Optical losses as a function of beam position on the mirrors in a 285-m suspended Fabry-Perot cavity

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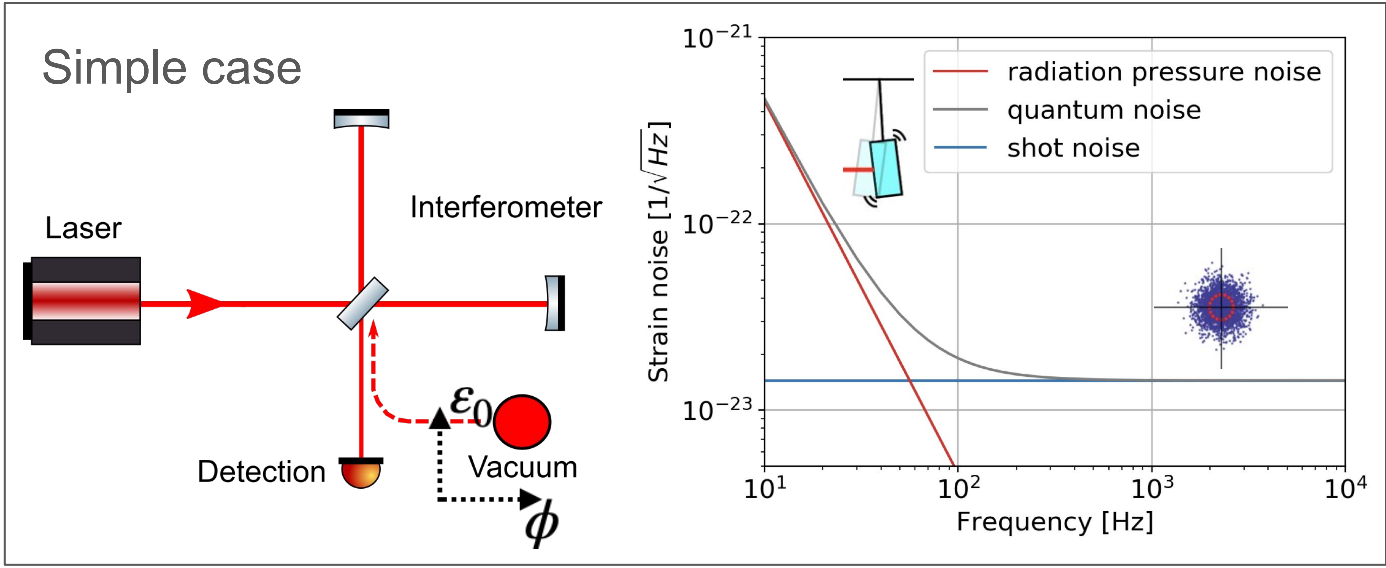
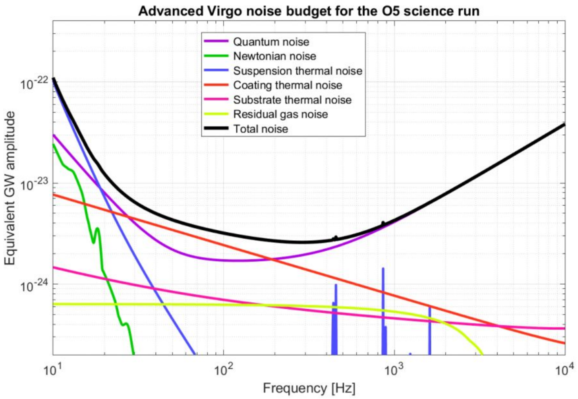
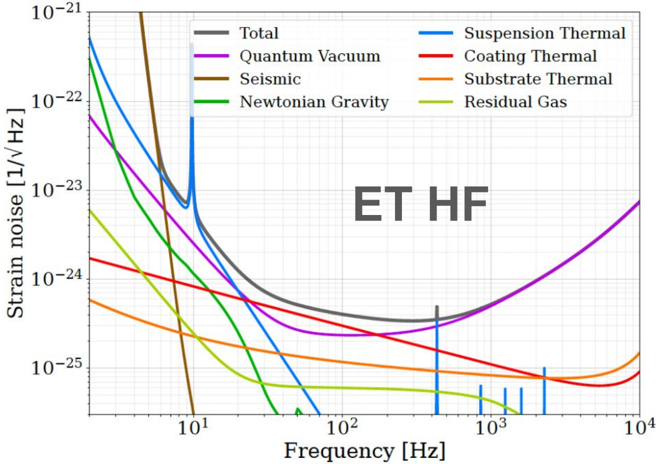
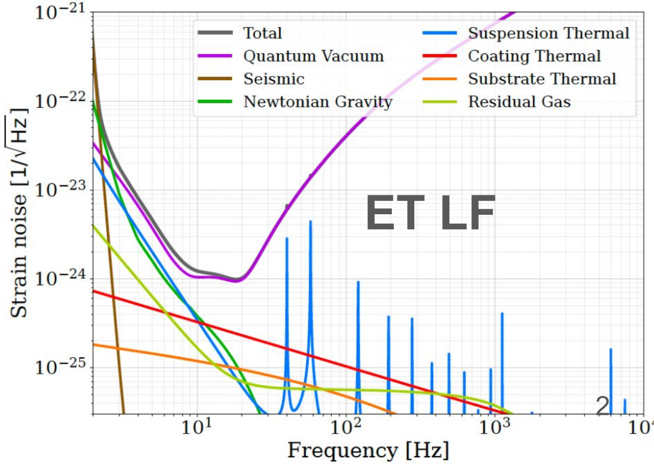
Quantum noise

