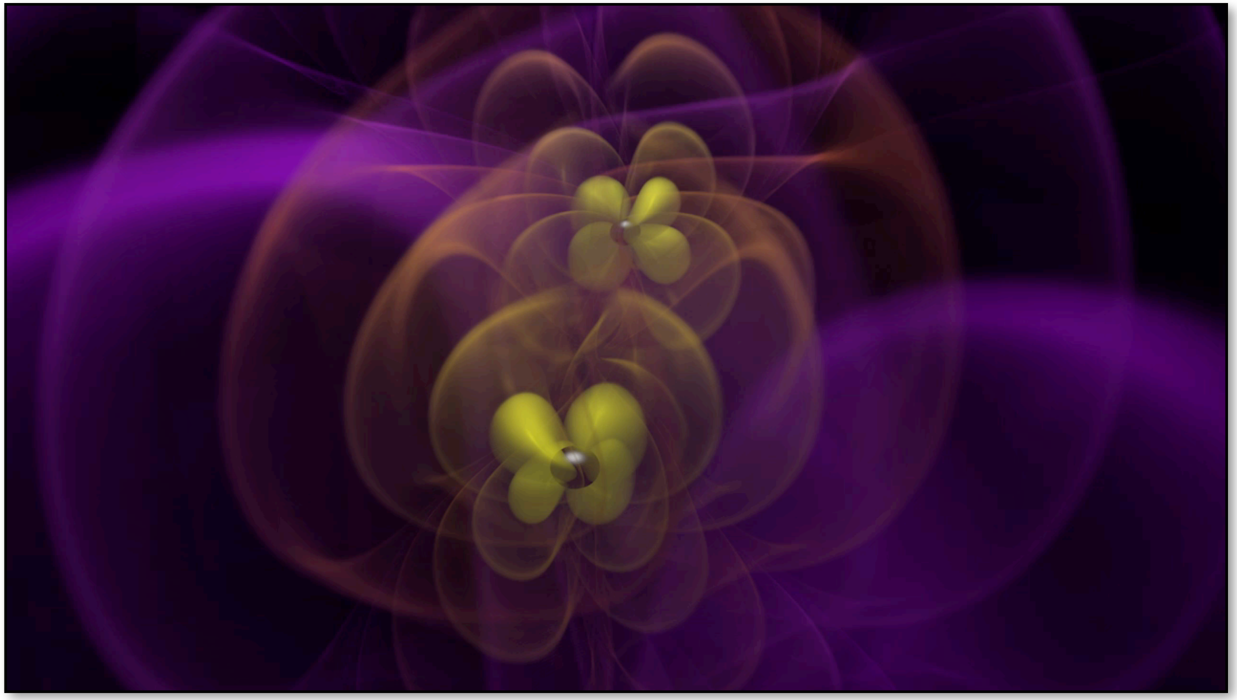
- **x-ray & γ-ray bands require space-based observatories**
- **Agreements in place between LVC and NASA**
  - Swift and Fermi
  - Possible Fermi Trigger from GW150914?
- **Science target for future missions**
  - Transient Astrophysics Observatory (TAO)
  - Lobster-eye optics



LIGO skymap (black contours) of GW150914 and EM follow-ups. The x-ray and gamma-ray coverage was provided by Swift and Fermi

Theory and Data Analysis

- **Numerical relativity**
  - Solve Einstein's Equations in a supercomputer
  - Used to predict GW and EM signals from astrophysical events



Merger of two black holes generating gravitational waves (Baker, et al.)

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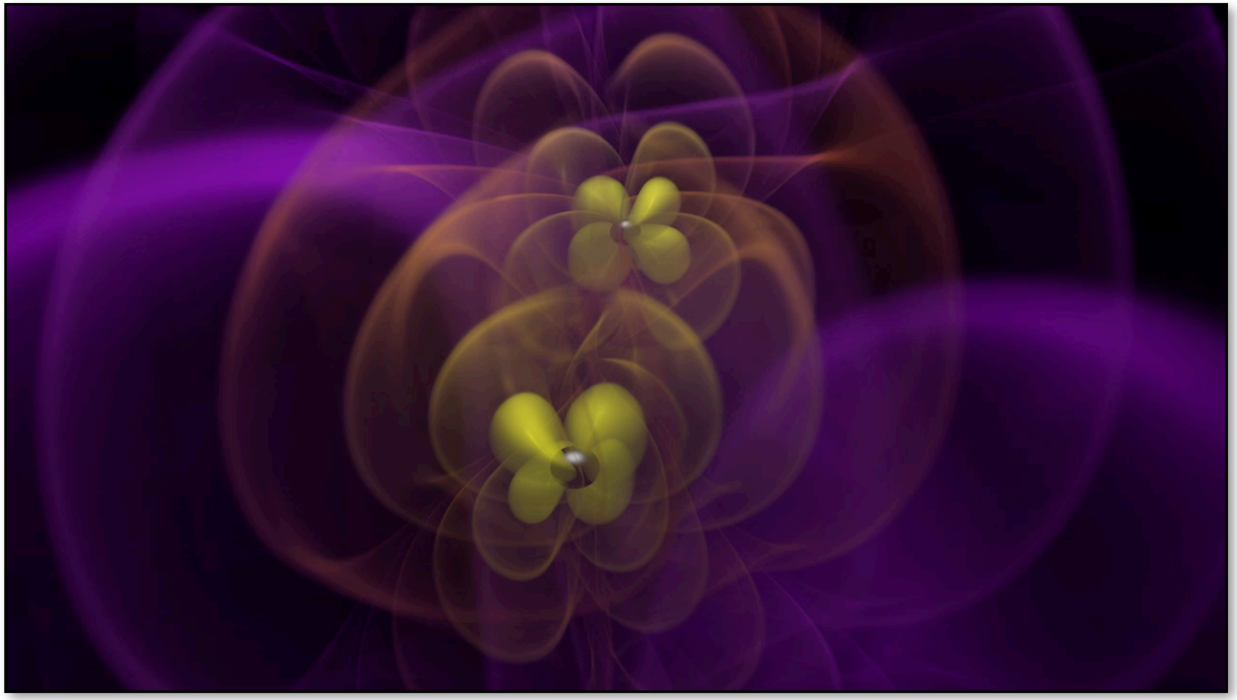

