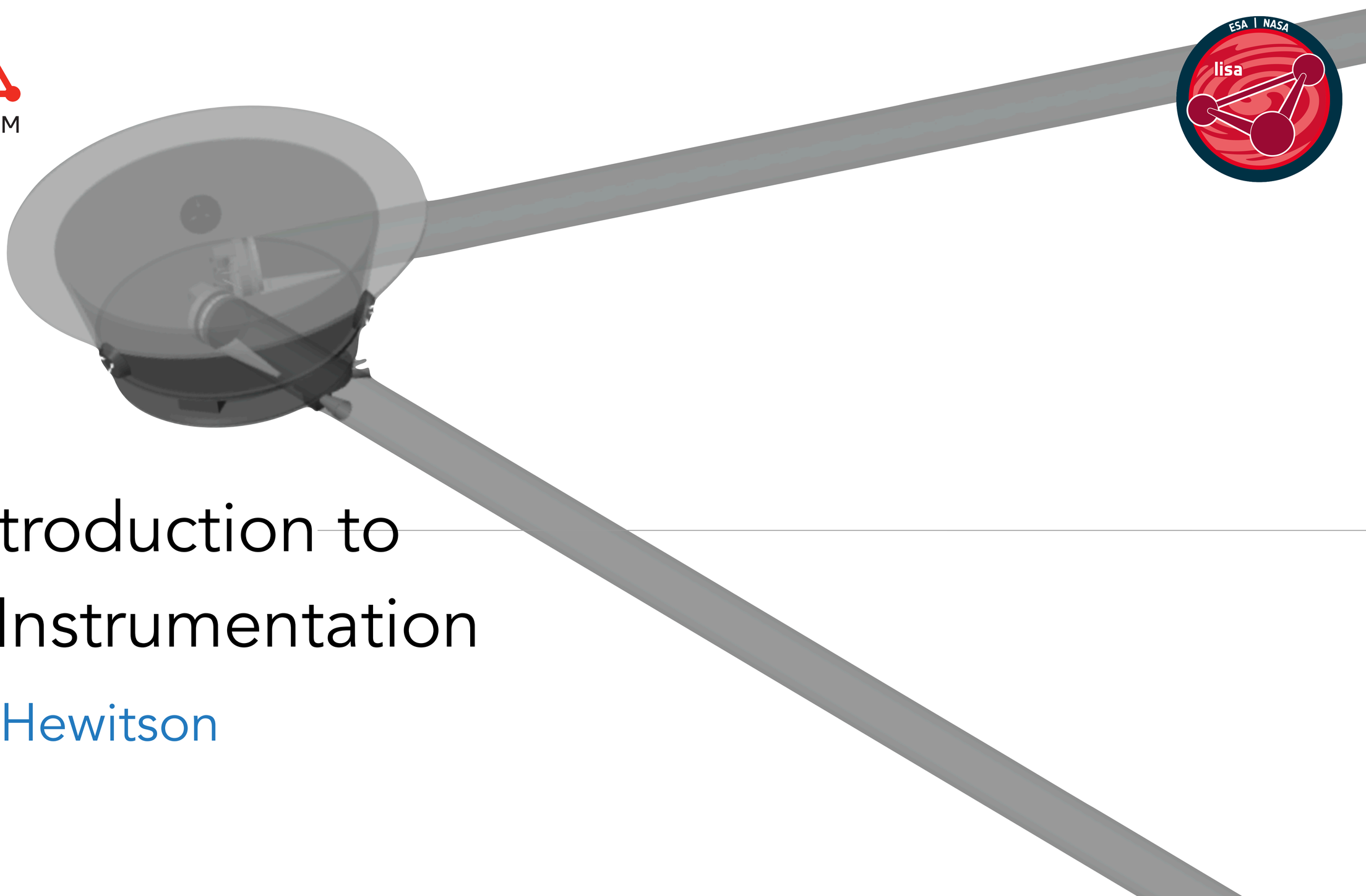
LISA CONSORTIUM



An Introduction to LISA Instrumentation

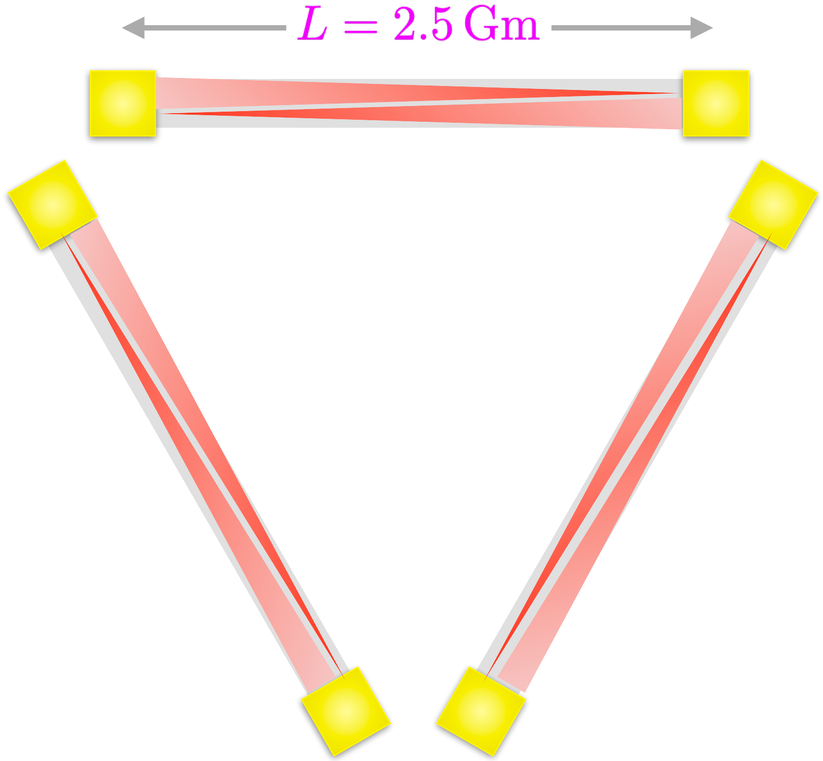
Martin Hewitson

Contents

- The LISA measurement
- Heritage from LISA Pathfinder
- Sensitivity and noise sources
- Organisation and responsibilities

https://lisa.pages.in2p3.fr/consortium-userguide/acronyms.html

The Concept…



Antenna

Pairs of free-falling test masses couple changes in space-time to macroscopic motions we can probe

