Development of the signal amplification system using a nonlinear optical effect for the next generation gravitational wave detector

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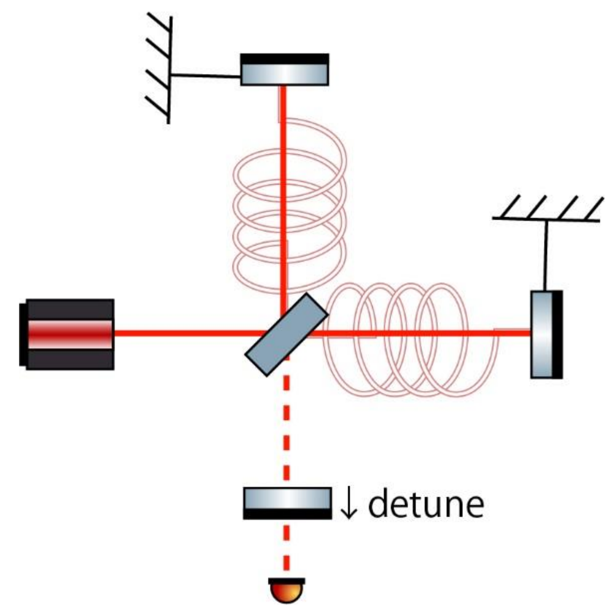
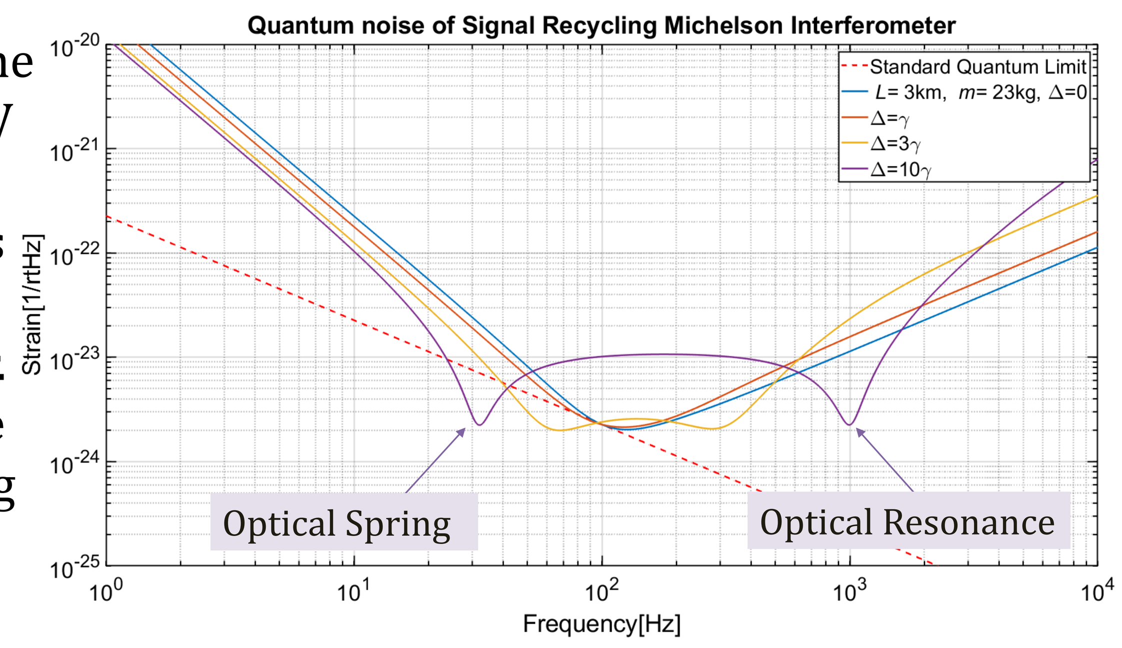
INTRODUCTION

