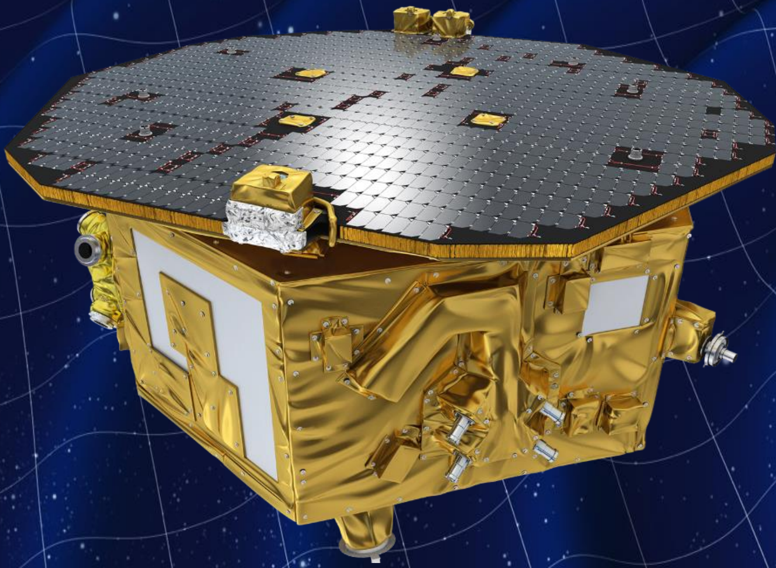
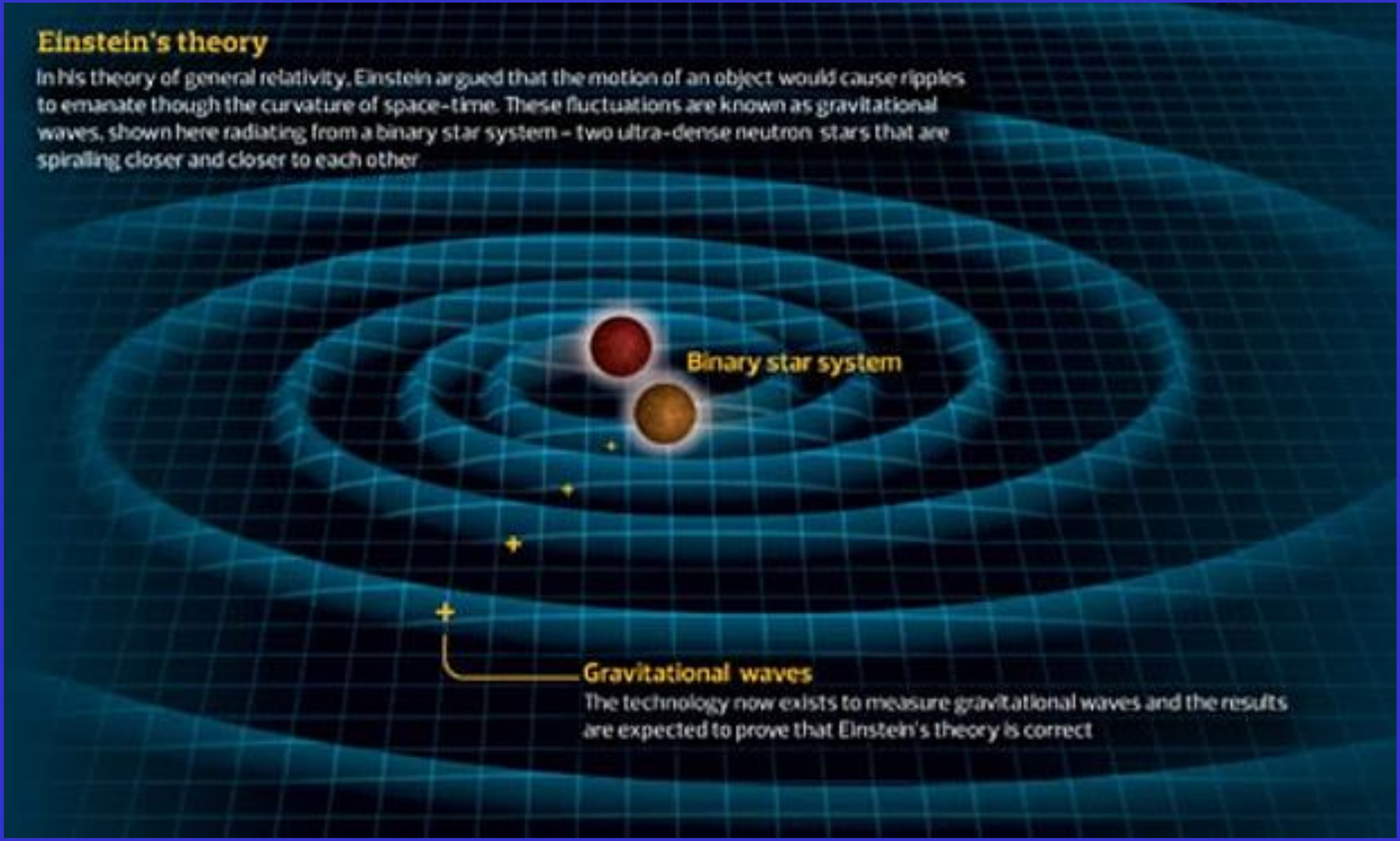


LISA Pathfinder and the way forward for Gravitational waves detection

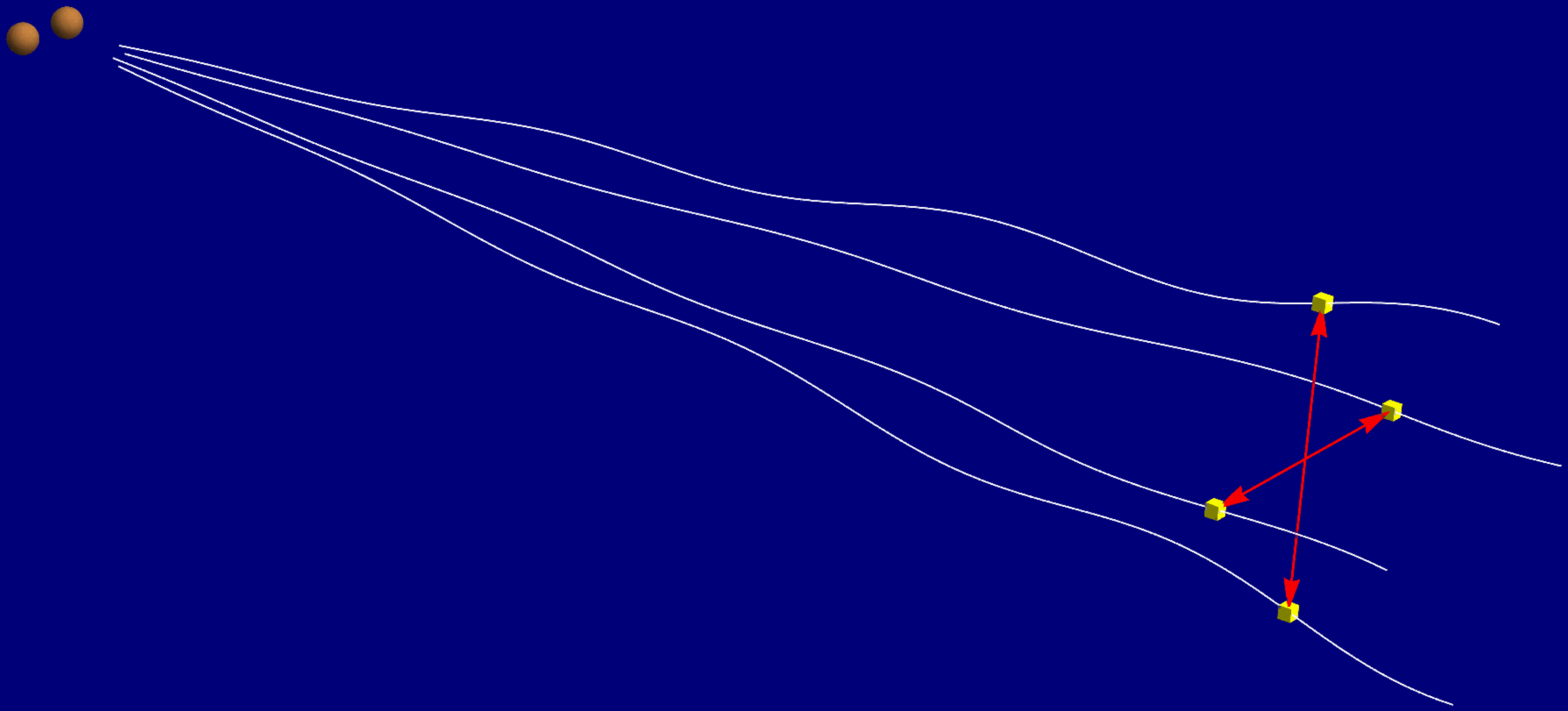
Maria Cristina Falvella
On the behalf of ASI

Gravitational Waves detection

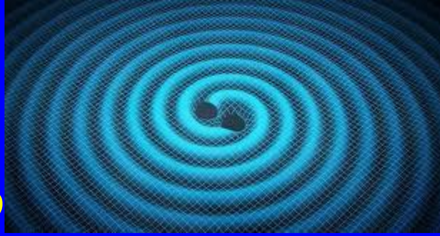
Gravitational waves are ripples in space-time predicted by Albert Einstein in his General Theory of Relativity.



Effects of gravitational waves on test masses

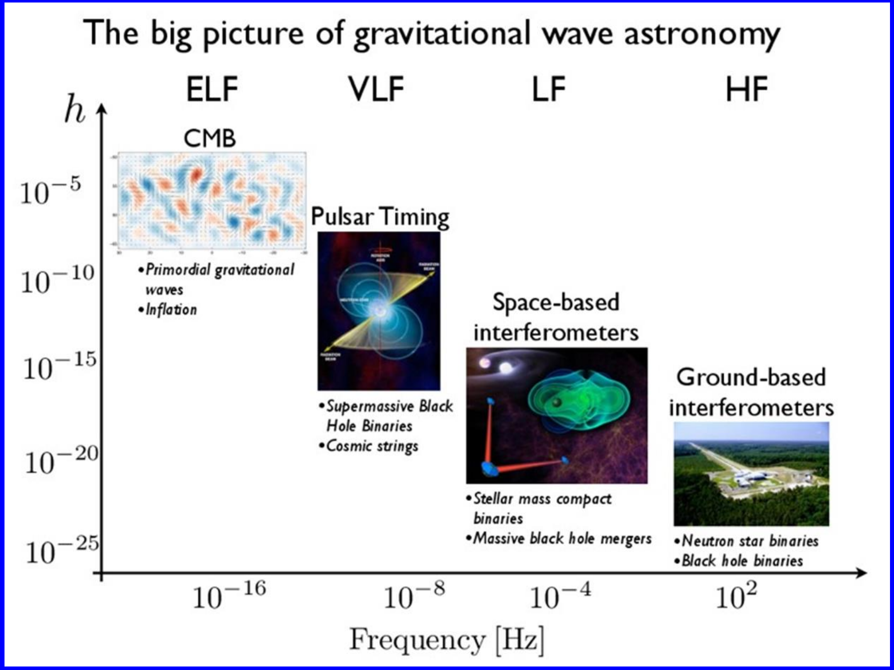


Ground and space observations



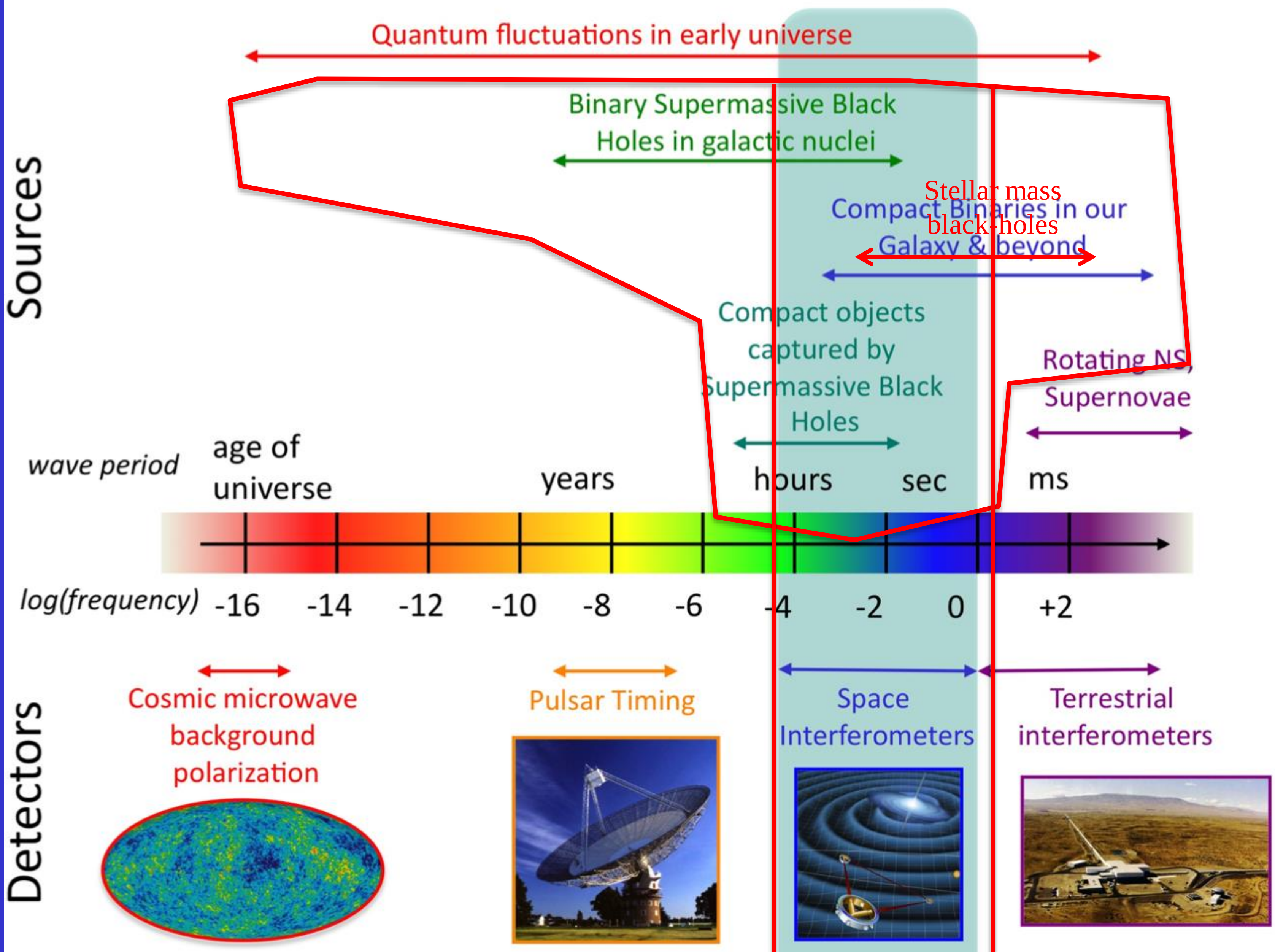
Ground-based detectors are already being used to try to identify high-frequency gravitational waves.

The recent detection of a gravitational wave signal from the merger of two black holes of a few tens of solar masses has inaugurated gravitational astronomy but the most predictable and powerful sources of gravitational waves emit their radiation at very low frequencies.

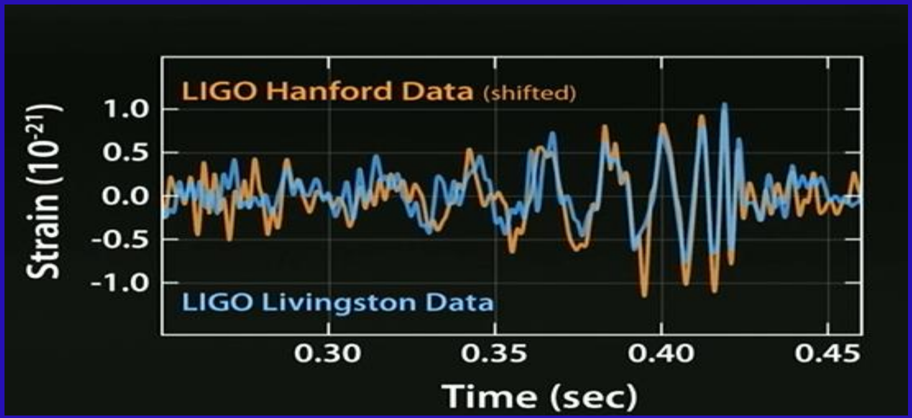


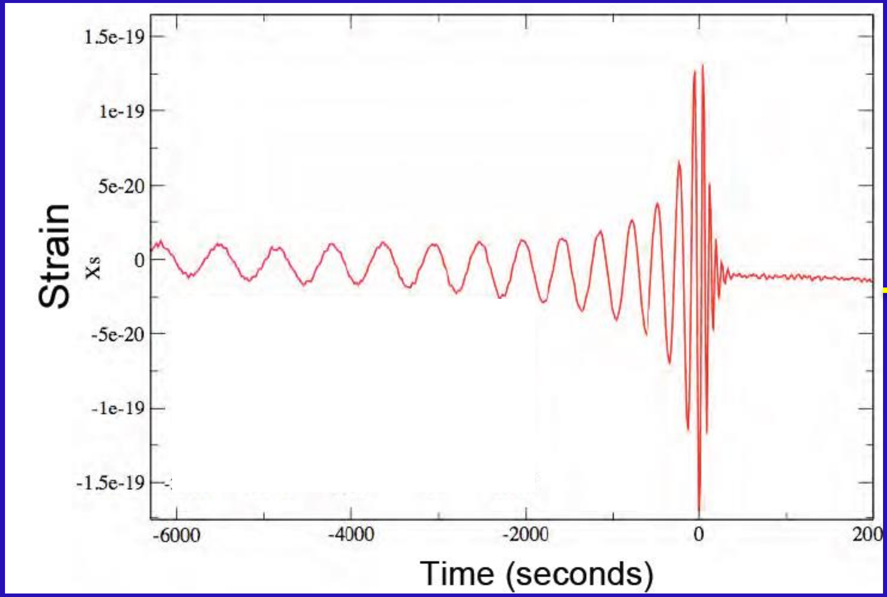
Mergers of two massive black holes liberate energies a million times that liberated by the event observed by LIGO, and will be detectable with high signal to noise ratio from the limit of the Universe.

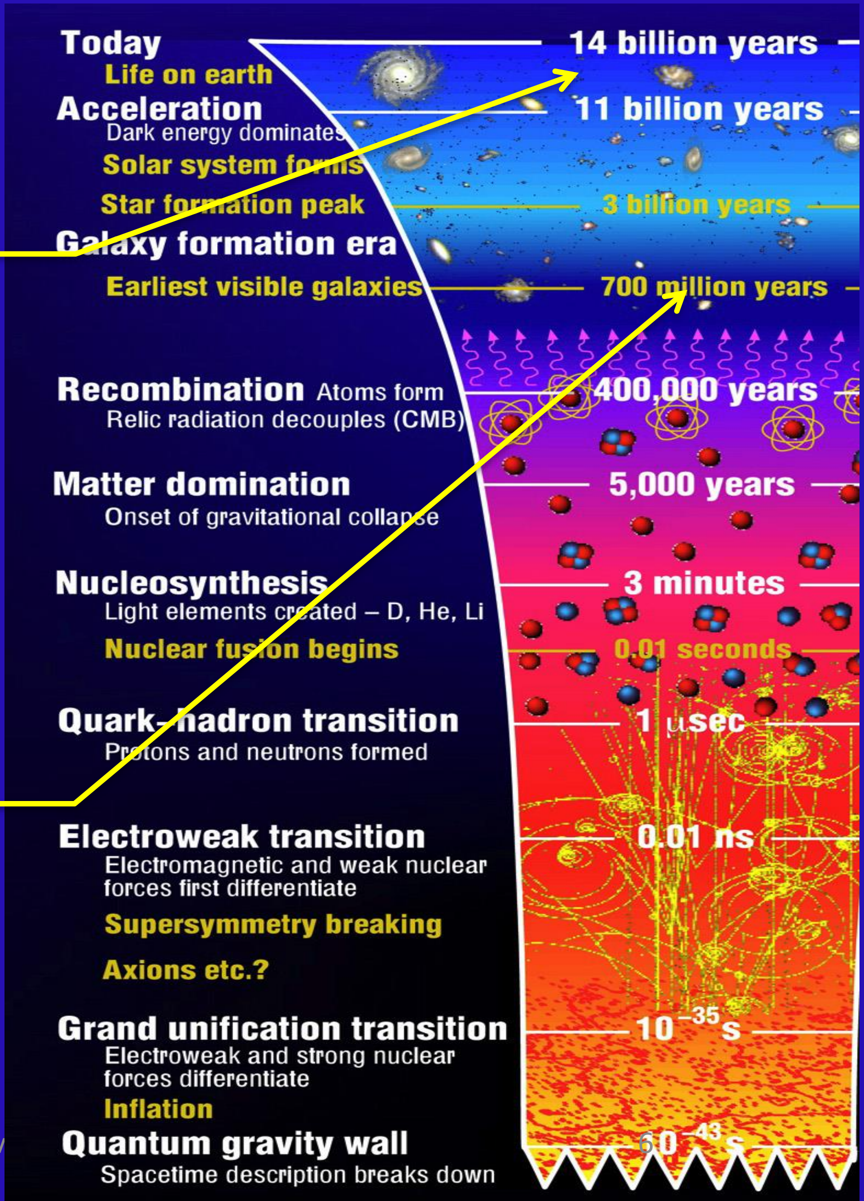
The Gravitational Wave Spectrum

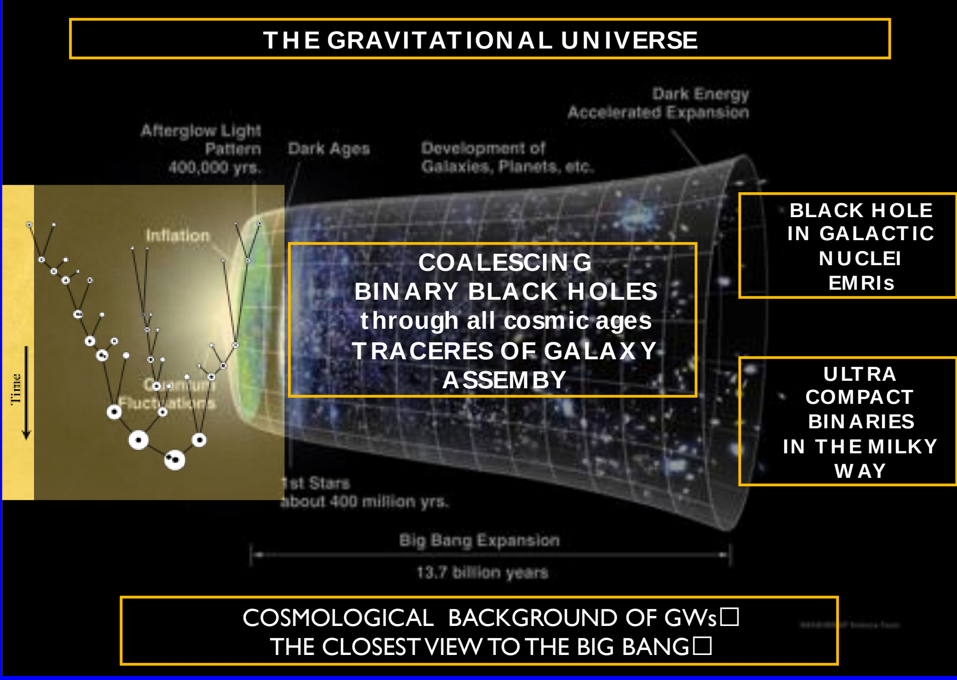


A deep universe observatory









The Gravitational Laboratory

- Does gravity travel at the speed of light ?
- Does the graviton have mass?
- How does gravitational information propagate: Are there more than two transverse modes of propagation?
- Does gravity couple to other dynamical fields, such as, massless or massive scalars?
- What is the structure of spacetime just outside astrophysical black holes? Do their spacetimes have horizons?
- Are astrophysical black holes fully described by the Kerr metric, as predicted by General Relativity?

