Self introduction: what I did in my two postdoc periods

Kentaro Komori

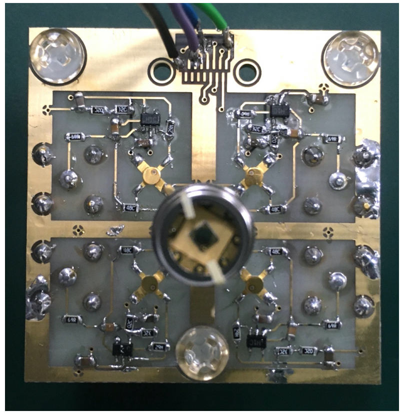
Lab seminar 2022/06/10

Contents

- My previous researches
- Filter cavity experiments in LIGO MIT
- LISA photo-receiver in JAXA
- Future plans

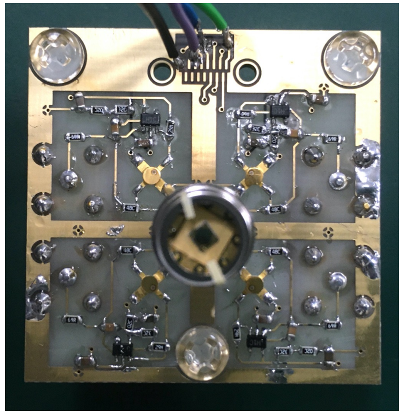
My previous researches

- Graduate students
  - Optomechanical torsion pendulum
  - Calculation of non-equilibrium thermal noise
  - Classical back-action evasion
  - KAGRA future
- First postdoc in LIGO MIT
  - Detuned filter cavity
  - Amplitude filter cavity
  - Optimization of filter cavity parameters
  - Calculation of fundamental limit of feedback cooling
- Second postdoc in JAXA/ISAS
  - LISA photo-receiver
  - SILVIA and DECIGO



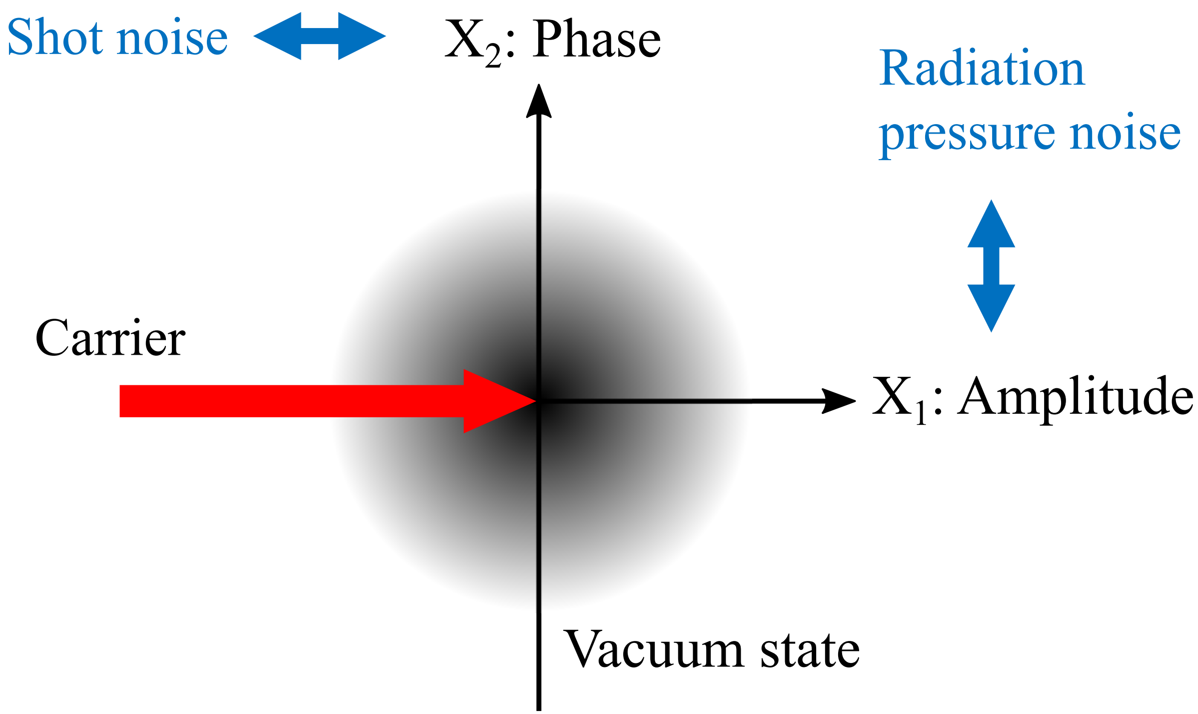
My previous researches

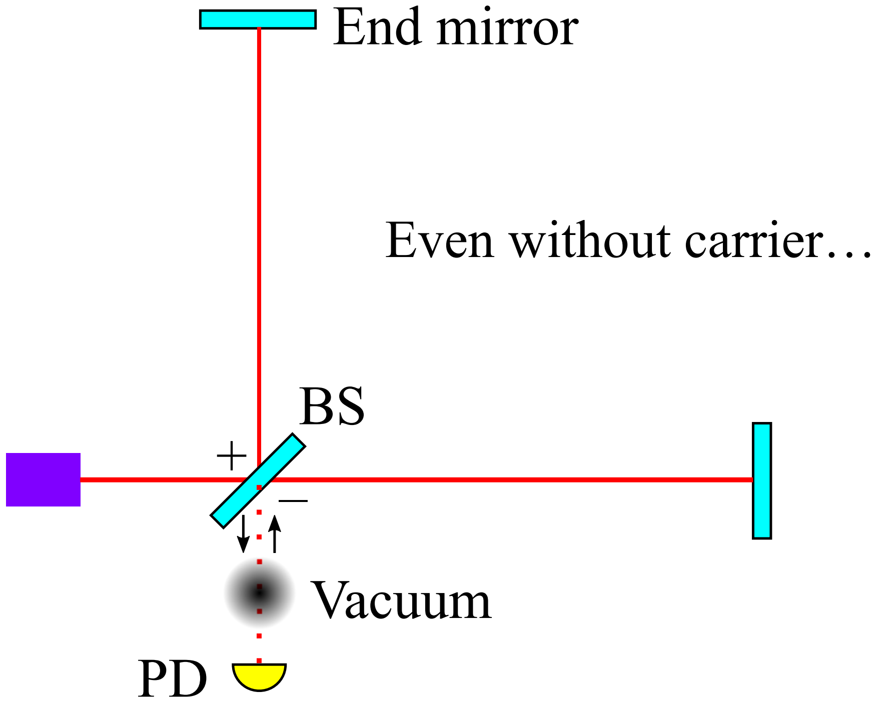
- Graduate students
  - Optomechanical torsion pendulum
  - Calculation of non-equilibrium thermal noise
  - Classical back-action evasion
  - KAGRA future
- First postdoc in LIGO MIT
  - Detuned filter cavity
  - Amplitude filter cavity
  - Optimization of filter cavity parameters
  - Calculation of fundamental limit of feedback cooling
- Second postdoc in JAXA/ISAS
  - LISA photo-receiver
  - SILVIA and DECIGO



