Thermo-refractive noise measurement in the Ad. Virgo OMC

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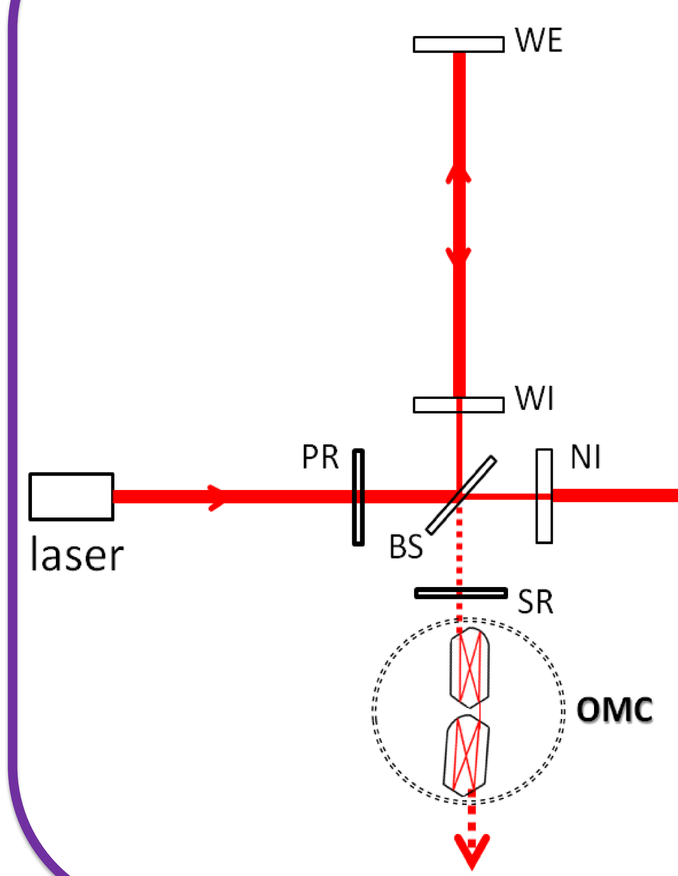
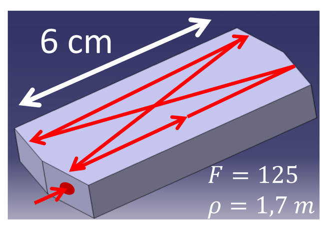
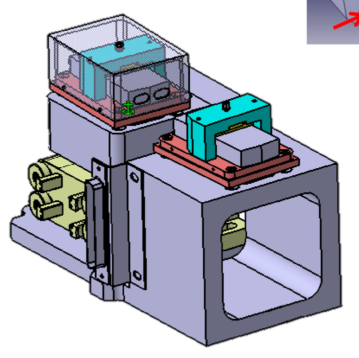
Summary

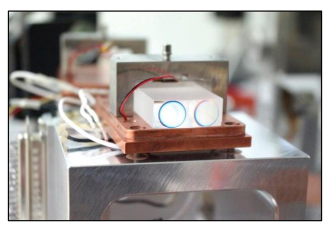
The Advanced Virgo OMC is composed of two monolithic cavities placed in series. The light is resonating in the fused silica substrate, which yields a length noise bounded by thermo-refractive noise. After introducing the specifications on the OMC length noise, tests and results of length-noise measurements at the level of the thermo-refractive noise will be presented.

