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Status of the LISA On Table experiment: a electro-optical simulator for LISA

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Abstract. The LISA project is a space mission that aim at detecting gravitational waves in space. An electro-optical simulator called LISA On Table (LOT) is being developed at APC in order to test noise reduction techniques (such as Timed Delayed Interferometry) and instruments that will be used. This document presents its latest results: TimeDelayed Interferometry of 1st generation works in the case of a simulated white noise with static, unequal arms. Future and ongoing developments of the experiment are also addressed.

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1. The Laser interferometer Space Antenna project (LISA)

The LISA project, like others, is born of the will to detect gravitational waves. Those local, propagating deformations of space-time are so weak **Erreur ! Source du renvoi introuvable.** that their detection represents one of the greatest scientific and technical challenges. Whereas several projects are based on ground (LIGO and VIRGO for instance), LISA chooses space as an alternative.

The mission consists of 3 satellites, separated by a few millions kilometers with a 1064nm laser beam propagating between them. The constellation would fly around the Sun on the same orbit as the Earth, 20° behind it. The whole system acts as a giant laser interferometer, allowing one to monitor the tiny variations (down to 1 pm) of the distance between the satellites due to a possible gravitational waves passing by. Figure 1 [1] presents the principle of LISA in the case of a mother satellite and two daughter satellites (eLISA design). The final design will have the same laser link between the two daughter satellites. The mother satellite sends a laser beam towards the daughter satellite. It is then injected into a phase locked loop (PLL) so that it can be sent back to the mother satellite. At this point it interferes with a local laser. This interference, heterodyne, generates a beat signal whose phase gives the information of the distance between the satellites.



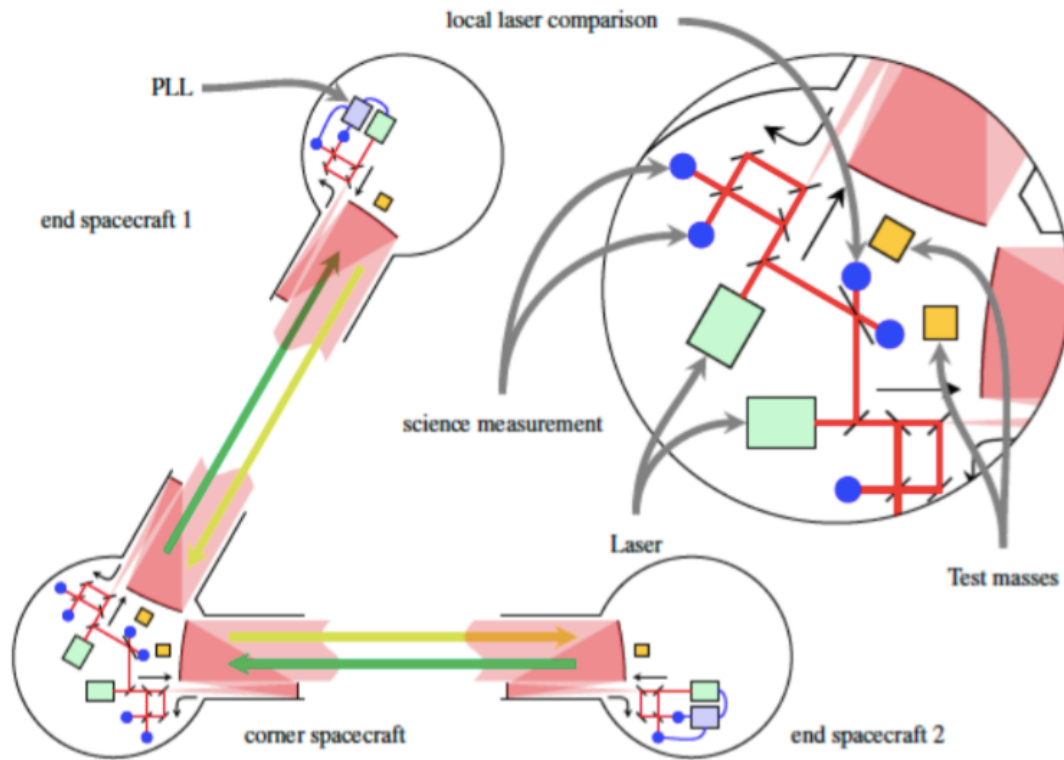


Figure 1: Principle of the measurement in LISA [1]

Such sensitivity goals require a deep knowledge of the noise sources in LISA and effective noise reduction techniques. Two of them, the most noticeable, will be discussed here: the drag-free principle, because of its originality and the time delayed interferometry, because it is the main technique tested by the experiment that is to be presented here.