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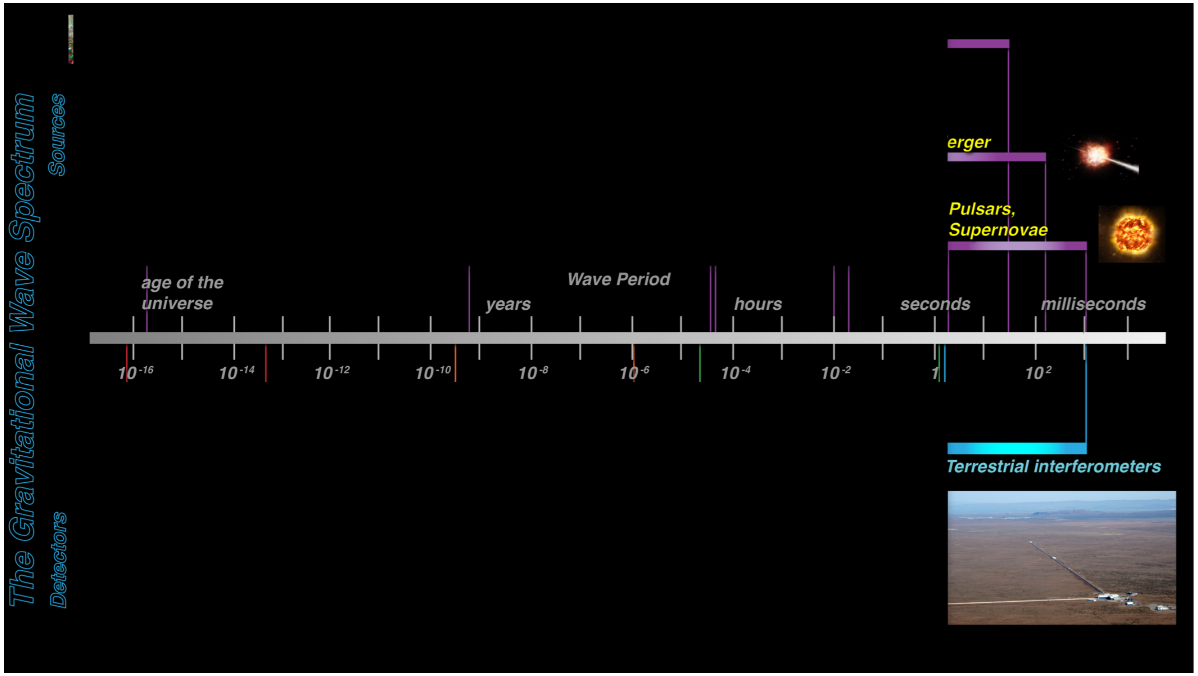
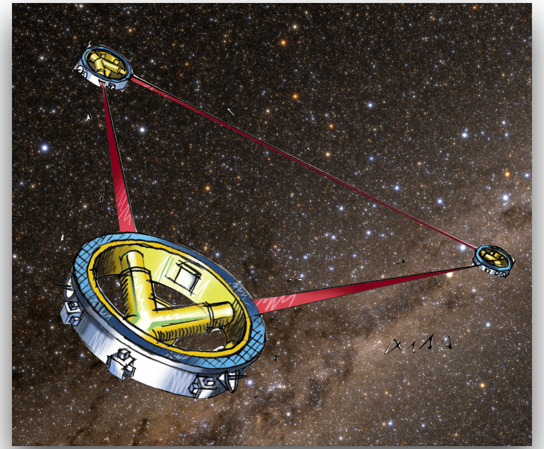
Laser Interferometer Space Antenna

