Development of frequency dependent squeezed light source for KAGRA

Yao-Chin Huang

Supervisor: Ray-Kuang Lee

Collaborators: M. Leonardi, E. Capocase, Y. Zhao, N. Aritomi (NAOJ);
Chien-Ming Wu, Yi-Ru Chen, Hsun-Chun Wu, Popo Yang (NTHU)

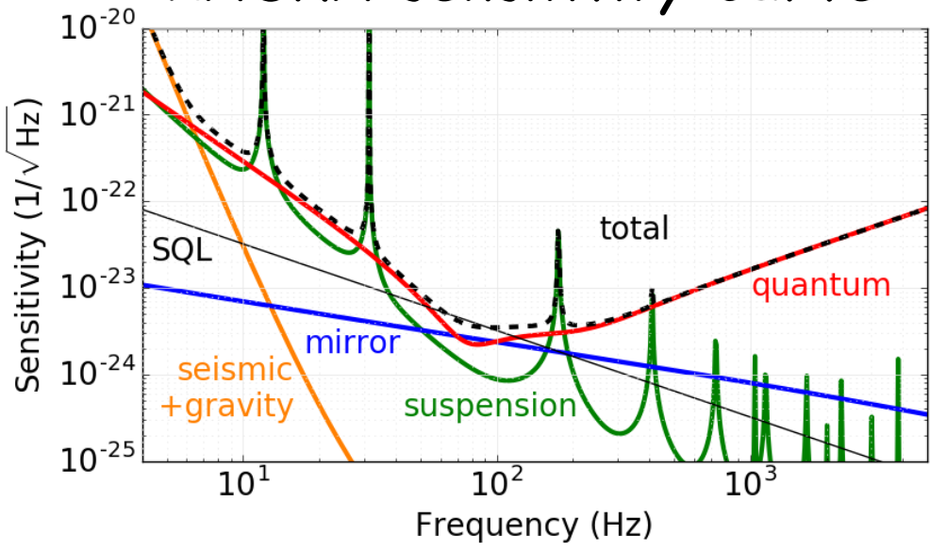
Content

- Quantum noise in gravitational wave detector
- Frequency dependent squeezing experiment in NAOJ (located in Mitaka, Tokyo)
- Preliminary result on frequency dependent squeezing

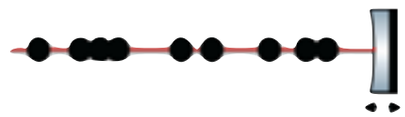
Filter cavity of 300m in TAMA

Quantum Noise in Gravitational Wave

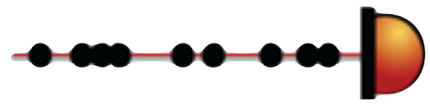
KAGRA sensitivity curve



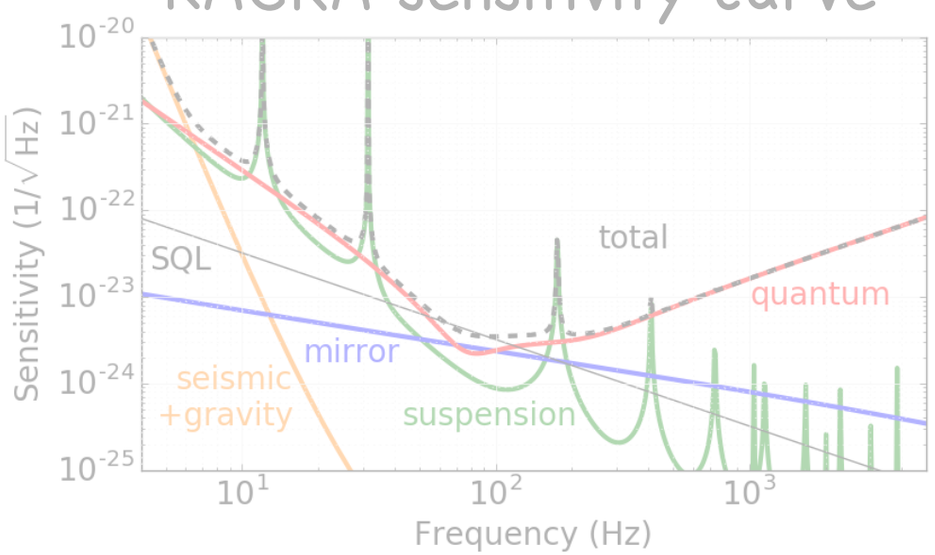
- Quantum noise limits the interferometer sensitivity
- Radiation pressure @ low frequency
  (e.g.: mirror motion)



