Intracavity squeezing/amplifier

GWADW Alyeska
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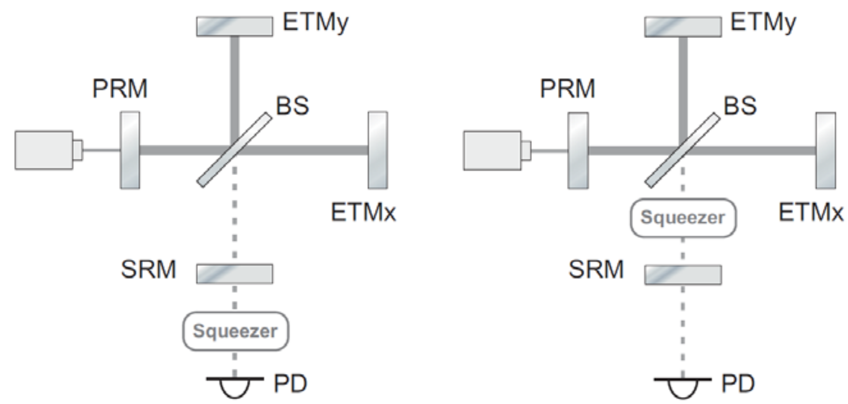
Intracavity techniques for GW



OPO in PRC:

- anti-squeezing in the PRC

Intracavity squeezing:

- squeezing in the SRC

Intracavity readout:

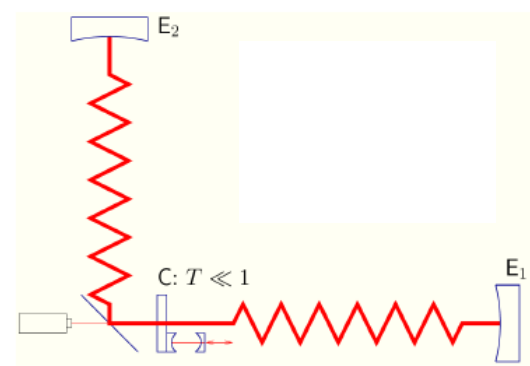
- locally readout the mirror motion (Braginsky, Khalili)

Intracavity filtering:

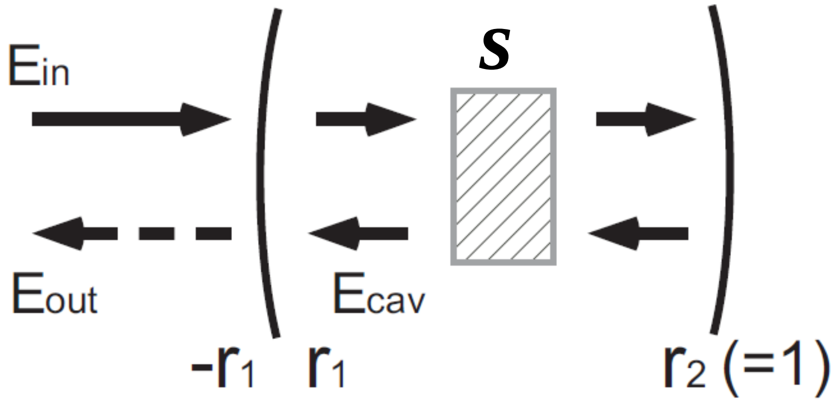
- filter cavity inside the SRC (Miao)

Intracavity amplifier:

- anti-squeezing in the SRC (Somiya)
- ponderomotive amplifier (Chen)



