

LISA:  
Opens the low-frequency  
gravitational universe!



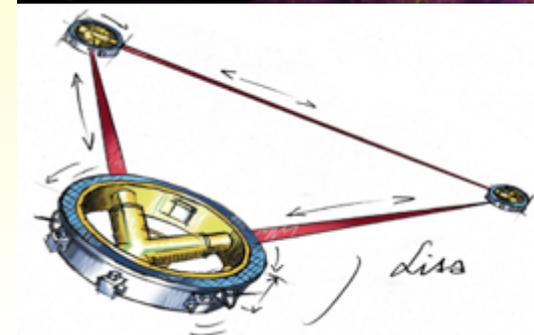
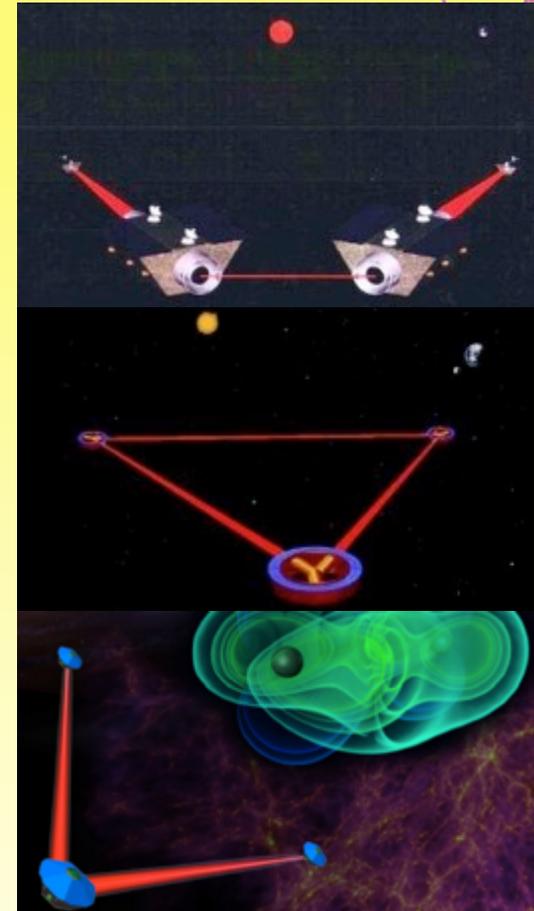
# 22 Years after the First LISA Symposium at RAL 1996



# LISA: A Mature Concept



- M3 proposal for 4 S/C ESA/NASA collaborative mission in 1993
- LISA selected as ESA Cornerstone in 1995
- 3 S/C ESA/NASA LISA appears in 1997
- Joint ESA-NASA Mission Formulation study 2005-2011
- Reformulation 2012-13 as ESA-led eLISA (evolving LISA)
- Now back to 3-arm LISA with NASA



# But then in March 2011...



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Published online 22 March 2011 | *Nature* **471**, 421 (2011) | doi:10.1038/471421a

**News**

## Europe makes do without NASA

### US budget crisis forces European Space Agency to abandon plans for joint mission.

**Stories by keywords**

- [European Space Agency](#)
- [L-Class missions](#)
- [LISA](#)
- [IXO](#)
- [ESJM-Laplace](#)

The European Space Agency (ESA) is pushing ahead without NASA support for its next big science mission, as the ongoing US budget crunch and competing priorities impose serious constraints on the US space agency (see [Nature 471, 278; 2011](#)). ESA last week told leaders of three large, or 'L-class', missions that are competing for funding to revise their proposals by leaving out the substantial US contribution that had previously been assumed.

"The decision was made very reluctantly," says David Southwood, director of science and robotic exploration at ESA. "NASA could not meet our timetable to launch."

22 April 2011

- [China hopes research centre can quell food-safety fears](#)  
22 April 2011

**Related stories**

- [US Mars mission takes pole position](#)  
08 March 2011
- [ESA on countdown to flagship mission selection](#)

**This article elsewhere**

[Blogs linking to this article](#)

# Then came 2015/2016....



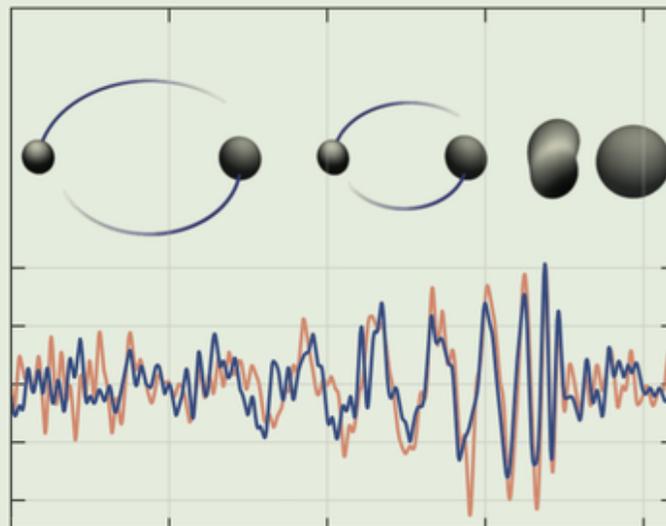
- And two things happened!



# PHYSICAL REVIEW LETTERS™

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Articles published week ending 12 FEBRUARY 2016

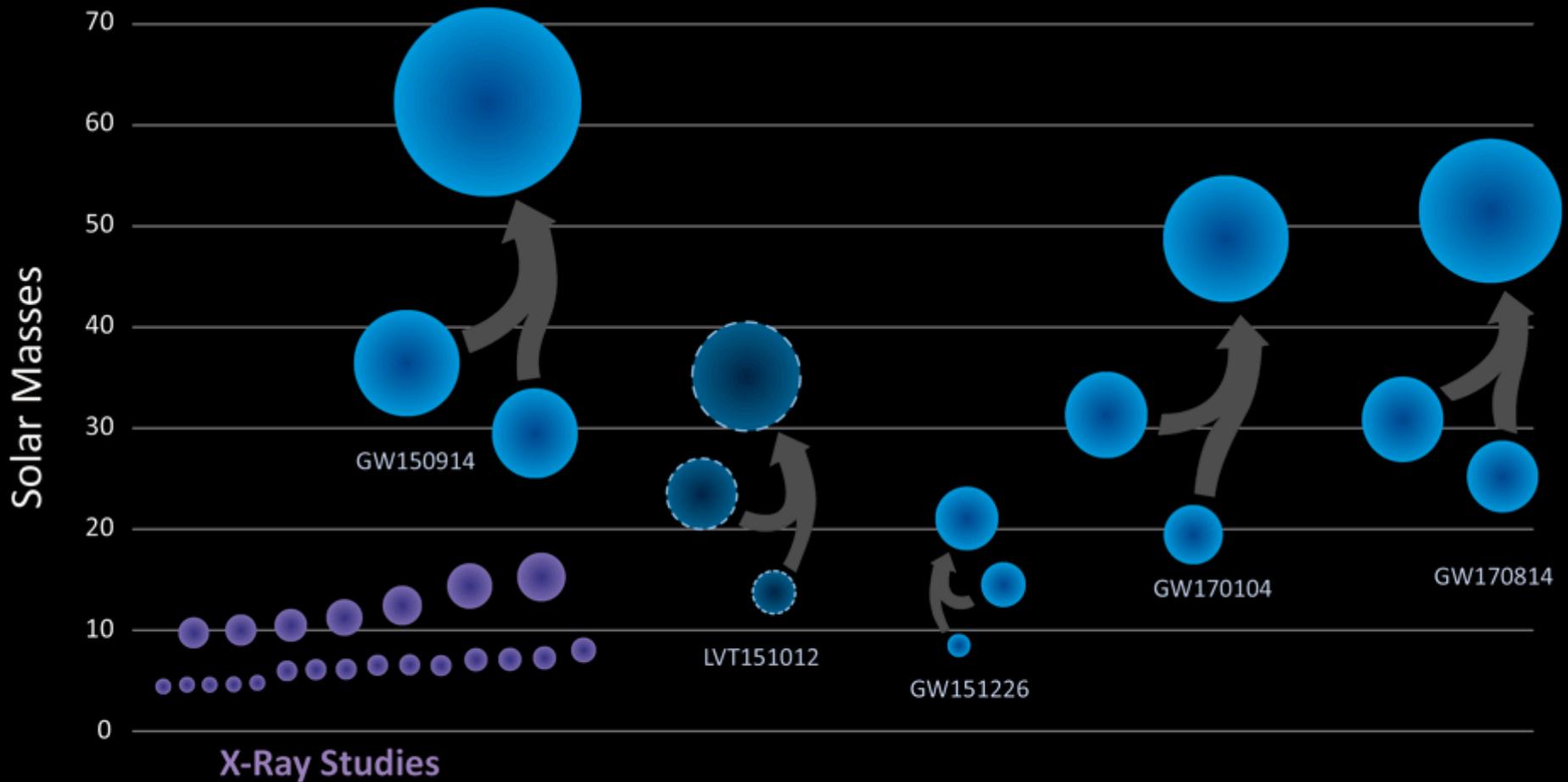


Published by  
**American Physical Society™**



Volume 116, Number 6

# Black Holes every Month!



Credit: LIGO/Caltech/Sonoma State (Aurore Simonnet)

# LISA Pathfinder

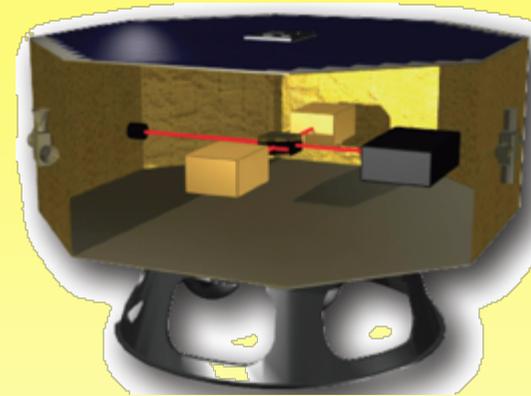


- Testing LISA technology in space!

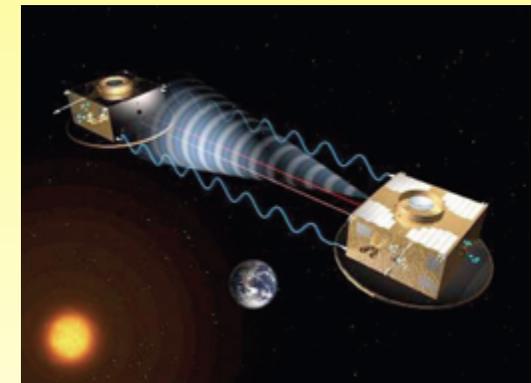
# First Proposed in 1998 as ELITE



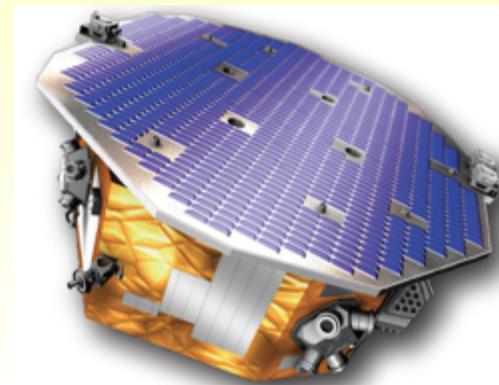
- European LISA Technology Satellite



- Renamed to SMART-2 in 2000
  - Tech demo for LISA and Darwin
  - Launch date 2006



- Descoped to LISA Pathfinder
  - Darwin demo cancelled



17 years later!  
September  
2015:  
Spacecraft is  
completed!