- **The HST/JWST for Gravitational Waves**
  - get away from terrestrial disturbances
  - access regions of the spectrum inaccessible from Earth





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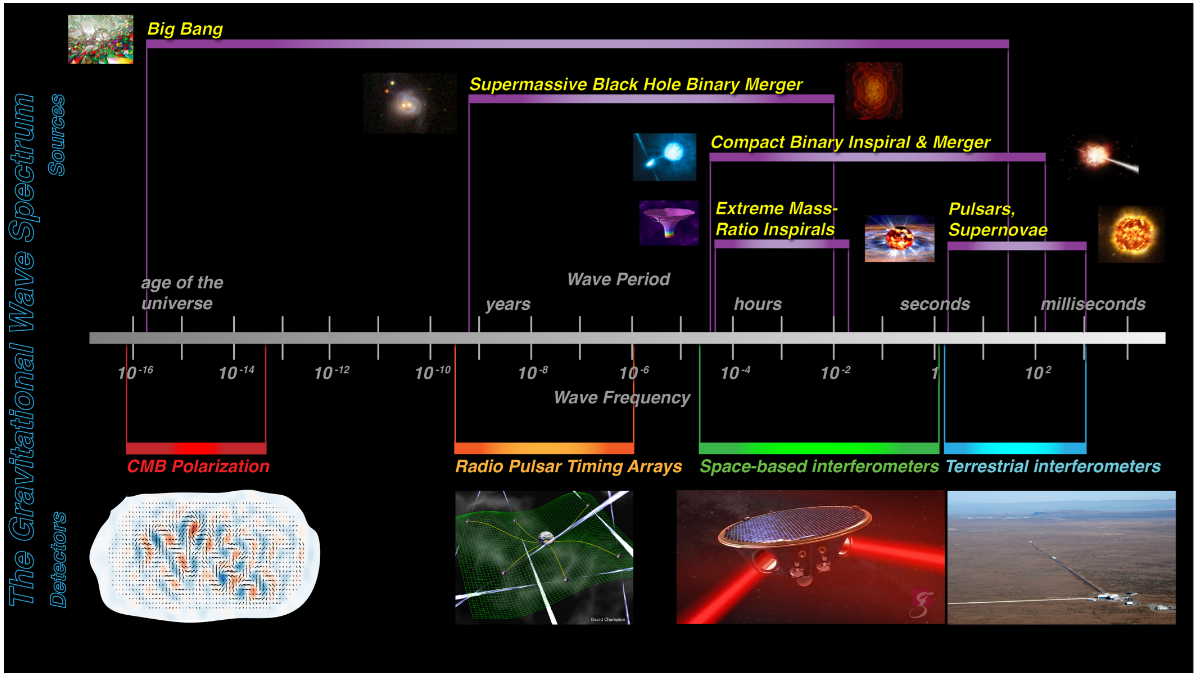

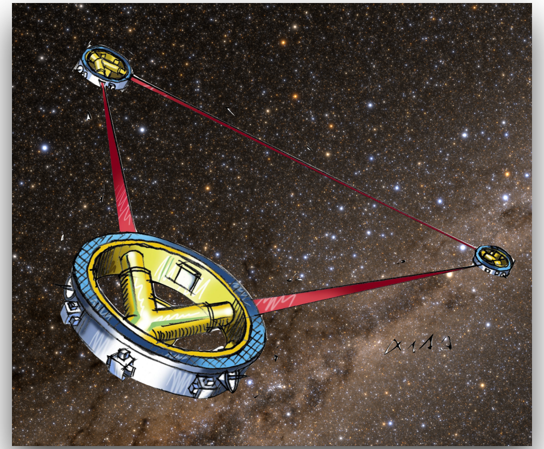

LISA Science

Massive Black Hole Mergers

visible to edge of observable universe
learn about galaxy and black hole formation
10 - 100 per year

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Extreme Mass Ratio Inspiral

Most extreme test of General Relativity
Learn about stellar populations in galactic cores
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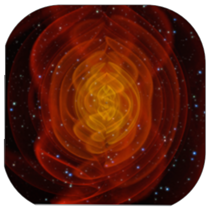

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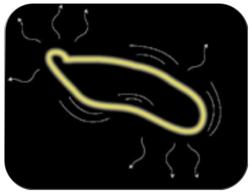
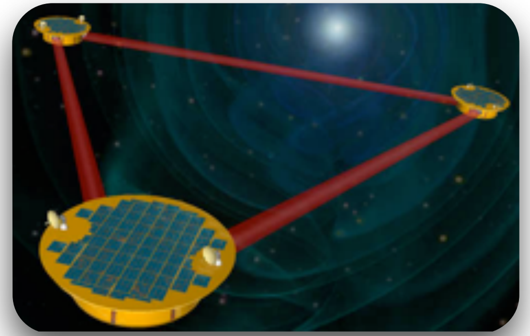


Unexpected sources

Exotic physics (cosmic strings, vacuum bubbles, etc.)
Exotic astrophysics (intermediate mass black holes)
???