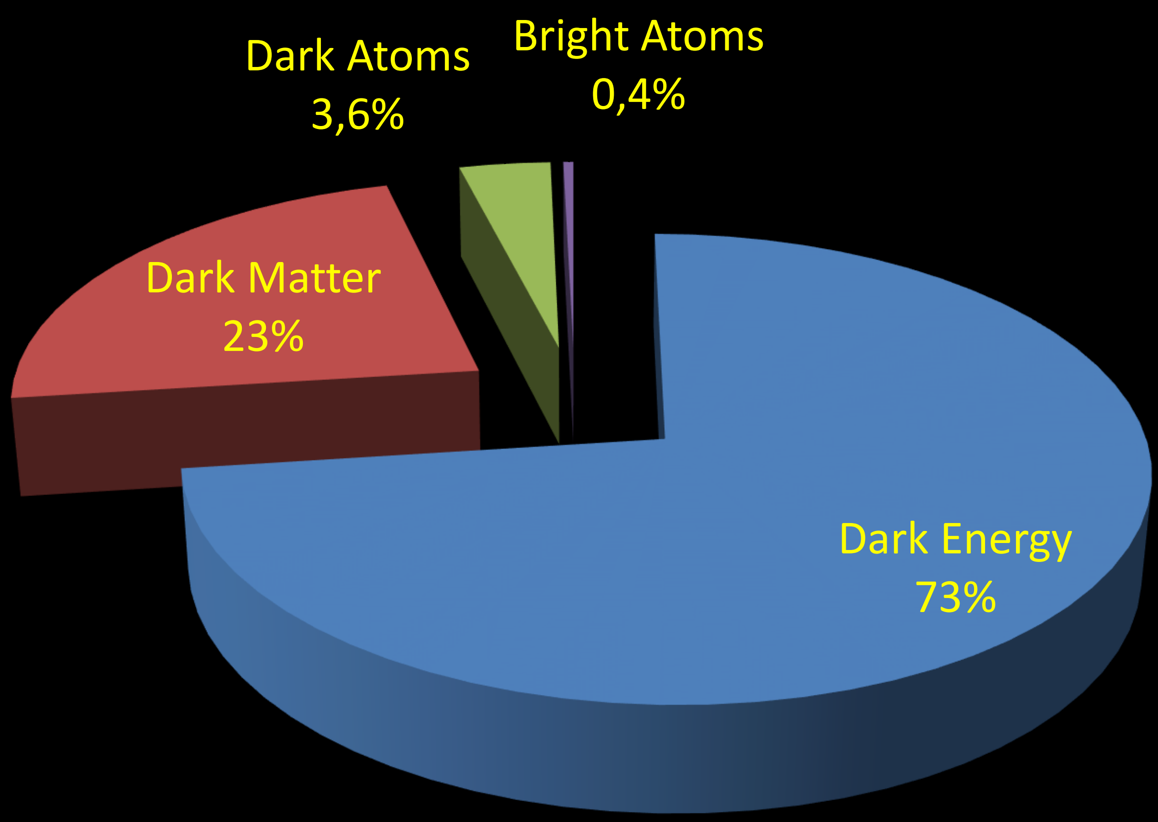
A mission in astrophysics, cosmology and fundamental physics

Event Rates and Event Numbers

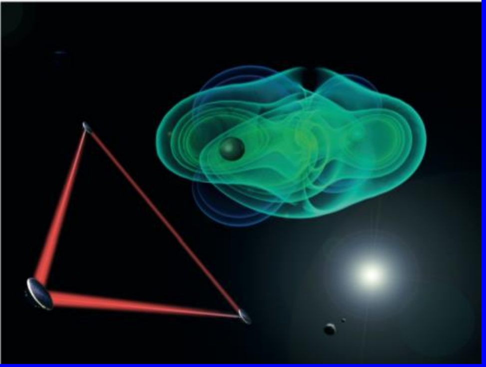
Frequency band	1×10^{-4} Hz to 1 Hz, (3×10^{-5} Hz to 1 Hz as a goal)
Massive black hole mergers	$10\,\text{yr}^{-1}$ to $100\,\text{yr}^{-1}$
Extreme mass ratio inspirals	$5\,\text{yr}^{-1}$ to $50\,\text{yr}^{-1}$
Galactic Binaries	~ 3000 resolvable out of a total of ~ 30×10^6 in the *eLISA* band

+ what we cannot predict

The Gravitational Universe



- 99,6 % of the Universe is made of no-bright atoms.



ESA 3rd large class mission

LISA-Laser Interferometer Space Antenna, an earlier concept for a spaceborne observatory for gravitational waves, and now used to describe a class of missions based on the original LISA concept.
LISA Pathfinder is testing key technologies for future LISA-like space missions to study the gravitational Universe.

THE ESA COSMIC VISION

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

Missions in the Cosmic Vision 2015-2025 Programme	
L1 mission	JUICE
L2 mission	Athena
L3 mission	Gravitational wave observatory
M1 mission	Solar Orbiter
M2 mission	Euclid
M3 mission	PLATO
S1 mission	CHEOPS
S2 mission	SMILE

M4 Candidate Missions in the Cosmic Vision 2015-2025 Programme
ARIEL, THOR, XIPE

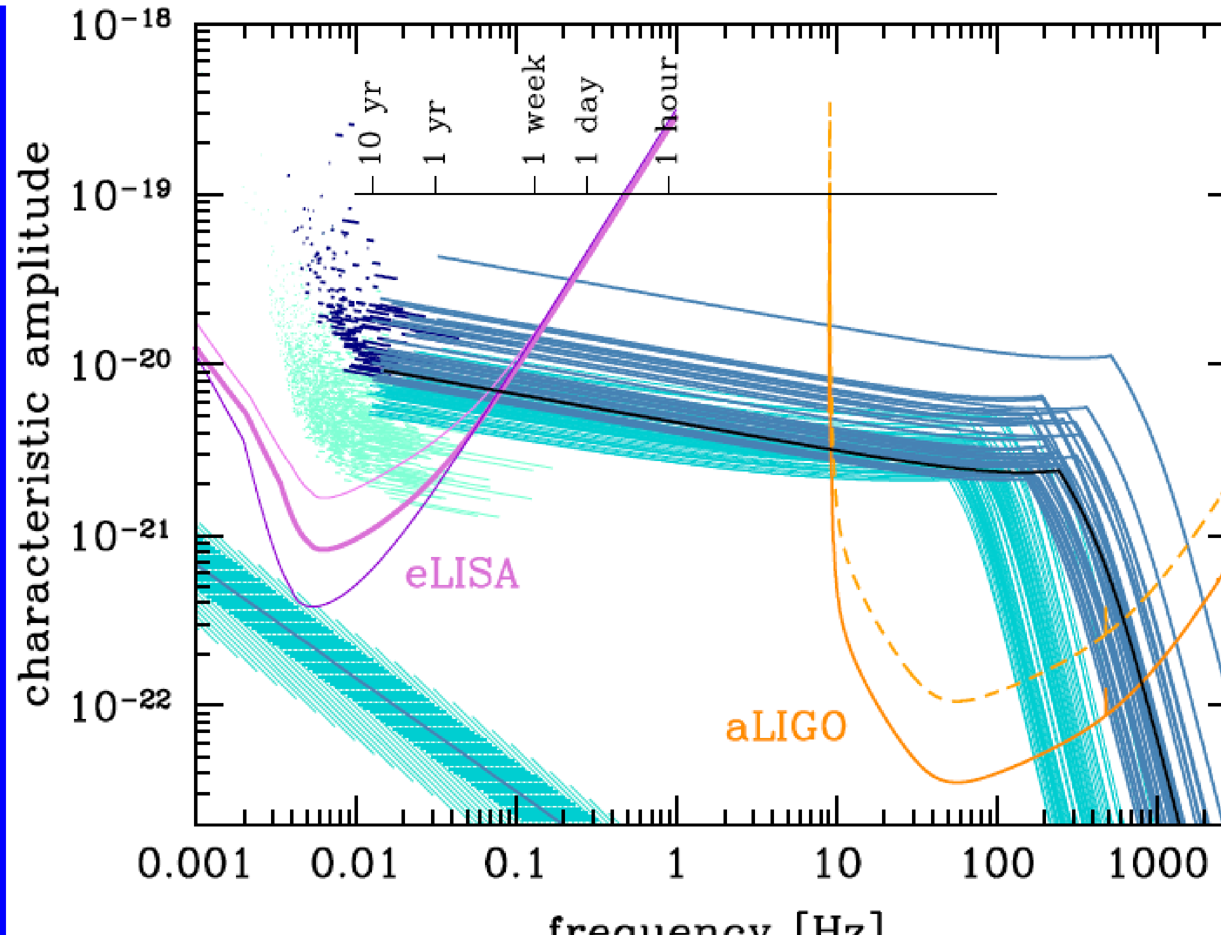
Editors' Suggestion

Prospects for Multiband Gravitational-Wave Astronomy after GW150914

Alberto Sesana

Phys. Rev. Lett. **116**, 231102 (2016) – Published 8 June 2016

Rates of black hole merger formations inferred from the recent detection of gravitational waves suggest that a future space based facility like eLISA can efficiently inform LIGO and other facilitates about locations of potential black hole mergers weeks in advance.

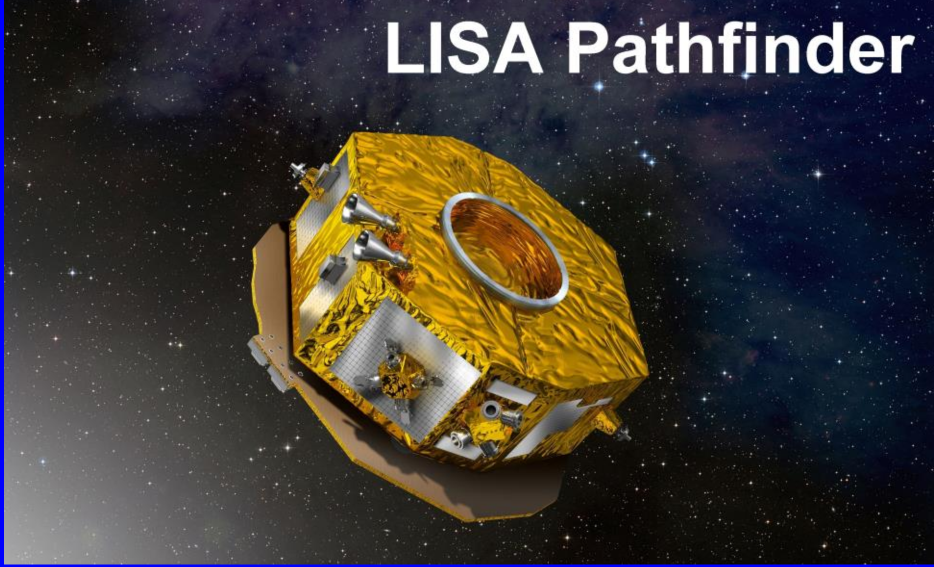


Looking for a path….

To explore the gravitational Universe requires an object- a test mass- to be in free fall.

Space is the ideal laboratory to measure for long periods of time.

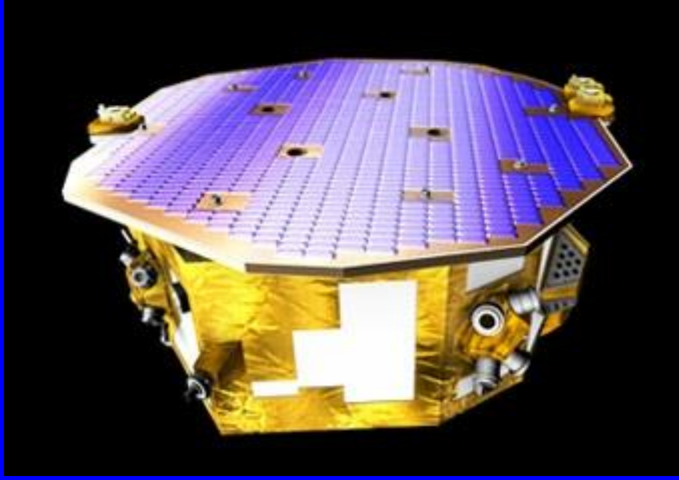
LISA Pathfinder was designed to be the technology precursor for a space based gravitational wave observatory



Contrary to ground based detectors like LIGO or Virgo, that operate in the audio-band, a GW observatory such as LISA, will explore the milli-Hertz frequency range, that cannot be explored from ground because of the intense gravitational noise of the Earth.

Mergers of two such black holes liberate energies a million times that liberated by the event observed by LIGO, and will be detectable with high signal to noise ratio from the limit of the Universe.

The basic concept



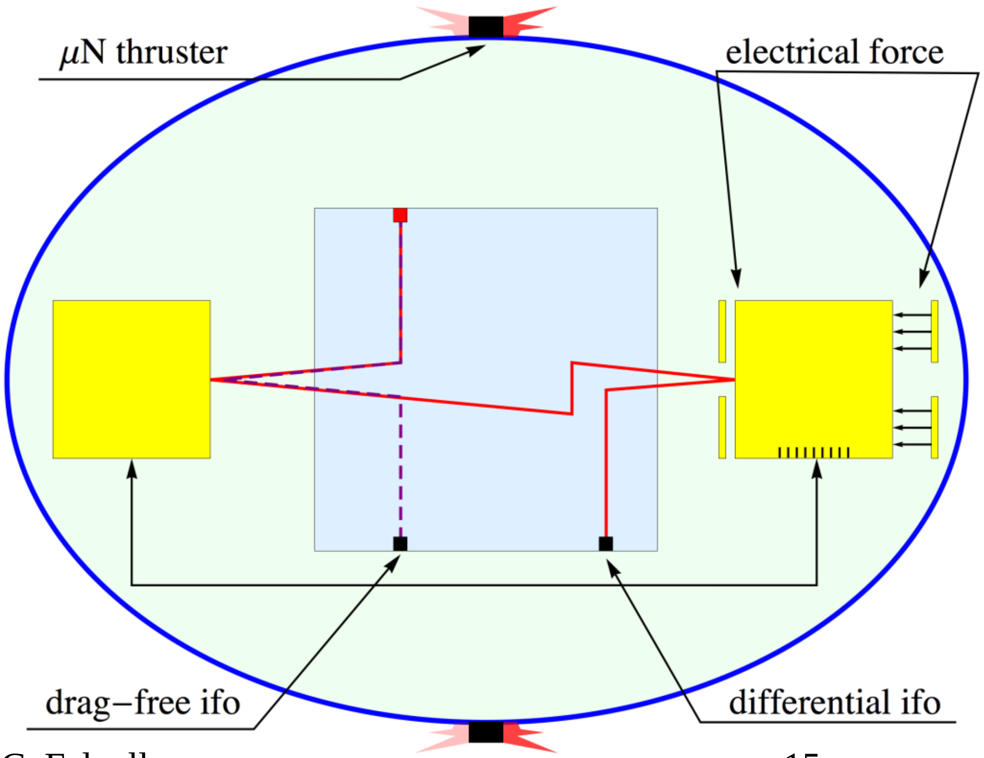
LISA Pathfinder is designed to test one of the key ideas behind gravitational wave detectors: free particles follow geodesics in space-time.

The mission can show this more accurately than has been done in the past by tracking two test masses nominally in free fall, using picometre resolution laser interferometry.

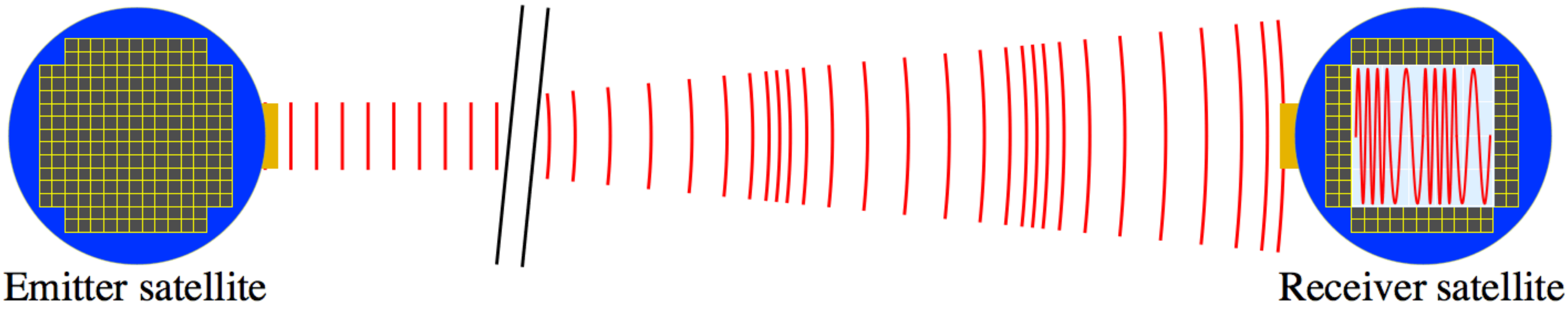
Several new technologies have been developed, firstly to isolate the test masses from external forces when they get to space, and secondly to allow for the extremely small distance measurements to be performed by an onboard interferometer.

LISA Pathfinder concept

- Test of 95% of noise does not need Million km separation
- Requires free-falling test-masses inside a single spacecraft
- LPF 2 TMs, 2 Ifos, Satellite chases one test-mass
- Second test-mass forced to follow the first at very low frequency by electrostatics (different from LISA)



The LISA link



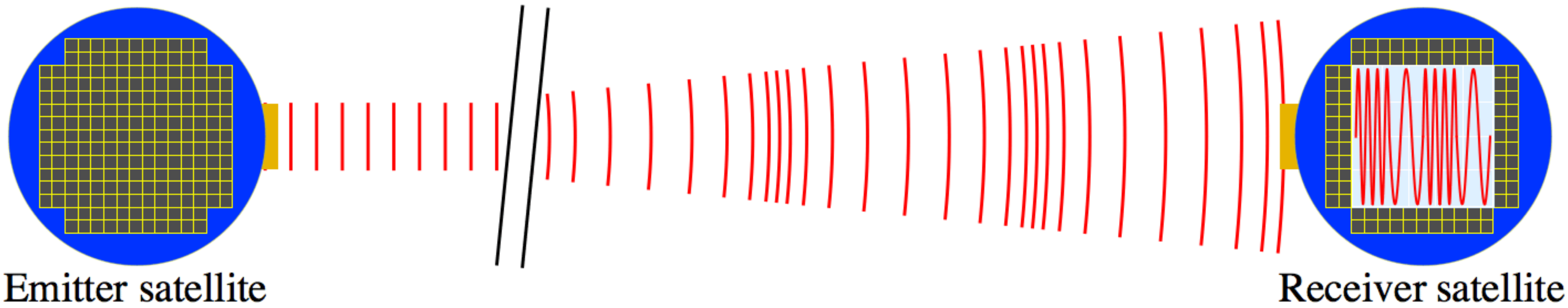
- GW curvature modulates the frequency of the received beam

$$\frac{d\nu_{rec.}}{dt_r} - \frac{d\nu_{em.}}{dt_e} = -\frac{c^2}{2\pi}\int_{beam} k^\sigma u^\nu R^\rho_{\nu\sigma 0} k_\rho \, d\lambda = \nu_o \left\{ \dot{h}_{receiver}(t) - \dot{h}_{emitter}(t - L/c) \right\}$$

PHYSICAL REVIEW D **88**, 082003 (2013)

Space-borne gravitational-wave detectors as time-delayed differential dynamometers

The eLISA link: a time delayed differential accelerometer



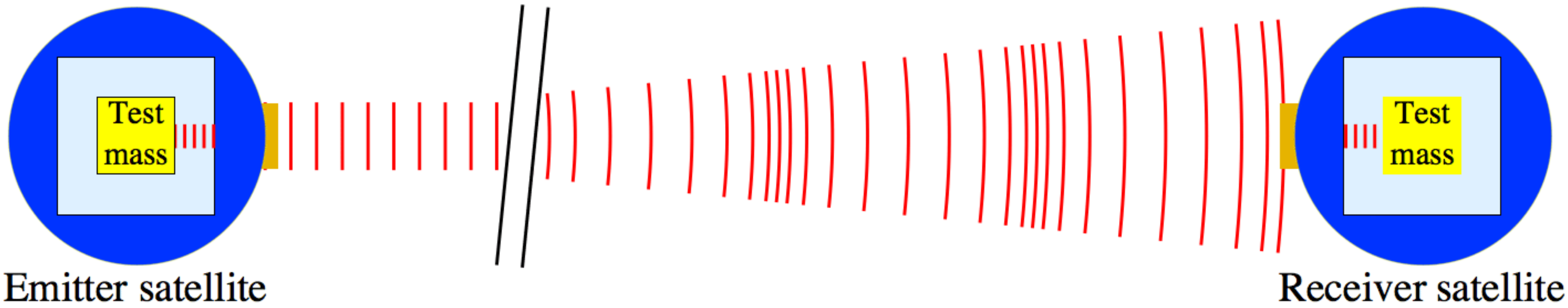
- Accelerations of satellites, *relative to their local inertial frame,* modulate frequency as curvature does.

