Squeezing in Gravitational Wave Detectors

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Abstract

<u>Goal</u>

Improve sensitivity of GW detector limited by quantum noise

<u>Requirements</u>

i. Squeezing at the entire detection bandwidth of ground-based GW-detectors (10～10kHz)
ii. Strong squeezing
iii. Stable squeezing
iv. Frequency dependent squeezing

Contents

I. Introduction

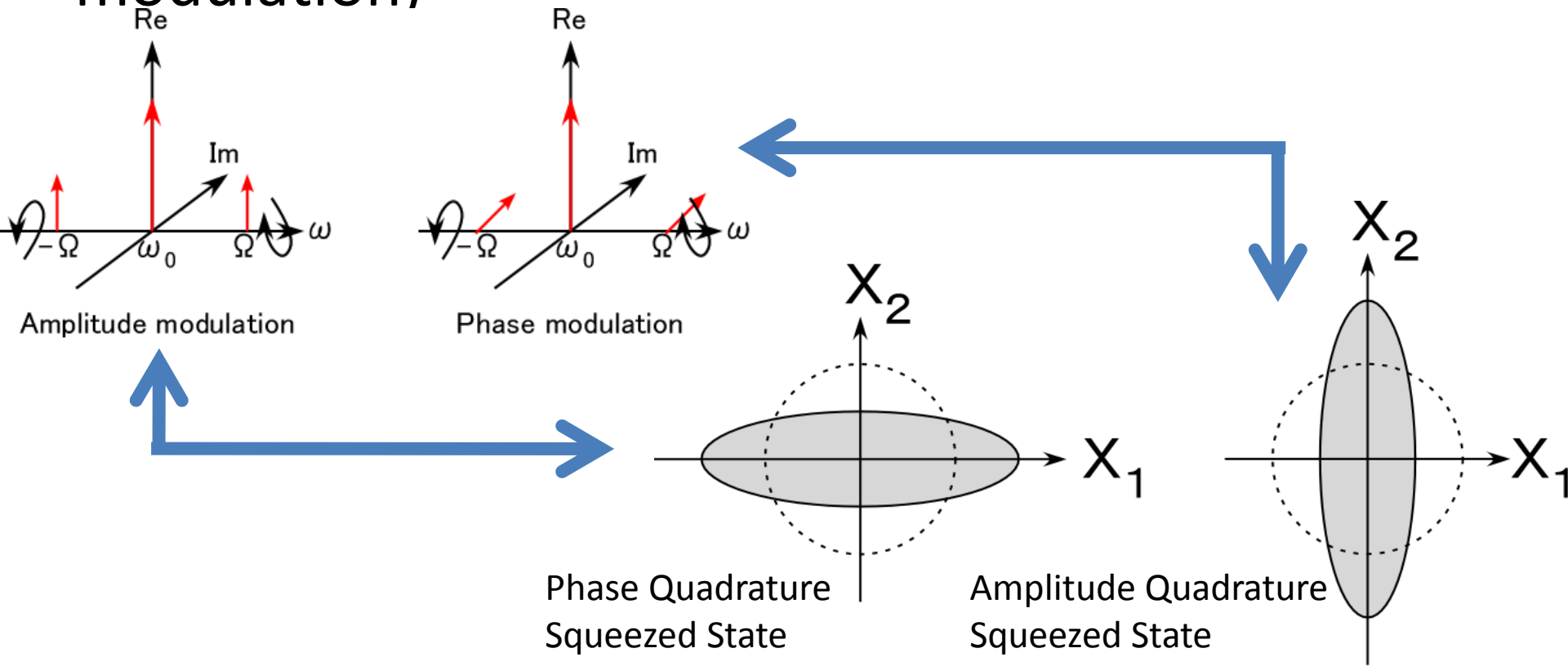
Quantum noise is the ultimate limit of laser interferometric GW detector's sensitivity caused by vacuum fluctuation

Advantages of squeezing

i. Reduction of shot noise without increasing laser power
ii. Reduction of quantum radiation pressure noise without raising mirror mass

II. What is a “Squeezed State”?

The sum of correlated quantum sidebands relative to the carrier frequency (looks like classical modulation)



III. Generation of a Squeezed State

Nonlinear process is capable of introducing correlations between the sidebands

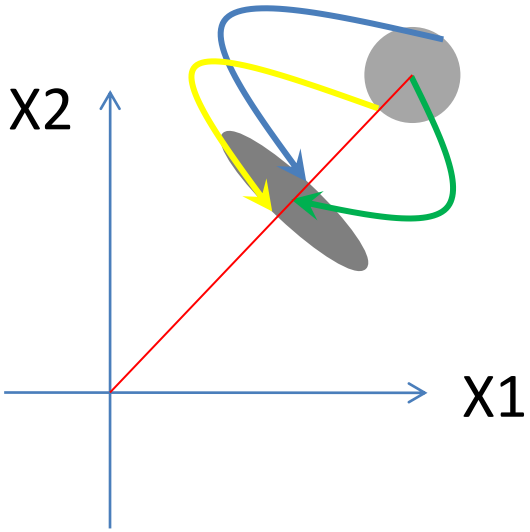
$$P=\chi^{(1)}E+\chi^{(2)}E^2+\chi^{(3)}E^3+\cdots$$

i. $\chi^{(1)} \Rightarrow$ can't generate squeezed state

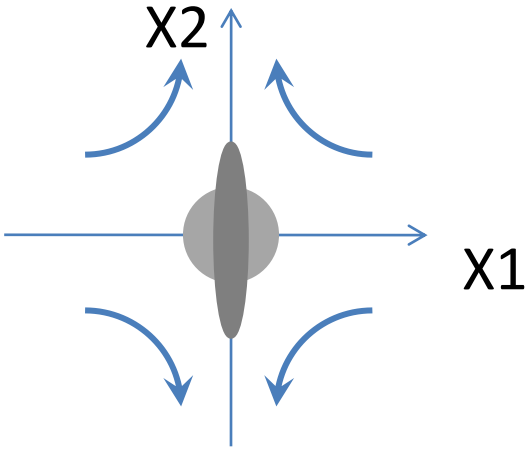
ii. $\chi^{(2)} \Rightarrow$ squeezing via Second-Harmonic-Generation and parametric amplification