Intracavity squeezing

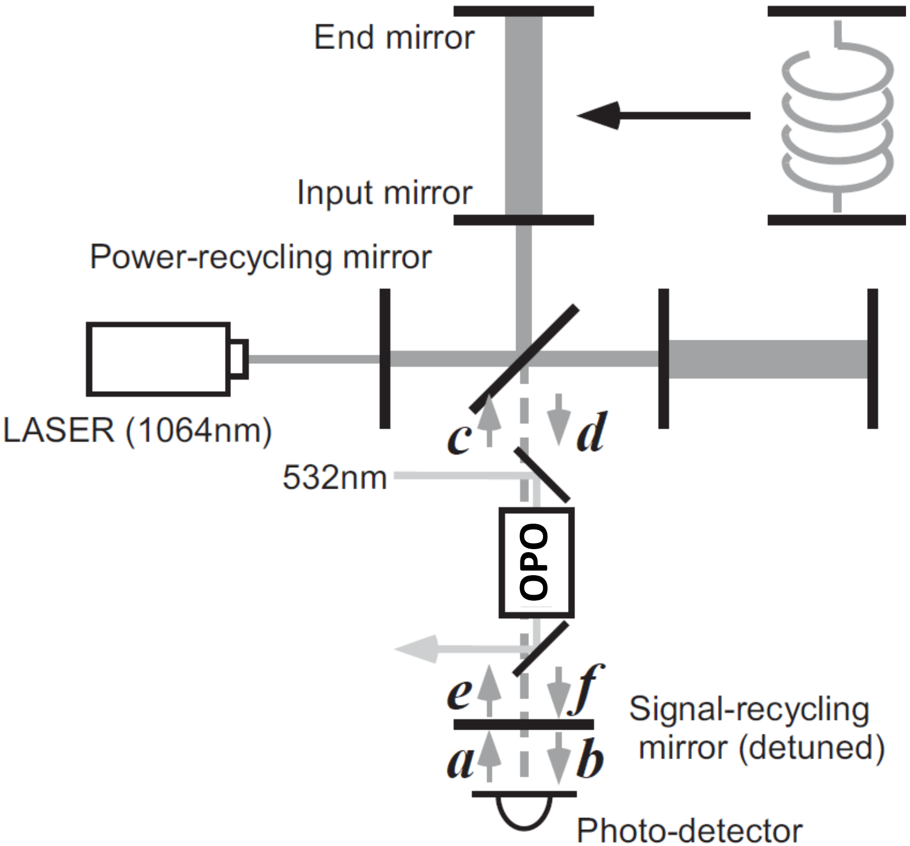


$$E_{out} = \Bigg(\underbrace{-r_1}_{\cong -1} + \underbrace{\frac{t_1^2}{1-r_1} \times s}_{\cong 2s} \Bigg) E_{in}$$

Assume E_{in} and E_{out} are the phase quadrature vacuum field. With $s=1/2$, squeezing factor would be nearly infinity.

In fact, this impedance matching technique is regularly used for a squeezer and it is known that the perfectly matched cavity would also infinitely increase the optical loss in the OPO.

