From the first results of LISAPathfinder to LISA : First step to observing gravitational wave from space

Antoine Petiteau

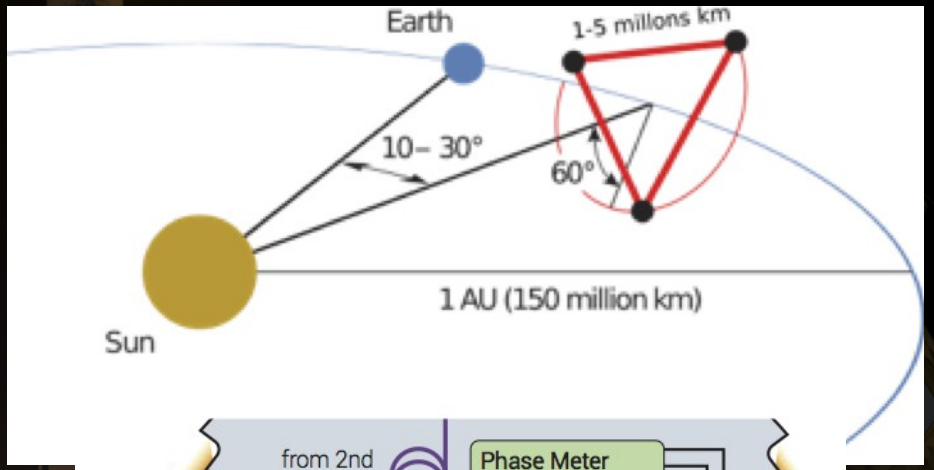
AstroParticule et Cosmologie – Université Paris-Diderot

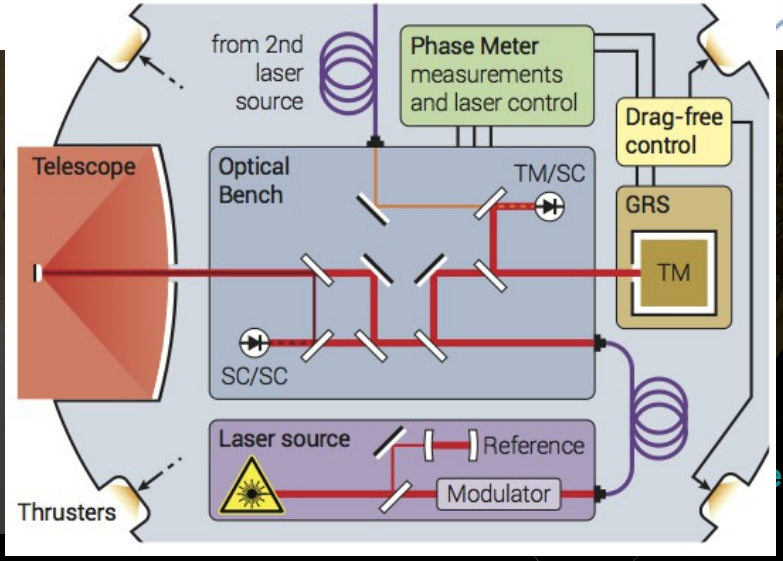
Journée GPhys

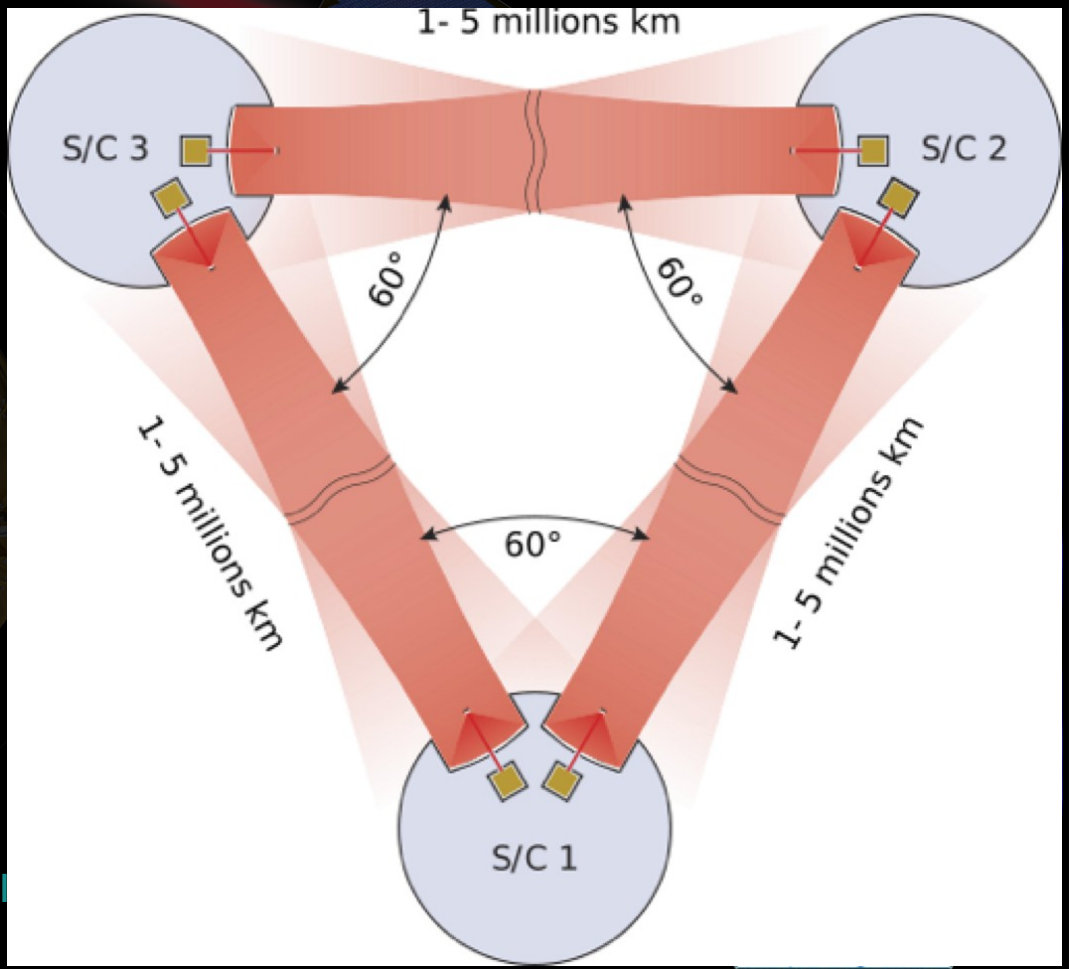
APC-Paris – 6th July 2016

Space based GW observatory : LISA

- 3 spacecrafts distant from few millions km: Large mission L3 @ ESA
  - spacecraft always adjusts on a free-falling test-mass using micro-thruster,
  - Exchanging laser beams to form several interferometers and detect very small relative deformations => Gravitaional waves

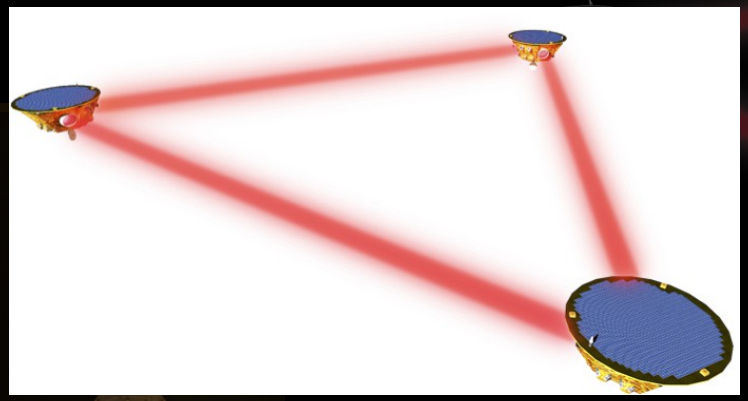






LISAPathfinder

- Technological demonstrator for LISA

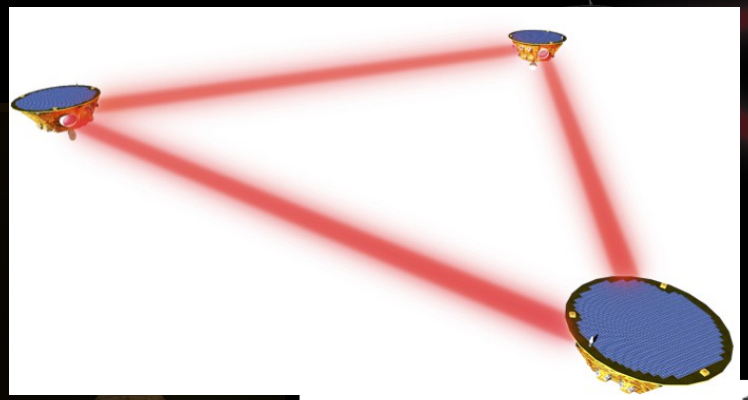


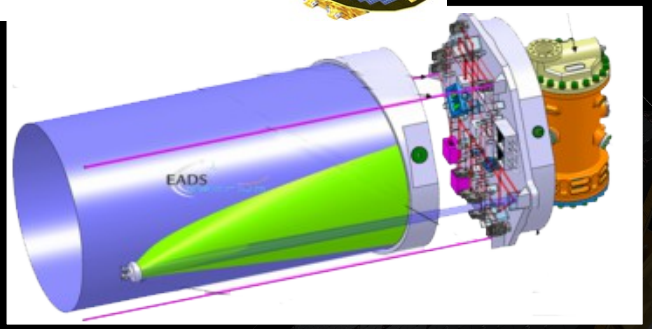
LISA :

- 3 spacecraft separated by millions of km
- Role of each spacecraft is to protect the fiducial test masses from external forces

LISAPathfinder

- Technological demonstrator for LISA





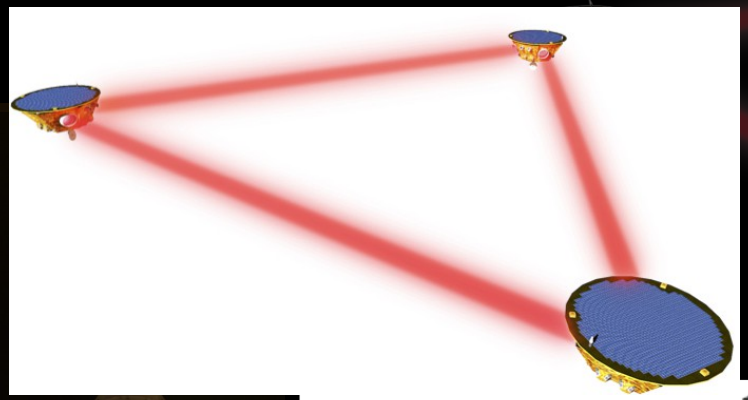
LISA :