OMC



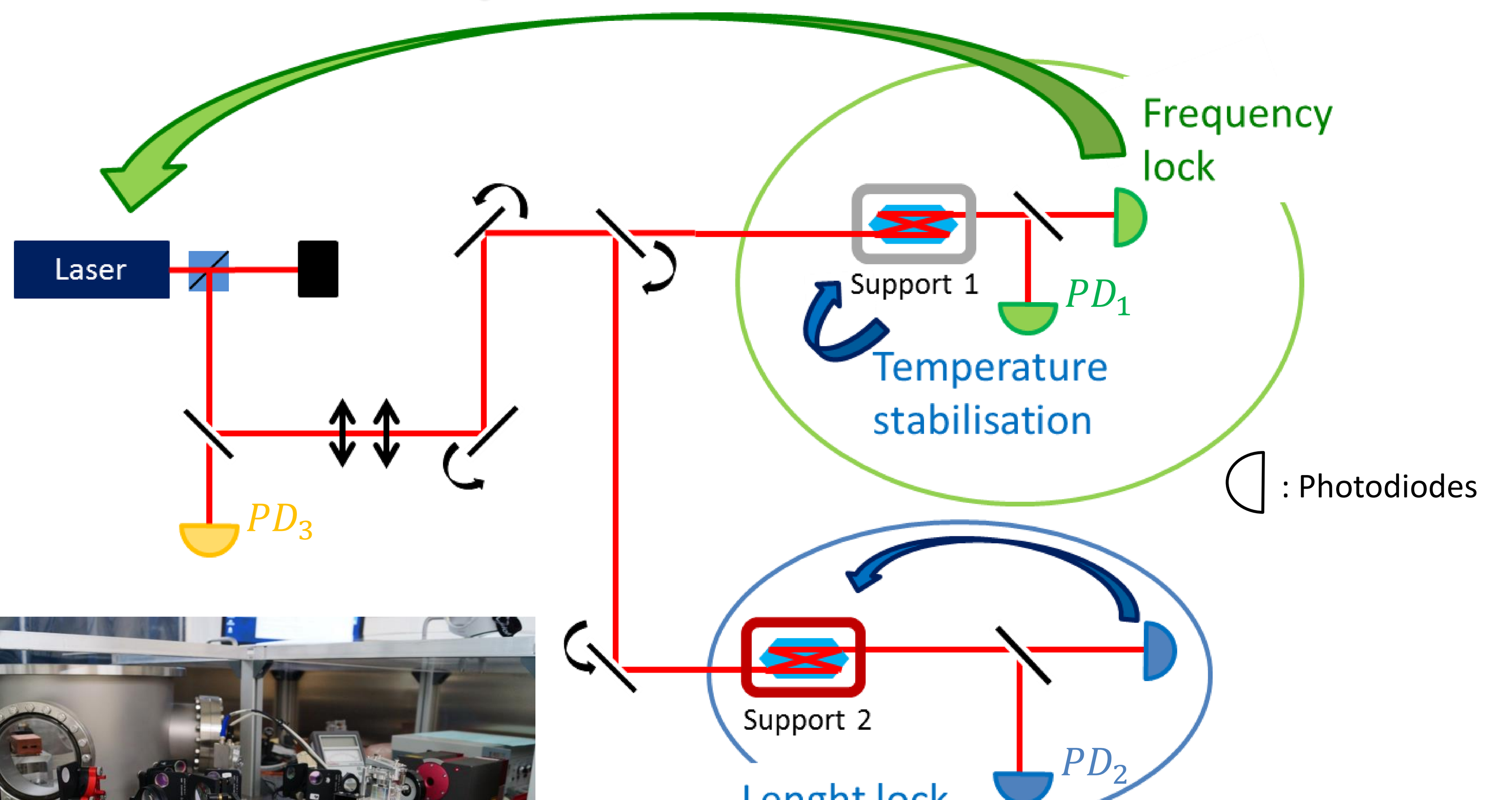


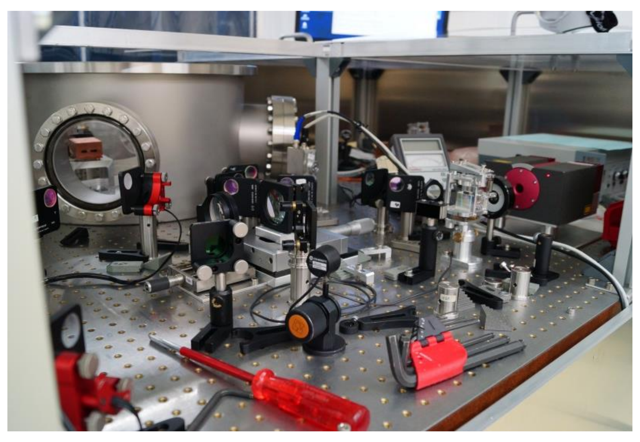




- The Output Mode cleaner is placed at the output of the interferometer to filter side bands and high order modes spoiling the DC detection.
- The Advanced Virgo OMC is composed of two monolithic cavities placed in series.