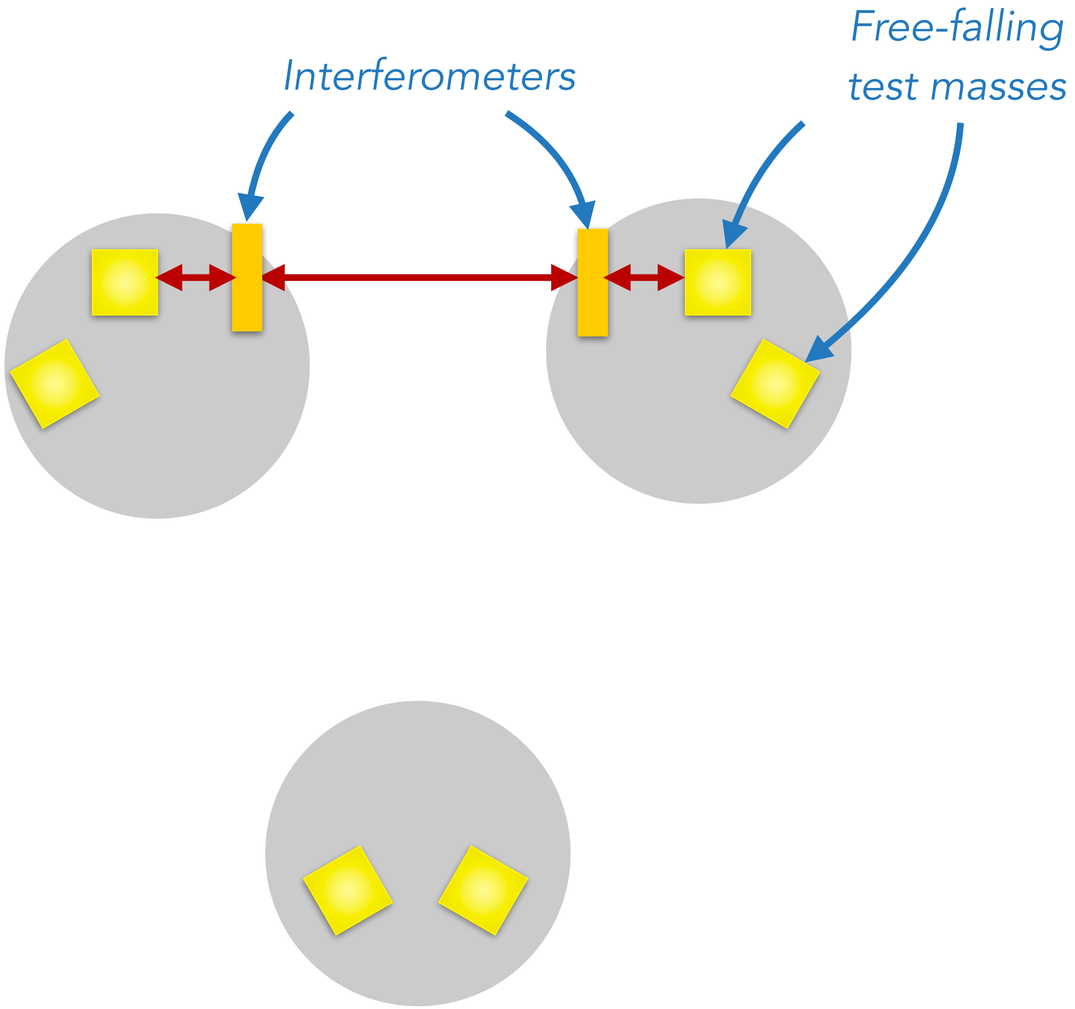
Readout

6 laser transponder links sense the relative motion of these test mass pairs

Interpretation

Relative motion and arm-length knowledge gives us strain induced along each link

Implementing the concept



Shield test masses in spacecraft

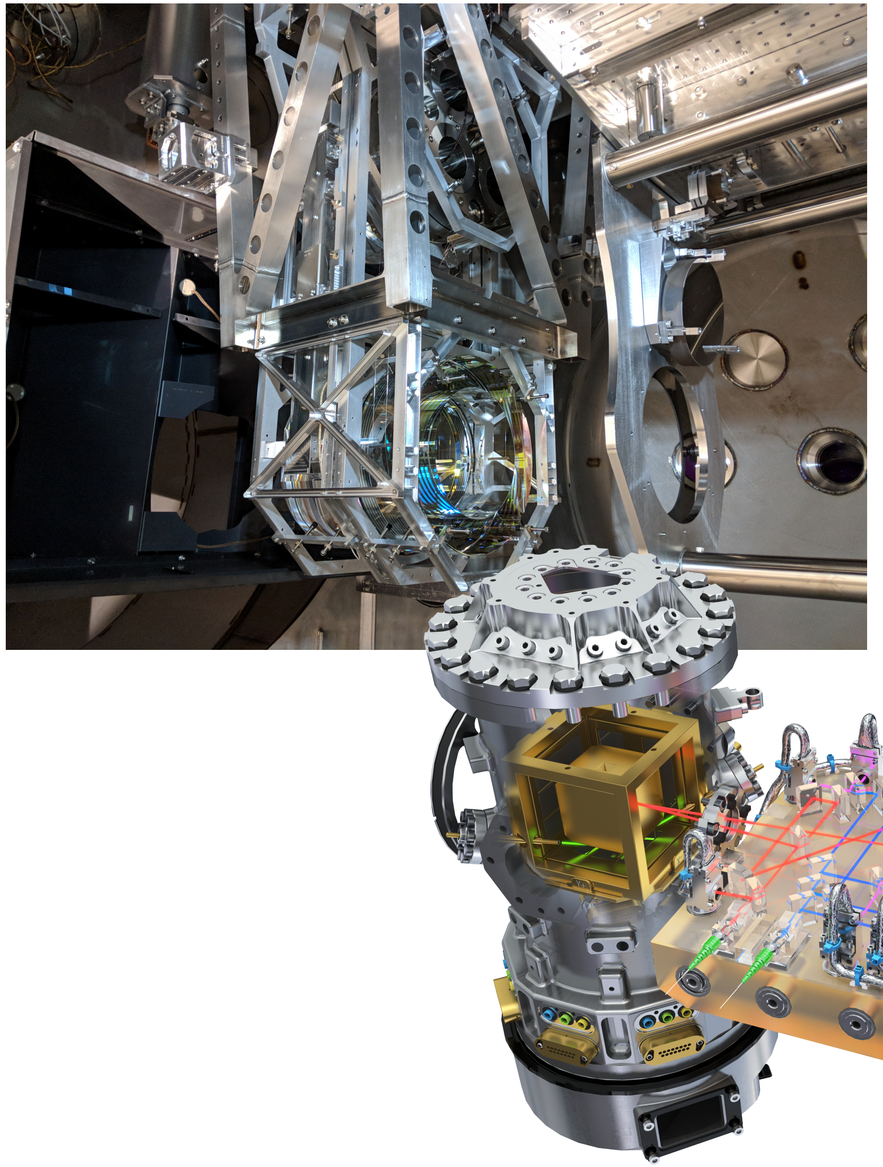
Measure SC motions against test masses

Measure relative SC motions (includes GW signal!)