Intracavity amplifier

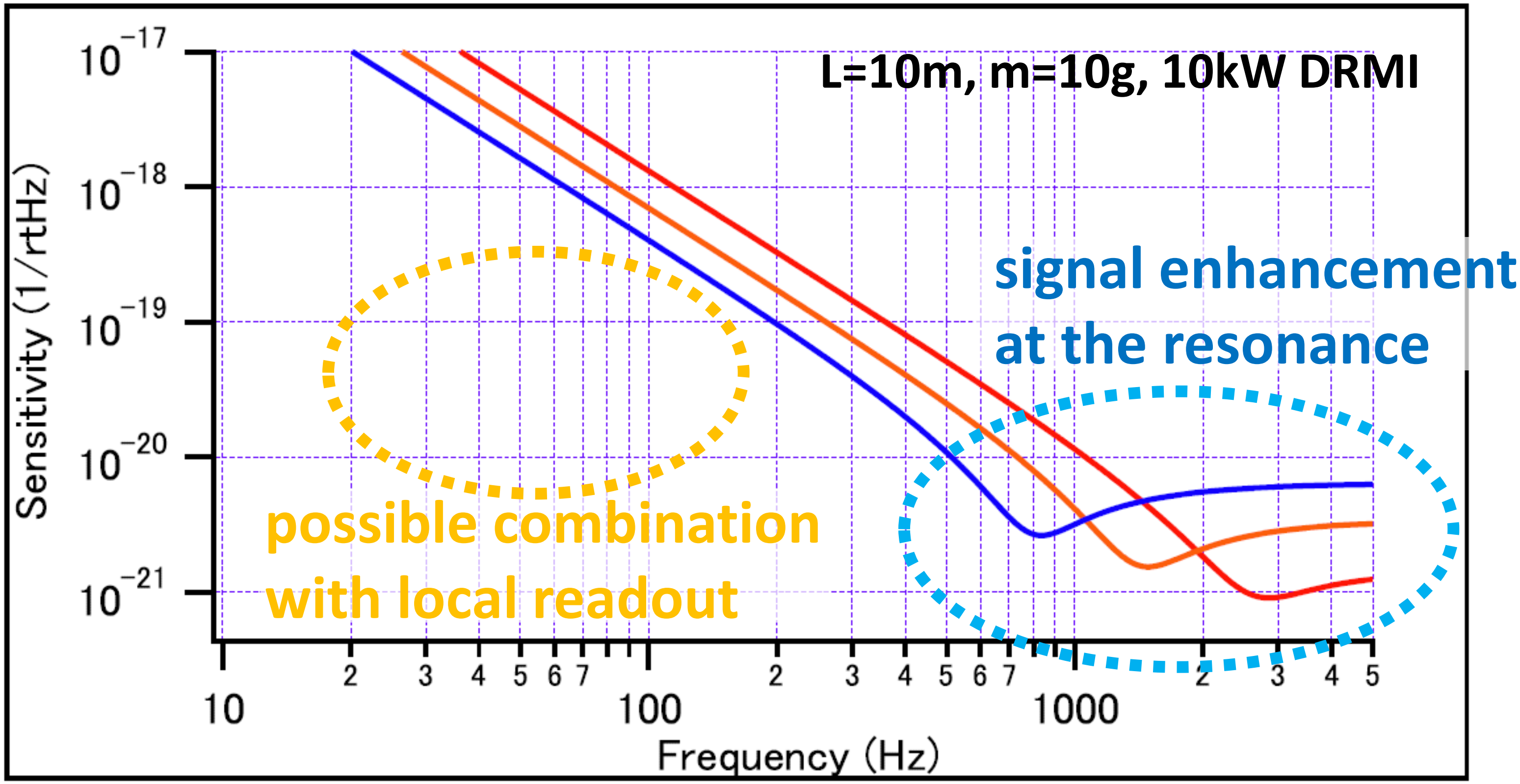


OPO can be used to increase the GW signal.

Both signal and noise increase so that no gain for SN ratio.

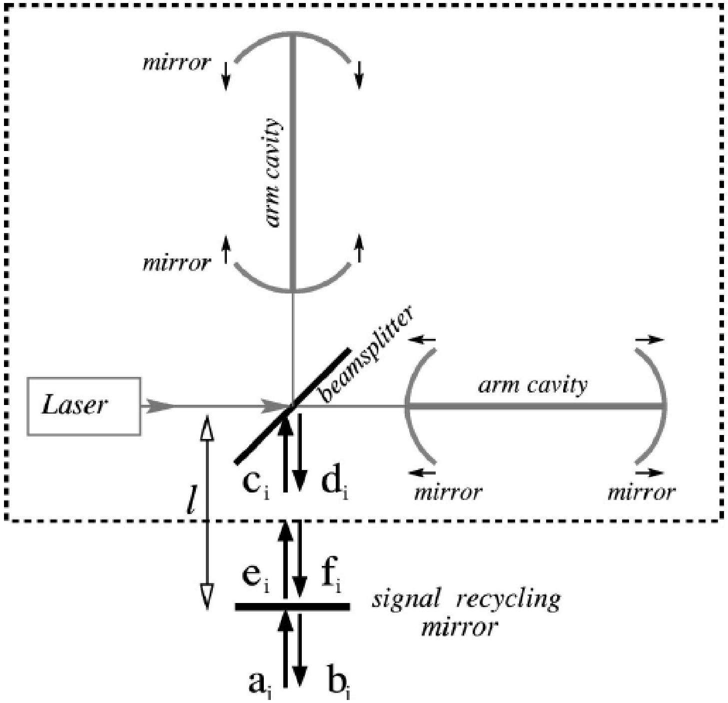
However, the dynamics will be changed (stiffer optical spring).

Usage of stiffer optical spring



- SN ratio improvement at the resonant frequency
- Strong against optical losses
- A hope to detect high-freq GW signals

Input-output relation of a detuned RSE



[Buonanno and Chen 2001]

$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = \frac{1}{M}\left[\begin{pmatrix} C_{11} & C_{12} \\ C_{21} & C_{22} \end{pmatrix}\begin{pmatrix} a_1 \\ a_2 \end{pmatrix} e^{2i\beta} + \sqrt{2K}\,\tau \begin{pmatrix} D_1 \\ D_2 \end{pmatrix} \frac{h_{GW}}{h_{SQL}} e^{i\beta}\right]$$

This M represents the rigidity of the spring.
Roots of $M=0$ give the optical spring freq.

$$\Omega^2(\Omega-\Omega_+)(\Omega-\Omega_-)+\frac{2\omega_0 I_0}{mL^2\gamma}(\Omega_+-\Omega_-)=0$$

Perturbation method from $I_0=0$ ($\Omega=0$) ⟶

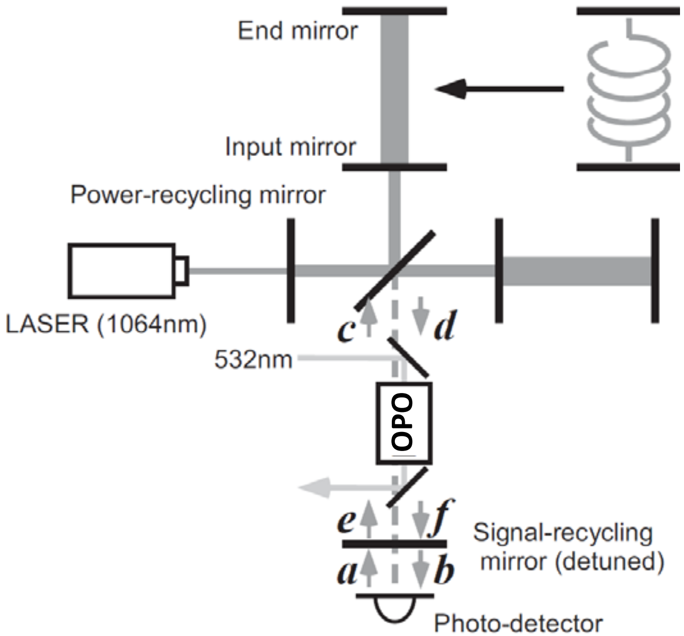
$$\Omega = \sqrt{\frac{8\omega_0 I_0}{mL^2\gamma^2}\frac{\sin 2\phi}{\left(r+\frac{1}{r}\right)-2\cos 2\phi}}$$

