Creep rate measurement setups for the hydroxide-catalysis bonded silica ears.

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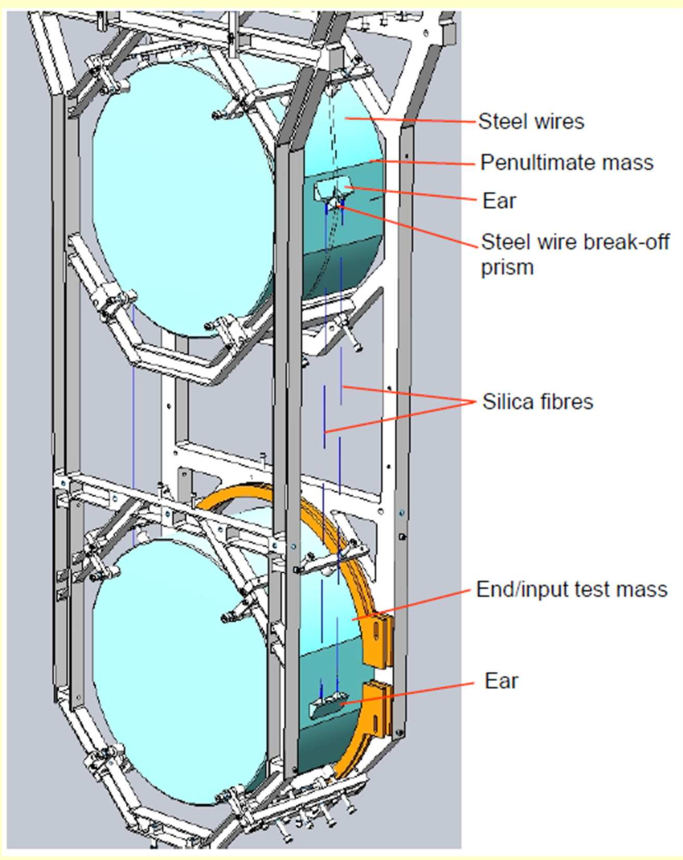
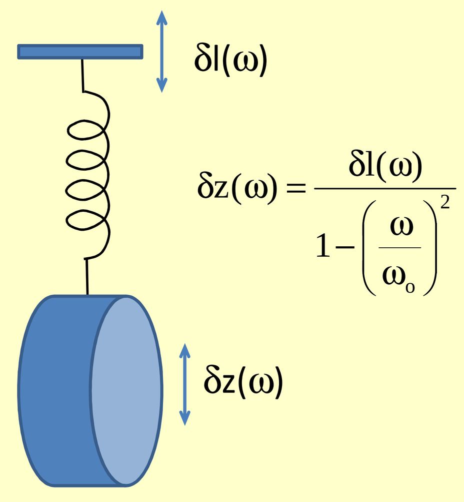


AdLIGO has been designed to have a strain sensitivity limit of 10^{-22} 1/sqrt(Hz) at 10 Hz. In order to reduce as much as possible the frequency of the vertical resonant modes of the suspension, and hence the thermal noise level, several suspension elements in AdLIGO are working at a stress level that could trigger creep. It is not clear if, or at which extend, the phenomenon of creep is associated with mechanical noise due to sudden change of local strain in the material. The proposed experiment outlined here will address this specific question.

The elements that are under a significant stress are the cantilever blades, steel wires, clamps, bolts, fused silica fibres and silicate bonding. This investigation is focused on the possible creep coming from the silicate bonding that is the most critical element considering the nature of the bonding and the shear stress at which it works.

Two optical readout systems for the creep rate measurement are being tested: the polarized Michelson interferometer and the Single Slit Diffraction detection. A capacitive transducer will be considered too.