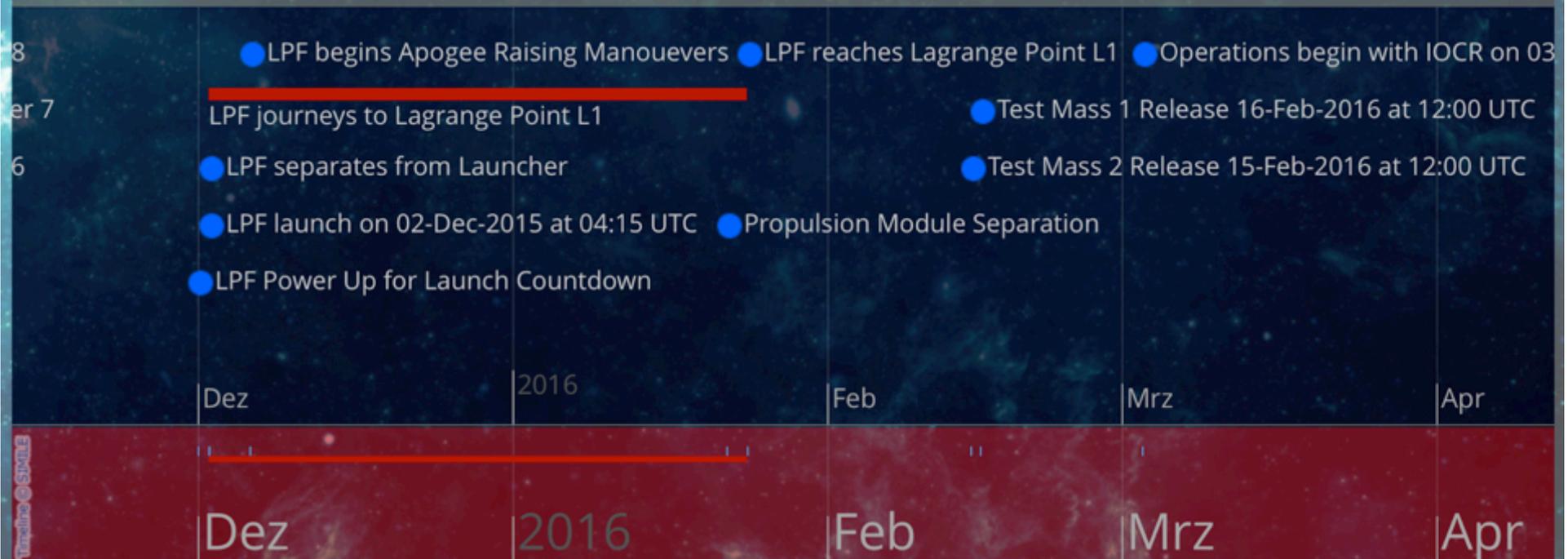
# 100 Years since GR Publication: Dec. 2, 2015



Countdown to LPF Launch

## LPF has launched!

### LISA Pathfinder Mission Timeline

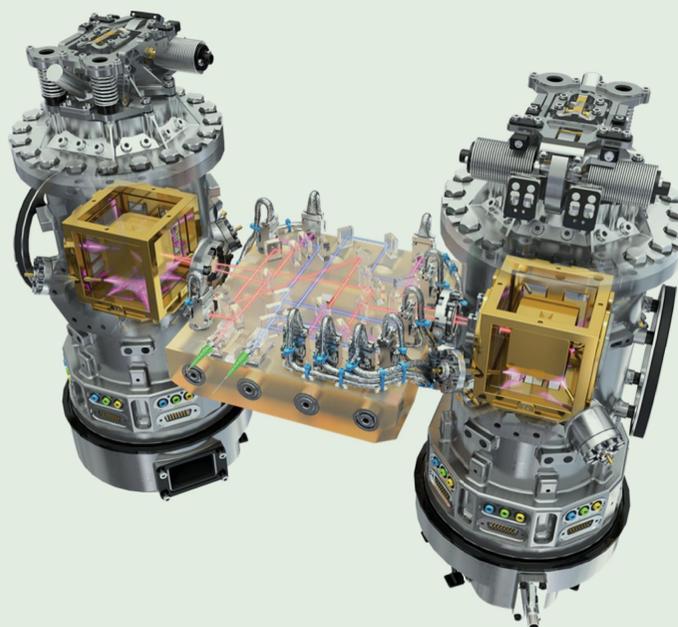




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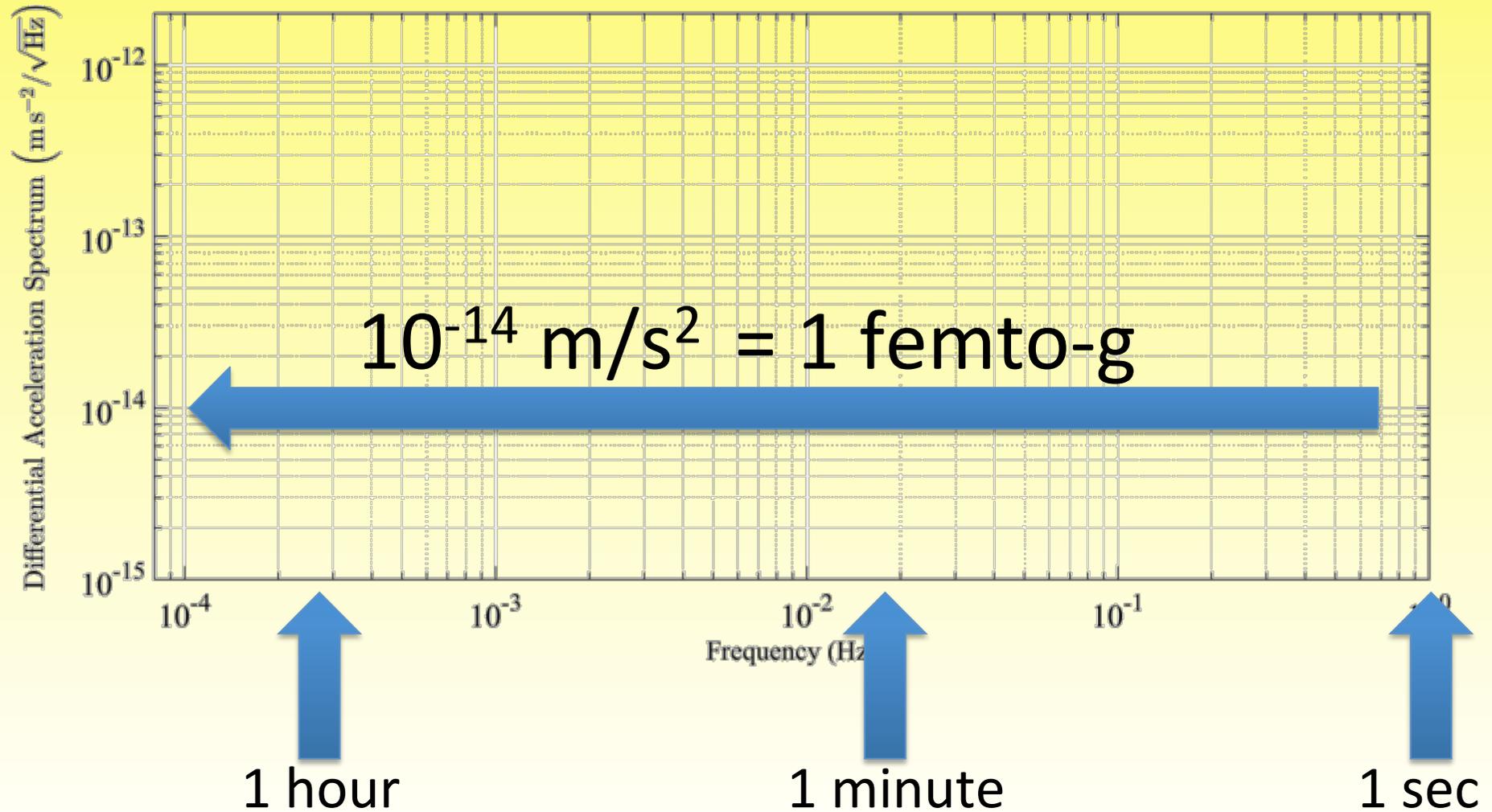


