LISAPathfinder

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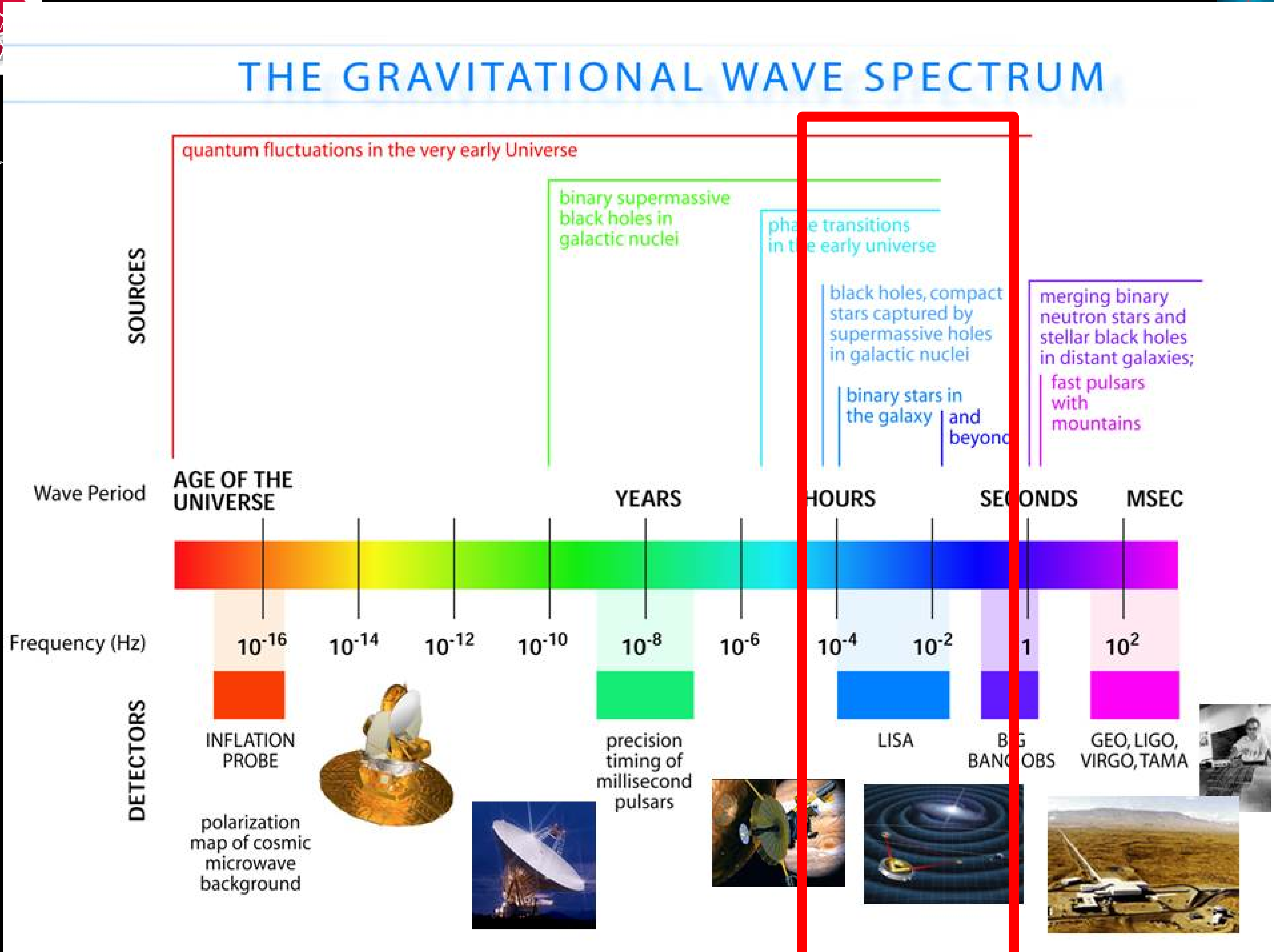
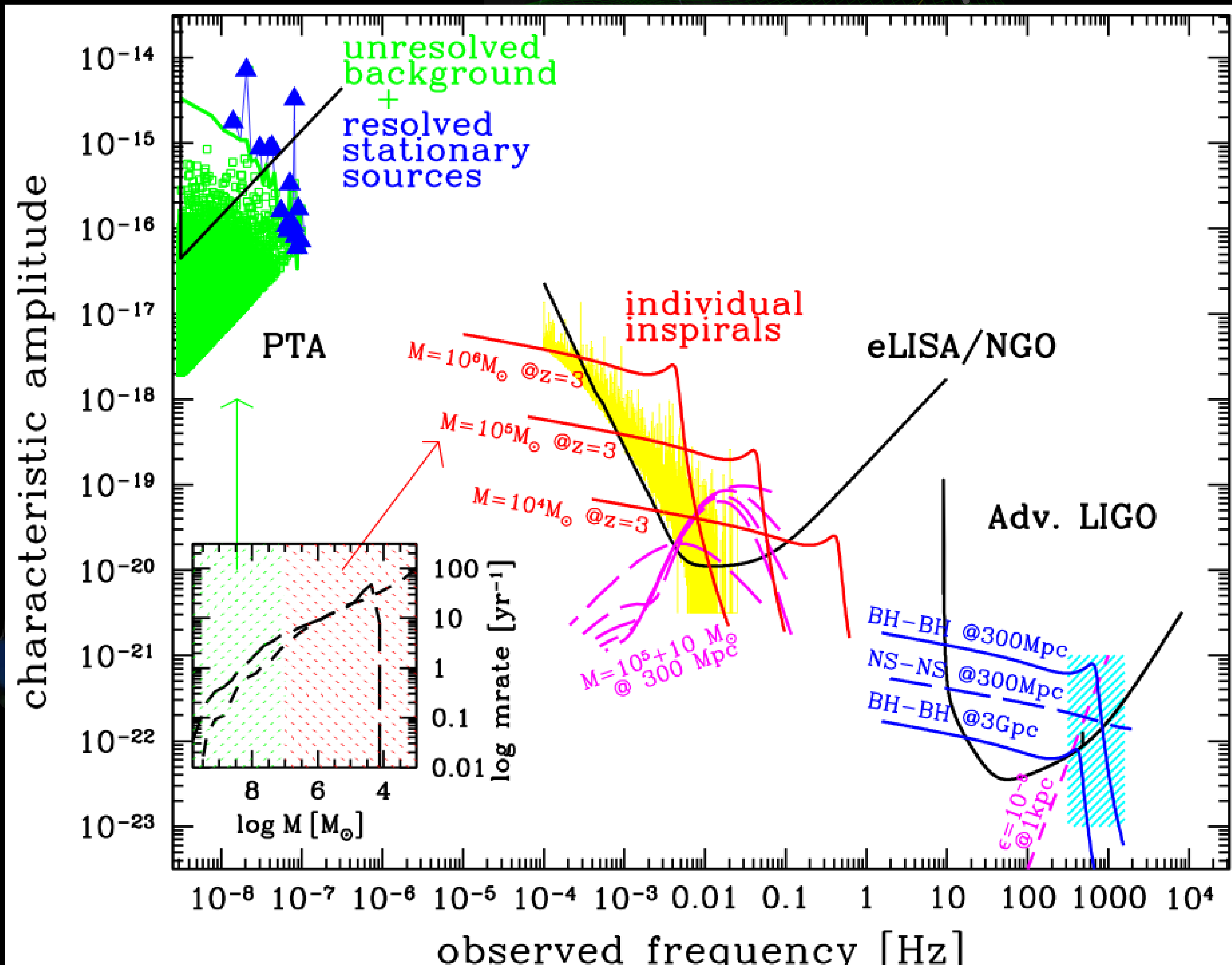
on behalf of the APC team (Eric Plagnol, Henri Inchauspe, Joseph Martino, Pierre Prat & Hubert Halloin)

Journée Gphys

IAP – 6th july 2015


THE GRAVITATIONAL WAVE SPECTRUM
SOURCES
quantum fluctuations in the very early Universe
binary supermassive black holes in galactic nuclei
pha e transitions in t e early universe
black holes, compact stars captured by supermassive holes in galactic nuclei
binary stars in the galaxy
and beyon
merging binary neutron stars and stellar black holes in distant galaxies;
fast pulsars with mountains
Wave Period
AGE OF THE UNIVERSE
YEARS
HOURS
SE ONDS
MSEC
Frequency (Hz)
10-16
10-14
10-12
10-10
10-8
10-6
10-4
10-2
1
102
DETECTORS
INFLATION PROBE
polarization map of cosmic microwave background
precision timing of millisecond pulsars
LISA
B G BAN OBS
GEO, LIGO, VIRGO, TAMA

Gravitational waves

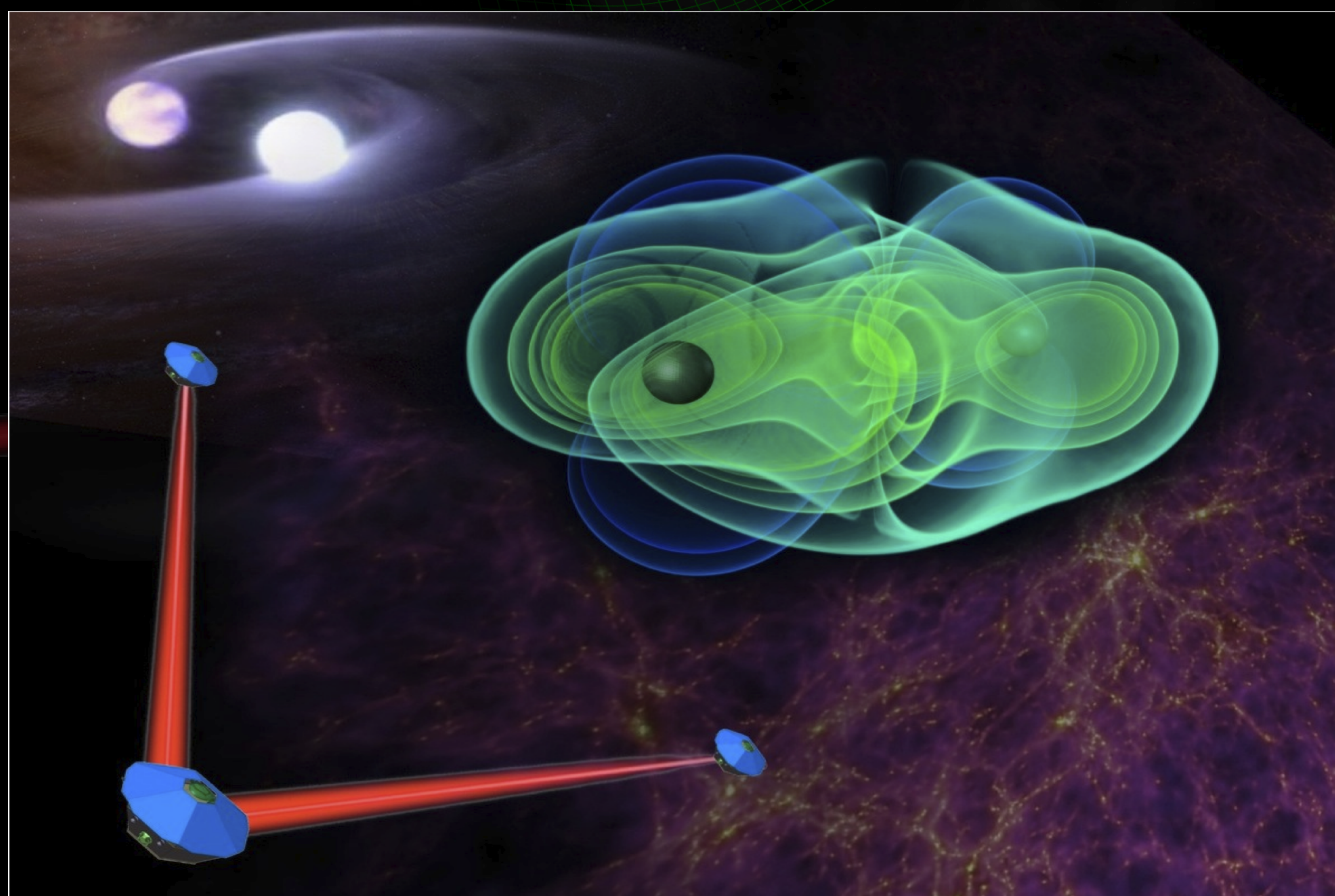


Sesana astro-ph.CO 1304.0767 (2013)