optical spring freq.

Note that denominator > 0

Input-output relation with intracavity amplifier

[arXiv:1403.1222]



Roots of $M=0$ read

$$\Omega^2(\Omega-\Omega_+)(\Omega-\Omega_-)+\frac{8\omega_0 I_0}{mL^2}\frac{\sin 2\phi}{\left(r+\frac{1}{r}\right)+\left(s+\frac{1}{s}\right)\cos 2\phi}=0$$

Perturbation method from $I_0=0$ ($\Omega=0$)

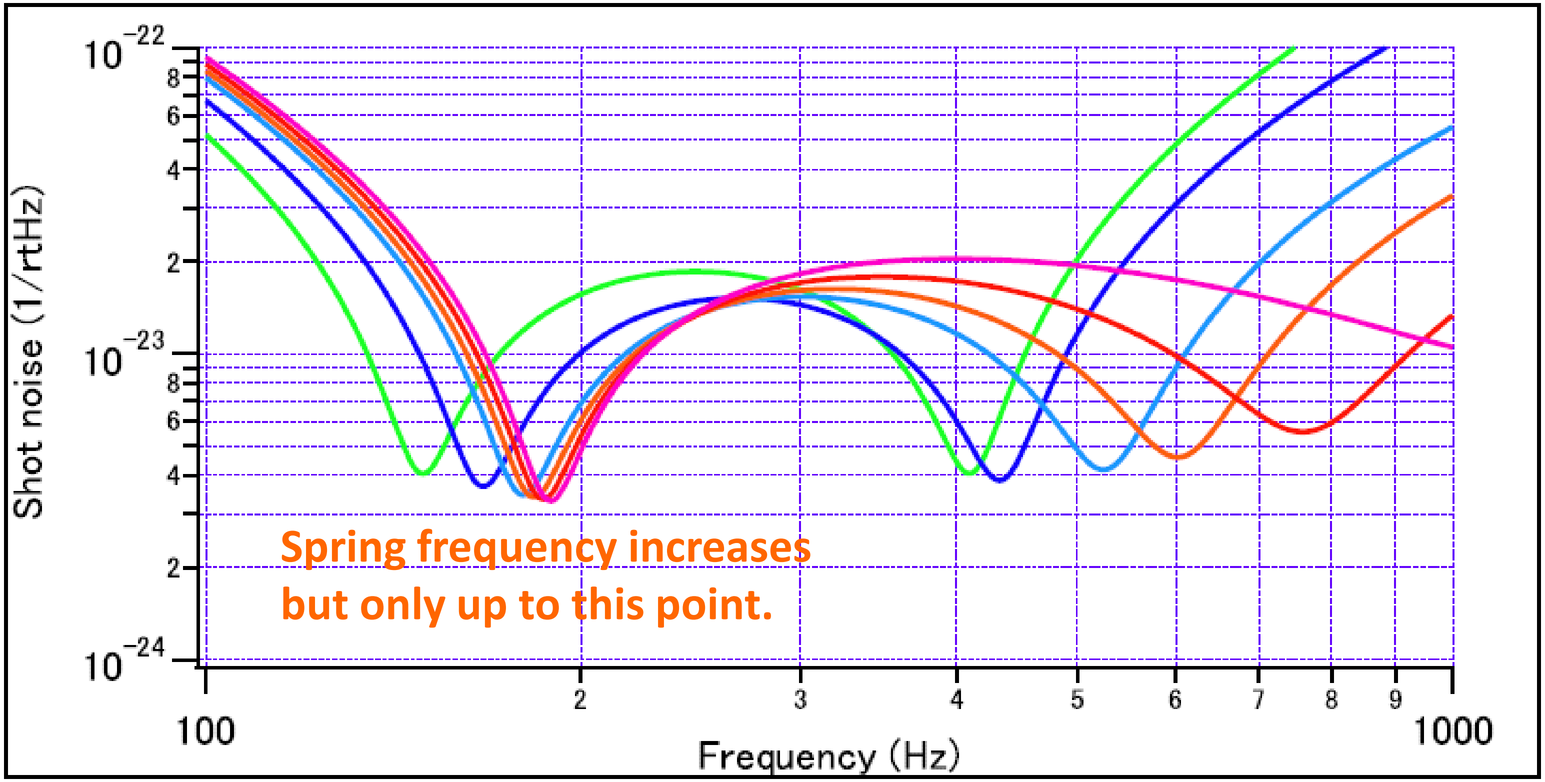
$$\longrightarrow \quad \Omega=\sqrt{\frac{8\omega_0 I_0}{mL^2\gamma^2}\frac{\sin 2\phi}{\left(r+\frac{1}{r}\right)-\left(s+\frac{1}{s}\right)\cos 2\phi}}$$