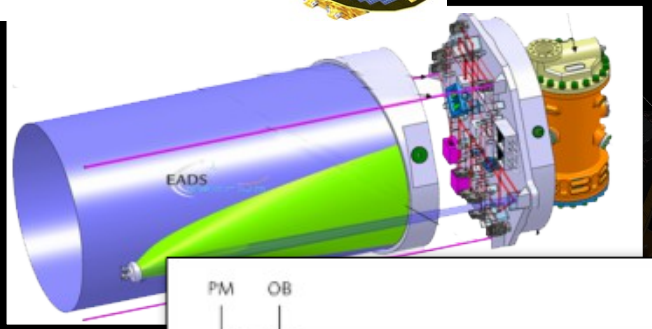
Locally measure distance from TM to SC using :

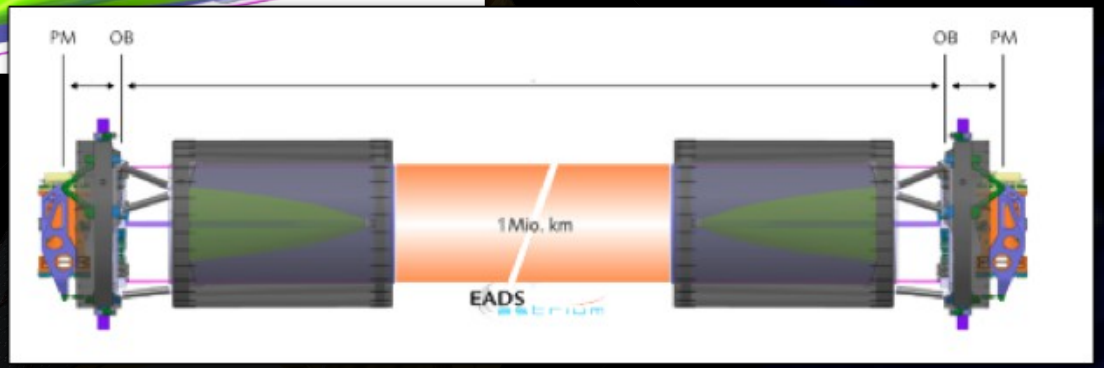
- Laser interferometry along sensitive axis (between SC)
- Capacitive sensing on orthogonal axes
- TM displacement measurements are used as input to DFACS which controls position and attitude of SC respect to the TM

LISAPathfinder

- Technological demonstrator for LISA



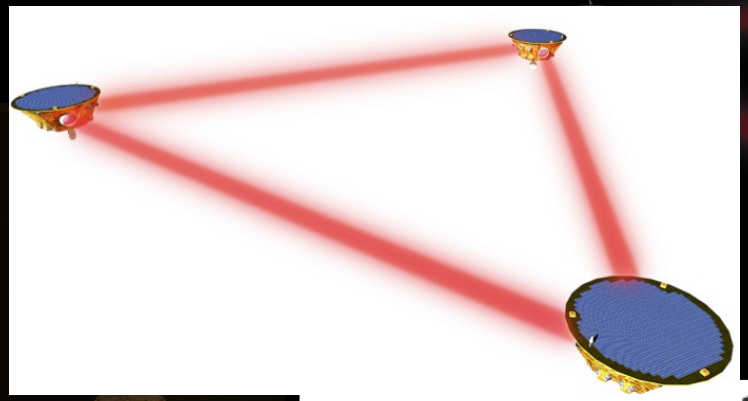


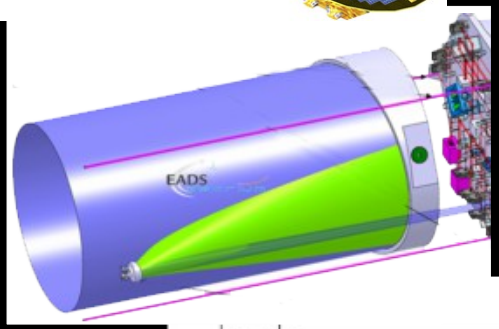


LISA :
Measure distance between SC using laser Interferometry
(TM1→s/c) + (s/c→s/c) +(s/c→TM2)

LISAPathfinder

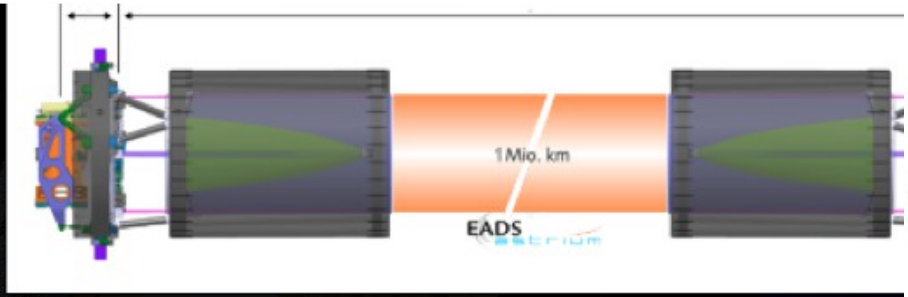
- Technological demonstrator for LISA

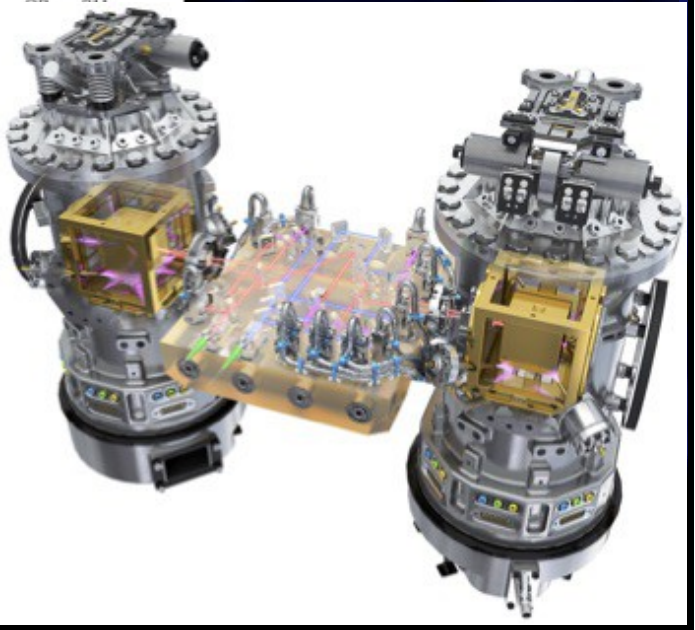




LISAPathfinder :

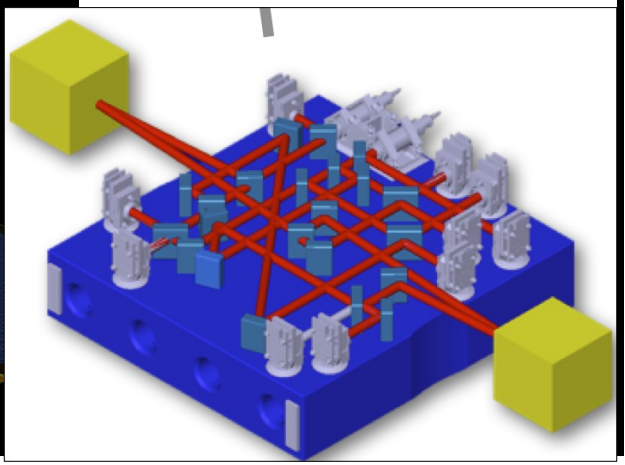
- 2 test masses / 2 inertial sensors
- Laser readout of TM1→SC and TM1→TM2
- Capacitive readout of all 6 DoF of TM
- Drag-Free and Attitude Control System
- Micro-newtonThruster

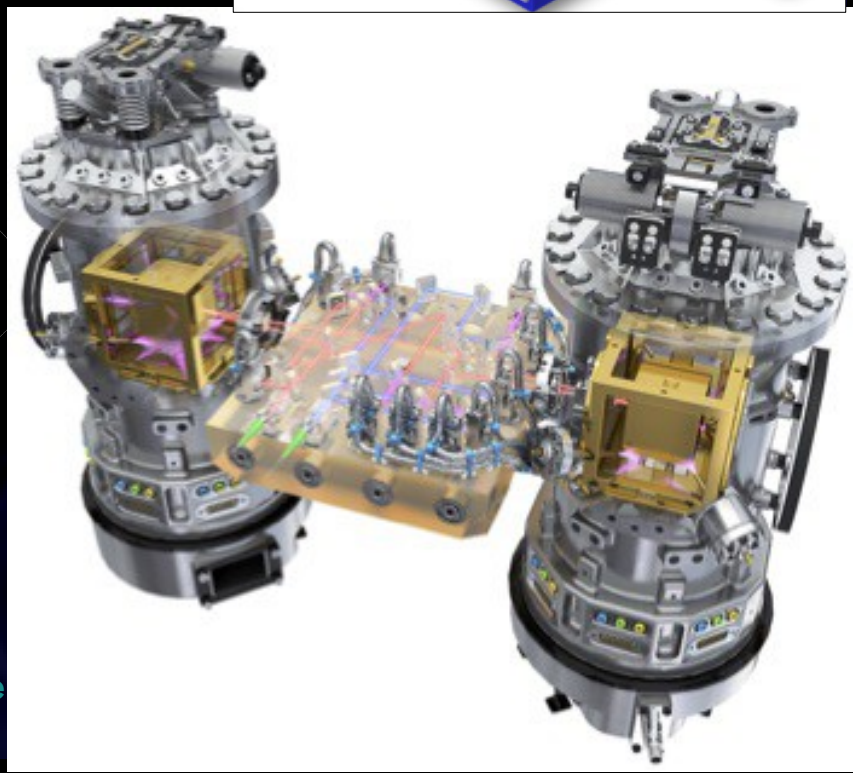




LISAPathfinder (LPF)