eLISA: space based GW observatory

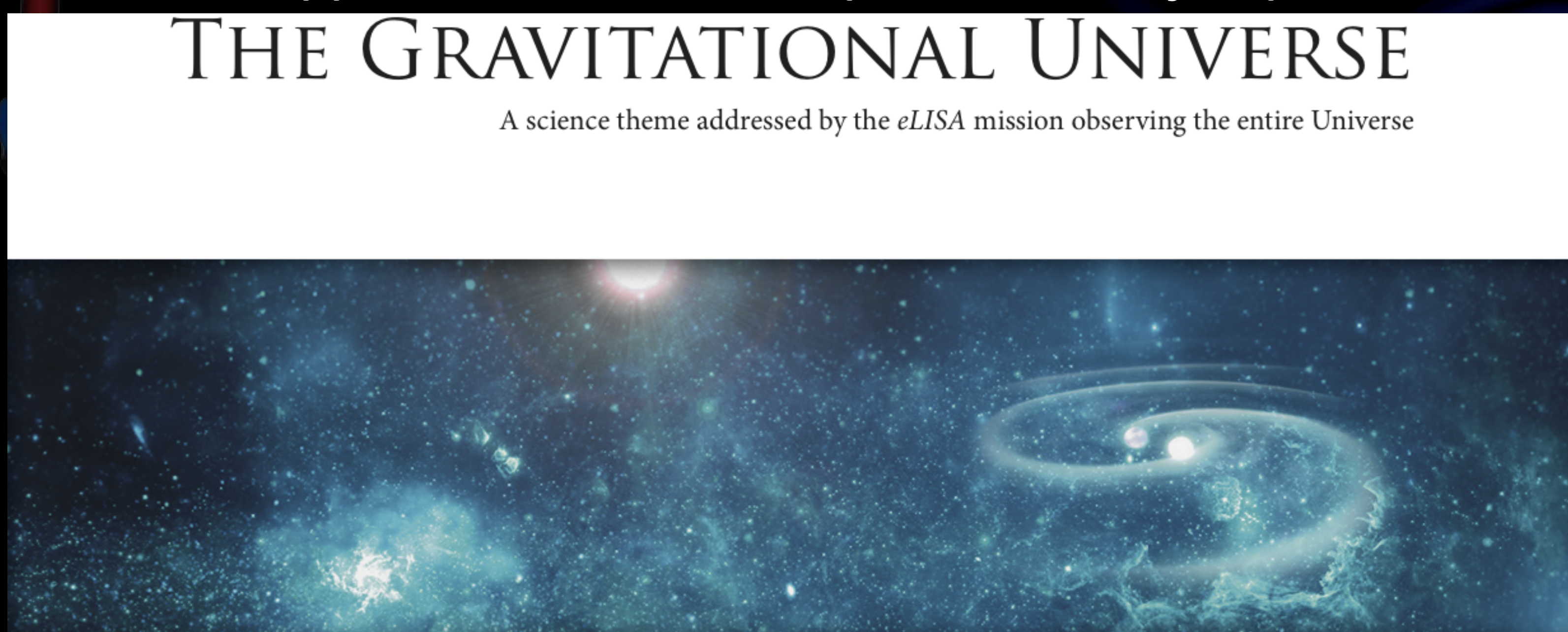
- A large number of sources expected in the frequnecy range 0.01 mHz to 1 Hz : we need armlength larger than Earth, no seismic noise … ==> Going to space !

==> eLISA : evolved Laser Interferometer Space Antennae



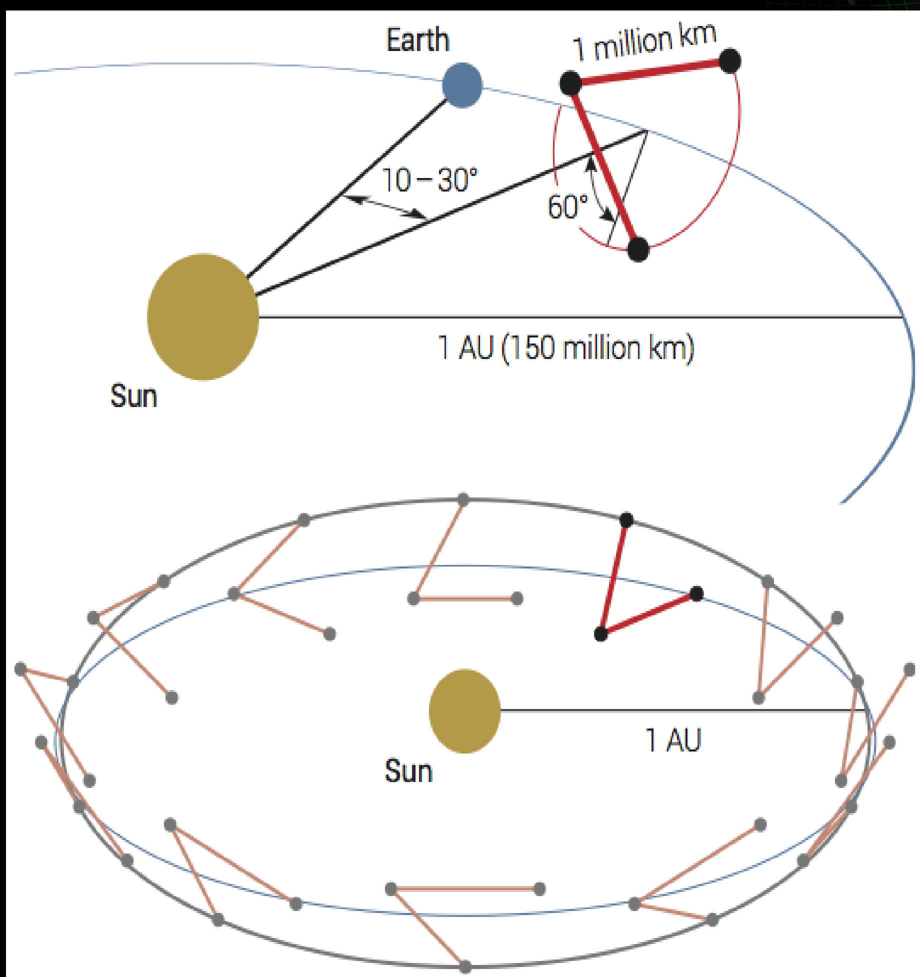
eLISA as ESA L3 mission

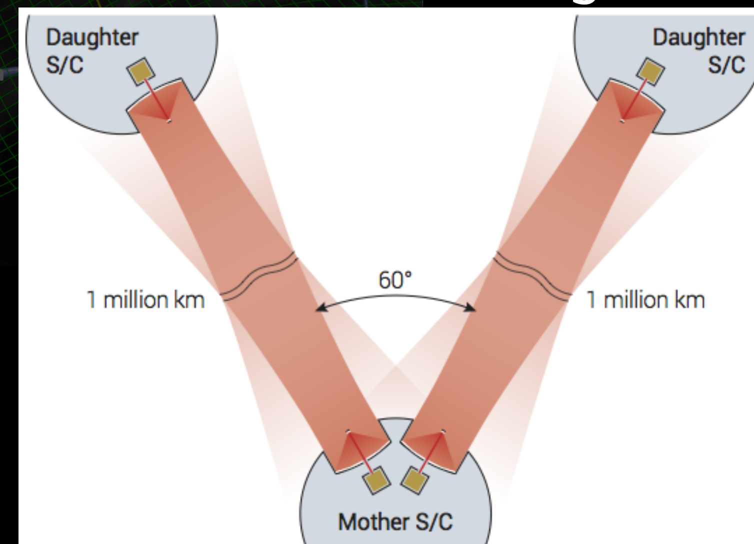
- 2013 : Theme "The Gravitational Universe" selected as ESA large mission L3 for launch in 2034.
- 2015 : LISAPathfinder launch (but how to keep expertise during 20 yrs ?)
- 2018 : L3 mission selection fixing the main instrument design
- ESA creates the GOAT (Gravitational Observatory Advisory Team) :
  - GOAT asks for design, technological and science studies : results have to be completed before 2016
  - ESA will support soon the developments of key aspects.

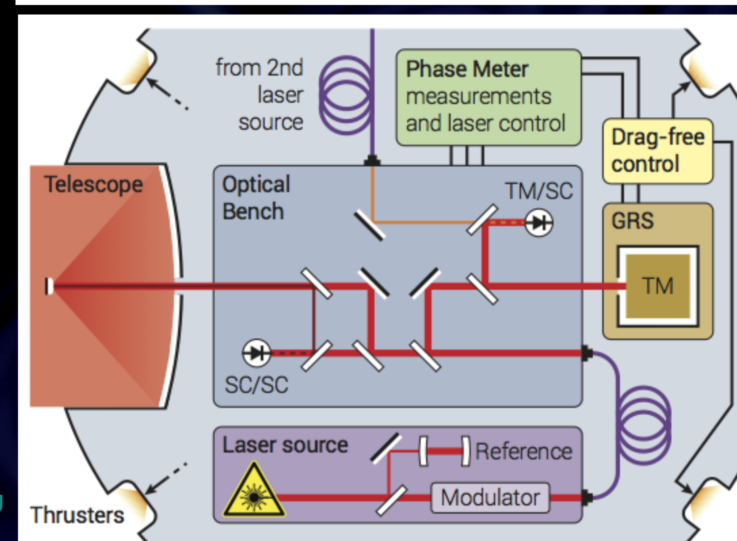


eLISA current concept

- 3 spacecrafts (SC) forming 2 arms of 1 million kilometres,
- SC always adjusts on a free-falling test mass using micro-thruster,
- Exchange of laser for forming an interferometer and measuring GW deformations