$$\left(c/\nu_o\right)\left(\dot{\nu}_{\text{receiver}} - \dot{\nu}_{\text{emitter}}\right) = c\left\{\dot{h}_{\text{receiver}}(t) - \dot{h}_{\text{emitter}}(t - L/c)\right\} + $$
$$+ a_{\text{receiver}}(t) - a_{\text{emitter}}(t - L/c)$$

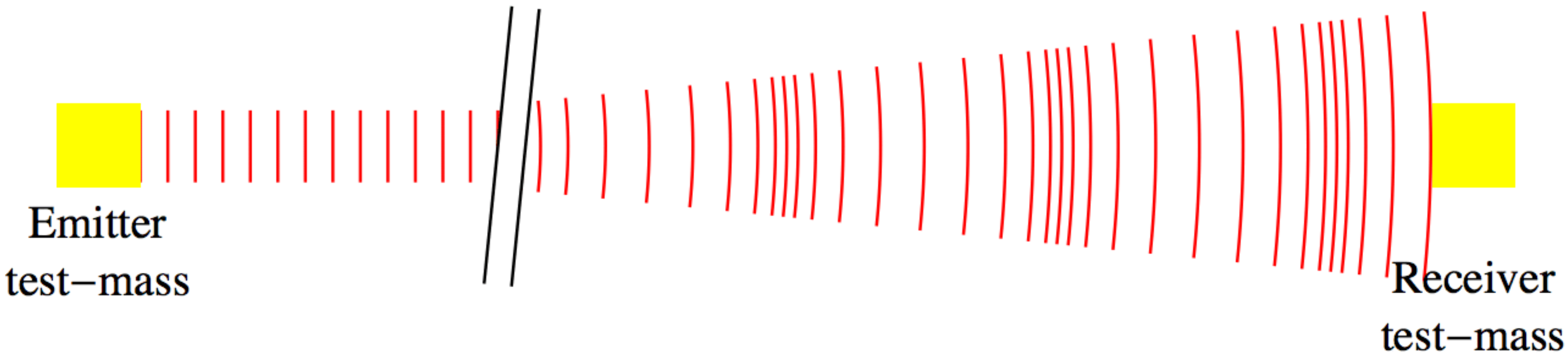
PHYSICAL REVIEW D **88**, 082003 (2013)

Space-borne gravitational-wave detectors as time-delayed differential dynamometers

The eLISA link: a time delayed differential accelerometer

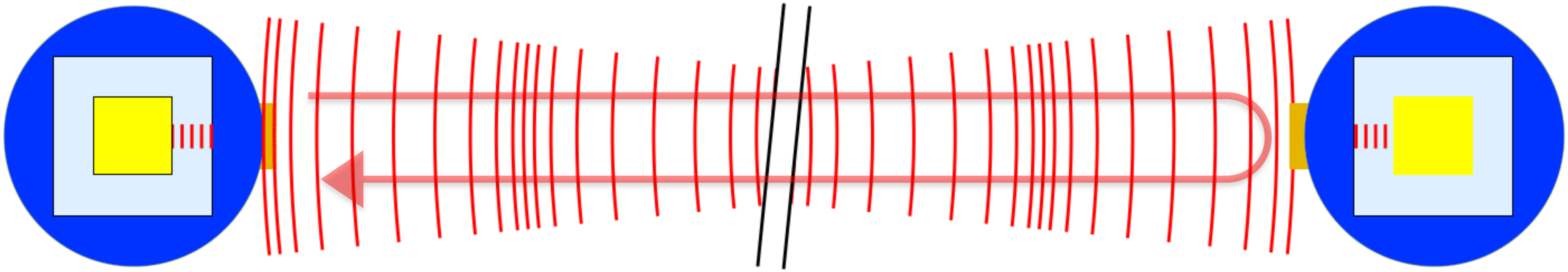


- Inertial reference test-masses are used to correct for satellite acceleration

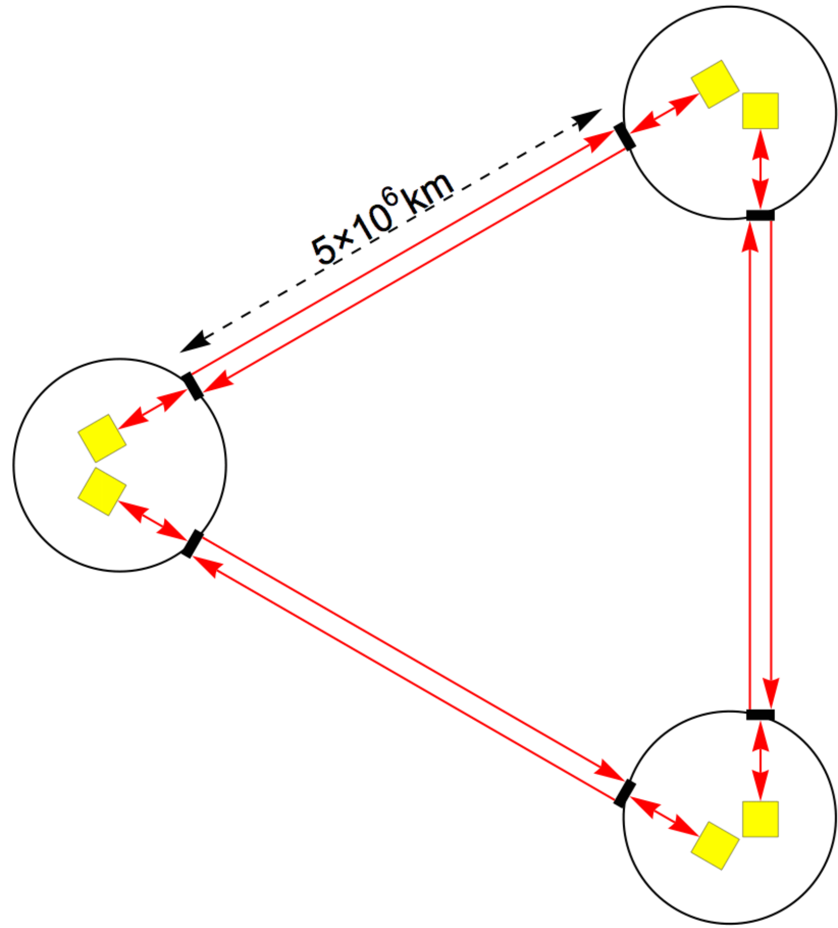


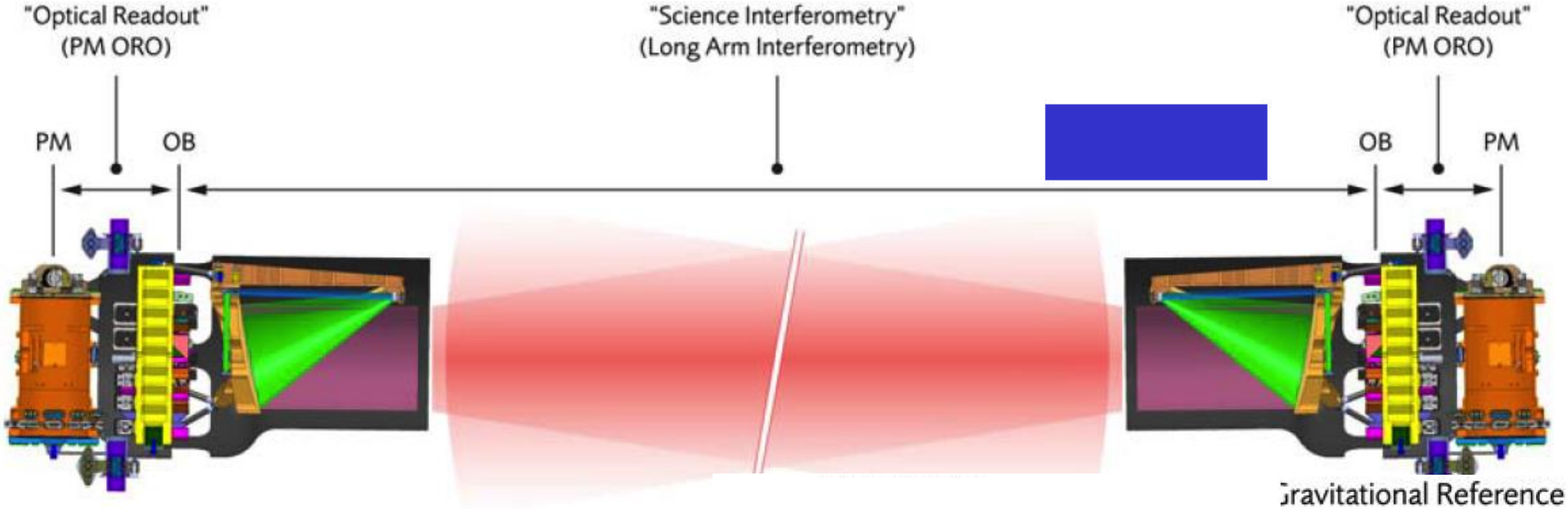
- Equivalent to directly tracking test-masses

The detector arm (eLISA)

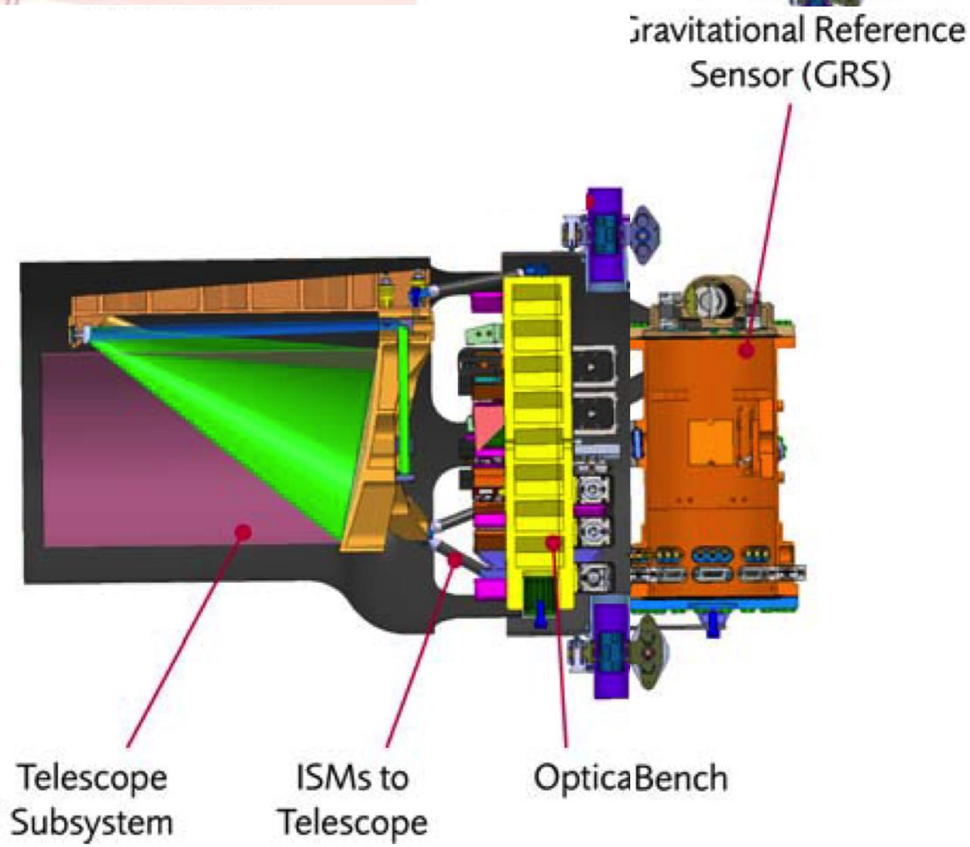


- Two counter-propagating, phase-locked links
- LISA: 3 arms 5 Mo km
- 10 pm/√Hz single-link interferometry @1 mHz
- Forces (per unit mass) on test-masses < 3 fm/(s^2√Hz) @ 0.1 mHz
- 3 non-contacting (“drag-free”) satellites

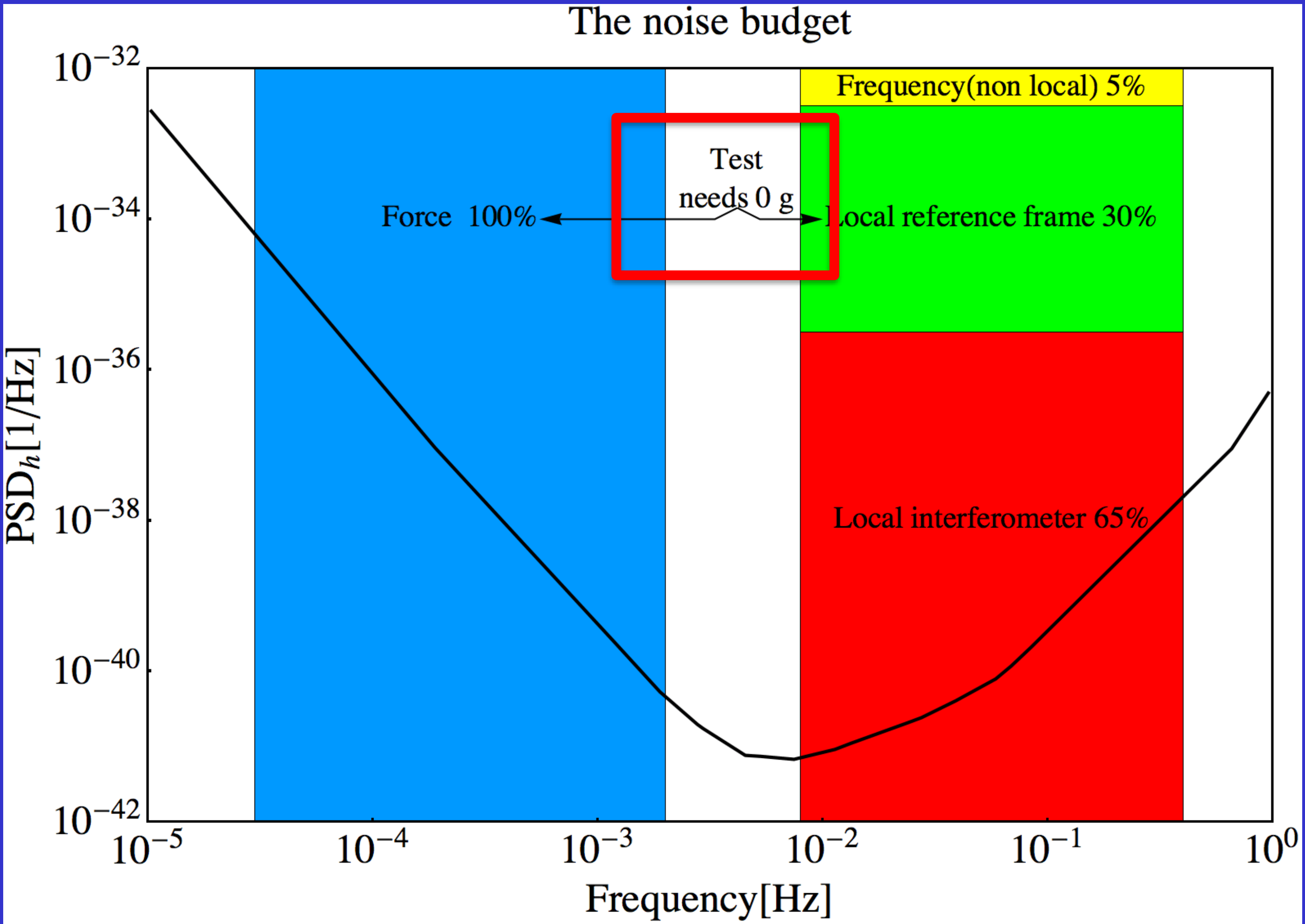




- eLISA instrument key elements:
  - The Gravitational Reference Sensor with the test-mass (also called Inertial Sensor)
  - The Optical Bench with the complete interferometry
  - A telescope to exchange light with the far satellite



Most of disturbances are local and can be tested within one satellite!



Easy to describe, challanging to realize

A spacecraft built to isolate the experiment from all other forces except gravity:

- **Orbit:** L1 to eliminate Sun radiation pressure and other effects
- **the spacecraft :** balanced so that it does not pull on the test masses with its own gravitational field
- **test masses**: in a special combination of gold and platinum to get a magnetic susceptibility was virtually zero
- **design**: shape of the masses, location of the lasers and thrusters, inertial sensors, laser metrology system, drag-free control system and an ultra-precise micro-propulsion system , etc.

LISA Pathfinder- a pioneering mission

- the first high-quality orbiting gravitational laboratory for Fundamental Physics missions
- It is conducting the first high-precision laser interferometric tracking of orbiting bodies in space
- it is performing the first nanometre and sub-nanometre formation flight of bodies in orbit
- it is the first time test masses of this kind are flying freely in space at a distance of several millimetres from their surroundings with no mechanical contact to them.

LISA PATH FINDER PAYLOAD

The payload in LISA Pathfinder cannot be considered as a discrete piece of hardware carried by the spacecraft.

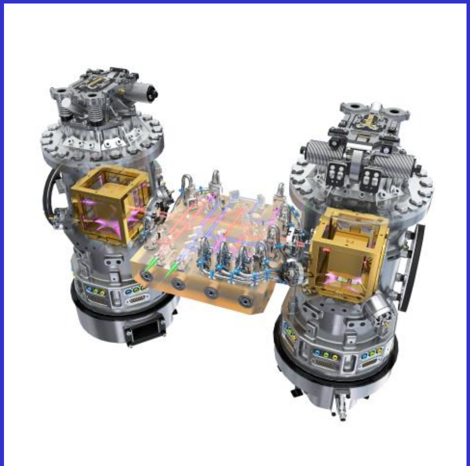
During science operations, the payload and the spacecraft act as a single unit: the attitude control of the spacecraft is driven by the payload.

LISA Pathfinder will carry two payloads:

- the LISA Technology Package (LTP)
- the Disturbance Reduction System (DRS).

THE LISA TECHNOLOGY PACKAGE

The LISA Technology Package is provided by a consortium of European National Space Agencies and ESA consists of two major subsystems:



-the Inertial Sensor Subsystem

- the Optical Metrology Subsystem

THE LISA TECHNOLOGY PACKAGE

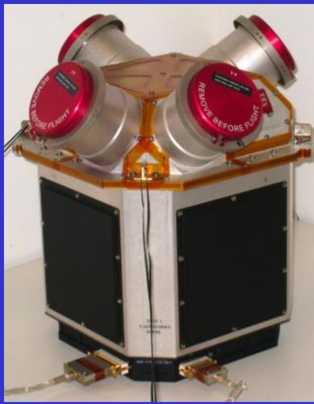
Country	Institute/Industry	Responsibility
France	APC/RUAG (CH)	Laser Modulator
Germany	AEI, Hannover	Co-PI, Interferometer Design
	Astrium GmbH	LTP Architect
	Tesat GmBH	Reference Laser Unit
Italy	University of Trento	PI, Inertial Sensor
	CGS	Inertial Sensor Subsystem (ISS)
	Thales Alenia Space	Test Mass Electrode Housing
The Netherlands	SRON	ISS Special Check Out Equipment
Spain	IEEC/University of Barcelona	Data Management Unit Data Diagnostic Unit
Switzerland	ETH Zurich/RUAG	ISS Front End Electronics
United Kingdom	University of Birmingham	Phasemeter Assembly
	University of Glasgow	Optical Bench Interferometer
	Imperial College London	Charge Management System
ESA	Thales Alenia Space/ RUAG	Caging Mechanism
	Astrium GmbH	LTP Architect

The Disturbance Reduction System

NASA contributes to the mission goals by validating additional technology for future drag-free spacecraft.

It will be run as a separate experiment and at different times from the full European system, but will start by receiving measurement input from the inertial sensors of the LISA Technology Package.

- .