Setup measurement





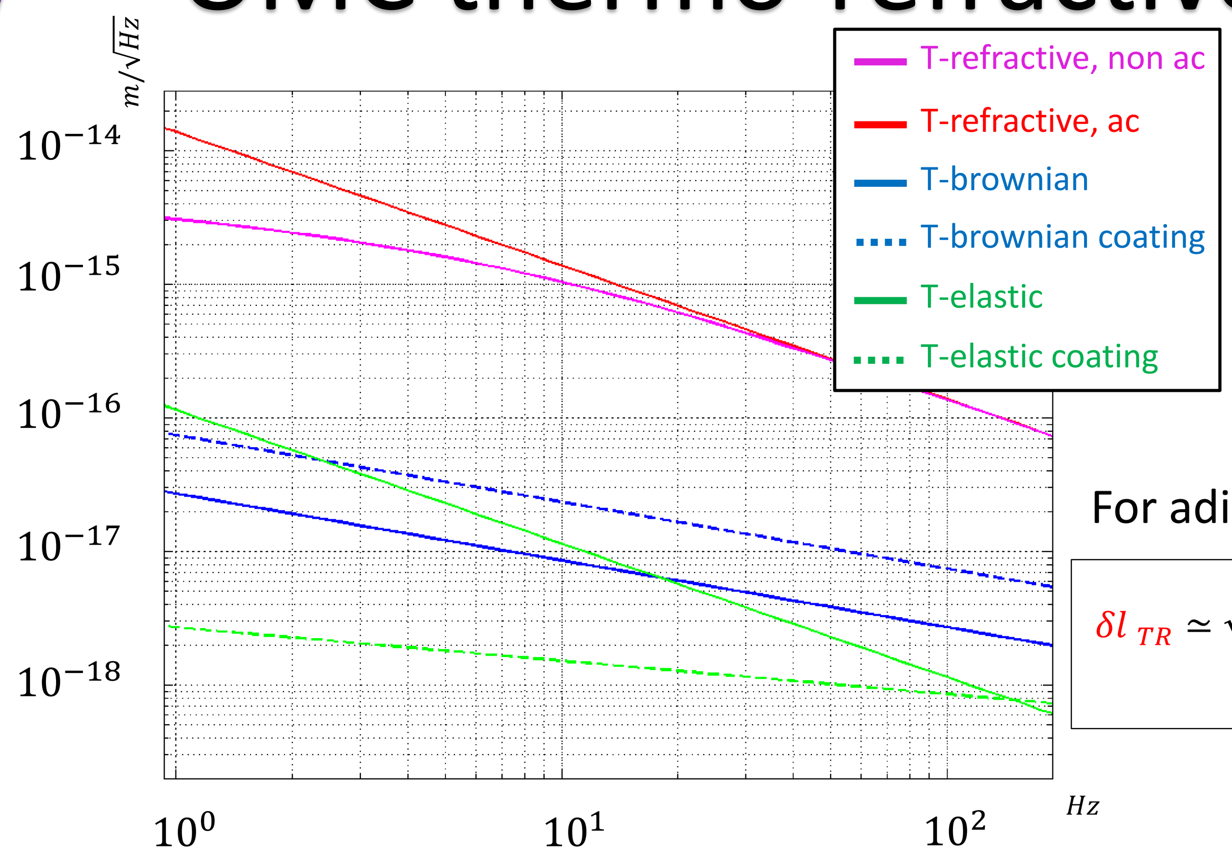
$$PD_1 = l_{cavity_1} + l_{frequency} + \alpha_1 P$$
$$PD_2 = l_{cavity_2} + l_{frequency} + \alpha_2 P$$
$$PD_3 = P$$
$$l_{cavity_1} - l_{cavity_2} = (PD_1 - \alpha_1 PD_3) - (PD_2 - \alpha_2 PD_3)$$