Quantum noise

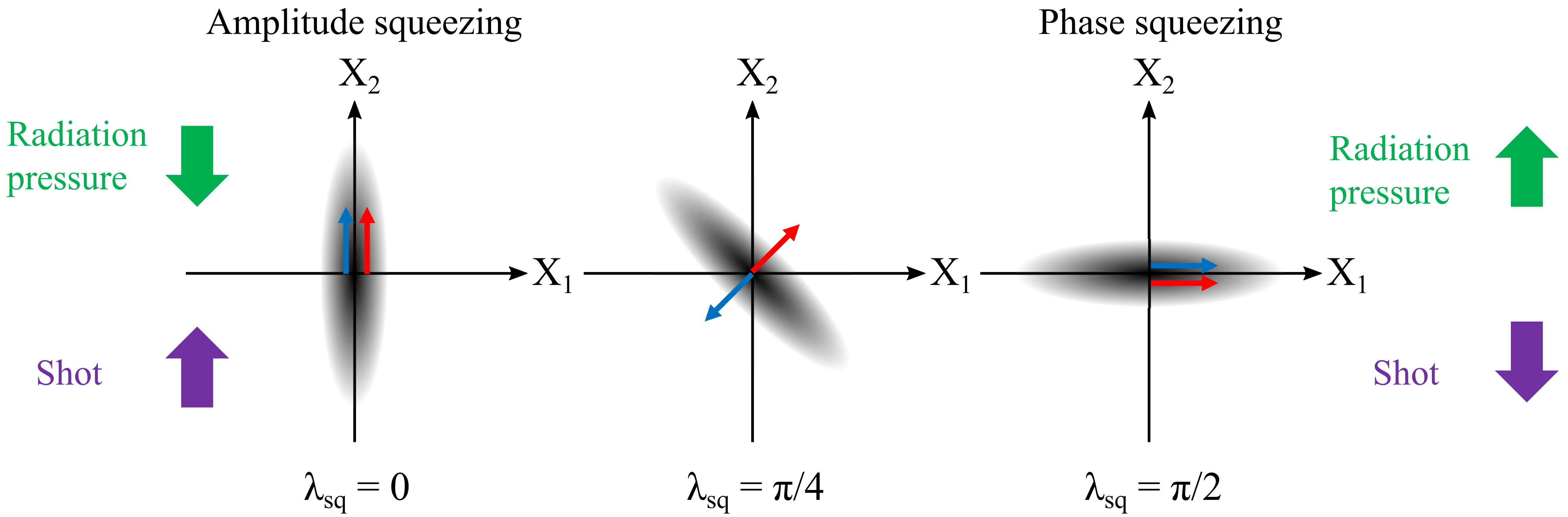
- Vacuum fluctuation coupling with laser light





Squeezing

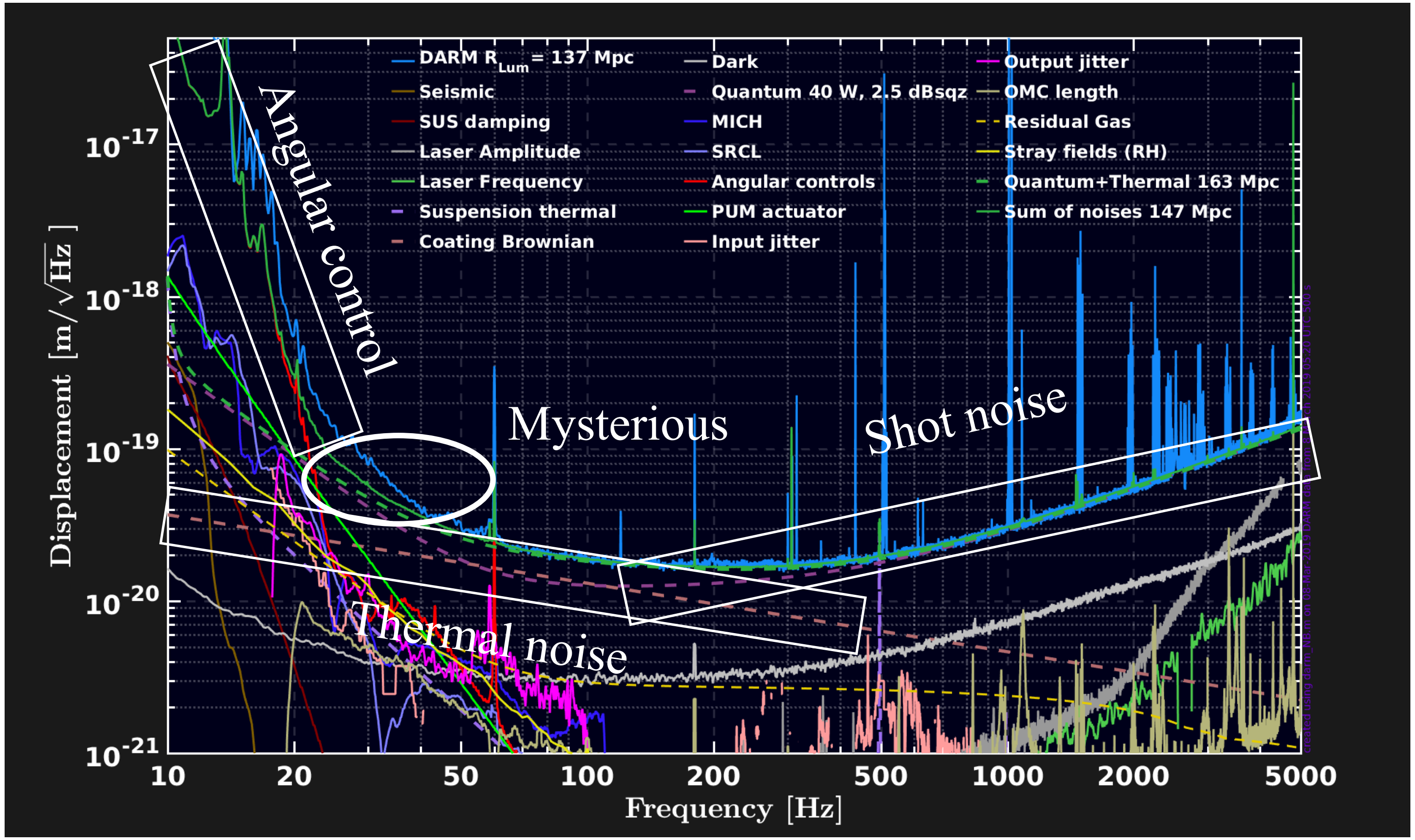
- Reducing the quantum noise by squeezing injection



- Phase squeezing reduces (increases) the shot (radiation pressure) noise at low (high) frequencies

LIGO sensitivity

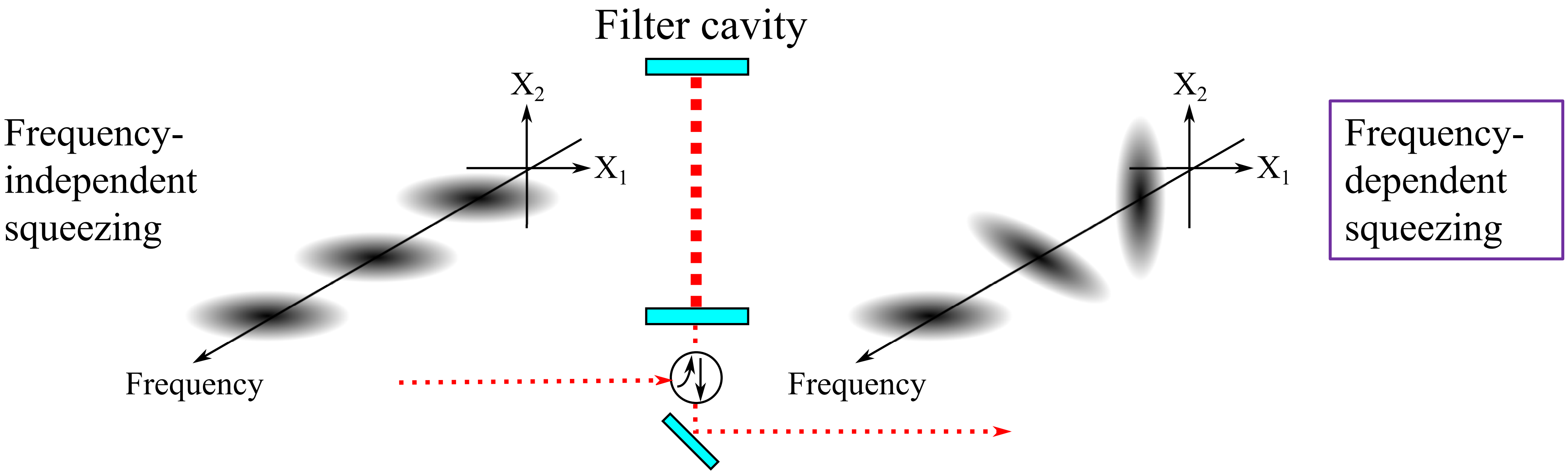
- Three noises mainly limit the sensitivity below 100 Hz
  - Angular control noise
  - Mysterious noise
  - Coating thermal noise
- Shot noise is dominant above 100 Hz
  - The largest squeezing is already not the best
  - Increasing the power or the filter cavity is required