Reconstruct test-mass to test-mass on ground in post-processing

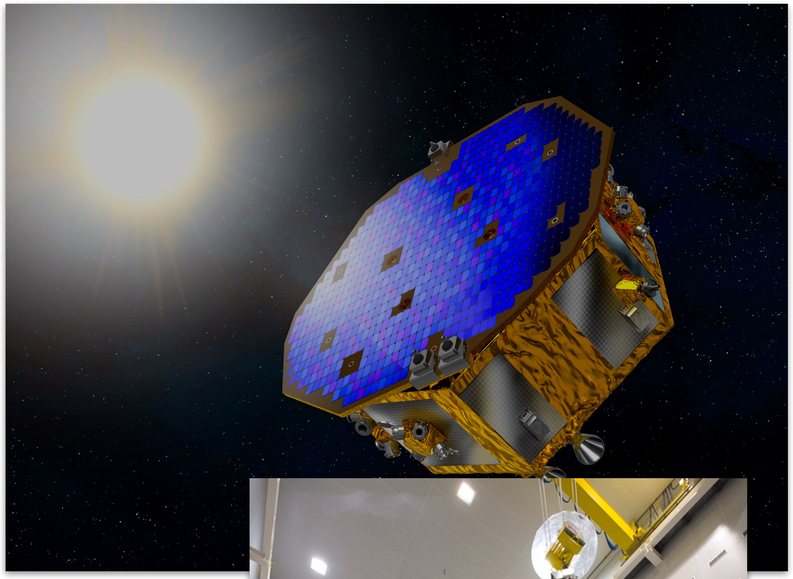
Some of the Challenges…

- Test-mass isolation:
  - suspensions on ground, free-fall in space
- Disturbances at low frequencies
  - on ground: external displacements, external forces
  - in space: small forces on test masses
- Interferometry challenges
  - temperature, thermo-mechanical stability, dynamic range
  - readout noise



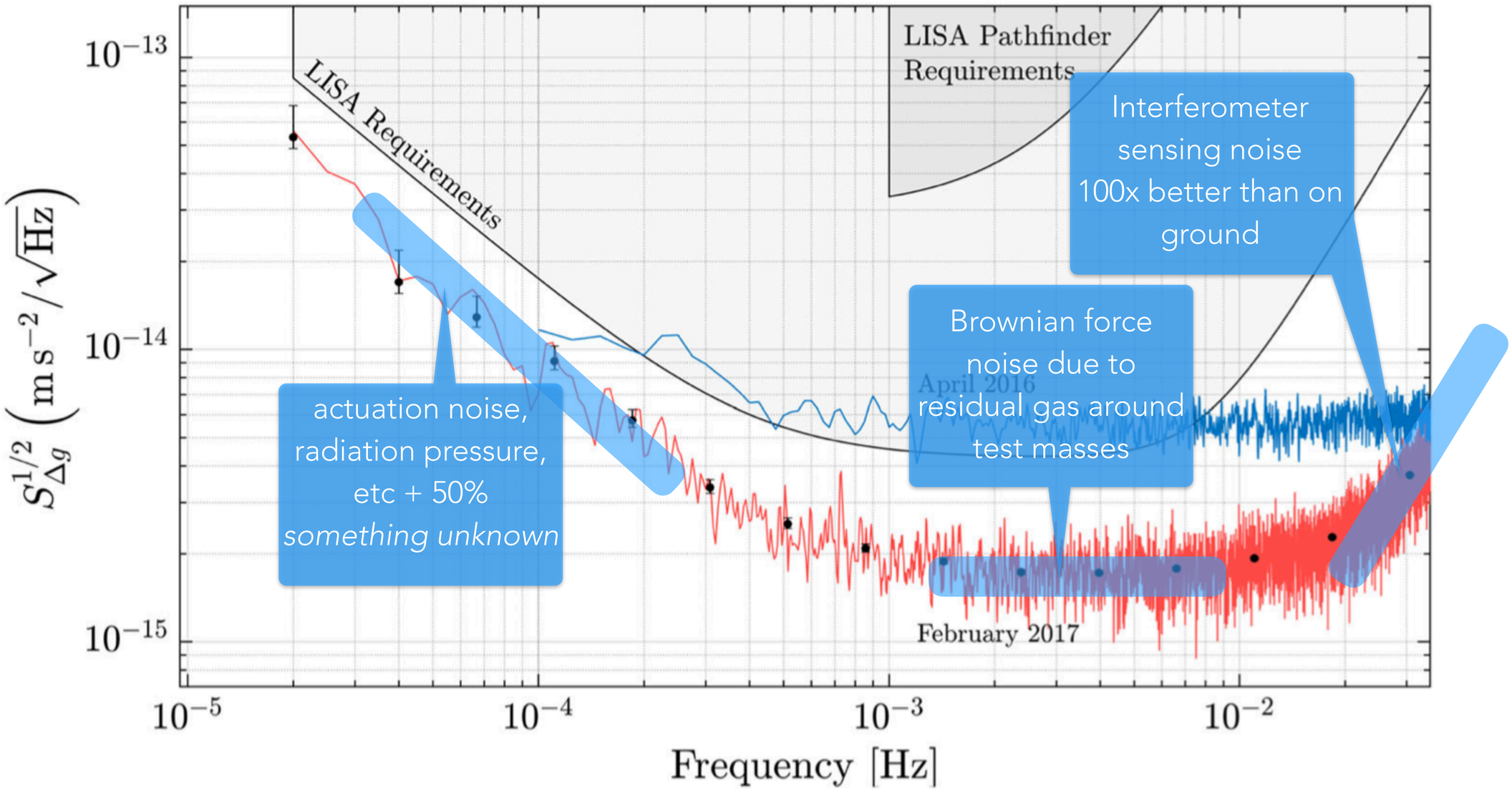
Achieving free-fall: The LISA Pathfinder Mission

- Aims to test most of the LISA performance budget
  - all relevant local test mass disturbance forces
  - local interferometry
- And much of the critical technology
  - drag-free control
  - test mass charge control
  - gravitational balancing
  - SC environment control (thermal, magnetic)
- Additional payload from NASA (ST7) to demonstrate
  - alternative drag-free control
  - alternative micro-Newton thrusters





What did we learn?



