From LISA Pathfinder to eLISA mission: A noise simulator for eLISA

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The Science of eLISA

eLISA (evolved Laser Interferometer Space Antenna) will be a new gravitational wave observatory which will allow us to have a completely new window on the Universe. Particularly, it will provide direct observations which still are inaccessible nowadays as:

- **Coalescence of supermassive black holes (> 10^5 M_S)**
- **EMRI (*Extreme Mass Ratio Inspiral*) which could provide strong constraints about General Relativity validation.**
- **Galactic binaries (about 6.10^7 sources - 3000 potentially observable).**
- **Verification binaries : galactic binaries which are known to exist.**
- **A stochastic background which can contain useful informations about cosmic inflation.**

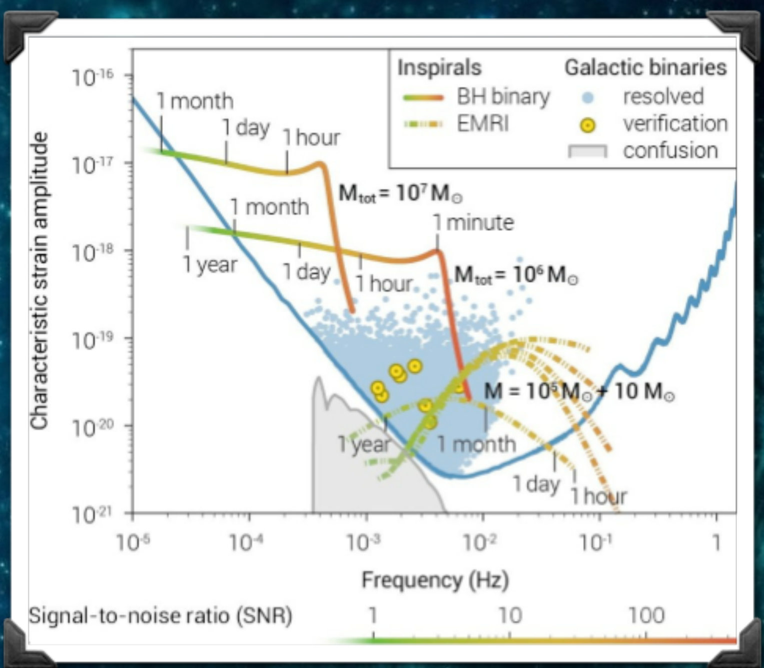

Fig. 1: Sensitivity curve and expected sources of GWs for eLISA

eLISA System

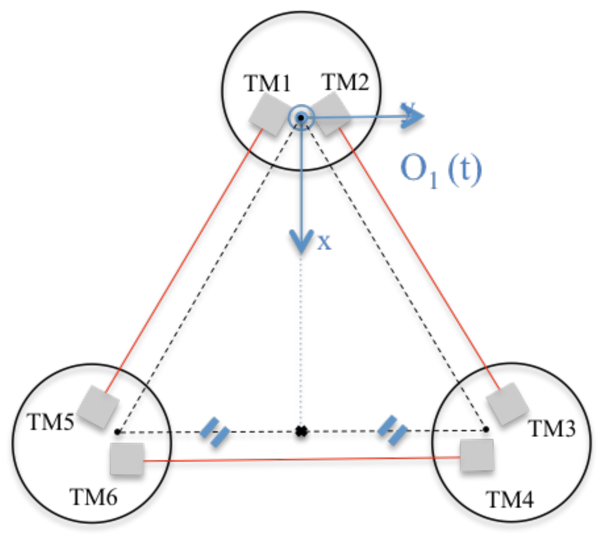

Fig. 2: eLISA constellation forms a space interferometer

The eLISA mission consists of 3 S/C orbiting around the Sun, forming a constellation in a quasi-equilateral triangular shape. The arm length of this thus formed space interferometer is planned to be 1 million km. Each S/C contains several bodies, i.e. the spacecraft (S/C) itself and one or two test masses (TMs). Note that in the eLISA configuration, the "Mother" S/C contains 2 TMs (as well as 2 optical benches and 2 telescopes) and the two other "Daughters" contain only one TM.

