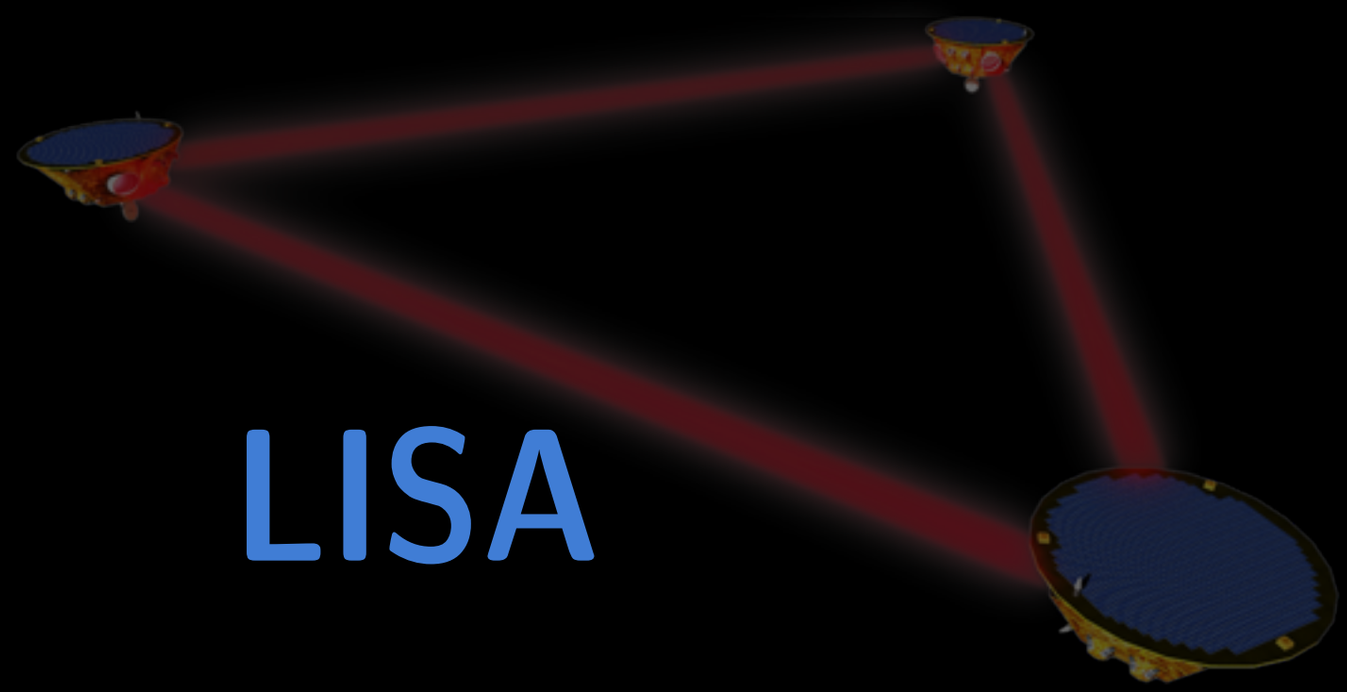


LISA

Antoine Petiteau et Joseph Martino

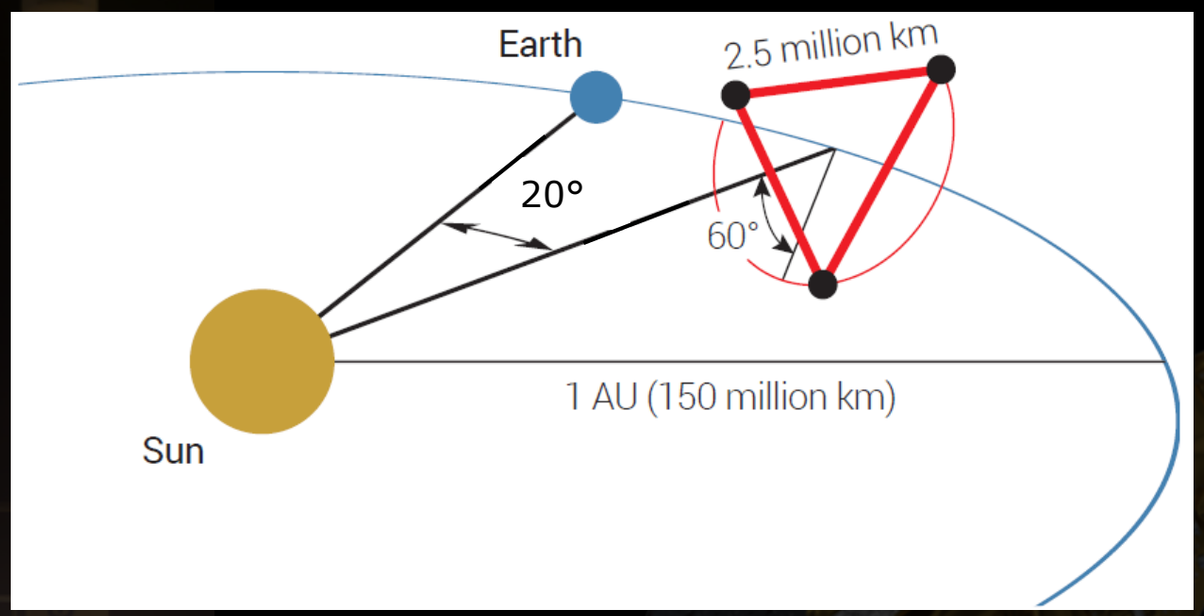
APC (CNRS/Université Paris-Diderot)

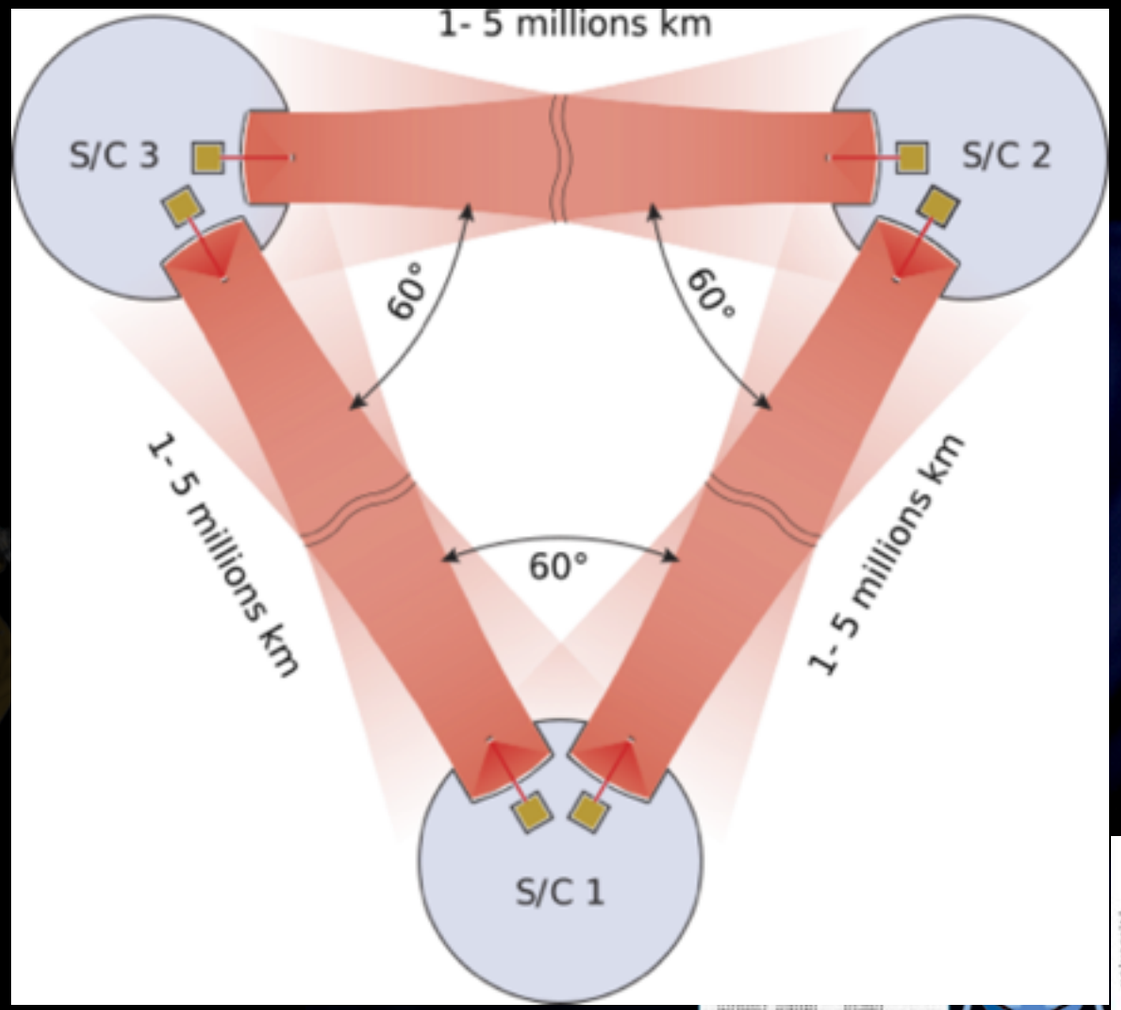
Réunion du groupe de travail "développement de détecteurs" du GDR Ondes Gravitationnelles

20 juin 2018 - Observatoire de Paris

LISA

- Laser Interferometer Space Antenna
- 3 spacecrafts on heliocentric orbits and distant from 2.5 millions kilometers
- Goal: detect relative distance changes of 10^{-21}: few picometers



