“Space missions"

Developing a LISA optical ground-support equipment testing facility

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Motivation

LISA ground support equipment

The Laser Interferometer Space Antenna (LISA) will be the first space-based gravitational wave observatory. LISA can be thought of as a high precision Michelson interferometer in space with an arm length of 2.5 million km. The optical benches are made by bonding silicate glass components to an ultra-low-expansion glass ceramic using coordinate-measurement-machine assisted alignment (fig.1). These meticulous, complex and time-consuming designs do not allow rearrangements of the optical components. Since we expect that the development, implementation, verification and testing phase of LISA will continue for about more than a decade, a need or desire for additional, picometer-stable, laser interferometers arises. To provide such optical ground support equipment in the future, we will construct a picometer-stable interferometer that will enables us to rearrange optical components to other topologies.

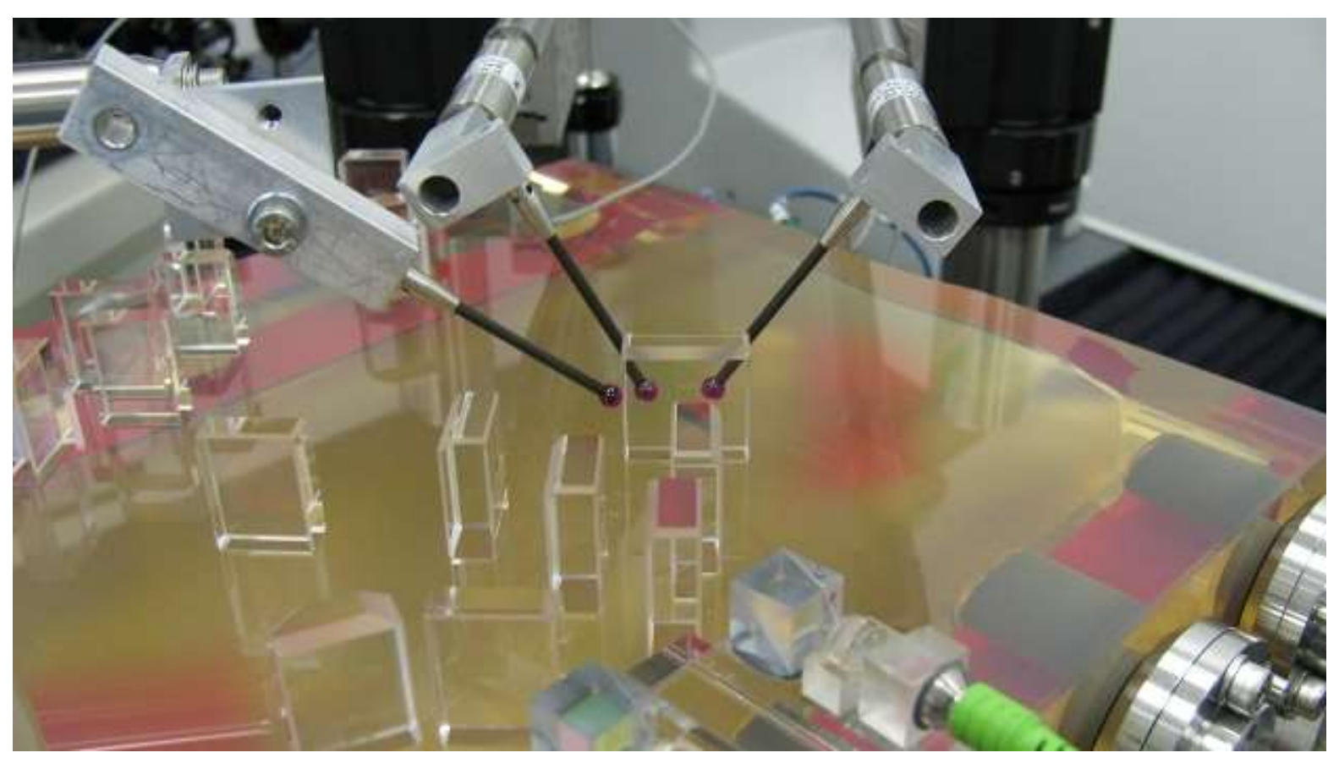

Fig.1 Construction of the LISA pathfinder optical bench (2013), University of Glasgow

