Parametric amplification for a high-frequency GW detection

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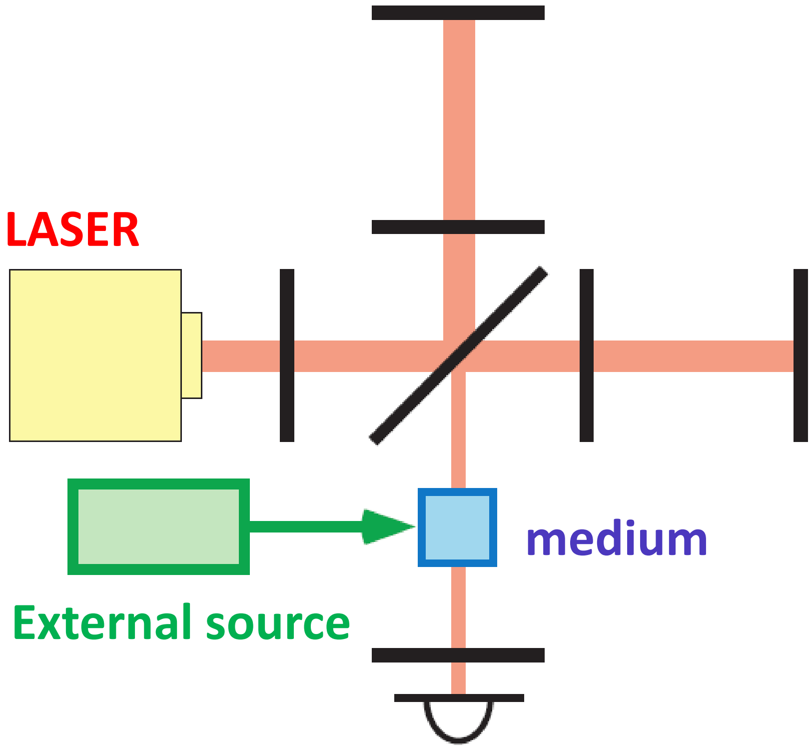
Intracavity regime



(1) Medium = Phase-squeezer

→ Intracavity squeezing

(2) Medium = Amplitude-squeezer

→ Signal amplifier

* SR cavity has to be detuned

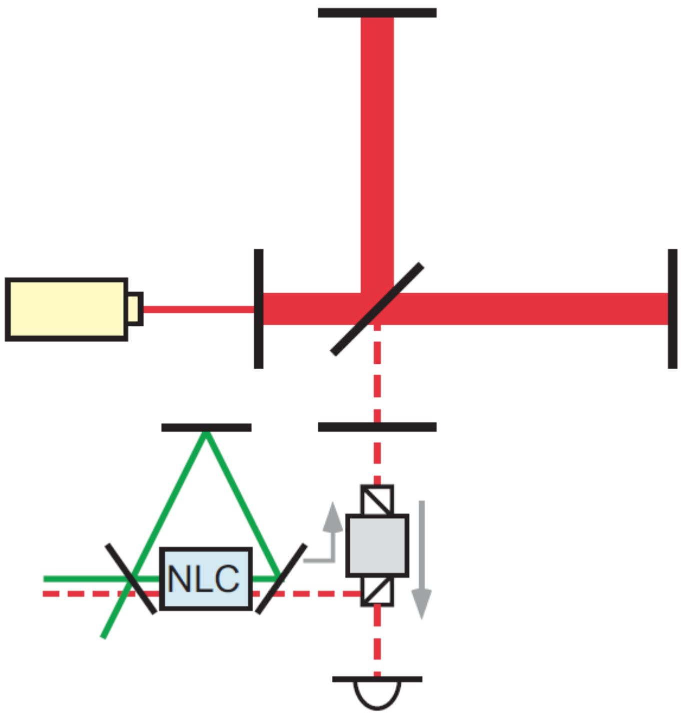
(3) Medium = Phase compensator

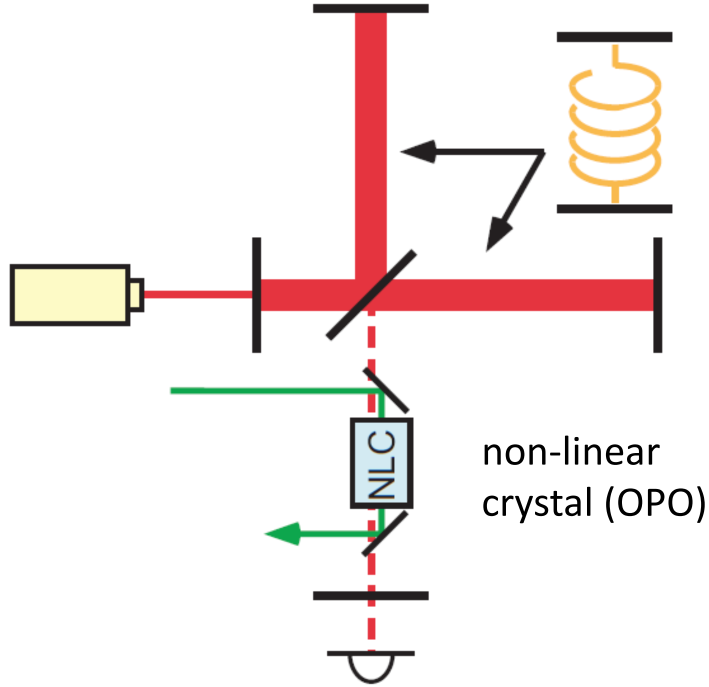
→ White-light cavity

This talk is about the signal amplifier.
The goal is to improve the sensitivity above a few kHz, aiming at BNS mergers, supernovae, etc.