1.1. Drag-free principle

Such a sensitivity requirement requires a deep knowledge of the noise sources in LISA and effective noise reduction techniques. The drag-free principle allows to get rid of external perturbations such as radiation pressure from the Sun. It consists of test-masses inside cavities in the satellites. Those test-masses are subject only to gravitation; a local interferometer monitors the position of the satellites with respect to their test-masses, so that one can deduce, in the end, the distance variations between the test-masses in two satellites, hence getting information on the effect of the gravitational wave. This principle has been tested and verified by the LISA Pathfinder in 2015. A $5.2 \pm 0.1 \text{ fm} \cdot \text{s}^{-2} / \sqrt{\text{Hz}}$ residual acceleration noise of test-masses has been achieved, which is far below requirements for LISA-Pathfinder and almost at the level of LISA requirements [3].

1.2. Time delayed interferometry (TDI)

TDI is a data-processing technique [4] that can reduce the noise level of LISA by a factor 10^8 , thus meeting the requirements for LISA. The distances between the satellites change over time (up to 30 000 km) since each spacecraft is independent, which induces a phase shift. Thus, noises do not compensate each other when signals interfere. TDI consists in recombining the data at the right time, knowing the positions of the satellites, which virtually create the situation of equal arm length in the interferometer.

2. LISA on Table (LOT)

The LOT is an experiment that has been developed for several years at the APC laboratory. It is an electro-optical simulator of LISA, the goals of which are to test experimentally the noise reduction techniques (TDI mainly) and various instruments (photodiodes, phasemeter...) in a representative acquisition chain. In this way, it can be seen halfway between a purely numerical simulator and a hardware prototype.

2.1. Principle

The principle of the LOT is diagrammed in Figure 2:

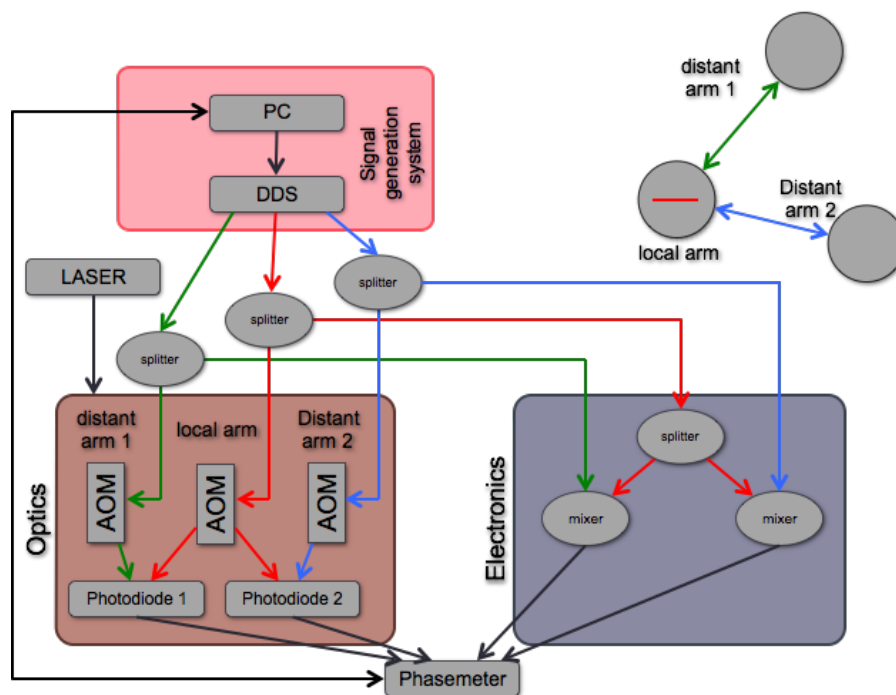


Figure 2: principle of the LISA On Table experiment

A signal generation system using direct digital synthesizers (DDS) produce three signals, that simulate the modulations imprinted on a local laser and two lasers coming from the distant satellites (their frequencies are around 110 MHz: 108, 112.5 and 112.7 MHz). Those modulations correspond to noises, gravitational wave signals, Doppler effect, or in general, anything one wants to simulate. The three signals are split between an optical simulator and an electronic simulator. In the optical one, the signals are imprinted on laser beams through acousto-optic modulators (AOM). The beam representing the local laser then interferes with each “distant arm” signals on photodiodes, hence reproducing the actual interference signals that are to occur in LISA. The electronic part makes the signals interfere in a same way, and every interference signals are monitored via a phasemeter.

