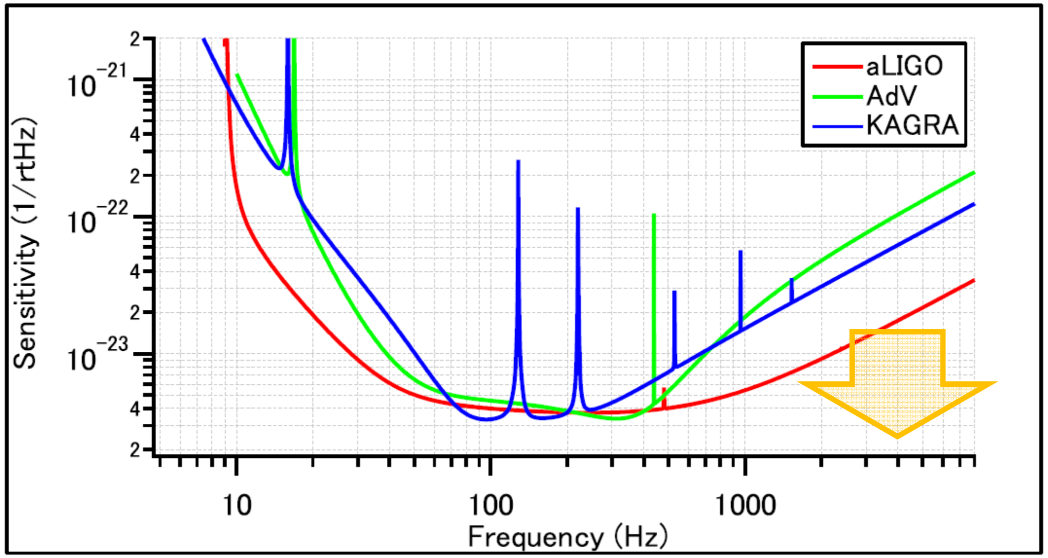
Parametric signal amplification

ET meeting @ Birmingham
Mar 27, 2017

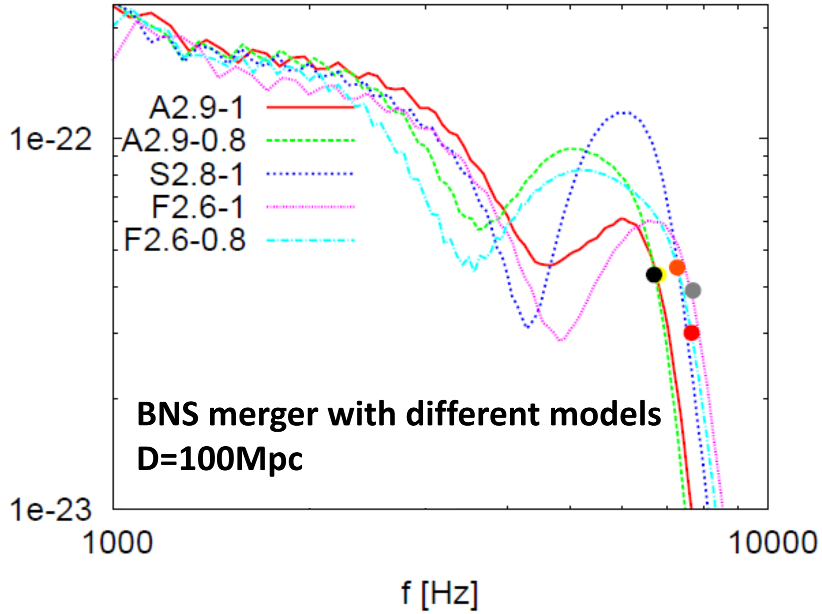
<u>K.Somiya</u>

K.Somiya

Observation of high-freq GW sources

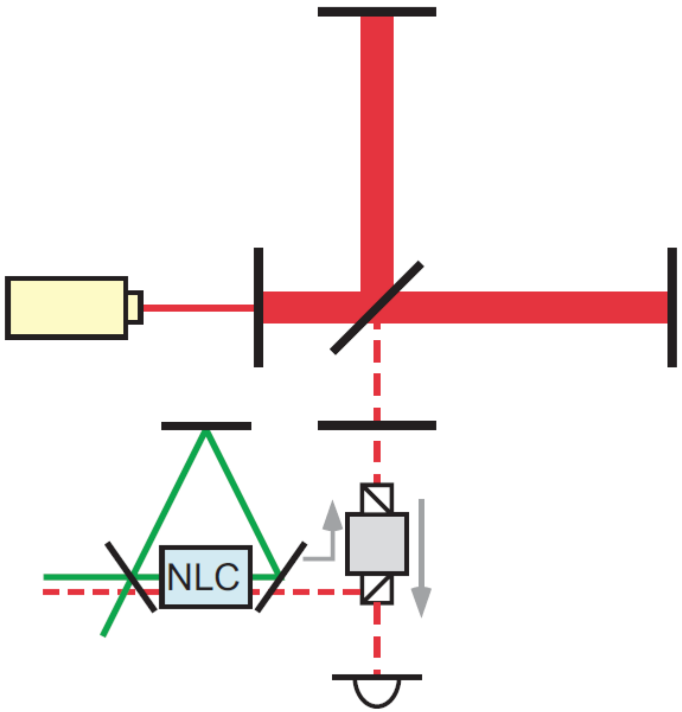


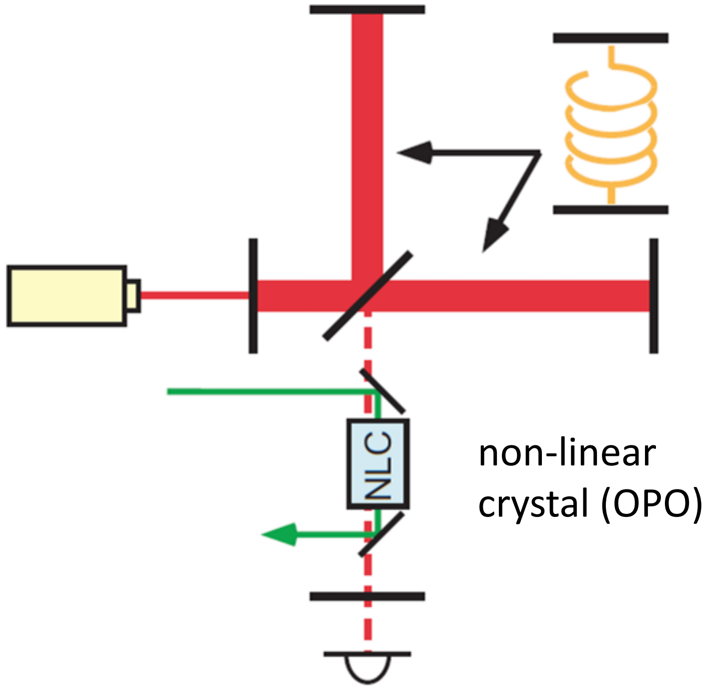
[Kiuchi, 2010]



- BNS merger appears above the cavity pole
- Increase of the laser power is essential but challenging
- Input squeezing is one possibility
- Another possibility would be <u>signal amplification</u>