iii. $\chi^{(3)} \Rightarrow$ squeezing via optical Kerr effect

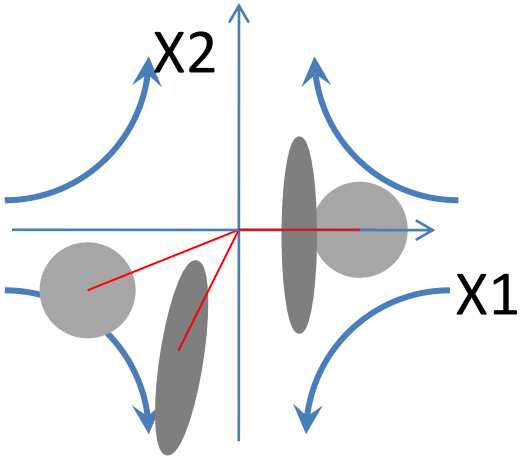
III-i. $\chi^{(2)}$ squeezing



SHG



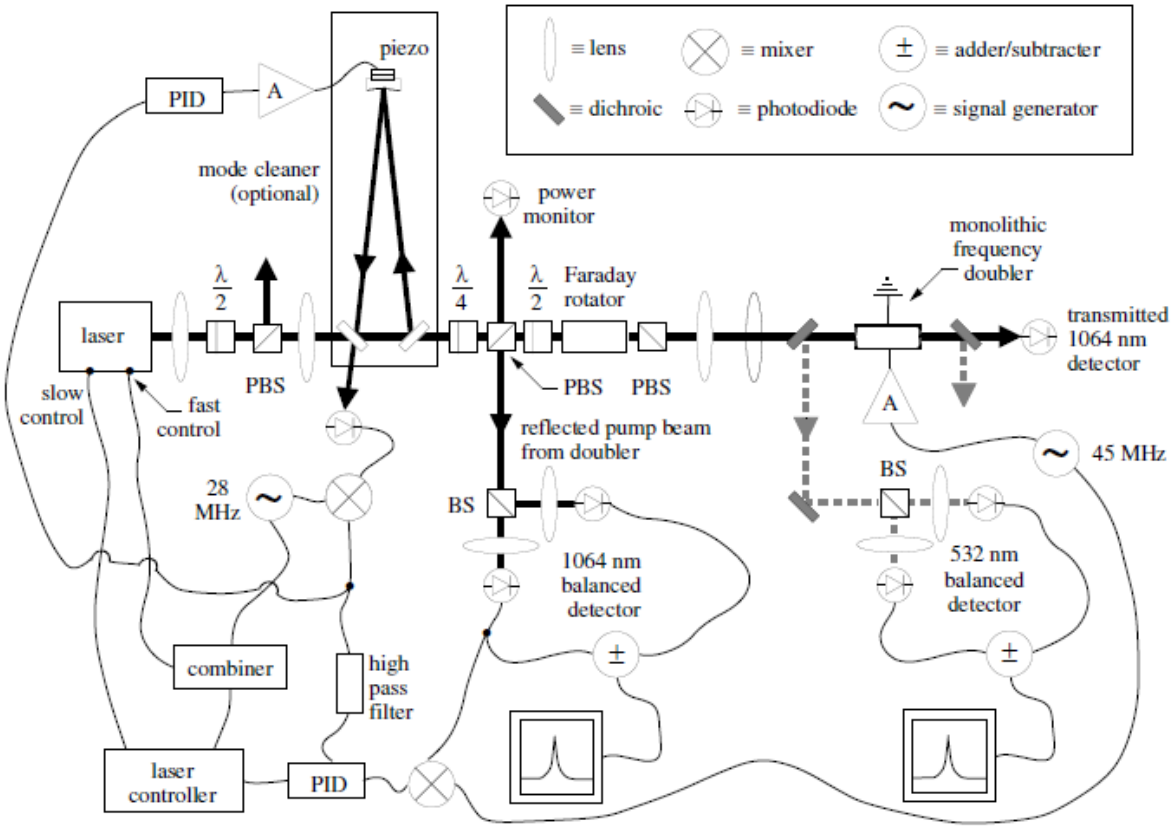
OPO



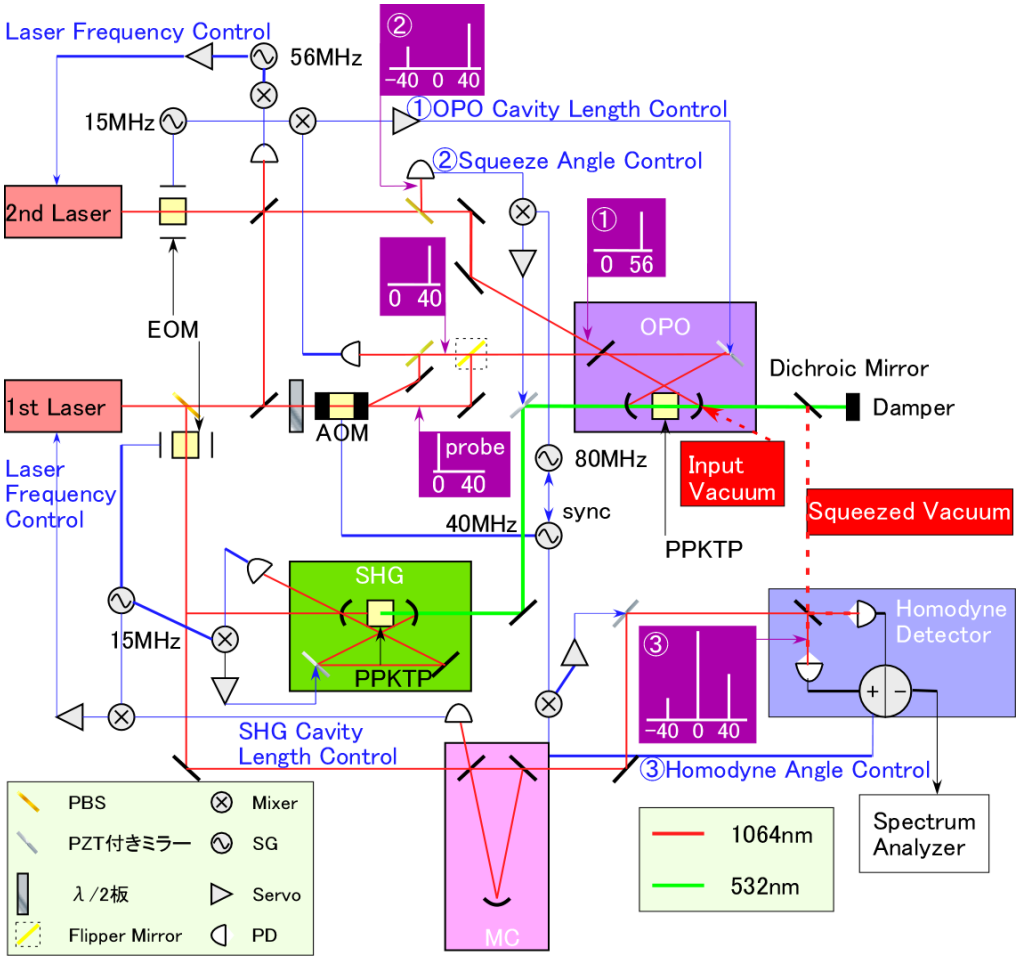
OPA

Squeezing via	SHG	OPO	OPA
Squeezing level	limited	not limited	not limited
Squeezing angle	amplitude	any angle	any angle
Seed noise	large	vacuum	large
Control	easy	difficult	easy