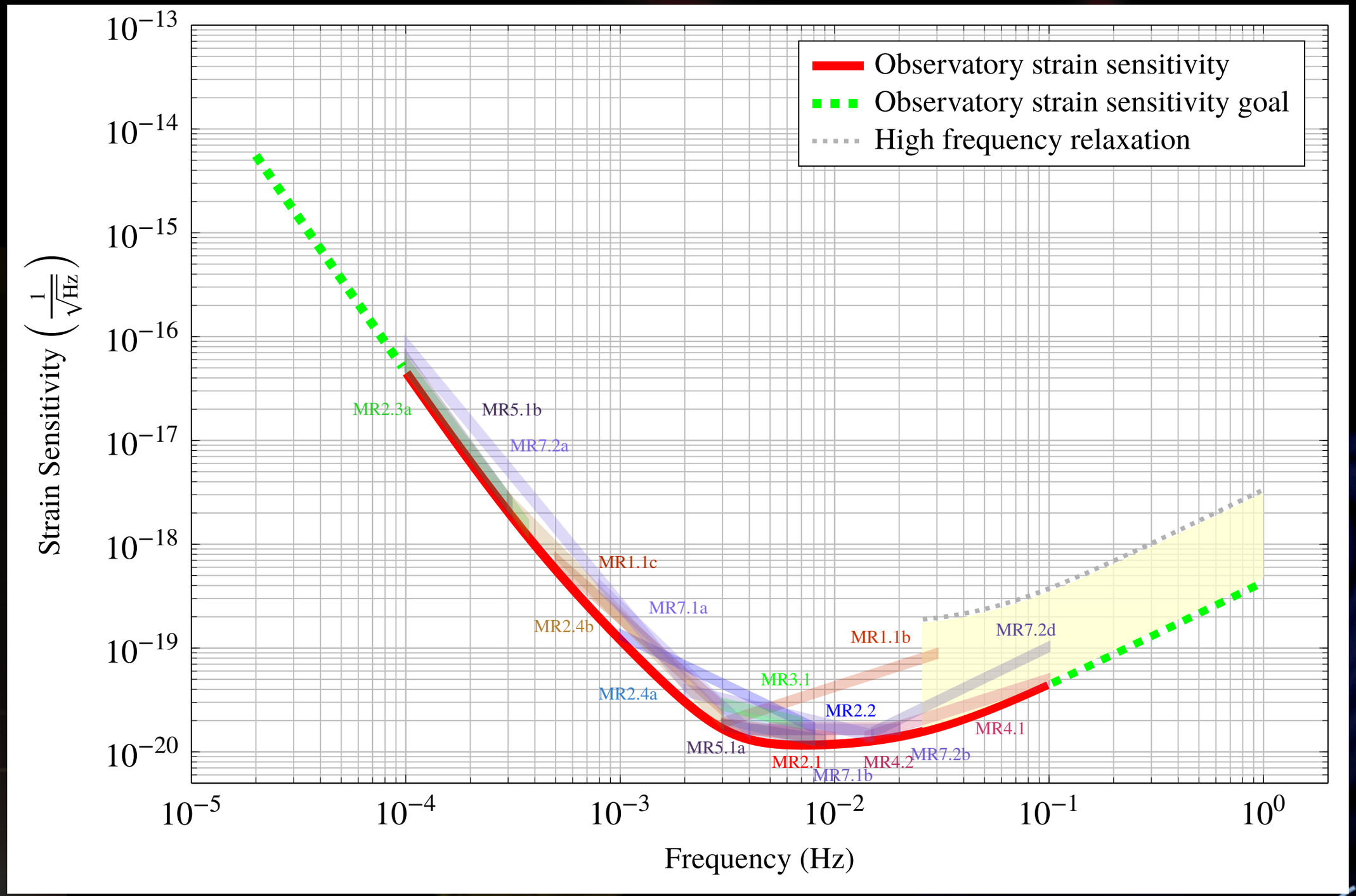


Science Objectives

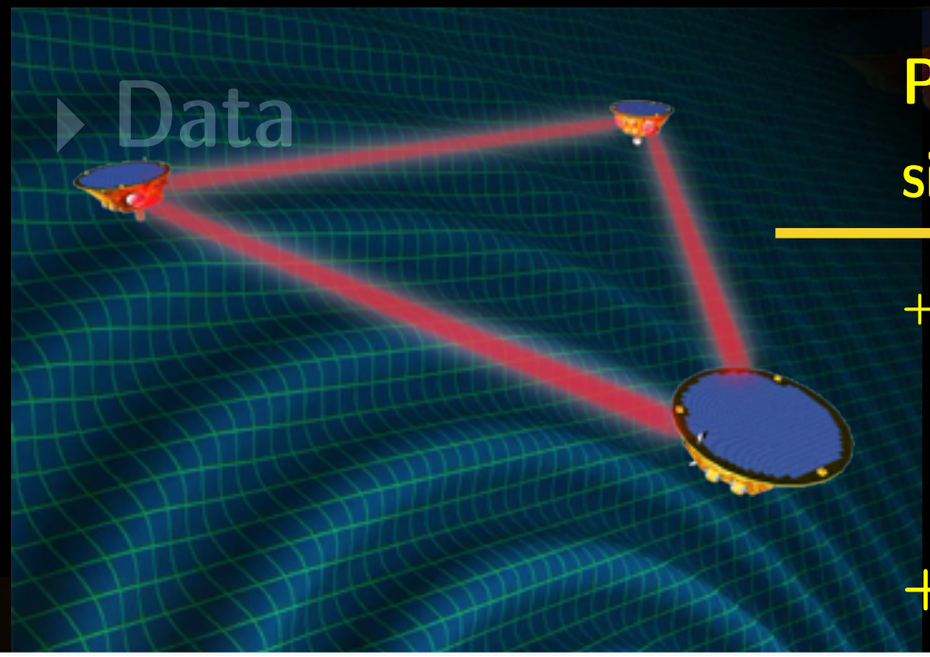
- SO1: Study the formation and evolution of compact binary stars in the Milky Way Galaxy.
- SO2: Trace the origin, growth and merger history of massive black holes across cosmic ages
- SO3: Probe the dynamics of dense nuclear clusters using EMRIs
- SO4: Understand the astrophysics of stellar origin black holes
- SO5: Explore the fundamental nature of gravity and black holes
- SO6: Probe the rate of expansion of the Universe
- SO7: Understand stochastic GW backgrounds and their implications for the early Universe andTeV-scale particle physics
- SO8: Search for GW bursts and unforeseen sources

Sensitivity

- Science Requirement Document from ESA Science Study Team



LISA data



Phasemeters (carrier, sidebands, distance)

+ Gravitational Reference Sensor
+ Auxiliary channels

Corrections, calibrations

Resynchronisation (clocks)

Time-Delay Interferometry
laser noise reduction

TDI data : 2 uncorrelated channels

GW data analysis

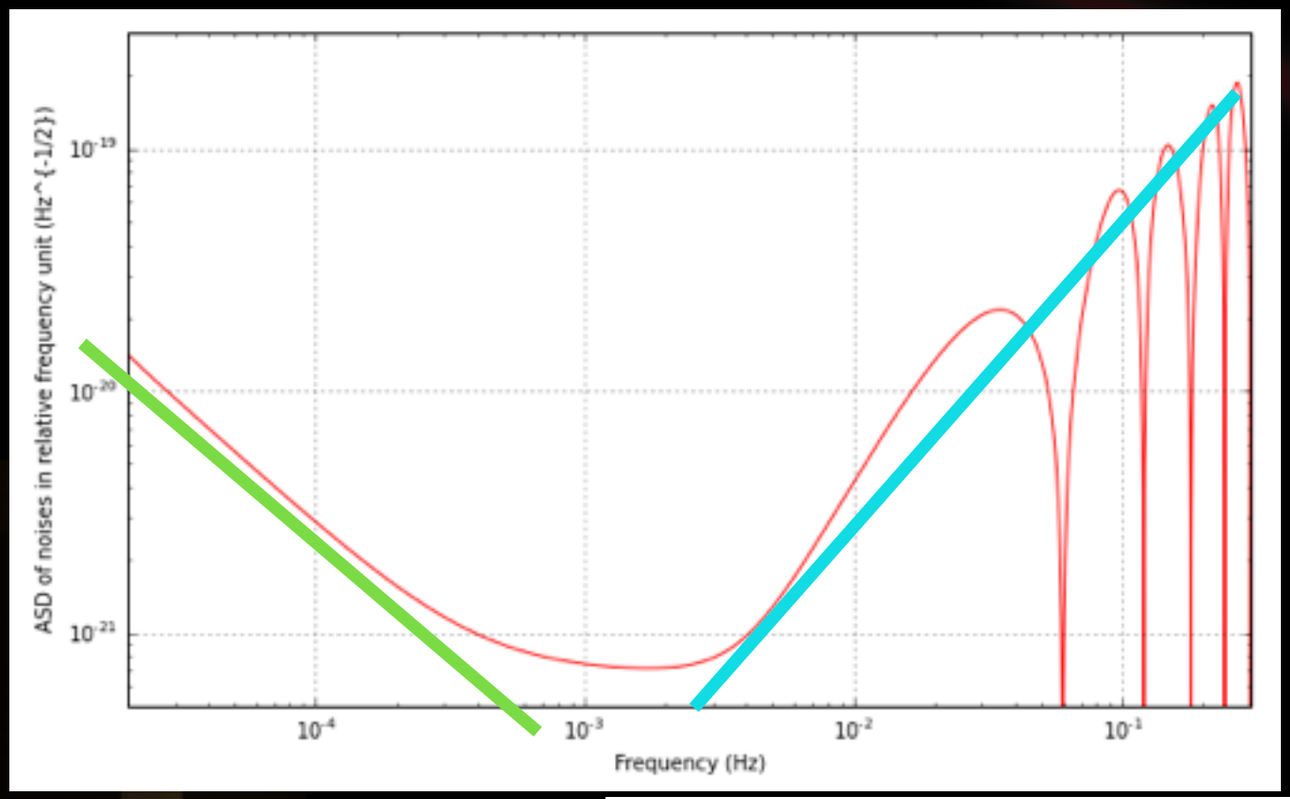
Catalog of GW sources
with extracted waveforms