Published by  
**American Physical Society**

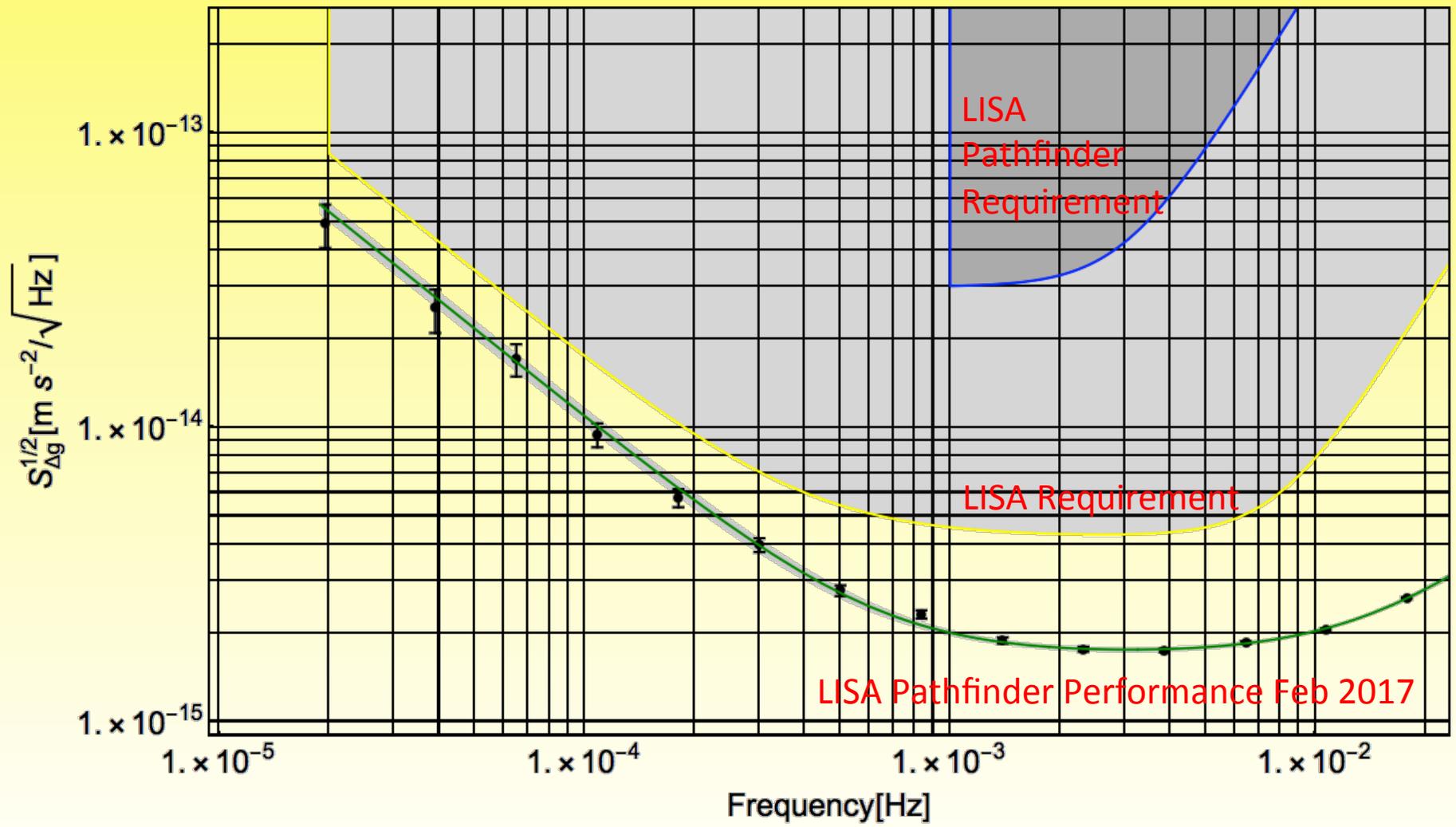


Volume 116, Number 23

# Acceleration Spectrum



# LISA Pathfinder shows: LISA Works!

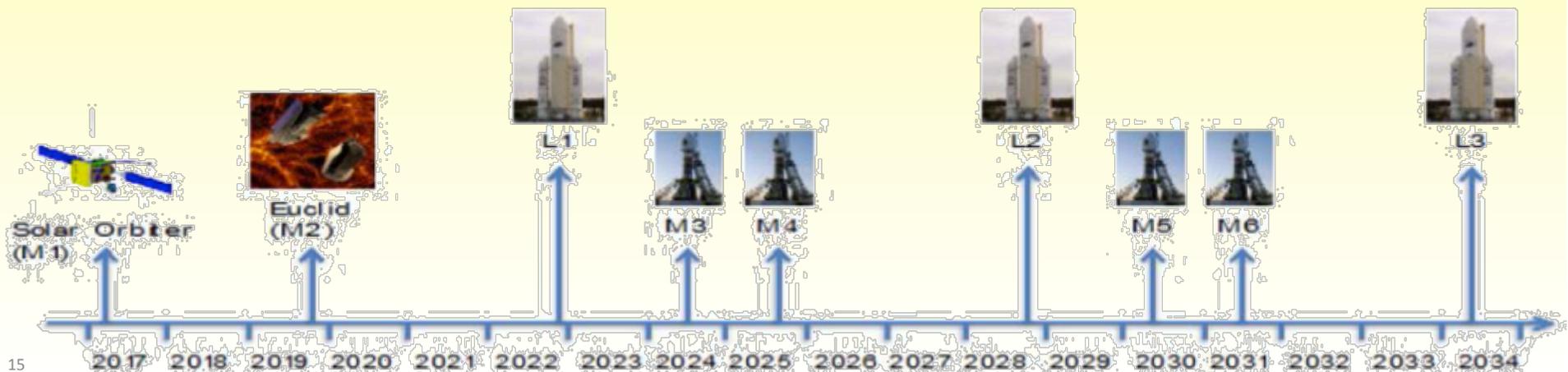


LISA Pathfinder Performance Feb 2017

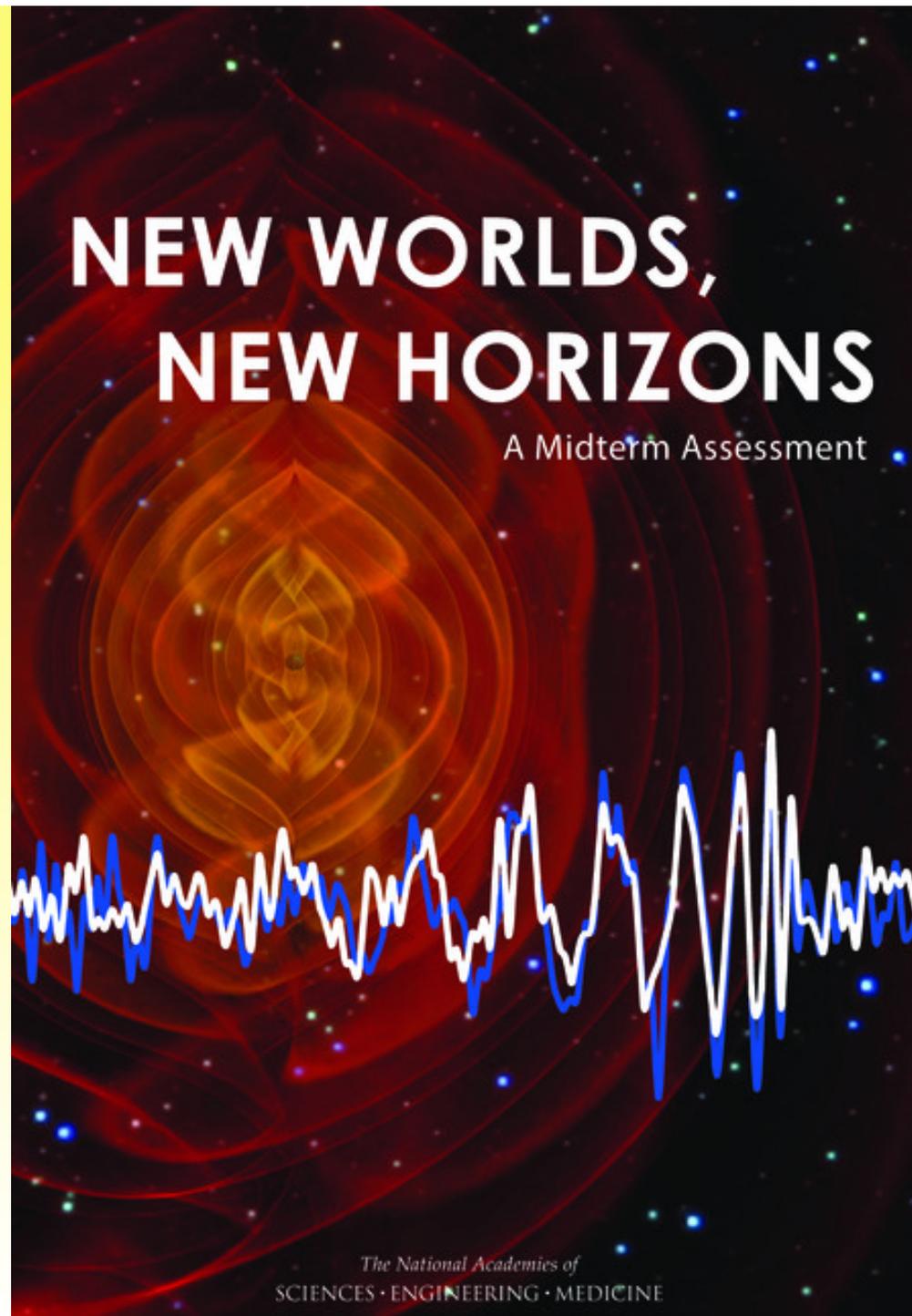
# ESA L2 and L3 Missions



- Call for Mission Concepts fall 2016



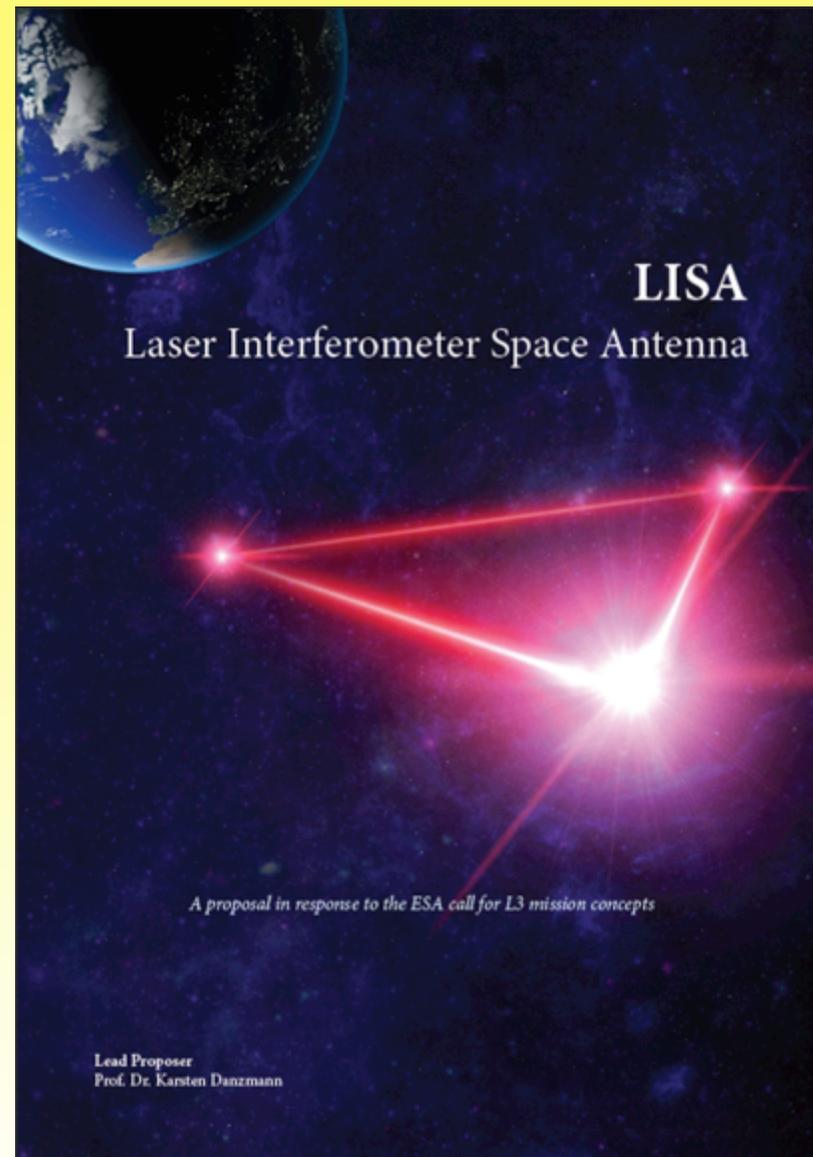
NASA is  
back in  
LISA!



# LISA Mission Concept Document



- Submitted on January 13th, 2017
- The LISA Consortium:  
12 EU Member States  
plus the US !

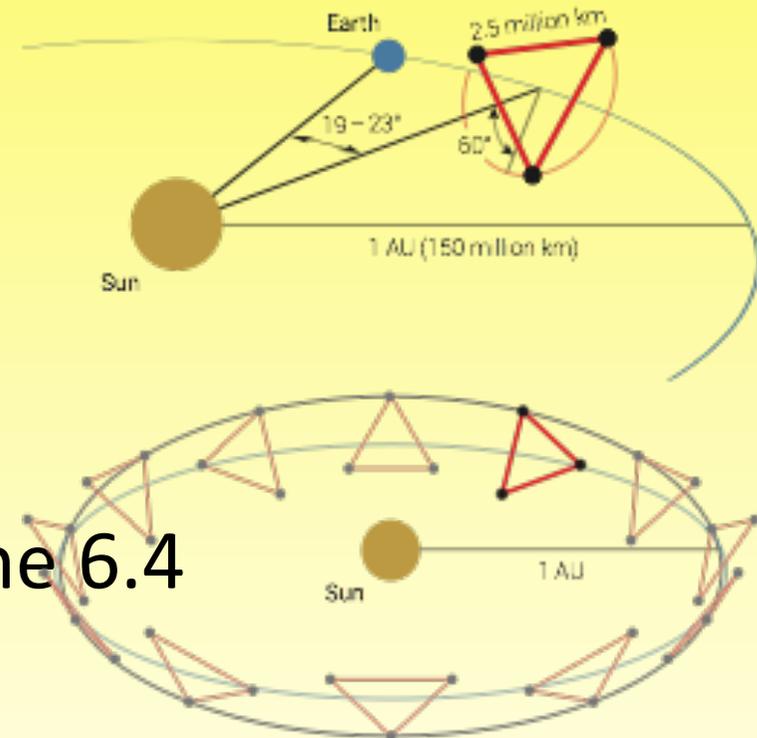


<https://www.lisamission.org/proposal/LISA.pdf>

# Mission Profile and Orbit



- Three arms of 2.5 Million km
- 2W lasers
- 30 cm telescopes
- Breathing angles  $\pm 1$  deg
- Doppler shifts  $\pm 5$  MHz
- Launch on dedicated Ariane 6.4
  - Transfer time  $\sim 400$  days
  - Direct escape  $V_{\infty} = 260$  m/s
  - Propulsion module and S/C composite



# ESA Member State Involvement



- Traditionally:
  - ESA: spacecraft bus
  - ESA member state agencies: science instrument
- In old ESA/NASA LISA:
  - Payload was European contribution paid for by ESA
  - Different from other L1 mission candidates
- In L3 LISA:
  - Use traditional approach of national consortium