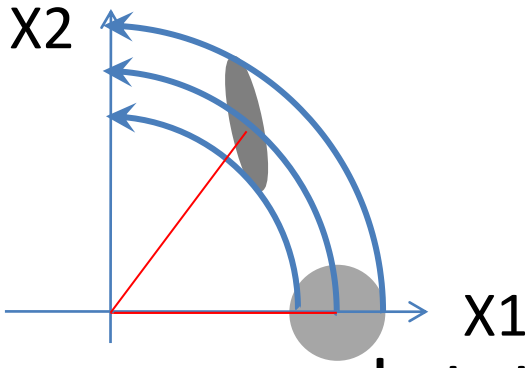
III-i-i. Squeezing Experiment via SHG



III-i-ii. Squeezing Experiment via OPO

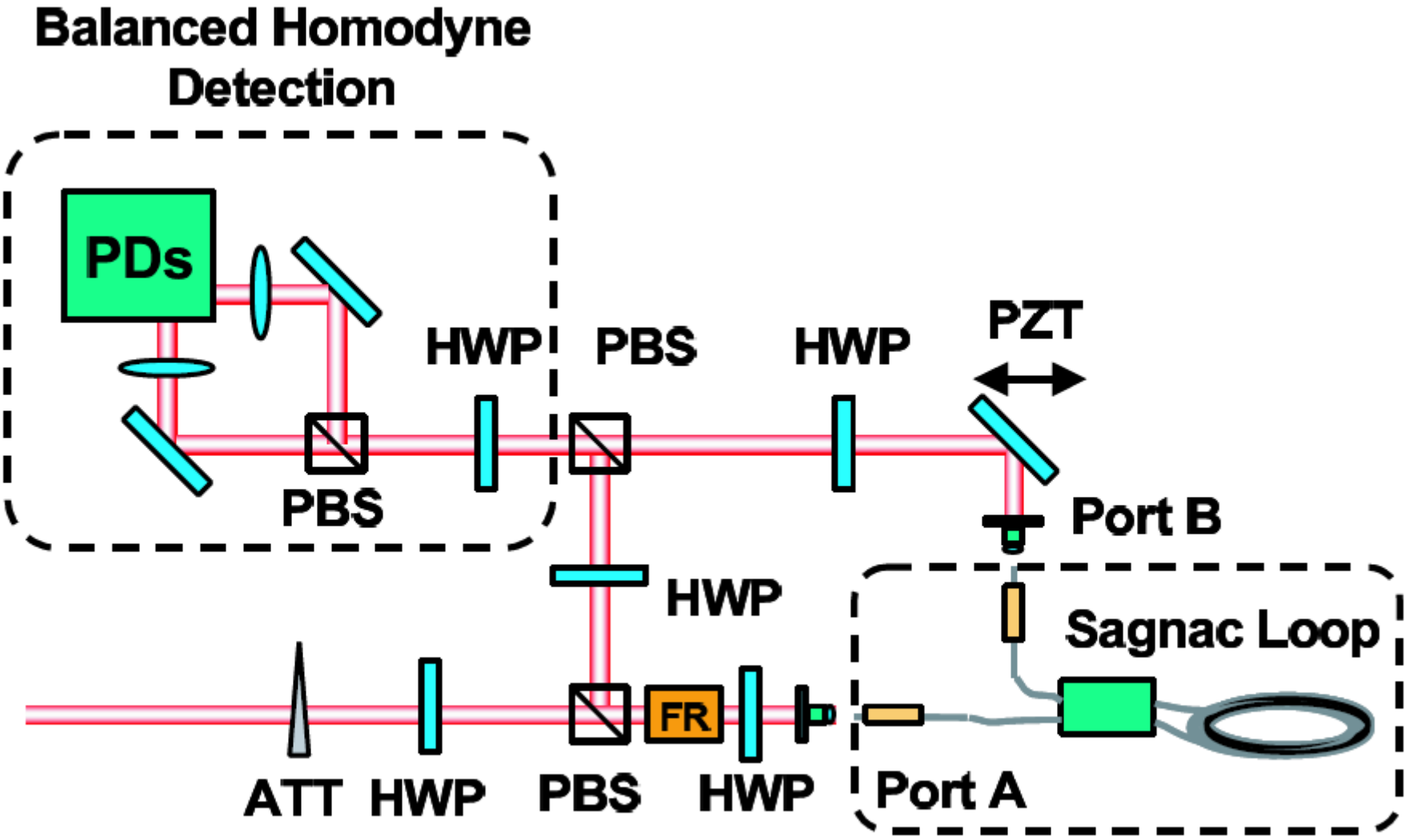


III-ii. $\chi^{(3)}$ squeezing

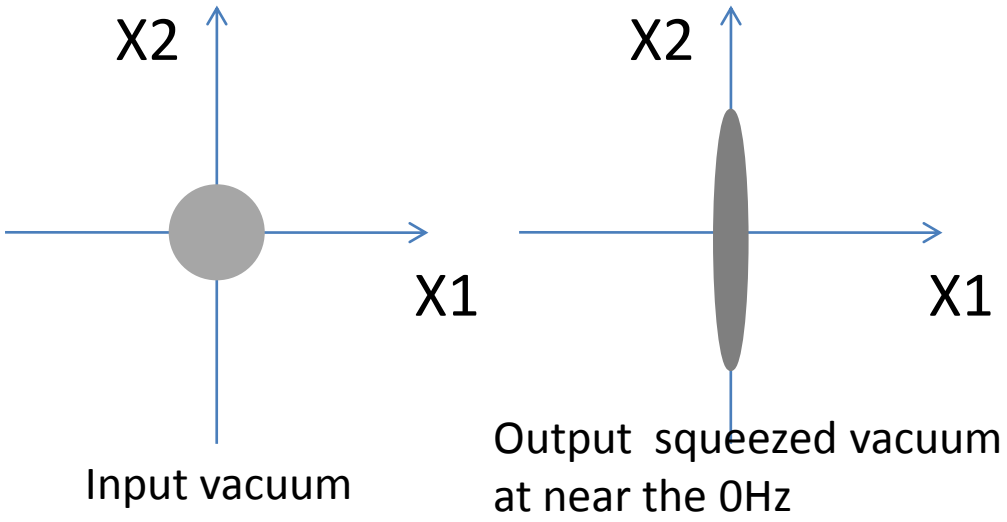


i. It's easy to generate squeezed state using optical fiber
ii. The extra noise using optical fiber (GAWBS : Guided Acoustic Wave Brillouin Scattering)
iii. It's able to generate a squeezed state without conversion of laser frequency
iv. It has low nonlinearity