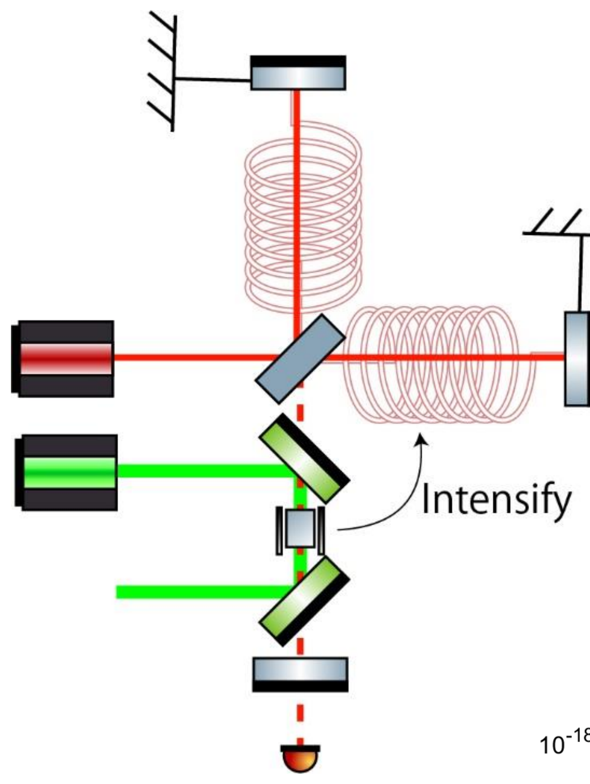


We focus on ~kHz Gravitational Wave (GW) (Supernova, binary neutron star merger, etc.) detector by using optical spring.

Optical spring can be made by detuning Signal Recycling Cavity (SRC) or Sideband Extraction Cavity. When detuning Δ larger than cavity pole γ, optical spring and optical resonance are appear and amplify GW signal.

A resonance frequency of the optical spring of currently GW detectors is about under 100Hz. If we use light mirrors or a high power laser, the optical spring becomes stiffer. But light mirror degrades the whole sensitivity, and creating high power lasers is difficult and causes several problems. (parametric instability etc.)

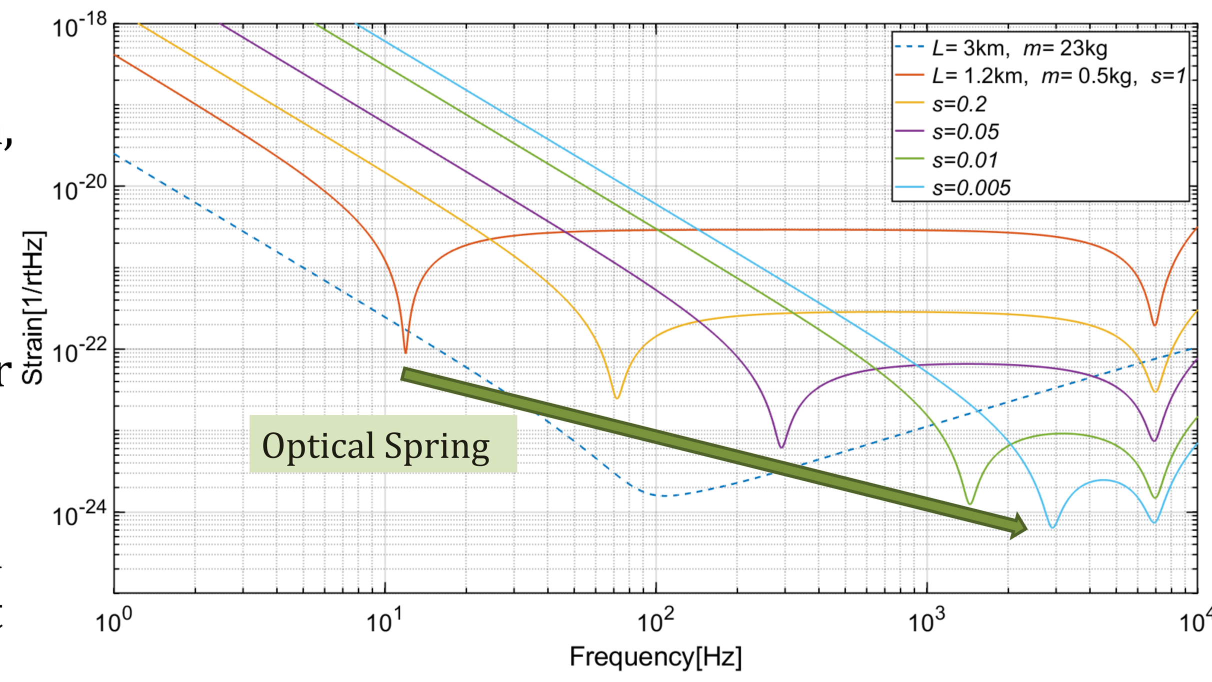




If we use intra-cavity squeezing by Optical Parametric Amplification (OPA), we can intensify the optical spring without causing any problems.