LLO logbook No.44041, typical LIGO sensitivity in O3a

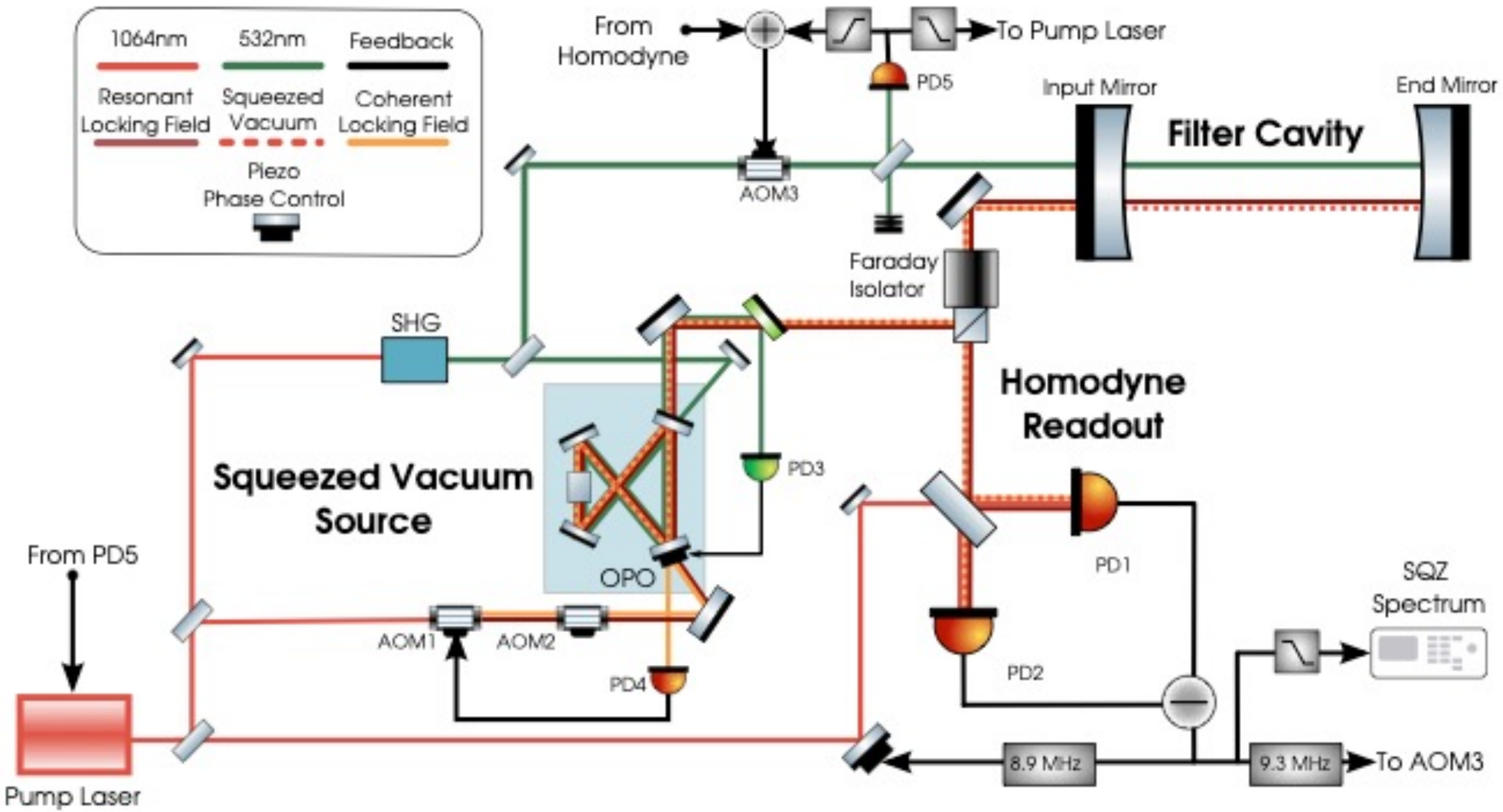
Frequency-dependent squeezing

➢Detuned filter cavity can prepare the optimum squeezed vacuum

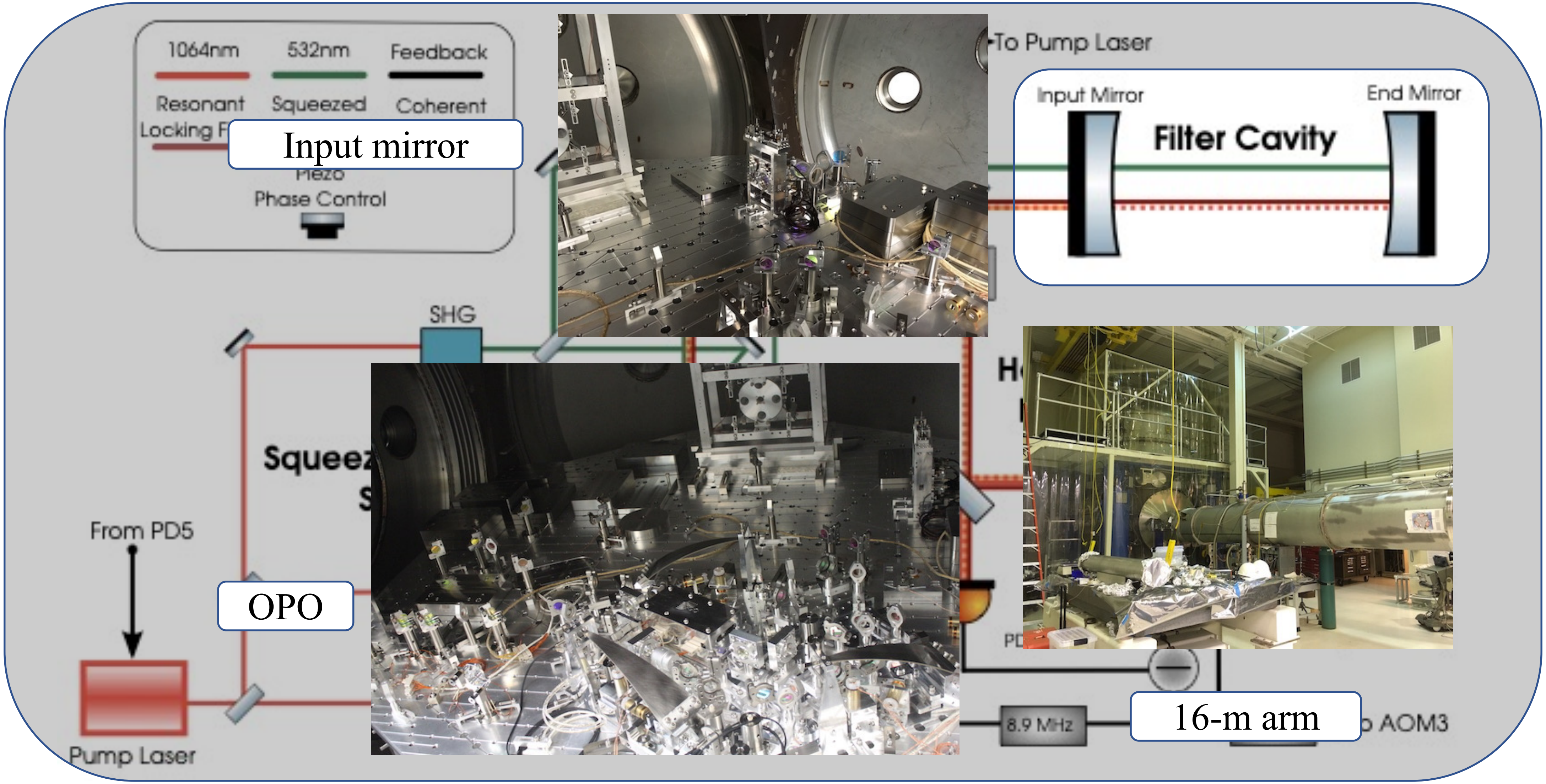


✓ Phase squeezing to reduce the shot noise at low frequencies with amplitude squeezing to reduce the radiation pressure noise simultaneously

