Parametric signal amplification for a high-frequency gravitational-wave detector

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Outline

Introduction

Optical spring
Parametric signal amplification

Experimental setup at Tokyo Tech.

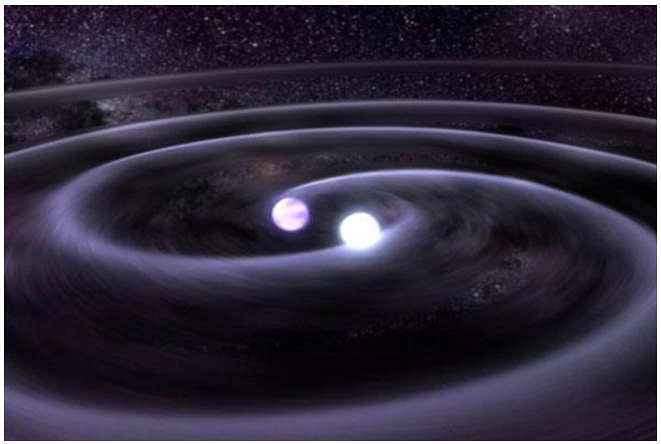
Result

Summary

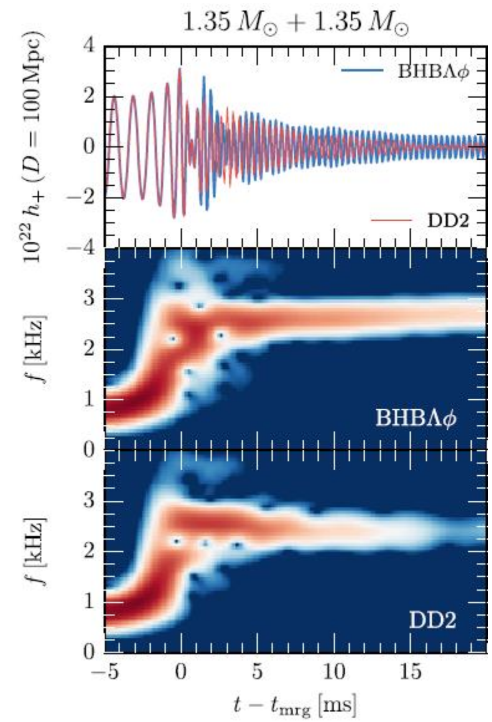
Gravitational Wave

GW sources in a few kHz band

→ binary neutron star merger, supernova, etc.



Artist's illustration of the final stages of a neutron-star merger.



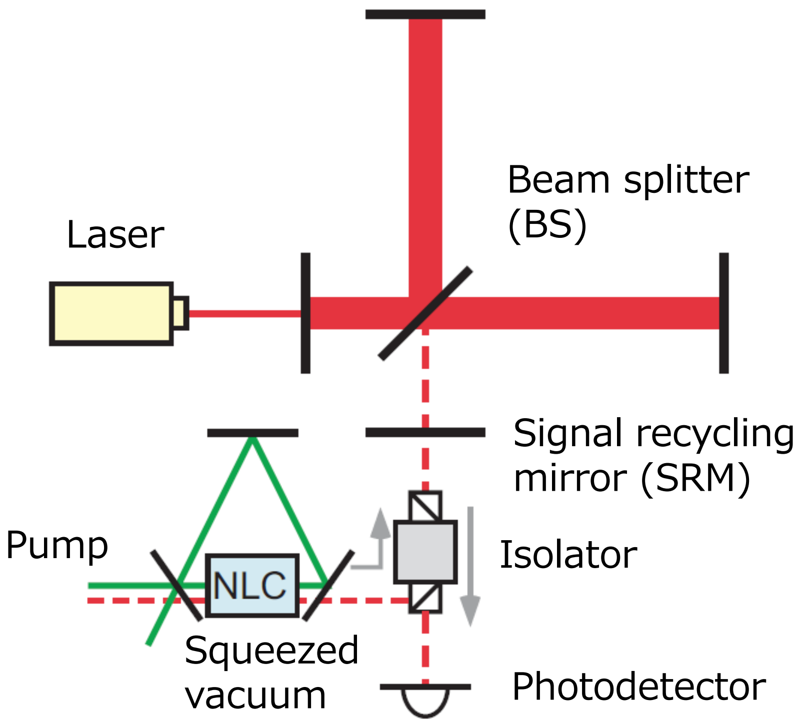
D. Radice, *et al.*, Astrophys. J. Lett. 842, L10 (2017).