Intra-cavity squeezing can enhance peak sensitivity without reducing bandwidth. When the signal recycling cavity strong detuned, we can make **stiffer optical spring by a signal amplification process of OPA** without changing the optical resonance frequency.

With this configuration, we can realize the GW detector that has better sensitivity at ~kHz band than KAGRA-like detector even use GEO-like parameters. The performance in this band is comparable to the next generation GW detector.



About SRMI

Our target is to do experimental verification about the interaction between internal squeezing and optomechanical effects.

Direct measurement of quantum noise that needs to reach the Standard Quantum Limit is extremely difficult. It is relatively easy to observe intensify of the optical spring and verify the sensitivity improvement indirectly.

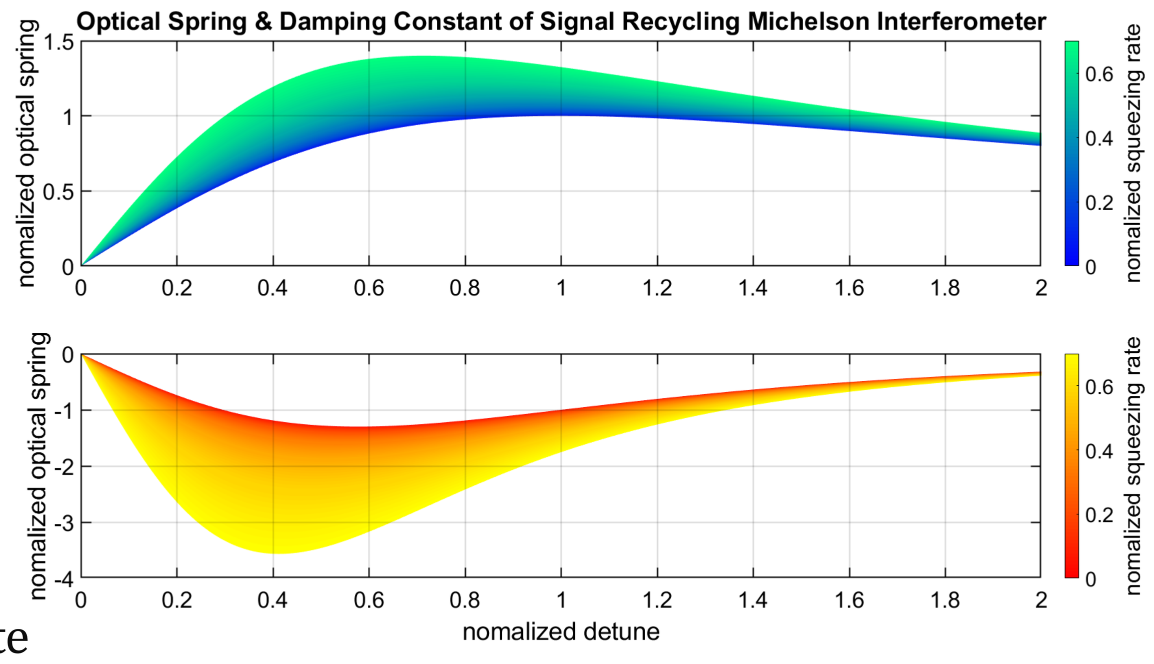
The optical spring of the Signal Recycling Michelson Interferometer (SRMI) is purely enhanced by a signal amplification process of OPA.

$$k_{\mathrm{opt}} \propto \frac{2\delta}{1+\delta^2-\sigma^2}$$

$$\Gamma_{\mathrm{opt}} \propto \frac{4\delta}{(1+\delta^2-\sigma^2)^2}$$

δ :normalized detune

σ :normalized squeezing rate



About FPC

The optical spring of SRMI that proportional to finesse is soft and difficult to observe and handle. ~µg scale test mass is required to constrain the oscillator dominantly with it.