LISA Mission Concept

Three-arm triangular constellation



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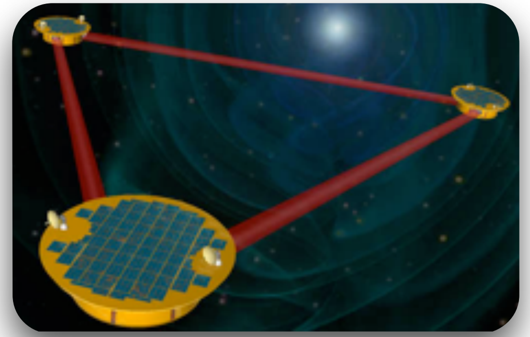

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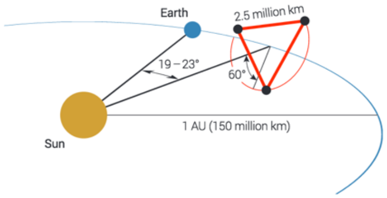
Passively-stable, Earth-trailing heliocentric orbit



(Arm length = 2.5 Mkm)

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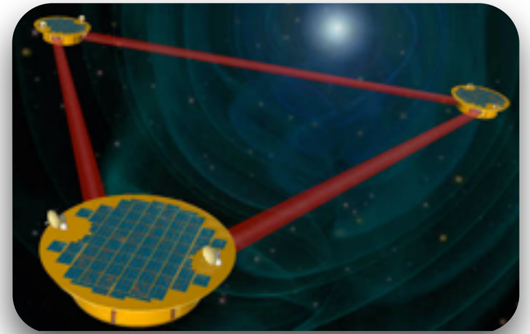

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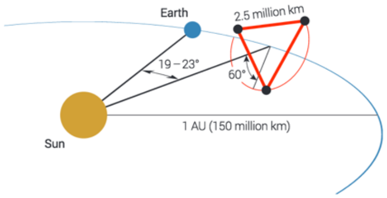

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Drag-free flight to realize ‘freely-falling’ test mass (LPF)

$$\delta\tilde{a} \sim 3\,\mathrm{fm/s^2/\sqrt{Hz}}$$

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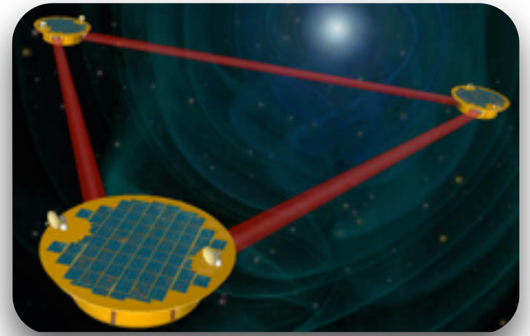

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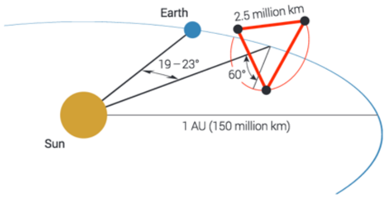

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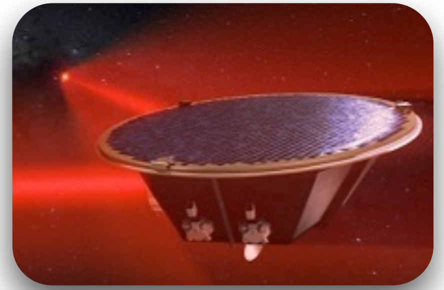
Heterodyne interferometry distance measurements