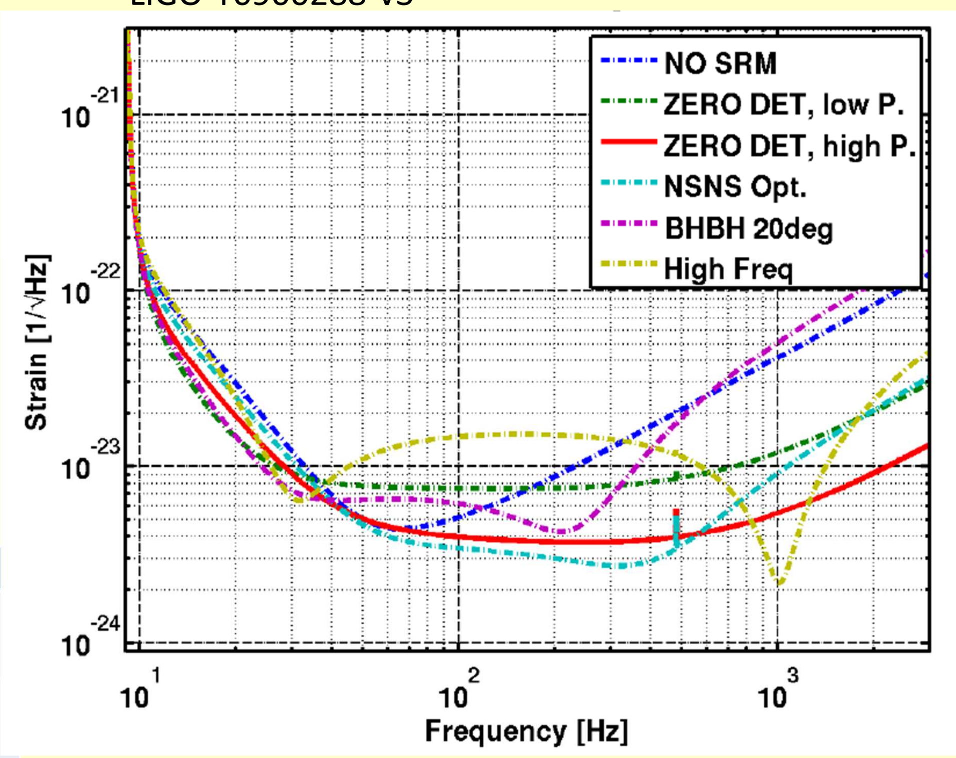
Creep noise is filtered by the vertical transfer function of the suspension that has the resonance at about 9 Hz



$$\delta z(\omega) = \frac{\delta l(\omega)}{1-\left(\frac{\omega}{\omega_o}\right)^2}$$

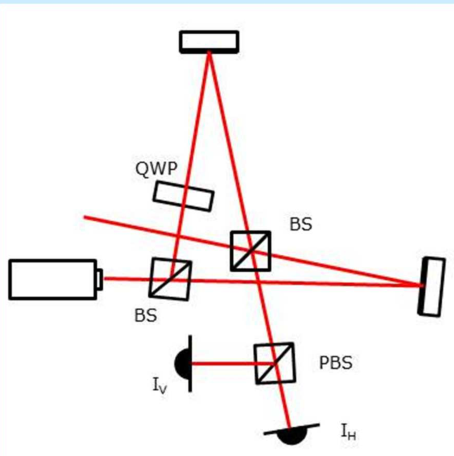
	10 Hz	25 Hz	100 Hz
Maximum vertical noise $\delta z(\omega)$ [m/sqrt(Hz)]	$2\cdot10^{-16}$	$2\cdot10^{-17}$	$8\cdot10^{-18}$
Maximum creep noise $\delta l(\omega)$ [m/sqrt(Hz)]	$5\cdot10^{-17}$	$1.3\cdot10^{-16}$	$1\cdot10^{-15}$

ALIGO SENSITIVITY CURVES
LIGO-T0900288-v3

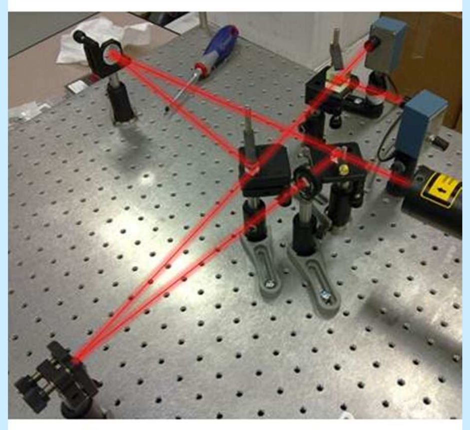


The polarized Michelson Interferometer

The displacement of the silica ear with respect the substrate can be measured with a Michelson interferometer. Both the reference mirror and the beam splitter have to be immune from the phenomenon of creep, hence, it would be better to mount these two elements in a fixed position.
Without any adjustment the Michelson interferometer is a non linear transducer. Problems of non optimal sensitivity and uncertainty in the displacement direction make the fixed reference mirror Michelson a poor displacement transducer.