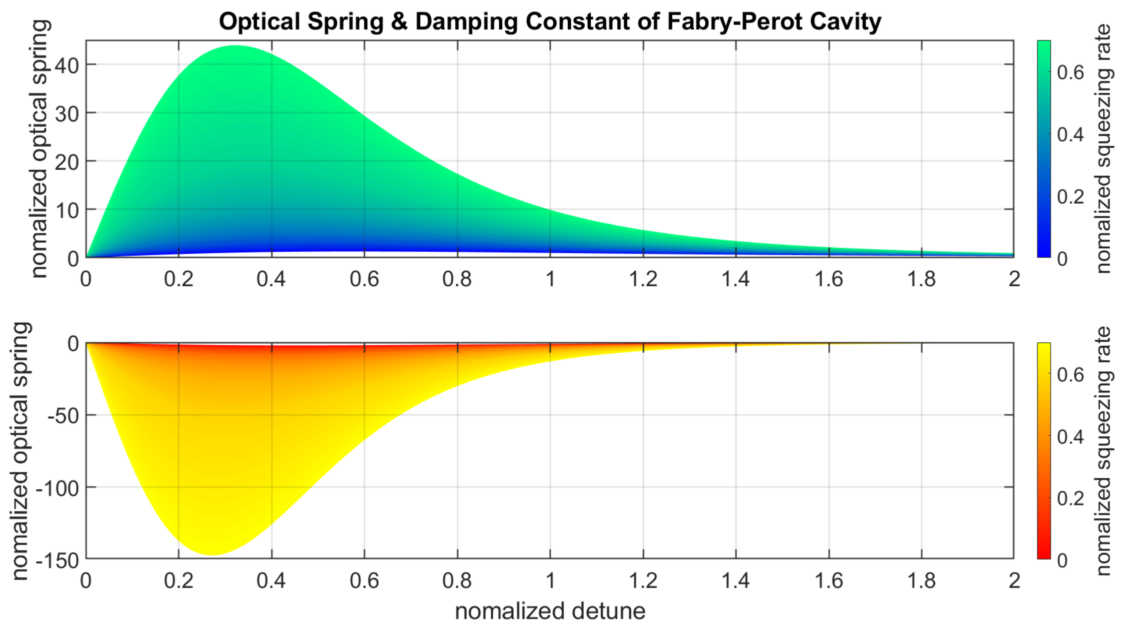
The optical spring of Fabry-Perot Cavity (FPC) that proportional to finesse squared is enough stiff, but OPA in the FPC changes not only the signal amplification process but also intra-cavity power and effective squeezing angle.

We can do experiments equivalent to that by SRMI by appropriately measuring and normalizing these effects. But this idea can only be applied to about optical spring, SRMI is essential to confirm the signal amplification process.

intra-cavity power

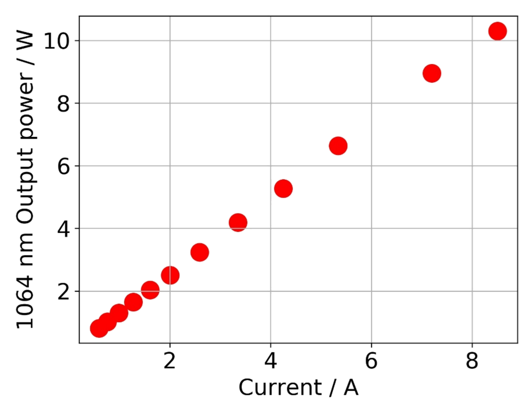
$$k_{\mathrm{opt}} \propto \frac{2(1+\delta^2+4\sigma+\sigma^2)}{(1+\delta^2-\sigma^2)^2} \times \frac{2\delta+4\sigma\frac{(1+\sigma)\delta}{(1+\sigma)^2+\delta^2}}{1+\delta^2-\sigma^2}$$

