Missatgers de la gravitació: les ones gravitacionals

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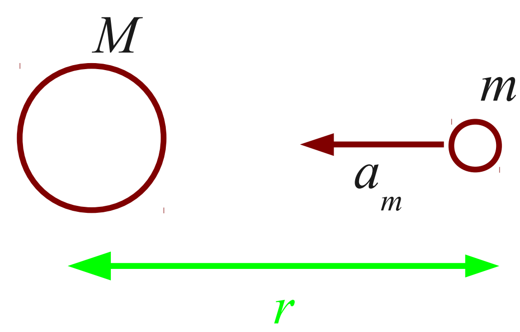
Preamble

In Newtonian Gravitation theory, gravitational fields ***propagate instantly*** (v=∞) to remote places, no matter how distant from the source.

$$m_i \times a_m = G \frac{M_g m_g}{r^2}$$

$m_i = m_g$ (EP) ↓

$$a_m(t) = G \frac{M(t)}{r^2(t)}$$



This is of course ***unacceptable***, as it would appear that Gravity is not subject to the ***laws of causality*** every other interaction complies with...

This alone is enough reason to search for a new theory of gravity –and, in fact, several people endeavoured to find it...

As one might expect, *GR* does predict a different behaviour of the gravitational field and predicts the so-called ***Gravitational Waves*** (GW).

Gravitational Waves

The definition of the GW is simplified when *weak fields* are considered, i.e., when space-time is *quasi-Lorentzian*, or quasi flat. This is actually what we expect to find in GW Astronomy *in practice* (the detectors will be placed in a quasi flat space-time region).

In this case we can take as reference a *flat space-time* –i.e., one where there are no gravitational fields, or are stationary. In this reference, a *GW* will be considered as a *weak perturbation* of the flat geometry:

$$g_{\mu\nu}(\boldsymbol{x},t) = \eta_{\mu\nu}(\boldsymbol{x},t) + h_{\mu\nu}(\boldsymbol{x},t) \quad , \qquad |h_{\mu\nu}(\boldsymbol{x},t)| \ll 1$$

Where:

$\boldsymbol{x}$ and t are Cartesian coordinates

$\eta_{\mu\nu}(\boldsymbol{x},t)$ is the flat metric

$h_{\mu\nu}(\boldsymbol{x},t)$ is the metric perturbation (GW)

Plane Gravitational Waves

Technical manipulations show that a major simplification is possible to describe plane waves propagating in the z direction:

$$h_{\mu\nu}(\boldsymbol{x},t) = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & h_+(z-ct) & h_\times(z-ct) & 0 \\ 0 & h_\times(z-ct) & -h_+(z-ct) & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$$

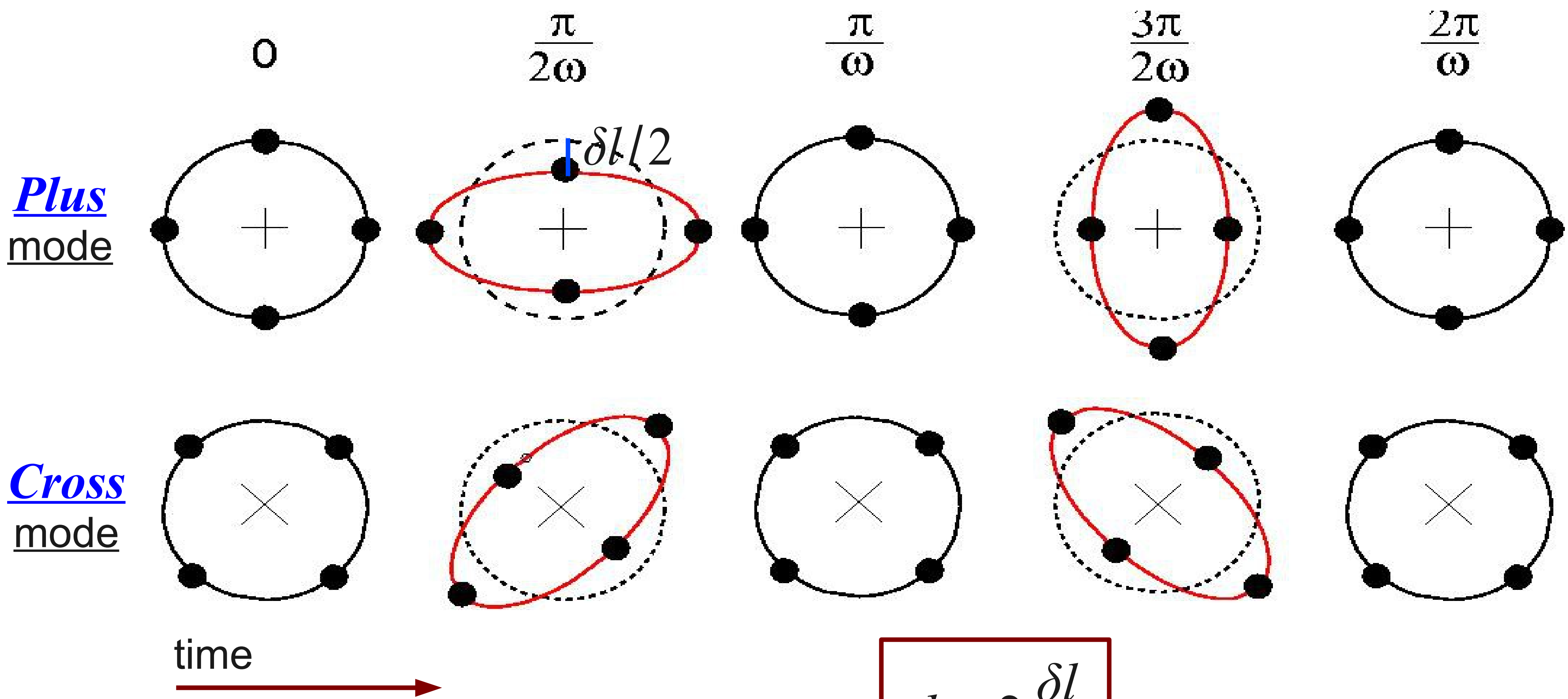
Therefore *GW*s:

1) *Travel at the* ***speed of light, c***
2) *Are* ***transverse***
3) *Have* ***two polarisation states***

GWs are ripples of the space-time fabric itself.

Polarisation states

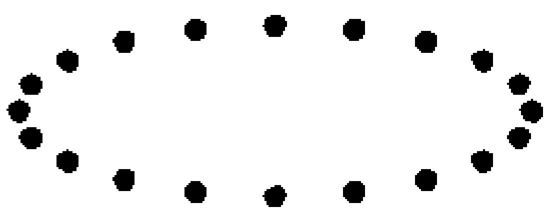
There are 2 polarisation states in a *GW*:



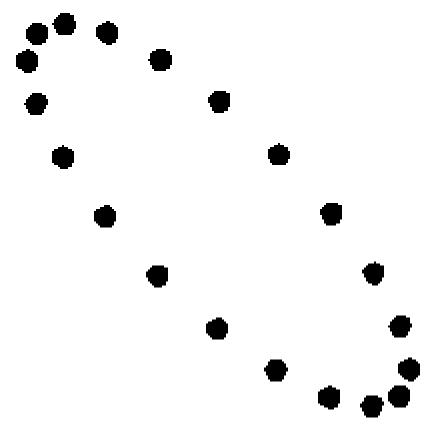
STRAIN: $$h = 2\frac{\delta l}{l}$$

Polarisation states

Plus mode



Cross mode



Gravitational Wave generation

The *GW* amplitudes h_+ and $h_\times$ obviously depend on the **physical properties of their sources**. More specifically, they are proportional to the source's ***quadrupole moment acceleration***:

$$h_{ij}(r,t) = -\frac{4G}{c^4}\,\frac{1}{r}\,\ddot{Q}_{ij}(t-r/c)$$

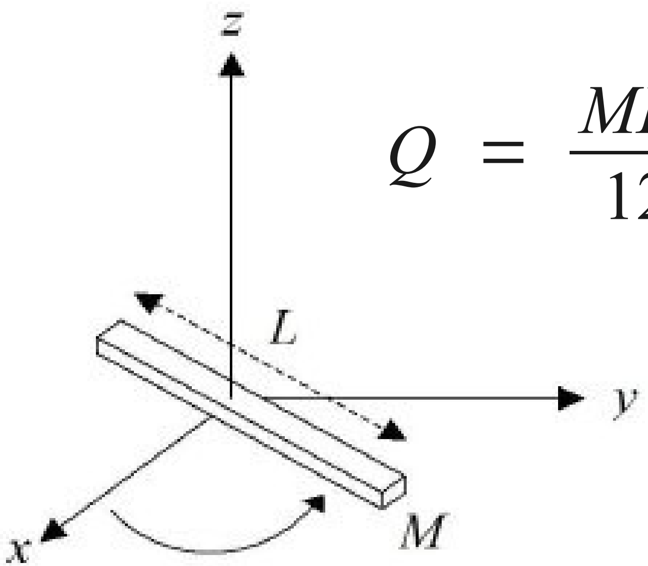
This ***quadrupole formula*** indicates that a *spherical distribution does not radiate* *GW*s.

It can be used for an *order of magnitude* estimate:

$$h \simeq \frac{2GM/c^2}{r}\,\frac{v^2}{c^2}$$

***GW*s are extremely weak!!!**
(space-time fabric is a very stiff medium)

GW generation: in the laboratory



$$\phi(t) = \omega t$$

$$Q = \frac{ML^2}{12}\begin{pmatrix} \cos^2\phi(t) - 1/3 & \cos\phi(t)\sin\phi(t) & 0 \\ \cos\phi(t)\sin\phi(t) & \sin^2\phi(t) - 1/3 & 0 \\ 0 & 0 & -1/3 \end{pmatrix}$$

$$h \simeq \frac{4G}{c^4}\frac{1}{r}\ddot{Q} = \frac{4G}{c^4}\frac{1}{r}\frac{ML^2\omega^2}{6}$$

A numerical example:

$$f = 1000\ \mathrm{Hz}$$

$$M = 1000\ \mathrm{kg}$$

$$L = 1\ \mathrm{m}$$

$$r = 100\ \mathrm{m}$$

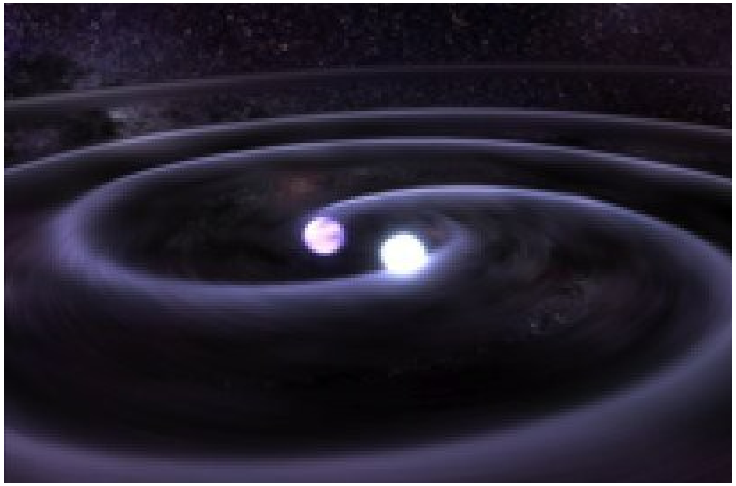
$$l = 100\ \mathrm{m}$$

$$h = 2\frac{\delta l}{l} \simeq 10^{-36} \rightarrow \delta l \simeq 10^{-34}\ \mathrm{m}$$

which means we need to look for much larger masses and speeds, i.e., look out into ***astrophysical objects***.

GW generation: AP event

Binary system:



- NS-NS
- $m_1 = m_2 = 2M_{Sun} = 4\text{x}10^{30}$ kg
- $f_{GW} = 16$ Hz
- $L = 1000$ km
- $r = 1$ Mpc ($= 3\text{x}10^{22}$ m)

$$h \simeq \frac{R_1 R_2}{L/2} \frac{1}{r} = \frac{4.3\,\text{km}\; 4.3\,\text{km}}{500\,\text{km}} \frac{1}{1\,\text{Mpc}} = 2.5 \times 10^{-21}$$

Earth diam.

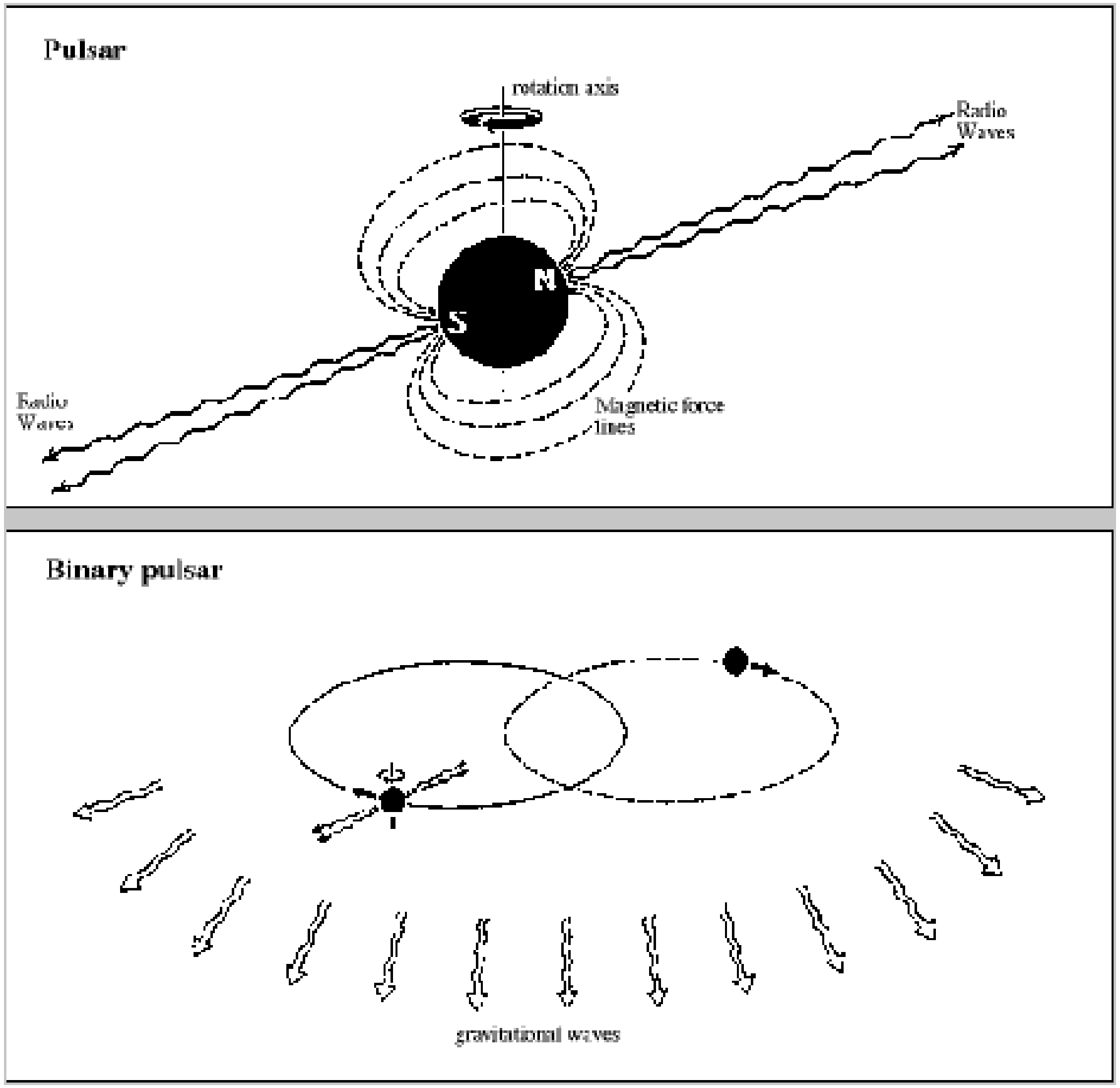
$$\delta l = 2h \times l = 2 \times 2.5 \times 10^{-21} \times 13 \times 10^{6}\,\text{m} = 6.5 \times 10^{-14}\,\text{m}$$

(Nuclear radius is 10^{-15} m!)

PSRB 1913+16

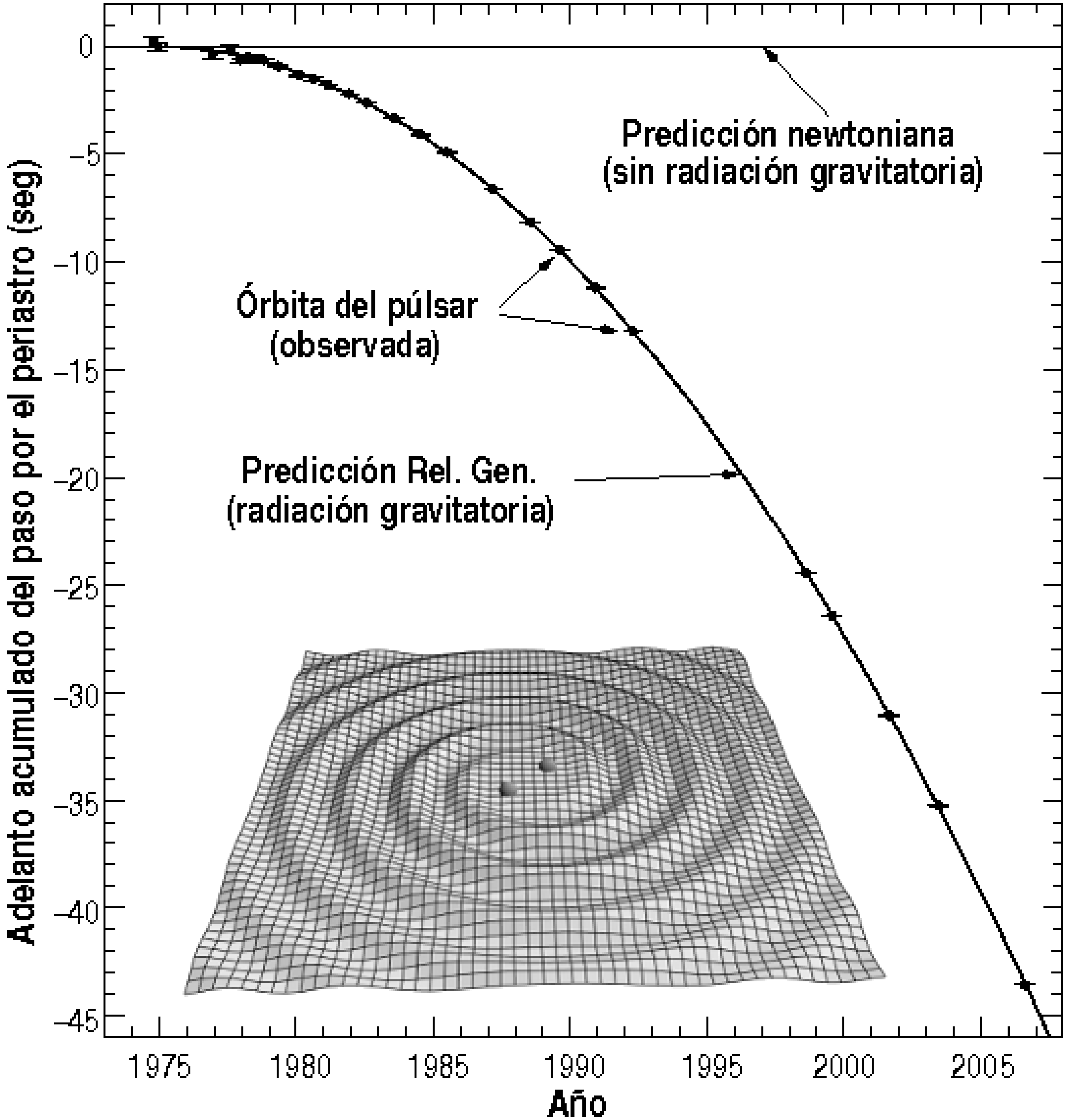
NOBEL Awards 1993

Rusell A. Hulse



Joseph H. Taylor, Jr

PSRB 1913+16



The binary pulsar 1913+16:

Discovered: Arecibo 1975

Tracking: > 30 years

Observational ***result***:

$$\frac{\dot{P}_{\text{measured}}}{\dot{P}_{\text{theory}}} \simeq \mathbf{1 \pm 10^{-3}} \quad (2010)$$

GW detection (Incomplete)

PSRB 1913+16

Some binary pulsar data:

Distance:	21,000 light years (6.5 kpc)
Mass of detected pulsar:	1.441 Solar masses
Mass of companion:	1.387 Solar masses
Rotational period:	*59.02999792988 millisec*
Diameter of neutron stars:	20 km
Orbital period:	**7.751939106 hours**
Semimajor axis:	1,950,100 km
Maximum orbital velocity:	300 km/sec
Rate of decrease of semimajor axis:	**3.5 m/year (2.4$10^{-12}$ sec/sec)**
Calculated lifetime:	**300,000,000 years**
GW emission frequency:	**~70 μHz**
GW emission amplitude:	**~2×10^{-23}**

GW Astronomy

Therefore:

- Relevant *GW* sources are ***far*** from Earth
- Detection poses a formidable problem

Benefit of detection:

- *GW*s carry *undistorted news* from source *interiors*

GW sources are often classified in four groups:

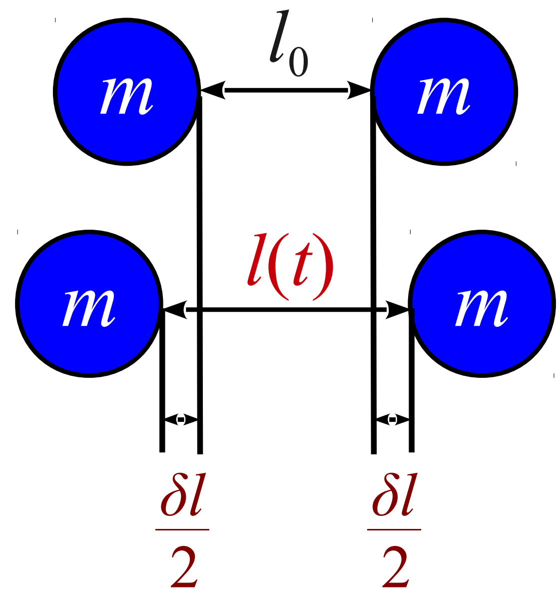
- ***Burst***, or short duration signals
- ***Periodic***, or long duration signals
- ***Stochastic*** backgrounds
- ***Other***, unforeseen signals

GW detection will thus spawn a *new branch* of Astronomy:

GW Astronomy

GW telescopes: basics

Free test masses at rest before *GW* comes:



Incoming GW causes ***relative distance* changes**:

$$l(t) = l_0 + \delta l = l_0 \left[1 + \frac{1}{2} h(t) \right]$$

where

$$h(t) = \left[h_\times (\boldsymbol{x}_0, t) \cos(2\varphi) + h_+ (\boldsymbol{x}_0, t) \sin(2\varphi) \right] \sin^2\theta$$

GW amplitudes are measured in ***metres/metre***.

For envisaged sources, $h \sim 10^{-18} - 10^{-26}$

GW telescopes

There are at present three ***detector concepts*** to sense the tiny motions induced by incoming GW signals:

Acoustic or resonant antennas:

- **EXPLORER, NAUTILUS, AURIGA, ALLEGRO**
- **Mini-GRAIL, Mario Schenberg**

Interferometric antennas:

- **VIRGO, LIGO, GEO-600, TAMA, LCGT, ET, LISA**

Pulsar timing:

- *Timing 26* ms *pulsars* *(100 ns resolution)*
- **NANOGrav Collaboration**

No undisputed signals have been sighted so far...

GW telescopes

Pulsar timing

Sources:
Background from MBH-binaries

Reach critical sensitivity: 2015

LISA

Sources:
SMBH mergers
EMRIs
Galactic binaries

Guaranteed signals
Largest SNR
Most science

LIGO,VIRGO,etc.

Sources:
NS/BH mergers
Supernovae,
Pulsars

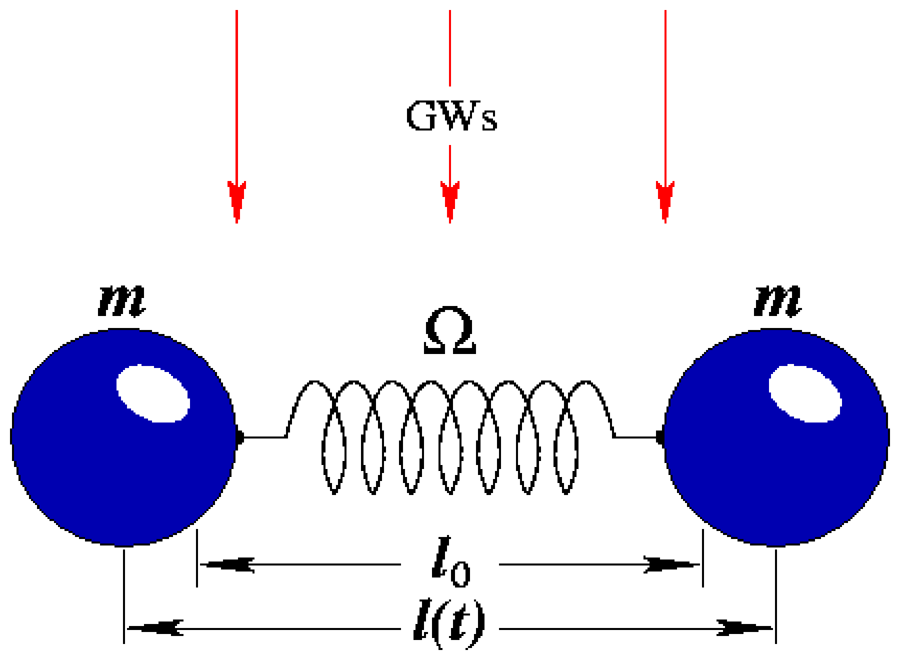
Reach critical Sensitivity: 2015

-9	-6	-5	-1	1	4
30 yr	10 d	1 d	10 s	0.1 s	0.1 ms

Frequency [log Hz]
(Period)

Acoustic GW detectors

The idea of these devices is to link the proof masses by a spring:

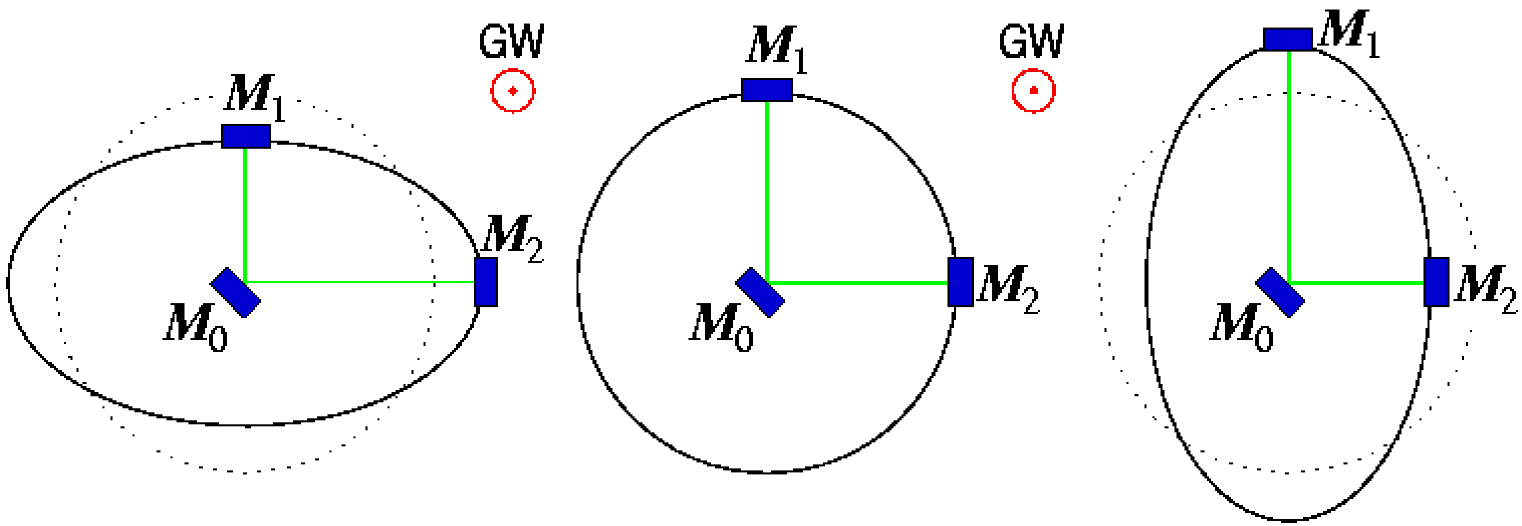


$$\ddot{l}(t)+2\beta\,\dot{l}(t)+\Omega^2\left[l(t)-l_0\right]=\frac{1}{2}\ddot{h}(t)\,l_0$$

GW signals get ***selectively amplified*** near frequency **Ω**.

Interferometric GW detectors

Idea of *interferometric* detectors is to sense δl by *interferometry*:



$$\delta\phi = 2\,\frac{\omega_{\rm laser}}{\Omega}\,h_0\,\sin\frac{\Omega L}{2c}\quad , \qquad \Omega \ll \omega_{\rm laser}$$

Note optimum arm-length: $L = \dfrac{\lambda_{\rm GW}}{2}$

Noise in GW detectors

GW detection is extremely demanding, hence new sources of noise, become important , and pose difficult challenges to Scientists and Engineers alike. For example,

In ***acoustic detectors:***

- Thermal noise → mK cryogenics
- Mechanical noise → seismic isolation
- Sensing and electronics → resonant transducers

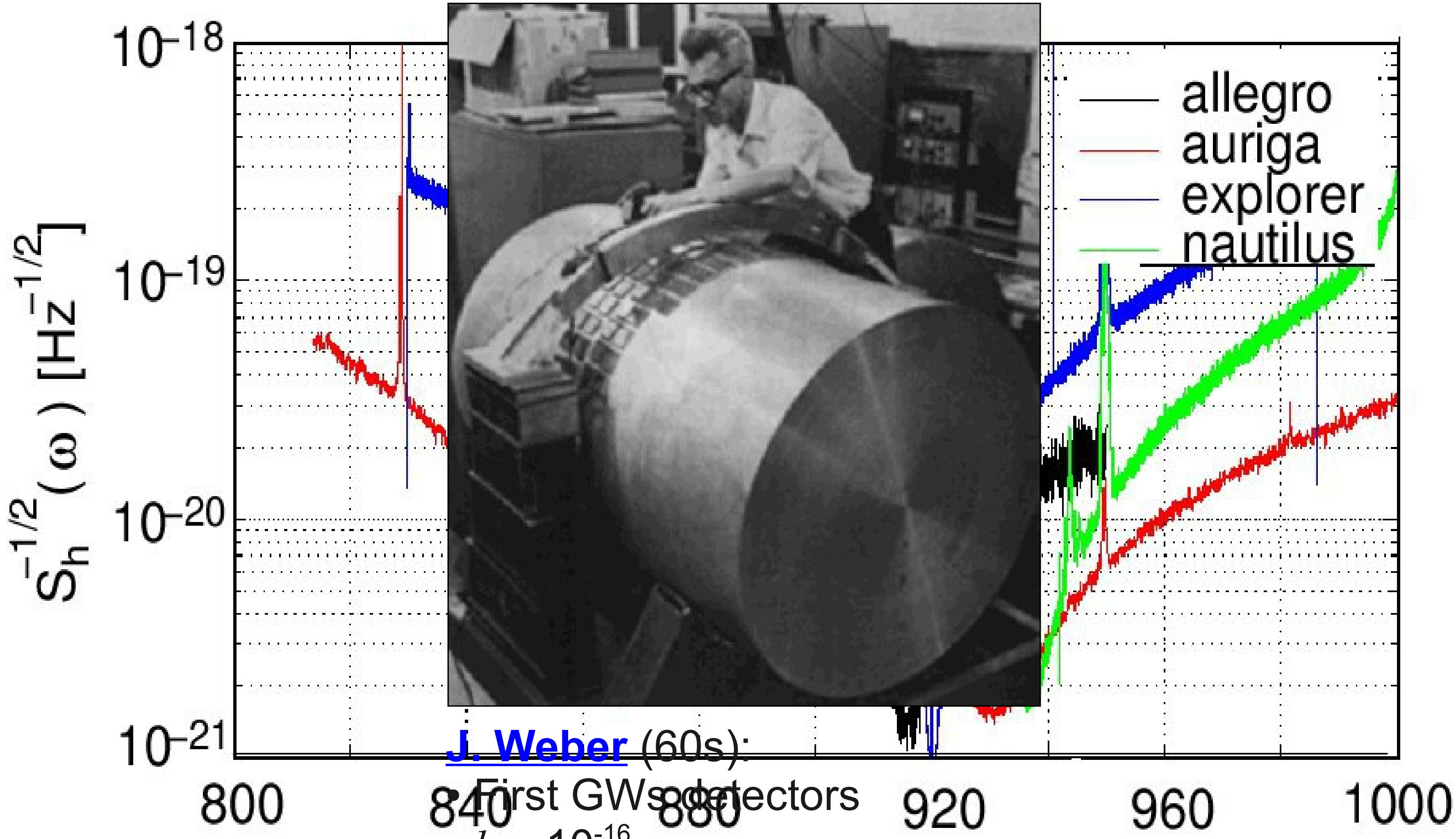
In ***interferometric detectors:***

- Optics → low loss optical parts
- Thermal noise → mirrors coating
- Light scattering → km long vacuum pipes
- Mechanical noise → multi-stage seismic isolation
- Shot noise → high power laser
  → light recycling

In ***all cases:***

- Elaborated Data Analysis techniques and algorithms

Acoustic GW detectors



J. Weber (60s):

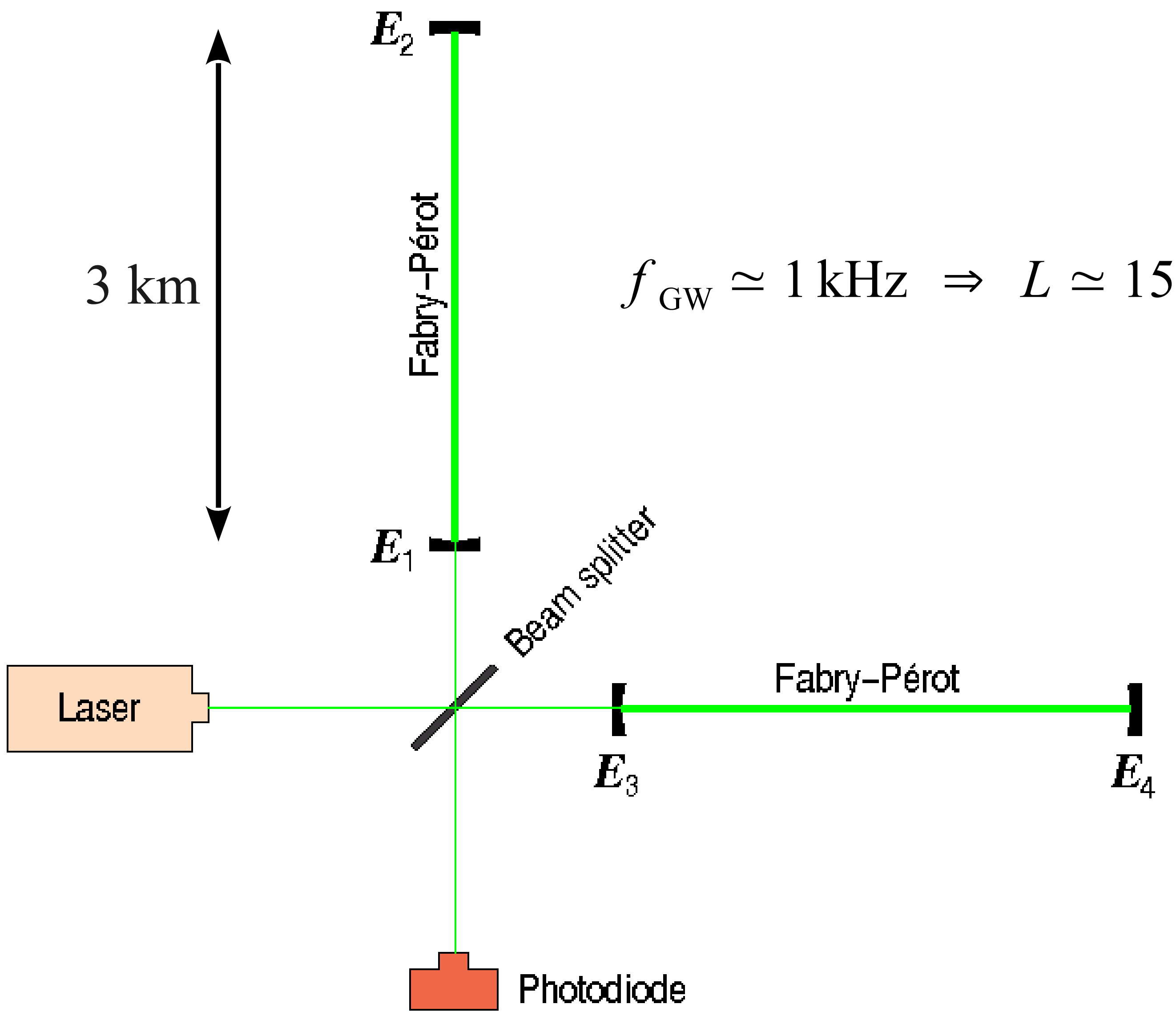
- First GWs detectors
- $h \sim 10^{-16}$
- Claimed he detected GWs

