Status of the frequency dependent squeezing experiment at TAMA

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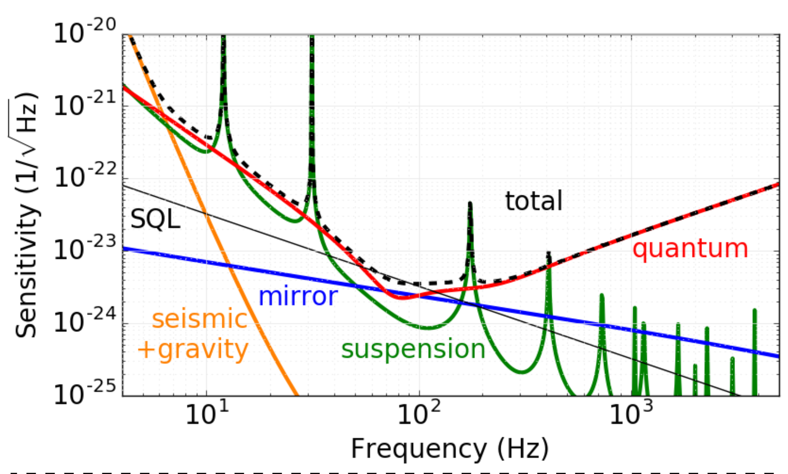
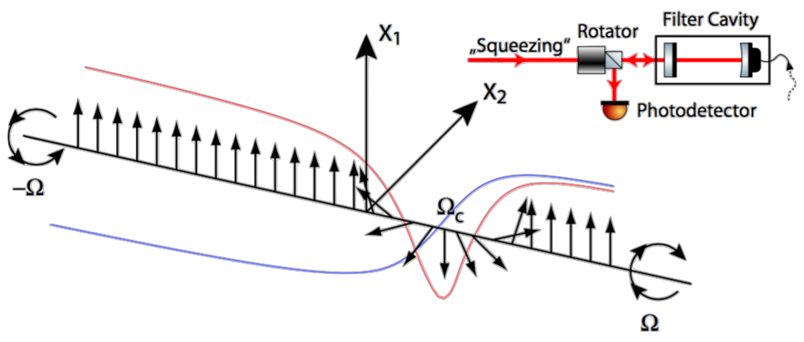
Squeezing and gravitational wave detector

Quantum noise has already been the limiting noise for gravitational wave detector especially at high frequency. Squeezing is proven to be effective for reducing quantum noise and has already been used for O3.

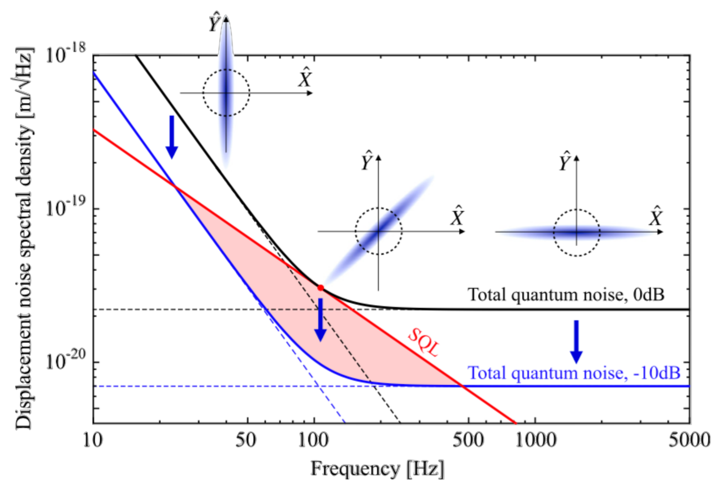


Quantum noise is expected to limit KAGRA sensitivity in almost the whole spectrum.

Quantum noise can be reduced by injecting squeezing inside the detector.



Filter cavity will change the phase of squeezed sideband to achieve frequency dependent squeezing.