Squeezer and amplifier

We assume a GEO-type interferometer (DRMI).



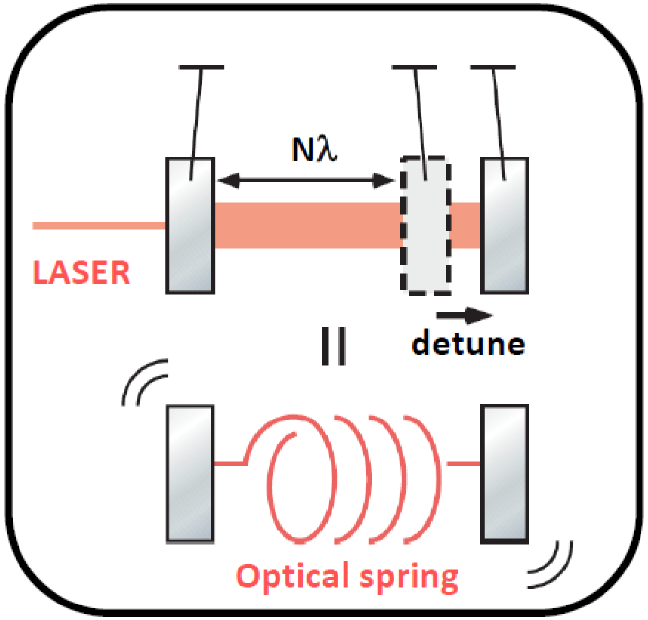


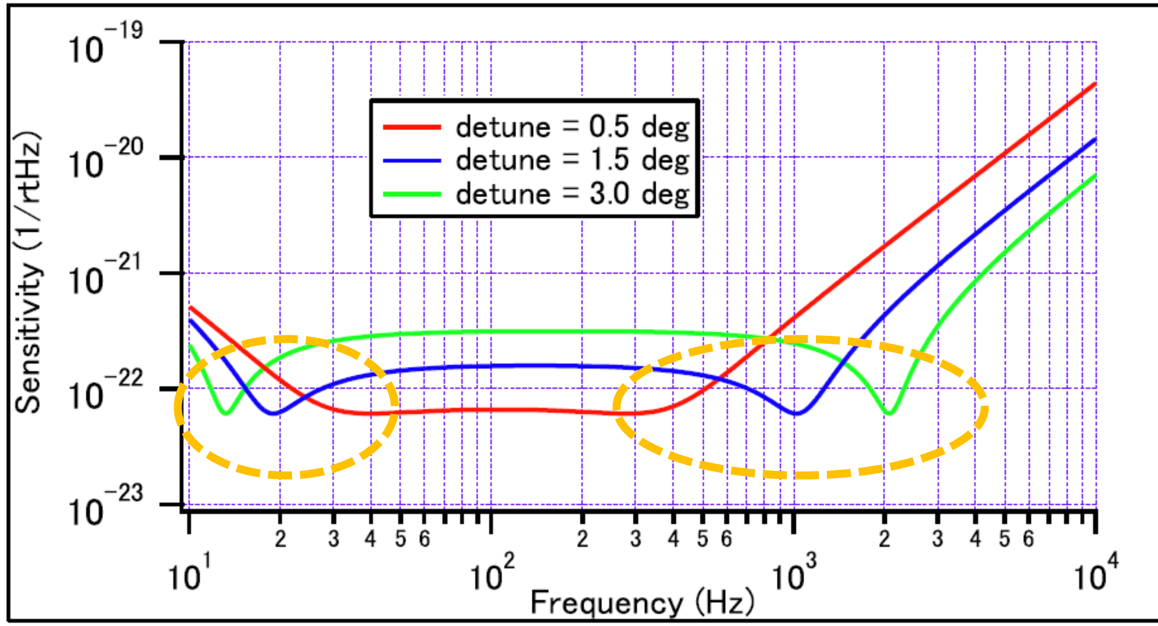
Input squeezing
- decreases noise
- weak against losses
- R&D complete