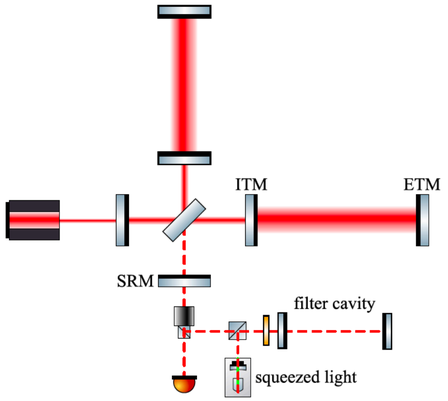
Interferometer sensing noise 100x better than on ground

Brownian force noise due to residual gas around test masses

actuation noise, radiation pressure, etc + 50% *something unknown*

Readout technique

- Ground based detectors lock optical cavities at a sensitive operating point to achieve the required performance
- Not (easily) possible in Space…
- Orbital motion of free-falling bodies produces large relative motions over long baselines
  - would need very strong (and noisy!) feedback forces to maintain ‘fixed' arm-lengths
  - this would need to be a mix of force on S/C (thrusters) and force on test masses
- Use another concept instead: heterodyne interferometry with phase tracking
  - can measure over many fringes



Strain

$$h \propto \frac{\Delta L}{L}$$

On Ground

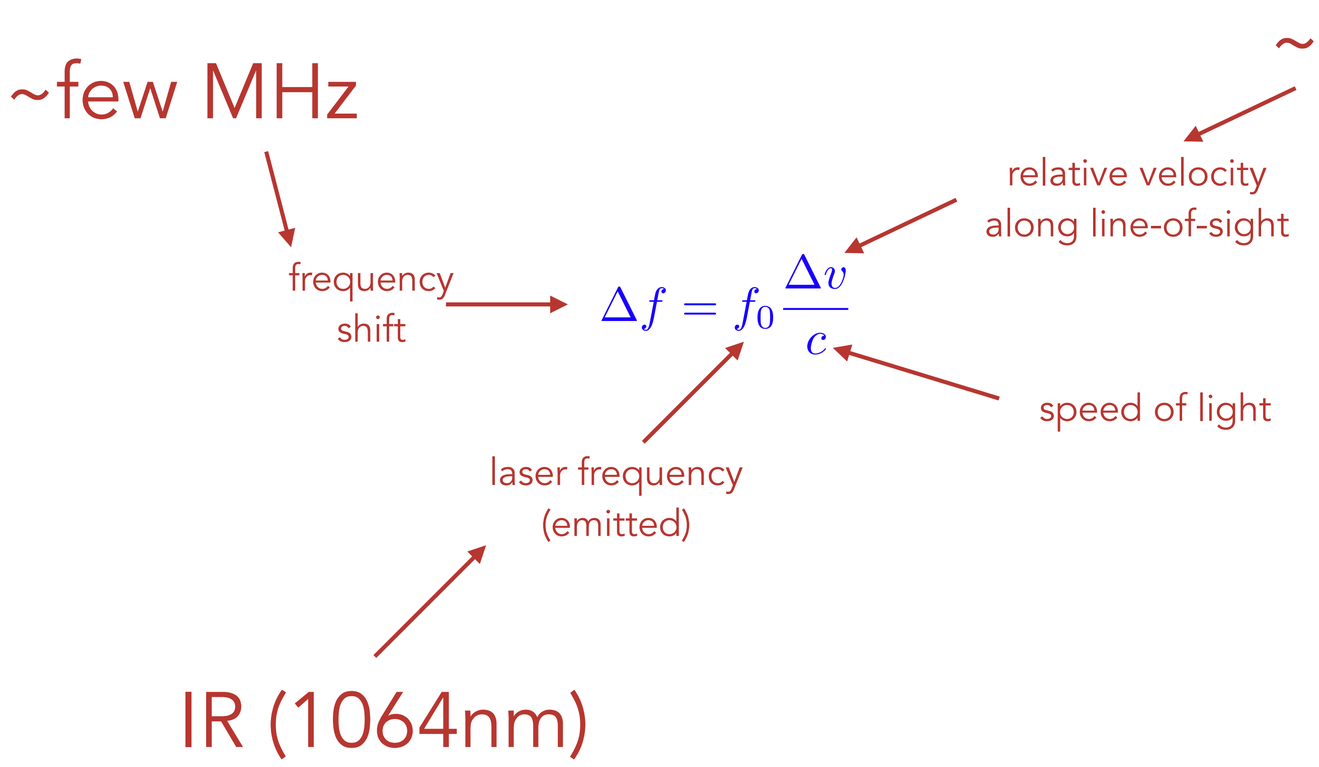
$$10^{-21} = \frac{4 \times 10^{-18}[\mathrm{m}]}{4000\,[\mathrm{m}]}$$

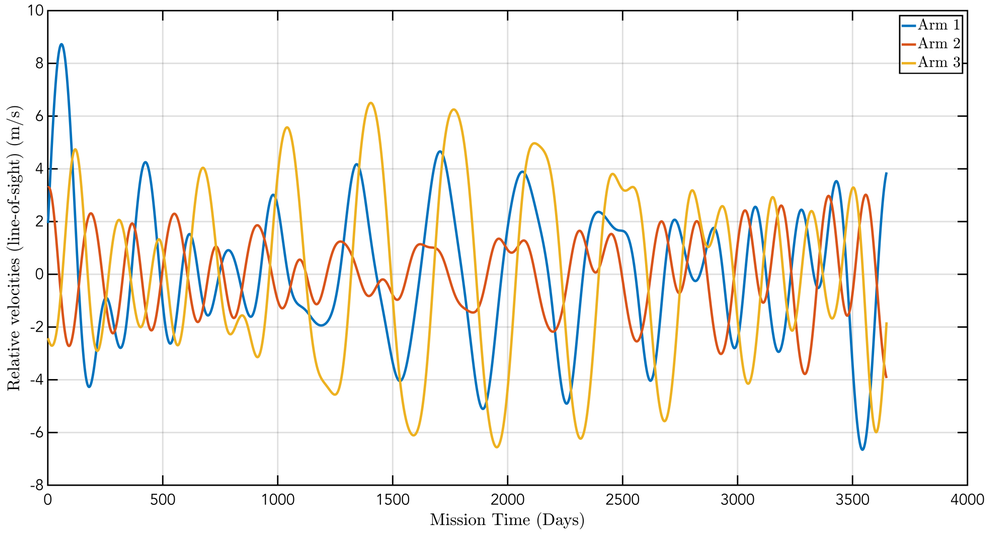
In Space

$$10^{-21} = \frac{2.5 \times 10^{-12}[\mathrm{m}]}{2.5 \times 10^{9}\,[\mathrm{m}]}$$