III-ii-i. Squeezing Experiment via Kerr

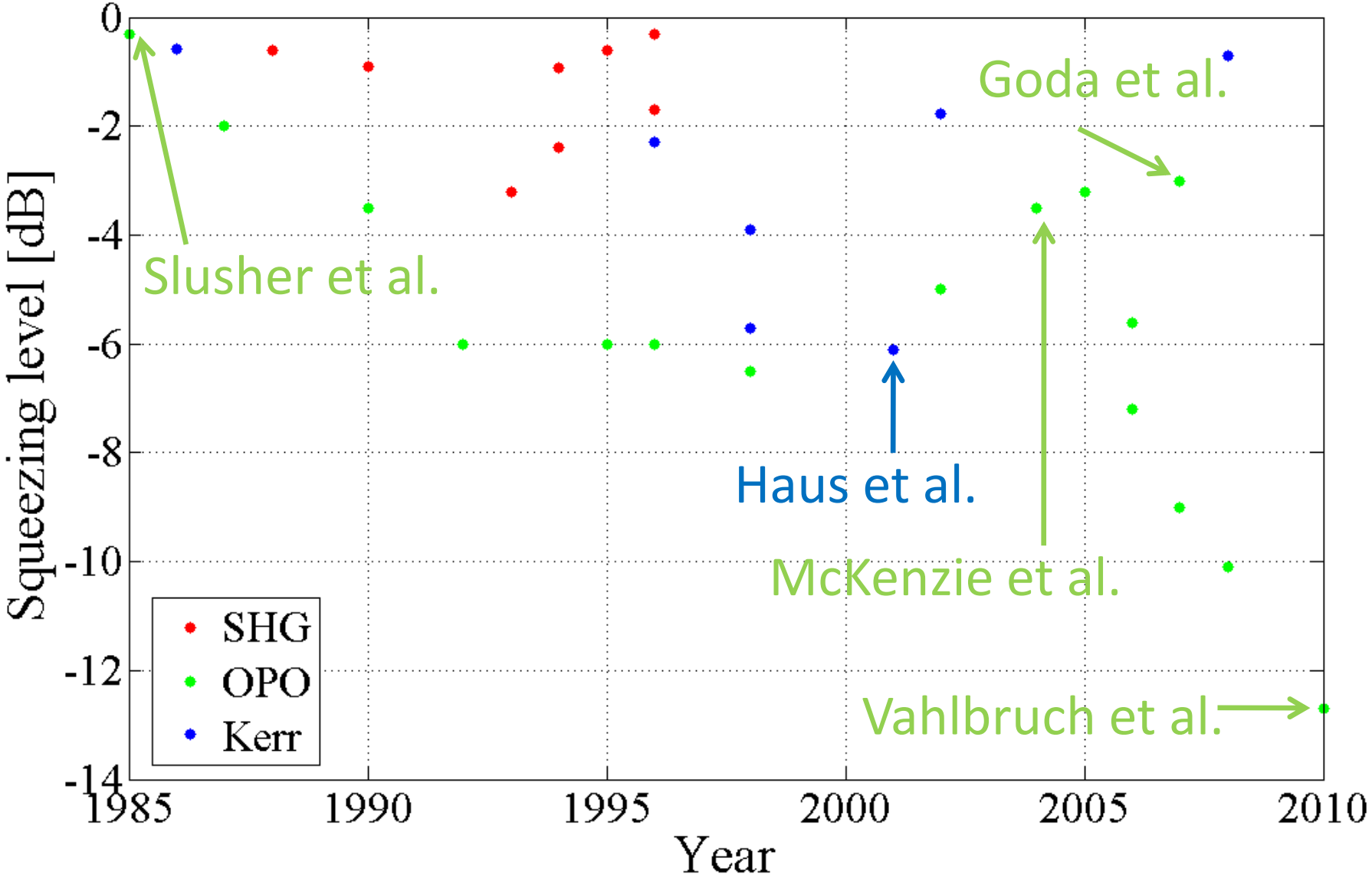


III-iii. Ponderomotive squeezing

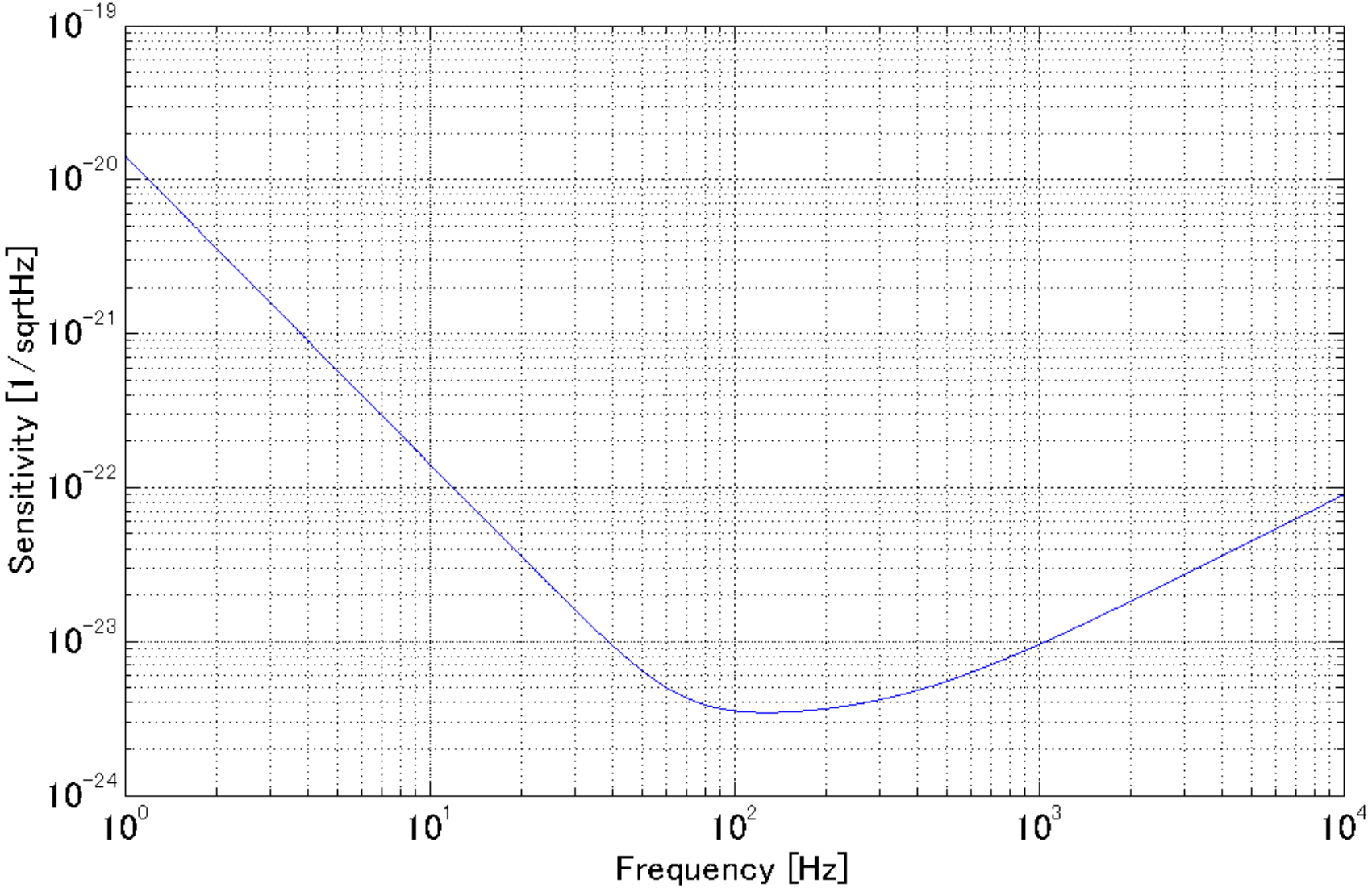


i. Laser interferometer can generate frequency dependent squeezing via radiation pressure
ii. This process don't have excess loss via nonlinear material (GRIIRA : Green-Induced Infrared Absorption)
iii. It has not measured yet

