In-flight thermal experiments for LISA Pathfinder

Ferran Gibert, on behalf the LTPDA team

Institut de Ciències de l'Espai (ICE-CSIC/IEEC)
Barcelona

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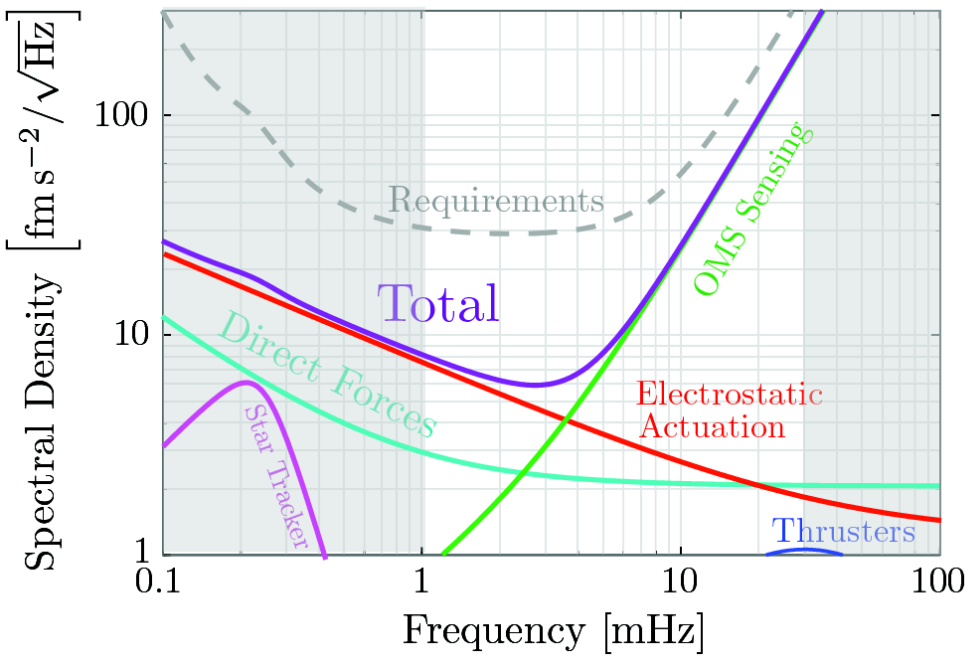
Temperature noise in LISA Pathfinder's LTP

- The LISA Technology Package (LTP) onboard LISA Pathfinder is sensitive to several environment fluctuations