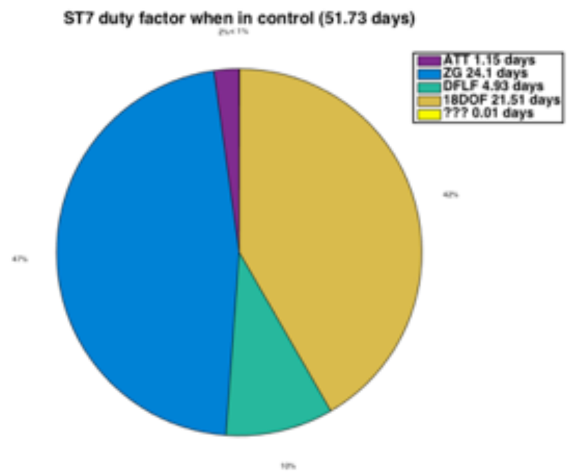


$$\delta\tilde{x} \sim 10\,\mathrm{pm/\sqrt{Hz}}$$

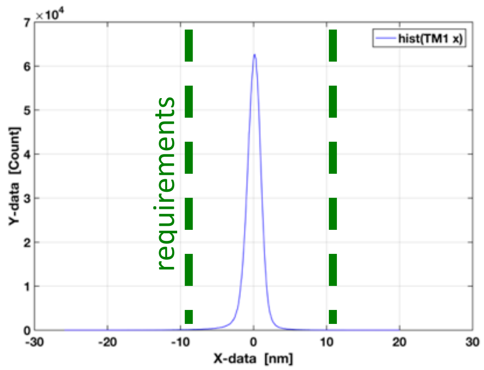
LISA Pathfinder

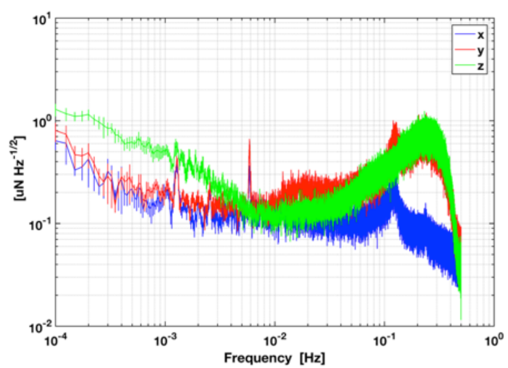
LISA Pathfinder – DRS Operations

- **DRS baseline mission**
  - Primary master payload on LPF from Jul - Dec, 2016
  - All goals met
- **Extended mission**
  - March 2017
  - Additional thruster experiments



Time-in-mode chart for DRS showing 51 days of active operations (above left). Histogram of position error during 18DOF mode, showing 2nm RMS error (above right). Thrust noise estimates showing sub-uN thruster noise performance (below)





LISA Pathfinder – LTP Operations & Analysis

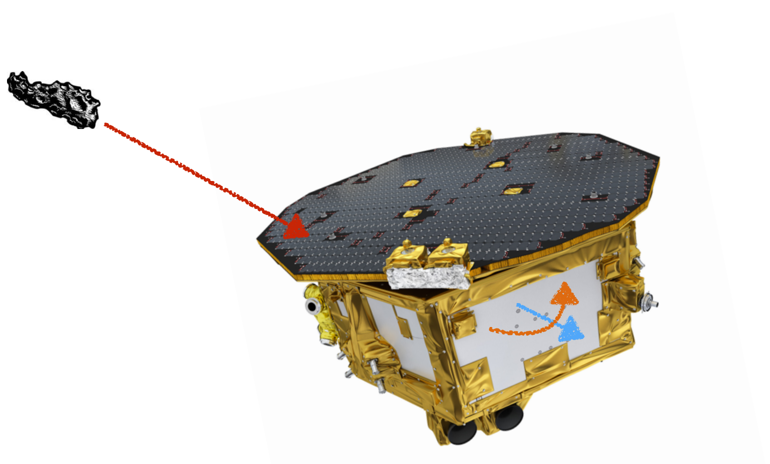
- **Small research group at GSFC**
  - Thorpe, Slutsky, & undergraduate interns
- **Participate as members of European analysis and operations consortium**
  - Work science operations shifts at ESOC in Darmstadt
  - Develop tools, run analyses, and contribute to papers

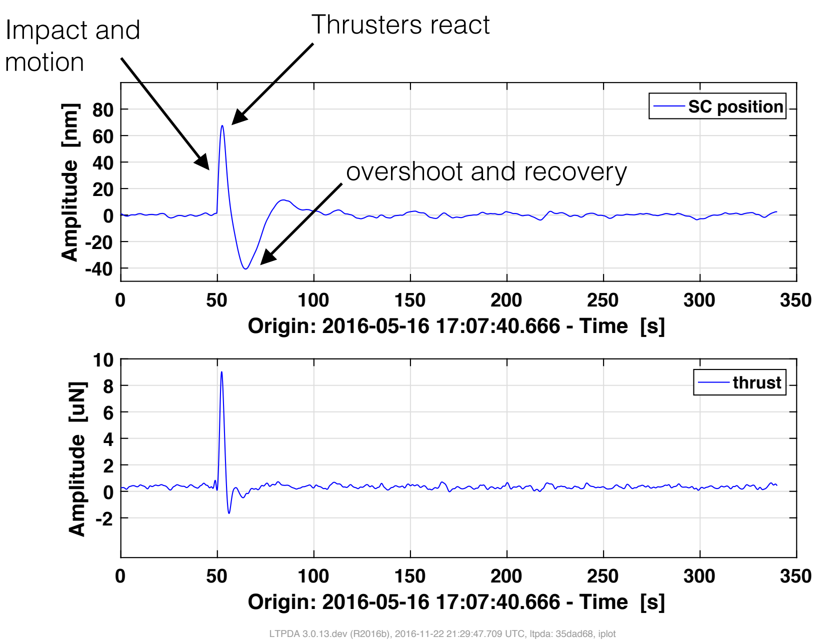

Sub-Femto-g Free Fall for Space-Based Gravitational Wave Observatories: LISA Pathfinder Results

(top) Two NASA co-authors on the PRL describing LPF's preliminary results. (bottom) LTP operations at ESOC in Darmstadt, Germany.

