Gravitational Wave Astronomy with LISA: Sounds from the Dark Side of the Universe!

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Albert-Einstein-Institut:

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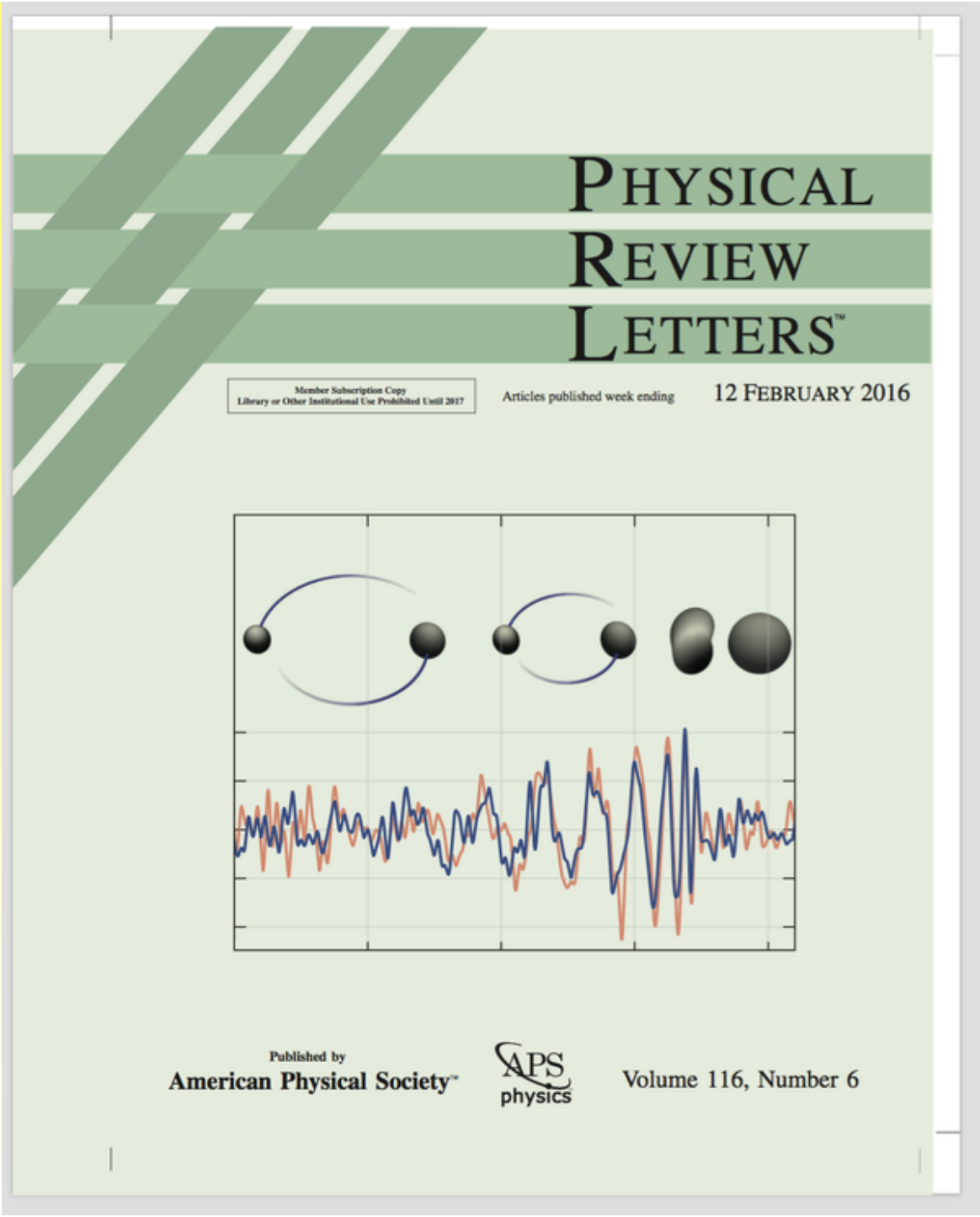
und

Institut für Gravitationsphysik der Leibniz Universität Hannover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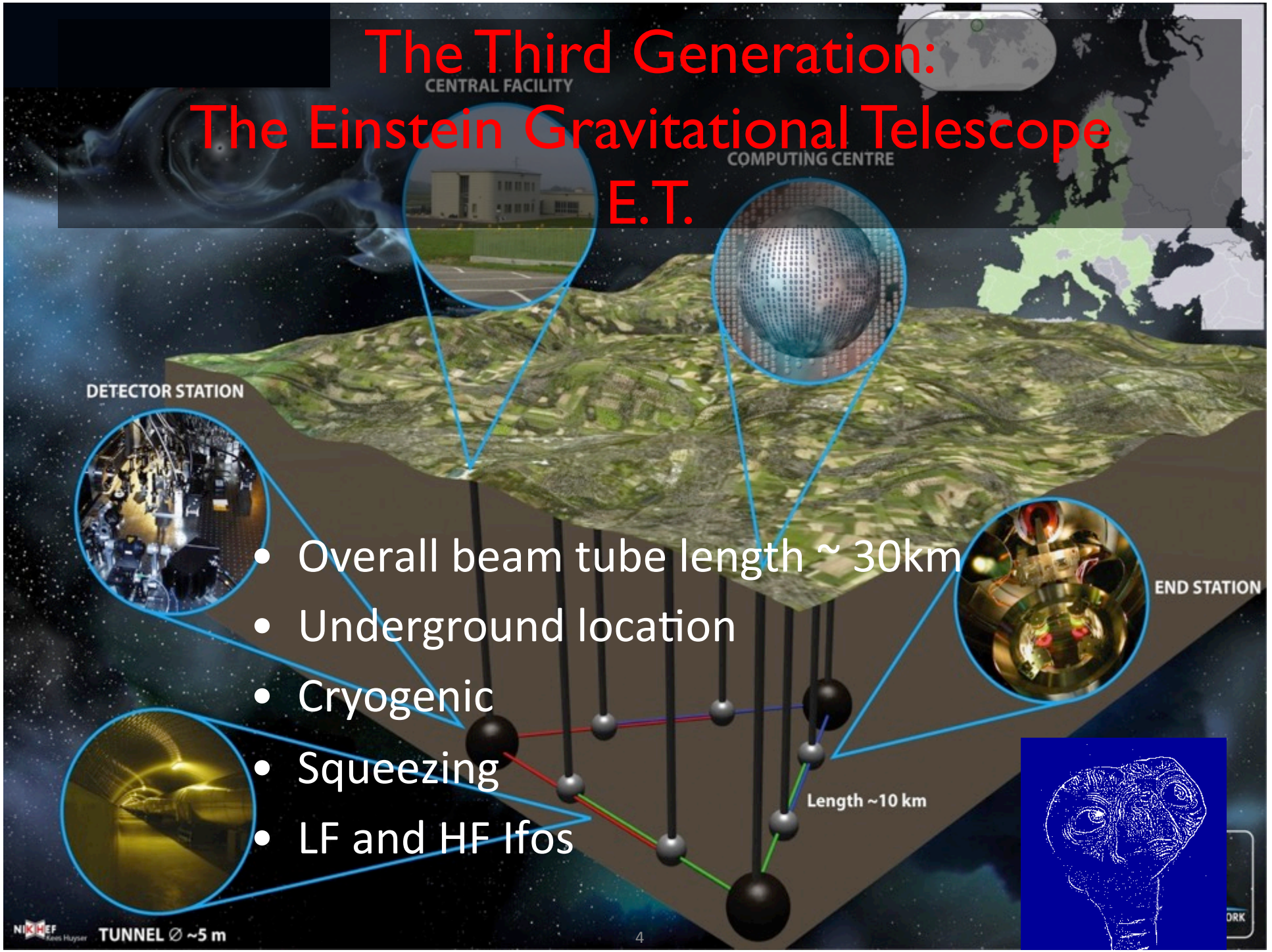
World-Wide Laser Interferometric Gravitational Wave Detector Network

3 km

m

Source: A. Lazzarini, modified

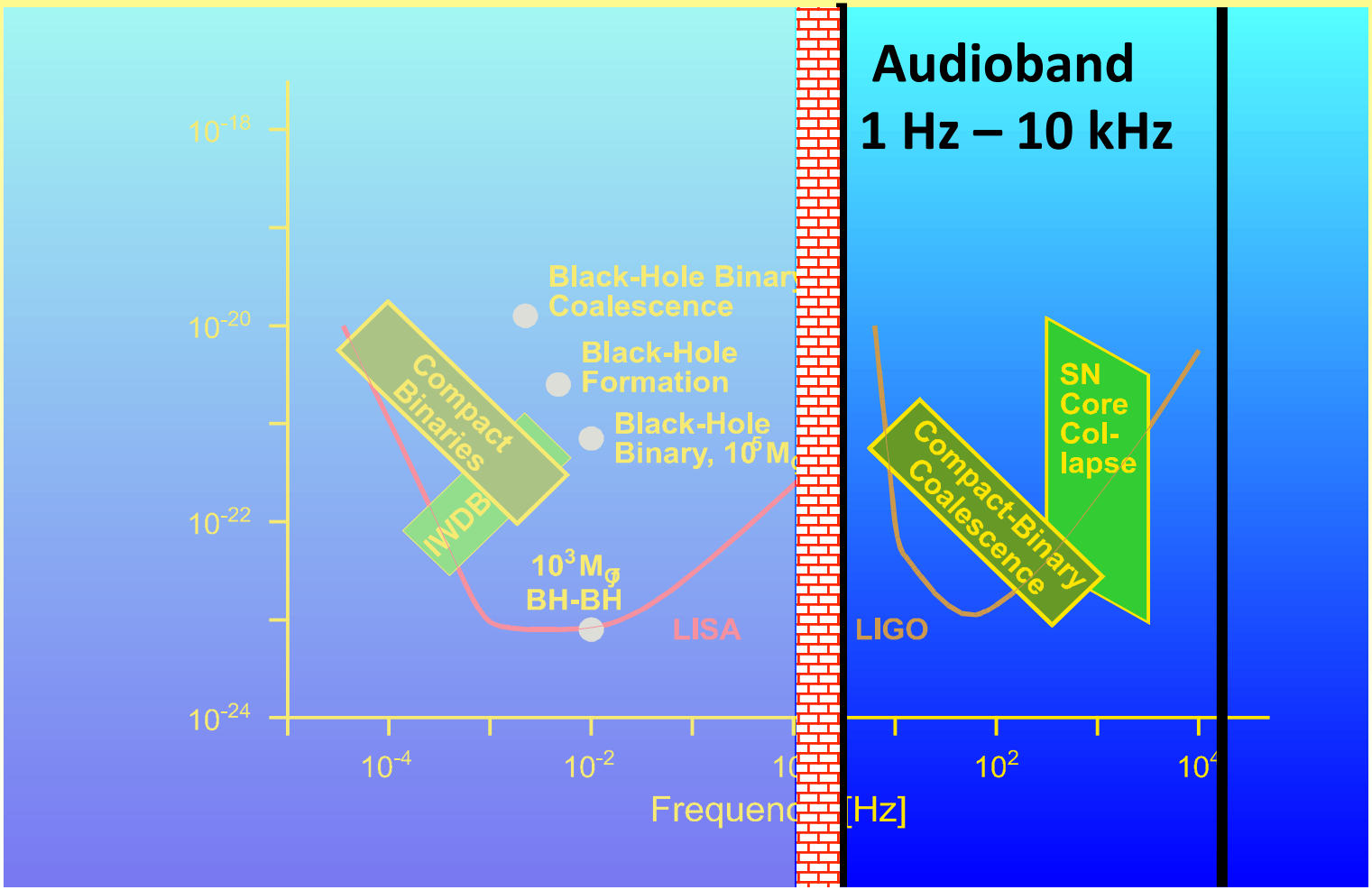
The Third Generation: The Einstein Gravitational Telescope E.T.