Experimental setup

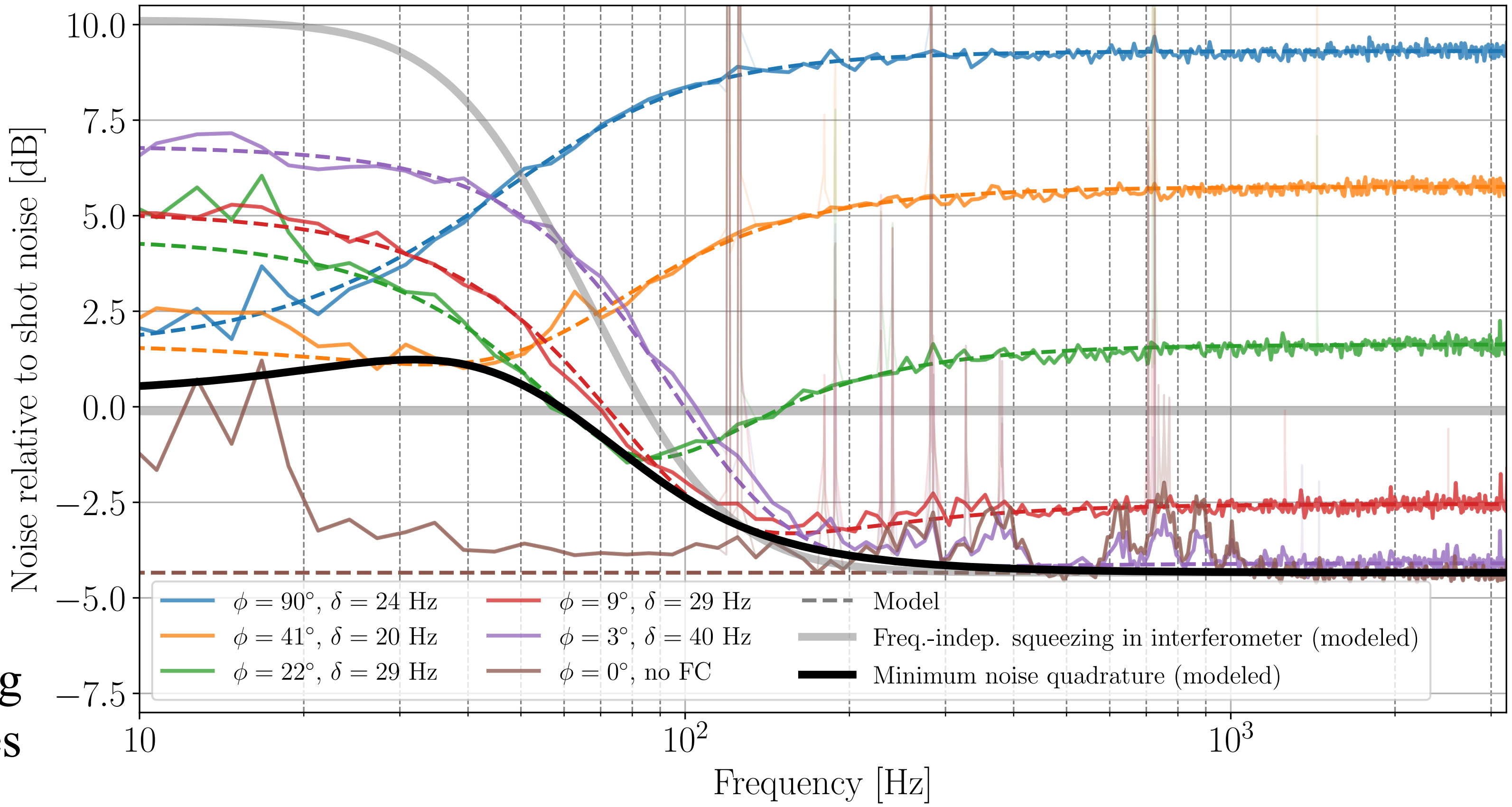


Experimental setup



Result

➢Squeezed angle rotates around the targeted frequency below 100 Hz

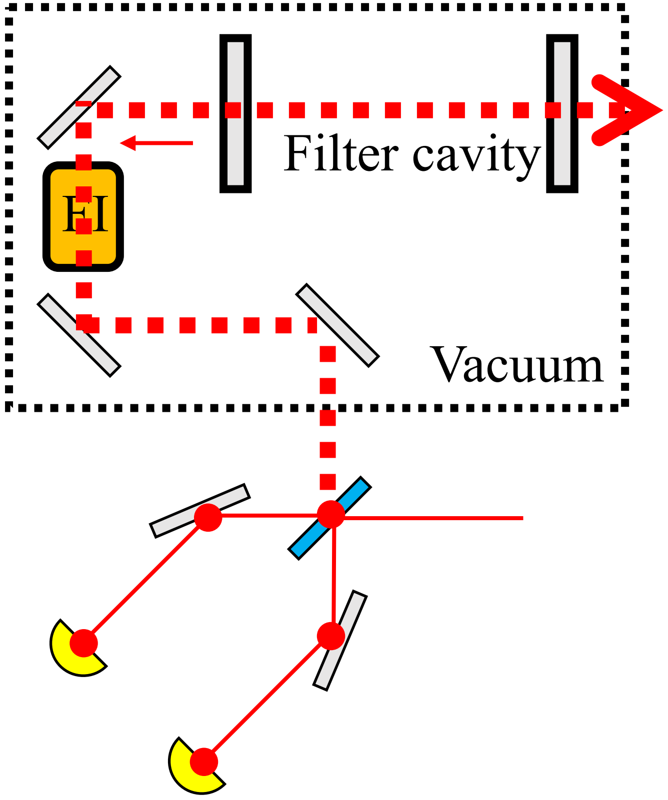


✓ Different colors correspond to each squeezing angle

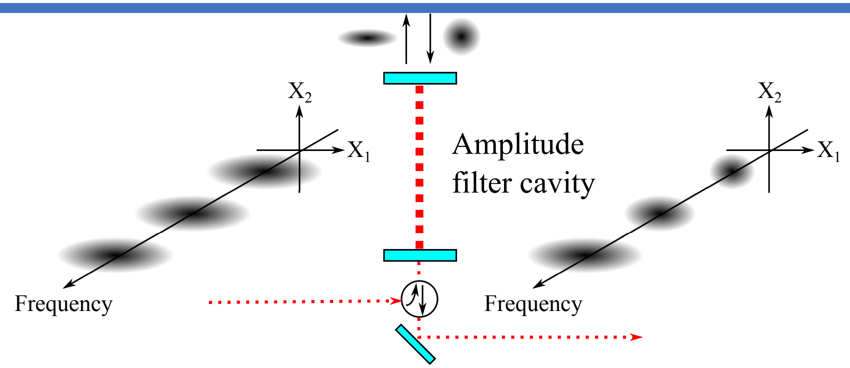
✓ Optical loss in the FC and the detuning fluctuation degrades the squeezing level at low frequencies