2.2. Optical layout

The optical layout of the optical part of the LOT is presented in Figure 3:

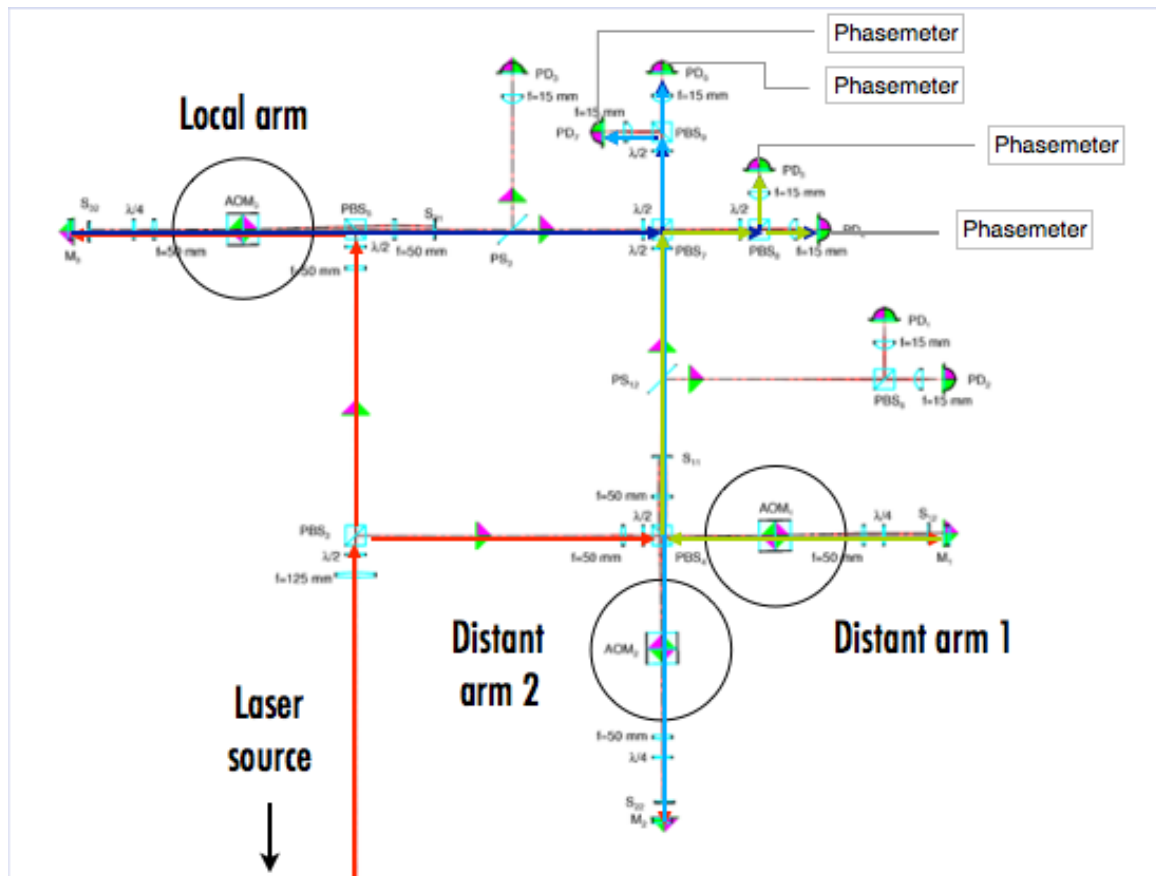


Figure 3: optical layout of the LOT

This layout corresponds to a modified Mach-Zehnder interferometer. A polarizing beam splitter splits a 1064nm laser beam. One part goes entirely through a first AOM corresponding to the local arm, whereas the other is split between two AOMs corresponding to the distant arms. Every AOMs are in a so-called cat's eye configuration: the beam goes twice through the AOM, and stay parallel in the end. Using a well-chosen configuration of $\lambda/2$ and $\lambda/4$ plates, one can have the beam to be completely transmitted or reflected in the different polarizing beam splitters. In the end, 2 interferences occur: the local arm with the first distant arm on one hand, the local arm with the second distant arm on the other hand.

3. Latest results and future developments

3.1. Latest results

Pierre Grüning has obtained the presented results during his PhD work [5]. They have been obtained using the following configuration: TDI first generation, static uneven arms. The simulated noise is a white noise. Blue lines are the noises from the optical part, red line the ones from the electronic part. Both upper lines are the signals before TDI is applied.