GW sources

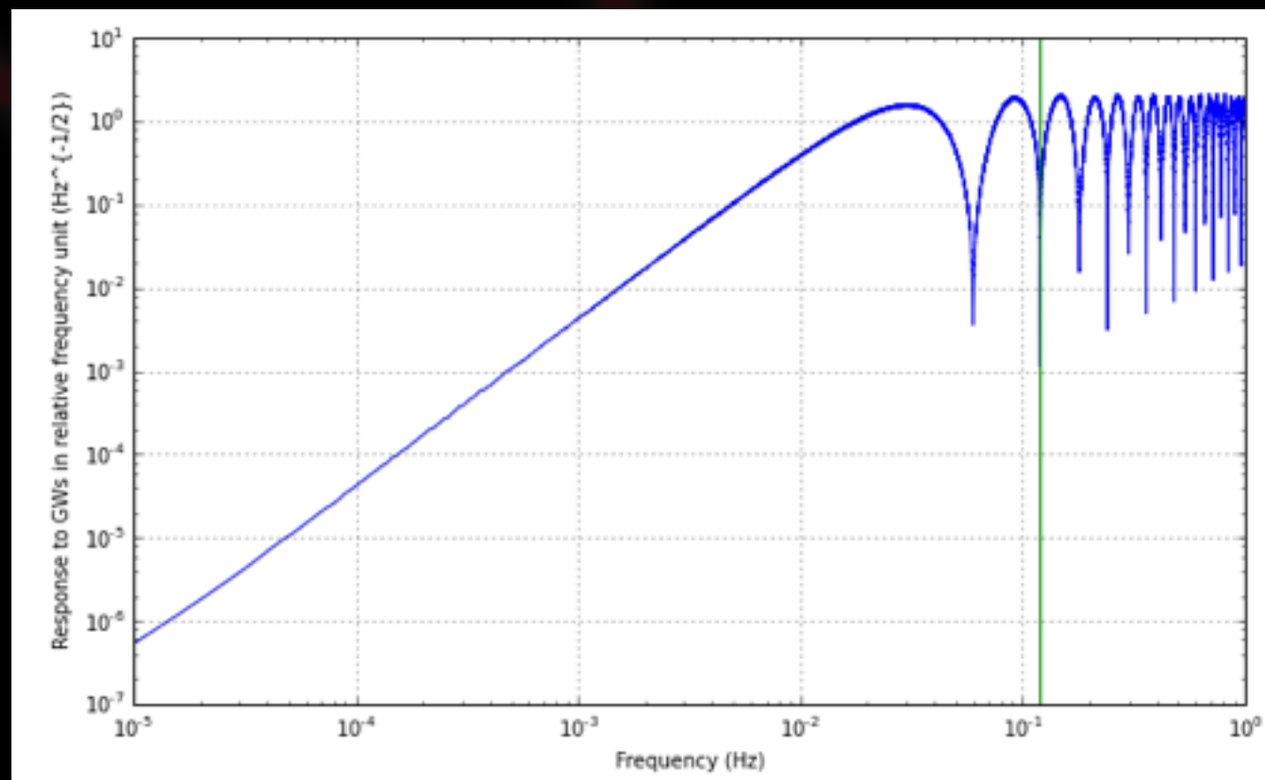
- 10-100/yr SMBHBs
- 10-1000/yr EMRIs
- 60 millions Galactic binaries
- Large number of Black Hole binaries
- Cosmological backgrounds
- Unknown sources

