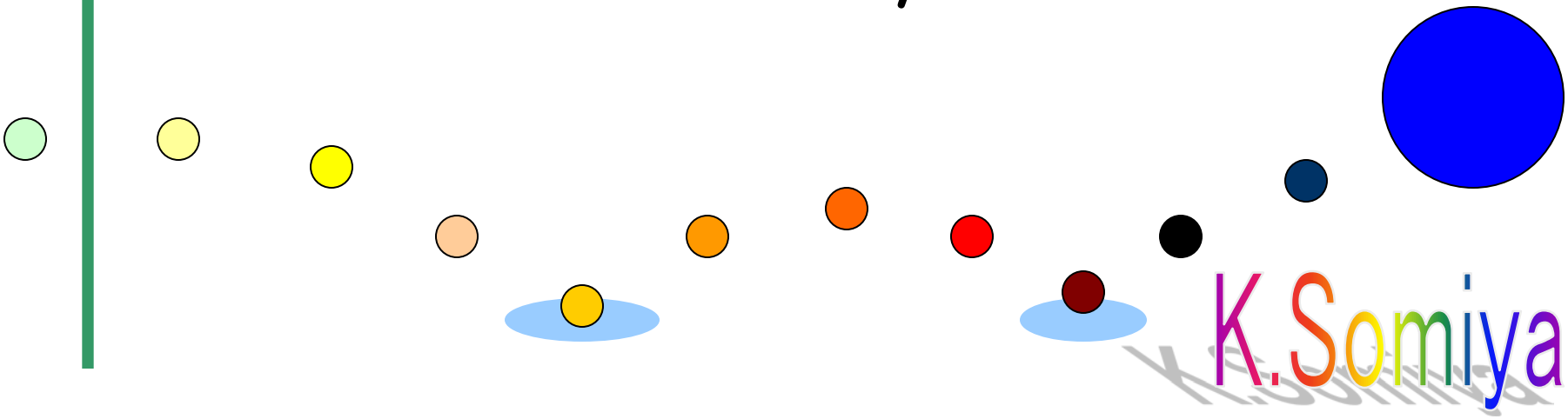
A new topology for future detectors

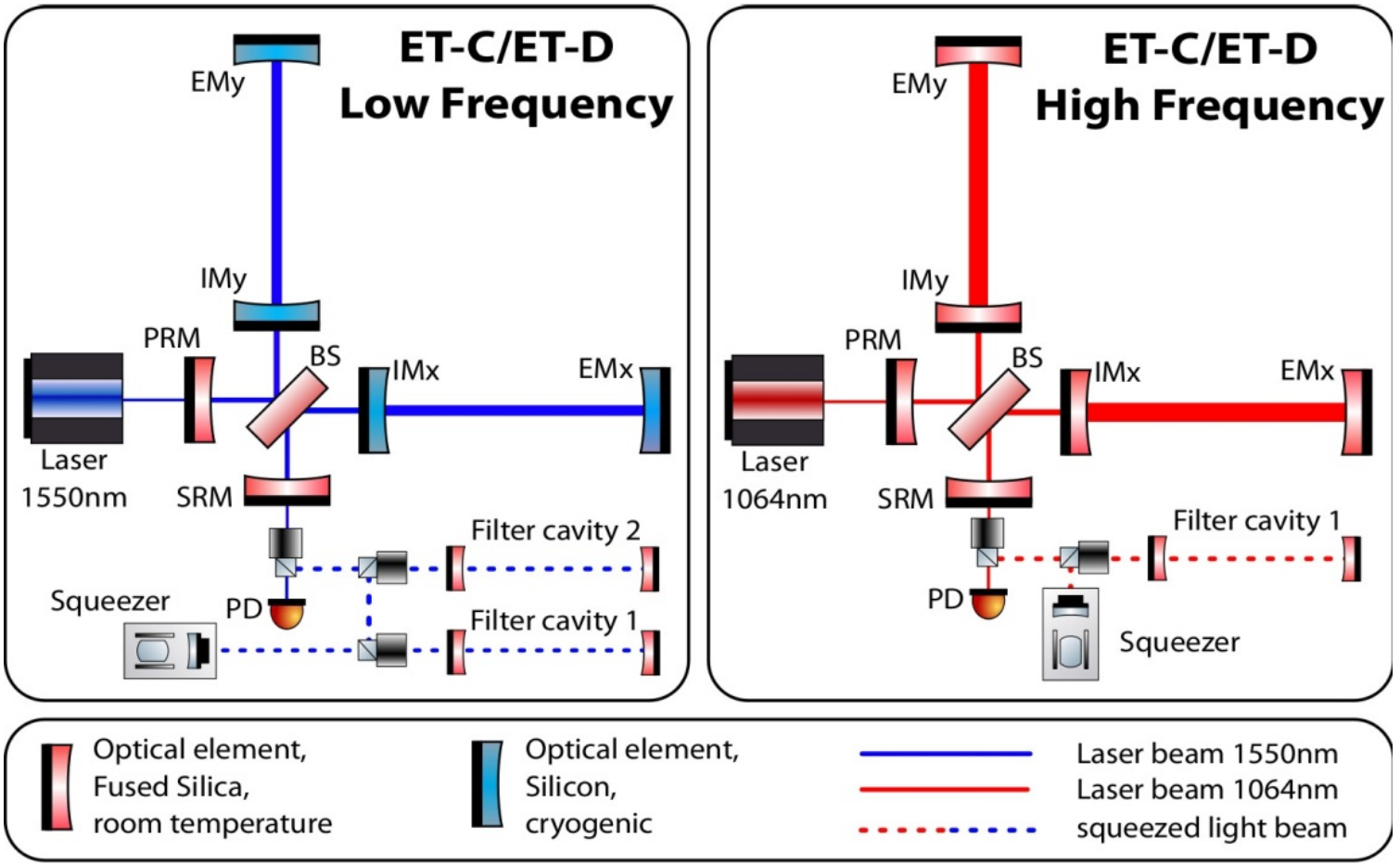
the 4th ET Meeting
Dec 4, 2012

Tokyo Inst of Technology

K.Somiya

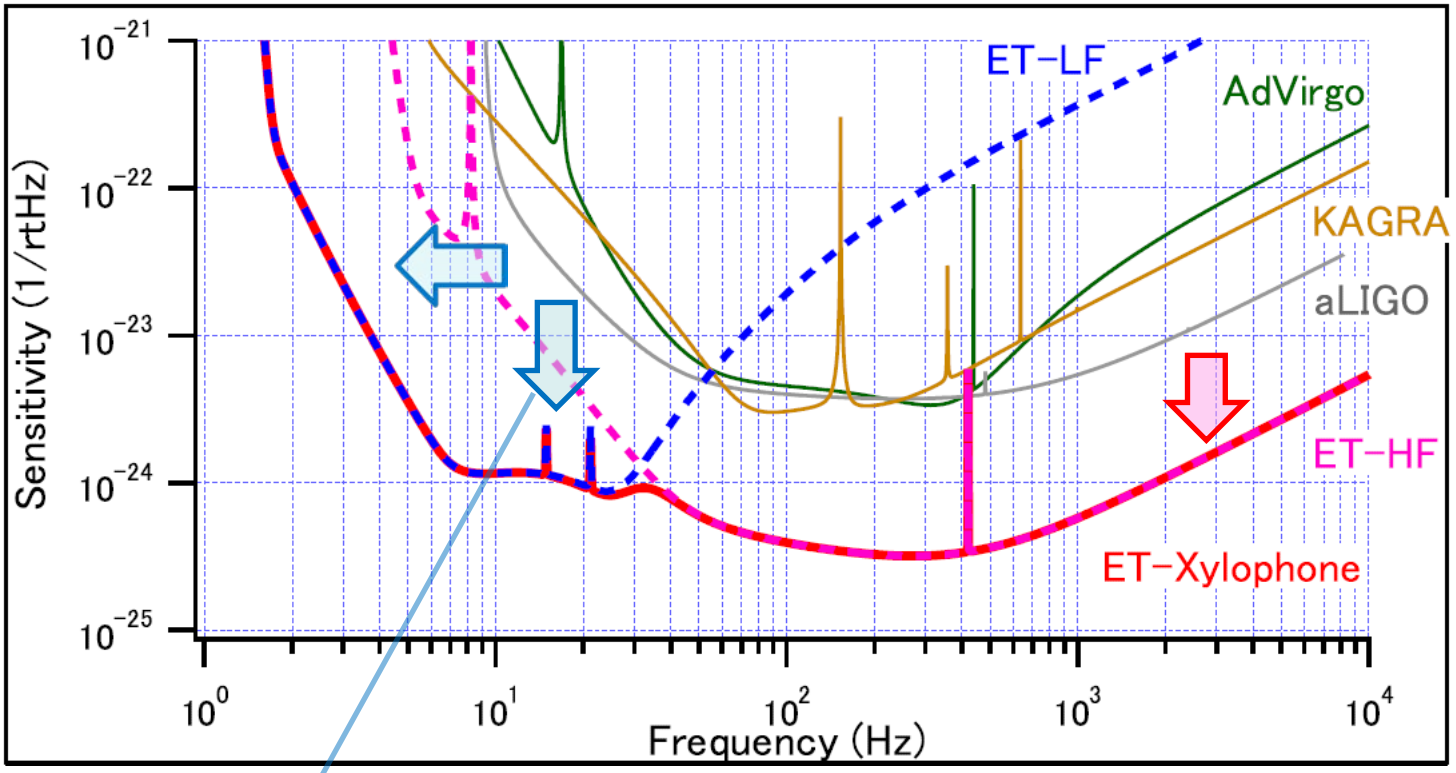


ET optical configuration



- Xylophone with 20K LF and 300K HF detectors
- Frequency-dependent squeezing with filter cavities

