In-flight thermal experiments for LISA Pathfinder

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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

<table>
<thead>
<tr>
<th>Effect</th>
<th>Est. Cont. [fm s(^{-2})Hz(^{-1/2})]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brownian noise</td>
<td>7.2</td>
</tr>
<tr>
<td>Magnetic noise</td>
<td>2.8</td>
</tr>
<tr>
<td>Stray voltages</td>
<td>1.1</td>
</tr>
<tr>
<td>Laser radiation pressure</td>
<td>0.7</td>
</tr>
<tr>
<td>Temperature gradient noise</td>
<td>0.4</td>
</tr>
<tr>
<td>Self-gravity noise</td>
<td>0.3</td>
</tr>
</tbody>
</table>
Temperature noise in LISA Pathfinder’s LTP

![Graph showing temperature noise in LISA Pathfinder's LTP with various noise sources and their contributions over frequency.]
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 \( F_{OG} = K_{OG} \exp\left(-\frac{\Phi}{T}\right) / T^2 \Delta T \)
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: $\sim 12 \text{ m Hz}^{1/2}$ at 1 m Hz, a factor $\sim 30$ 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

   \[ \alpha = \frac{\partial F_x}{\partial \Delta T_x} \]

   \[ \Delta T_x = \frac{(T_3 + T_4) - (T_1 + T_2)}{2} \]

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

   \[ S_{\text{Brown. Force}} = 4k_B T \beta \]

   with \( \beta \propto P \)
Electrode Housing thermal experiment

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

\[ \text{RM} \propto T^{-1} \quad \text{RP} \propto T^3 \quad \text{OG} \propto \exp\left(-\frac{\Theta_{\text{act}}}{T}\right) T^{-2} \]

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: \( \sim 1.5 \) 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
Simulation campaigns

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 \( (\Delta T_{\text{abs}} = 2 \text{ K}) \)

In-flight thermal experiments for LISA Pathfinder – Ferran Gibert – May 22nd, 2014
Output signal on o12
Compute thermal coefficients through heterodyne method
One value per absolute temperature
Final coefficients error < 1.4%
Outgassing dominates contribution.

Thermal coefficients:

IFO response:
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 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 $7.4 \times 10^{-15} \text{ m s}^{-2} \text{Hz}^{-1/2}$
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