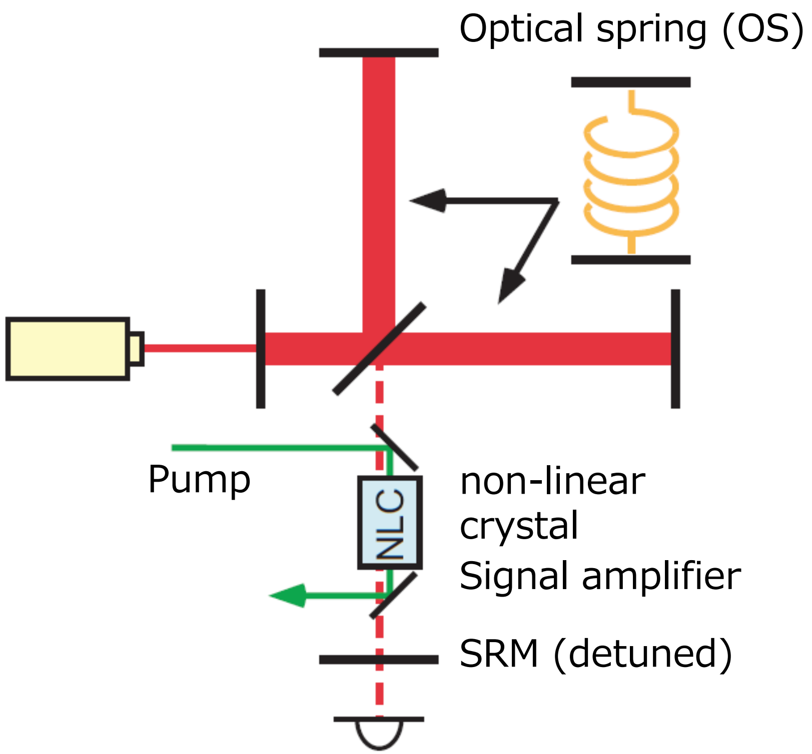
The high-frequency signal cannot be detected by currently GW detectors because of sensitivity degradation due to shot noise.

By improving the sensitivity in the kHz band, we significantly boost our understanding of the Universe.

Squeezer and amplifier

For improving the detection sensitivity in a high-frequency band.