optical spring freq.

Note that denominator can be zero!

Input-output relation with intracavity amplifier

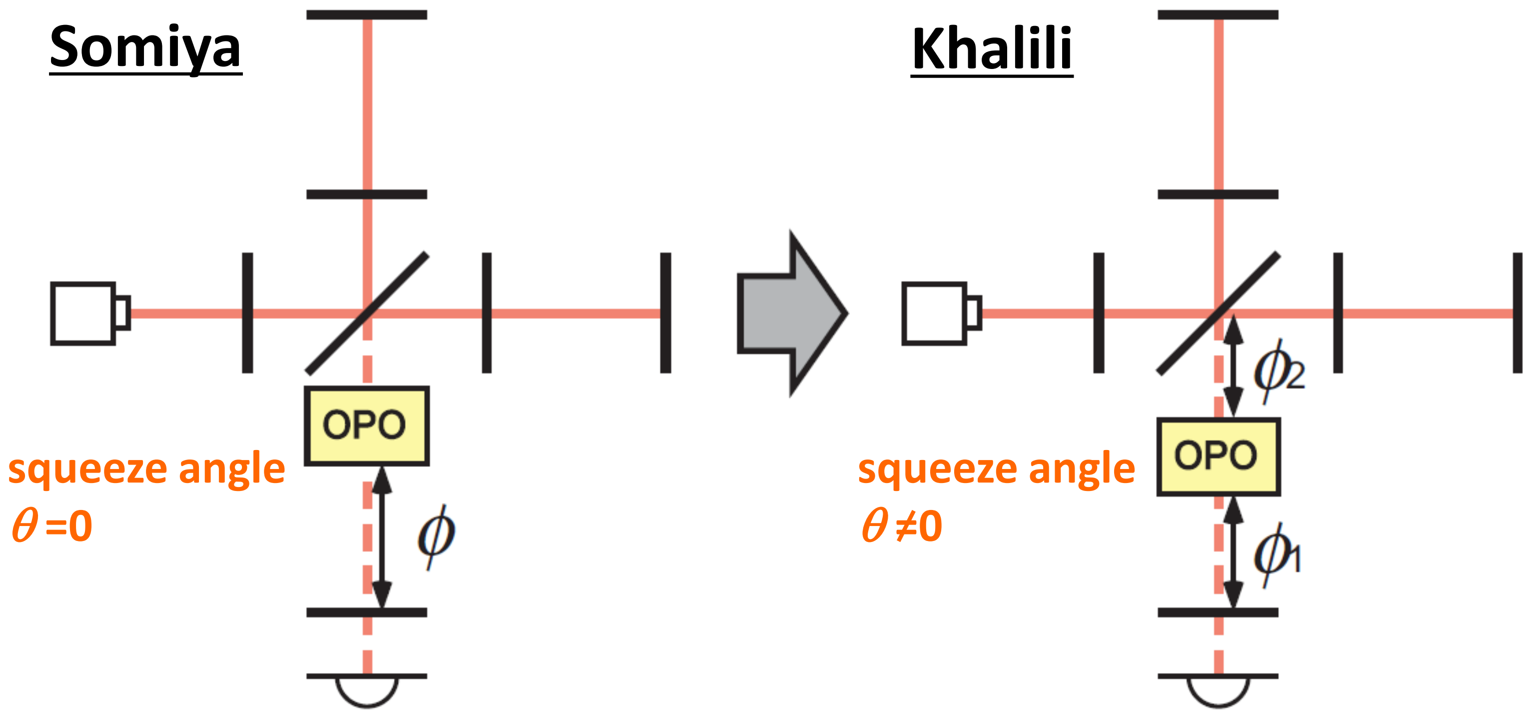
L=300m, SRM=95%, SQ=1.0, 0.8, 0.65, 0.6, 0.55, 0.5



- Behavior is different from increasing the laser power
- Spring frequency does not exceed a certain frequency (which is probably $\Omega_{\pm}$ i.e. a limit of the pertubation method)