# What is the instrument on LISA?

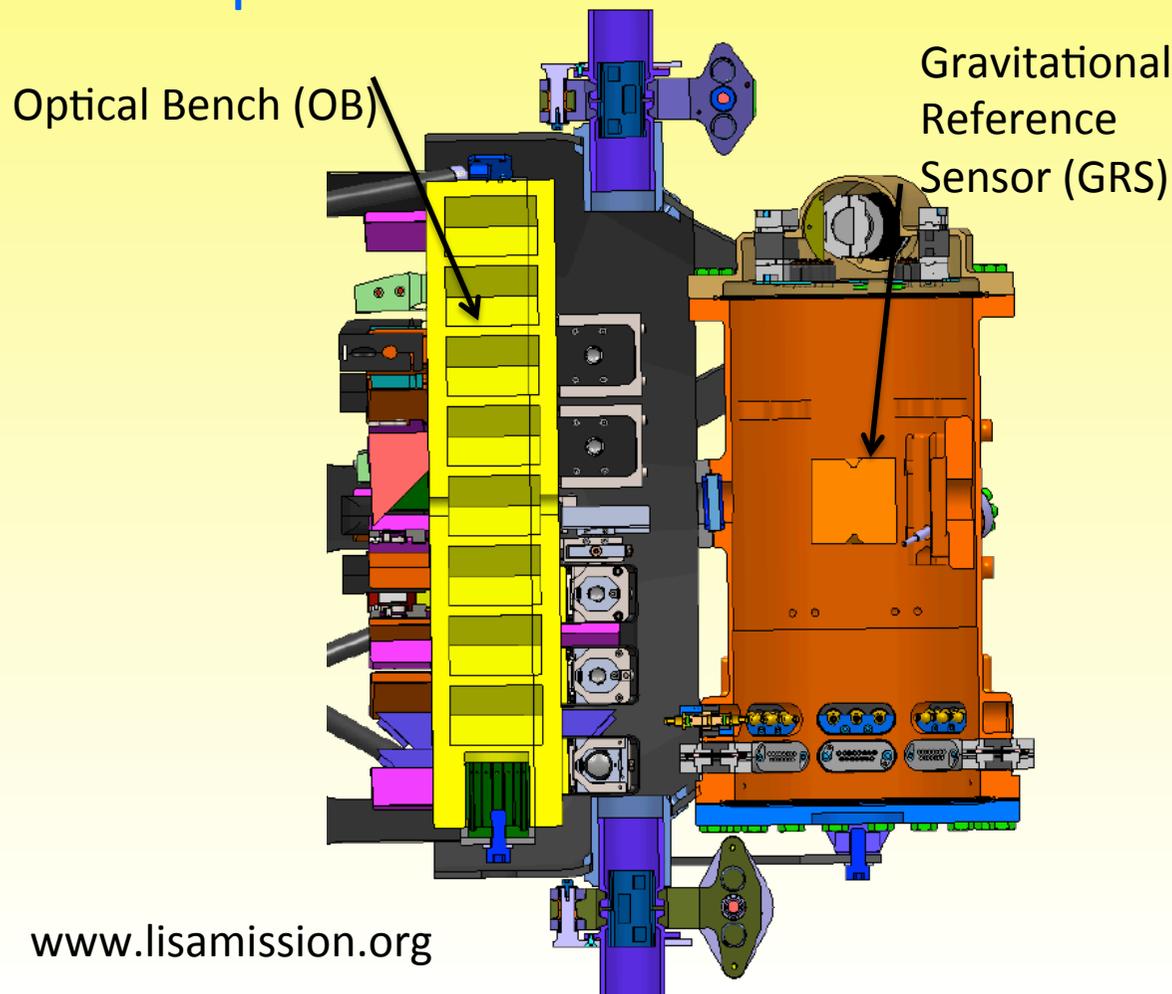


- Treat like focal plane instrument for Astronomy mission
- ESA responsible for:
  - Satellite platform, including:
    - Telescope, laser and structure for optical assembly mounting
- Member States fund:
  - Scientific consortium to deliver instrument consisting of:
    - Optical Bench with attached Inertial Sensor and detached Phasemeter, Payload Computer

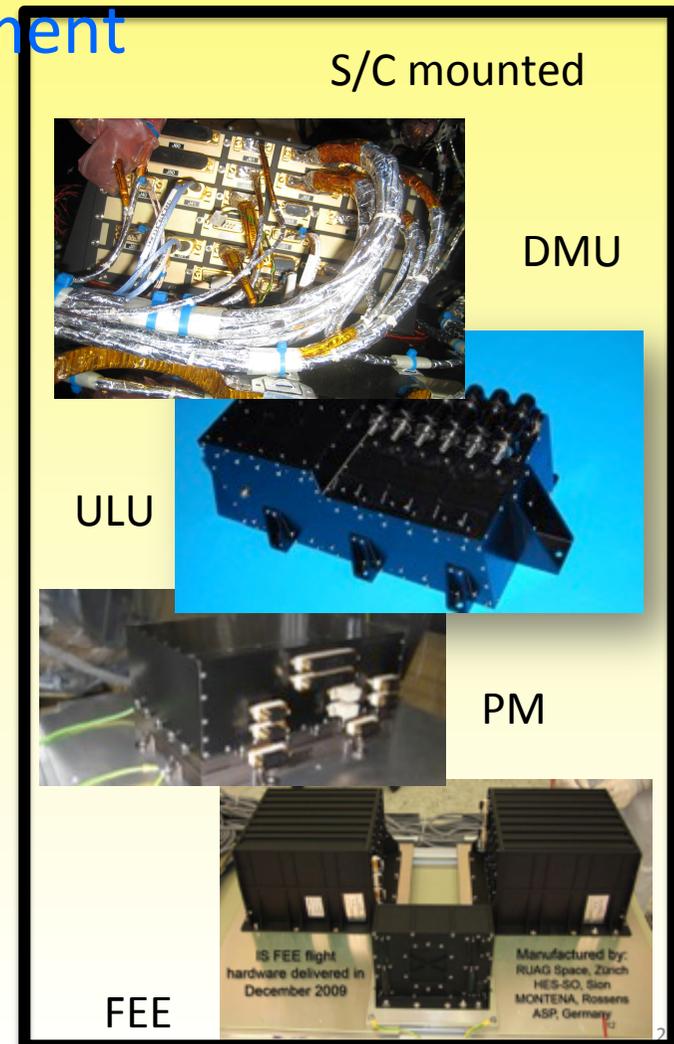
# The Science Instrument



- Provided by LISA Consortium (D, F, I, UK, ES, CH, DK, NL, SE, PT, HU, RO) plus USA
- Also provided LISA Pathfinder Instrument



[www.lisamission.org](http://www.lisamission.org)





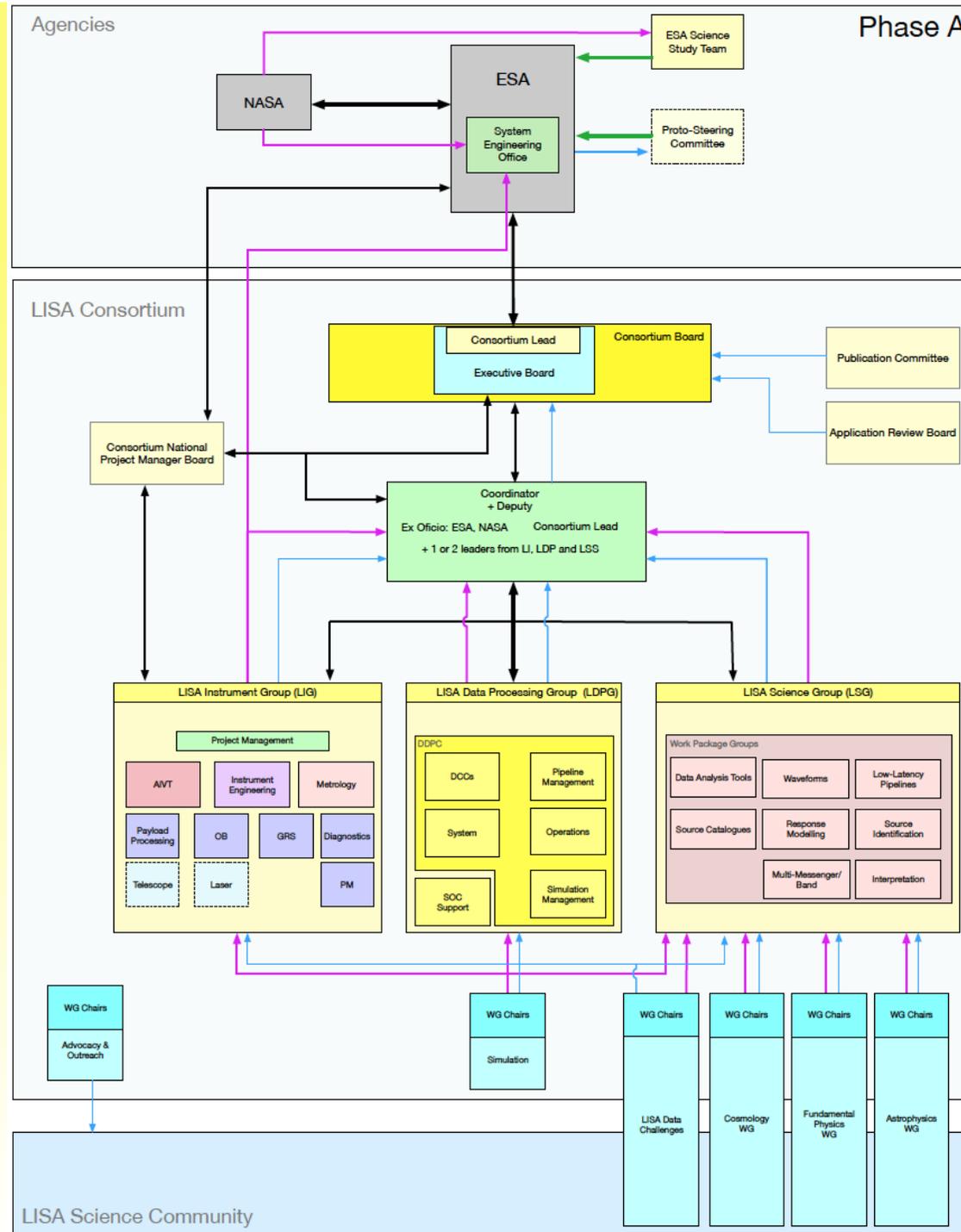
## Laser Interferometer Space Antenna

Ref : LISA-LCST-MIS-PL-001	
Issue : 1	Revision : 0
Date : 2018/02/15	Page : 1/ 23

# LISA Consortium Management Plan

<b>N/Ref :</b>	LISA-LCST-MIS-PL-001
<b>Title</b>	<b>LISA Consortium Management Plan</b>
<b>Abstract</b>	LISA Consortium Management plan.

# LISA Organigram in Phase A



# ESA SPC selected LISA as L3 !



cosmic vision



ESA

SCIENCE & TECHNOLOGY

COSMIC VISION

## Missions

- Show All Missions

## Cosmic Vision 2015–2025

- Cosmic Vision
- Candidate Missions
- M-class Timeline
- L-class Timeline

## Cosmic Vision themes

- The Hot and Energetic Universe
- Planets and Life
- The Solar System
- Fundamental Laws
- The Universe

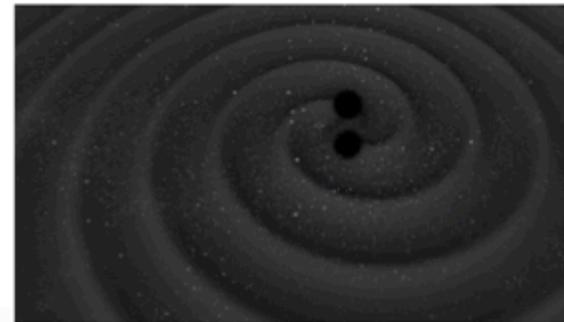
## GRAVITATIONAL WAVE MISSION SELECTED, PLANET-HUNTING MISSION MOVES FORWARD

20 June 2017

**The LISA trio of satellites to detect gravitational waves from space has been selected as the third large-class mission in ESA's Science programme, while the PLATO exoplanet hunter moves into development.**

These important milestones were decided upon during a meeting of ESA's Science Programme Committee today, and ensure the continuation of ESA's [Cosmic Vision](#) plan through the next two decades.

The '[gravitational universe](#)' was identified in 2013 as the theme for the third large-class mission, L3, searching for ripples in the fabric of spacetime created by celestial objects with very strong gravity,