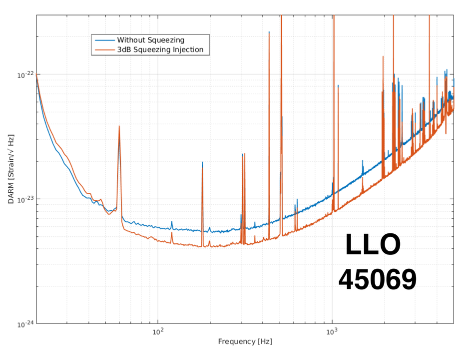


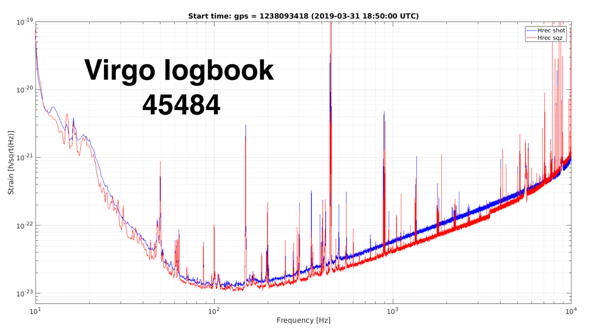
Low frequency quantum noise is due to radiation pressure noise and can be mitigated by amplitude squeezing.

High frequency quantum noise is due to shot noise and can be mitigated by phase squeezing.

Frequency independent squeezing for O3:

Now frequency independent squeezing is used for O3. LLO sensitivity with and without squeezing and Virgo squeezing level is shown below. From LLO noise budget, we can see clearly squeezing decreases high frequency noise while increases low frequency noise.





Frequency dependent squeezing is planned for O4 in LIGO and Virgo and is one of the candidate future upgrade plan for KAGRA.