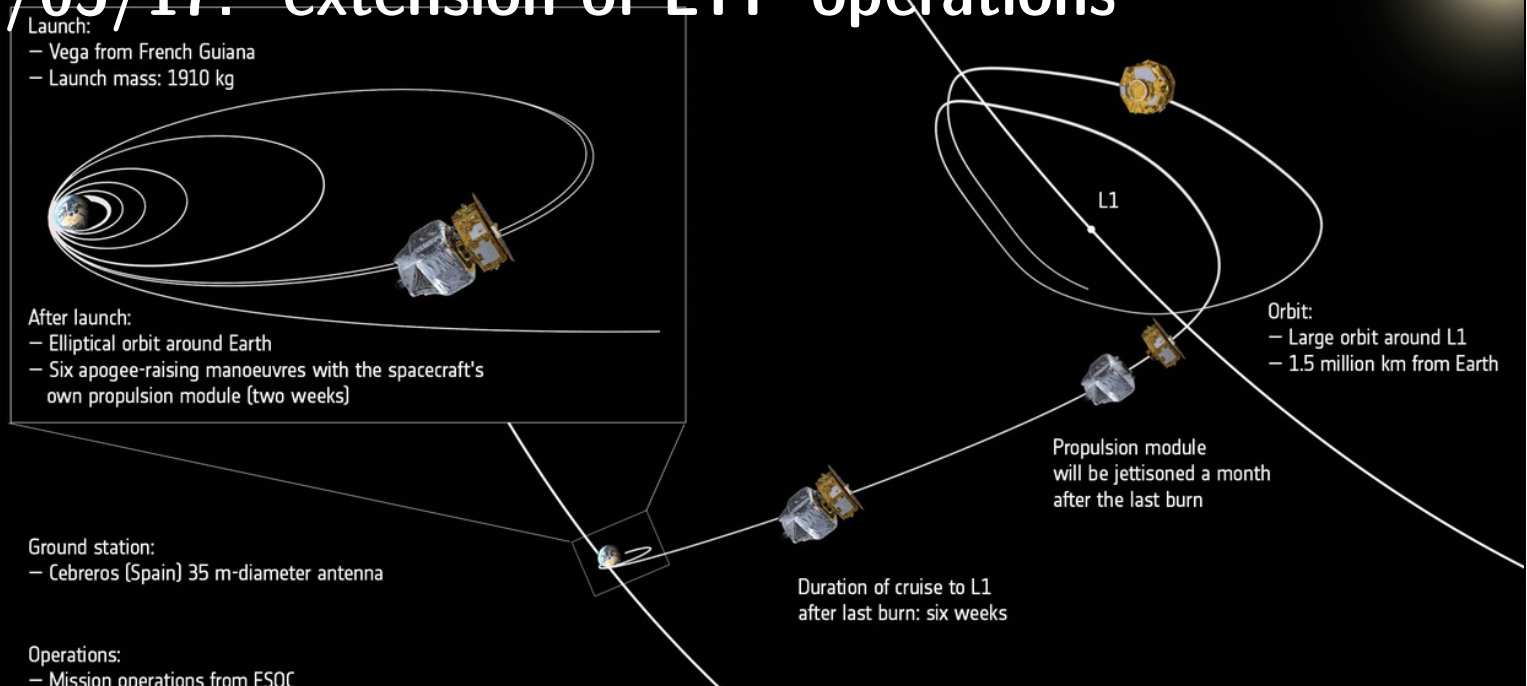
- Basic idea : reduce one LISA arm in one spacecraft.
- LISAPathfinder is testing :
  - Inertial sensor,
  - Interferometric measurement between 2 free-falling test-masses,
  - Drag-free and attitude control system
  - Micro-thrusters
  - ....





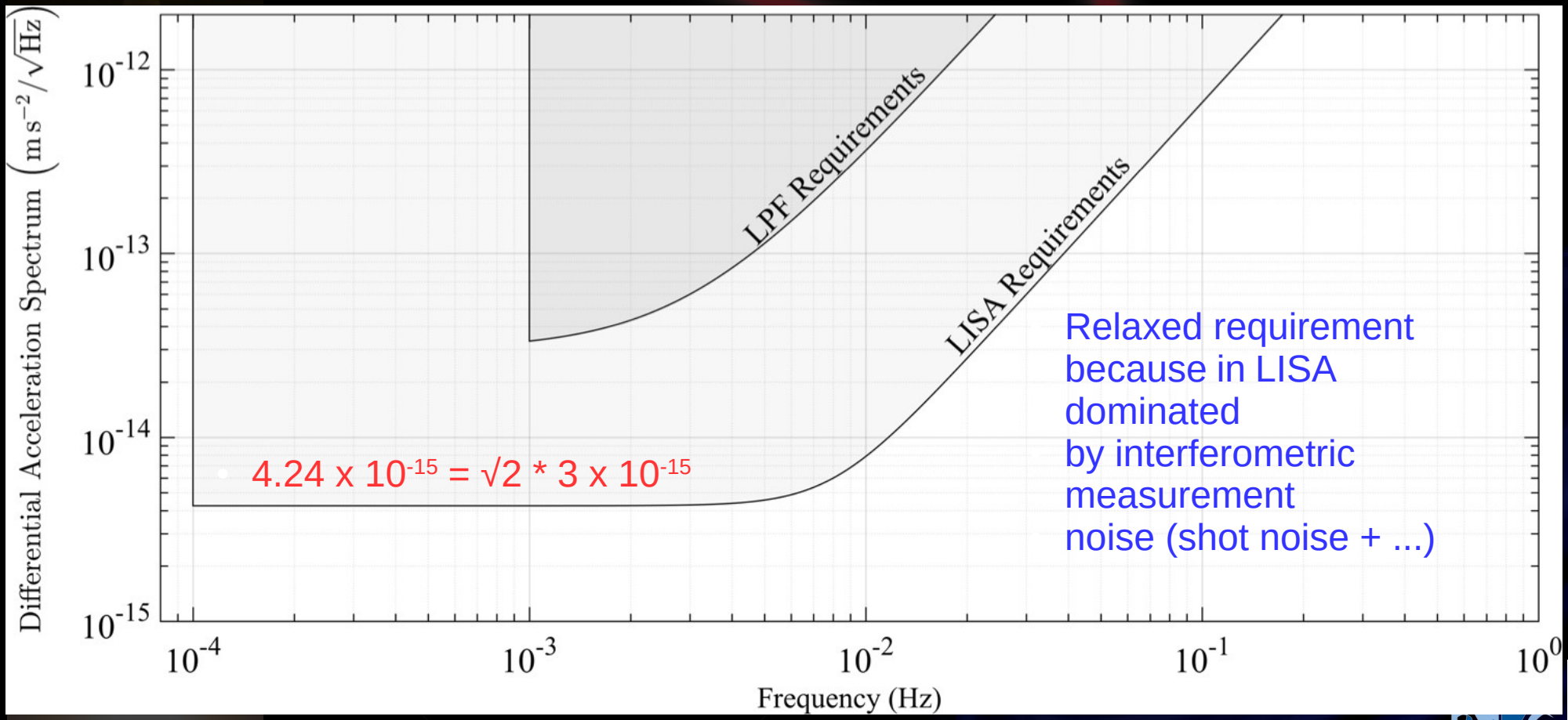
LISAPathfinder timeline

- 3/12/15: Launch from Kourou
- 22/01/16: arrived on final orbit & separation of propulsion module
- 17/12/15→ 01/03/2016: commissioning
- 01/03/16 → 27/06/16: LTP operations(Europe)
- 27/06/16 → 10/16: DRS operations (US)
- 01/11/16 → 31/05/17: extension of LTP operations



Requirements : LISAPathfinder vs LISA

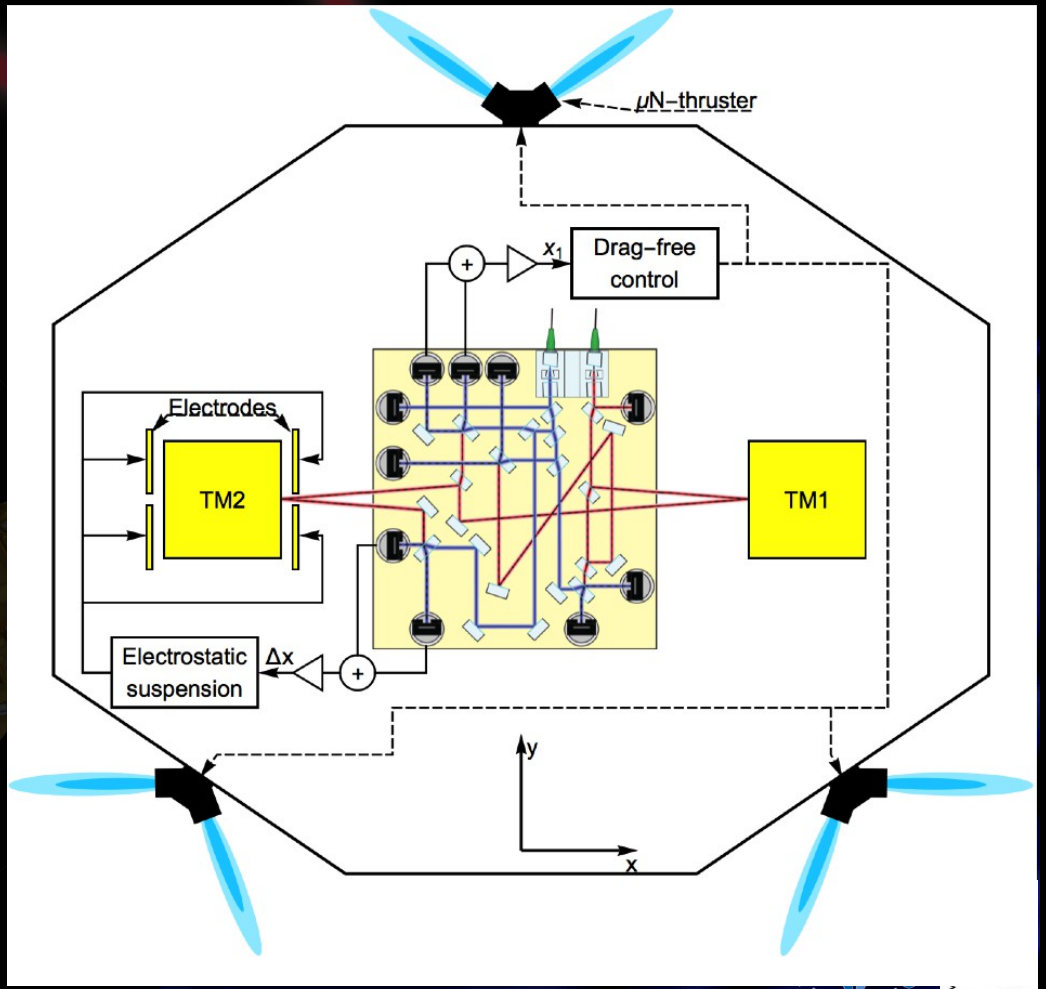
- Main LISAPathfinder measurement : Δg : differential acceleration between the 2 test-masses