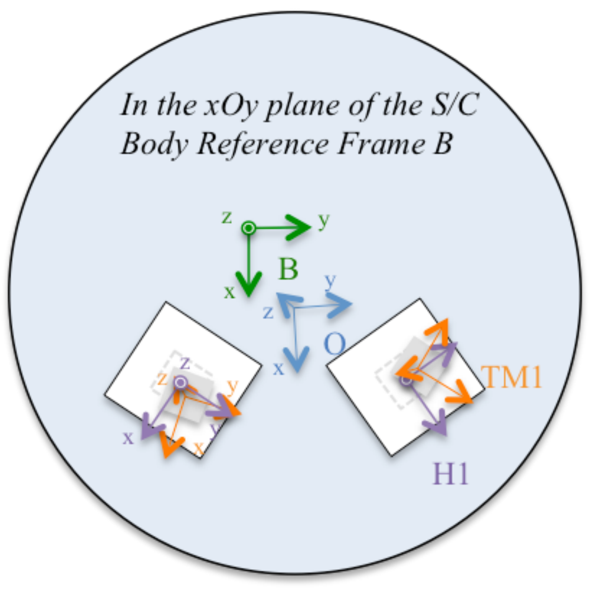

Fig. 3: Bodies involved in a S/C and their corresponding reference frames

The simulator computes the evolution of the 3x6 coordinates and their 3x6 corresponding derivatives per S/C over time. This includes the position of the center of mass (CoM) of the S/C and those of the TMs, their attitude, their linear and angular velocities. Great care has been taken in defining the reference frames w.r.t. which the different coordinates are expressed.

Simulator Objectives

One of the main aims of the simulator is to calculate the residual acceleration along the sensitive axis (i.e. the laser link), thus testing the efficiency of the drag-free strategy. The simulator calculates, at all times, the forces applied to the TMs, either due to external disturbances or commanded by the control law in order to keep them centre and well oriented in their housing. Projecting these applied forces over the sensitive axis, besides taking into account stiffnesses effects, provides finally an assessment of the acceleration noise.

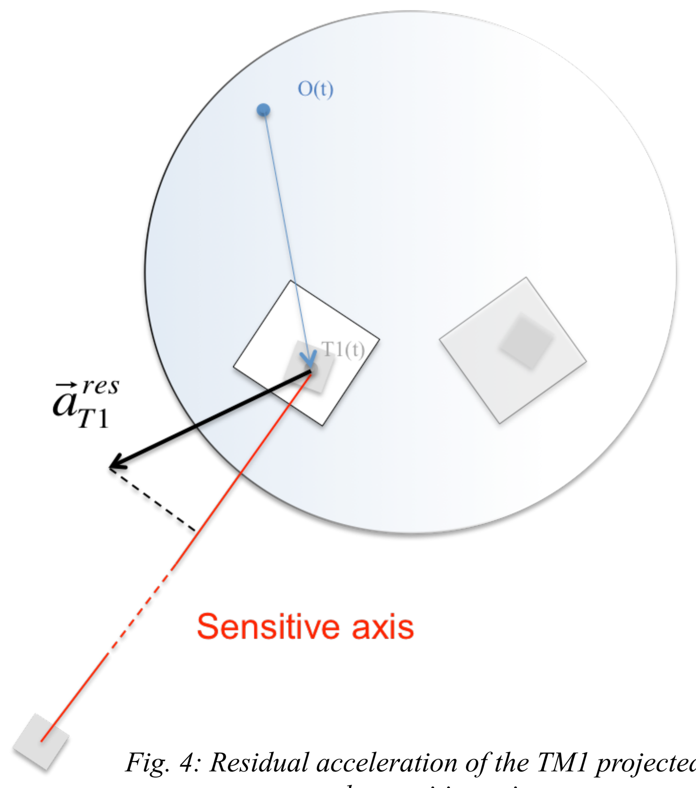

Fig. 4: Residual acceleration of the TM1 projected on the sensitive axis

State Space Model

In the eLISA system control loop, many subsystems come into play, as much for the actuation as for the measurements. In the simulator, all the subsystems are represented as symbolic blocks, all connected with links that represent inputs and outputs, see figure 2. Each block has a state space representation that models the subsystems properties, as for instance cross-talk matrices or time delays. A corresponding noise block is added to all actuations and measurement signals. Each noise is described by an amplitude and a frequency dependence by means of a transfer function.