Search here

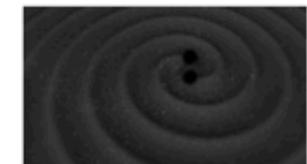


9-Jul-2017 18:39 UT

## Shortcut URL

<http://sci.esa.int/jump.cfm?oid=59243>

## Images And Videos



- Merging black holes
- Searching for exoplanetary systems

# Start of Phase 0: CDF Study



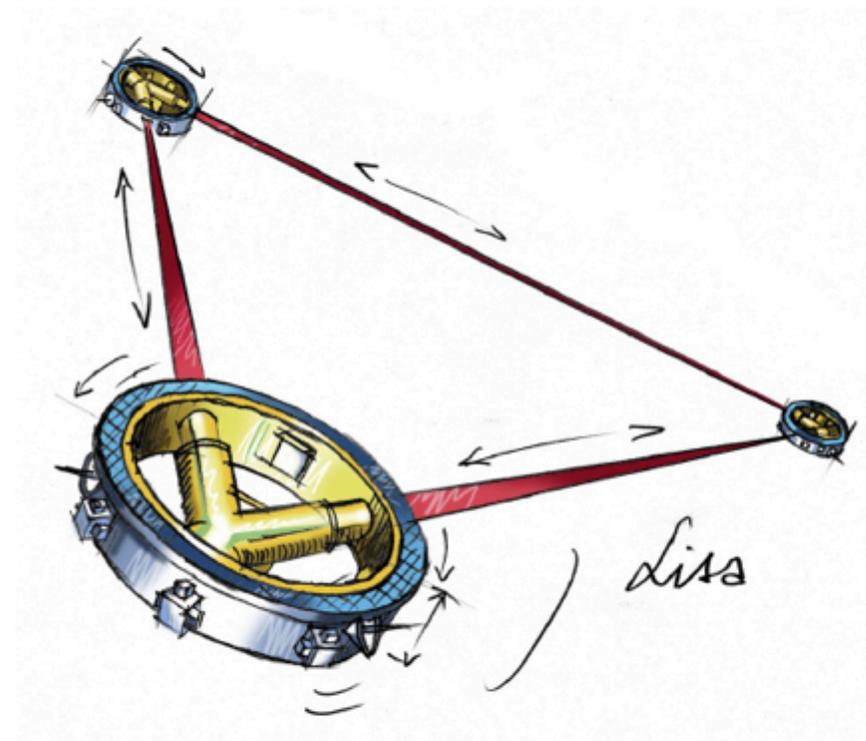
## LISA Study Introduction

**Systems**

**Session 1**  
**ESTEC, 08-03-2017**

Prepared by the CDF\* Team

(\* ) ESTEC Concurrent Design Facility



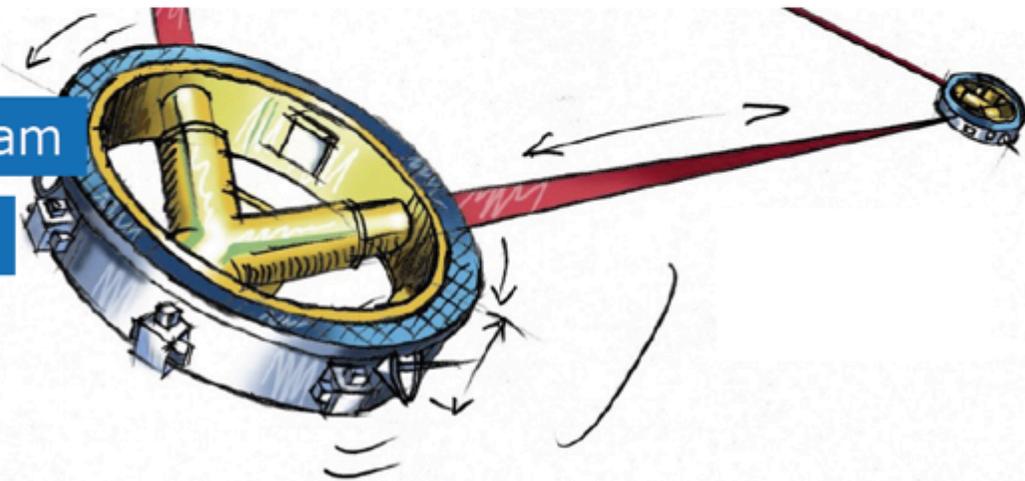
# ESA and NASA are in it together!



## L3/LISA ESA-NASA Technical Interface Meeting #1

L3 Study Team

04/05/2017



ESA UNCLASSIFIED - For Official



European Space Agency

# ITT for LISA Phase A



**Subject:** Invitation to Tender AO/1-9136/17/NL/BW

**Title:** LISA Phase-A System Study for a Gravitational Wave Observatory

**Our ref:** Item no. 17.164.07 in the list of ESA intended Invitations to Tender  
**Item:** E/0600-00 – General Studies Programme  
E/0401-01 – Mission Preparation – Science Programme

Dear Sirs,

The European Space Agency (the Agency) hereby invites you to submit a tender for the above subject.

This Invitation to Tender (ITT) was published on EMITS on **20 December 2017** and consists of four documents as follows:

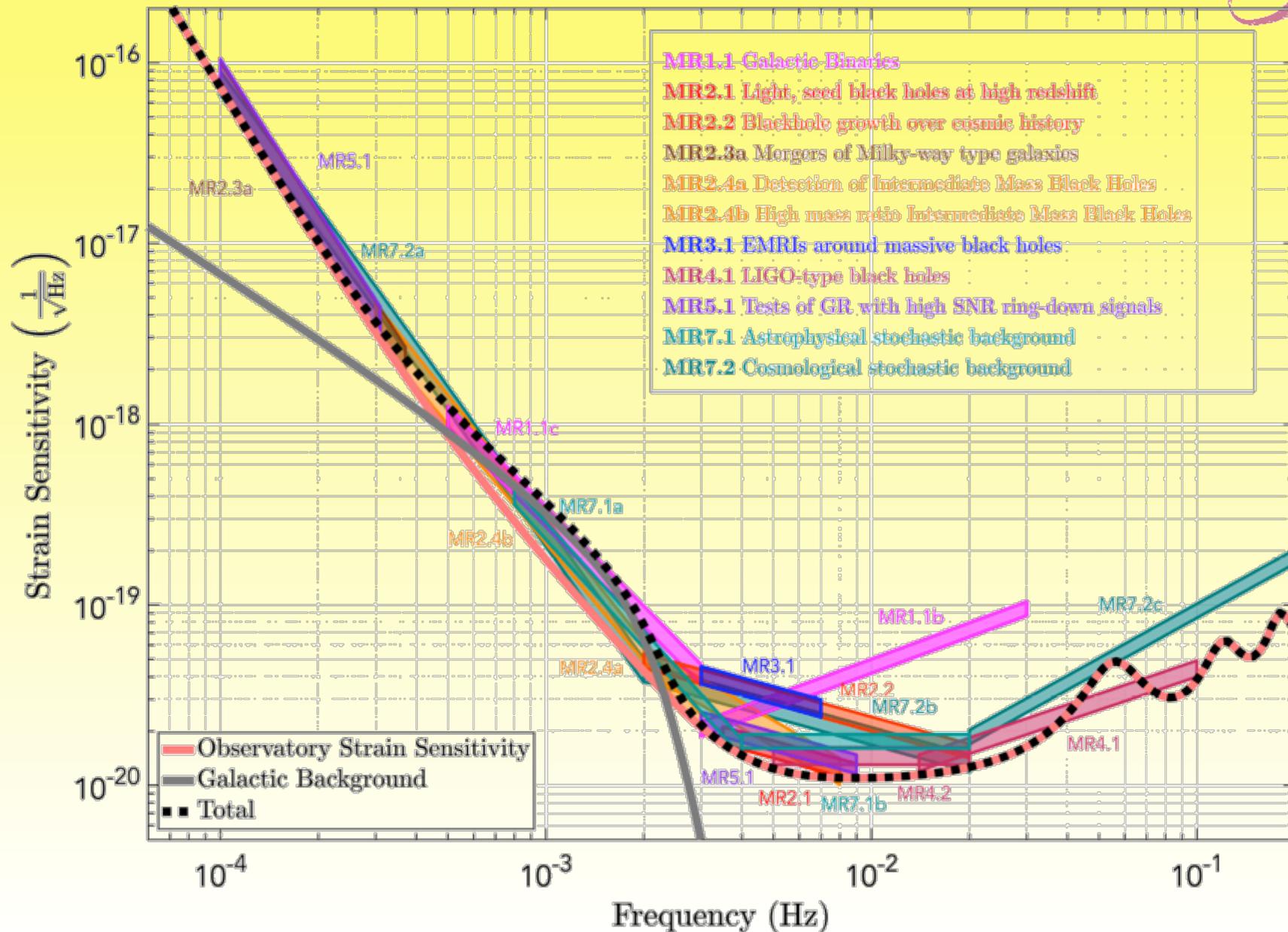


## DESIGN DESCRIPTION

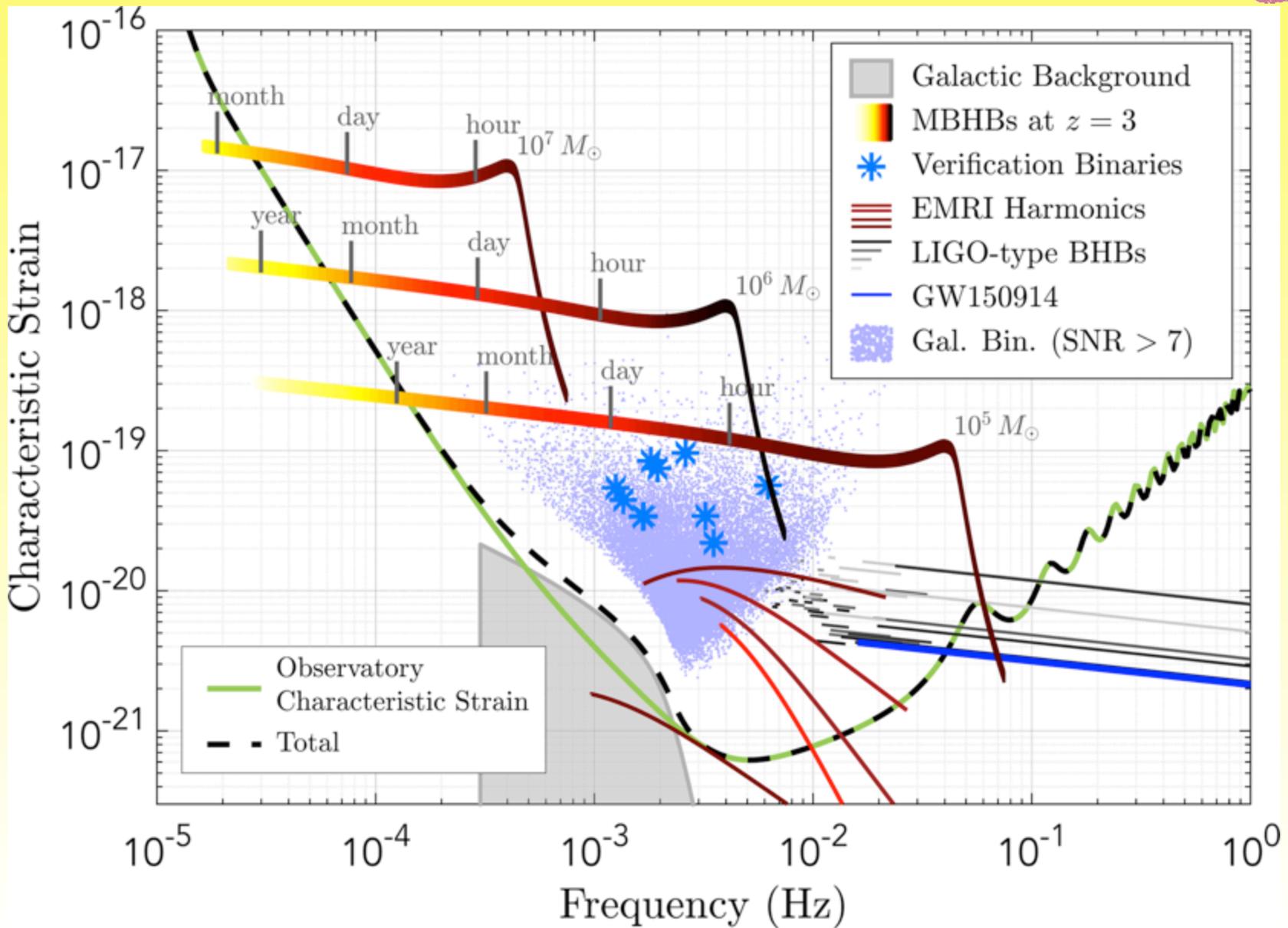
### LISA Payload Description Document

<b>Prepared by</b>	<b>LISA Instrument Group</b>
<b>Reference</b>	<b>ESA-L3-EST-INST-DD-001</b>
<b>Issue/Revision</b>	<b>1.1</b>
<b>Date of Issue</b>	<b>December 4, 2017</b>
<b>Status</b>	<b>Issued</b>

