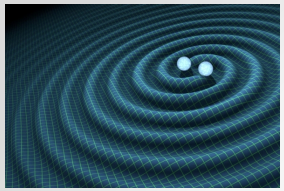
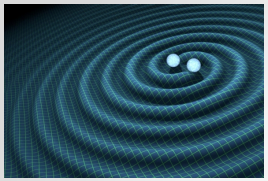


L3 Study: The LISA Gravitational Wave Detector

David Shoemaker, MIT
L3 Study Group Chair
3 January 2017

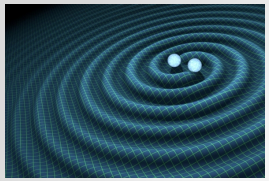


What is LISA?

- LISA is the name of the proposed 'L3' ESA mission for a space-based gravitational-wave observatory
  - L3 = ESA's third Large mission (JUICE is L1, Athena is L2)
- Uses laser interferometry to record gravitational-wave amplitude time series
- Studies very massive – up to 10^7 $M_\odot$ – astrophysical systems via their gravitational-wave emission
- Launch of 4-year nominal mission in early 2030's

- NASA L3ST is the Study Team supporting NASA's role in the ESA-Led mission
- Informing NASA on technical contributions, organizing astrophysics developments supporting the LISA mission

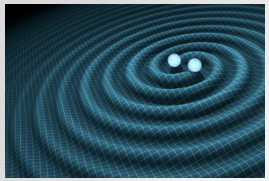
- Here: Status Update on the mission



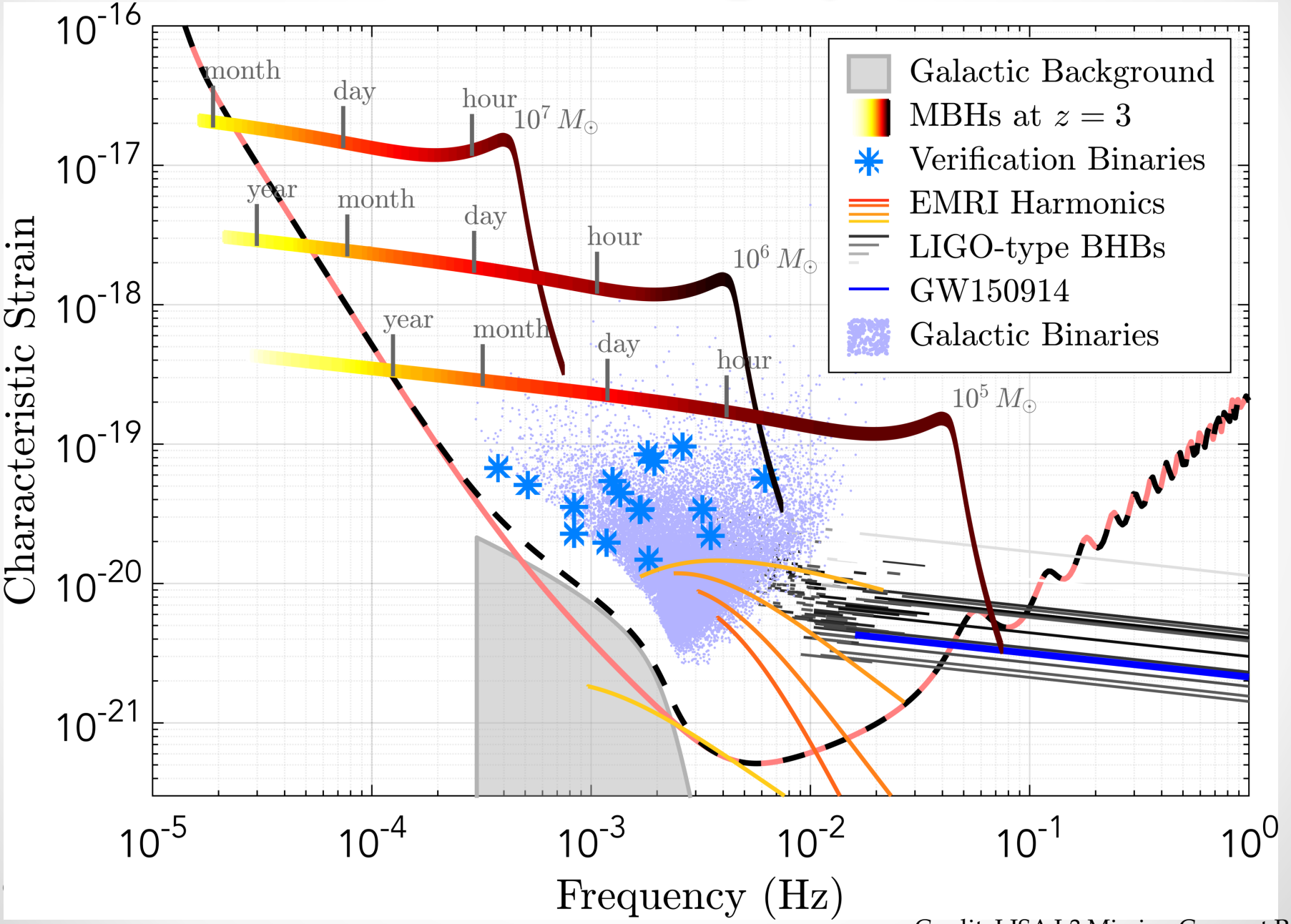
A very welcome nudge from the Decadal Mid-term assessment

- *RECOMMENDATION 4-4: NASA should restore support this decade for gravitational wave research that enables the U.S. community to be a strong technical and scientific partner in the European Space Agency (ESA)-led L3 mission, consistent with the Laser Interferometer Space Antenna's high priority in the 2010 report New Worlds, New Horizons in Astronomy and Astrophysics (NWNH).*

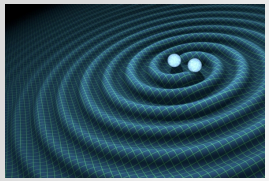
- *One goal of U.S. participation should be the restoration of the full scientific capability of the mission as envisioned by NWNH.*