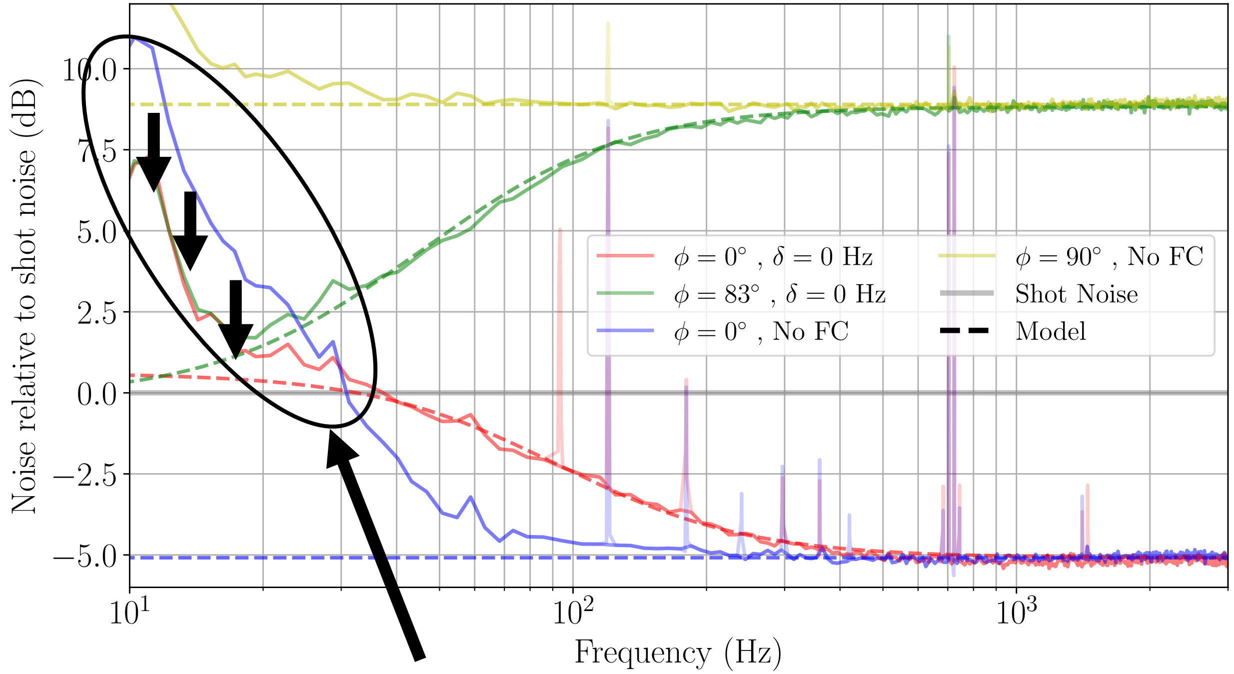
Interesting discussion

➢Scattered light also degrades the squeezing level



Scattering point candidates





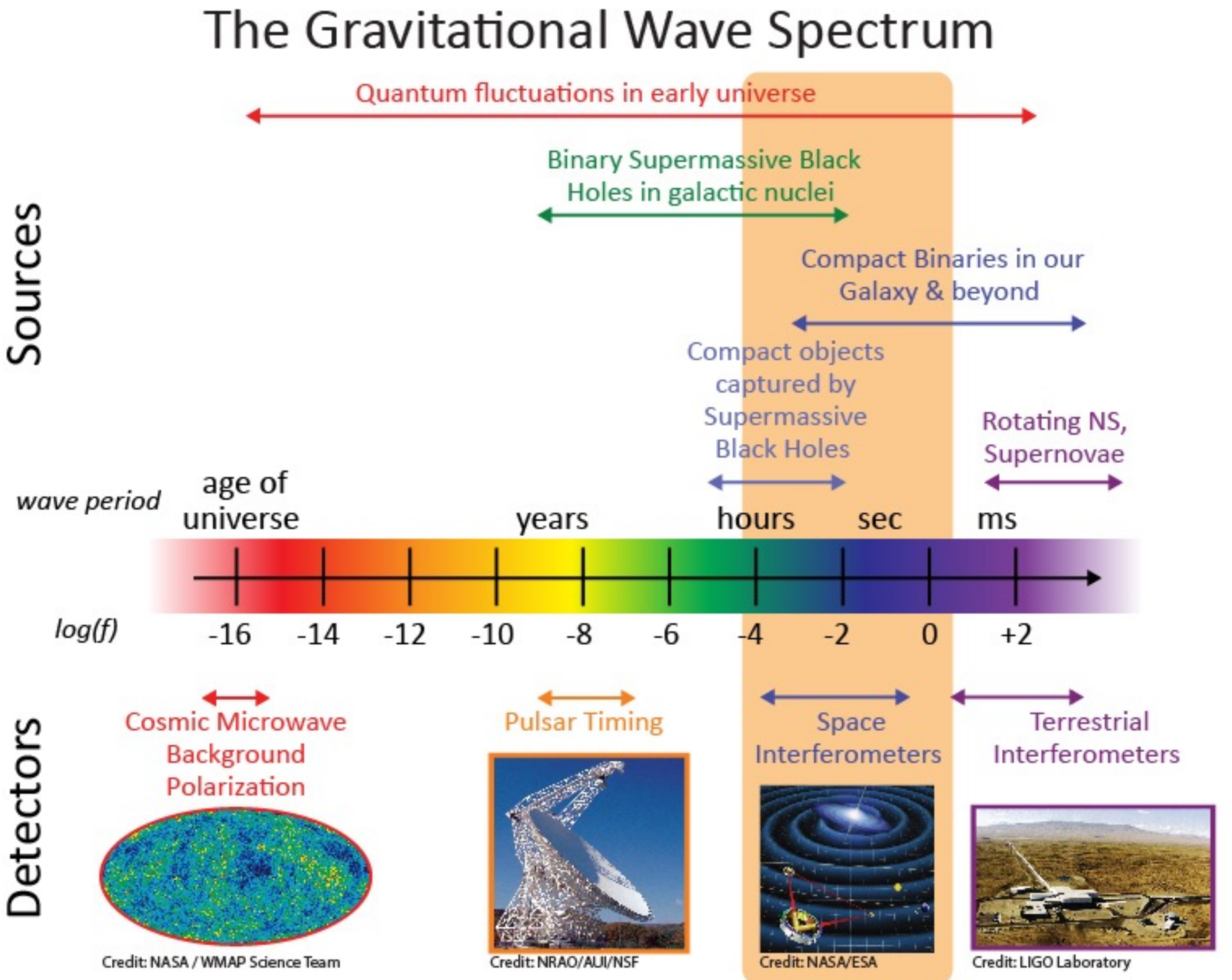
✓ Back scattering is eaten by the amplitude filter cavity

Multi-wave-length GW

➢ Evolution of astronomy and astrophysics with multi-wave-length GW observation
  - History of cosmic structure
  - Origin of super massive BHs
  - More precise test of GR

⇩

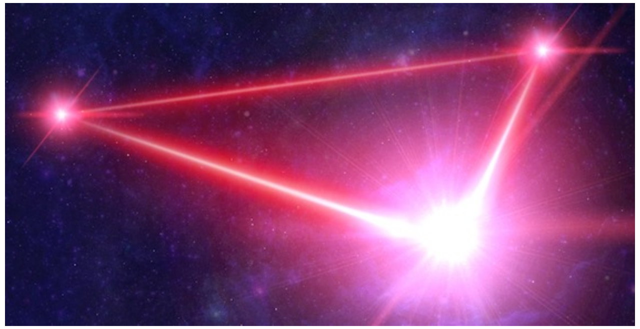
GW from massive BHs at low frequencies



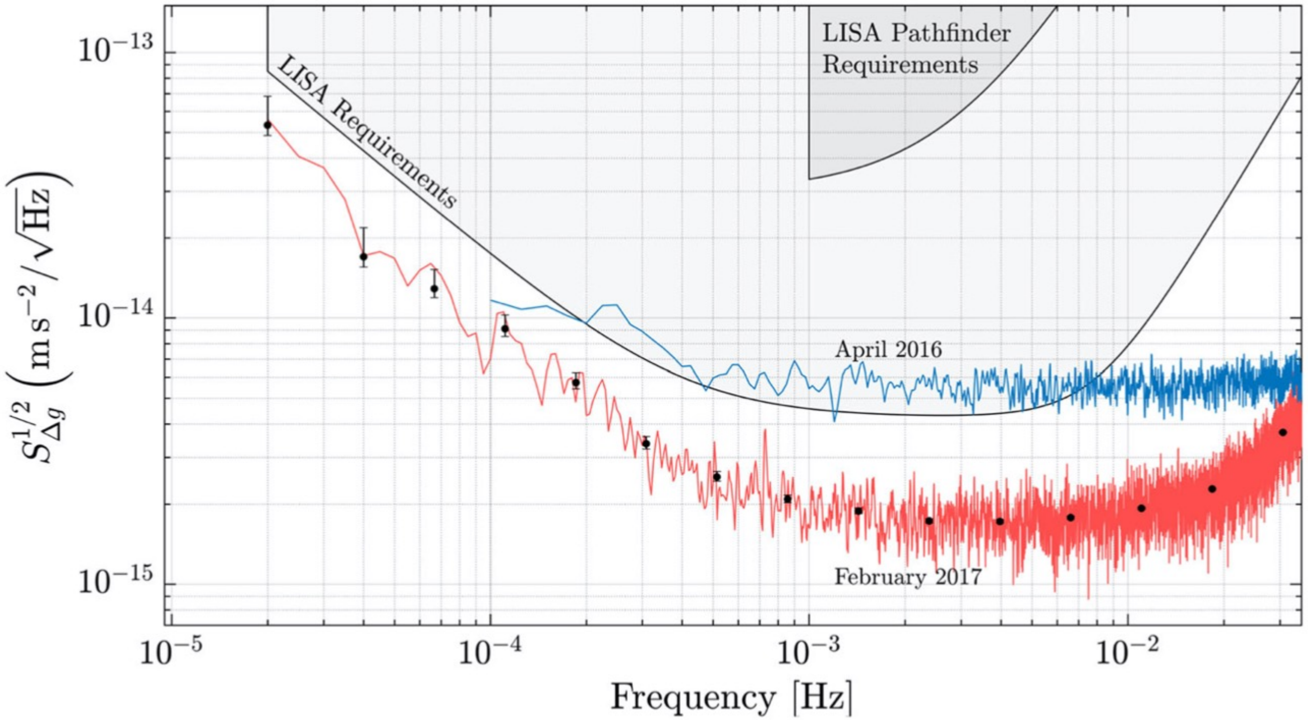
Credit: NASA

LISA

- Laser Interferometer Space Antenna
  - 3 space crafts (SCs), 2.5 million km
  - GW observation around mHz
  - Plan to be launched in 2034