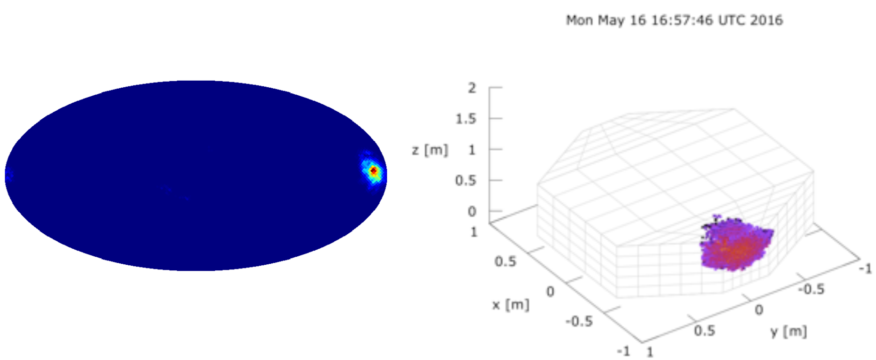
Science of opportunity - Micrometeoroids

- **Use LPF as an precision accelerometer to detect & measure impacts from dust**
  - Unique tool for studying dust population
  - Potential auxiliary science for LISA





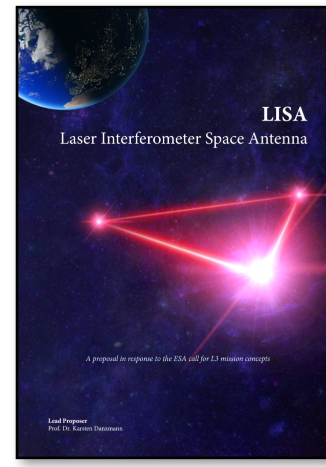
Nanogram particles impact the spacecraft and cause anomalous accelerations (above). By reconstructing the external force from the sensor signals and force commands(left) , the magnitude, direction, and location of the impact can be estimated (below)



Current Mission Status

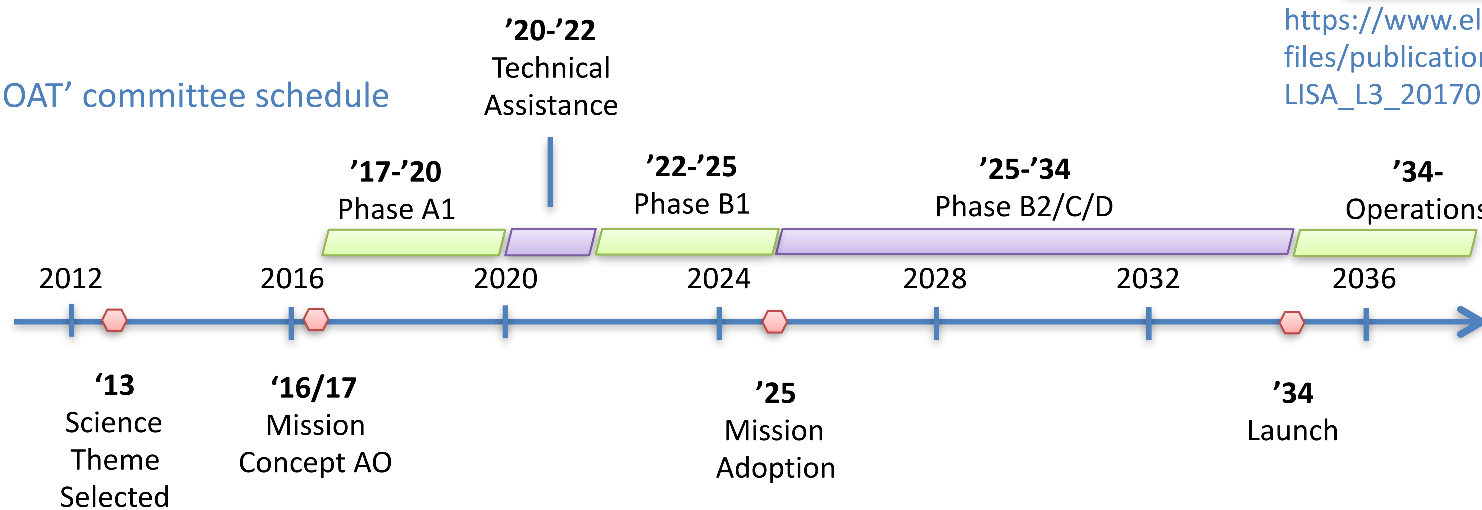
- **ESA selected GW science for ‘L3’ opportunity**
- **Mission concept proposal completed this month**
  - Organized by eLISA consortium (Europe)
  - Significant US participation (incl. NASA)
- **NASA/ESA Negotiations ongoing**
  - 20% Nominal contribution
  - Full participation in mission development & science