Parametric amplifier
- increases signal
- strong to losses
- R&D on-going

Optical spring

With GEO parameters:
L=1200m, SRM=98%, m=5.6kg



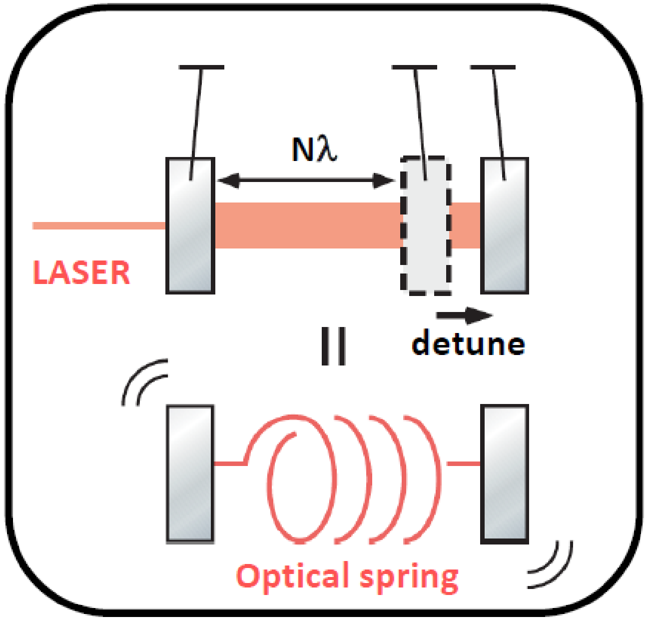


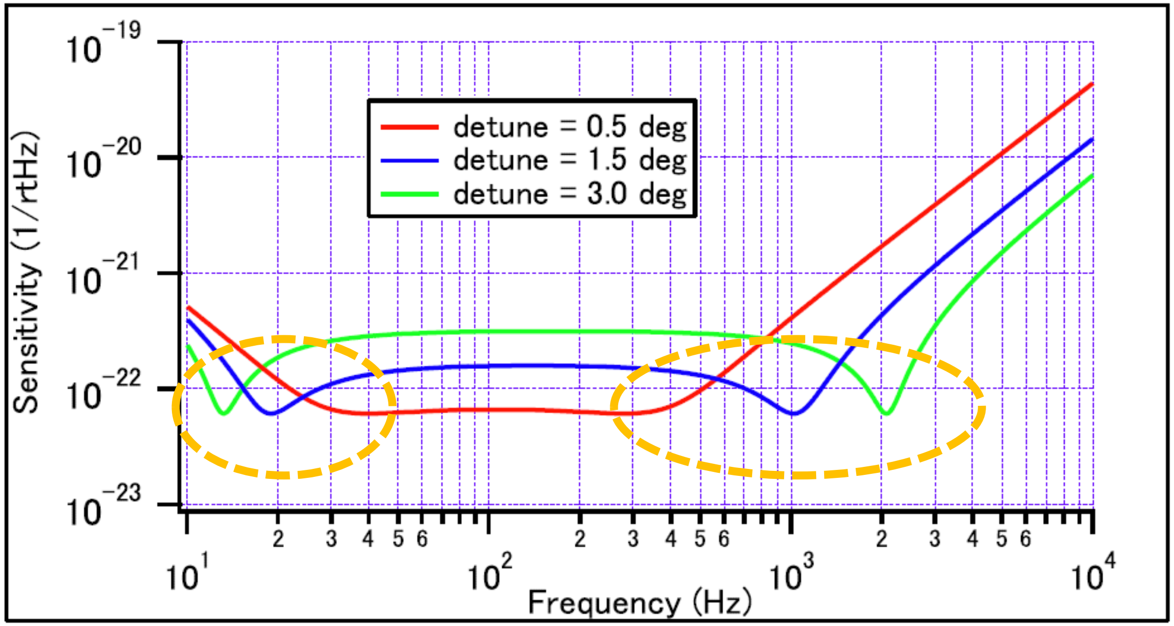
Optical spring $\Omega \propto \sqrt{\dfrac{\sin 2\phi}{\left(r+\frac{1}{r}\right) - 2\cos 2\phi}}$ **decrease with the detune phase**

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

Optical spring

With GEO parameters:
L=1200m, SRM=98%, m=5.6kg



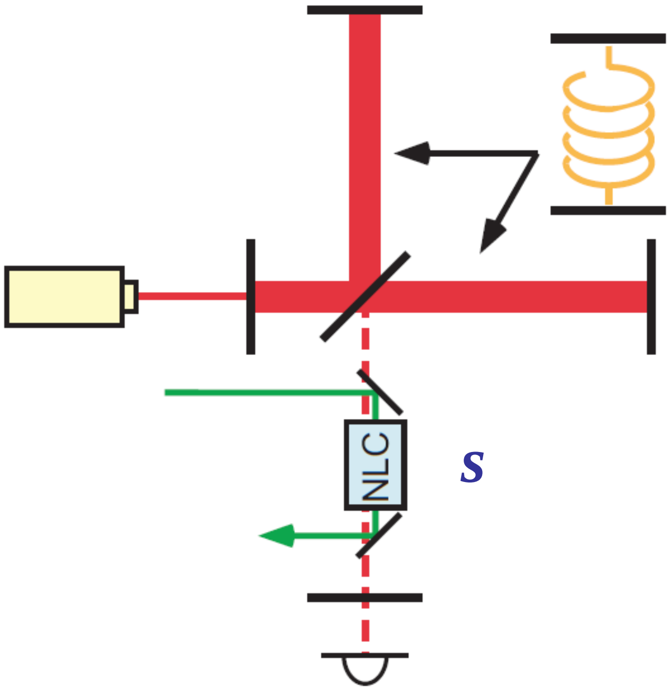


Spring freq cannot exceed the optical resonance.
Highest frequency is given with $\Omega_{spr}=\Omega_{reso}$:

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

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

Parametric signal amplification



Optical spring w/o OPO

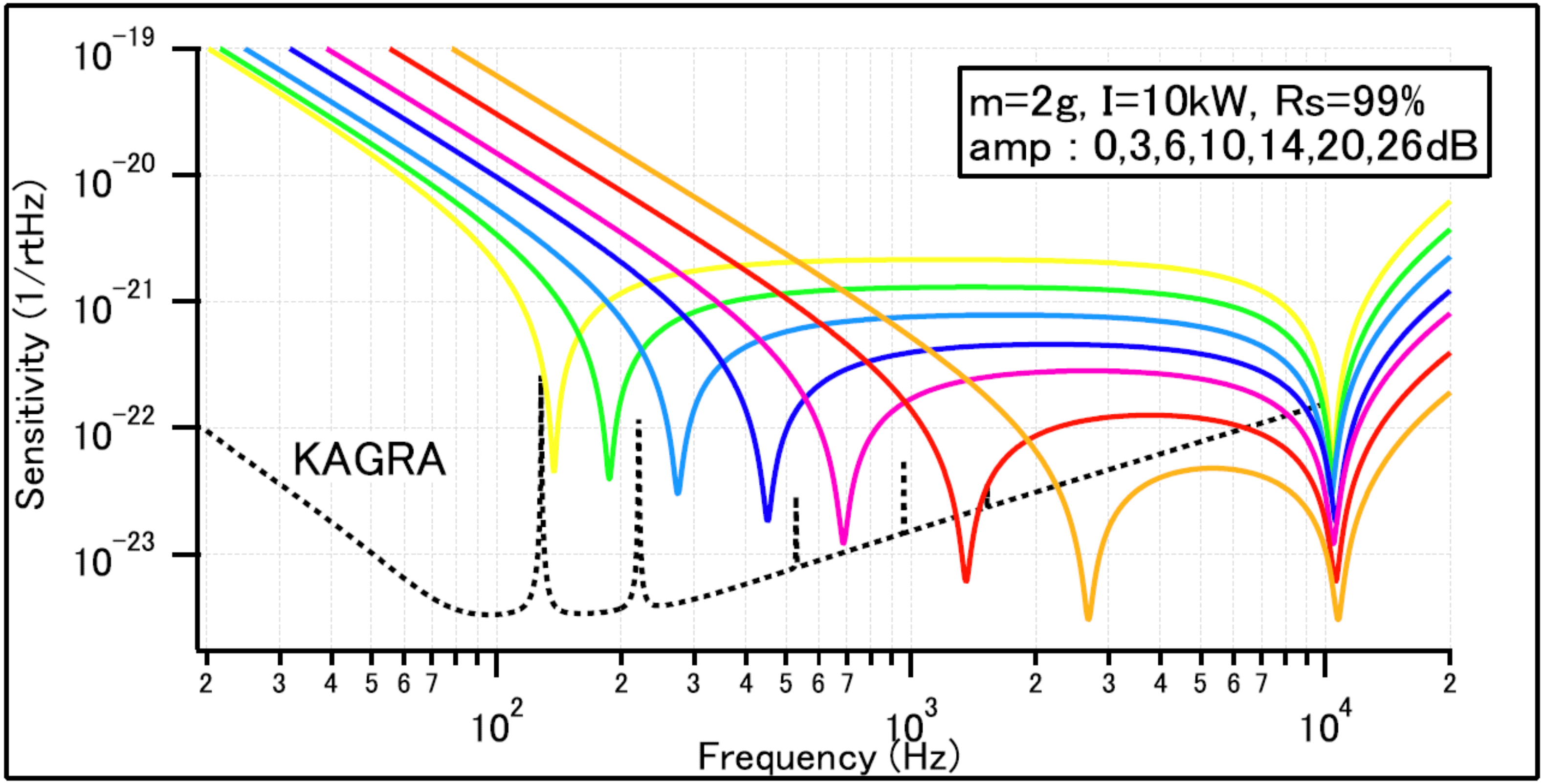
$$\Omega \propto \sqrt{\frac{\sin 2\phi}{\left(r+\frac{1}{r}\right)-2\cos 2\phi}}$$

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.