- Quantum noise is a **limiting noise** for **current/future** detectors



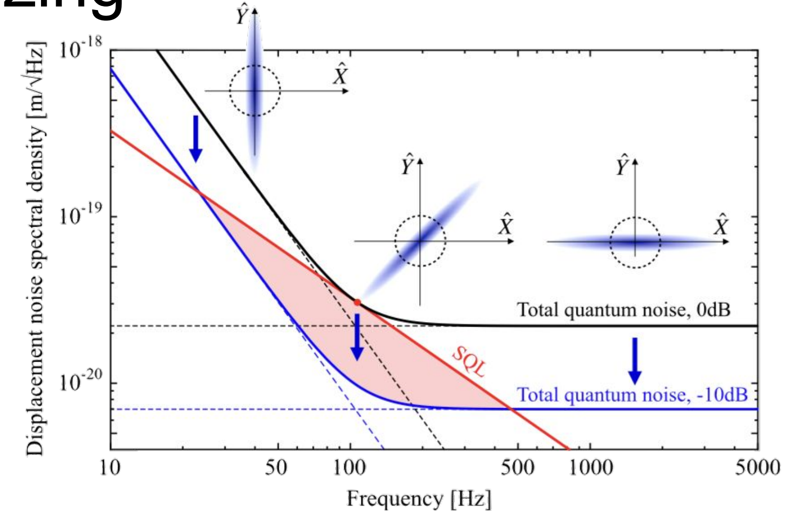


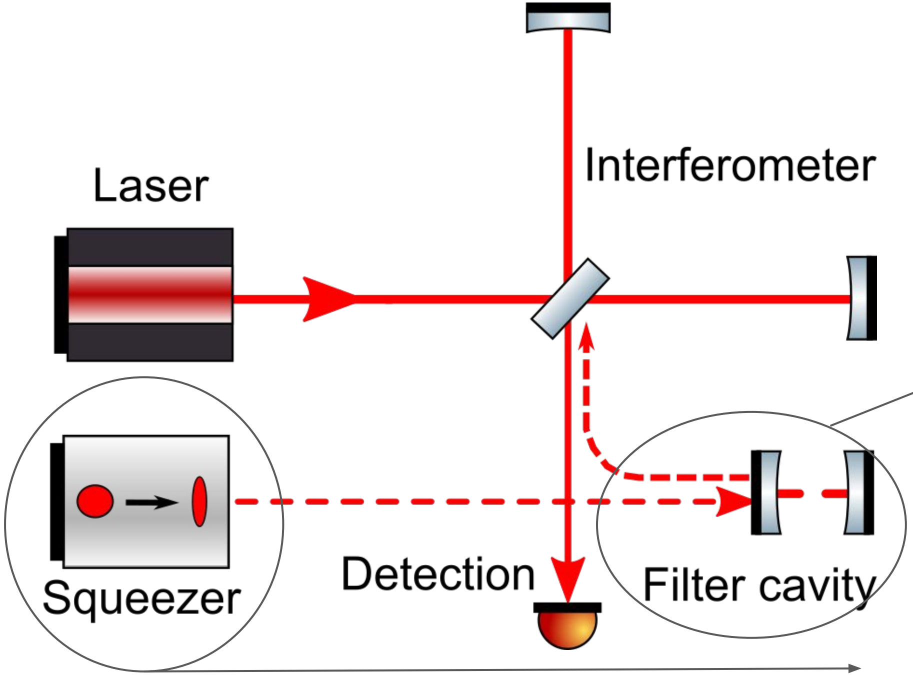




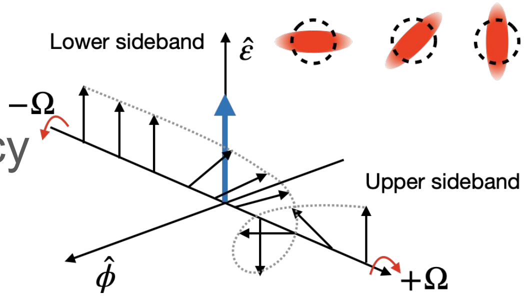
Reducing quantum noise with squeezing

- Quantum noise reduction relies on the use of **squeezed vacuum** and **filter cavity**