ET Sensitivity

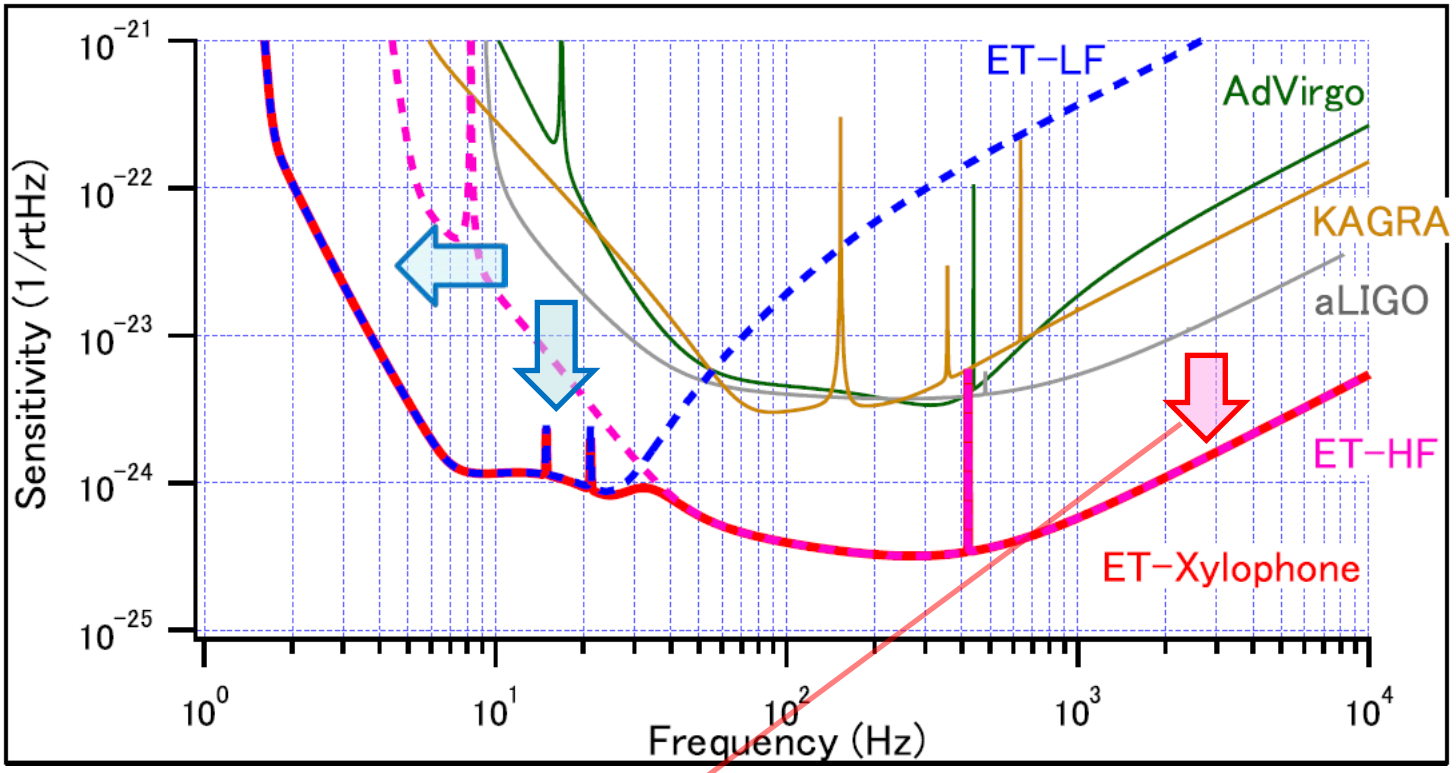


[Low-frequency Sensitivity]

- Underground & Cryogenic
- Detuned RSE with filter cavity
- Alternative configuration: Speed-meter

-> Stefan's talk

ET Sensitivity



[High-frequency Sensitivity]

- √10 for squeezing
- √4 for power
- √2.5 for length

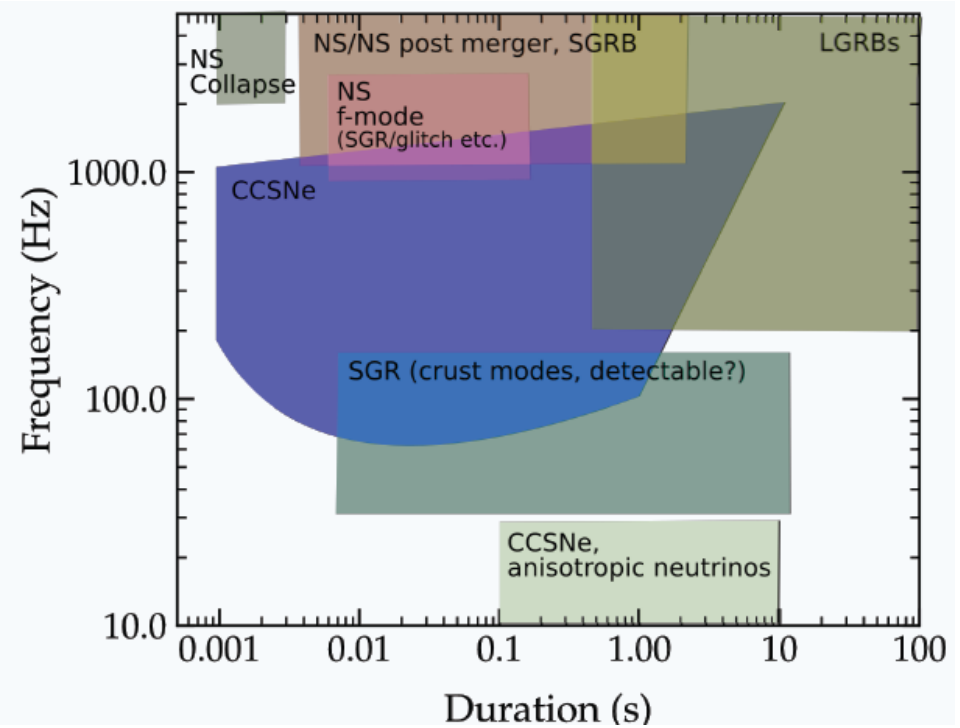
} x10 better than 2G

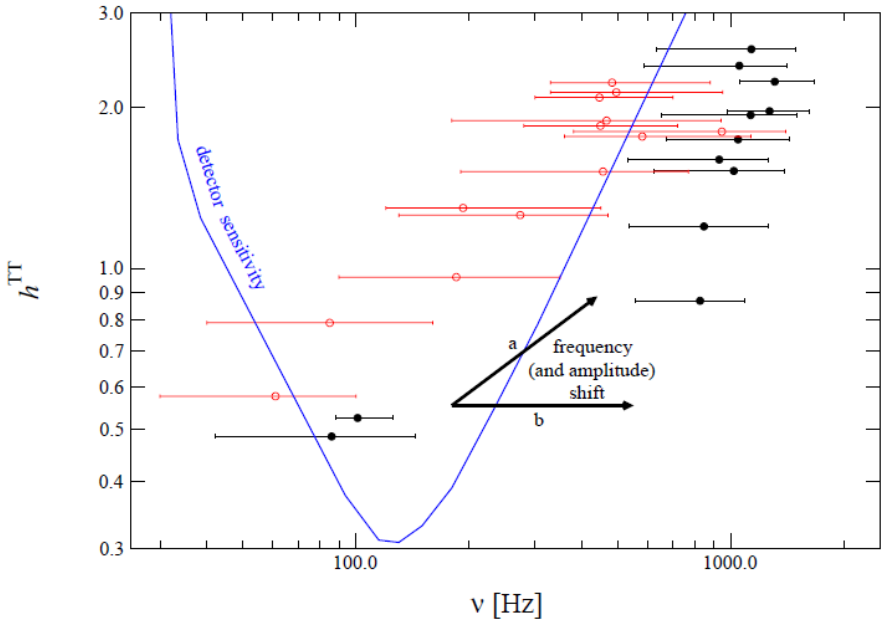
- Limited by shot noise above 1kHz

GW at high frequencies

- Supernovae
- GRB
- LMXB
- BNS coalescences

[Ott 2011]