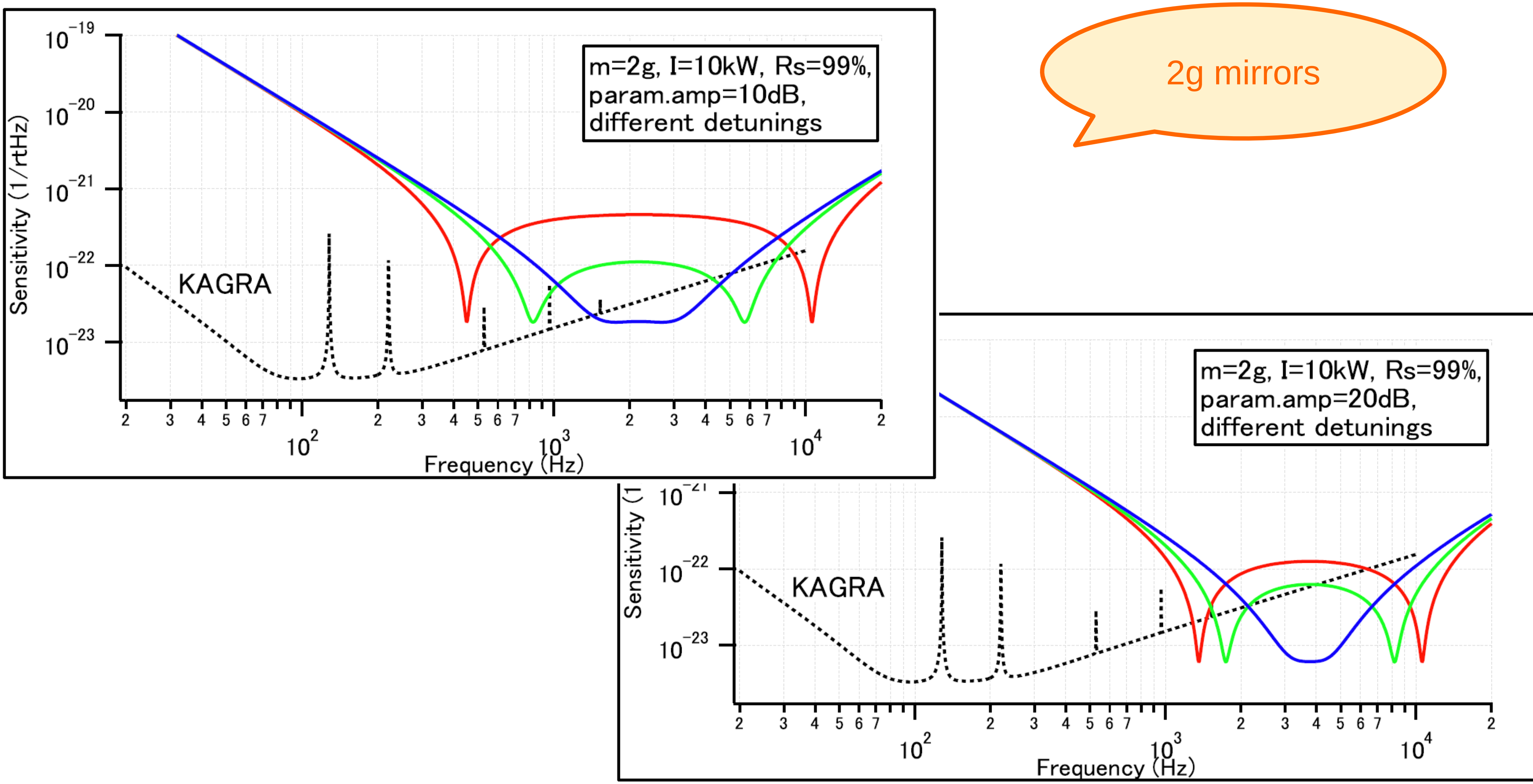
Optical spring shifts



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

Quantum noise spectra with 2g mirrors