LISA Astrophysics

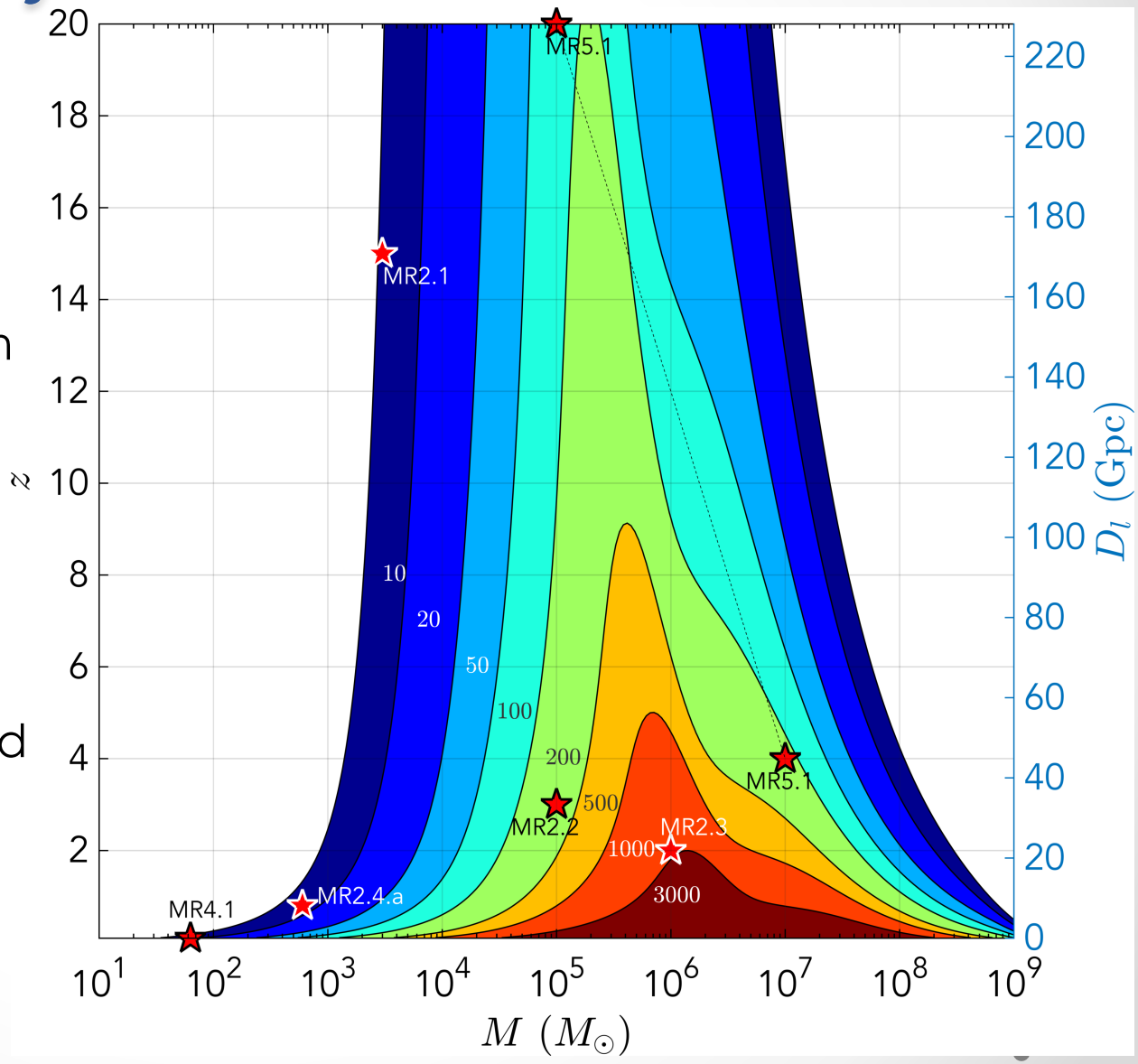


Credit: LISA L3 Mission Concept Proposal

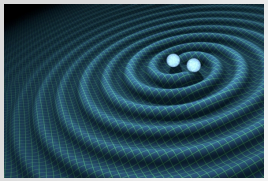


LISA's reach for Binary Black Holes

- Wide range of masses accessible
- Very high SNR (~1000) for 'nearby' (z ~3) mid-band binaries
- Can reach to cosmic dawn
- Can deduce
  - Masses
  - Distance
  - Position
  - Polarization
  - Spin of components and final BH
  - Spin alignment, precession

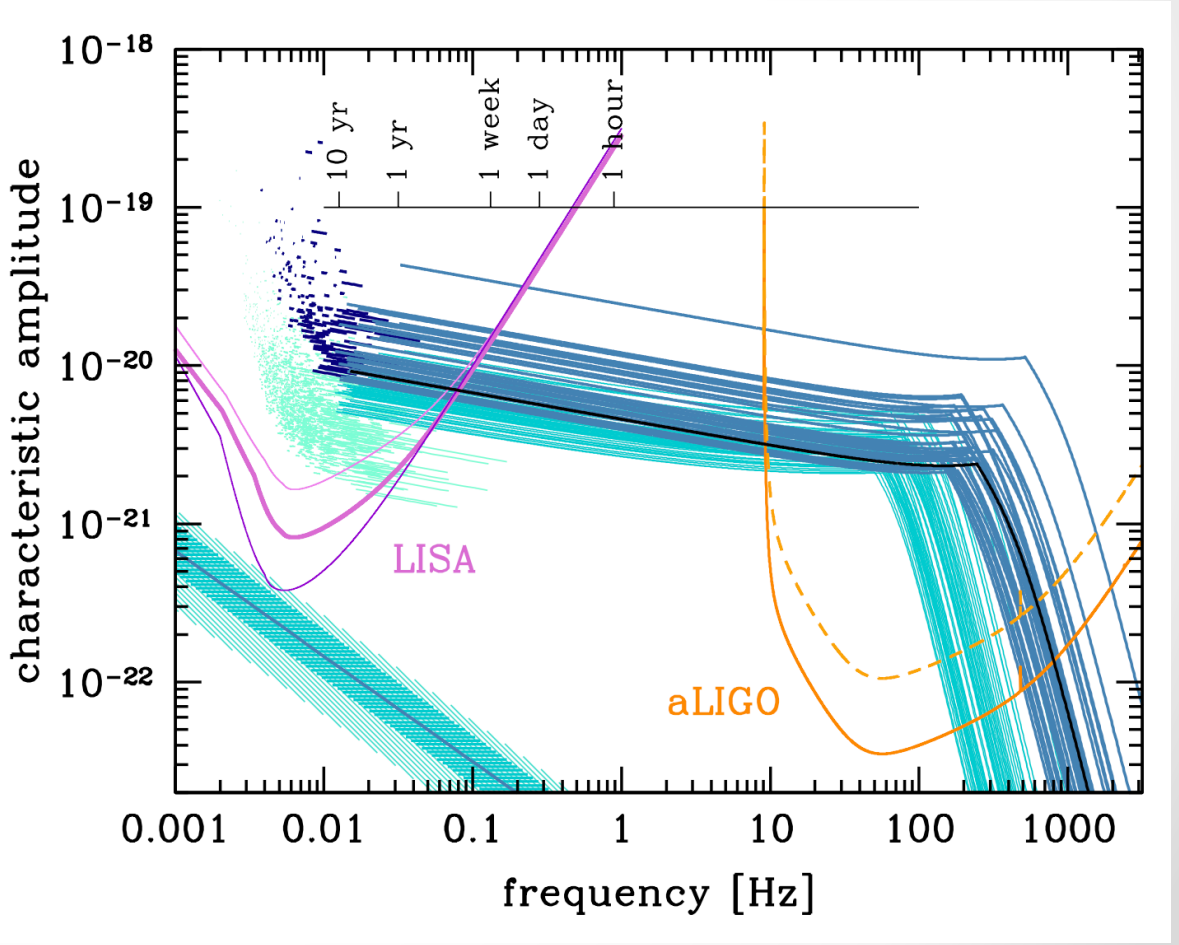


Credit: LISA L3 Mission Concept Proposal

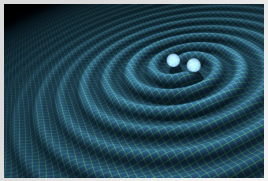


Astrophysics with Binary Black Holes

- Study the formation and evolution of compact binary stars in the Milky Way Galaxy
- Understand the astrophysics of stellar origin black holes
- Joint gravitational and electromagnetic observations
  - Low-latency alerts for EM observation (1 day)
  - High-precision pointing information (1 deg^2)
- Multi-band measurements with LISA and LIGO-like detectors