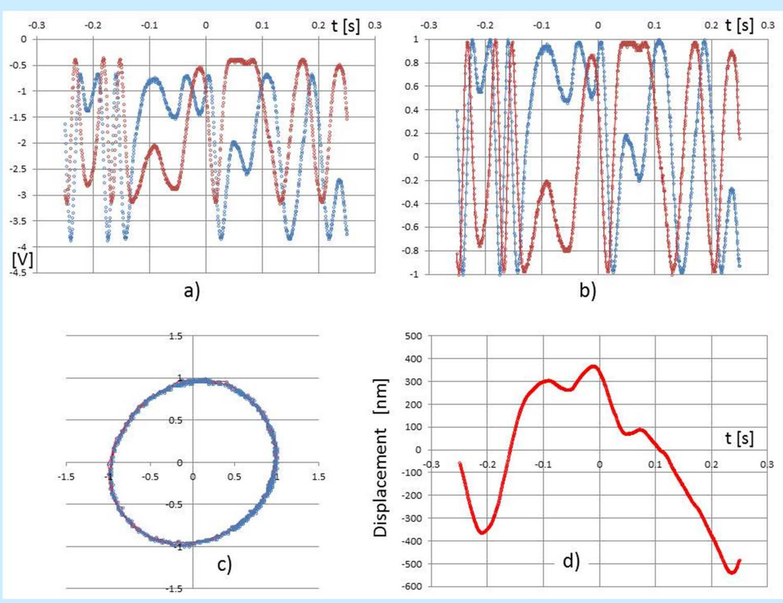
In order to avoid the previous problems we have tested a Michelson that uses two orthogonally polarized electric fields. Using a Quarter Wave Plate the two signals are set in quadrature. Once detected separately the two polarizations can be combined to give the phase related to the optical path difference and the mirror displacement can be given with its direction without any uncertainty. This optical scheme has been tested on an optical bench.

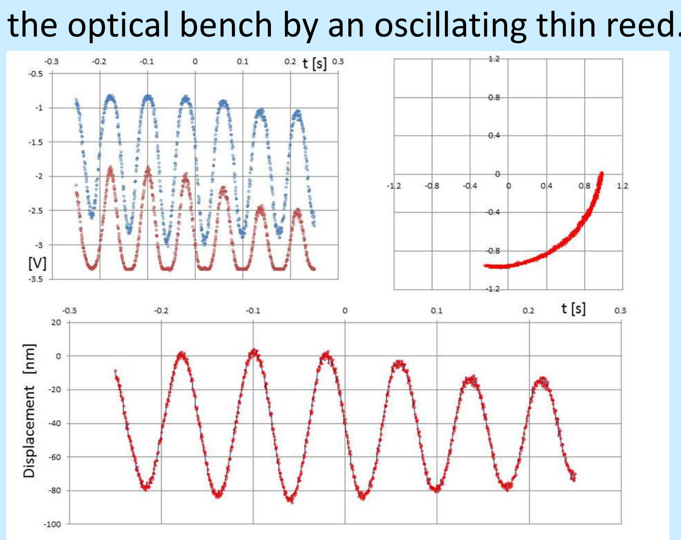


At left some preliminary results are shown.

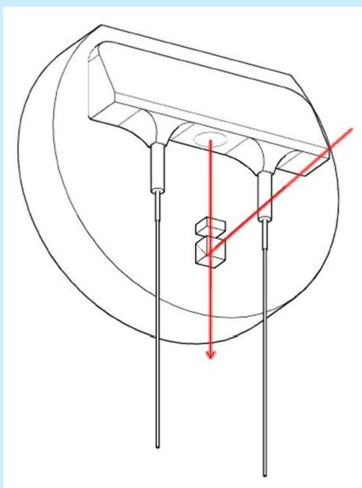
a) Time series of the signals, in Volt, coming from the two polarizations;
b) The signals have been normalized;
c) The polar plot of the two signals shows a little ellipticity due to a probable misalignment of the QWP;
d) Finally, in the last plot the displacement is reconstructed from the phase of plot c) and the knowledge of the wavelength.