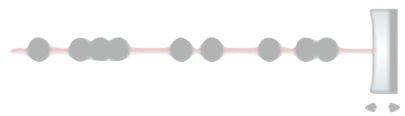
- Shot noise @ high frequency
  (e.g.: photon detector)



Quantum Noise in Gravitational Wave



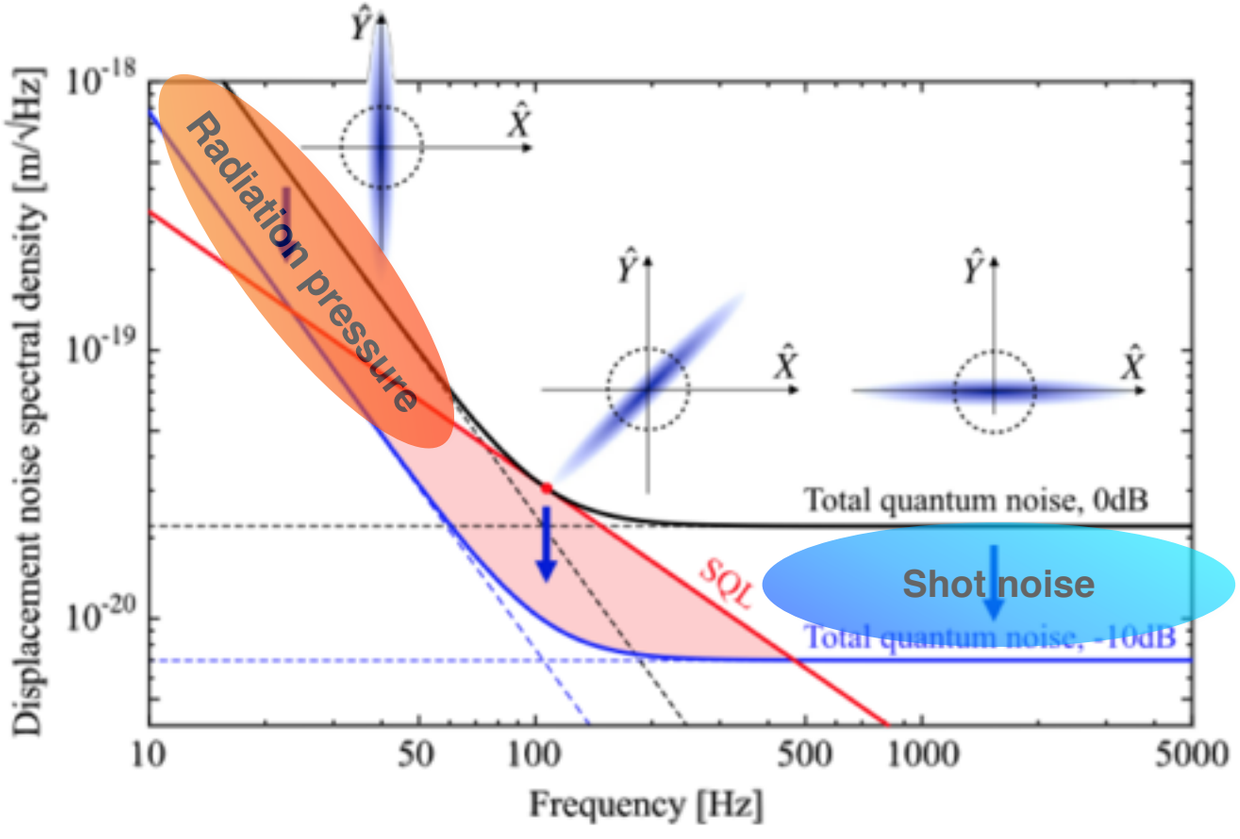
- Quantum noise limits the interferometer sensitivity
- Radiation pressure @ low frequency
  (e.g.: mirror motion)



- Shot noise @ high frequency
  (e.g.: photon detector)