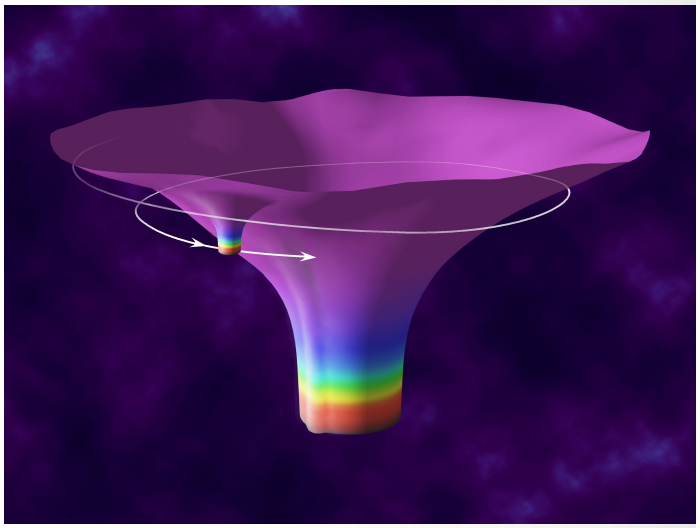


Credit: Sesana PRL 116, 1102



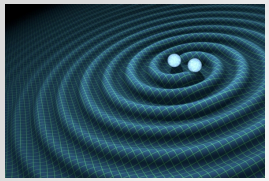
Fundamental Physics

- Precision study of ring-down characteristics of post-merger objects for consistency with GR

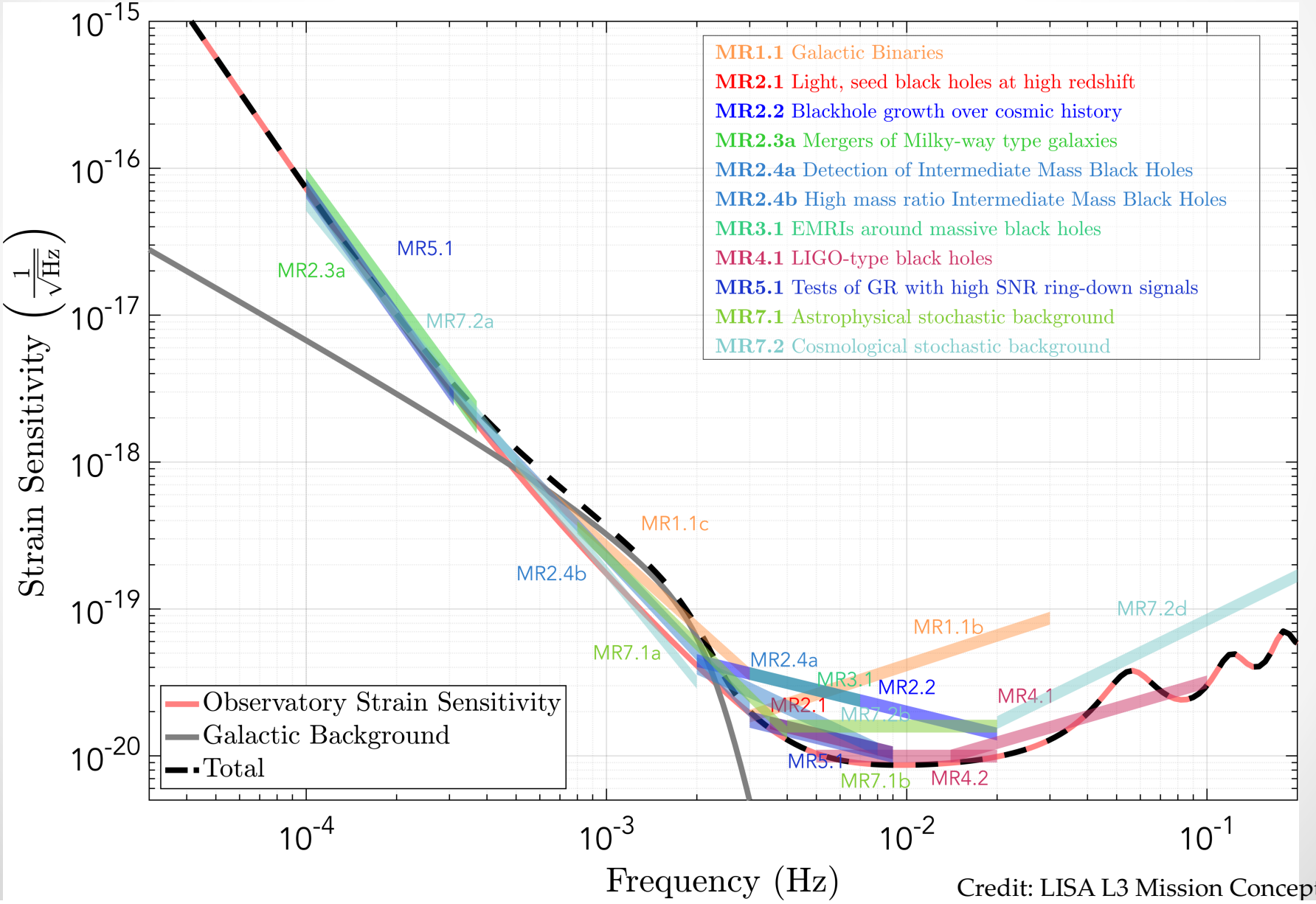


- Use extreme mass ratio inspiral (EMRI) binaries to explore the multipolar structure of massive black holes

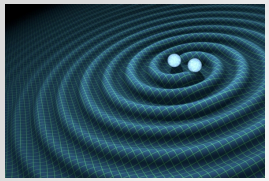
- Test the propagation properties of GWs
- Constrain cosmological parameters through joint GW and EM observations
- Study stochastic gravitational wave backgrounds
  - Astrophysical -- measurement
  - Cosmological – probably an upper bound
- Search for bursts, cusps and kinks of cosmic strings



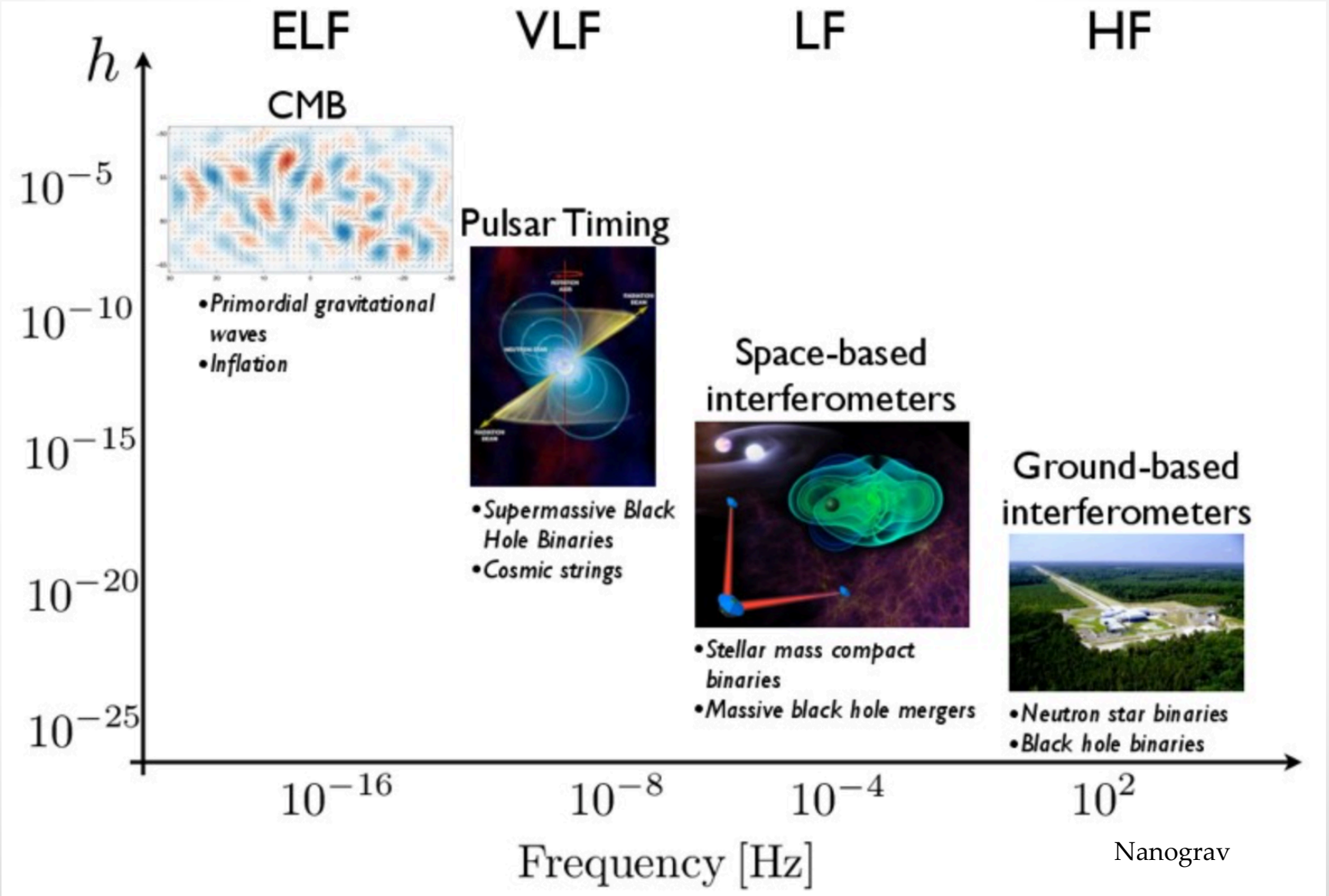
Science-imposed mission performance; 4-year mission