TAPSI

Toolset for adjustable picometer-stable interferometer

TAPSI is a toolset for adjustable picometer-stable interferometers (fig.2). It combines a glass-ceramic optical bench with thermally compensated optical mounts which are mounted on the bench using invar insets, screws and holders. We are going to use a Zerodur plate with invar threaded sleeves due to the low expansion coefficient. The goal of TAPSI is the easy setup of an interferometer and changing the position of the components. In addition, the beam deflection can also be changed at a later date due to the commercial mirrors holder. We investigate this approach to reduce the time and cost of implementing such interferometers. Adjustable components have been used previously in combination with ULE baseplates (University of Florida, 2020) and here we aim to expand on these development by making also the position of the components freely adjustable.

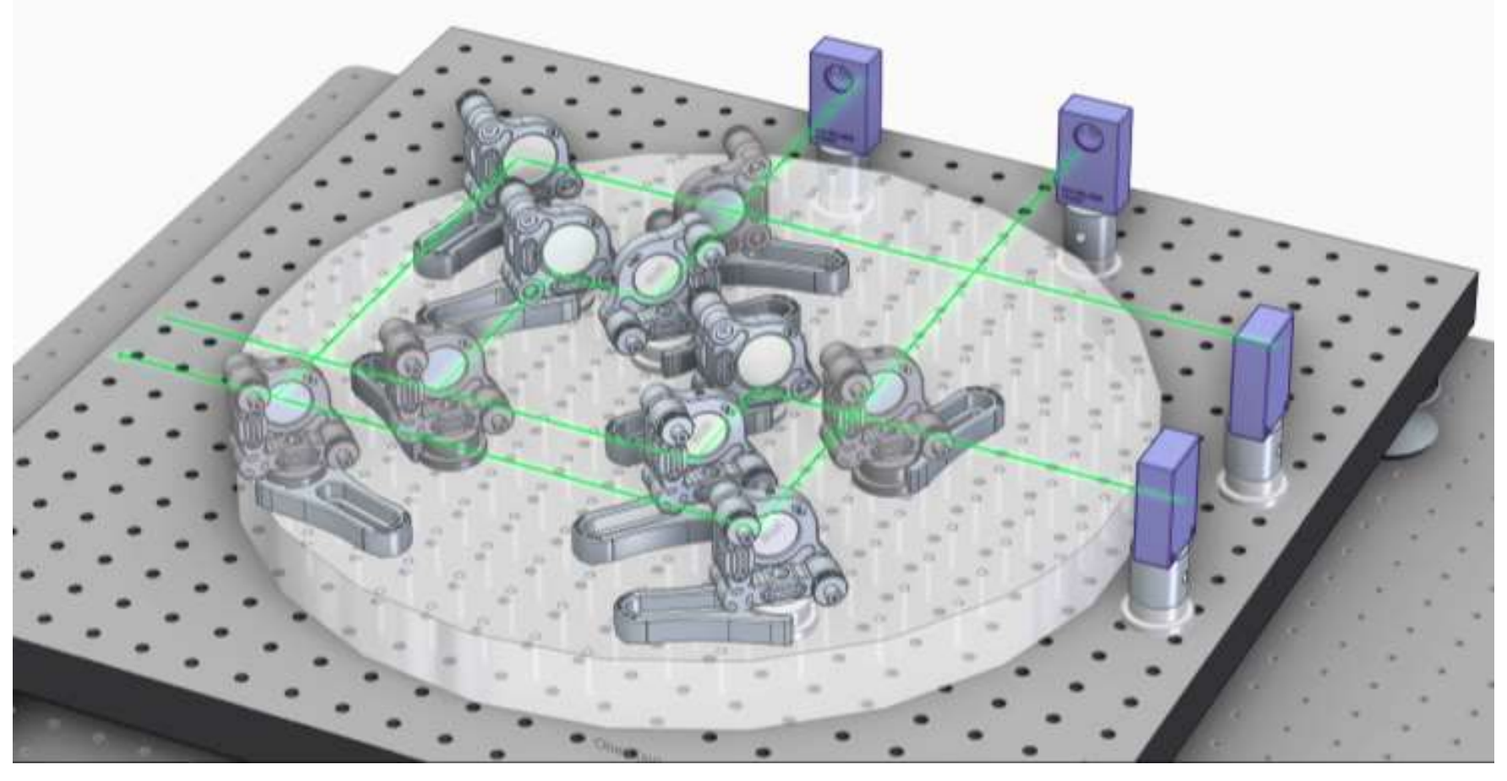

Fig2 TAPSI setup: thermally compensated optical mounts on a Zerodur plate

Test facility

Figure 3 shows the experiment which will be placed in a vacuum chamber. To make sure the thermal fluctuation is further suppressed a thermal shield encloses the experiment. Both the chamber and the shield will be made of aluminum. Seismic isolation is ensured by the optical table and an additional breadboard inside the chamber.

Our test facility will be set up in a dedicated laboratory at the University of Hamburg (DESY campus) which should provides stable temperature (+-0.3K) and humidity control (+-5%) The vacuum chamber will also be placed below a flow-box.