Acoustic GW detectors: NAUTILUS

- Resonance: ~1 kHz
- Single capacitive transducer
- Sensitivity: **~ 5×10^{-21}**

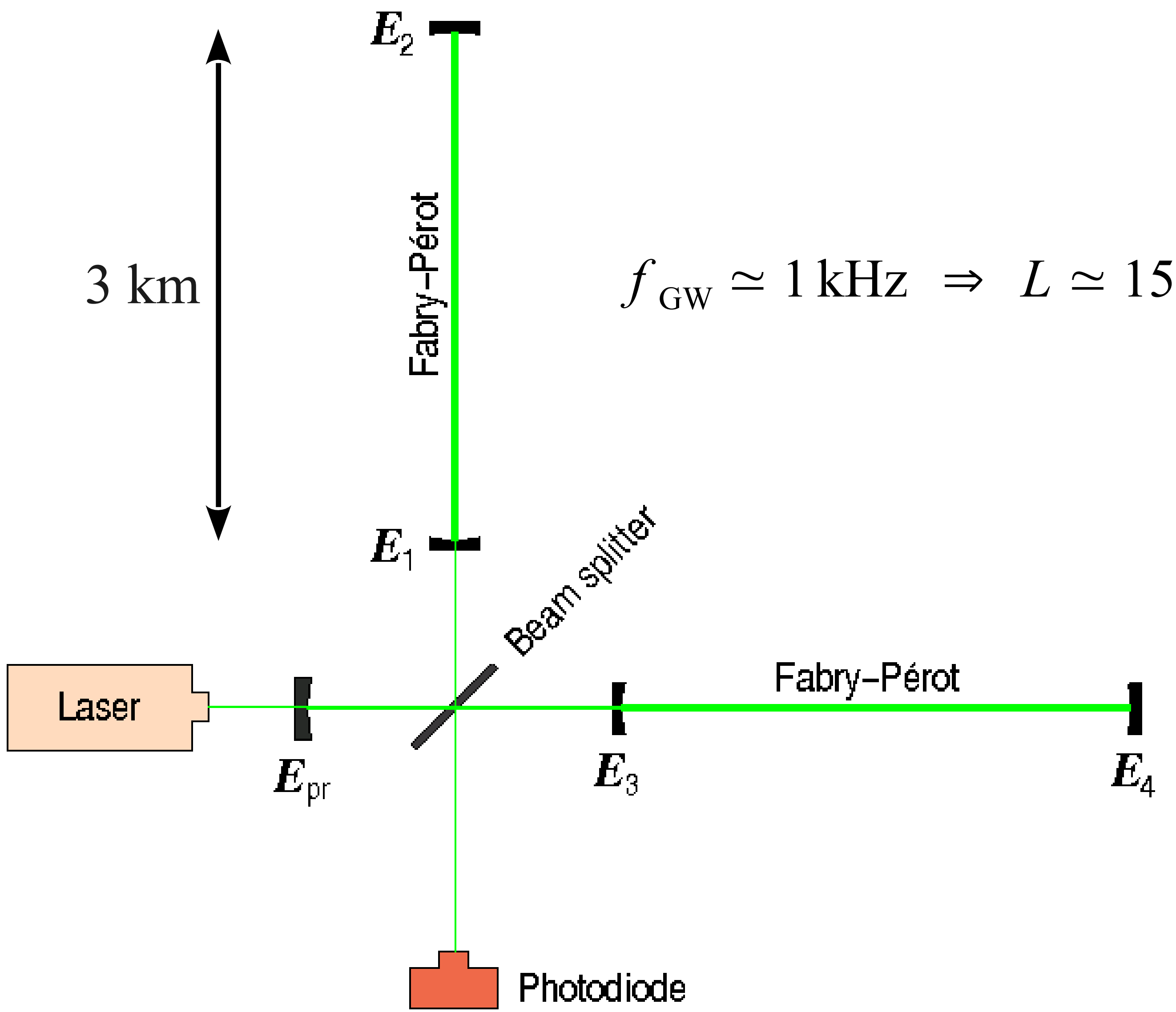
Dilution refrigerator: **50 mK**

Interferometric detectors: recycling



$$f_{\rm GW} \simeq 1\,{\rm kHz} \;\Rightarrow\; L \simeq 150\,{\rm km}$$

Interferometric detectors: recycling



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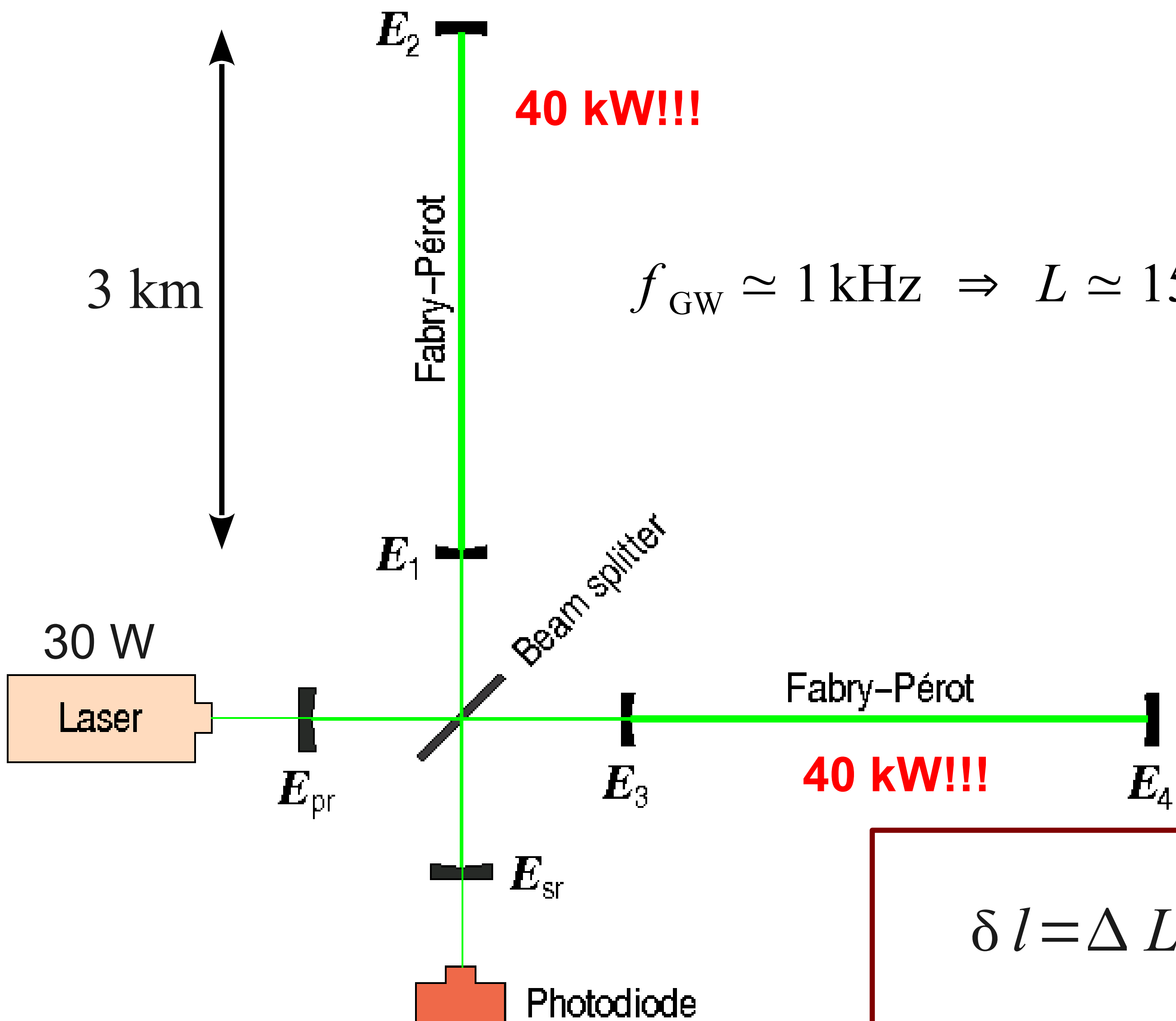
Interferometric detectors: recycling



$$f_{GW} \simeq 1\,\text{kHz} \;\Rightarrow\; L \simeq 150\,\text{km}$$

$$\delta l = \Delta L \frac{\delta \nu}{\nu}$$

Laser noise cancels out!

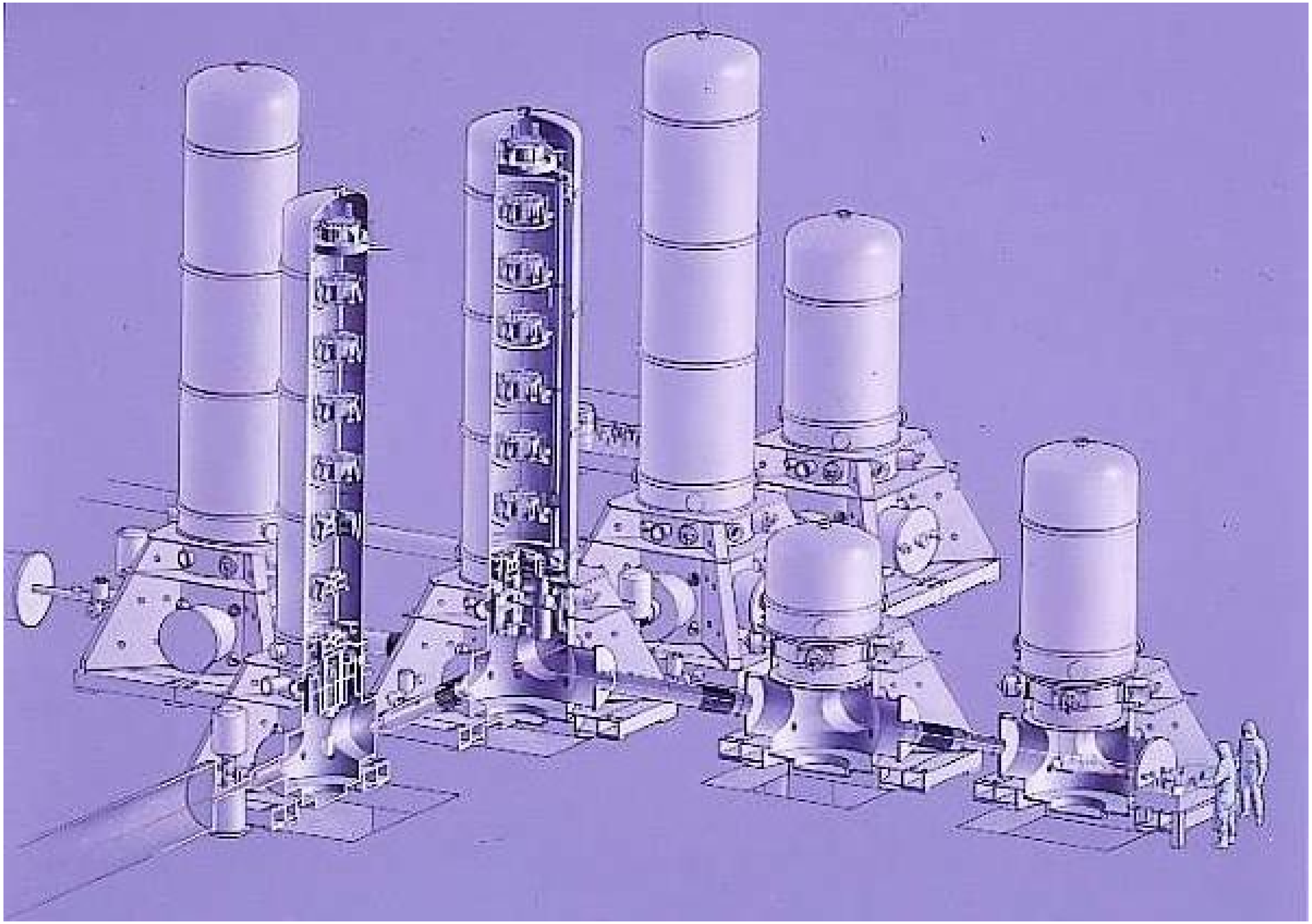
The LIGO site

HANFORD (WA, USA)

LIVINGSTONE (LA, USA)

The VIRGO site: Cascina (Pisa)

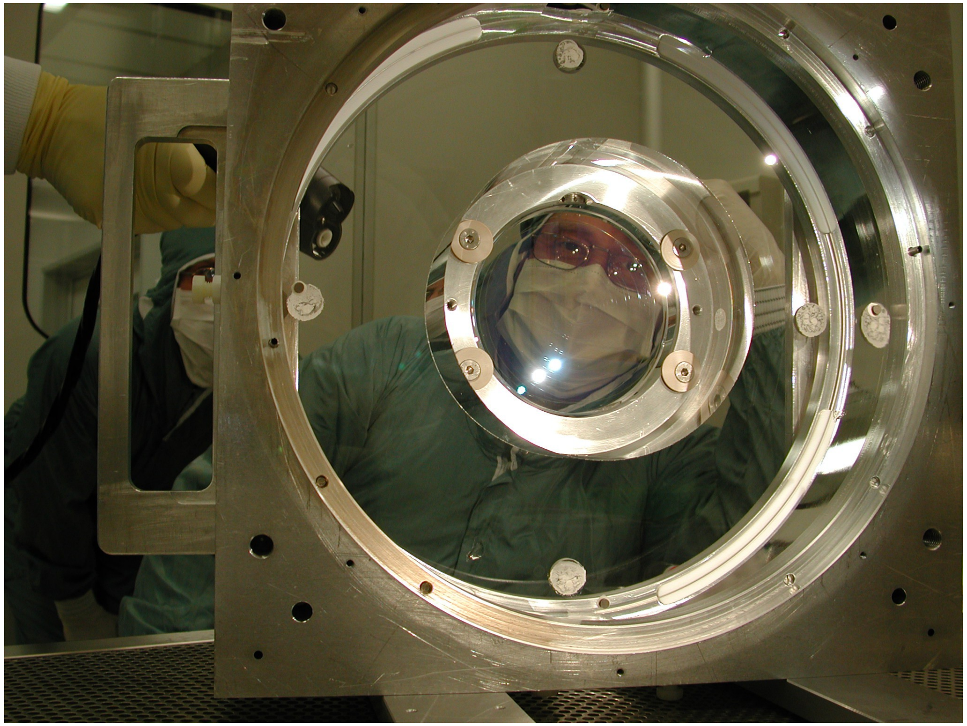
The VIRGO site: Cascina (Pisa)



Suspension towers, central building

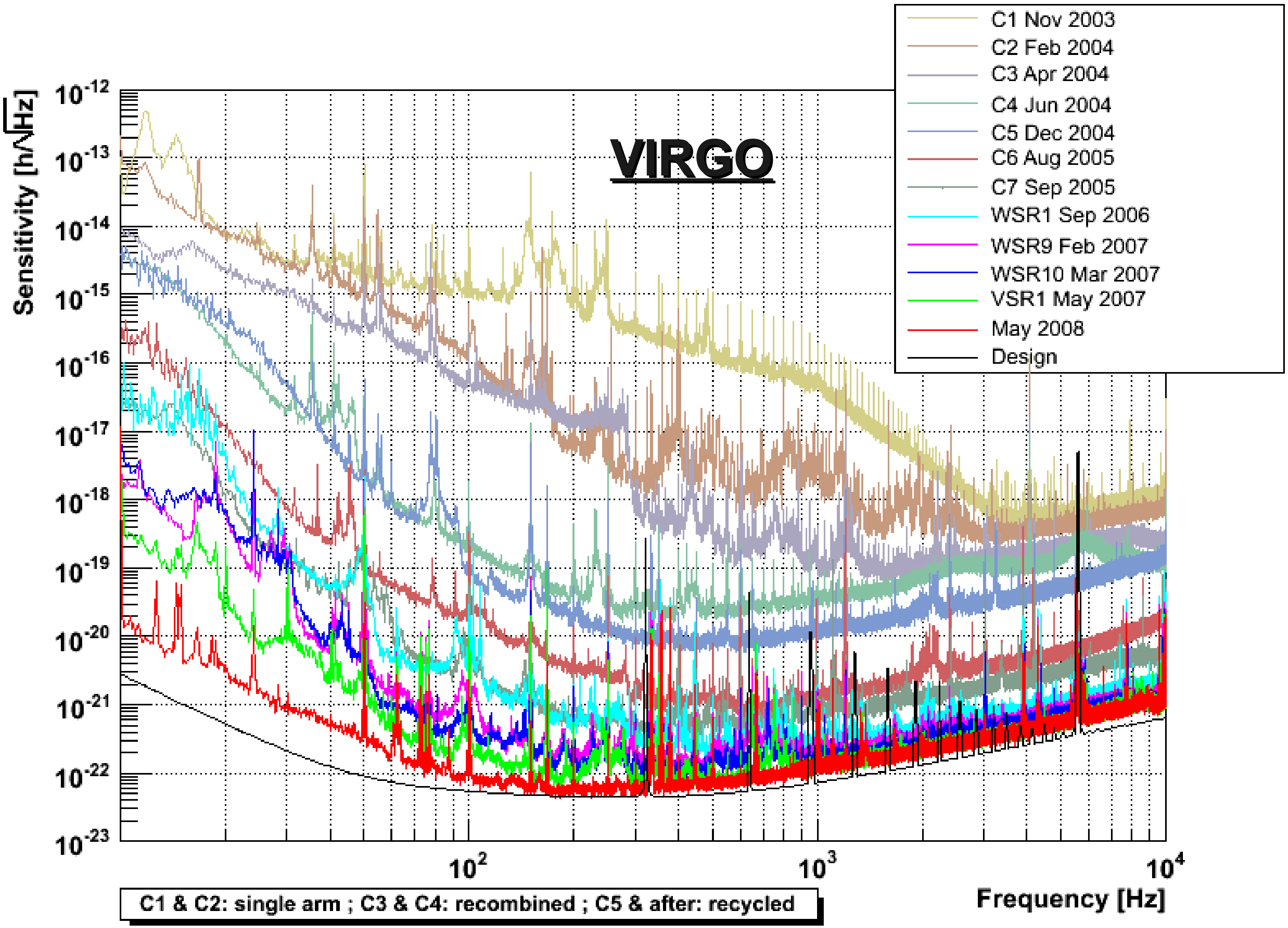
The VIRGO site: Cascina (Pisa)

North pipe

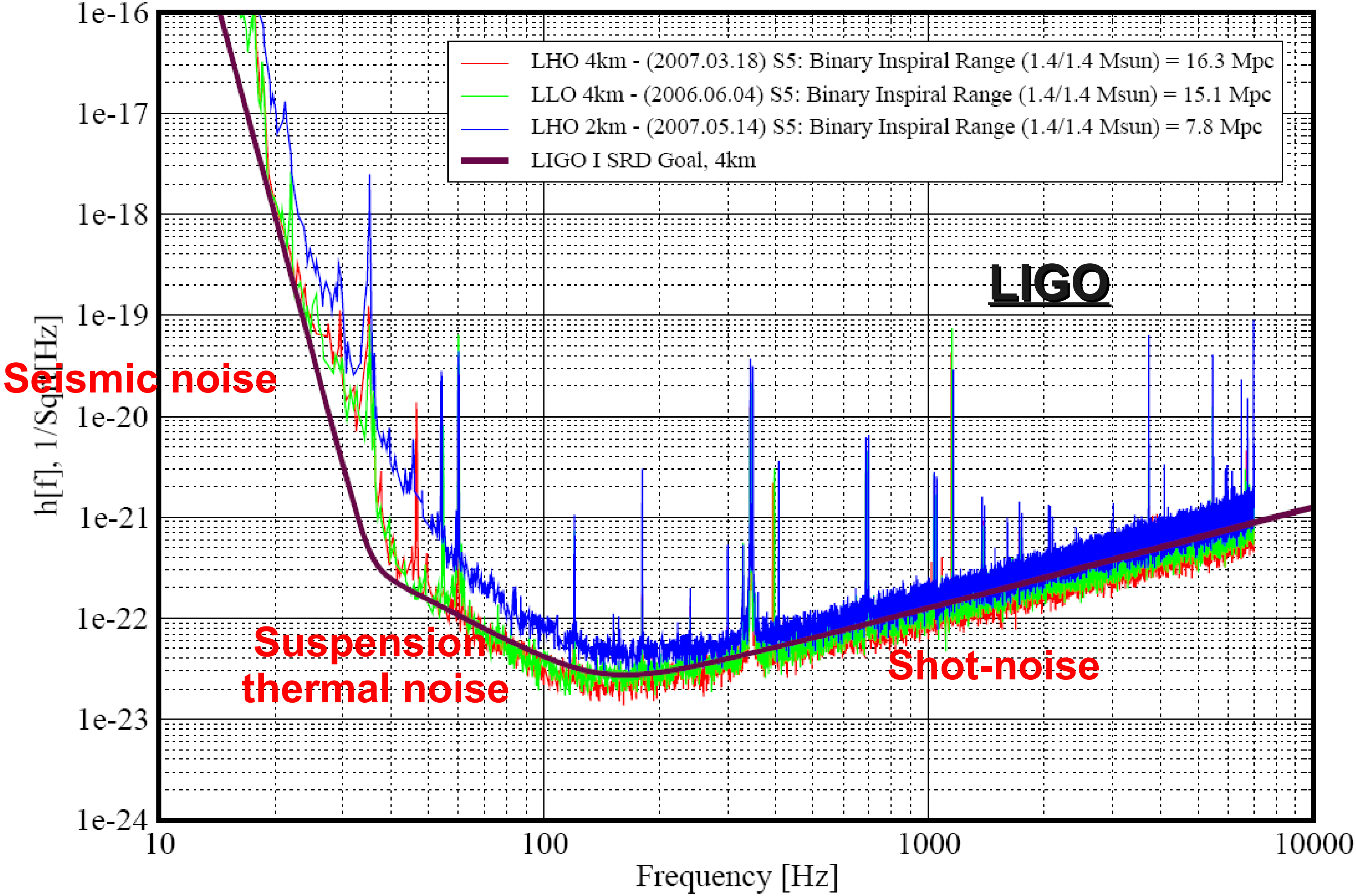


Power recycling mirror

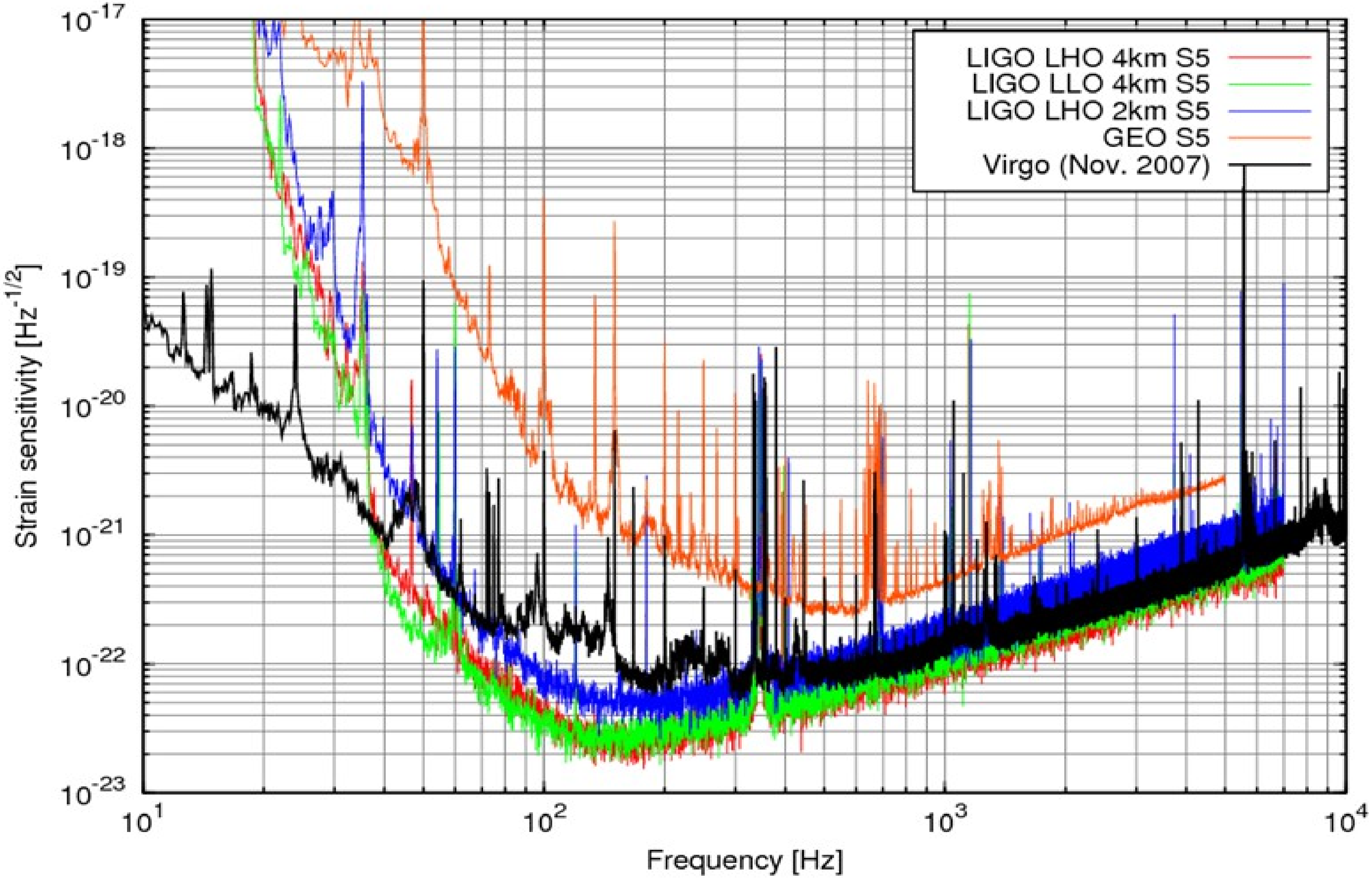
Interferometric detectors: sensitivity



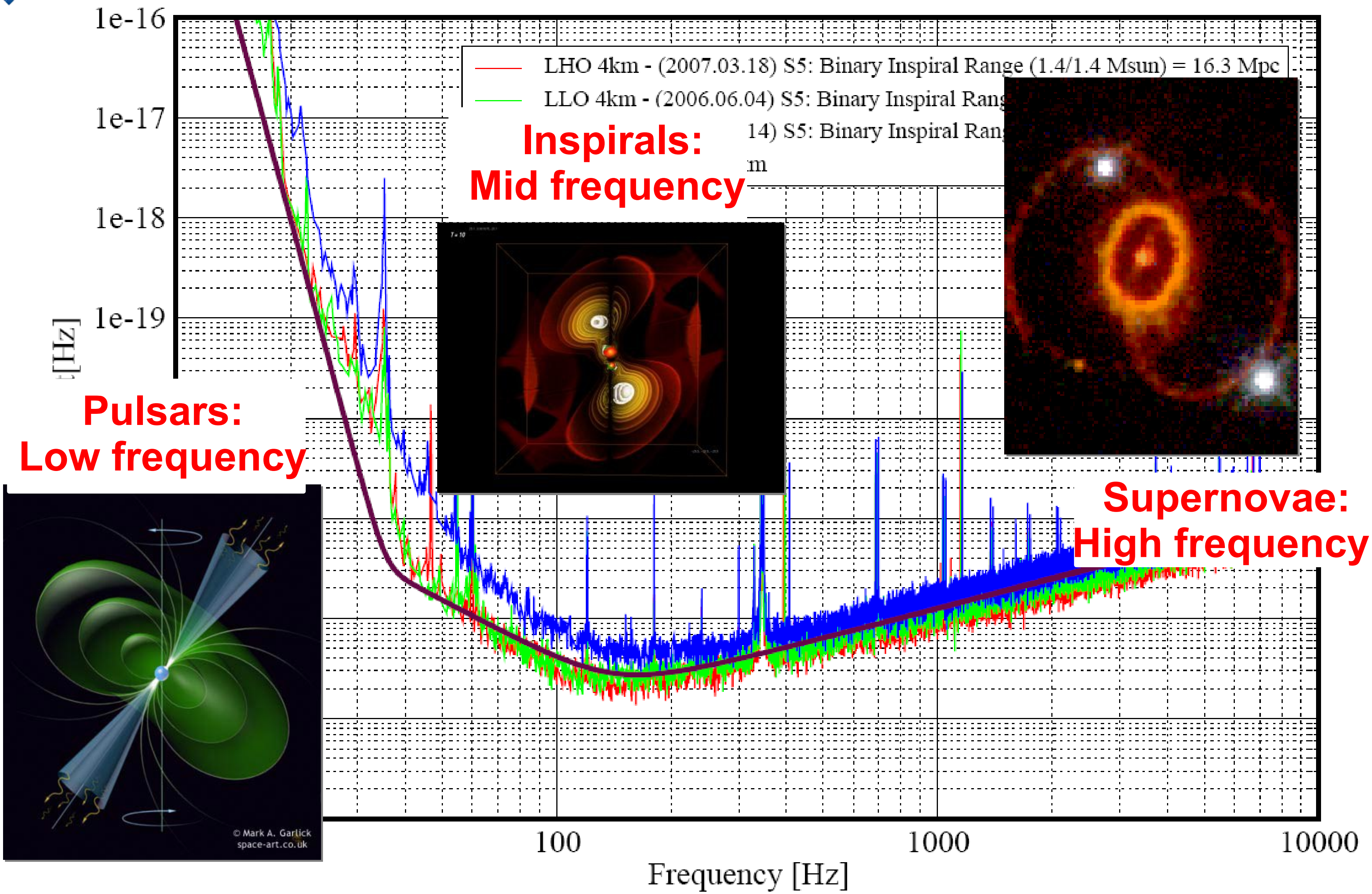
Interferometric detectors: sensitivity



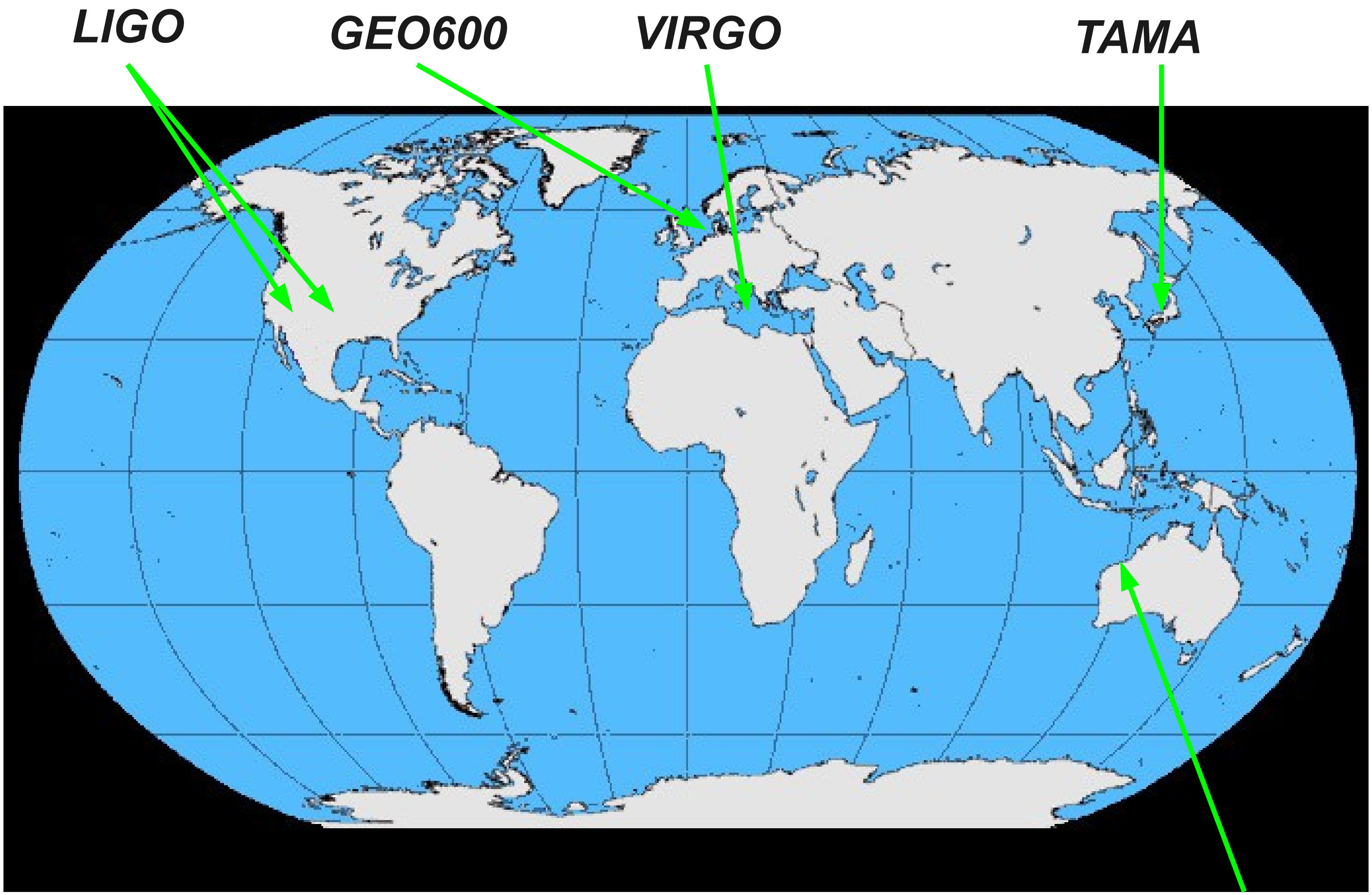
Compared sensitivities



Interferometric detectors: AP targets



Worldwide collaboration



ADVANCED LIGO and ADVANCED VIRGO are on their way

Ground based GW telescopes

Resonance frequency in an elastic solid: $f = L^{-1} v_{\text{sound}}$

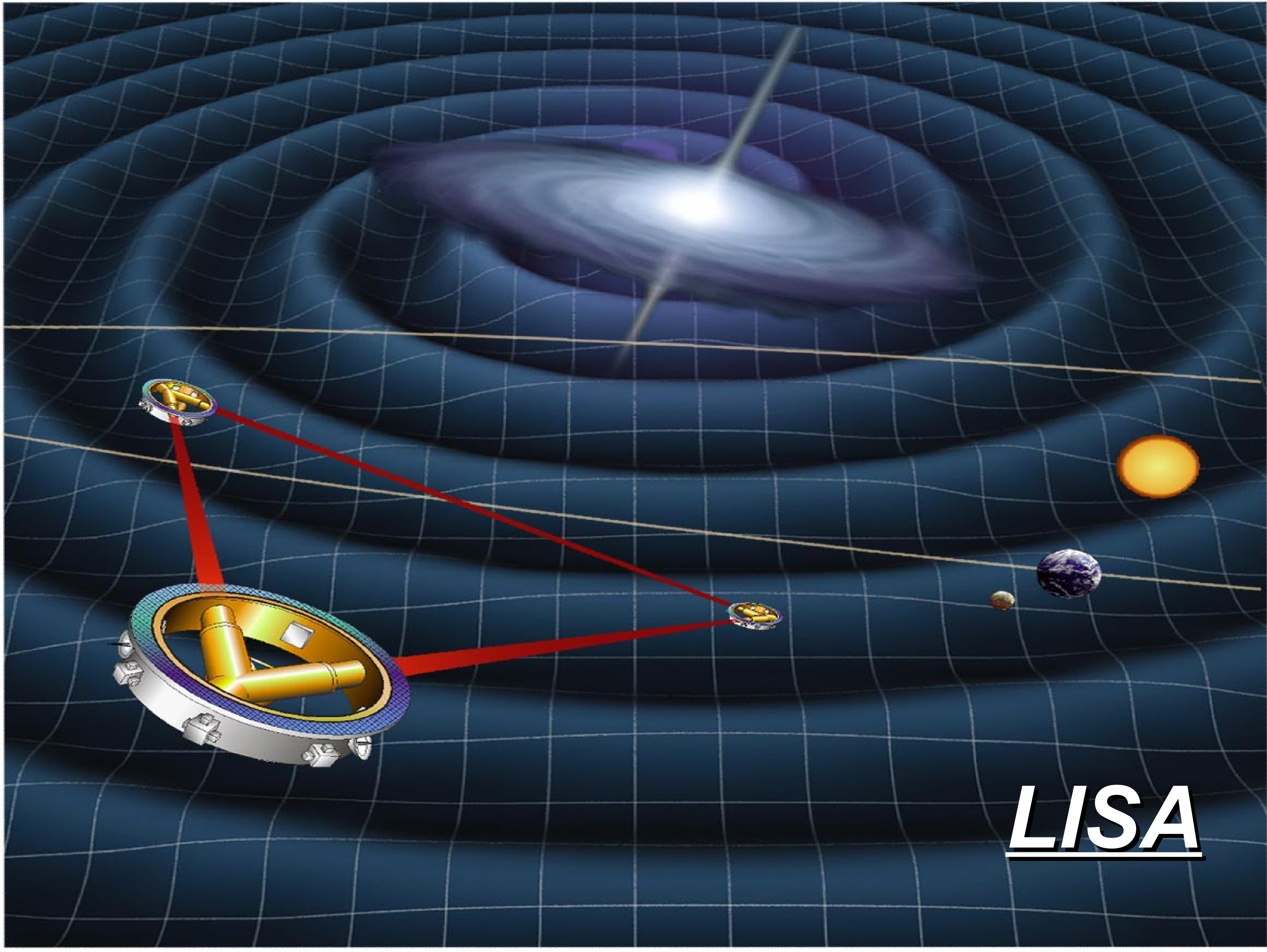
Typically, $v_{\text{sound}} \sim 1000$ m/s, f=1 kHz ➔ **$L \sim 1$ m**

In a *LIGO/VIRGO*-like GW detector, size is an issue to reach low frequency sensitivity, but gravity gradients and seismic noise set the real limits. We end up in a sort of optimum size of **$L_{\text{arm}} \sim$ 1-10 km** and a frequency band again around 100-1000 Hz .