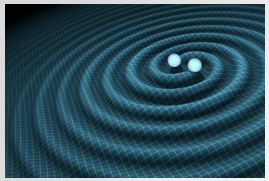
Credit: LISA L3 Mission Concept Proposal



LISA's place in the spectrum

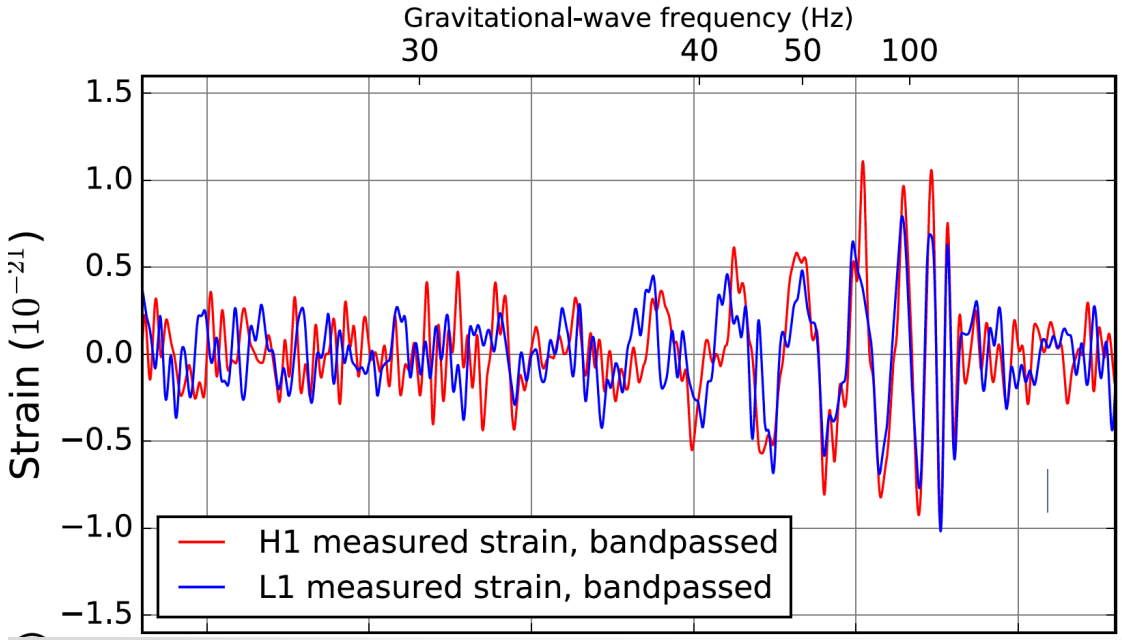


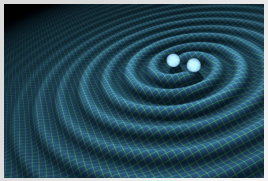
Nanograv



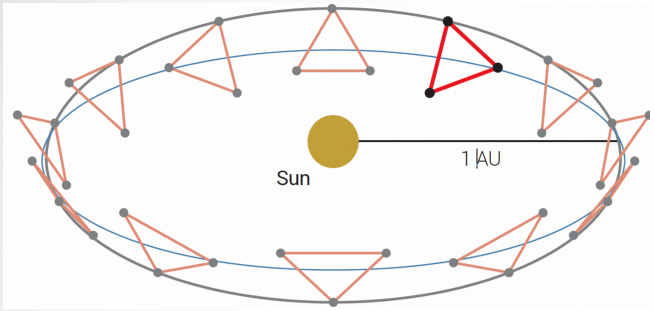
LIGO and LISA

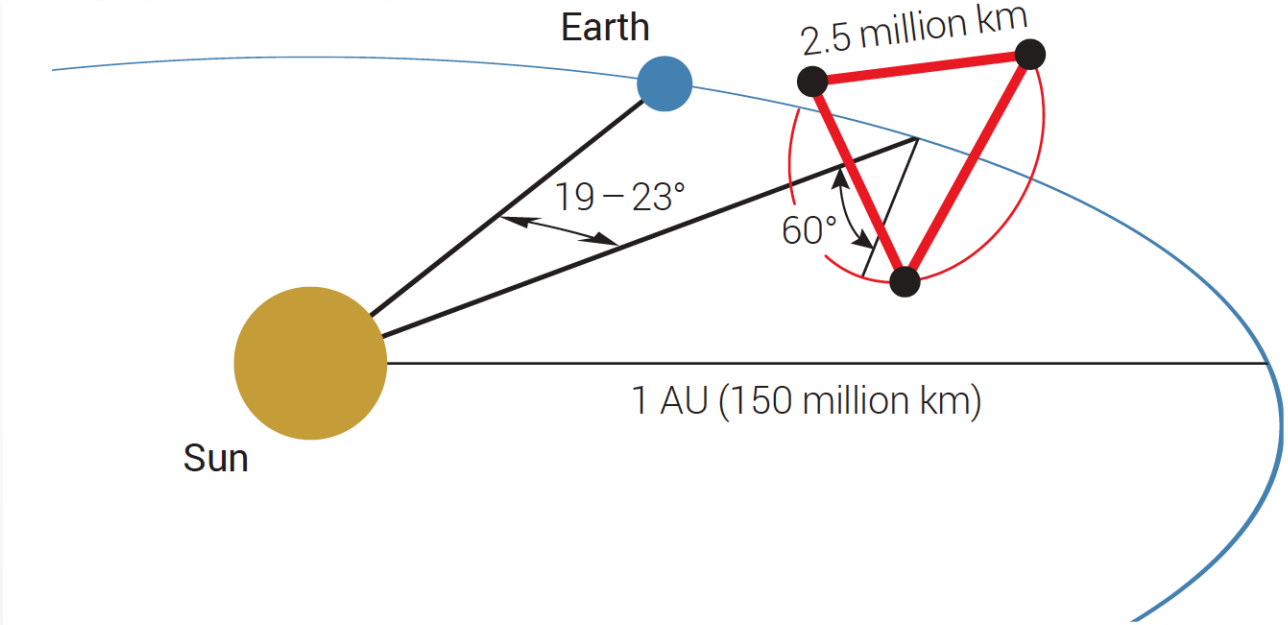
- LIGO's observation of gravitational waves→ observation principle works
- Existence of ~60 $M_{\odot}$ BH confirmed
- Stellar BHs are more massive and more plentiful than we have assumed. Potential implications for EMRIs
- Multi-detector observation of binaries from LISA band to LIGO band assured