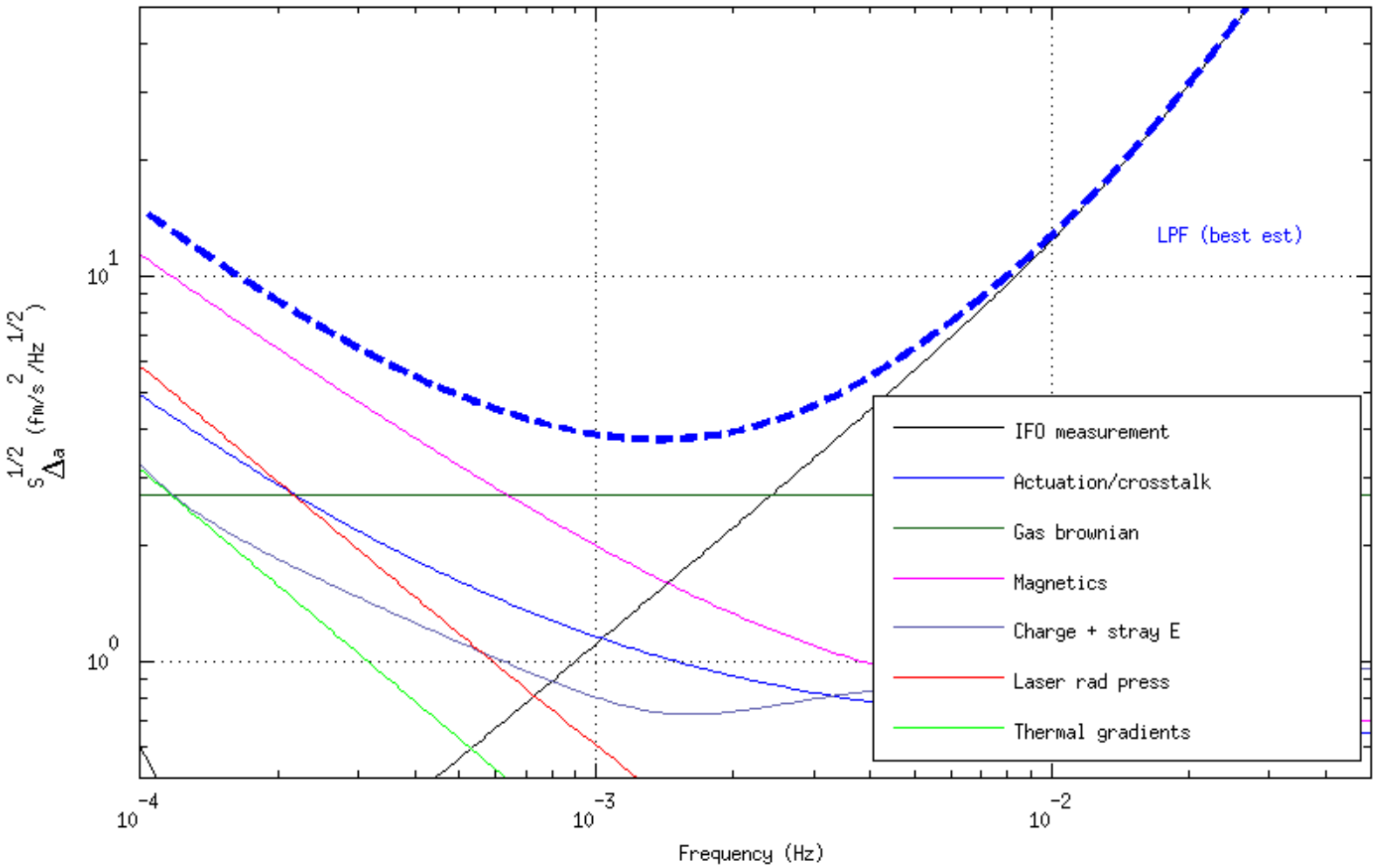
- Best estimates
  Antonucci et al, CQG.29-124014



- Direct non-actuation forces include:
  Antonucci et al, CQG.28-094002

Effect	Est. Cont. [fm s^{-2}Hz$^{-1/2}$]
Brownian noise	7.2
Magnetic noise	2.8
Stray voltages	1.1
Laser radiation pressure	0.7
Temperature gradient noise	**0.4**
Self-gravity noise	0.3

Temperature noise in LISA Pathfinder's LTP

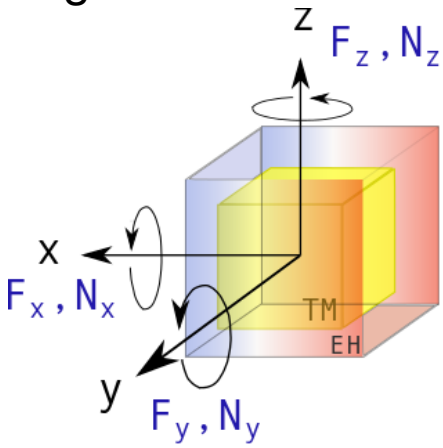


Temperature noise in LISA Pathfinder's LTP

In general, **temperature fluctuations** at the LTP affect the system through different ways:

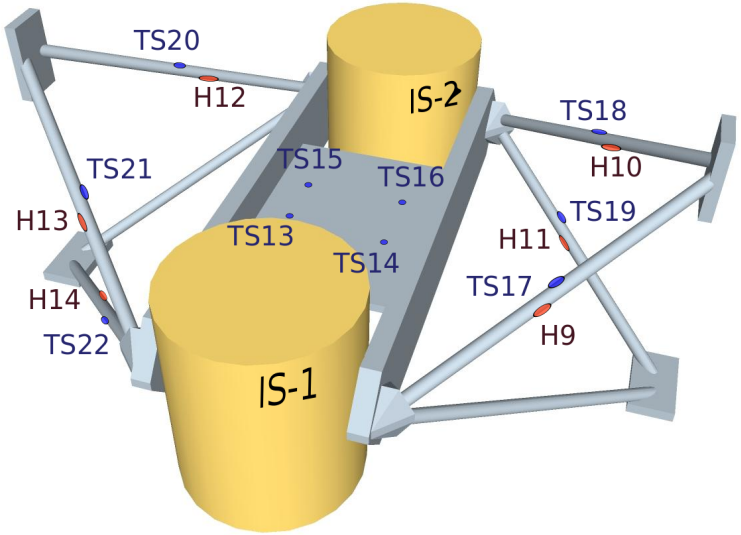
1. **Thermoelastic** distortion of the LTP Core Assembly **structure**
2. **Thermoelastic** distortion of some **optical parts**
3. **Forces** and **torques** on the Test Masses through the following effects:

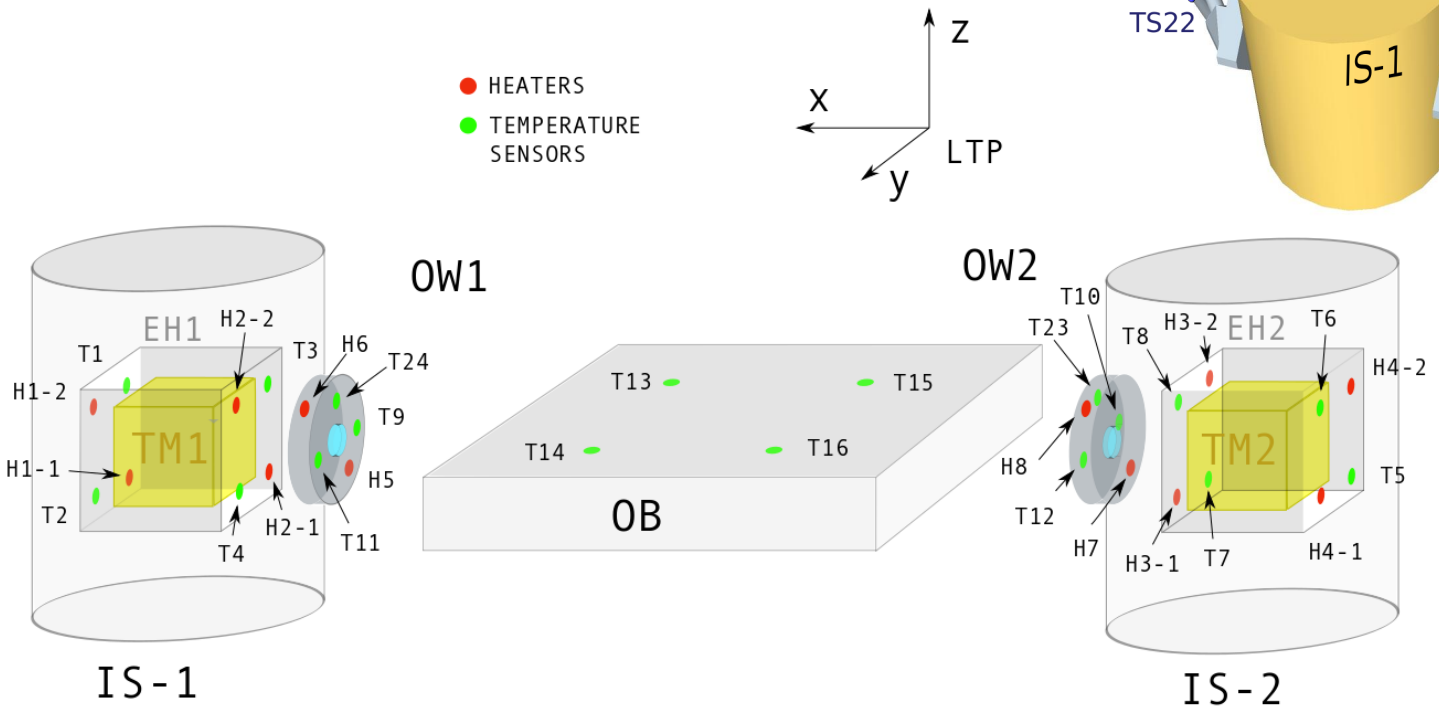
- Radiometer effect $F_{RM} = K_{RM} P / T \Delta T$
- Radiation pressure $F_{RP} = K_{RP} T^3 \Delta T$
- Asymmetric outgassing $F_{OG} = K_{OG} \exp(-\frac{\Theta}{T}) / T^2 \Delta T$