Squeezer and amplifier

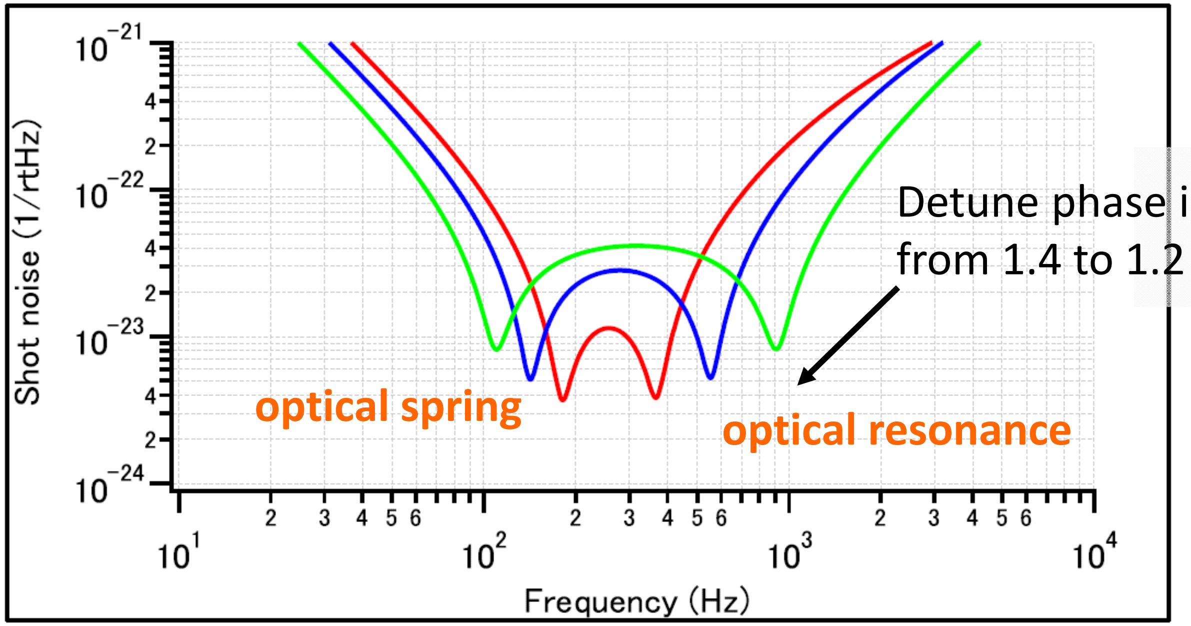




Input squeezing
- decreases noise
- weak against losses

Parametric amplifier
- increases signal
- strong to losses(?)

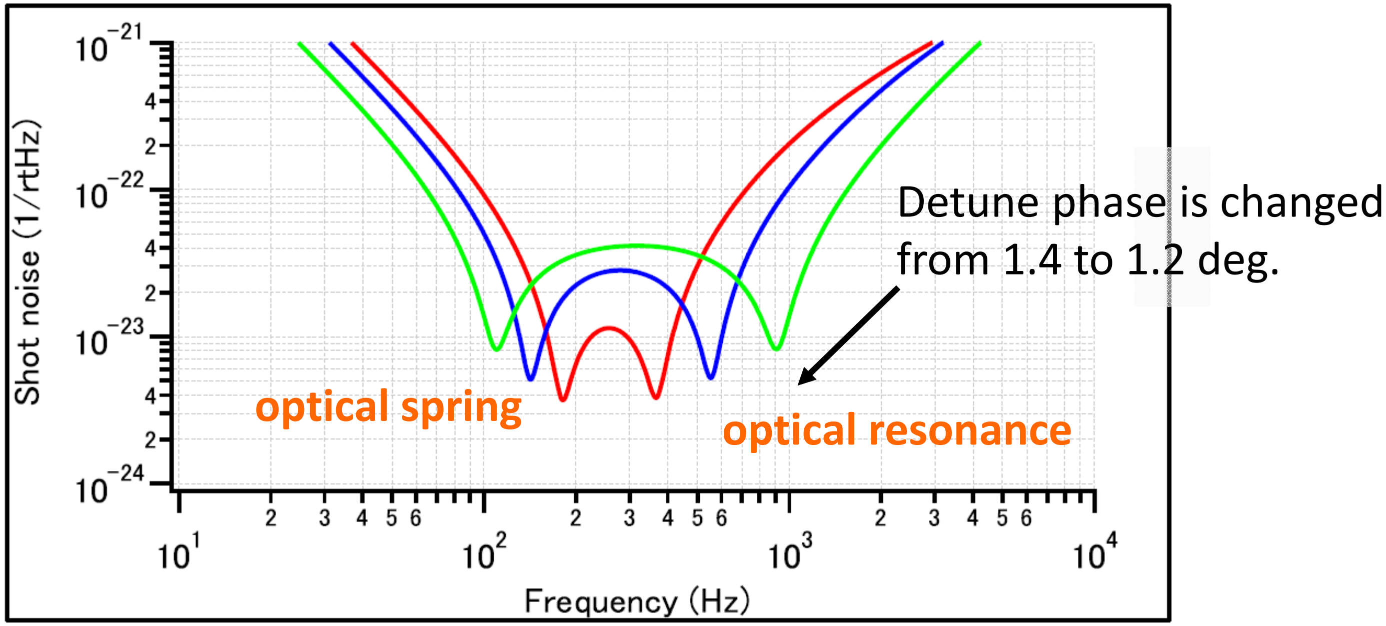
Optical spring frequency



Optical spring $$\Omega \propto \sqrt{\frac{\sin 2\phi}{\left(r+\frac{1}{r}\right) - 2\cos 2\phi}}$$ decrease with detune phase

Optical resonance $$\Omega \propto \frac{\sin 2\phi}{\left(r+\frac{1}{r}\right) + 2\cos 2\phi}$$ increase with detune phase

Optical spring frequency

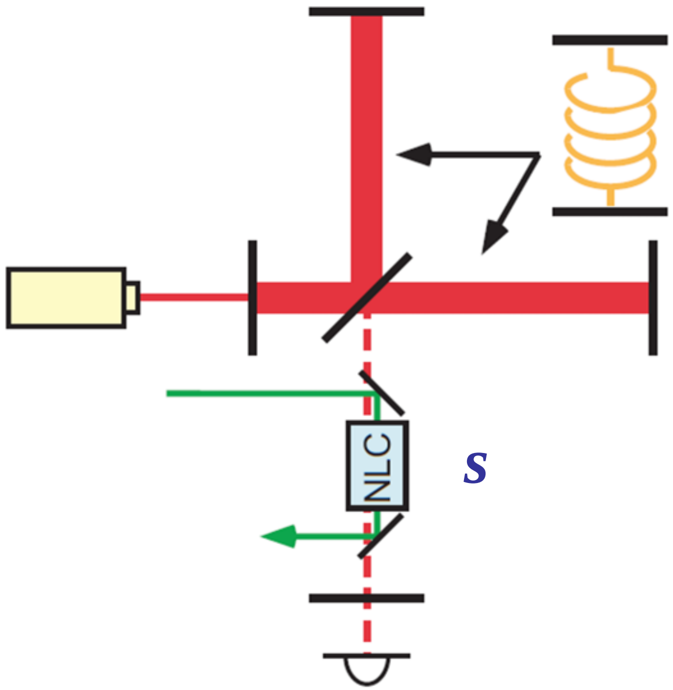


Spring freq cannot exceed the optical resonance.
Highest frequency is given with $\Omega_{spr}=\Omega_{reso}$:

$$\Omega \cong \sqrt[3]{\frac{8 I_c \omega_0}{mLc}}$$

Optical spring stiffness is given by the circulating power, arm length, and the mirror mass.