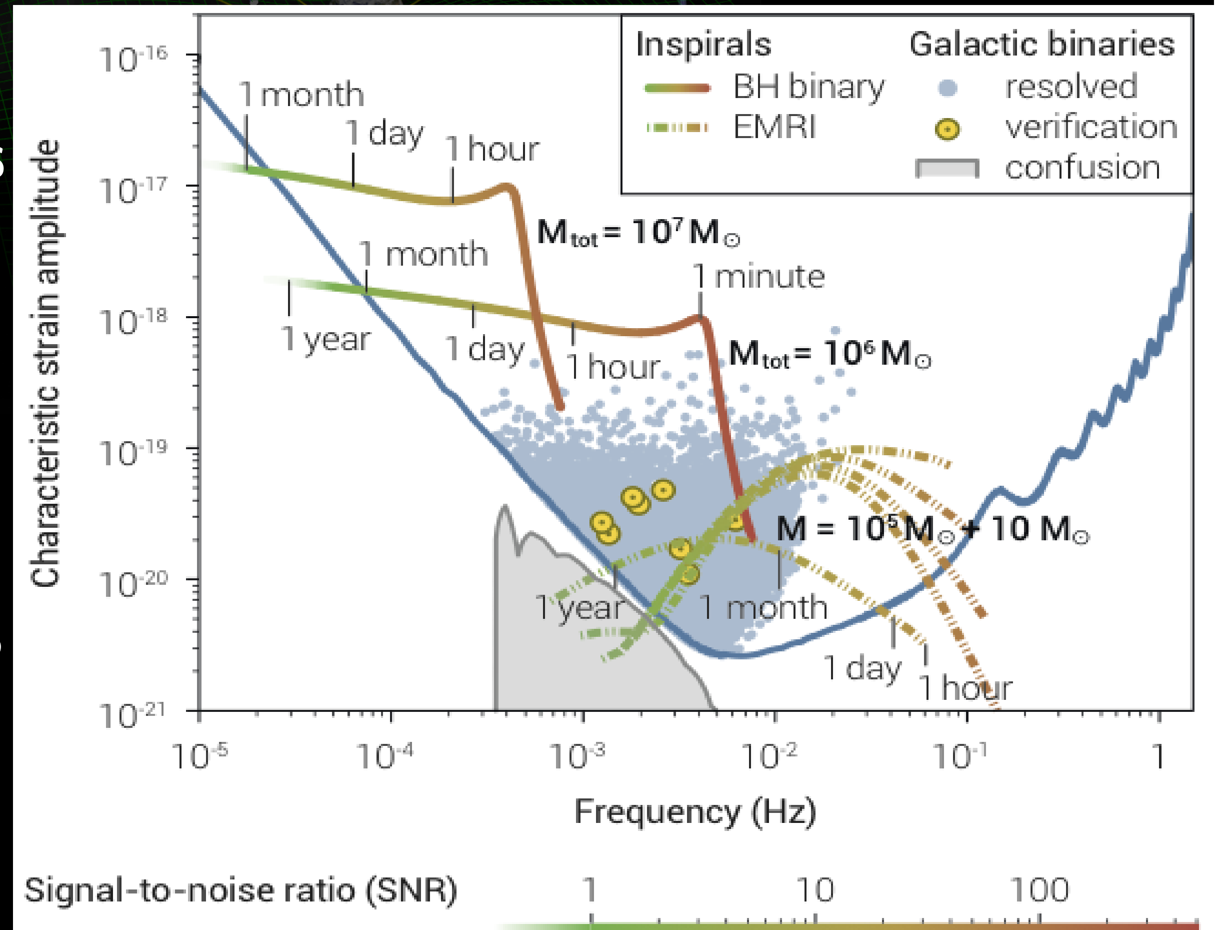






eLISA sources

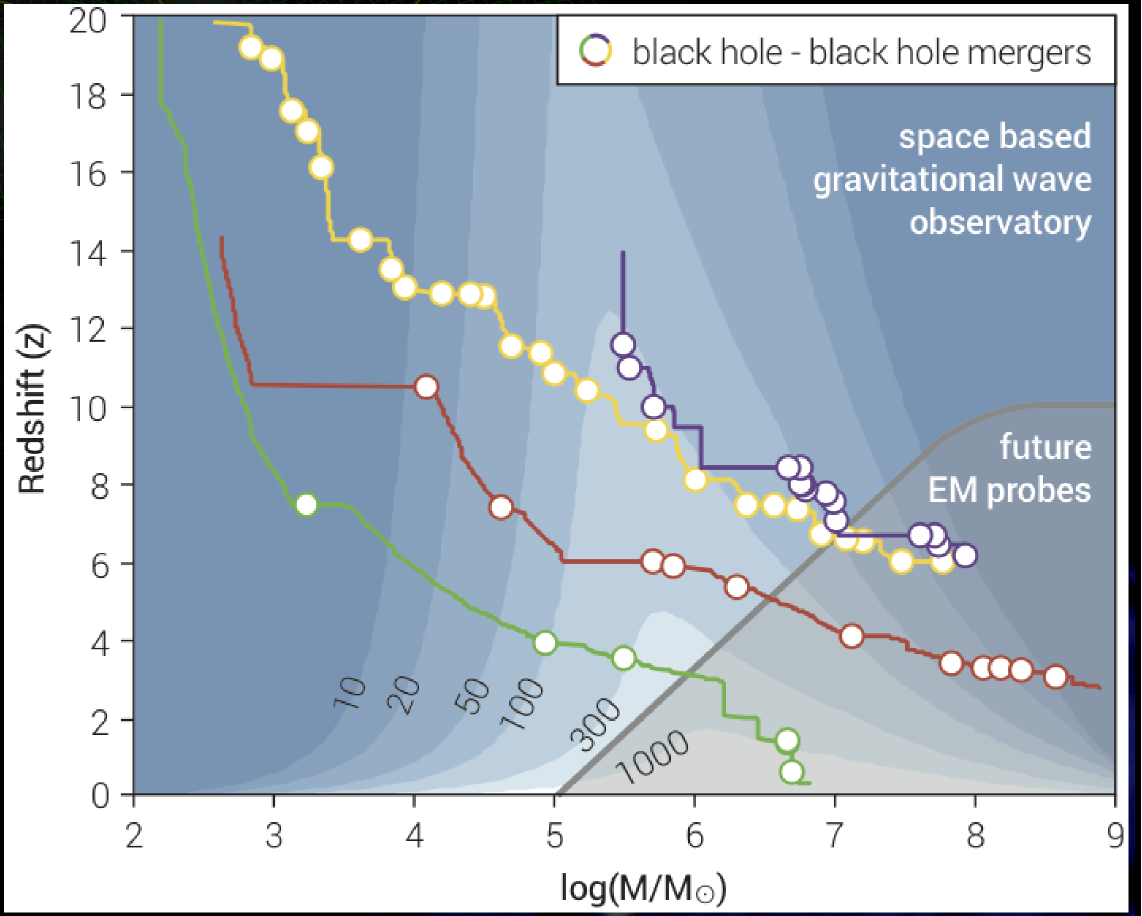
- Galactic binaries : few tens millions in Galaxy and about 3000 resolvable including **verification binaries**, i.e. sources already observed (about ten more are coming with Gaia) → **guaranteed** sources
- Massive Black Hole Binaries
- Extreme Mass Ratio Inspirals
- Bursts : cosmic string cusps, ...
- Cosmological background,
- **All the unknown sources !**



université PARIS DIDEROT PARIS 7

MBH binaries observed by eLISA

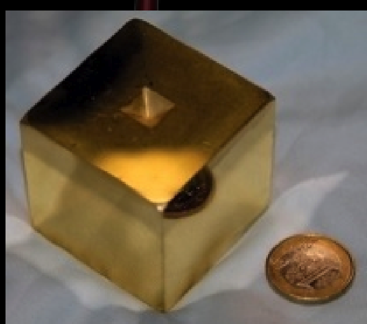
- From study of A. Sesana et al.
- $10^4 < M < 10^7 M_{Sun}$
- Until $z = 10 - 20$ depending on the masse.
- Typically from 10 to 100 events per years depending on the model : light / heavy seed and coherent / chaotic accretion

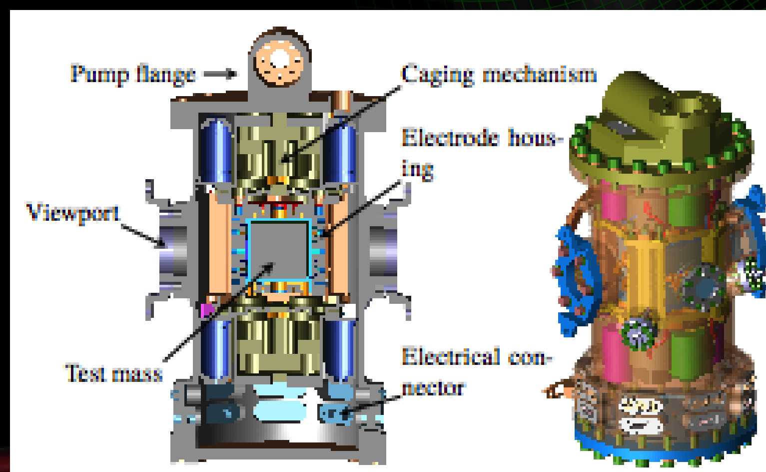


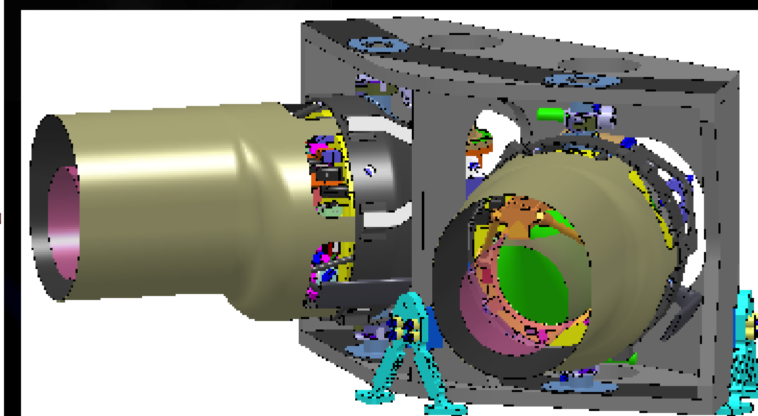
- SNR from 10 to few thousands in the band during days to month
- Observation of inspiral, merger and ringdown

eLISA in next years

- Enlarge scientific community around eLISA: future of GW astronomy,
- Science potential and data analysis has to be studied in details (GOAT),
- Detailed concept has to be defined : preliminary studies based on eLISA/NGO ...
- LISAPathfinder !

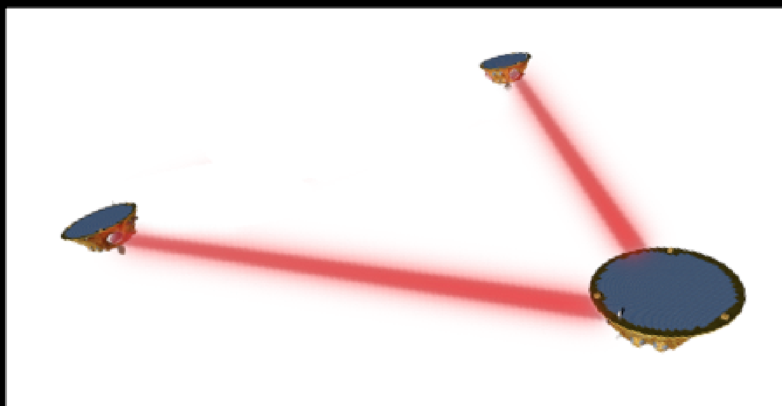






LISAPathfinder

- Technological demonstrator for eLISA

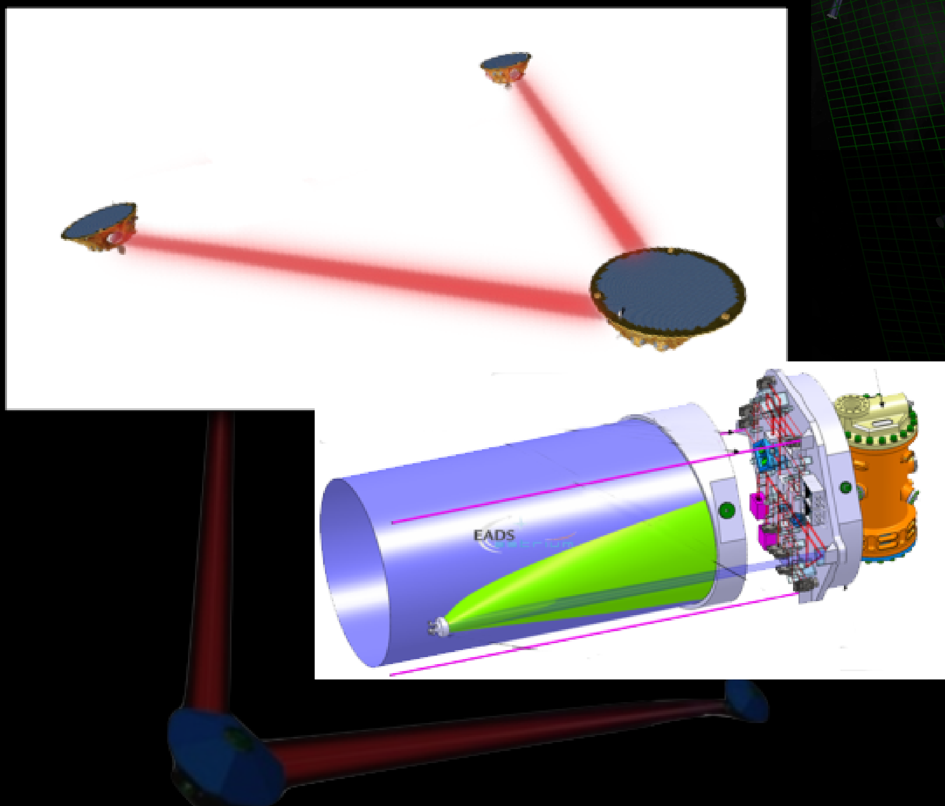


eLISA :
3 spacecrafts separated by one millions of km

The role of each spacecraft is to protect it's fiducial test mass from external forces

LISAPathfinder

- Technological demonstrator for eLISA



eLISA :

- Locally measure distance from Test Mass (TM) to spacecraft using:

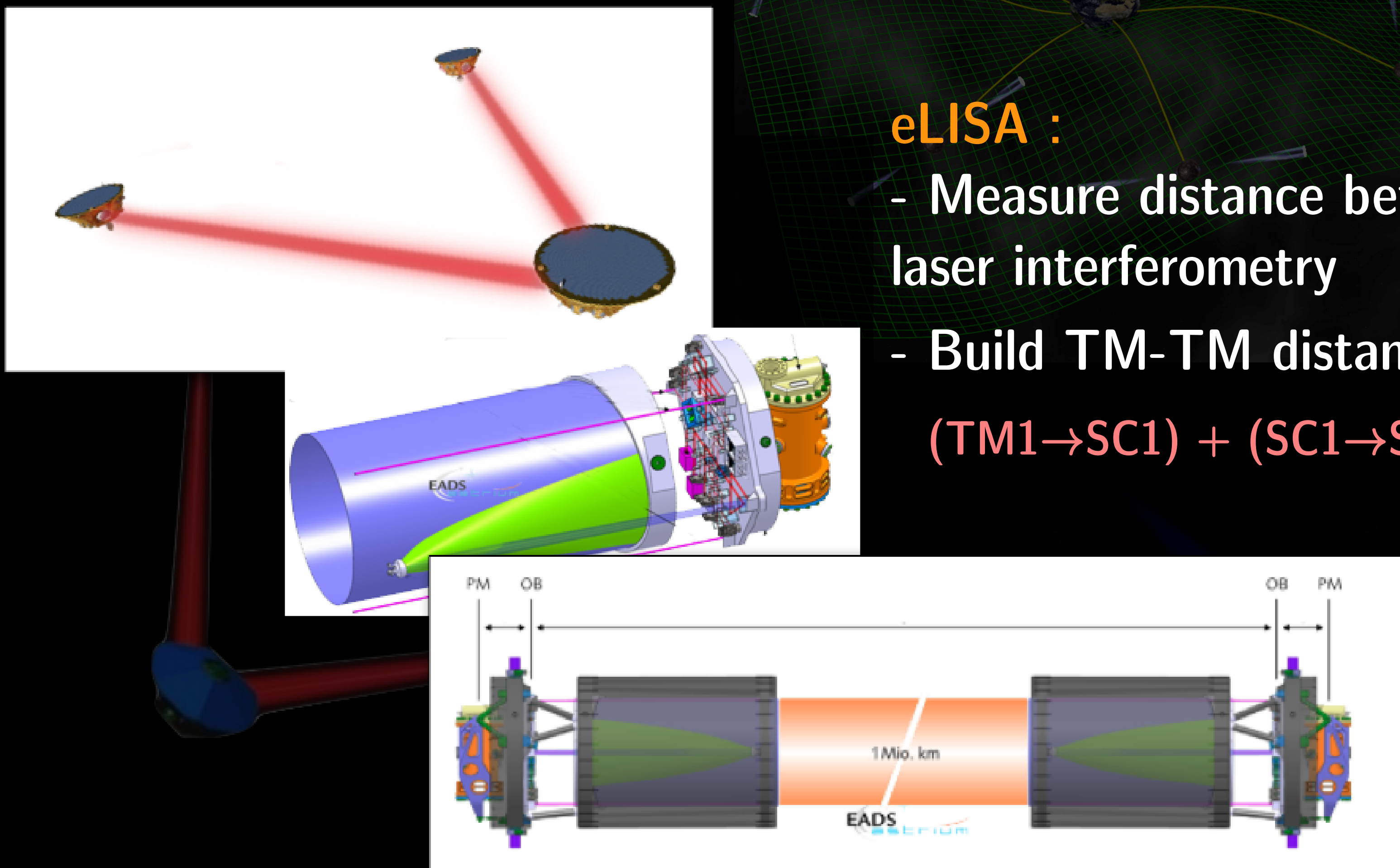
  + Laser interferometry along sensitive axis (between spacecraft)

  + Capacitive sensing on orthogonal axes

- TM displacement measurements are used as input to DFACS which controls position and attitude of spacecraft with respect to the TM

LISAPathfinder

- Technological demonstrator for eLISA

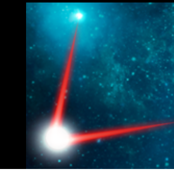


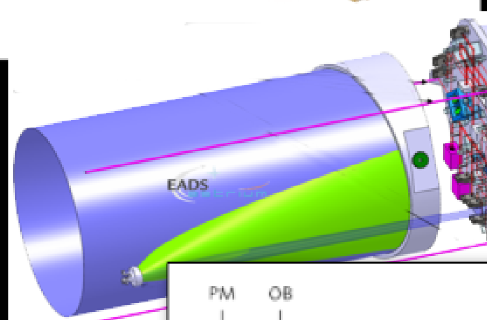
eLISA :

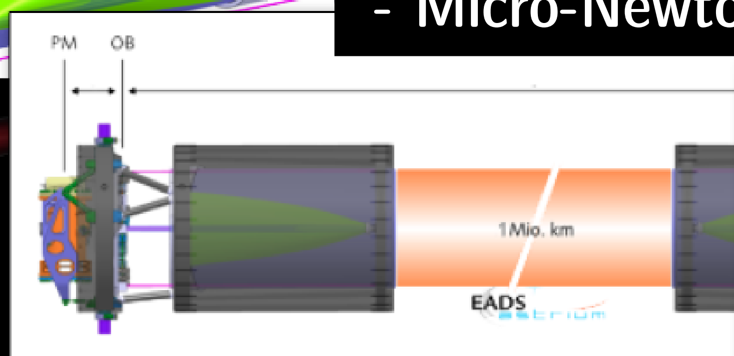
- Measure distance between SC using laser interferometry
- Build TM-TM distance by combining:
  (TM1→SC1) + (SC1→SC2) + (SC2→TM2)

LISAPathfinder

- Technological demonstrator for eLISA

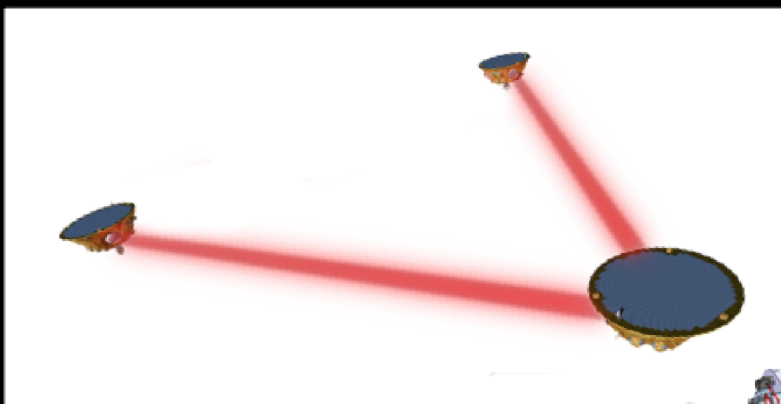


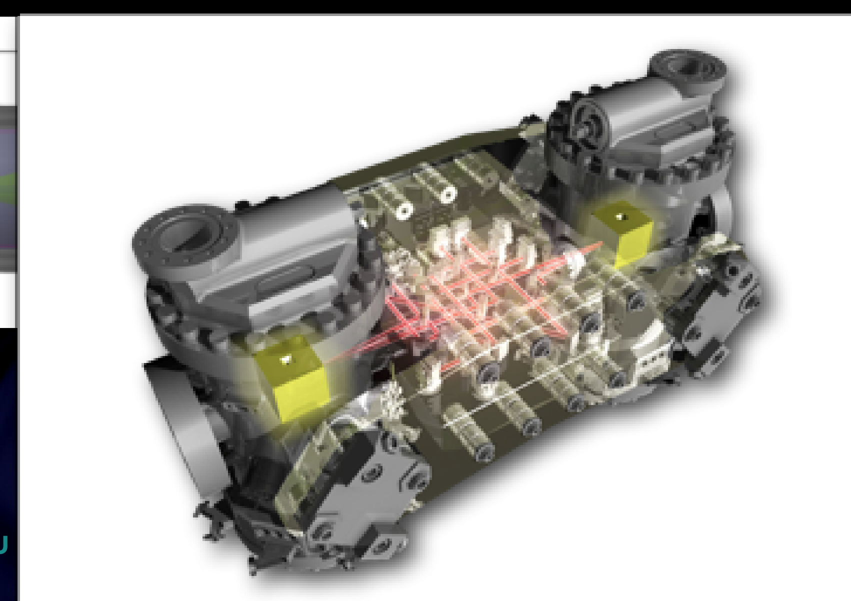




LISAPathfinder :

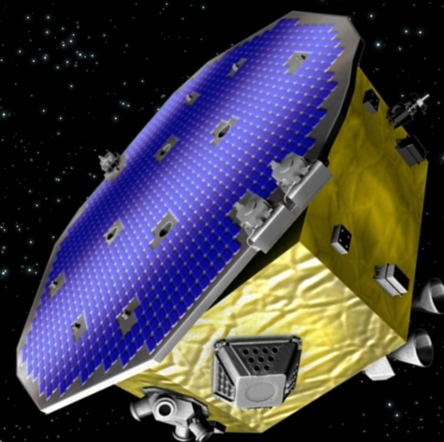
- 2 test masses / 2 inertial sensors
- Laser interferometric readout of $TM_1 \rightarrow SC$ & $TM_1 \rightarrow TM_2$
- Capacitive readout of all 6 dof of test masses
- Drag-Free and Attitude Control System
- Micro-Newton Thrusters

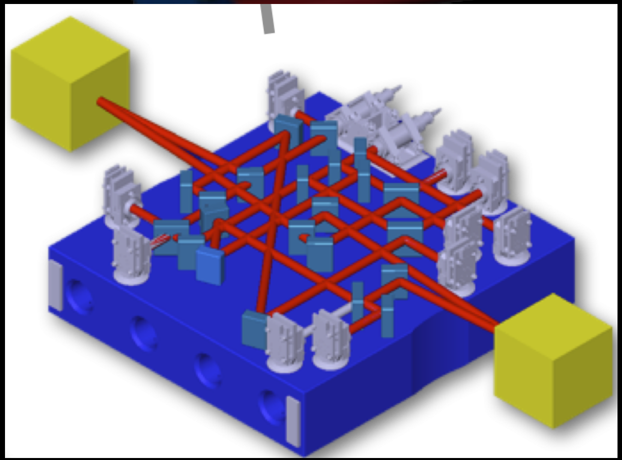


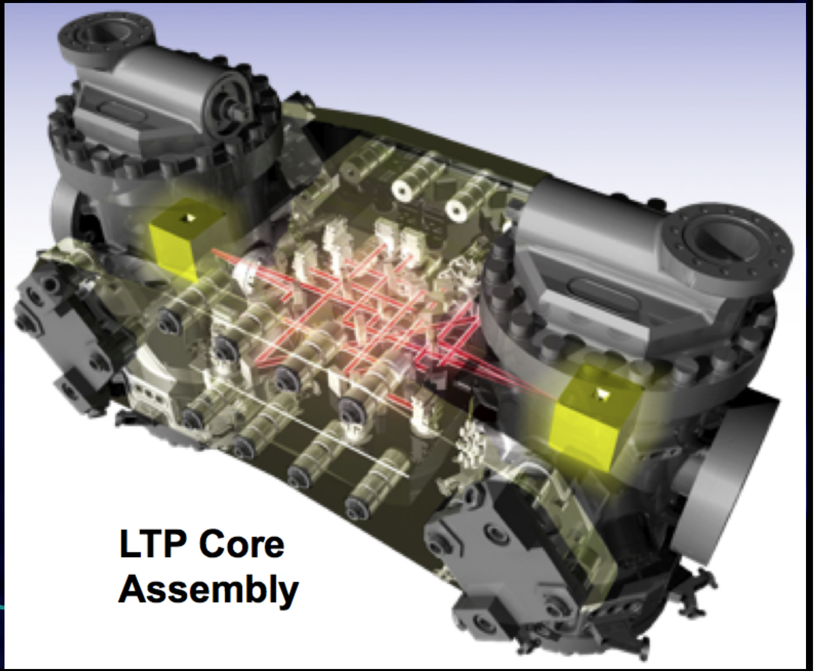


LISAPathfinder Technology Pkg

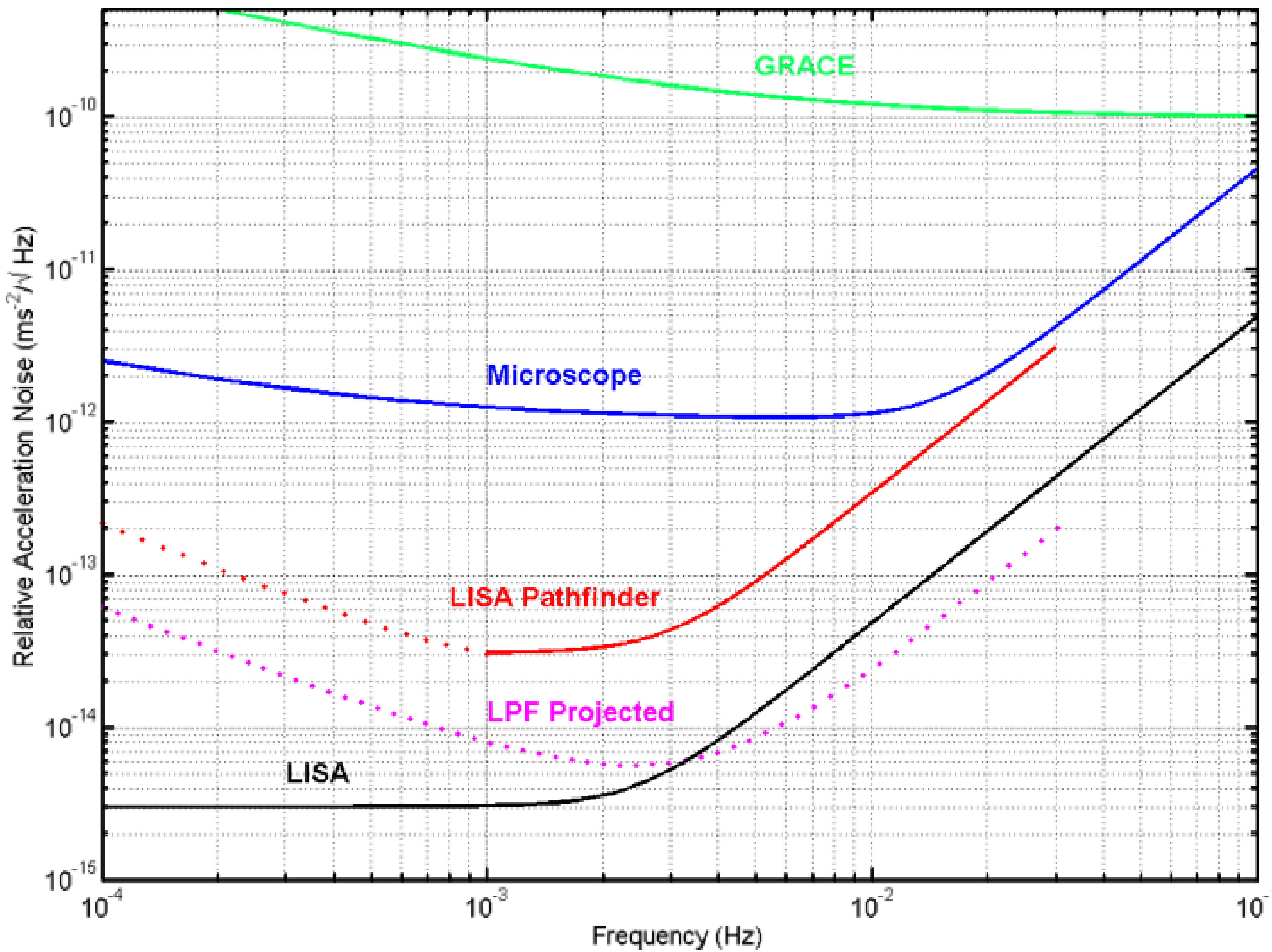
- 2 Au:Pt test massess housed in separate vacuum enclosures.
- The LISAPathfinder will test in flight :
  - Inertial sensor,
  - Interferometry between free floating TMs,
  - Drag Free and Attitude Control System
  - Micro-Newton propulsion technology