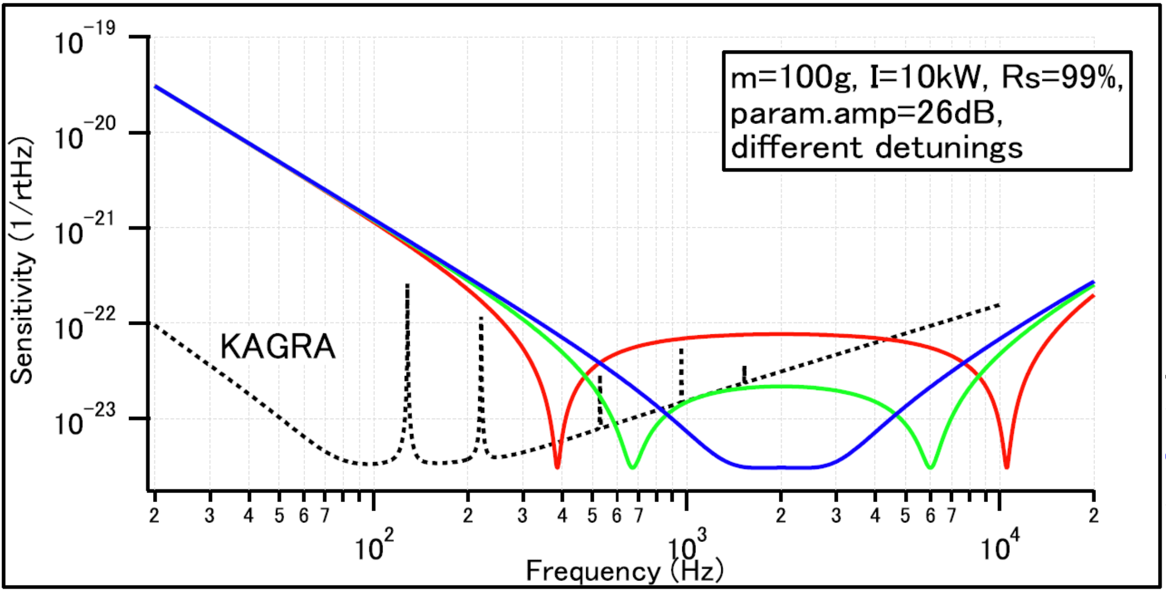
2g mirrors

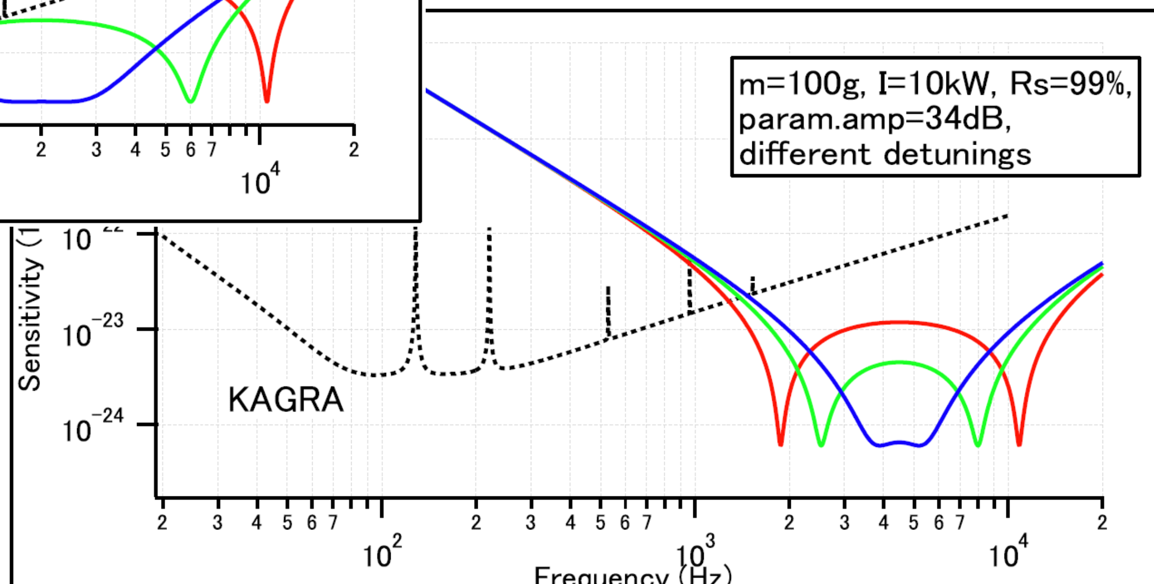


The higher the OPO gain, the sharrower but deeper the quantum noise spectrum.