LISA PATHFINDER TEAM

ESA PROJECT MANAGER César García Marirrodriga
PROJECT SCIENTIST Paul McNamara
SPACECRAFT OPERATIONS MANAGER Ian Harrison

SCIENCE TEAM

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Oliver Jennrich, ESA

Philippe Jetzer, University of Zurich, Switzerland

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Martijn Smit, SRON, The Netherlands

Carlos Sopuerta, IEEC, Barcelona, Spain

Ira Thorpe, NASA

Stefano Vitale, University of Trento, Italy PI

Harry Ward, University of Glasgow, Scotland

CO-INVESTIGATORS
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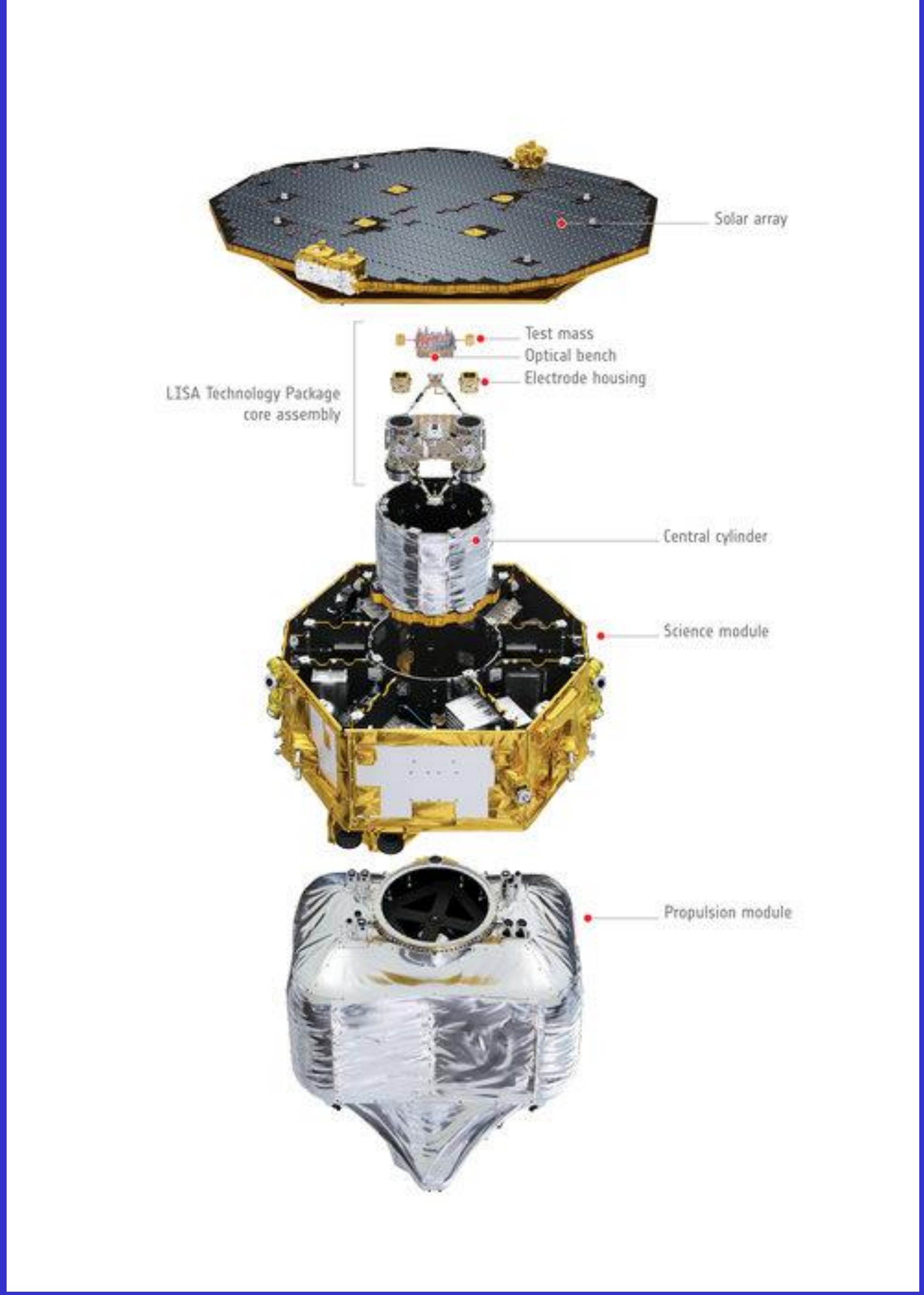
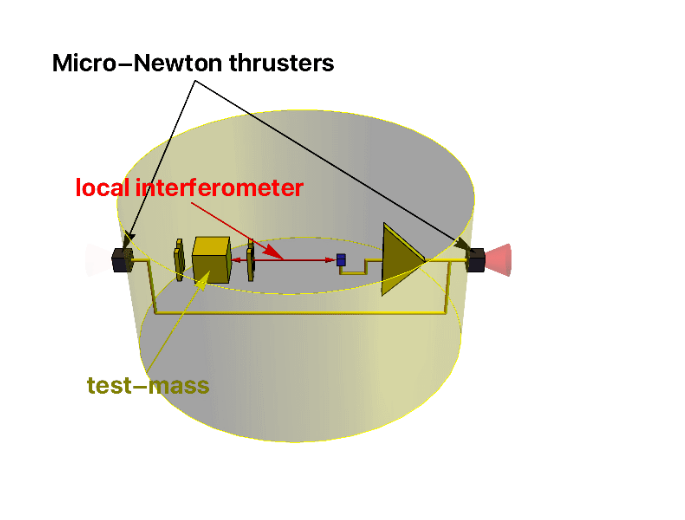
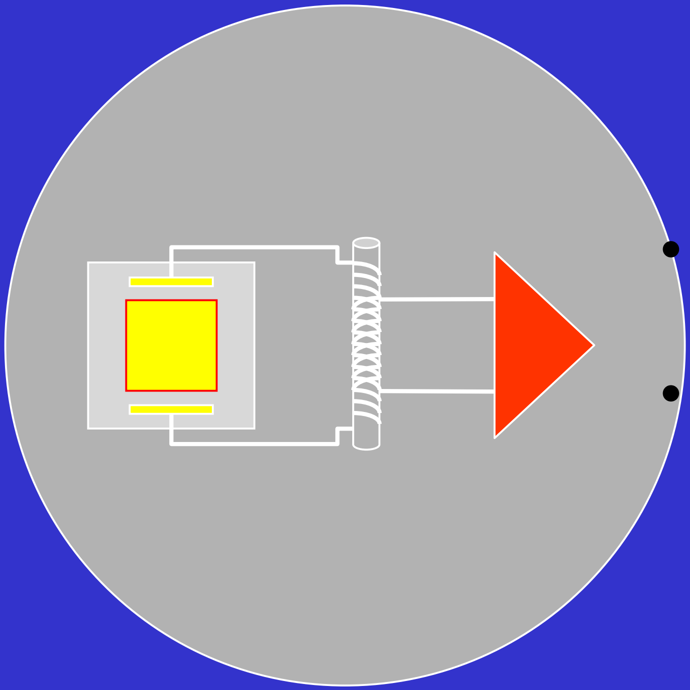
Inertial Sensor Front End Electronics (ISS FEE): Domenico Giardini, ETH Zurich, Switzerland
UV Lamp Unit (ULU): Tim Sumner, Imperial College London, UK
Inertial Sensor Special Check-Out Equipment (ISS SCOE): Martijn Smit, SRON, Netherlands
Laser Modulator (LM): Antoine Petiteau, AstroParticule et Cosmologie, France
Optical Metrology Subsystem (OMS): Karsten Danzmann, AEI, Hannover, Germany
Optical Bench Interferometer (OBI): Harry Ward, University of Glasgow, UK
Phase Meter Assembly (PMA): Mike Cruise, University of Birmingham, UK
Data Management Unit (DMU): Carlos Sopuerta, IEEC, Spain
Data Diagnostic Subsystem (DDS): Carlos Sopuerta, IEEC, Spain

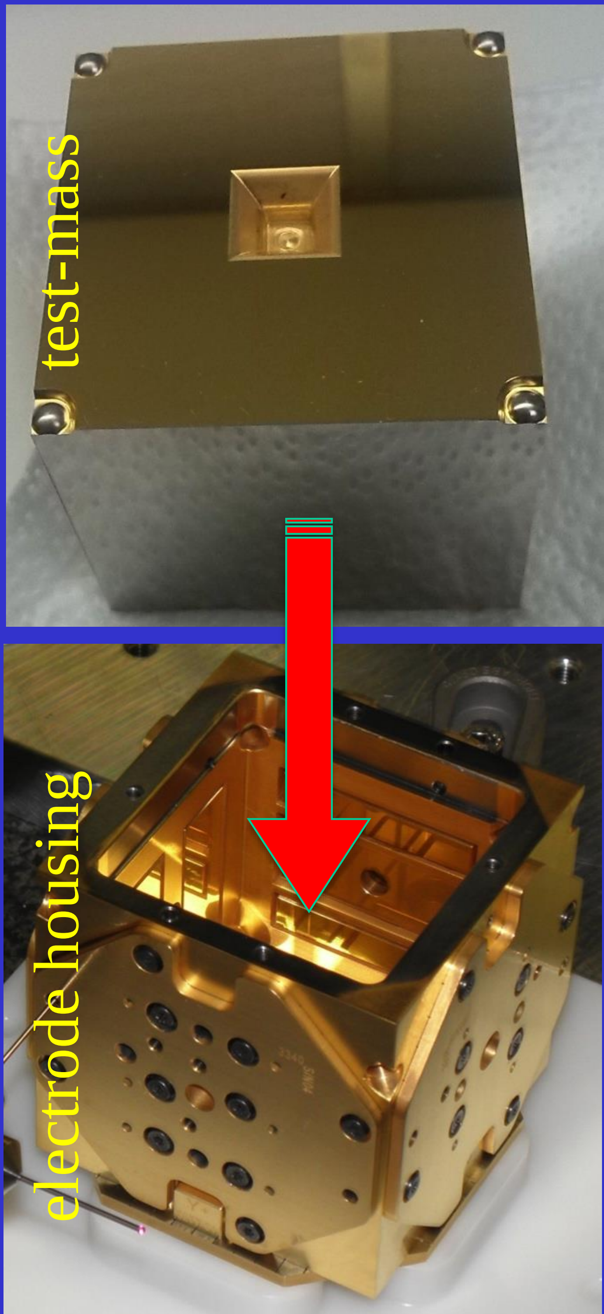

Solar array
Test mass
Optical bench
Electrode housing
LISA Technology Package
core assembly
Central cylinder
Science module
Propulsion module

Test-masses and drag-free





- Spacecraft chases test-mass along sensitive direction (drag-free)
- 3-4 mm clearance between test-mass and electrodes
- Other test-mass degrees of freedom controlled via electrostatic forces
- 46 mm gold–platinum cubes
- The cubes sit 38 cm apart linked only by laser beams.

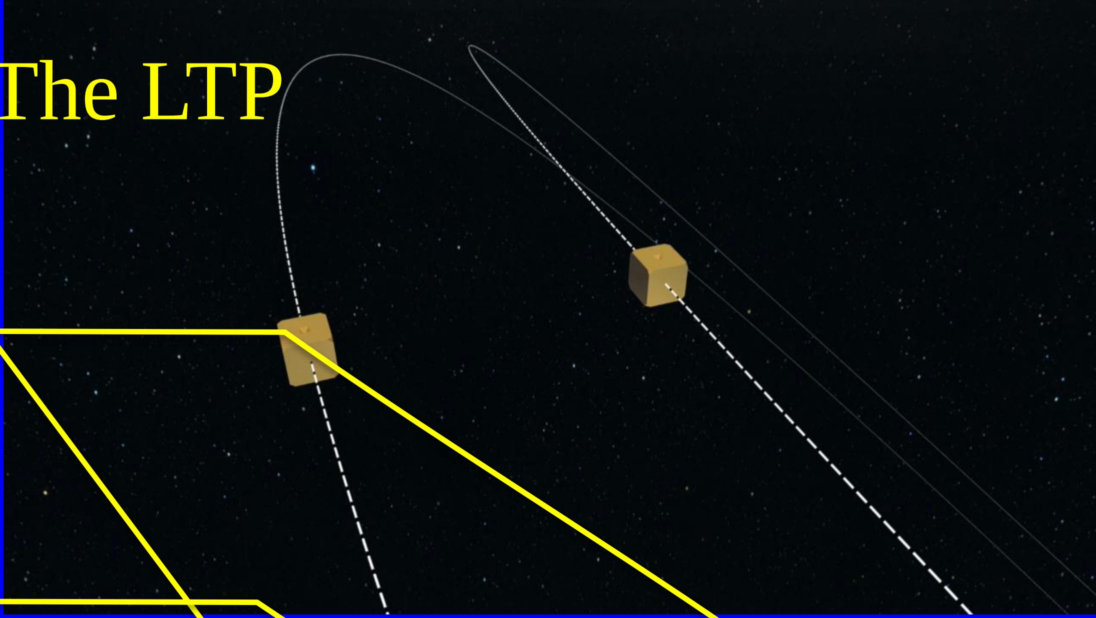


LISA Pathfinder

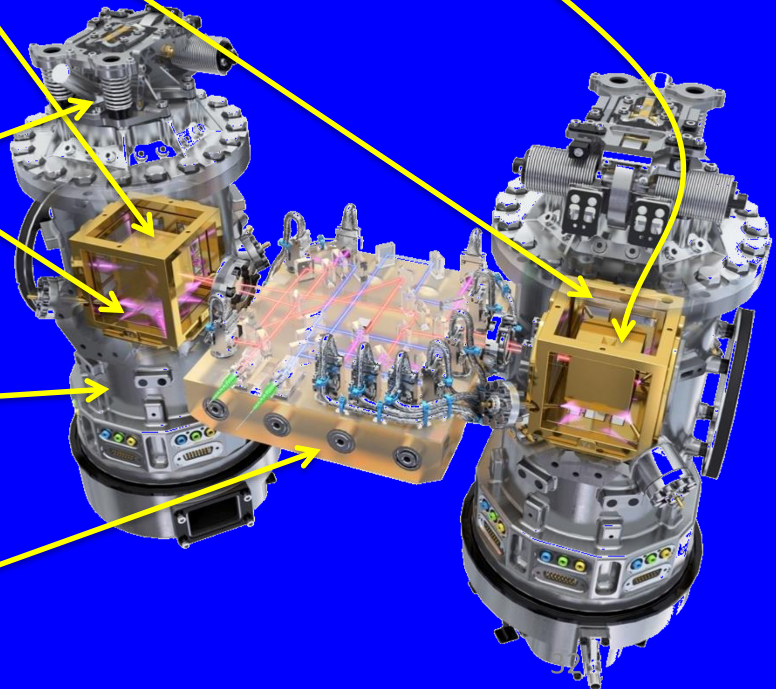
1. A test of the entire local measurement (95 % of noise) with a requirement at 3 fg/√Hz @ 1 mHz
2. A verification step in the development of LISA using same hardware/processes to carry them at TRL 8-9.
3. A final in-orbit consolidation test for our physical model of free fall. Integrates the results of extensive ground testing

Notice : Requirements in 1. are relaxed relative to LISA, but relaxation only applies to allow for less demanding test conditions, not to H/W design.

The LTP

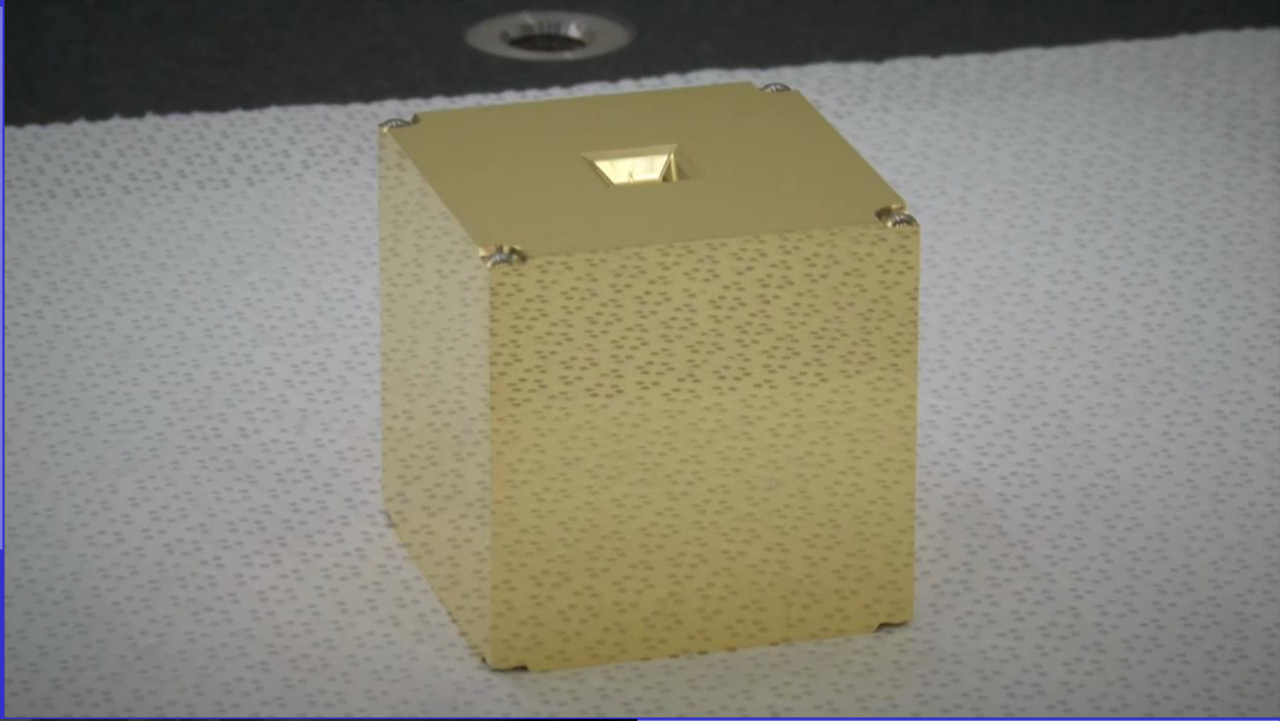


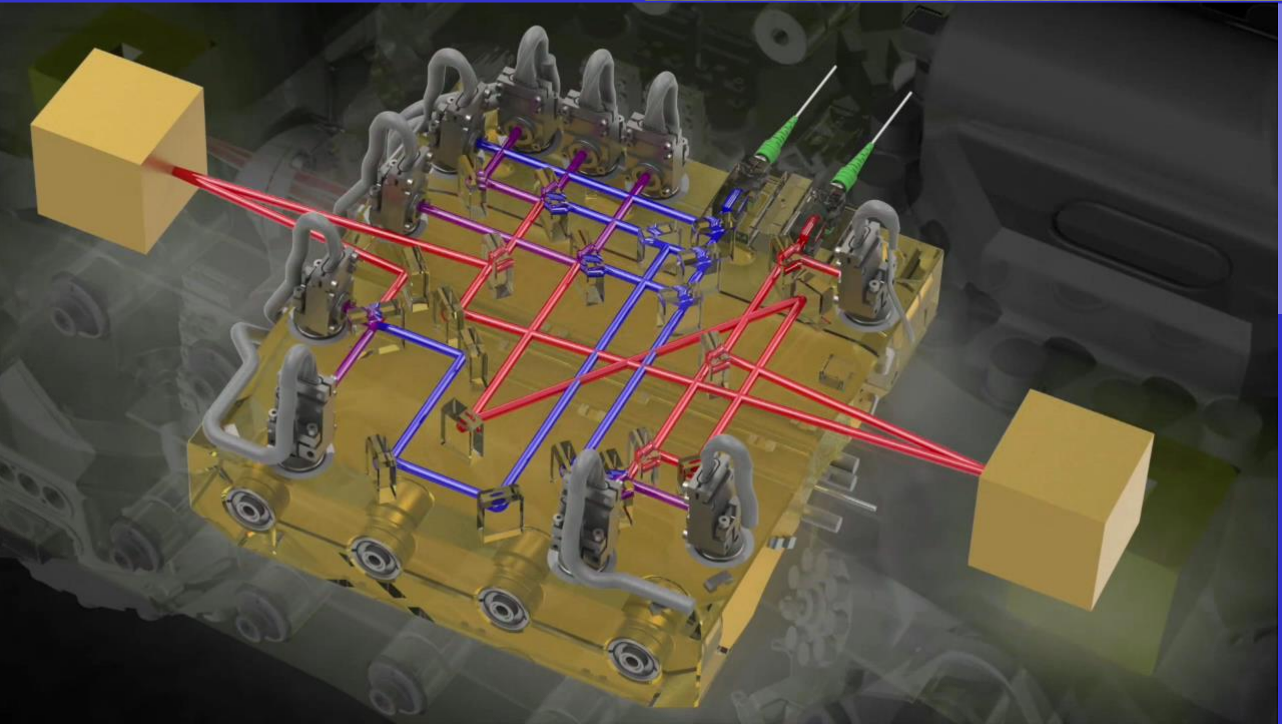
- Test masses gold-platinum, highly non-magnetic, very dense
- Electrode housing: electrodes are used to exert very weak electrostatic force
- UV light, neutralize the charging due to cosmic rays
- Caging mechanism: holds the test-masses and avoid them damaging the satellite at launch
- Vacuum enclosure to handle vacuum on ground
- Ultra high mechanical stability optical bench for the laser interferometer