Khalili's discovery in 2015

[in preparation]

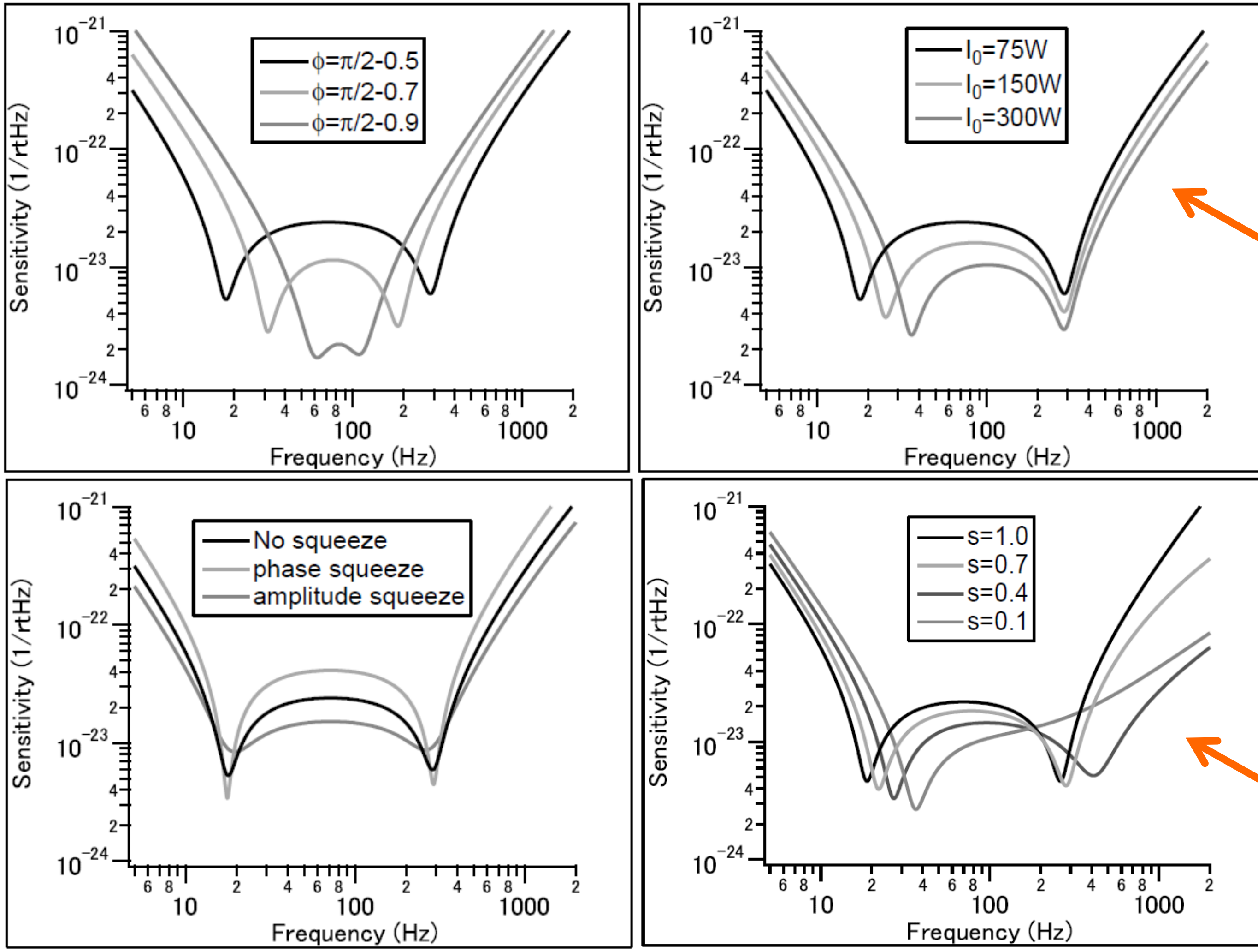


OPO location and squeeze angle turned out to be important.
With $\theta = \pi/4$ and ϕ_1 finely selected, the effective power reads

$$I_c = I_c^{unsqz} \times s$$

Comparison

[arXiv:1403.1222]