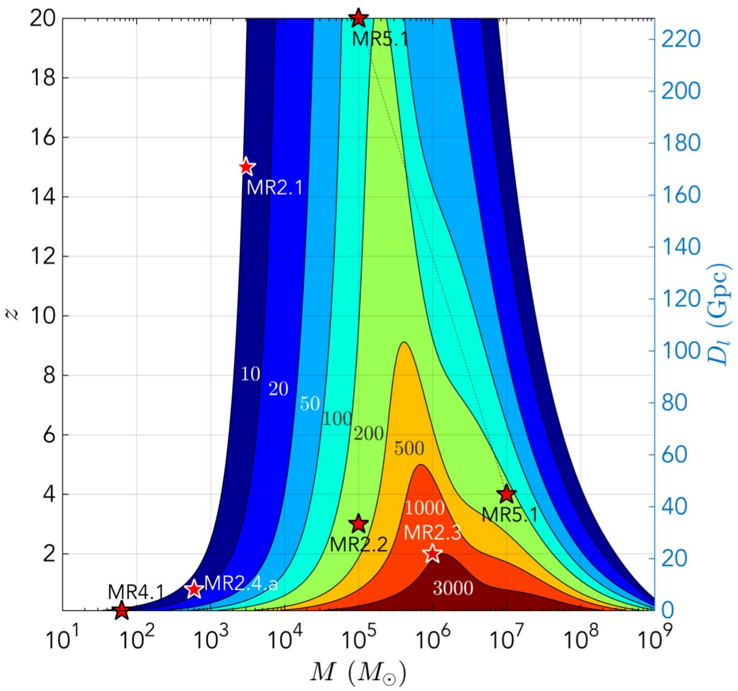
- Success in LISA PathFinder
  - Launched in 2016
  - Sub-femto-g acceleration noise around mHz

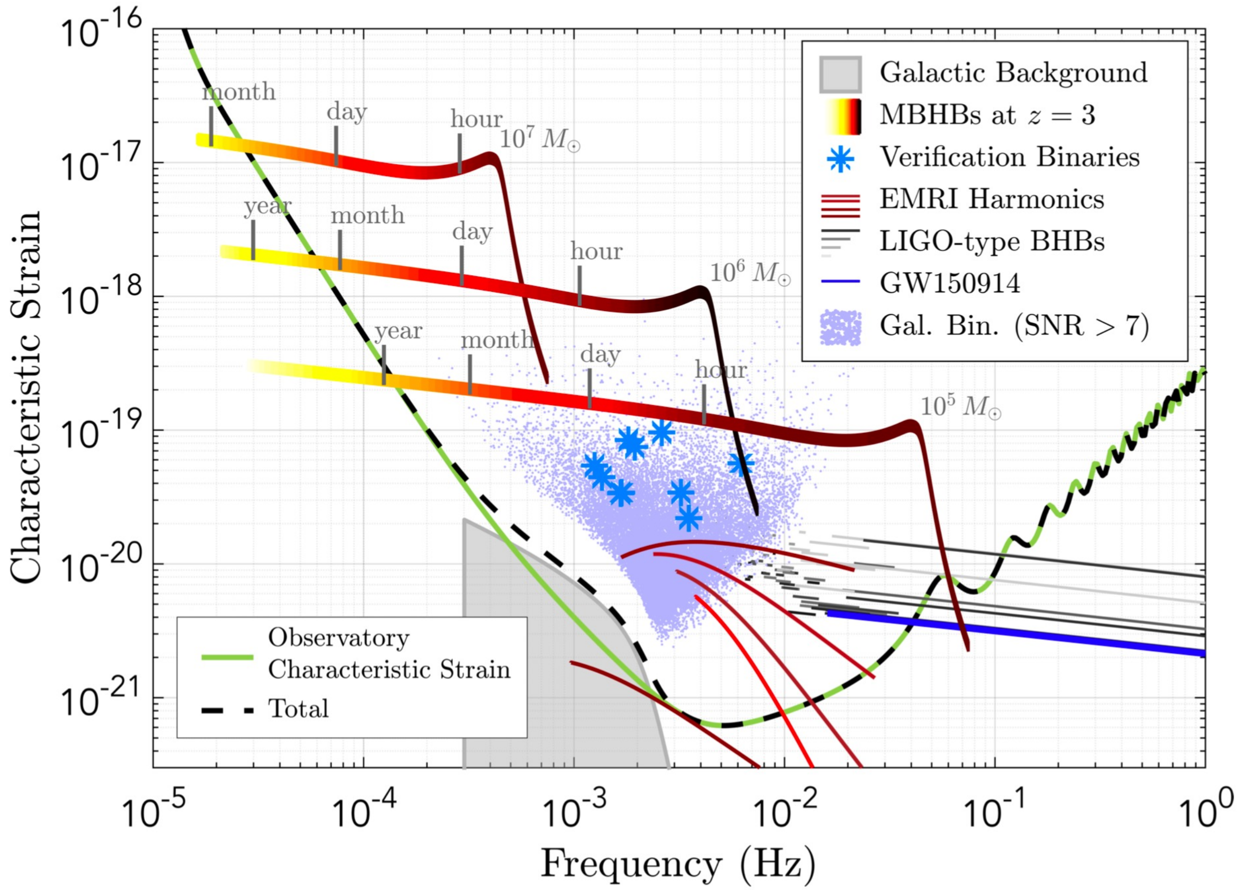


PRL 120, 061101 (2018)

Scientific targets

- ➢BBH $10^4 \sim 10^7\ M_\odot$ beyond the first star era
- ➢Tracing the origin, growth, and merger history of massive BHs
- ➢White dwarf binaries in our galaxy