Parametric signal amplification



Optical spring w/o OPO

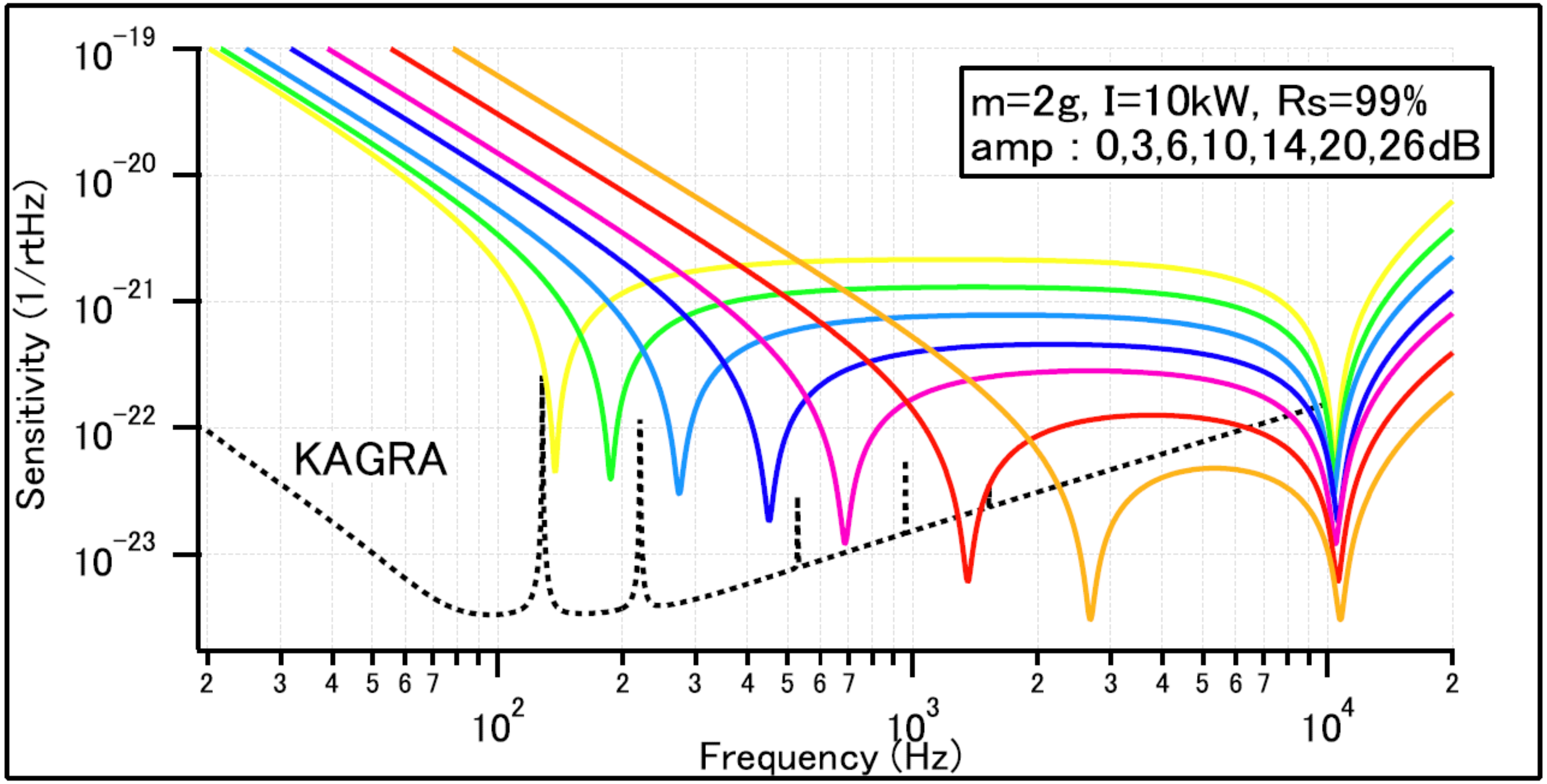
$$\Omega \propto \sqrt{\frac{\sin 2\phi}{\left(r+\frac{1}{r}\right)-2\cos 2\phi}}$$

Optical spring with OPO

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

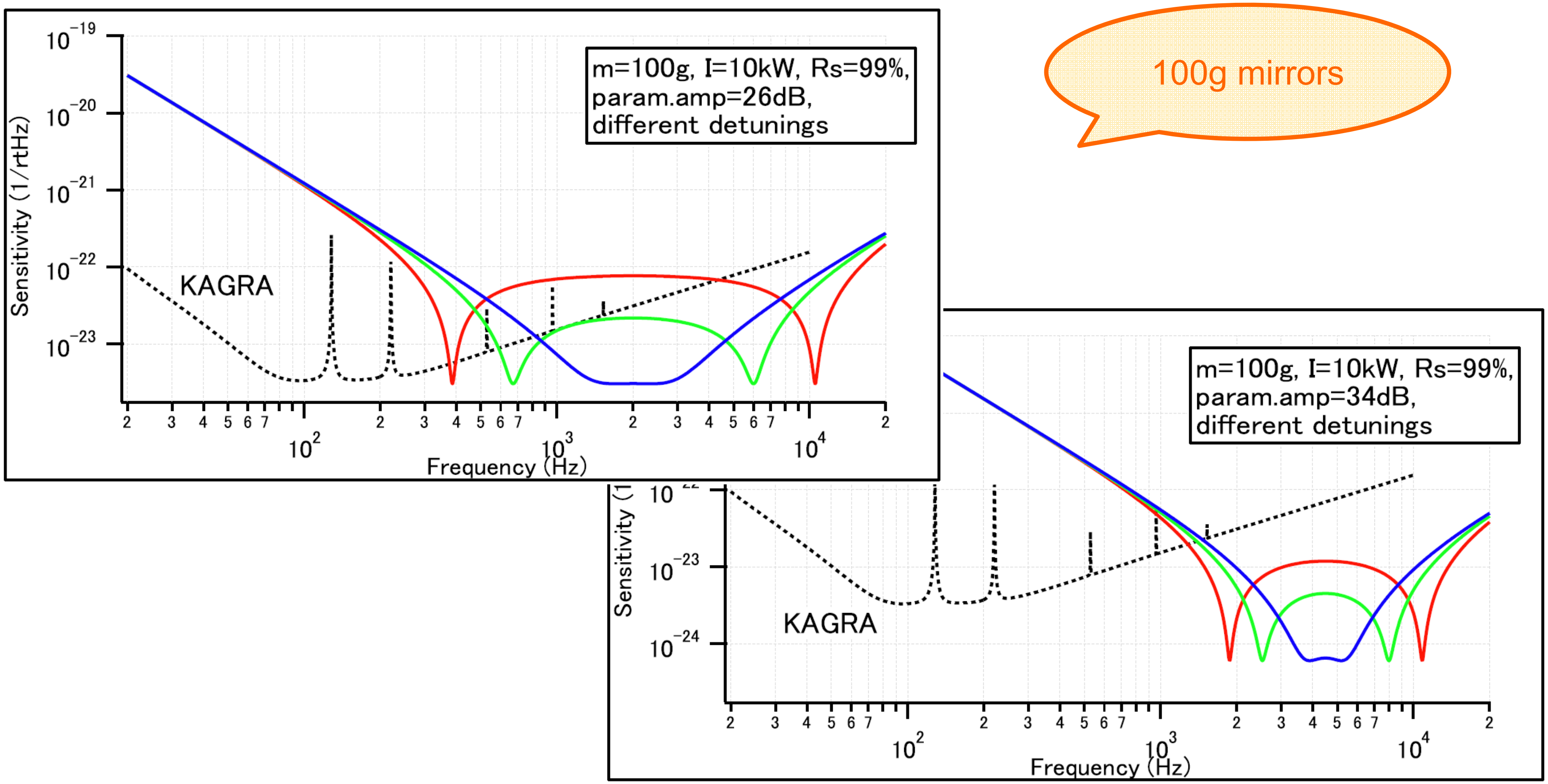
Optical spring frequency can be enhanced by tuning the OPO gain s.

Optical spring shifts



Increasing the OPO gain, the optical spring frequency shifts to higher frequencies.

Quantum noise spectra with 100g mirrors



The higher the OPO gain, the narrower but deeper the quantum noise spectrum.

Optical losses

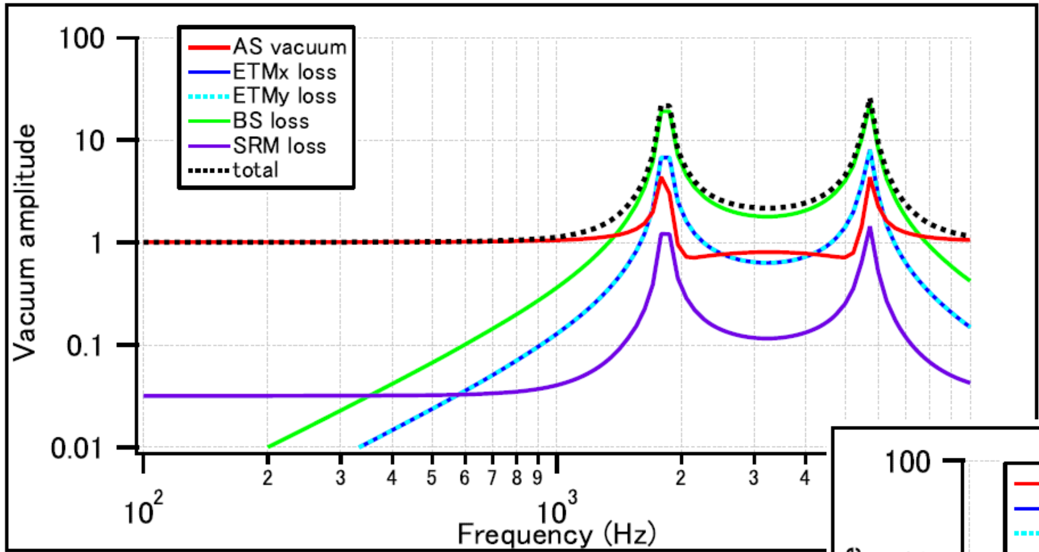
- So far we did not include optical losses

- Compared with the squeezing, the amplification should be strong against external losses

- The amplification, however, turns out to be not so strong against internal losses as the losses also amplify with the signal