Requirements : LISAPathfinder vs LISA

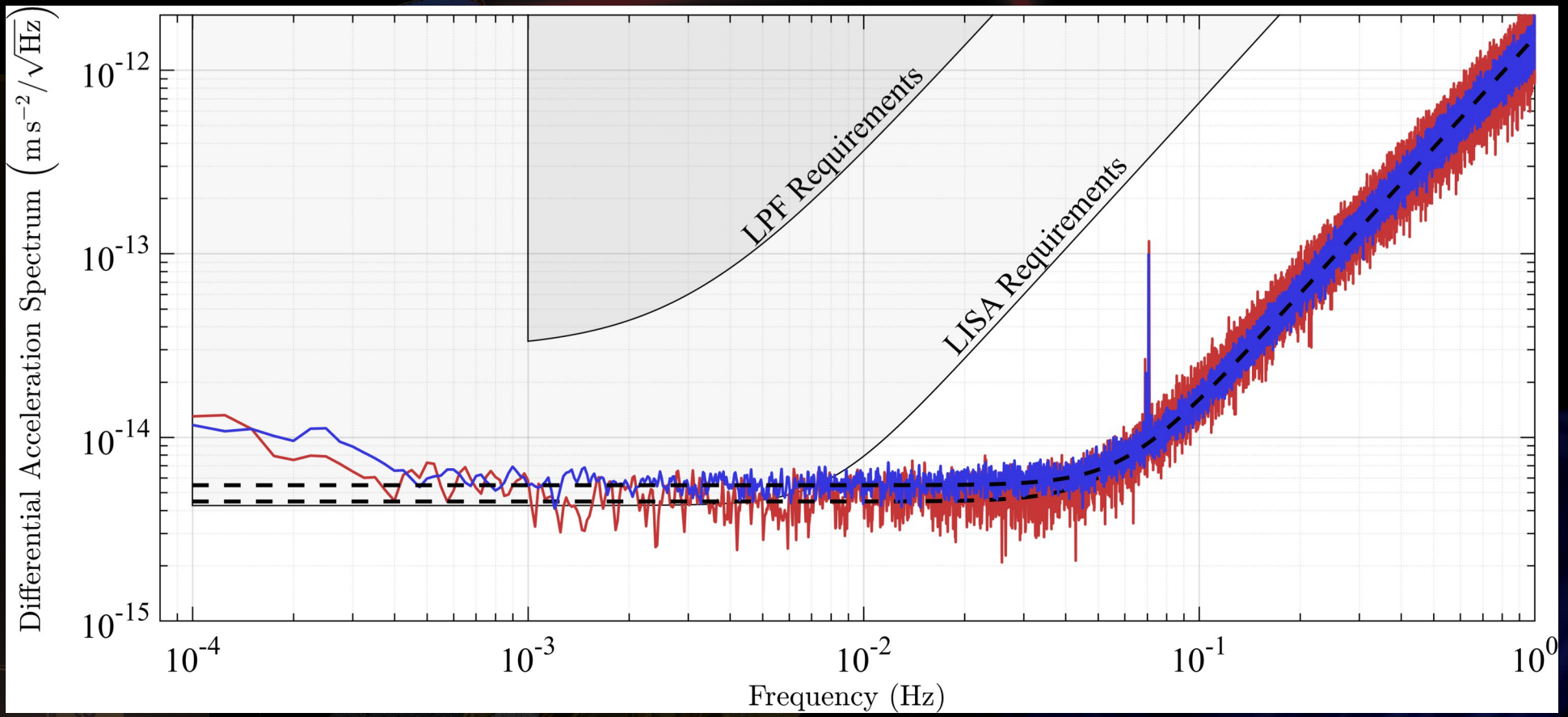
Why the LISAPathfinder requirements are restricted compare to LISA ones ?

- We understand limitations with LISAPathfinder and correct for them in LISA
- Short arm limitation :
  - Gravitational field not perfectly flat => constant electrostatic actuation on test-mass 2
- f > 1 mHz : limit duration of industrial testing
- Industrial margin



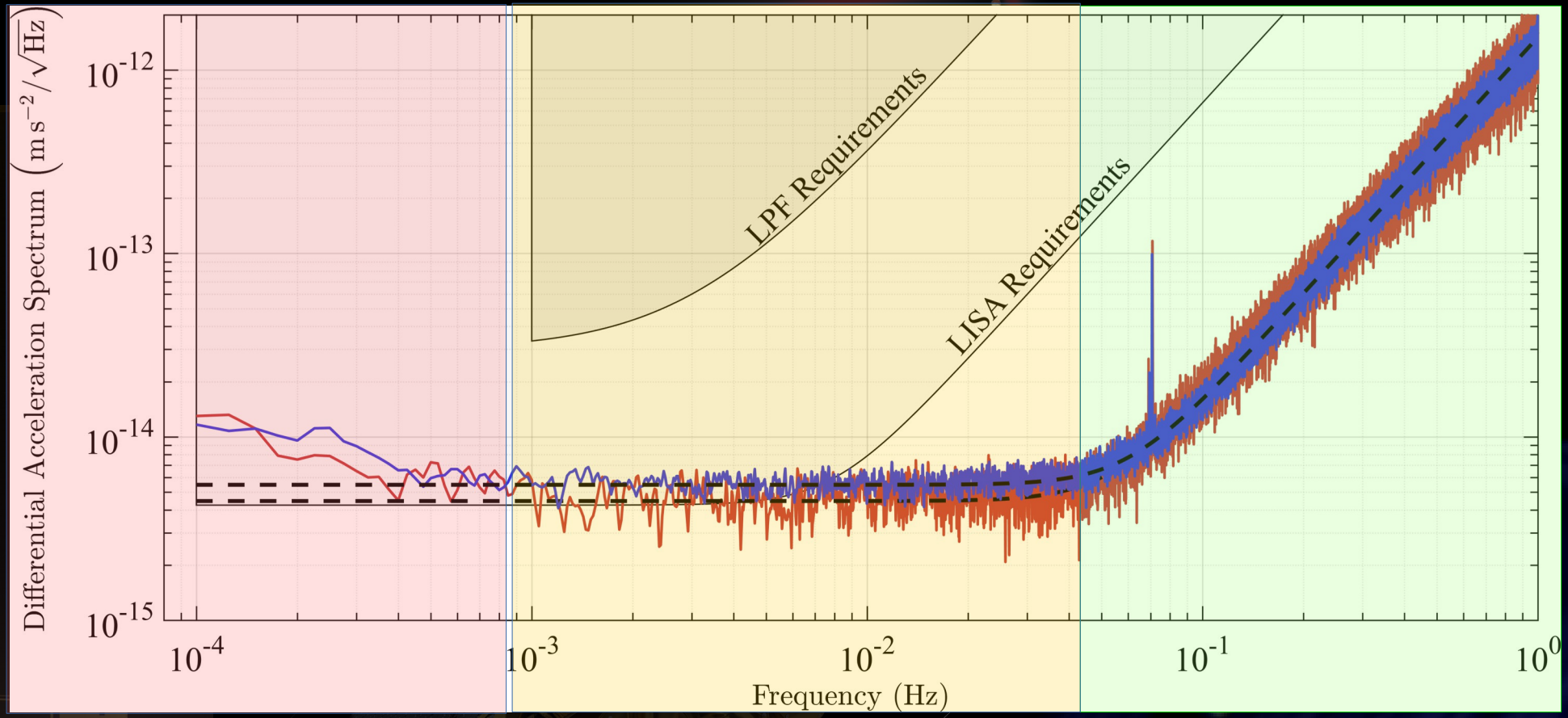
First results

M. Armano et al. PRL 116, 231101 (2016)



First results

M. Armano et al. PRL 116, 231101 (2016)



Low frequency noise
Investigation in progress
...

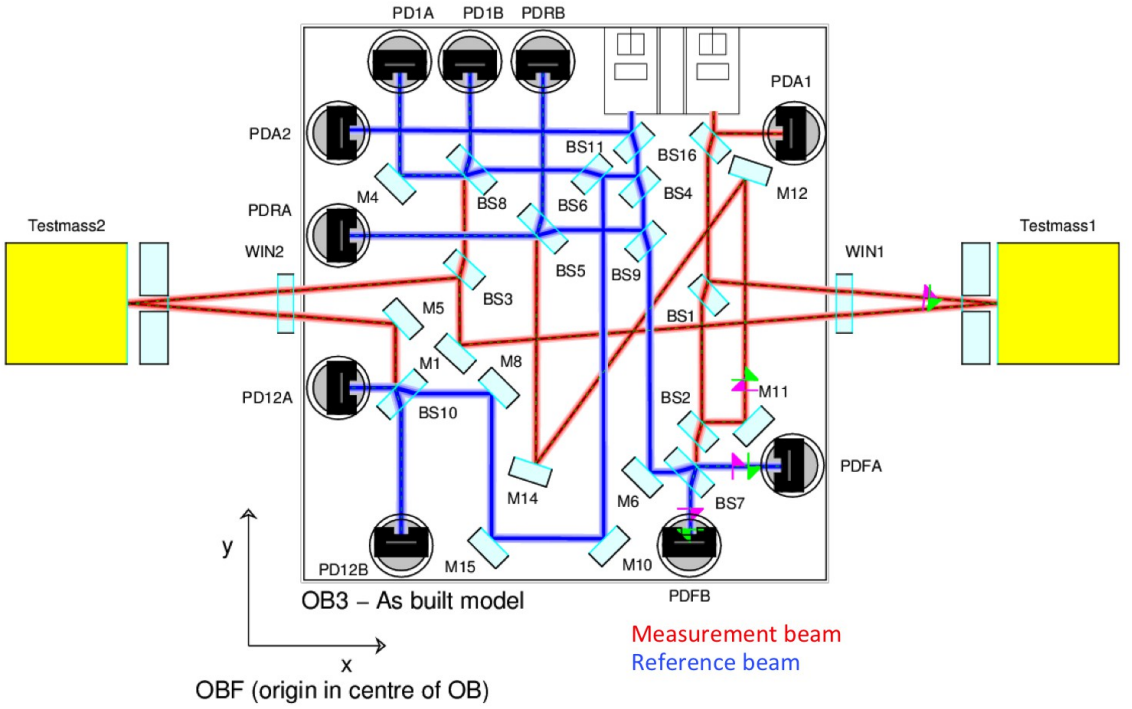
Brownian noise
Molecules within the noise
hit test-masses