The Thermal Diagnostics Subsystem

- 24 Temperature sensors
- 14 Heaters





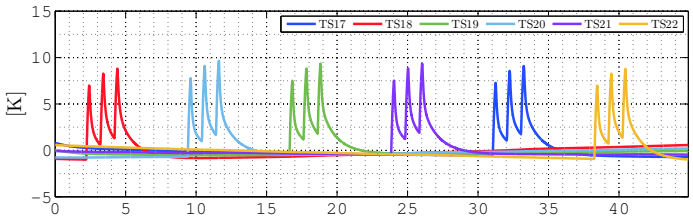
Thermal Diagnostics Experiments

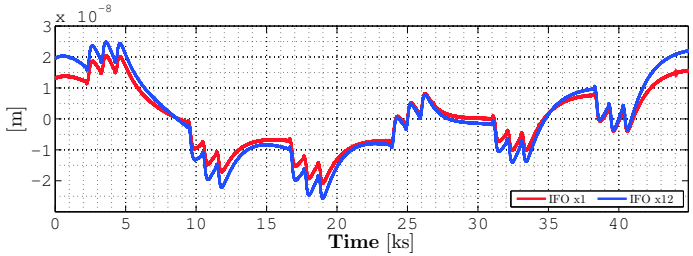
- Three kinds of thermal experiments:
  - **Strut thermal experiments**
  - **Optical Window thermal experiments**
  - **Electrode Housing thermal experiments**

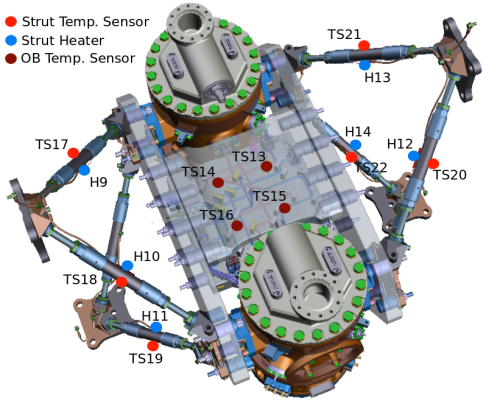
Strut experiments

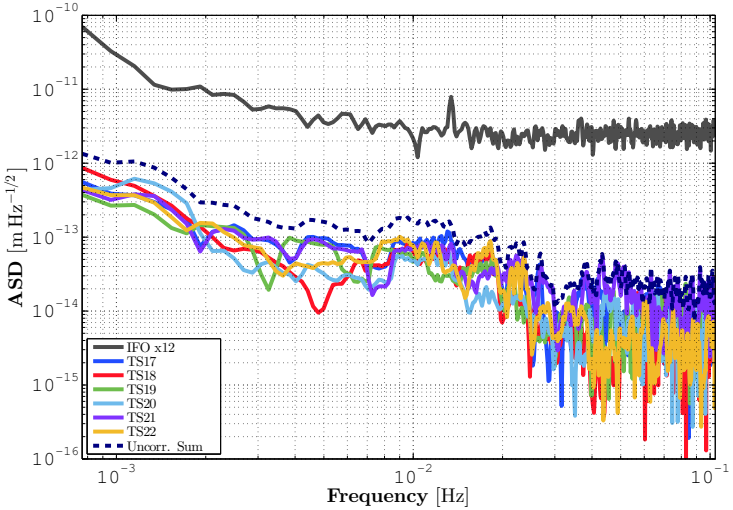
- Series of heat pulses to be applied individually on each strut.
- On-ground tested in realistic conditions during the satellite's *On-Station Thermal Test* (OSTT) in 2011 at IABG mb H facilities (Ottobrunn, Germany)

  Manuscript on arXiv 1405.5442 (May 2014)
- Thermal contribution: $\sim 12\,\mathrm{m\,Hz}^{1/2}$ at $1\,\mathrm{m\,Hz}$, a factor ~ 30 below the IFO main measurement.