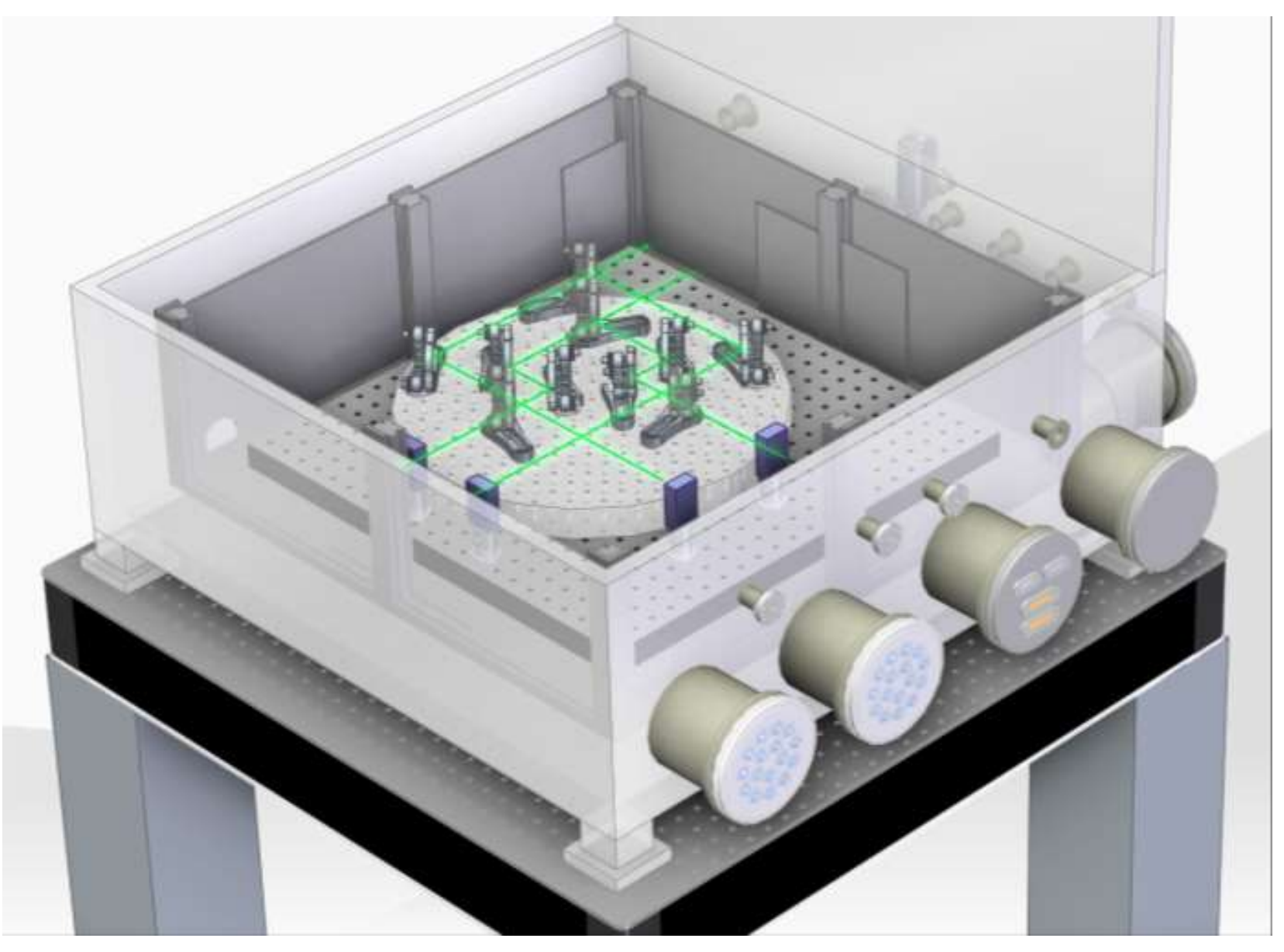

Fig.3 3D Solid Edge model of the test facility

Experiments

Stability and noise investigation

We are going to investigate the length stability and the noise behavior by setting up the three interferometers shown on the right (fig.4,5,6). In addition we will test the tilt stability by using the differential wave front sensing technique with quadrant photodiodes. Our experiments will be build as heterodyne interferometers with a wavelength of 1064 nm that will be used in LISA.

The first experiment (fig.4) investigates the length stability of the TAPSI toolset by comparing the length of an unequal arm-length interferometer with a sufficiently stable reference. As a stable reference we will make use of the athermal glass etalon which is currently under investigation (Shreevathsa C. S.).

This athermal glass etalon, which provides thermal expansion and refractive index changes that cancel each other almost perfectly, is also used for the second experiment (fig.5). Here we want to study frequency stabilization using such a material.