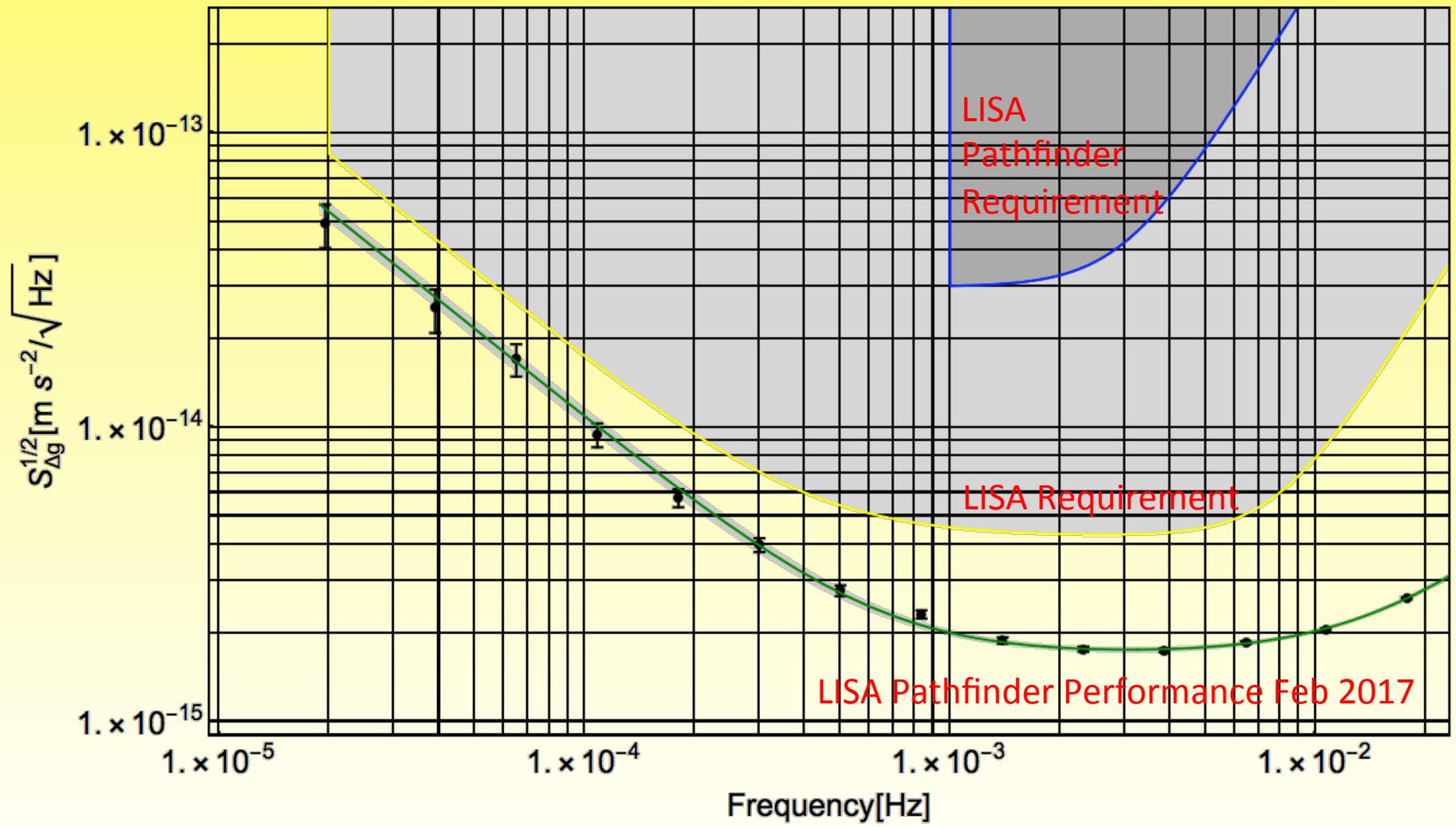
# LISA Requirements



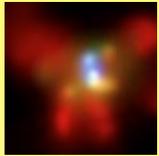
# LISA Sources



# LISA Pathfinder shows: LISA Works!

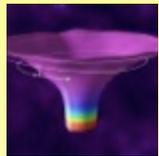


# LISA for Astrophysics, Cosmology, and Fundamental Physics



## Massive Black Holes ( $10^4$ to $10^8 M_{\odot}$ )

- When did the first Black Holes appear in pre-galactic halos and what is their mass and spin?
- How did Black Holes form, assemble and evolve from cosmic dawn to present time, due to accretion and mergers?
- What role did Black Holes play in re-ionisation, galaxy evolution and structure formation?
- What is the precise luminosity distance to loud standard siren black hole binaries?
- What is the distance – redshift relation and the evolution history of the universe?
- Does the Graviton have mass?



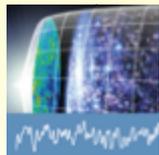
## Extreme Mass Ratio Inspirals, EMRIs ( $1$ to $10 M_{\odot}$ into $10^4$ to $5 \times 10^6 M_{\odot}$ )

- How is the stellar dynamics in dense galactic nuclei?
- How does dynamical relaxation and mass segregation work in dense galactic nuclei?
- What is the occupation fraction of black holes in low-mass galaxies?
- How large are deviations from Kerr Metric, and what new physics causes them?
- Are there horizonless objects like boson stars or gravastars?
- Are alternatives to GR viable, like Chern-Simons or scalar tensor theories or braneworld scenarios?



## Ultra-Compact Binaries in Milky Way

- What is the explosion mechanism of type Ia supernovae?
- What is the formation and merger rate of compact binaries?
- What is the endpoint of stellar evolution?



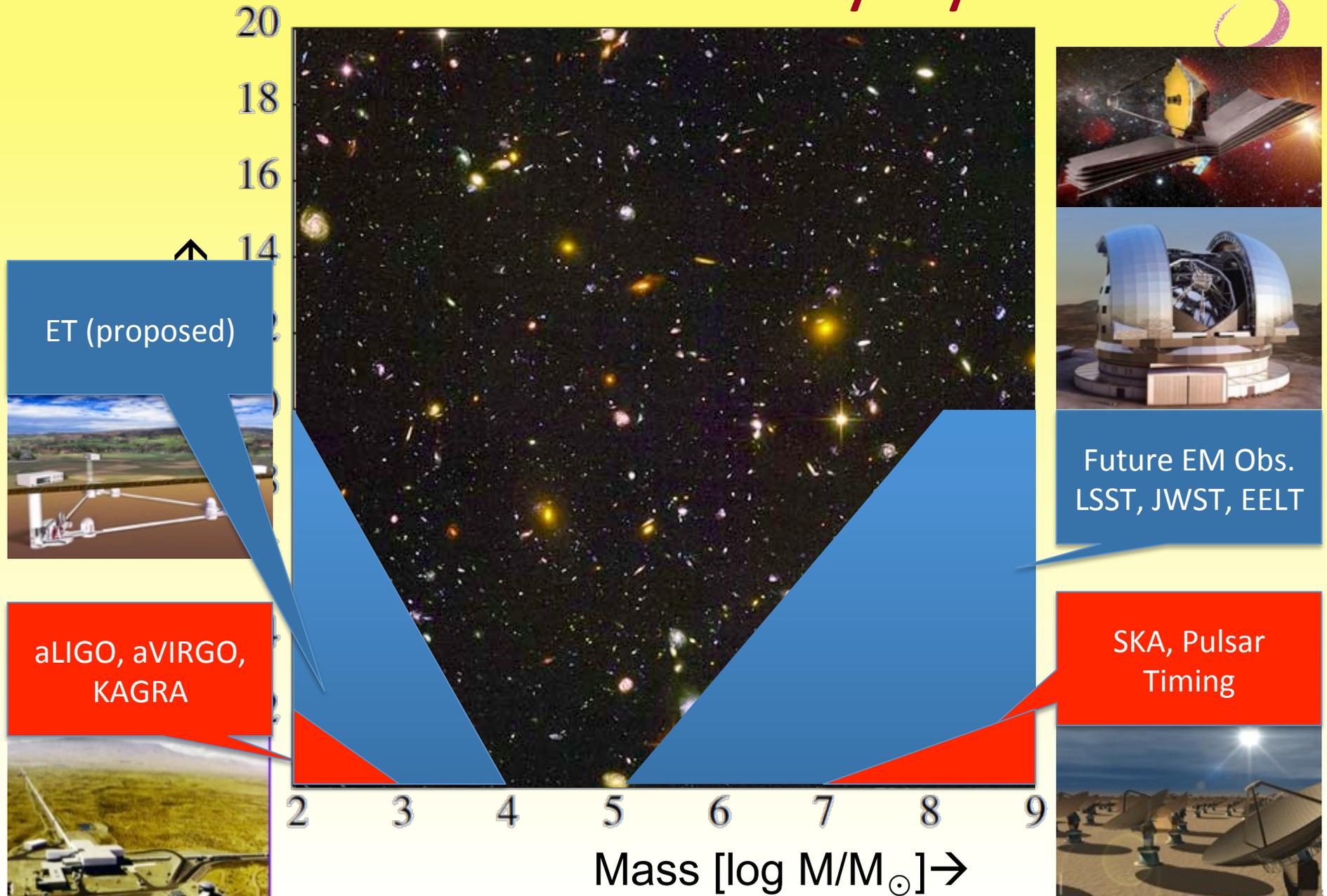
## Stochastic Signals

- Directly probe Planck scale epoch at 1 TeV to 1000 TeV before decoupling of microwave background
- Were there phase transitions and of which order?
- Probe Higgs field self coupling and potential, and search for supersymmetry.
- Are there warped sub-millimetre extra-dimensions?
- Can we see braneworld scenarios with reheating temperatures in the TeV range?
- Do topological defects like Cosmic Strings exist?

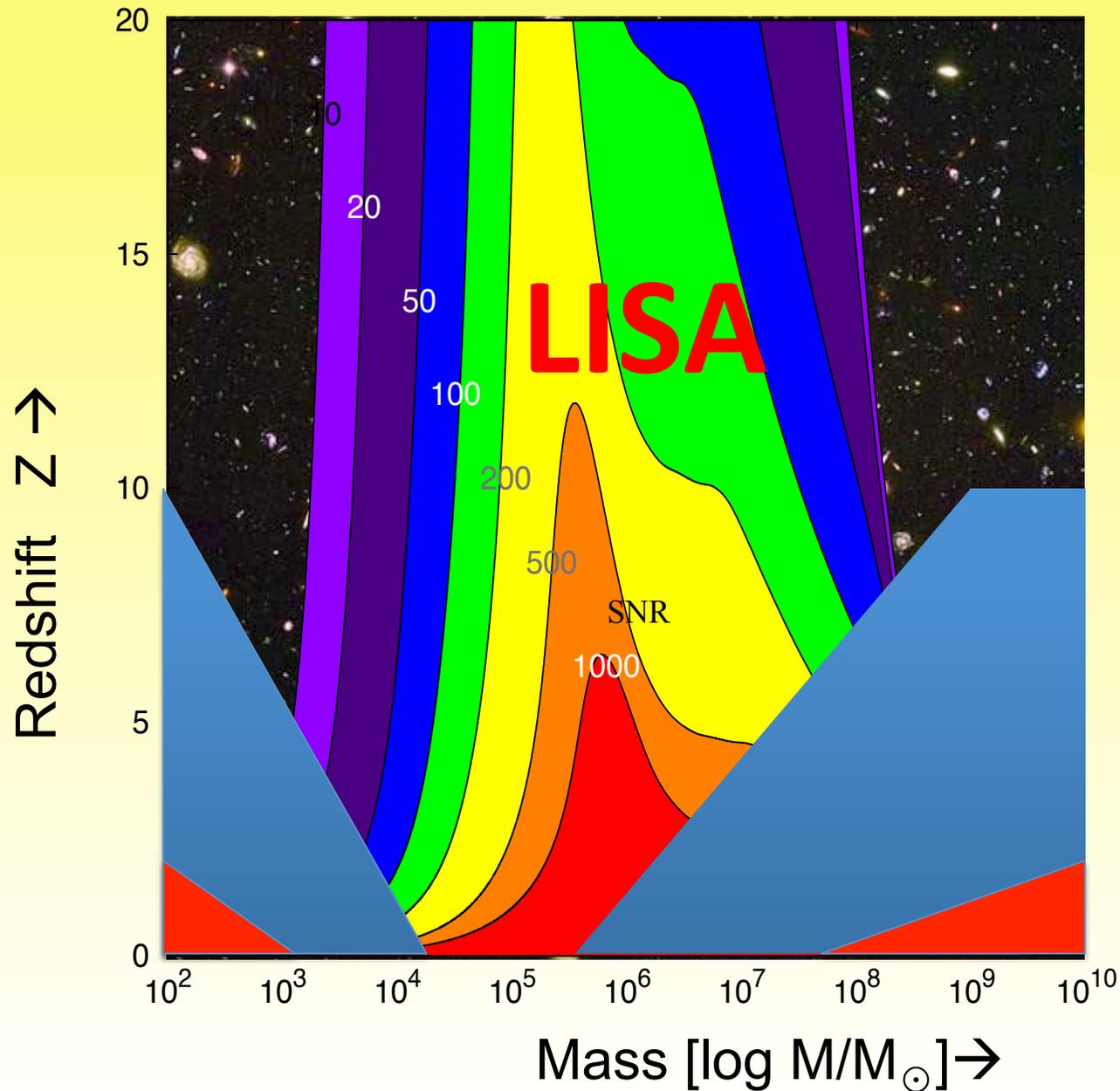
???