The displacement was obtained pushing the mirror mount with a finger. Below, the same kind of signal processing has been done when a periodic oscillation has been applied on the optical bench by an oscillating thin reed.



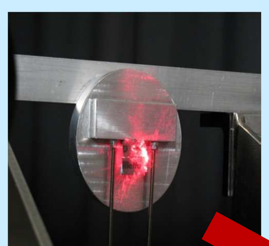


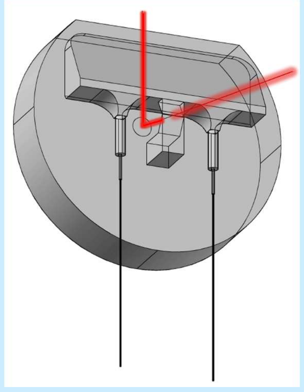
In order to simplify the optical scheme, we are planning to use a QWP designed for half the wavelength of the He-Ne laser. In that way the laser can pass twice in the plate. The drawing at left shows the 5 mm beam splitter and the plate bonded on the substrate. The reference mirror is given by one of the BS face that has to be aluminized. Depending on the machining tolerances, the simple aluminized circle on the ear might be replaced by a corner cube.



The Single Slit Diffraction

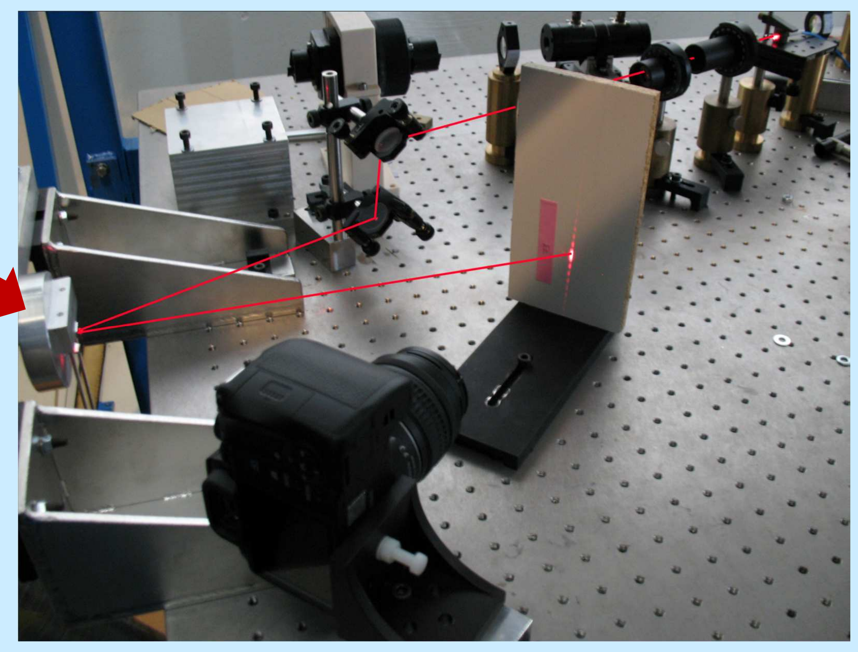
The detection of a single-slit diffraction pattern by a digital camera is being tested as a method for a precise measurement of the creep rate.
This method has been tested on a monolithic aluminum ear and substrate system shown at right..
The slit edges are made with razor blades