- The measurement has been done on a optical bench which is not suspended and not in the vacuum.
- Two cavities are locked and placed in parallel with two photodiodes in transmission. One photodiode is used to keep the cavity in resonance, the other to make the measurement.
- The error signal is obtained by dithering the laser frequency at 9 kHz with its PZT.
  - The laser frequency is modified according to the error signal obtained in transmission of the first cavity.
  - The second cavity is locked on the laser. Its temperature is modified, with two Peltier cells placed under the copper plate on which the cavity is mounted.
- The laser power noise (LPN) and the laser frequency noise (LFN) pollute the measurement. The LPN is subtracted at each cavity ($-\alpha P$), while the subtraction of the cavities signals ($l_{cavity_1} - l_{cavity_2}$) removes the LFN.

Conclusion

- OMC thermal length measurement observed between 10-20 Hz is in agreement with the thermo-refractive noise theory.
- Measurement is polluted at high frequencies by mechanical vibrations and probably by thermal fluctuation on the bench at low frequencies
- Thermo-refractive noise in the OMC and in the central interferometer are not a problem for Advanced Virgo. It could be one with the silicon substrates in ET detector.

OMC thermo-refractive noise



$$\varphi = \frac{2\pi}{\lambda} L \beta \sqrt{< u(T)^2 >_\tau} \ ^*$$
$$\beta = \frac{dn}{dT}$$
$$< u(T)^2 > = \frac{k_B T^2}{DC\ \pi (\frac{w}{\sqrt{2}})^2 L}$$

For adiabatic case (ac):

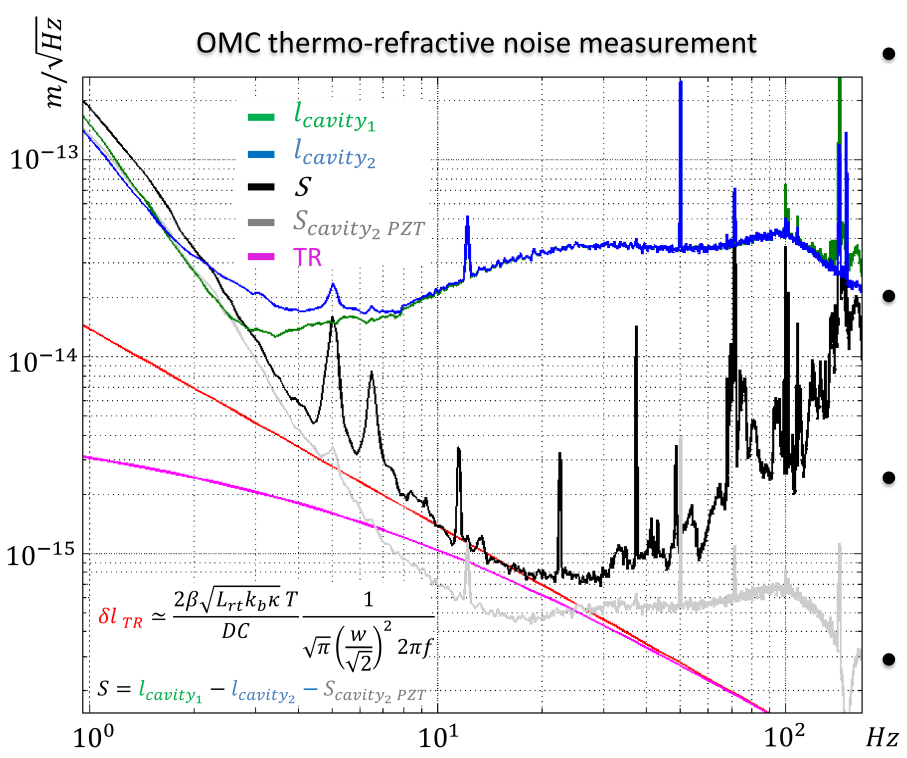
$$\delta l_{TR} \simeq \sqrt{2}\, \frac{2\beta\sqrt{L k_b \kappa}\, T}{DC} \frac{1}{\sqrt{\pi}\left(\frac{w}{\sqrt{2}}\right)^2 2\pi f}$$