## The Unknown !

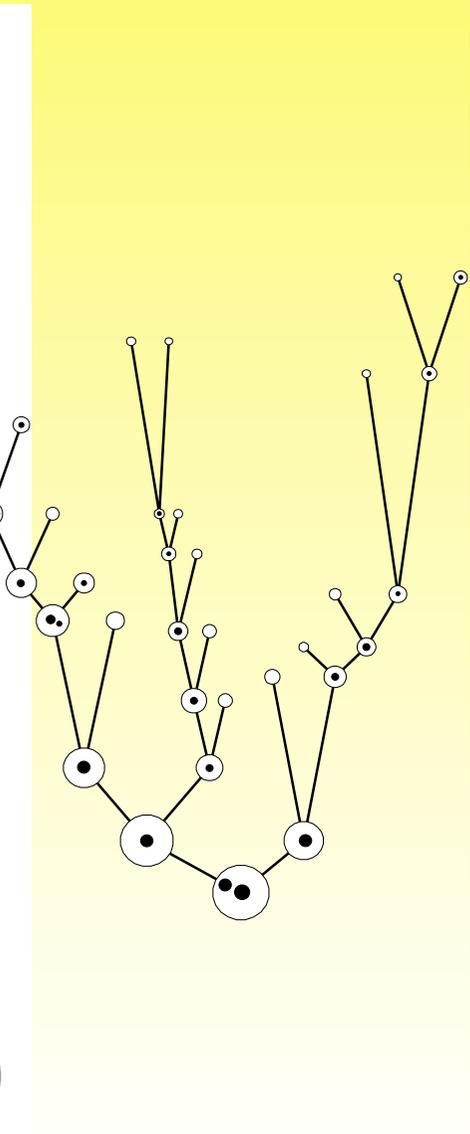
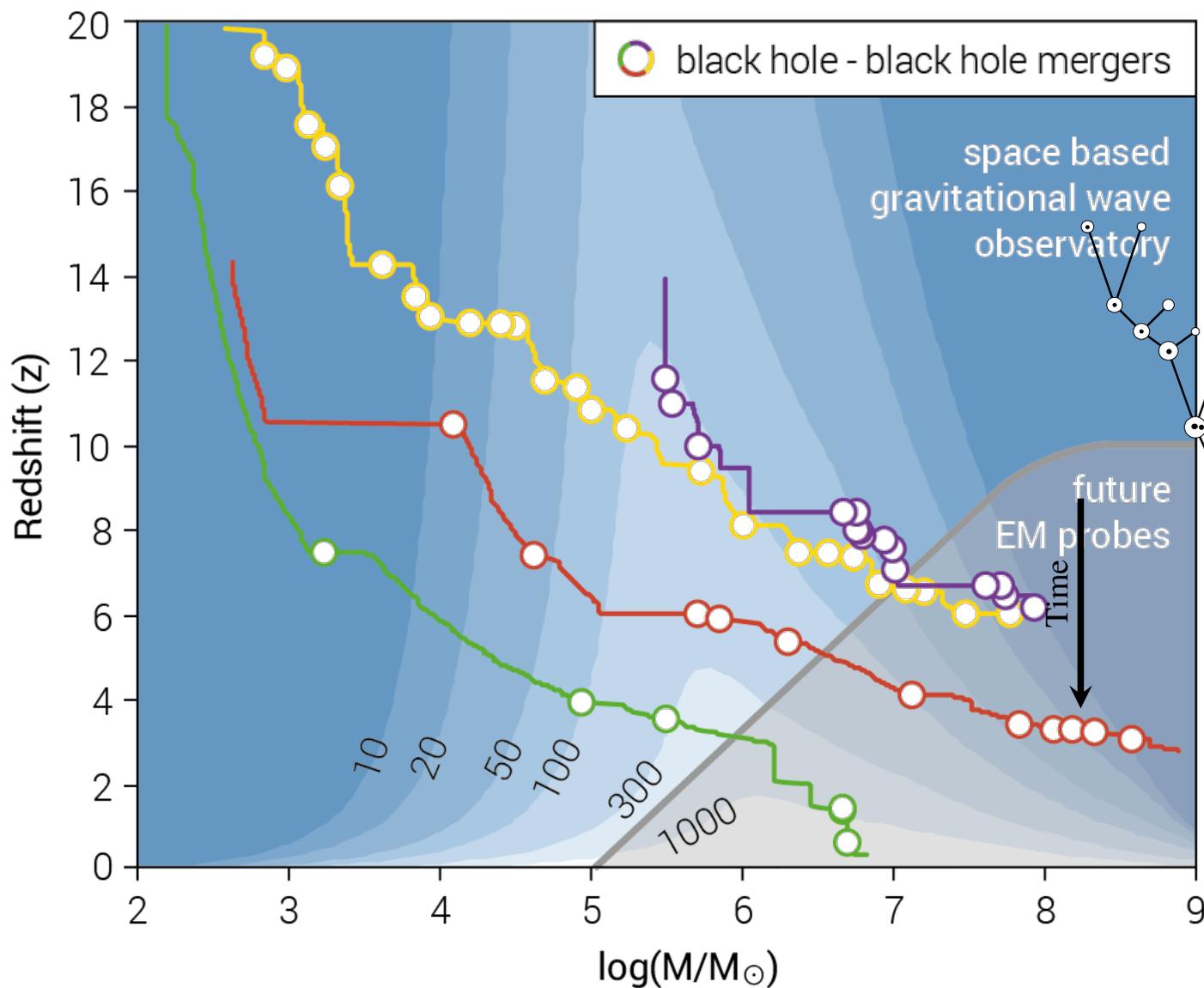
# Black Hole Astronomy by 2030



# Black Hole Astronomy by 2030



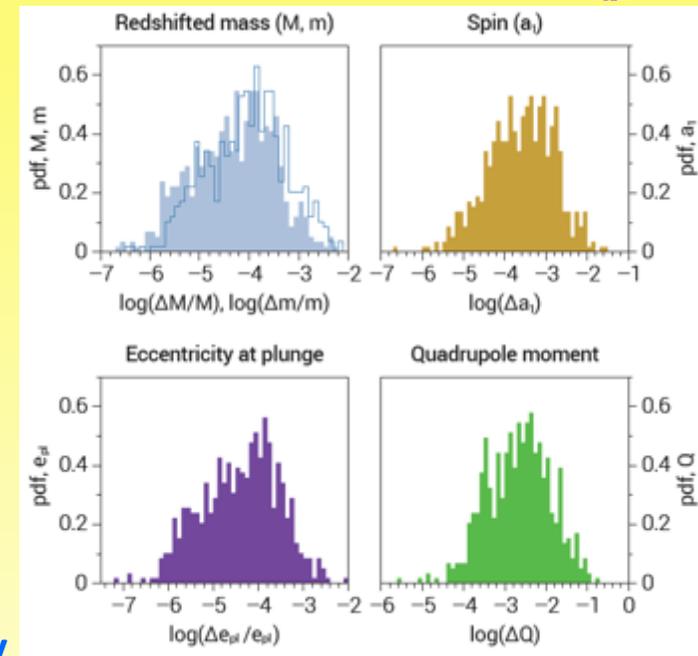
# All Binary Black Holes cross LISA band: Trace Galaxy Mergers



# Extreme Mass Ratio Inspirals



- SNR 20 up to  $z \approx 0.7$  for  $10^5$ - $10^6 M_\odot$
- Dozens of events per year
- Mass, spin to 0.1% – 0.01 %
- Quadrupole moment to  $< 0.001 M_\odot^3 G^2/c^4$



- Do Black Holes have hair?

## – New objects in General Relativity

- Boson Stars, Gravastars, non-Kerr solutions (e.g. Manko-Novikov)

## – Deviations from General Relativity

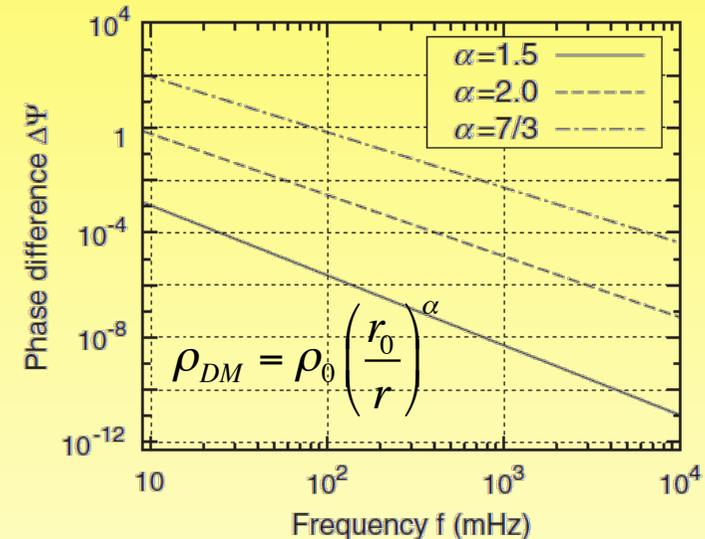
- Chern-Simons, Scalar-Tensor, light scalar fields (axions) and black hole bomb instabilities

- Each has specific GW fingerprint!

# Dark Matter Probe



- Dark Matter spike around BH changes inspiral GW phase
- Sensitive even to Dark Matter interacting only gravitationally



PRL **110**, 221101 (2013)

PHYSICAL REVIEW LETTERS

week ending  
31 MAY 2013

## New Probe of Dark-Matter Properties: Gravitational Waves from an Intermediate-Mass Black Hole Embedded in a Dark-Matter Minispike

Kazunari Eda,<sup>\*</sup> Yousuke Itoh, and Sachiko Kuroyanagi

*Research center for the early universe, School of Science, University of Tokyo, Tokyo 113-0033, Japan*

Joseph Silk

*Institut d' Astrophysique, UMR 7095, CNRS, Université Pierre et Marie Curie Paris VI, 98 bis Boulevard Arago, Paris 75014, France*

# Cosmology with Standard Sirens

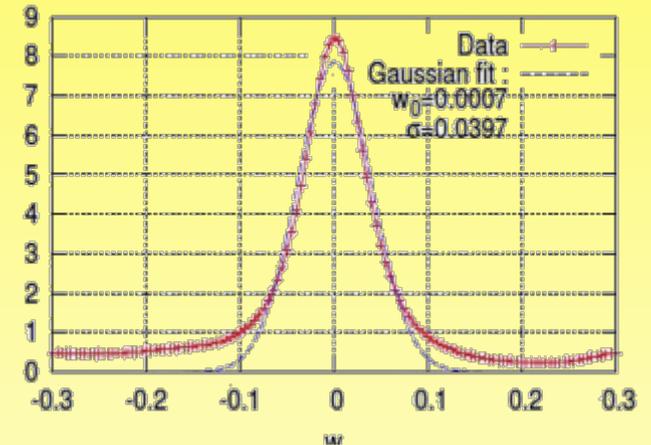


- With luminosity distances, LISA gives accurate and independent measurements of  $H_0$  and  $w$ .

- EMRIs, *without* EM counterparts:
- Hubble const.  $H_0$  to  $\pm 0.4\% = \pm 0.3 \text{ km s}^{-1} \text{ Mpc}^{-1}$  after 20 EMRI detections:  $\sim 3$  months LISA (MacLeod & Hogan, PRD, 2008; SDSS)
- Compare WMAP:  $\pm 1.2 \text{ km s}^{-1} \text{ Mpc}^{-1}$ .
- MBH mergers out to  $z = 3$ , *no* EM counterparts:
- Dark energy equation of state parameter  $w$  to  $\pm 2\text{-}4\%$  in 3 years (Petiteau et al, ApJ, 2011; Millennium).
- Compare EUCLID:  $\pm 2\%$ .