Input squeezing

- decreases noise (wideband)
- weak against losses

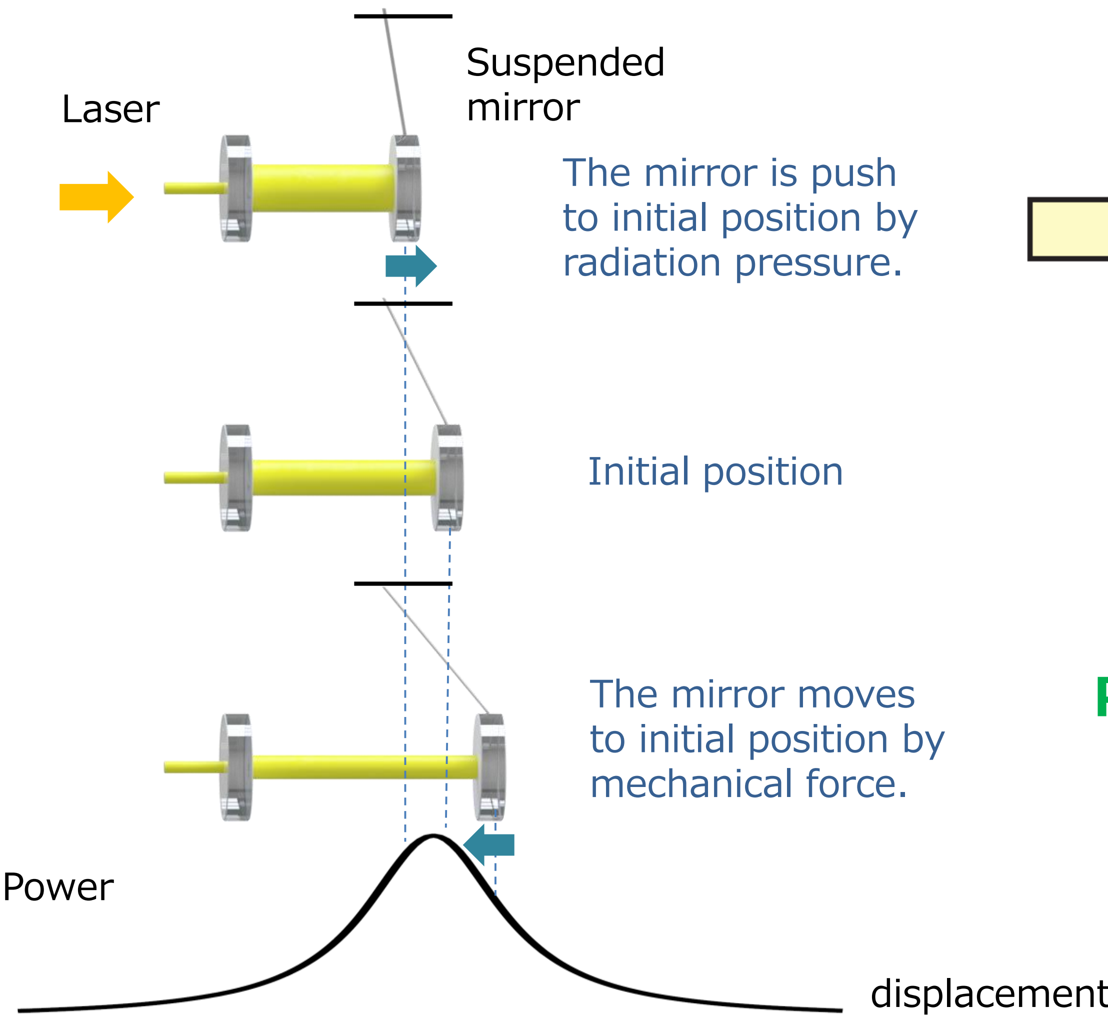
Parametric amplifier

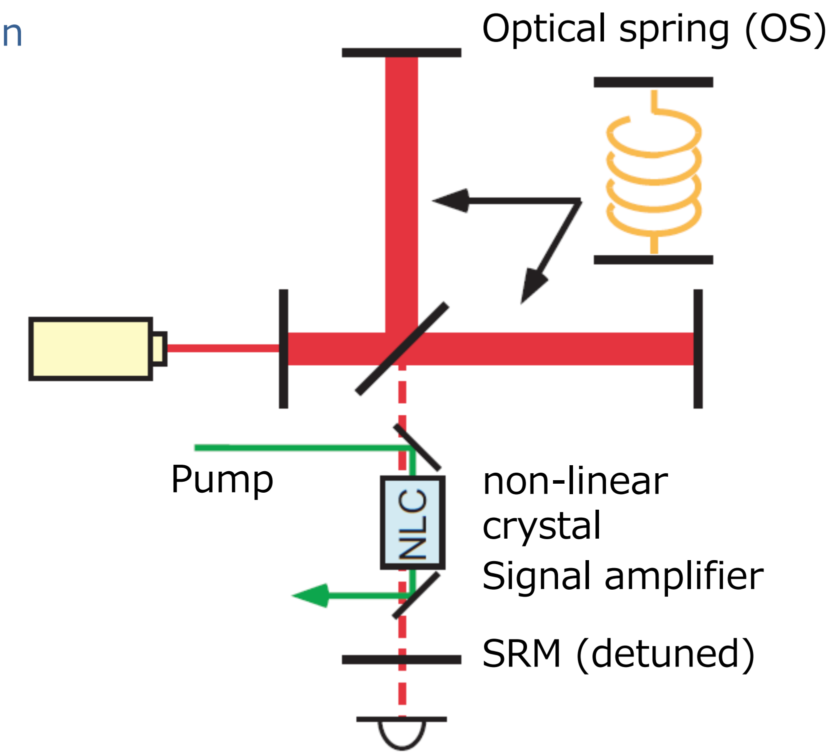
- increases signal (particular frequency)

Squeezer and amplifier

For improving the detection sensitivity in a high-frequency band.

Optical spring (OS): Induced by interaction between electromagnetic radiation and mechanical motion.

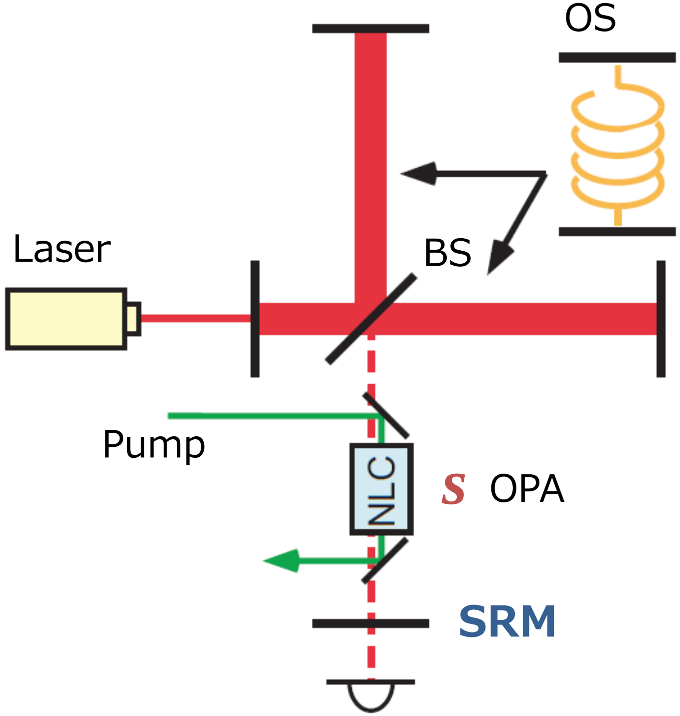




Parametric amplifier

- increases signal (particular frequency)

Parametric signal amplification



r: reflectivity of SRM
ϕ: detuned phase of SRM

Optical spring w/o OPA

$$\Omega \propto \sqrt{\frac{\sin 2\phi}{\left(r+\frac{1}{r}\right) - 2\cos 2\phi}}$$