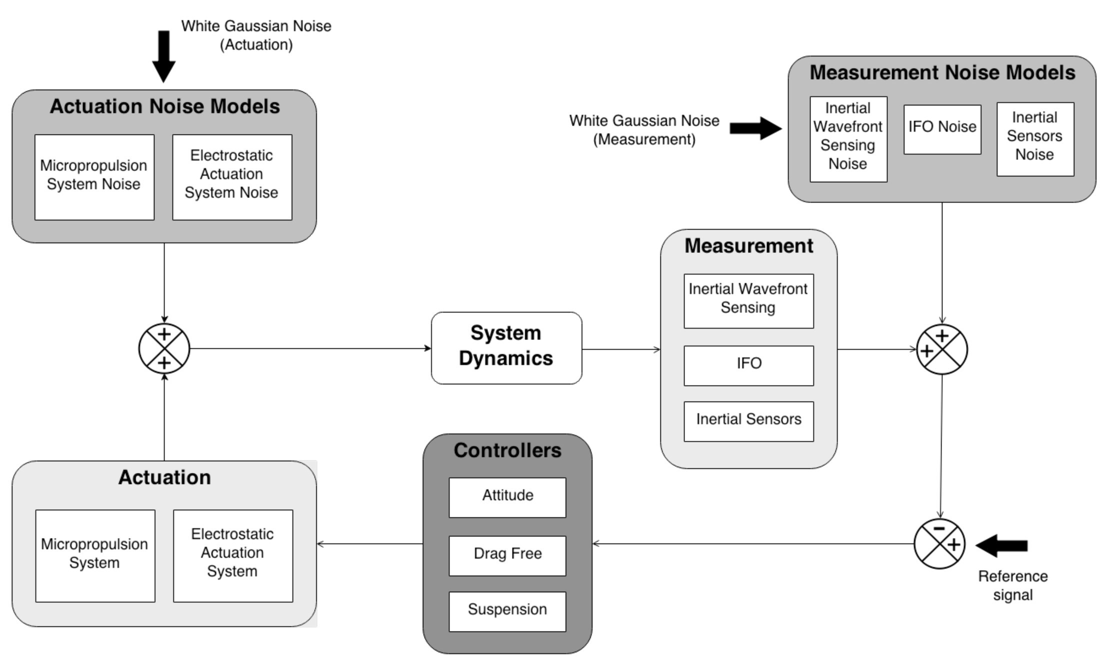

Fig. 5: Block diagram of the simulator

Noise Decomposition

The simulator has been run for a mission duration of about a couple of days, enough to evaluate, over the eLISA measurement band, the behavior of the system. At the end, the simulator provides the evolution of the 18 coordinates of the system (and their derivatives) from which the residual acceleration can be computed and their associated Power Spectral Density (PSD). Several runs have been made, activating only one source of noise at a time. A final calculation is done with the presence of all noises. Figure 6 shows, as a function of frequency, the total noise budget superimposed on the contribution of each component.