Contribution of each optical loss

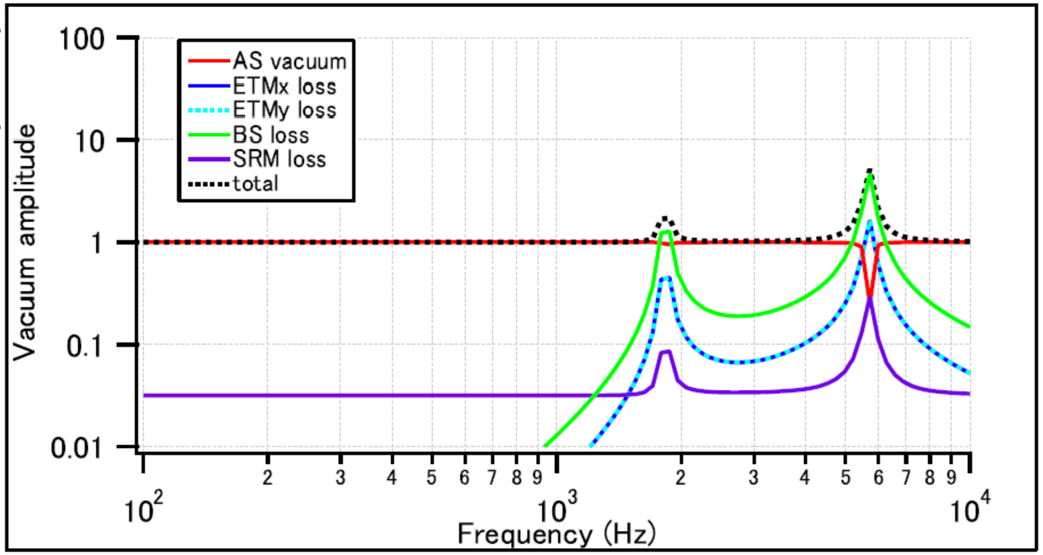
L=1200m, I=10kW, SQ=34dB
Thomas code is used.



- 50ppm losses in each arm
- 100ppm losses in BS
- 1000ppm losses in SRM

↑ Homodyne angle = 90 deg

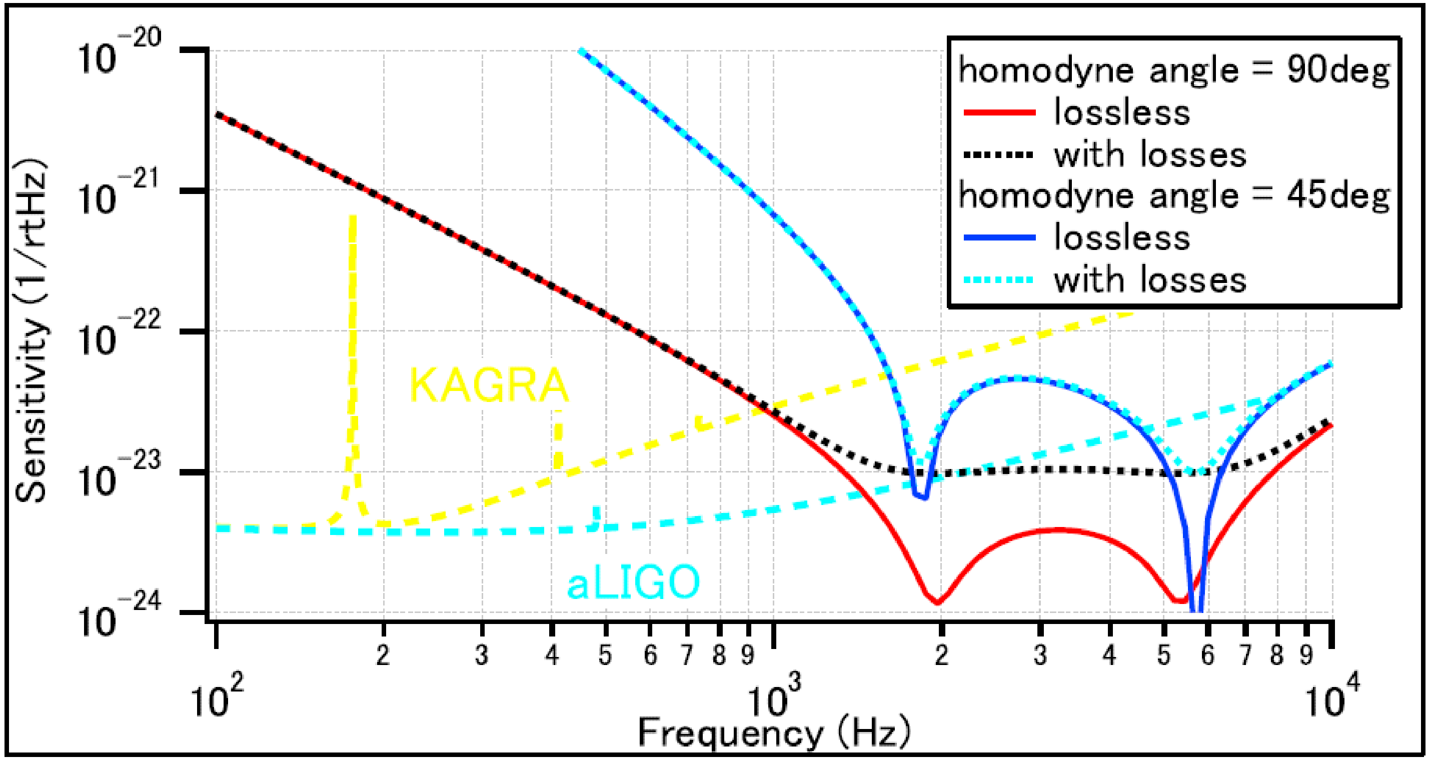
Homodyne angle = 45 deg →



It is a little strange that the loss vacuum increases at any quadrature: my student is now working on this issue.

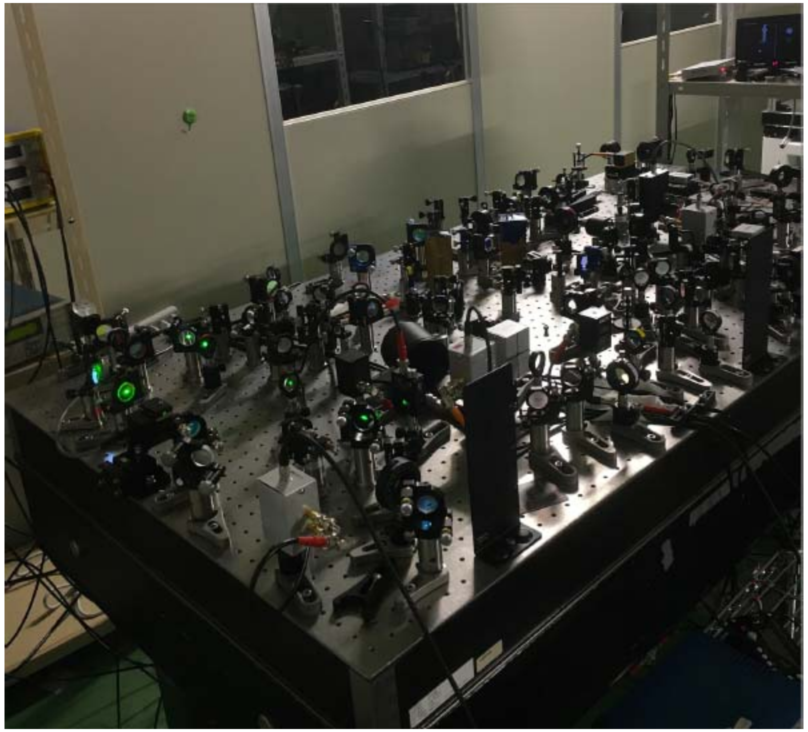
Including optical losses

L=1200m, I=10kW, SQ=34dB
Thomas code is used.

