LISA ON TABLE: Simulating interferometric signals and testing TDI

Léon Vidal

Laboratoire Astroparticule et Cosmologie, CNRS UMR 7164, Université Paris-Diderot, 10 rue Alice Domon et Leonie Duquet, 75013 Paris, France

leon.vidal@apc.in2p3.fr

Introduction

Gravitational waves are very small variations of space-time metric which can be detected with high precision laser interferometry. The **LISA** detection method consists of measuring the distance fluctuations between free falling test masses. As with any detector, the signal-to-noise ratio must be optimised. Due to the architecture of LISA, the gravitational wave signals are embedded in 8 orders of magnitude of laser frequency noise. A noise reduction method called Time Delay Interferometry (**TDI**) was developpped in the 90's to reduce this dominant noise. For several years and with the support of CNES, an interferometric electro-optical bench for metrological demonstration named Lisa On Table (**LOT**) has been set up at APC. The objective of this bench is to simulate realistic LISA data to demonstrate experimentally several aspects of TDI, characterize its frequency response and assess the noise residuals.

LISA

LISA is a constellation of three satellites forming an equilateral triangle with sides of 2.5 million kilometers. Each satellite exchanges lasers with the rest of the constellation and follows test masses that are isolated from external perturbations.

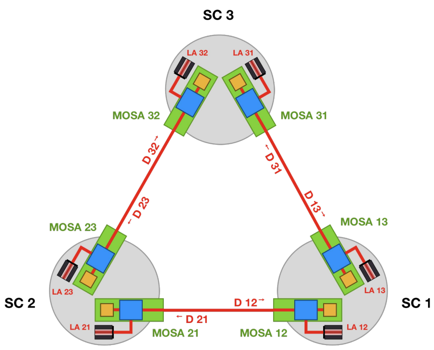

Figure 1: LISA simplified constellation

Distance fluctuations between these test masses due to gravitational waves are transcribed as variations of the laser phases. Interferometric measurements are performed between local and distant test masses in each spacecraft and mainly suffers from laser frequency noise.

LISA ON TABLE

LOT simulates a simplified phase locked constellation (transponder mode):
1 Mother spacecraft "communicates" with 2 distant Daughters spacecraft.

The drag-free system is considered perfect: S/C and test-masses dynamics are identical. First, a software part allows to select signal models to simulate laser noise. These are time delayed by mathematical models to simulate one LISA arm length $L_j(t)$:

$$D_{ij}(t)f(t) = f\left(t - \frac{L_{ij}(t)}{c}\right)$$

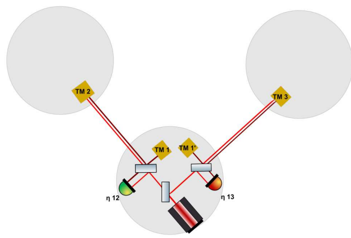

Figure 2: LOT configuration

These instructions are sent to Direct Digital Synthesizers (DDS) to become RF electronic signals. The resultant signals are then combined in an electronical interferometer through mixers.

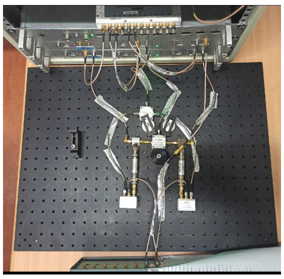

Figure 3: Electronical interferometer

At the end, the phase of the resulting beats are acquired by a phasemeter which digitises them:

$$\eta_{ij}(t) \sim D_{ij}(t)f(t) - f(t)$$

These outputs are used as inputs for TDI algorithm.

TDI Algorithm

TDI consists on recombining LISA data, applying delays to reconstruct a virtual equal arms interferometer in order to remove laser noise from phase measurements. These TDI combinations become more complex when more realistic constellation motions are taken into account.

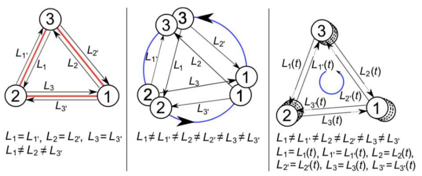

Figure 4: Motions of LISA constellation

For a simplified static constellation, TDI X1 is used to delete the laser frequency noise:

$$X(t) \to (D_{12}^2 - 1)\eta_{13}(t) - (D_{13}^2 - 1)\eta_{12}(t) \quad (1)$$

For LISA, TDI X2 combination will synthesises an equal-arm interferometer for a rotating constellation with flexing arms.

Preliminary results

We respectively chosen 2499123,65 and 2530559,17 kilometers for L_{12} and L_{13} arm lengths.

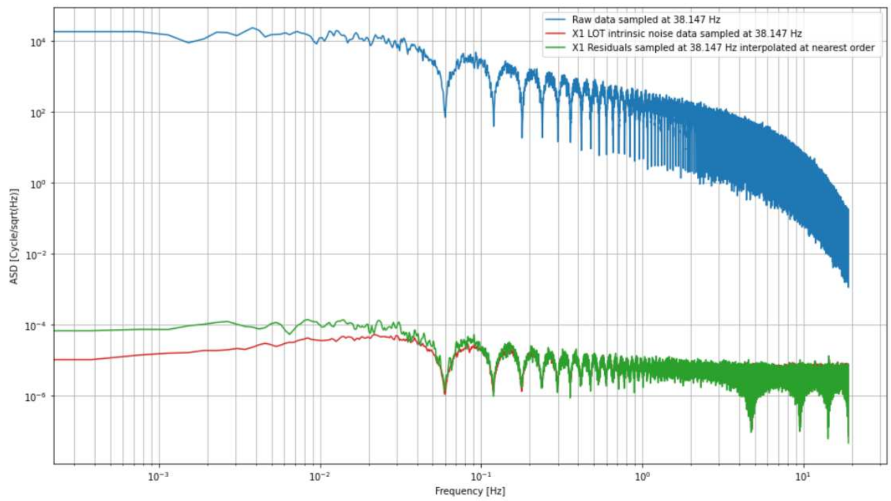

Figure 5: TDI X1 for unequal rigid arms

After generation of TDI variables (blue curve) with the expected laser noise level in LISA, we apply X1 combination and plot the amplitude spectral density of the residuals (green curve).
TDI 1.0 is reducing the laser noise about 8 orders of magnitude in the milihertz range. At higher frequency (above 0.1Hz), the intrinsic noise of LOT (red curve) limits the reduction factor. Next step is to reduce the laser noise with TDI X2 for a flexing constellation.

Thanks

Thanks to Jean-Baptiste Bayle for Figure 1 and Markus Otto for Figure 2.