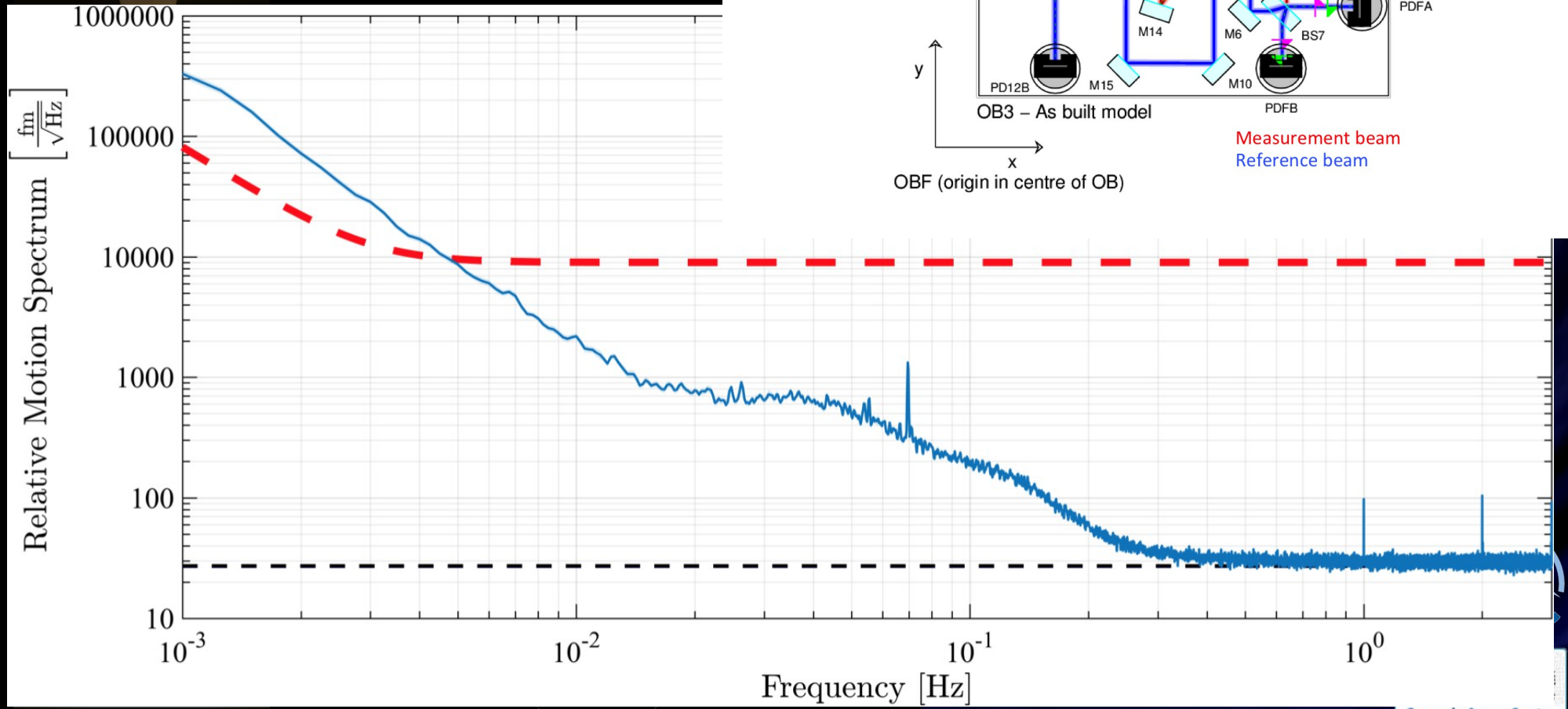
Interferometric noise
Not real test-mass
motion

High-frequency limit

- High frequency limits :
  - Interferometric precision :

    30 fm.Hz$^{-1/2}$.
  - Orientation of test-masses





Mid-frequency limit

Noise in 1 – 10 mHz : brownian noise due to residual pressure :

- Molecules within the housing hitting the test-masses
- Possible residual outgassing

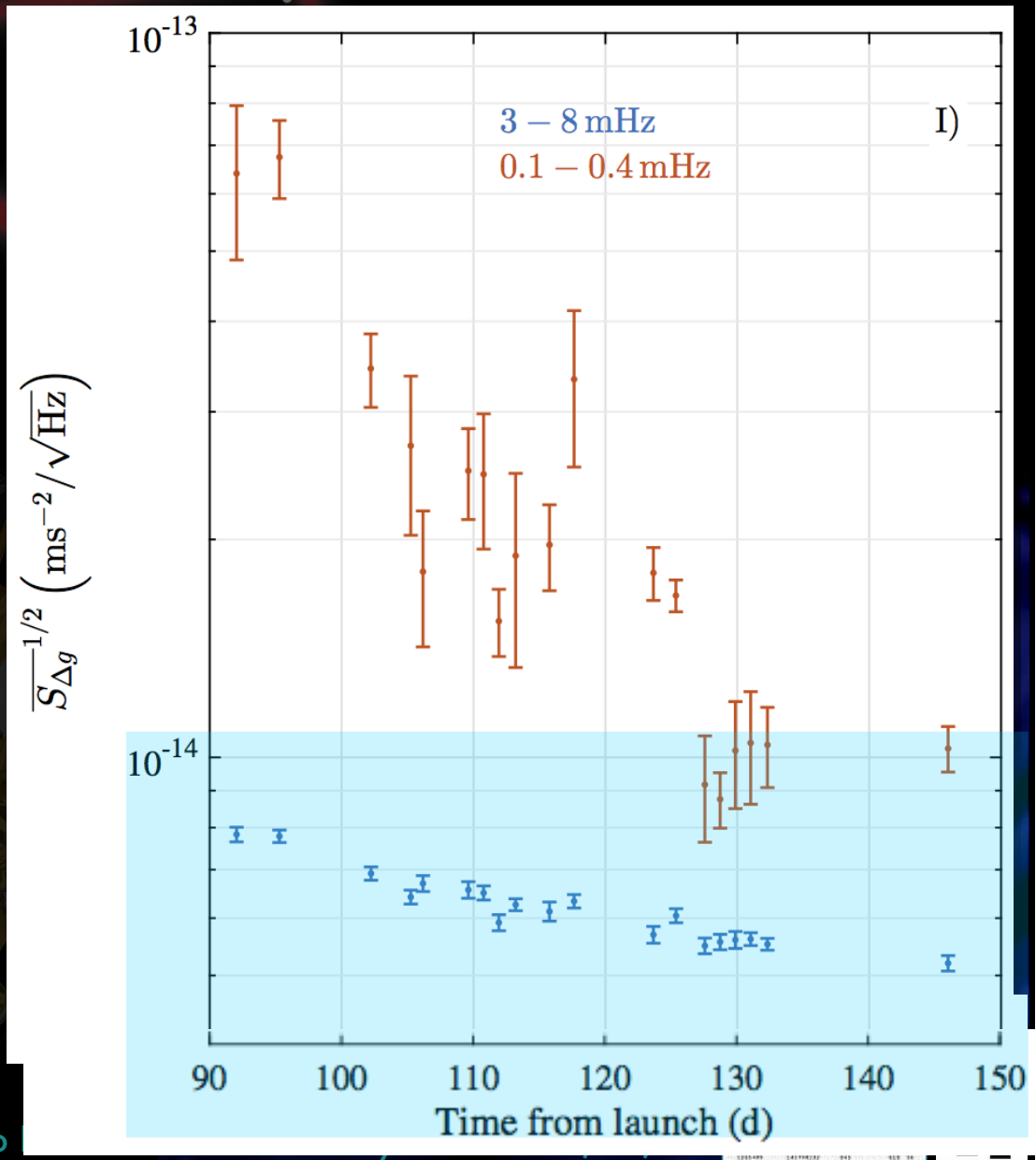
➢ Evolution :

- Pressure decreases with time => constant improvement ... if we don't hit something else

➢ For LISA :

- Better evacuation system ...