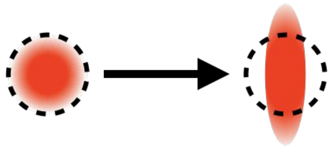




- Impose frequency dependence

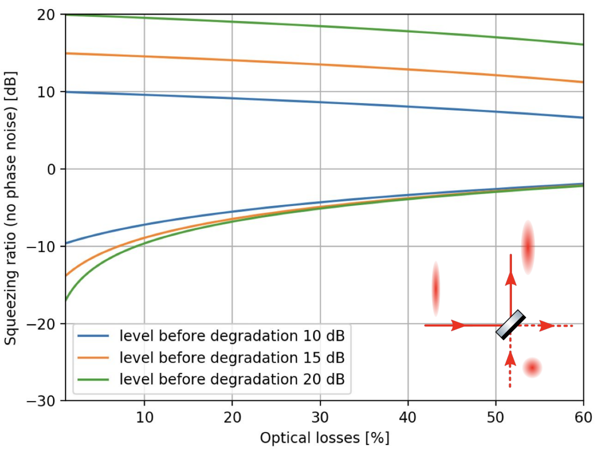


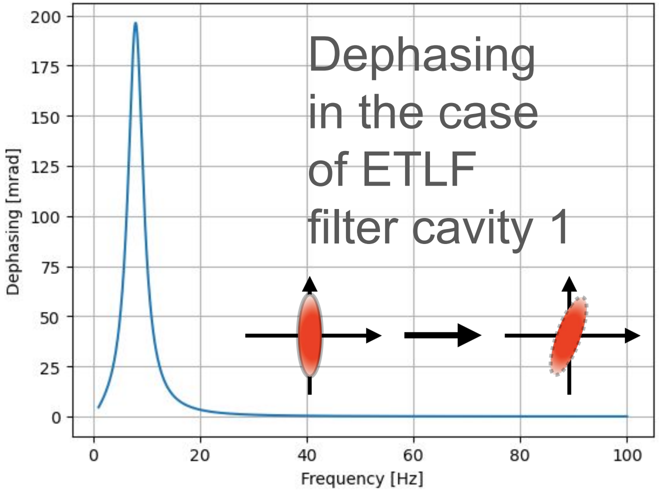
- Produce squeezed vacuum

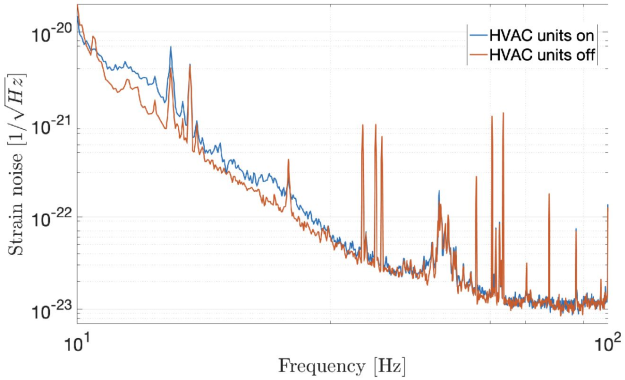


Issue when using Filter cavities: optical losses

- The optical losses in filter cavity mainly come from **scattered light**
- These could introduce problems such as **degradation**, **dephasing**, and **backscattered noise**



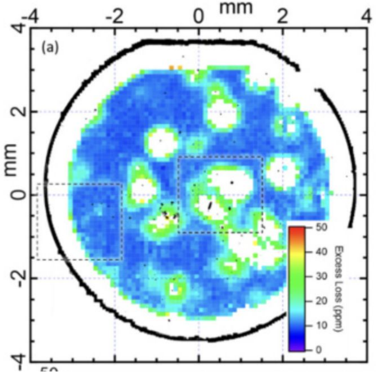




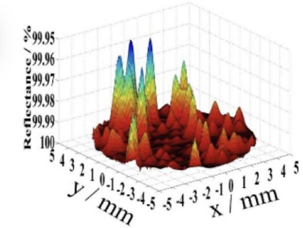
AdV sensitivity before (blue) and while all heating, ventilation, and air-condition (HVAC) units were off (red)

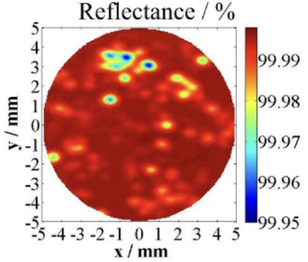
How optical losses were characterized?

- For cavities **less than 1 meter**, mirror losses map was acquired



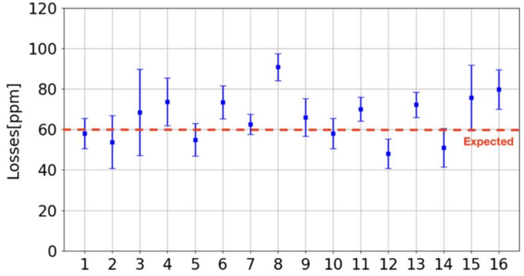
G. W. Truong, et. al., Optics Express, 27, 14, 2019





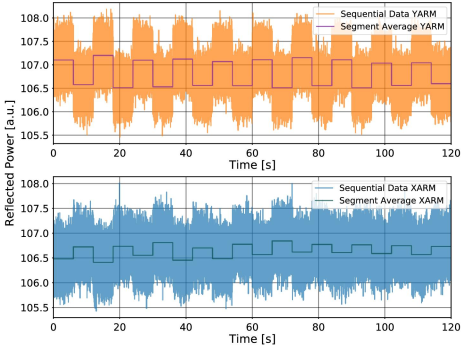
H. Cui, et. al., Optics Express, 25, 5, 2017

- For cavities with **hundred-meter scale**, only some statistics were made:



E. Capocasa, et. al., PRD, 98, 022010, 2018

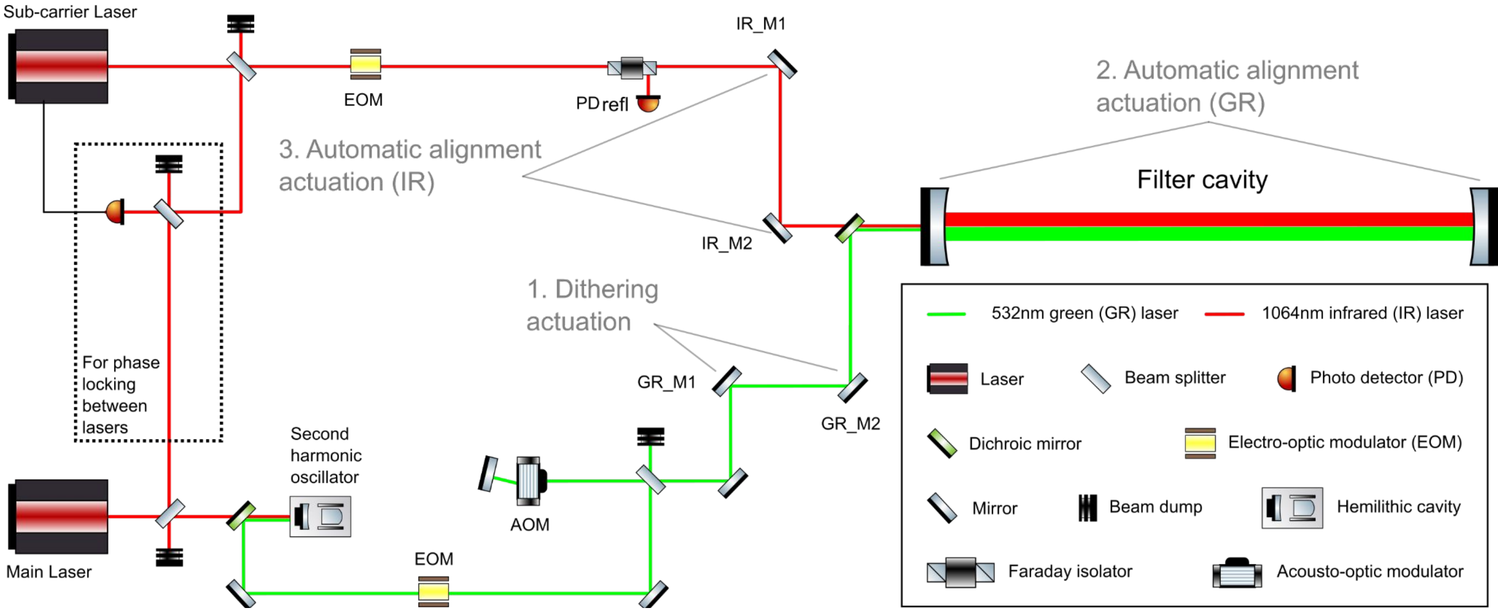
Y. Drori, et. al., JOSA A, 39, 5, 2022



Since optical losses are important, we wonder how is the mapping of them

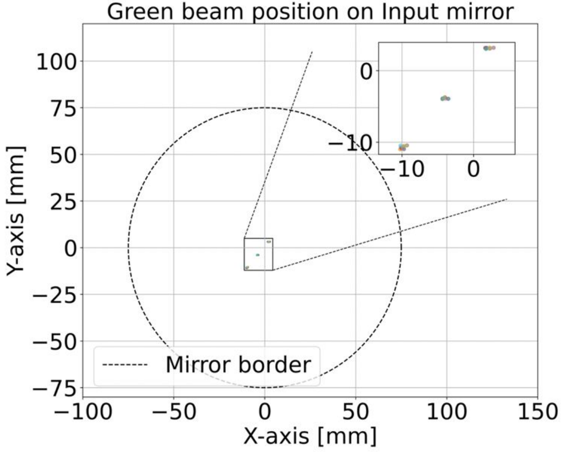
Above all, we are curious about something that we have never seen before

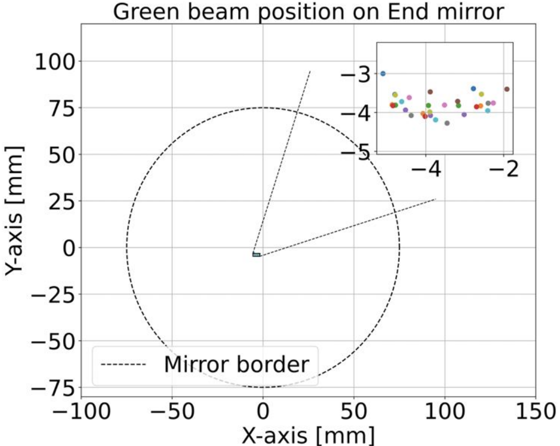
Characterization of Virgo filter cavity mirrors



Methodology step 1 – mapping

- Put mirrors at appropriate angles
- Beam position on mirrors will be determined

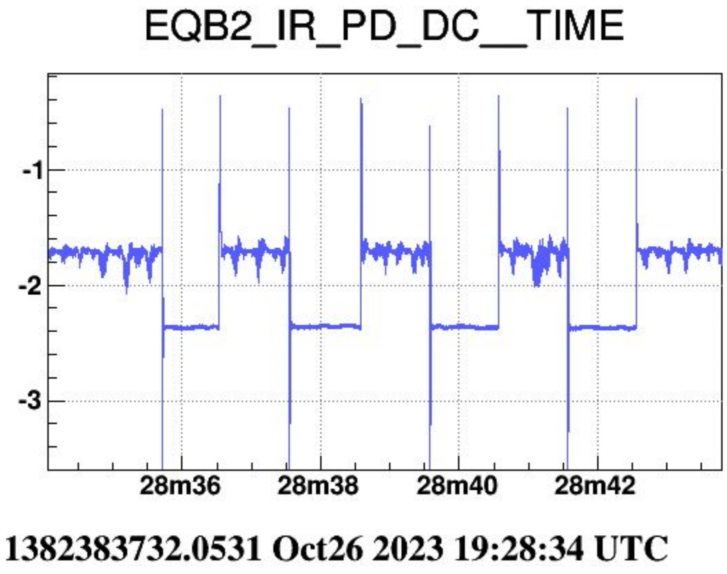




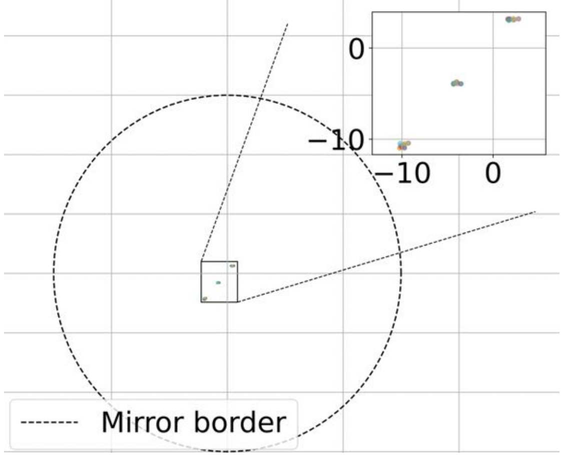
The characterization of Virgo filter cavity mirrors