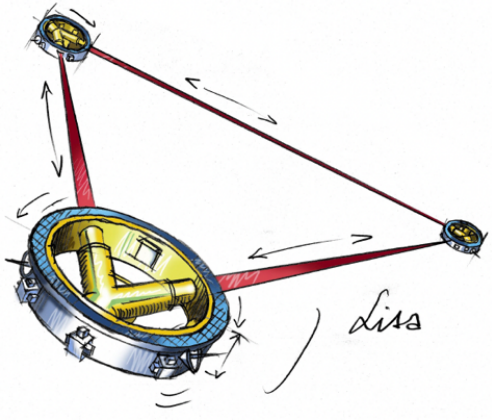




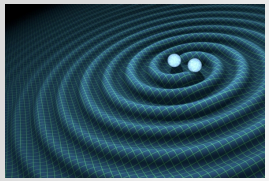
LISA Constellation and Orbit





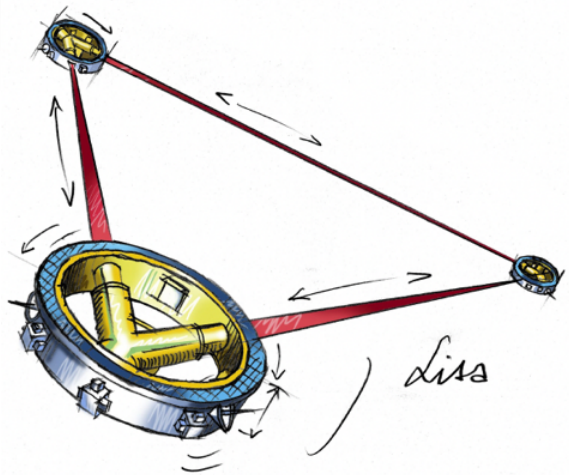


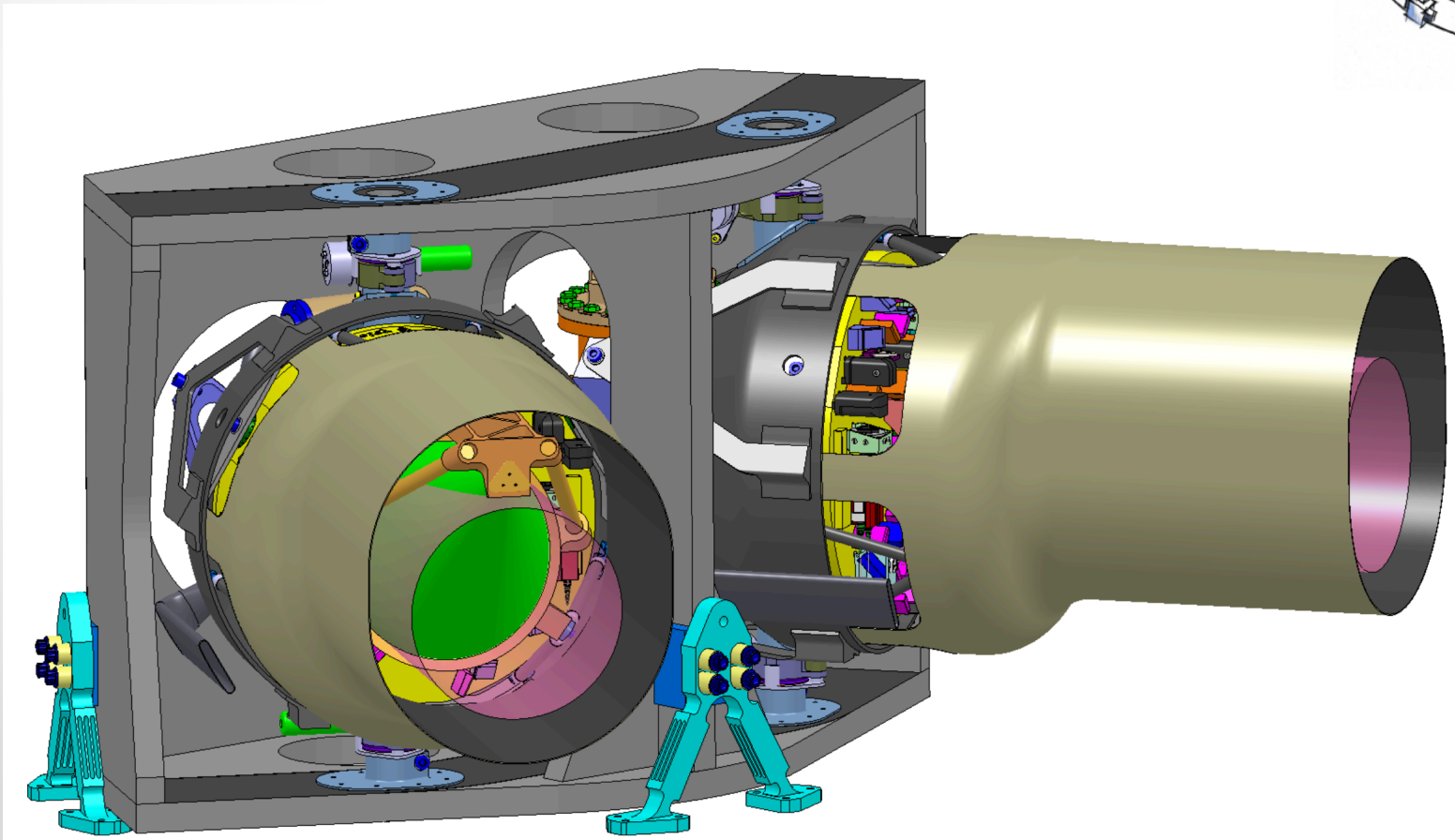
Credit: LISA L3 Mission Concept Proposal



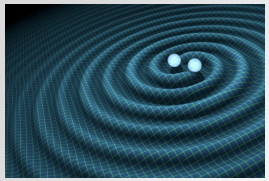
Send/Receive Telescopes

- 30 cm Diameter
- Sends ~2 watts of 1 micron Nd:YAG light
- Receives ~100 pW from sister spacecraft