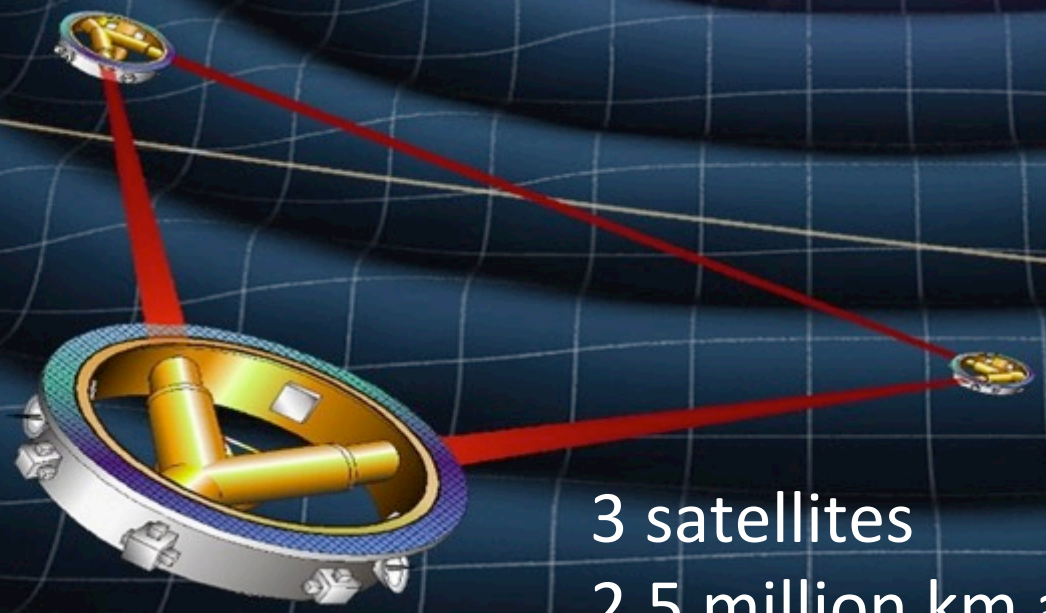
- Overall beam tube length ~ 30km
- Underground location
- Cryogenic
- Squeezing
- LF and HF Ifos

Sources of Gravitational Waves

- Ground-based detectors: Audioband



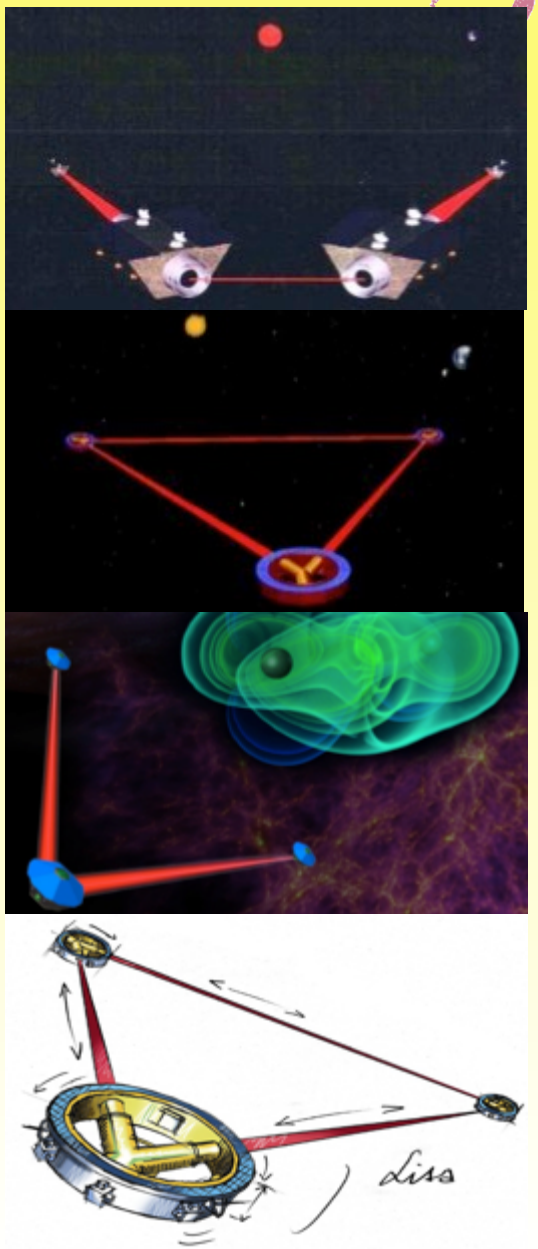
LISA:
Opens the low-frequency gravitational universe



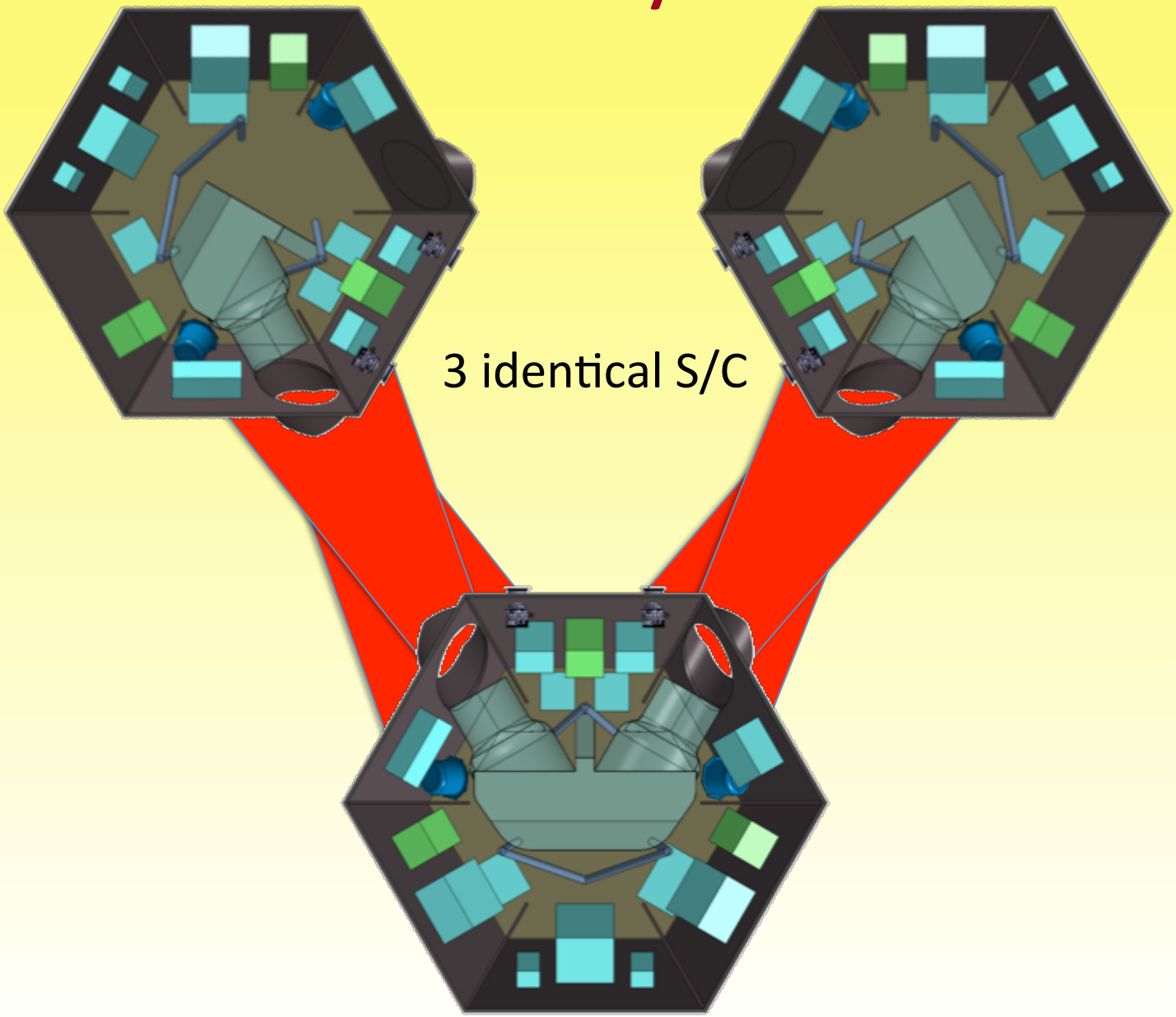
3 satellites
2.5 million km arms
50 million km behind Earth

LISA: A Mature Concept

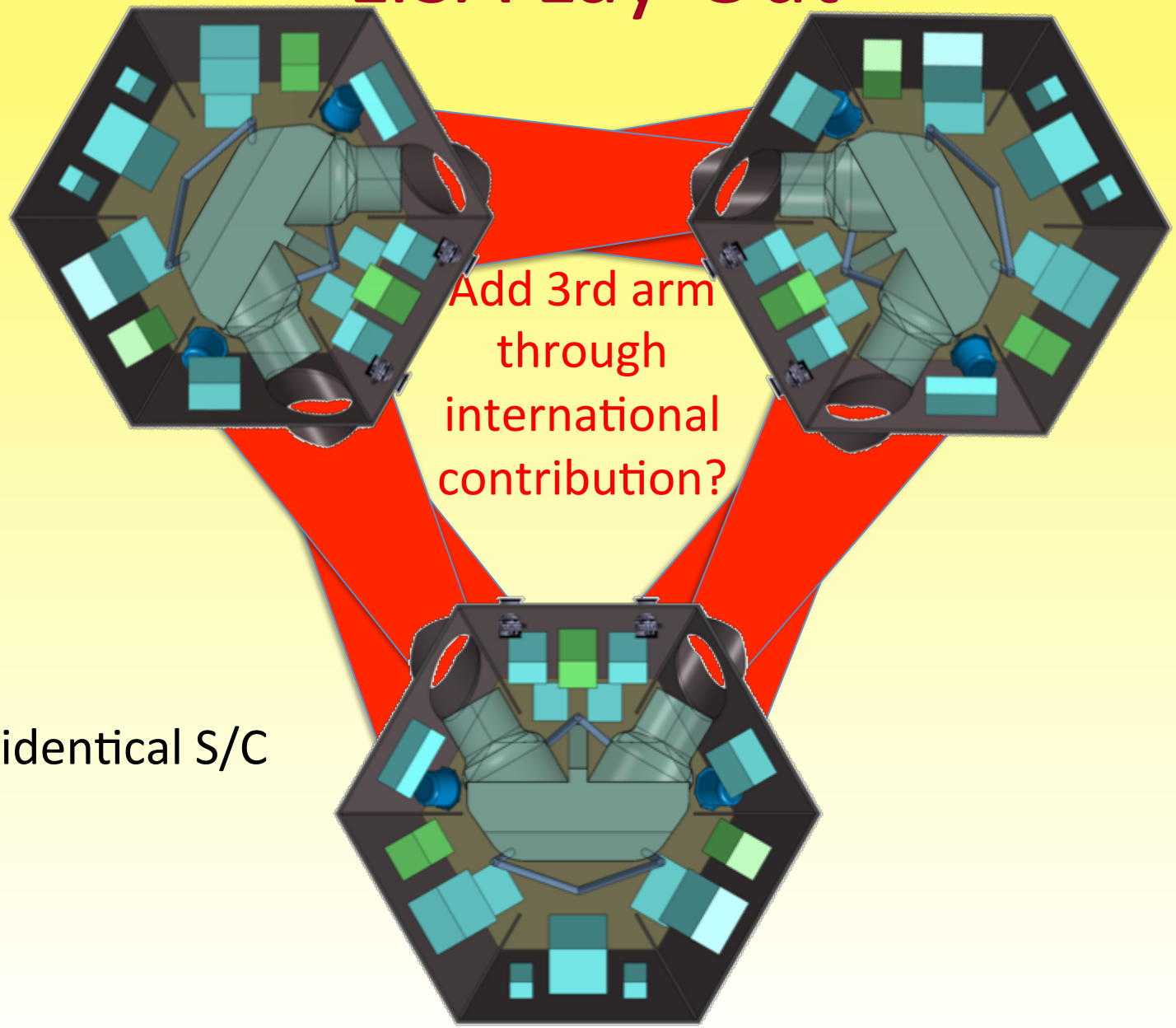
- M3 proposal for 4 S/C ESA/NASA collaborative mission in 1993
- LISA selected as ESA Cornerstone in 1995
- 3 S/C ESA/NASA LISA appears in 1997
- Joint ESA-NASA Mission Formulation study 2005-2011
- Reformulation 2012-13 as ESA-led eLISA (evolving LISA)
- Now back to 3-arm LISA with NASA