IV. The History of “Squeezing”



V. Squeezing in LCGT



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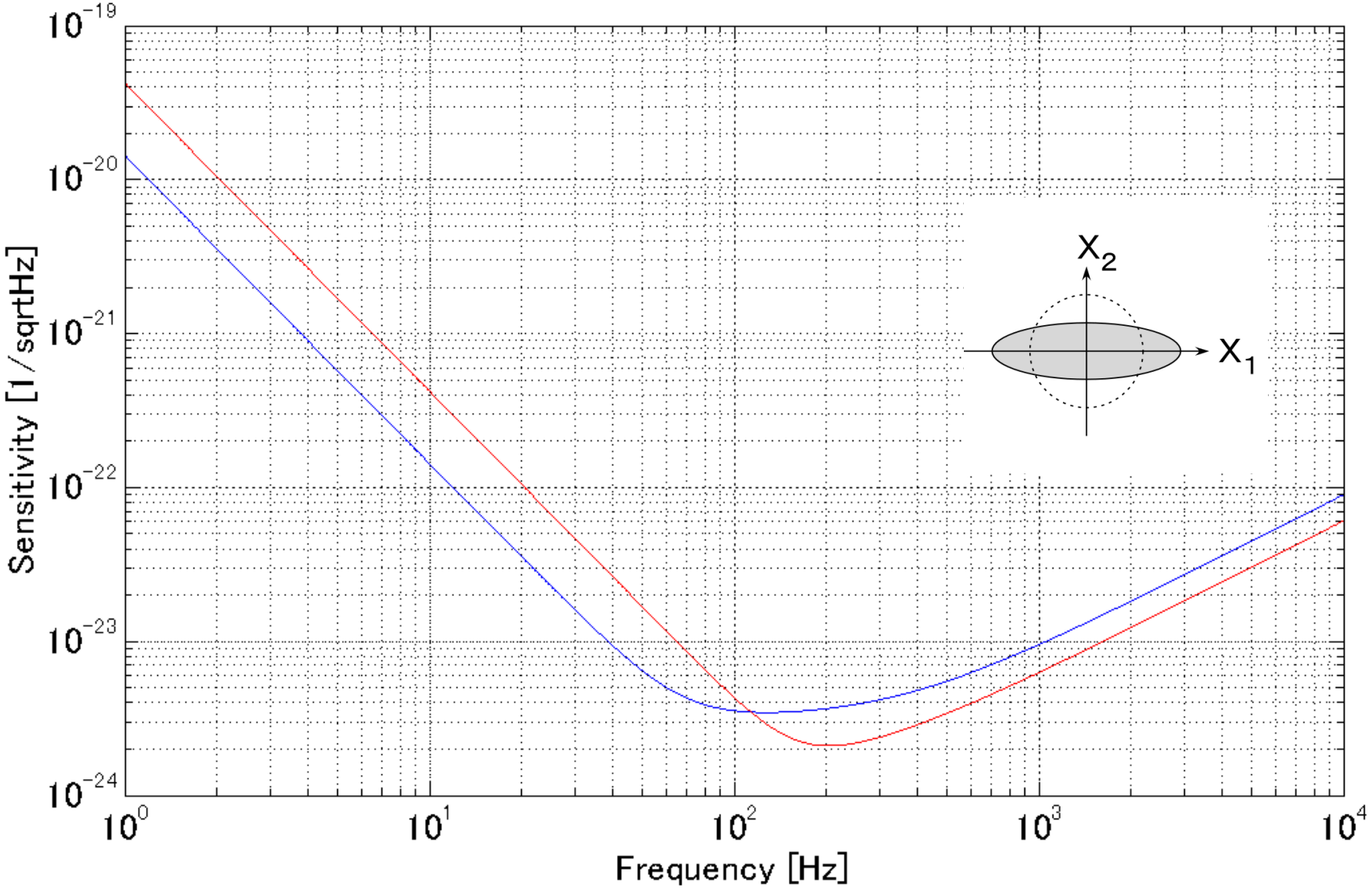

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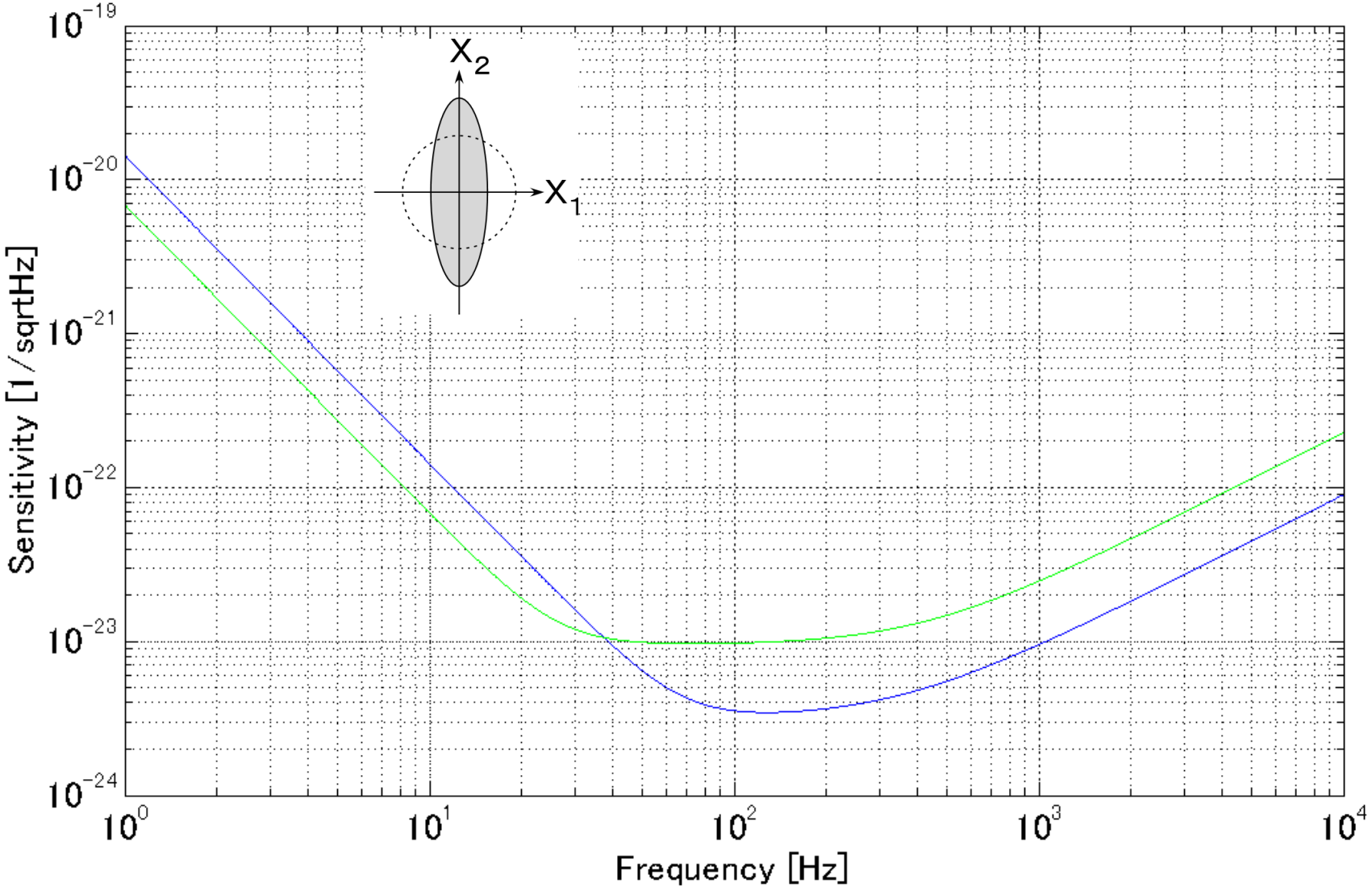