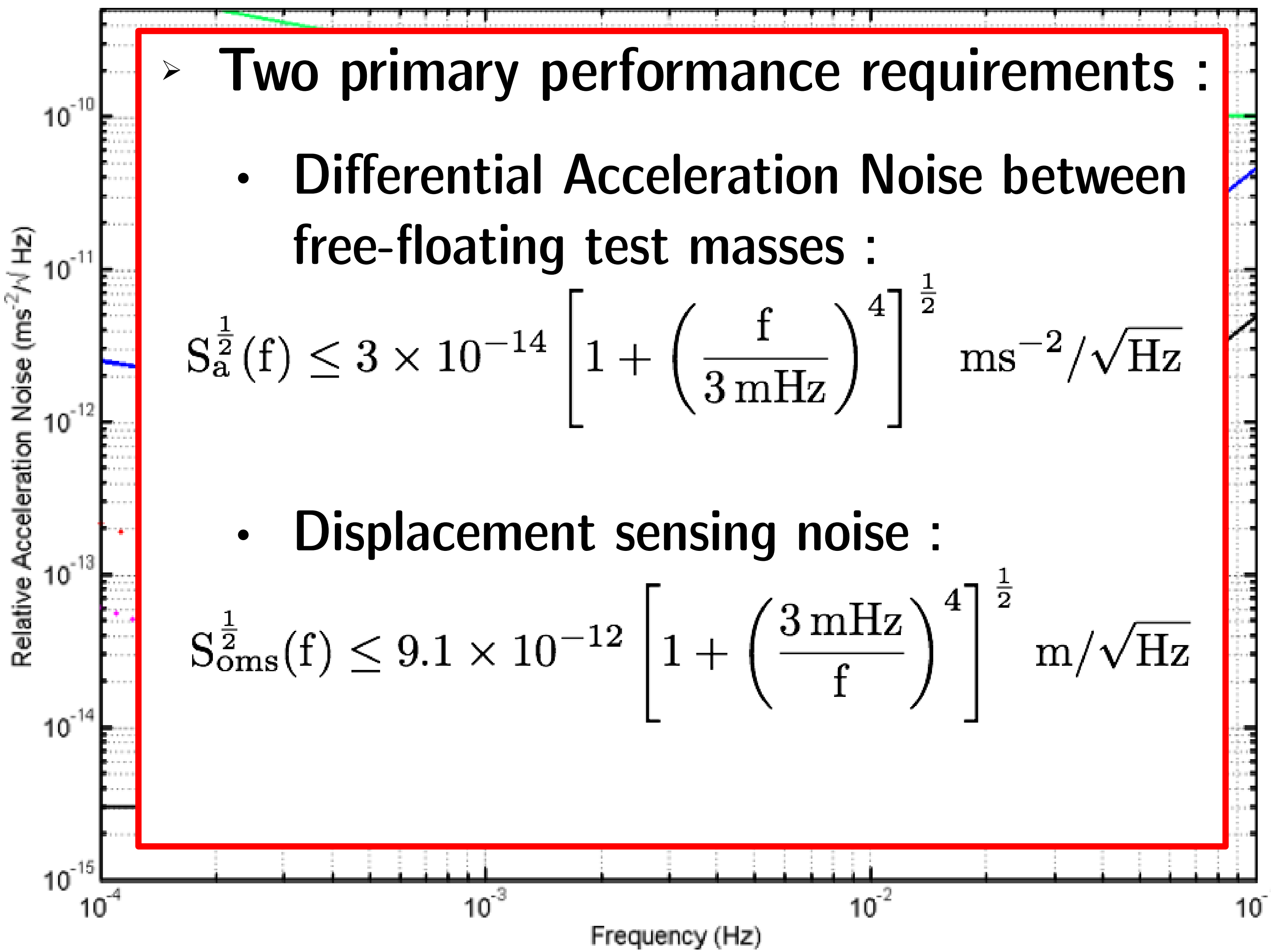




Performances comparison



Performances comparison



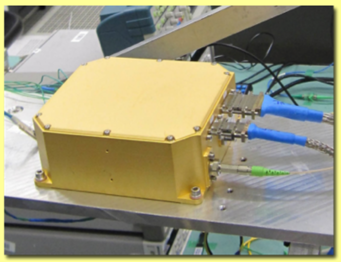
- Two primary performance requirements :
  - Differential Acceleration Noise between free-floating test masses :

$$S_a^{\frac{1}{2}}(f) \leq 3 \times 10^{-14} \left[1 + \left(\frac{f}{3\,\mathrm{mHz}}\right)^4\right]^{\frac{1}{2}} \ \mathrm{ms^{-2}/\sqrt{Hz}}$$

  - Displacement sensing noise :

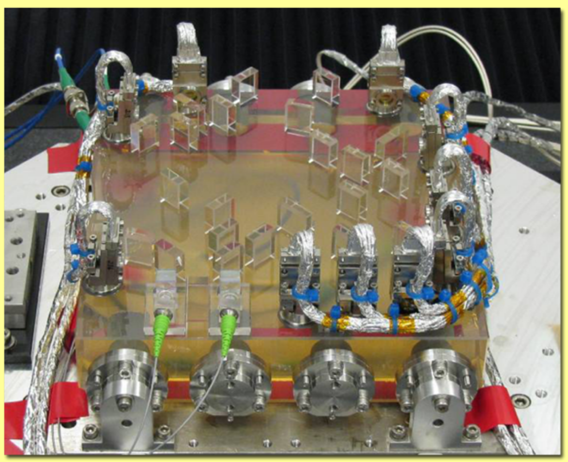
$$S_{oms}^{\frac{1}{2}}(f) \leq 9.1 \times 10^{-12} \left[1 + \left(\frac{3\,\mathrm{mHz}}{f}\right)^4\right]^{\frac{1}{2}} \ \mathrm{m/\sqrt{Hz}}$$