Broadband Quantum Noise Reduction

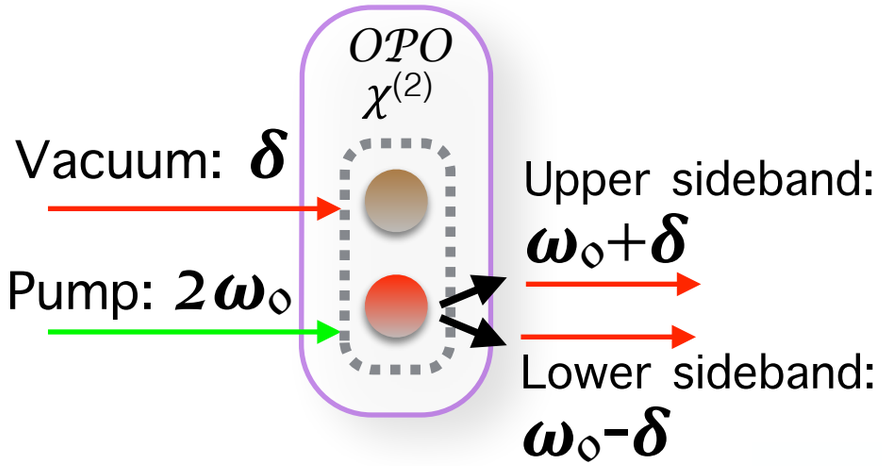
- We couldn't avoid quantum noise since coming from quantum nature of light, but we could reduce it.
- Frequency dependent Squeezing injection with various squeezing angles allowed broadband quantum noise reduction.