Possible implementation on a real sample

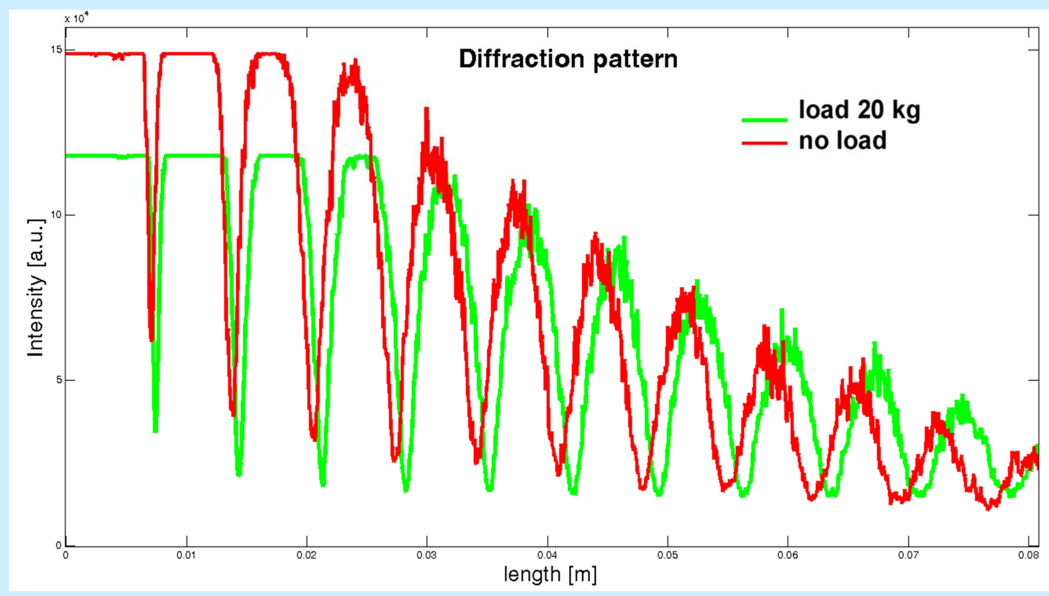
20 kg load applied to the mock-up sample



The slit width d is:

$$d = \frac{L\lambda}{\Delta x}$$

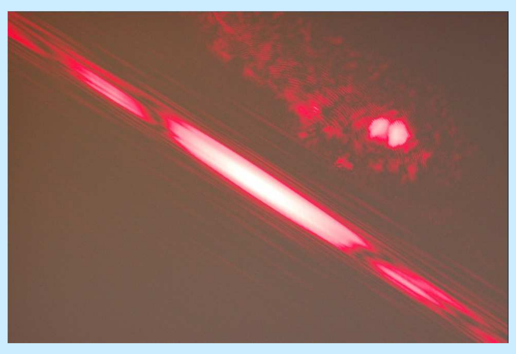
L is the screen distance
Δx is the distance between two adjacent minimum positions



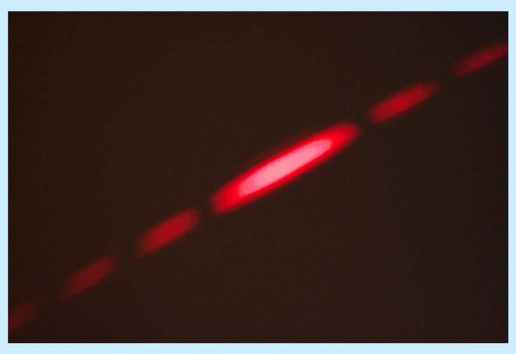
At right: diffraction pattern detection in two cases. Red curve: no load is applied. Green curve: a load of 20 Kg is attached to the ear.. The change of diffraction correspond to a slit width reduction of about 500 nm.

Although this system is rather simple, it is not immune from practical problems that have to be resolved