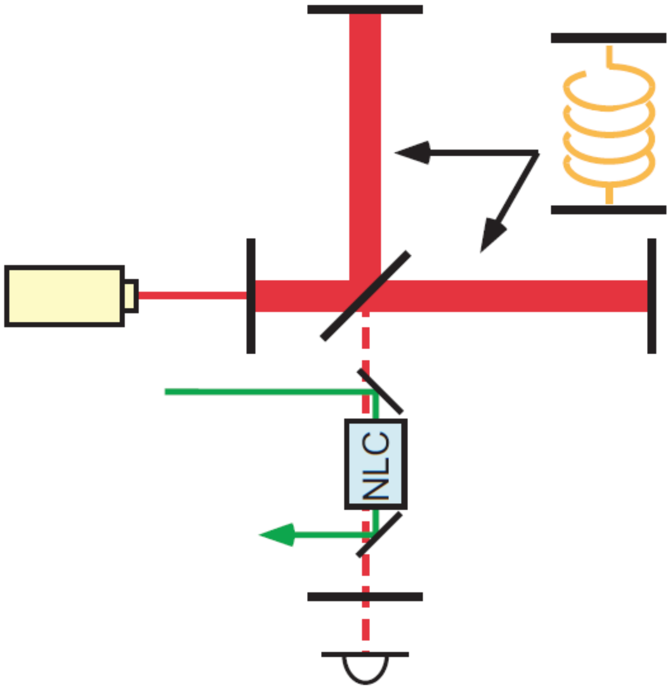
Optical spring with OPA

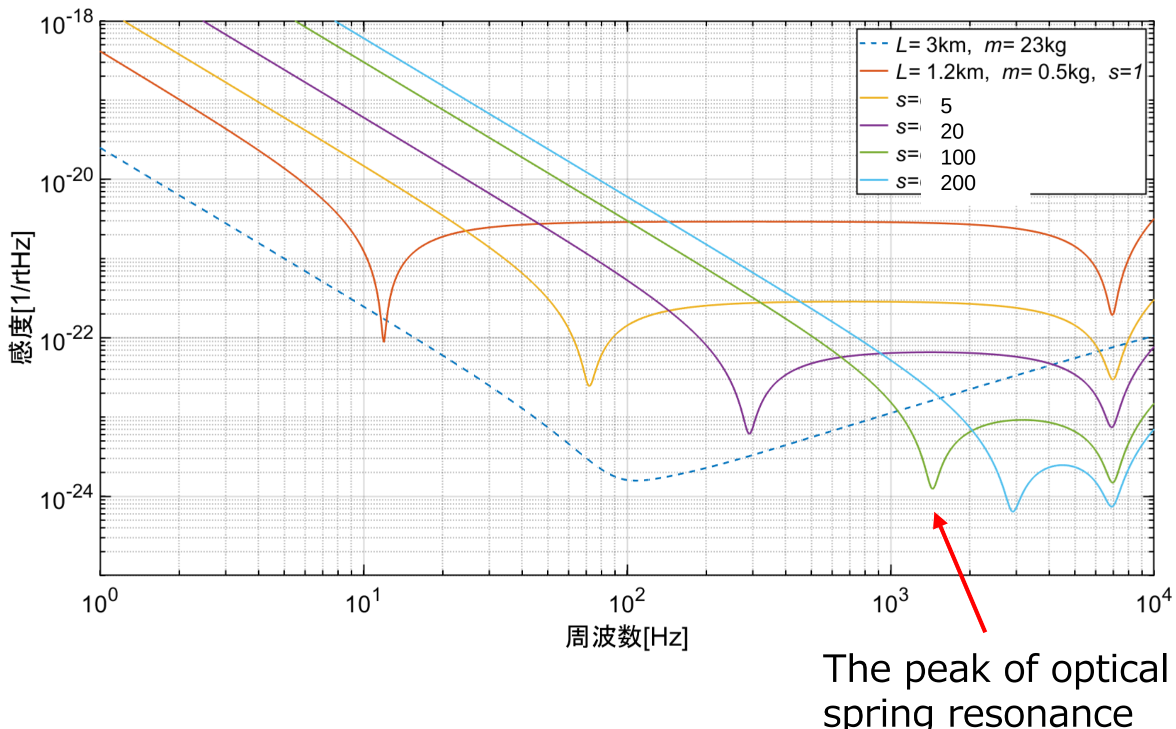
$$\Omega \propto \sqrt{\frac{\sin 2\phi}{\left(r+\frac{1}{r}\right) - \left(s+\frac{1}{s}\right)\cos 2\phi}}$$

Optical spring frequency can be enhanced by tuning the optical parametric gain s.

Sensitivity estimation

Sensitivity of signal recycling Michelson interferometer (SRMI) with OPA





When the optical parametric gain s is large, the optical spring frequency become high.

How to do experiment

Improvement of the detection sensitivity in HFB.