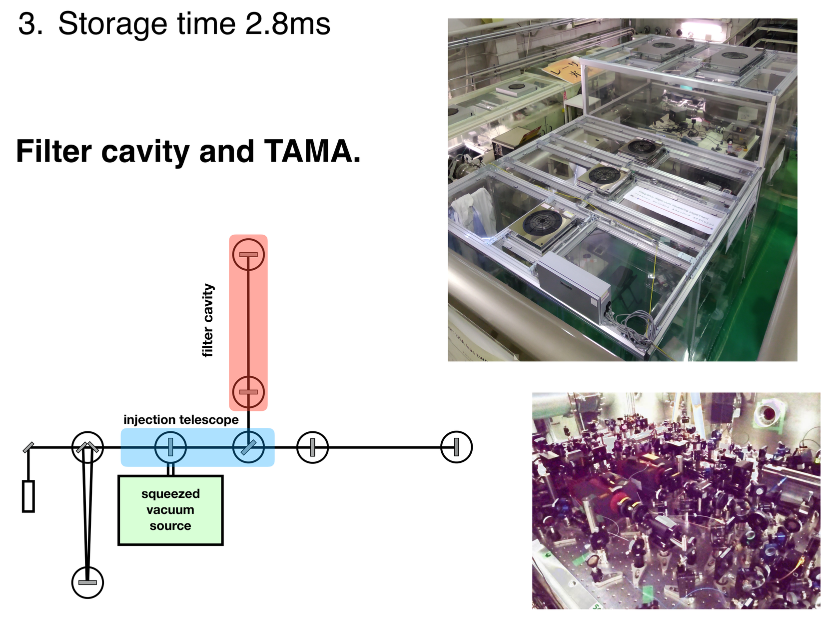
Project overview

Goal of experiment

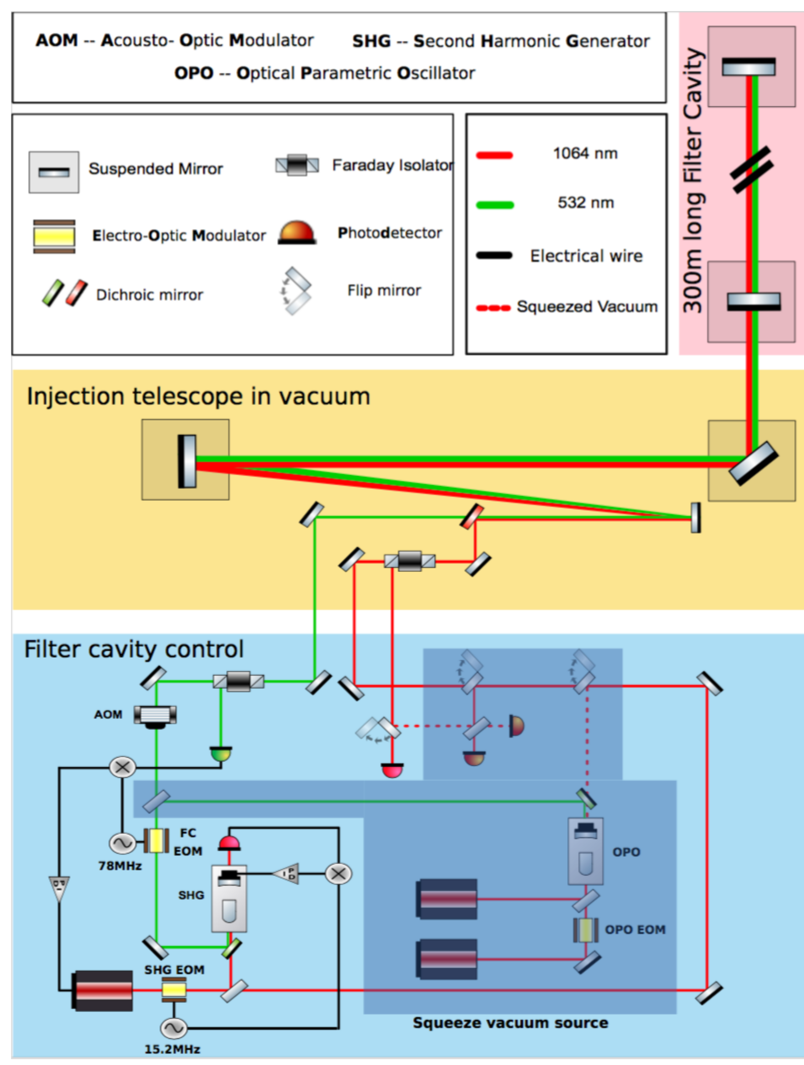
Full scale filter cavity prototype to demonstrate frequency dependent squeezing with rotation at 70Hz.

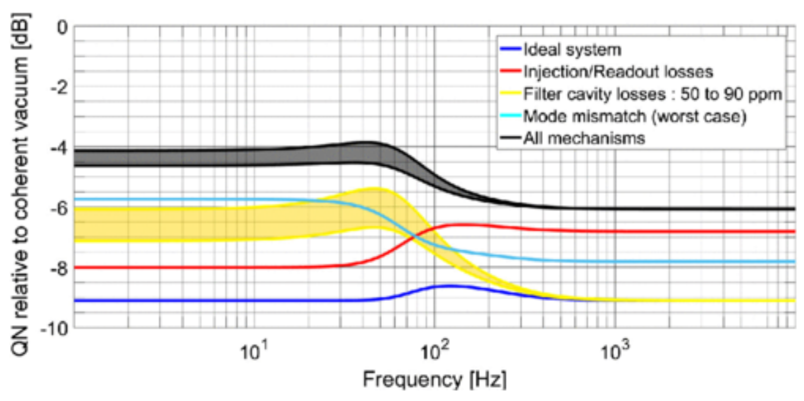
1. Cavity length: 300m
2. Finesse: 4400
3. Storage time 2.8ms

Filter cavity and TAMA.