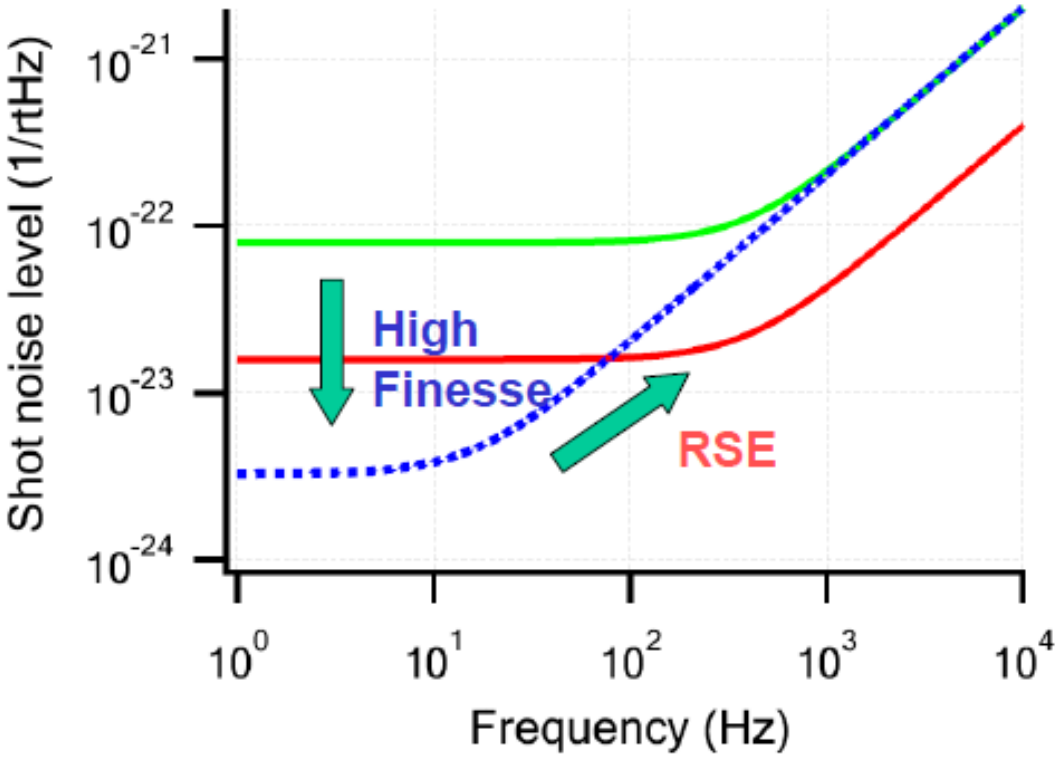
[Dimmelmeier 2002]

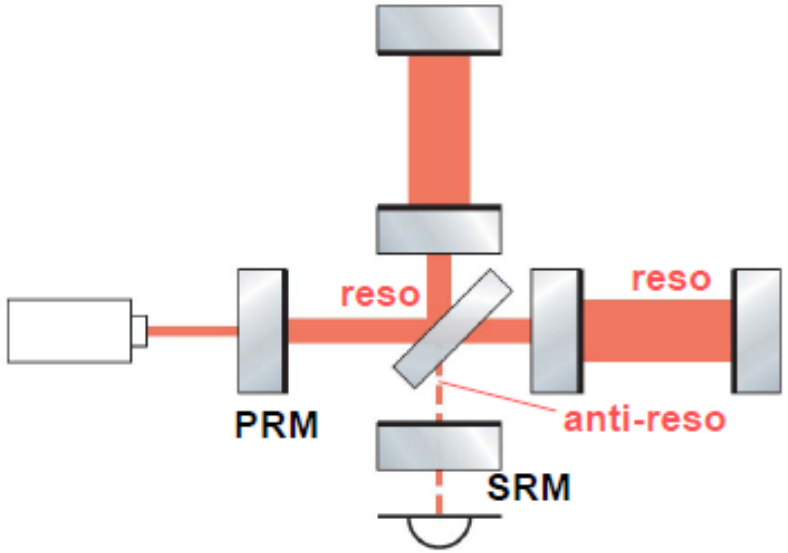
More Astronomical interests at high freq.

Advanced configurations for HF GWs

- Optical bar regime [Braginsky 1997] [Rehbein 2007]
- Optical lever [Khalili 2002] [Chen 2003]
- Parametric amplifier [KS and Chen, GWADW 2010]
- Intra-cavity squeezing

Bandwidth of conventional IFOs

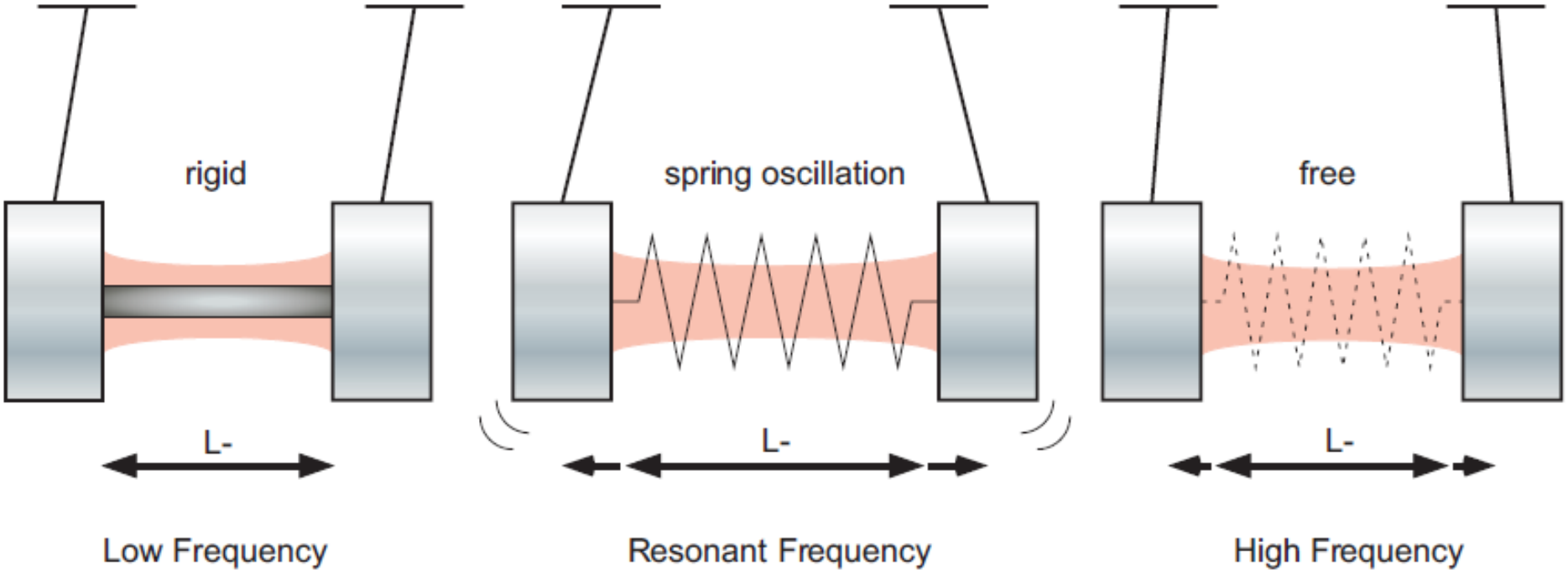




In RSE, carrier is in anti-resonance in the SRC.
If the arm were shorter, SR gain could be more.