→ It is tough to do…

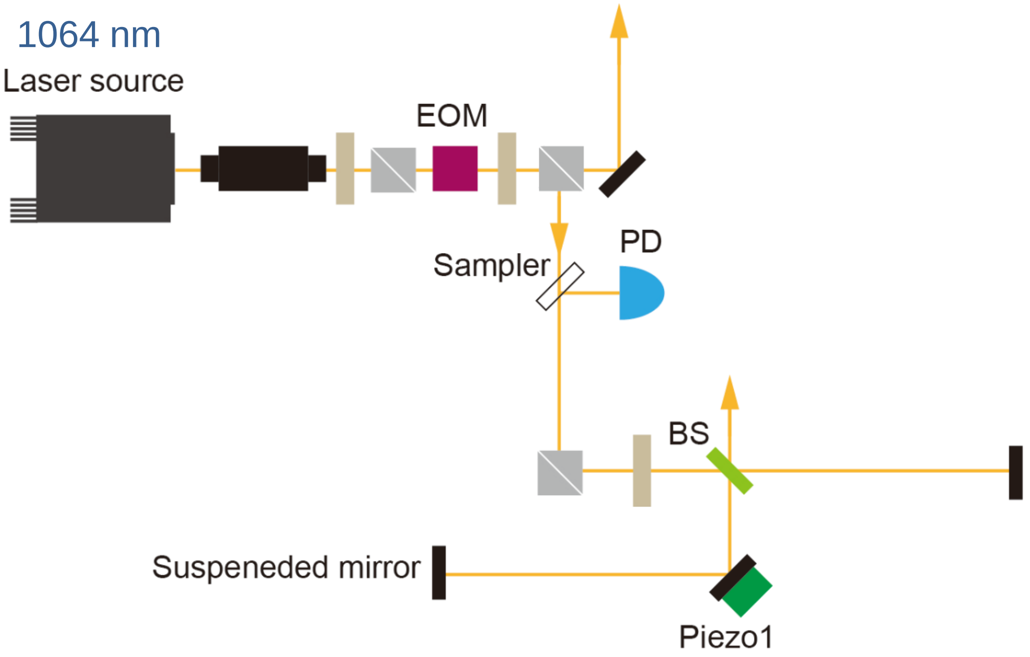
Confirmation of the signal amplification by measuring the resonance frequency of optical spring (OS).

Experimental steps

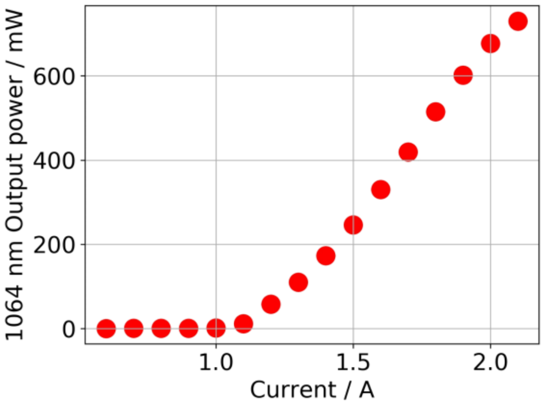
- Construction of MI and SRC
- Construction of the stabilization system for MI and SRC
- Generation of the pump laser (532 nm) by the 2nd harmonic generation (SHG)
- Confirmation of the OPA effect
- Confirmation of the resonance frequency of OS

Experimental setup

Piezo1: Stabilize the MI system



Laser output power



Suspended mirror

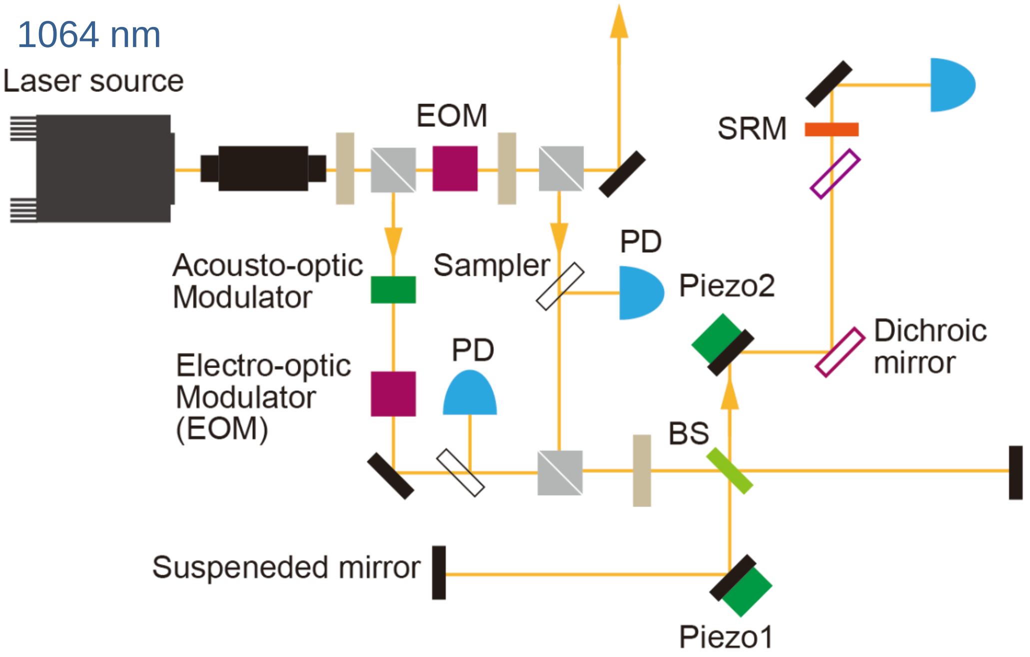
Diameter: 6 mm
Weight: 0.2 g
Resonant frequency: 16 Hz
Mount made of polyester