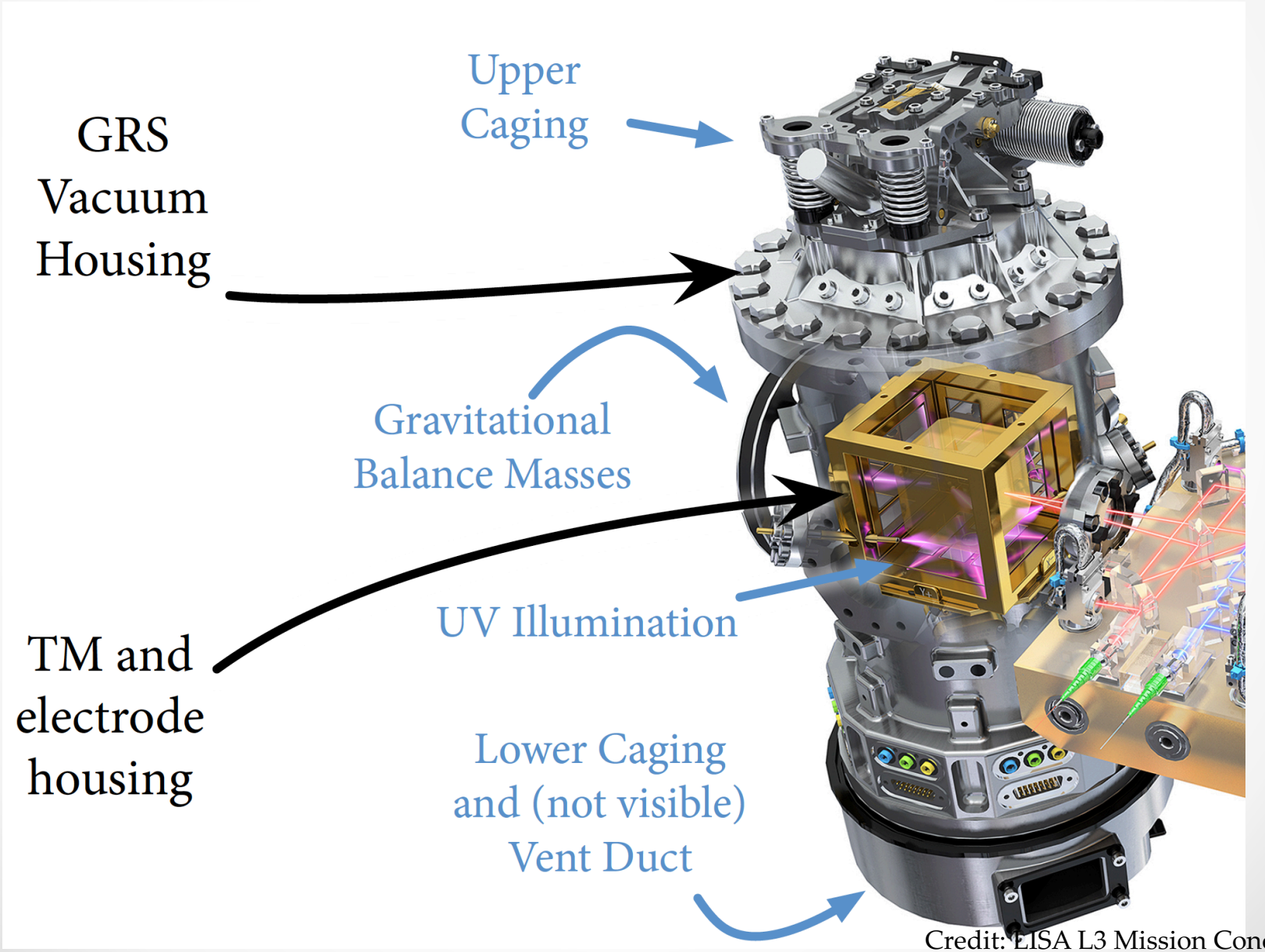




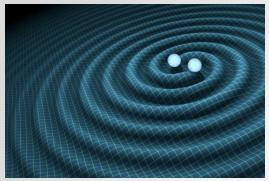
Credit: LISA L3 Mission Concept Proposal



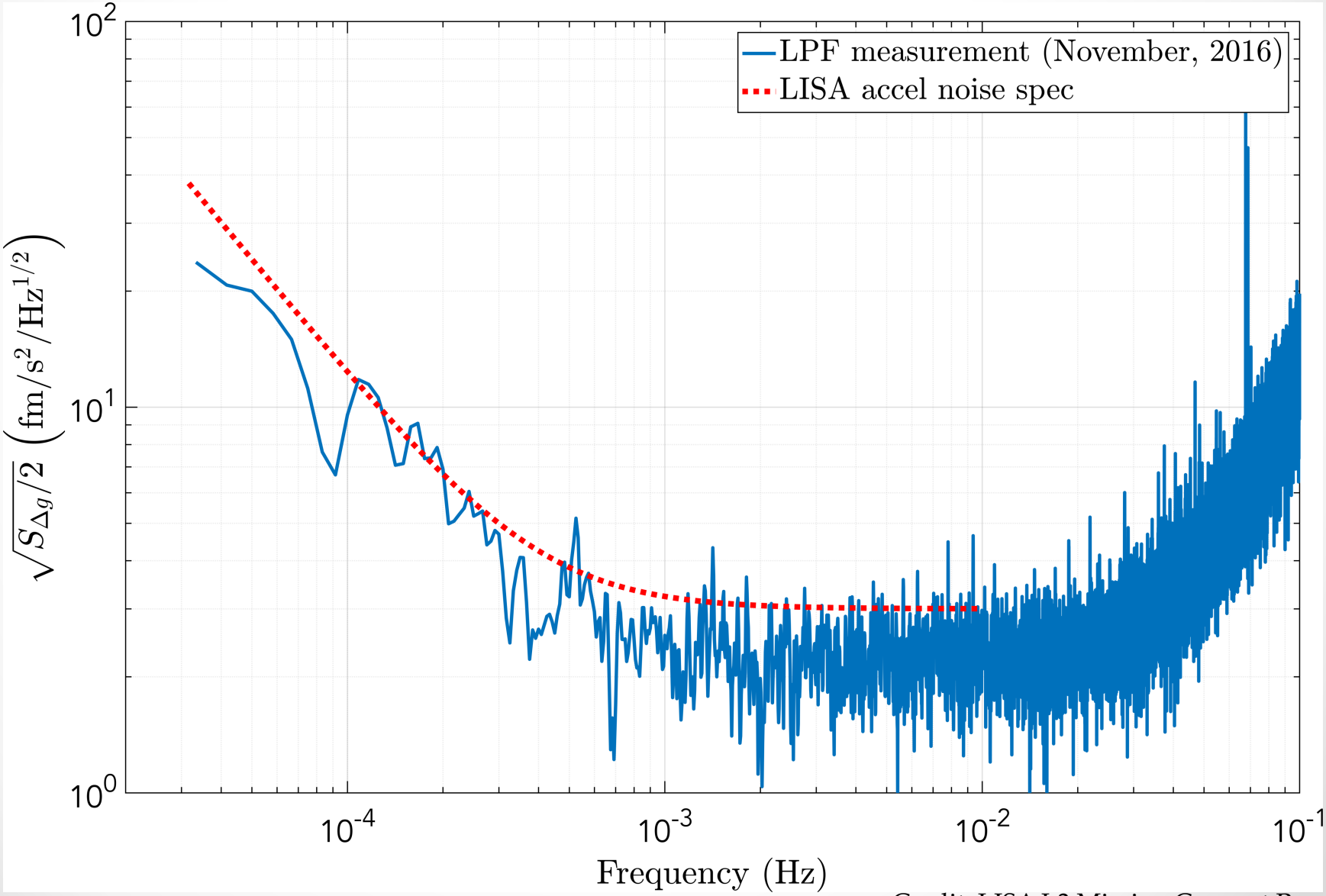
Gravitational Sensor (as flown on LISA Pathfinder)



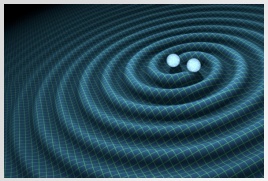
Credit: LISA L3 Mission Concept Proposal