Test-mass and accessories: the gravity reference sensor

CGS-OHB, U.Trento-INFN, ETH Zurich, Ruag, TAS-I, Imperial College, IEEC

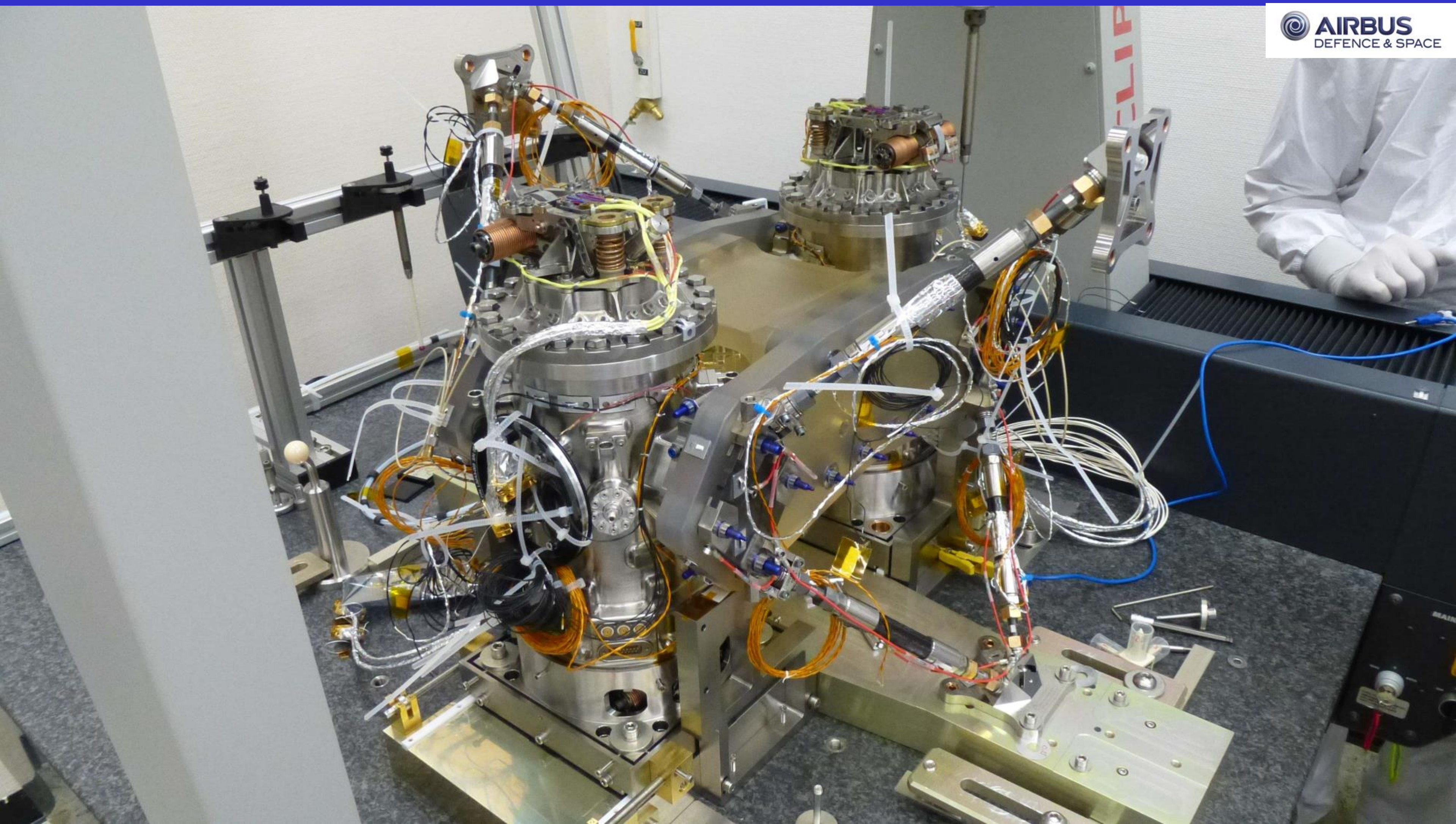




Laser interferometer

U. Glasgow, AEI-Max Planck, U. Birmingham, AIRBUS DS, APC-CNRS, IEEC,

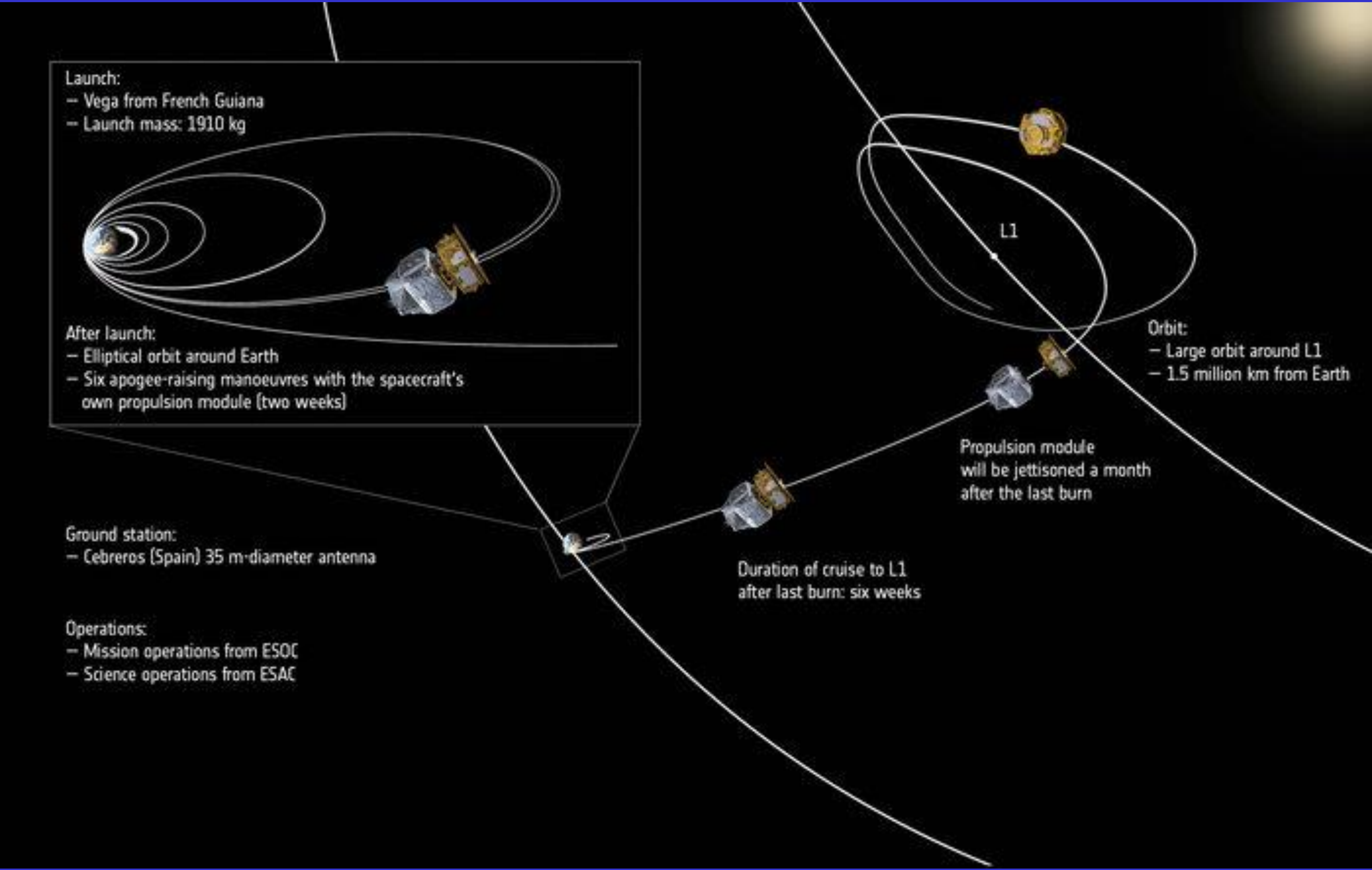
LTP Core assembly



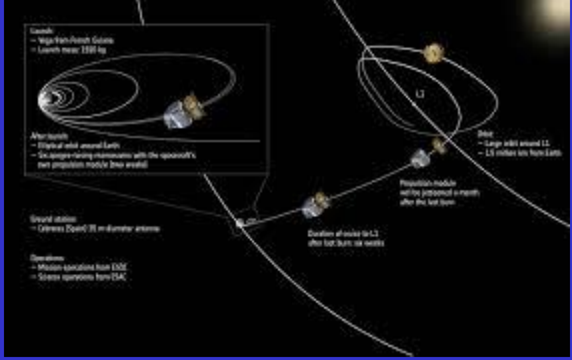
Integration with satellite


S
W
IABG
S
SOUTH
IABG
W
WEST
esa
LISA PATHFINDER
Gravitational wave detection technology for LISA

Satellite and launcher


Launch:
– Vega from French Guiana
– Launch mass: 1910 kg
After launch:
– Elliptical orbit around Earth
– Six apogee-raising manoeuvres with the spacecraft's own propulsion module (two weeks)
Ground station:
– Cebreros (Spain) 35 m-diameter antenna
Operations:
– Mission operations from ESOC
– Science operations from ESAC
L1
Orbit:
– Large orbit around L1
– 1.5 million km from Earth
Propulsion module will be jettisoned a month after the last burn
Duration of cruise to L1 after last burn: six weeks

Finally in orbit!!!!



- LISA Pathfinder launched on 3 December 2015
- transfer to L1 completed on 22 January 2016.
- initial set-up and calibration phases:3 months
- in-flight demonstration of the experimental technology
- Science operations: 90 days for the LTP and 90 days for DRS

Sequence of events

Launch Dec 3rd 2015

Launch, Transfer

Industrial Commissioning

IOC

R

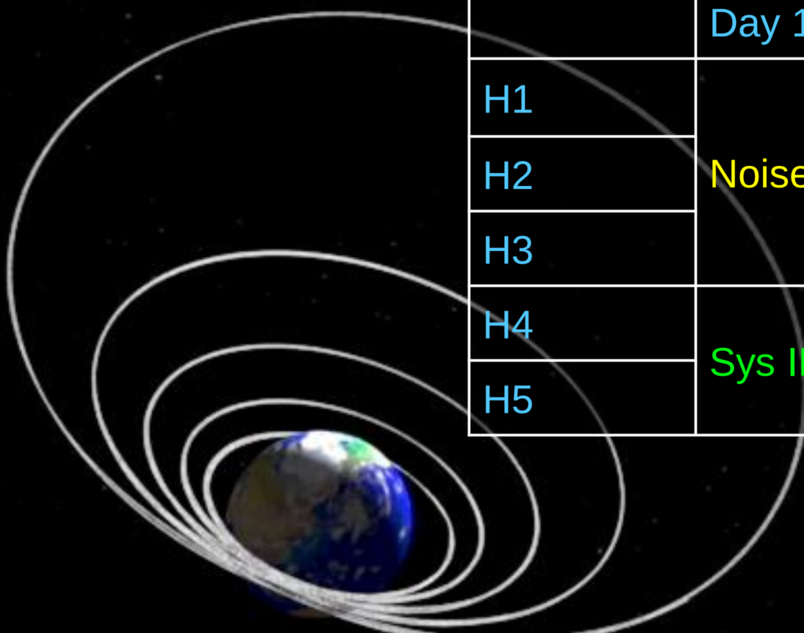
LTP Science Ops

03-01 to 06-25

NASA Operations

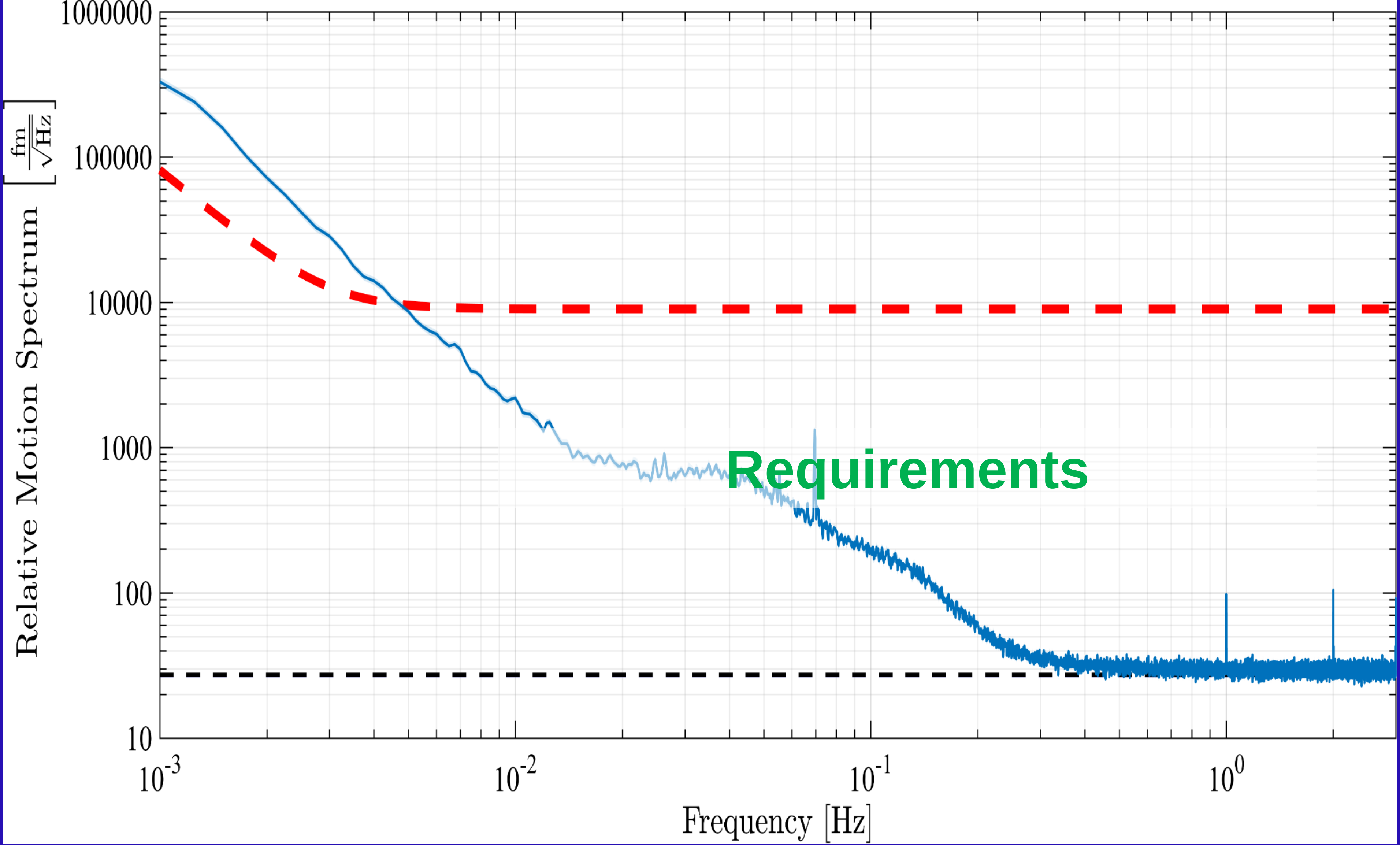
LTP extended 01-11 to 31-5

	Day 1	Day 2	Day 3	Day 4
H1	Noise Run	Discharge	Noise Run	Discharge
H2		Working Point		Stray Potentials
H3				
H4	Sys ID			
H5				



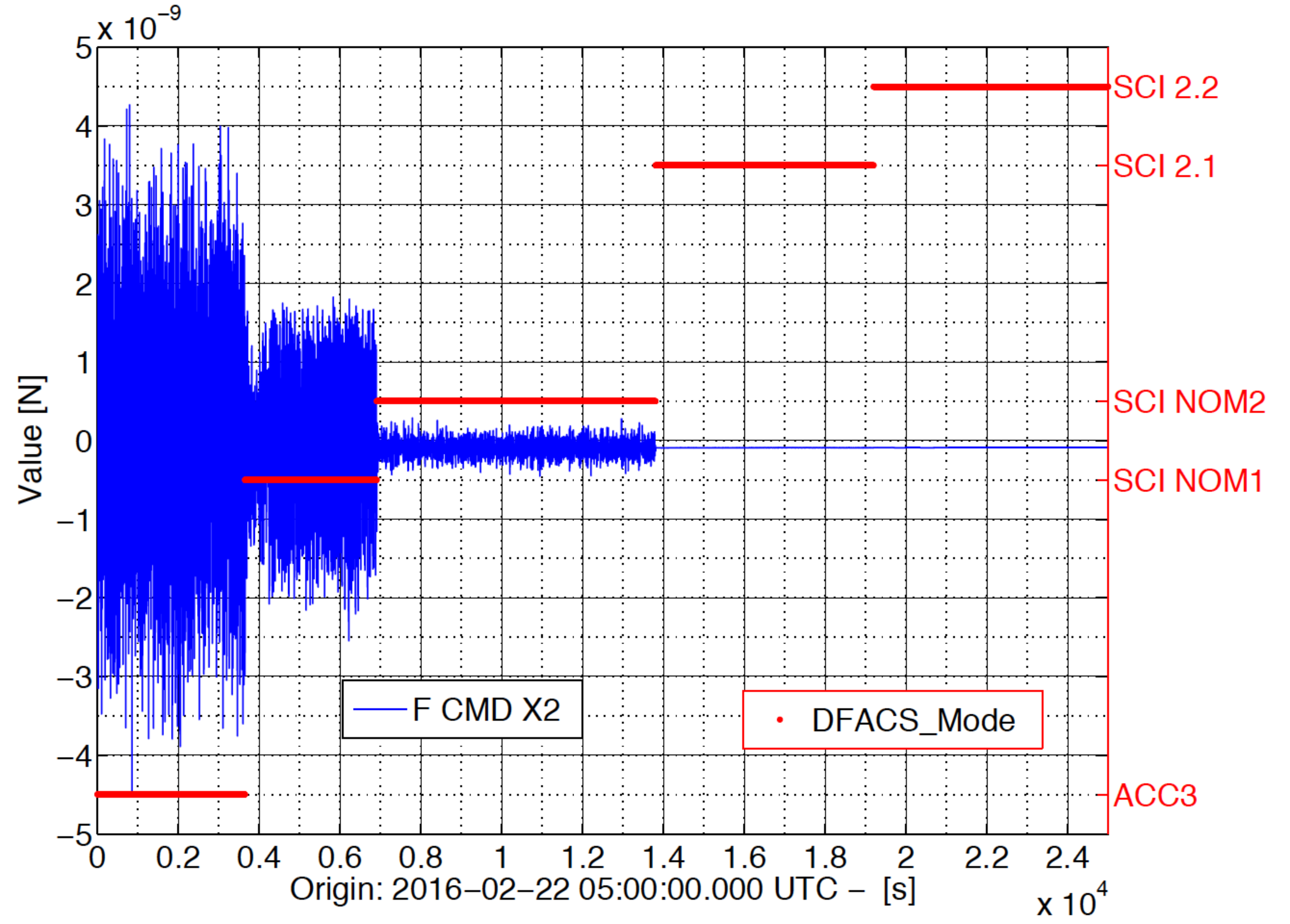
Commissioning timeline

Date	**Milestone**
11 January	Switch-on of LISA Technology Package
2 February	Release of test mass launch locks and opening of venting valve
15 & 16 February	Test Mass
18 February	Alignment
22 February	First entry
1 March	Start of Sci

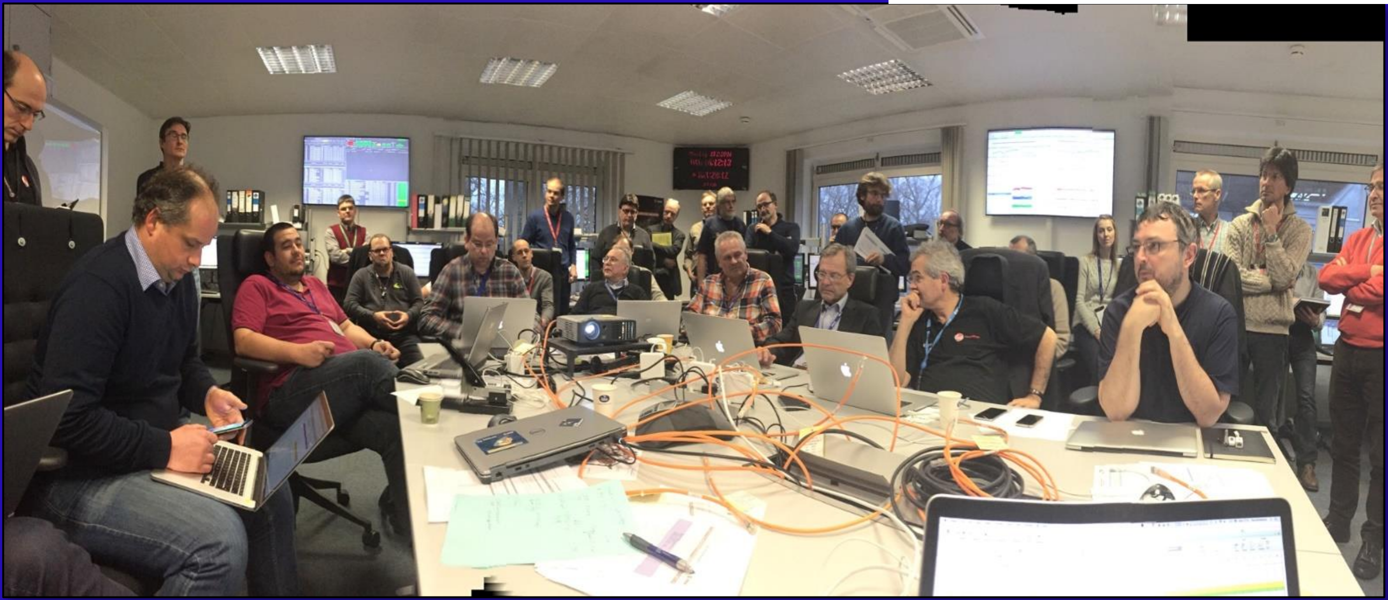


Interferometer noise

Transition to drag-free: force commanded on test-mass 2



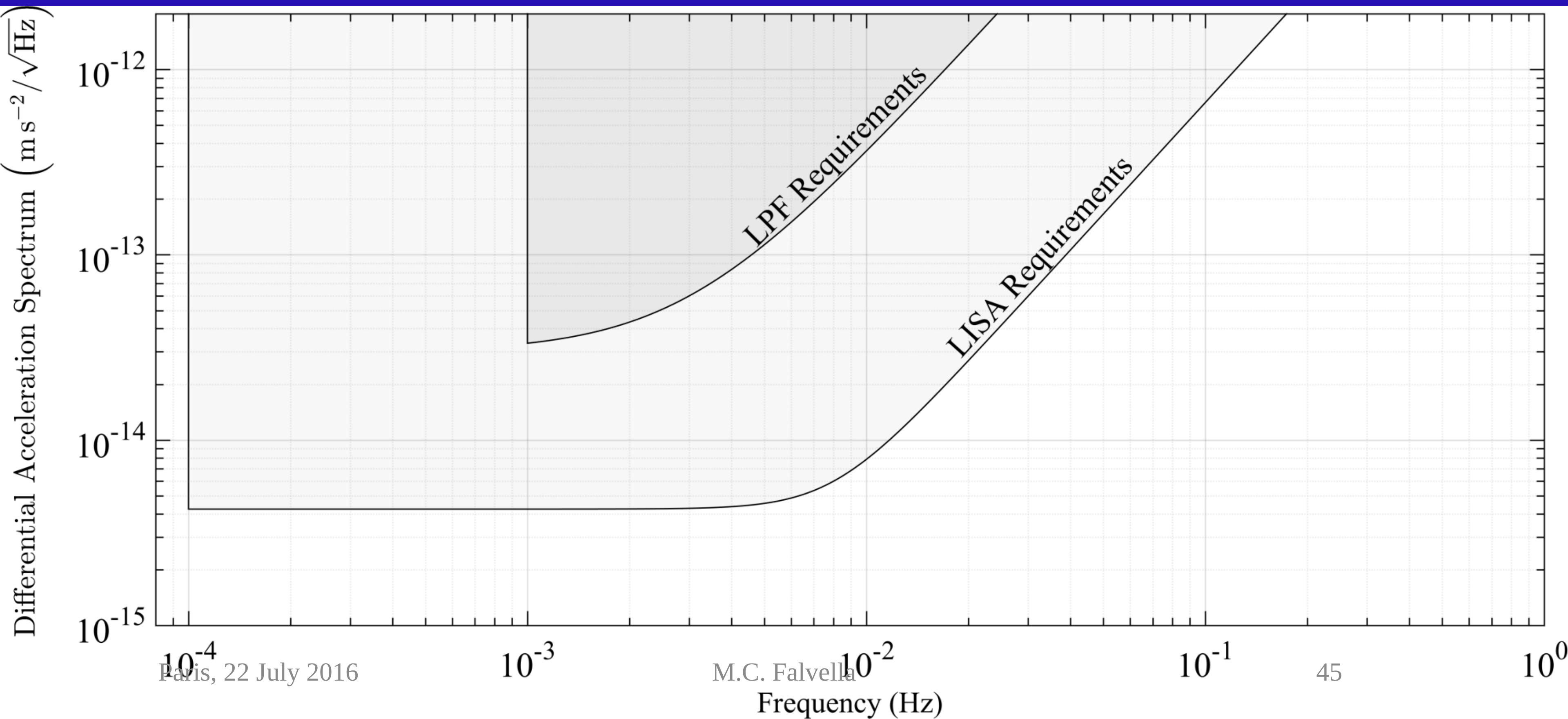
08:00	–	08:01	DC compensation voltages via CMS. Set to 0 for simulation.	con_cms_dccoef0_:V001	[1']
08:01	–	09:00	<59 minutes>		
09:00	–	12:00	Stray Potentials (POTVAVZ) TM1 [-20mV 0 +20mV]	inv04113_003	[180']
12:00	–	15:00	Stray Potentials (POTVAVY) TM1 [-20mV 0 +20mV]	inv04112_003	[180']
15:00	–	18:00	Stray Potentials (POTVAVX) TM1 [-20mV 0 +20mV]	inv04111_003	[180']
18:00	–	21:00	Stray Potentials (POTVAVZ) TM2 [-20mV 0 +20mV]	inv04123_003	[180']
21:00	–	00:00	Stray Potentials (POTVAVX) TM2 [-20mV 0 +20mV]	inv04121_003	[180']
00:00	–	03:00	Stray Potentials (POTVAVY) TM2 [-20mV 0 +20mV]	inv04122_003	[180']
03:00	–	04:00	Charge Estimate TM1	inv04011_001	[60']
04:00	–	05:00	Charge Estimate TM2	inv04021_001	[60']
05:00	–	07:00	Acceleration Noise Measurement	inv00002	[120']
07:00	–	07:01	Set max force TM2 x to 600pN, phi1 = 3pNm, phi2 = 3pNm	con_fee_maxf____:V15	[1']
07:01	–	08:00	<59 minutes>		