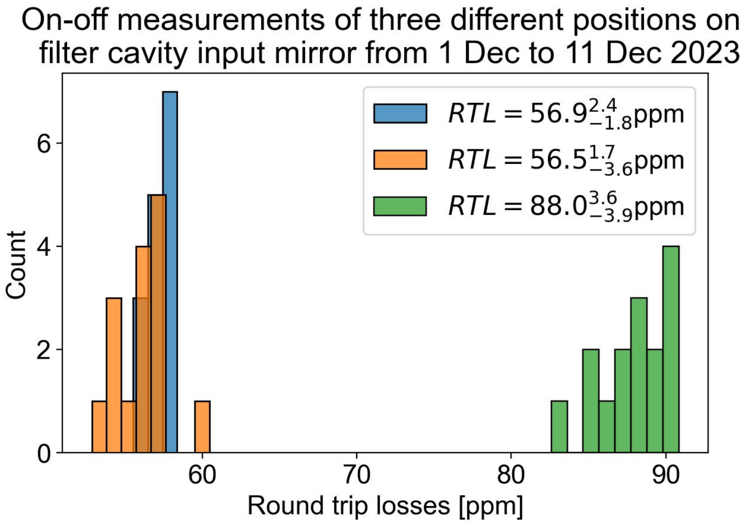
Methodology step 2 – losses measurement

- Losses are measured with on/off resonance method



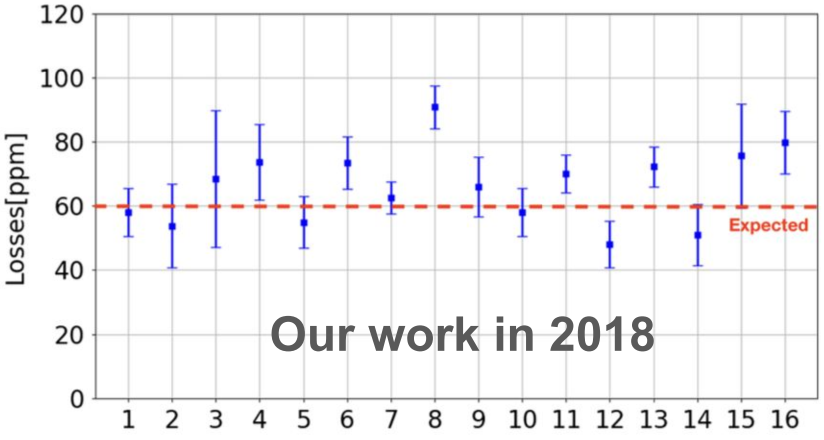
- Repeatability and errors were verified