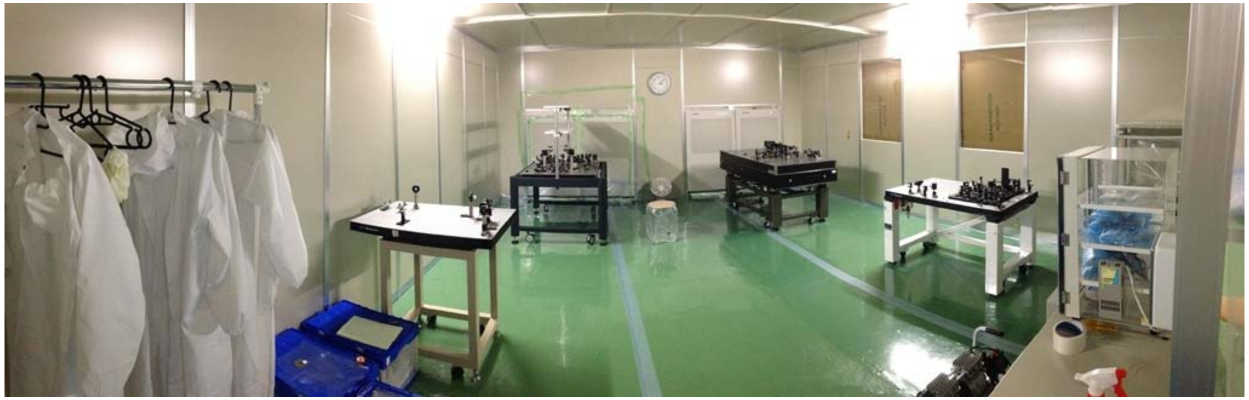


The sensitivity is better than aLIGO above 3kHz.

Table-top experiment at Tokyo Tech



- 200mg mirror
- 10W laser (600mW + fiber amp)
- PPKTP for SHG/OPO
- Detuned SRMI (no PR)
- The goal is to see the shift of the optical spring frequency by a TF measurement



Experiment plan

(1) Generation of 532nm

(2) Operation of SRMI with fixed mirrors

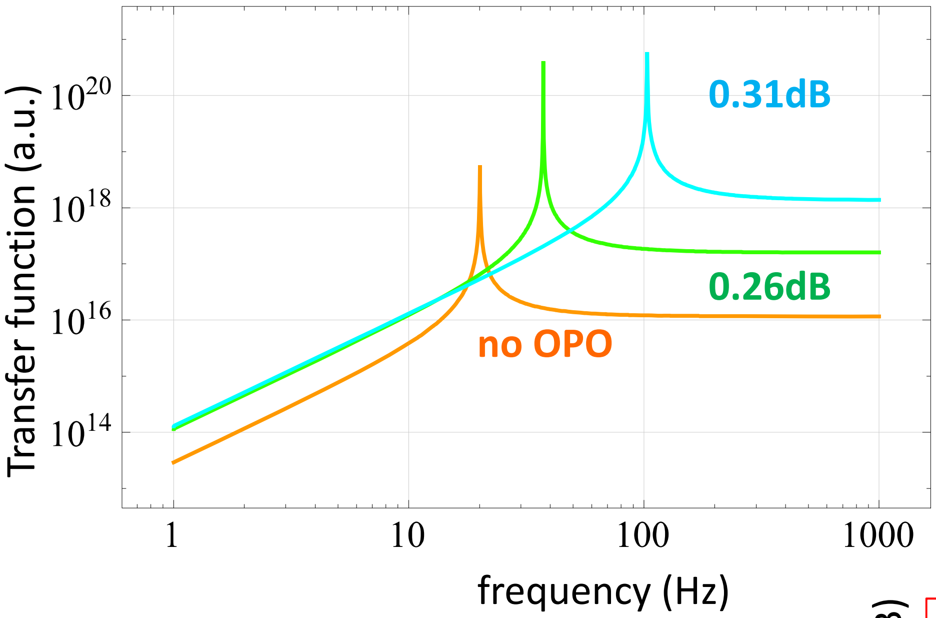
(3) Operation of SRMI + unlocked OPO with fixed mirrors

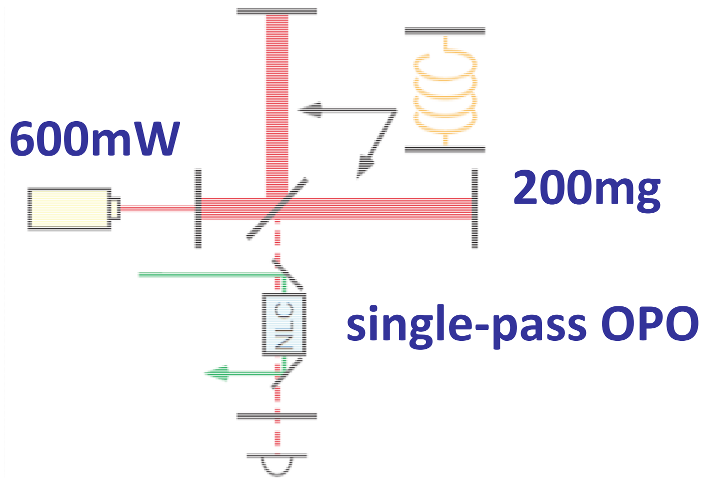
(4) Operation of SRMI + unlocked OPO with a suspended mirror

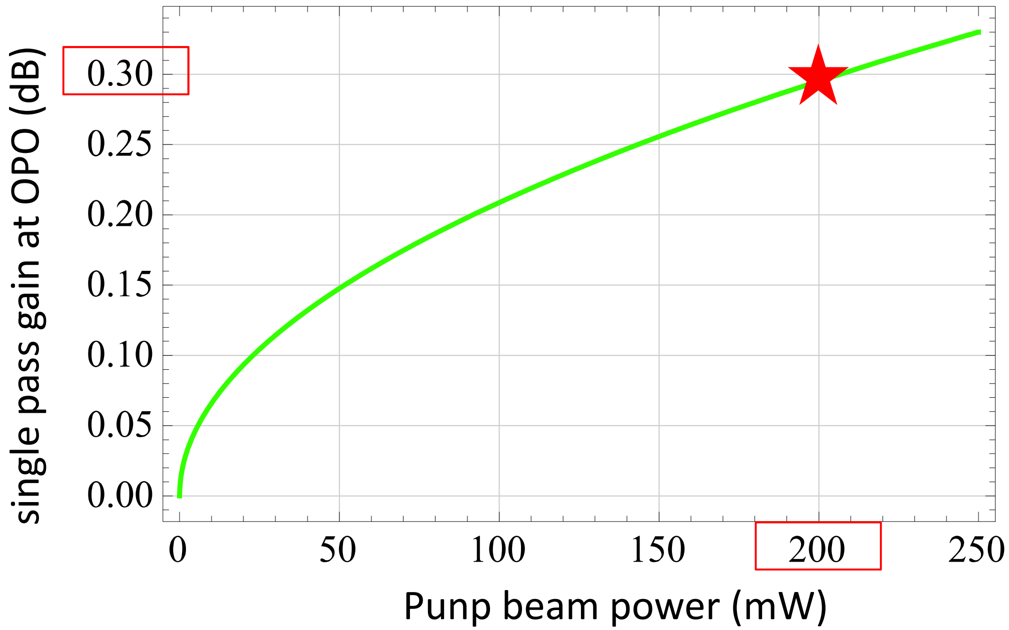
(5) Operation of SRMI + locked OPO with a suspended mirror

We have done (1)-(3) in 2016.
Now we are developing a suspension system.
Control scheme of the OPO is not yet considered.

How much 532nm do we need?





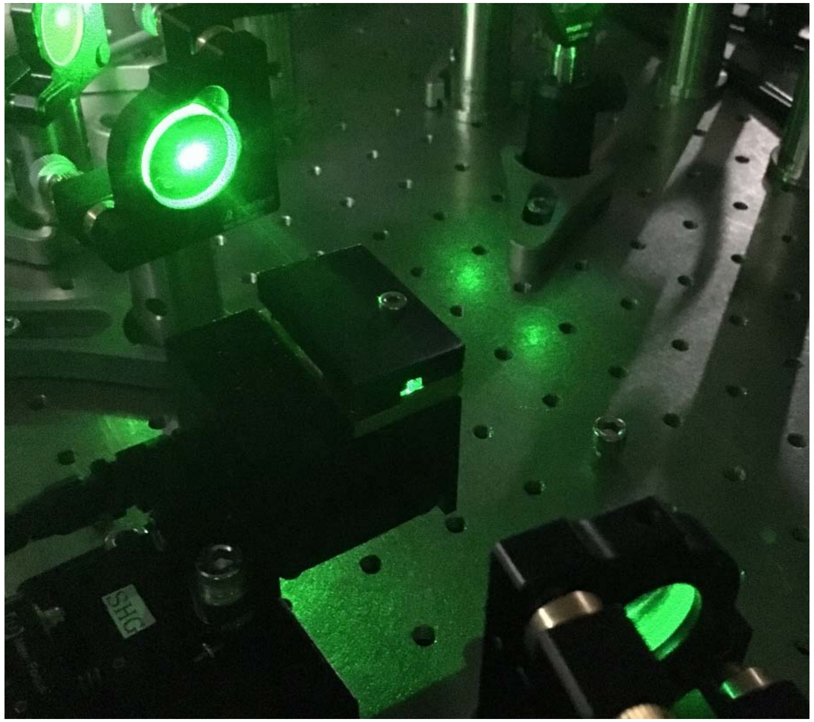


In order to see the shift of the optical spring, we need 0.3dB of a single-pass OPO gain in our experimental setup.