LISA L3 Mission Proposal



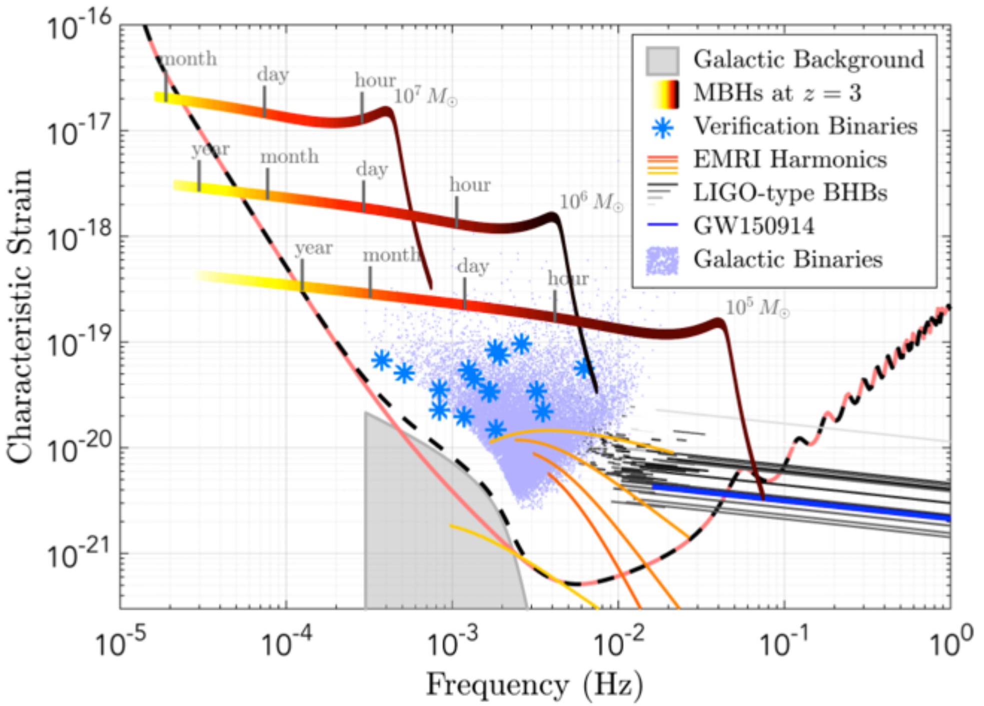
https://www.elisascience.org/files/publications/LISA_L3_20170120.pdf

ESA ‘GOAT’ committee schedule



LISA L3 Mission Concept

- **Adopts LISA architecture**
  - Three 2.5Mkm arms
  - 30cm telescopes
  - 2W laser (EOL)
  - LPF gravitational reference
  - 4 year nominal mission
- **Fully covers L3 science theme**
  - MBH-MBH binaries to high redshift (z > 20)
  - Extreme-mass ratio inspirals
  - Compact binaries in Milky Way
  - LIGO precursor events



LISA instrument sensitivity (black dashed line) compared with sources (colored traces) shows rich variety and number of astrophysical targets

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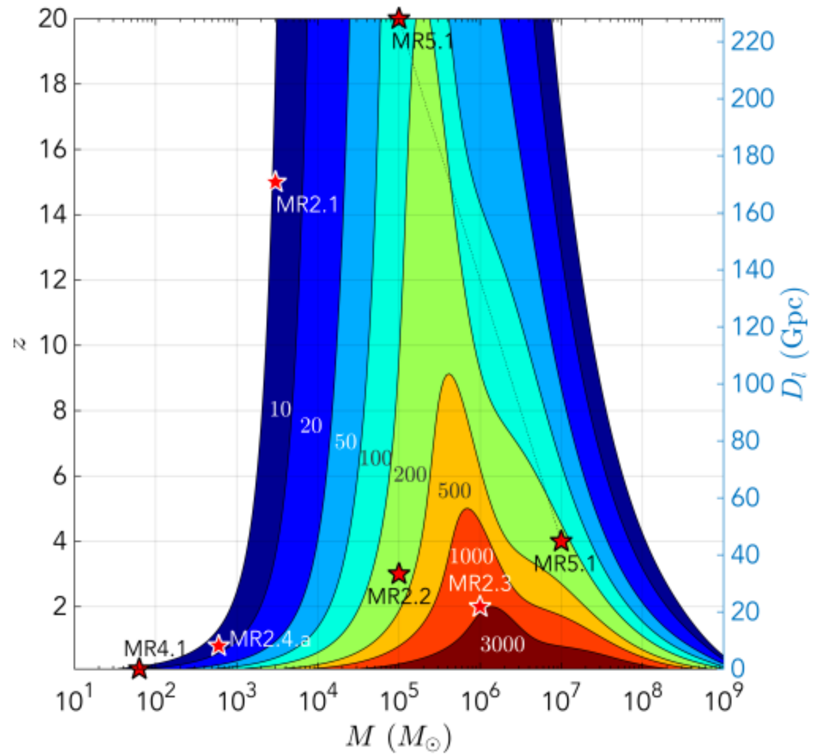
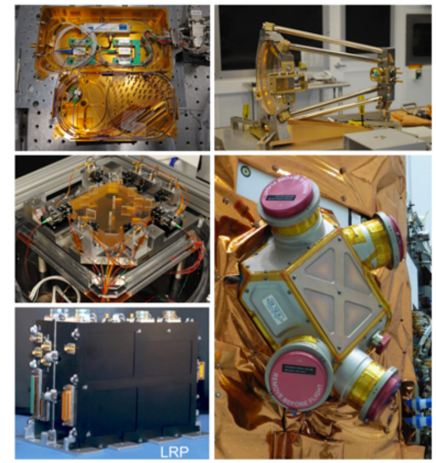