PD: Photodetector
BS: Beam Splitter
Piezo: Piezoelectric Actuator

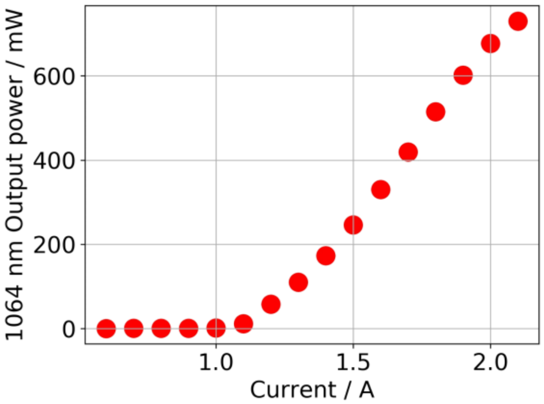
Experimental setup

Piezo1: Stabilize the MI system
Piezo2: Stabilize the SRC
by using the sub-carrier light

Subcarrier: Modulated by AOM and EOM



Laser output power



Suspended mirror

Diameter: 6 mm
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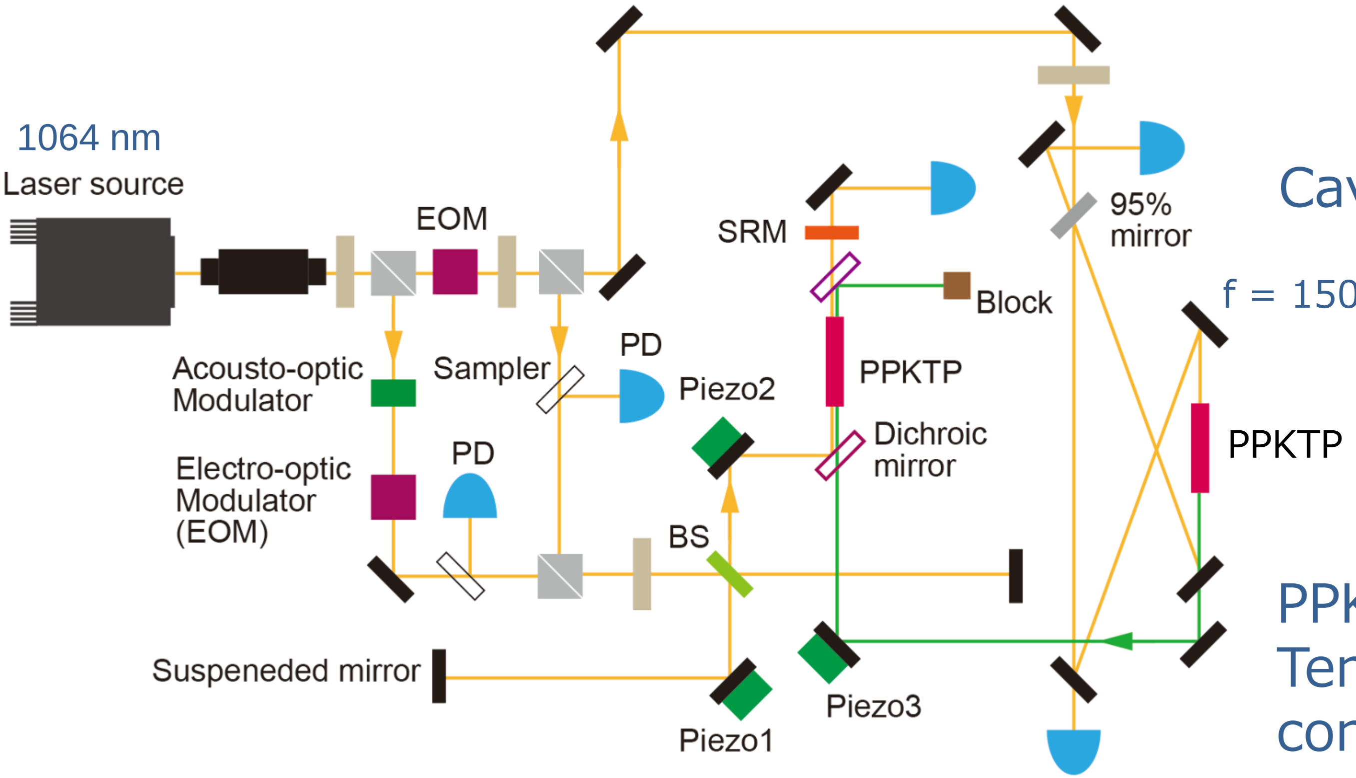
SRM: Signal recycling mirror

Experimental setup

Piezo1: Stabilize the MI system
Piezo2: Stabilize the SRC by using the sub-carrier light