Features of the LISA Concept

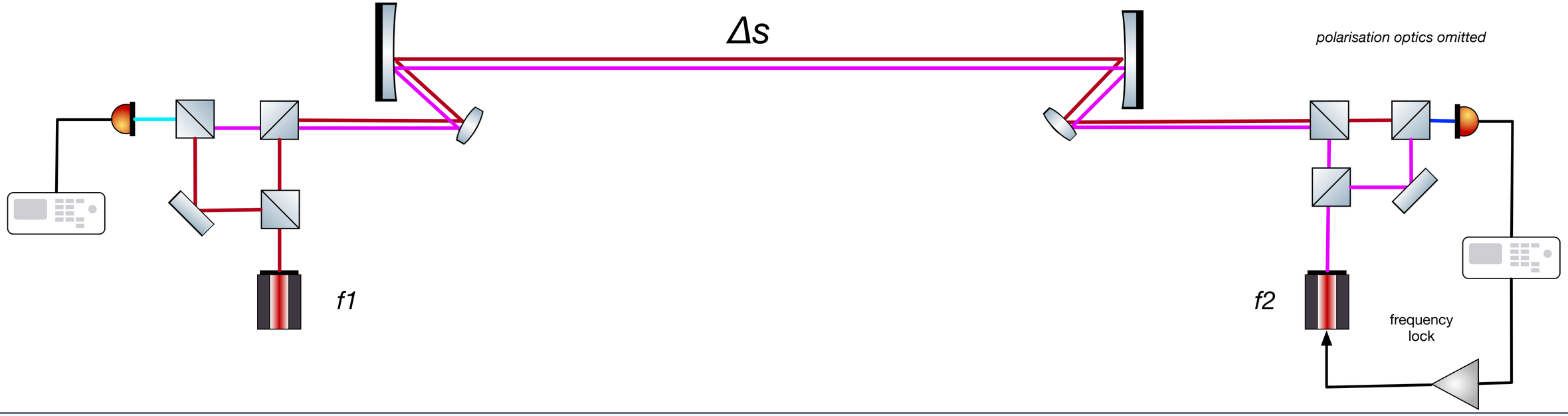
- Transmitted lasers are subject to doppler shifts due to orbital motions
- Line-of-sight relative velocities of S/C impose frequency shifts on received light





Transponder scheme

- send out one beam to far S/C
- in far S/C compare received beam to local beam
  - control difference of the two laser frequencies
  - Laser 2 is now locked to Laser 1
    - f2-f1 is kept constant
- Far S/C returns this Laser 2 to S/C 1
  - measure phase difference between two lasers
    - encodes GW signal + S/C motion + frequency noise of Laser 1



Frequency noise

- Remember: we are measuring the beat between two lasers
  - GW signal shows up as phase sidebands on that beat
  - We measure the phase of that optical beat using a phasemeter
- If one of the lasers changes frequency, then the beat note changes frequency, and hence phase
- If the frequency of both lasers fluctuates, this gives phase noise sidebands on the beat signal
- *Therefore: Frequency changes in the laser are indistinguishable from GW signal*

$$\tilde{\phi}(f) = \frac{2\pi\Delta L}{c}\tilde{\nu}(f)$$

$$\tilde{\phi}(f) = \frac{2\pi 2.5\times10^{9}[\mathrm{m}]}{3\times10^{8}[\mathrm{m}]} \times 100\frac{\mathrm{Hz}}{\sqrt{\mathrm{Hz}}}$$

$$= 5236\frac{\mathrm{rad}}{\sqrt{\mathrm{Hz}}}$$

convert phase to equivalent displacement

$$x = \frac{\lambda}{2\pi}\phi$$

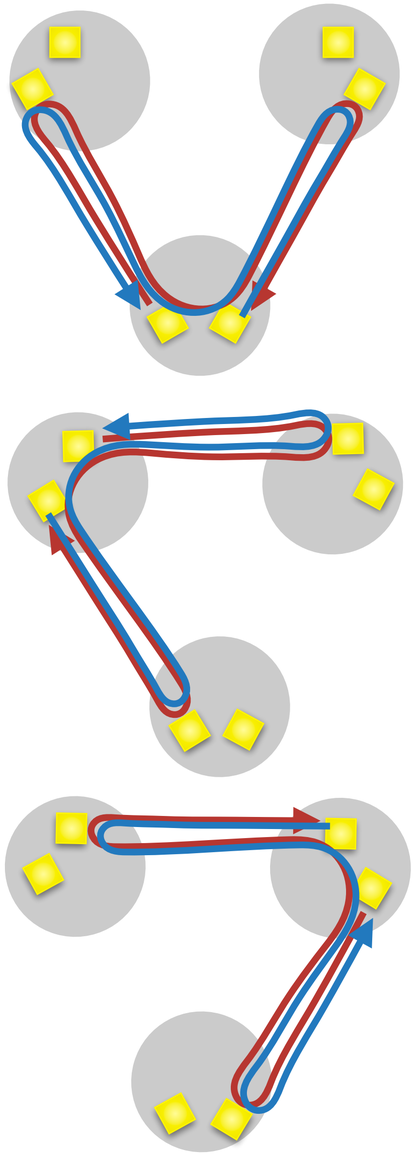
$$\tilde{x} = \frac{\lambda}{2\pi}\tilde{\phi}$$