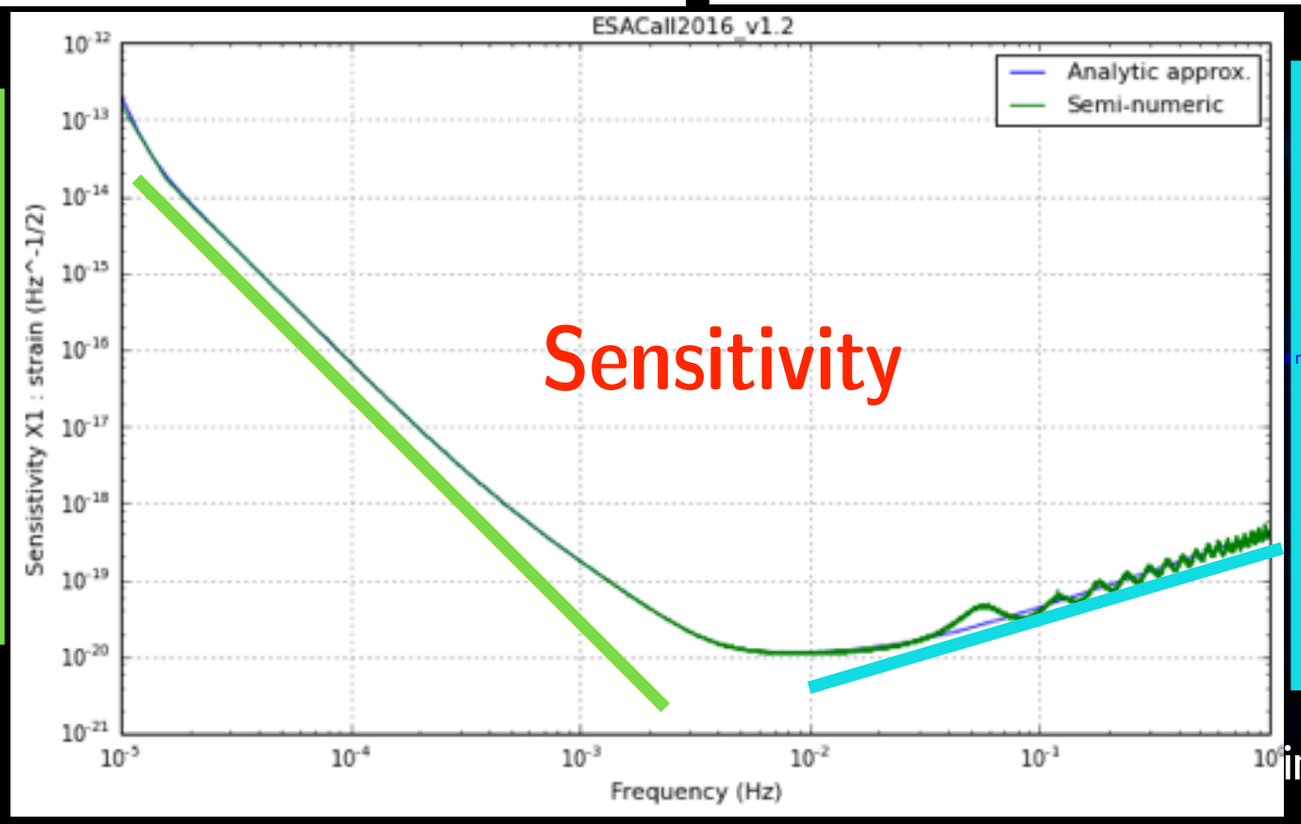
Sensitivity

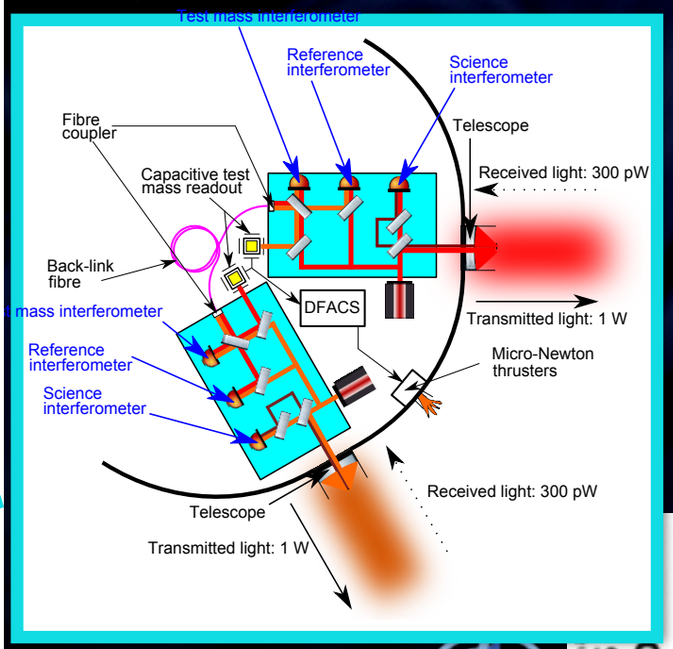
Noises



Response of the detector to GWs







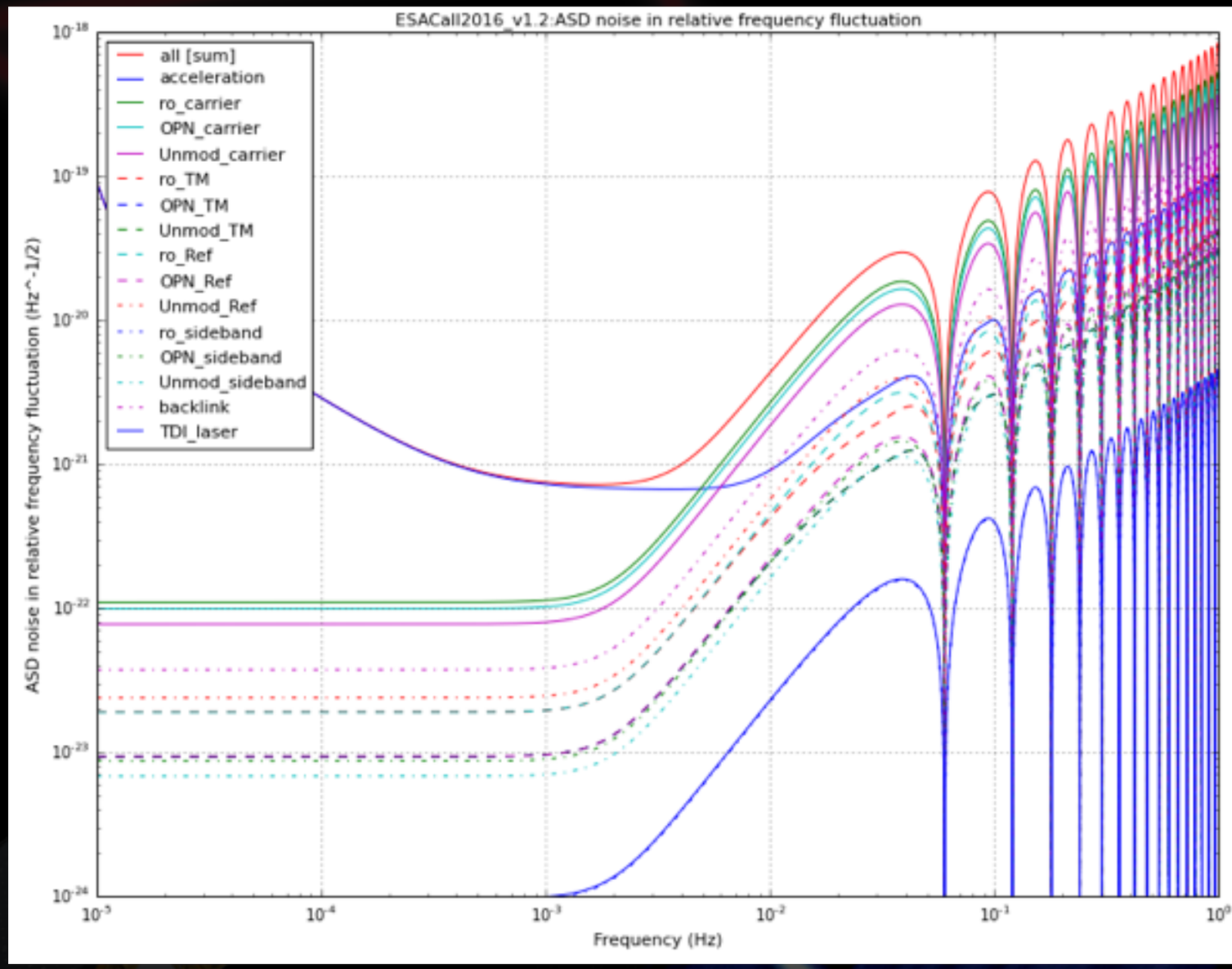
in 2018

LISA concept

- 3 arms, 2.5 km
- Launch Ariane 6.4
- Propulsion:
  - micro-prop: cold gaz
  - prop. module
- Frequency band:

$$\begin{aligned} 100\,\mu\text{Hz} \le f \le 0.1\,\text{Hz} \quad &\text{req.} \\ 20\,\mu\text{Hz} \le f \le 1\,\text{Hz} \quad &\text{goal} \end{aligned}$$

- Noise budget:
  - Acceleration => LISAPathfinder
  - Interferometric Measurement System

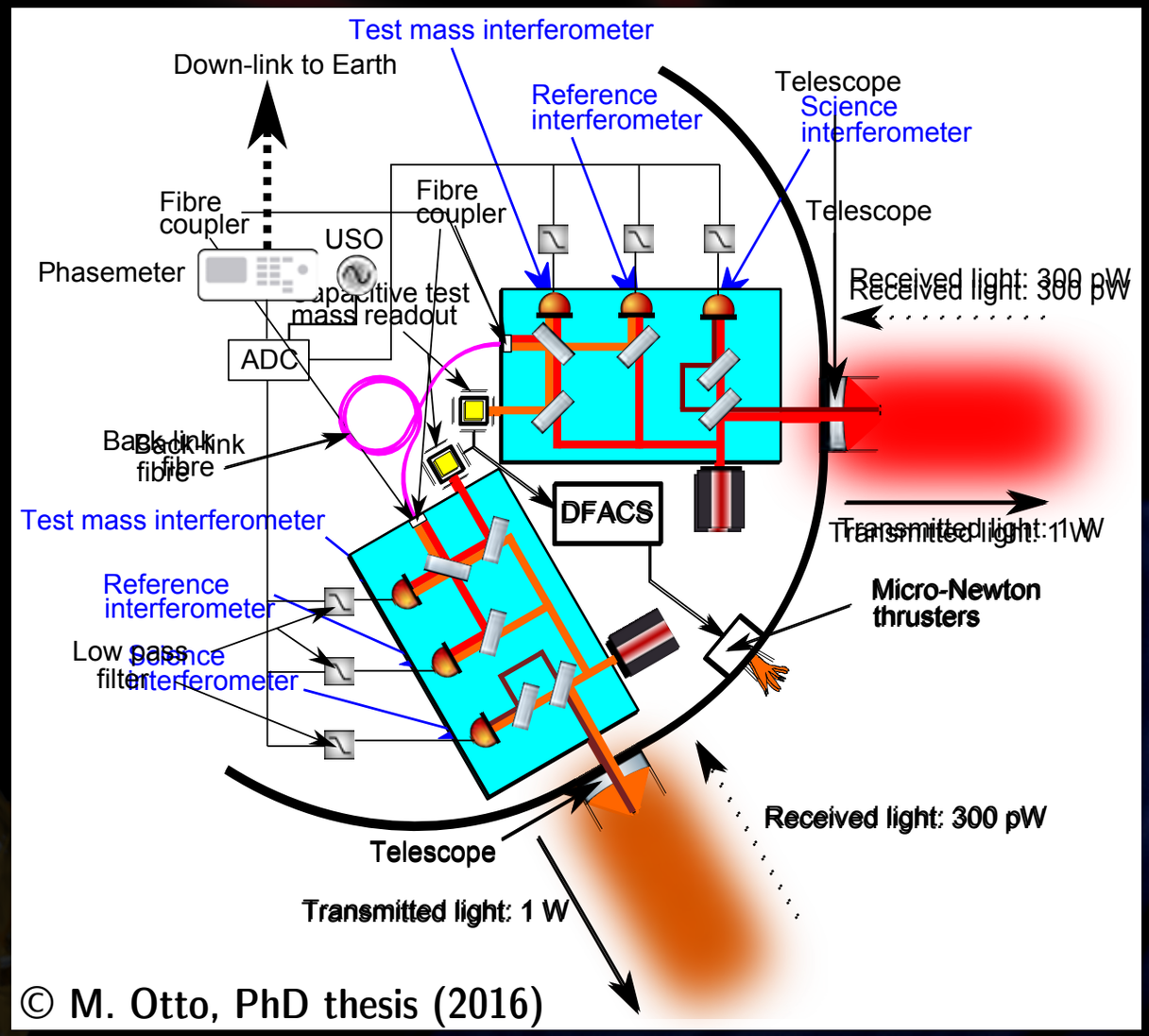


$$S_a^{1/2} \le 3\cdot 10^{-15}\frac{\text{m s}^{-2}}{\sqrt{\text{Hz}}}\cdot\sqrt{1+\left(\frac{0.4\,\text{mHz}}{f}\right)^2}\cdot\sqrt{1+\left(\frac{f}{8\,\text{mHz}}\right)^4}$$

$$S_{\text{IFO}}^{1/2} \le 15\cdot 10^{-12}\frac{\text{m}}{\sqrt{\text{Hz}}}\cdot\sqrt{1+\left(\frac{2\,\text{mHz}}{f}\right)^4}$$

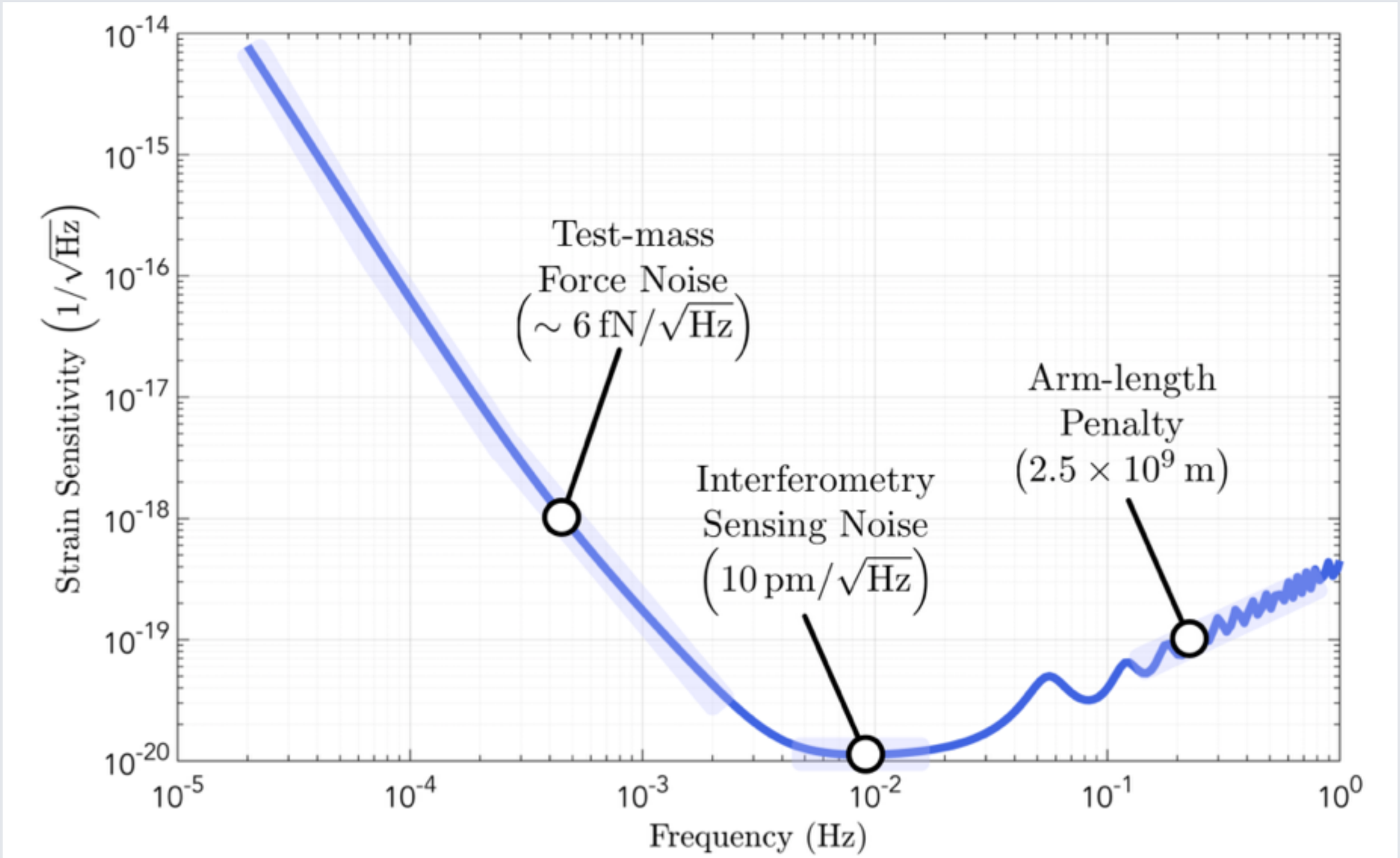
LISA

- Exchange of laser beam to form several interferometers
- Phasemeter measurements on each of the 6 Optical Benches:
  - Distant OB vs local OB
  - Test-mass vs OB
  - Reference using adjacent OB
  - Transmission using sidebands
  - Distance between spacecrafts
- Noises sources:
  - Laser noise : 10^{-13} (vs 10^{-21})
  - Clock noise (3 clocks)
  - Acceleration noise (see LPF)
  - Read-out noises
  - Optical path noises