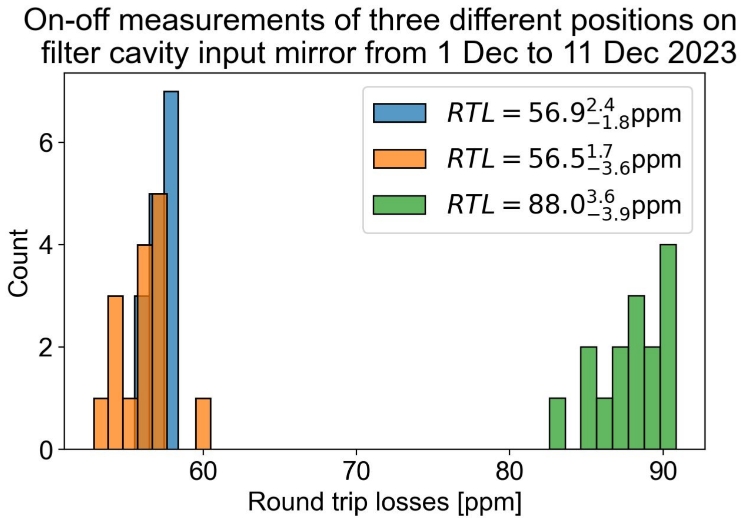




A **more deterministic** measurement

- A recall of previous measurement
- Our new measurement

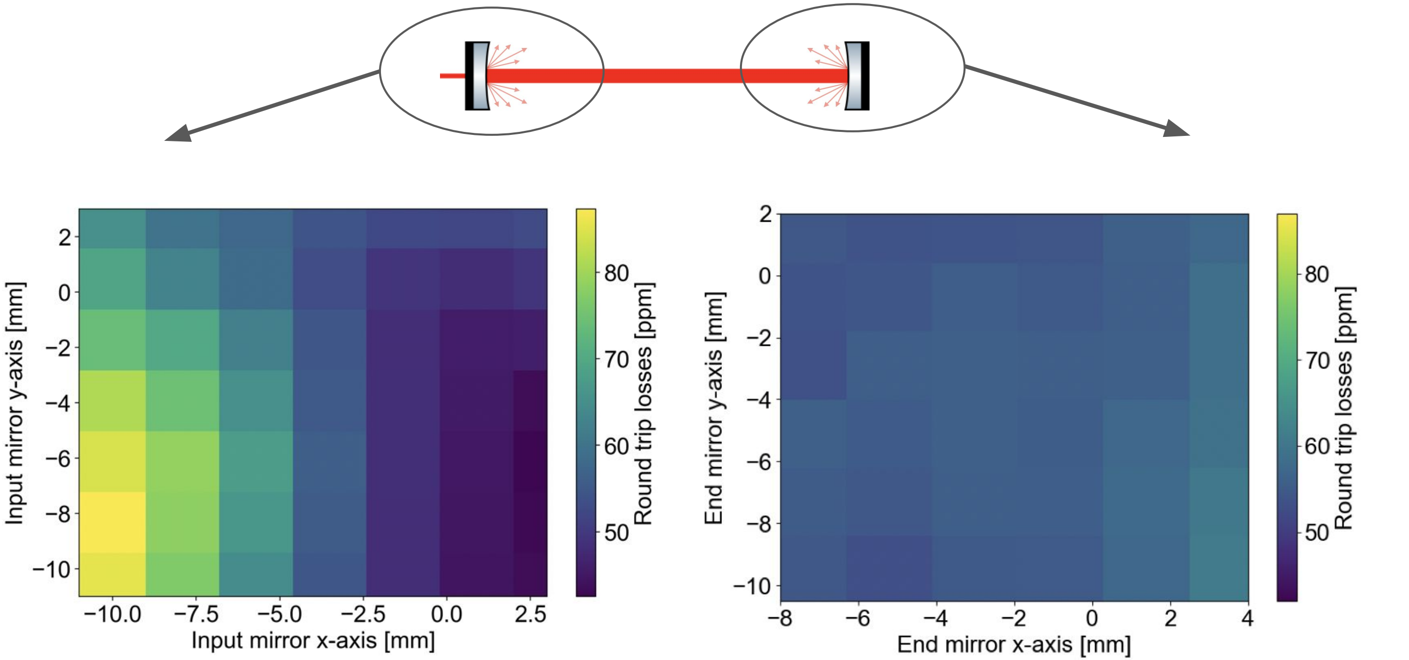




A reduction of statistic error from ~20 ppm to less than 4 ppm

A surprising measurement result

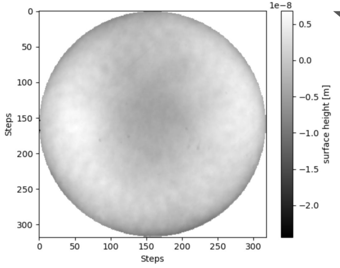
We reconstructed mirror losses maps for input and end mirrors

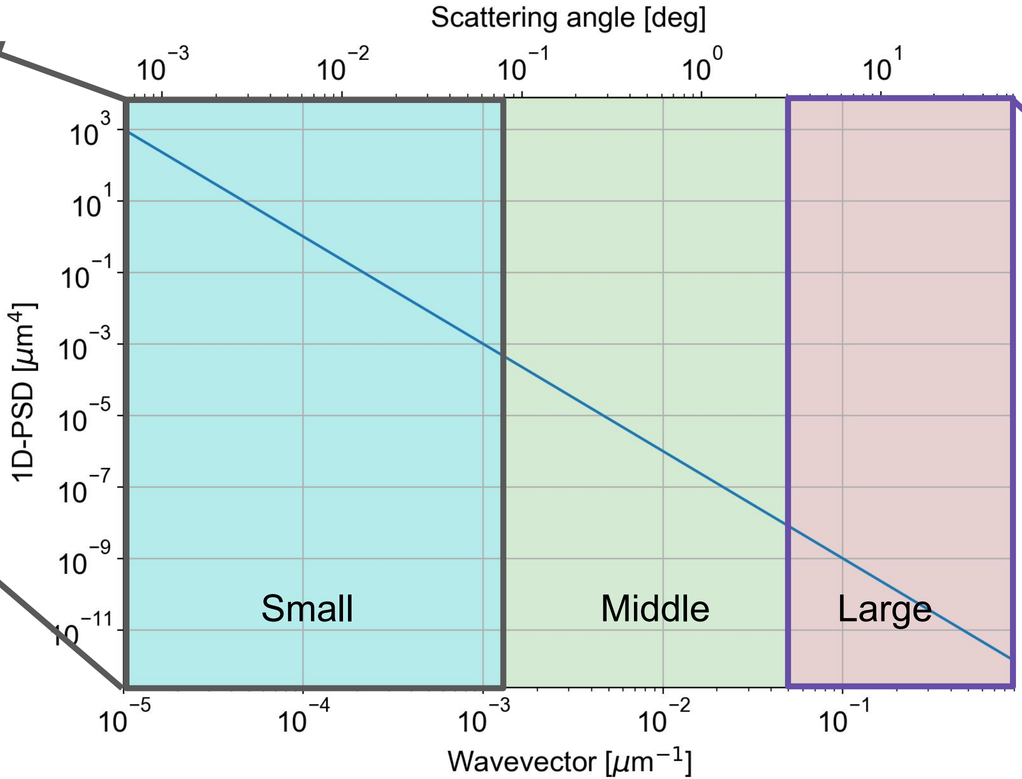


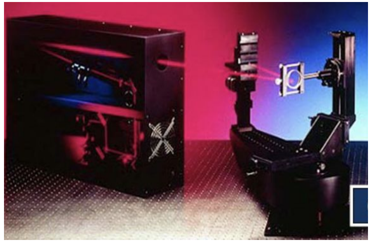
- **Variation of 50 ppm** (from 40 to 90 ppm)
- **49 points** measured within **30 minutes**, thanks to Virgo automation system

Why we get such surprising result?