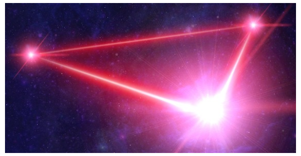
LISA proposal

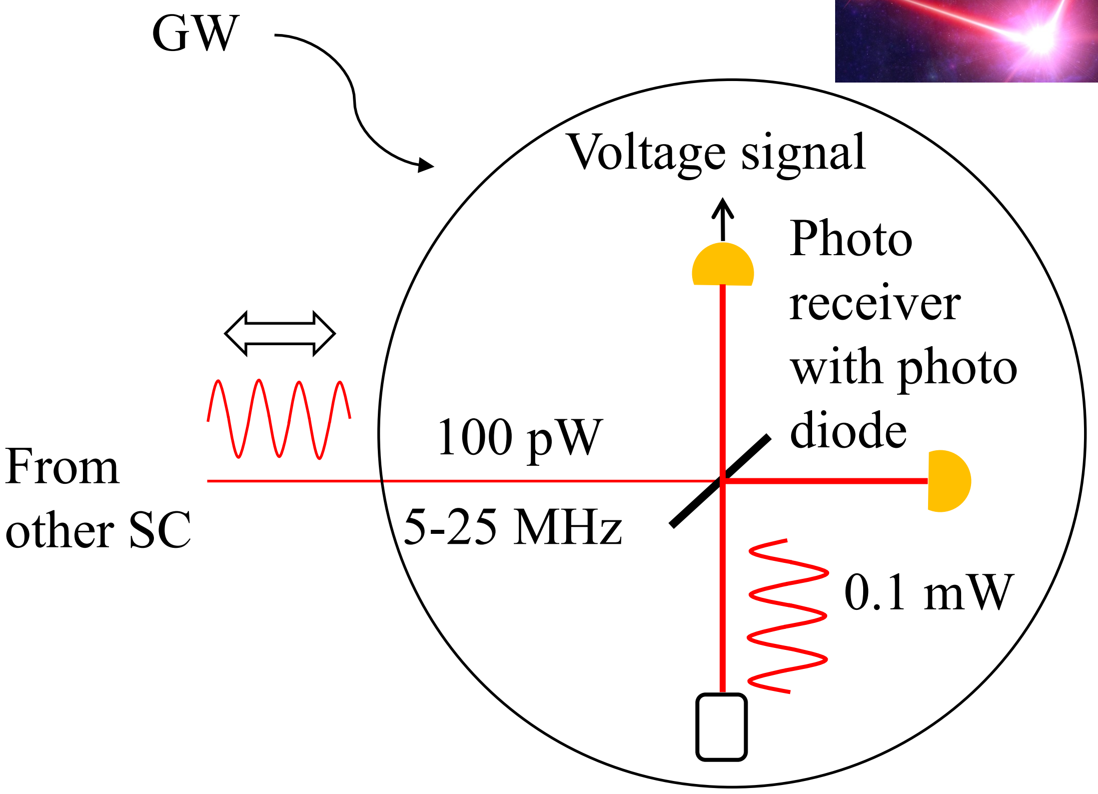
How to measure GWs in LISA

- Phase fluctuation of laser light
  - Caused by GWs between SCs

- Heterodyne measurement
  - Doppler shift because of non-zero relative speed of SCs (100 m/s -> 10 MHz)
  - Measurement of the beat frequency of 5-25 MHz
  - Conversion of photo current to voltage signal

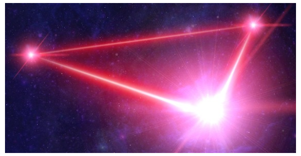
- 10-100 pW from other SCs
  - Diffraction loss through 2.5 Gm



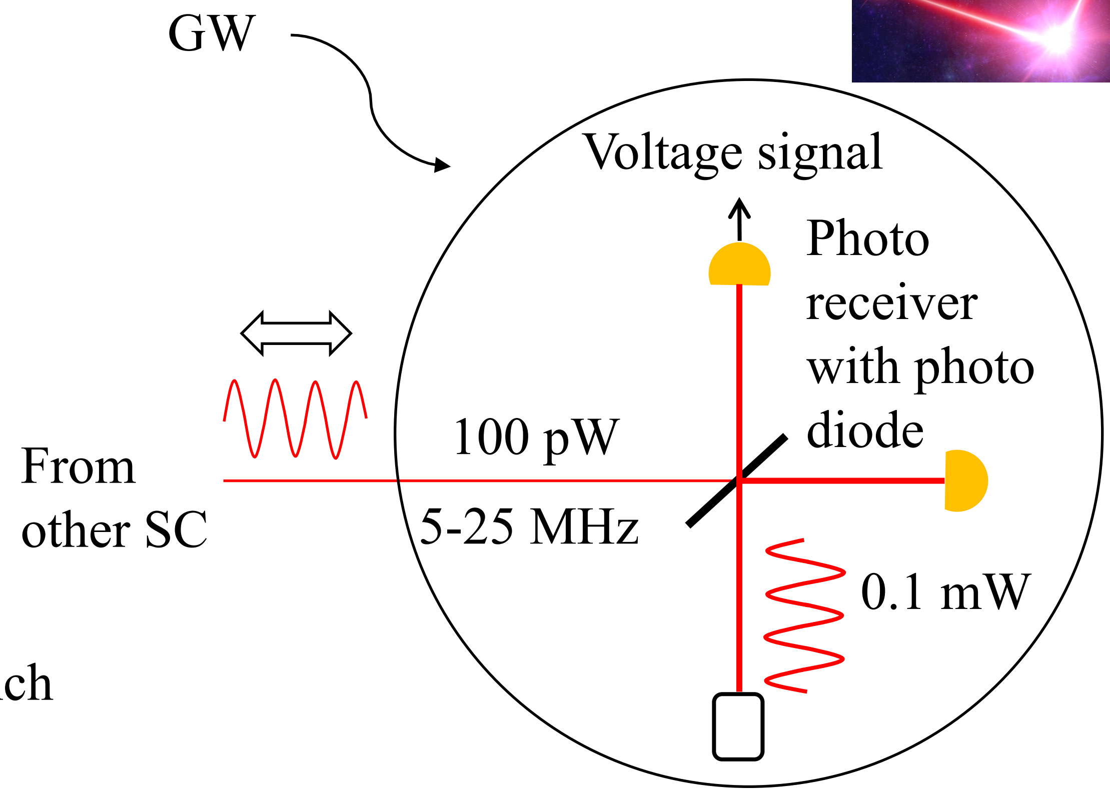


Laser source
- Nd:YAG
- 1064 nm ~ 282 THz (NIR)

Requirements on the photo receiver



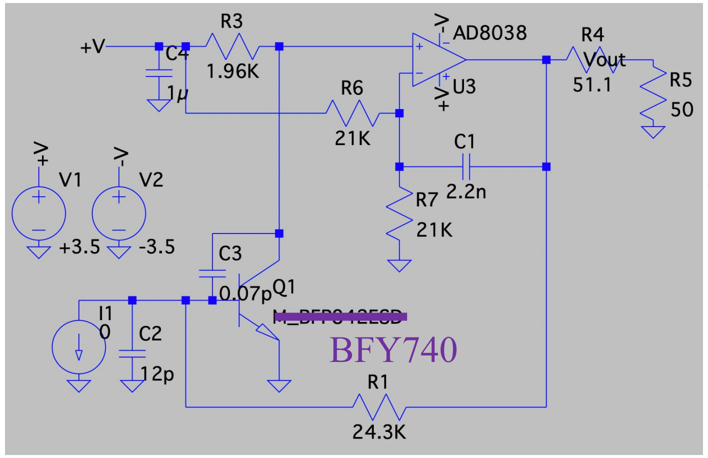
- High bandwidth
  - Constant gain at 5-25 MHz
- Low noise
  - Below shot noise of 0.1 mW (5 pA/√Hz) at 5-25 MHz : 2 pA/√Hz
  - Junction capacitance ~ 10 pF with φ > 1 mm PD
- Low power consumption
  - Suppressing thermal fluctuation of the optical bench
- Compactness
  - Size of the circuit board < 40 mm * 40 mm



Laser source
- Nd:YAG
- 1064 nm ~ 282 THz (NIR)