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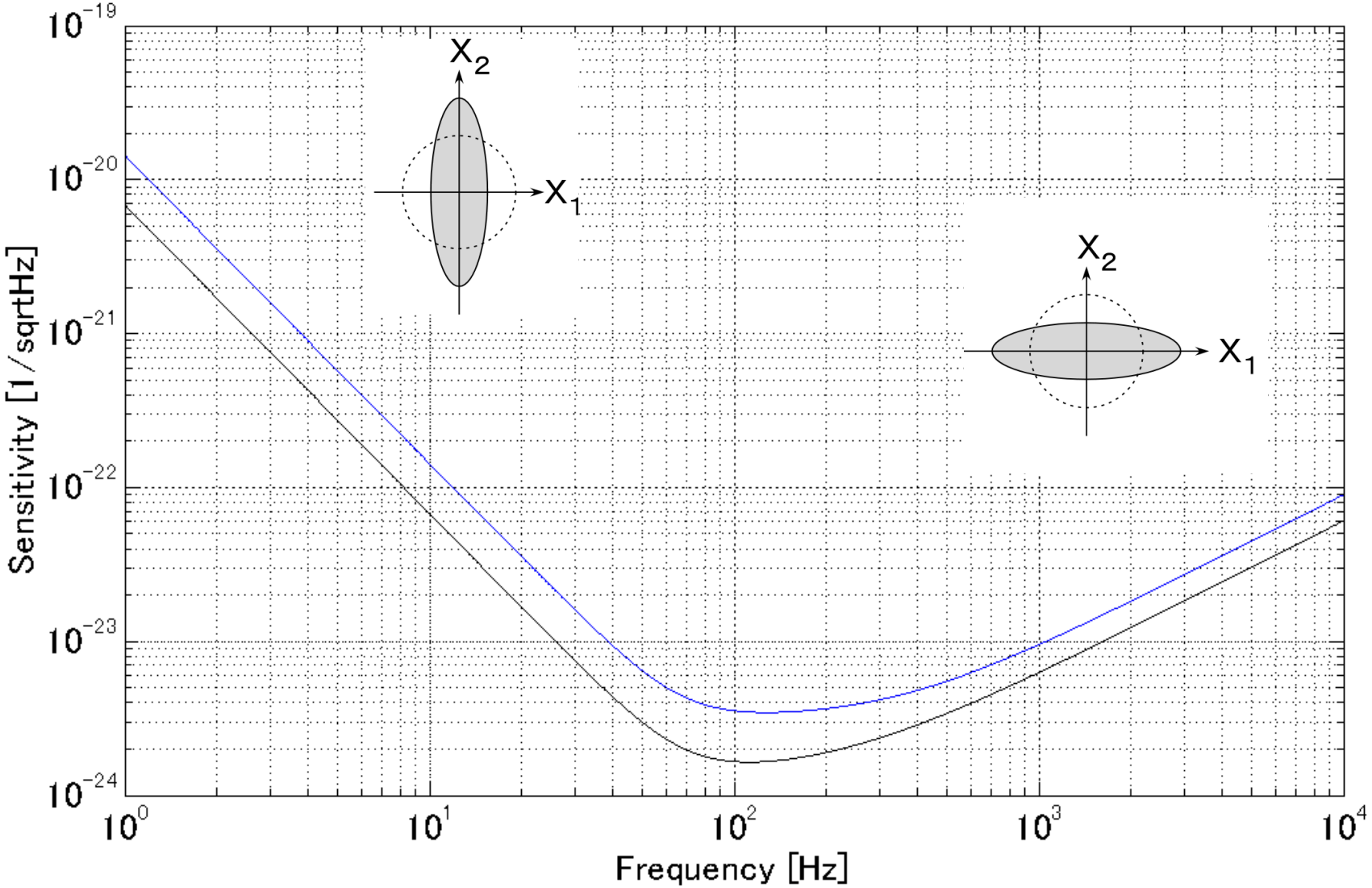
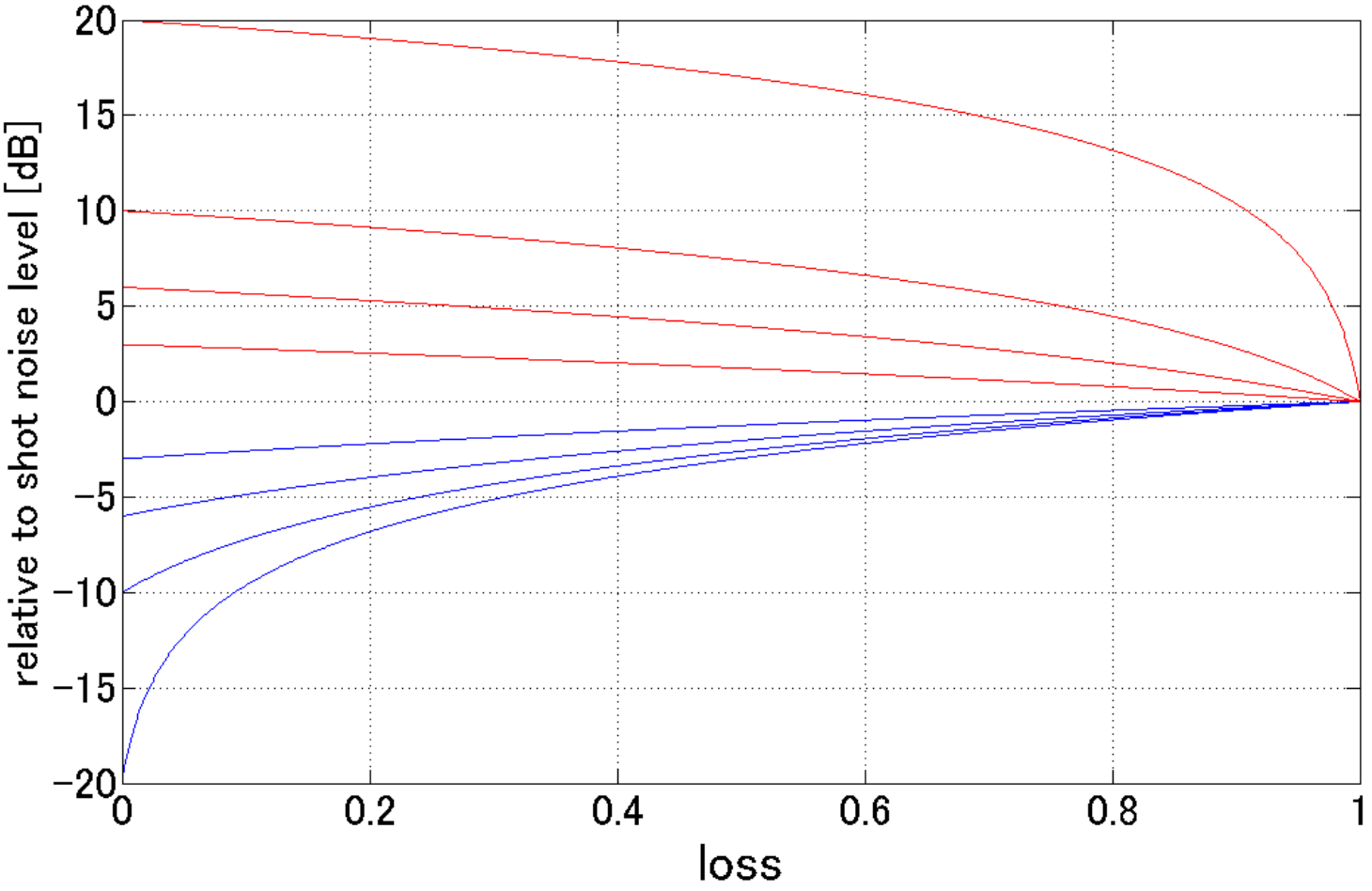