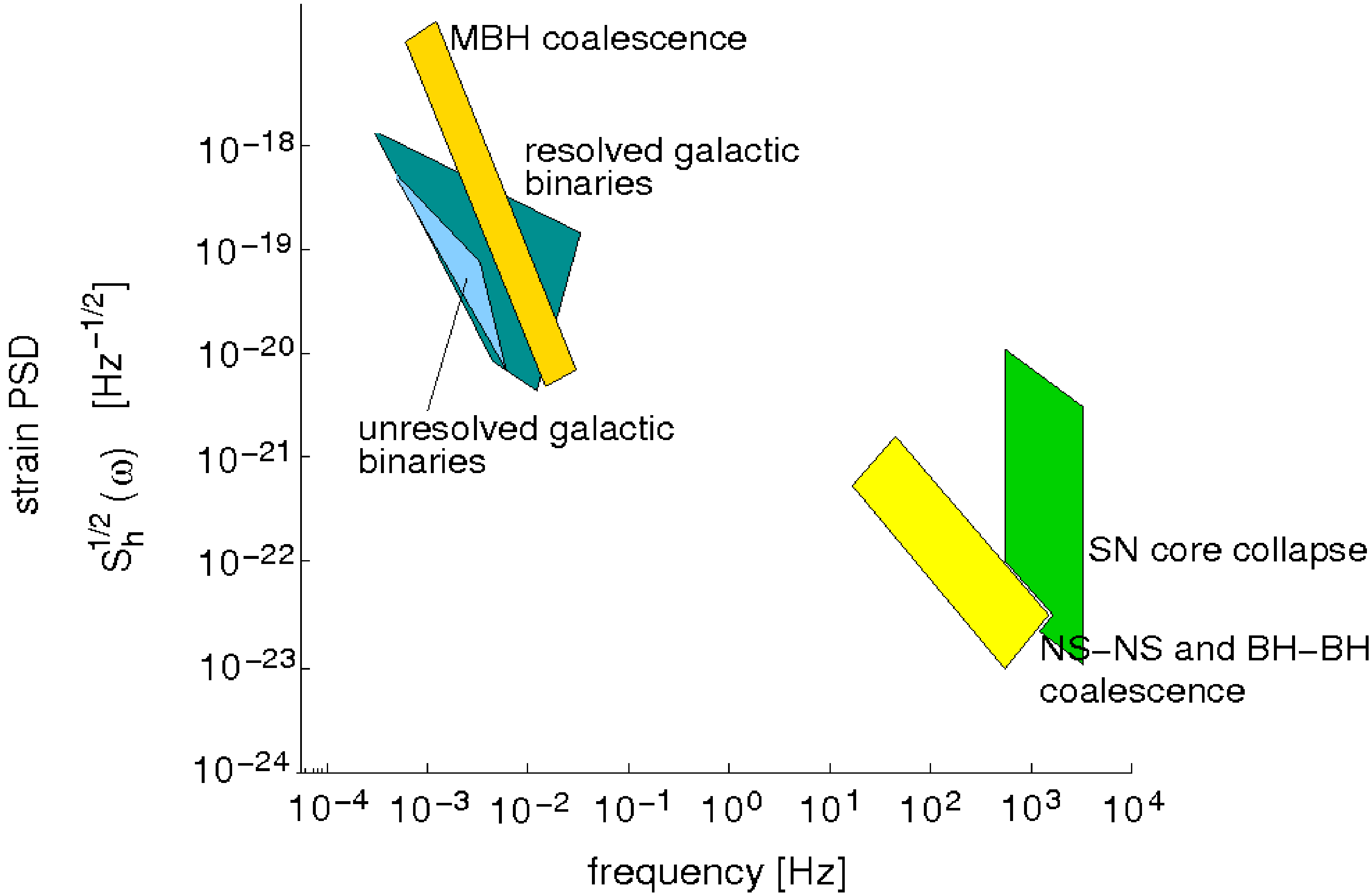
***A significant shift towards lower band GW frequencies requires significant*:**

- ***up-scaling of current detector size***
- ***quieter observatory environment***

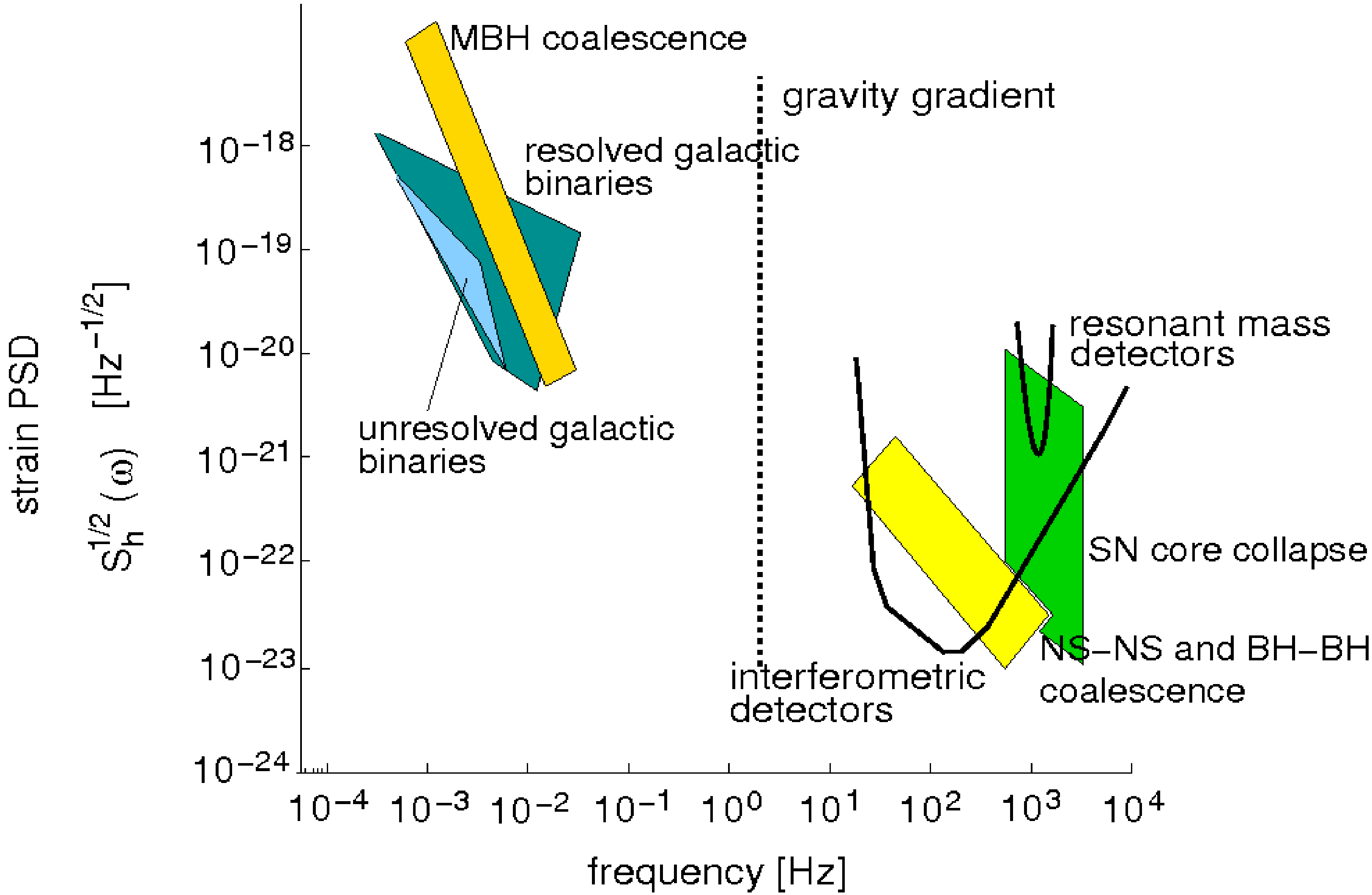
We need to go out to space…


LISA

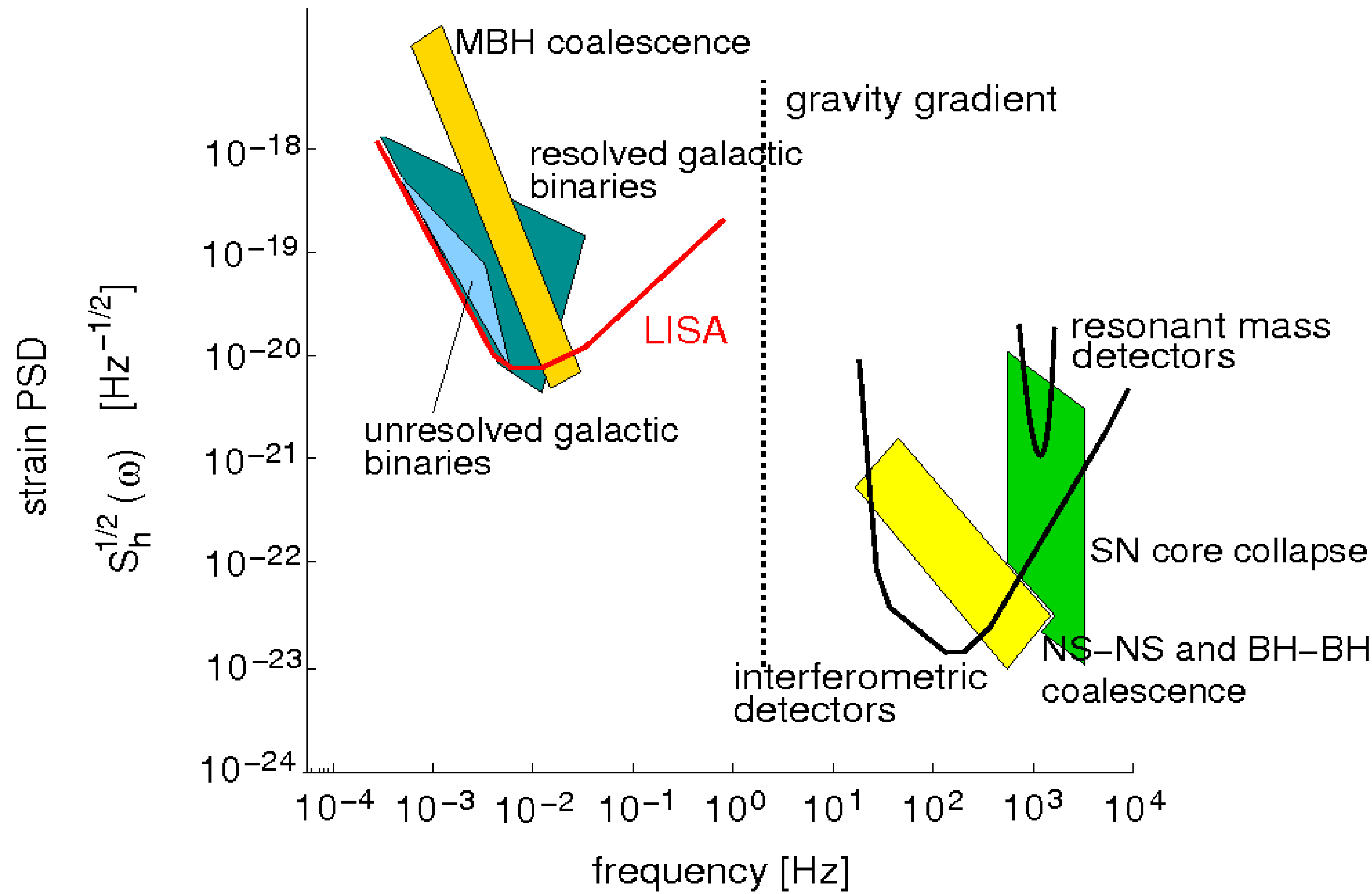
Some relevant GW sources



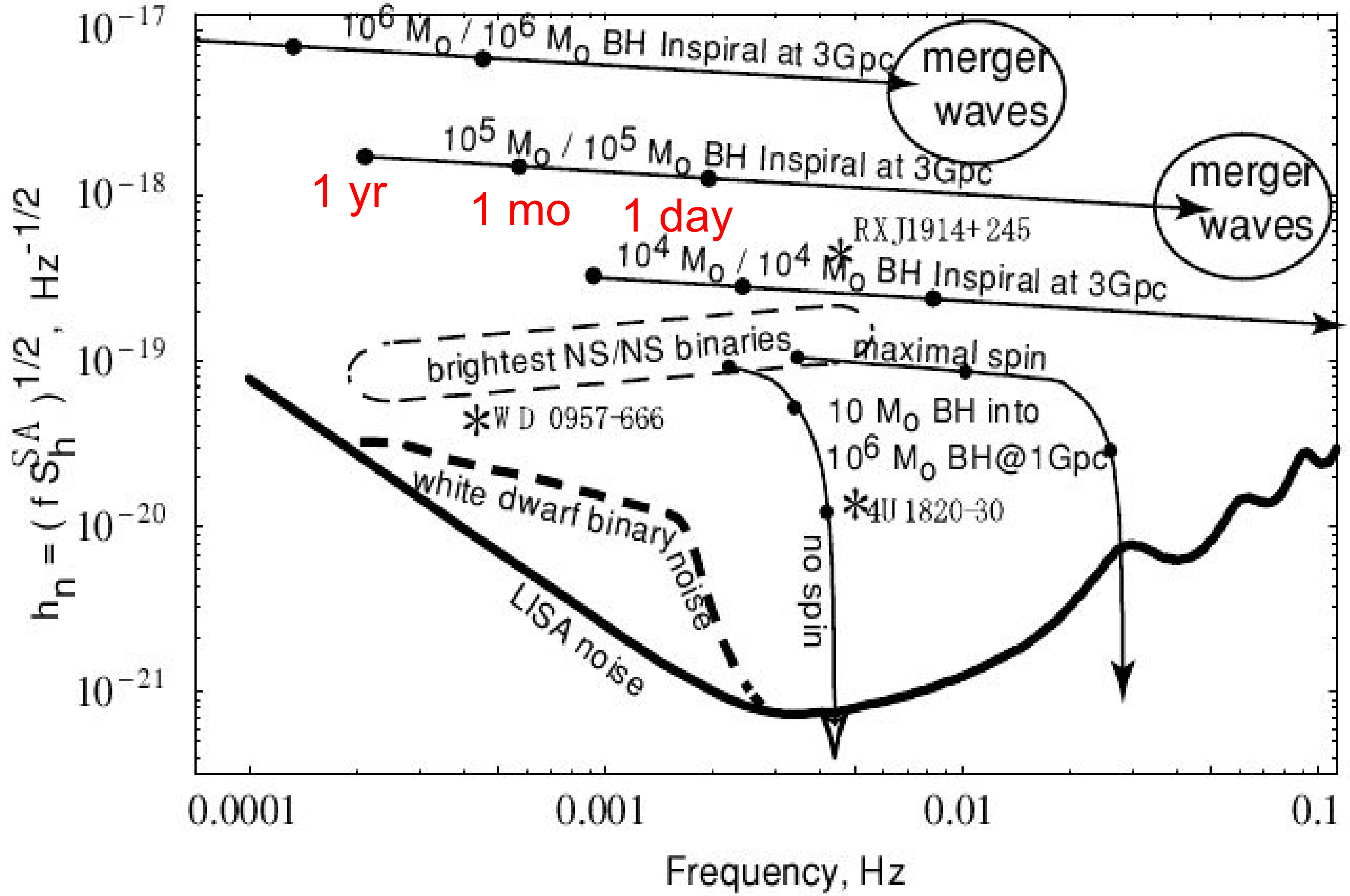
Some relevant GW sources



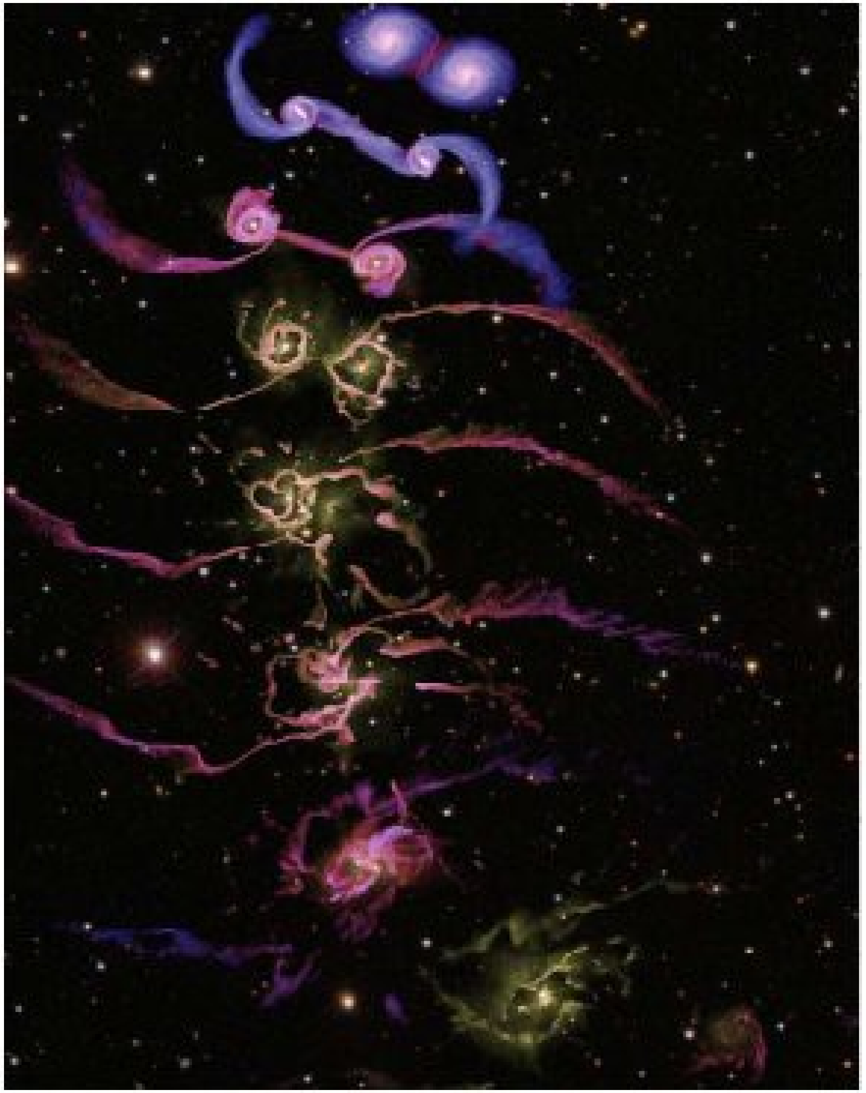
Some relevant GW sources

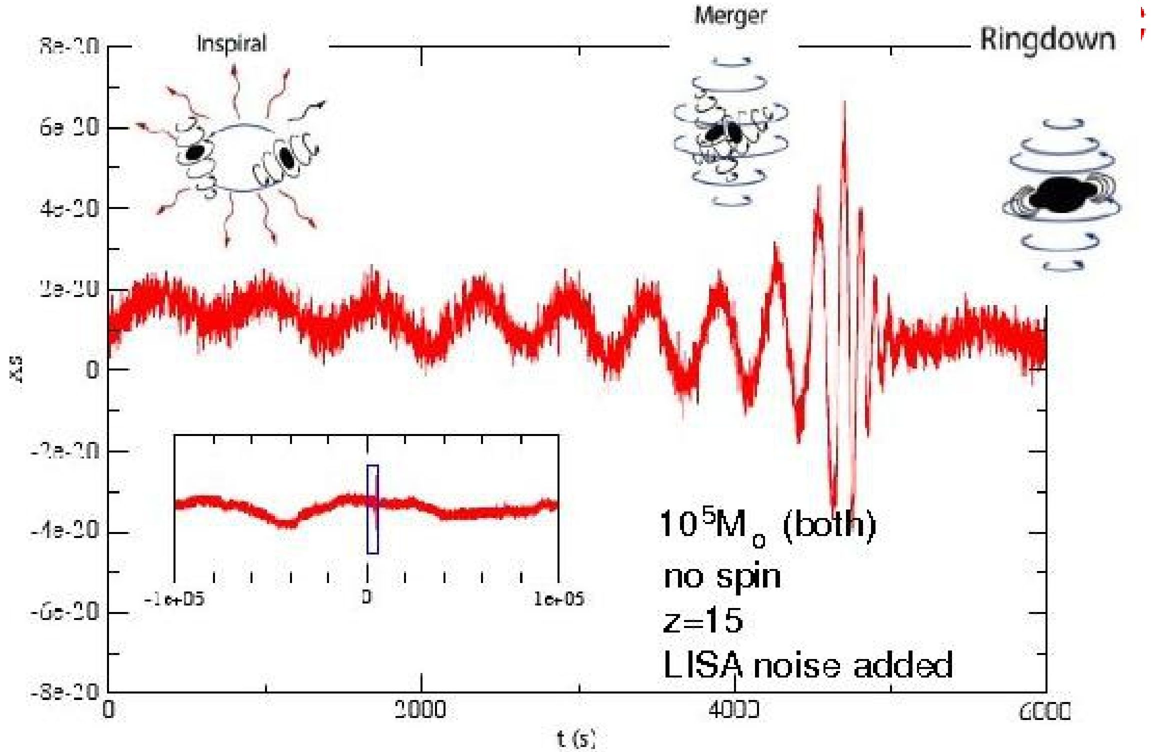


More GW sources



Binary system of galaxies



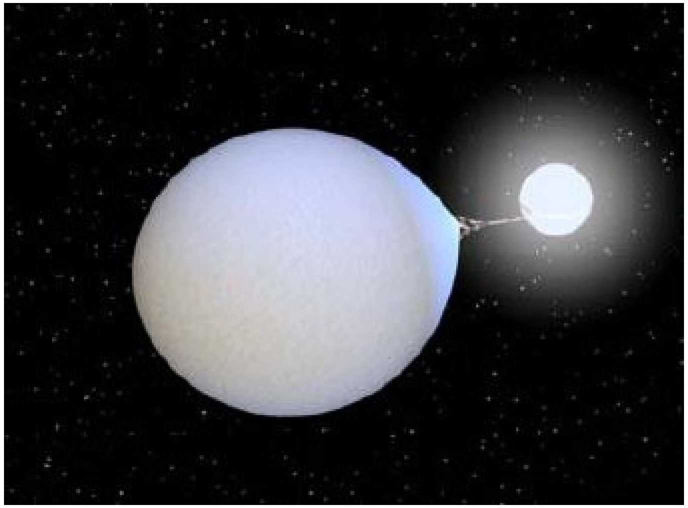


· Formation, growth and merger: history of galaxies formation
· SMBH: **1/year**
· MBH to SMBH: **100/year**
· System properties (mass, spin, orientation...)

EMRIs

- 10M BH and 10^6M MBH
- GR testbed: precision probes of Kerr metric

Galactic binaries



- Verification binaries (>20)
- Mass, distance, orbits,...
- History of stars in our galaxy
- Too many: 10^5 (WDB noise)

Others:

- Stochastic background
- Strings
- Dark energy
- **Unexpected!**

LISA's secured galactic signals

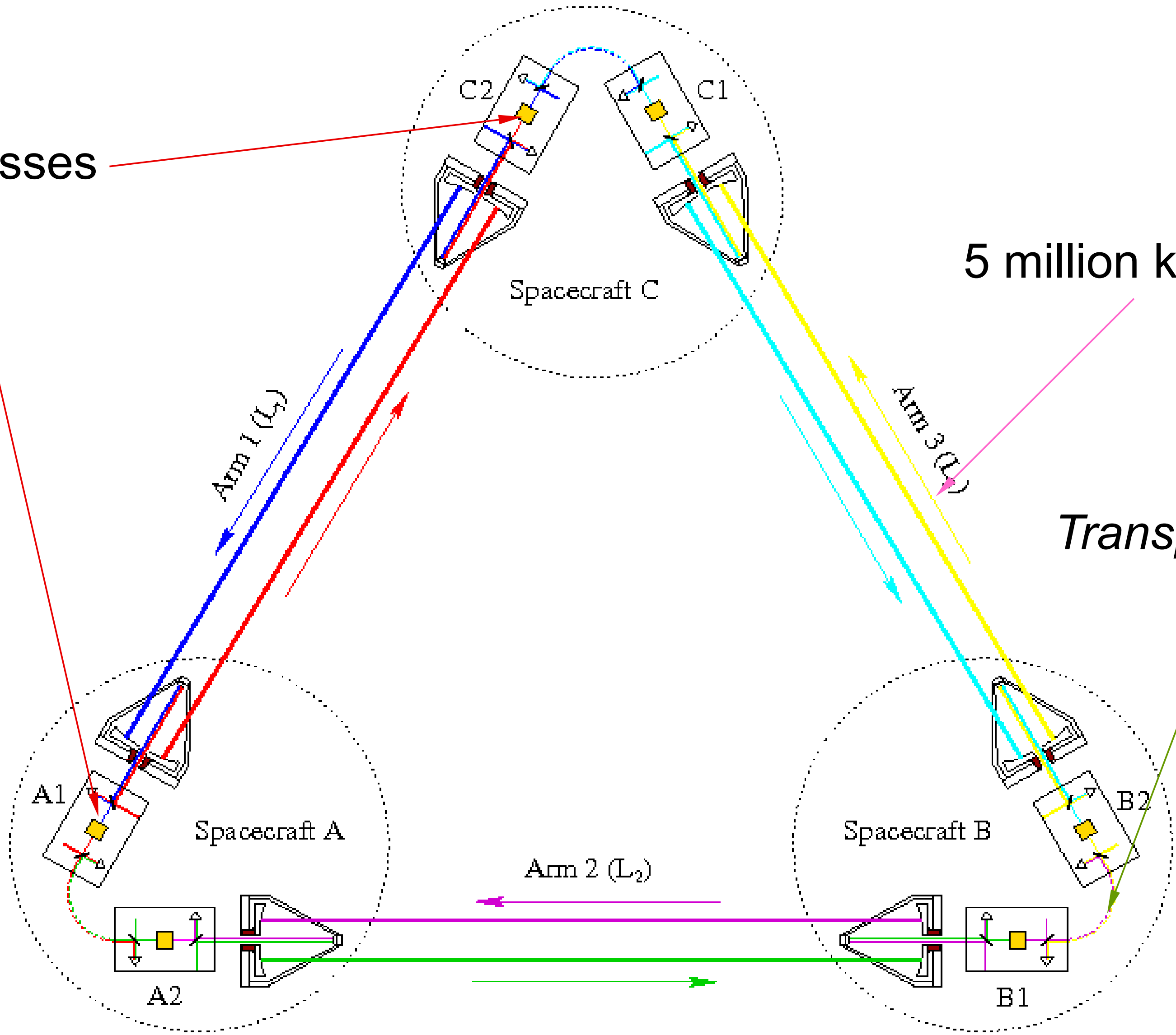
Class	Source	Dist/pc	f/mHz	$M_1/M_\odot$	$M_2/M_\odot$	$\tau/10^8$ y	$h/10^{-22}$
WD+WD	WD 0957-666	100	0.38	0.37	0.32	2	4
	WD 1101+364	100	0.16	0.31	0.36	20	2
	WD 1704+481	100	0.16	0.39	0.56	13	4
	WD 2331+290	100	0.14	0.39	>0.32	<30	>2
WD+sdB	KPD 0422+4521	100	0.26	0.51	0.53	3	6
	KPD 1930+2752	100	0.24	0.50	0.97	2	10
Am CVn	RXJ 0806.3+1527	300	6.2	0.4	0.12	–	4
	RXJ 1914+245	100	3.5	0.6	0.07	–	6
	KUV 05184-0939	1000	3.2	0.7	.092	–	0.9
	AM CVn	100	1.94	0.5	.033	–	2
	HP Lib	100	1.79	0.6	0.03	–	2
	CR Boo	100	1.36	0.6	0.02	–	1
	V803 Cen	100	1.24	0.6	0.02	–	1
	CP Eri	200	1.16	0.6	0.02	–	0.4
	GP Com	200	0.72	0.5	0.02	–	0.3
LMXB	4U 1820-30	8100	3.0	1.4	<0.1	–	0.2
	4U 1620-67	8000	0.79	1.4	<0.03	–	.06
W UMa	CC Com	90	0.105	0.7	0.7	–	6