With : L = 124 mm, w= 321 µm

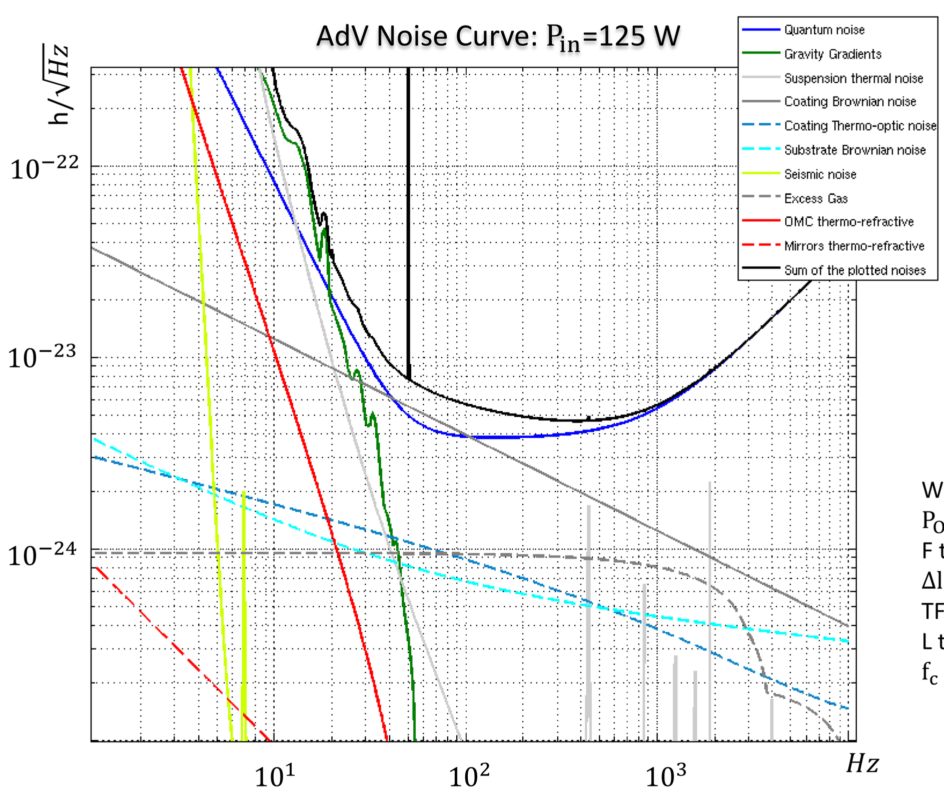
- The OMC length noise produces a power variation which can pollute the gravitational wave signal.
- For such fused silica cavities the dominant thermal noise is the thermo-refractive (TR) noise. Its origin is the fluctuation of the refractive index n with the temperature T.

* 1.Physics Letters A, 324 :345-360

Measurements and projection on the sensitivity curve



- The black curve corresponds to the substraction between the two cavities and with the PZT feedback noise removed.
- The measurement between 10-20 Hz is at the level of the thermo-refractive noise.
- At low frequencies, the thermal fluctuation of the air on the bench is suspected to be dominant.
- At high frequencies, clusters of peaks are produced by bench vibrations.



$$\delta h_{TR,OMC} = 32 P_{OMC} F^2 \frac{\delta l_{TR,OMC} \Delta l_0}{\lambda^2 \times TF \times L}$$

$$\delta h_{TR,mirrors} = \frac{\delta l_{TR,mirrors}}{\frac{2F}{\pi} \times L} \sqrt{1 + \left(\frac{f}{f_c}\right)^2}$$

With :
P_{OMC} the power in TEM00 carrier at the input of the OMC
F the finesse of the Fabry Perrot cavity
Δl_0 the OMC lock precision
TF (Transfer Function) the optical response of the interferometer
L the Fabry Perrot cavity length
f_c cavity pole frequency

The solid red line and dashed red line represent the contribution of the TR noise in the OMC and the central interferometer (BS+NI+WI+2*CP) respectivly.