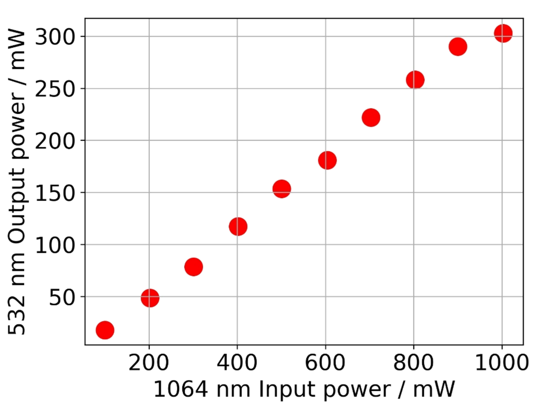
effective squeezing angle

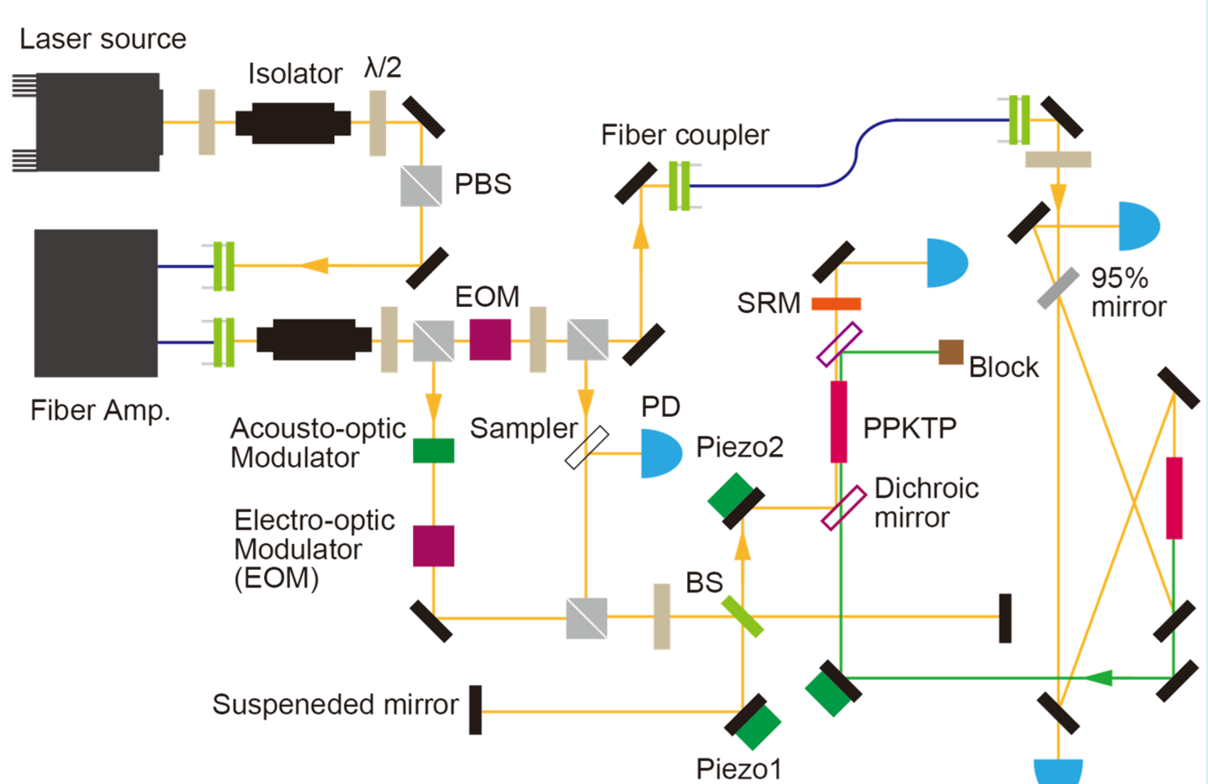


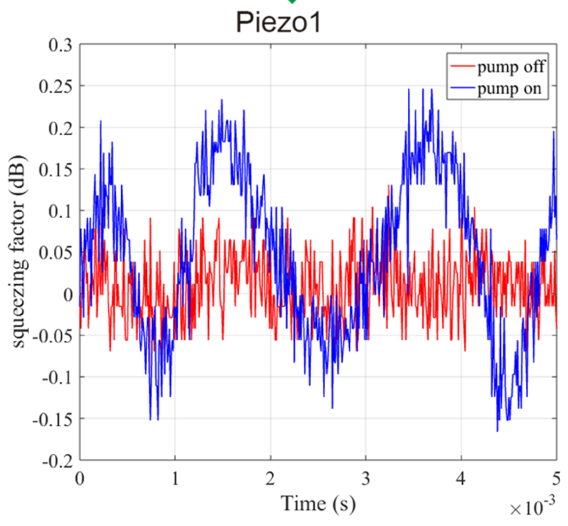
SRMI Experiment

We are doing both SRMI and FPC experiments.