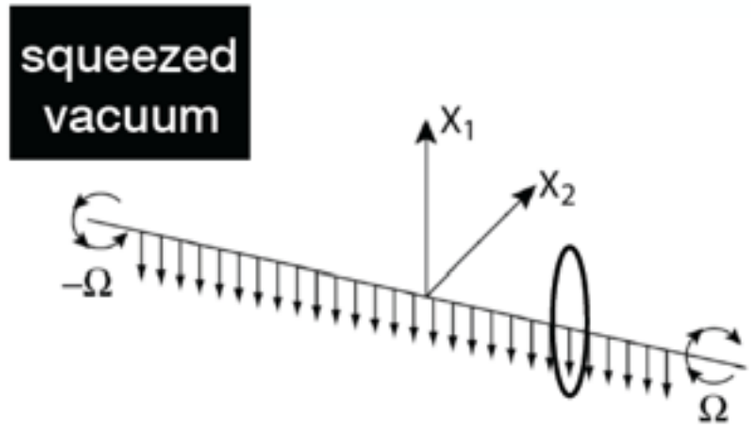


Squeezing Source Generation

Frequency independent squeezing

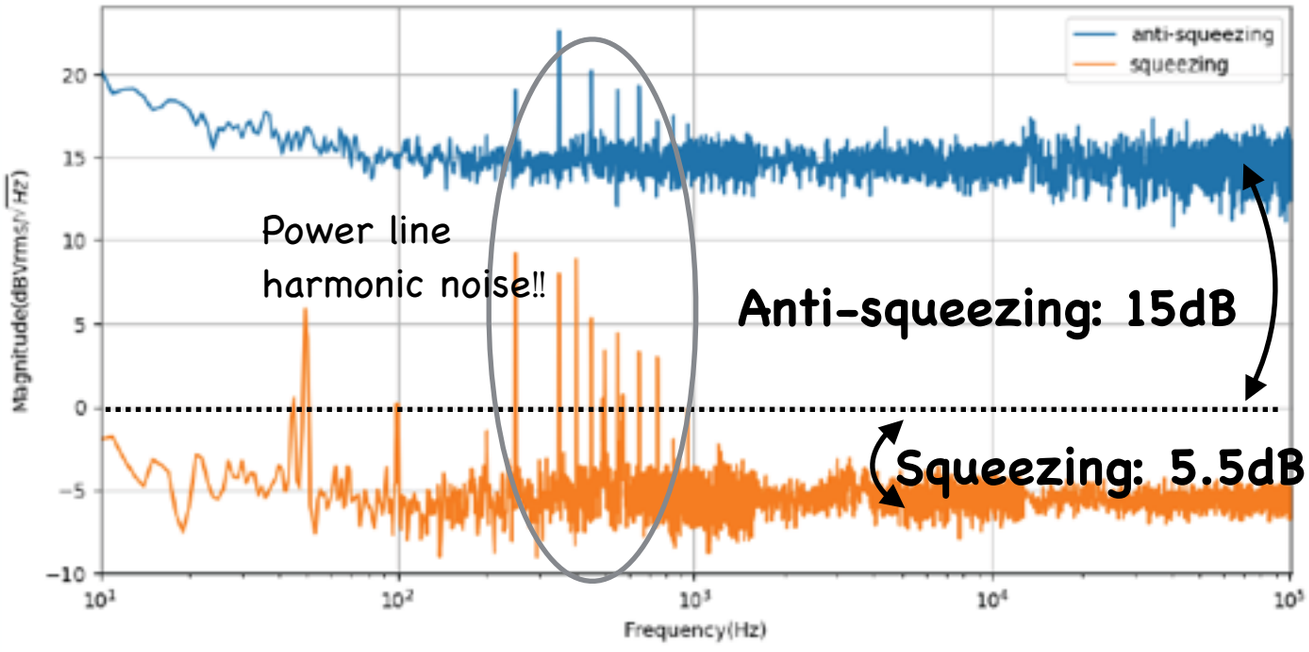
- Squeezed vacuum could be produced through nonlinear interaction process (optical parametric oscillation, OPO).
- Squeezing could be represented as the correlation between upper and lower sidebands.





Experiment situation:

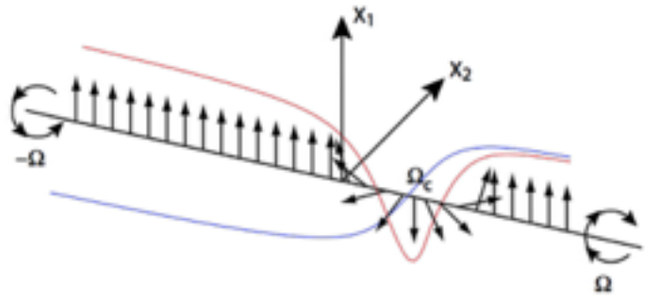
- Pump power: 40mW
- Squeezing level: 5.5dB
- Anti-squeezing level: 15dB