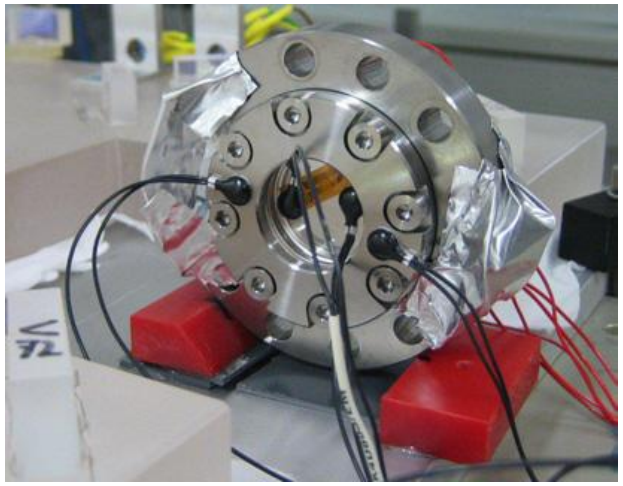


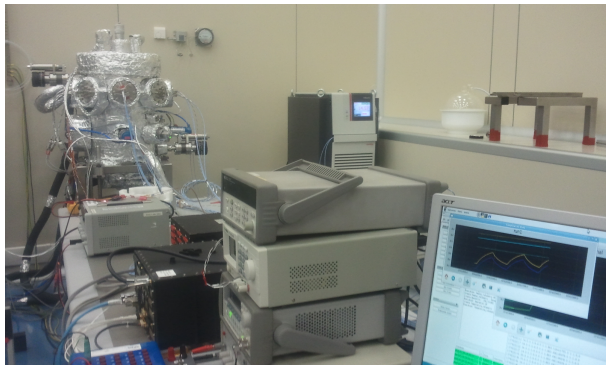




Optical Window experiments

- Heat pulses on each Optical Window
- Tested through ground campaigns:
  - OW campaign at AEI (2007) to measure IFO pathlength response.
    Nofrarias et al, CQG 24 5103-5121
  - OW system thermal response tested at the *Inertial Sensor Housing* (ISH-EQM) Thermal Vacuum campaign, run by CGS (Tortona, 2013).





Electrode Housing thermal experiment

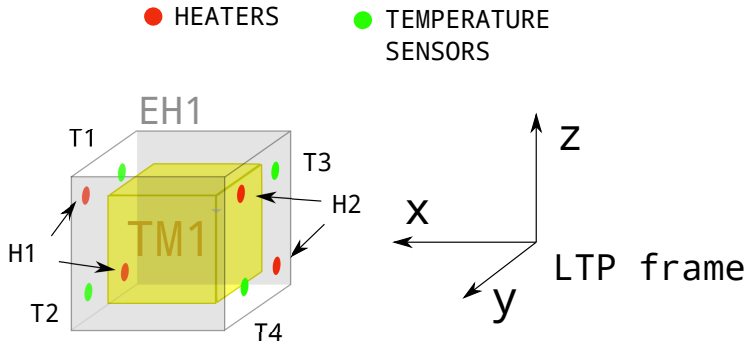
- Heat up alternatively the +/-X sides of the EH to create a **temperature gradient signal** across the Test Mass.
- Objectives:
  1. Obtain coefficients of the thermal contributions

$$\alpha = \frac{\partial F_x}{\partial \Delta T_x} \qquad \Delta T_x = \frac{(T_3 + T_4) - (T_1 + T_2)}{2}$$

  2. Disentangle the contribution of each thermal effect (RM, RP, OG)

Assessing the contribution of the Radiometer effect allows to estimate the pressure in the EH
$\rightarrow$ Brownian noise estimation, since:

$$S_{Brown.Force} = 4k_B T \beta \qquad \text{with } \beta \propto P$$



Electrode Housing thermal experiment

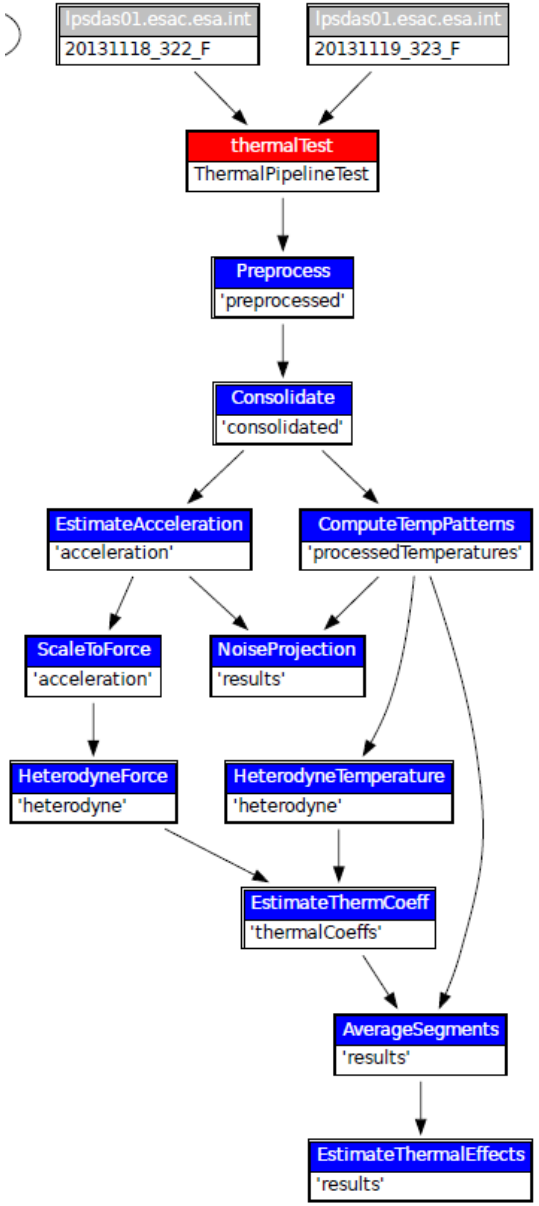
- In order to disentangle the effects: modify the absolute temperature, since:

$$\mathrm{RM} \propto T^{-1} \qquad \mathrm{RP} \propto T^{3} \qquad \mathrm{OG} \propto \exp\left(-\frac{\Theta_{act}}{T}\right) T^{-2}$$

- On-ground tests carried out by means torsion pendulums
  - University of Trento's extensive investigation on torsion pendulums
- Still, extensive simulation required to understand the coupling with the full LPF dynamics.

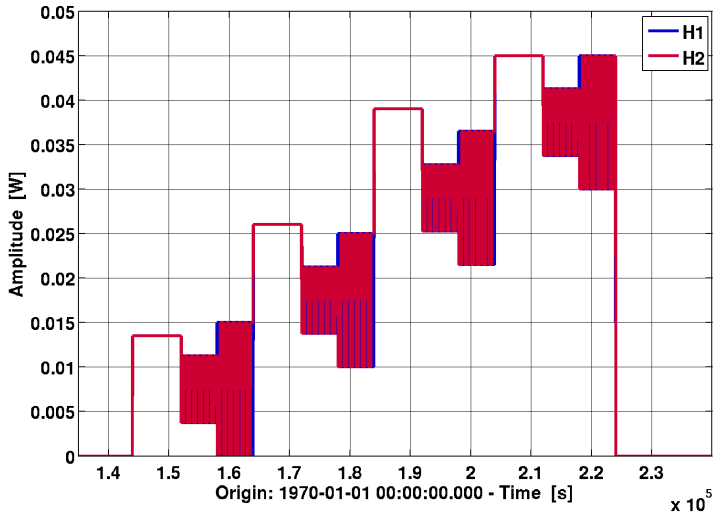
Simulation campaigns: STOC Sim 4

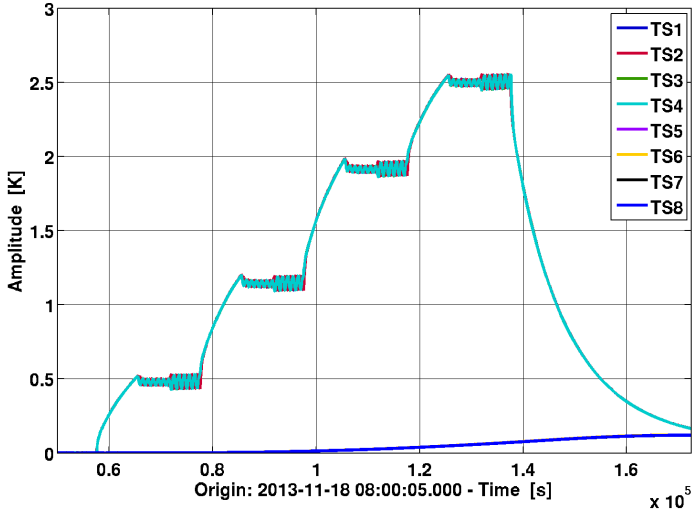
- A 8 days-length campaign to simulate LPF experiments (November 2013)
  - EH experiment simulation: ∼1.5 days
- Data generated by a satellite simulator running at TC level
- Forces and torques modelled as SSM including:
  - Data from thermal model of the whole spacecraft (ESATAN coded)
  - A radiative model of the EH-TM system
  - The expected contributions (provided by UTN)
- Data analysis through specific LTPDA *pipeline*