Analysing the scattered light in three regions







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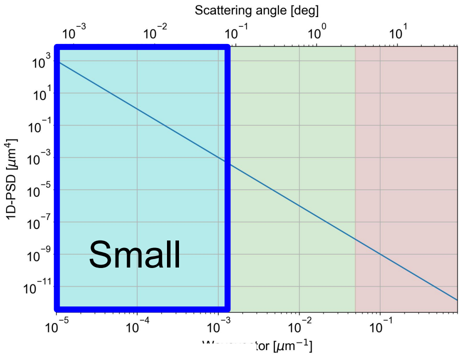
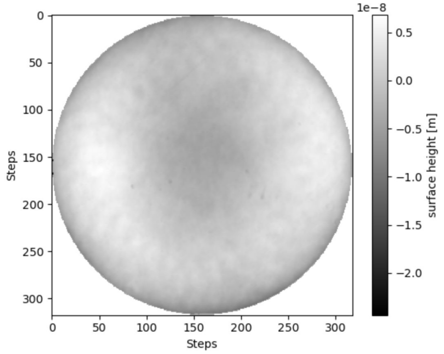
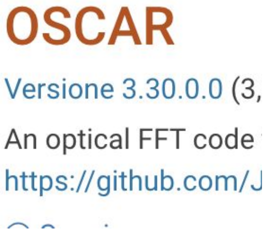


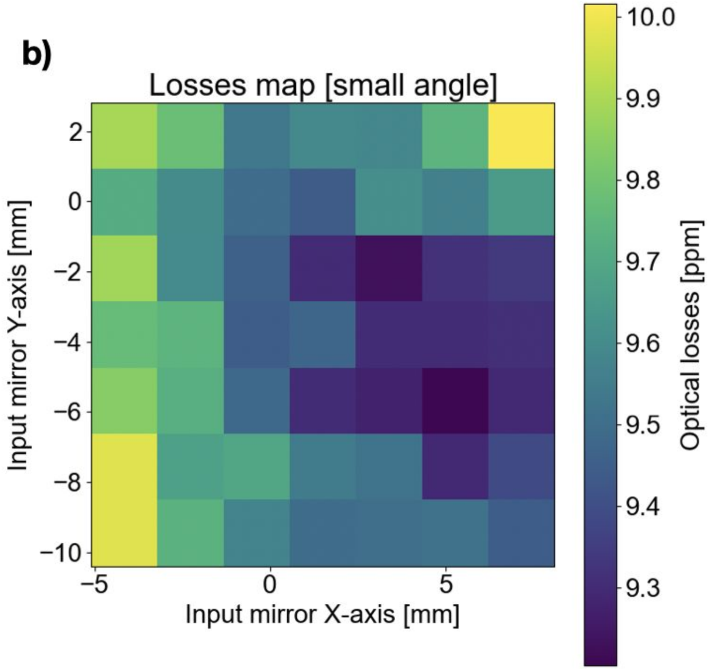
Analysis 1 – Surface map

Predict losses by combining:

- Surface map
- OSCAR simulation tool







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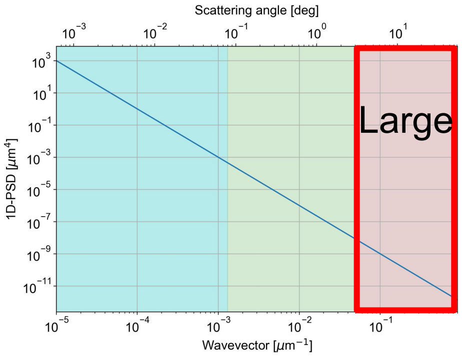
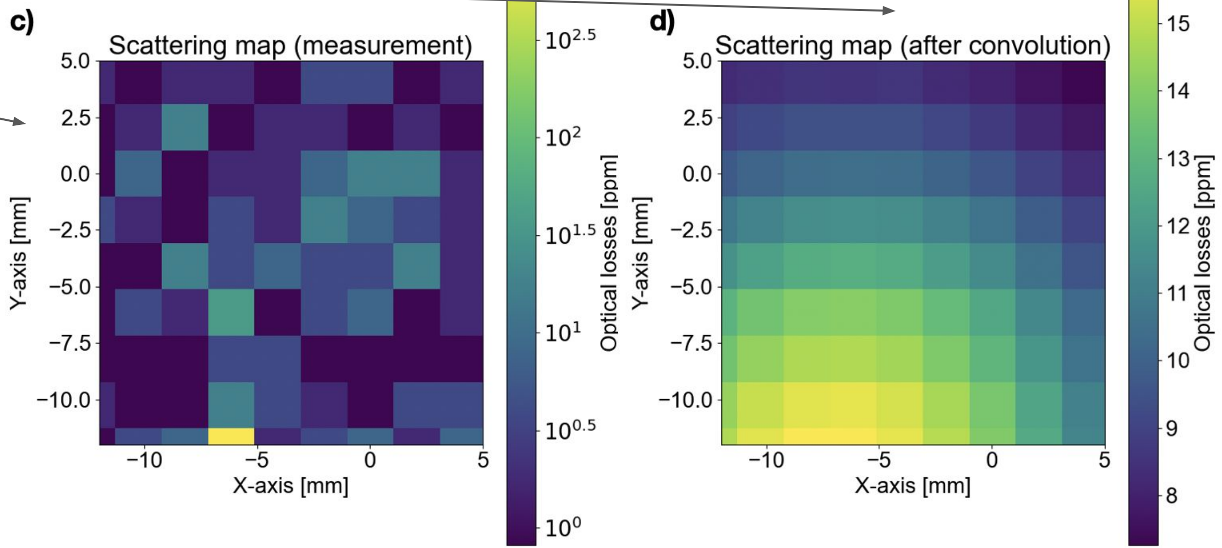


Analysis 2 – Coated mirror characterization

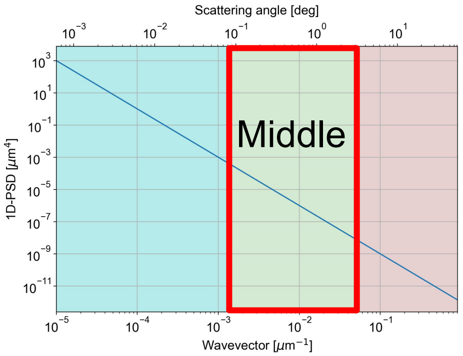
Scatterometer measurement

Convolute it with real beam size



Why we get such surprising result?