NGO Lay-Out



LISA Lay-Out



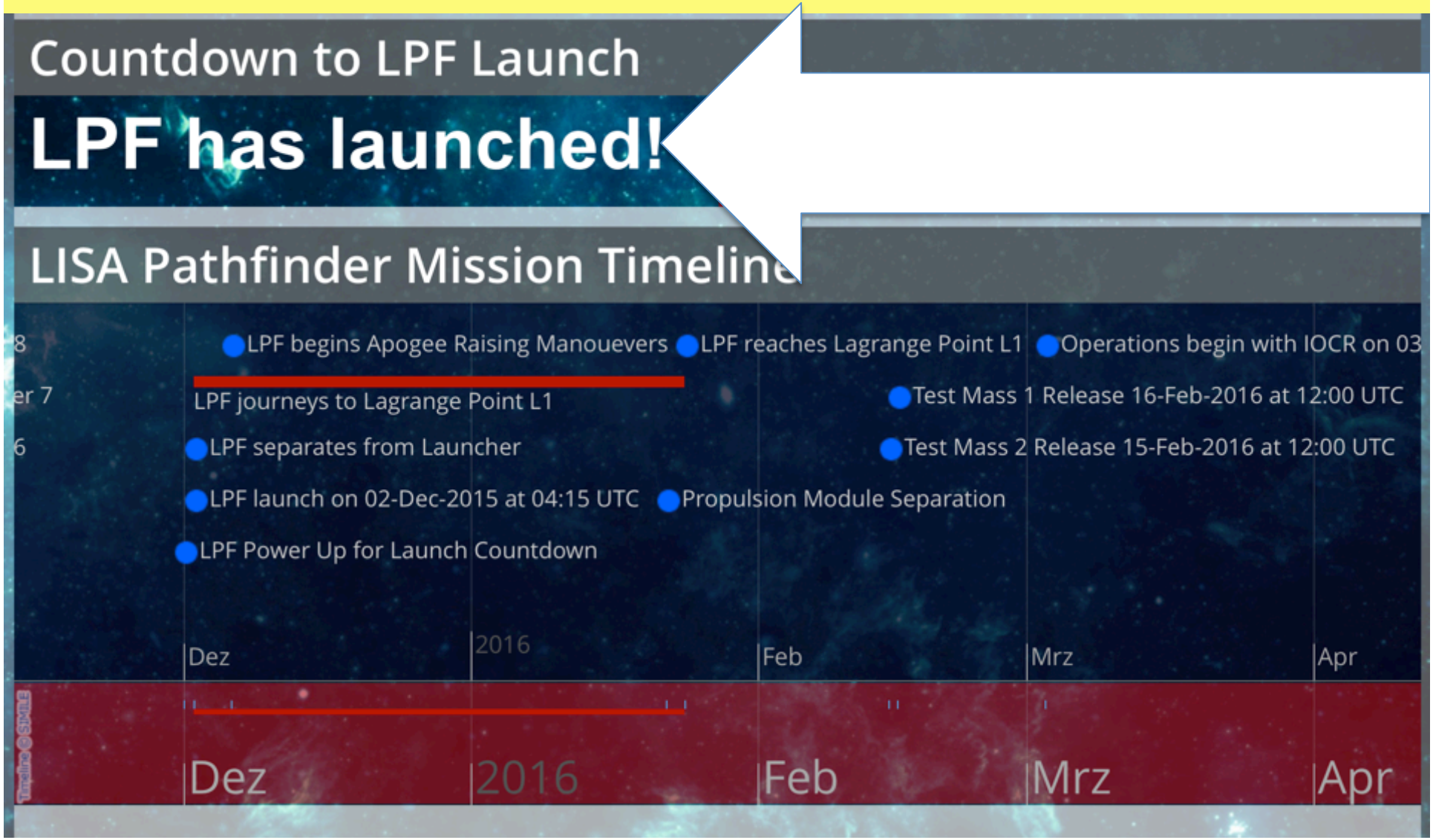
3 identical S/C

LISA Pathfinder

- Testing LISA technology in space!

September 2015: Spacecraft is completed!

100 Years since GR Publication: Dec. 2, 2015



Science Operations

- LISA Pathfinder is an orbiting physics laboratory
- Different experiments each day
- Near – realtime data analysis

DOY154: 02/06/16, (08:00 – 08:00)

Location: unknown

	08:00	–	07:30	DWS Noise Floor	inv06602:V001 [1410']

DOY155: 03/06/16, (08:00 – 08:00)

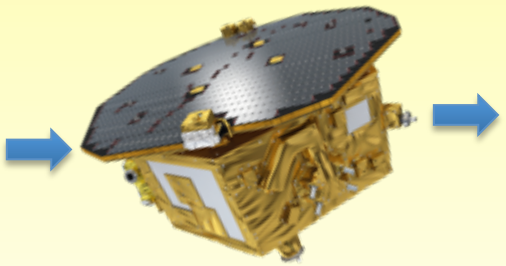
Location: unknown

	08:00	–	08:10	Set max force authority to UURLA	con_fee_maxf___:V022 [10']
	08:10	–	08:12	Unload SDM19	con_SDM19_unload:V001 [2']
	08:12	–	08:14	Load SDM20	con_SDM20_load___:V001 [2']
	08:14	–	19:14	(Short) Charge Burst - TM1	inv04210:V007 [660']
	19:14	–	06:14	(Short) Charge Burst - TM2	inv04220:V007 [660']
▸	06:14	–	08:10	Discharge TMs	inv04330:V001 [116']

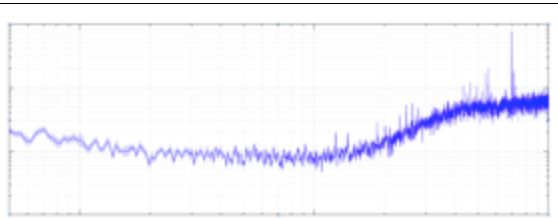
DOY156: 04/06/16, (08:00 – 08:00)

Location: unknown

	08:00	–	11:00	New SysID - Drag-free injections- UURLA	inv01101:v003 [180']
	11:00	–	16:00	New SysID - Suspension injections - UURLA	inv01102:v006 [300']
	16:00	–	17:00	Change Max Authority to default (2200pN)	con_fee_maxf_dft:V001 [60']
	17:00	–	20:00	New SysID - Drag Free injections	inv01101:V003 [180']
	20:00	–	01:00	New SysID - Suspension Injections	inv01102:V006 [300']
	01:00	–	02:00	Transition to CST1: SCI12 with matched stiffness	con_dfa_c1_s12MS:V004 [60']
	02:00	–	02:30	Set matched force authority to 5nN on TM1x and TM2x	con_fee_maxf____:V024 [30']
	02:30	–	05:30	New SysID - Drag Free injections	inv01101:V003 [180']
▸	05:30	–	10:30	New SysID - Suspension Injections	inv01102:V006 [300']



```
%% Settings
hostname  = '195.74.167.200';
directory = '20160320_F';

repopl    = plist(...
  'hostname', hostname, ...
  'database', directory);

inv_start  = '2016-03-21 02:00:00 UTC'; % From end SK up to start of the engineering day
inv_end    = '2016-03-21 09:00:00 UTC';

duration = timespan(inv_start, inv_end);
numh = round(duration.getNsecs/3600);

invName    = ['inv000' num2str(numh)];
invDir     = ['inv000' num2str(numh)];
% parameters = LTPDATelemetry.lpf_essential;
parameters = params;

ipl = plist(...
  'name',         invName, ...
  'start',        inv_start, ...
  'stop',         inv_end, ...
  'parameters',   parameters, ...
  'directory',    invDir, ...
  'repositories', repopl);

investigation = LPFInv(ipl);
```



Press Conference June 7th, 2016

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Materials

Science for the public

LISA PATHFINDER

Press conference about the LISA Pathfinder mission

Presentation of first results on June 7, 2016, in Hanover

May 25, 2016

Media representatives are cordially invited to a press conference in Hanover about the first results from the LISA Pathfinder mission. LISA Pathfinder is an ESA satellite mission which tests core elements of a gravitational-wave observatory in space.

The press conference takes place on June 7, 2016, at 11:15 CEST at the

Max Planck Institute for Gravitational Physics (Albert Einstein Institute, AEI)
Institut für Gravitationsphysik of Leibniz Universität Hannover
Callinstr. 38, 30167 Hannover
(room 103)

Doors open at 11:00 CEST. The press conference in Hanover is a parallel event to an ESA press conference in Madrid.

Media representatives are asked to register by June 5 by email with Benjamin Knispel or by telephone (+49(0)511-762-19104). Please also let us know if you would like to conduct interviews with individual scientists after the press conference.

Gravitational waves are a consequence of Einstein's general theory of relativity. Their first direct detection on Earth was achived by the LIGO detectors in September 2015. Future gravitational-wave observatories in space will observe low-frequency gravitational waves not detectable on Earth. They will detect supermassive black holes with the mass of million Suns throughout the entire Universe.

CONTACT

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Fax: +49 511 762-17182
Email: benjamin.knispel@...

FURTHER INFORMATION

Call for Media by ESA
about the first results from ESA's LISA Pathfinder mission

LISA Pathfinder
Information about LISA Pathfinder on the LISA homepage

LISA Pathfinder vodcasts
All LPF vodcasts about the progress and development of the LISA Pathfinder project

Liftoff for LISA Pathfinder

anzeigen

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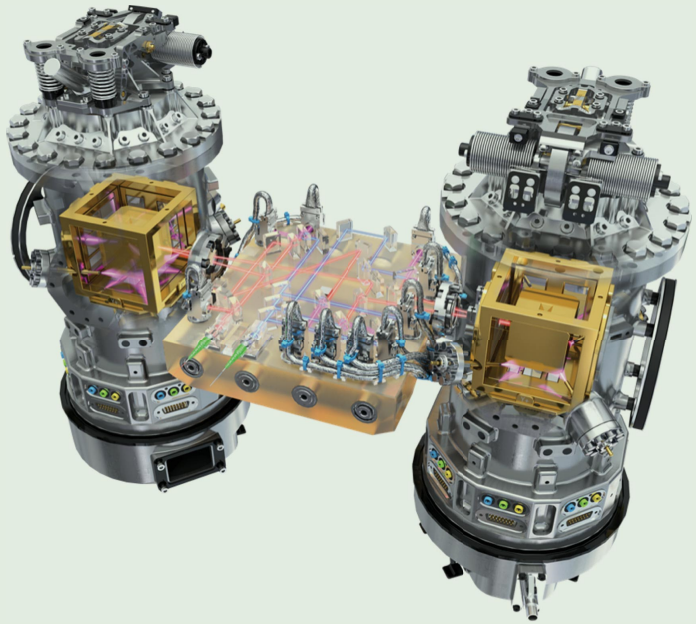