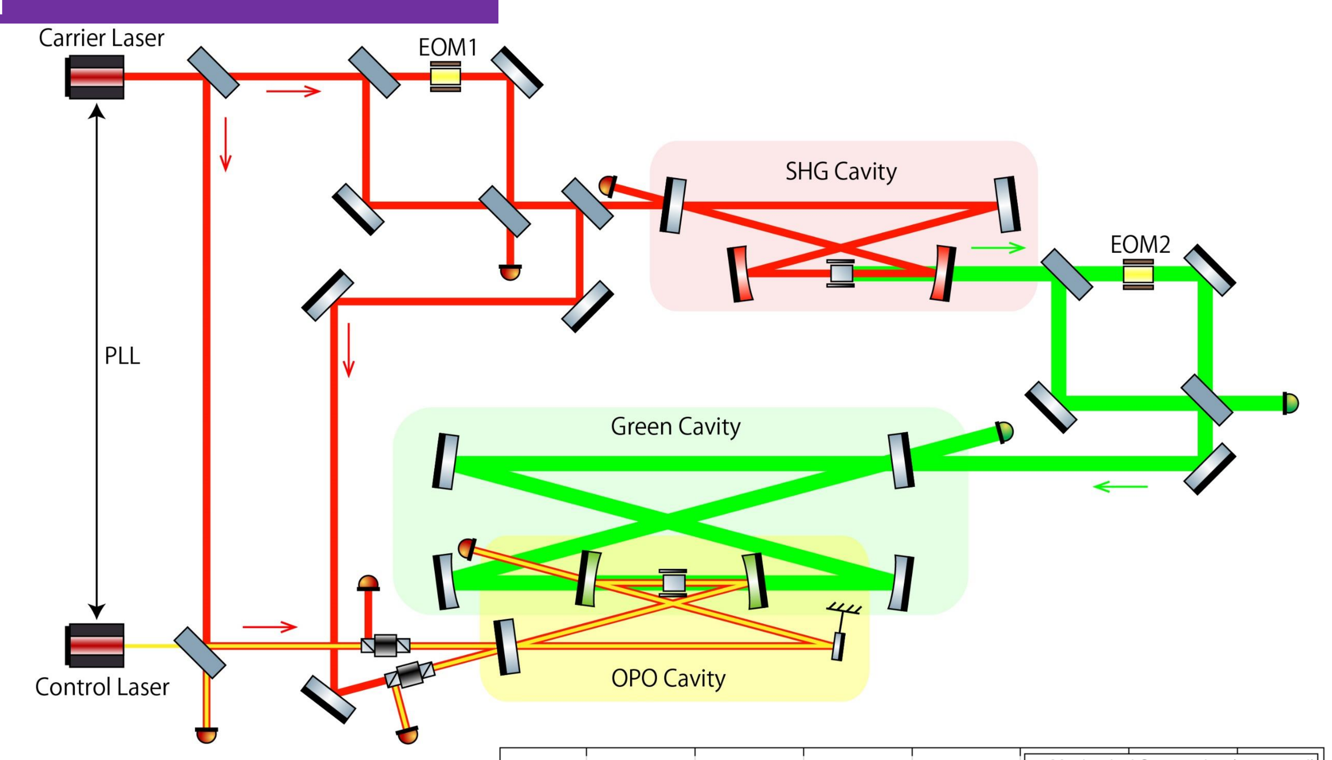




➢ What we did
- High power green source by fiber Amp
- Single pass OPA
- SRMI locked with subcarrier

➢ What we will do
- Observe optical spring of SRMI
- OPA lock with RF sidebands

FPC Experiment



➢ What we did
- Optical spring was observed
- Remade suspension made by BeCu
- Phase Locking Loop (PLL) succeed

➢ What we will do
- Construct each cavity