LISA concept

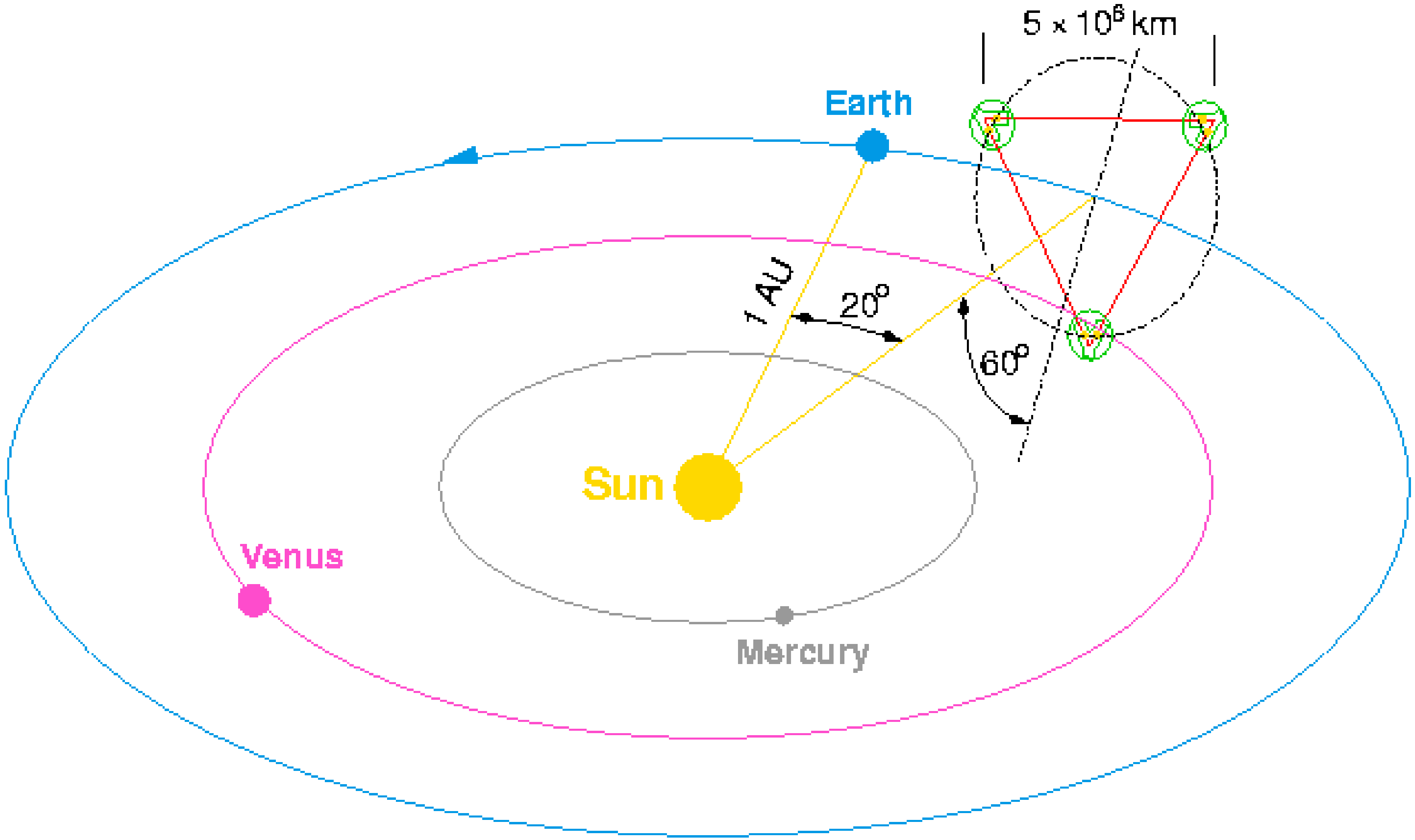
Test masses

5 million km, 30 mHz

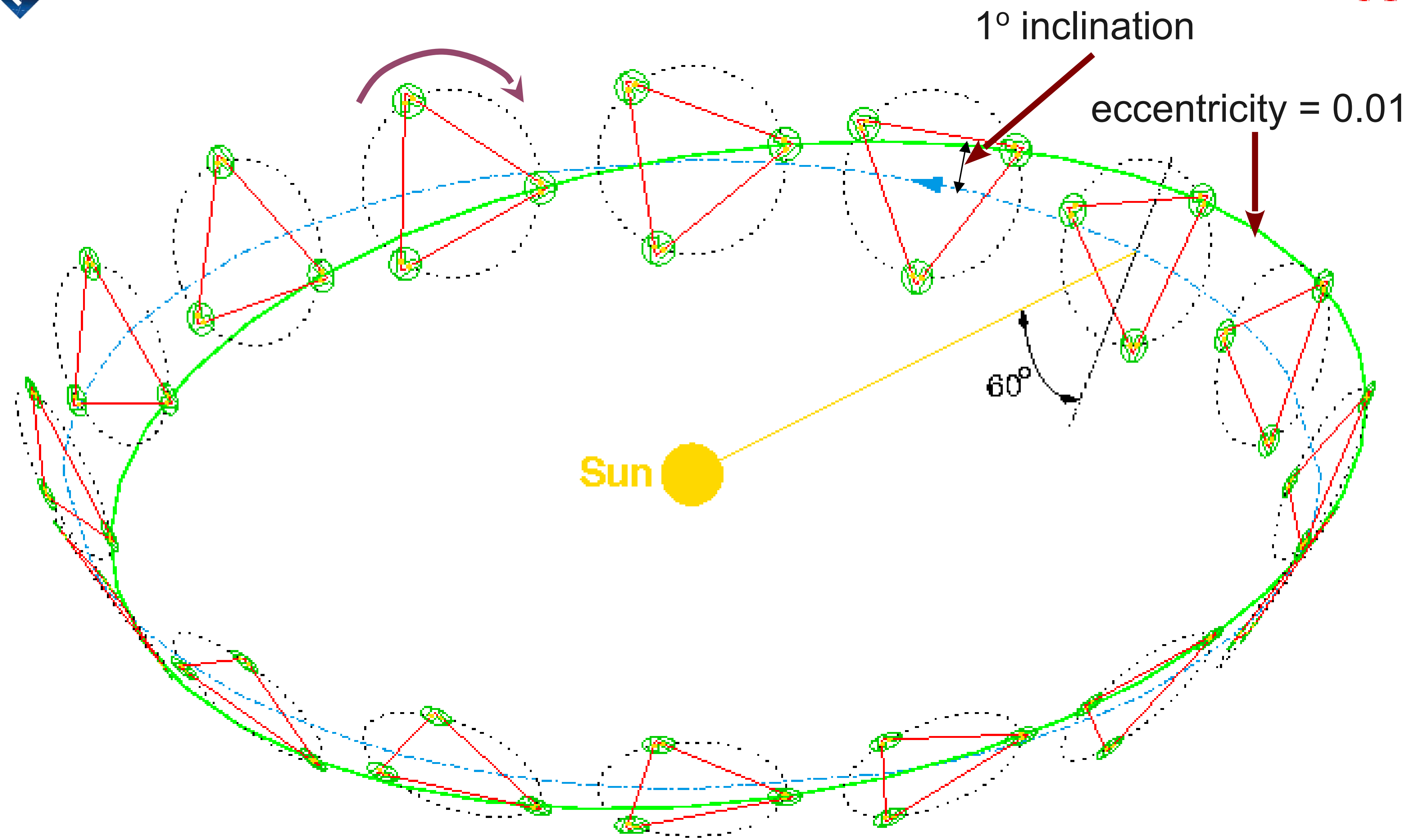
Transponder scheme



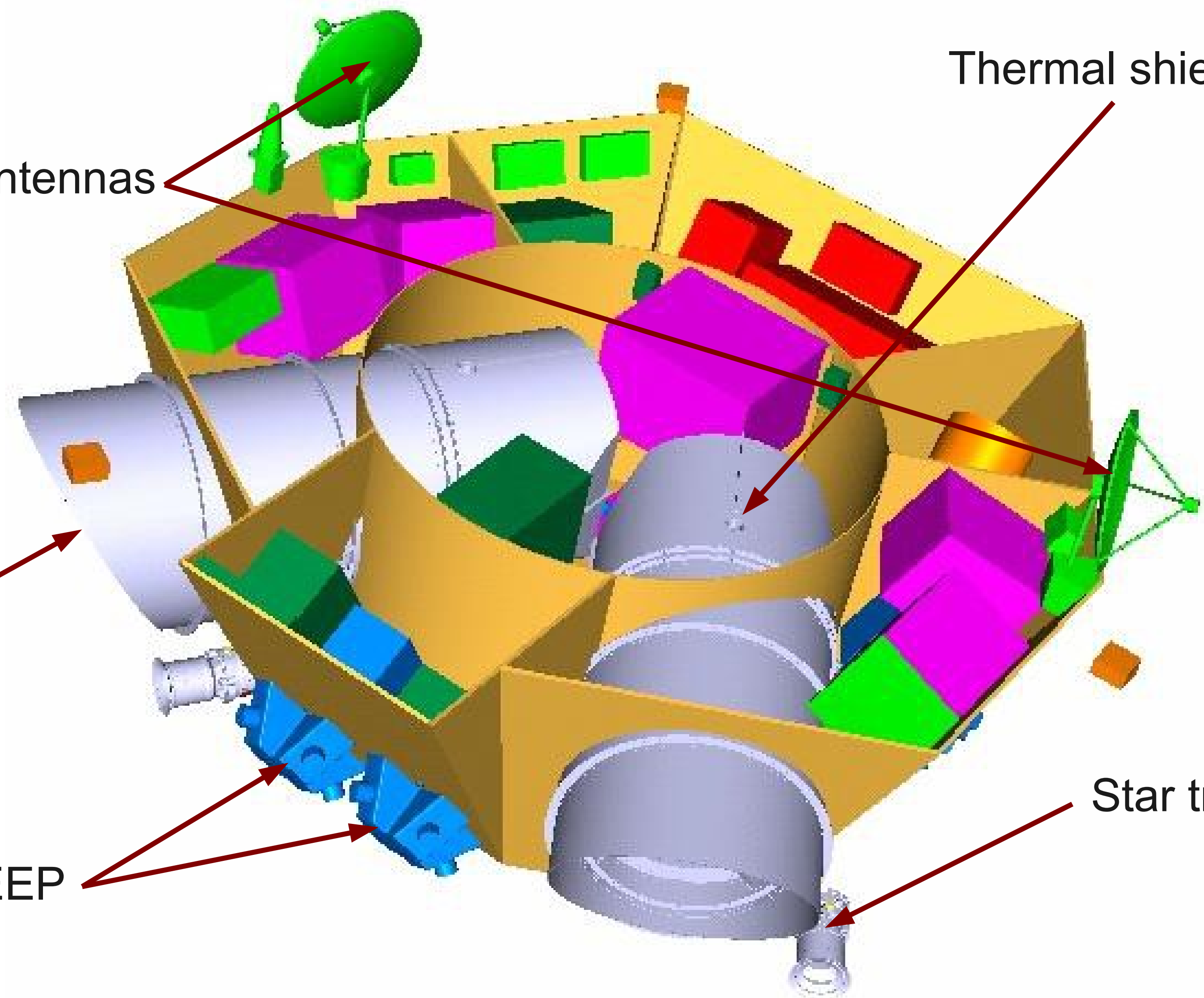
LISA orbit



LISA orbit



The LISA science-craft



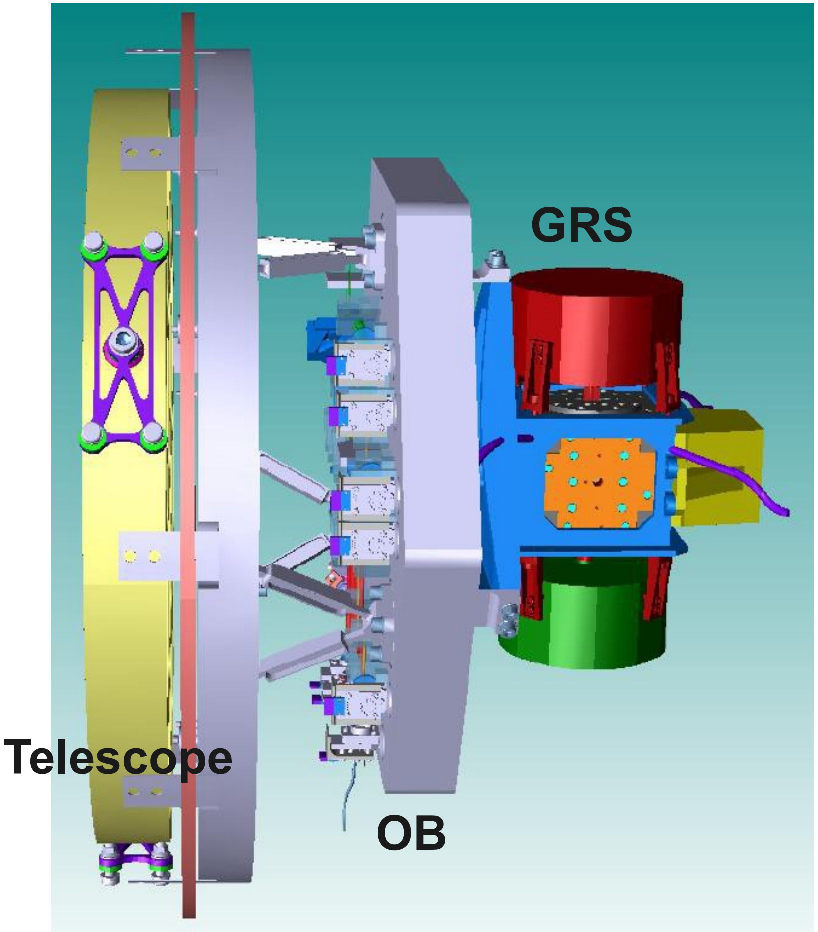
The LISA core instruments

There are two subsystems of major conceptual relevance:

- The *drag-free* subsystem
- The *optical metrology* subsystem

Each of these has in turn various other important subsystems:

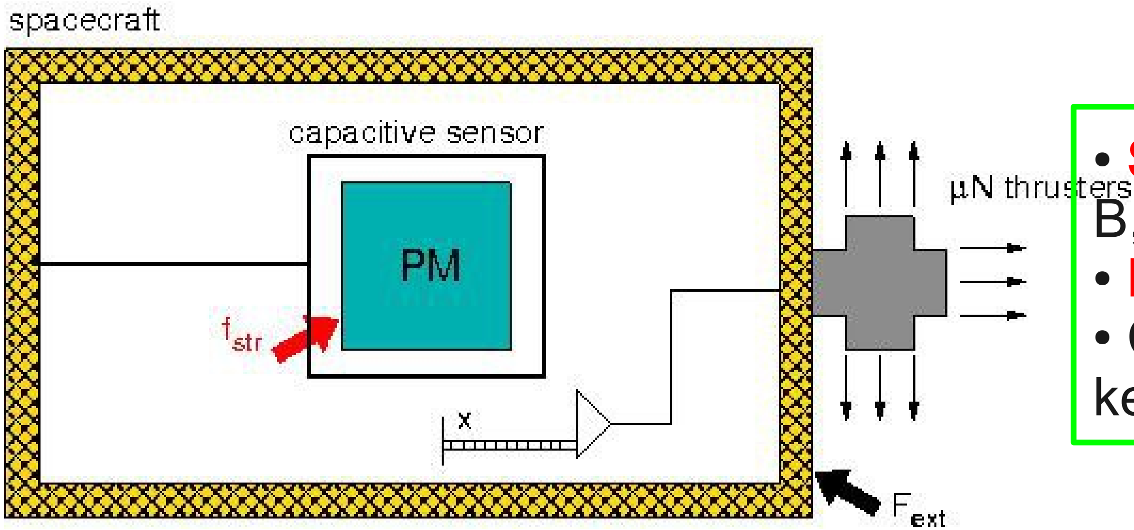
- *Drag-free*:
    - TM position sensors (capacitive)
    - Micro-thruster actuators
    - Caging mechanisms
- *Optical Metrology*:
    - Laser assembly
    - Optical bench
    - Phasemeter



The Drag-free: GRS

Proof masses have to be in ***free-fall***: only subjected to inertial forces:

$$\delta a(f) < 3\times 10^{-15}\left[1+\left(\frac{f}{8\,\mathrm{mHz}}\right)^2\right]\frac{\mathrm{m}}{\mathrm{s}^2}\,\frac{1}{\mathrm{Hz}^{1/2}}\,,\ 0.1\,\mathrm{mHz} < f < 1\,\mathrm{Hz}$$



- **Stray forces** minimized by design (T, B, g, etc.)
- **External forces** shielded by SC
- Capacitive sensor+DFACS+thrusters keep SC centered to PM

To be tested by **LISA Pathfinder** in 2014.

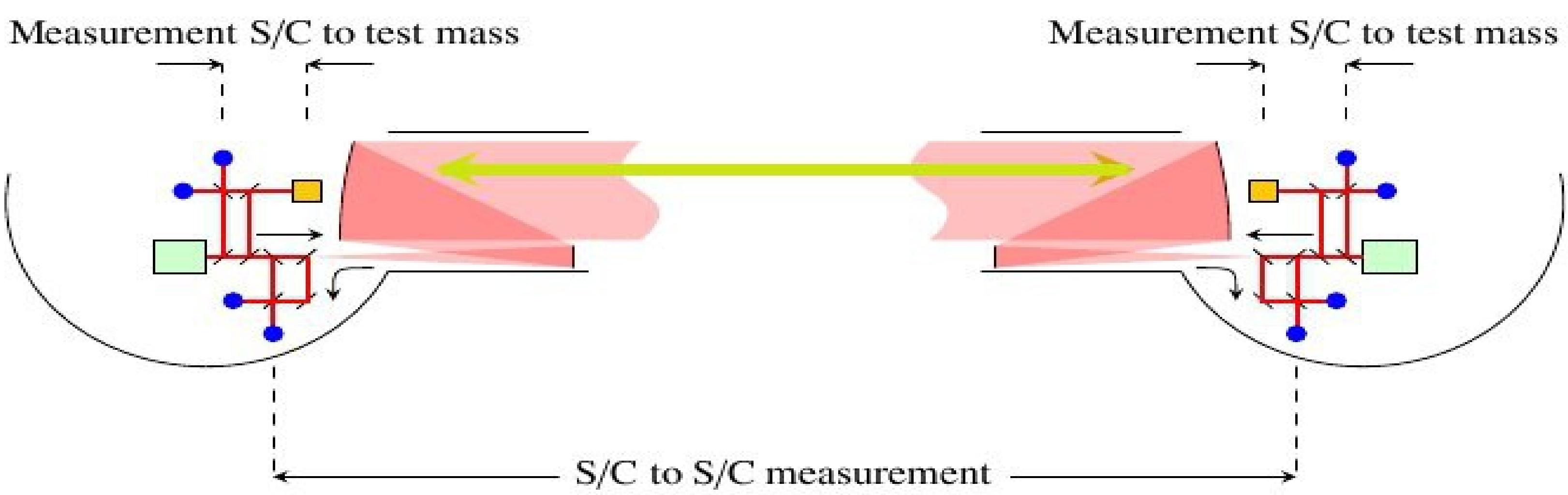
LISA interferometry

Once we have the PM in free-fall we have to measure the distance between them at the picometer level to detect GW:

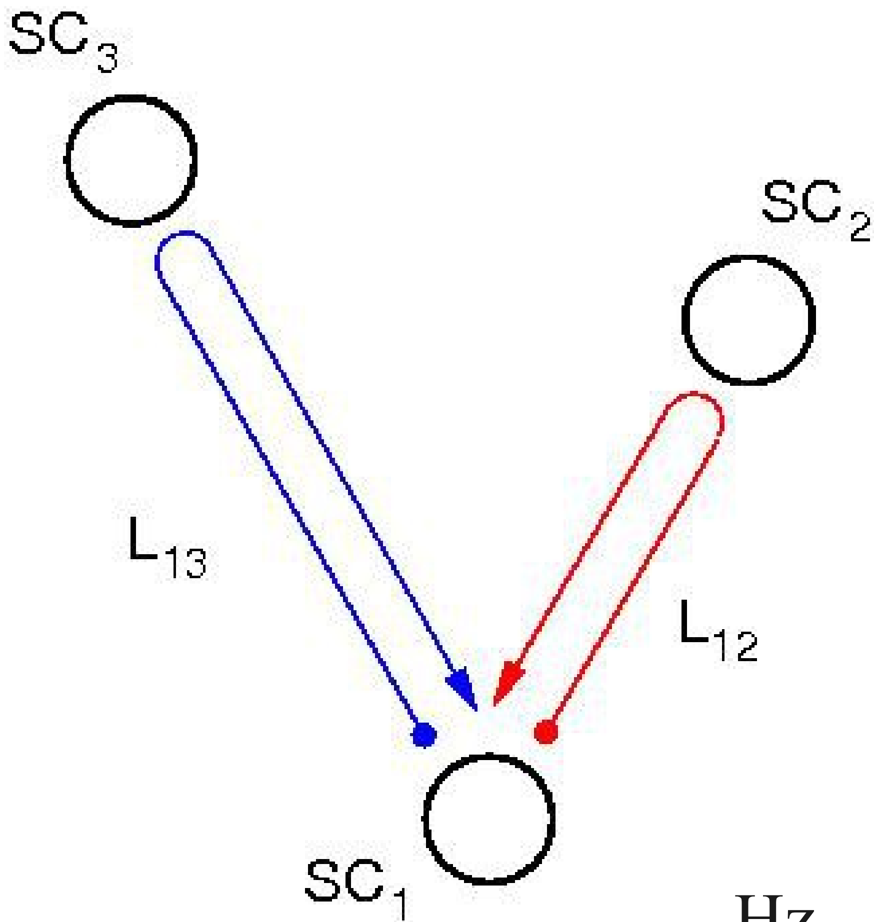
$$\delta l(f) < 18\times 10^{-12}\left[1+\left(\frac{2.8\,\mathrm{mHz}}{f}\right)^{4}\right]^{1/2}\frac{\mathrm{m}}{\mathrm{Hz}^{1/2}},\ 0.1\,\mathrm{mHz} < f < 1\,\mathrm{Hz}$$

Inteferometry is split in:

- **PM-SC interferometer**
- **SC-SC interferometer**



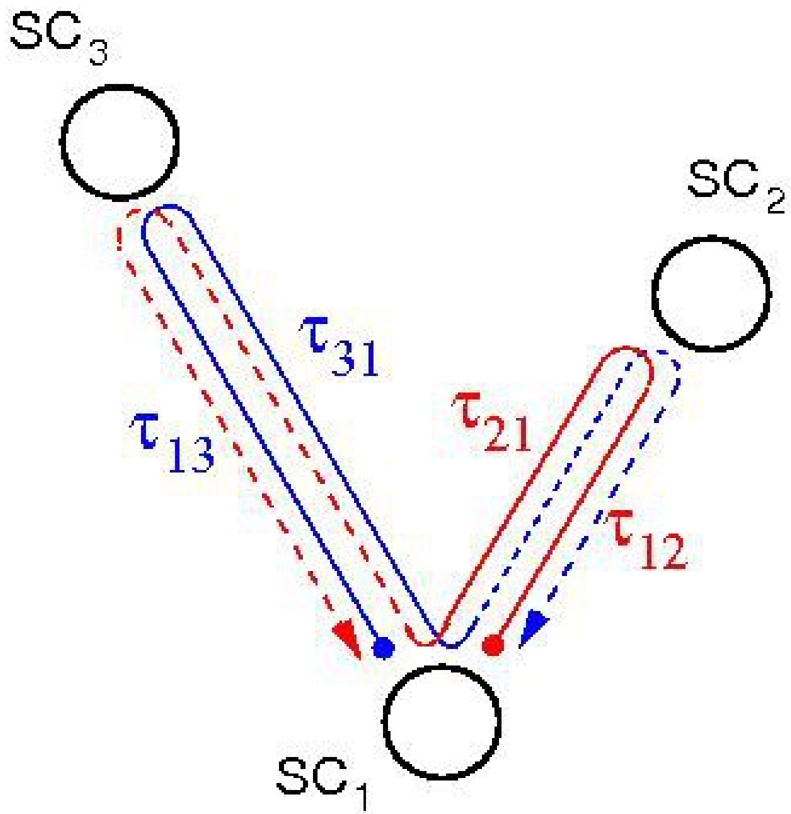
LISA interferometry: TDI



$$\delta l(f) = \Delta L \frac{\delta \nu(f)}{\nu} = 50000\,\mathrm{km}\,\frac{10\,\frac{\mathrm{Hz}}{\mathrm{Hz}^{1/2}}}{282\,\mathrm{THz}} \simeq 2\,\frac{\mu\,\mathrm{m}}{\mathrm{Hz}^{-1/2}}$$

...and we need 18 pm/Hz$^{1/2}$!!!

LISA interferometry: TDI

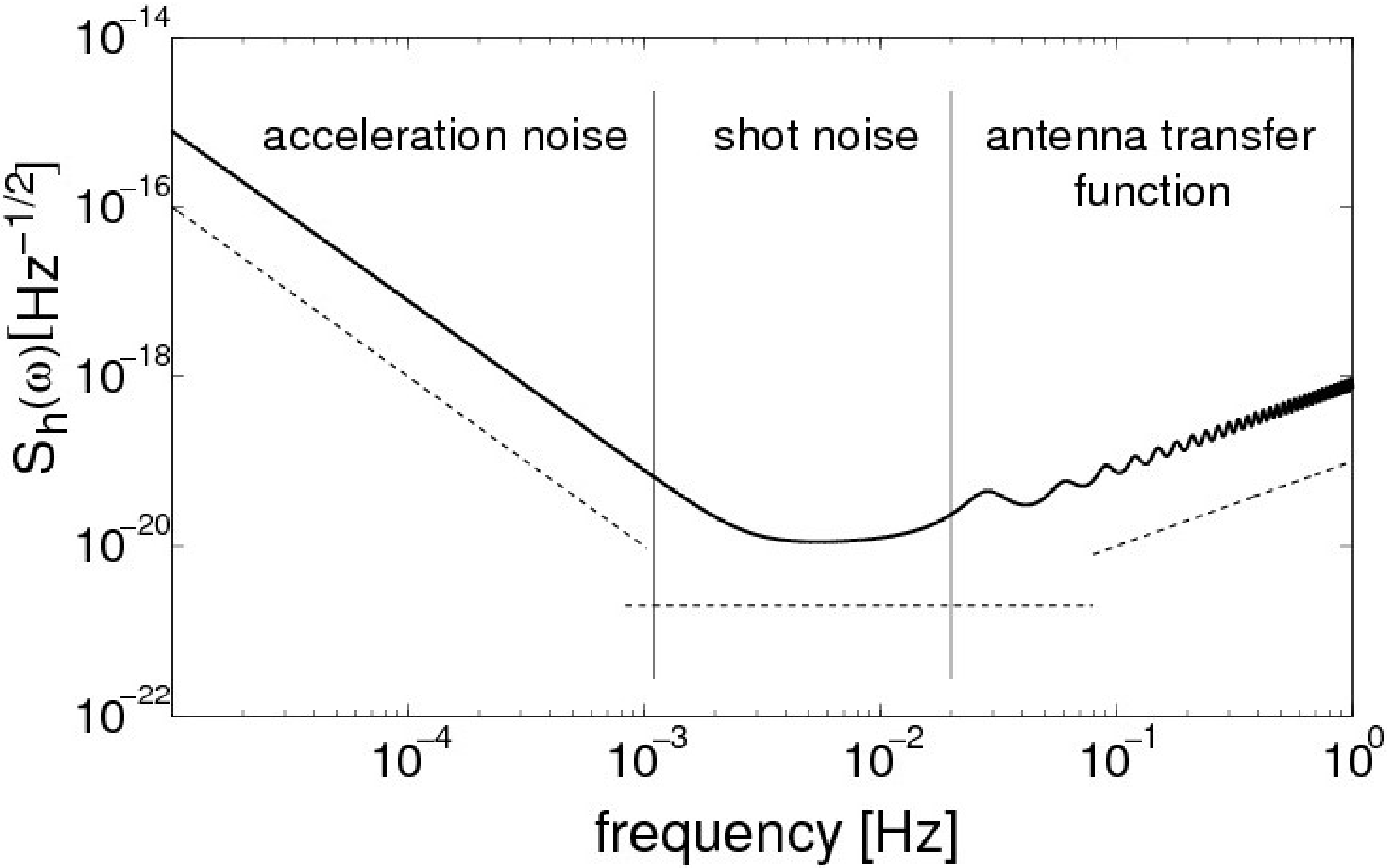


$$Y_{12}(t)=\phi_1(t)-\phi_1(t-2\tau_2)+h_{12}(t-\tau_2)+h_{21}(t)$$

$$Y_{13}(t)=\phi_1(t)-\phi_1(t-2\tau_{13})+h_{13}(t-\tau_3)+h_{31}(t)$$

$$X(t)=Y_{12}(t)-Y_{13}(t)-Y_{12}(t-2\tau_{13})+Y_{13}(t-2\tau_{12})=f(h_{ij},\tau_{ij})$$

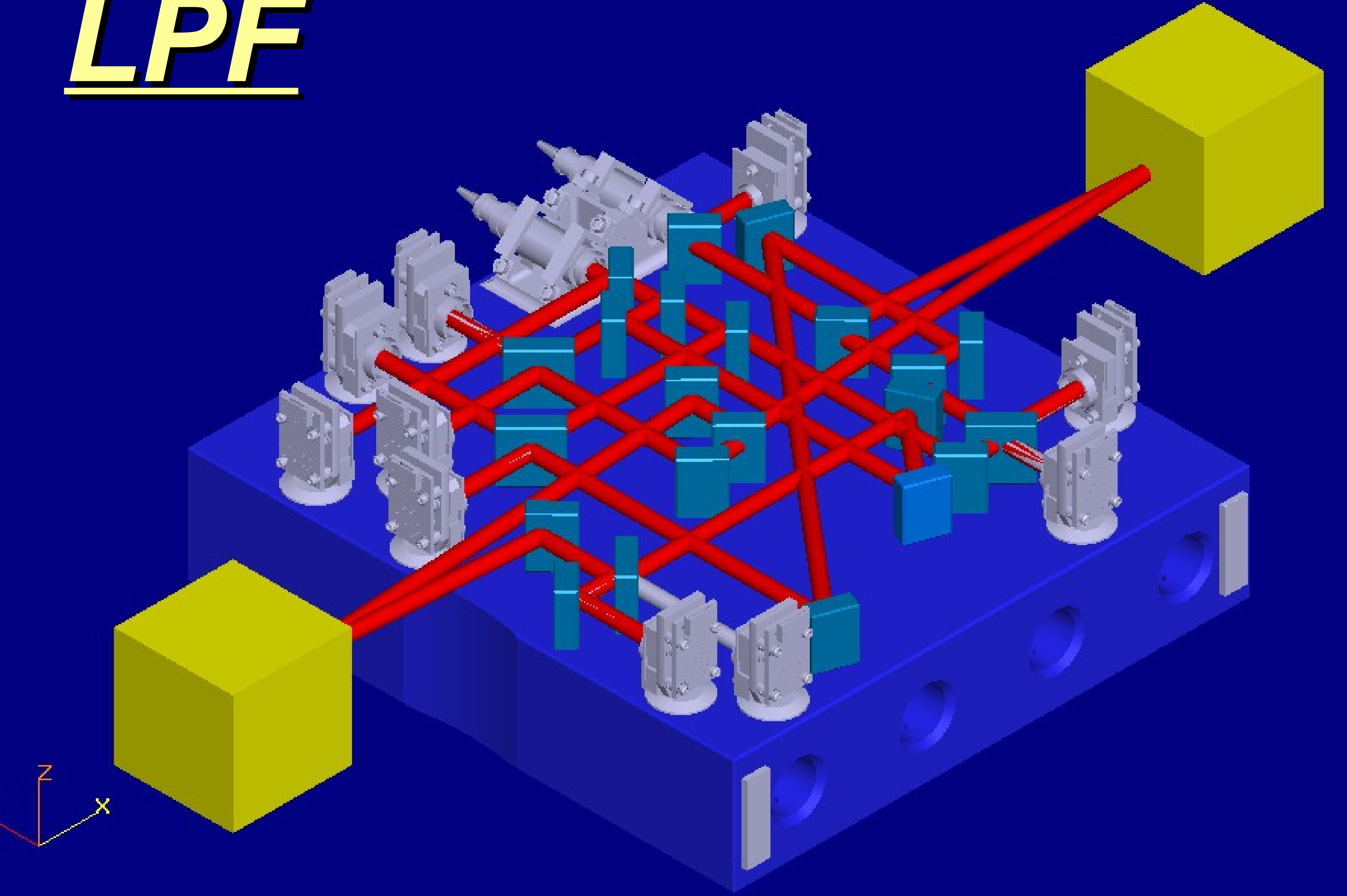
LISA sensitivity



LISA is really challenging...

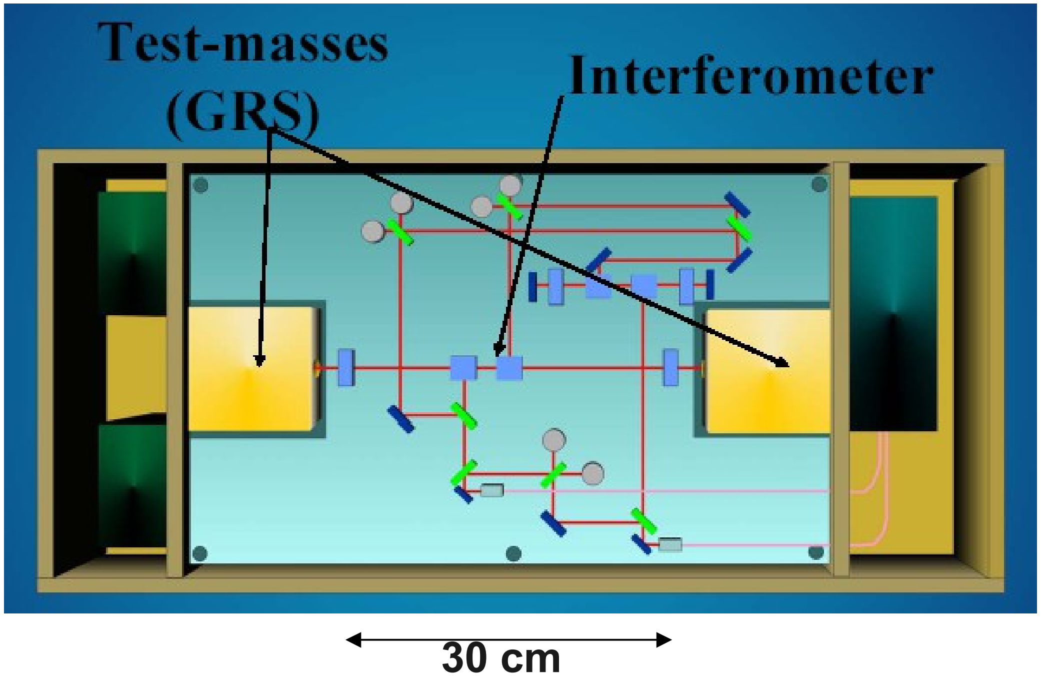
...and expensive!!