SNR as a function of total BH mass and redshift for LISA concept for merger of black holes. LISA will conduct the **widest and deepest astrophysical survey** ever.

How US can participate in L3

- **Hardware**
  - Major instrument systems
  - Instrument components & subsystems
  - spacecraft components
- **Mission Development**
  - Participate in trade studies
  - engineering and technical support as needed
- **Science**
  - Science case
  - Data analysis
- **Operations & Analysis**
  - Data centers
  - Science centers / guest investigator programs



US GW Technology gallery (above). NASA supercomputing resources (below)

NASA's L3 Study Team (L3ST)

- **HQ-sponsored Study Team formed Dec. 2015**
  - Investigate and analyze options for US participation in L3
  - Main body of 14 scientists from academia & NASA centers plus group of 6 technical experts
  - Interim Report published June 2016
  - Next Face-to-Face meeting Tuesday / Wednesday in DC

L3ST group photo, Salt Lake City, UT in April 2016

National Aeronautics and Space Administration

L3 Study Team Interim Report

June 20th, 2016

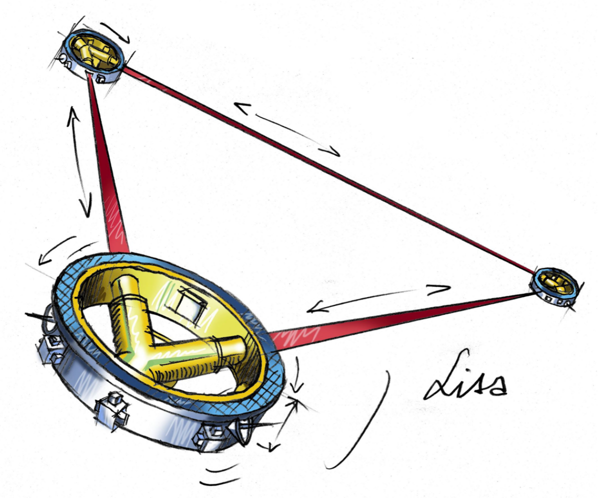
www.nasa.gov

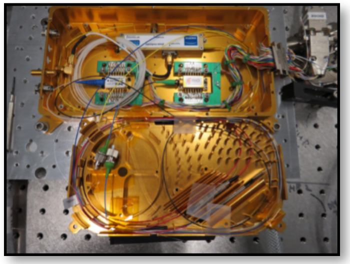
L3ST Interim Report

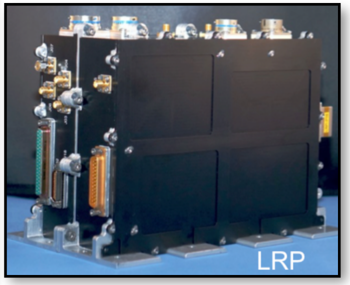
https://pcos.gsfc.nasa.gov/studies/L3

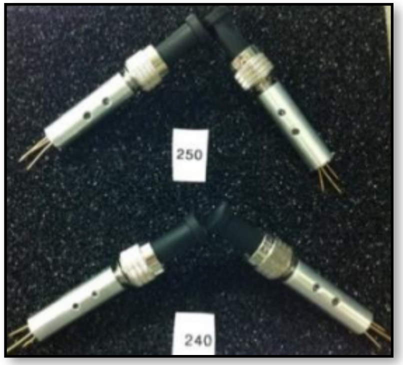
L3 Study Office

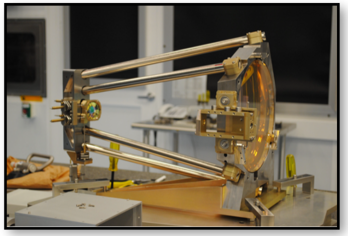
- **'Proto-project' to coordinate US activities**
  - Technology development
  - Technical interaction with ESA
  - Development of Analysis tools
  - Science Case











Potential US technology contributions (laser, thrusters, phase meter, UV discharge, telescopes)

Summary

- **GW Astronomy is here!**
- **NASA has important roles to play**