M. Armano et al. PRL 116, 231101 (2016)

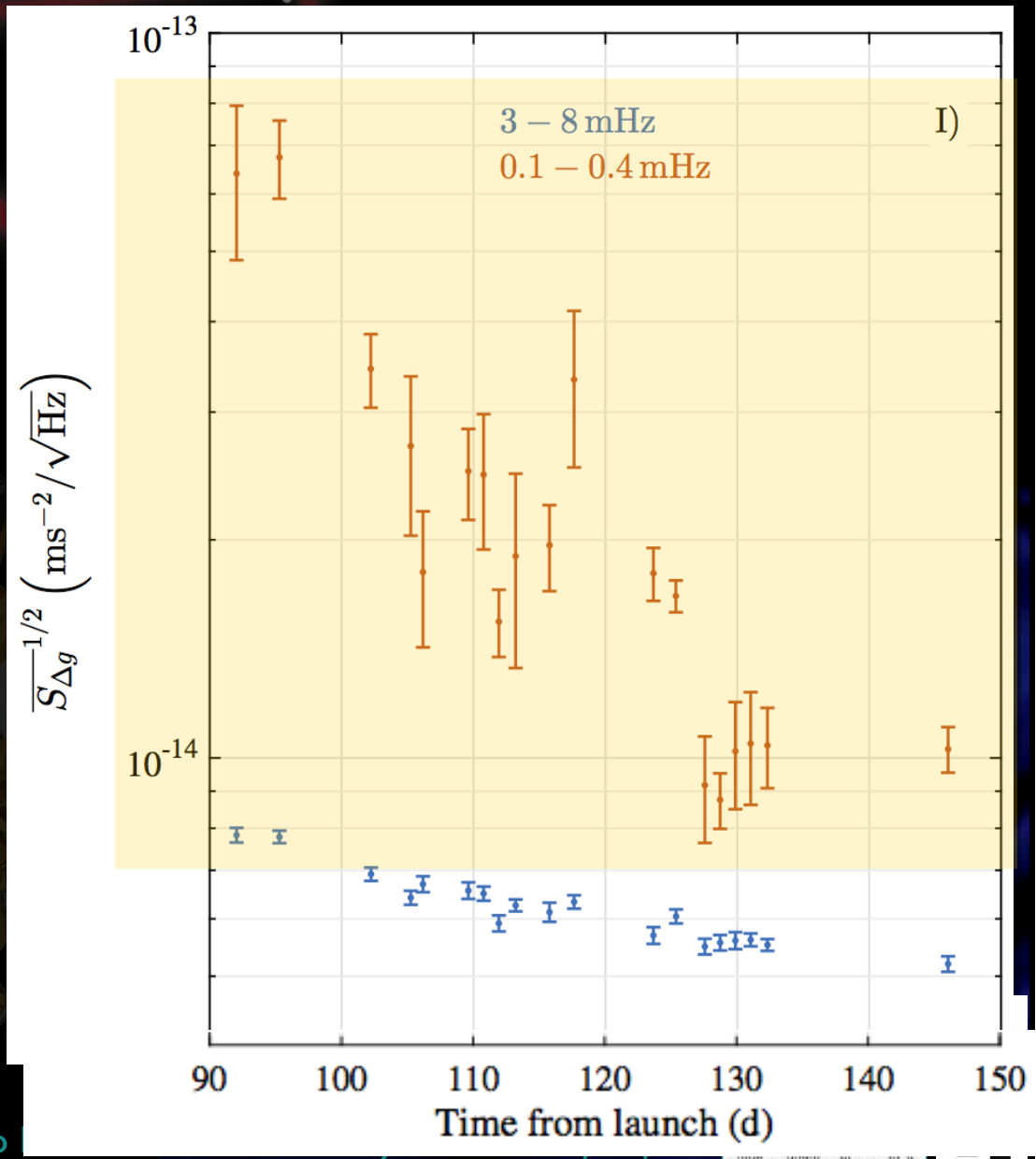


Low-frequency limit

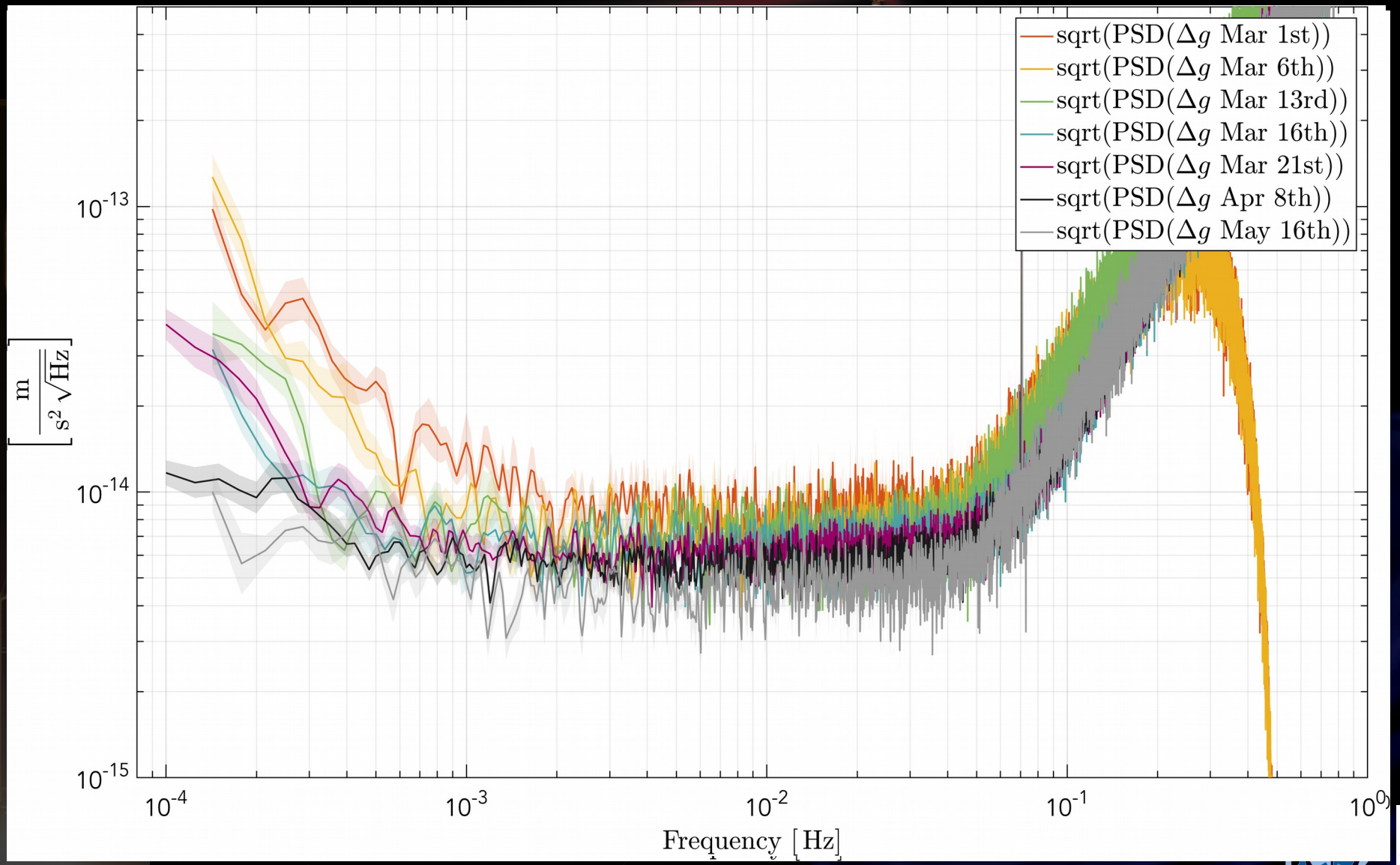
- Noise in 0.1 – 1 mHz : not yet understood but seems to :
  - Decrease with time
  - In 1/f ?
  - Correlation with temperature ?

  Work in progress …
- For f < 0.1 mHz :
  - Need long noise measurements => mission extension