$$= \frac{1064[\mathrm{nm}]}{2\pi}5236\frac{\mathrm{rad}}{\sqrt{\mathrm{Hz}}}$$

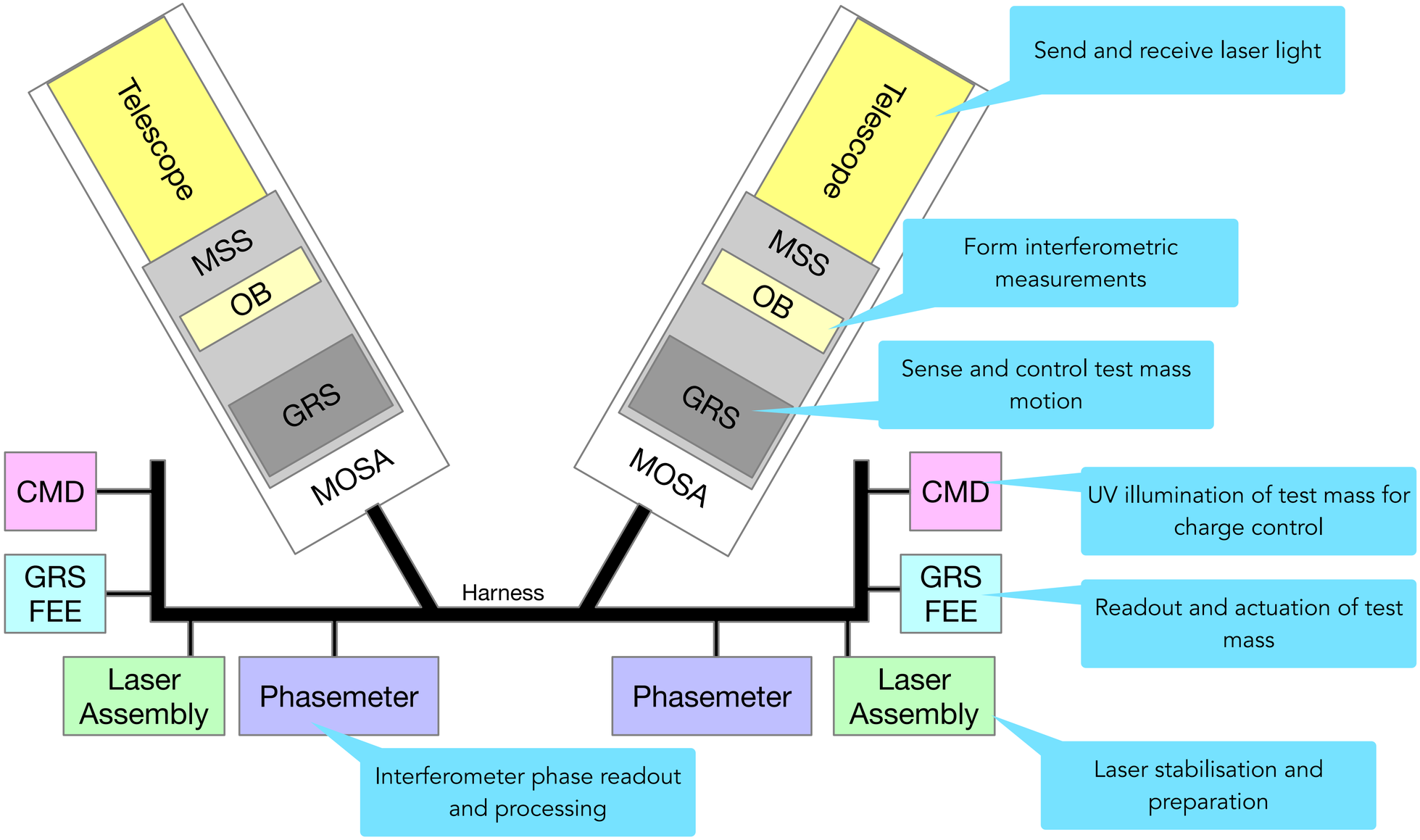
$$= 0.9\frac{\mathrm{mm}}{\sqrt{\mathrm{Hz}}}$$

Time-Delay Interferometry (TDI)

- We measure the GW signals in 6 different interferometers around the constellation
- We also make reference measurements, laser-to-laser, on each S/C
- These are all combined in delayed, linear combinations to cancel frequency noise
- Effectively produce 3 quasi-independent Michelson-like combinations