LPF



LISA PathFinder

1. One *LISA* arm is *squeezed* to 30 centimetres:



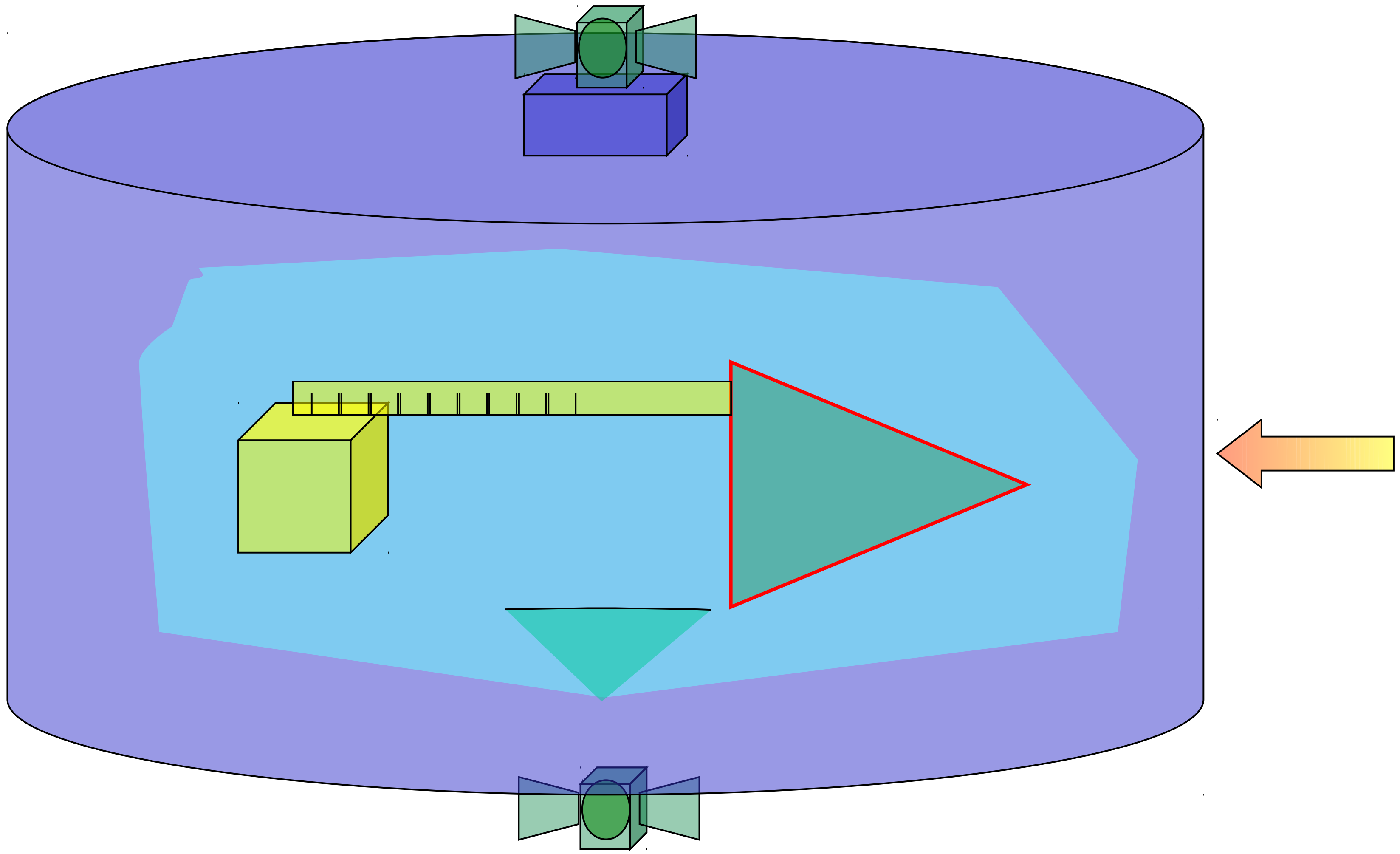
***LTP* Objectives :**

- ***Drag-free***
- ***Interferometry***
- ***Diagnostics***
- ***TM charging***
- ***Telemetry***
- ***Data processing***

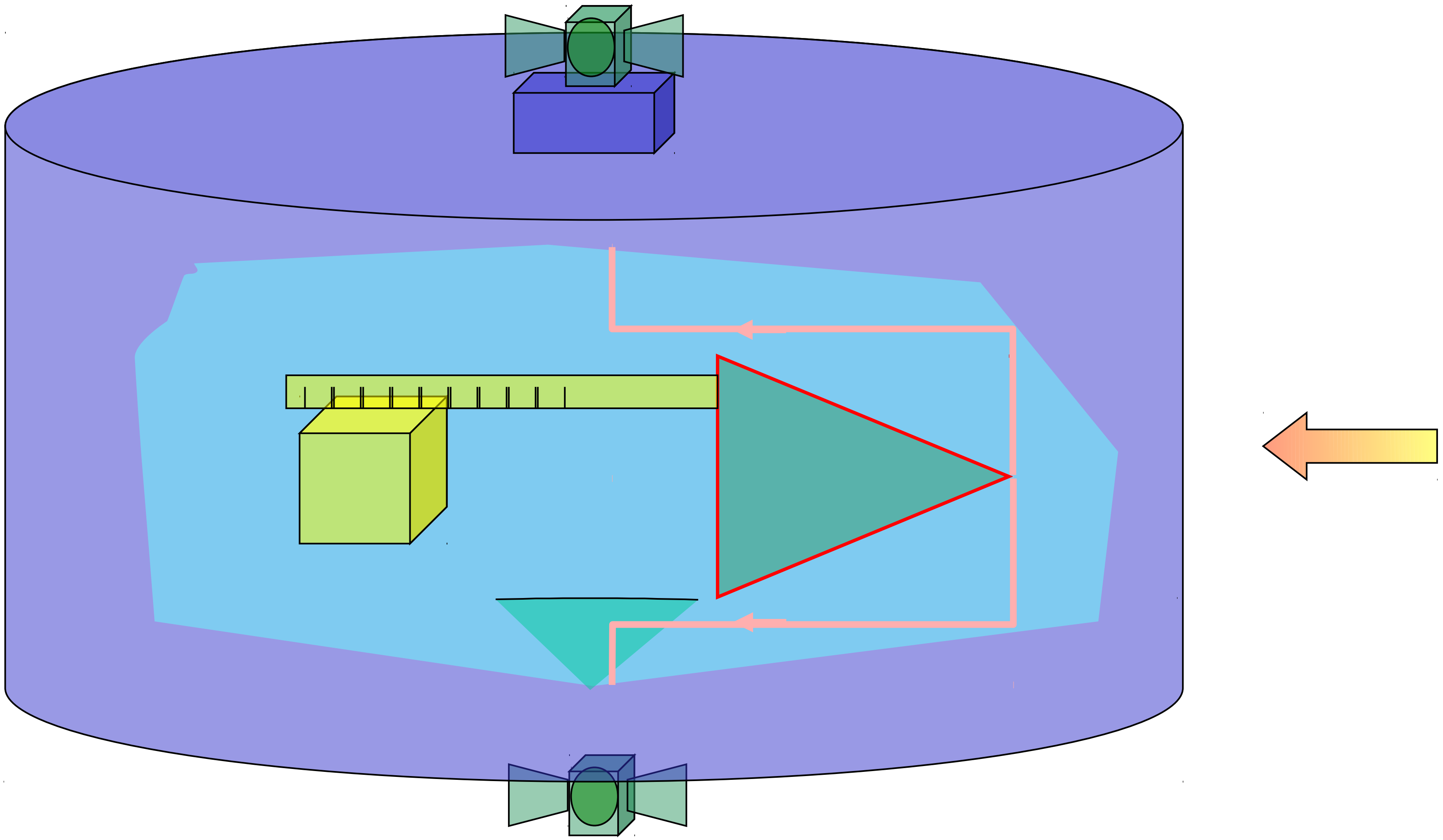
2. *Relax sensitivity* by one order of magnitude, also in band:

$$\delta a(f) \leq 3\times10^{-14}\left[1+\left(\frac{f}{3\ \mathrm{mHz}}\right)^2\right]\ \mathrm{m\,s^{-2}\,Hz^{-1/2}},\ 1\ \mathrm{mHz} \leq f \leq 30\ \mathrm{mHz}$$

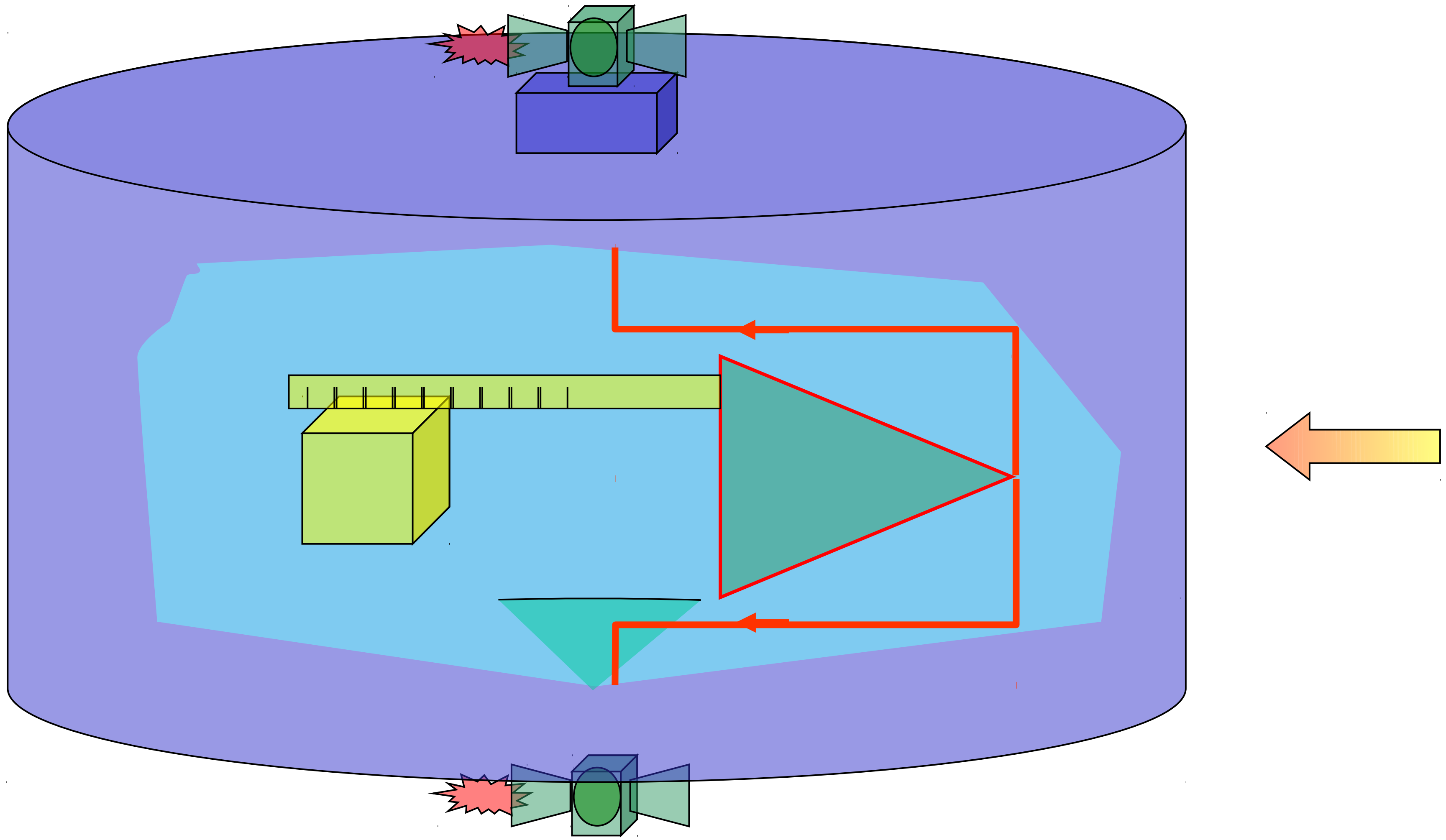
Drag-free sequence



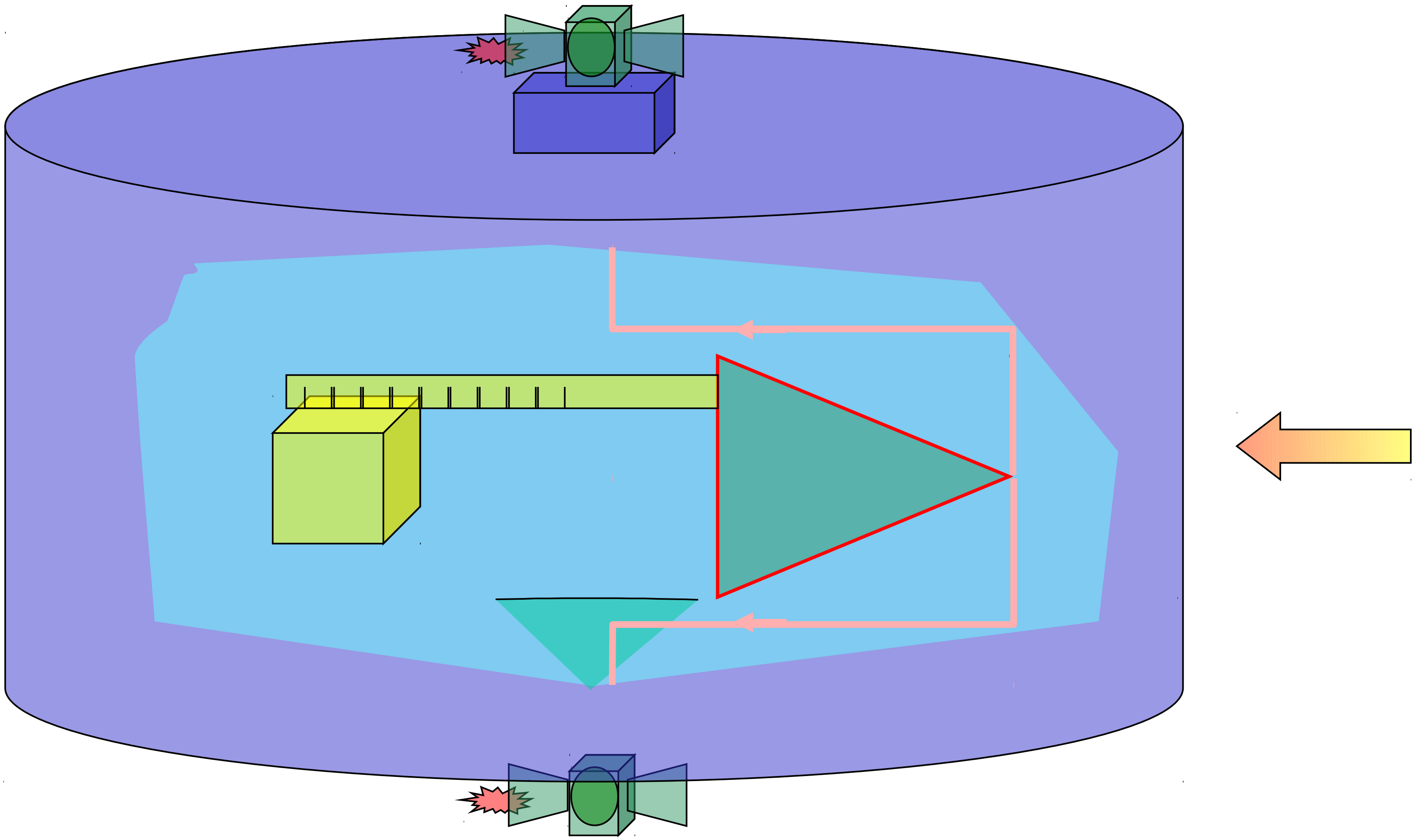
Drag-free sequence



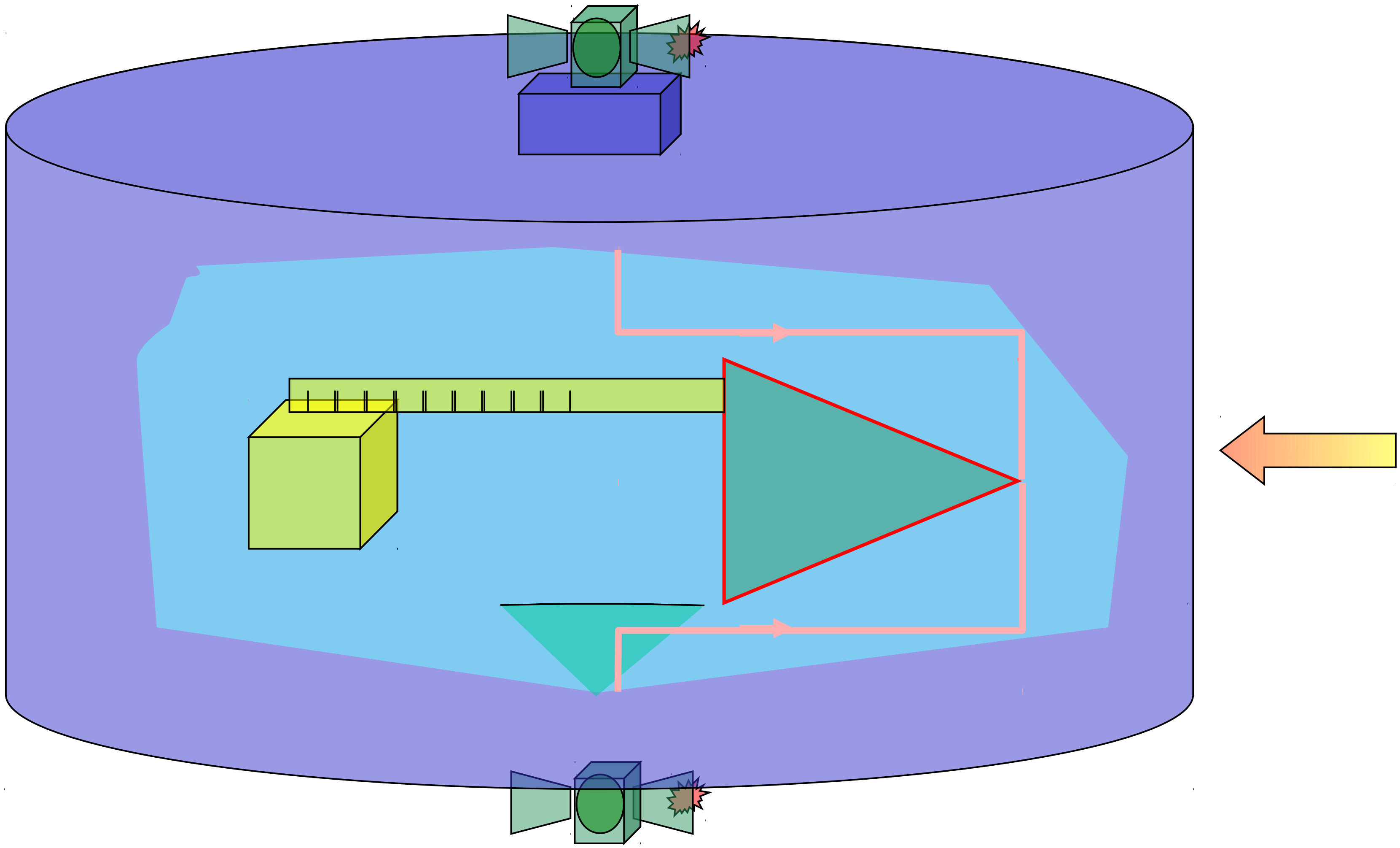
Drag-free sequence



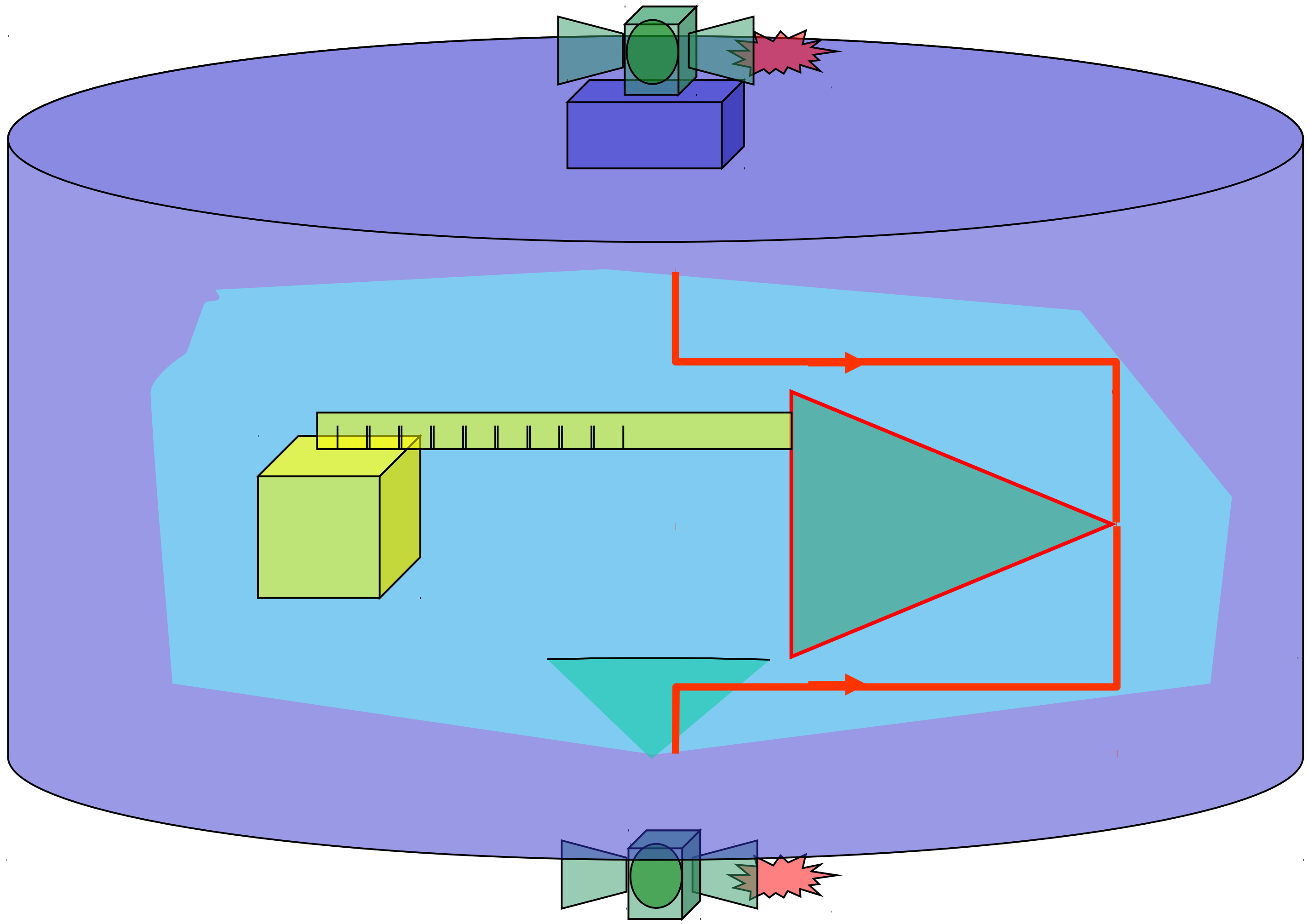
Drag-free sequence



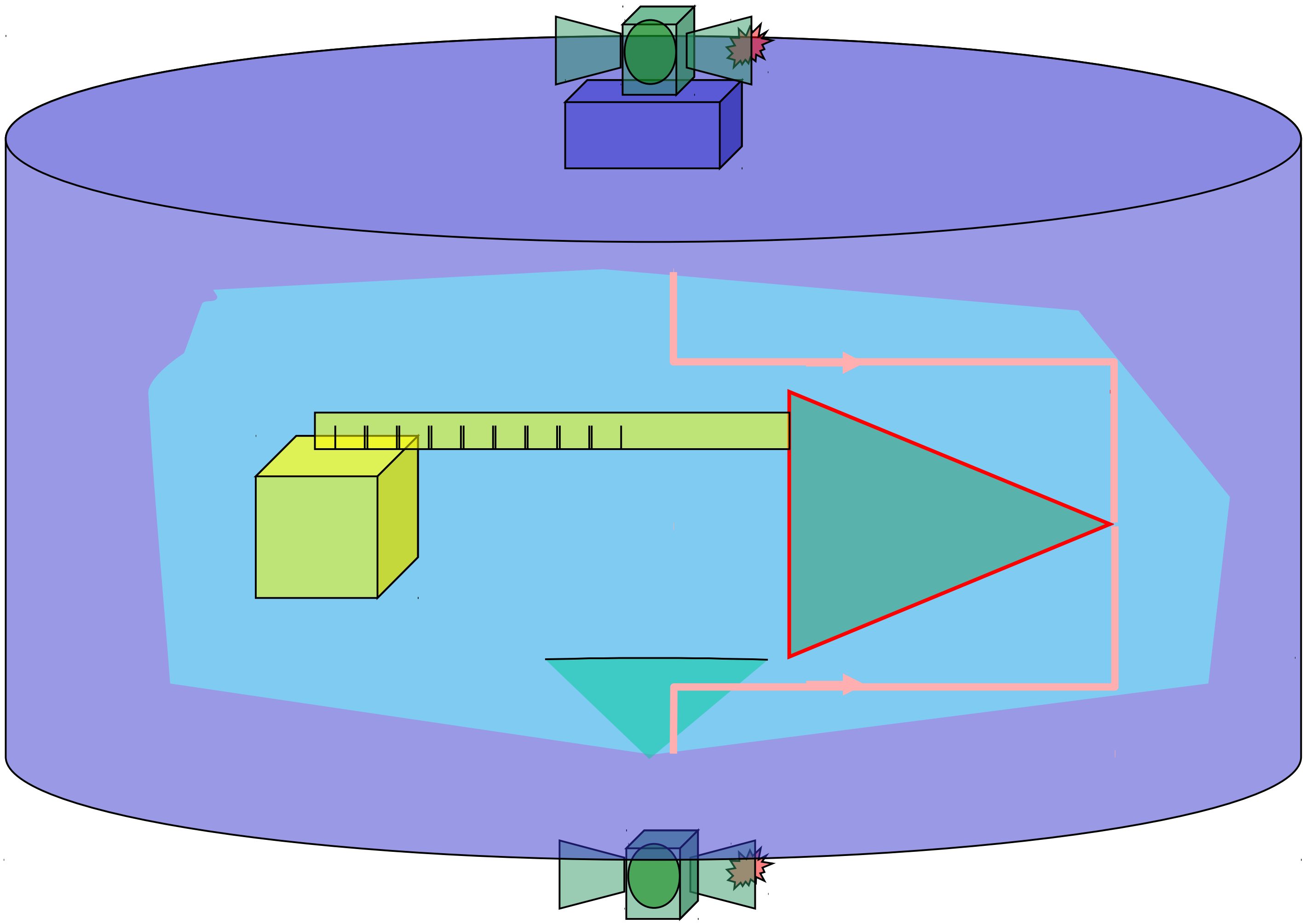
Drag-free sequence



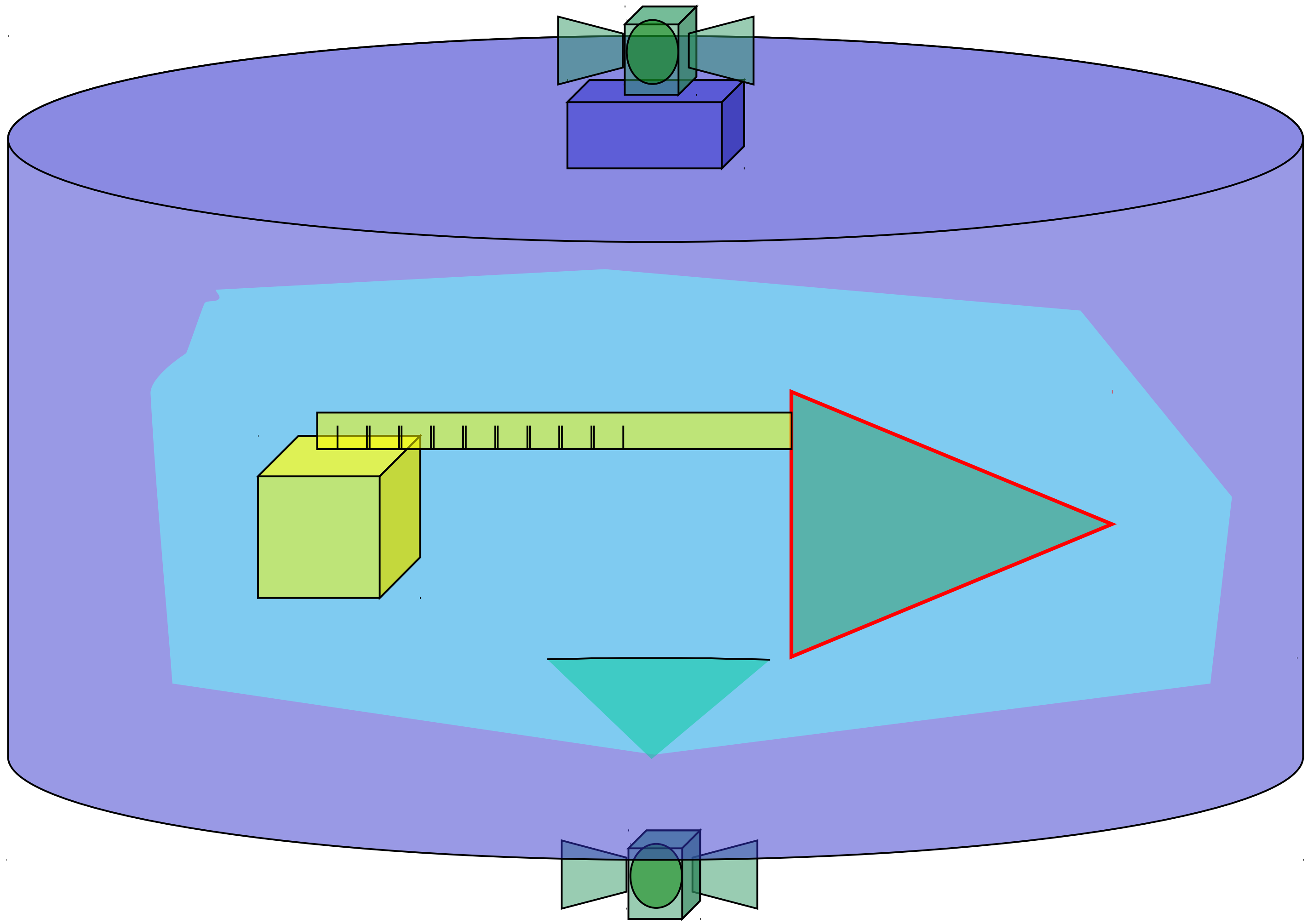
Drag-free sequence



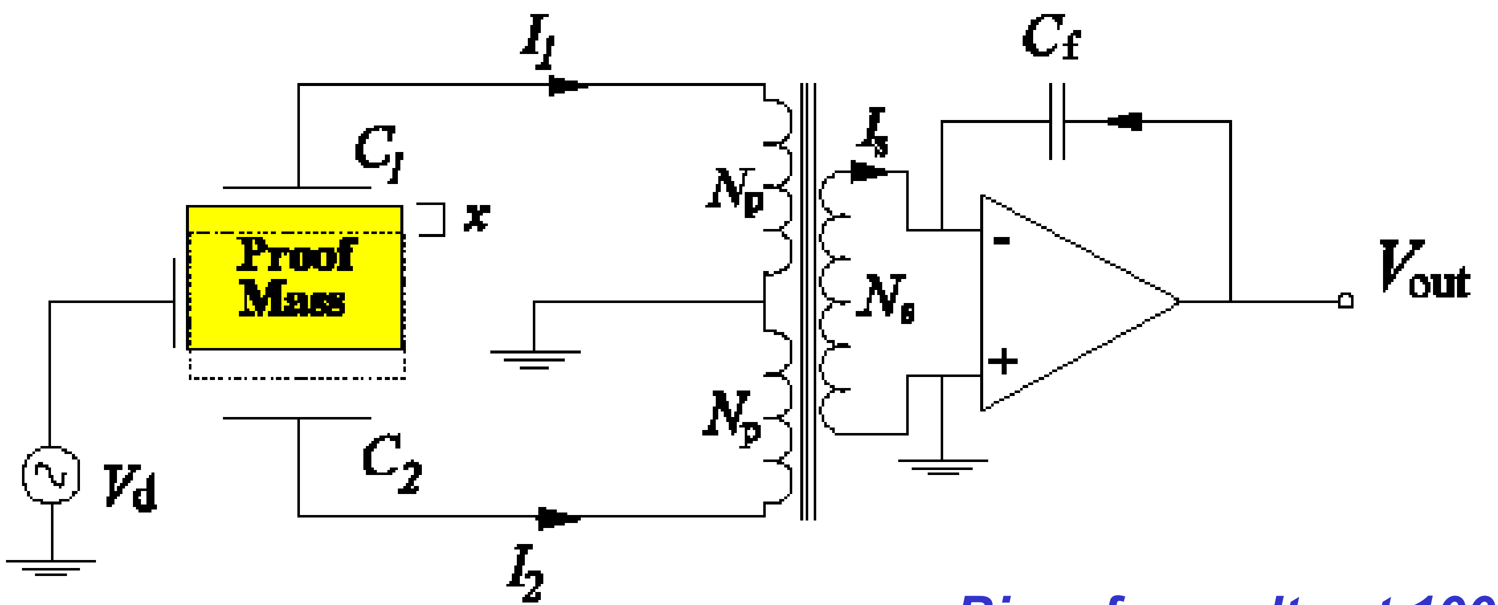
Drag-free sequence



Drag-free sequence



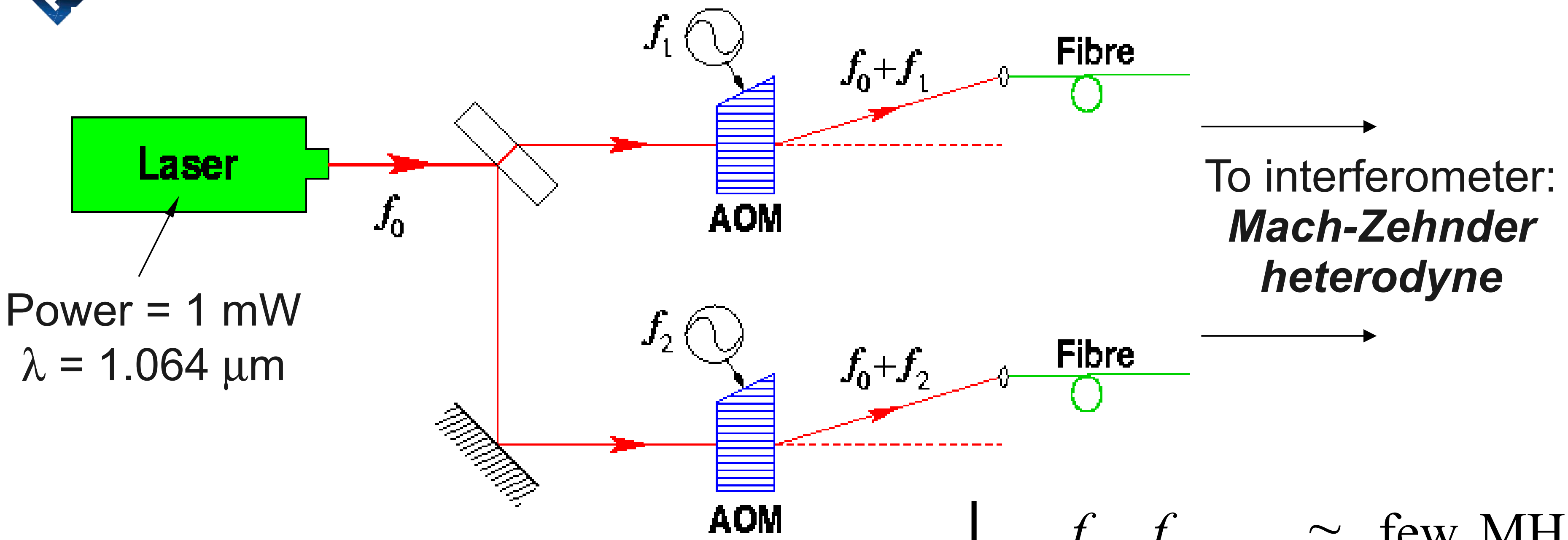
Capacitive position sensing



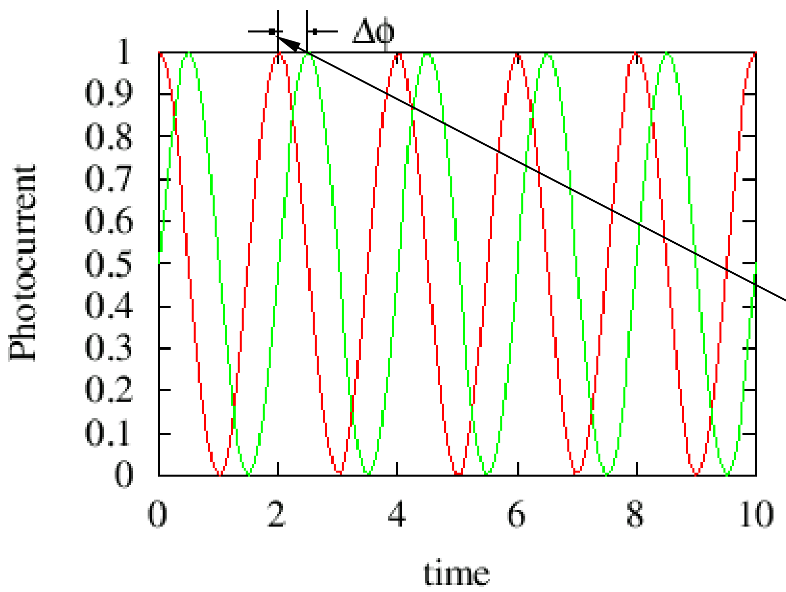
Bias: few volts at 100 kHz

$$V_{\rm out}(t) \;\propto\; \frac{N_s}{N_p}\left(C_1 - C_2\right) \Rightarrow V_{out}(t) \;\propto\; x\,\sin\left(2\pi f_{\rm d}\, t\right)$$

The LPF laser and phase-meter



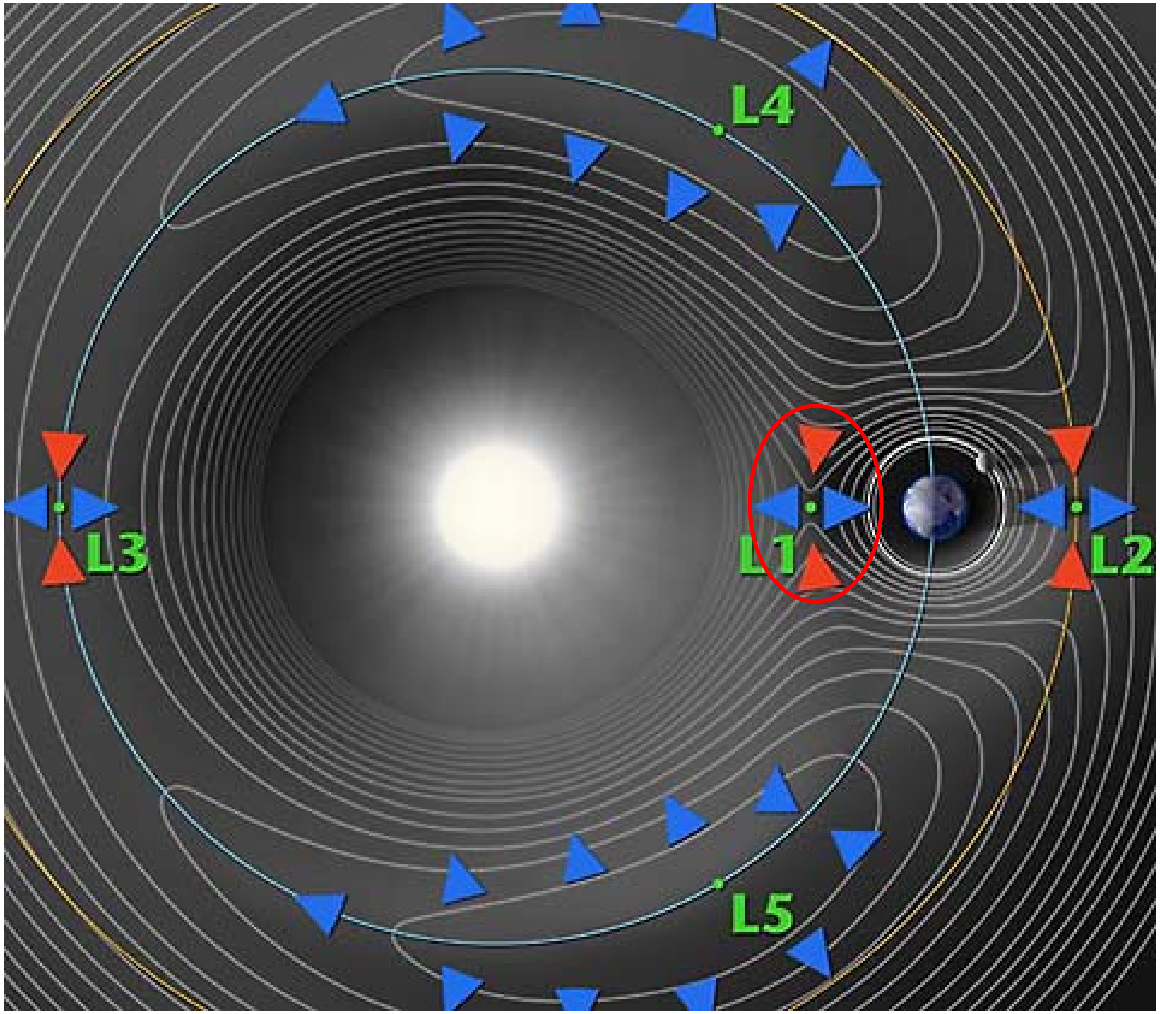
$$\left| \begin{array}{rcl} f_1,\ f_2 & \simeq & \text{few MHz} \\ f_{het} = f_1 - f_2 & \simeq & 1\ \text{kHz} \end{array} \right.$$