A remote laboratory

LISA and LISA Pathfinder disturbance acceleration requirements

- LPF amplitude requirement relaxed because single spacecraft experiment more noisy
- Frequency requirement relaxed to cut down ground testing time



Limitation of a single satellite test

LISA

- Each test-mass in one link is drag-free
- Inertial forces are negligible
- Force gradients couple each test-mass to its own spacecraft

LISA Pathfinder

- Spacecraft cannot follow both test-masses at once. One test mass is controlled (noisy)
- Spacecraft reference frame is significantly non-inertial → centrifugal force
- Force gradients couple both test-masses to same spacecraft

Best Estimate Before Launch

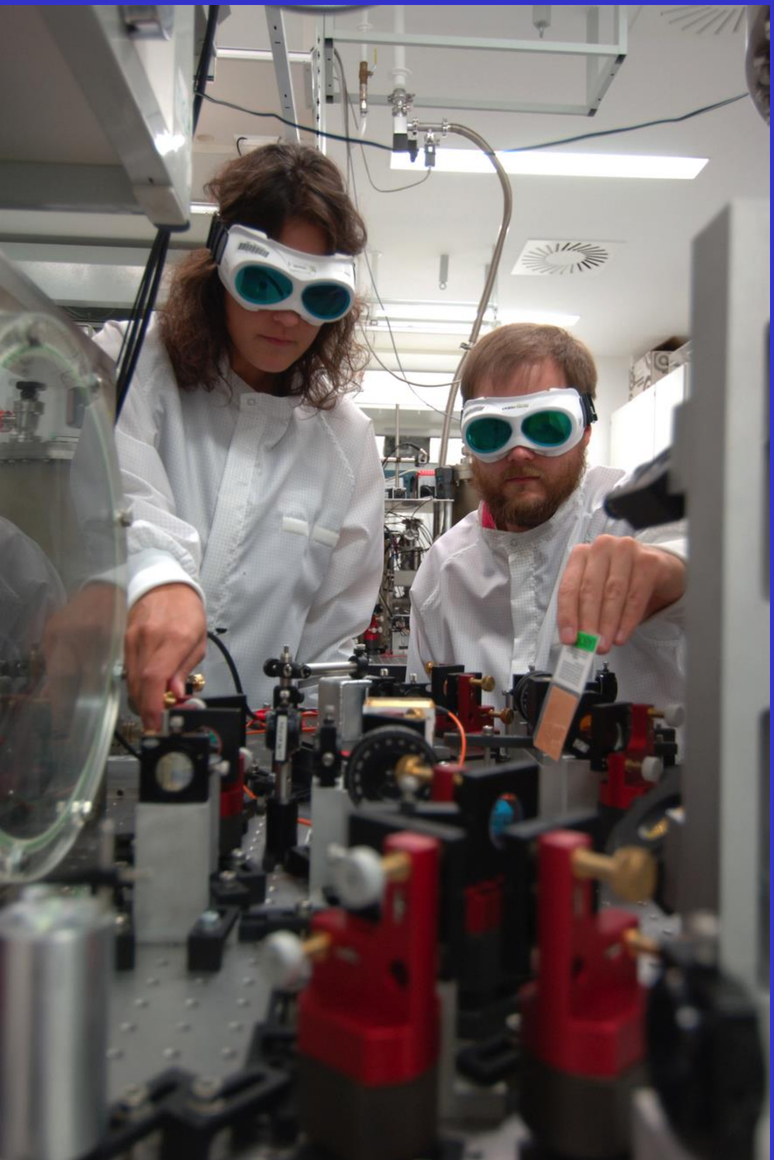
Class. Quantum Grav. **28** (2011) 094002 F Antonucci *et al*

Table 2. Leading sources of differential force-per-unit-mass disturbances and their PSD values at 1 mHz.

Source	PSD (fm s^{-2} $Hz^{-1/2}$)	Estimated from
Actuation, x-axis	7.5 (0.8)[a]	Measurement of flight-model electronics stability
Brownian	7.2	Measurement with torsion pendulum
Magnetics	2.8	Measurement of magnetic field stability
Stray voltages	1.1	Upper limit from the torsion pendulum test campaign
Laser radiation pressure	0.7	Measurement of laser power stability
Force from dynamics of other DoF	0.4	From simulated dynamics of DoF other than x, and estimated worst-case values of $\overleftrightarrow{\delta D}$ and $\overleftrightarrow{\delta C}$
Thermal gradient effects	0.4	Upper limit from the torsion pendulum test campaign
Self-gravity noise	0.3	Upper limit from thermo-elastic stability simulations
Noisy charge	0.1	Upper limit from the charge simulation and measured voltage balance
Coupling to SC motion via force gradients	0.1	From the estimation of stiffness and simulated SC jitter
Total	10.9 (7.9)[a]	Root square sum

[a] The values within parentheses refer to the free-flight mode. See the text for explanation.

Effects studied over years in the laboratory: Knowledge pushed forward in different fields of physics



1, NUMBER 15 — PHYSICAL REVIEW LETTERS — 10 O

Achieving Geodetic Motion for LISA Test Masses: Ground Testing Results

PHYSICAL REVIEW D **76**, 102003 (2007)

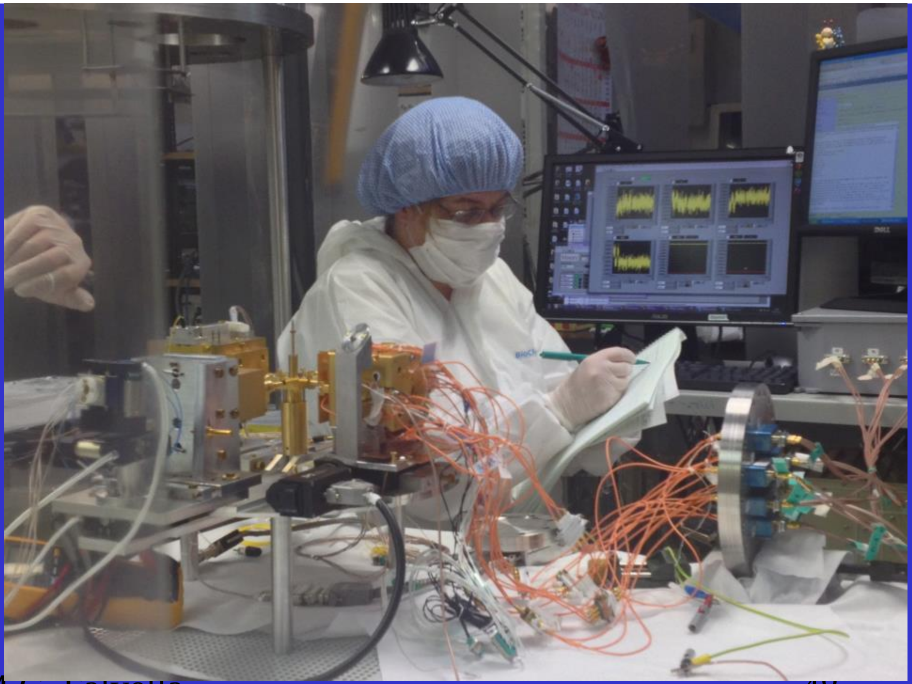
Thermal gradient-induced forces on geodesic reference masses for LISA

03, 140601 (2009) — PHYSICAL REVIEW LETTERS — week endi 2 OCTOBER

Increased Brownian Force Noise from Molecular Impacts in a Constrained Volume

108, 181101 (2012) — PHYSICAL REVIEW LETTERS — week 4 MA

Interaction between Stray Electrostatic Fields and a Charged Free-Falling Test Mass



Last Best Estimate

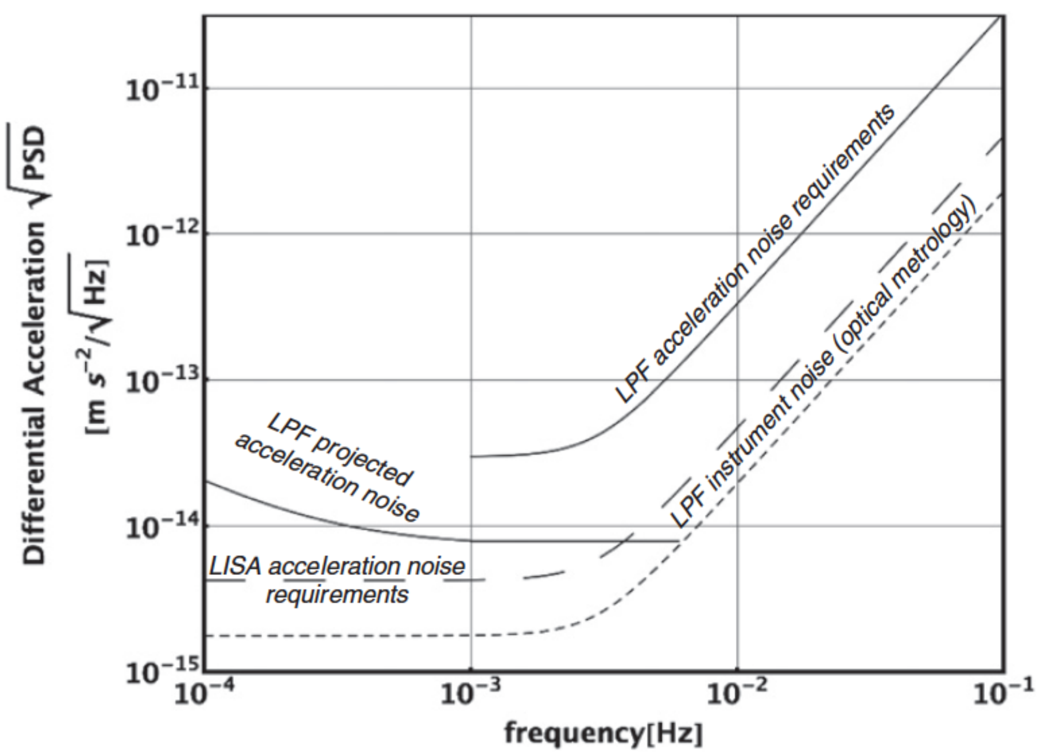
Class. Quantum Grav. **28** (2011) 094002 F Antonucci *et al*

Table 2. Leading sources of differential force-per-unit-mass disturbances and their PSD values at 1 mHz.

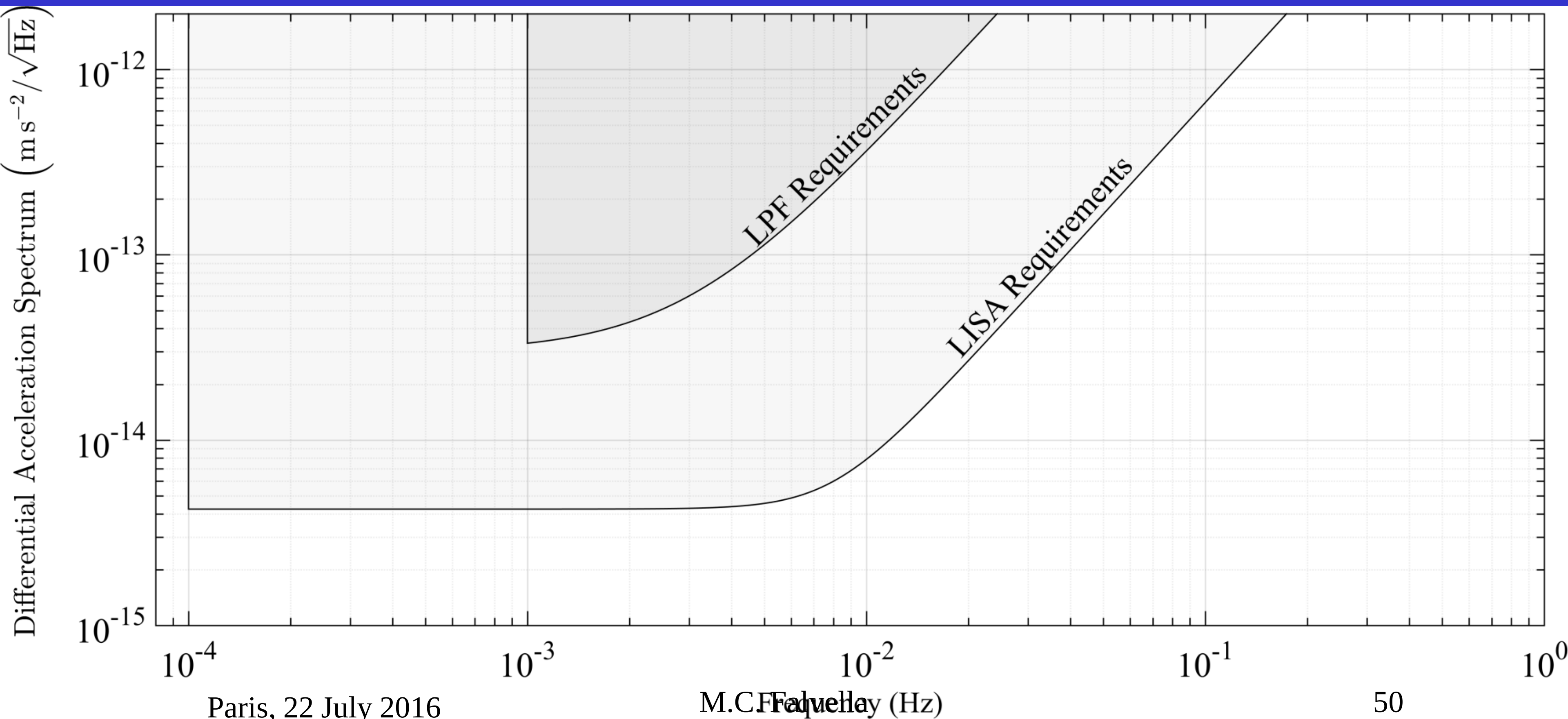
Source	PSD (fm s^{-2} $Hz^{-1/2}$)	Estimated from
Actuation, *x*-axis	7.5 (0.8)[a]	Measurement of flight-model electronics stability
Brownian	7.2	Measurement with torsion pendulum

depends on value of gravitational force to be compensated

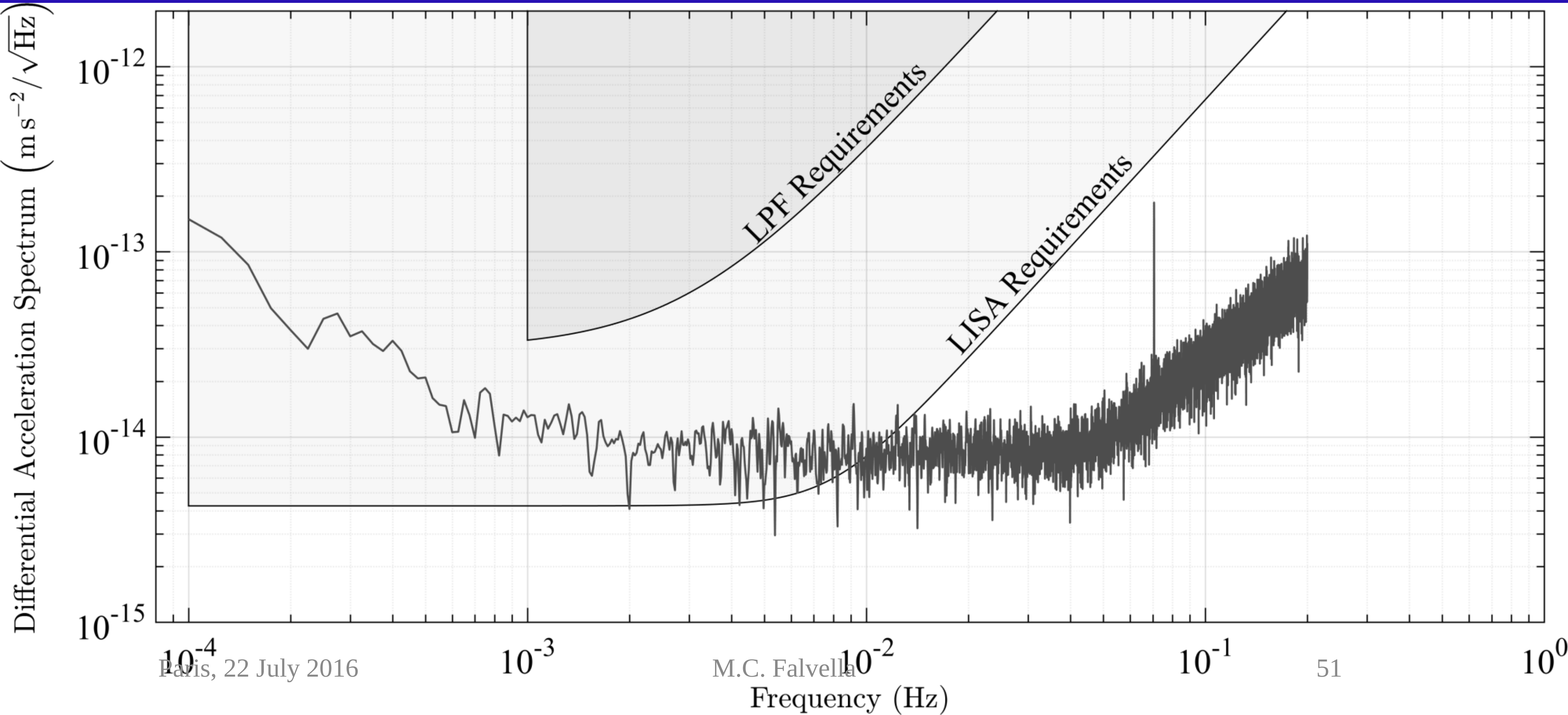
Class. Quantum Grav. **28** (2011) 094002



LISA and LISA Pathfinder disturbance acceleration requirements

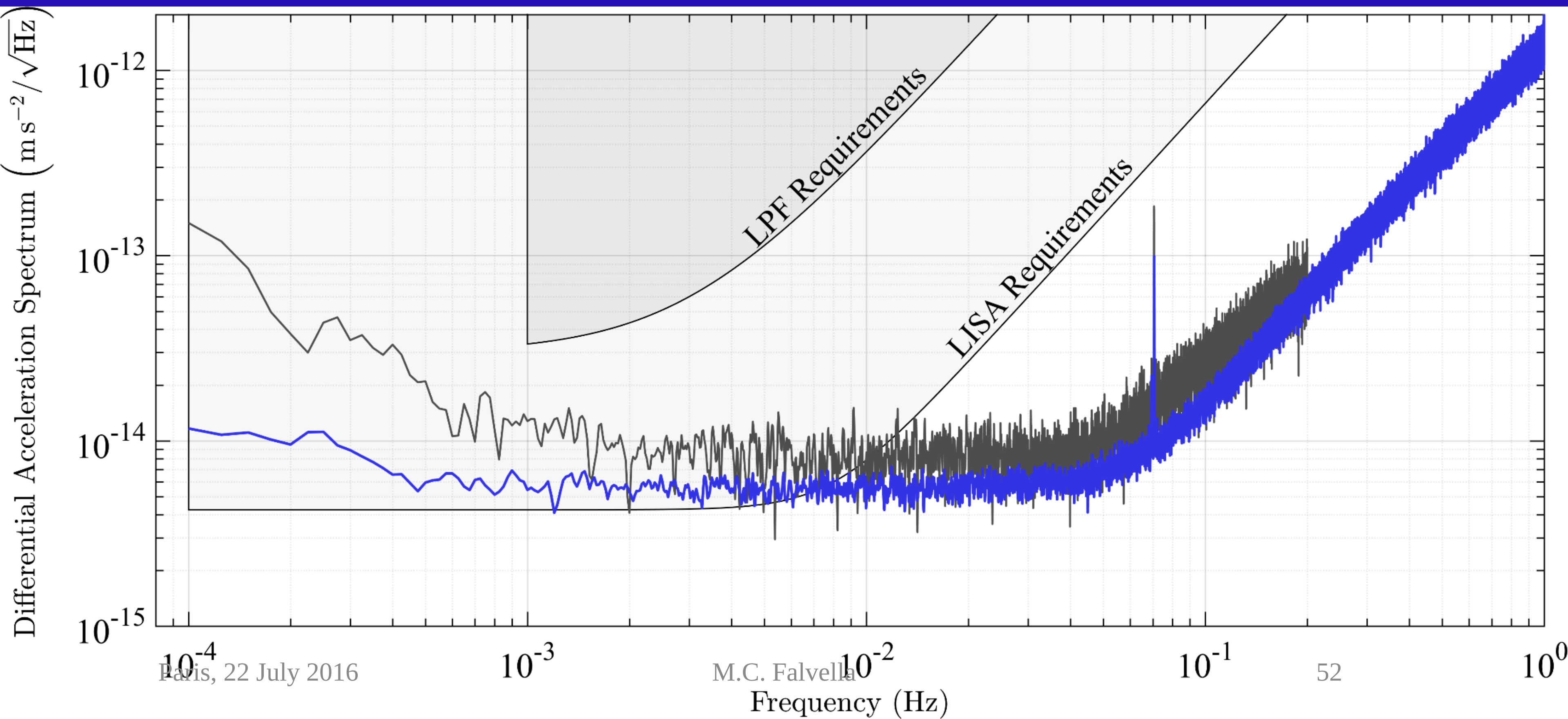


First day of operation. March 1st, 2016

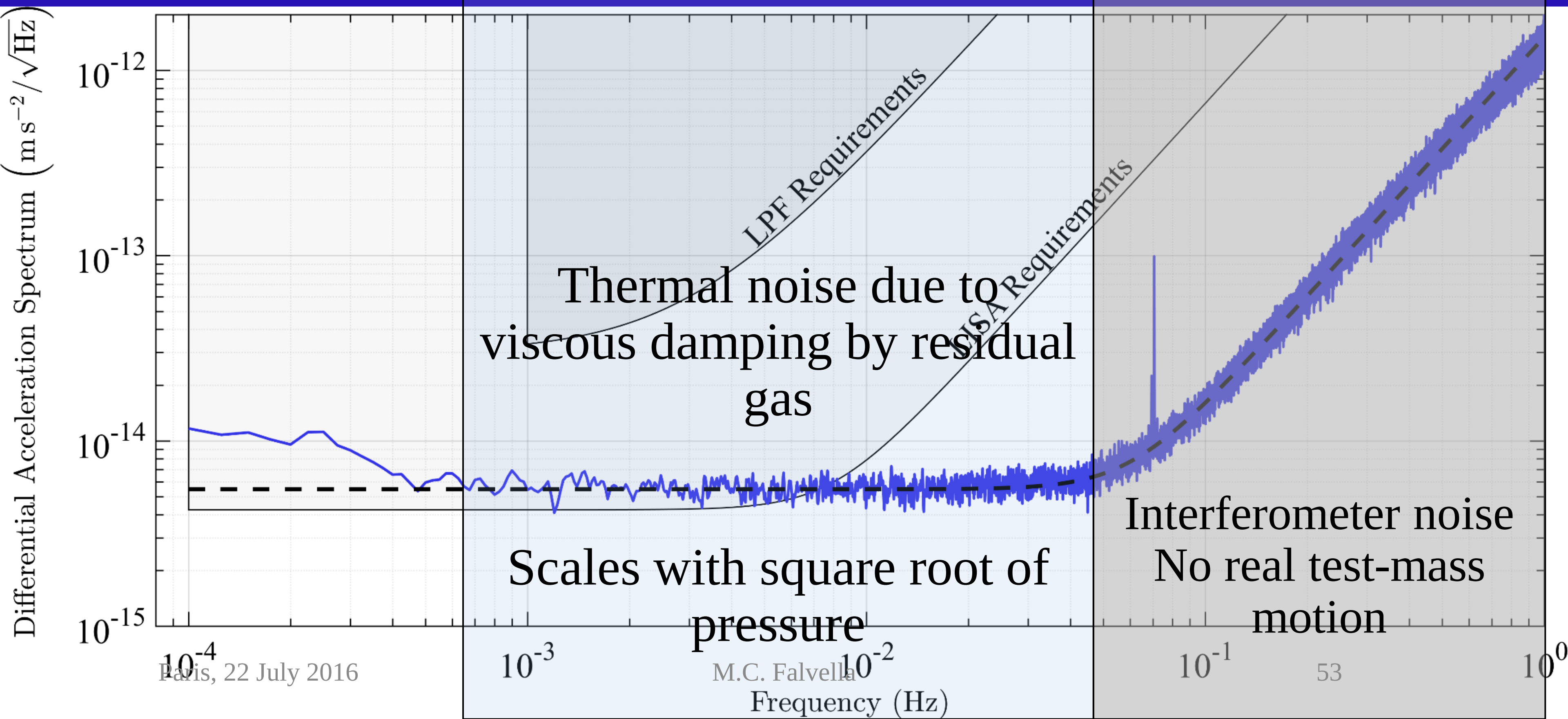


April 8-14, 2016.