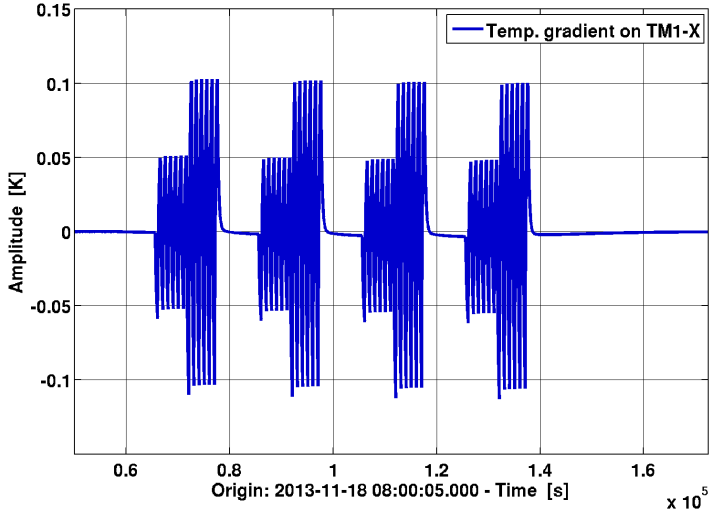


EH experiment simulation: Inputs

- Activation of H1 and H2 alternatively to induce temperature gradient signal
- Repeat pattern at four absolute temperature levels
  - Peak-to-peak of 100 mK and 200 mK
  - Oscillations around four absolute temperature levels ($\Delta T_{abs} = 2\,\mathrm{K}$)

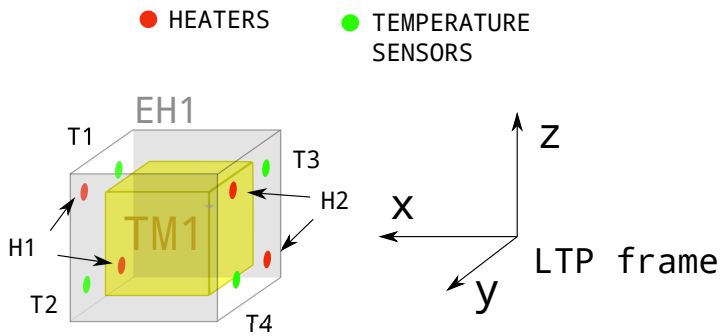




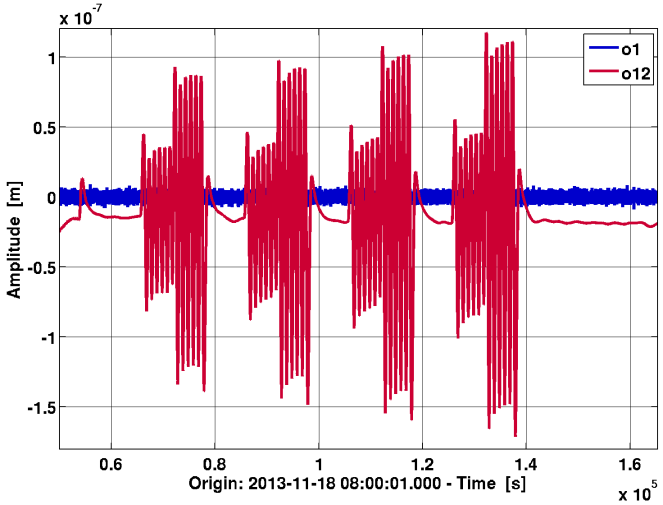


EH experiment simulation: Data analysis (1)