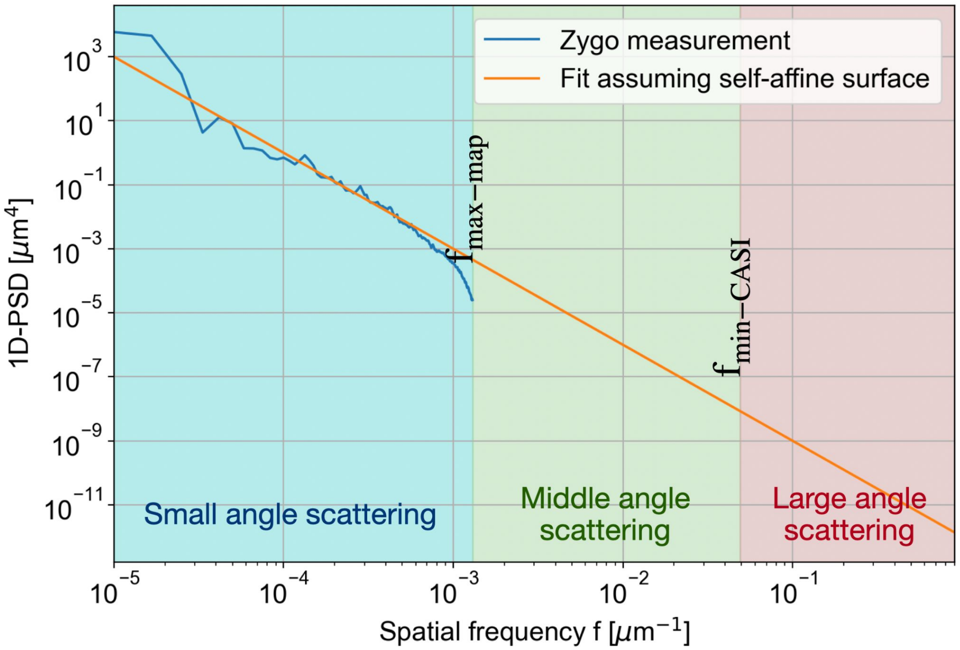
Analysis 3 – The missing middle



We extend the surface map measurement, then we integrate it

$$\sigma^2_{\mathrm{middle}} = 2\pi \int_{f_{\mathrm{max-map}}}^{f_{\mathrm{min-CASI}}} C^{\mathrm{iso}}(f) f \, df$$

$$TIS = \left(\frac{4\pi\sigma}{\lambda}\right)^2$$



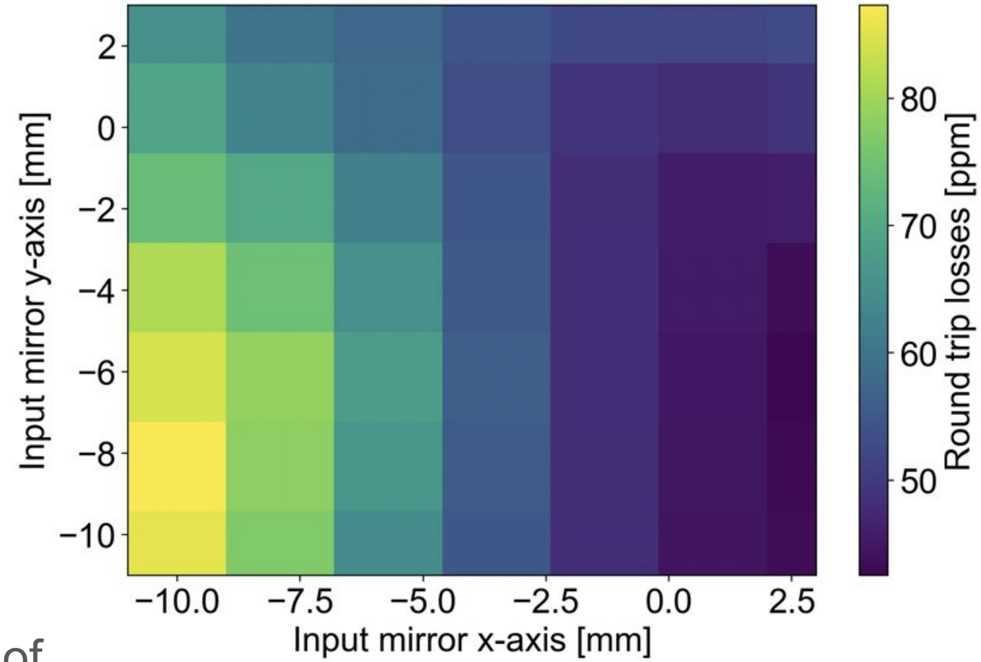
Comparing result and analysis

TABLE III. Estimated losses from mirrors characterization before cavity integration

Small angle scattering	10 ppm
Middle angle scattering	0.7 ppm
Large angle scattering	15-24 ppm
End mirror transmission	3.9 ppm
Absorption and clipping	< 1 ppm
Total	**29.6-38.6 ppm**

The difference may come from contamination

To guarantee performance, an ***in-situ* mapping of the losses would be an essential step** for the commissioning of super mirrors used in gravitational wave detection



Conclusion

- **Measured** a mirror map for hundred meter scale cavity after its integration
- **Analyzed** mirror characterization before its integration, which explains partly the measurement
- **Indicated** some probable contaminants on mirrors
- Our result signifies <u>**the importance of *in-situ* losses map for commissioning**</u>

Next step

- Mirror cleaning may be required
- Middle angle scattering could be better estimated if we consider defects
- Measuring losses at another wavelength could be interesting

Thanks to the support from co-authors/Virgo QNR/LMA…

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Phys. Rev. Applied

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Thank you!

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