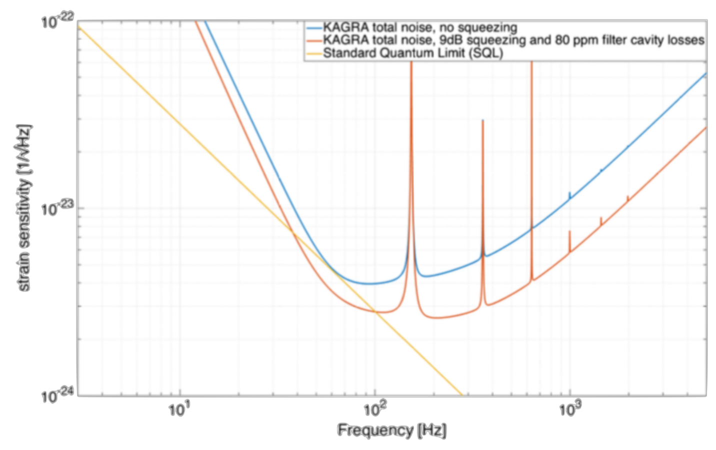


The vacuum squeezed generation scheme is based on GEO design.





Squeezing degradation budget. Quantum noise relative to coherent vacuum in the signal quadrature for an ideal system (blue curve) is compared that with squeezing, taking into account degradation mechanisms (one by one).

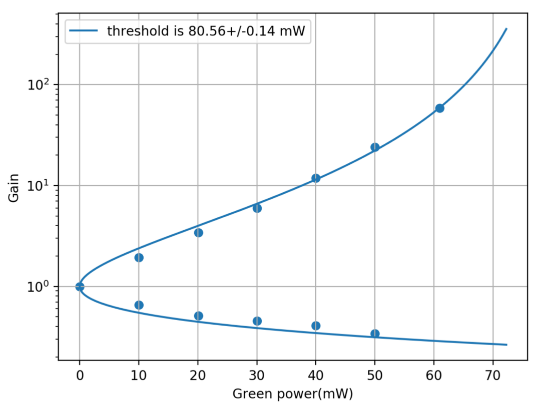


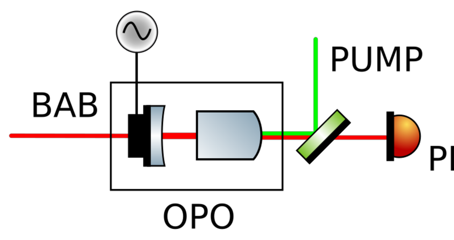
Improvement in KAGRA sensitivity using 9 dB frequency-dependent squeezing, considering lossy cavity and other degradation mechanisms.

Status

- Filter cavity installation, control and characterization has been achieved
- Squeezed vacuum source installation has been finished
- 3dB of squeezing and 17dB of anti-squeezing has been measured
- Commissioning of the squeezed vacuum source is going on
- KAGRA consistent DGS system implemented
- Automatic alignment system design is finished

Parametric gain measurement:



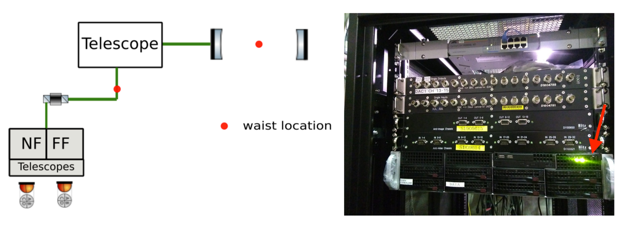


- Measurement is done by sending green and (BAB)bright alignment beam inside OPO.
- Pump green light (de)amplifies BAB.
- It shows the squeezing ratio for different green power.

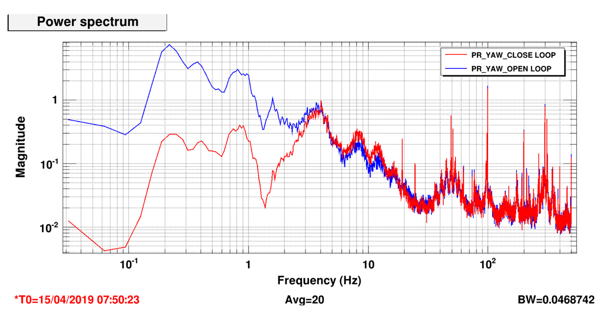
Automatic alignment system design:

To sense separately tilt and shift inside filter cavity.