V-i. Filter cavity

Filter cavity is necessary to produce frequency dependent squeezing

i. It can reduce both shot noise and radiation pressure noise
ii. It's difficult to build
iii. Many variations are exist

V-ii. Loss effect



V-iii. Science

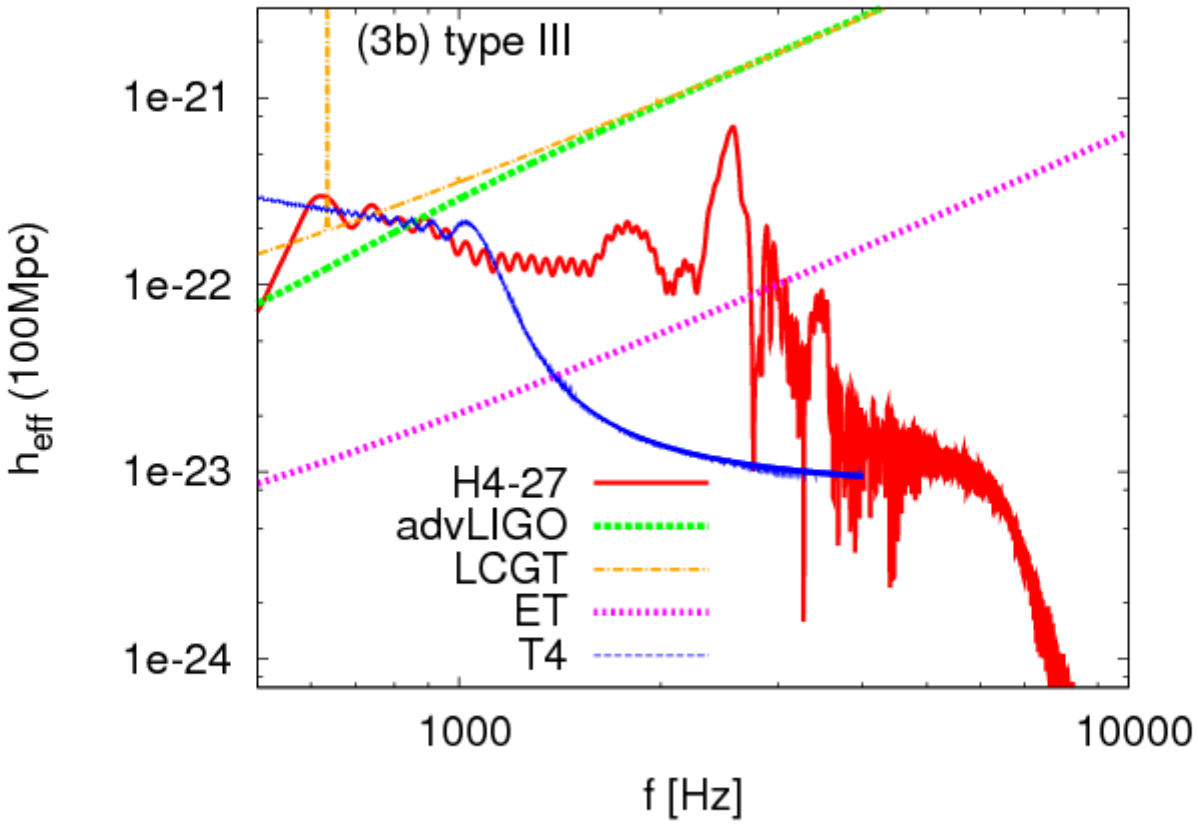
Source (100 Hz ～ 10 kHz)

i. The merger of binary neutron stars
ii. The merger of neutron star and black holes binary

Result

i. The nature of high density nuclear matter
ii. The mechanism of generation of short γ-ray bursts

V-iii-i. Science



K. Hotokezaka et al., PRD. **83**.124008 (2011)

VI. Summary

- Squeezing is important

  Reduction of quantum noise without increasing laser power and mirror mass

  It's possible to obtain additional scientific result from LCGT inputted squeezed vacuum

i. OPO is a good squeezer

  high level squeezing, stable control

ii. Squeezer via Kerr effect is interesting

  simple set up, can be used in space

iii. Interferometer may be a good squeezer

  don't have excess loss via nonlinear material

iv. Filter cavity

  beat quantum noise at all the frequency at the same time

v. Loss effect

  It's can be avoided (we need to improve mode matching, Faradays, optical elements)