Signal:

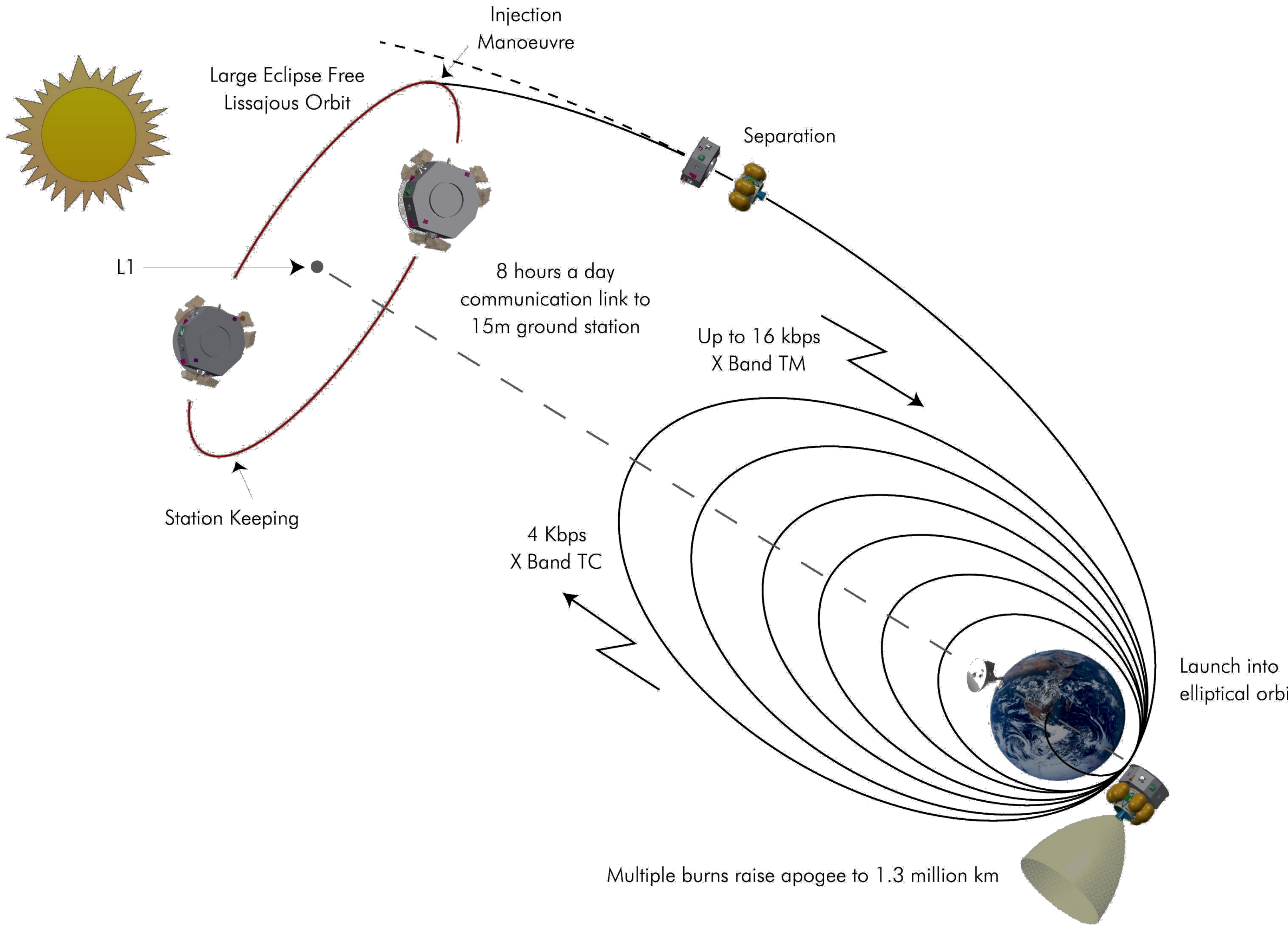
$$\cos[\Delta\phi(t)] = \cos\left[2\pi\left(f_{het}\,t - \frac{\Delta l(t)}{\lambda}\right)\right]$$

LPF orbit

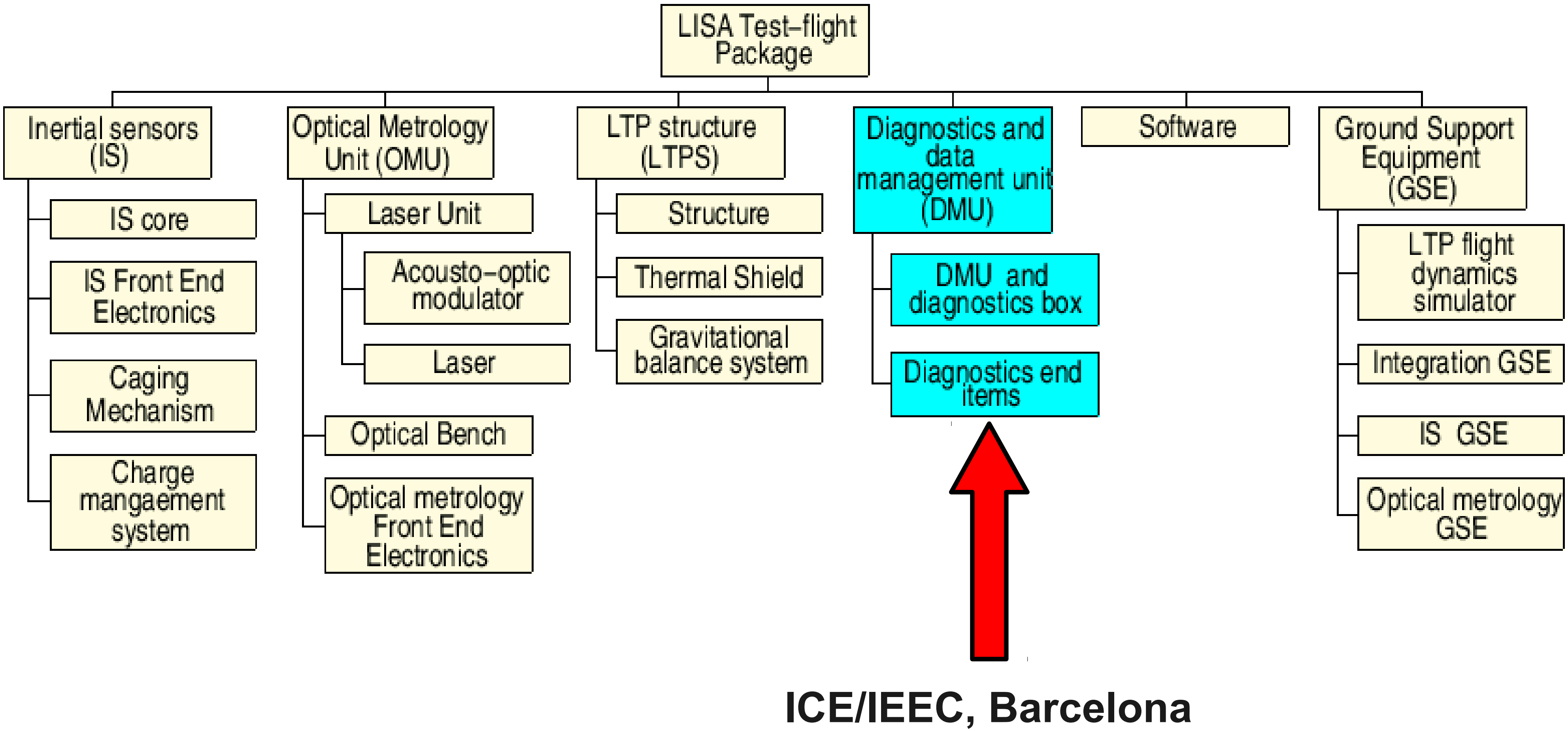


- *Lagrange L1*
- Travel time: ~3 months
- Mission lifetime: ~6 months

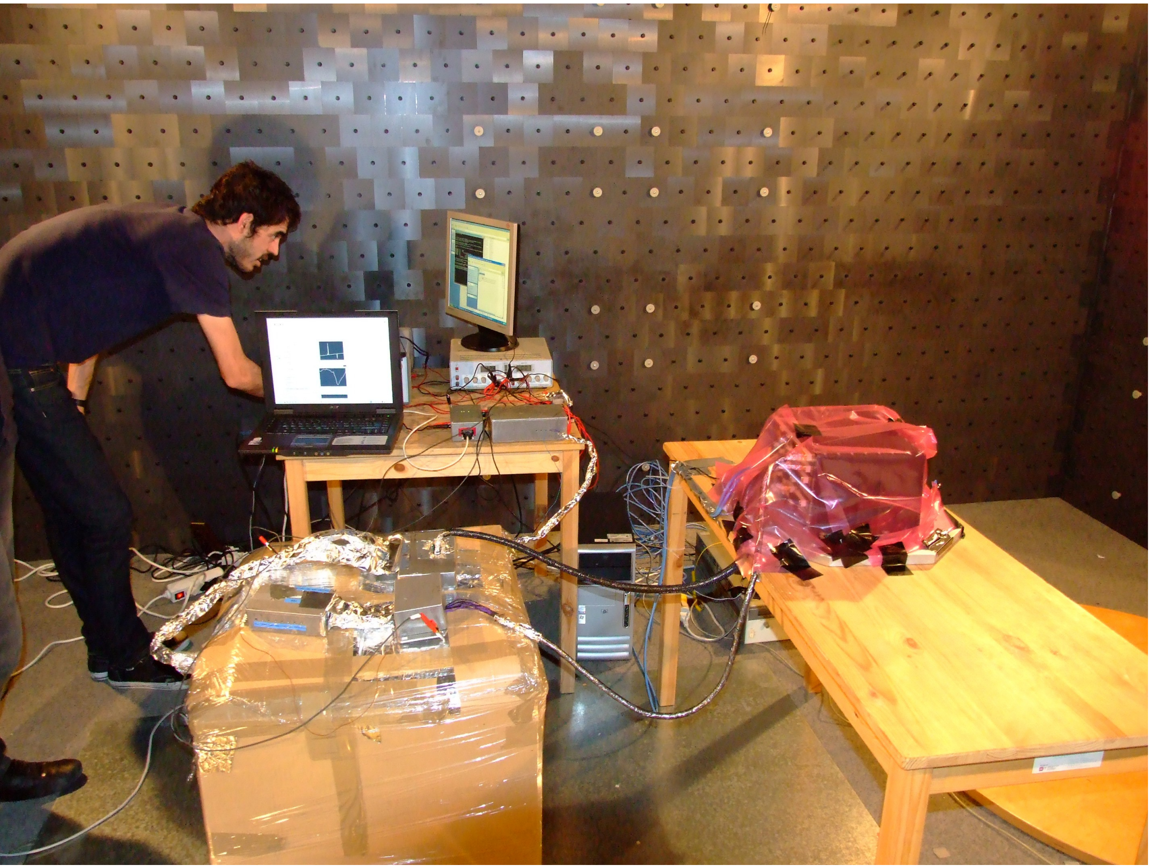
LPF orbit injection manoeuvres



LTP functional architecture



Thermal diagnostics

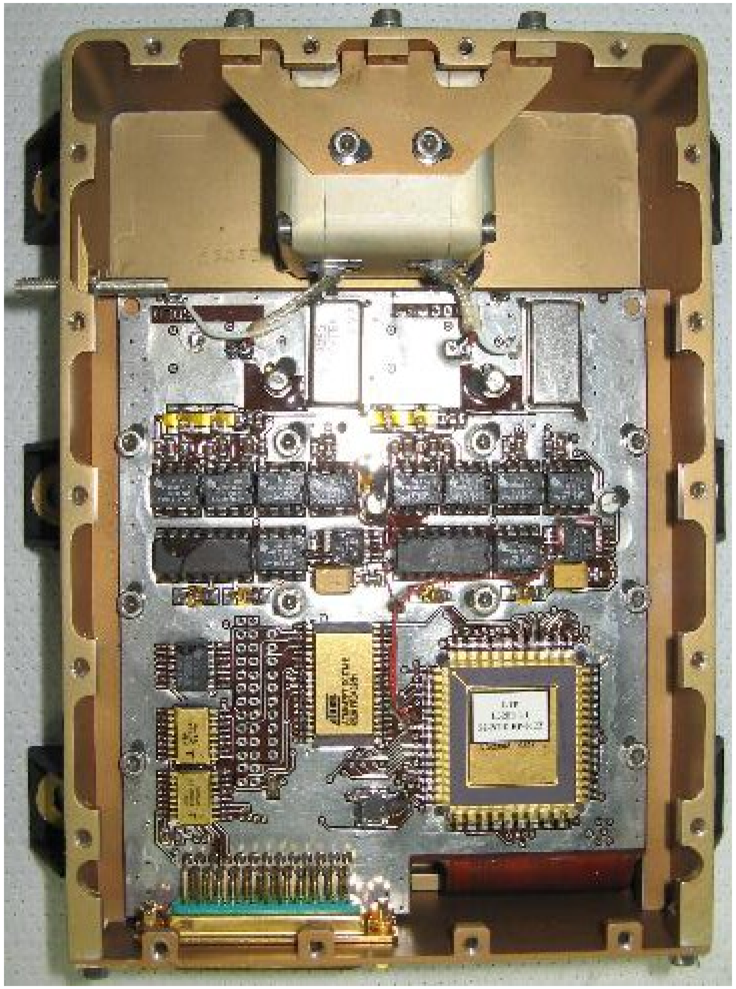


Thermal diagnostics sensors tests at UPC

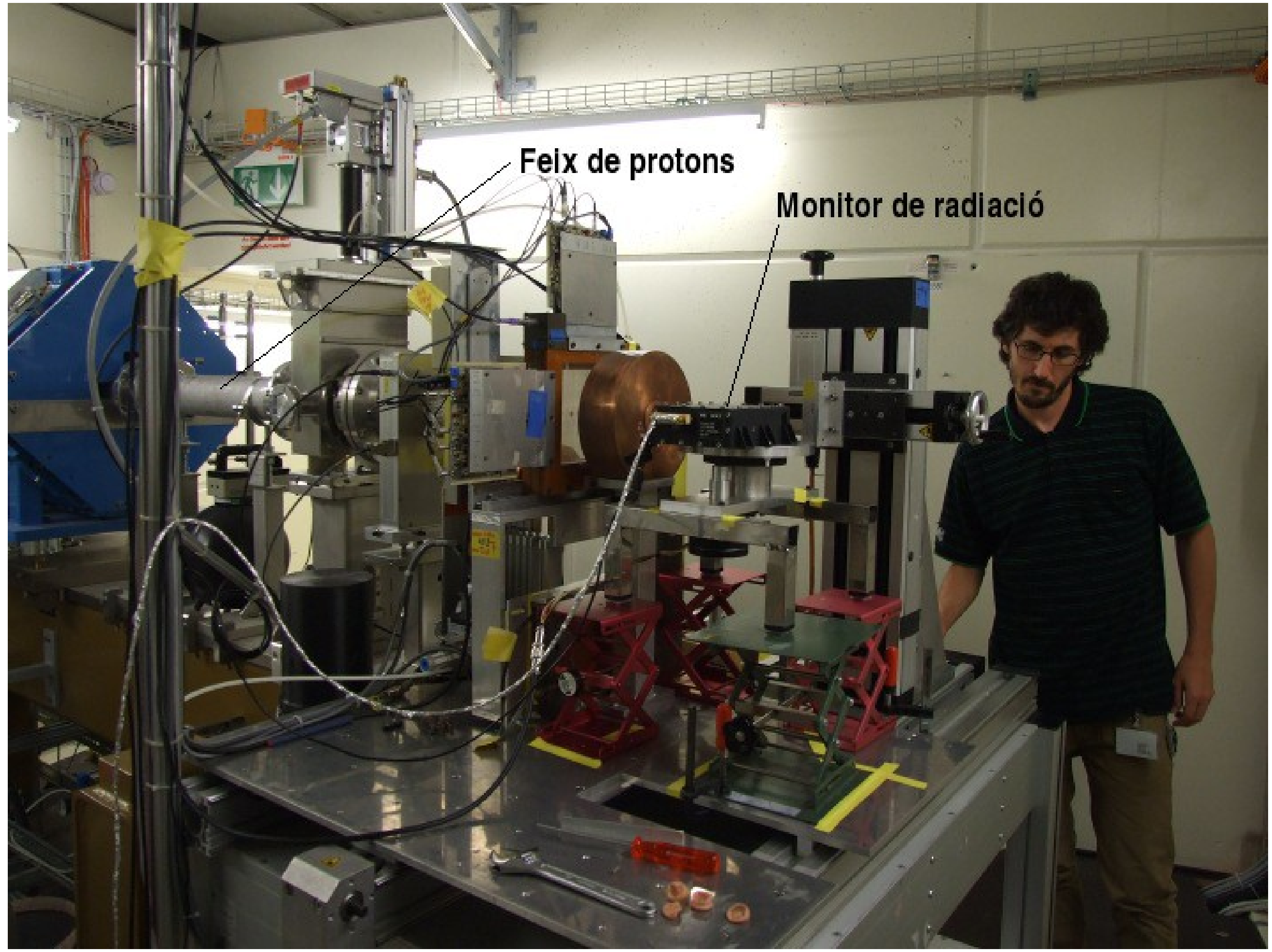
Thermal sensors and heaters on OW

Magnetic diagnostics

Radiation Monitor



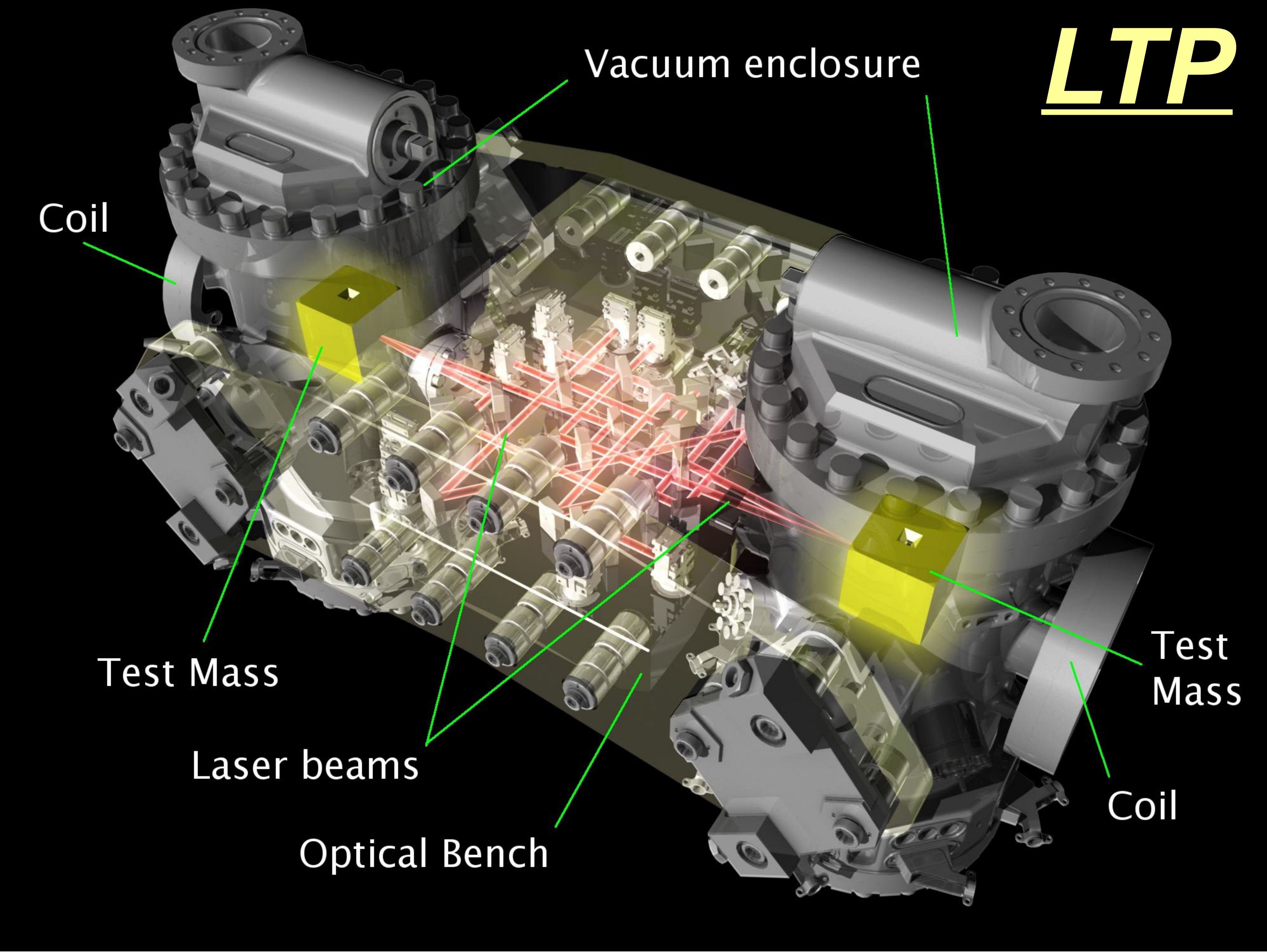
RM interior



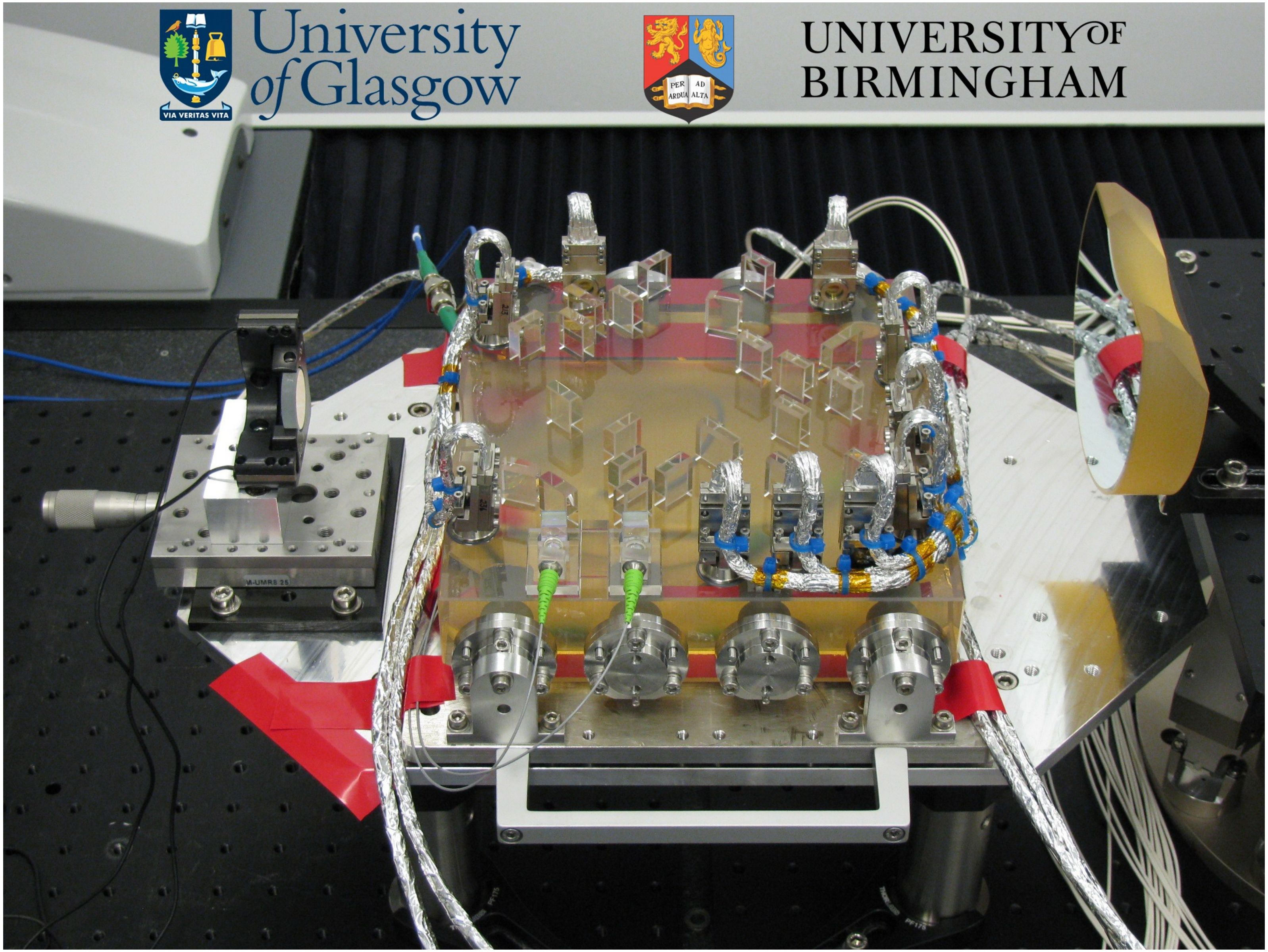
Ready for a proton beam irradiation at PSI (CH)

The DMU

A few pretty photos and graphs on LPF, in particular from the Munich OSTT carried through in October-November 2011.

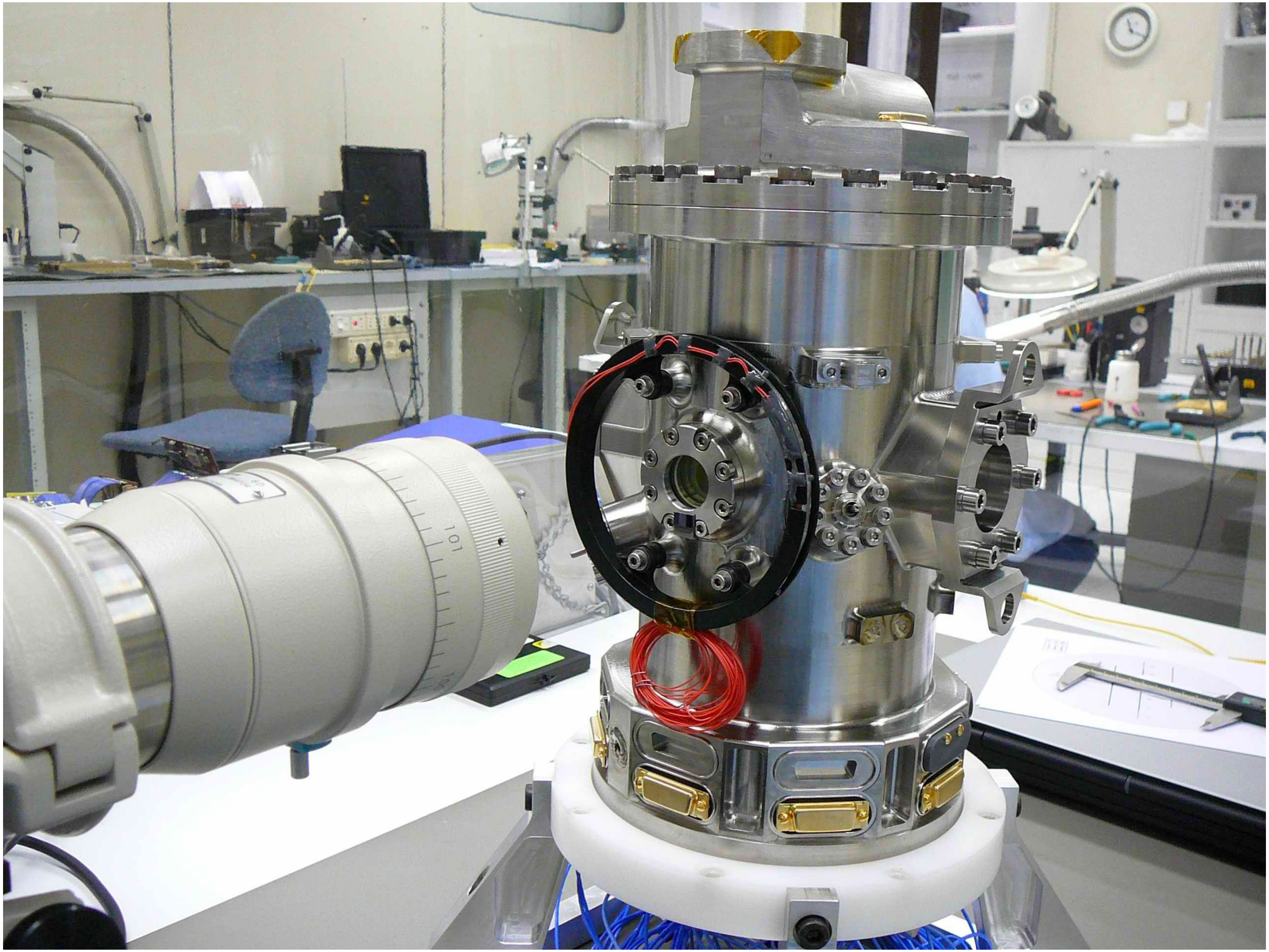

LTP
Vacuum enclosure
Coil
Test Mass
Laser beams
Optical Bench
Test Mass
Coil

LTP OB FM

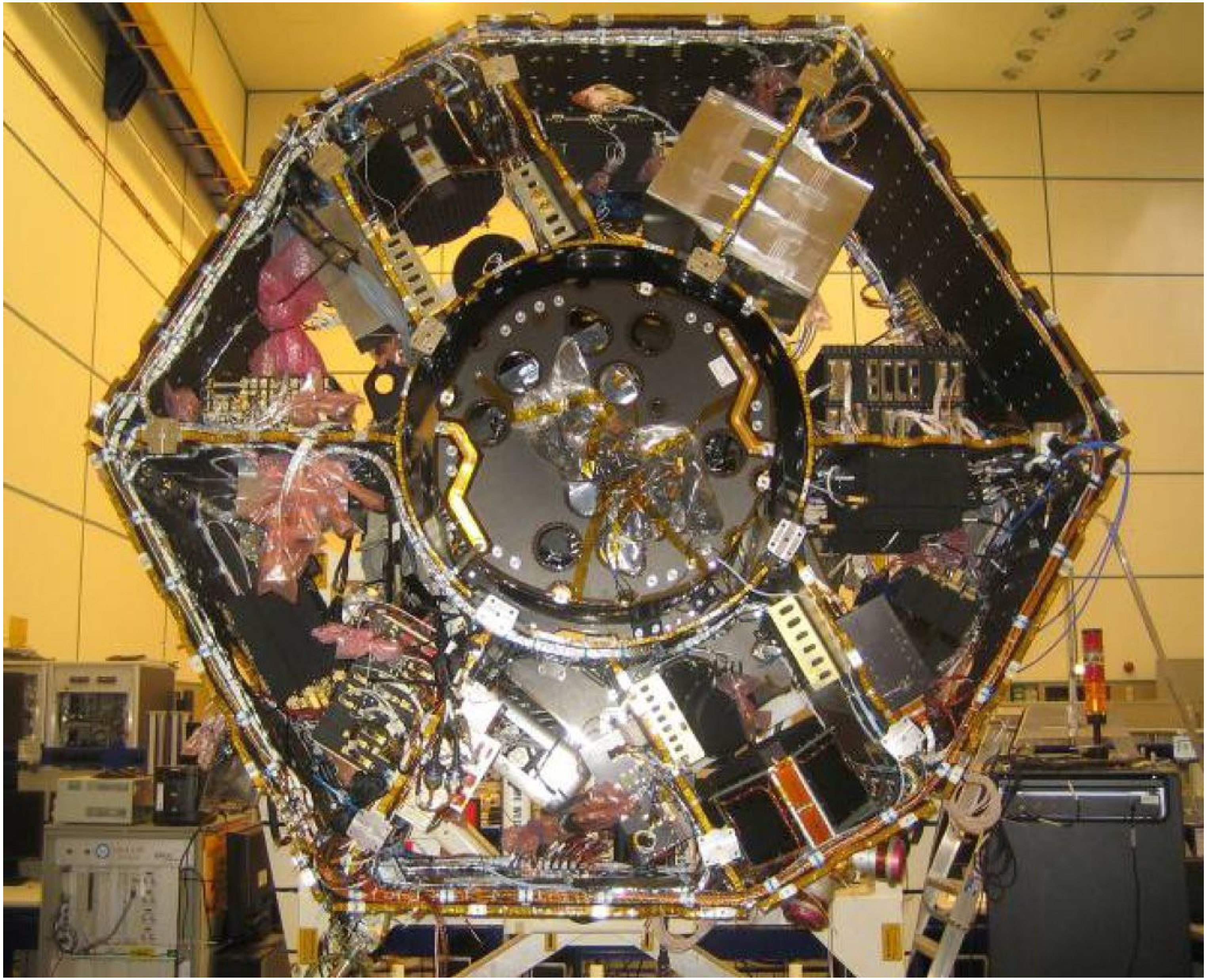

University of Glasgow
VIA VERITAS VITA
UNIVERSITY OF BIRMINGHAM
PER ARDUA AD ALTA