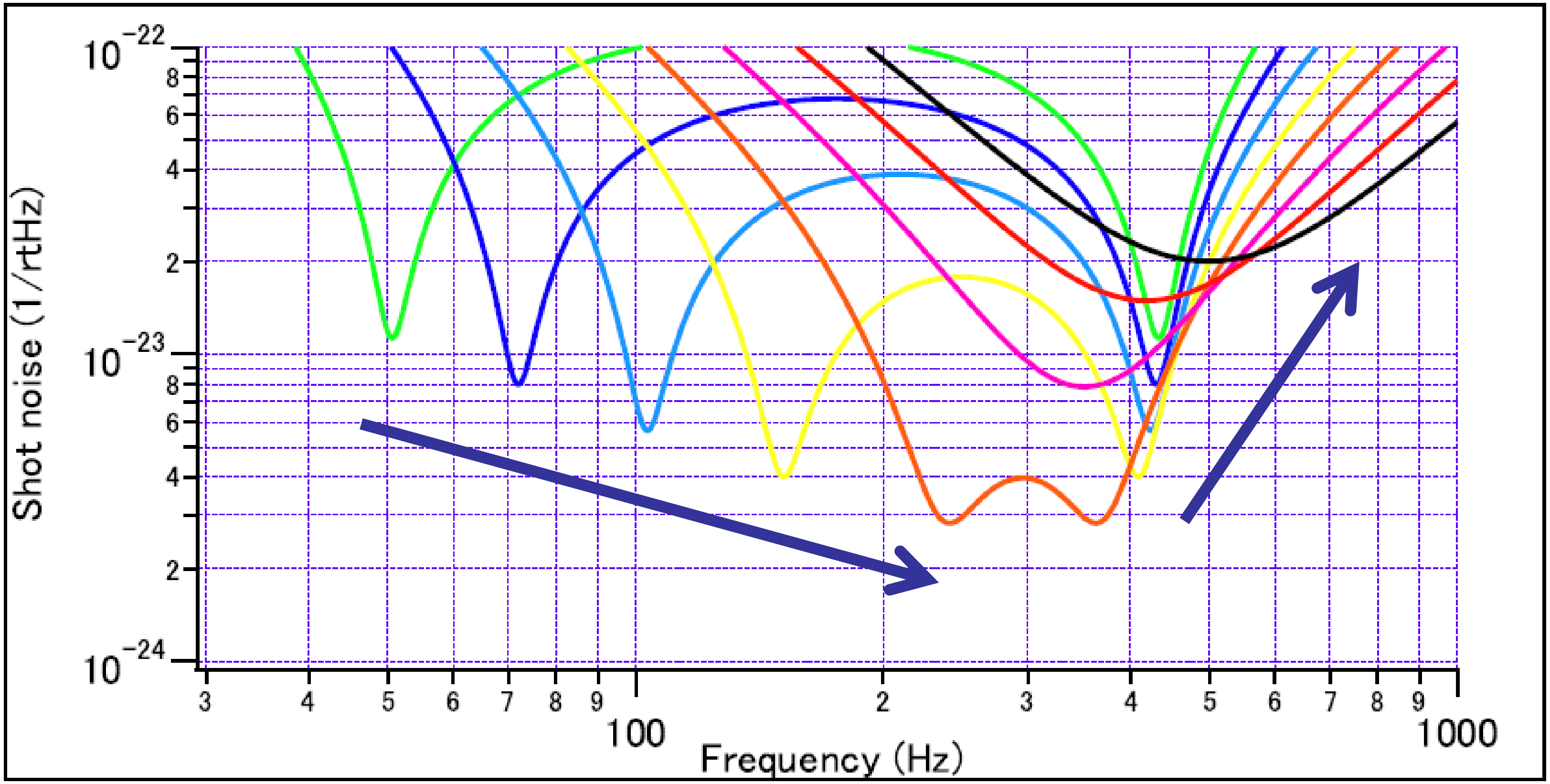
Khalili's amplifier would look like this.

Our amplifier looks like this.

More detailed calculations with optical losses are in Kataoka's poster.

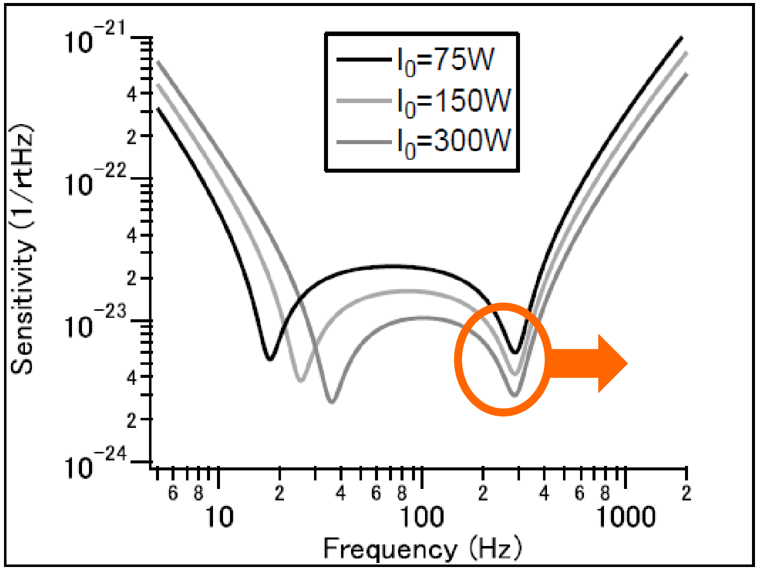
Optical spring with even higher power

L=300m, SRM=95%, I0=100W, 200W, 400W, ...