Bow-tie cavity: Generate 532 nm light by SHG
Stabilized by the PDH method



Cavity length: 1.2 m

PPKTP crystal: Temperature controlled by a oven

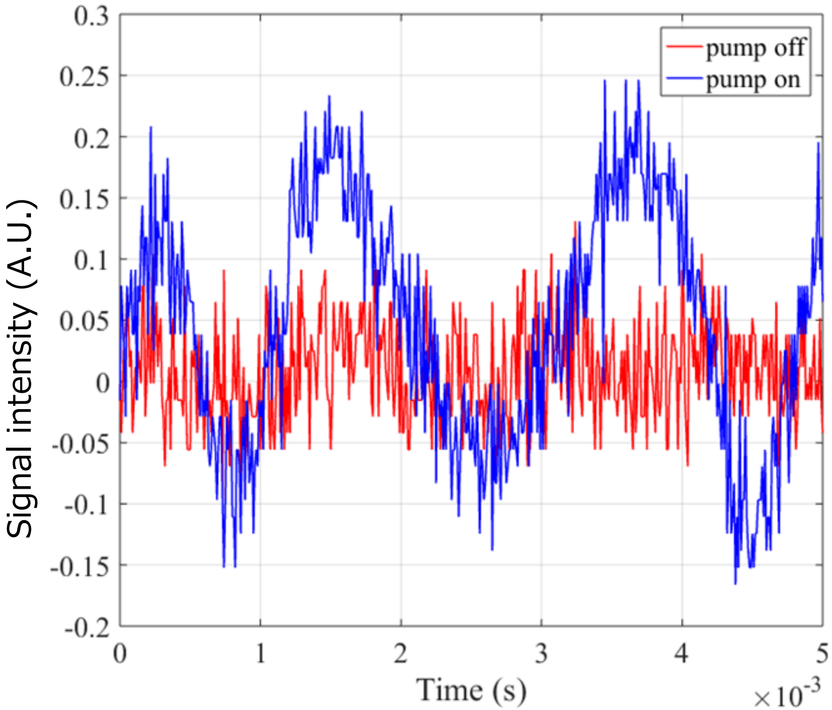
PD: Photodetector
BS: Beam Splitter
Piezo: Piezoelectric Actuator

SRM: Signal recycling mirror
PPKTP: Periodically Poled $KTiOPO_4$
PDH: Pound-Drever-Hall

Results

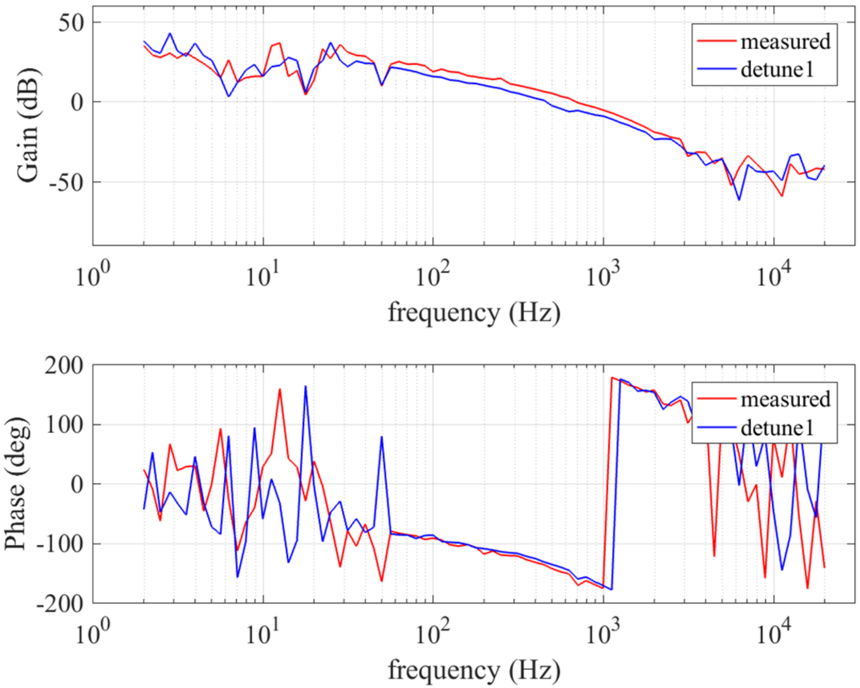
Pump power (532 nm): 90 mW

Measurement of OPA



Confirm the signal amplification of the 1064 nm light.