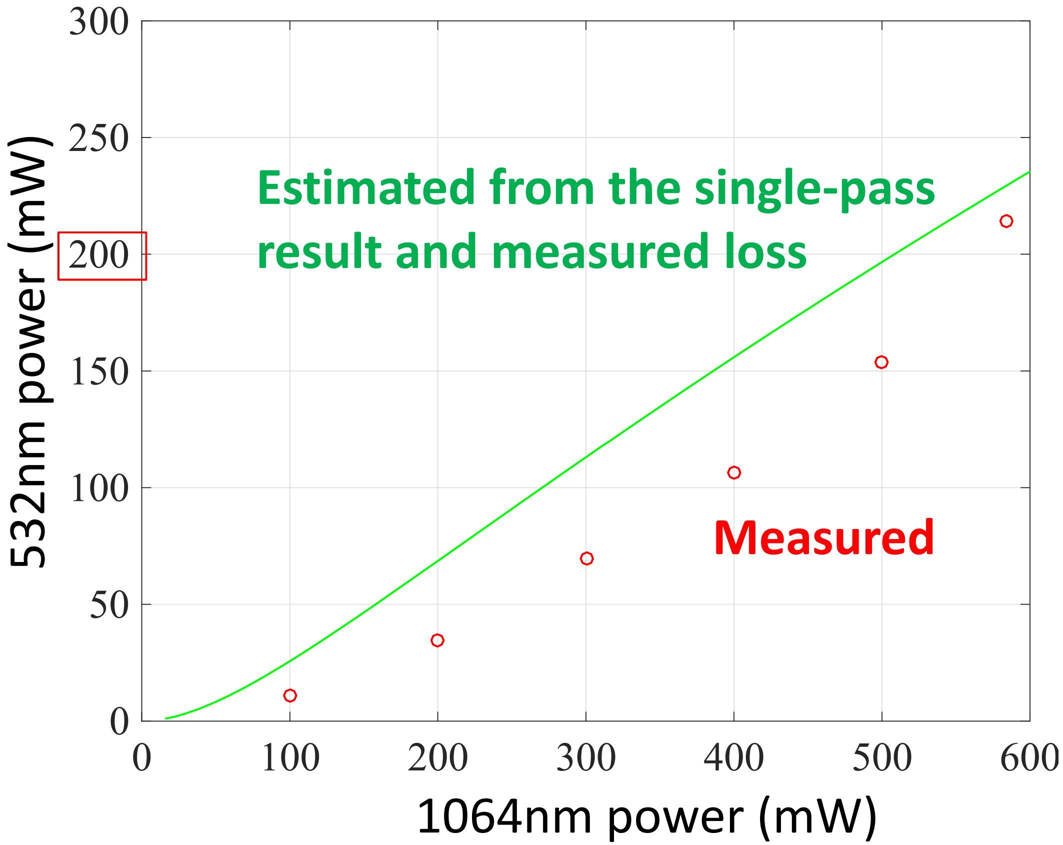
Required 532nm power is 200mW.

Generation of 532nm

[Kataoka, thesis '17]



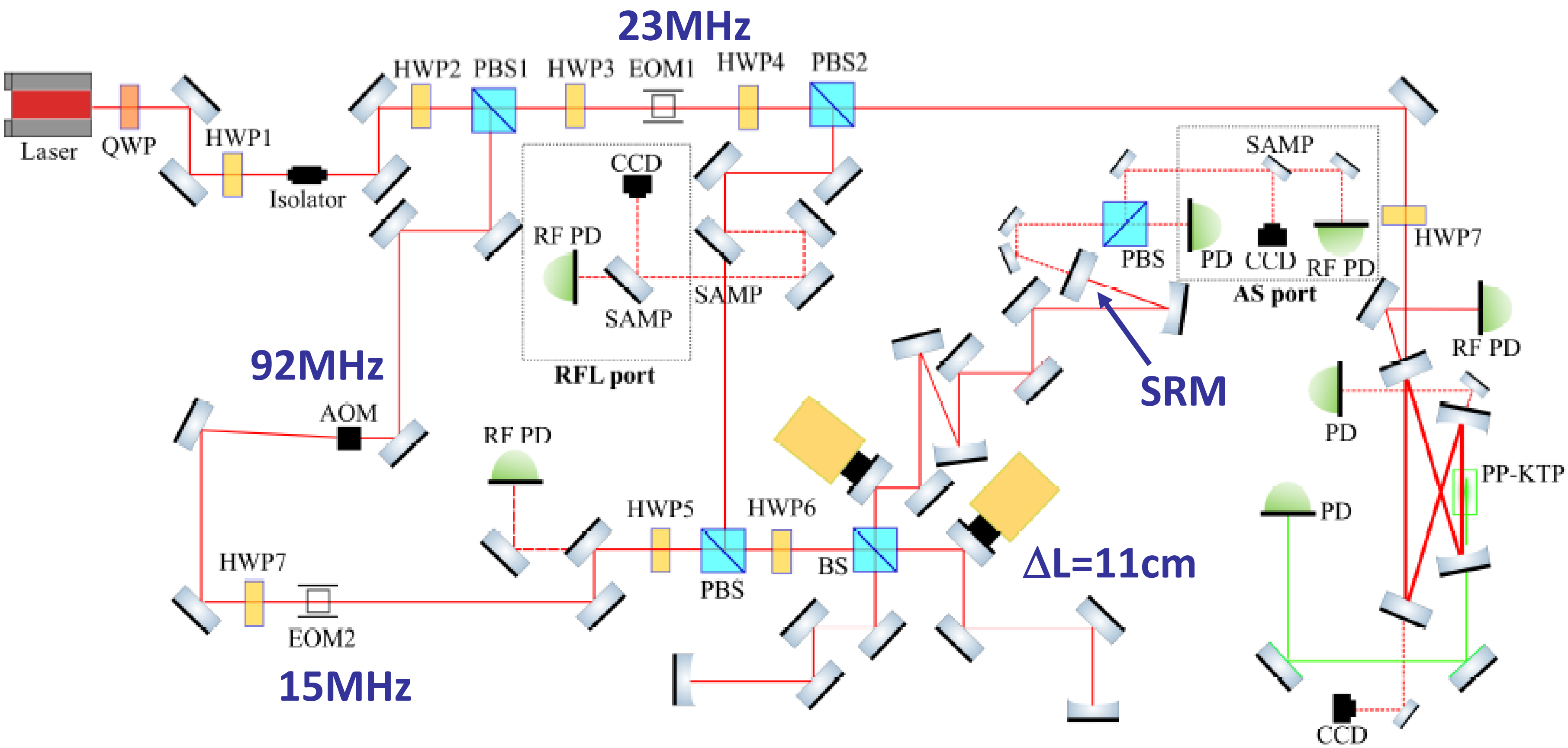
Finesse of the bowtie SHG cavity is 126.



The efficiency is a bit lower than expected but the requirement has been satisfied.