Core of LISAPathfinder : LISA Technology Package

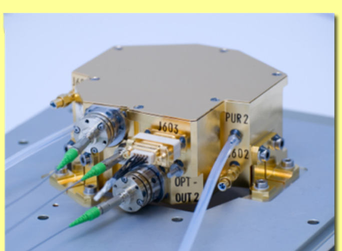


Reference Laser Unit

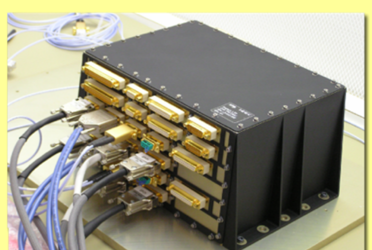
Phasemeter



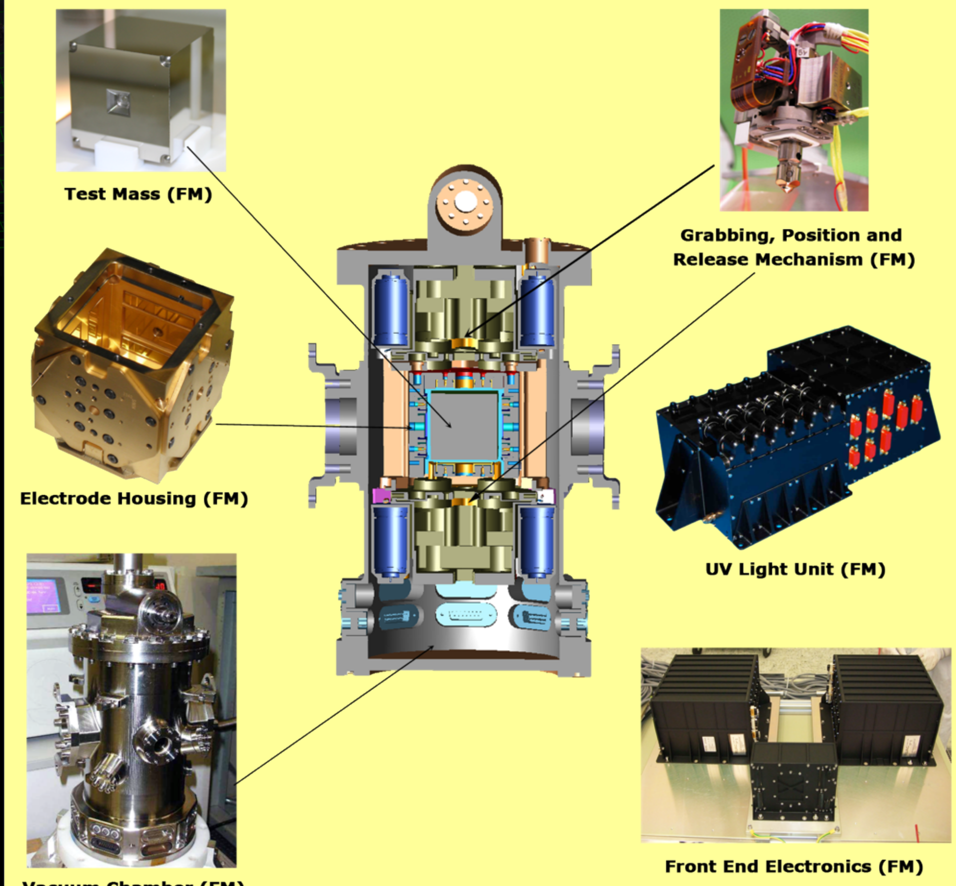
Optical Bench Interferometer



Laser Modulator

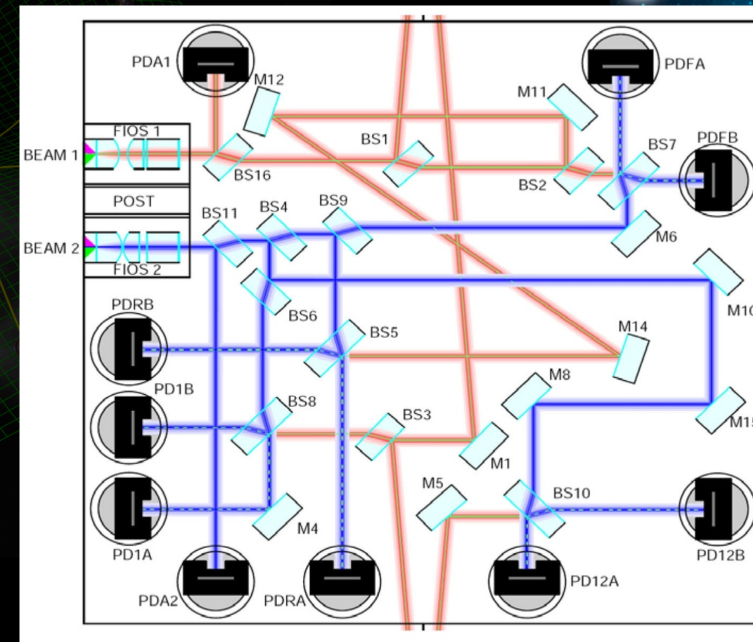


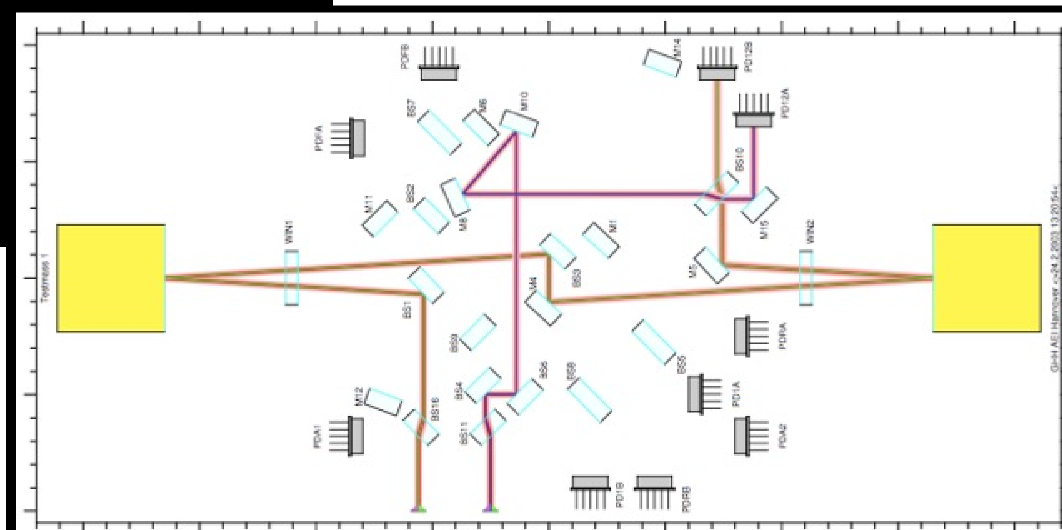
Data Management Unit

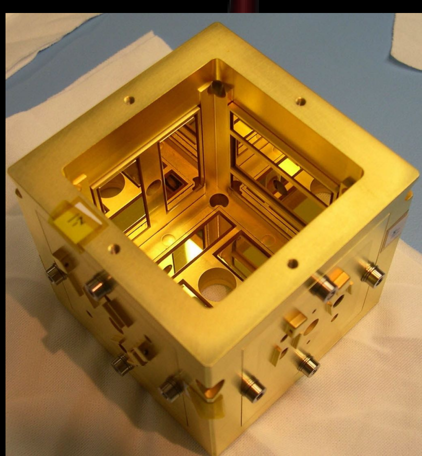


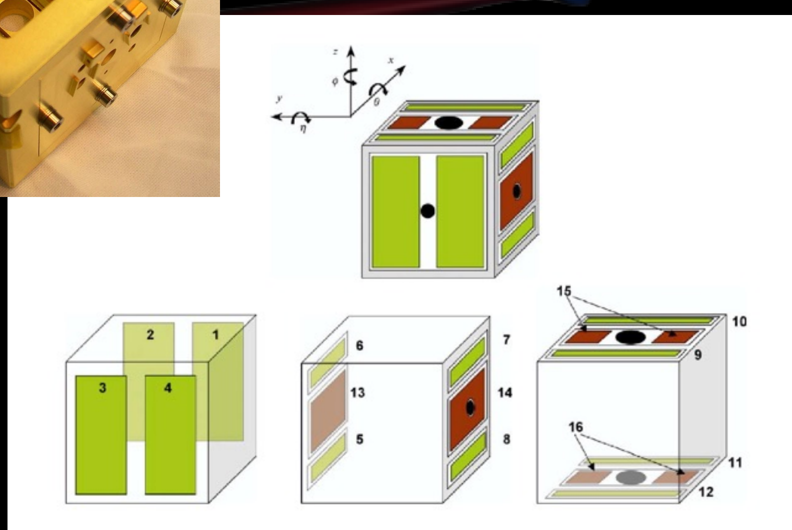
Measurement systems

- Heterodyne laser interferometry along sensitive axis (between test massses)
- Capacitive sensing via electrodes around the test masses : controling all degree of freedom



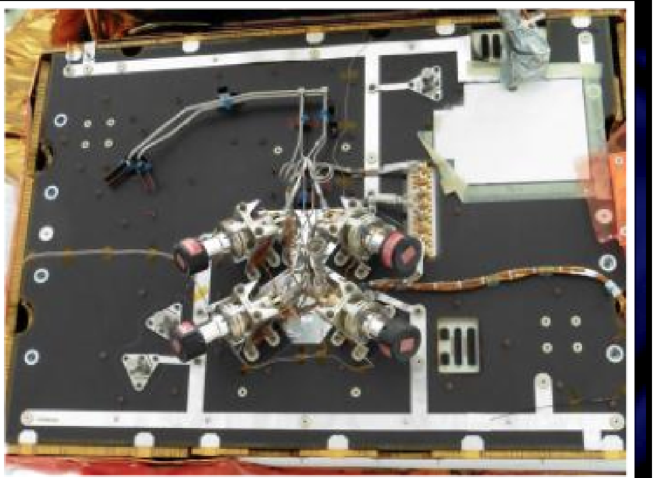






Drag free system

- Spacecraft protect the proof mass in the center of its housing using microthrusters



Thrusters on S/C (Feb 2015)

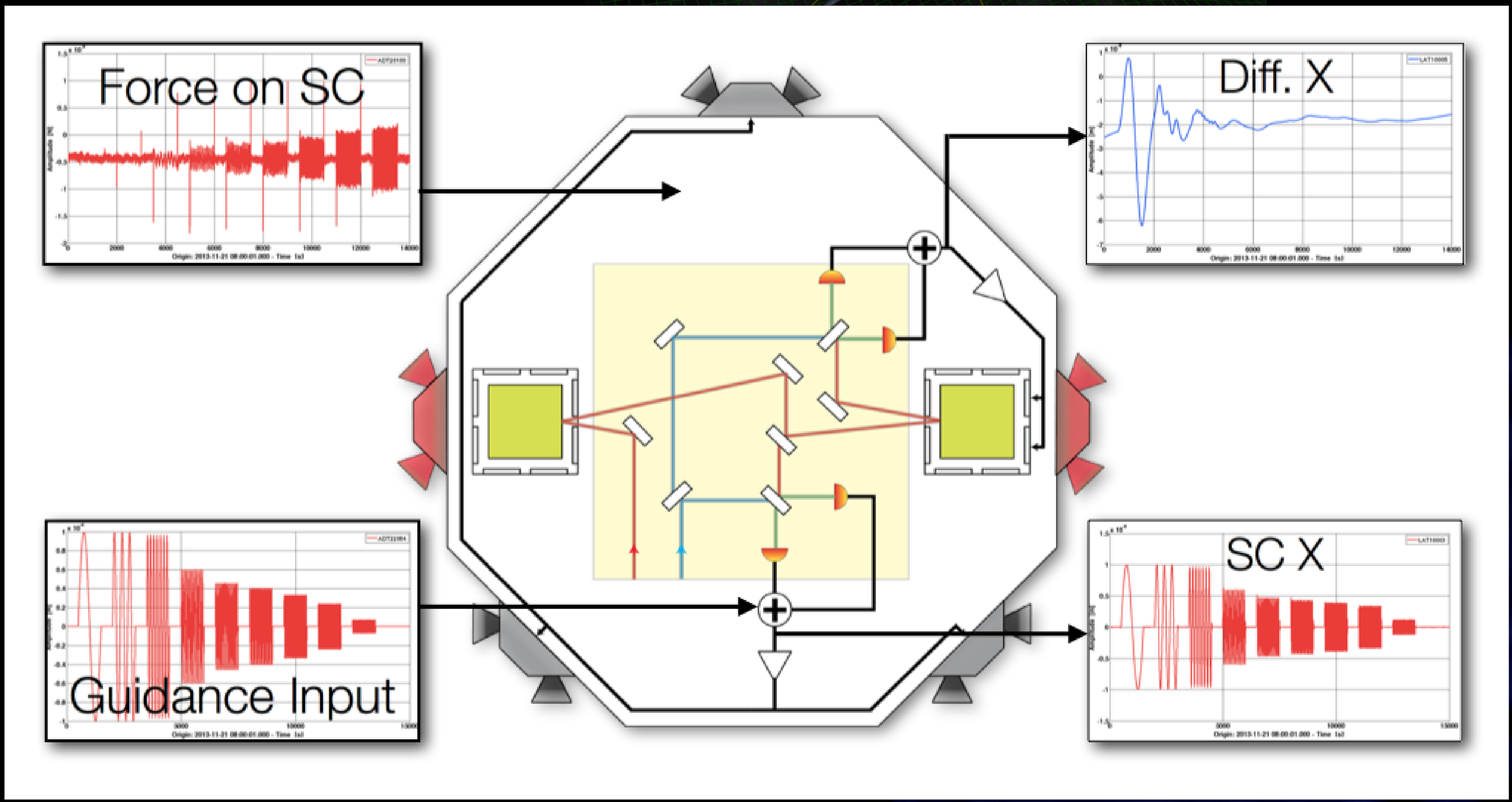
LISAPathfinder : in-fligth activities

- Goal understand the noise performance we observe
- Optimise the system to reach the best noise performance
- Pick from a menu of available pre-designed experiments to characterise and optimise the system
- Rough scheme:
  1. long noise measurement
  2. identify limiting noise source
  3. measure/assess the coupling and/or key parameters
  4. minimise noise and/or coupling
  5. goto 1

Start	End	Sim Time (s)	Sim Time (H)	Duration (H)	Description
13-Nov-13 8:00	13-Nov-13 14:00	0	0	6.0	Decage and transition to Acc3
13-Nov-13 14:00	13-Nov-13 20:00	21600	6	6.0	Acc3
13-Nov-13 20:00	14-Nov-13 8:00	43200	12	12.0	Nom2
14-Nov-13 8:00	15-Nov-13 8:00	86400	24	24.0	Science 1.2
15-Nov-13 8:00	15-Nov-13 14:00	172800	48	6.0	DC bias estimate TM1 (Q step, lamps)
15-Nov-13 14:00	15-Nov-13 20:00	194400	54	6.0	DC bias estimate TM1 (Q step, lamps) with changed dc biases
15-Nov-13 20:00	16-Nov-13 2:00	216000	60	6.0	DC bias estimate TM1 (Q step, lamps) with changed dc biases
16-Nov-13 2:00	16-Nov-13 8:00	237600	66	6.0	Acceleration noise run
16-Nov-13 8:00	16-Nov-13 12:00	259200	72	4.0	Guidance phi1
16-Nov-13 12:00	16-Nov-13 16:00	273600	76	4.0	Guidance phi2
16-Nov-13 16:00	16-Nov-13 20:00	288000	80	4.0	Guidance y1
16-Nov-13 20:00	17-Nov-13 0:00	302400	84	4.0	Guidance y2
17-Nov-13 0:00	17-Nov-13 4:00	316800	88	4.0	Guidance Phi
17-Nov-13 4:00	17-Nov-13 6:00	331200	92	2.0	Acceleration noise run
17-Nov-13 6:00	17-Nov-13 7:00	338400	94	1.0	Fast Discharge TM1
17-Nov-13 7:00	17-Nov-13 8:00	342000	95	1.0	Fast Discharge TM2
17-Nov-13 8:00	18-Nov-13 8:00	345600	96	24.0	OSTT / Station Keeping
18-Nov-13 8:00	18-Nov-13 9:00	432000	120	1.0	Fast Discharge TM1
18-Nov-13 9:00	18-Nov-13 10:00	435600	121	1.0	Fast Discharge TM2
18-Nov-13 10:00	18-Nov-13 17:00	439200	122	7.0	Magnetics Coil 1
18-Nov-13 17:00	19-Nov-13 0:00	464400	129	7.0	Magnetics Coil 2
19-Nov-13 0:00	20-Nov-13 8:00	489600	136	32.0	Thermal
20-Nov-13 8:00	20-Nov-13 9:00	604800	168	1.0	Fast Discharge TM1
20-Nov-13 9:00	20-Nov-13 10:00	608400	169	1.0	Fast Discharge TM2
20-Nov-13 10:00	21-Nov-13 5:00	612000	170	19.0	Long Q estimate TM2
21-Nov-13 5:00	21-Nov-13 8:00	680400	189	3.0	DC bias estimate TM1 (Q step, lamps) - shorter
21-Nov-13 8:00	21-Nov-13 12:00	691200	192	4.0	SC X guidance
21-Nov-13 12:00	21-Nov-13 16:00	705600	196	4.0	TM sus x guidance
21-Nov-13 16:00	21-Nov-13 20:00	720000	200	4.0	SC X guidance
21-Nov-13 20:00	22-Nov-13 0:00	734400.0	204.0	4.0	TM sus x guidance
22-Nov-13 0:00	22-Nov-13 4:00	748800.0	208.0	4.0	Fool SC X, TM1 X
22-Nov-13 4:00	22-Nov-13 8:00	763200.0	212.0	4.0	Fool SC X, TM1 X, TM2 X