Concept of the bar regime

With detuning…

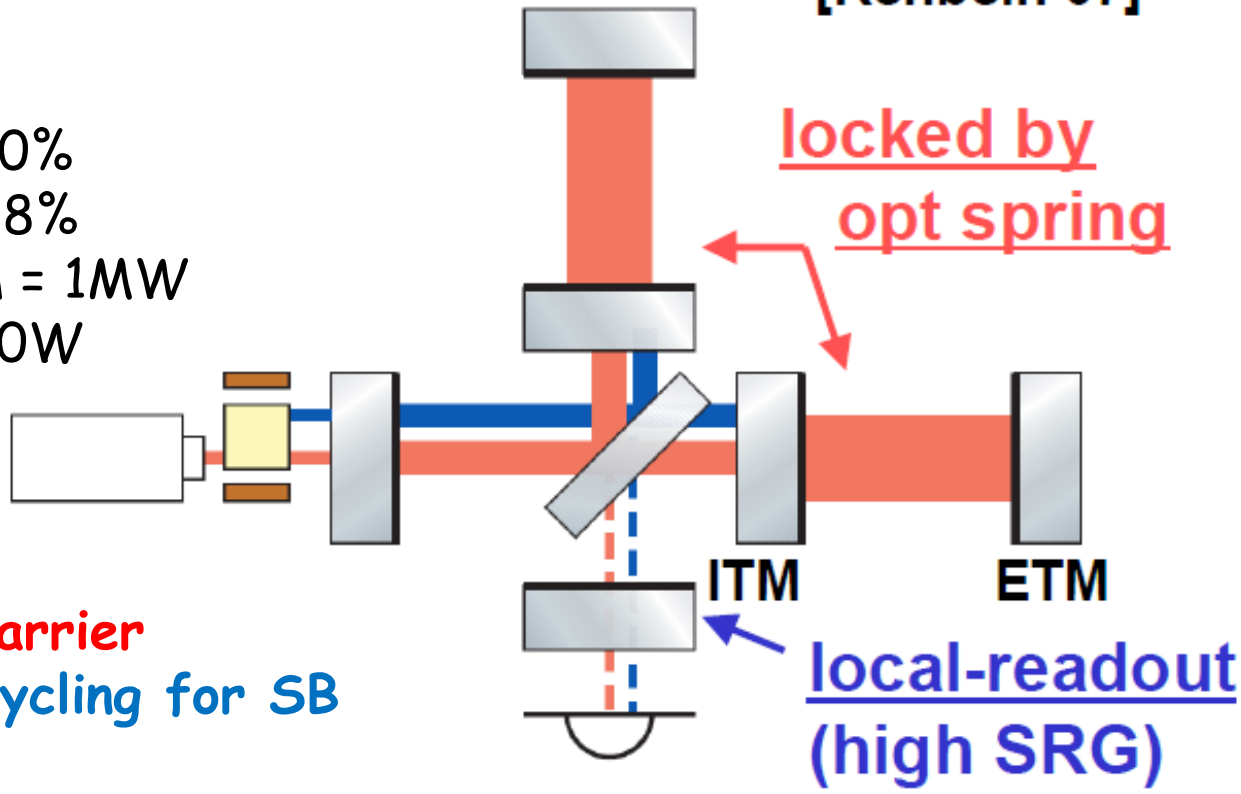


ITM and ETM move together below resonance.
GW can be measured by a local motion of ITM.

Optical Bar in ET

ETM mass = 10kg
ITM mass = 1g
ITM reflectivity = 80%
SRM reflectivity = 98%
Carrier power in arm = 1MW
SB power at BS = 100W

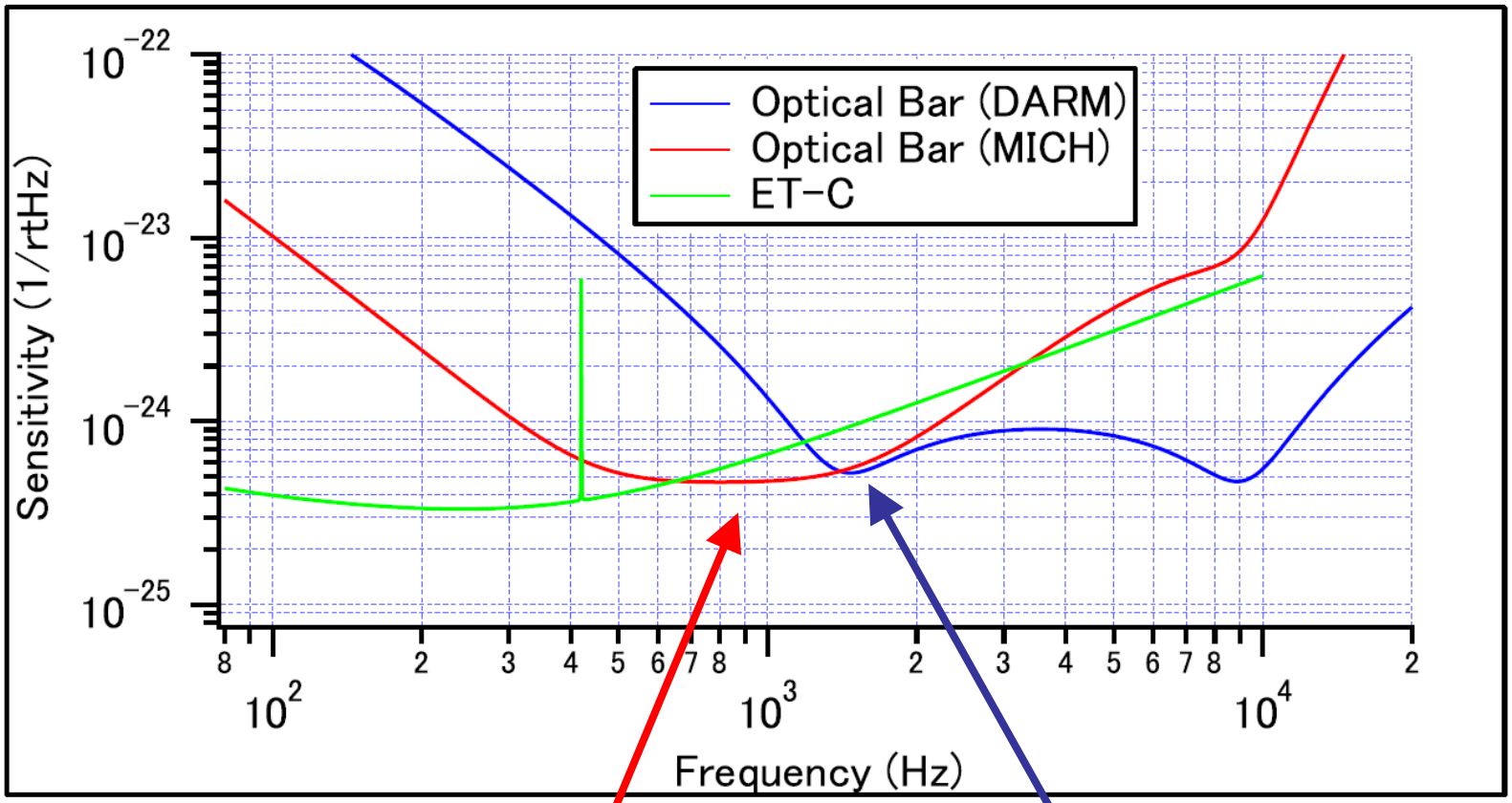
[Rehbein 07]



Detuned RSE for Carrier
Broadband dual recycling for SB

Small mirrors and low-finesse arm cavities to raise the optical spring frequency.