M. Armano et al. PRL 116, 231101 (2016)



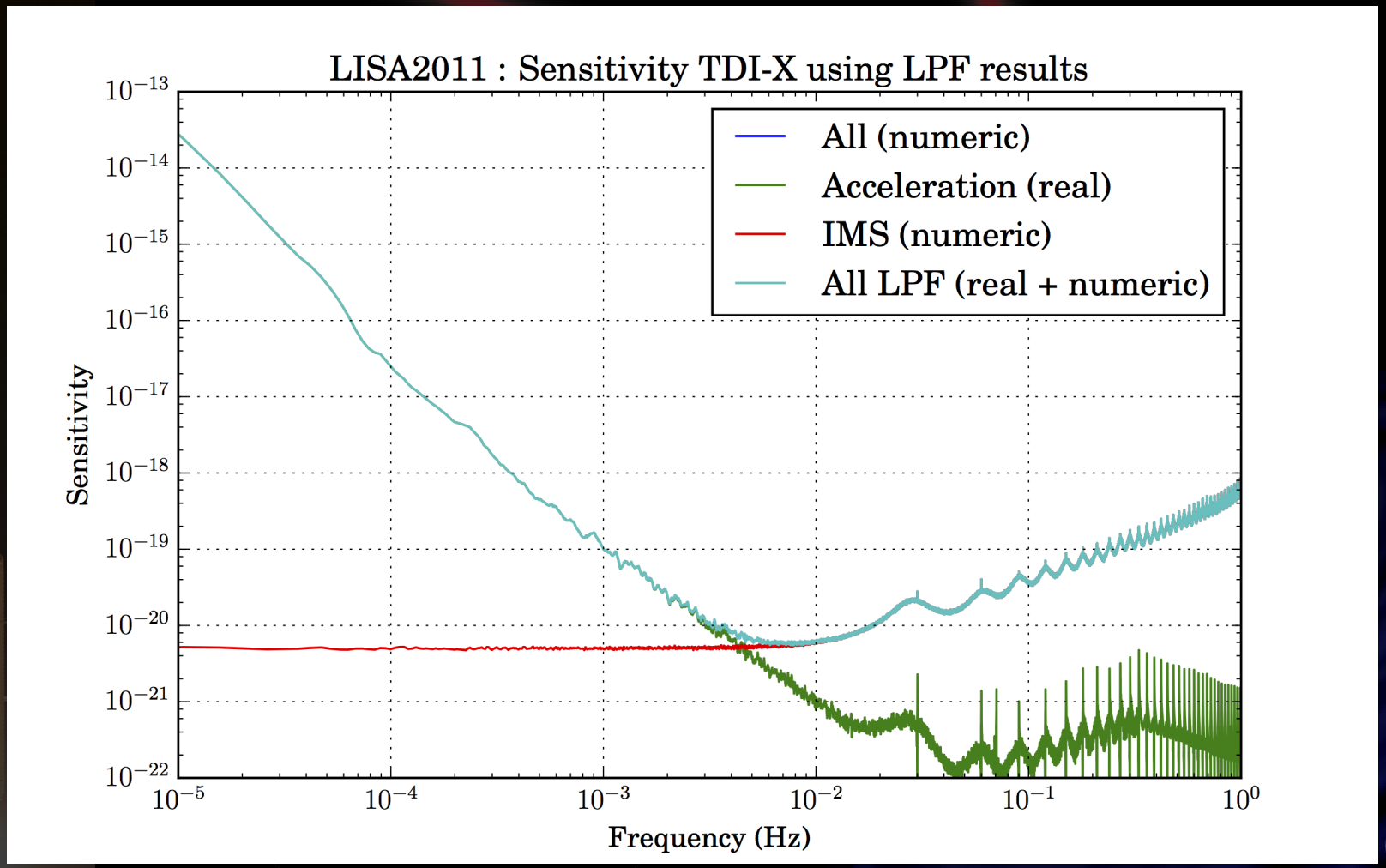
3 months of operations



by M. Hewiston

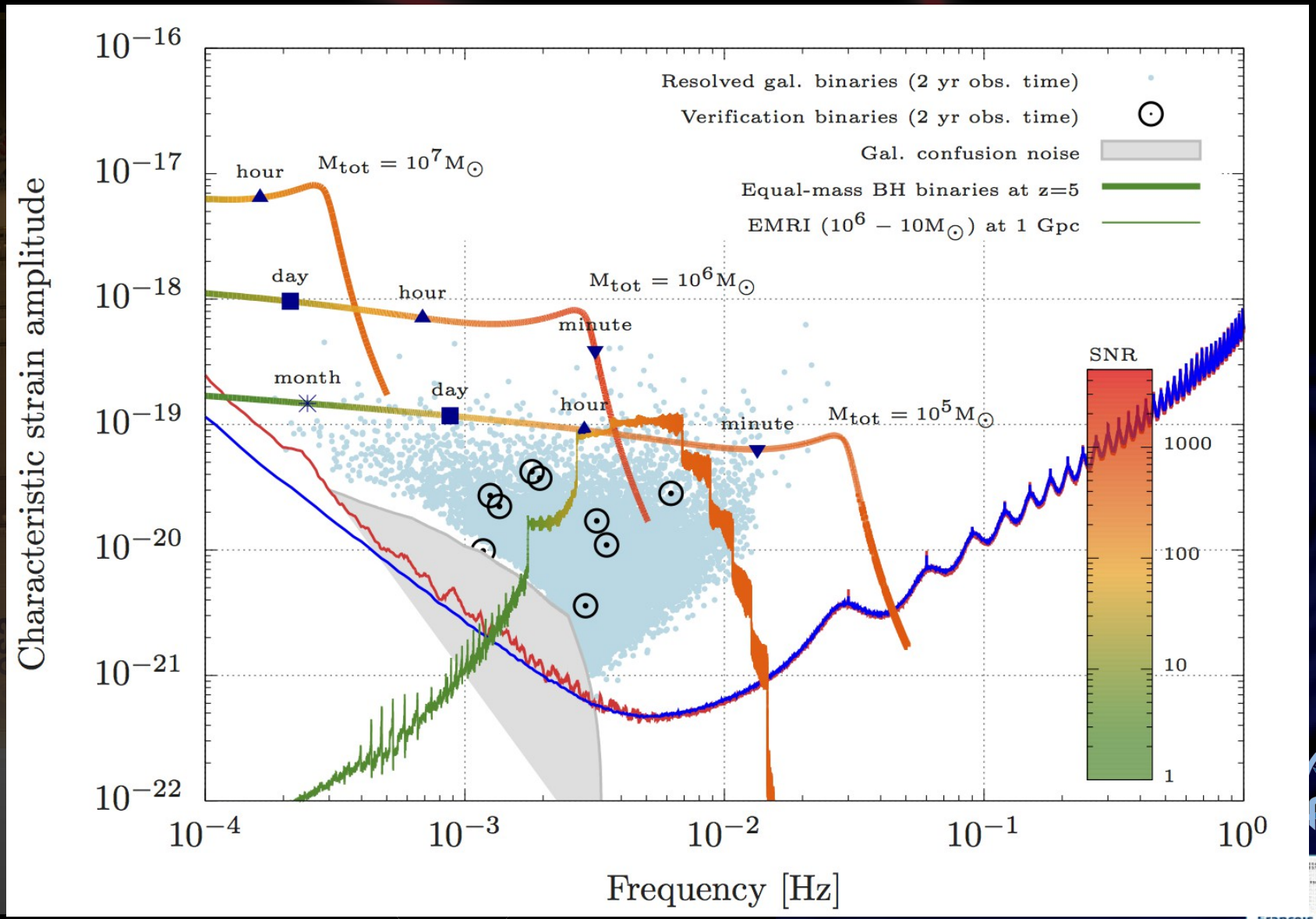
From LISAPathfinder to LISA

- LISAPathfinder noise + LISA interferometric measurement noise (high frequencies) and 5 million kilometers arms.



From LISAPathfinder to LISA

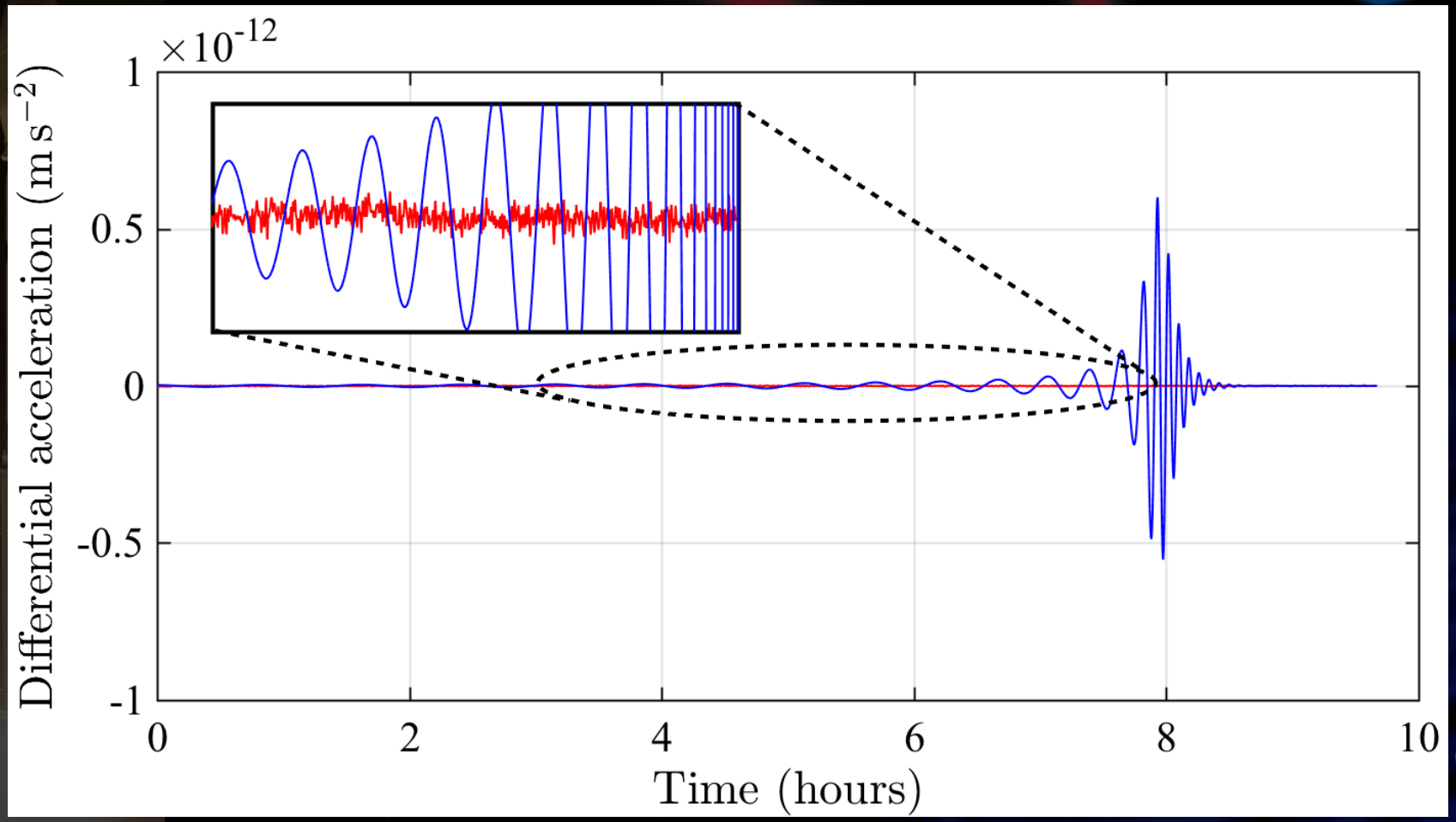
- LISAPathfinder noise + LISA interferometric measurement noise (high frequencies) and 5 million kilometers arms.



LPF ⟶ LISA: SMBH binaries

Supermassive black hole binaries of millions solar masses

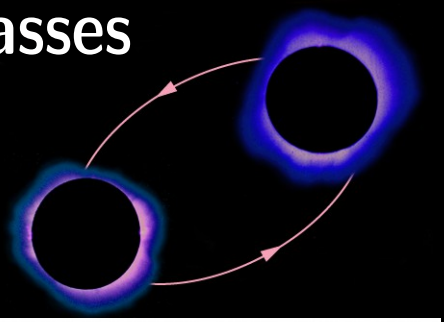
- $5x10^5$ - $5x10^5$ M_{Sun} at redshift z=5 with LPF-LISA



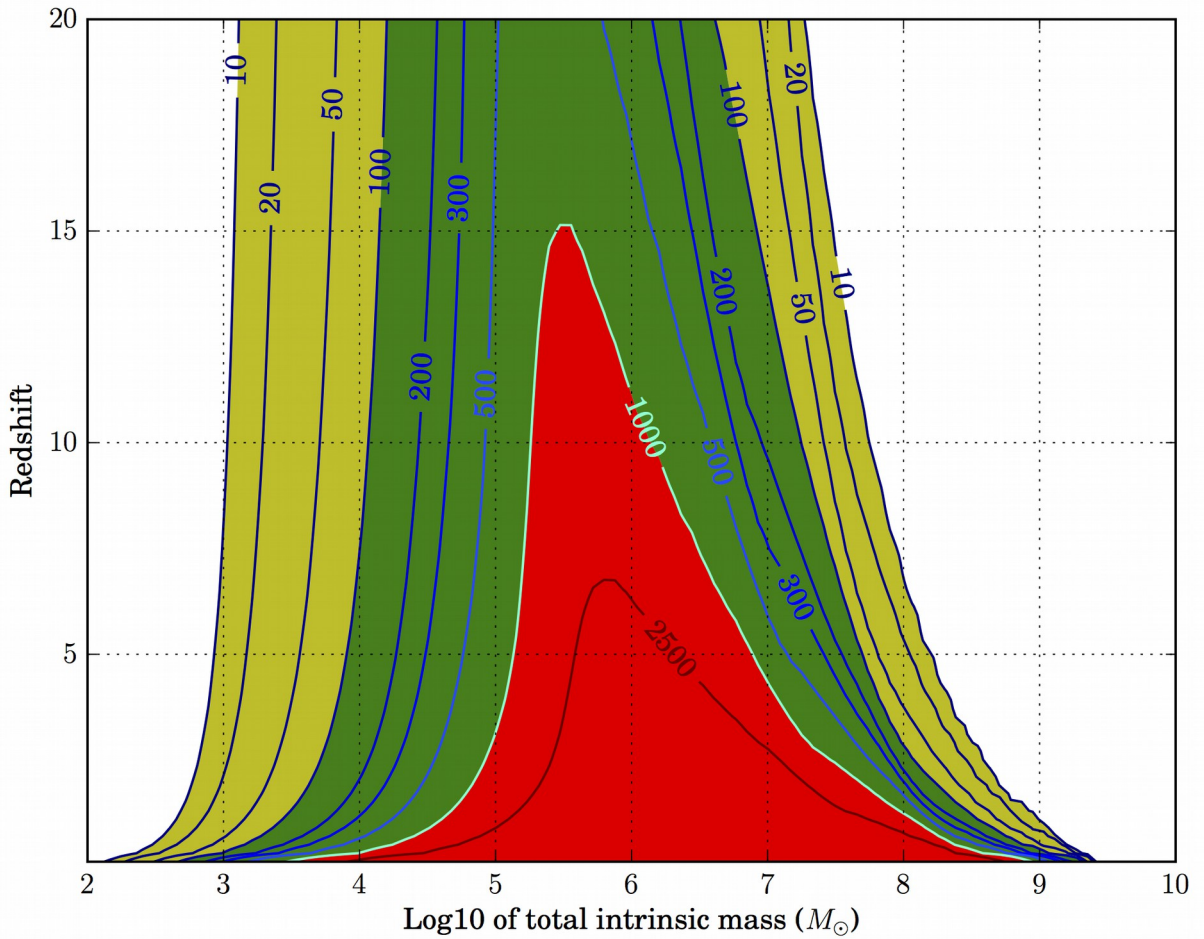
LPF ⟶ LISA: SMBH binaries

Supermassive black hole binaries of millions solar masses

- With LPF-LISA, observation of SMBH binaries mergers at very high redshift (10 - 20)