LTP OB

LTP GRS



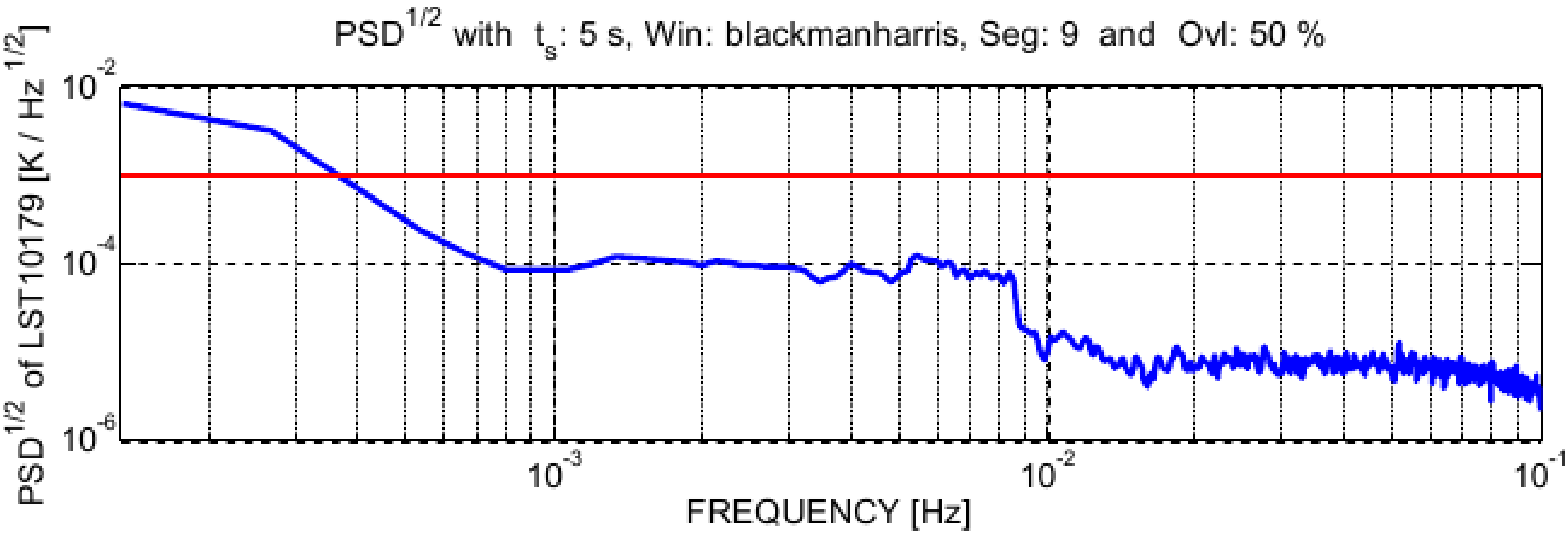
LPF chassis



OSTT at IABG, Munich Oct-Nov 2011

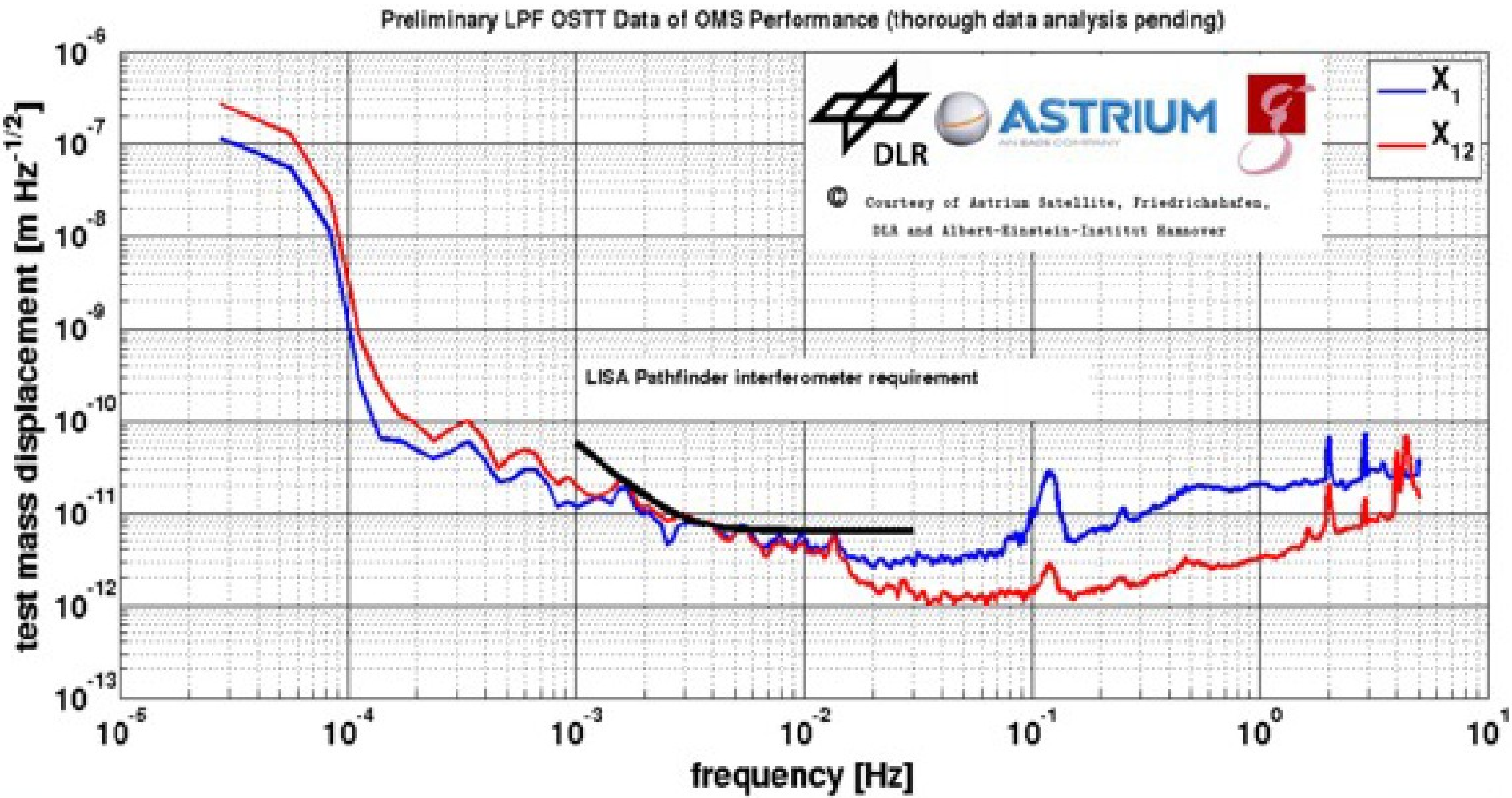
OSTT at IABG, Munich Oct-Nov 2011

OSTT at IABG, preliminary results



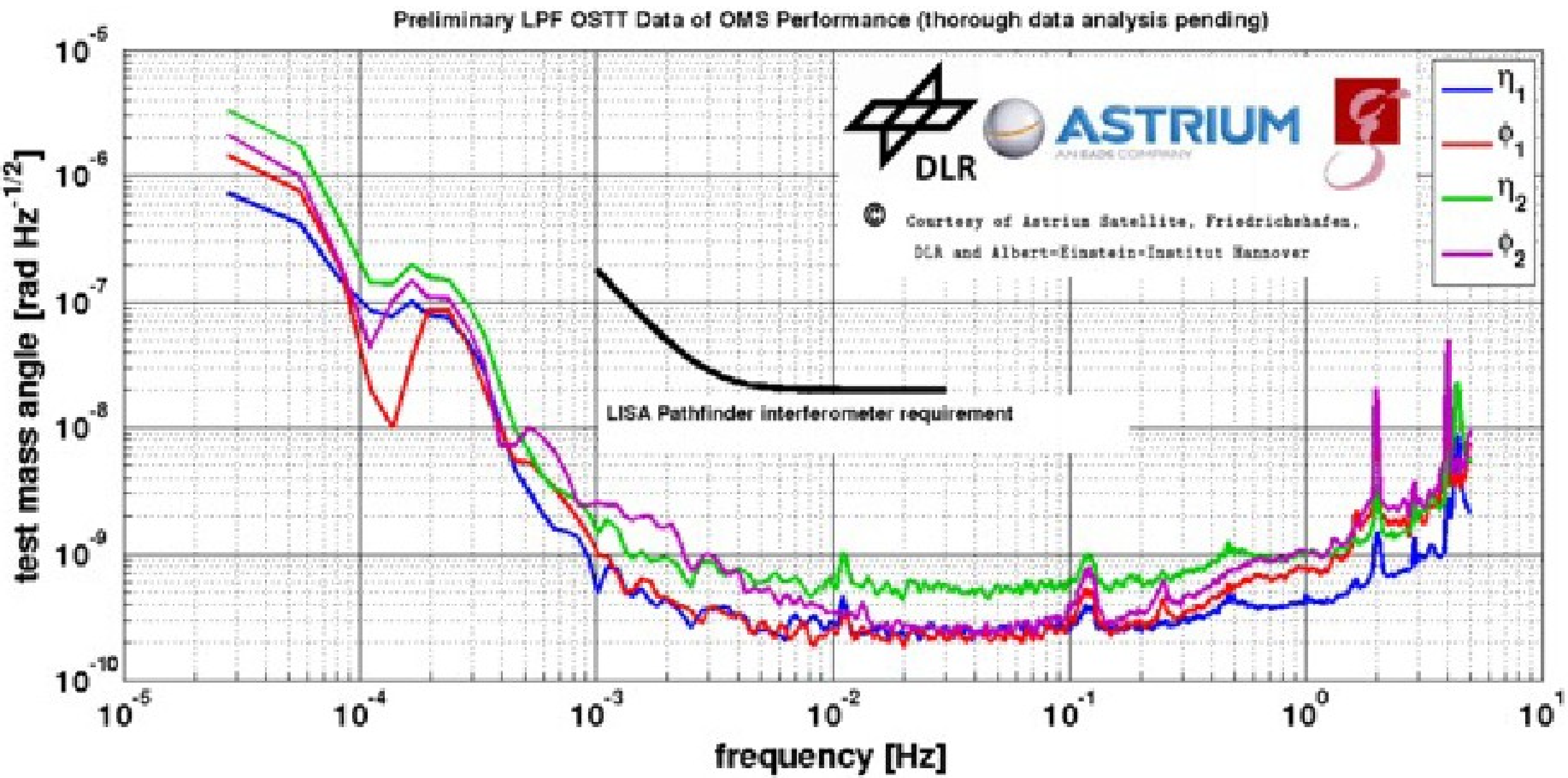
Thermal stability near Optical Bench

OSTT at IABG, preliminary results



Interferometer displacement noise

OSTT at IABG, preliminary results



Interferometer angle sensing noise

Further longer term problems

• But ***highly political and economical issues*** eventually emerged which blocked the joint venture between ESA and NASA to go ahead with LISA.

• NASA's inability to stick with ESA's Cosmic Vision Programme, and conversely, for ESA, launched in Europe a redefinition of the large three missions to compete for a slot in in its first launch opportunity, so called, L1, launch in 2024.

• Pre-April 2011 LISA design was reassessed by all three missions with the idea to obtain the highest scientific return compatible with half the original budget (i.e., only ESA money) and still worth flying.

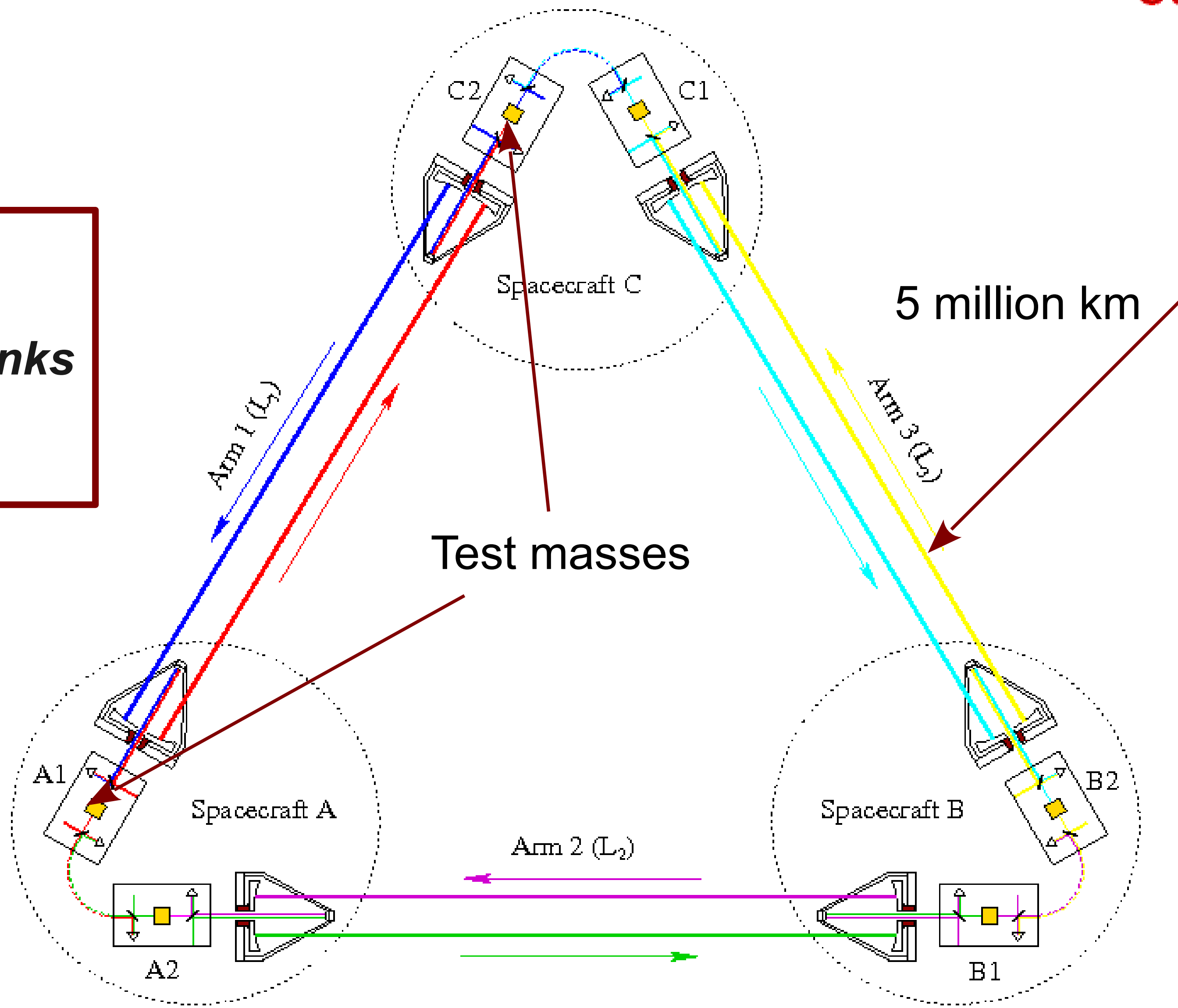
• In all cases (JUICE, Athena, NGO) a certain amount of de-scoping was of course unavoidable, but the excersise was completed and documentation submitted to the ESA Science Advisory body, then later, with a proposal based on scientific merit, to the SPC –the final decisory body.

• Let's go into some detail on the specific case of LISA –redubbed NGO.

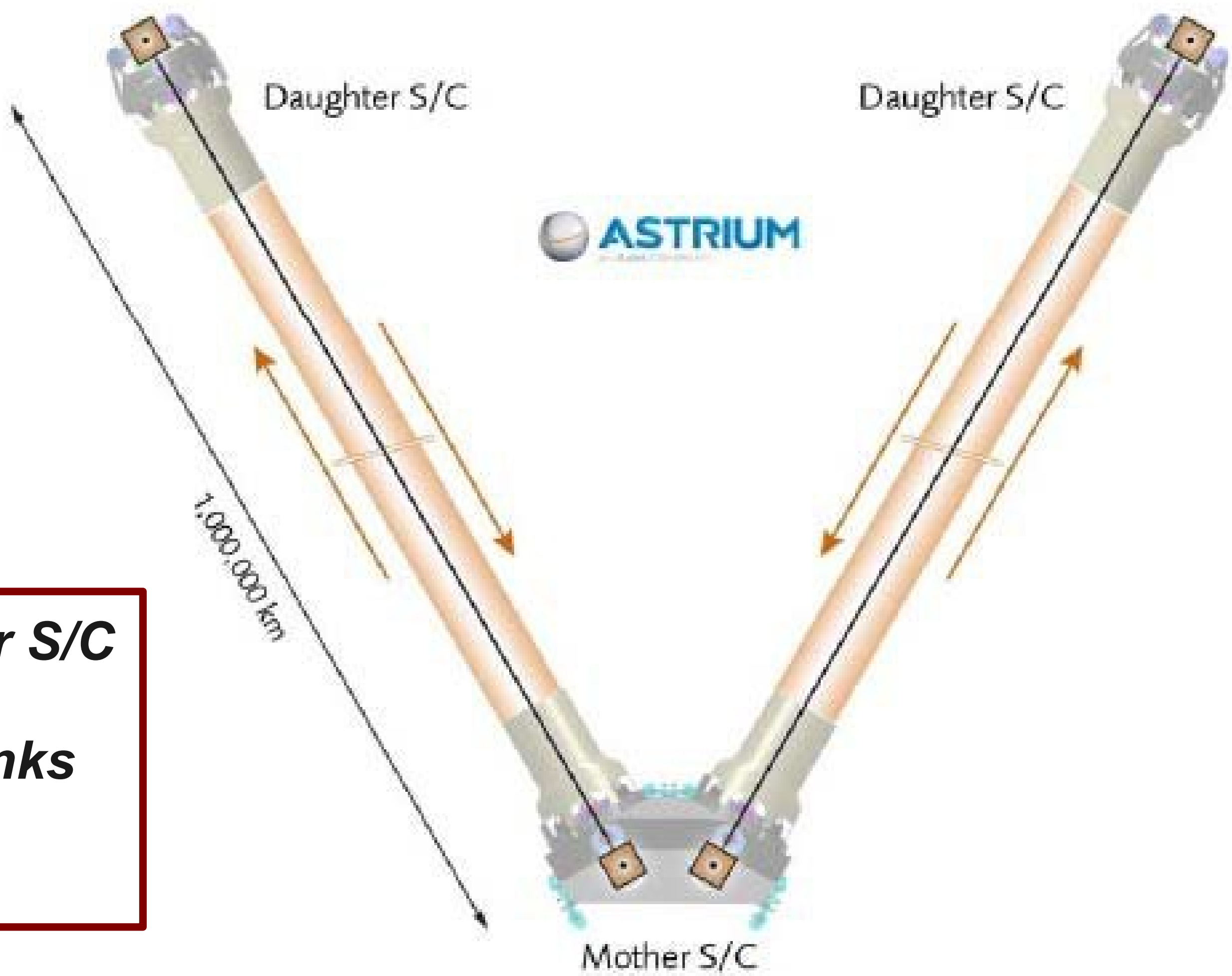
2011-12 descope: NGO

LISA concept

- 3 identical S/C
- 6 TMs and 6 laser links
- 5 Mkm arms

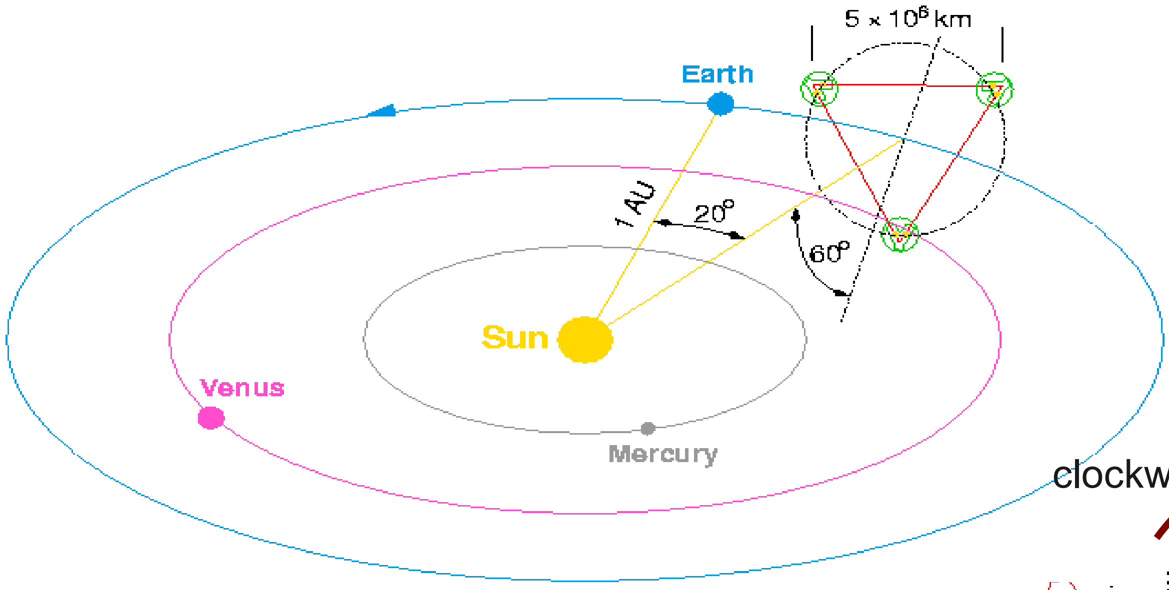


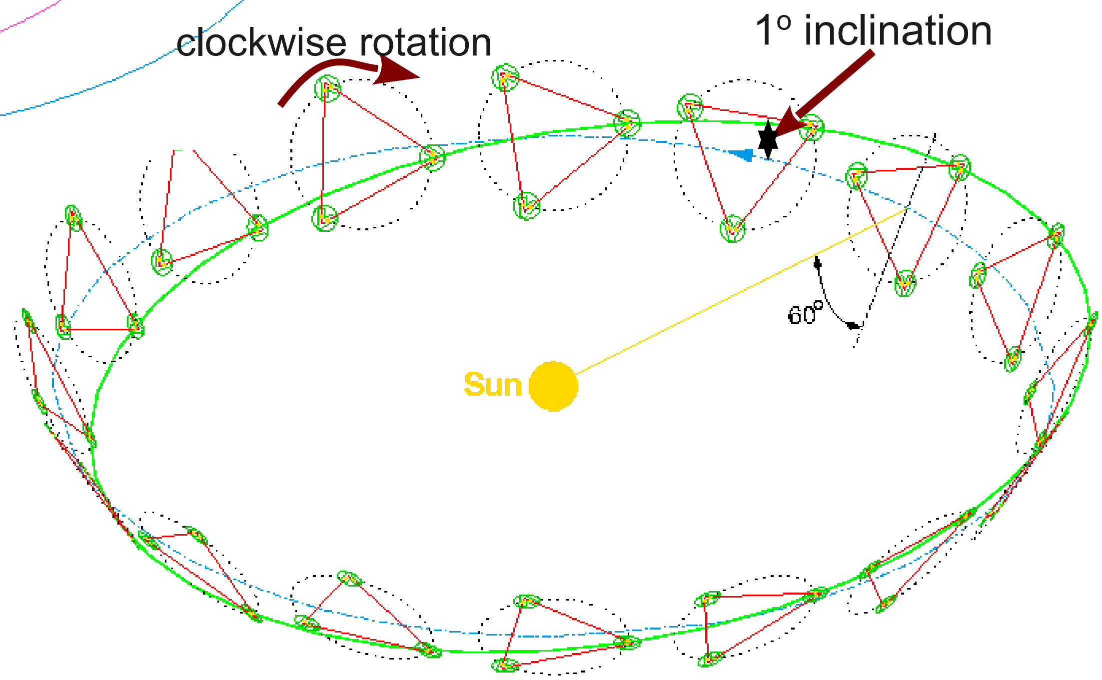
eLISA-NGO concept



- ***1 Mother + 2 daughter S/C***
- ***4 TMs and 4 laser links***
- ***1 Mkm arms***

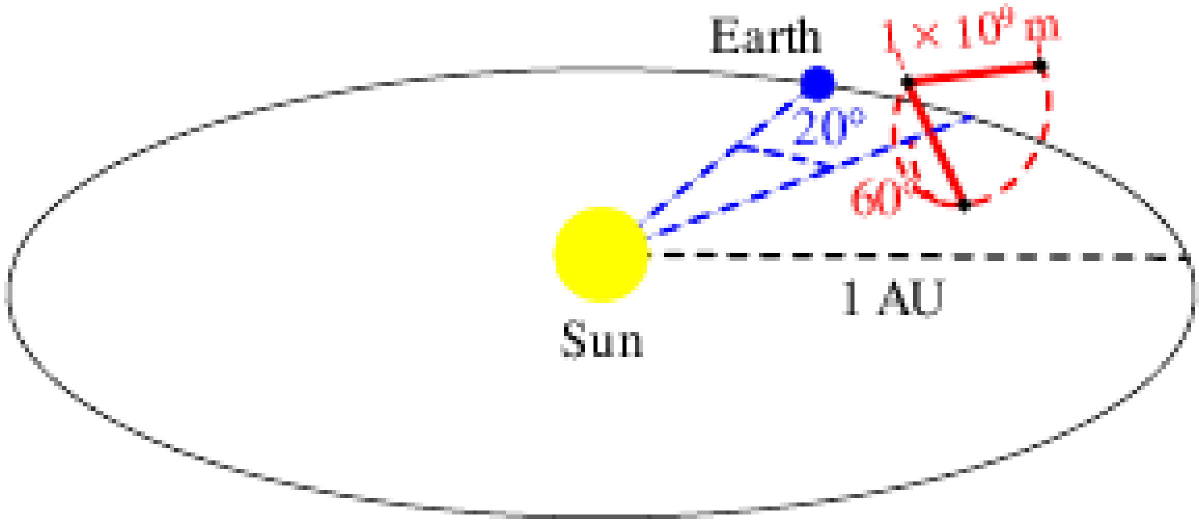
LISA orbits

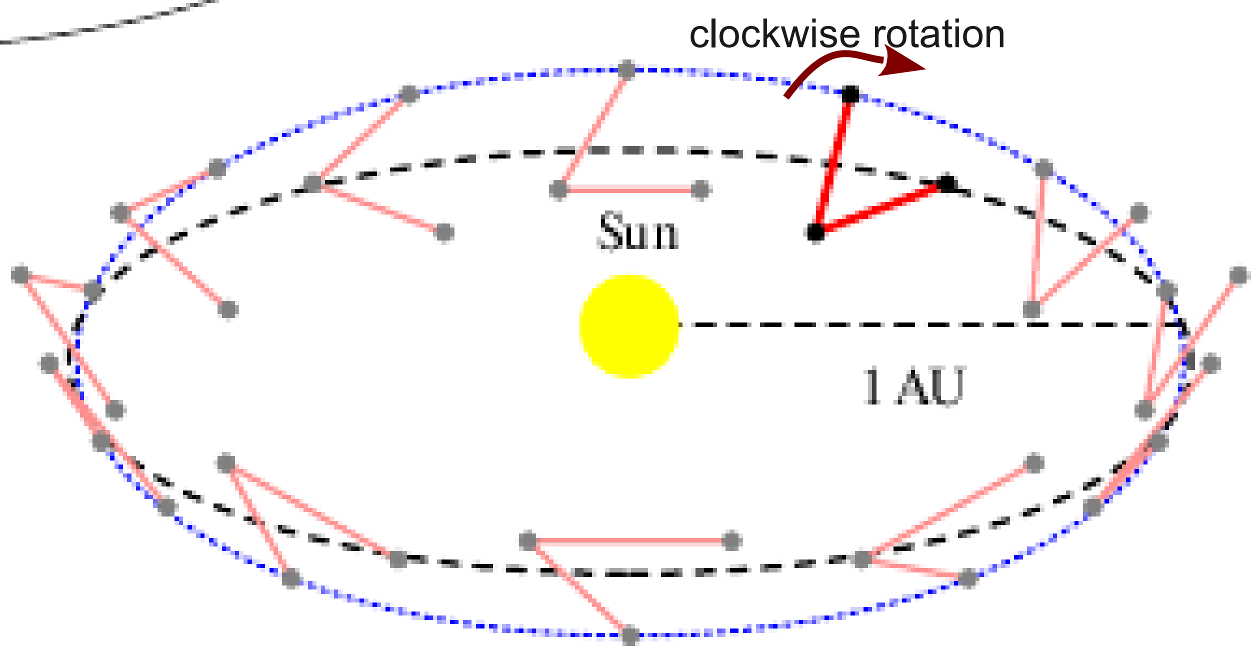




- *LISA trails Earth by 20° constant*
  - *Lifetime: 5 years nom. + 5*

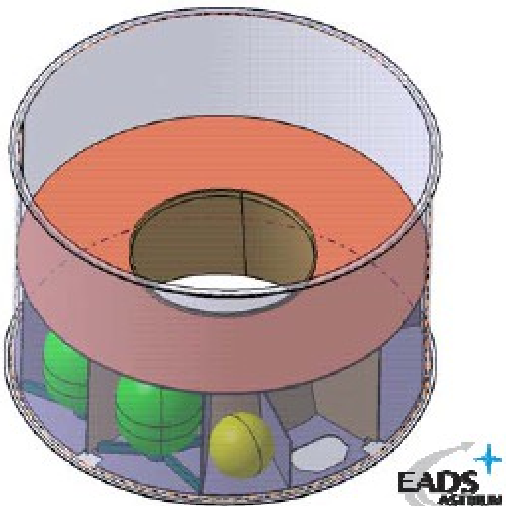
eLISA-NGO orbits

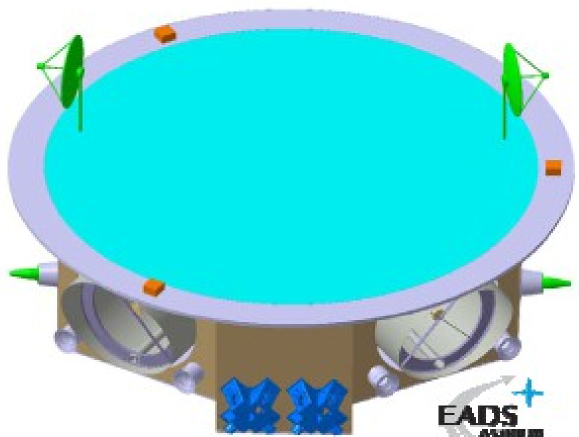


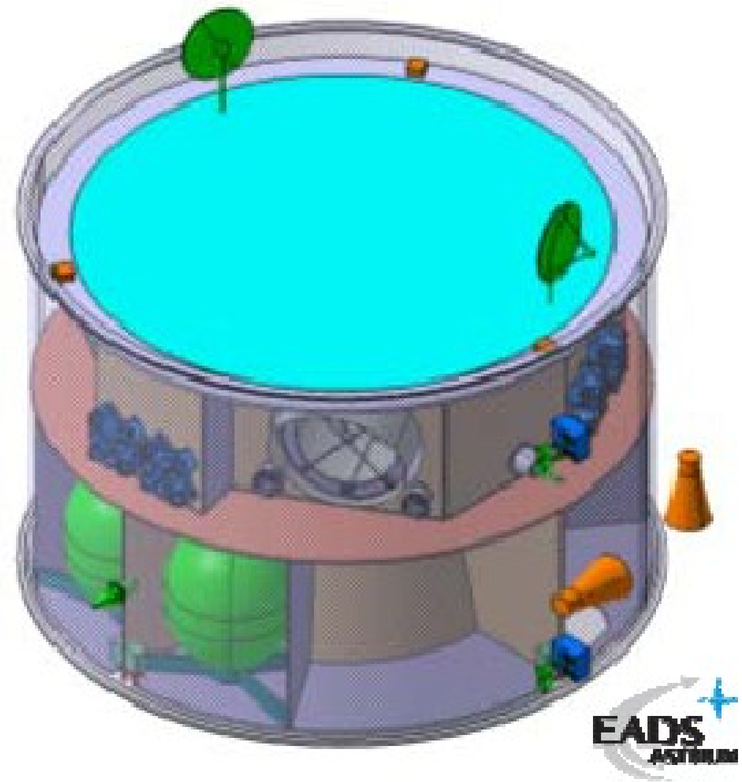


- ***eLISA-NGO trails Earth but drifts away from 10º to 20º in 4 years and to 25º in 6 years***
- ***Lifetime: 2 years nom. + 2 + 2***

LISA propulsion mod.

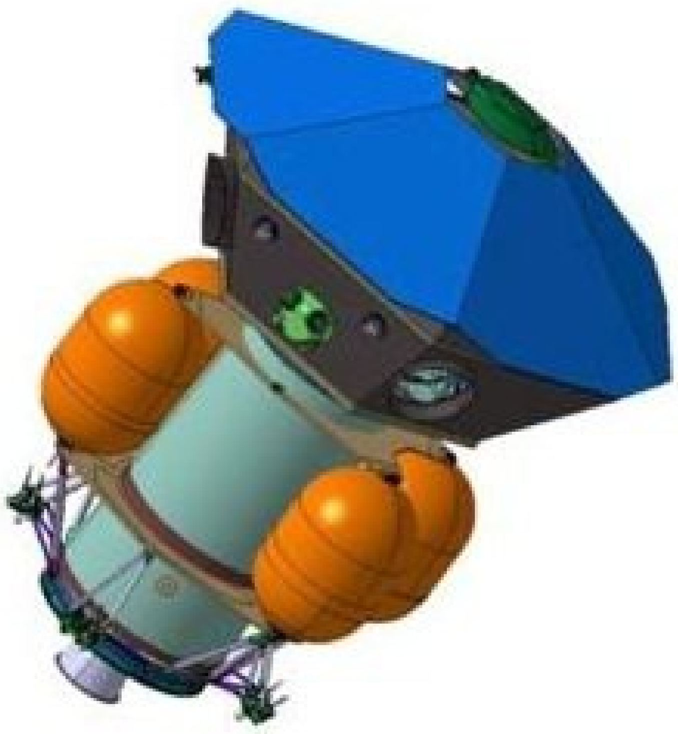

Propulsion Module

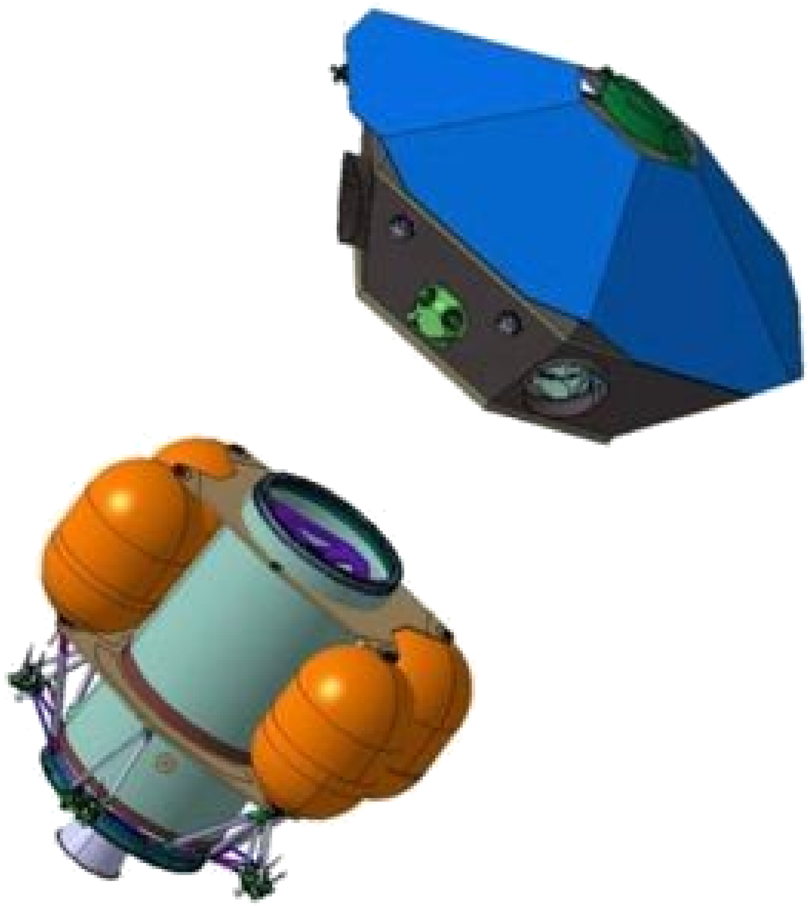

Sciencecraft


LISA Sciencecraft on Propulsion Module

LISA specific propulsion module

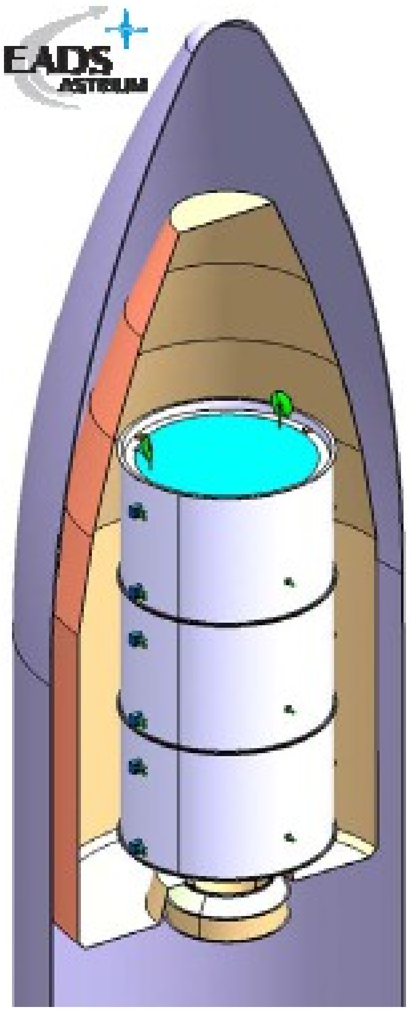
eLISA-NGO propulsion mod.