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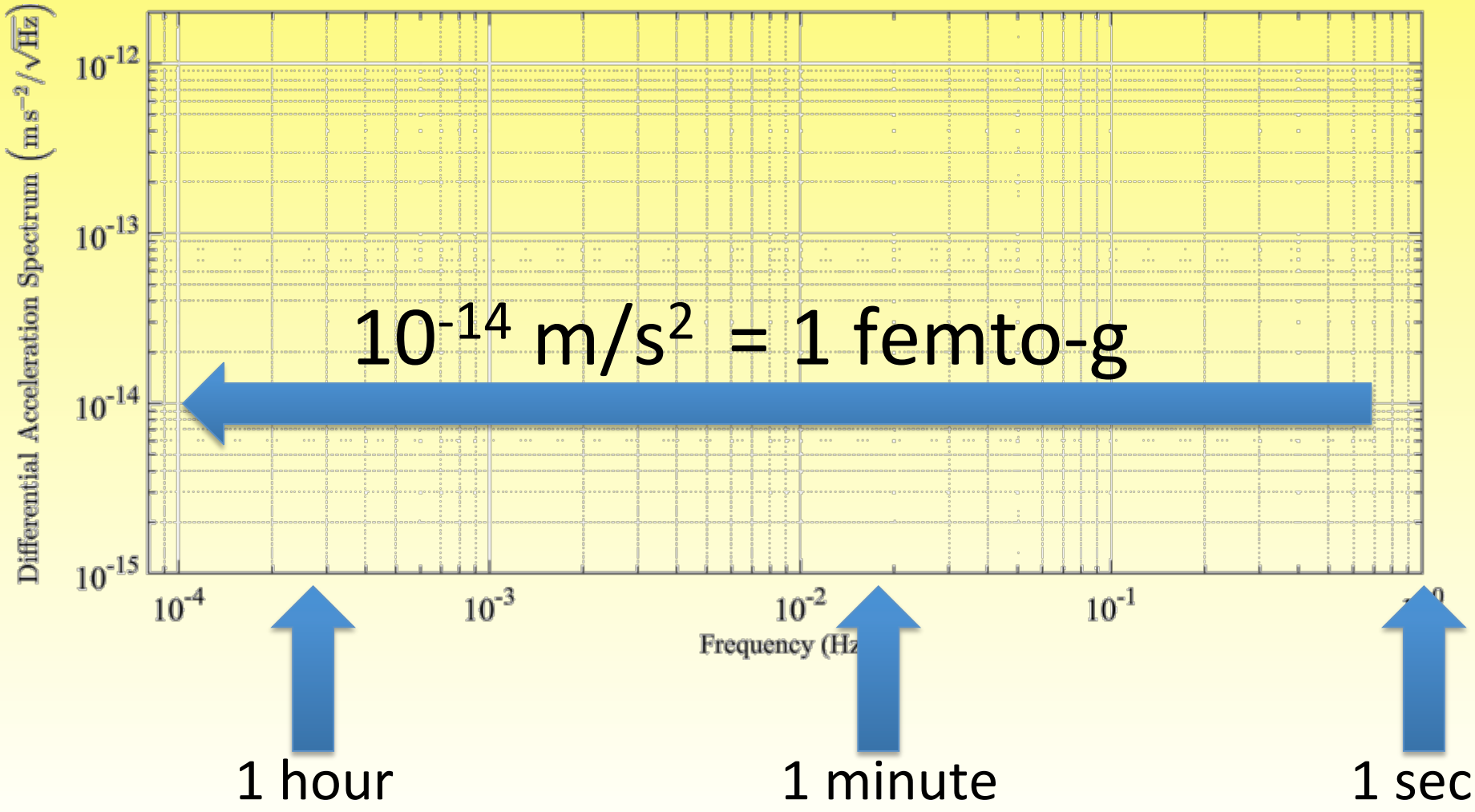
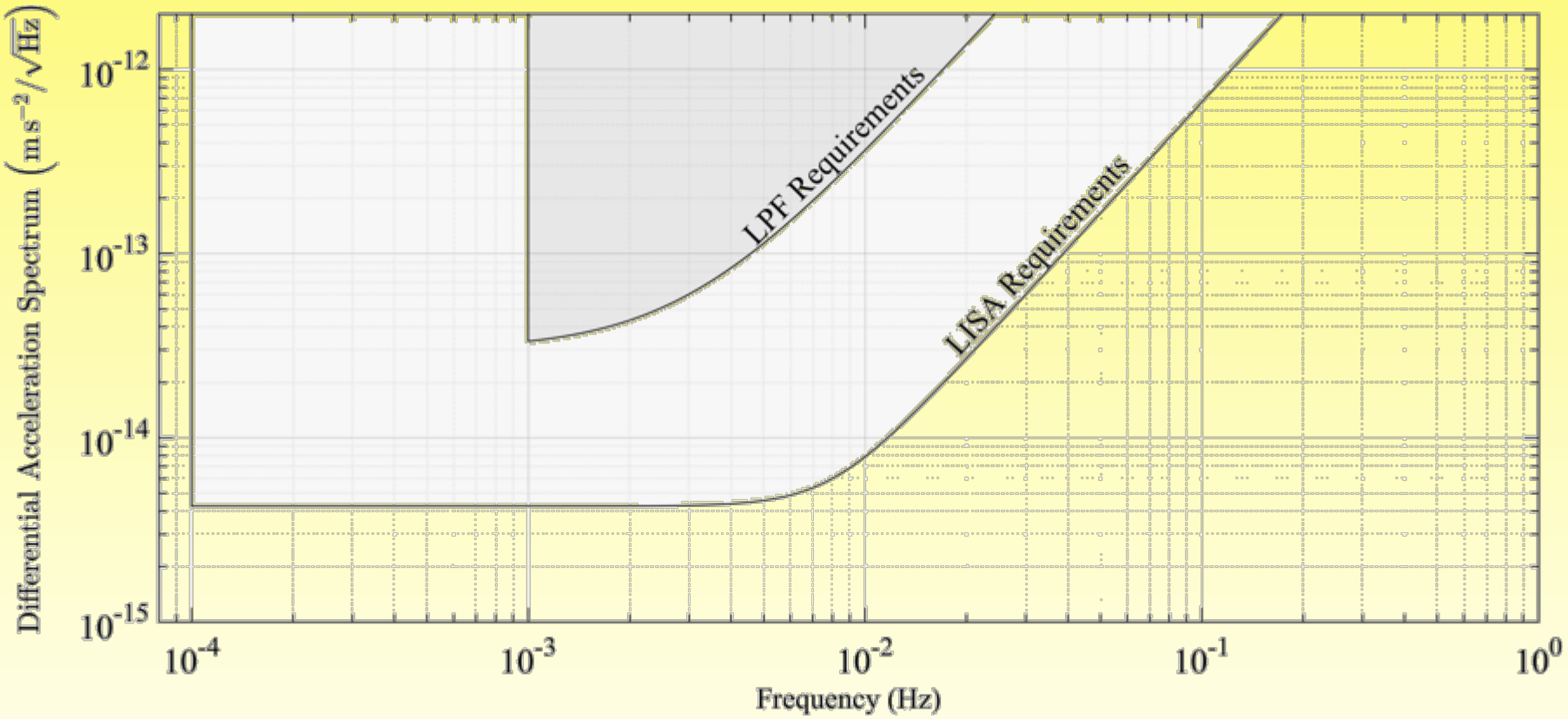
APS physics