Setup

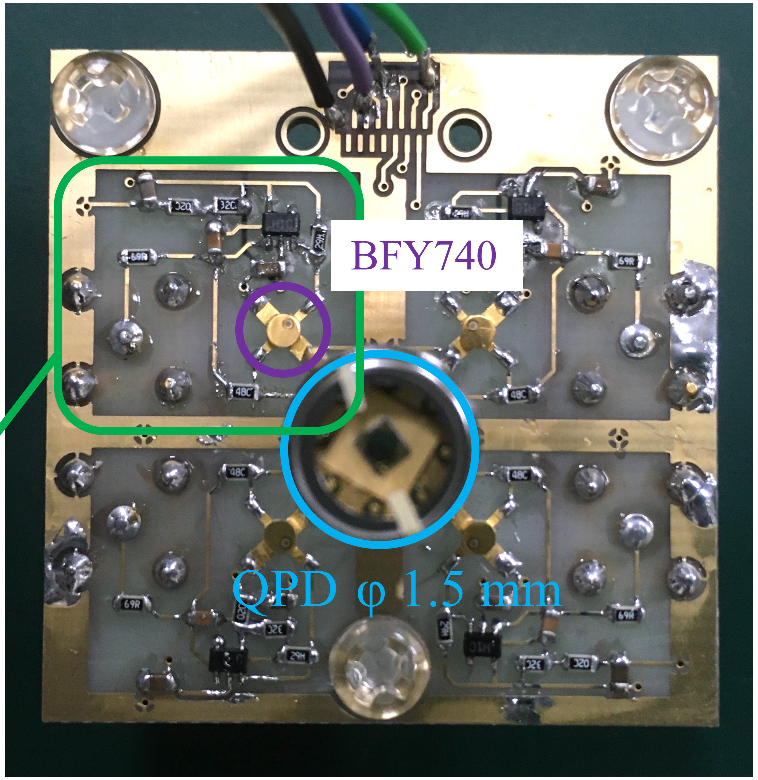
Filter to suppress RF noise



Power supply

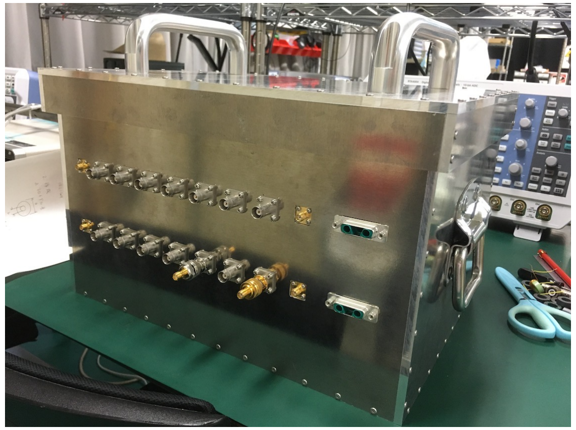
36 mm

36 mm



Power consumption 12 mW/ch

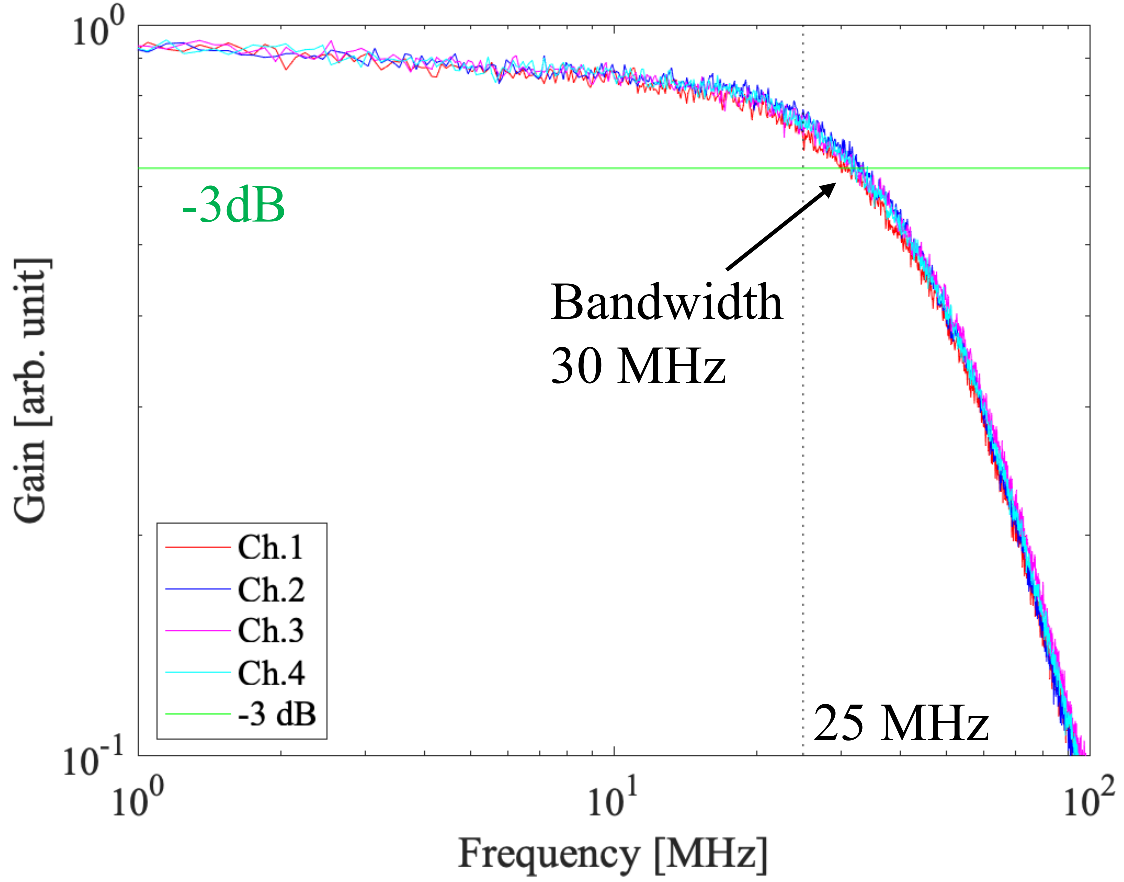
Box to shield EMs

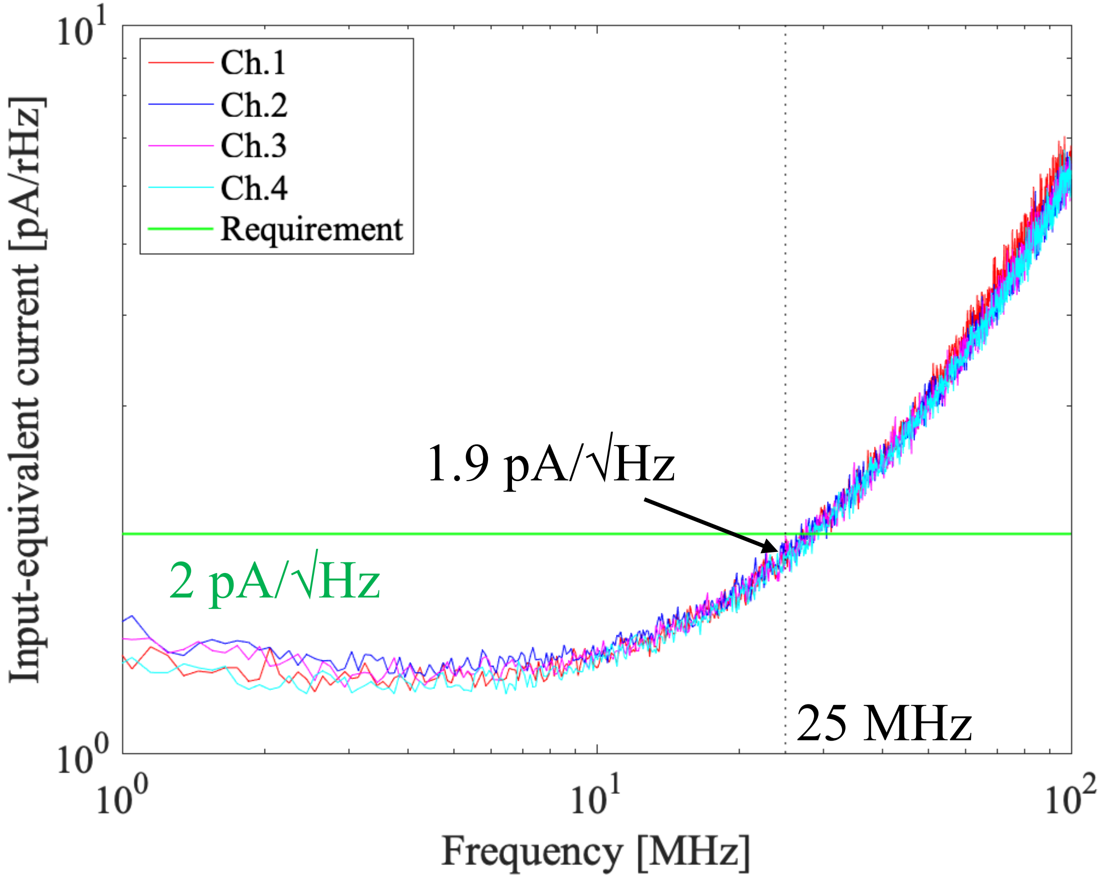


R&S spectrum analyzer with the floor noise of ~1 nV/√Hz

Results

➢Measurement of 4 channels





Results

	Requirement	This work
Bandwidth (-3 dB)	25 MHz	30 MHz
Input equivalent noise	< 2 pA/√Hz	1.9 pA/√Hz
PD size	> φ 1 mm	1.5 mm
Power consumption	< 50 mW/ch	12 mW/ch
Circuit board size	< 40 mm * 40 mm	36 mm * 36 mm

➤Our photo receiver with space-based transistors satisfies all requirements

Future plans

- Long signal recycling cavity
  - Demonstration of the signal enhancement

- Ground state cooling of a sub-mg pillar
  - Resolved sideband regime (good cavity) with our familiar configuration

- Optomechanical torsion pendulum

- Test of CSL model using a violin mode of a thin wire

Summary

- Filter cavity experiments
  - Demonstration of the frequency-dependent squeezing

- LISA photo-receiver
  - Satisfying the requirements

- Future