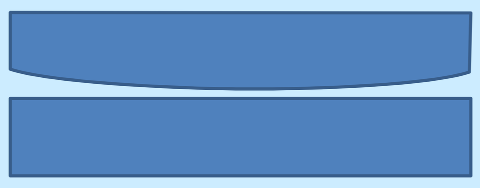
POOR QUALITY OF SLIT EDGES



LACK OF PARALLELISM OF EDGES



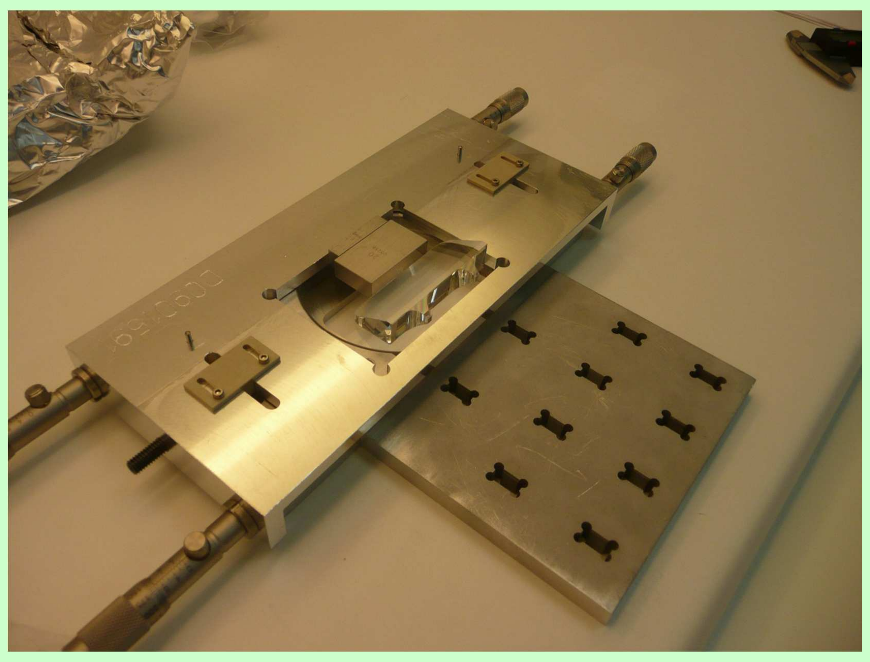
The problem of parallelism could be avoided using a slightly curved shape of one edge. In this case the method of measurement consists of finding the narrower gap between the edges

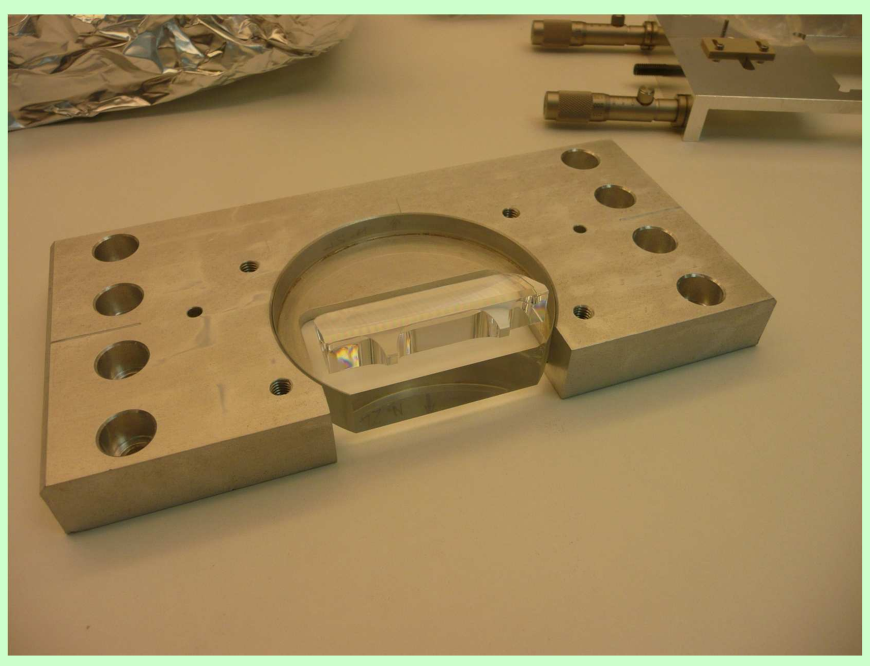


A proposal for the direct detection of creep noise

Currently there are no data available regarding creep rate measurements on Hydroxide-Catalysis bonding. Even if the measurements proposed above will detect the phenomenon of creep, there are not any reliable models that will predict the level of noise in the aLIGO suspension. Although analysis of the GEO600 detector data has not shown any evidence of excess noise due to creep caused by hydroxide catalysis bonds in the mirror suspensions above the measurement sensitivity, risk mitigation considerations suggest that measuring directly the bond creep noise on samples to the higher sensitivity of advanced detectors is a prudent research step.

Below one can see the samples of silica ears bonded on silica disks prepared at the University of Glasgow. On these sample s the first creep rate measurements will be taken using the displacement readouts described above.