Volume 116, Number 23

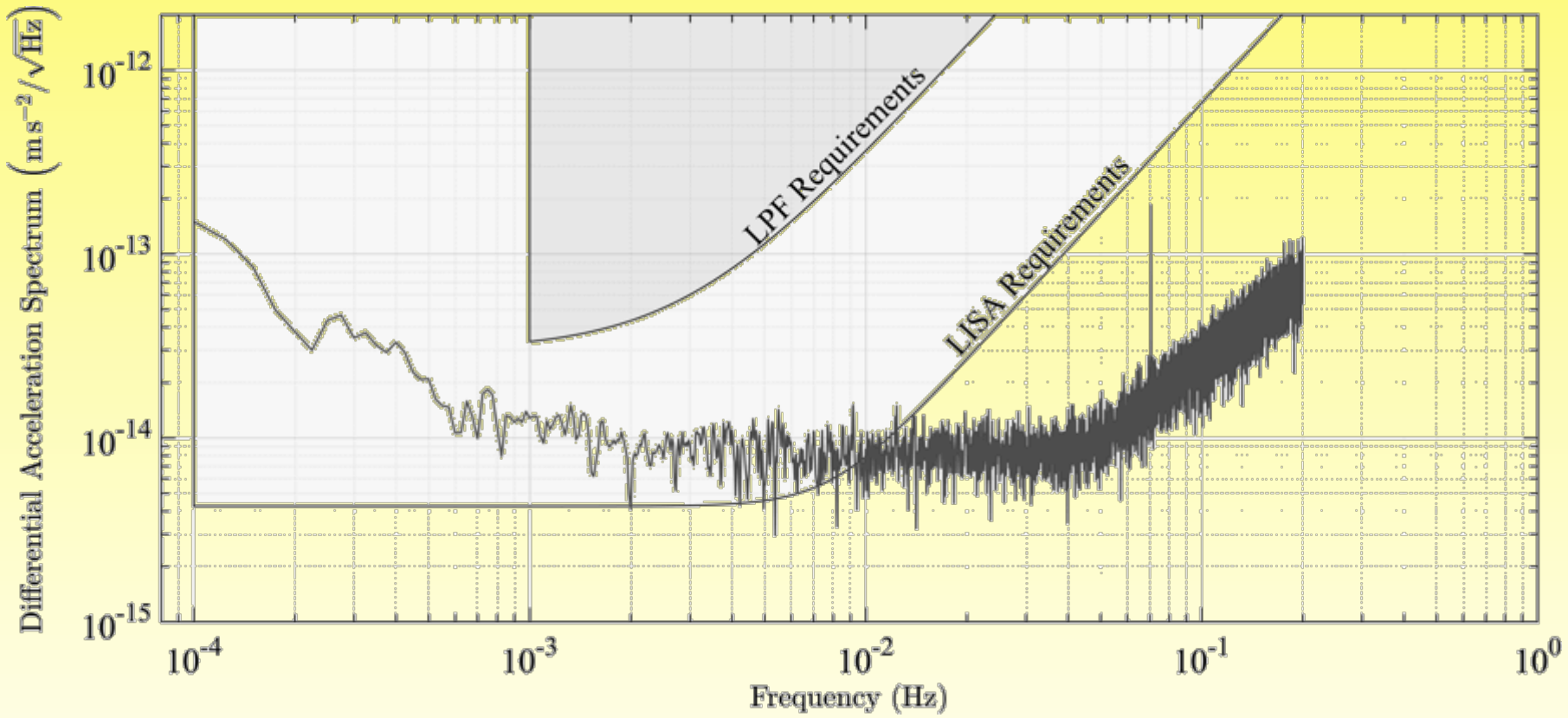
Acceleration Spectrum



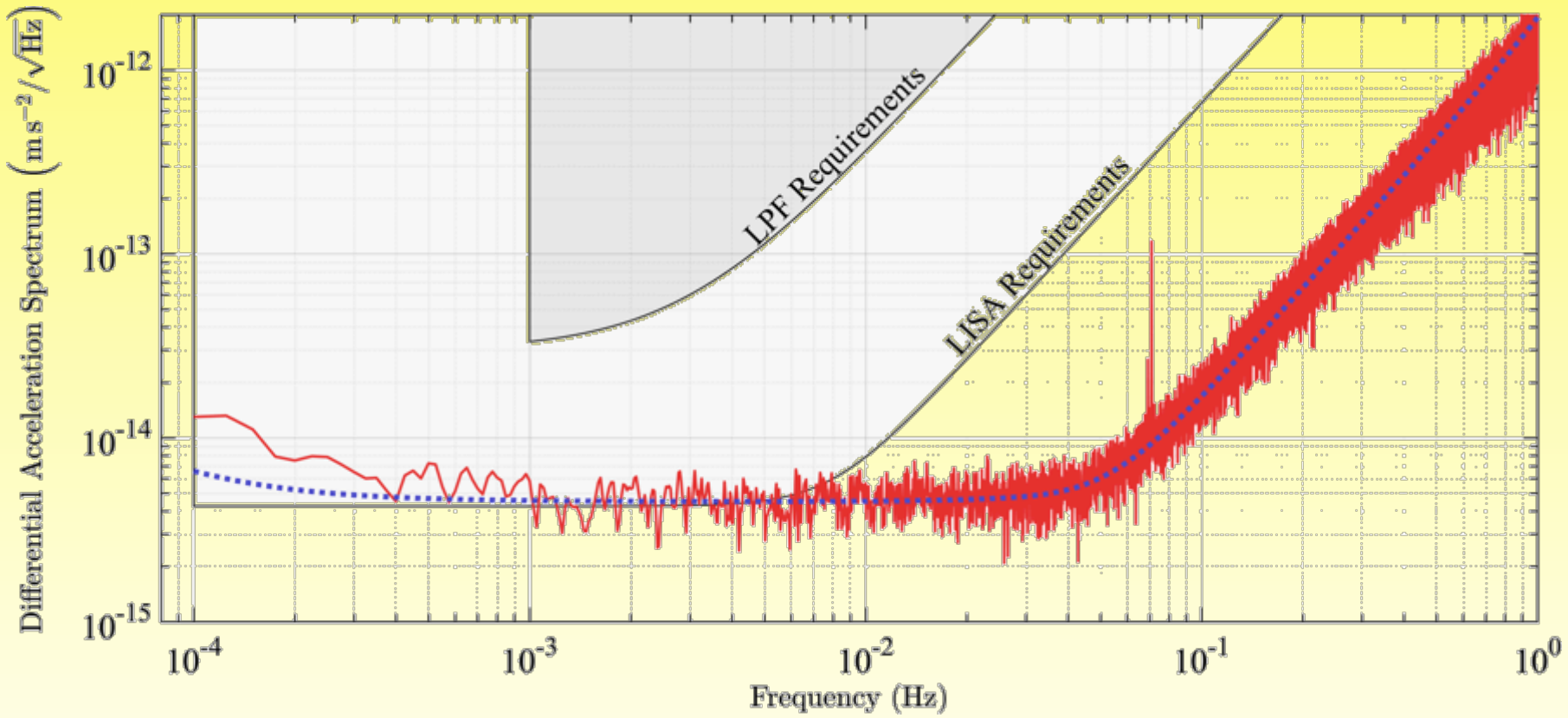
LISA and LPF Requirements



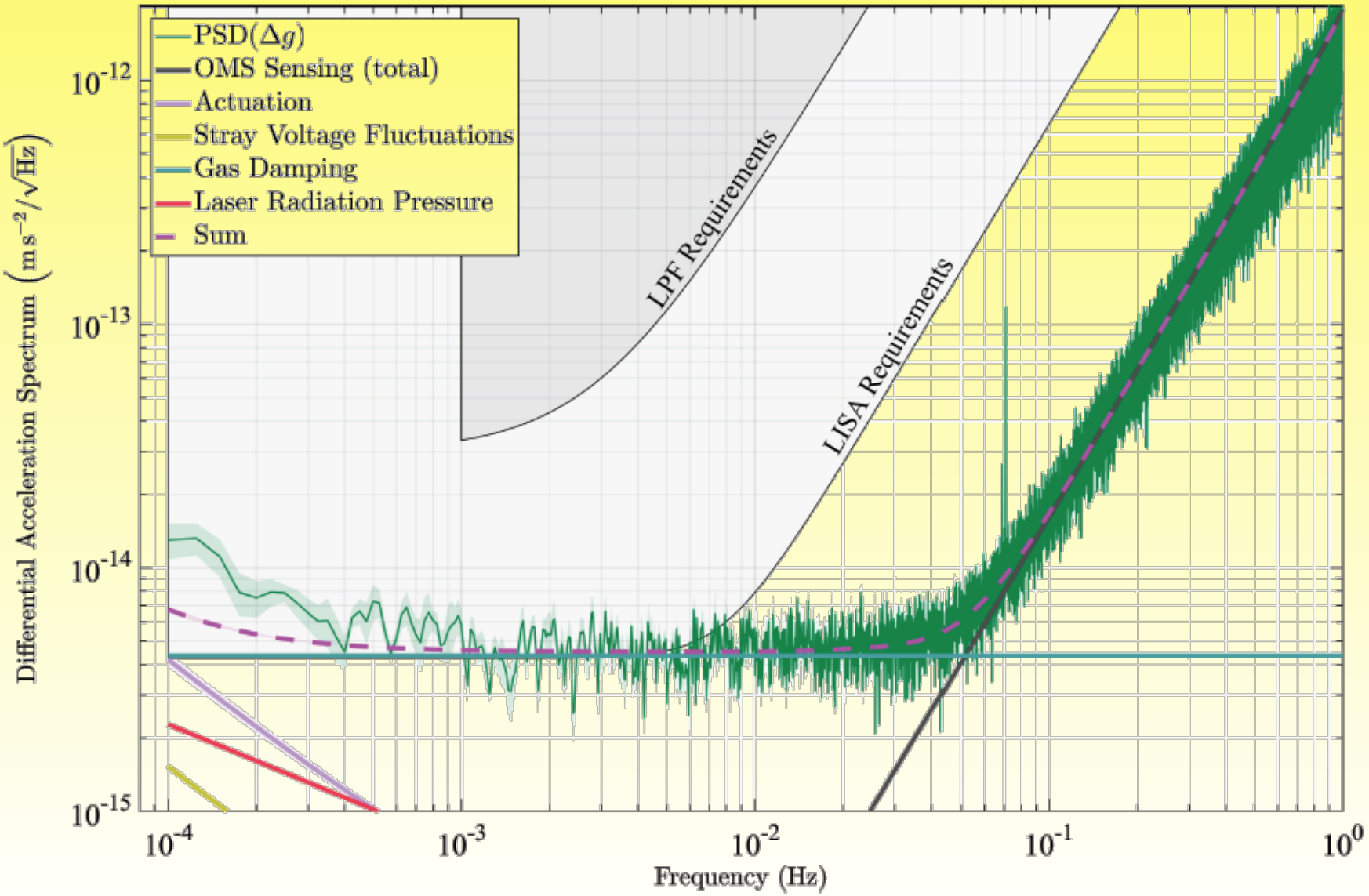
First Day of Operations: March 1, 2016



May 16, 2016, System Optimized Investigations Ongoing

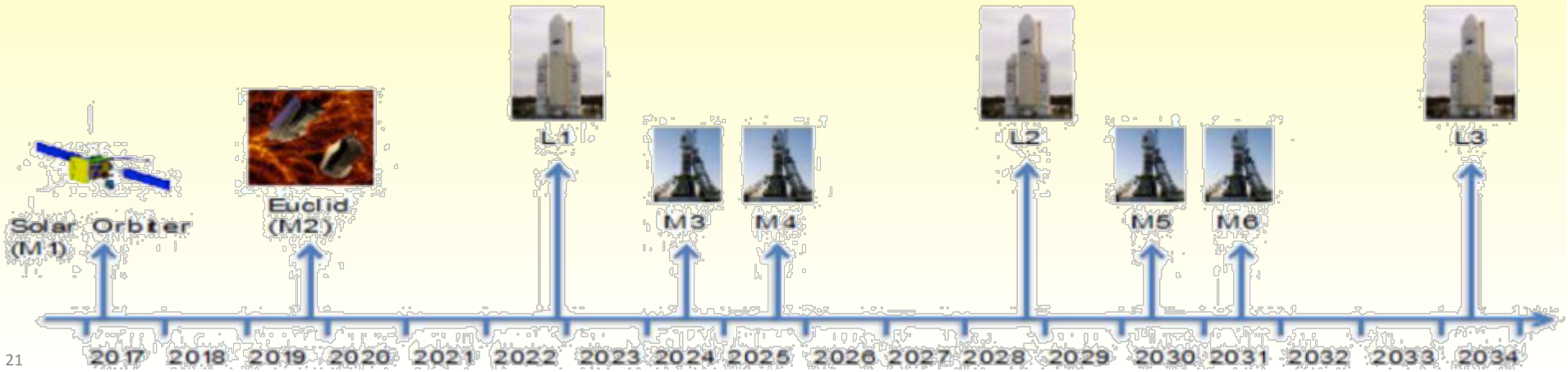


What do we know?