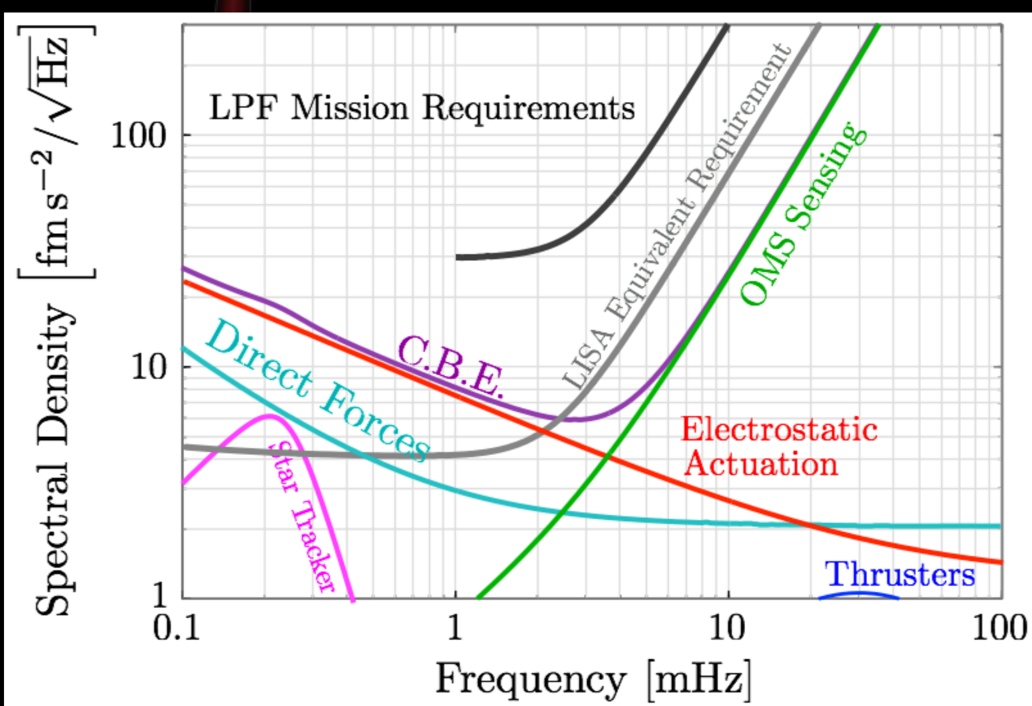
Example of experiment

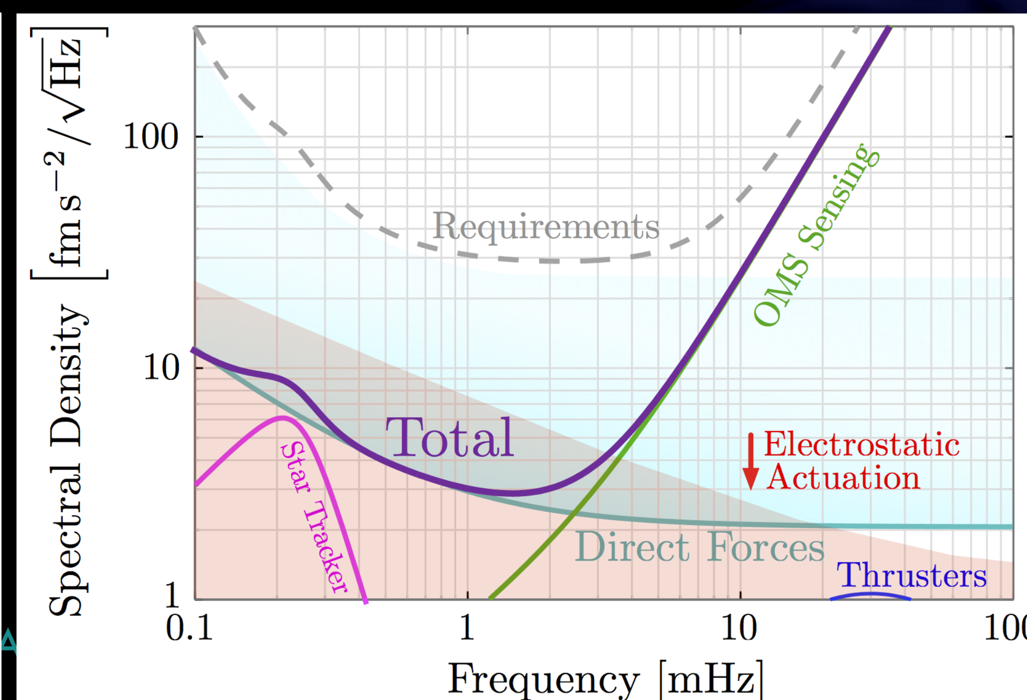
- **System Identification : Goal is to measure the key parameters needed for estimating the residual differential acceleration.**



LISAPathfinder

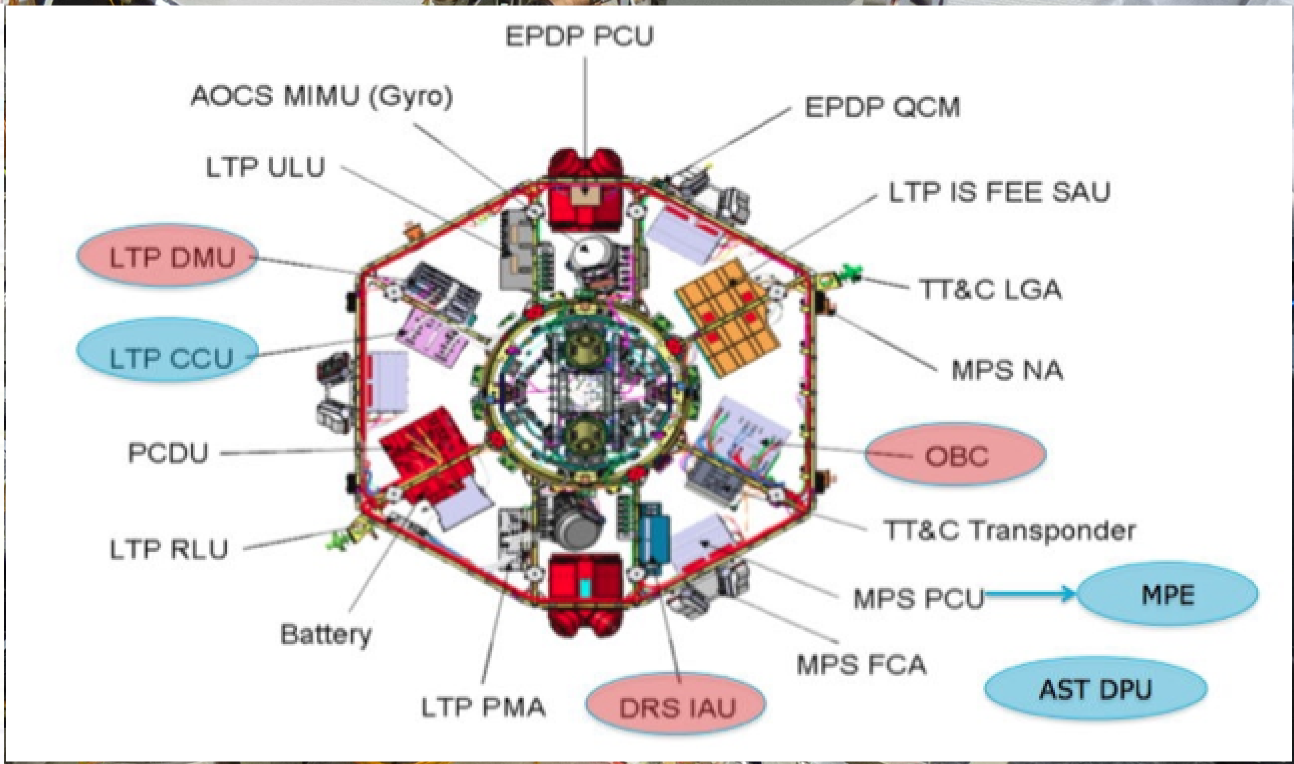
- Data analysis :
  - Fitting model to estimate parameters of the system: few hundred parameters but usually only few parameters are relevant,
  - Methods : Linear Fit, MCMC, EMCEE (MCMC on running on FACe/APC cluster : for quick analysis and large number of parameters)
- **Sensitivity:** expected performance from ground measurements largely beats requirements



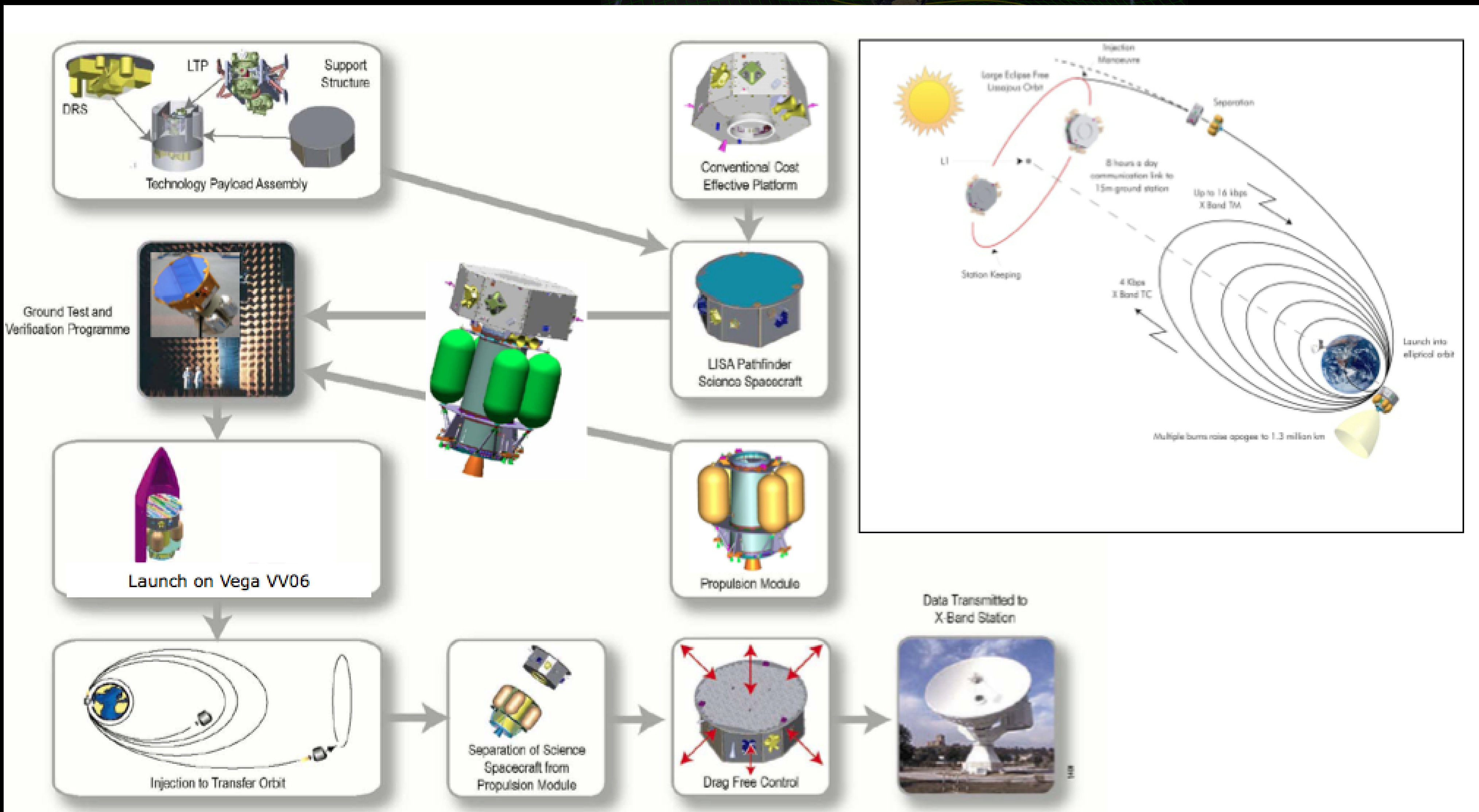


LISAPathfinder

- Spacecraft ready !