Optical Bar in ET

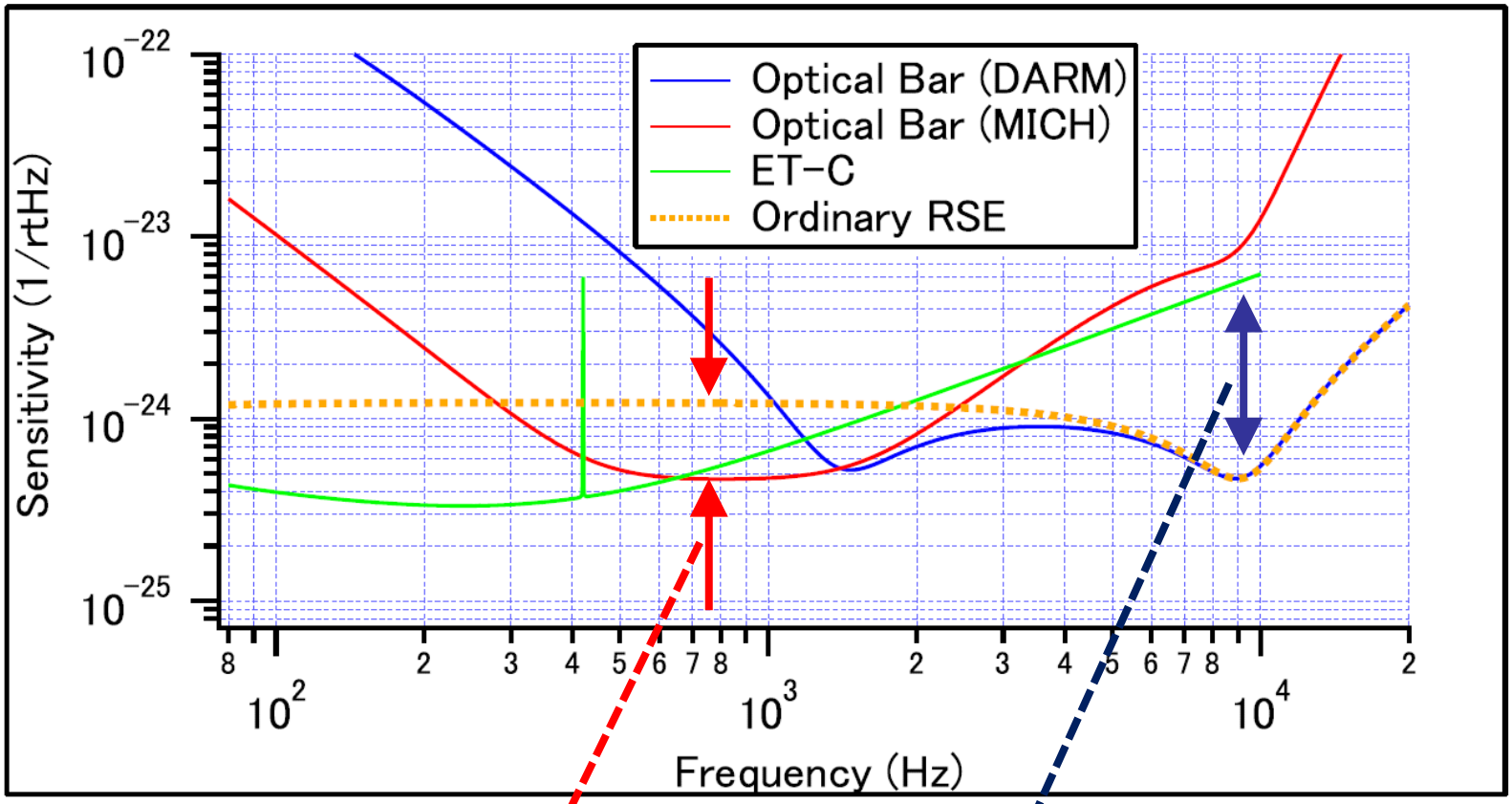


Local readout of a rigid bar

Optical Spring

GW detection both in ordinary L- measurement and local control of central Michelson IFO.

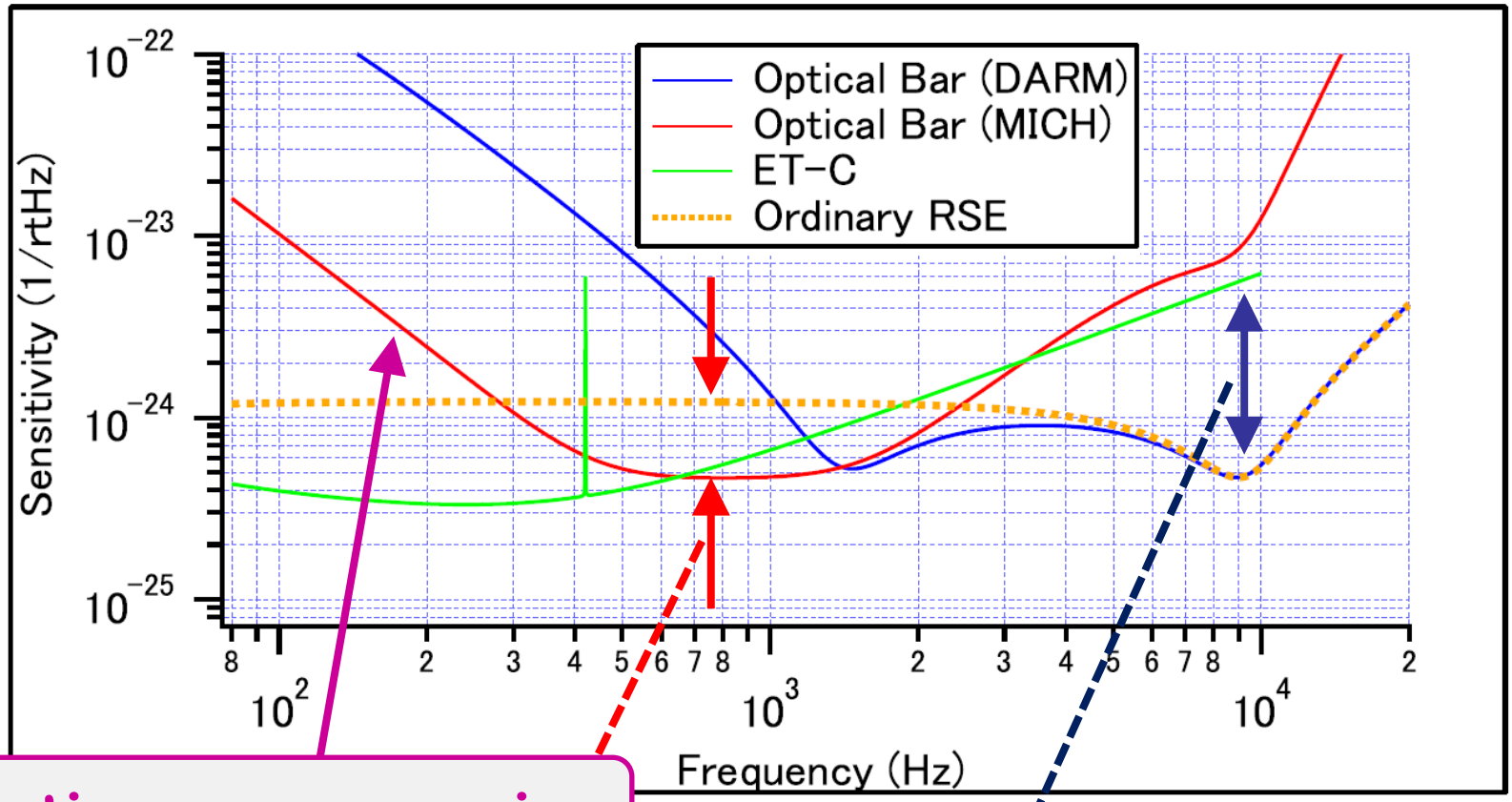
Optical Bar in ET



High SR gain in
the short Michelson IFO

High optical resonance
with low finesse arms

Optical Bar in ET



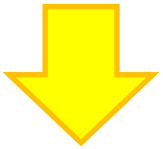
radiation pressure noise

High SR gain in
the short Michelson IFO

High optical resonance
with low finesse arms

Optical Bar to Optical Lever

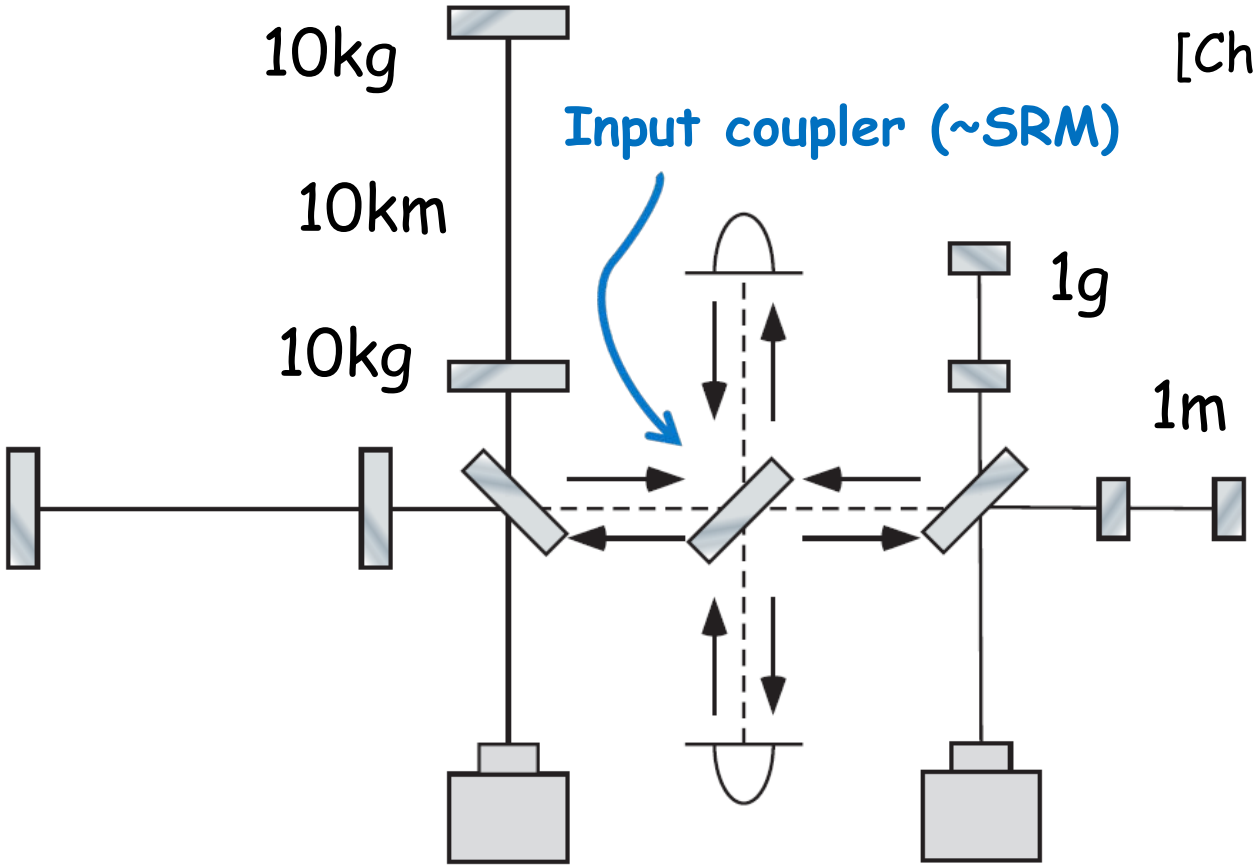
Optical Bar: high power on the small mirror to raise the spring frequency