- The results in http://link.aps.org/doi/10.1103/PhysRevLett.116.231101
- Decreased because of elapsed time and basic instrument optimization



The limiting disturbances



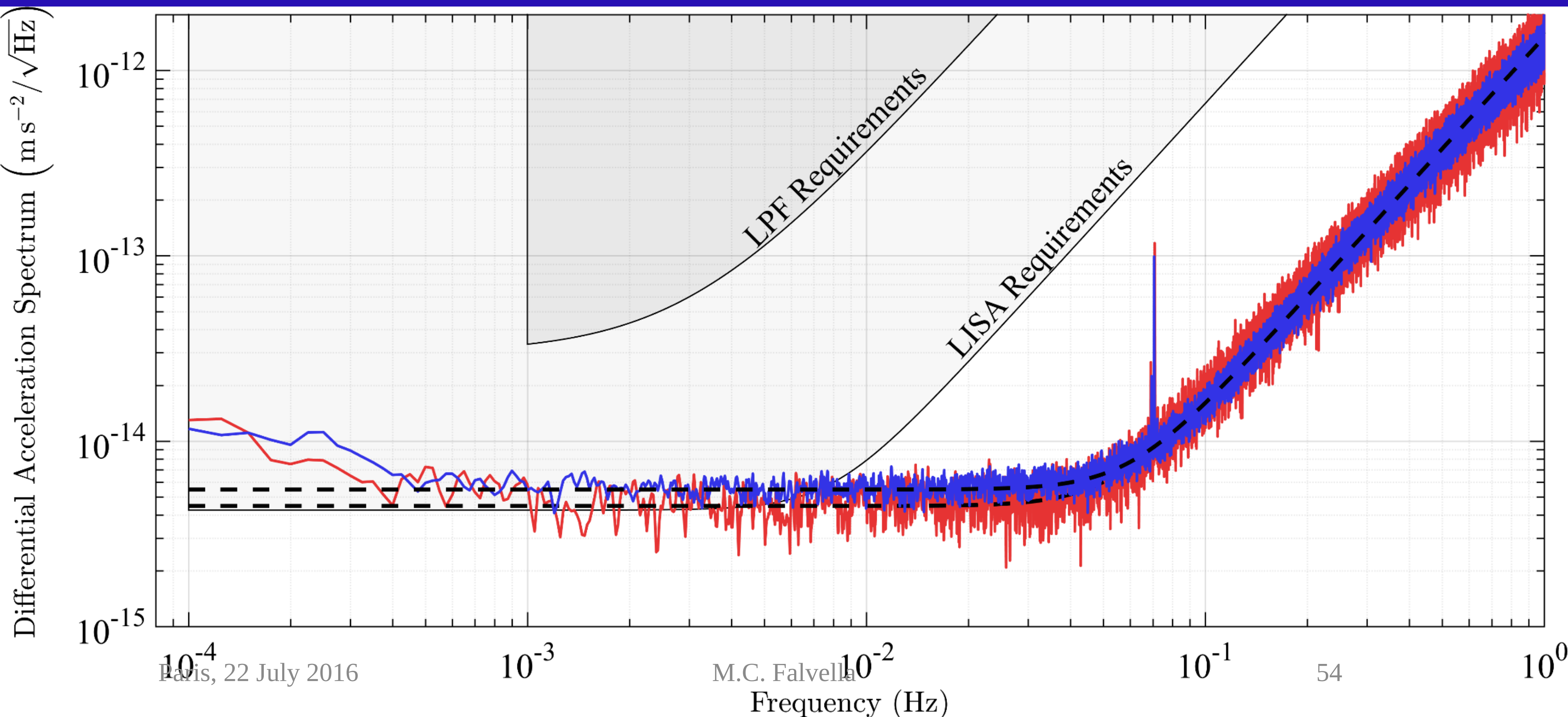
Thermal noise due to viscous damping by residual gas

Scales with square root of pressure

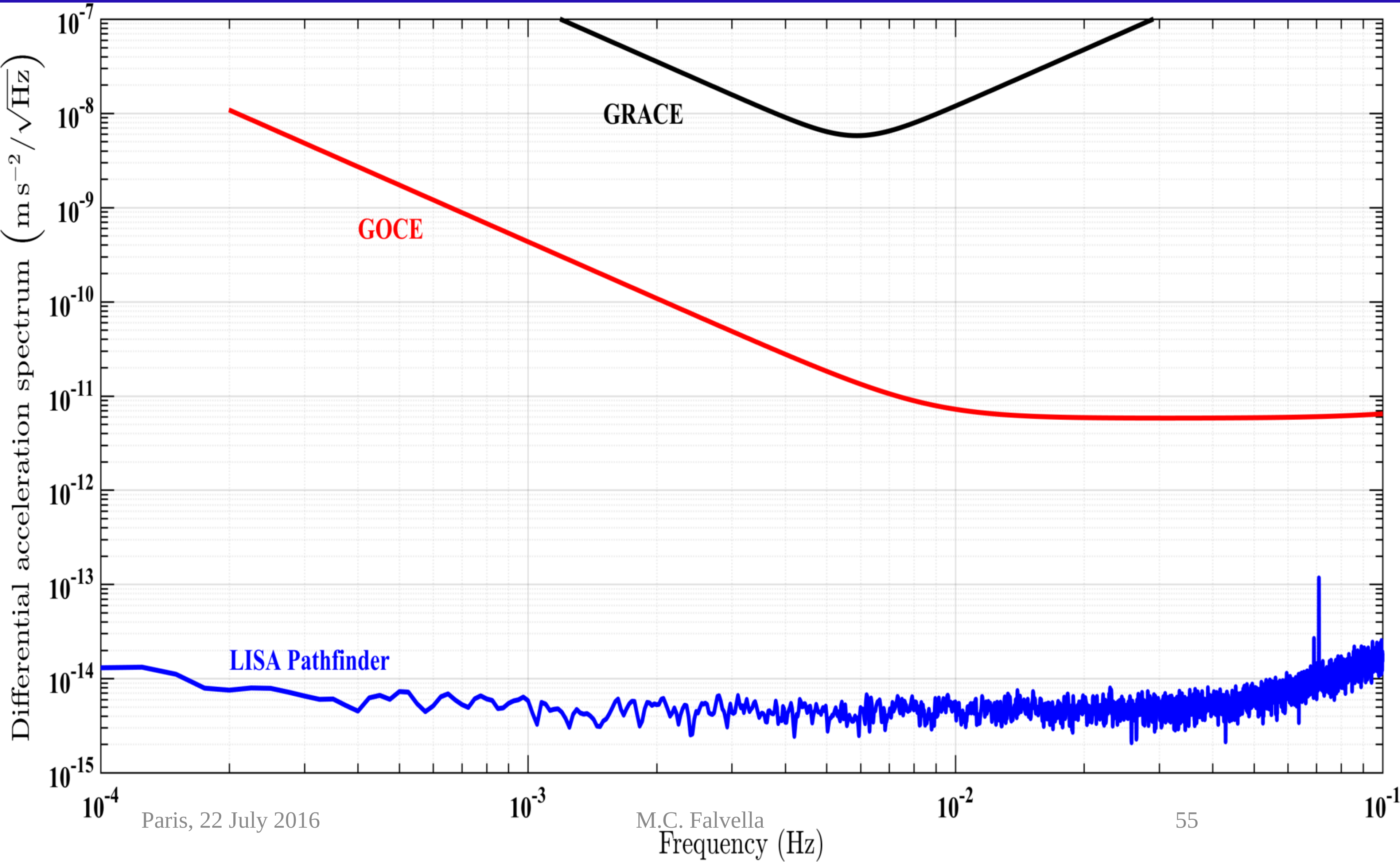
Interferometer noise
No real test-mass motion

May 16-18, 2016.

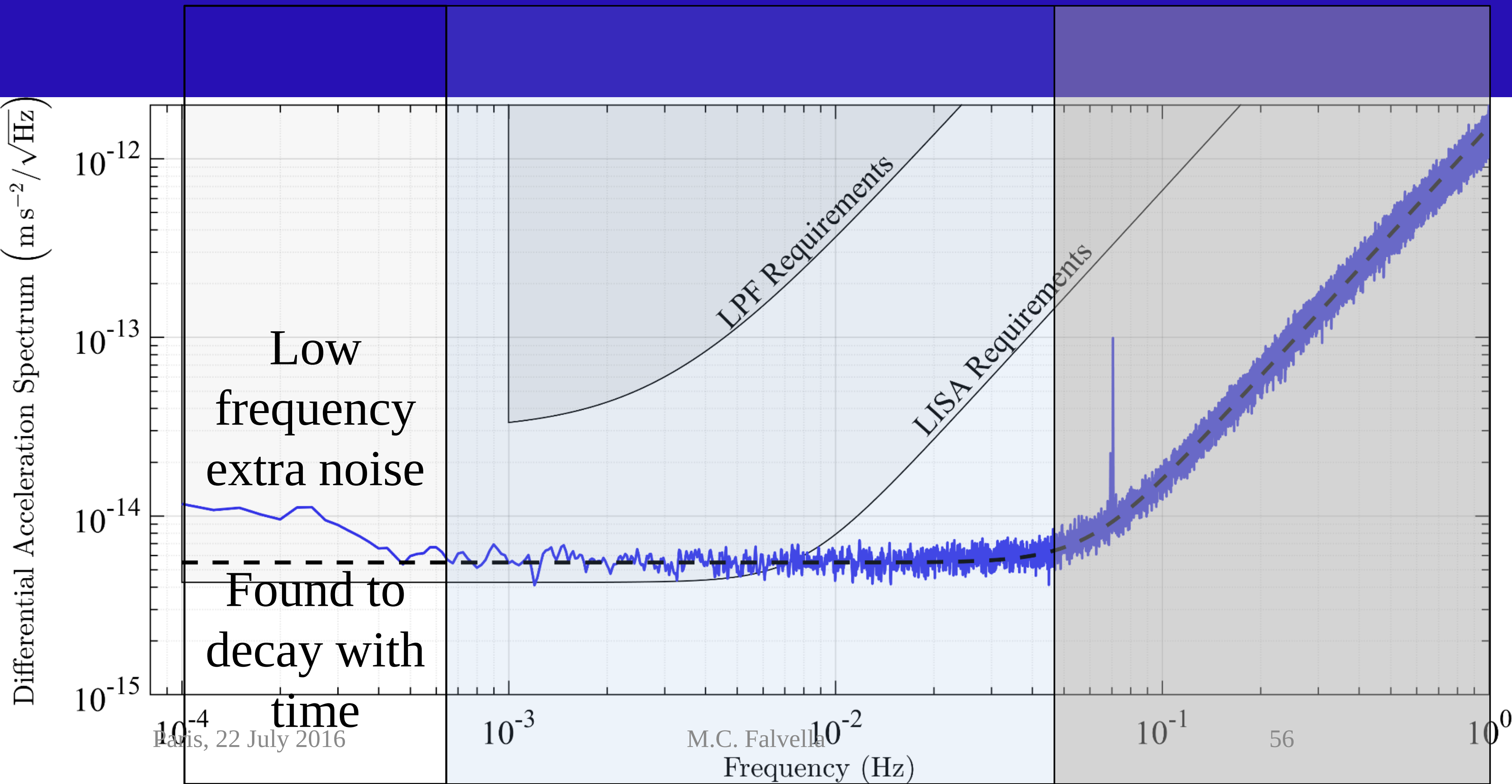
- System continuously vented to outer space
- Pressure gone further down



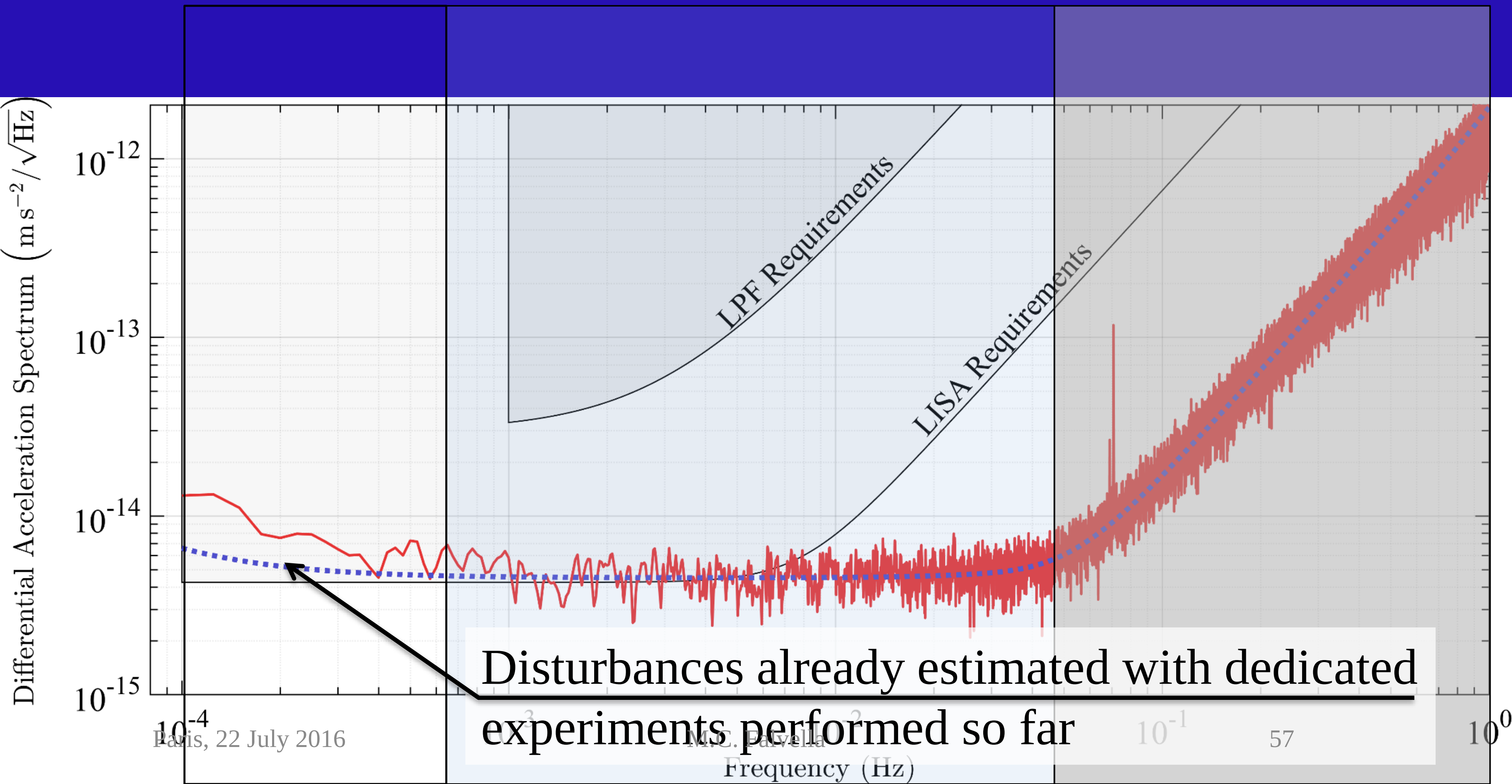
Sub-femto-g differential accelerometry: orders of magnitude improvement in the field of experimental gravitation



The limiting disturbances

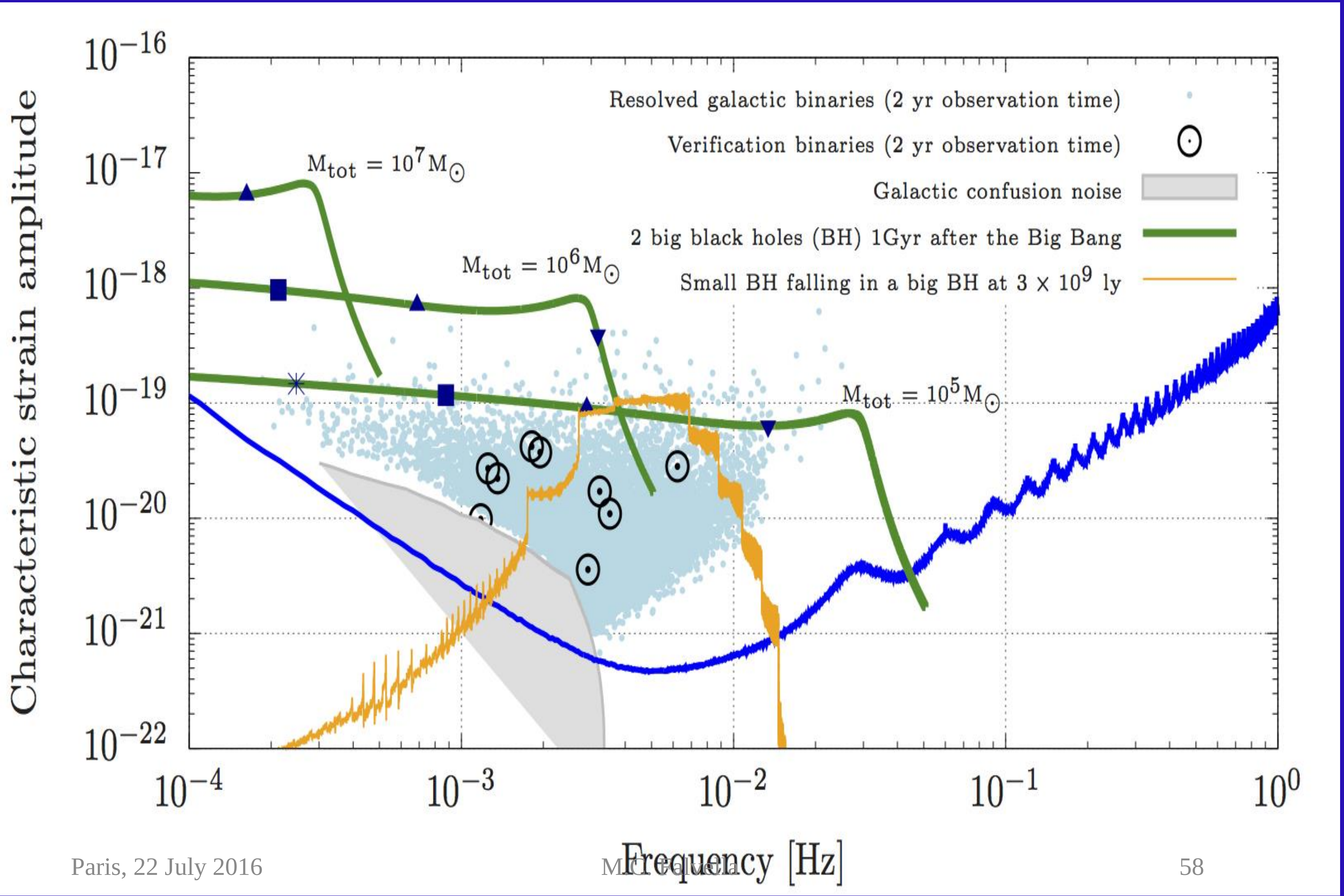


The limiting disturbances

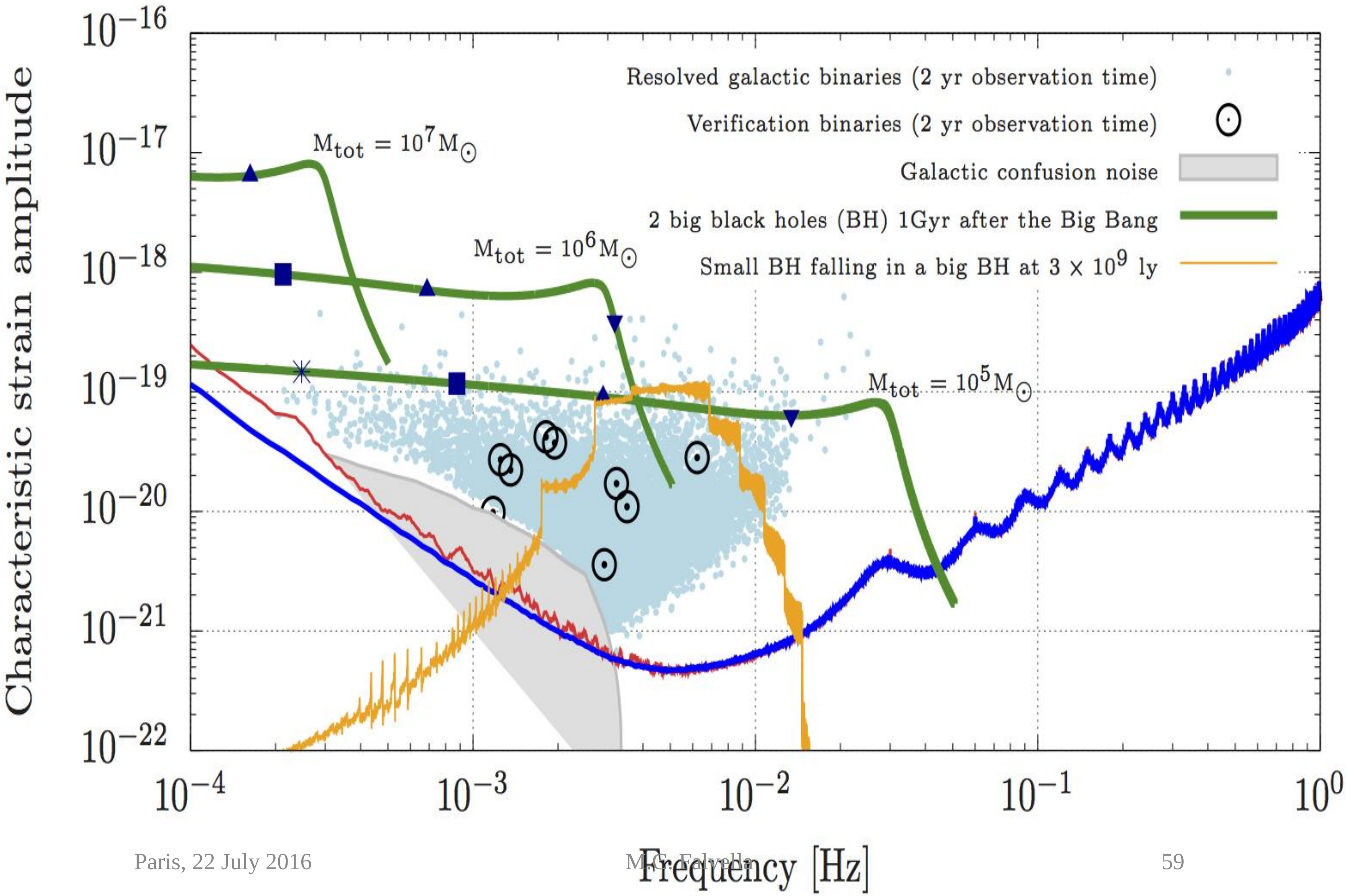


Disturbances already estimated with dedicated experiments performed so far

The two main categories of gravitational-wave sources for LISA are the galactic binaries and the massive black holes (MBHs) expected to exist in the centres of most galaxies.Noise almost entirely modeled: original LISA requirements at hand