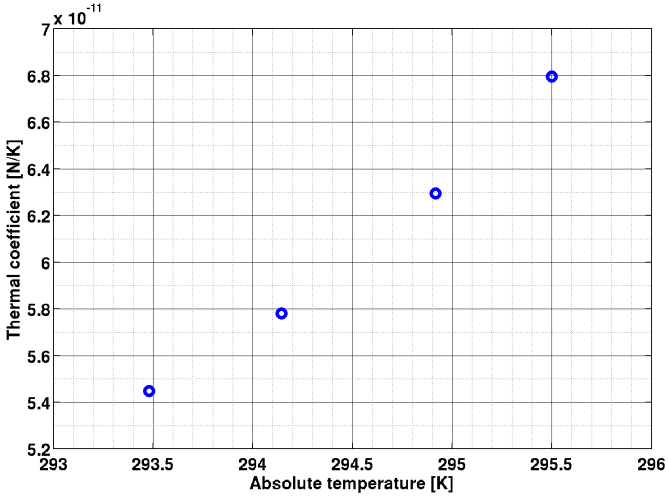
- Output signal on o12
- Compute thermal coefficients through *heterodyne* method
- One value par absolute temperature
- Final coefficients error <1.4%
- Outgassing dominates contribution.



IFO response:

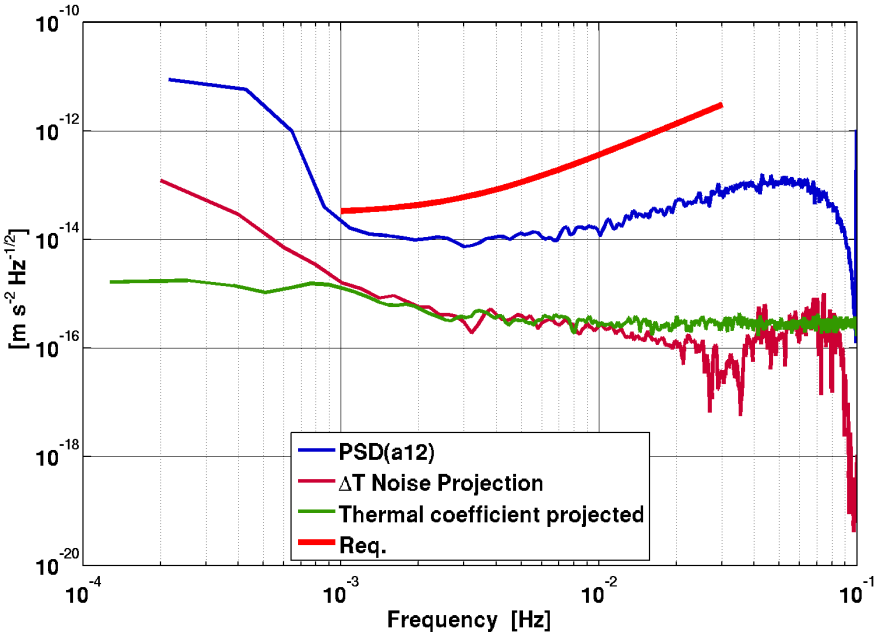


Thermal coefficients:



EH experiment simulation: Analysis (2)

- Noise projection:
  - Transfer functions applied on segments of just noise
  - Temperature fluctuation contribution: a factor 30 below IFO acc. noise



- About the **Brownian noise** contribution:
  - Too short absolute temperature increment ($+2\,\mathrm{K}$) impeded the identification of the thermal effects
  - An **upper bound** for radiometer effect estimates a pressure of 2.3e-5 Pa, setting the Brownian noise to $7.4 \times 10^{-15}\,\mathrm{m\,s^{-2}Hz^{-1/2}}$

Summary

1. Temperature noise contribution at the LTP to be studied onboard LISA Pathfinder through dedicated experiments.
2. Optical Window and Strut thermal experiments on-ground tested.
3. Simulations of the EH heating experiments conclude that:
   - Global thermal coefficients can be recovered with enough precision.
     - Analysis to be applied on other degrees of freedom (**y**, **z**, η, ϕ)
   - Upper limit set for Brownian noise
     - A too short absolute temperature range due to input power limitations may impede the identification of the different thermal effects in the EH.
     - Effort required to improve analysis or look for potential alternatives.

That's all!

Questions, please