© M. Otto, PhD thesis (2016)

Lisa Sensitivity

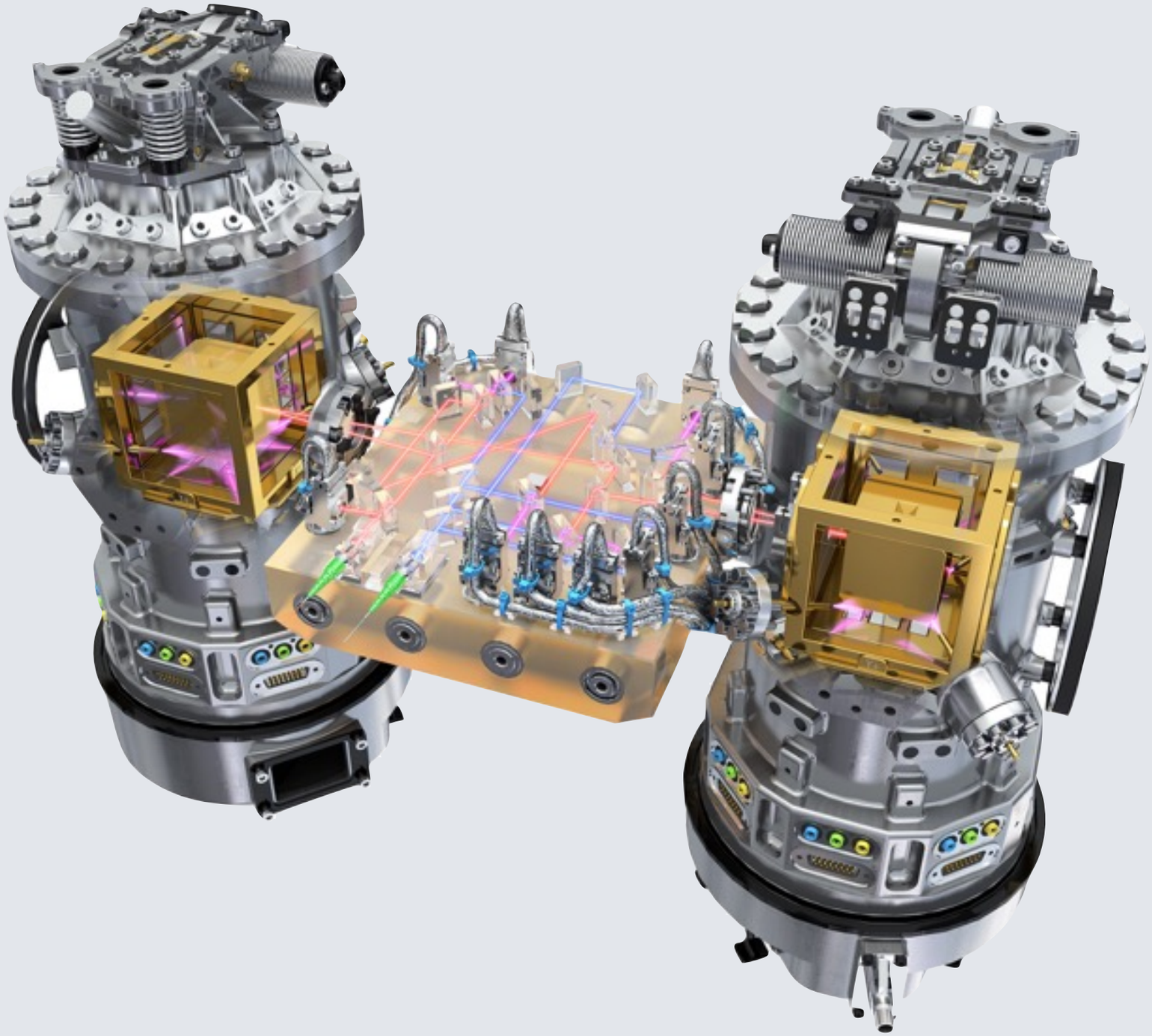


LPF : stabilité masse d’épreuve

- Masses Tests = miroirs
- Or/platine 2kg - 4cm
- 2 masses par Satellite

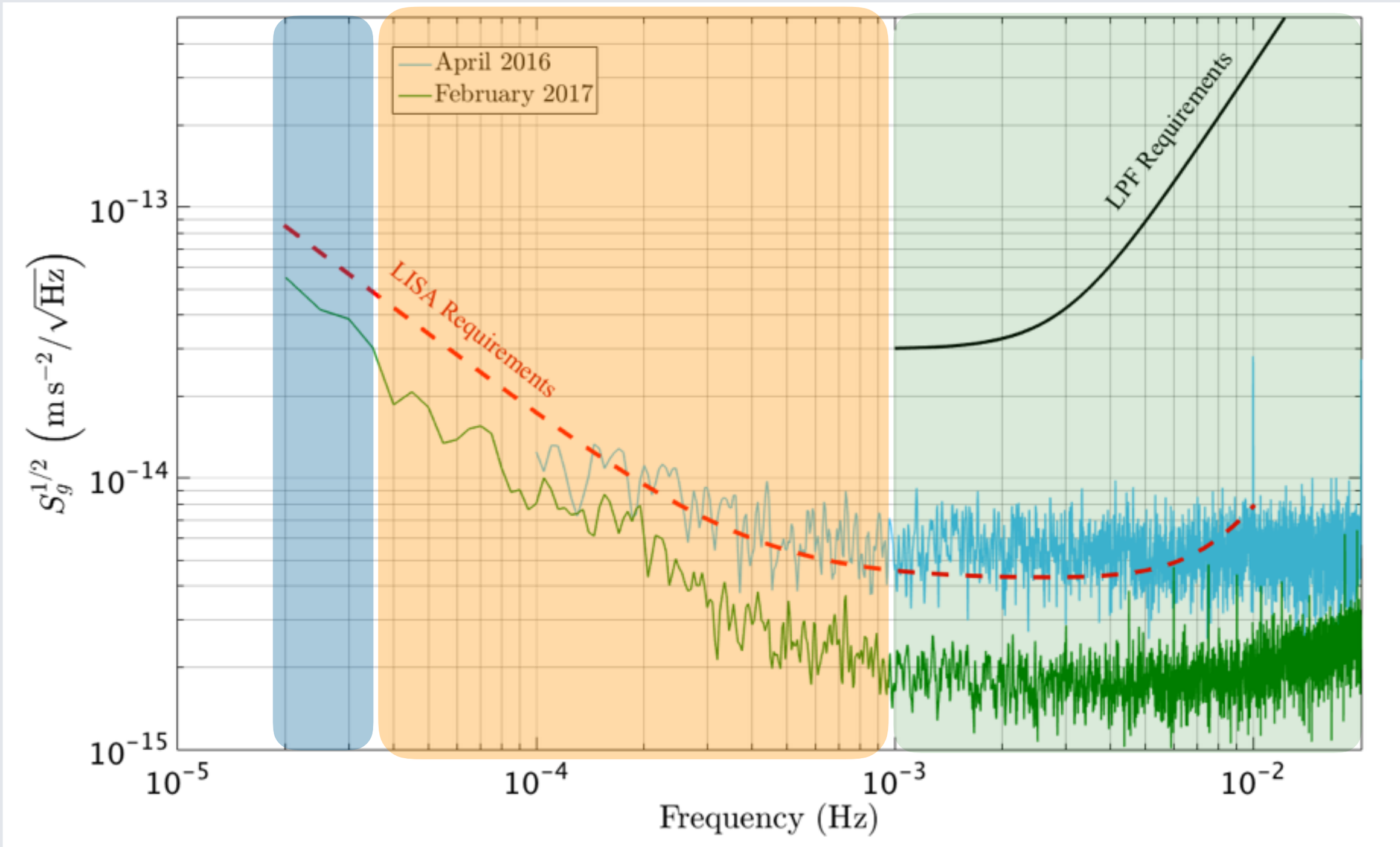
- **Jusqu’à quel niveau peut on isoler la masse des perturbations externes autres que gravitationnelles ?**
  - Vent solaire, micro-météorite
- **Impact de l’environnement de mesure sur la masse.**
  - Effet thermique, vide, pression de radiation, gravité locale etc…
- **Peut on mesurer des déplacements de l’ordre du pm ?**
  - Interférométrie hétérodyne dans l’espace.