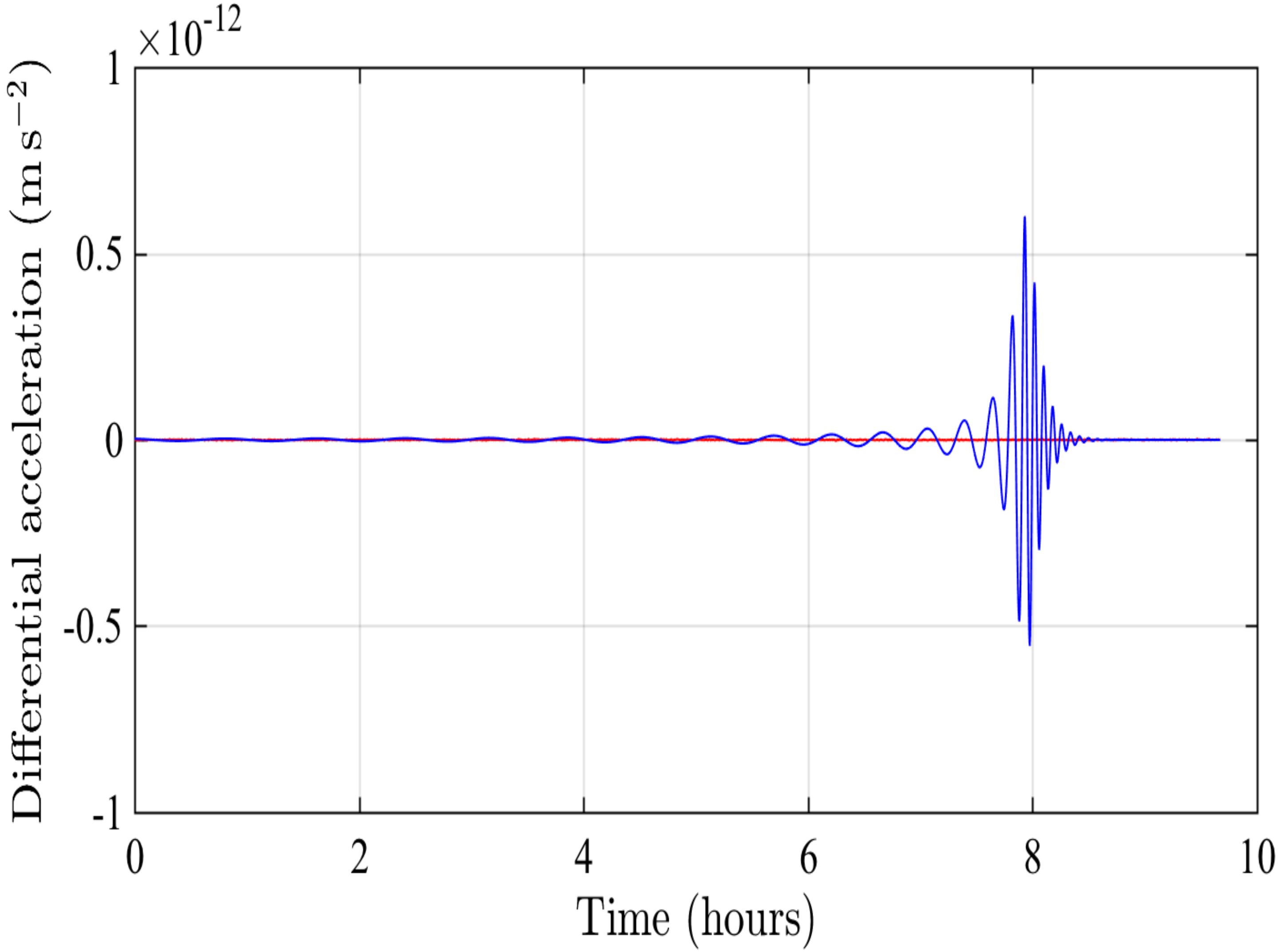


With current demonstrated sensitivity most science obtained anyway



Simulated LISA acceleration signal for two $5\times10^5\ M_\odot$ black-holes with their galaxies merging at 12.5 billion light-years

LISA Pathfinder acceleration data



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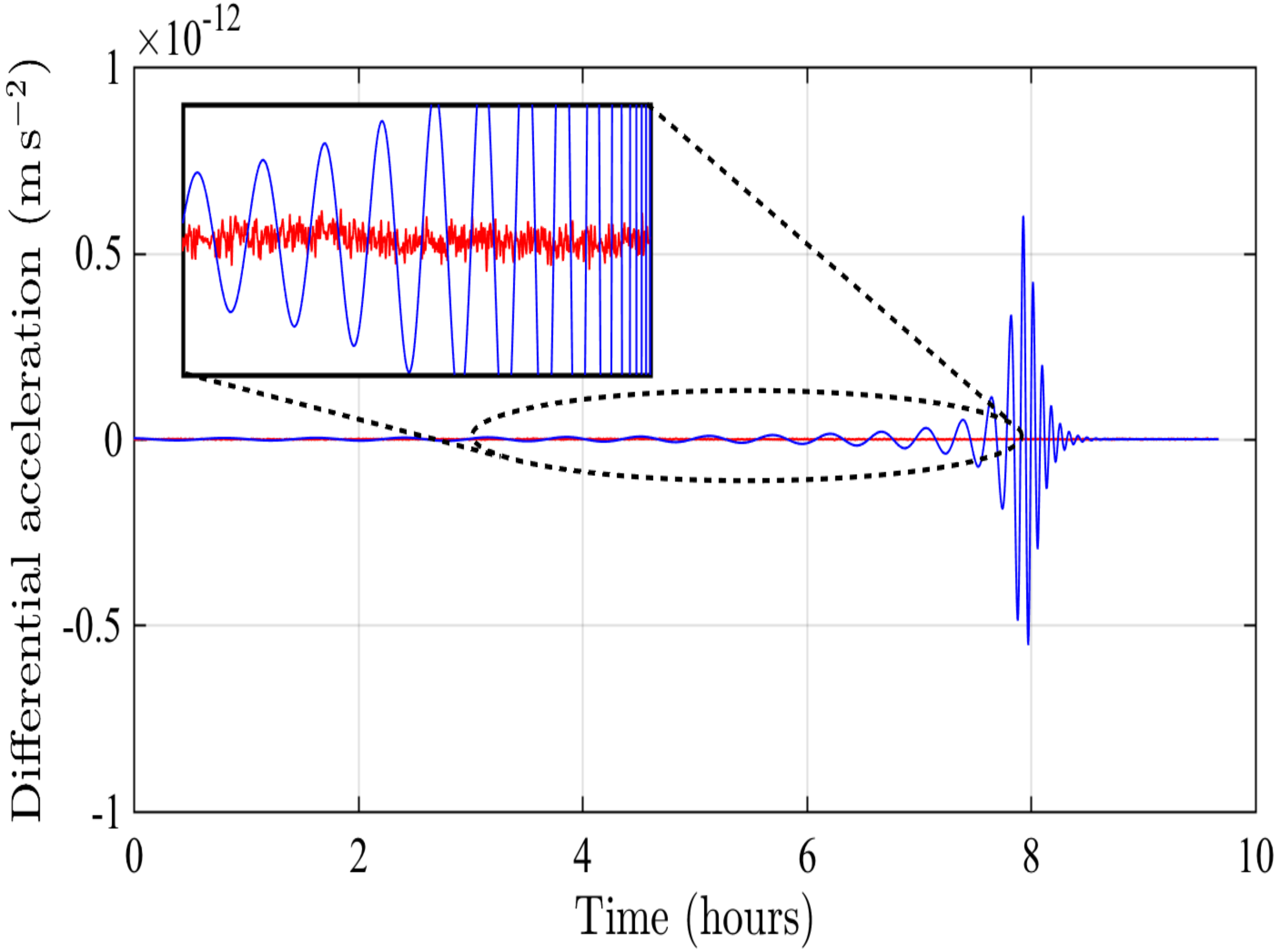


Next

- LISA pathfinder investigations continuing till May 31, 2017
- ESA plans for GW observatory

Gravitational Observatory Advisory Team

Final Report

Summary

As a result of its meetings, the analysis of requested inputs, and much detailed scientific and technical work by the gravitational wave community, the Gravitational Observatory Advisory Team (GOAT) can report to the ESA Executive in summary as follows:

- an L3 mission in gravitational waves is technically feasible, with laser interferometry between free-falling test masses as a well-established technical baseline;
- the scientific potential of a space mission in gravitational wave astronomy is compelling, and made more so by the recent Advanced–LIGO results;
- the technical and scientific knowledge base now residing in Europe as a result of LISA Pathfinder argues for the timely implementation of a gravitational wave observatory under European leadership.

Short term next steps

Issue the Call for L3 mission (planned in late 2016)

- Structure the community and defines
  - The baseline mission
  - The P/L Consortium
- Structure Member States contributions for L3 payload
- Enables coordination with MS preparation activities

Initiate Phase A with industry

- Kick-off targeted in 2017, 2-year study

Consolidate collaboration framework with NASA

- Progressive consolidation expected by the end of Phase A, and finalization prior to the mission adoption

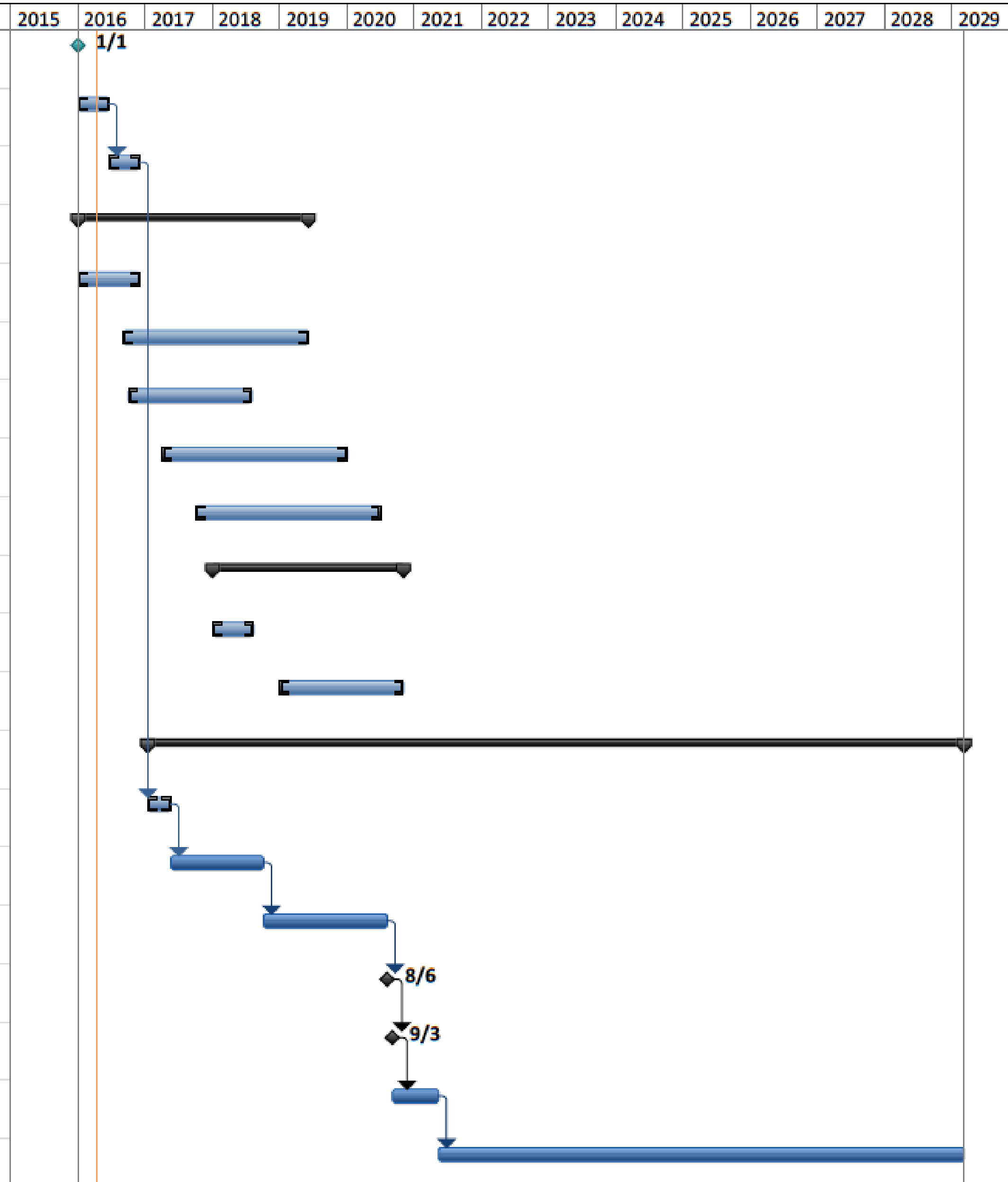
Investigate possible collaboration framework with other partners

Technology Workplan (Current)

Workplan 2015/2016 L3 Mission Theme	Status
New Activities to be launched in 2016	
Phase Reference Distribution for Laser Interferometry *Budget: 800 kEUR, Duration: 16 months*	ITT Issued
Metrology Telescope Design for a Gravitational Wave Observatory Mission *Budget: 600 kEUR, Duration: 12 months*	ITT Issued
Gravitational Wave Observatory Metrology Laser *Budget: 3500 kEUR, Duration: 36 months*	ITT in preparation
Optical Bench Manufacturing Industrialization Study *Budget: 400 kEUR, Duration 12 months*	ITT in preparation

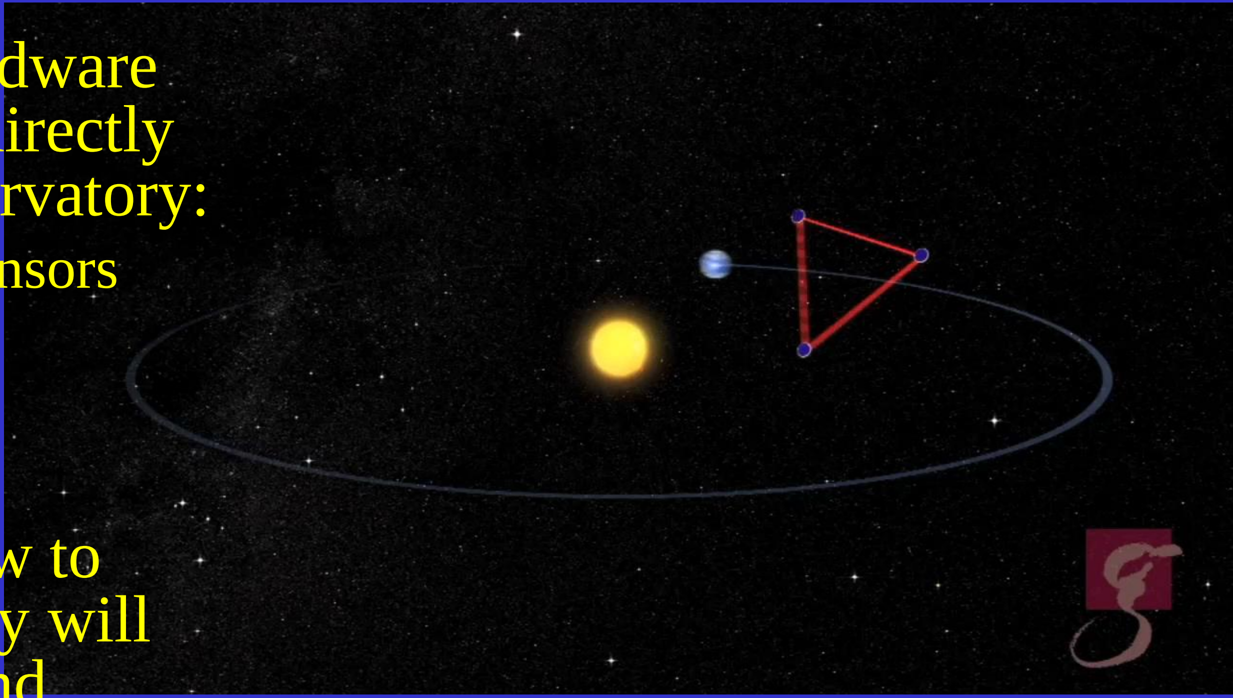
A possible schedule

Task Name	Duration	Start	Finish
GOAT recommendations	0 days	Fri 1/1/16	Fri 1/1/16
First LISA Pathfinder in-orbit results	6 mons	Fri 1/1/16	Thu 6/16/16
Call for L3 Mission	6 mons	Fri 6/17/16	Thu 12/1/16
High priority Technology Developments	**894 days**	**Fri 1/1/16**	**Wed 6/5/19**
ITT process (rolling over 1/month)	12 mons	Fri 1/1/16	Thu 12/1/16
High Priority (TDA (for EM, 3 yr)	36 mons	Thu 9/1/16	Wed 6/5/19
High prioirty TDA (for EM, 2 yr)	24 mons	Sat 10/1/16	Thu 8/2/18
Medium prioirty TDA (for EM)	36 mons	Sat 4/1/17	Thu 1/2/20
Lower priority/late developments	36 mons	Sun 10/1/17	Thu 7/2/20
Payload pre-developments	**741 days**	**Mon 1/1/18**	**Mon 11/2/20**
AO for Payload consortium	8 mons	Mon 1/1/18	Fri 8/10/18
System risk reduction	24 mons	Tue 1/1/19	Mon 11/2/20
Space system development	**3170 days**	**Fri 1/13/17**	**Thu 3/8/29**
phase A ITT	4.5 mons	Fri 1/13/17	Thu 5/18/17
Phase A	18 mons	Fri 5/19/17	Thu 10/4/18
Phase B1	24 mons	Fri 10/5/18	Thu 8/6/20
Mission adoption review	0 days	Thu 8/6/20	Thu 8/6/20
SPC adoption & IPC approval	0 days	Thu 9/3/20	Thu 9/3/20
ITT and contractor selection	9 mons	Fri 9/4/20	Thu 5/13/21
Phase B2/C/D (8.5 yrs)	102 mons	Fri 5/14/21	Thu 3/8/29



The Gravitational Wave observatory after LISA Pathfinder

- The physics of the observatory demonstrated down to critical details
- Substantial part of hardware and methods may be directly transferred to the observatory:
  - Gravity Reference Sensors
  - Drag-free control
  - Local interferometer
  - ……..
- Important steps on how to operate the observatory will have been practiced and understood
- A key “go ahead” for LISA



SUCH AN OBSERVATORY WILL LIKELY BE THE MOST POWEFUL ASTROPHYSICAL EXPLORER OF THE DEEP AND EARLY UNIVERSE AND THE MOST ACCURATE LABORATORY TO STUDY GENERAL RELATIVITY AND GRAVITATION IN THE SO-CALLED FIELD REGIME.

THE JOINT STUDY OF ELECTROMAGNETIC SPECTRUM AND GRAVITATIONAL WAVE MESSAGERS WILL OPEN A NEW ERA FOR ASTROPHYSICS MAKING THE BEST USE OF THE MOST POWERFUL OBSERVATORIES AND IT WILL OPERATING IN SPACE

THE GOLDEN ERA FOR GRAVITATIONAL WAVE DETECTION

- LISA mission @ ESA Cosmic Vision
- 3 Dec 2015 : LISAPathFinder launch
- 12 Feb 2016: high-frequency gravitational waves, emitted by a pair of merging black holes, were directly detected for the first time with the Advanced Laser Interferometer Gravitational-Wave Observatory.

Italy Statement

The Italian delegation recommended that ESA and its Member States urgently reconsider the planning of the science program in order to optimally meet the unique opportunity that the new scenario opens to capitalize on its investment and in order to maintain European worldwide leadership in this high profile field of space science.

In order to achieve this goal , Italy proposes:

- To constitute a working group to identify the guidelines for a revision of the Cosmic Vision program by the June 2016 SPC.
- To elaborate a roadmap for the short term development of the needed technologies .
- To postpone the adoption of new missions after the conclusions of this working group will be available.

SUPPORT LISA MISSION

- Express your point of view

- Invite the team

- Join the team

- Support the development

Wishing a go on for LISA development soon,
THANKS FOR YOUR ATTENTION!!!