Operation of SRMI

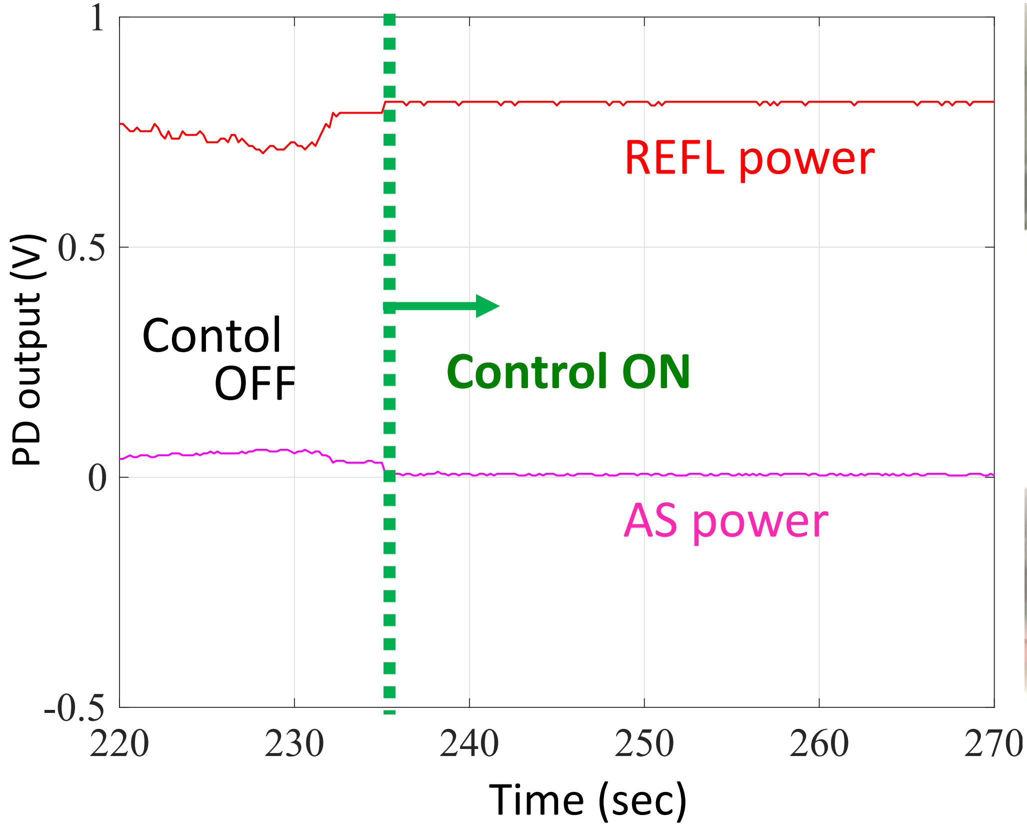
[Kataoka, thesis ‘17]

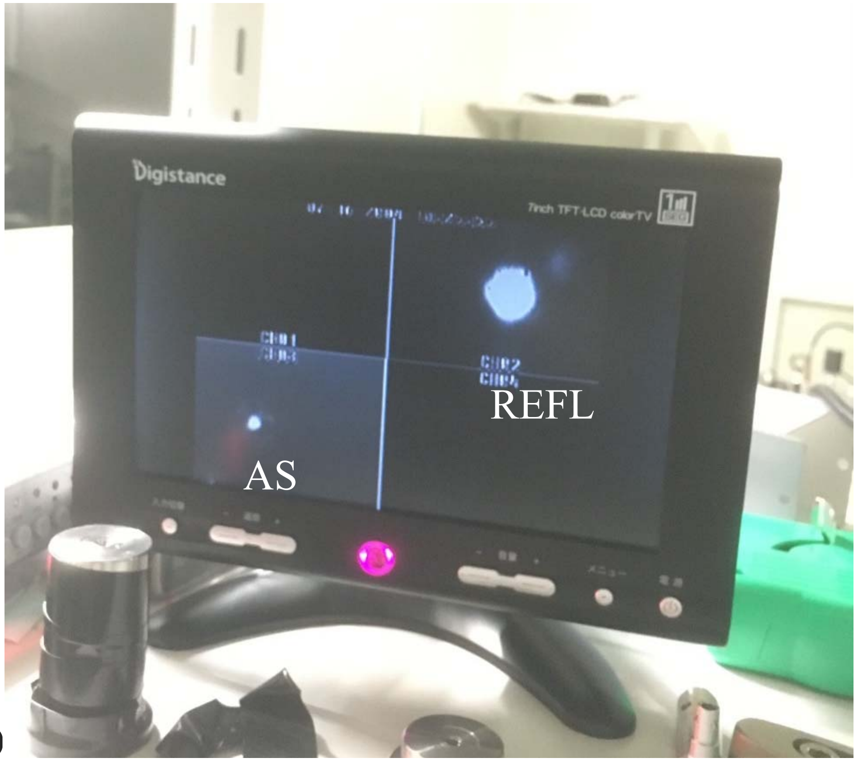


- 92MHz subcarrier is used to lock the SRMI
- MICH is locked to the bright fringe of subcarrier
- SRCL is locked to the resonance of subcarrier

Operation of SRMI

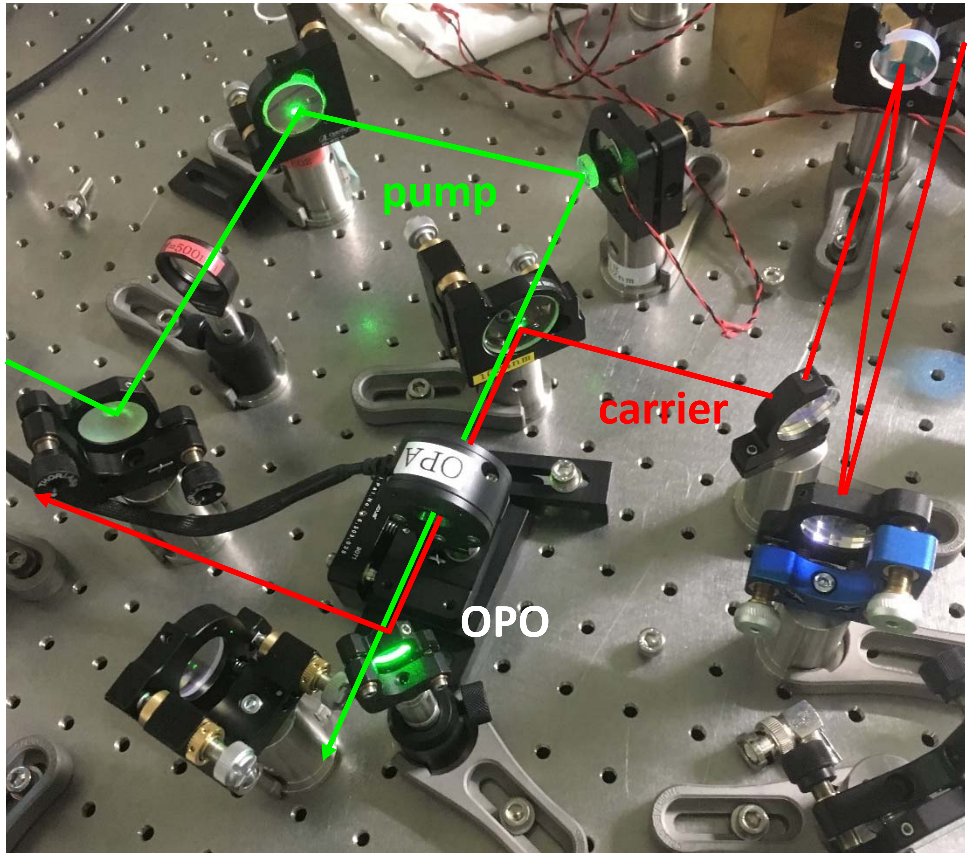
[Kataoka, thesis ‘17]



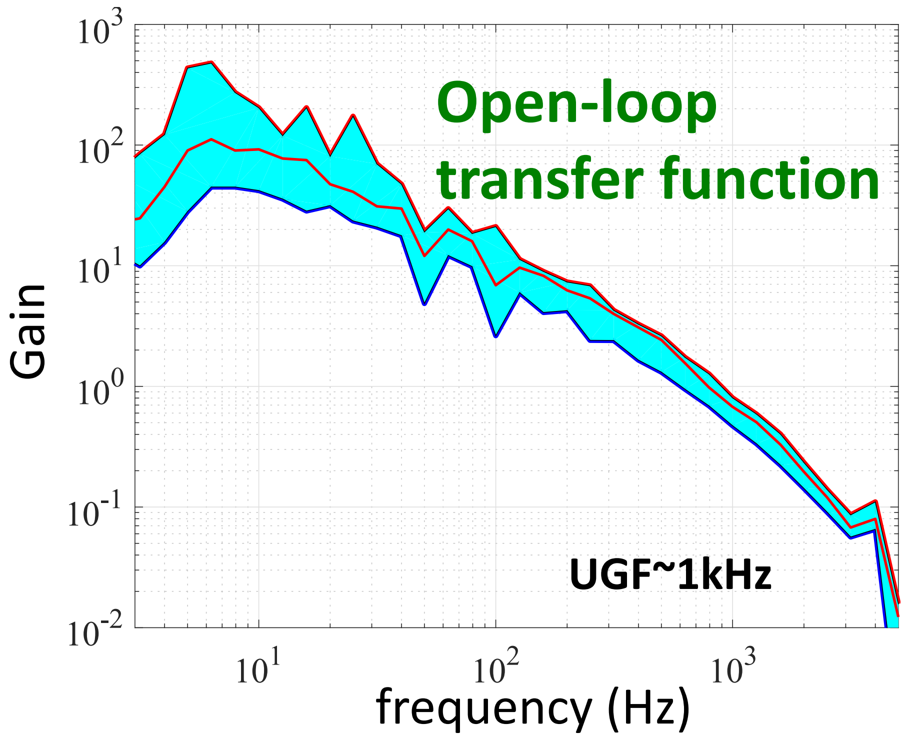


- **The lock was kept for more than 30 min**
- **UGF is 700Hz**
- **Currently it is a tuned SRMI**