After TDI, the noise of the optical part goes down by a factor $5 \cdot 10^7$ and meet the reference noise level (obtained when there is no simulated noise). It means that in this case TDI works, all the remaining noise comes from the system itself.

The noise in the electronic part goes down by a factor 10^8 but is still 20 times higher than the reference. It is thought that there is a remaining jitter noise between the DDS channels; a solution to this problem is under development at the laboratory.

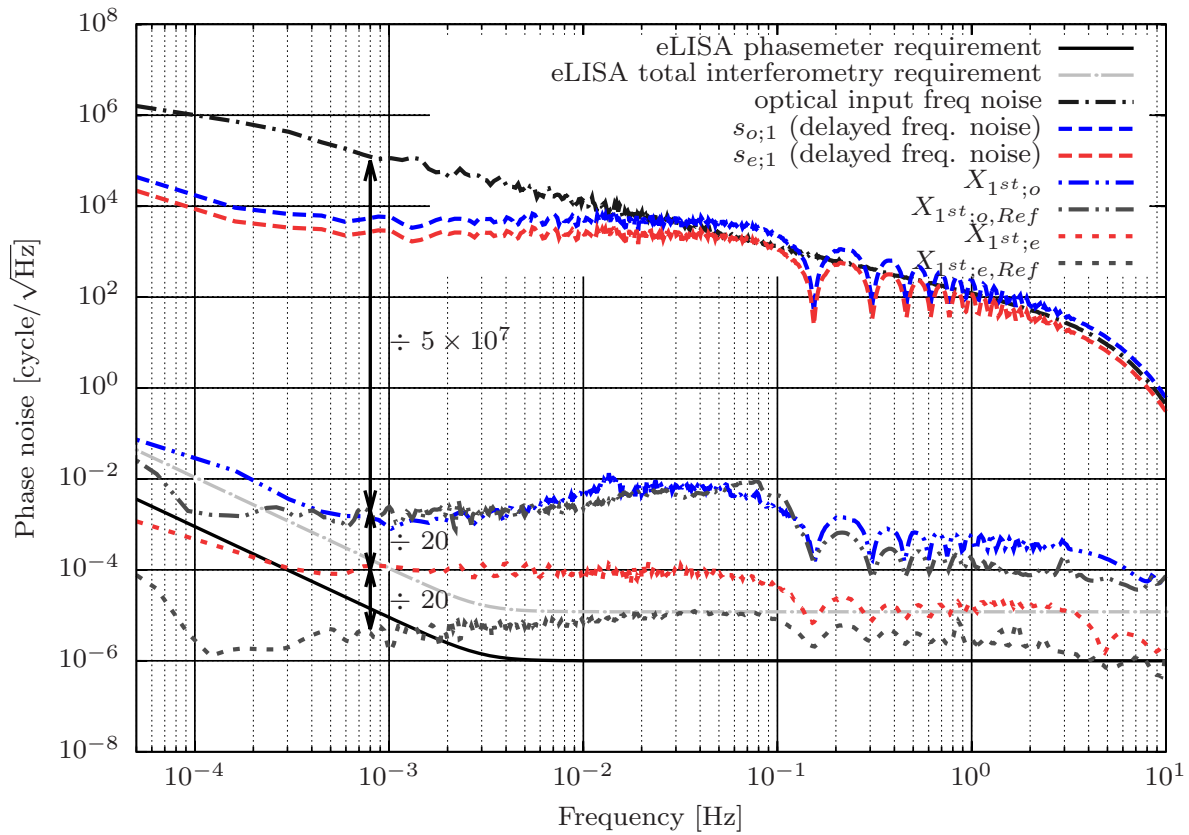


Figure 4: Latest results obtained by P Grüning with TDI 1st generation, static uneven arms, white noise

3.2. Future development

Important developments of the optical part of the LOT are ongoing. First, one wants to lower the system noise level by operating the instrument under primary vacuum. For this purpose, the LOT has been installed in a large vacuum chamber, as seen in Figure 5. Preliminary studies let expect a one order of magnitude noise reduction. The optics still has to be tuned to the optimal operating point.



Figure 5: The optical part of the LOT in its vacuum chamber

Secondly, one wants to perform new simulations, such as Doppler effect and clock noise transfer. The latter needs another modulation of the signal that is to be generated by electro-optical modulators (EOM) placed right after the first beam splitter (before the AOMs). Those EOM have been installed and are ready to be used.

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