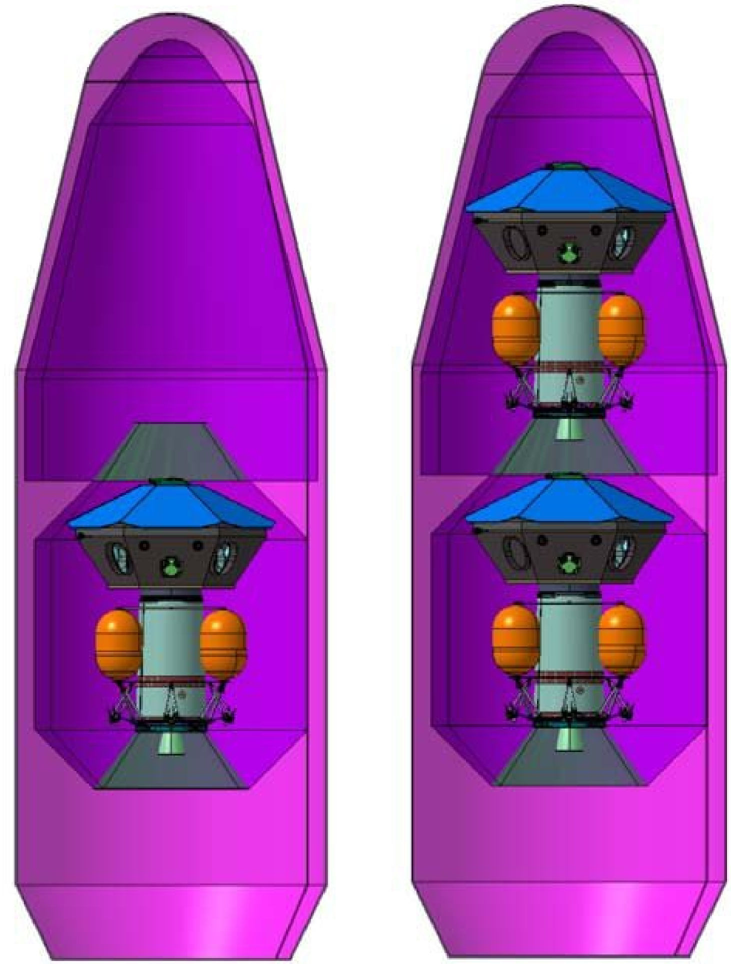


Fully inherited from LISA PathFinder

LISA vs eLISA-NGO LV



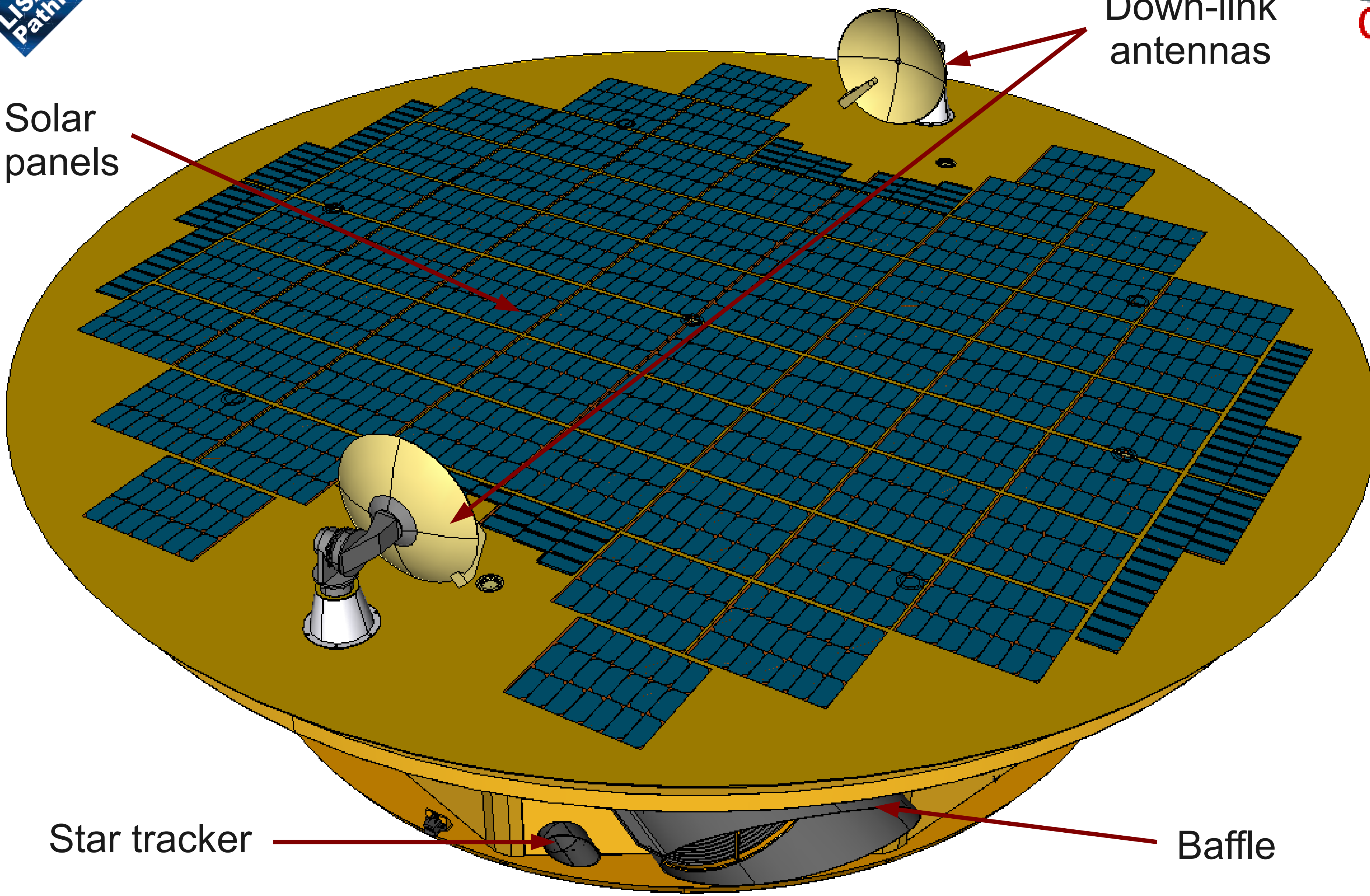
Three LISA S/C incl. Propulsion-
Modules on Atlas V



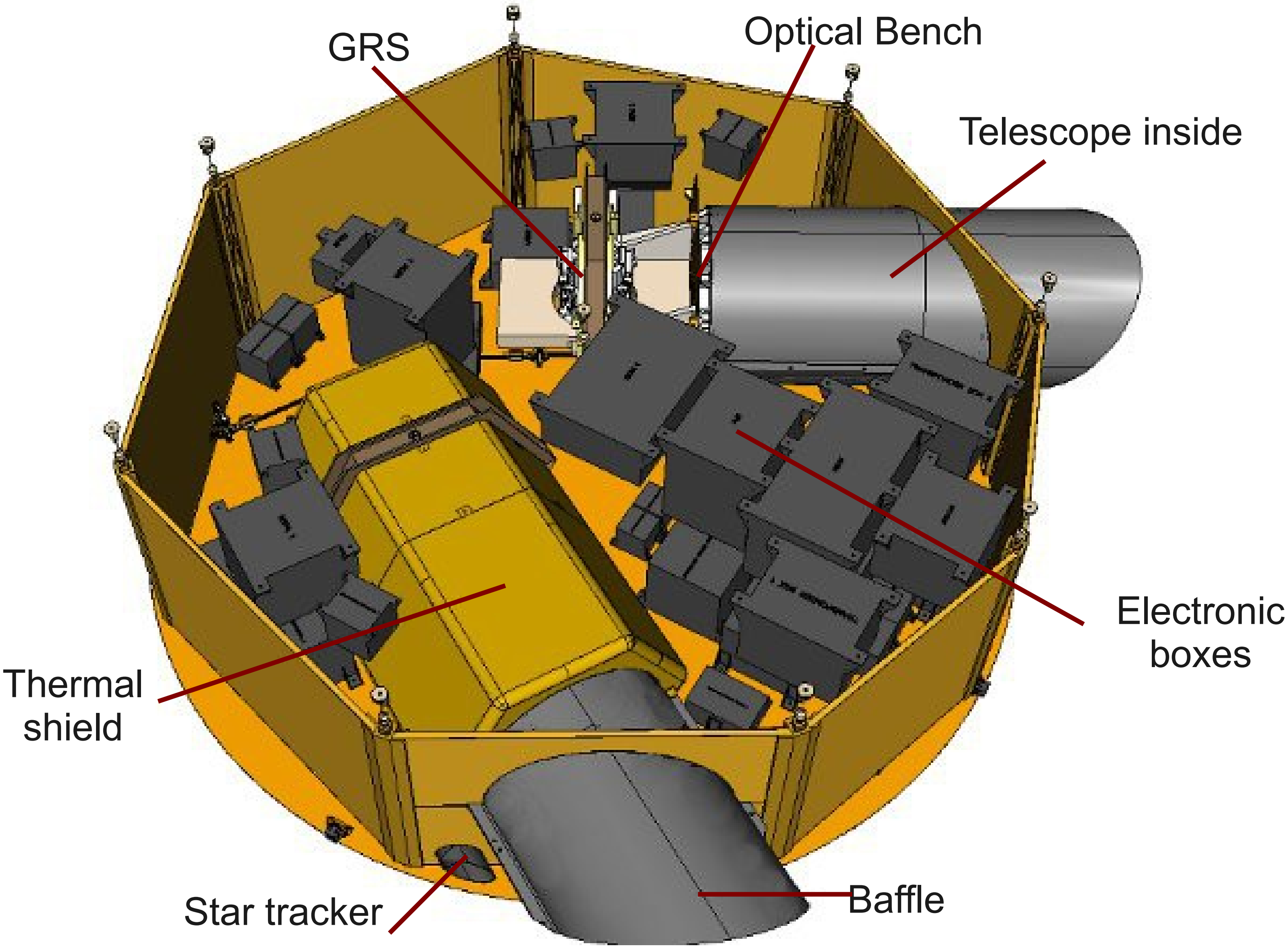
Mother Daughters

2 Soyuz LVs

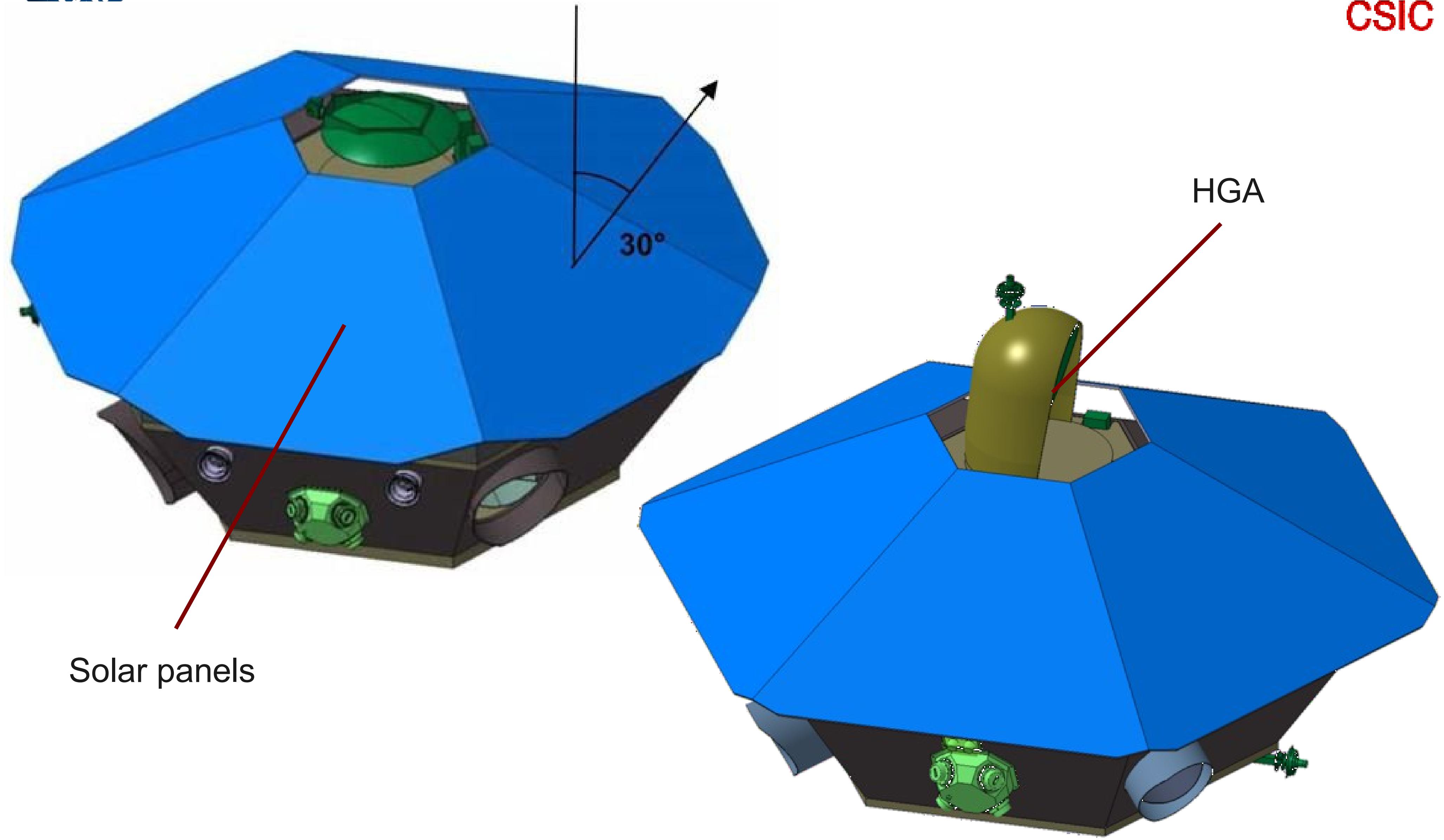
The LISA science-craft



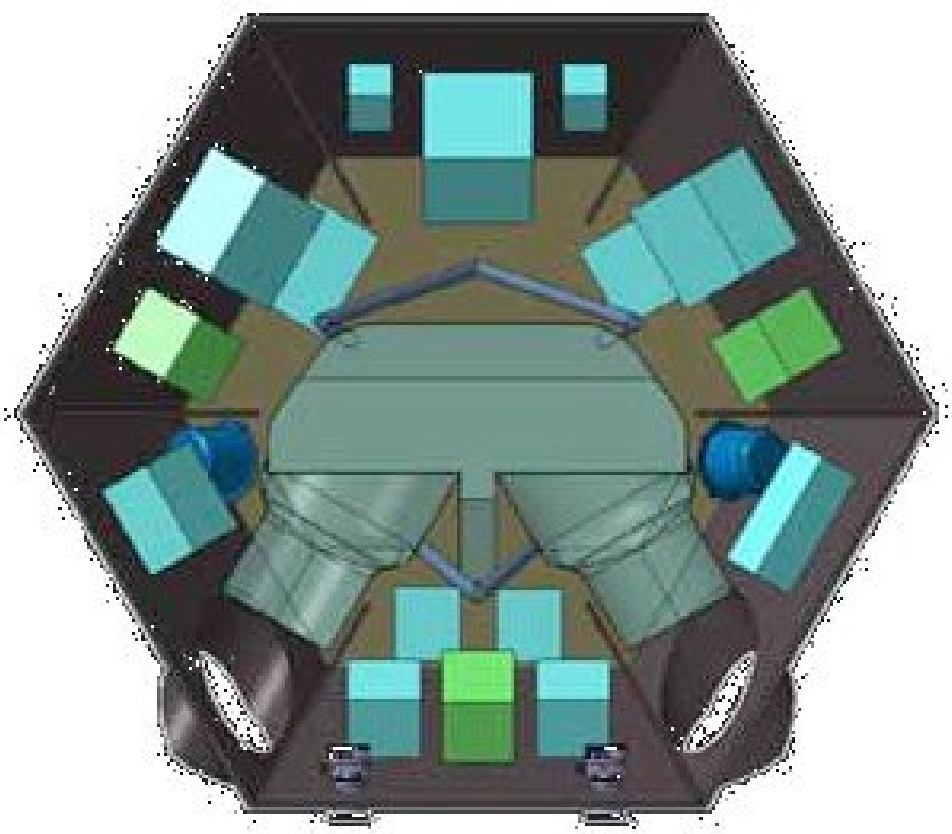
The LISA science-craft



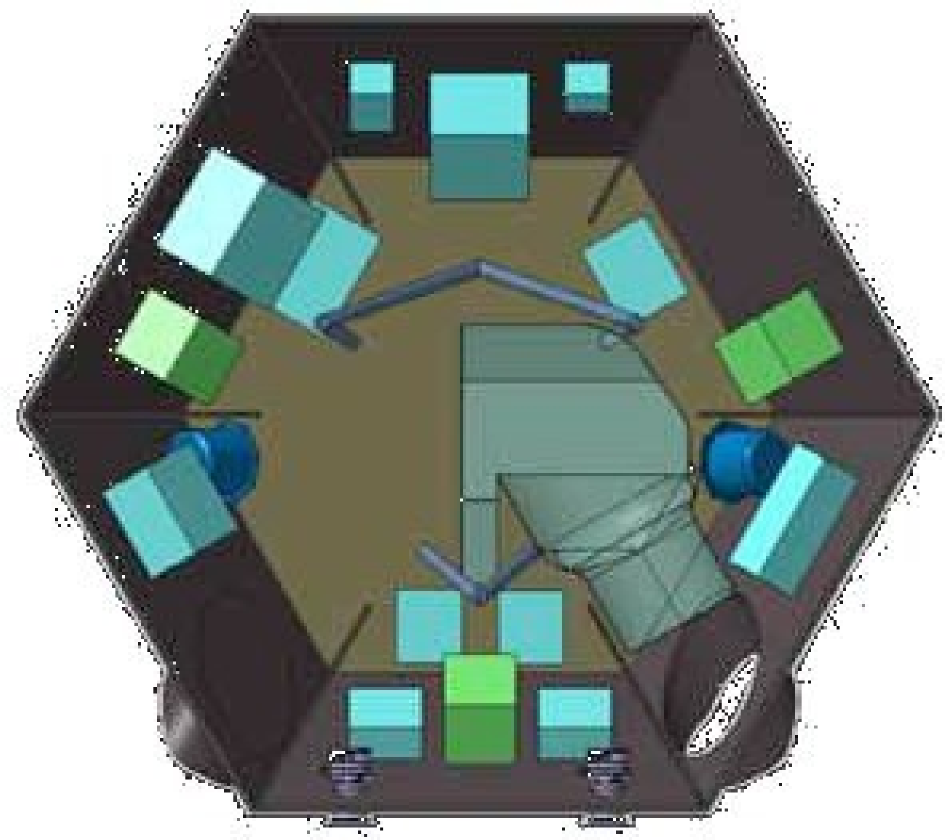
The eLISA-NGO science-craft



The eLISA-NGO science-craft

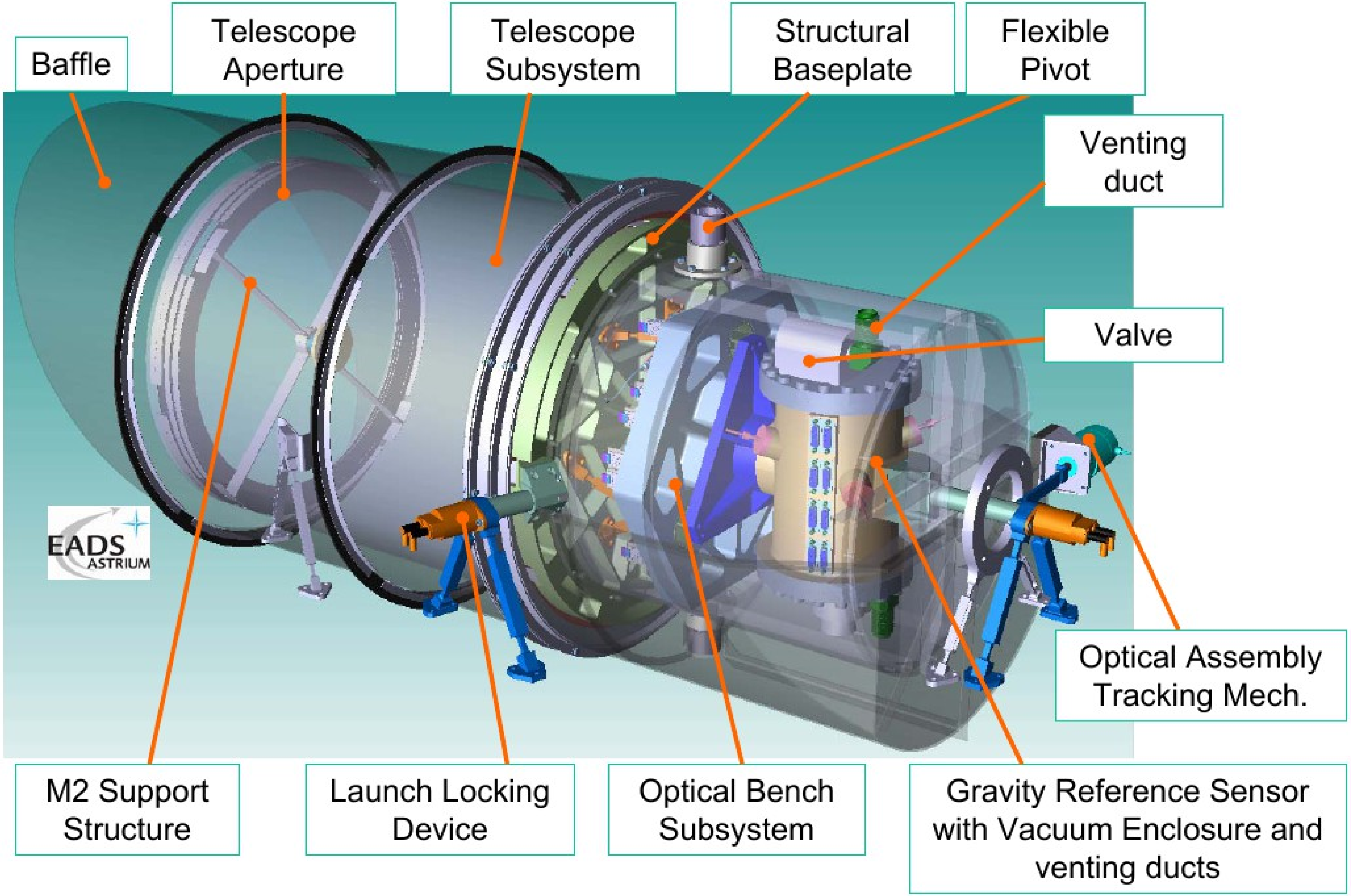


Mother S/C

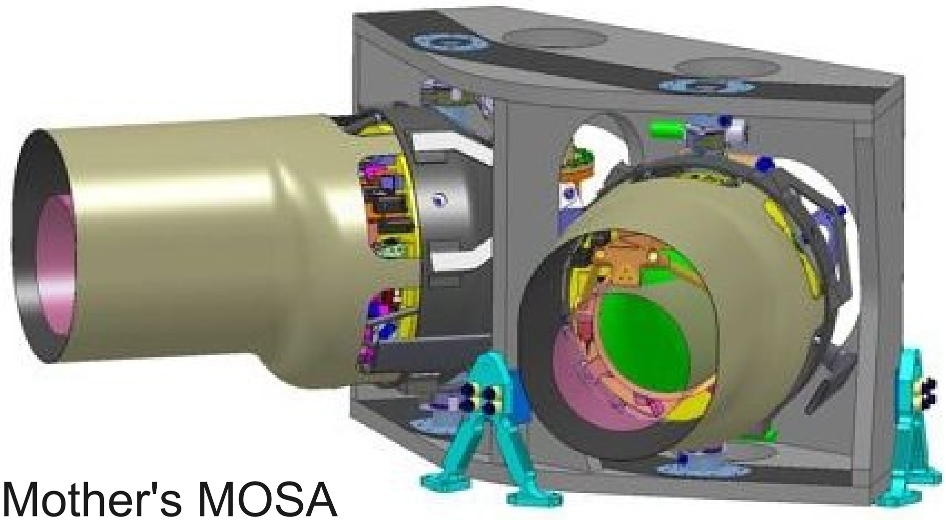


Daughter S/C

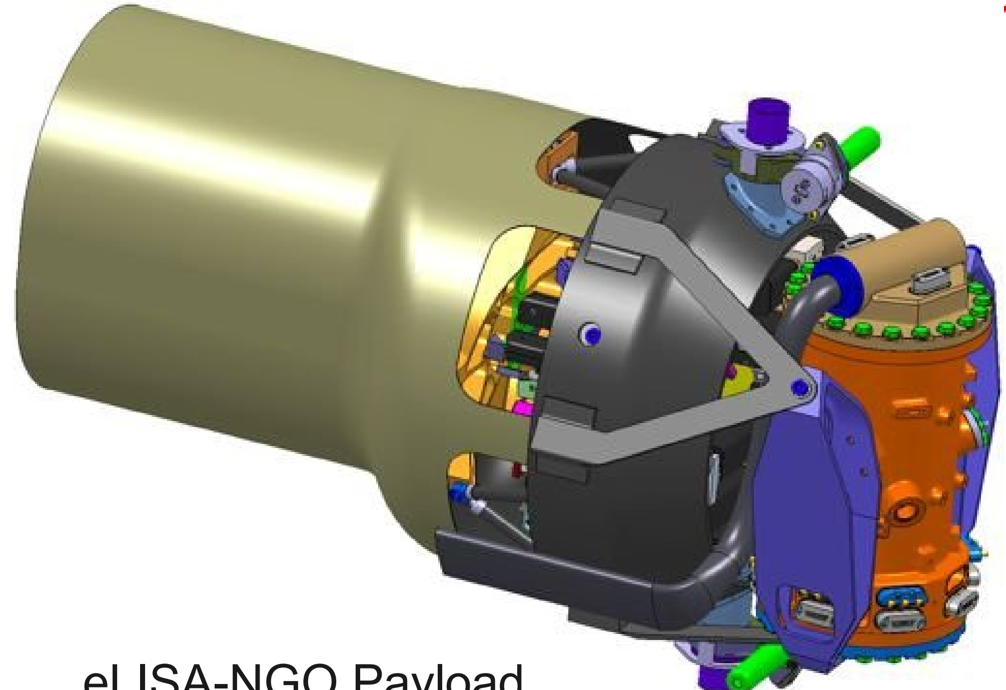
LISA's telescope and payload



eLISA-NGO telescope and payload

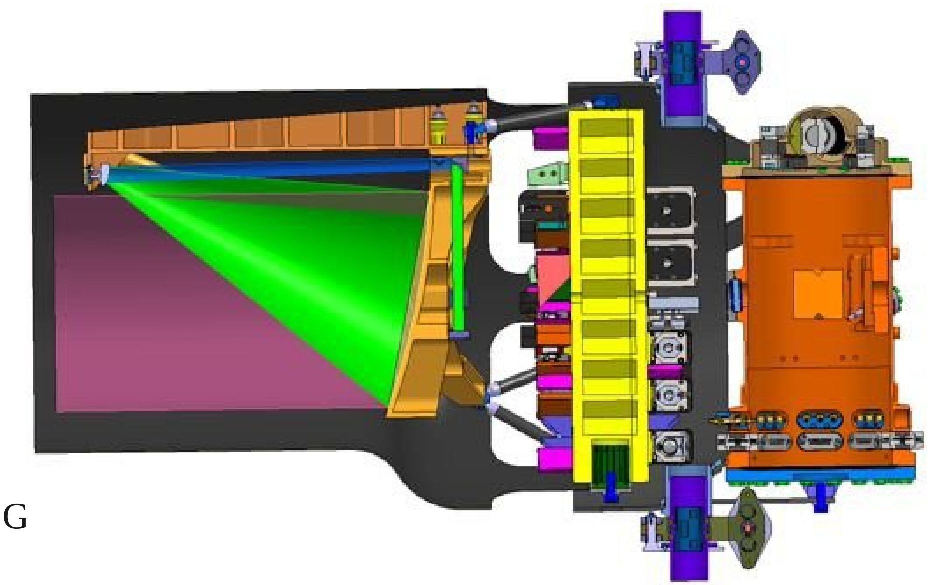


Mother's MOSA



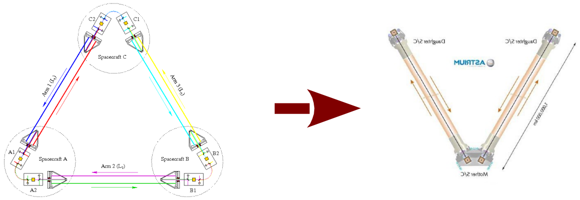
eLISA-NGO Payload

- ***Telescope diameter 40 -> 20 cm***
- ***Laser power 2W -> 1-1.5 W***
- ***Point-ahead angle mechanism no longer needed***
- ***Reduction of instrument height***



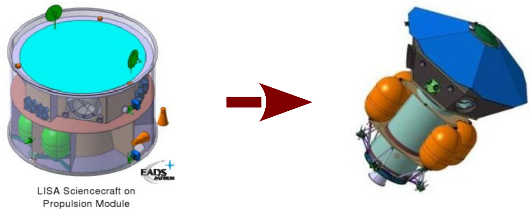
De-scoping summary (mission)

Constellation



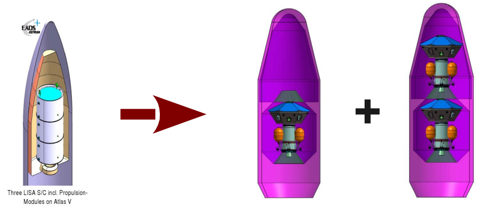
- *1 Mother + 2 daughter S/C*
- *4 TMs and 4 laser links*
- *1 Mkm arms*

Prop Module



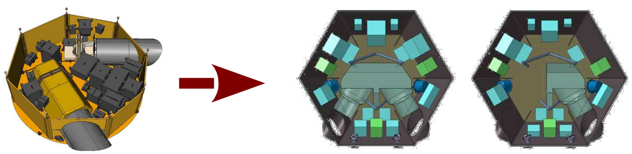
- **Prop Mod inherited from LPF**

Launchers



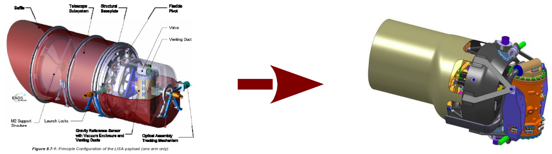
- **2 Soyuz L vs or 1 A-V**

Spacecraft



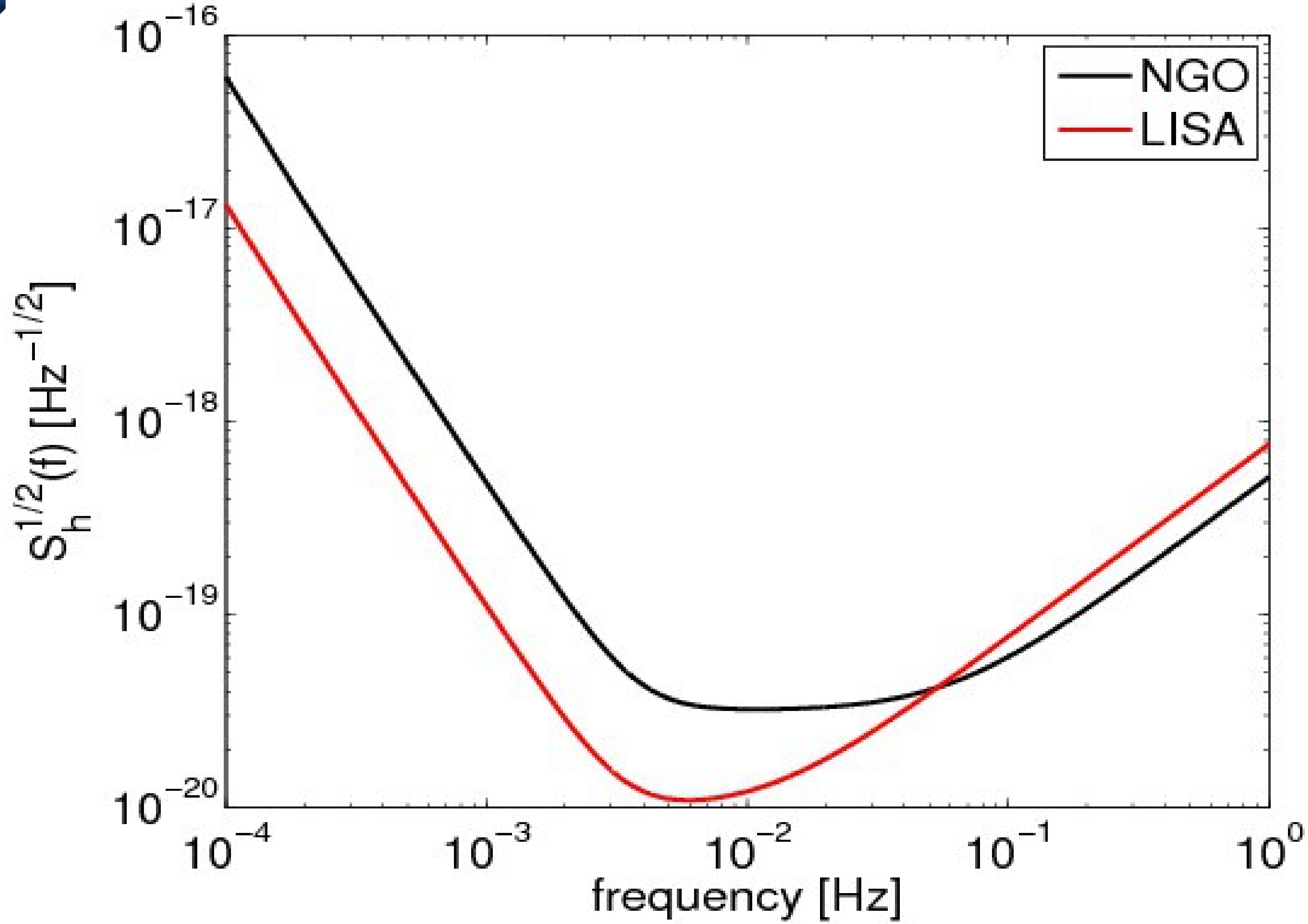
- **LPF S/C, light tayloring**

Payload



- *Telescope diameter 40 → 20 cm*
- *Laser power 2W → 1-1.5W*
- *No point-ahead mechanism*
- *Instrument height reduction*

LISA vs. NGO



NGO
LISA
$S_h^{1/2}(f)$ [Hz$^{-1/2}$]
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
frequency [Hz]

Scientific yield

SOURCES	NGO	LISA
Galactic binaries	~4500	>20000
Verification binaries	>7	>20
MBH binaries	~30	hundreds
MBH mass uncertainty	0.1%	0.01%
EMRIs	Tens	Thousands

In conclusion

• On its meeting of May 3 2012, the SPC gave priority to JUICE, a Jupiter system explorer, to launched in 2022.

• LISA (NGO) received the highest grade in scientific value, so there is a chance that a new opportunity is offered by the second large mission, L2, for a launch in 2024-2026.

• National teams are now working in a LISA rebuild, given its official acknowledge-ment as a first class scientific mission.

• Most, or many, people think one of the main obstacles to make it to L1 has been the delays continually being incurred by LISA PathFinder. It is with this in mind that support is being granted by some countries to do everything possible to speed LPF as much as possible so that a new proposal of GW observatory for L2can be really supportive of the most delicate technologies in low-frequency drag-free laser interferomety missions.

• Spain seems –barring crisis-- to have this in its agenda. The Group at IEEC continues the research along the suitable lines.

LISA, una historia viva. J. A. Lobo. (Edicions UPC).

End of presentation