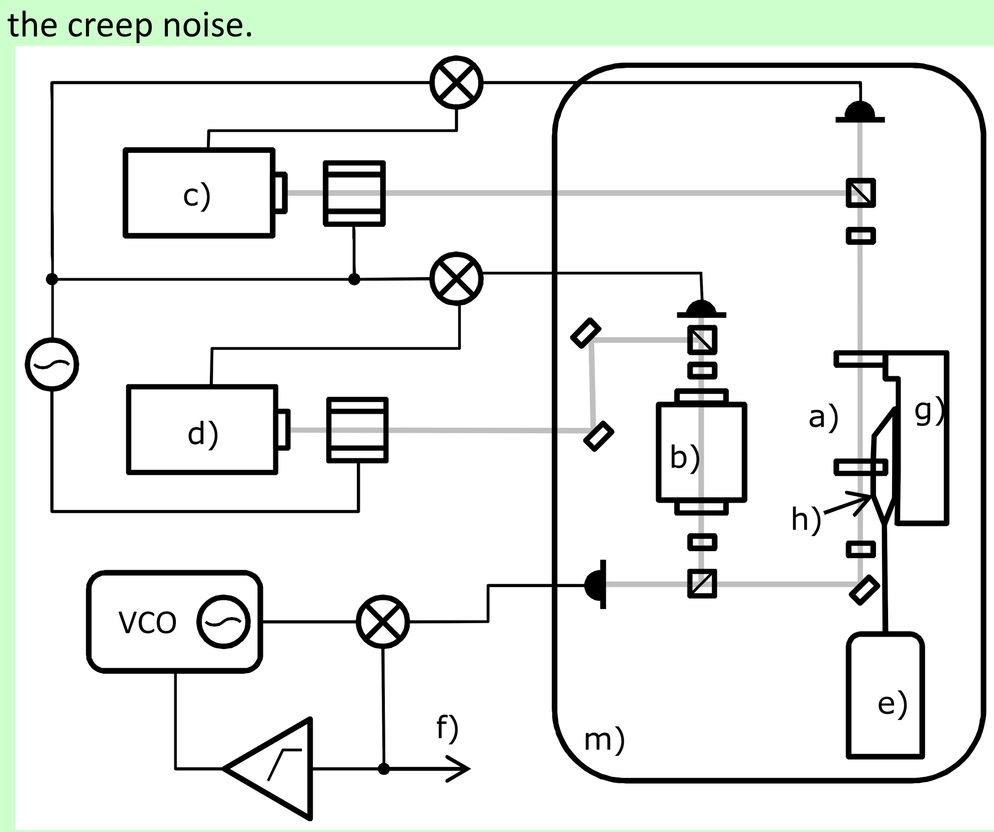


The load will be applied through fused silica fibres welded onto the horns protruding from the ears.

From the numbers shown in the table at the top of the poster it is evident that the creep noise detector has to have a sensitivity limit of about 10^{-17} m/sqrt(Hz). Such low level of noise can be achieved with 2 optical cavities: one of them is taken as a reference while the other is the measuring cavity. The choice between suspended and rigid cavity has fallen on the latter one because of its better performance at the low frequency as compared to the suspended configuration. The drawback of this choice is due to the lack of tunability. In order to separate the cumulative effect of creep from the high frequency noise, the beating note from the two cavities is detected in homodyne through a VCO which has the task to follow the low frequency change of length of the measuring cavity. The high frequency component of the demodulated signal is related to the creep noise.

To minimize the excess noise, the two cavities will be mounted on the same optical table inside a vacuum tank. The drawing at right shows the conceptual design of the detector.

The displacement noise of the measuring cavity a) modulates the frequency of one of the lasers, c). The beating between the frequency modulated signal and the signal coming from a reference cavity b) is read by a homodyne system that precise follows the slow varying frequency shift. The fast varying signal at the output f) is proportional to the microscopic creep in the measuring cavity. g) silica substrate; h) silicate bonded ear; e) weight; m) vacuum tank; d) laser locked to the reference cavity.



The reference cavity b) is much longer than the measuring cavity g) making the system much more sensitive to the displacement noise on the latte r cavity than to the former.

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