LPF - Laboratoire dans l'espace



Résultats

Thermal noise **Actuation Noise + excess noise** **Brownian**



Quelques chiffres

- Amélioration du vide 10µPa->1µPa

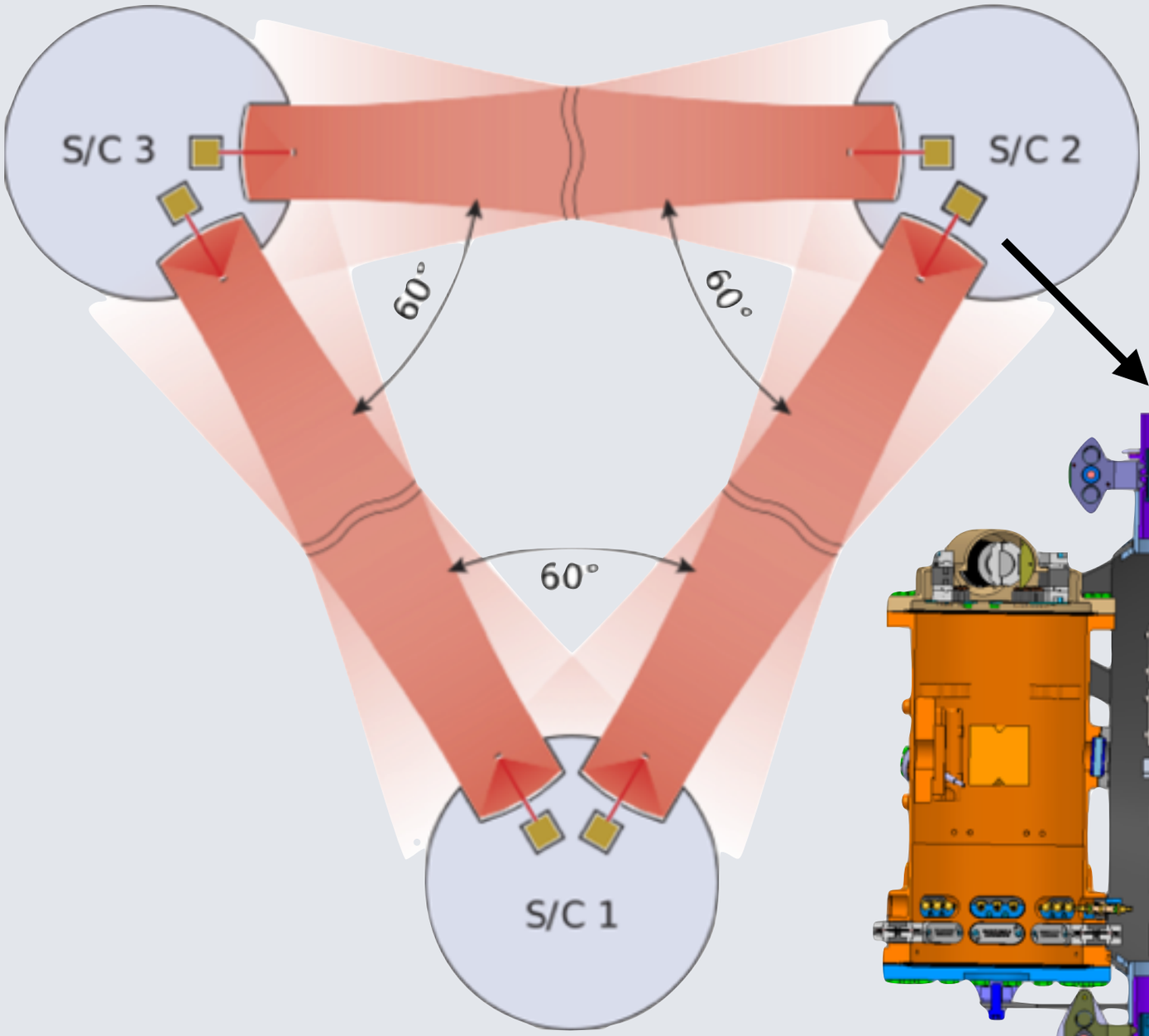
  Venting

  Température 22°C à 11°c
- Stabilité en température : 50uK/sqrt(Hz)
- Bruit Interférometrique : 35 fm/sqrt(Hz)
- Soustraction de glitches 5/semaines => 6.5 jours à 18 jours
- Equilibrage gravitationnel : ajout de masse de compensation (1.8kg)

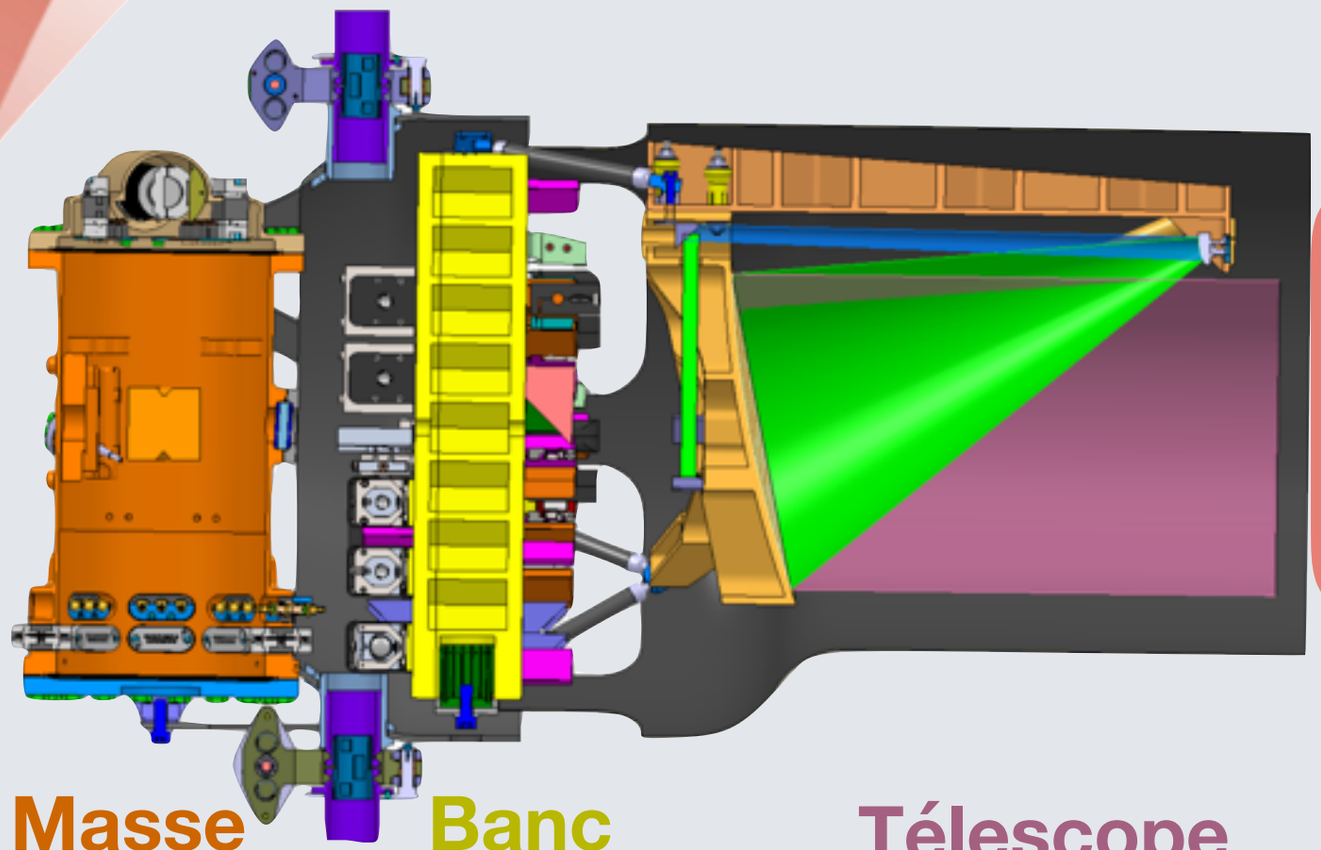
  Design = 650 pm s^-2

  Mesure = 25 pm s^-2

Mesure : interférométrie

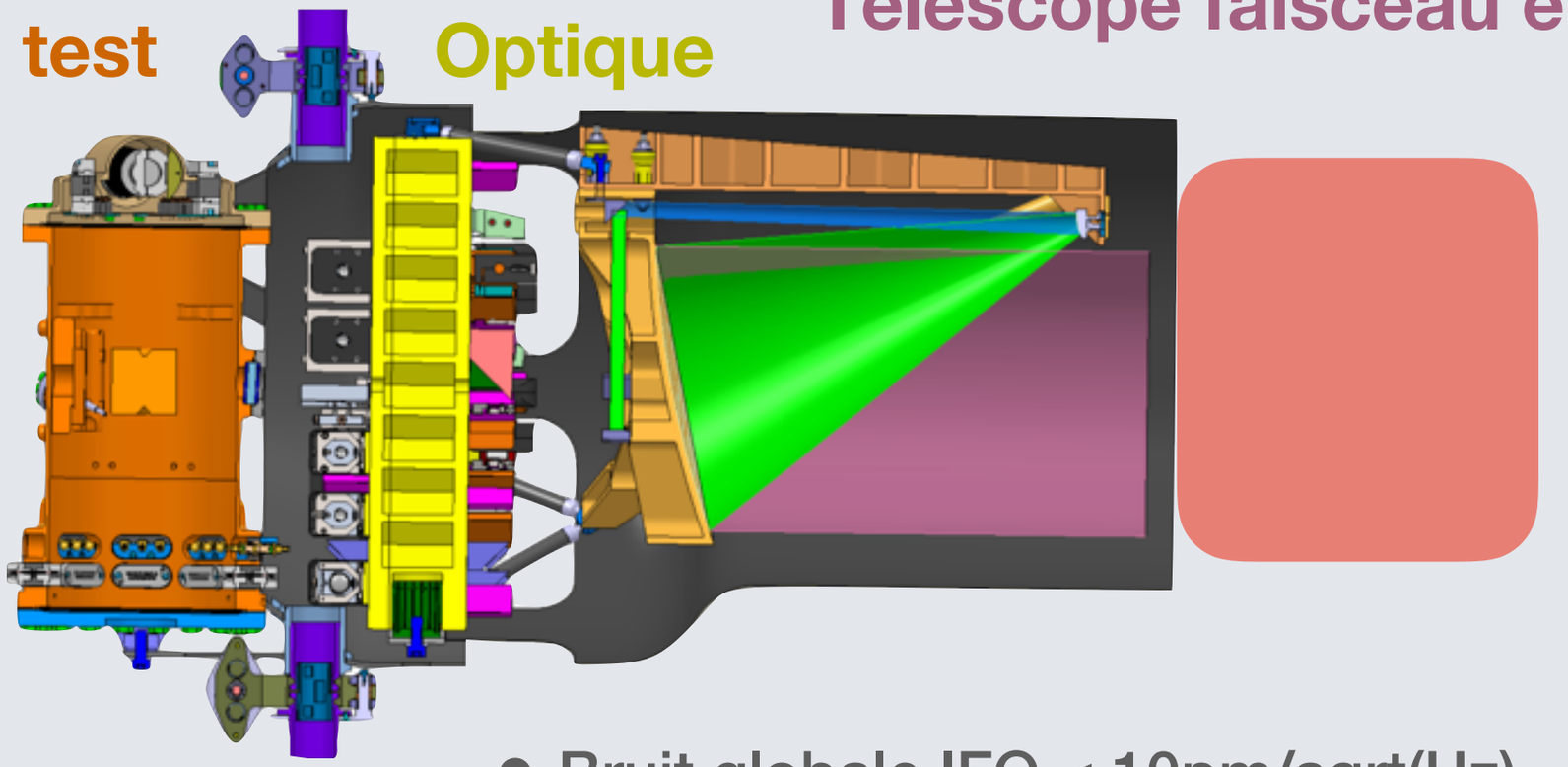


- Laser 2W - 2.5 Millions km
- Beatnote au MHz
- 3 IFO’s pour un lien test mass/ test mass