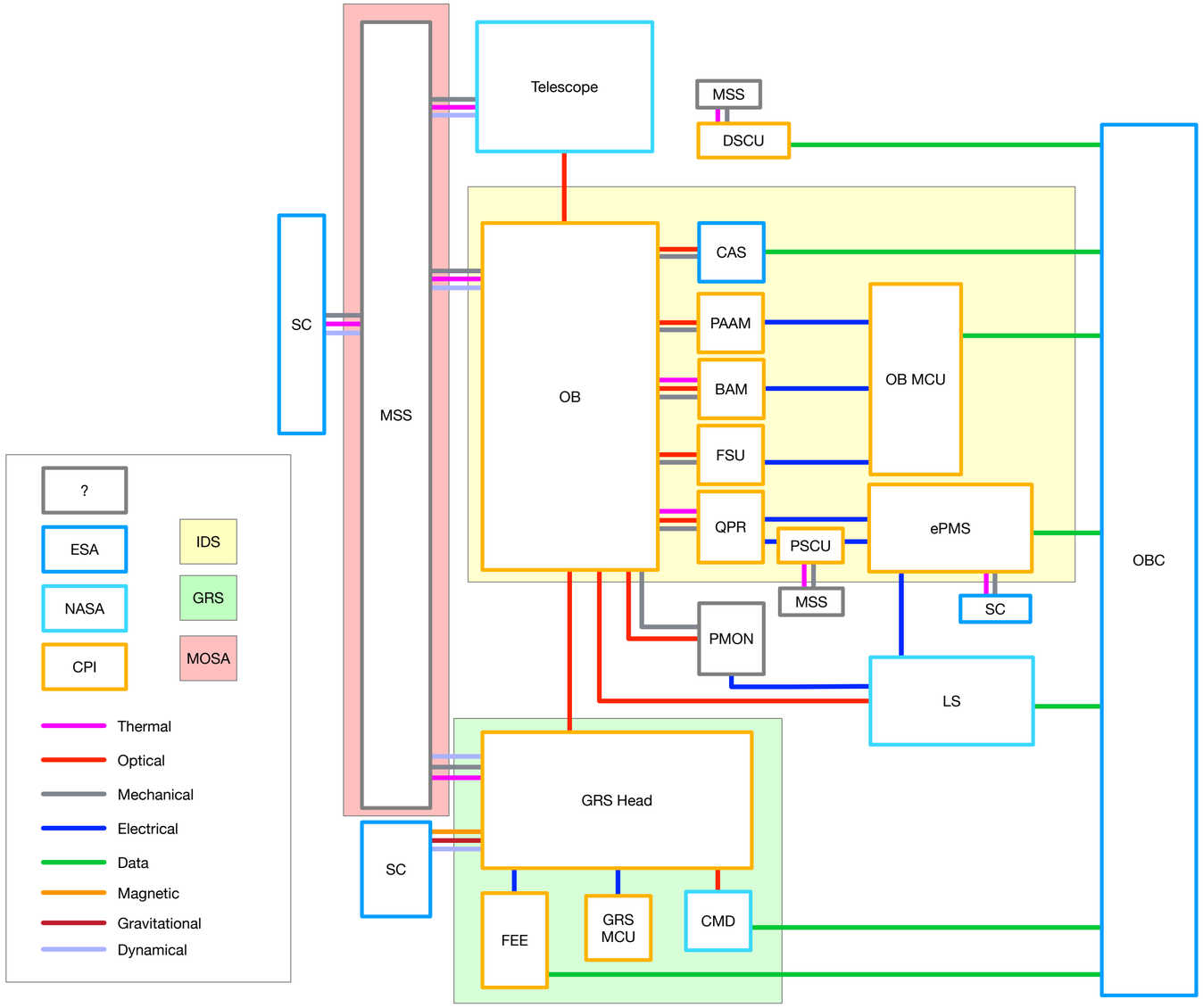


Key components & functions

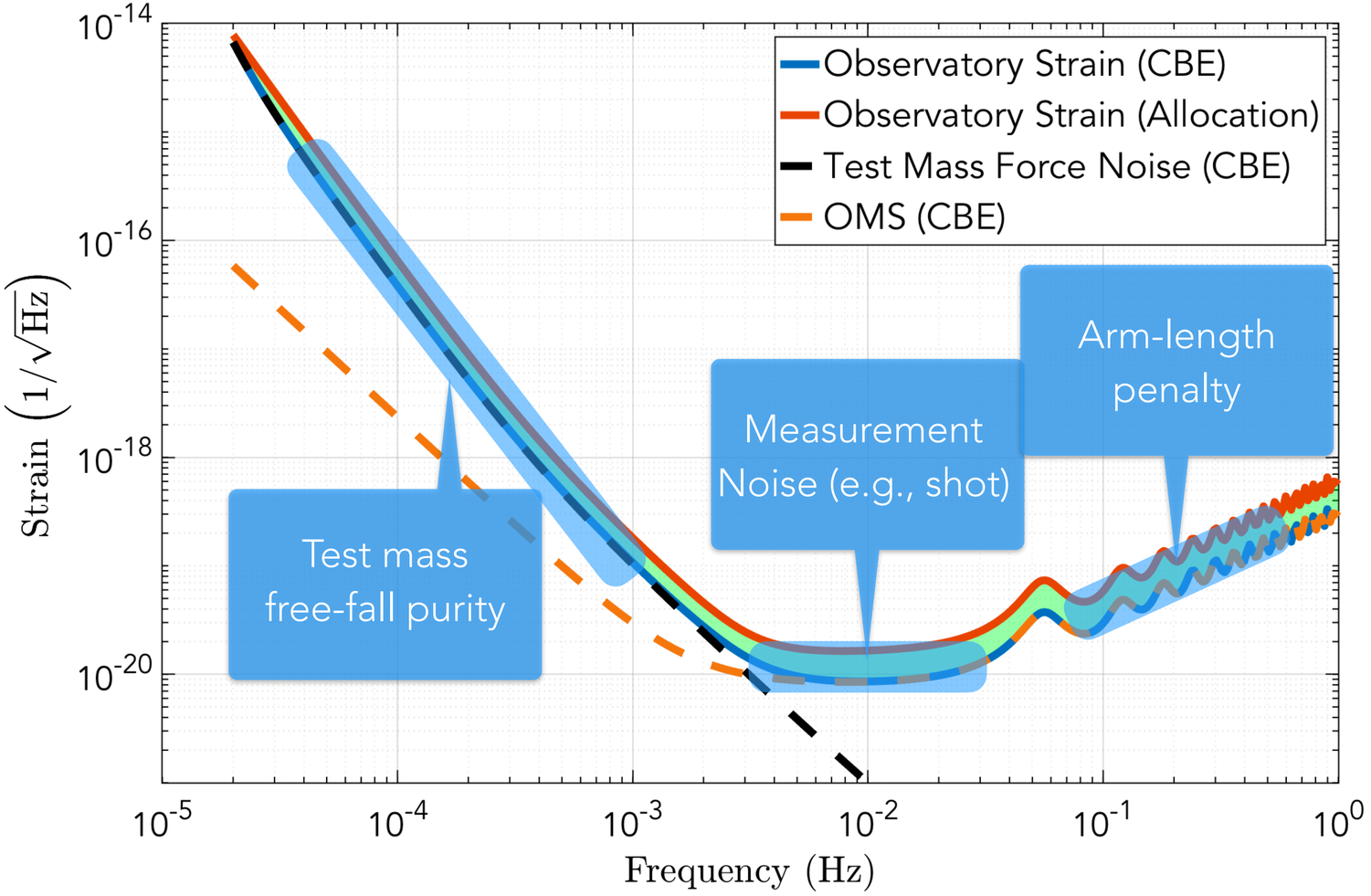


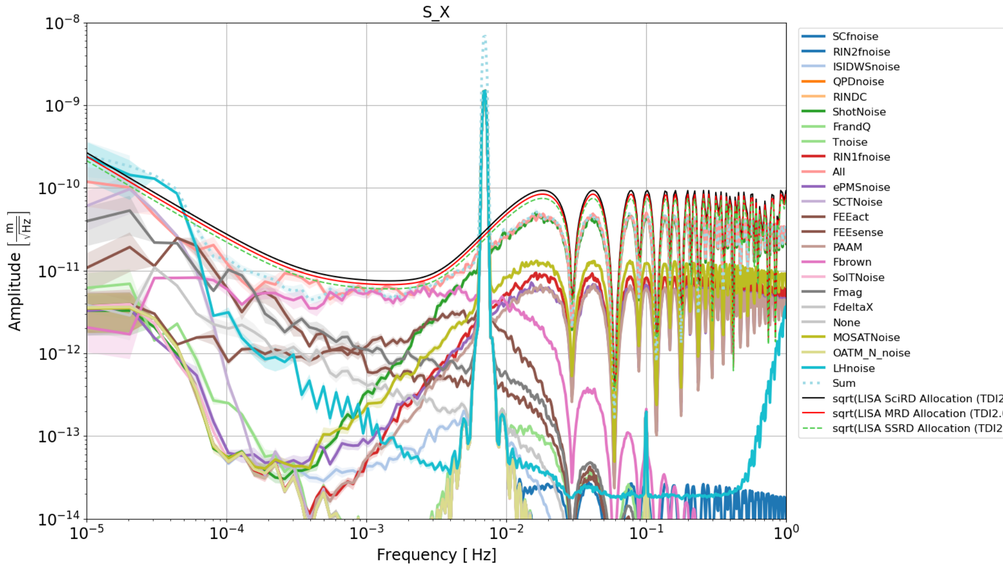
Sub-System architecture & interfaces

- 3 key flight subsystems provide by Consortium
  - Interferometry
  - Gravitational Reference Sensor
  - Science Diagnostics