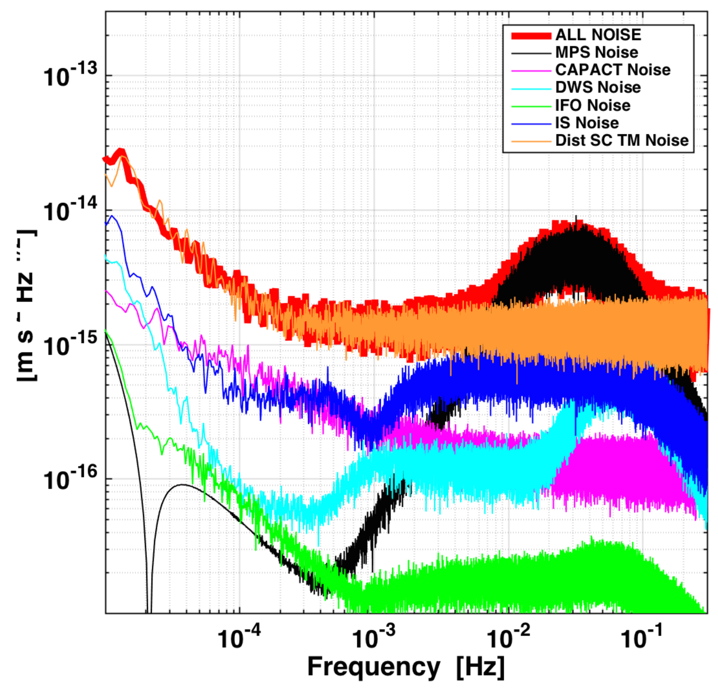

Fig. 6: Decomposition of the contribution of individual noises on the residual acceleration in frequency domain

LISA Pathfinder mission: in the road to L1

Main scientific objectives:

- To confirm that we can make free-floating two TMs inside a satellite with sufficiently low differential acceleration noise. The requirements are 3.10^{-14} $m.s^{-2}.Hz^{-1/2}$ at 1 mHz.
- To understand the nature of the residual disturbances. In particular, to verify that our current models of the various disturbances can reasonably fit with the observed differential acceleration noise and to assess the level of the unexplained residual acceleration noise.
- To test the optical metrology system in flight and confirm that we can reach 6 $pm/Hz^{-1/2}$ accuracy at 1 mHz.

LISA Pathfinder will be launched at the beginning of December in Kourou by a Vega rocket. For at least 3 months, physicists will endeavor to demonstrate LPF capability to reach the very challenging noise acceleration requirement. Several teams will relay to analyze the results of numerous investigations performed in order to assess the performances achieved and to evaluate various key parameters of the system from various in-flight measurements, which will provide at the end a better understanding of the physics involved.

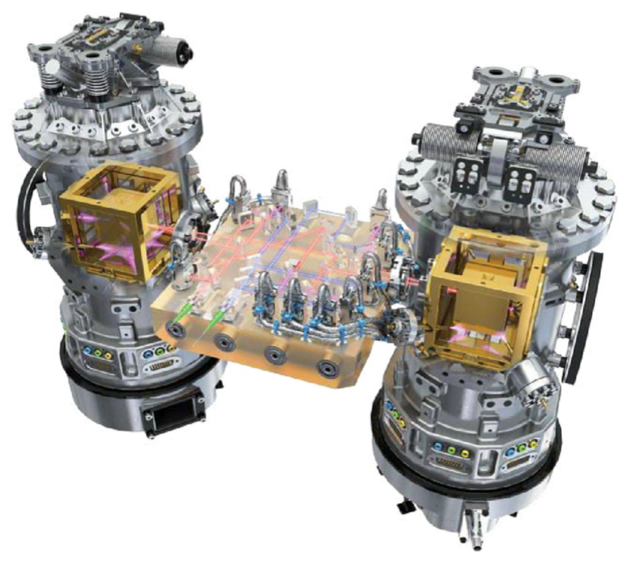

Fig. 7: Computer aided design of the core of LISA Pathfinder: LISA Technology Package (LTP)

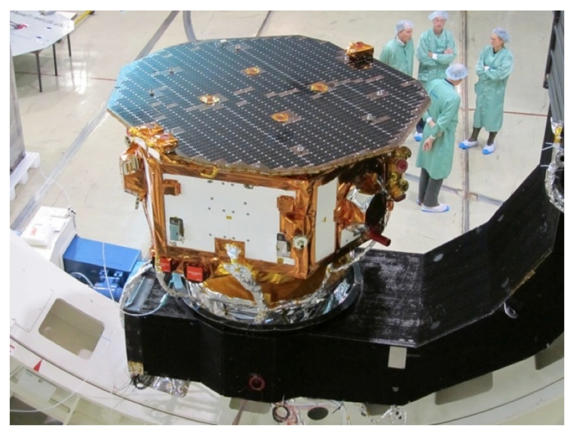

Fig. 7: Picture of LISA Pathfinder satellite during OSTT campaign (On-Station Thermal Tests) in which conditions close to space environment are obtained. Credit: Airbus Defence and Space GmbH, Friedrichshafen.