Masse test **Banc Optique** **Télescope**

Mesure : interférométrie



- Bruit globale IFO < 10pm/sqrt(Hz)
- Couplage rotation bruit sur l'axe sensible :

  Wave front error : λ/30

  Alignements mécanique : 20µm - 100µrad
- Lumière parasite faisceau émise 2w - 100pW - ?
- Stabilité méca - 10nm/sqrt(Hz) à 1mHz - 10 nrad/sqrt(Hz)
- Stabilité température - 10µK/sqrt(Hz) @ 2mHz

LISA technology requirements

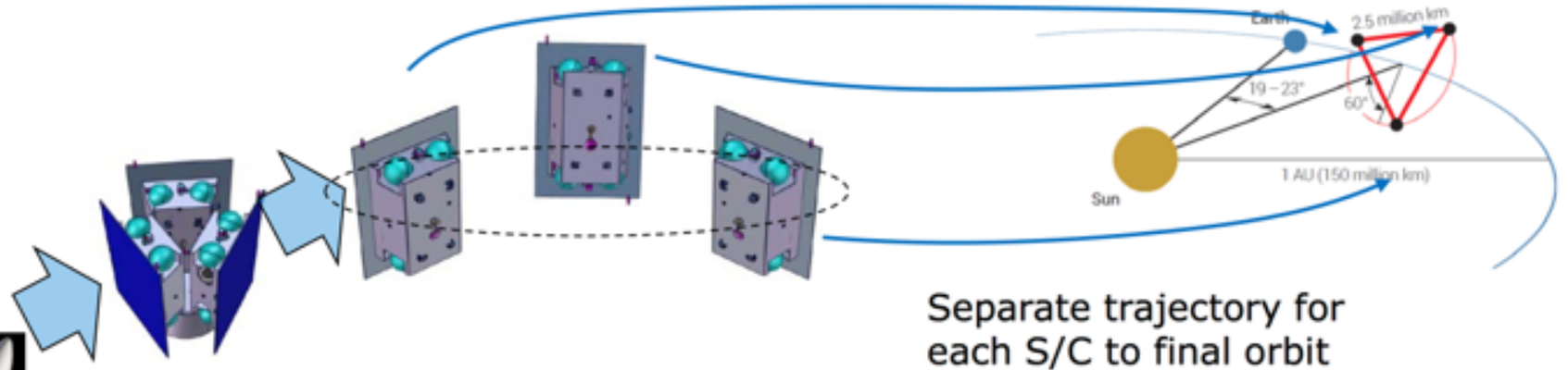
- Free flying test mass subject to very low parasitic forces:
  - ✓ Drag free control of spacecraft (non-contacting spacecraft)
  - ✓ Low noise microthruster to implement drag-free
  - ✓ Large gaps, heavy masses with caging mechanism
  - ✓ High stability electrical actuation on cross degrees of freedom
  - ✓ Non contacting discharging of test-masses
  - ✓ High thermo-mechanical stability of S/C
  - ✓ Gravitational field cancellation

Validated with LISAPathfinder

- Precision interferometric, local ranging of test-mass and spacecraft:
  - ✓ pm resolution ranging, sub-mrad alignments
  - ✓ High stability monolithic optical assemblies
- Precision million km spacecraft to spacecraft precision ranging:
  - ➡ High stability telescopes
  - ➡ High accuracy phase-meter and frequency distribution
  - ➡ High accuracy frequency stabilization (incl. TDI)

Ground-based demonstrators

ESA Phase 0 mission

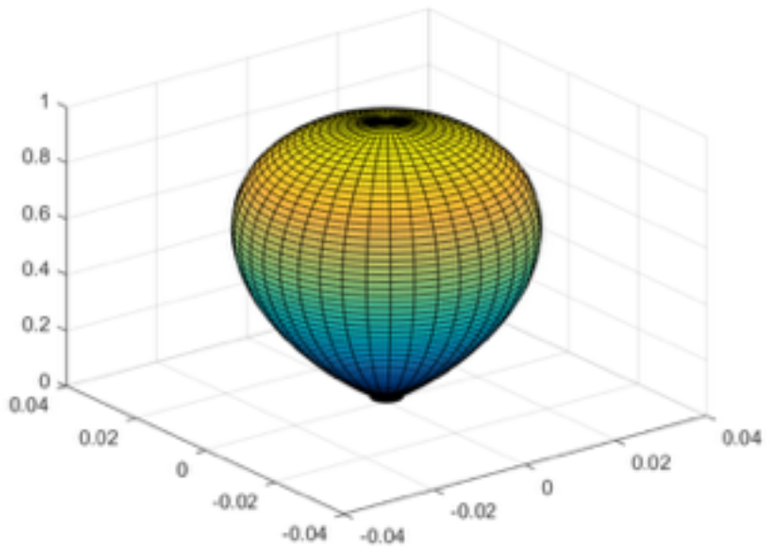


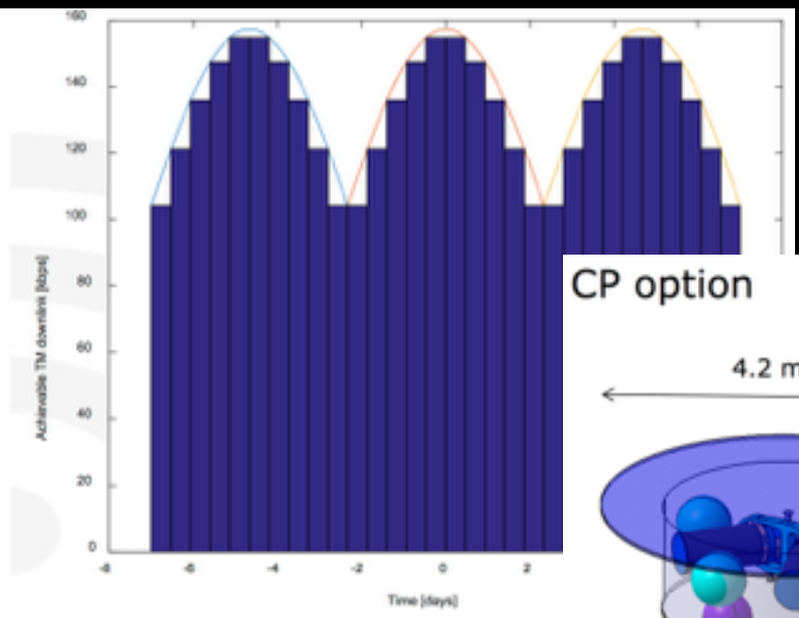
Separate trajectory for each S/C to final orbit

Separation of the stack right after launch

Launch in stacked configuration
Direct injection into escape trajectory

	CP	EP	EP+
Chemical Propulsion	314.8	190.2	4.4
Electric Propulsion	0.0	80.7	170.6
Propulsion dry	**315**	**271**	**175**
Cprop mass	1115	0	0
Eprop mass	0	148	117
Microprop mass	200	240	20
Total	**3244**	**1881**	**1522**



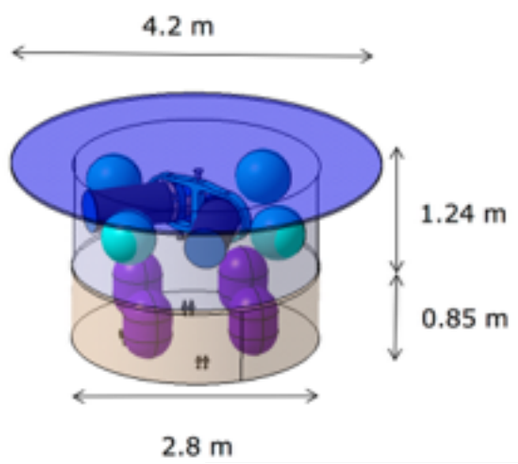


Dish
Average rate: 132.7 kbps
Max rate: 154.8 kbps
Min rate: 104.2 kbps
Margin: 4.1 dB (>3 dB)

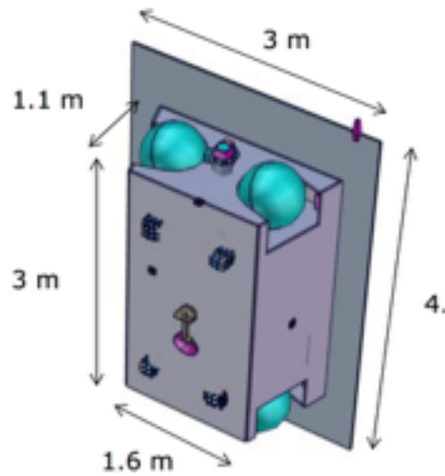
MGA (CP option)
Max rate: 13 kbps
Margin: 4.0 dB (>3 dB)