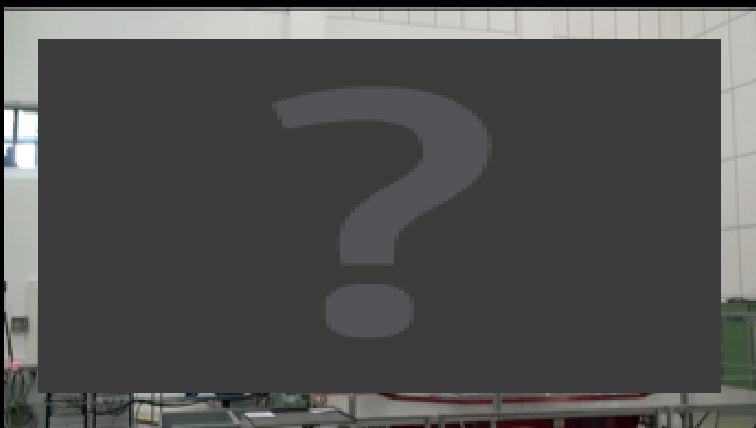


LISAPathfinder

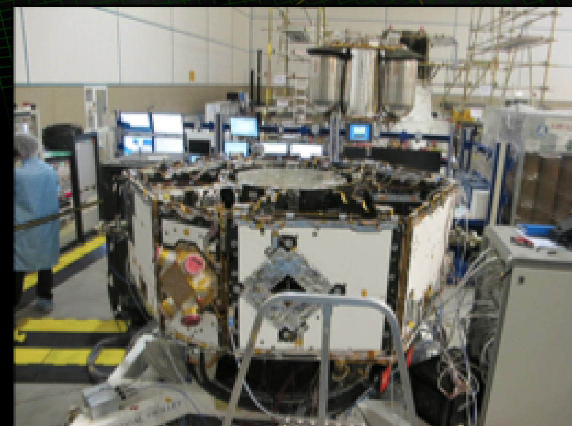


LISAPathfinder

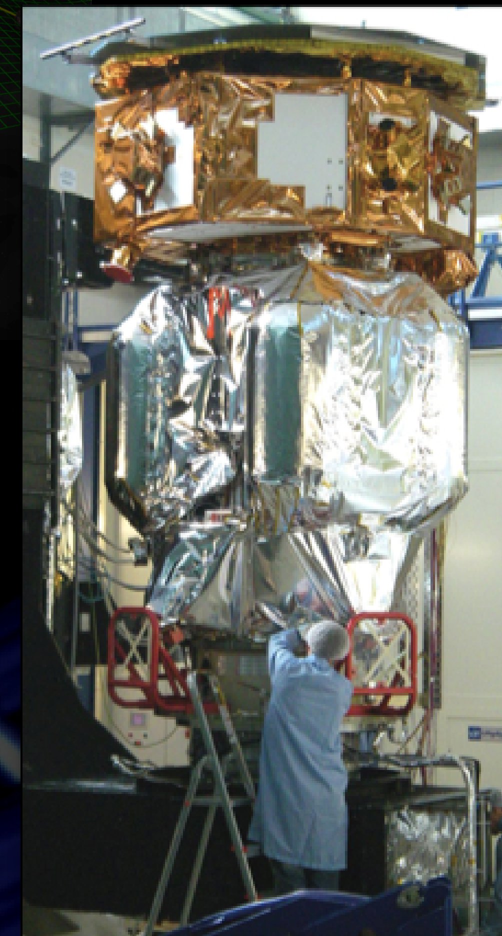
- Spacecraft ready and tested !



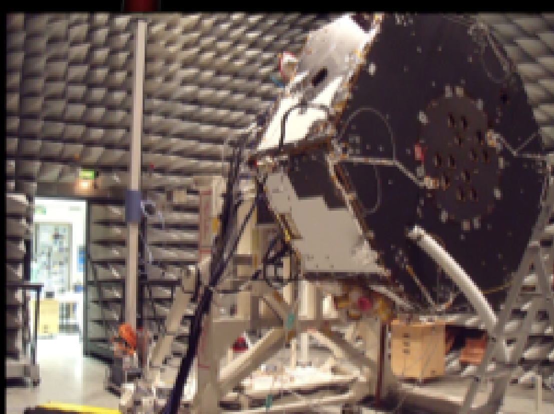
Vibration and shock tests



close loop tests



Transfer orbit thermal tests

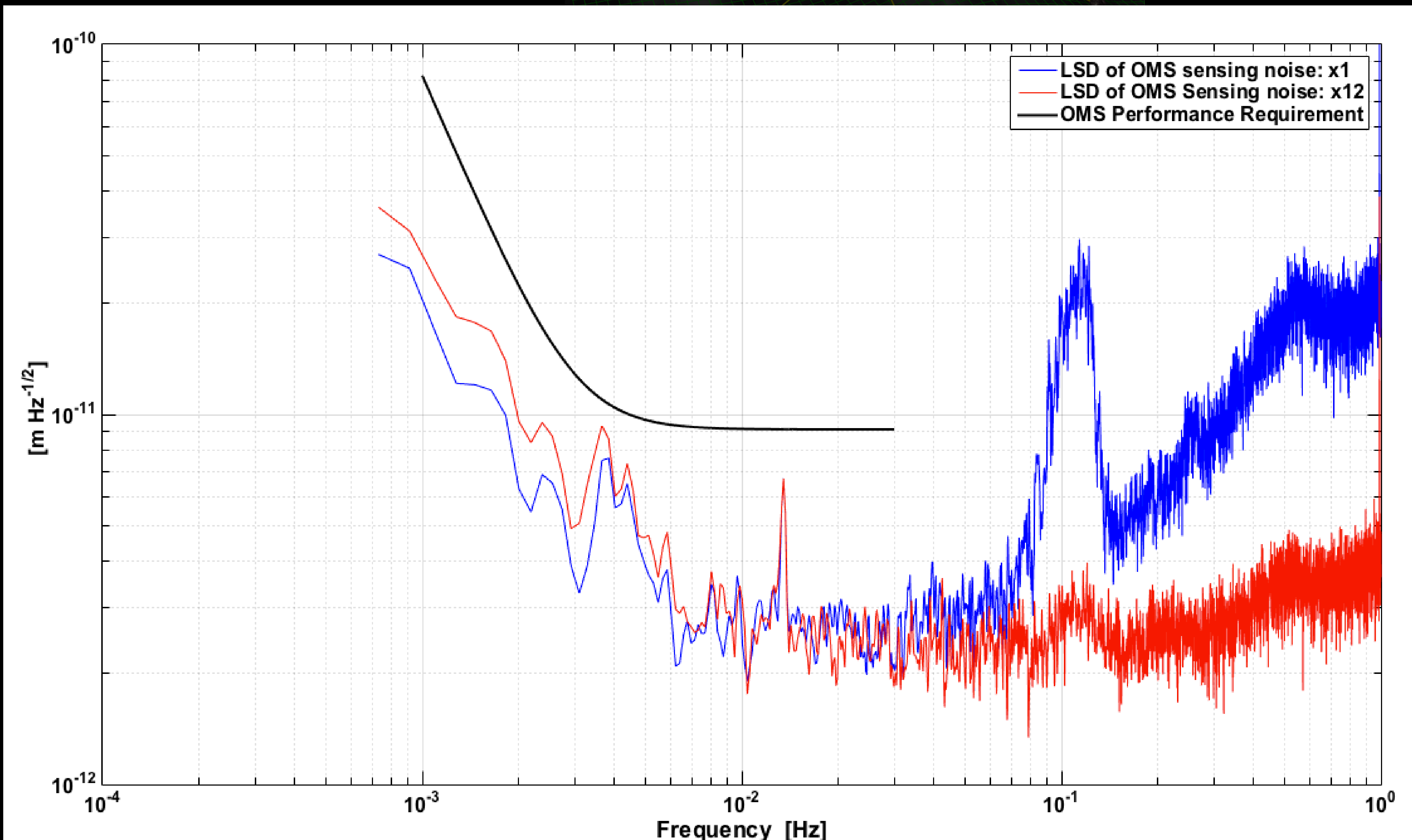


EMC

On station thermal tests

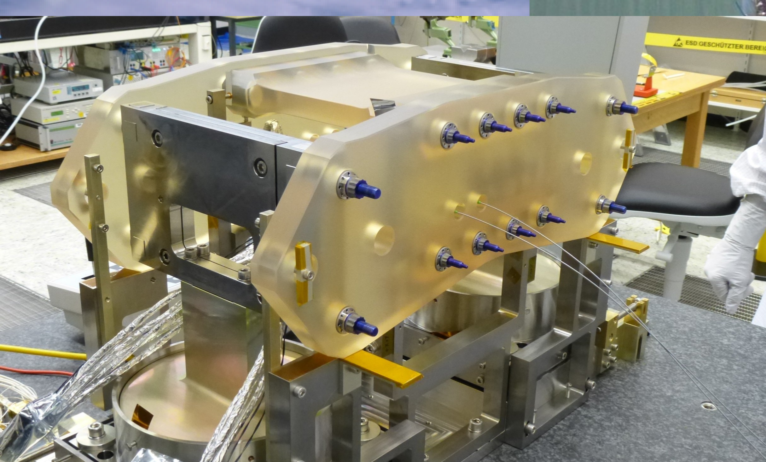
On ground measurements

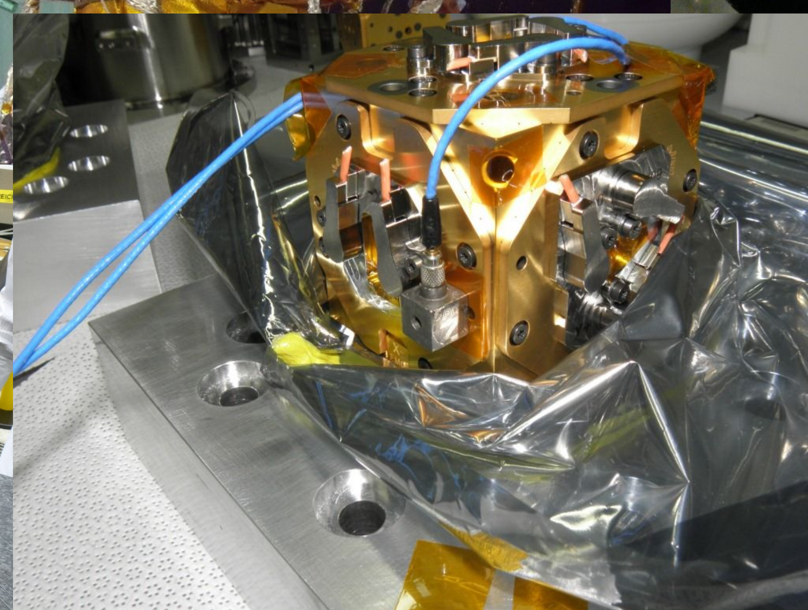
- On ground measurements of the performance of the Optical Measurement System : better than requirements !

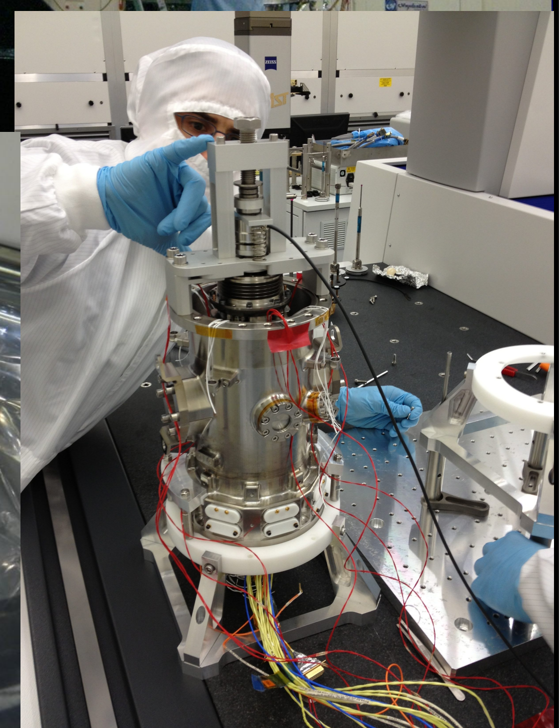


LISAPathfinder

- Ready to be launch on 15 Nov 2015 :
  next VEGA launch (VV06)







Conclusion

- LISAPathfinder is a complex instrument giving a lot of informations on the system ==> technology transfer to eLISA
- The most stable system on a geodesic ever construct by human !
- The success of LISAPathfinder will open the way to eLISA
- In 2034 eLISA will observe a large number of sources expected … and unexpected !In the next year(s) :
  - LISAPathfinder launch in November
  - Pulsar Timing Array reaches the sensitivity where there are probable gravitational sources : possible detection in the next years
  - Advanced LIGO starts to take data during the summer

The future of gravitational wave astronomy is very bright !

We are opening a new window on the Universe and the physics !

Nov. 2015 : LISAPathfinder launch ...
and then ... eLISA
Stay tuned ! Thank you !