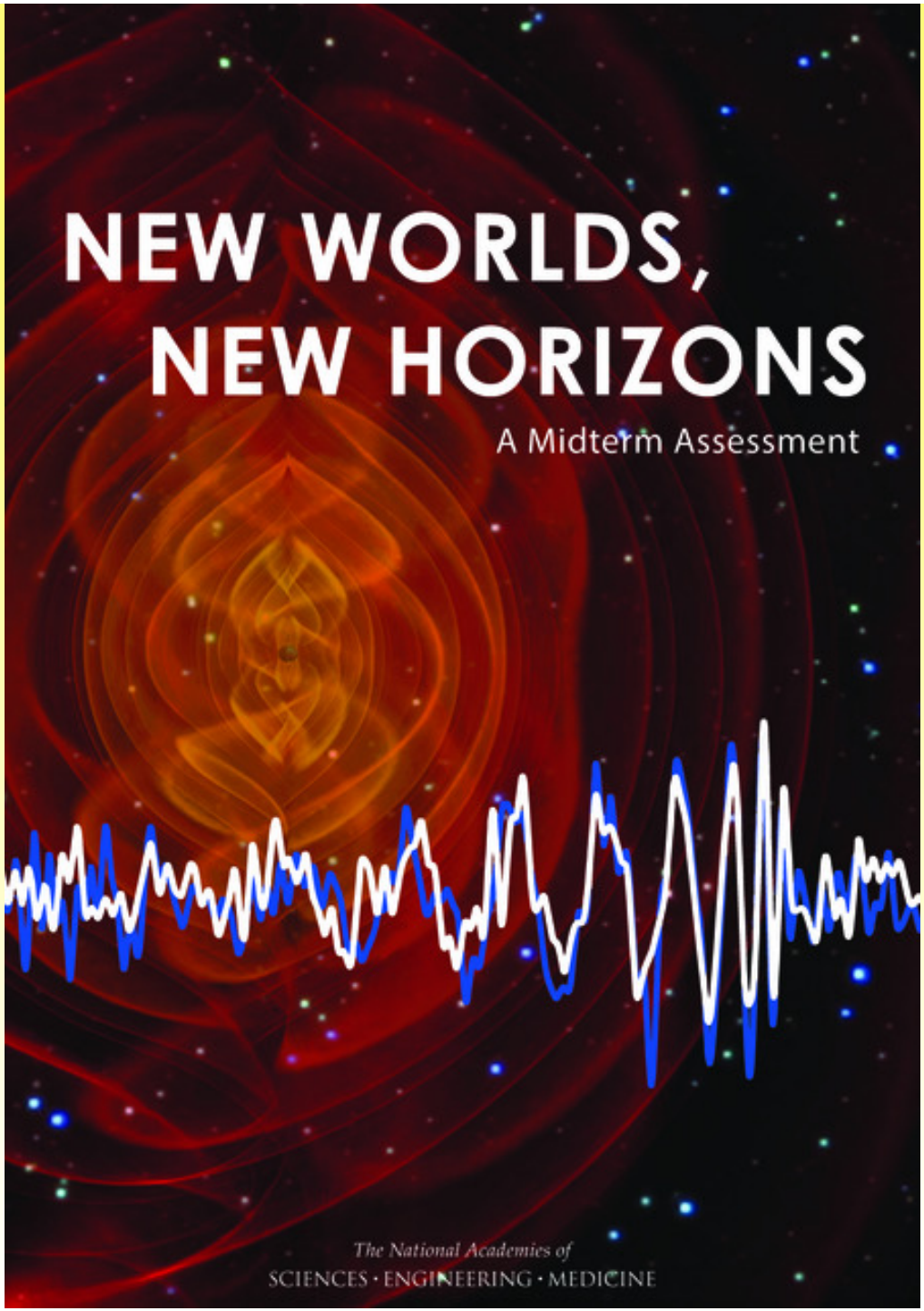


ESA L2 and L3 Missions

- Call for Mission Concepts fall 2016

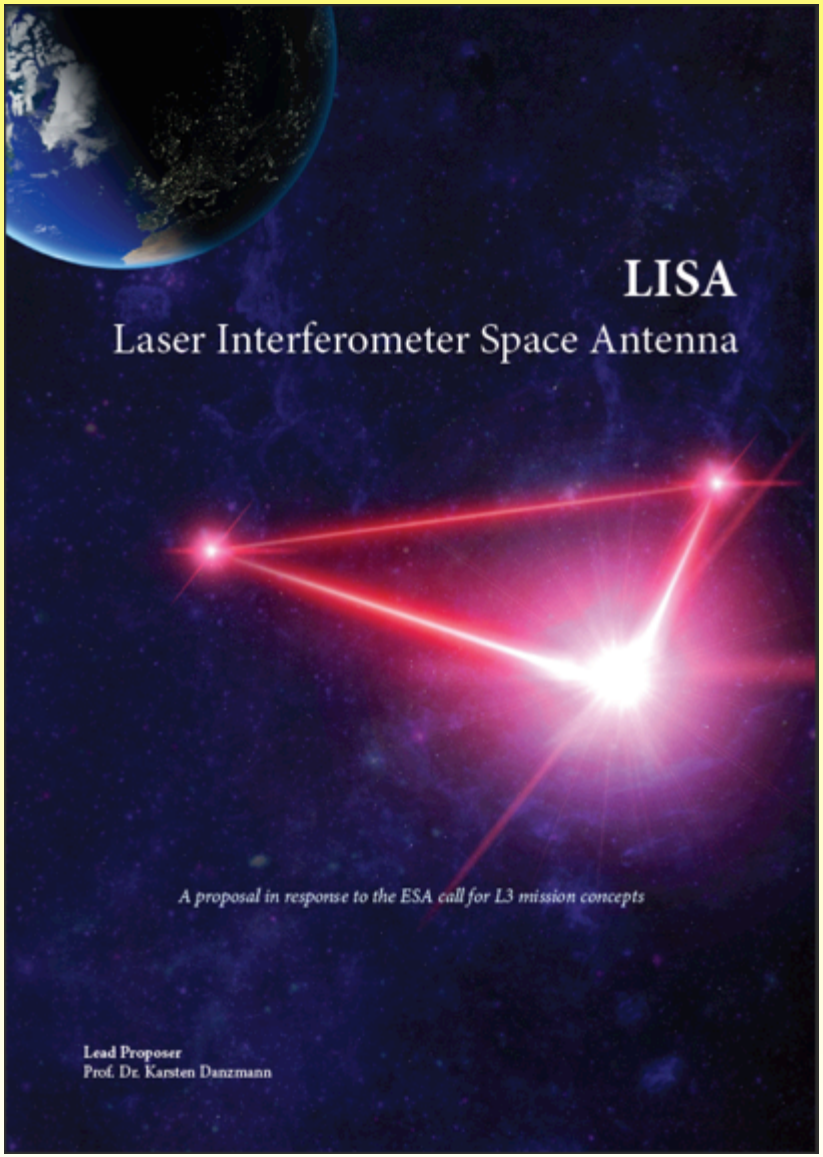


NASA is back in LISA!



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

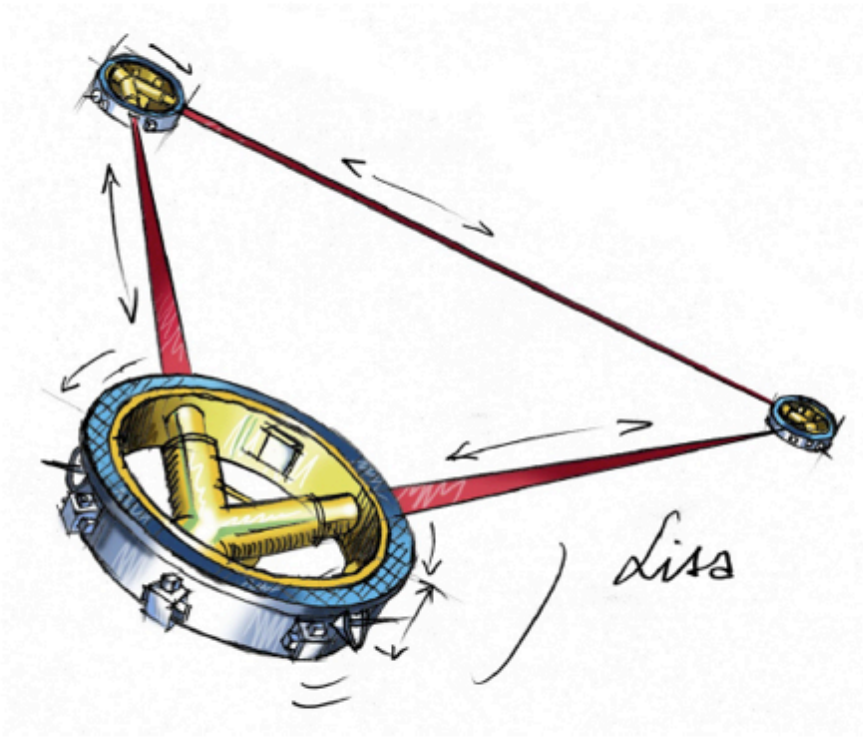
Start of Phase 0: CDF Study

LISA
Study Introduction

Systems

Session 1
ESTEC, 08-03-2017

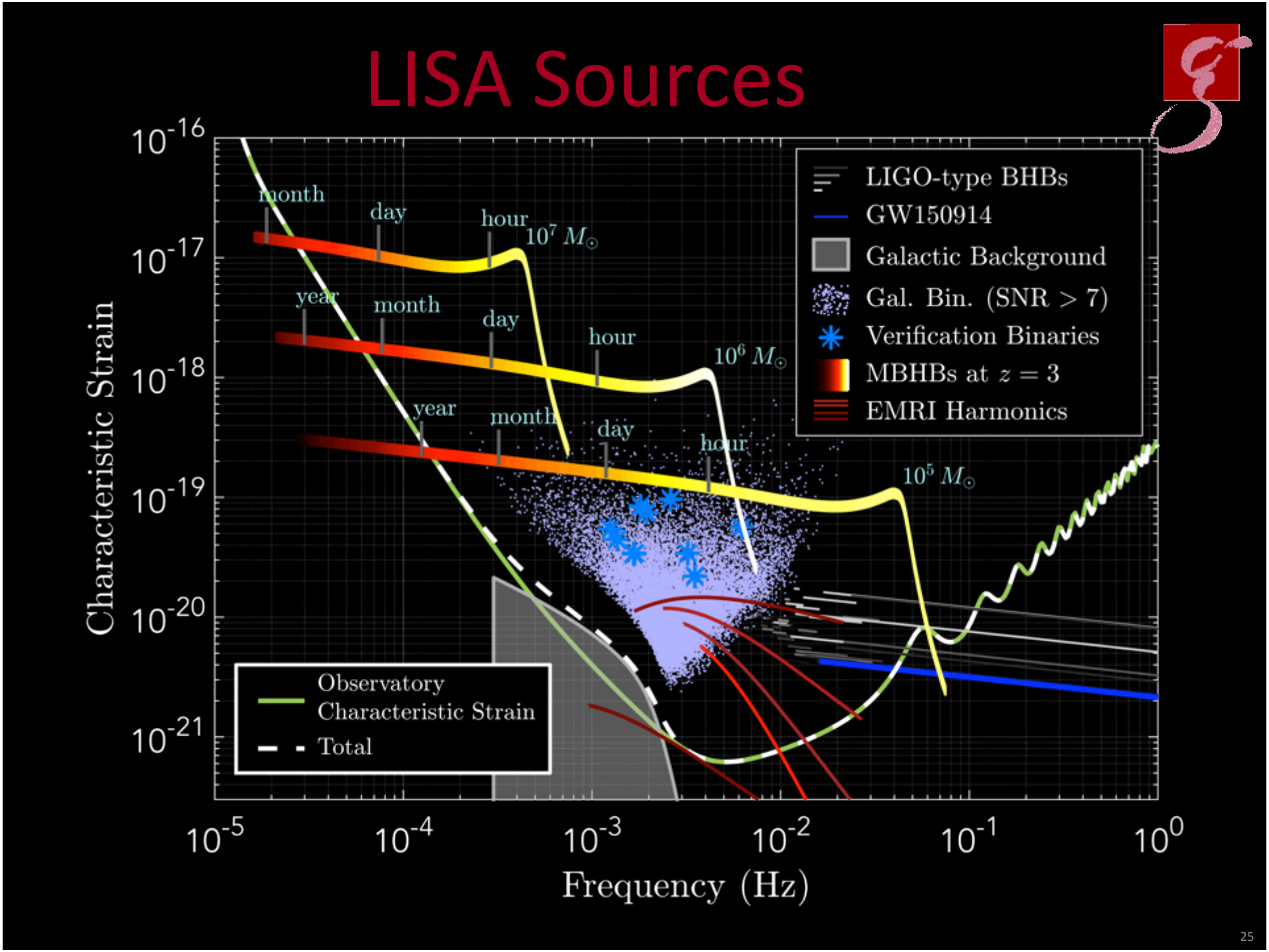
Prepared by the CDF* Team



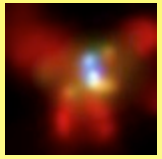
(*) ESTEC Concurrent Design Facility

ESA UNCLASSIFIED – For Official Use - Privileged

LISA Sources



LISA for Astrophysics, Cosmology, and Fundamental Physics



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

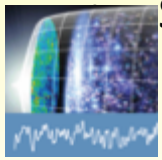
- When did the first Black Holes appear in pre-galactic halos and what is their mass and spin?
- How did Black Holes form, assemble and evolve from cosmic dawn to present time, due to accretion and mergers?
- What role did Black Holes play in re-ionisation, galaxy evolution and structure formation?
- 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 x 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?