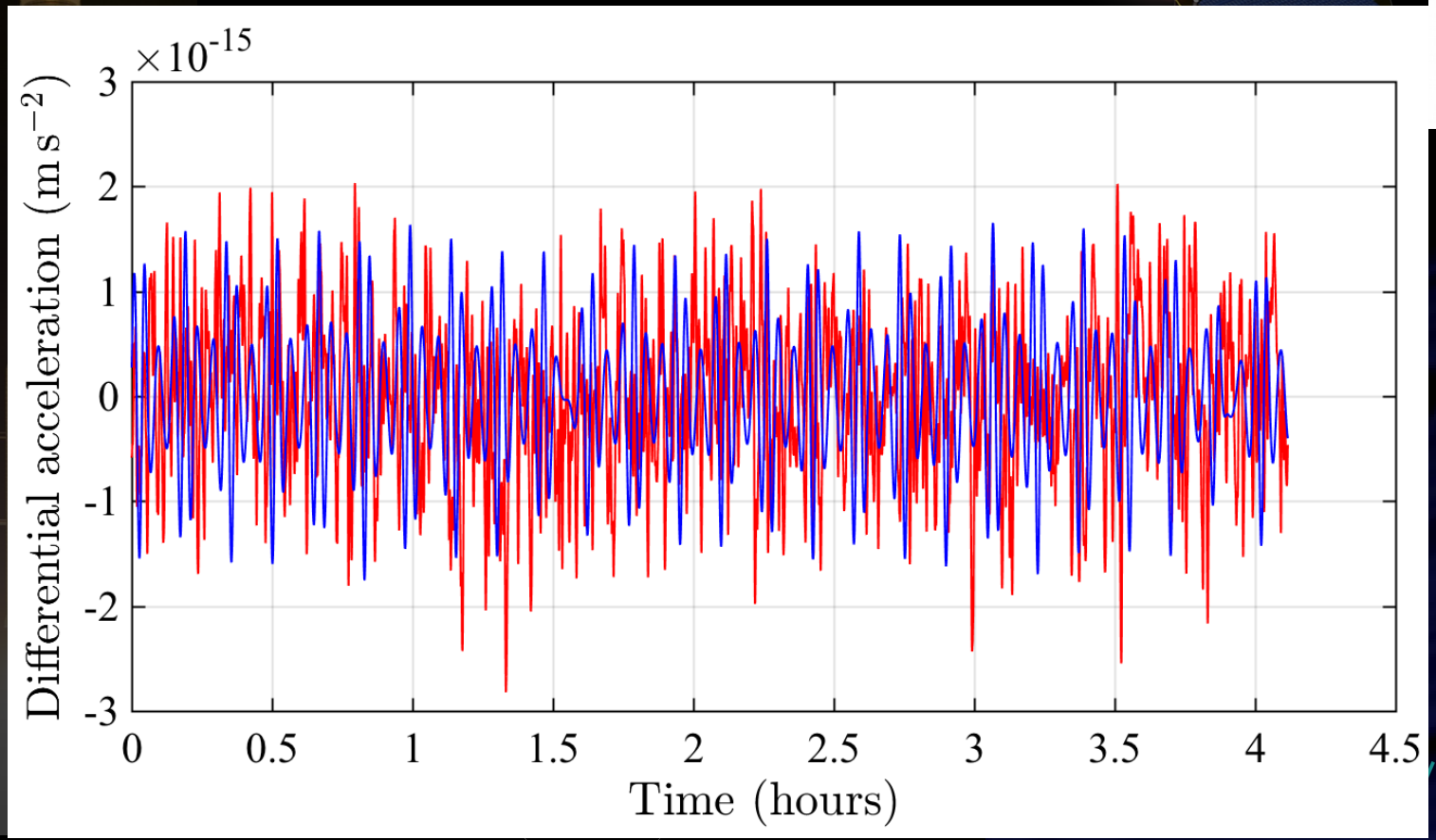


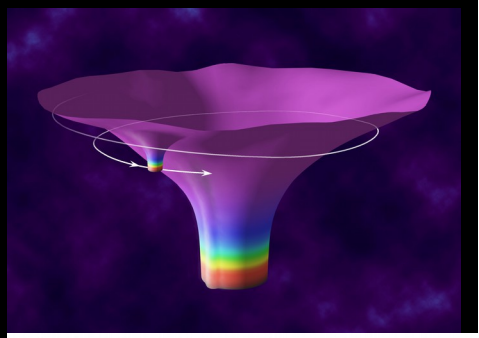
For more informations on the estimation of parameters with various eLISA configuration see A. Klein et al. PRD 93, 024003 (2016)

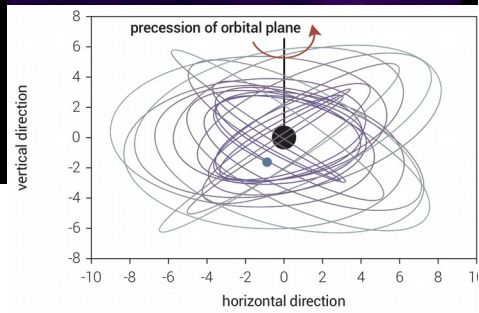


LPF → LISA: EMRIs

- **EMRIs** : Extreme Mass Ratio Inspiral :
  - 10^6 M_{sun} – 10 M_{Sun} at 1 Gpc : signal vs LISAPathfinder noise : coherent signal over year
  - => SNR about few hundred







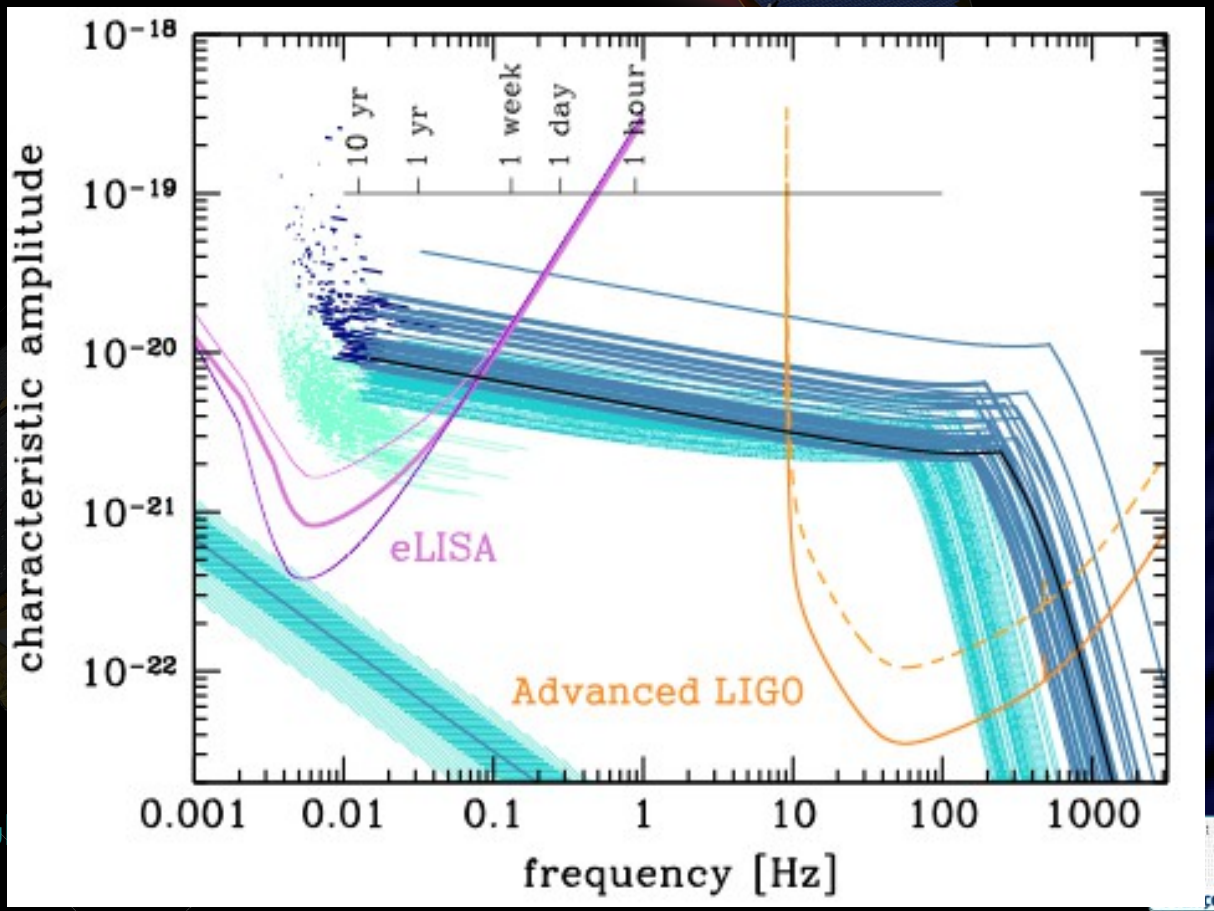
LPF⟶(e)LISA : BH binaries

- LIGO-type source (GW150914) : binaries with 2 black holes of few tens solar masses
- Detected by LISA several years before entering in LIGO/Virgo frequency band => multi-observatory GW astronomy

Sesana et al.

PRL 116,

231102 (2016)



Conclusion

- LISAPathfinder (LPF) :
  - Success => we can build instrument to observe gravitational wave source from space
  - Work in progress until May 2017 to understand and improve LISAPathfinder performances, in particular at low frequency
- Accelerate ESA planning for (e)LISA => launch 2029 (?)
  - Call for mission (2016) → phase A in 2 years → start construction 2020
- We need to define the best instrument NOW
- Several challenges : instrument, data analysis, sources modeling, astrophysical prediction, cosmology, ...
- eLISA : Huge scientific potential

LISAPathfinder à l'APC

Eric Plagnol

Antoine Petiteau

Henri Inchauspe

Joseph Martino

Pierre Prat

Hubert Halloin

Eric Fraisse

Jean-Baptiste Bayle

Pierre Binétruy

Gérard Auger