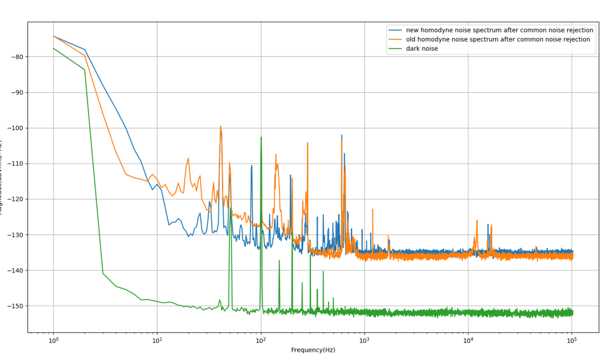
We designed two independent telescope with Gouy phase 90 degree difference. One is far field and error is within 1 degree. The other is near field and error is within 10 degree.



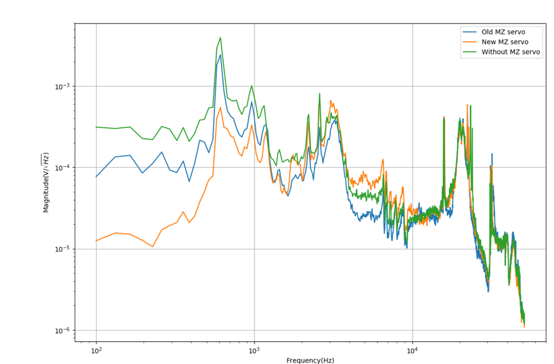
DGS system upgrade: With the help of Miyakawa-san, Yamamoto-san and Fuji-san. We have new DGS system working. It is shown on the right side that one of the mirrors is controlled!



Bench related servo upgrade: We have four cavities, one Mach-Zehnder interferometer and two coherent control loops. Thanks to the hard work of Pierre, we have a much better low frequency noise performance for each of them. The unity gain frequency of each loop is around several kHz.



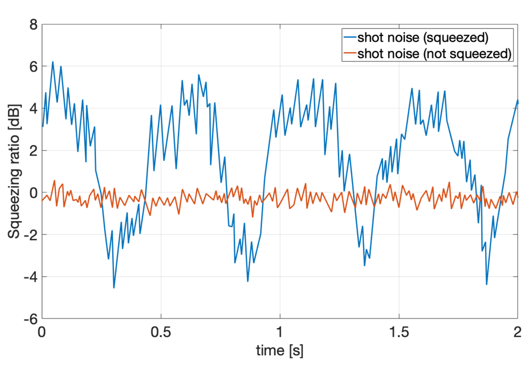
Here is the noise spectrum for homodyne local oscillator. We can see our new servo reduces low frequency noise by almost 10dB.



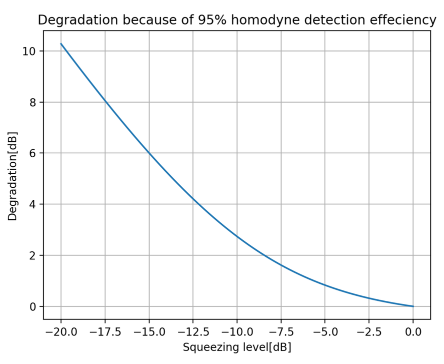
Here is the noise spectrum of pump beam going to OPO. The new servo reduces low frequency noise by a factor of 10.

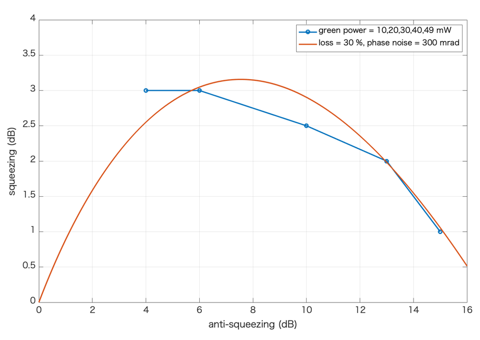
Squeezing measurement:

After the locking of OPO, PLL and installation of homodyne. We performed the first measurement of squeezing with pump green power of 20mW. The result is shown on the right side.