Quantum noise spectra with 100g mirrors

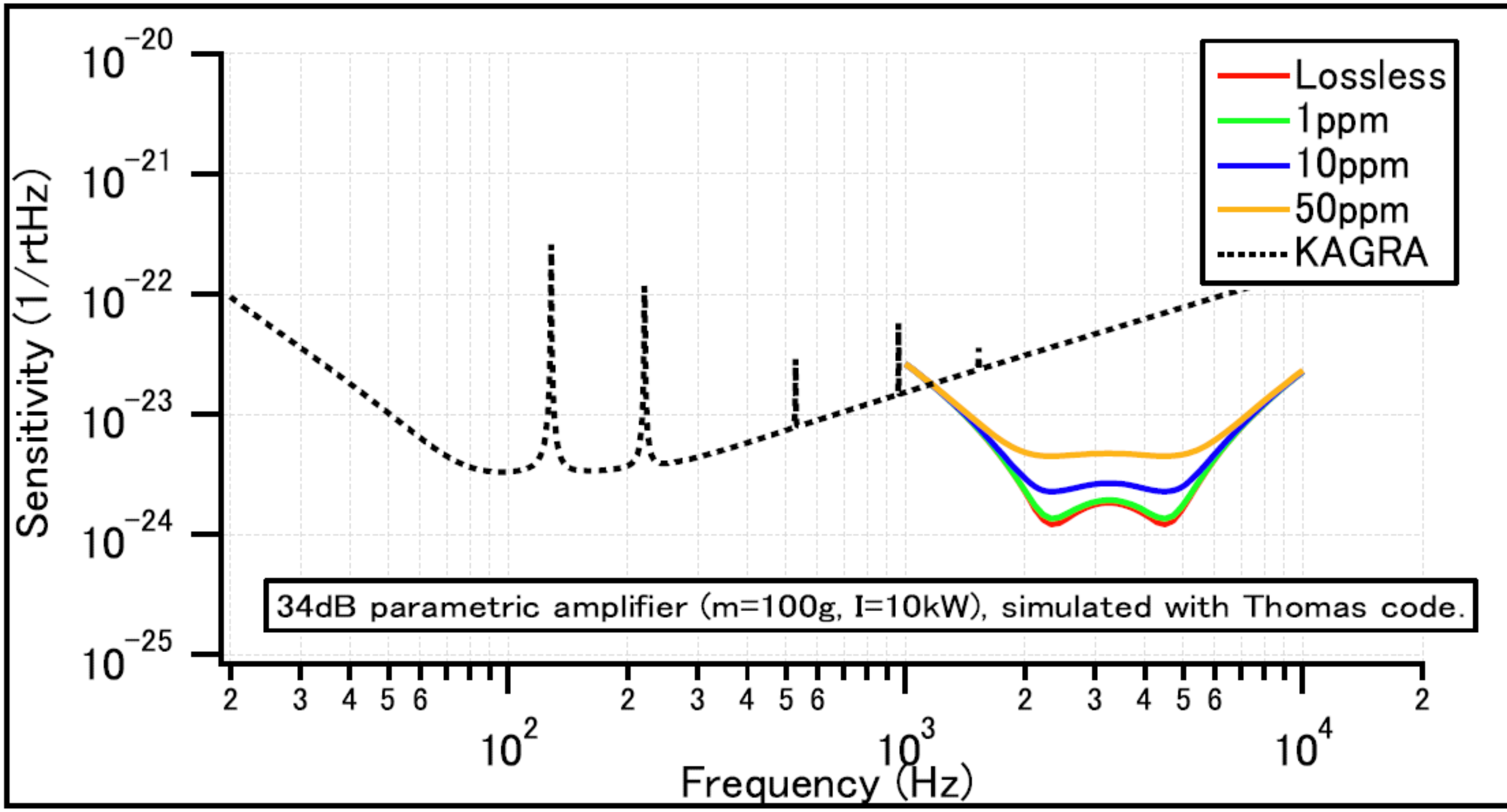
100g mirrors





With heavier mirrors, the sensitivity improvement is more but the required OPO gain becomes higher.

Including optical losses



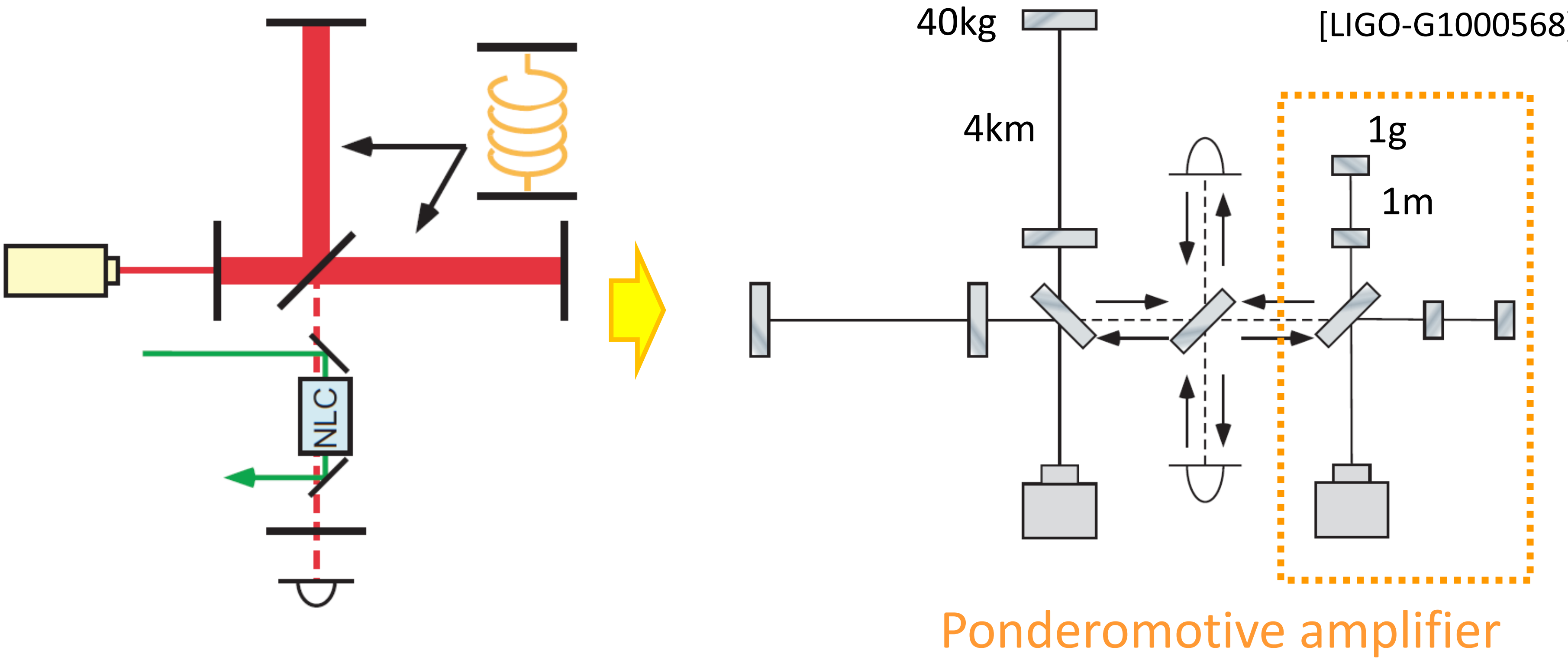
- Optical loss of the test mass does not change the spring frequency but the sensitivity becomes a bit worse.
- Optical loss in the SRM does not affect the sensitivity.