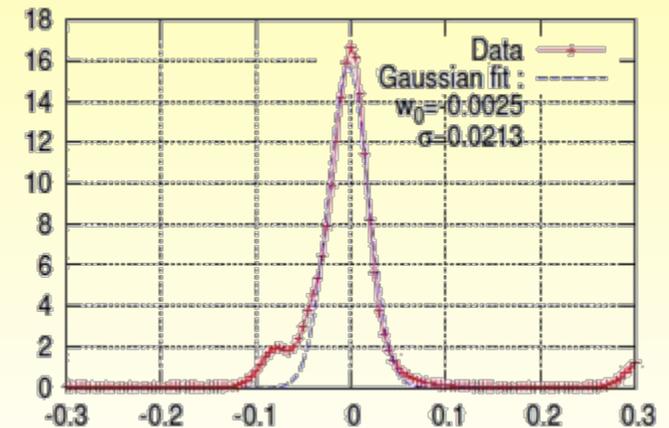
No identifications

(b) without electromagnetic counterpart



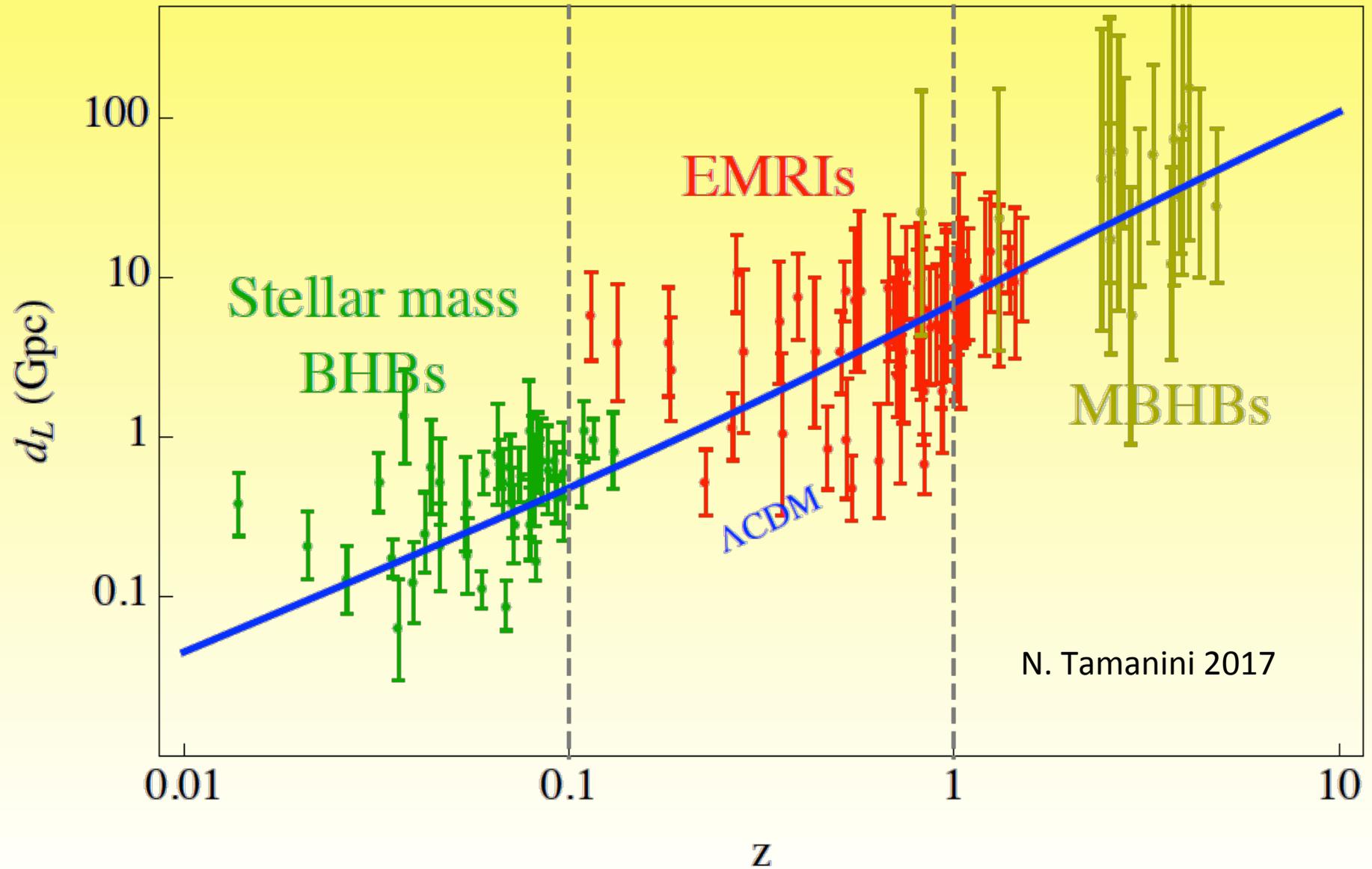
With identifications

(f) improved WL + merger



Dark Energy equation-of-state parameter  $w$

# LISA Cosmology

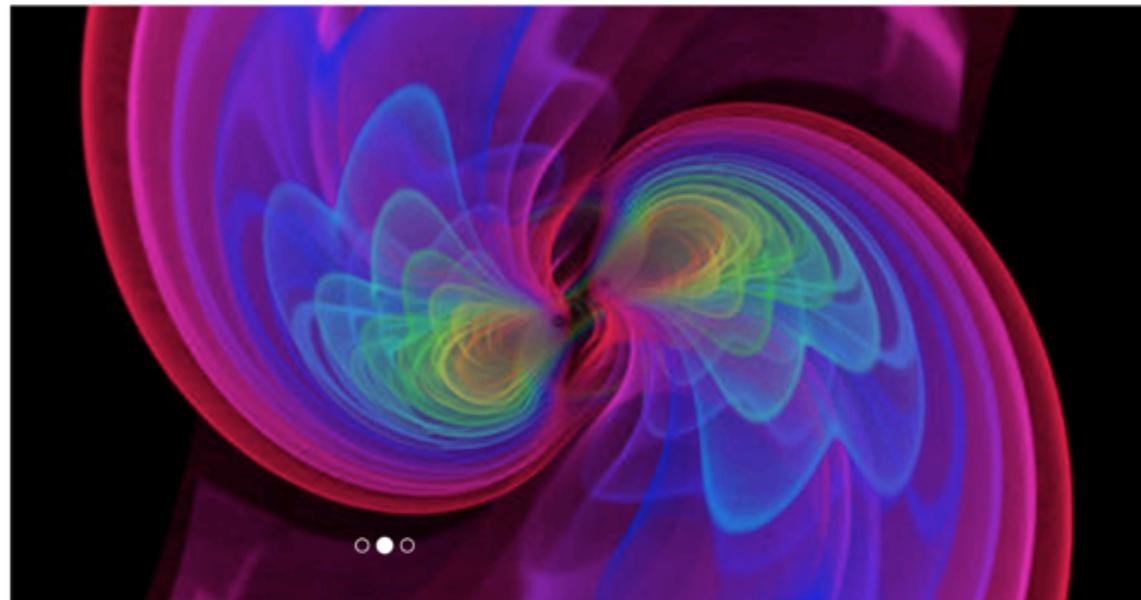
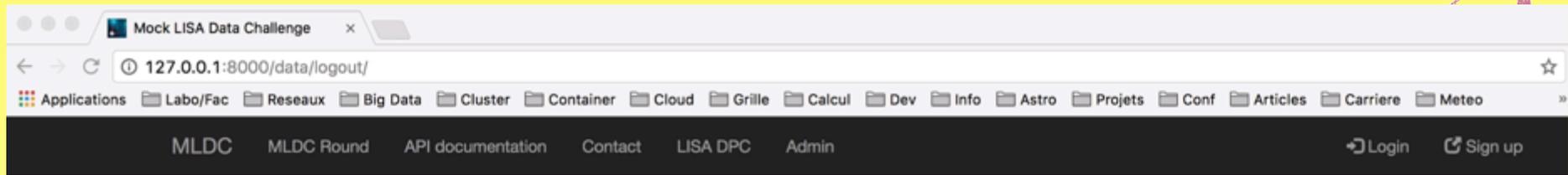


# The new LISA Data Challenge (LDC)



- Resurrecting data challenges
- Project hosted under git-lab:
  - <https://gitlab.in2p3.fr/stas/MLDC> (sign up is required)
- Project oriented:
  - Each data set aims at particular data analysis problem
- Ultimate goal:
  - Build a robust data analysis pipeline for the LISA mission.
- Web-page will be open shortly for everyone to sign up for the challenge and download the simulated data set.

# LDC webpage



## Welcome on the MLDC website

In support of the Laser Interferometer Space Antenna (LISA) gravitational wave observatory, a Web site and application for the Mock LISA Data Challenge is provided.

You can find information of the MLDC on the [MLDC Round](#) page. Release data of the LISACode simulation code can be find at [Object list](#). A request form can be find at [Query](#). Contact information are at [Contact](#).

### Data Processing Center (DPC)

MLDC Web application is part of the DPC of LISA. The goal of the DPC is to provide tools for code developpement and execution for the data analysis. The platform is reachable at [LISA DPC](#).

### News

New dataset is provided...

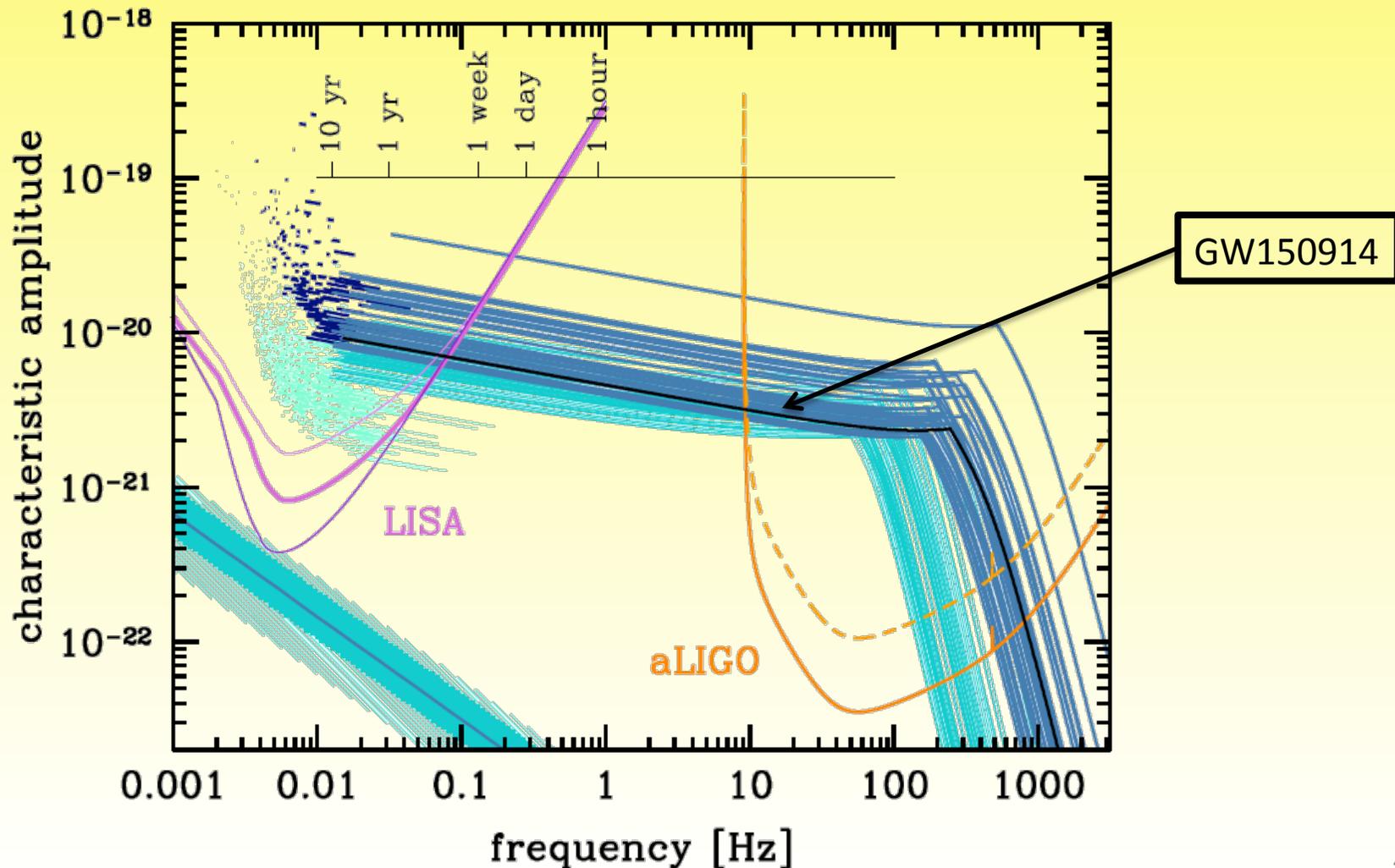
Website 1.0 is ready

Work in progress:  
missing query form, formulary,  
login registration.

# LISA: LIGO Event Predicted 10 Years in Advance!



- Accurate to seconds and within a square-degree!



# ESA L2 and L3 Missions



- Call for Mission Concepts fall 2016
- Decision on L3 Adoption 2021
- Launch of L2 in 2028
- Launch of L3 in 2034
- **LISA shall be ready for an early launch!**