LISA Performance





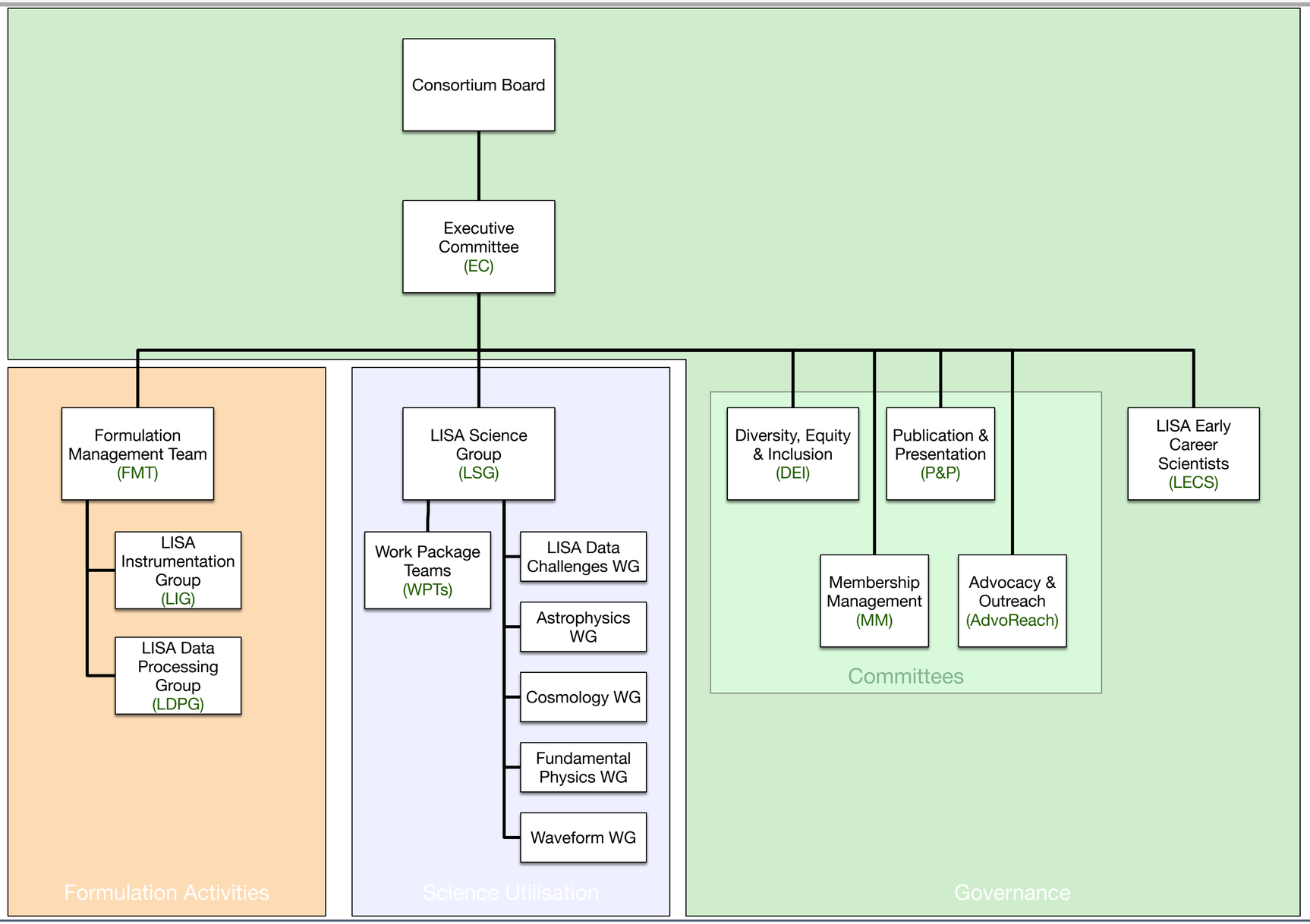
The LISA Consortium

- A large group of scientists from all over the world
  - 1568 members
  - 823 associate members
  - 716 full members
- Organised to
  - Support the mission development
  - Prepare for utilising the LISA data

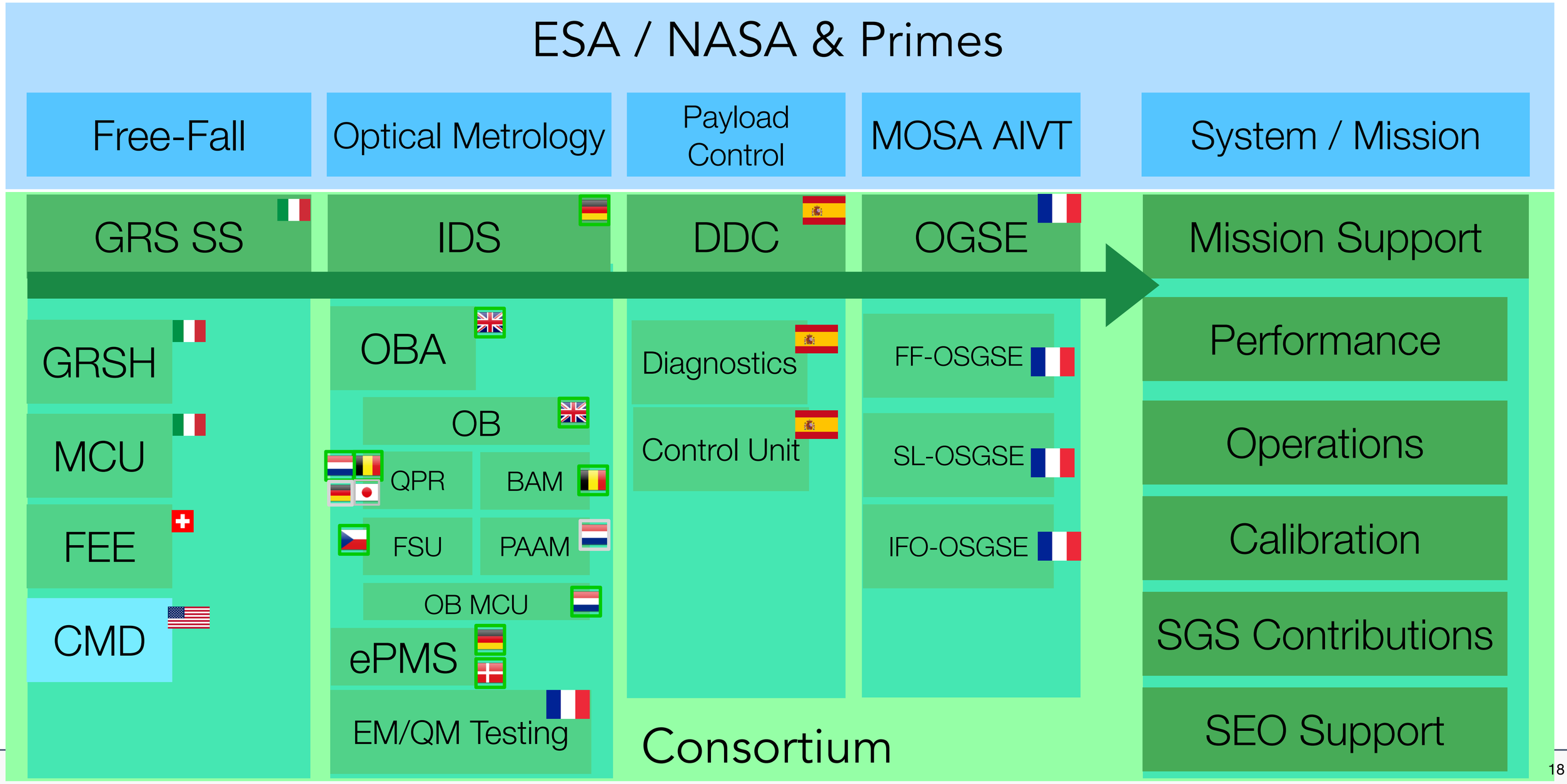


Consortium structures

- Established Formulation Management Team to establish
  - Stronger links between instrument and on-ground processing teams
  - Task-driven approach to improve efficiency
- 4 subsystem teams managing the national contributions
- Organised around two facets of the Consortium:
  - mission formulation and development work;
  - science utilisation and research work.



Consortium national contributions



Thanks!