The detection efficiency of homodyne is measured as 95% now. We estimated the degradation level for each level of squeezing.





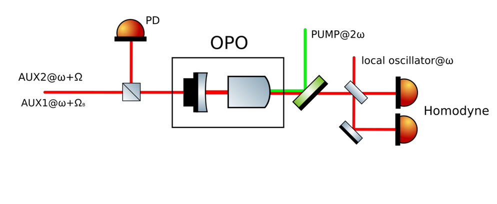
By assuming phase noise of 300mrad, we could explain what we observed at the beginning. This pushed us more to realize coherent control loop for squeezing.

Phase noise will lead to the mixing of squeezing and anti-squeezing. Anti-squeezing has large uncertainty and will easily degrades squeezing which has small uncertainty.

$$V_{squeezing} = V_{squeezing}cos^2(\delta\theta) + V_{antisqueezing}sin^2(\delta\theta)$$

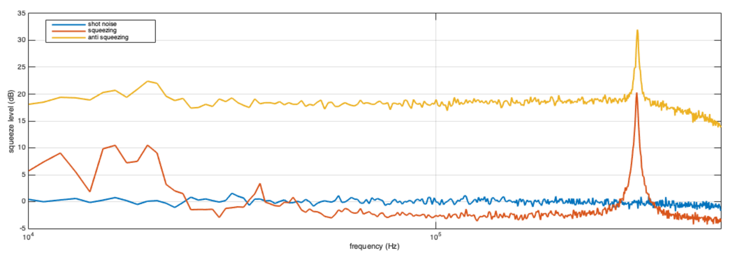
Squeezing and coherent control:

Coherent control is used to stabilize phase noise of squeezing.

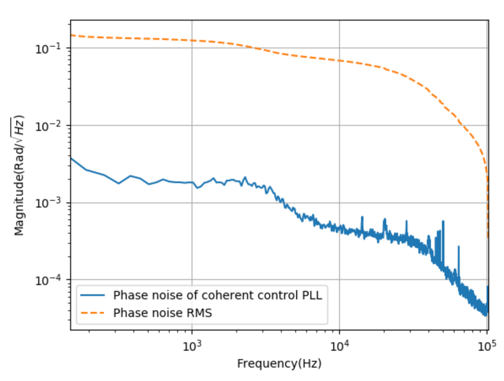


Coherent control scheme is shown on the left side.

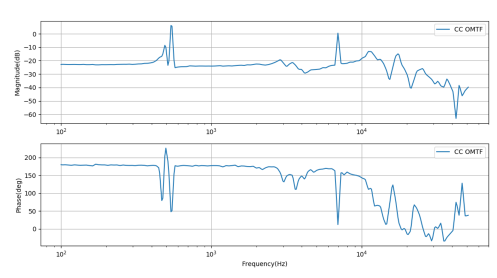
OPO reflection PD is used to sense green pump light phase. OPO transmission homodyne is used to sense local oscillator phase.



We managed to lock coherent control loop but with a very low unity gain frequency(around 100Hz). With the locking of this loop, we could measure noise spectrum of homodyne. The result is shown on the right side. We can see from this spectrum that our excessive noises appear below 40kHz.



We also measured the coherent control laser PLL phase noise. If this phase noise is too large, we will bring this noise to coherent control loop. According to the left measurement, RMS phase noise of this loop is 149mrad.



From this opto-mechanical transfer function, we can see many peaks which are limiting our loop. We will solve this problem soon.

Next step

- **Squeezed vacuum source improvement**
- **Installation of cavity automatic alignment**
- **Injection of squeezing into the filter cavity**

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