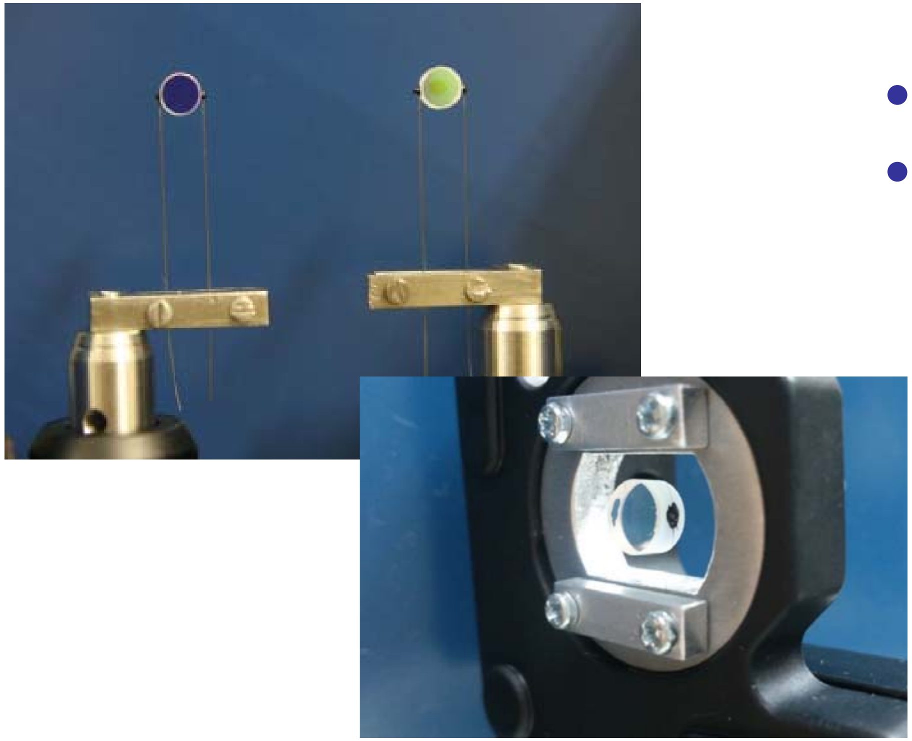
Operation of SRMI + OPO in SRC



- OPO is roughly aligned and modematched to carrier
- OLTF gain decreased at LF

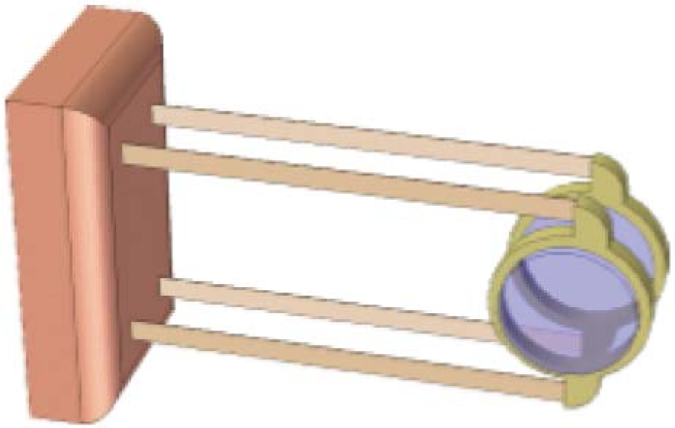


Development of a small-mirror suspension


previous suspensions

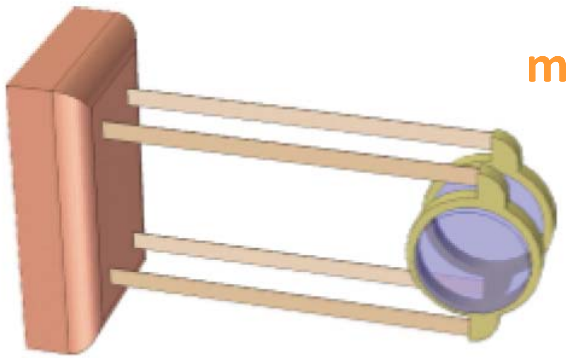
- Thermal noise is not an issue
- Optical spring frequency w/o OPO is about 20Hz so suspension freq is better to be <~10Hz

- For the SRMI operation, it would be good if pitch/yaw freq are much higher than the longitudinal mode

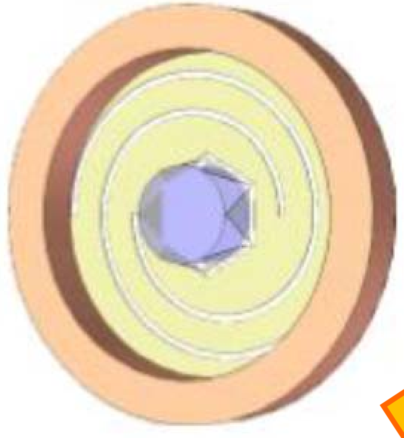

designed by John Winterflood

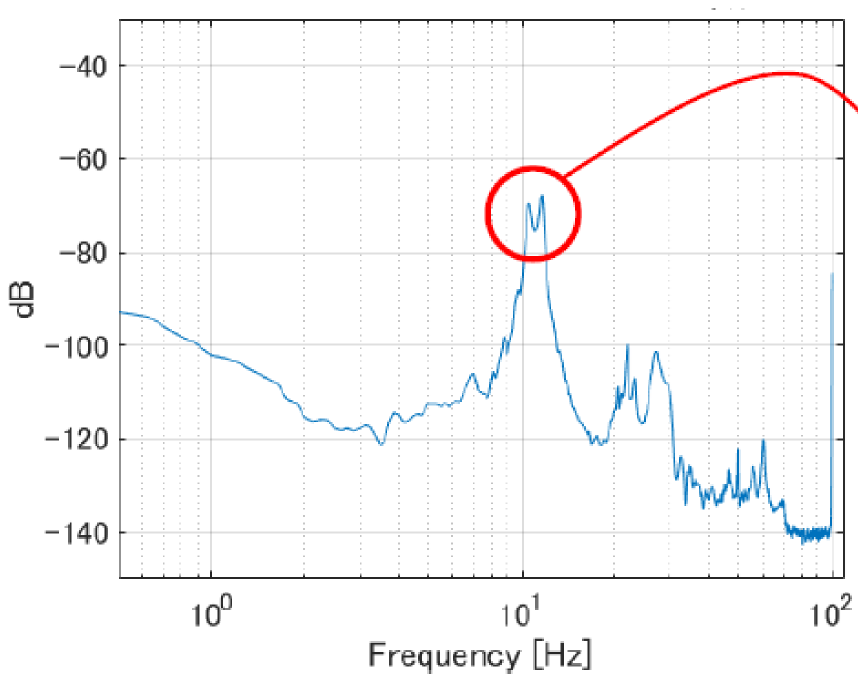
Development of a small-mirror suspension

[Hisatomi, thesis '17]



more compact





10.6Hz
and 11.6Hz

We need to damp them.

Summary

- Parametric amplification of GW signal can be a way to improve the sensitivity at high frequencies
- An issue is that optical losses are amplified at the optical spring freq together with GW signals
- We built a prototype experiment at Tokyo Tech and locked SRMI with an intracavity OPO
- We are to install a small mirror and now working on its suspension system (damping)