Optical lever: high power on a big mirror and lower power on a small mirror

Optical lever is rather like an amplifier.

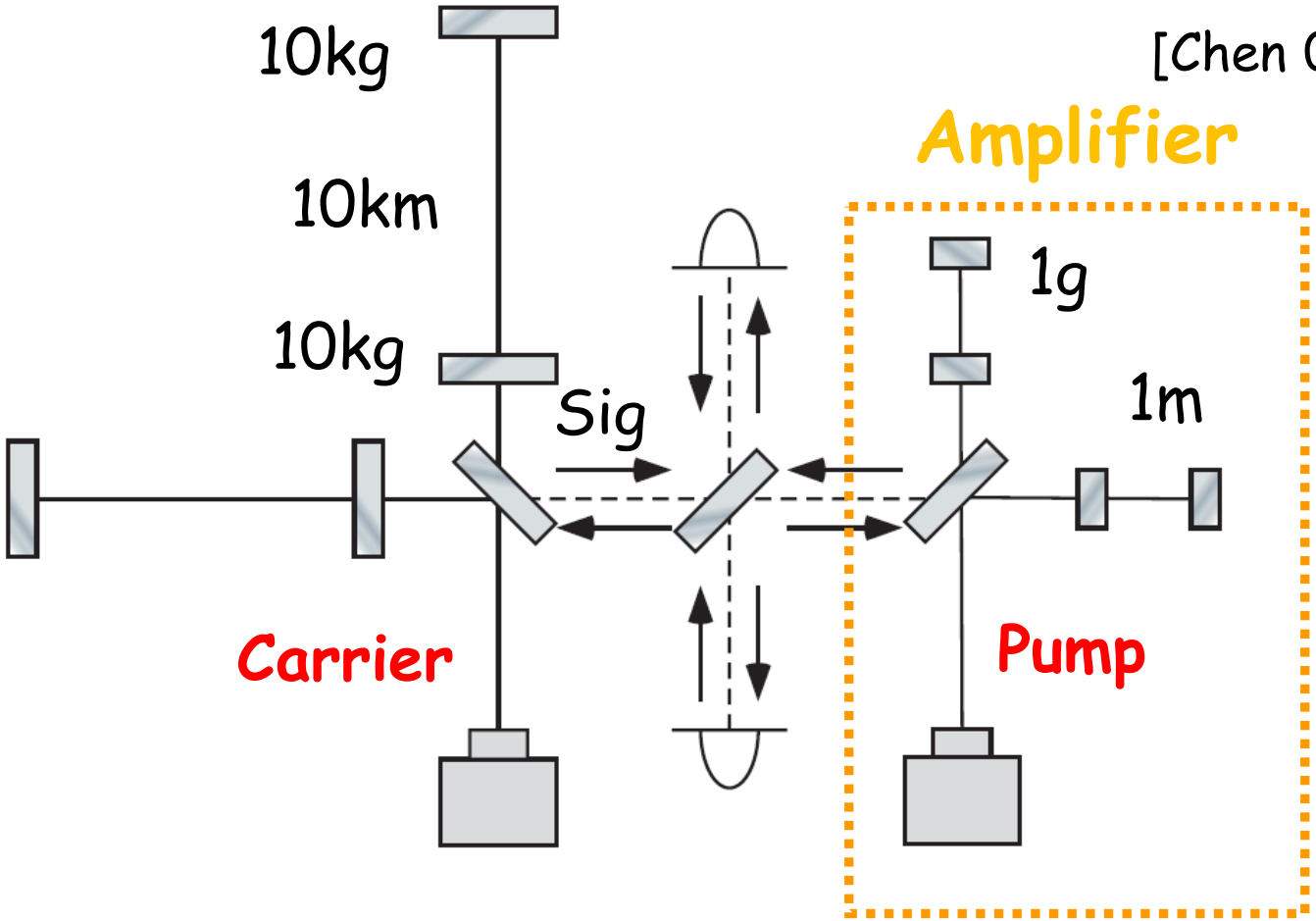
Ponderomotive amplifier (Optical Lever)



[Chen 03]

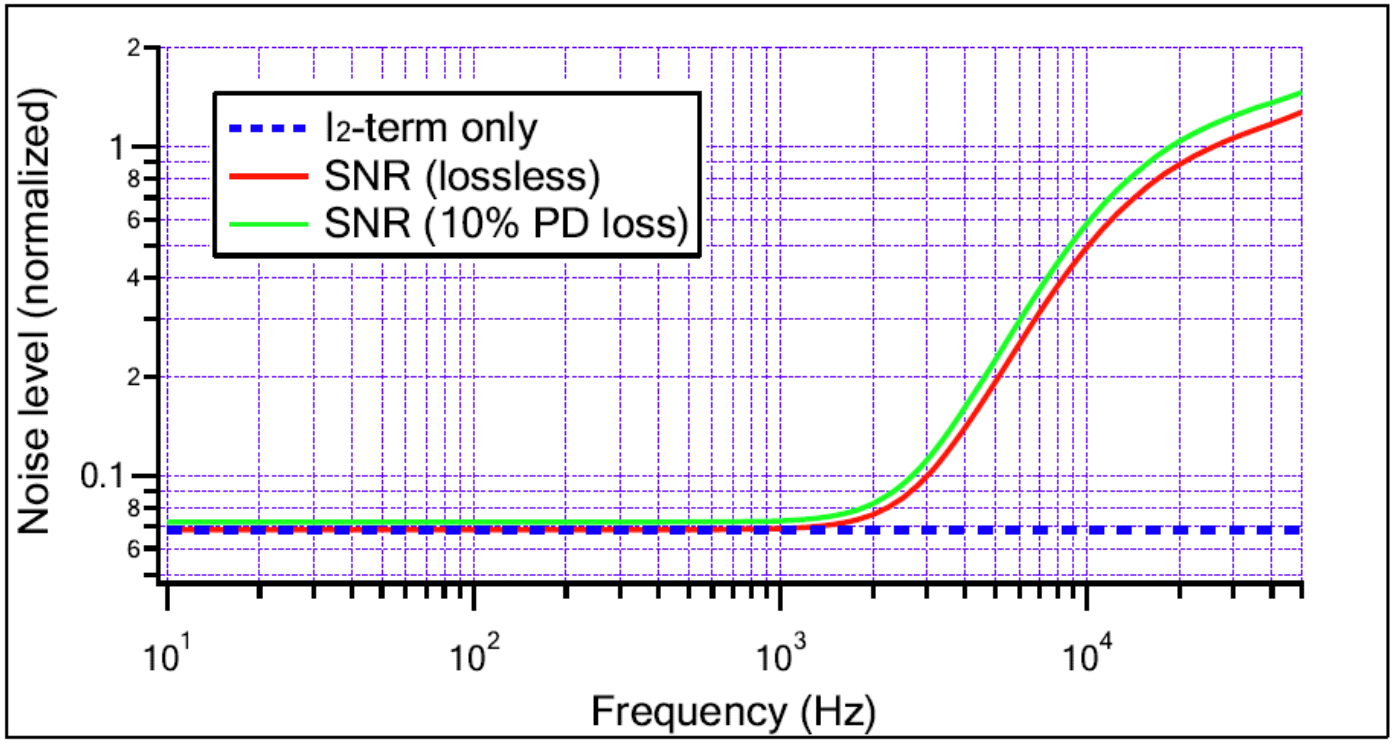
High power on big mirrors.
Low power on small mirrors.