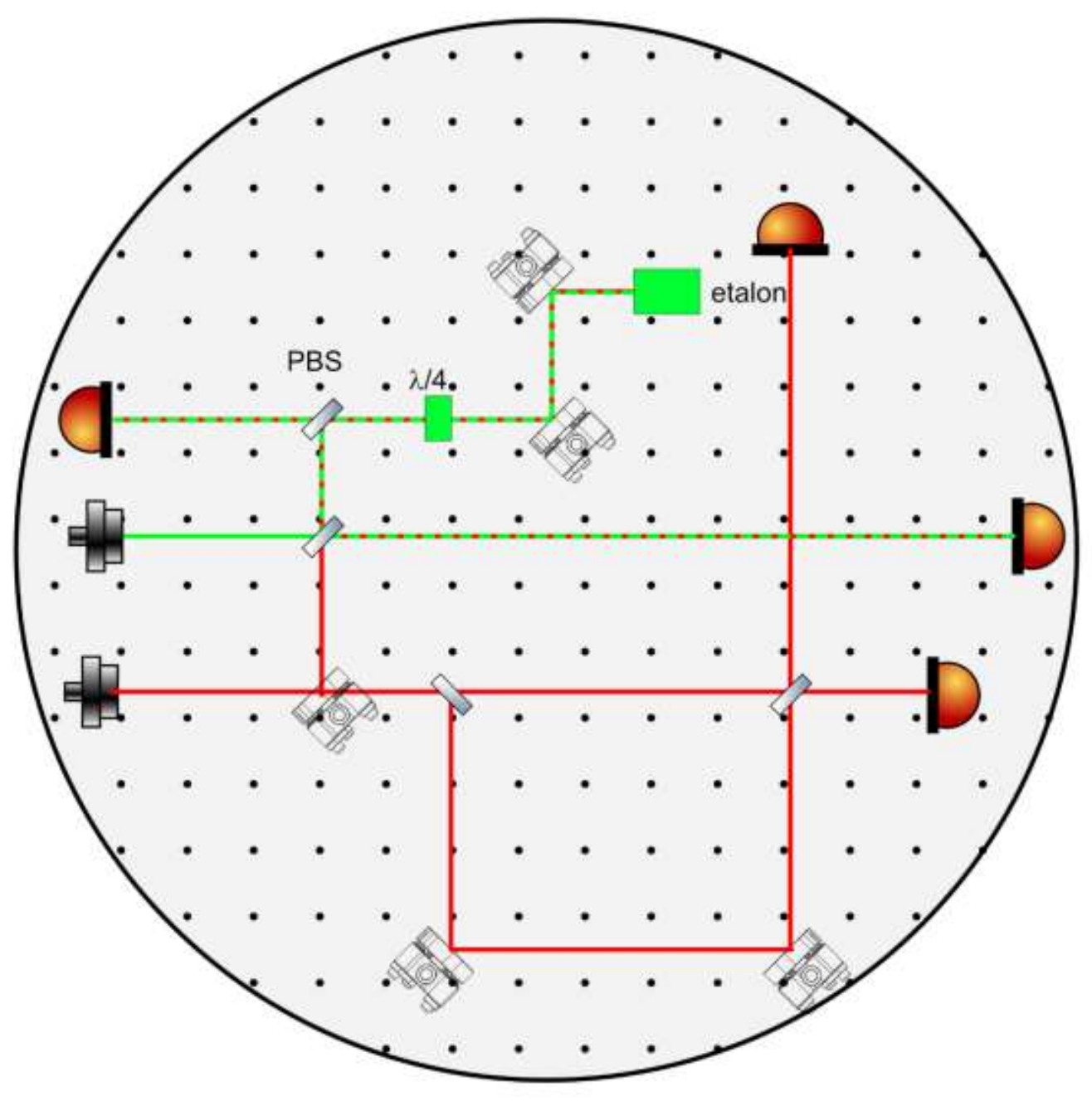

Fig.4 TAPSI stability experiment

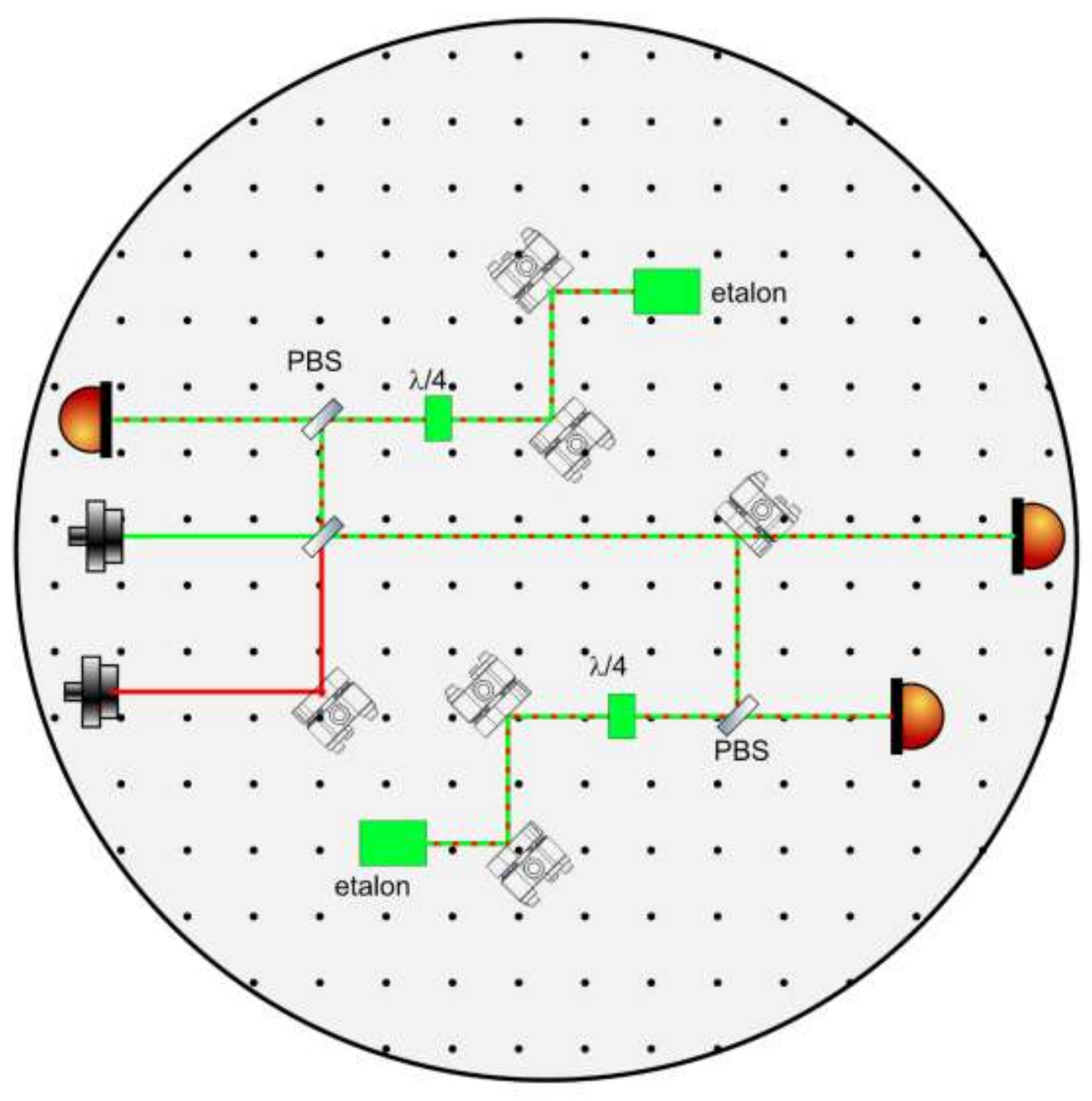

Fig.5 Athermal glass frequency stabilisation experiment

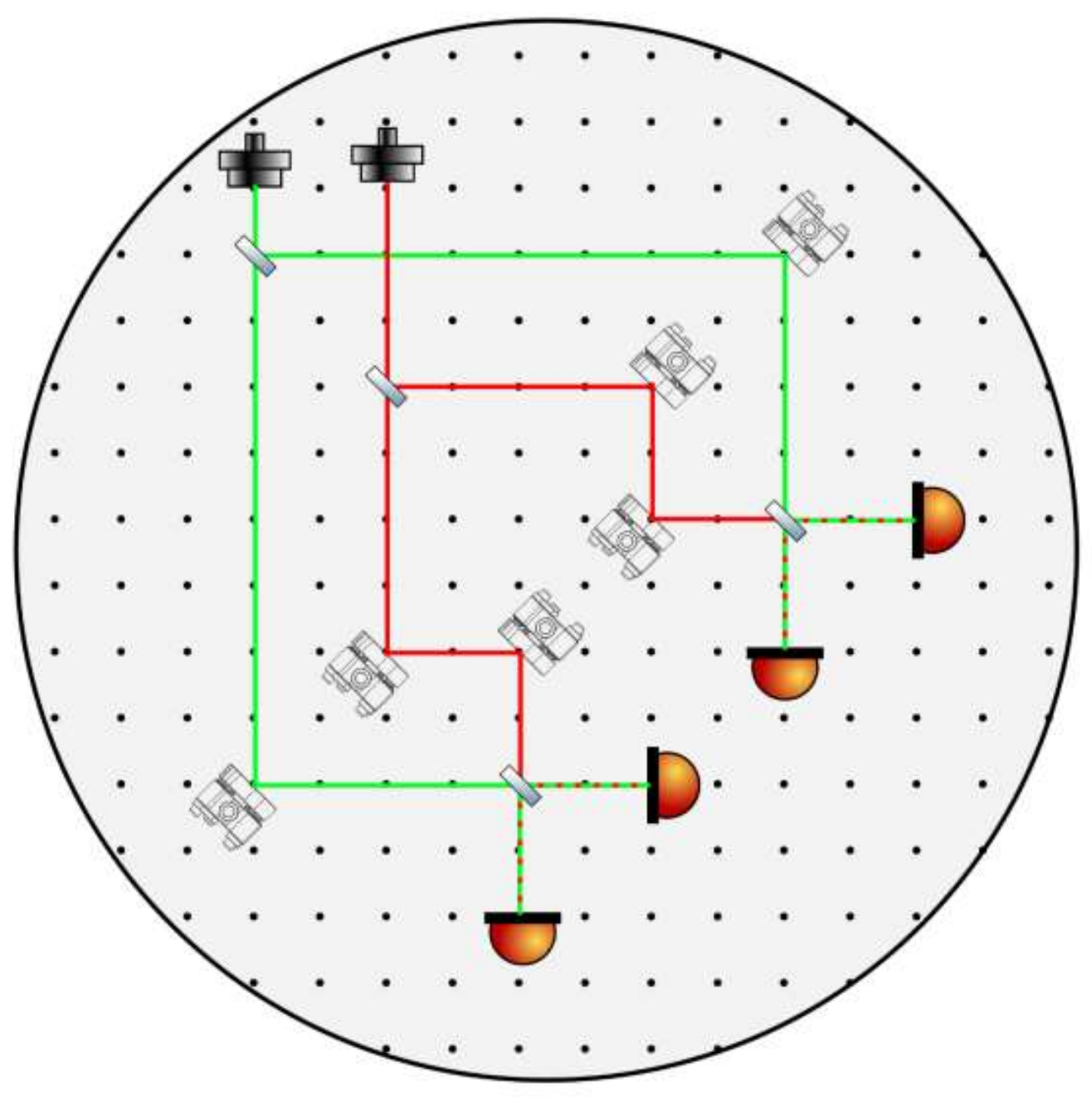

Fig.6 Concealed noise interferometer experiment

The noise-study interferometer (fig.6) will use a simplistic optical layout, mainly providing a set of optical signals that should be equivalent. Using relatively high optical power and multiple phasemeter readout channels for each photodiode segment we will be able to probe the noise floor down to new levels of precision. Here we then test if the current noise models, including shot-noise, quantisation noise, relative-amplitude noise and photo receiver noise, fit to the experimental values or if further noise reduction techniques need to be applied in this regime

Temperature noise

Optical bench / Mirror holders

One source of temperature noise results from the thermal expansion of the Zerodur plate. To give an estimation of the actual length change, we assumed a temperature behavoir in our chamber just like measured in a similar test facility (M. Dehne, fig.8). The amplitude spectral density of the Zerodurplate was calculated to be far below the 1 pm requirement for LISA (fig.9).

Next we looked into the geometric tilt to length coupling, more specifically, at the mirror holder deviation. Due to the mirror holder deviation the beam experiences a deflection which results in a pathlength change (fig.7). We calculated the ASD of our thermally compensated mirror holders and plottet the results in figure 9 as well. The corresponding noise plot is well below our 1 pm requirement.

So in conclusion the thermal expansion of the Zerodur plate and the geometric tilt to length coupling of our mirror holders should be sufficient.

LISA requirement

$$u_1(f) = \sqrt{1 + \left(\frac{2\,mHz}{f}\right)^4}$$

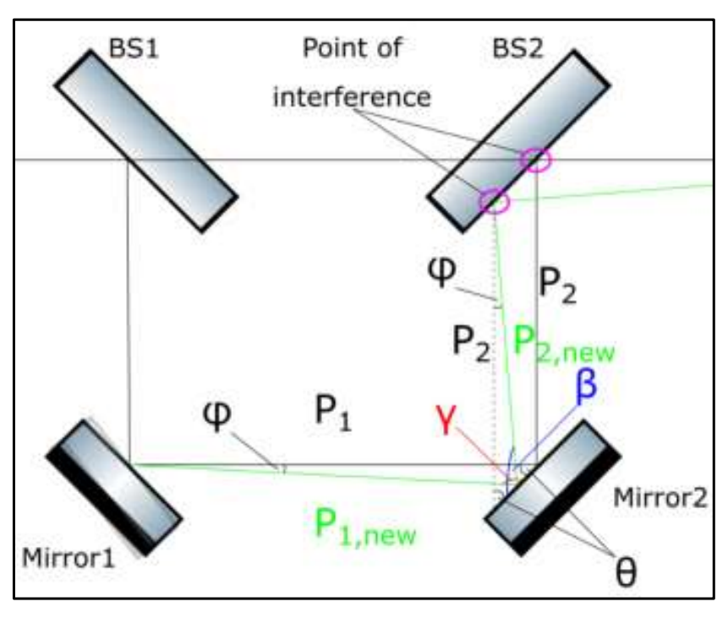

Fig.7

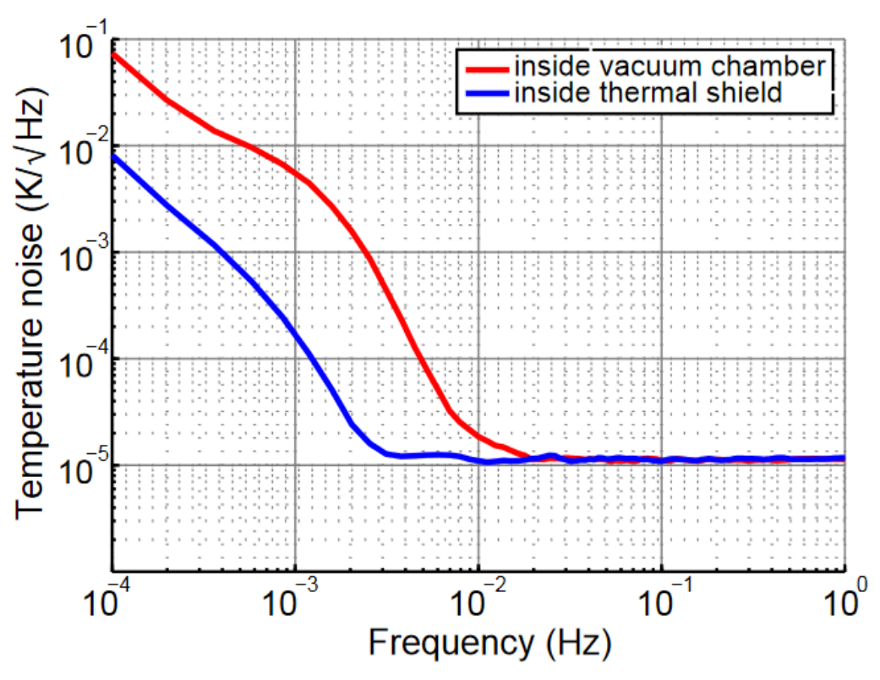

Fig.8

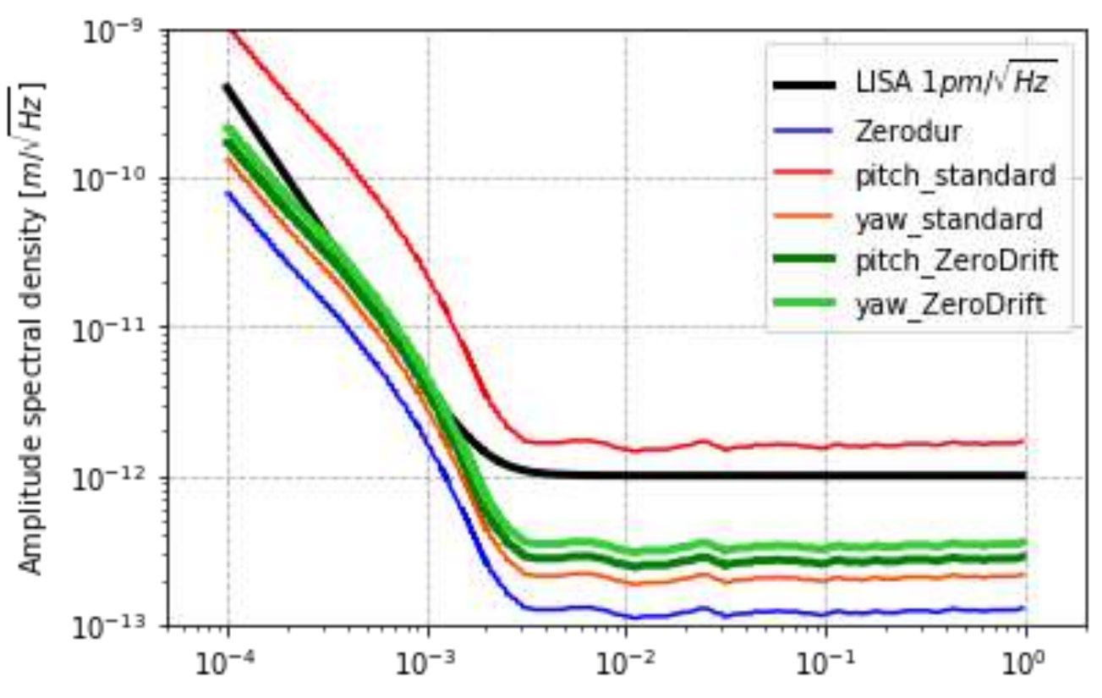

Fig.9

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