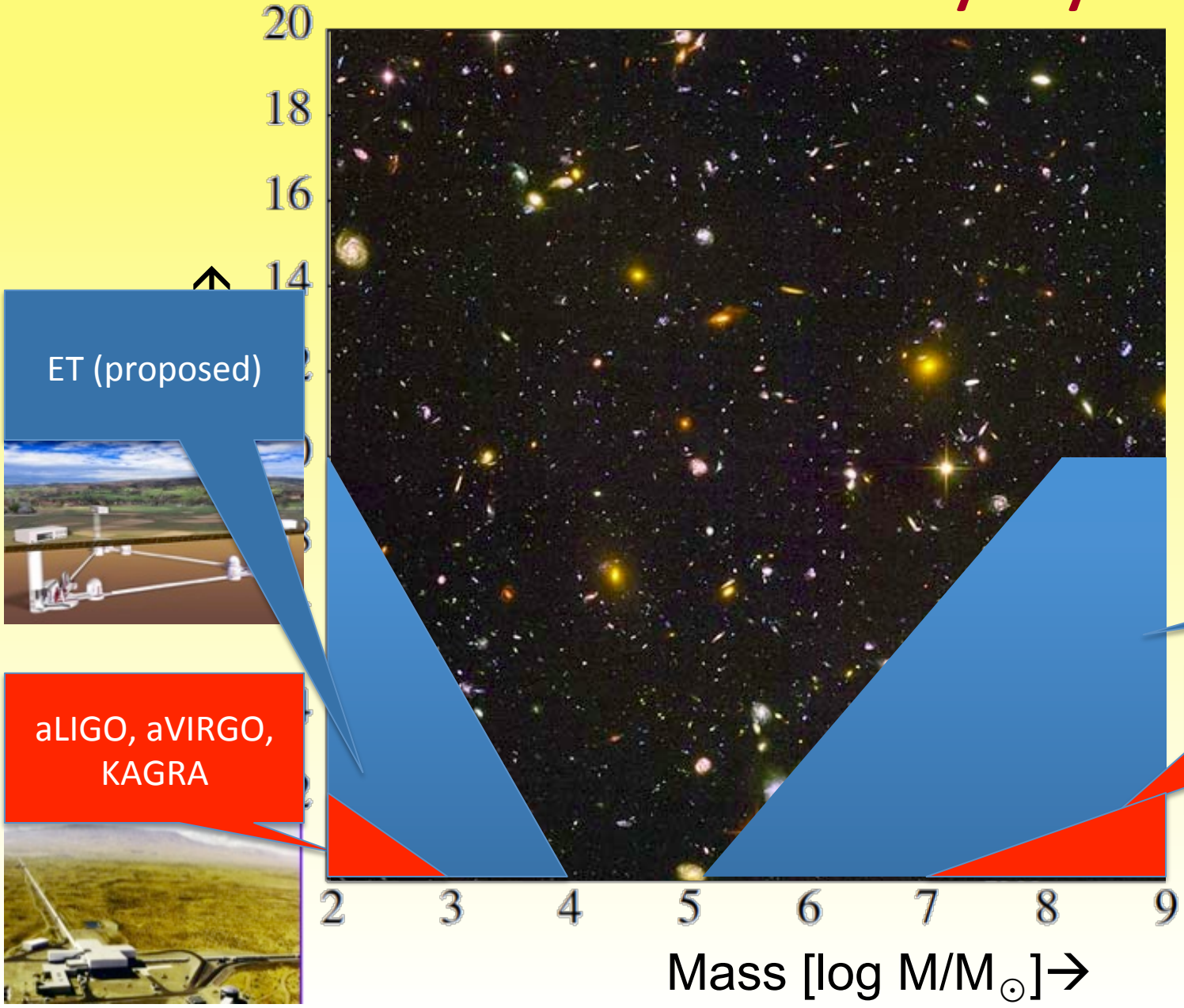


Stochastic Signals

- 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

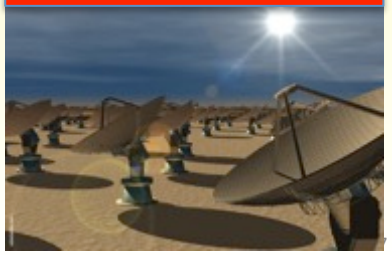


Future EM Obs.
LSST, JWST, EELT

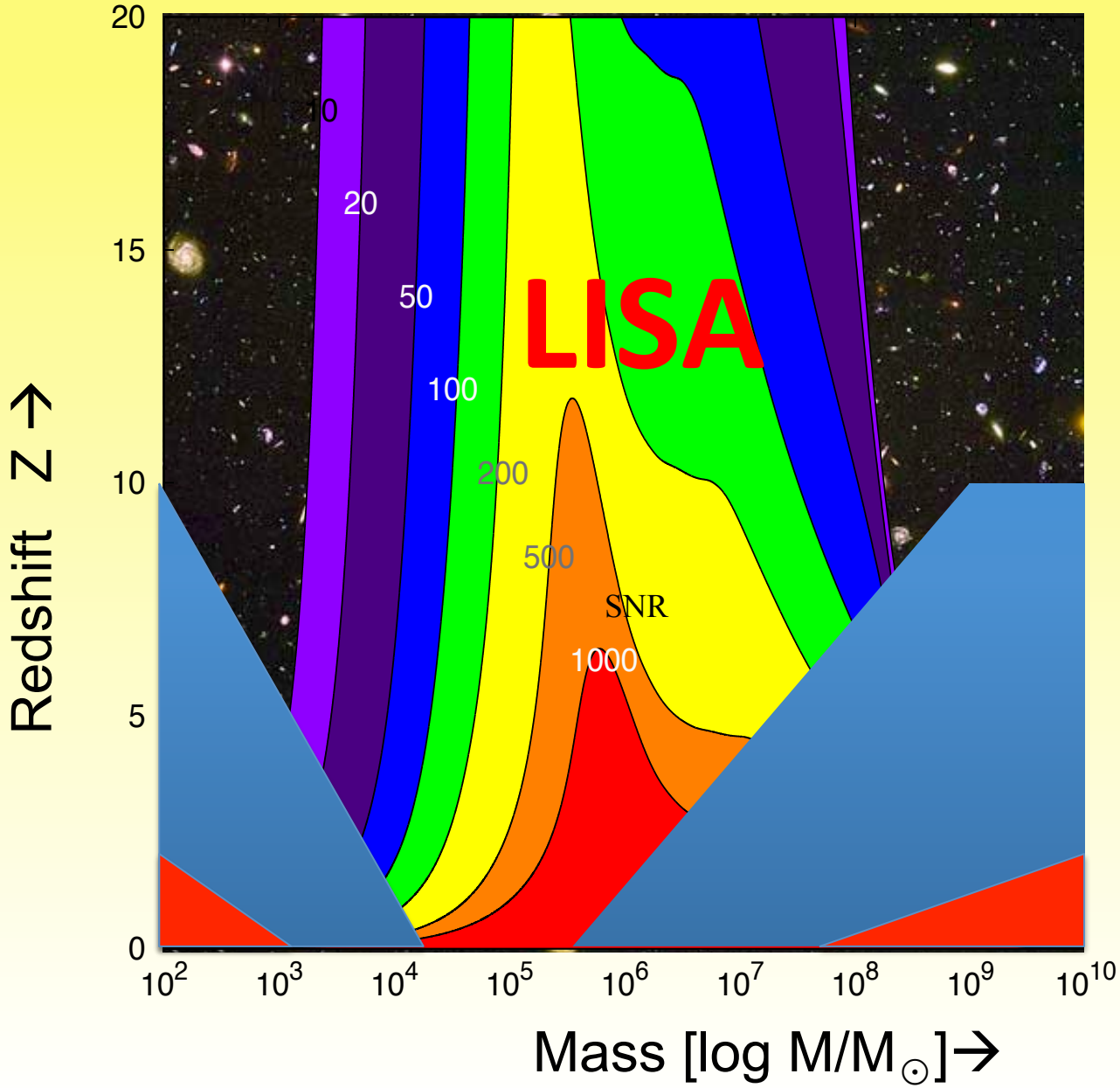
ET (proposed)

aLIGO, aVIRGO,
KAGRA

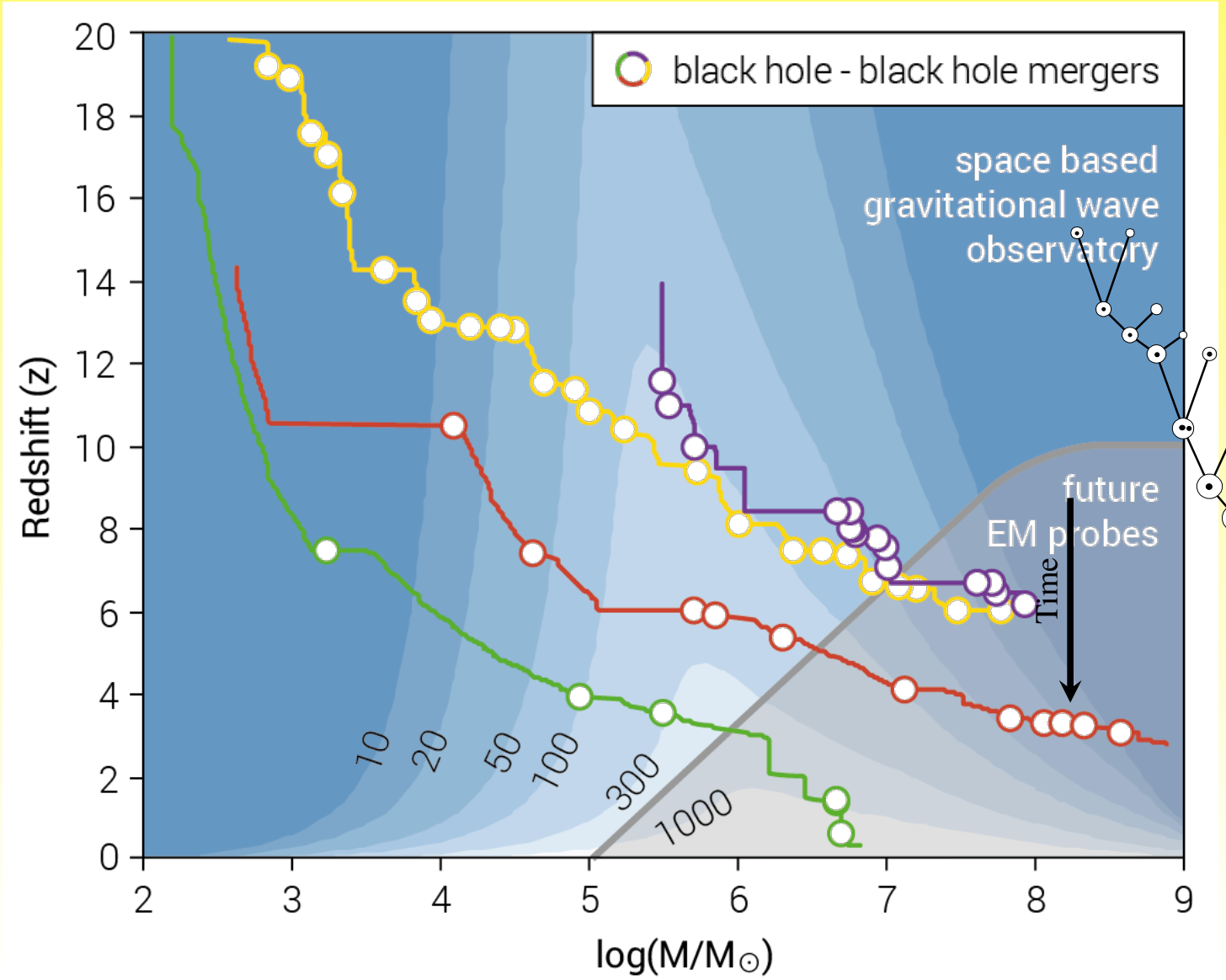
SKA, Pulsar
Timing

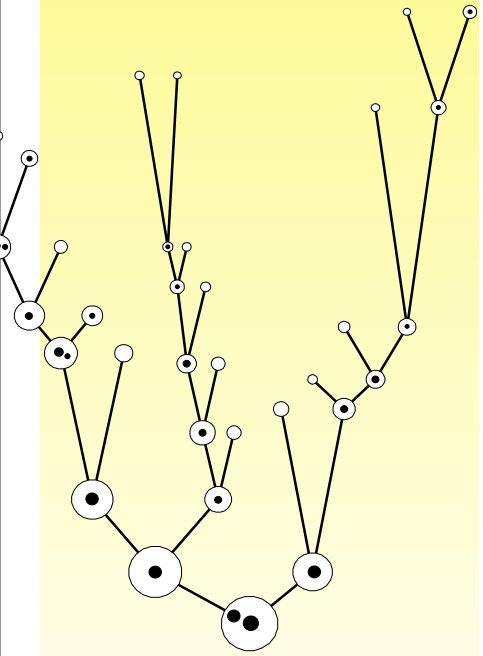


Black Hole Astronomy by 2030



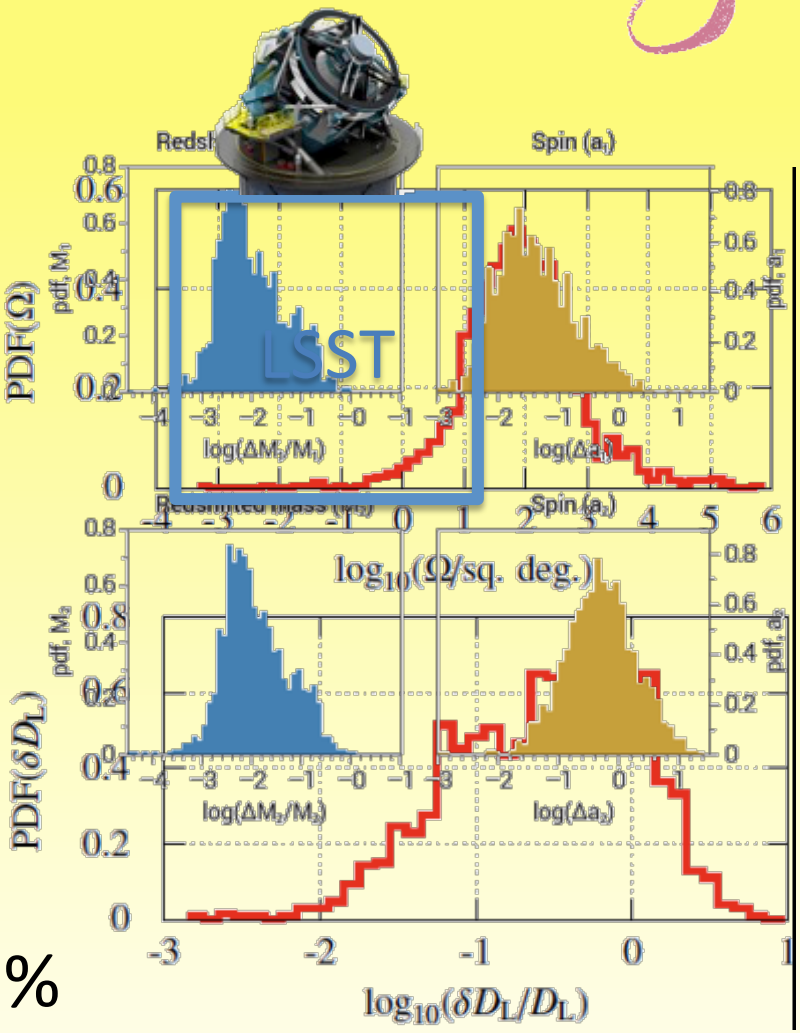
All Binary Black Holes cross LISA band: Trace Galaxy Mergers