Ponderomotive amplifier (Optical Lever)



High power on big mirrors.
Low power on small mirrors.

Sensitivity gain with PA



Main IFO
L=4km, m=40kg,
I_0=1kW, F=120

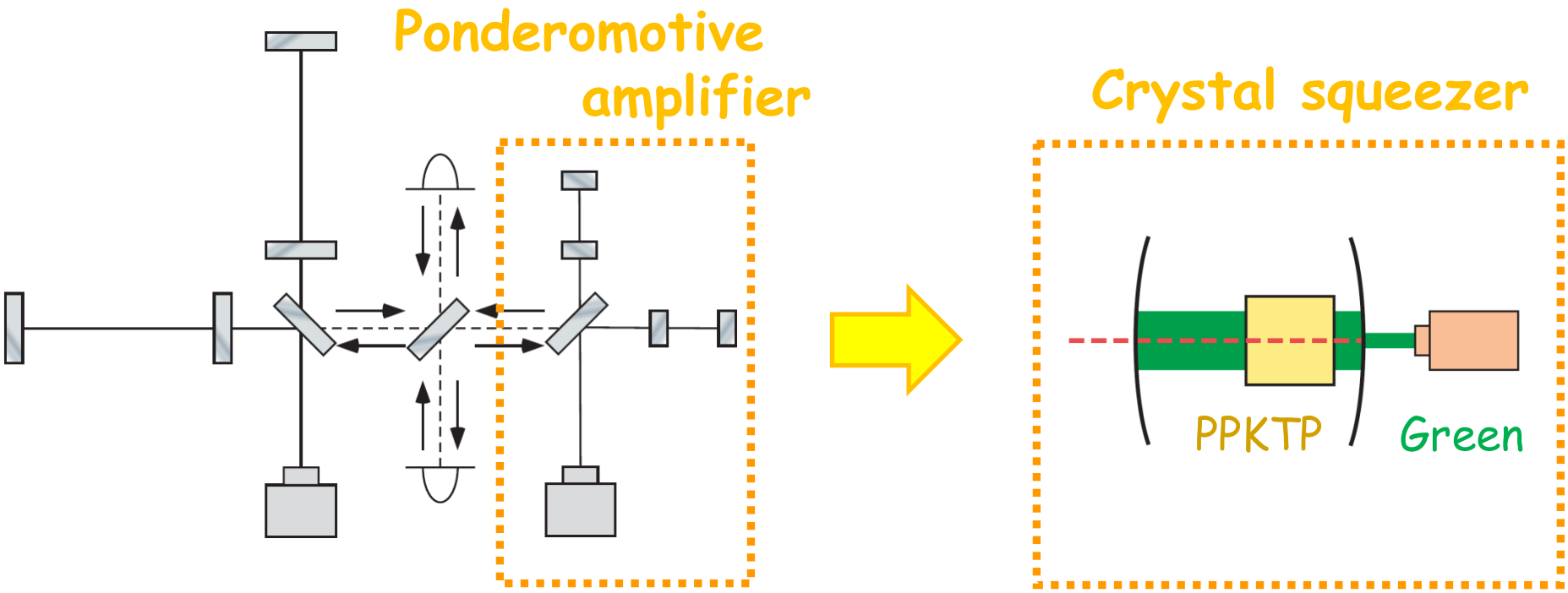
Amplifier
L=10cm, m=1g,
I_0=100W, F=6000

Input coupler
R=81%, ϕ=1.5rad

Sorry that I only have a result for LIGO…

- Big reduction of shot noise up to kHz
- Strong against optical losses

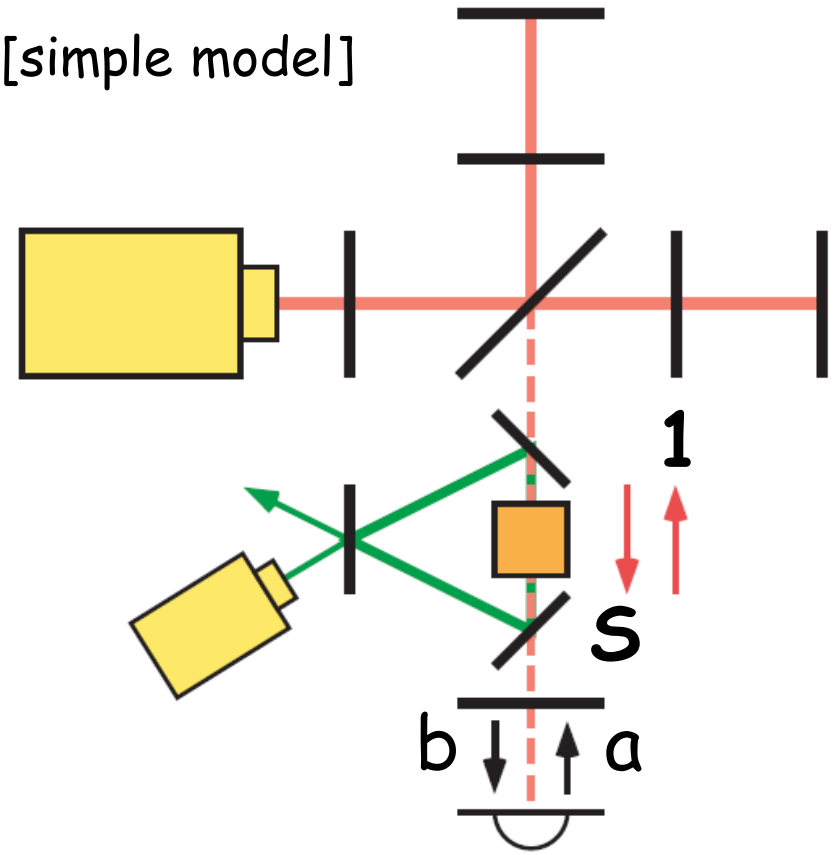
Can we replace PA by a crystal squeezer?



- Squeezing procedure is similar
- Crystal squeezing can be even done at MHz

Parametric amplifier with OPO

[simple model]



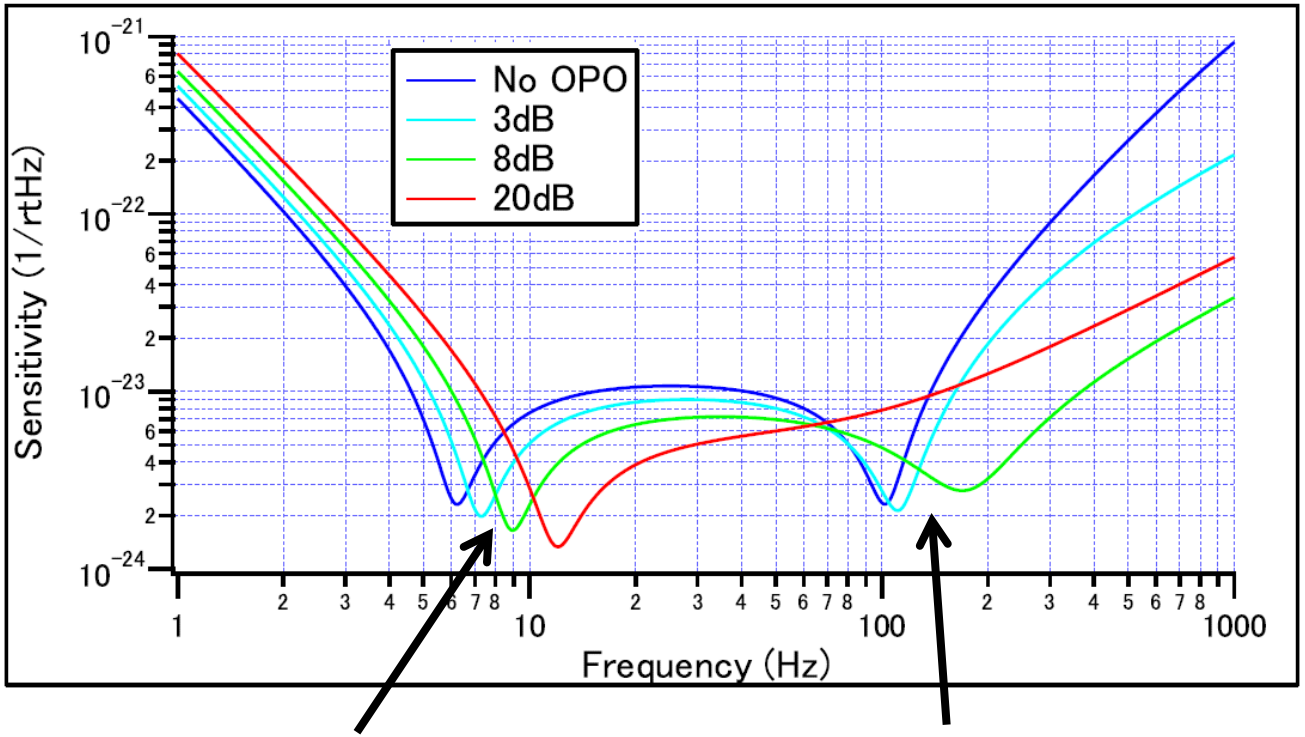
- The gain turns out to be zero without the detuning