LISA Pathfinder compared to LISA Mission requirements



Credit: LISA L3 Mission Concept Proposal

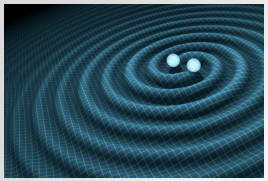


Some requirements, specs

From the LISA L3 Mission Concept Proposal

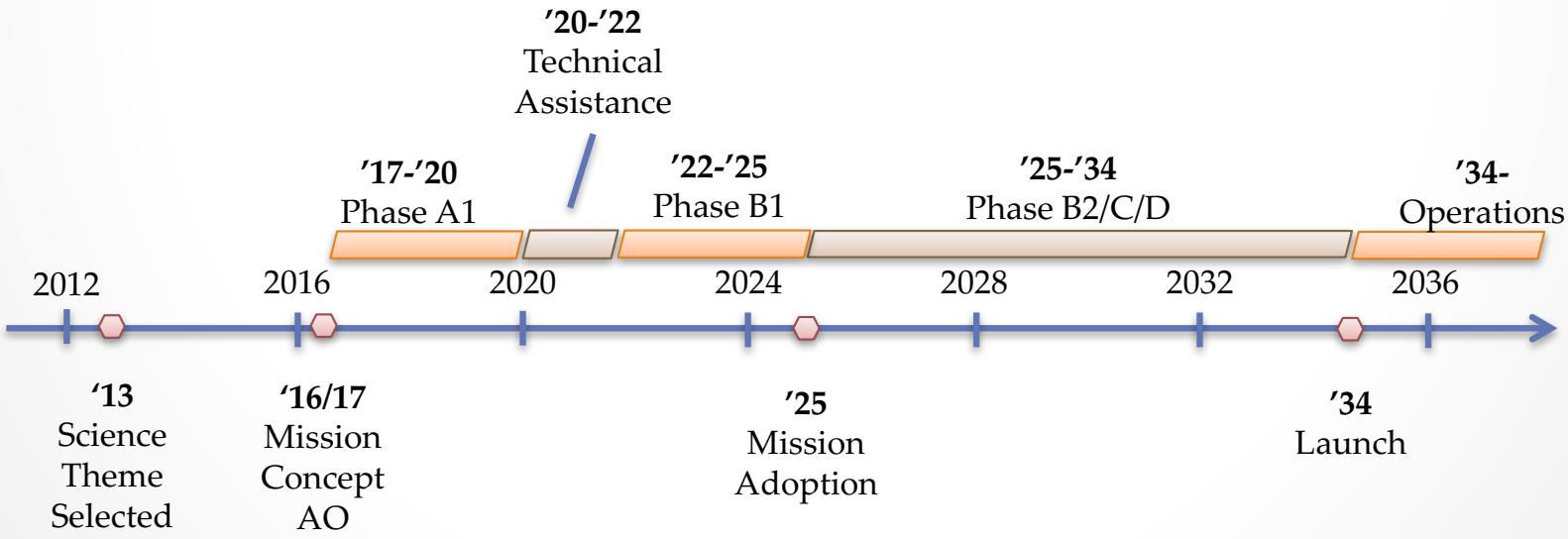
Parameter	Value
Nominal mission duration	4 years
Extended mission duration	10 years
Orbits	3 heliocentric orbits
Transfer time	< 18 months
Range to Earth	50-65 Gm
Arm length	2.5 Gm
Number of Links	6 links/3 arms
Measurement Bandwidth	Req: 100 μHz $\leq f \leq$ 0.1 Hz
	Goal: 20 μHz $\leq f \leq$ 1 Hz
S/C Power Requirements	$\leq$ 760 W
Laser Power	2 W (out of the fiber)
Telescope Diameter	30 cm
System wavefront quality	λ/20 RMS
Data latency	< 1 day
Communication Needs	334 MB/day

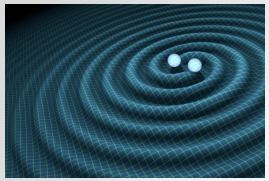
Item	Mass [kg]
Ariane 6.4 Launch Capacity	7000.0
Total Launch Mass	**6076.3**
Stack and Launch Adapter	500.0
Wet Stack Mass	5576.3
Total Propellent	2050.0



What's the Roadmap for LISA?

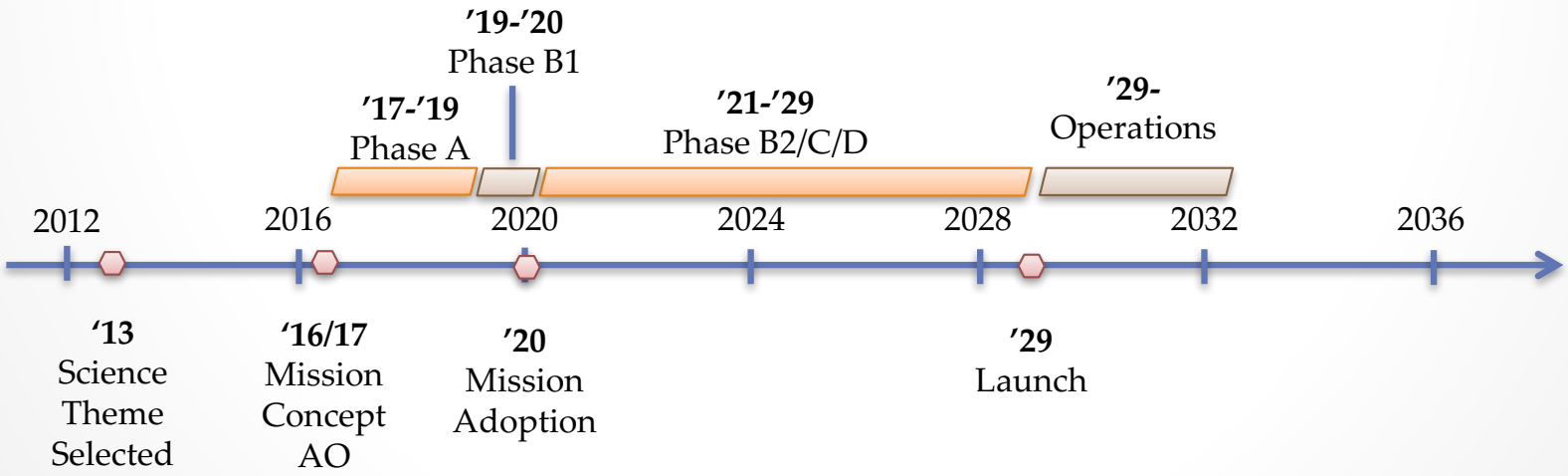
- Nominal timeline, From ESA's Gravitational Observatory Assessment Team (GOAT) Final Report
- http://sci.esa.int/cosmic-vision/57910-goat-final-report-on-the-esa-l3-gravitational-wave-mission/