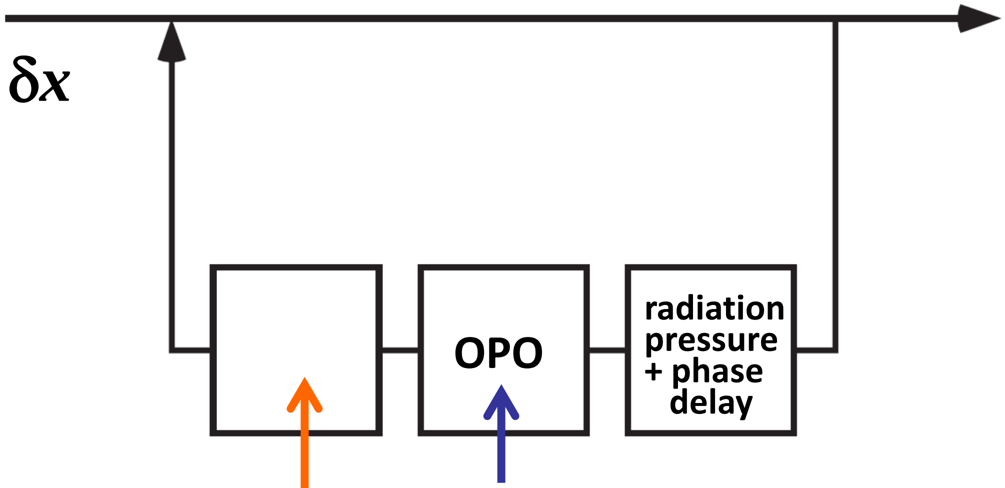


After optical spring reaches the optical resonance, the sensitivity starts to get worse with power.

Miao's idea



Optical spring is a sort of feedback system.



OPO just add some gain.

What we need to broaden the bandwidth is a phase compensator.

- **Can we realize a phase compensator?**
- **How far can we push up the optical spring frequency?**
- **White-light interferometer?**

Summary of the overview

- **There are a number of intracavity methods**
- **Intracavity parametric amplifier is a way to push up the optical spring frequency**
- **Khalili has modified Somiya's method to make it more powerful**
- **Miao has pointed out a concept to further increase the optical spring frequency with a phase compensator**

Supplementary slides

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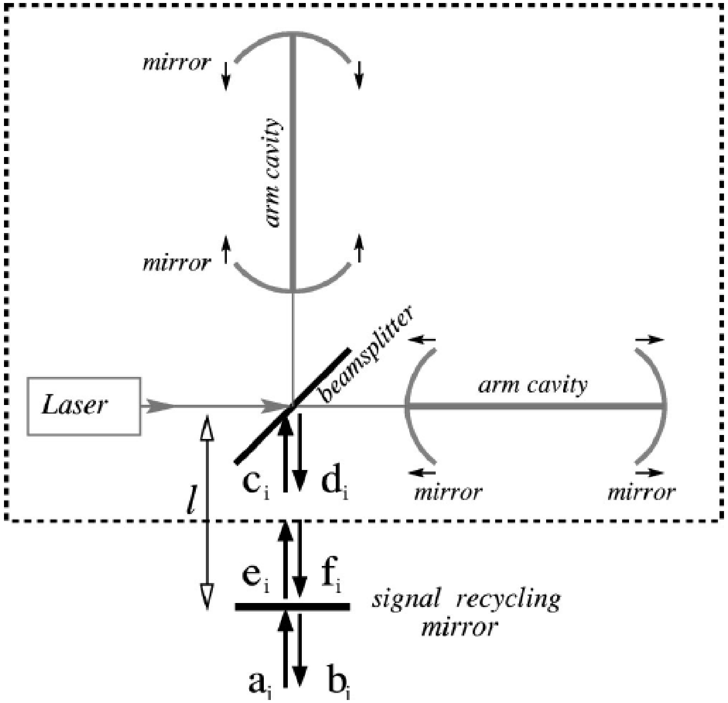

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$$\Omega_\pm = \frac{\pm 2r\gamma \sin 2\phi - it^2\gamma}{1+2r\cos 2\phi + r^2}$$

$$\Omega = \sqrt{\frac{8\omega_0 I_0}{mL^2\gamma^2}}\,\frac{\sin 2\phi}{\left(r+\frac{1}{r}\right)-2\cos 2\phi}$$

Perturbation method from $I_0=0$ ($\Omega=0$)