Summary

- Parametric amplifier helps shifting the optical spring to higher frequencies
- The heavier the mass, the more sensitivity gain but with higher OPO gain
- Optical loss of the test mass does matter but not too much (SRM loss does not matter; OPO loss has not been implemented yet)
- This could be a suitable scheme for GEO-HF upgrade

Supplementary slides

Frequency-dependent parametric amplifier



- The right panel is from our slides in GWADW 2010
- It is Yanbei's idea to realize Khalili's optical lever
- Signal amplification at each frequency

Frequency-dependent parametric amplifier

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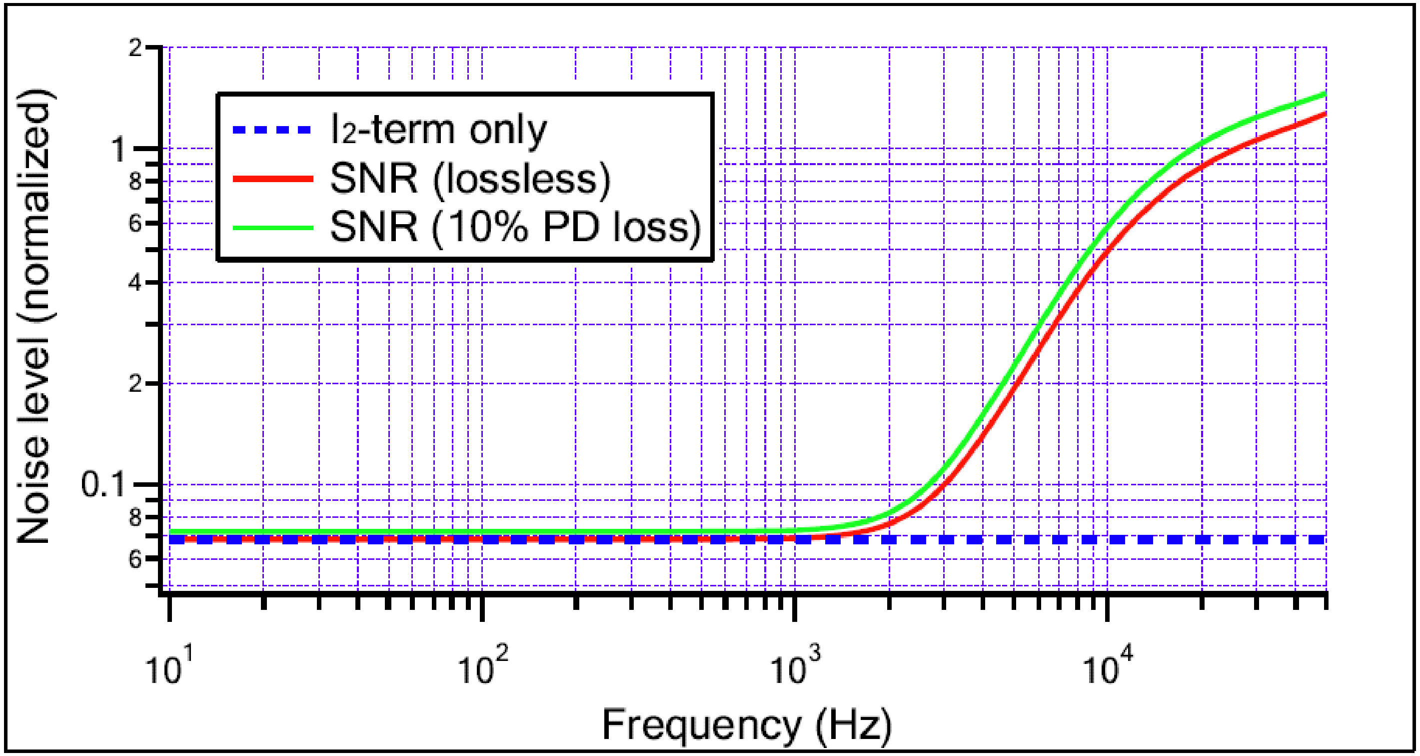

- Signal amplification below a few kHz
- We should reinvestigate this technique