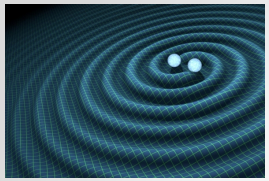




Possible Faster Timeline

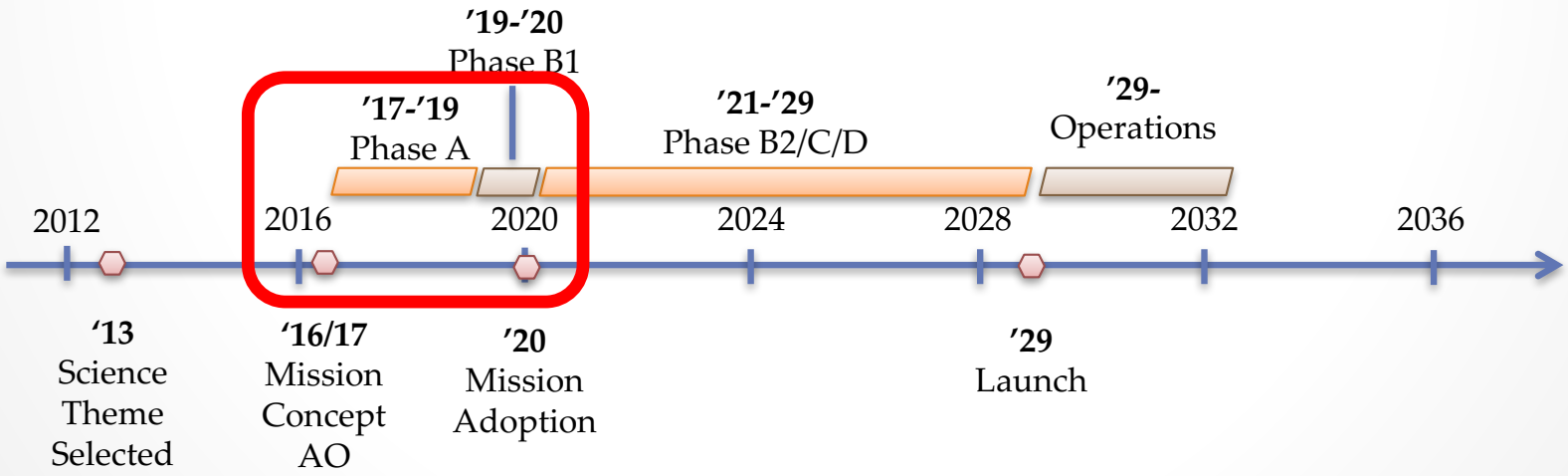
- From an unpublished GOAT Special Report, requested by ESA:
- What is the fastest credible schedule from a technical perspective?

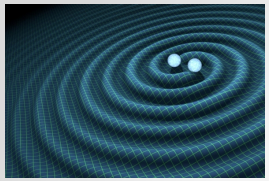




Possible Faster Timeline

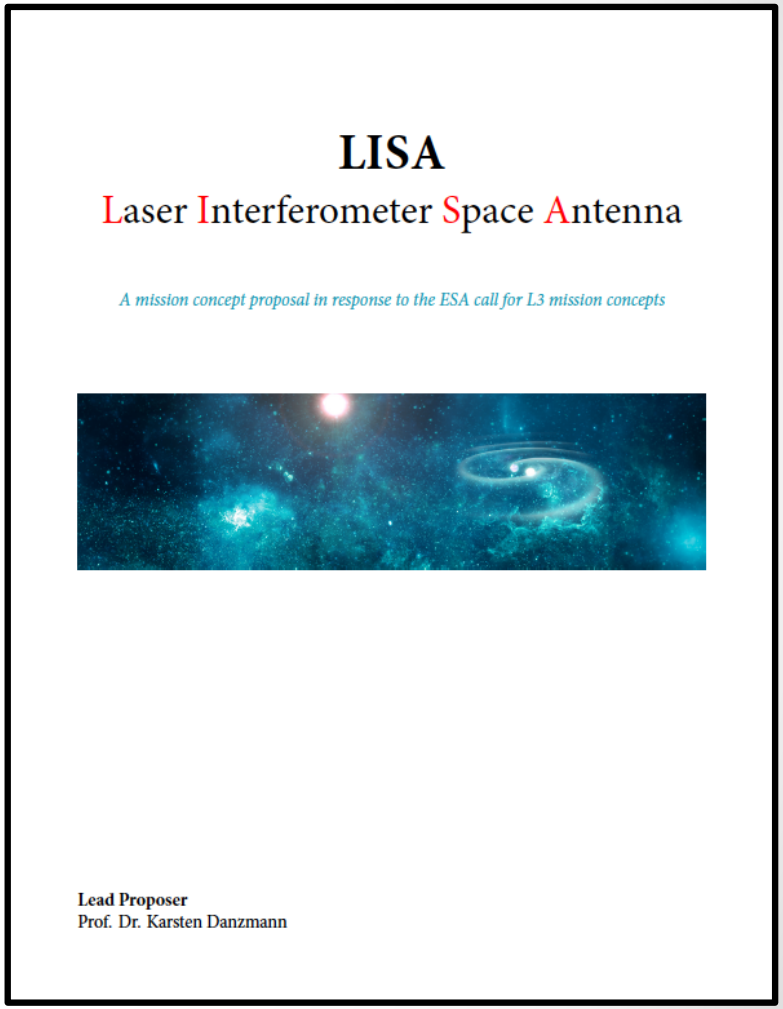
- From an unpublished GOAT Special Report, requested by ESA:
- What is the fastest credible schedule from a technical perspective?





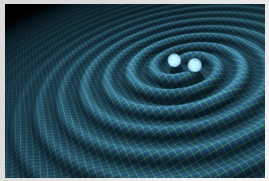
Near-term priorities: Response to ESA Call

- ESA Call issued Oct 25, 2016
  - Mission to fulfill Gravitational Universe science theme
  - 1.05B€ ESA cost cap, plus…
  - Contributions from EU states, and…
  - NASA Planning 20% contribution
- LISA consortium proposal in final editing, due Jan. 16, 2017
  - Selection May 2017
- Significant US participation in Consortium leadership and proposal, in both…
  - Science, and…
  - Technology/Mission/Requirements



LISA Consortium website:
http://www.elisascience.org

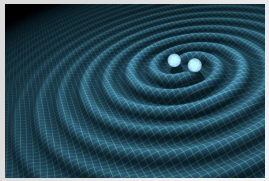
ESA Mission Concept Call Page:
http://www.cosmos.esa.int/web/2016-l3-mission-call



Near-term priorities: Technology Development

- L3ST 'handing off' technology development to the new L3/LISA Study Office
- NASA will Build on past and ongoing work
  - Flight Projects
    - ST7 (Microthrusters & dynamic control systems)
    - LRI on GRACE-FO (Phase measurement & Long-baseline interferometry)
  - SR&T activities
    - Lasers, telescopes, thrusters, phasemeters, & optical structures.
- Hope some activity will go to the greater US LISA Community of Technologists!
- ESA stepping up also – Invitations to Tender out
- Objective: attempt the earlier Timeline

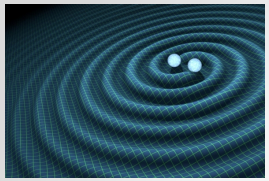
http://pcos.gsfc.nasa.gov/studies/L3/L3ST_Interim_Report-Final.pdf



Near-term priorities: Science Analysis Development

- Pursue new ideas in Science
  - Identify 'Science Gaps' – where do we know we don't know things?
  - First draft of that in a (so-far) internal L3ST document
  - Talk with larger observational and theory community to identify common projects, joint observations, theories to confirm
- Raise the 'TRL level' of the simulation and analysis tools
  - Develop a common LISA analysis environment
  - Carry out detailed Mock LISA Data Challenges (MLDC)
  - Develop data quality tools from LPF, LIGO etc., EM experience
  - Where possible, share effort with other domains in GW and EM astronomy
- Support the Phase A iterations on the mission requirements
- Support the Technology Development as needed

- These are all core L3ST activities -



Near-term priorities: Science Advocacy

- Expand the community actively involved in LISA
  - Next L3ST in-person meeting Jan 31 afternoon (at APS meeting, DC)
  - Let me – dhs@mit.edu – know if you would like to attend https://pcos.gsfc.nasa.gov/studies/L3
- The current NASA L3ST and TAG:

  John Baker, Pete Bender, Emanuele Berti, John Conklin, Neil Cornish, Curt Cutler, Kelly Holley-Bockelman, Scott Hughes, Shane Larson, Sean McWilliams, Cole Miller, Norna Robertson, David Shoemaker, Ira Thorpe, Michele Vallisneri, Jordan Camp, Bill Klipstein, Jeff Livas, Kirk McKenzie, Guido Mueller, John Ziemer
  - Working closely with NASA HQ
  - In the context of the ~340-person LISA Consortium

LISA: a completely new tool for the astronomer's and astrophysicist's toolbox