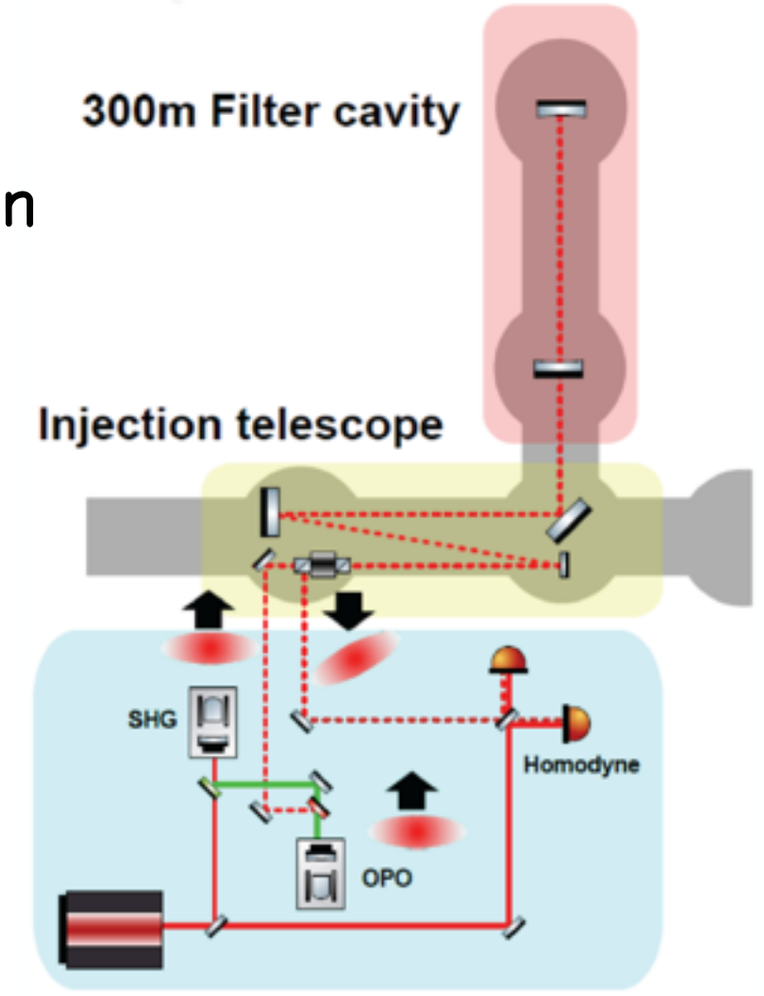


Preliminary Result:

Frequency dependent squeezing

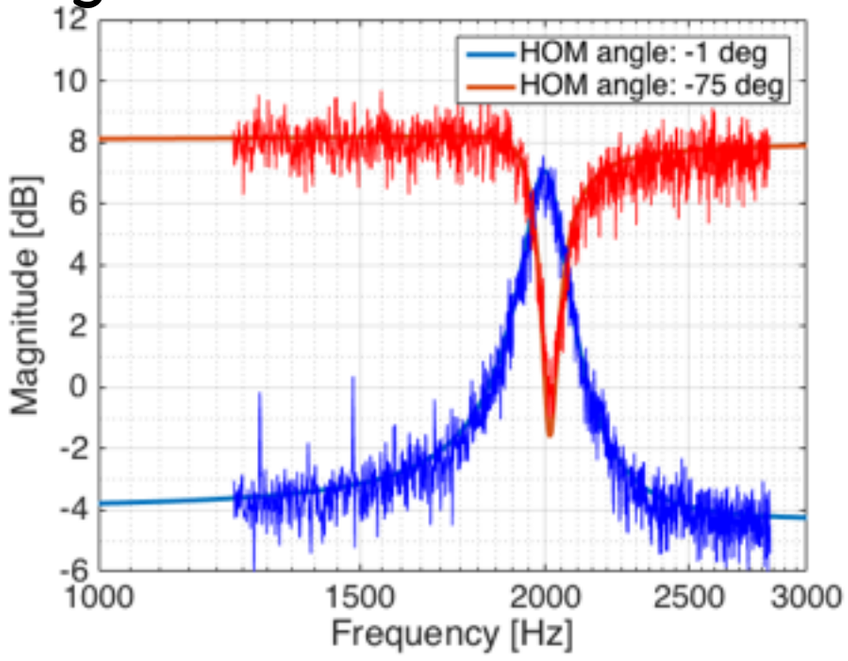
- Filter cavity modified the phase relation between upper and lower sidebands.





- Frequency dependent squeezing could be generated by reflected frequency independent squeezing off a detuned optical cavity.

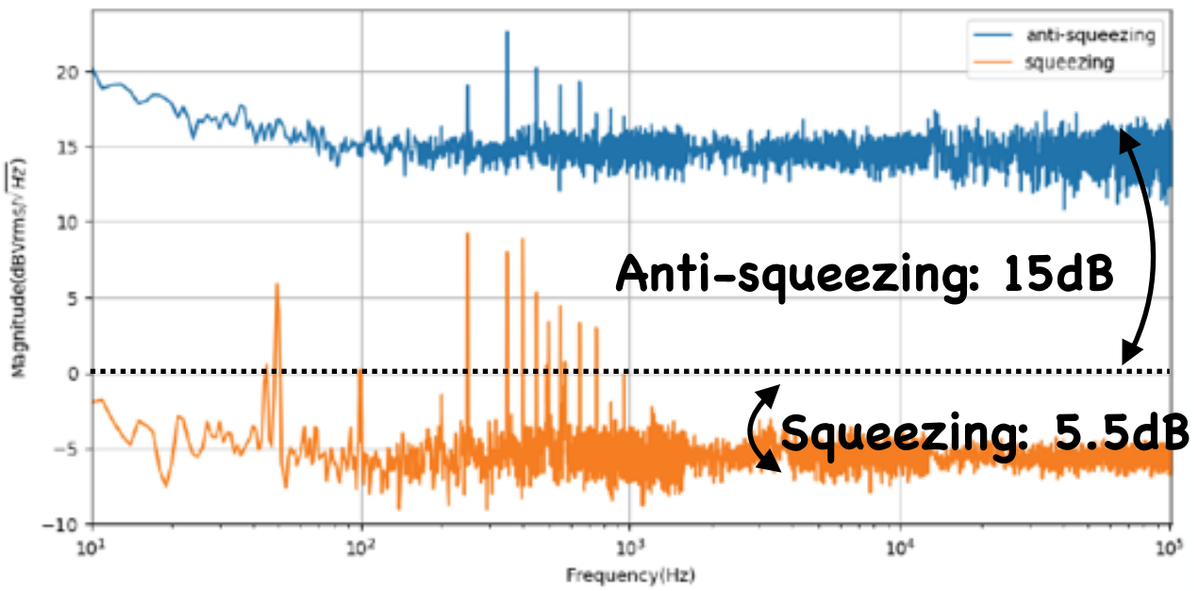
- Measured the frequency dependent squeezing with filter cavity detuning of 2kHz.
  - Red curve showed that the anti-squeezing is rotated to squeezing.
  - Blue curve showed that the squeezing is rotated to anti-squeezing.