- Optical spring frequency moves as if $I_0 \rightarrow I_0/s$

- Optical resonance moves as if $\cos\phi \rightarrow \cos\phi\,(s^2+1)/2s$

The amplifier does not increase the signal but increase the spring frequency.

Sensitivity curve



Optical spring shift

$I_0 \rightarrow I_0/s$

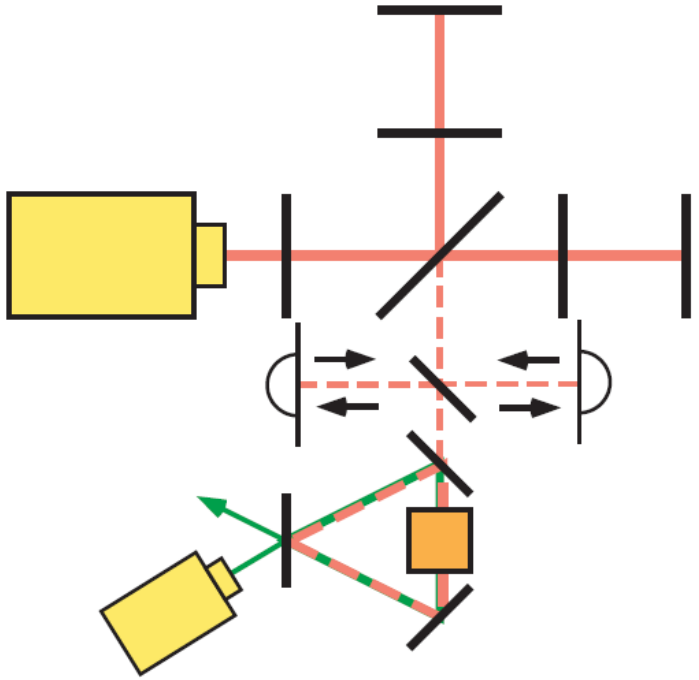
Optical resonance shift

$\cos\phi \rightarrow \cos\phi\,(s^2+1)/2s$

The amplifier changes the dynamics and shifts the spring frequency (different from input SQ).

Discussion on parametric amplifiers

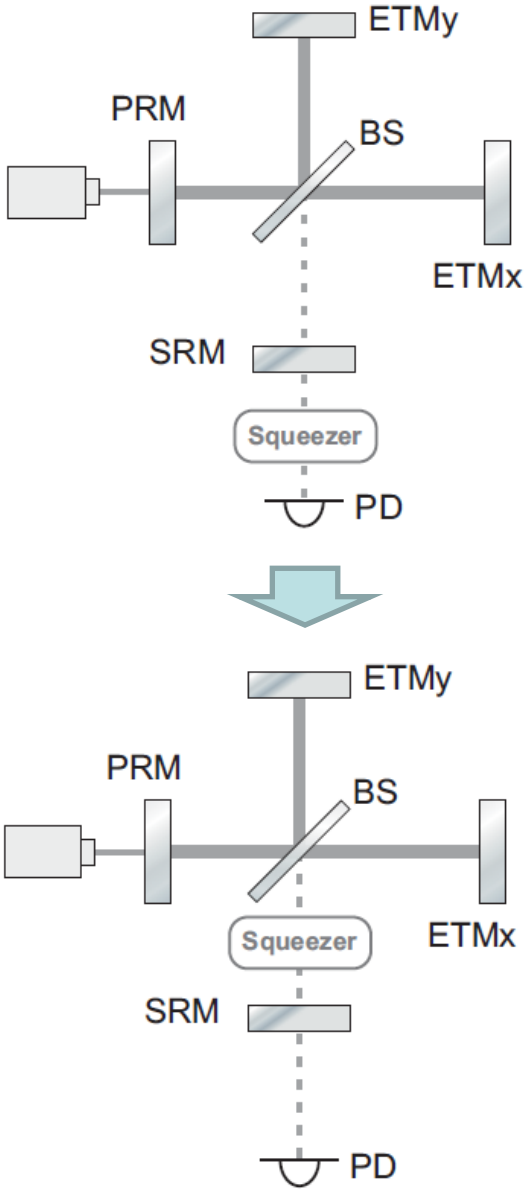
[complex model]

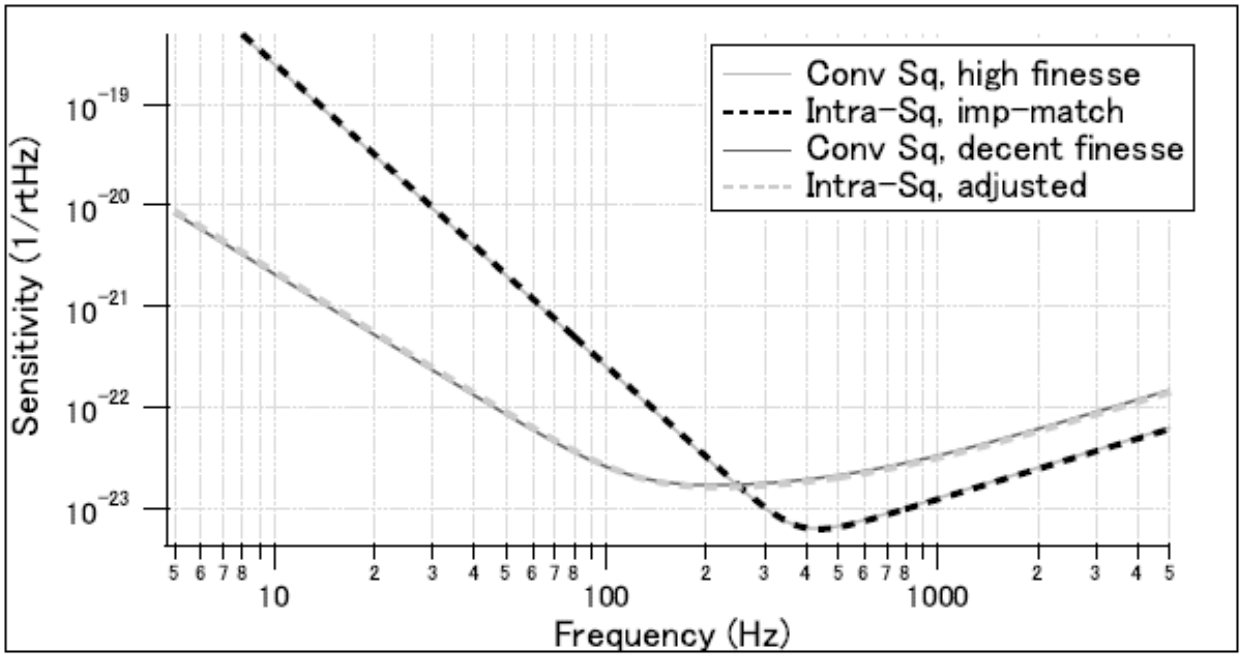


- An OPO will be needed to realize a few dB squeeze
- Frequency-dependent SQ would make a broadband signal amplification
  -> Ponderomotive amplifier
  -> Combine with speedmeter?

- More theoretical investigation necessary
- R&D experiment started at Tokyo Tech

Intracavity squeezing?





- Impedance-matched SRC possible
- Conventional sensitivity can be realized with a lower power
- Very weak against losses

Summary

- Study of a possible better configuration for ET-HF
- Optical Bar in ET
  - high power and RP noise issues
- Introduction of Ponderomotive amplifier
- Amplifier with intra-cavity squeezer
  - shift of optical spring frequency
- Intracavity squeeze is weak against losses

Supplementary slides

Intracavity squeezing with losses