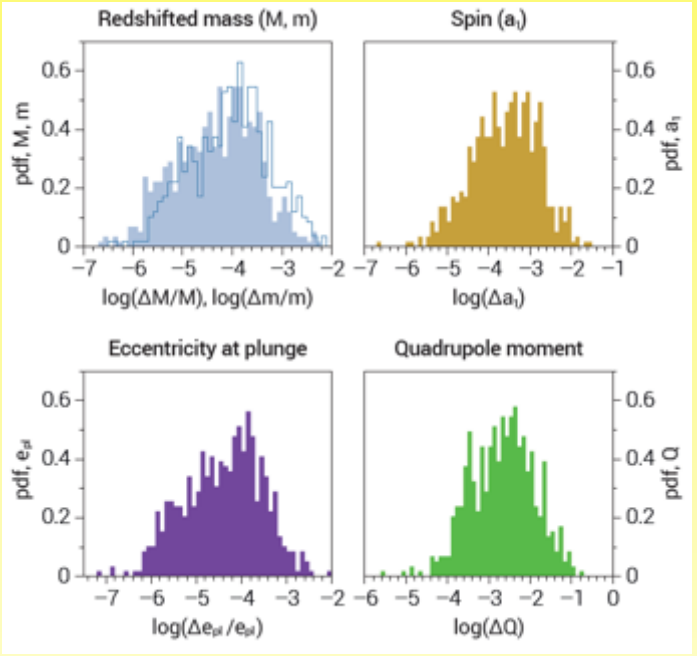
LISA Black Hole Physics at high SNR

- BBH rest mass 10^4 – 10^7
- Out to redshift z >> 10
  - if they exist
- 100s of events per year
- Redshifted mass to 0.1%-1%
- Absolute spin to 0.01-0.1
- Luminosity distance 1% – 10 %
- Sky location 0.1° - 10 °



Extreme Mass Ratio Inspirals

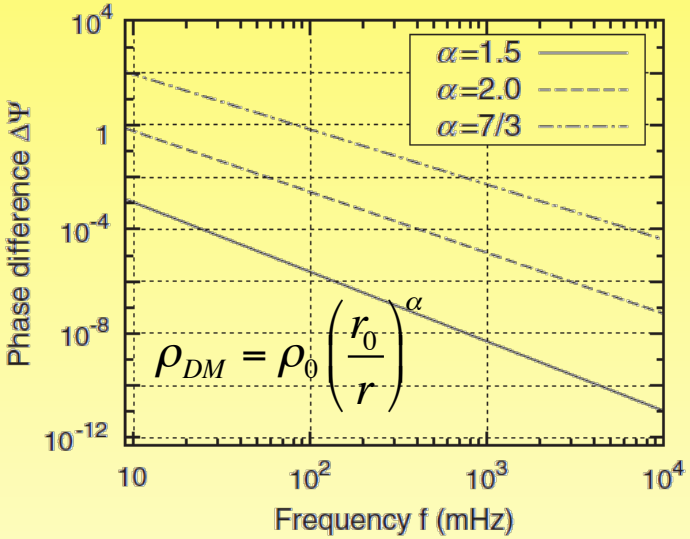
- SNR 20 up to z ≈ 0.7 for 10^5-10^6 $M_\odot$
- Dozens of events per year
- Mass, spin to 0.1% – 0.01 %
- Quadrupole moment to < 0.001 $M_\odot^3 G^2/c^4$



- 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,* 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

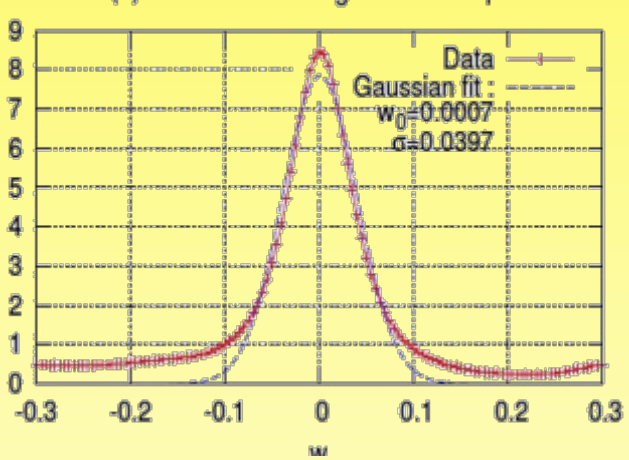
Cosmology with Standard Sirens

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

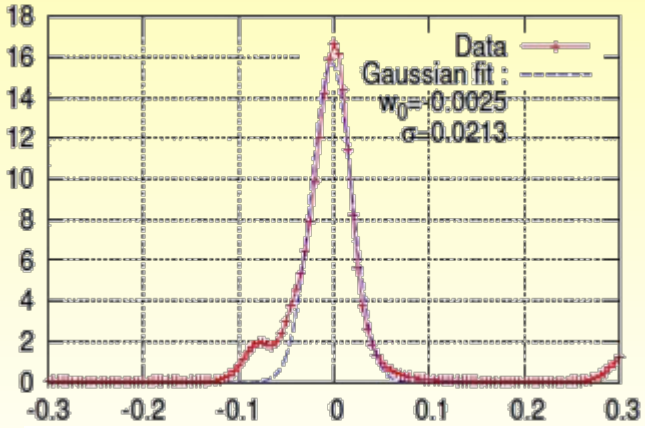
- **Using EMRIs, *without* identifications, LISA can determine H_0 to ±0.4% = ±0.3 km s^{-1} Mpc^{-1} after just 20 EMRI detections: ~3 months LISA data. (MacLeod & Hogan, PRD, 2008; SDSS) Today (WMAP) ±1.2 km s^{-1} Mpc^{-1}.**

- **Using massive mergers out to z = 3, again with *no* identifications, LISA can (in 3 years) determine dark energy equation of state parameter w to ±2-4%. (Petiteau et al, ApJ, 2011; Millennium). Compare EUCLID ±2%.**

No identifications



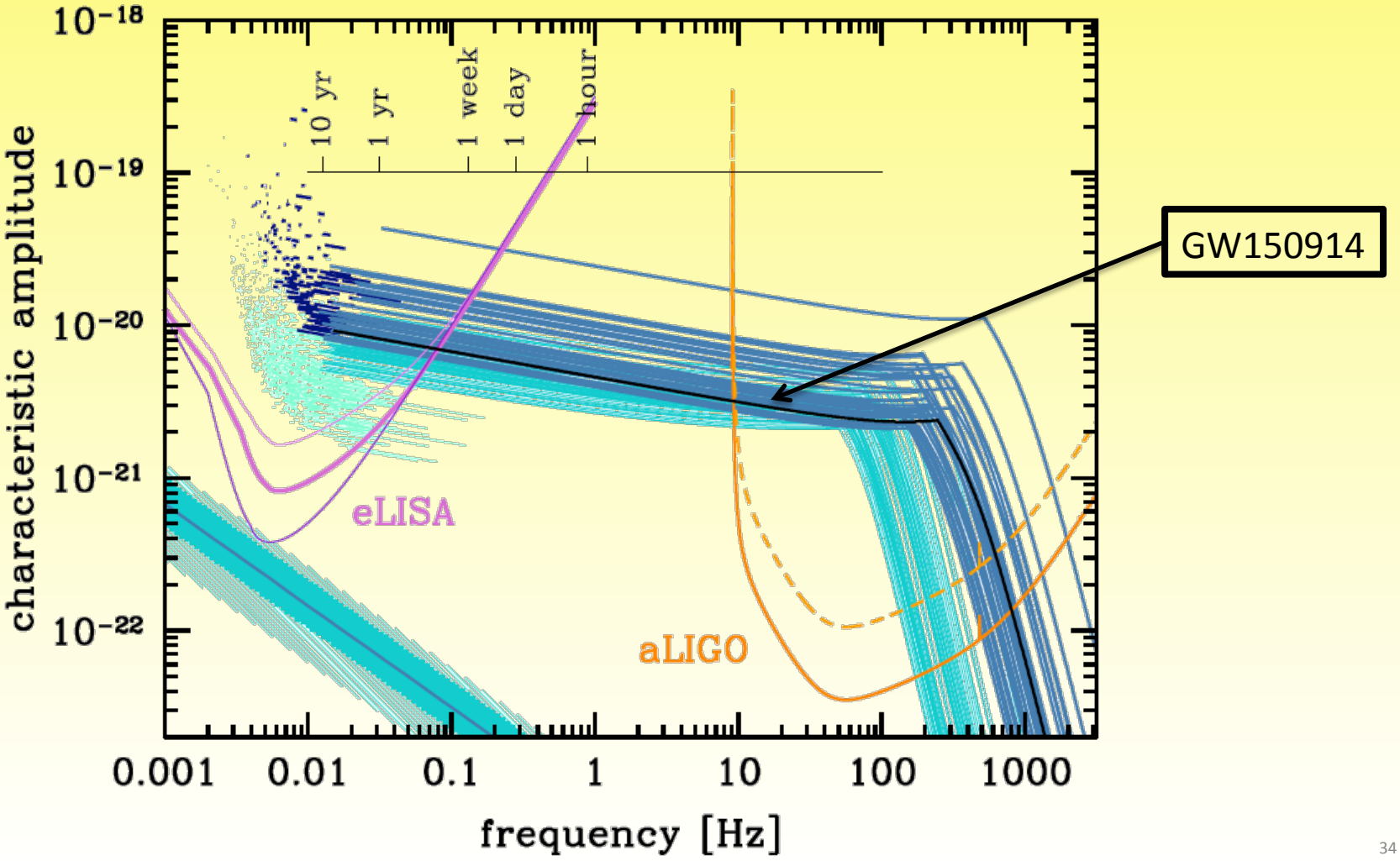
With identifications

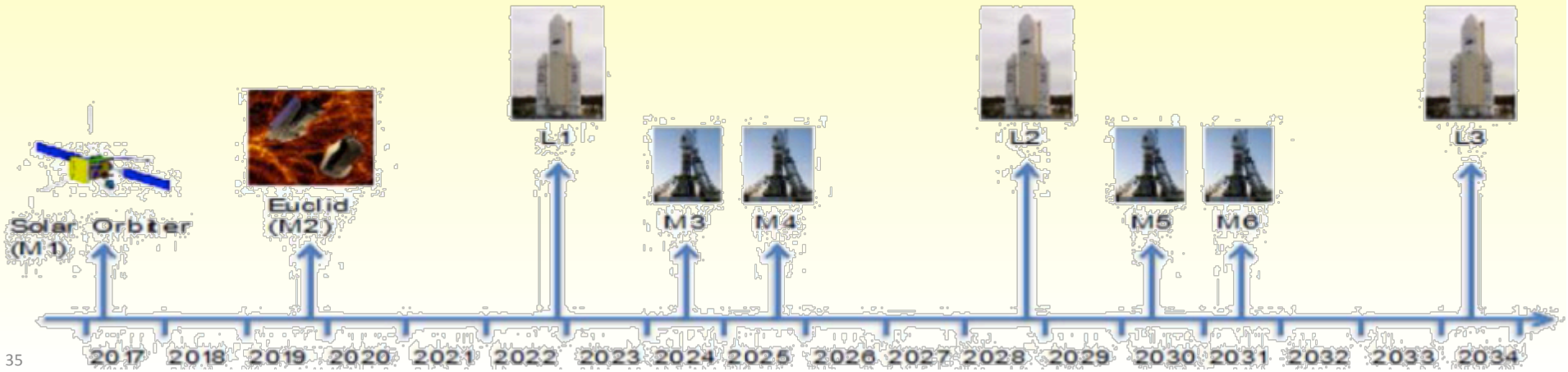


Dark Energy equation-of-state parameter w

LISA: LIGO Event Predicted 10 Years in Advance!

- Accurate to seconds and within 0.1 square-degree!



ESA L2 and L3 Missions

- Call for Mission Concepts fall 2016
- Decision on Implementation 2020
- Launch of L2 in 2028
- Launch of L3 in 2034
- LISA shall be ready for an early launch!