Measurement of the OS frequency

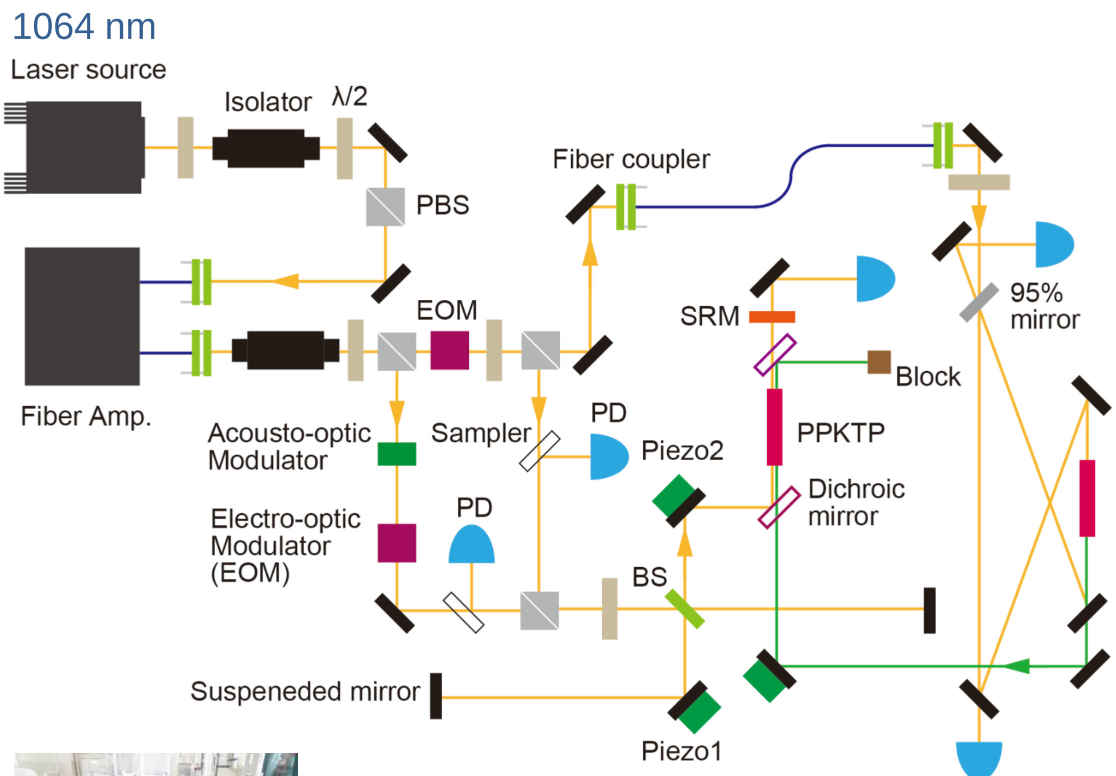


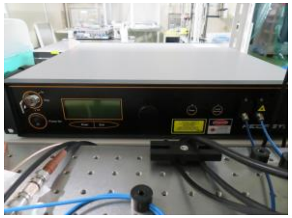
The Peak and shift of the OS frequency do not observed.

We need the improvement for the setup.

Improvement of the setup

Fiber amplifier: Installed in the setup

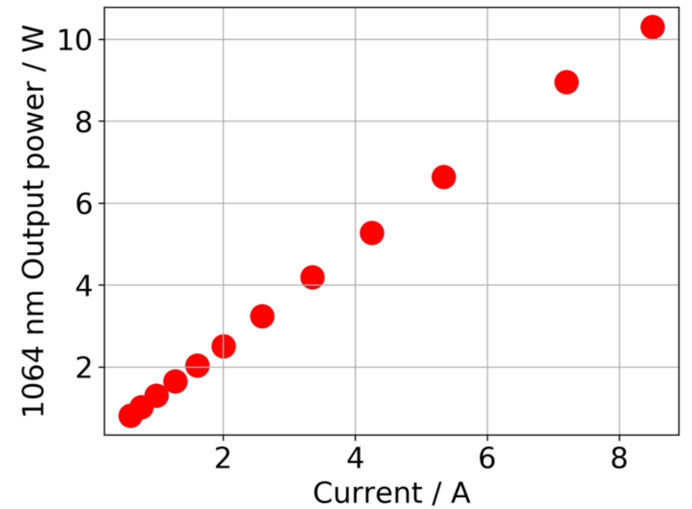




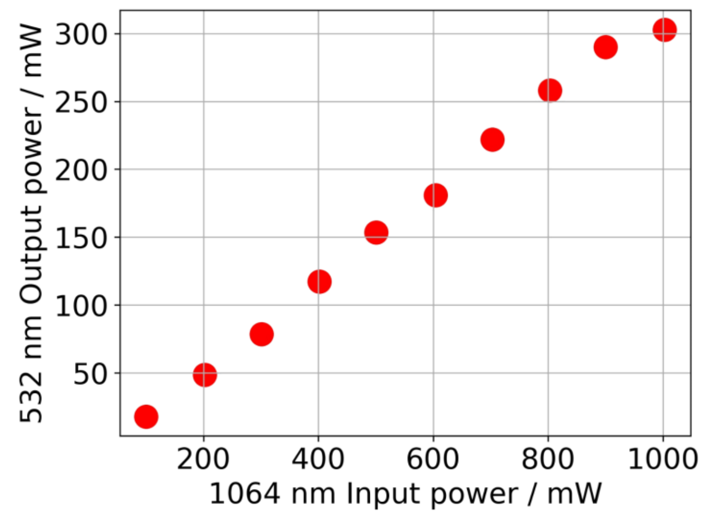
Fiber amplifier

Maximum output power: 10 W

Output power after the fiber amp.



Output power of the pump



532 nm power: achieved over 300 mW

Summary

Parametric amplification of GW signal can be a way to improve the sensitivity at high frequencies.

Confirmation of the signal amplification by measuring the resonance frequency of optical spring (OS).

Introduce the fiber amplifier to increase the power.

1064 nm	Confirm the output power of over 10 W.
532 nm	Confirm the output power of over 300 mW.

Future plan

Confirmation of the resonance frequency of OS
by using the improved powers.