LGA
Max rate: 52 bps
Margin: 3.1 dB

CP option



EP and EP+ option



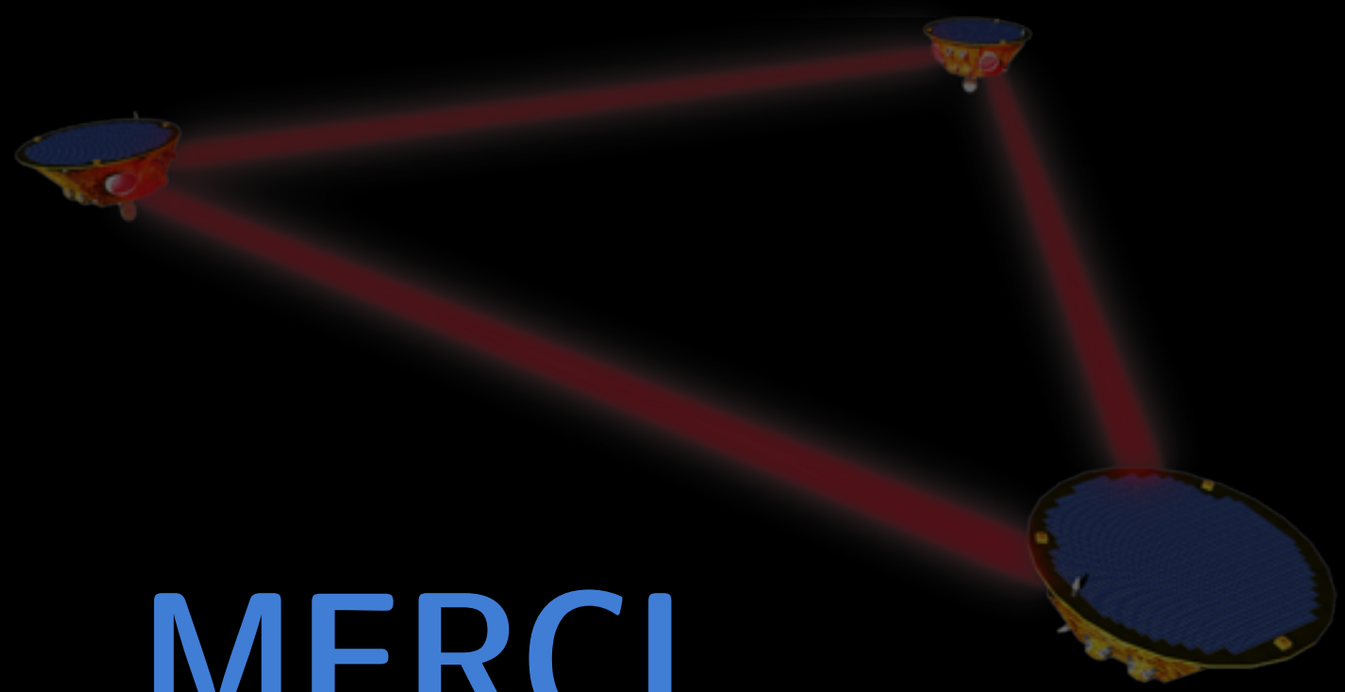
LISA timeline

- 25/10/2016 : Call for mission
- 13/01/2017 : Submission of «LISA proposal» (LISA consortium)
- 8/3/2017 : Phase 0 mission (CDF 8/3/17 → 5/5/17)
- 20/06/2017 : LISA mission approved by SPC
- 06/2017 : Phase 0 payload (CDF June → November 2017)
- 2018→2020 : Competitive phase A: 2 companies compete
- 2020→2022 : B1: start industrial implementation
- 2022-2024 : mission adoption
- During about 8.5 years : construction
- 2030-2034 : launch Ariane 6.4
- 1.5 years for transfert
- 4 years of nominal mission

GW observations !

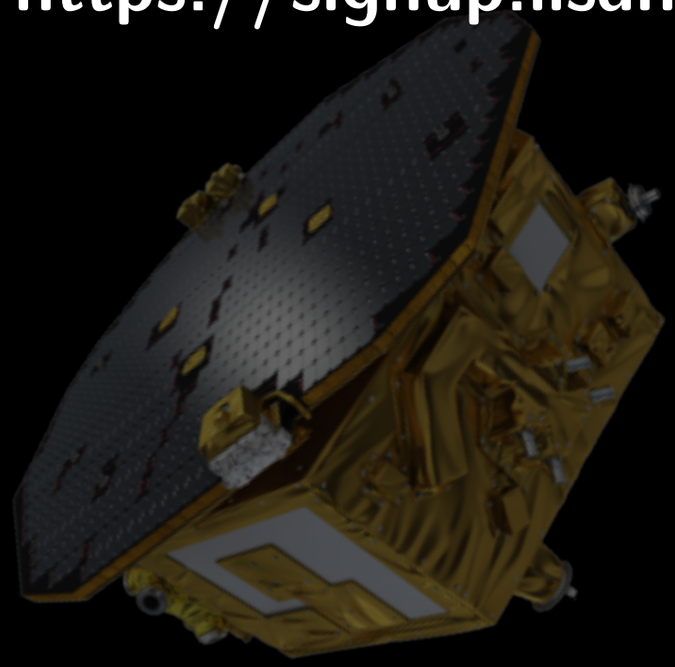
Summary

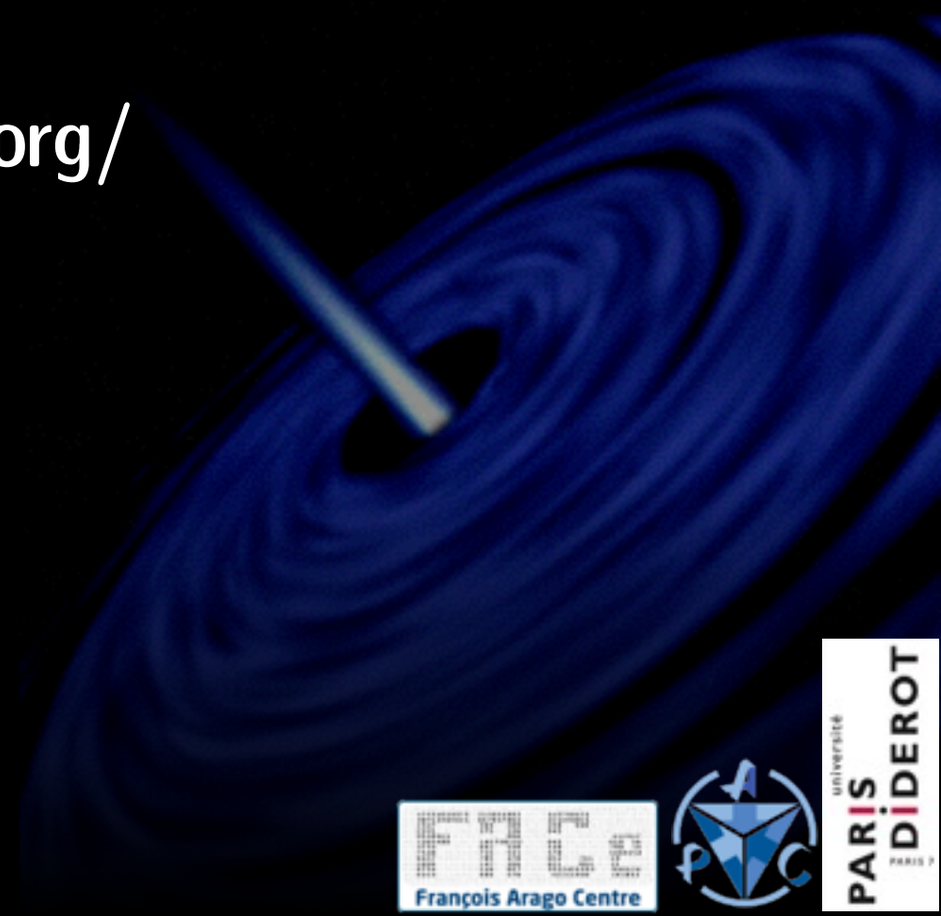
- LISA will observe GWs between 10^{-5} and 1 Hz:
  - Large number of sources: compact objects binaries with large range of masses, stochastic backgrounds, ...
  - Huge scientific potential: physics, astrophysics, cosmology, ...
- LISAPathfinder: success
  - Performances $>$ 7 times better than the requirements
- LISAPathfinder + detections of Ground-based observatories
  $\Rightarrow$ Green light for LISA: large extension of the new window opened with LIGO/Virgo
  $\Rightarrow$ speed-up of the ESA planning:
  - Already done: call for mission, selection, phase 0
  - Now in phase A



MERCI

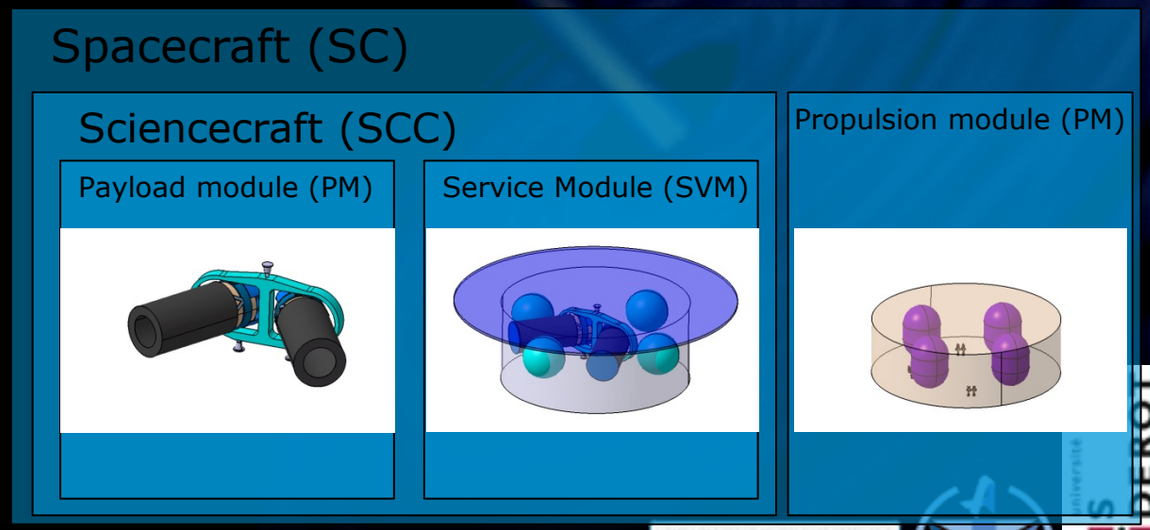
https://signup.lisamission.org/





ESA Phase 0 mission

- 13 Concurrent Design Facility from March to May 2017
- Conducted by ESA with few members of the consortium
- Drivers: thermal stability/range, mechanical stability, mass, power, data rate, volume, integration, ...
- Several studied options:
  - Propulsion: chemical (CP) / electrical (EP & EP+)
  - Micro-propulsion: cold-gas (CP & EP)/ electrical (EP+)
  - Communication,
  - Shape,
  - Launch strategies, orbits,
  - ...



LISA

- Spacecraft (SC) should only be sensible to gravity:
  - the spacecraft protects test-masses (TMs) from external forces and always adjusts itself on it using micro-thrusters
  - Readout:
    - interferometric (sensitive axis)
    - capacitive sensing