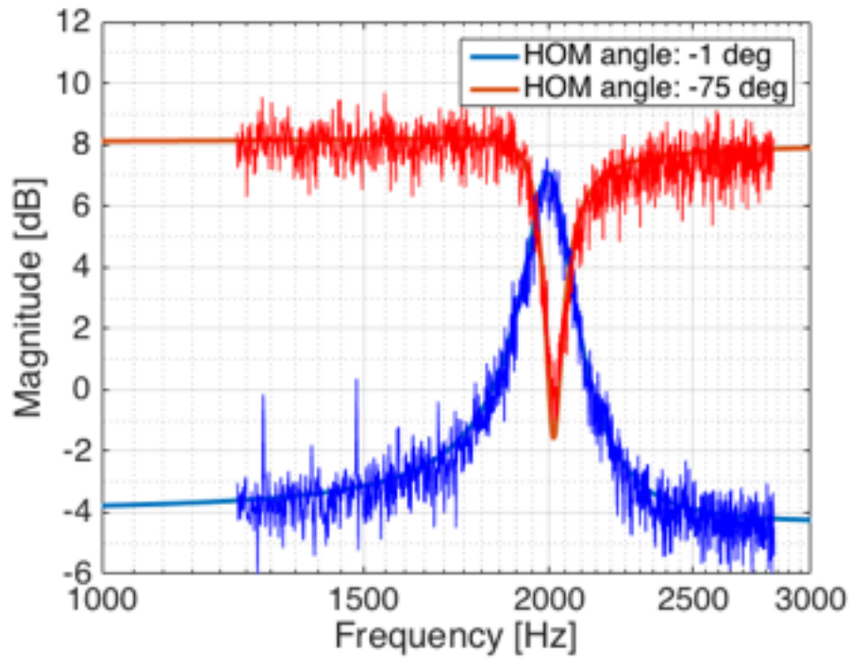
Summary

- We could generated 5.5dB of frequency independent squeezing, which is mainly limited by losses and phase noise.
- Some preliminary result about frequency dependent squeezing with filter cavity.

Frequency independent squeezing



Frequency dependent squeezing



Future Plan

- Improve squeezing match to filter cavity to reduce injection loss.
- Improvement of filter cavity locking accuracy.
- Toward frequency dependent squeezing in low audio-frequency.

Backup Slide

Filter Cavity Design:

Cavity parameter	Design	Real value
Length	300 m	300 m
Mirror diameter	10 cm	10 cm
Input mirror radius of curvature	415 m	438 m
End mirror radius of curvature	415 m	445 m
Input mirror transmissivity (1064 nm)	0.14%	0.136%
End mirror transmissivity (1064 nm)	< 5 ppm	3.9 ppm
Finesse (1064 nm)	4290	4425
Input mirror transmissivity (532 nm)	1.4%	0.7%
End mirror transmissivity (532 nm)	1.4%	2.9%
Finesse (532 nm)	445	172
Beam diameter at waist	1.65 cm	1.68 cm
Beam diameter at the mirrors	2.06 cm	2.01 cm

PRD 98, 022010 (2018)

Optical Bench Design: