Advanced R&D hub for future GW detectors with TAMA300

2024/12/4
NAOJ Future Planning Symposium
Yoichi Aso (NAOJ GWSP)

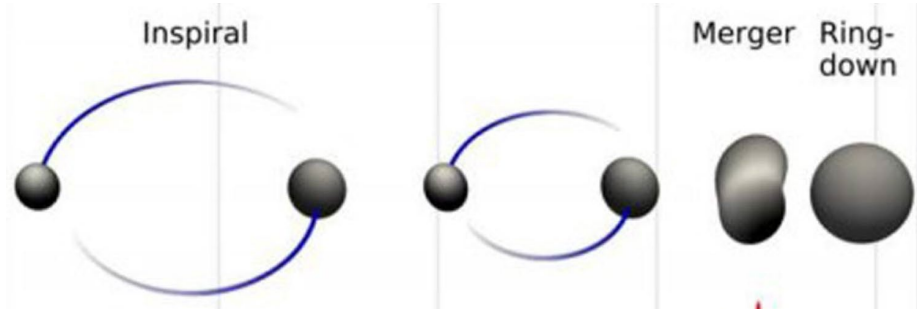
Gravitational Wave Astronomy

PRL **119**, 161101 (2017)

First detection: 2015 Sept. 14 Binary Black Hole Merger
Multi-messenger observation: 2017 Aug. 17 Binary Neutron Star Merger

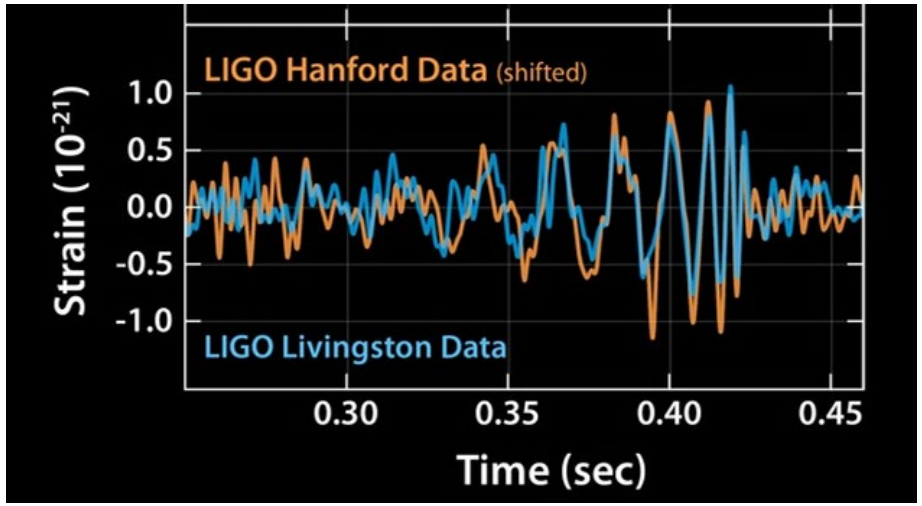
GW170817

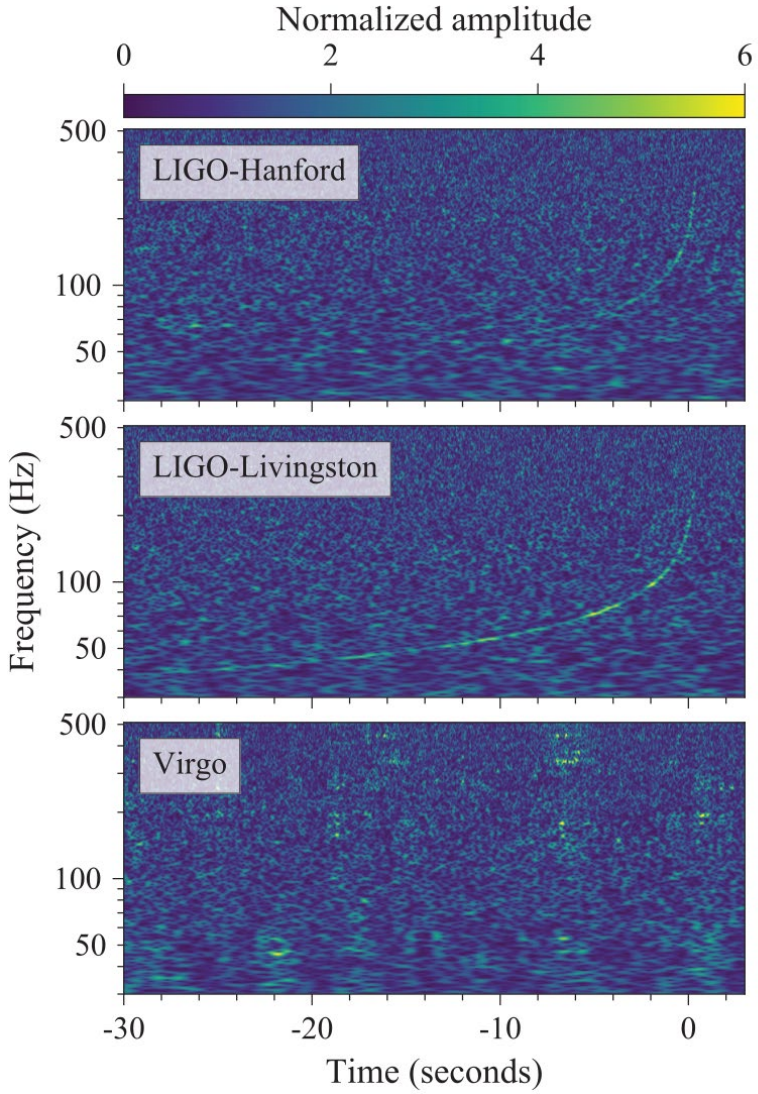
More than 90 GW transient events have been published
O4 observation is on going



GW150914

PRL **116**, 061102 (2016)





Japanese GW community

- A long history of GW research (detector side)
  - Resonant bar detectors (70s-80s)
  - 3m interferometer prototype (90s)
  - TAMA300 (~2000)
  - KAGRA (2010-)

KAGRA arm tunnel

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Need to keep the momentum

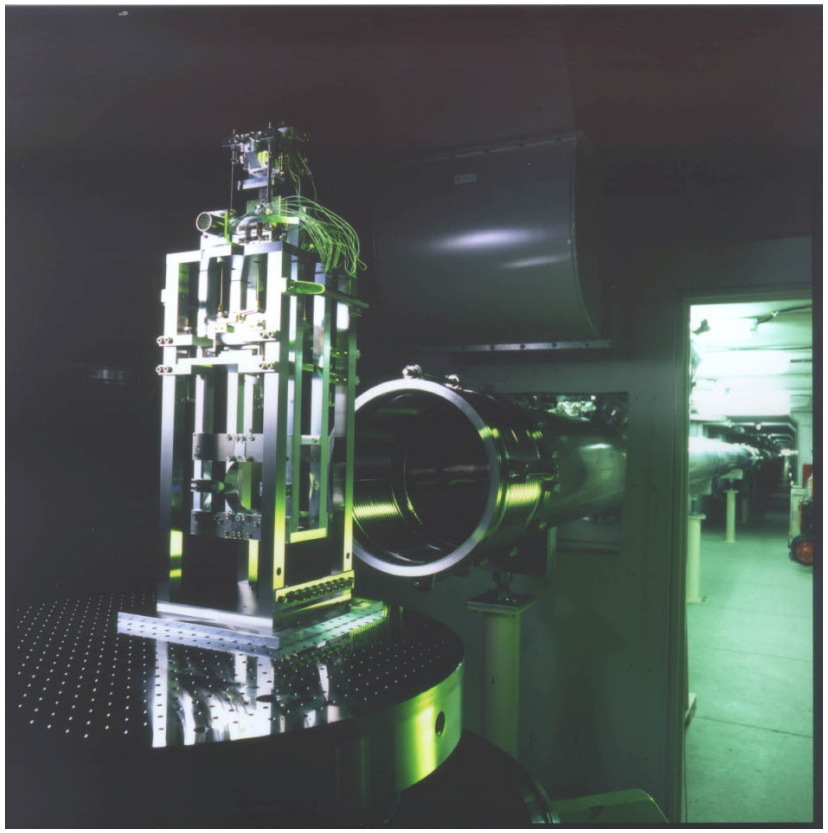
Attracting talented young researchers is essential

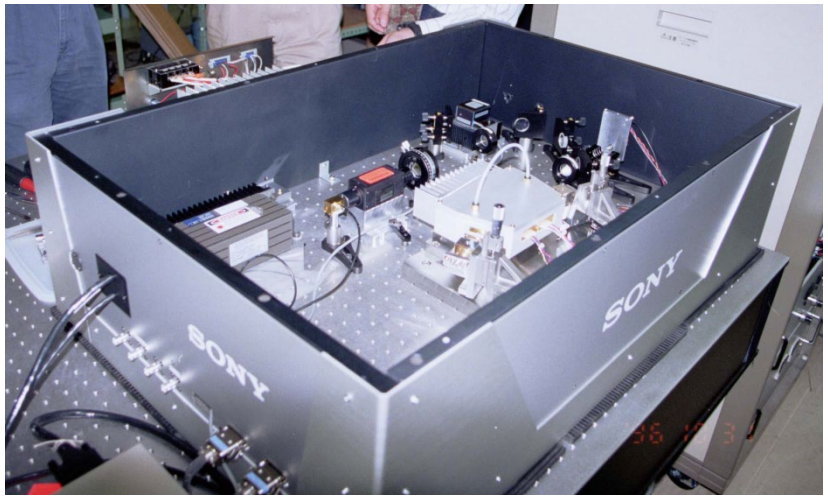
What are the advantages of Japanese GW research groups?

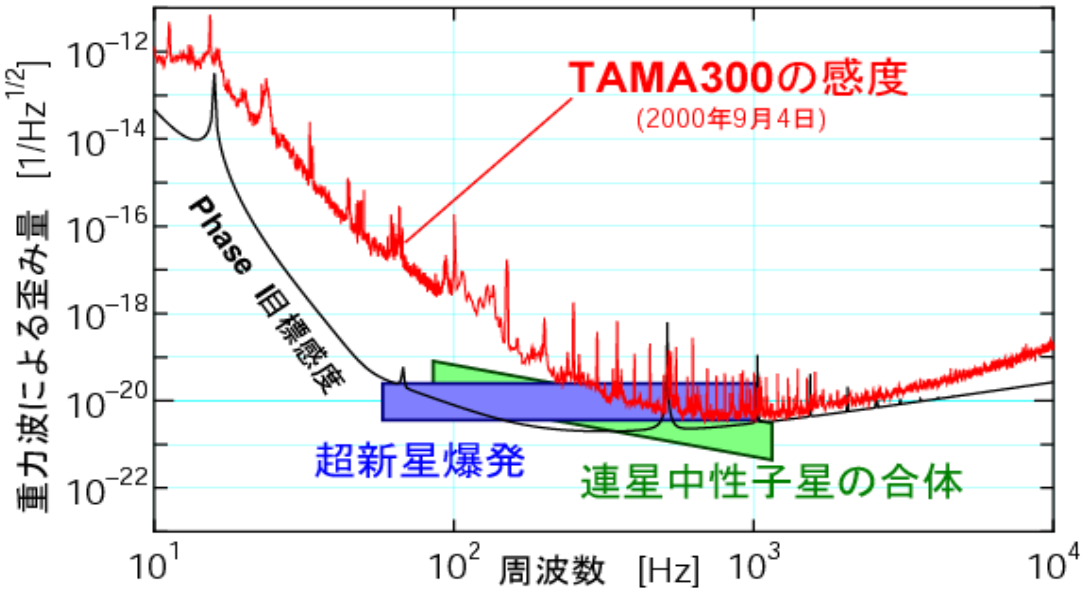
- Cryogenic technologies
- Experience in underground detector construction/operation
- Large scale R&D facility: TAMA300

TAMA300

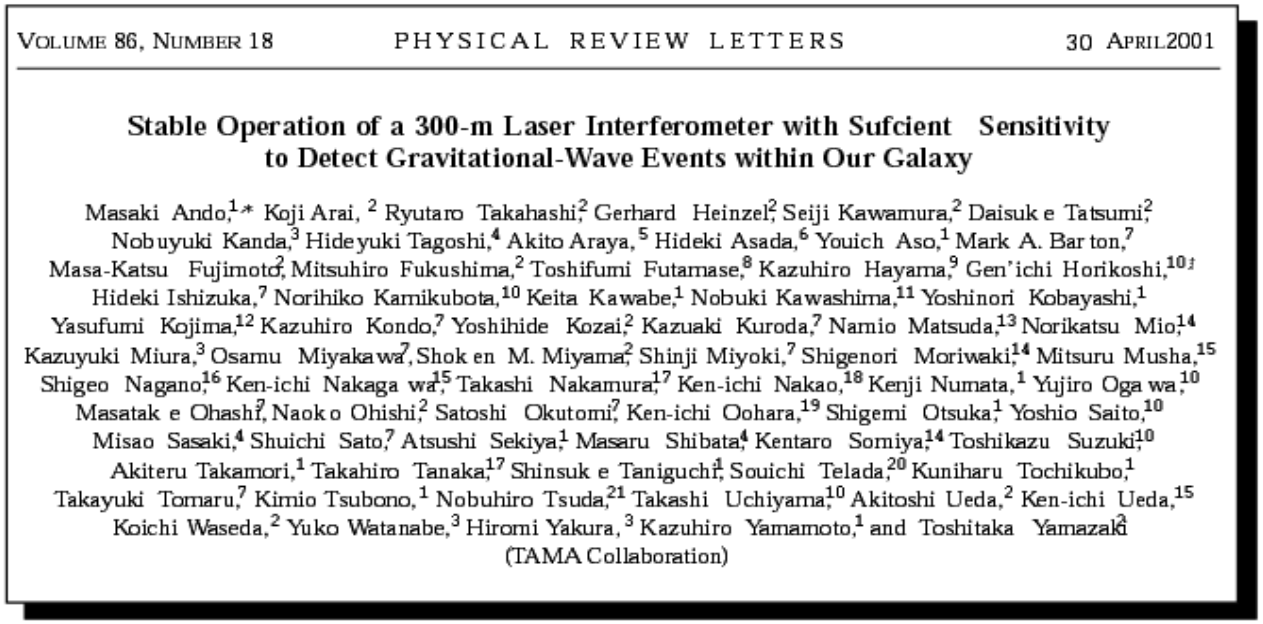
- Prototype GW detector
- Baseline length: 300m
- Construction started in 1995







The world's best sensitivity Sept. 2000



VOLUME 86, NUMBER 18 PHYSICAL REVIEW LETTERS 30 APRIL 2001

Stable Operation of a 300-m Laser Interferometer with Sufcient Sensitivity to Detect Gravitational-Wave Events within Our Galaxy

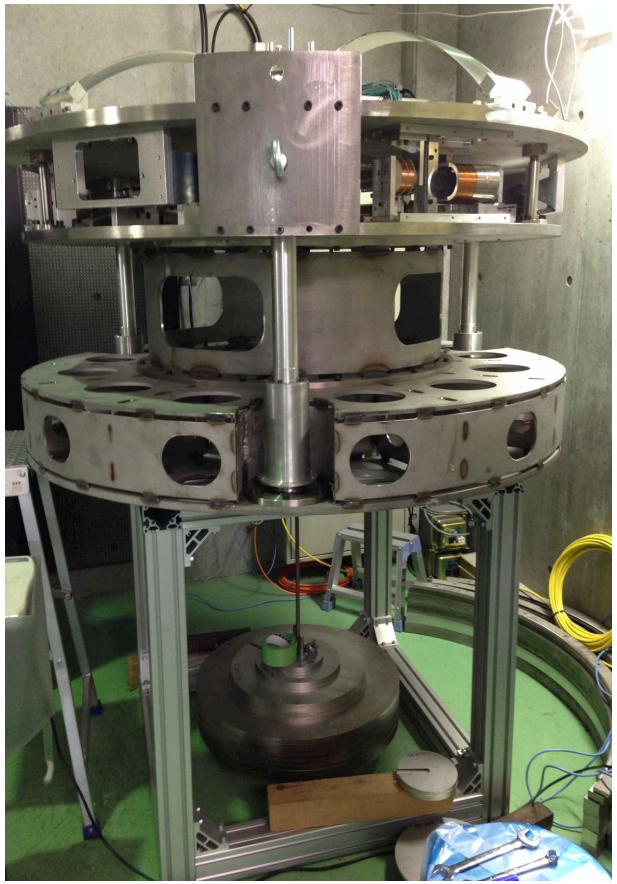
Masaki Ando,[1,*] Koji Arai,[2] Ryutaro Takahashi,[2] Gerhard Heinzel,[2] Seiji Kawamura,[2] Daisuke Tatsumi,[2] Nobuyuki Kanda,[3] Hideyuki Tagoshi,[4] Akito Araya,[5] Hideki Asada,[6] Youich Aso,[1] Mark A. Barton,[7] Masa-Katsu Fujimoto,[2] Mitsuhiro Fukushima,[2] Toshifumi Futamase,[8] Kazuhiro Hayama,[9] Gen'ichi Horikoshi,[10] Hideki Ishizuka,[7] Norihiko Kamikubota,[10] Keita Kawabe,[1] Nobuki Kawashima,[11] Yoshinori Kobayashi,[1] Yasufumi Kojima,[12] Kazuhiro Kondo,[7] Yoshihide Kozai,[2] Kazuaki Kuroda,[7] Namio Matsuda,[13] Norikatsu Mio,[14] Kazuyuki Miura,[3] Osamu Miyakawa,[7] Shoken M. Miyama,[2] Shinji Miyoki,[7] Shigenori Moriwaki,[14] Mitsuru Musha,[15] Shigeo Nagano,[16] Ken-ichi Nakagawa,[15] Takashi Nakamura,[17] Ken-ichi Nakao,[18] Kenji Numata,[1] Yujiro Ogawa,[10] Masatake Ohashi,[7] Naoko Ohishi,[2] Satoshi Okutomi,[7] Ken-ichi Oohara,[19] Shigemi Otsuka,[1] Yoshio Saito,[10] Misao Sasaki,[4] Shuichi Sato,[7] Atsushi Sekiya,[1] Masaru Shibata,[4] Kentaro Somiya,[14] Toshikazu Suzuki,[10] Akiteru Takamori,[1] Takahiro Tanaka,[17] Shinsuke Taniguchi,[1] Souichi Telada,[20] Kuniharu Tochikubo,[1] Takayuki Tomaru,[7] Kimio Tsubono,[1] Nobuhiro Tsuda,[21] Takashi Uchiyama,[10] Akitoshi Ueda,[2] Ken-ichi Ueda,[15] Koichi Waseda,[2] Yuko Watanabe,[3] Hiromi Yakura,[3] Kazuhiro Yamamoto,[1] and Toshitaka Yamazaki[3]
(TAMA Collaboration)

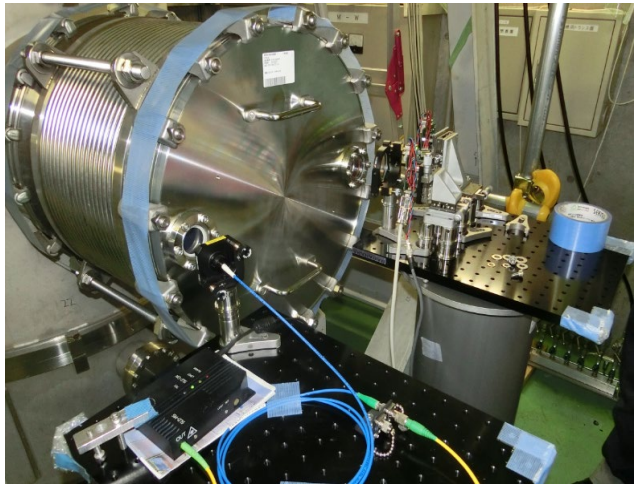
Physical Review Letters (April 2001)

1000h continuous observation Sept. 2001

TAMA pioneered the technologies for large-scale GW detectors

Full-scale test of KAGRA vibration isolation system





R&D hub for GW research

Summary

- Cutting edge research for GW detector technology
- Attract young researchers
- Provide a training ground for young researchers
  - The same digital control system as KAGRA/LIGO
  - Similar electronics as KAGRA/LIGO

Science Goal

Exploring the Universe with gravitational wave observations

Science Objectives

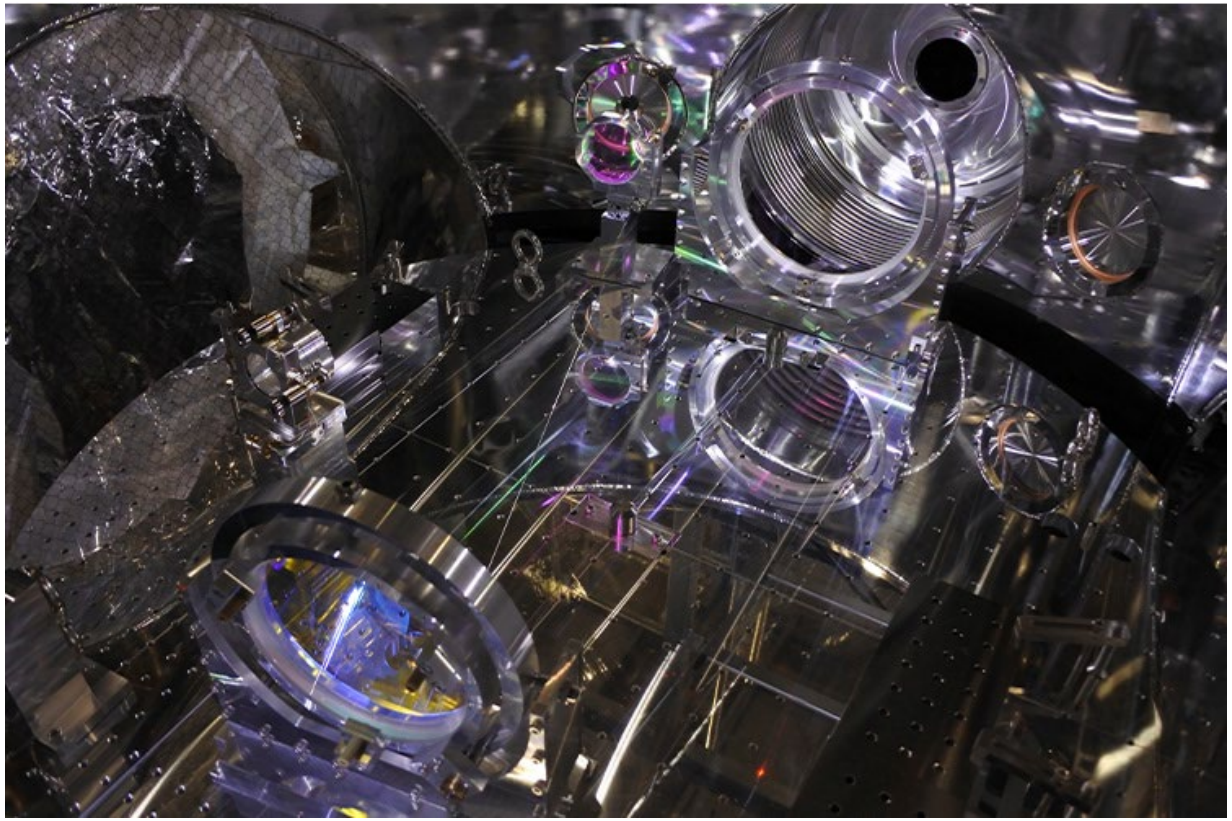
- Develop new technologies to improve GW detectors
- Attract and train young researchers for the next generation instrumental science of GW detection

Past and present R&D activities in NAOJ

Science Investigations/
Instruments and data to be returned

Transmission beam monitoring system

Optics



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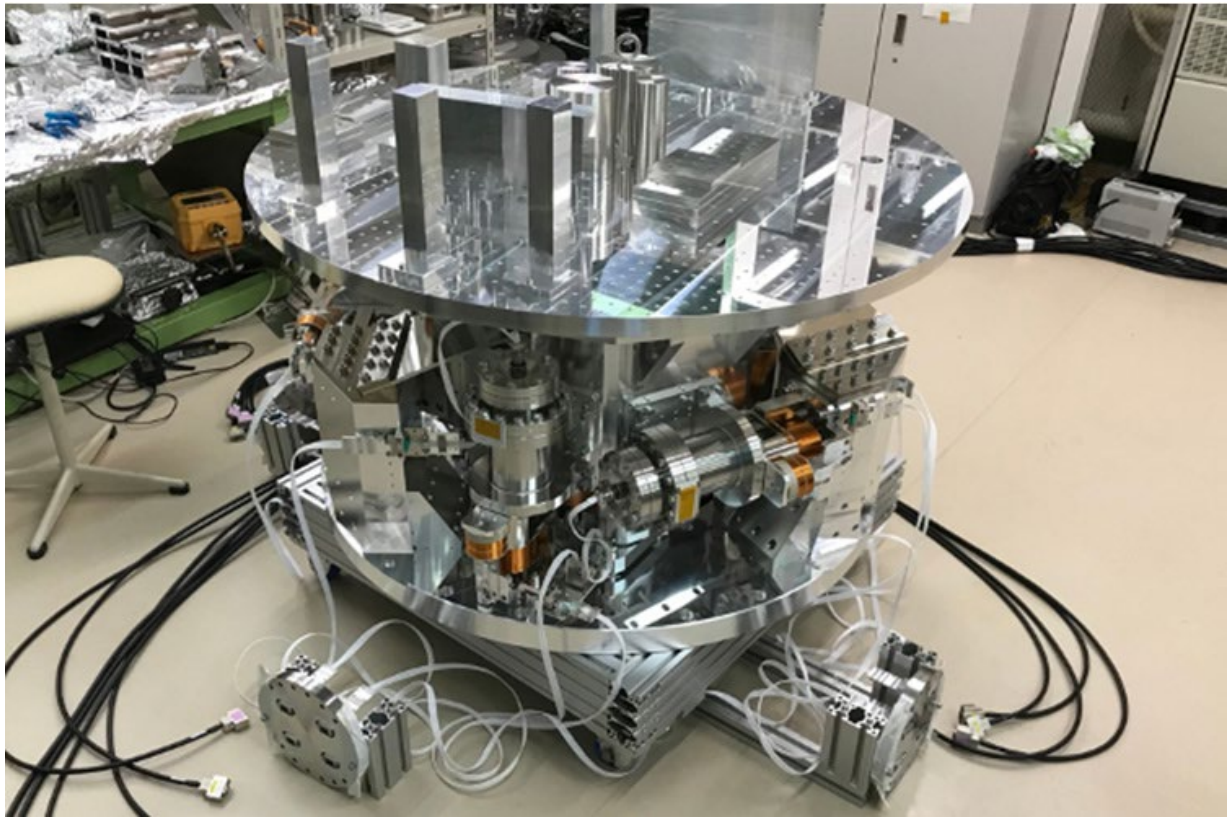

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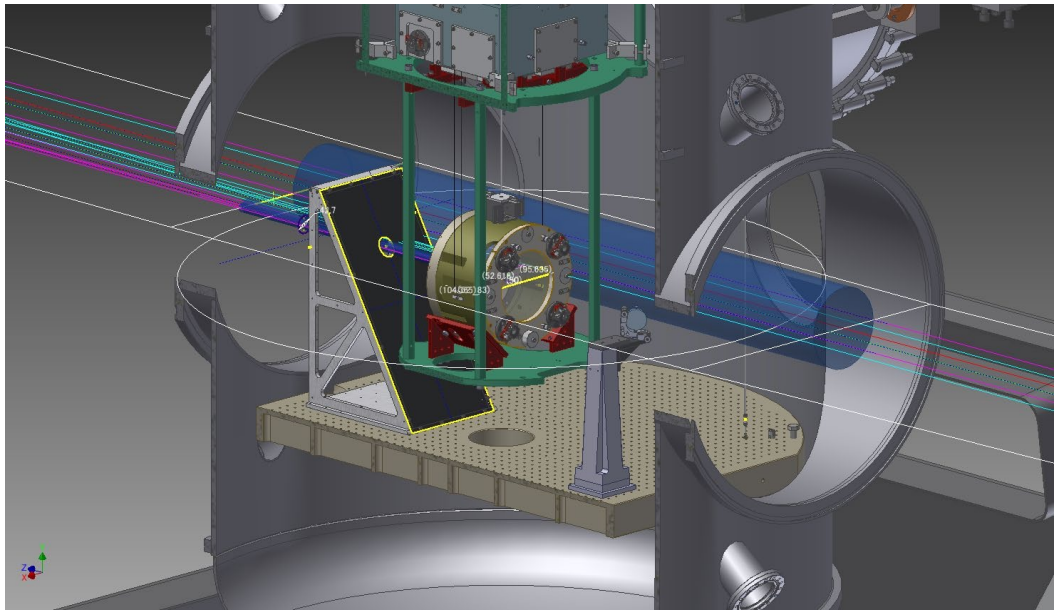
Vibration isolation system

Optical Baffles



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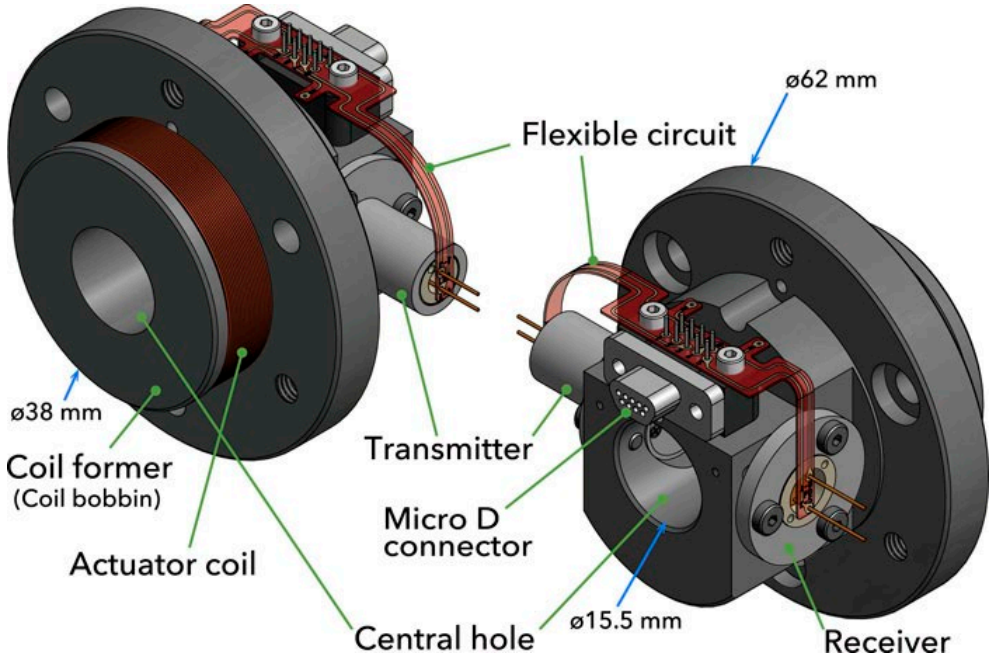
Shadow sensors



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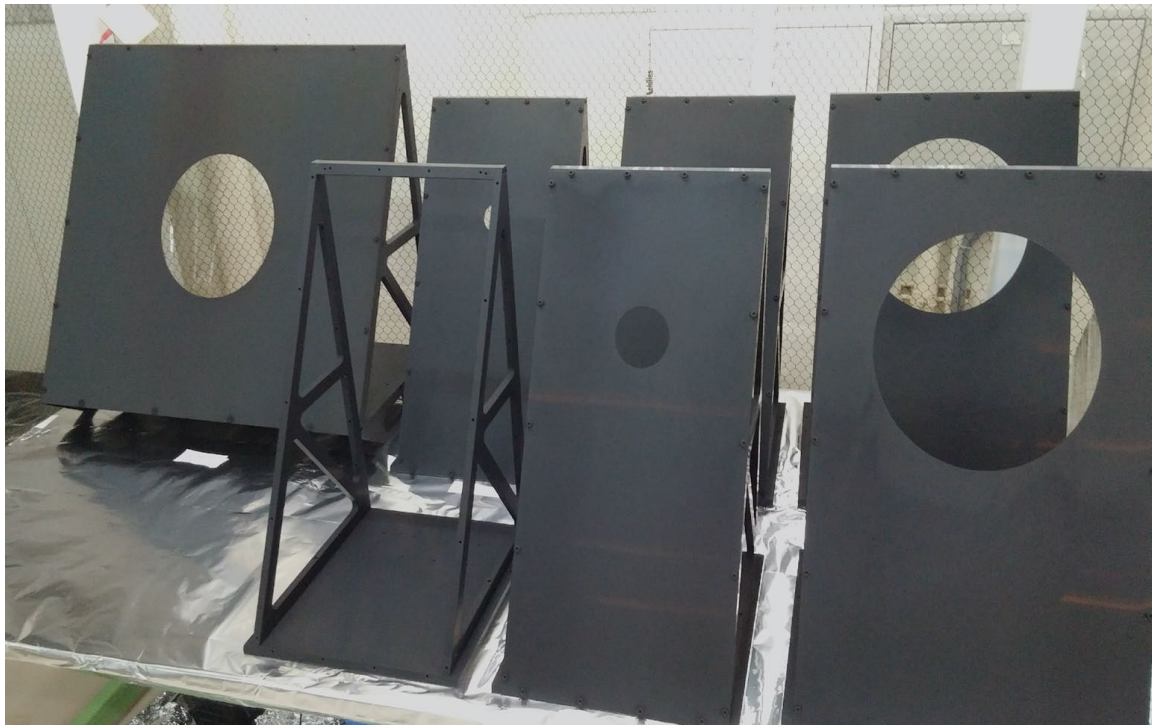


Frequency Dependent Squeezing

Quantum Noise of an Interferometer

Shot Noise

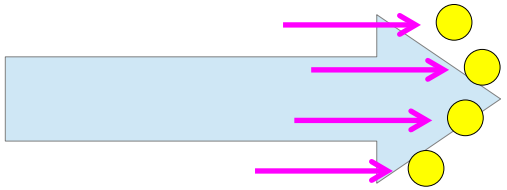
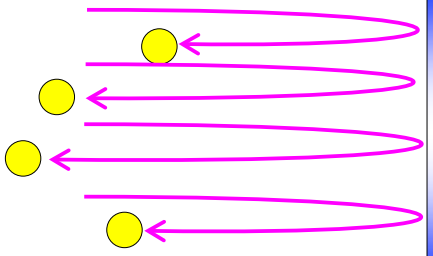
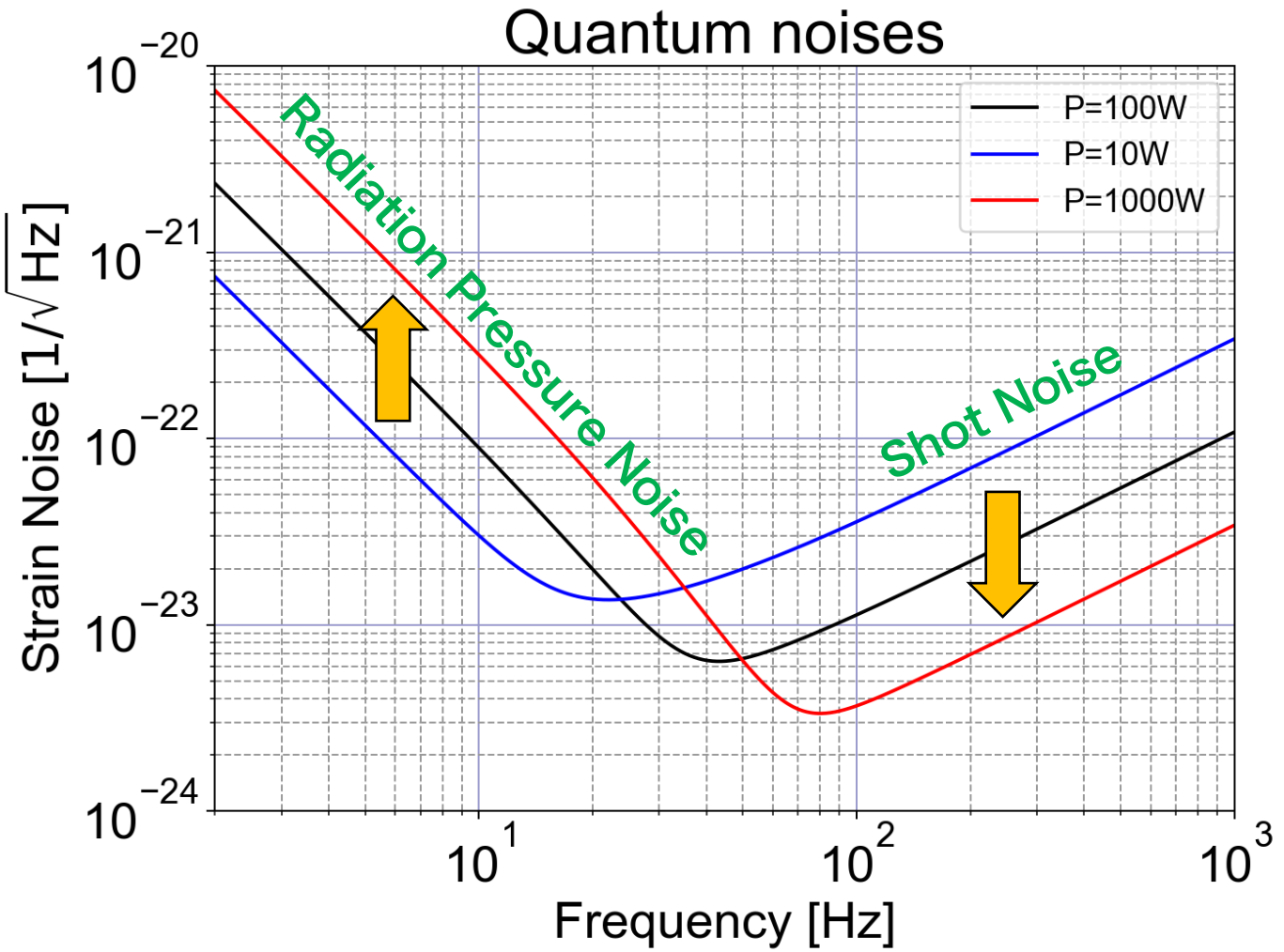


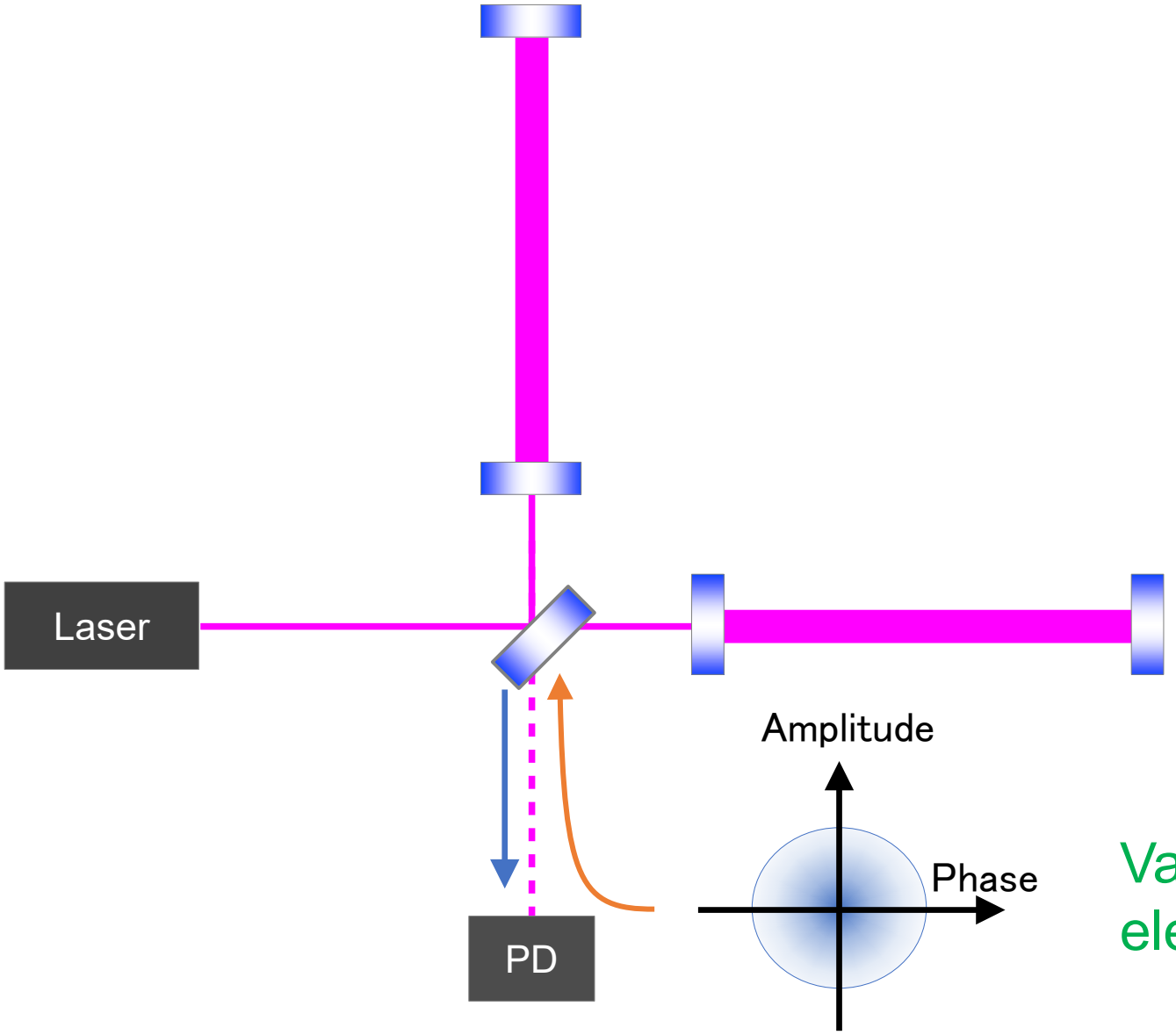
Photo Detector

Radiation Pressure Noise

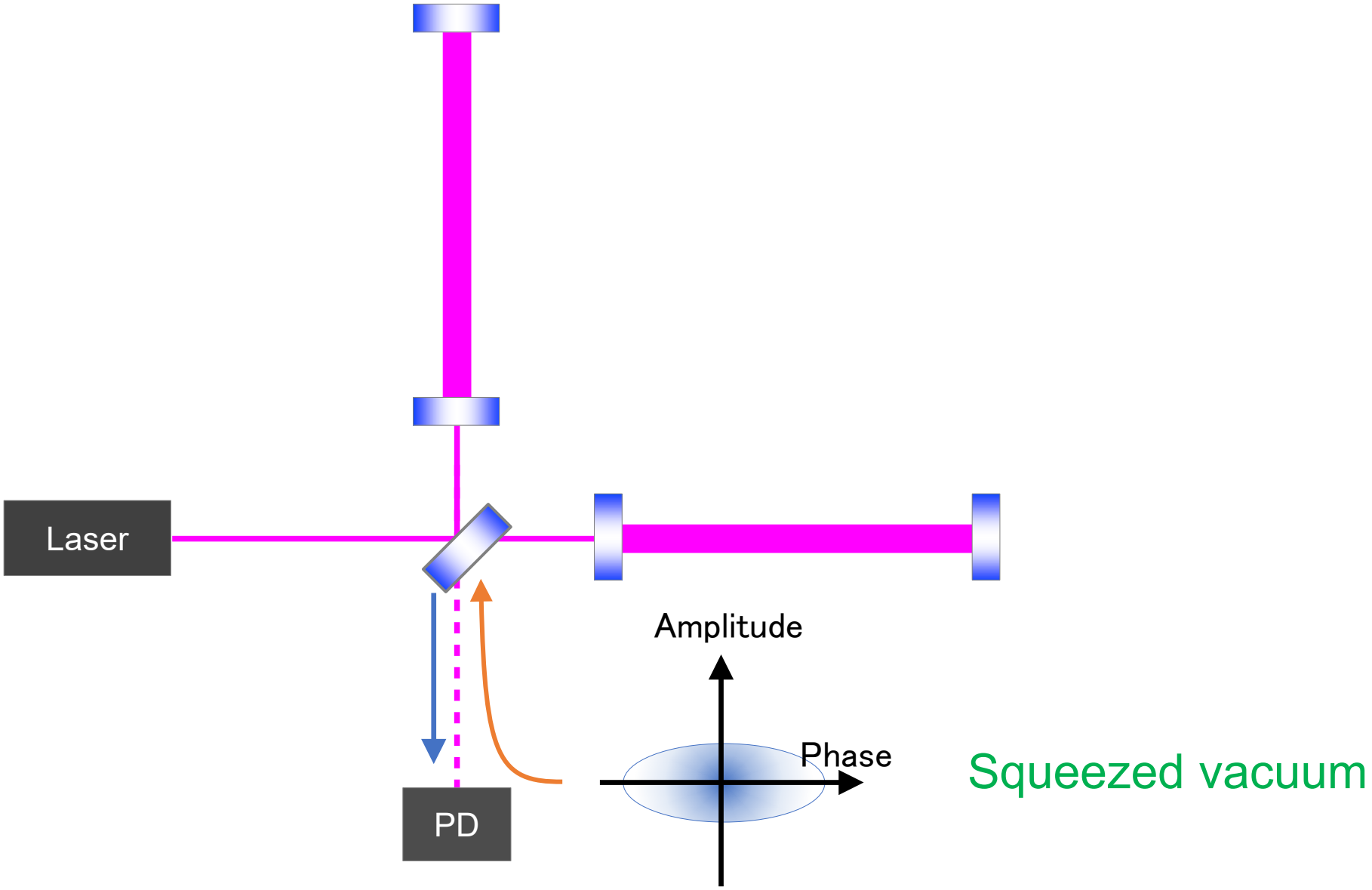


Mirror



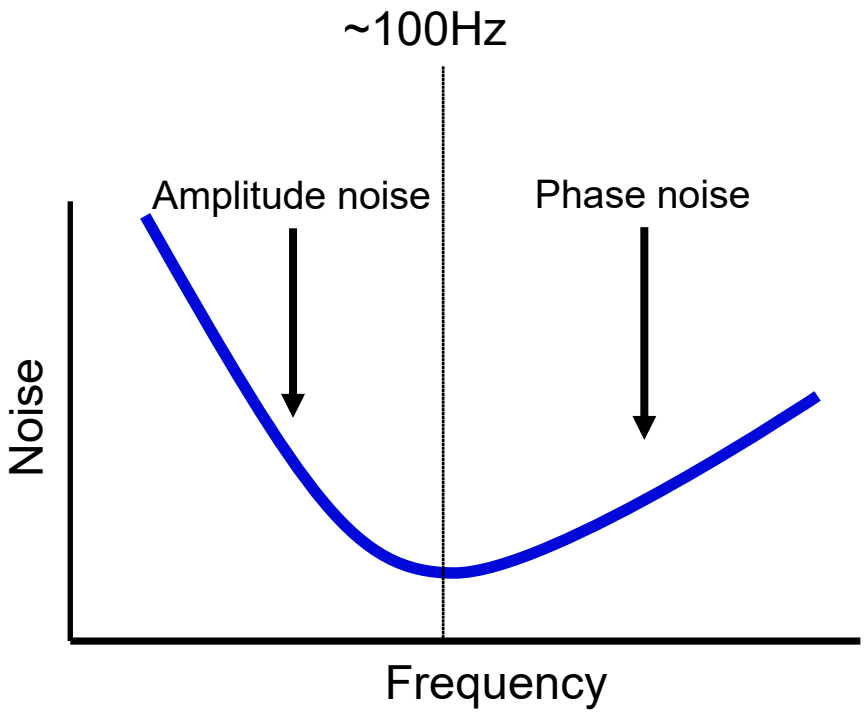


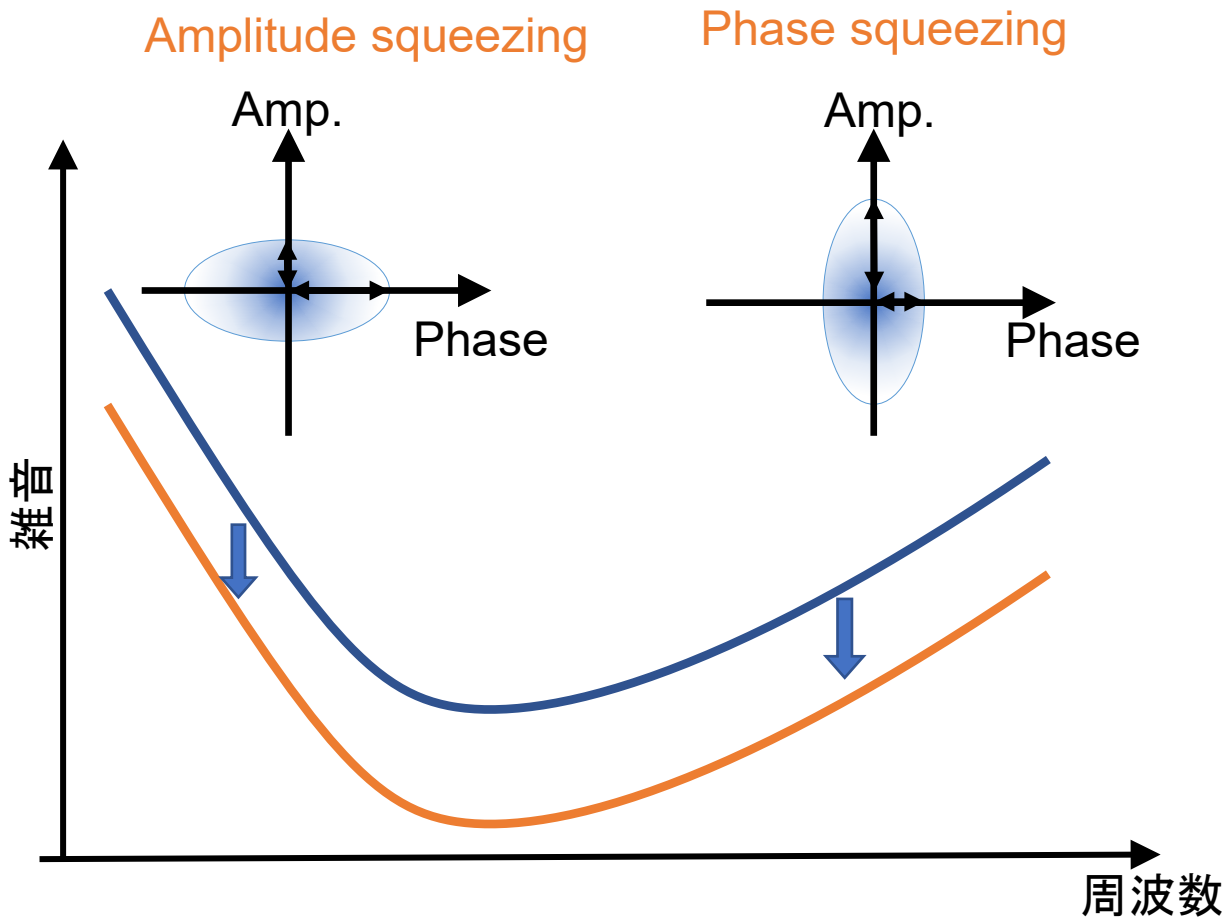
Vacuum fluctuation of electro-magnetic field



Squeezed vacuum

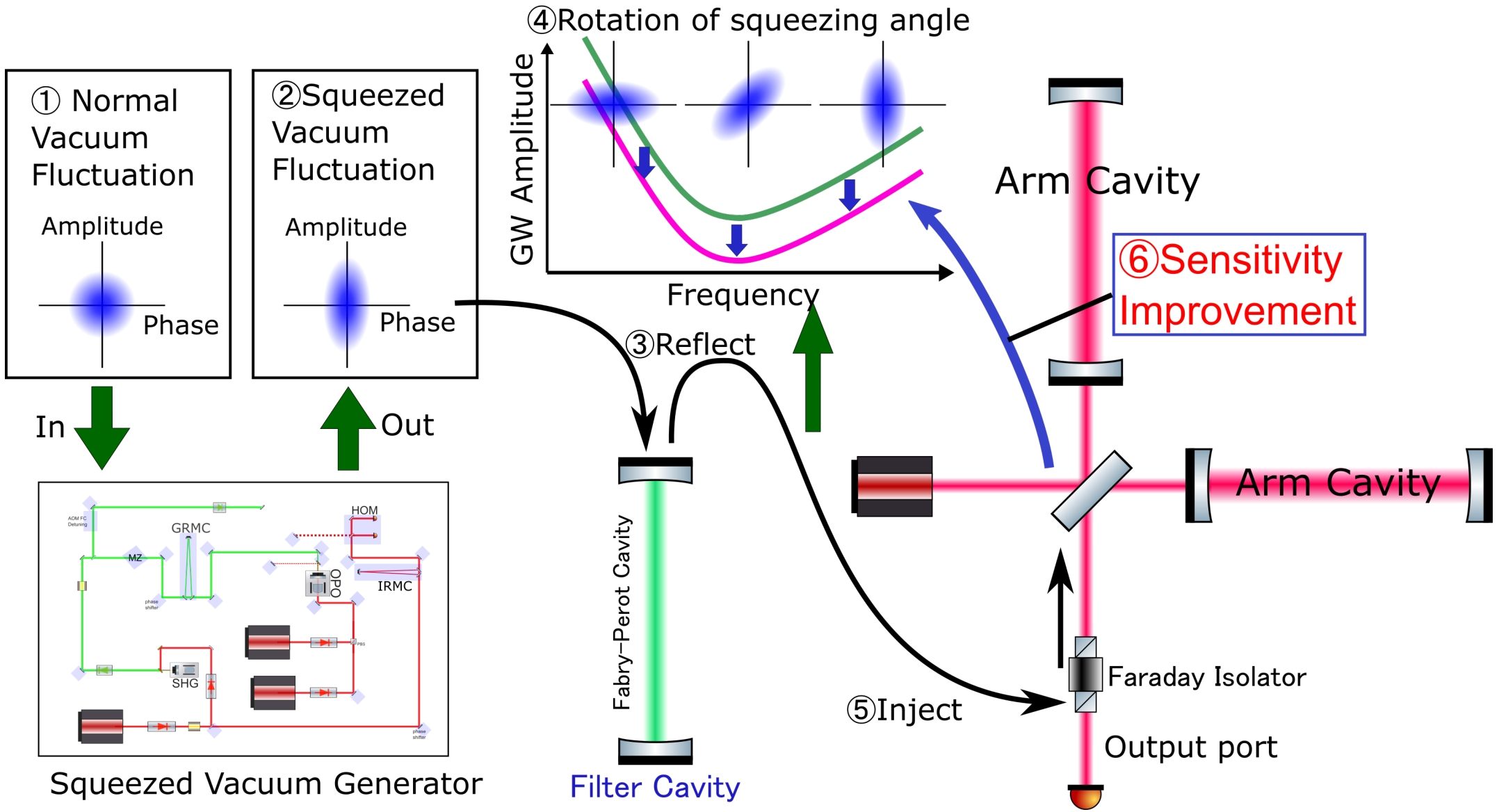
Different noise dominates at different frequencies



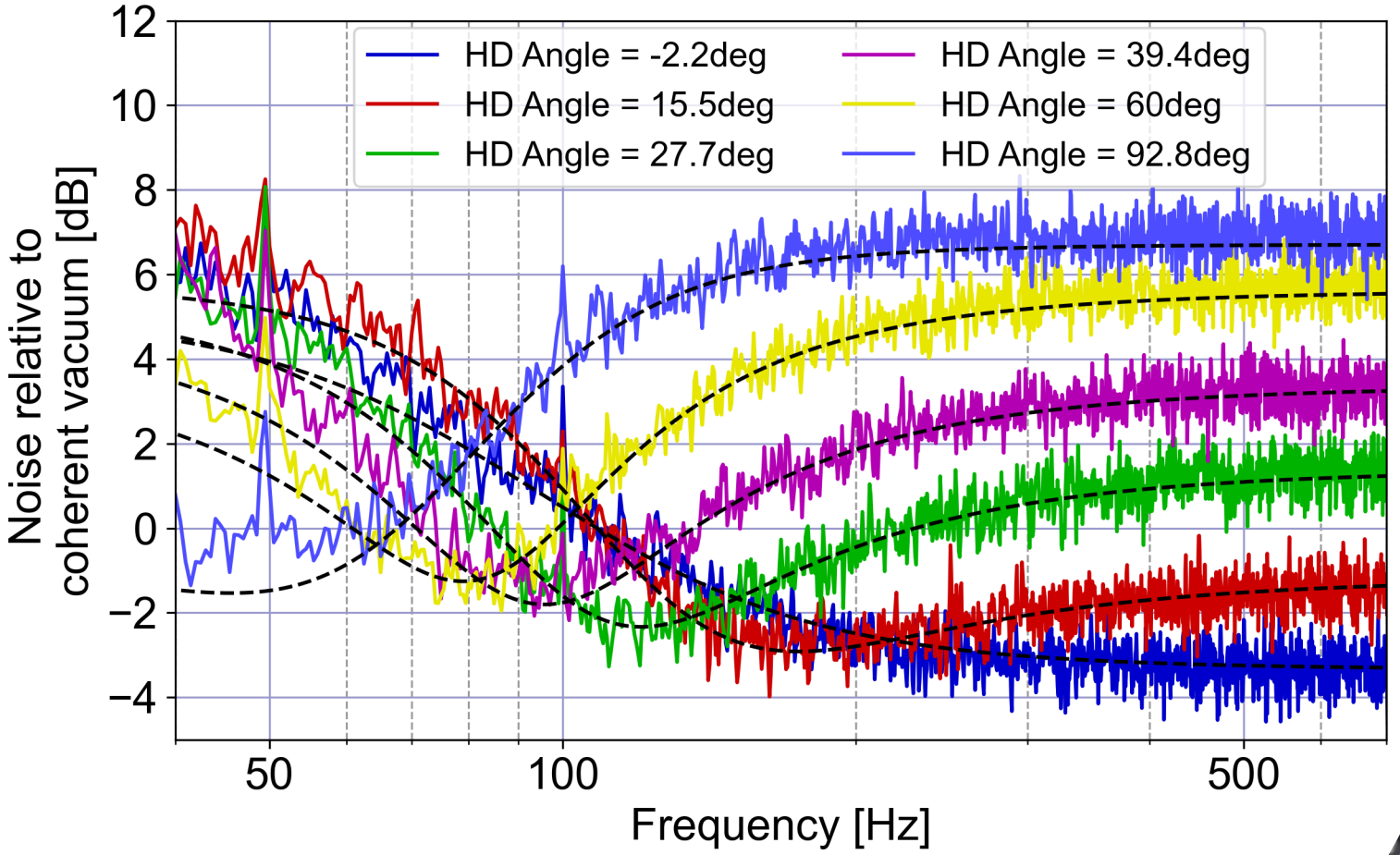


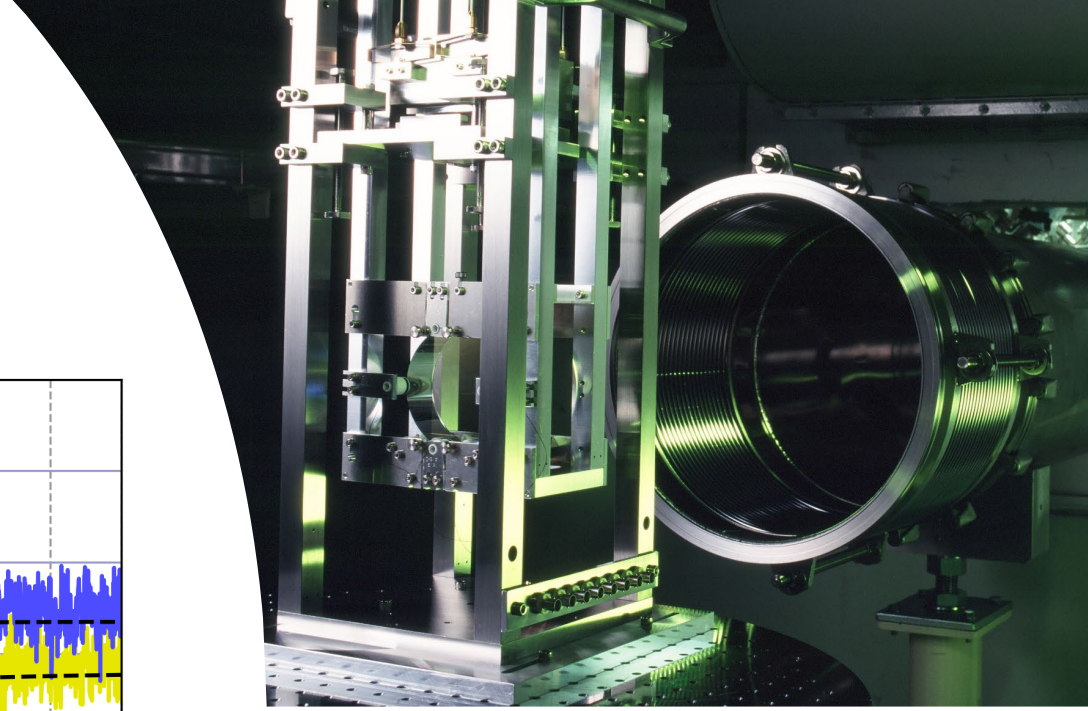
Need to change the direction of squeezing

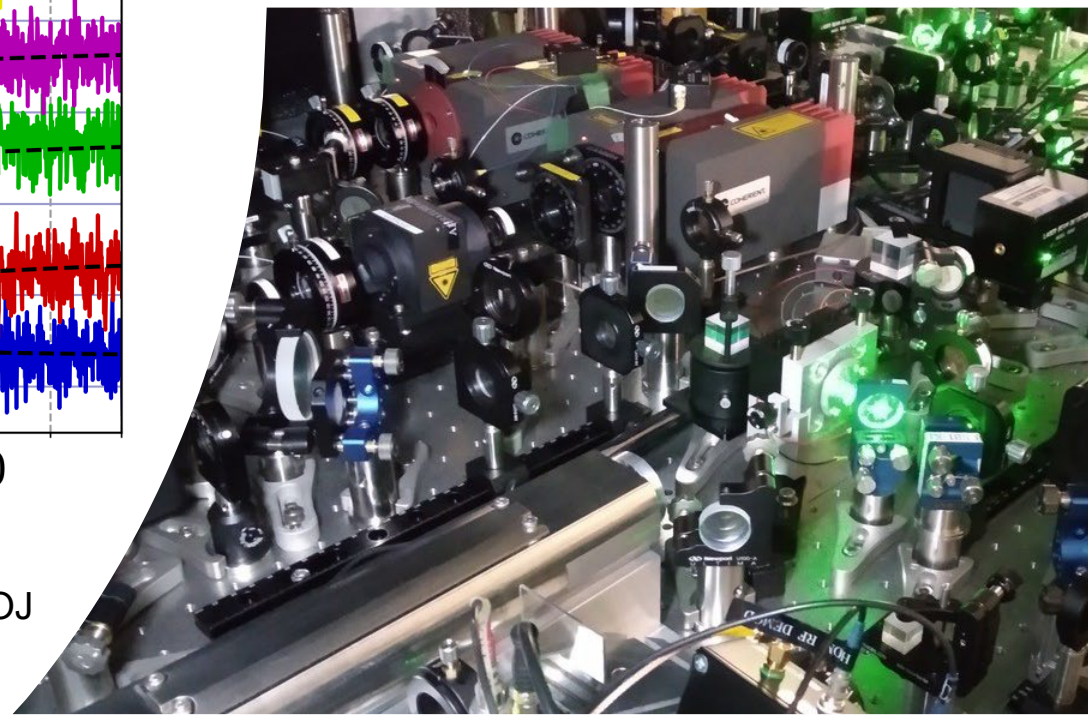
Frequency dependent squeezing with a filter cavity



World's first realization of frequency dependent squeezing at low frequencies







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Development of High-Quality Sapphire mirrors

What we want

- Low optical absorption
- Low birefringence inhomogeneity

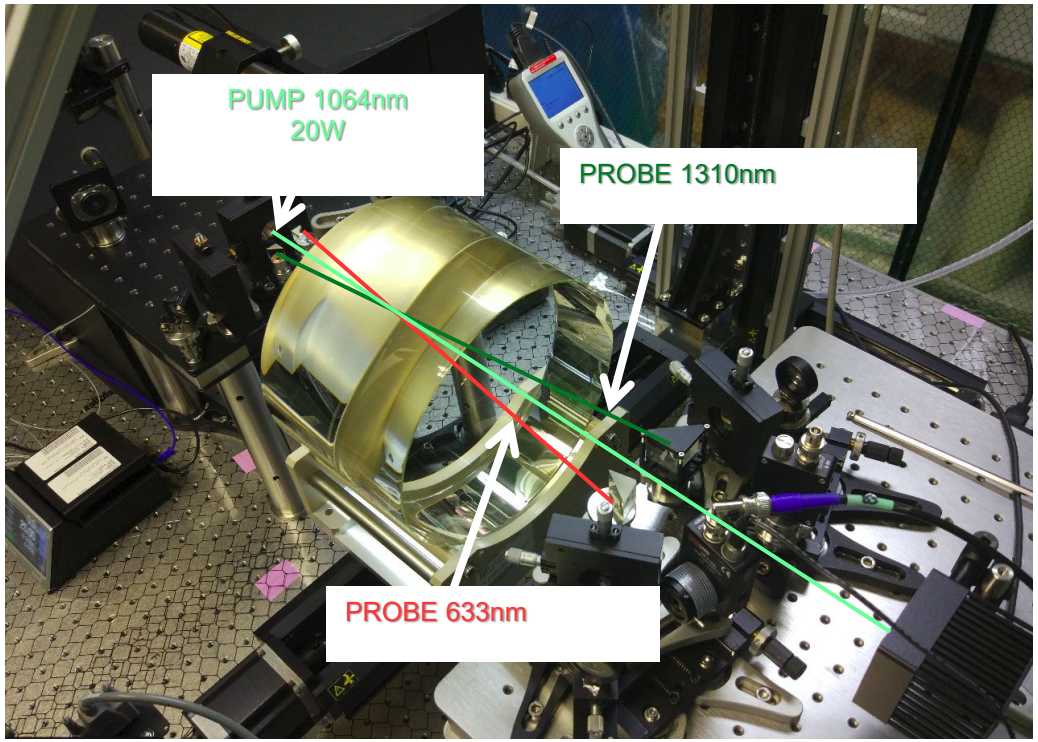
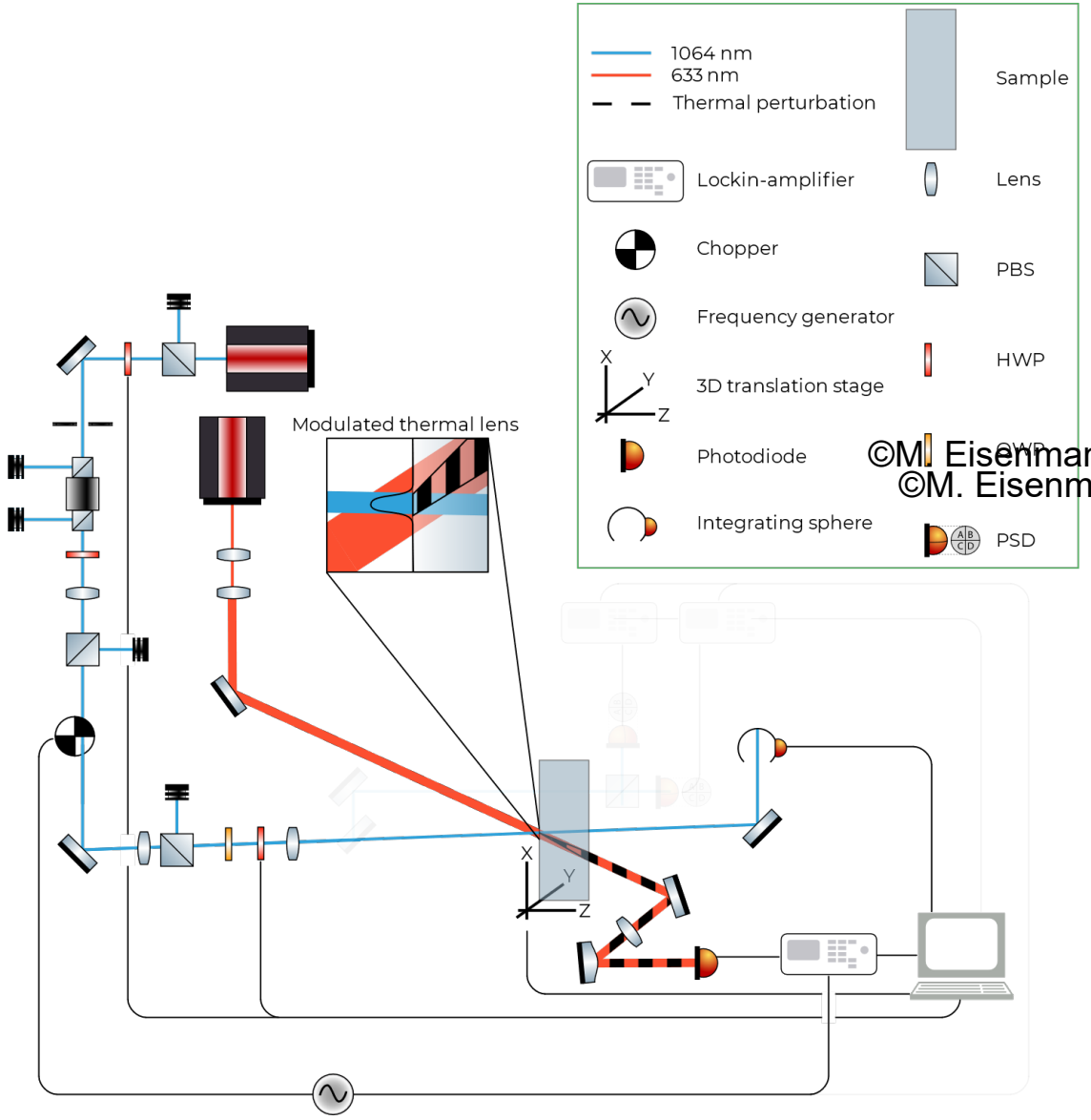


Photo-thermal Common Path Interferometry



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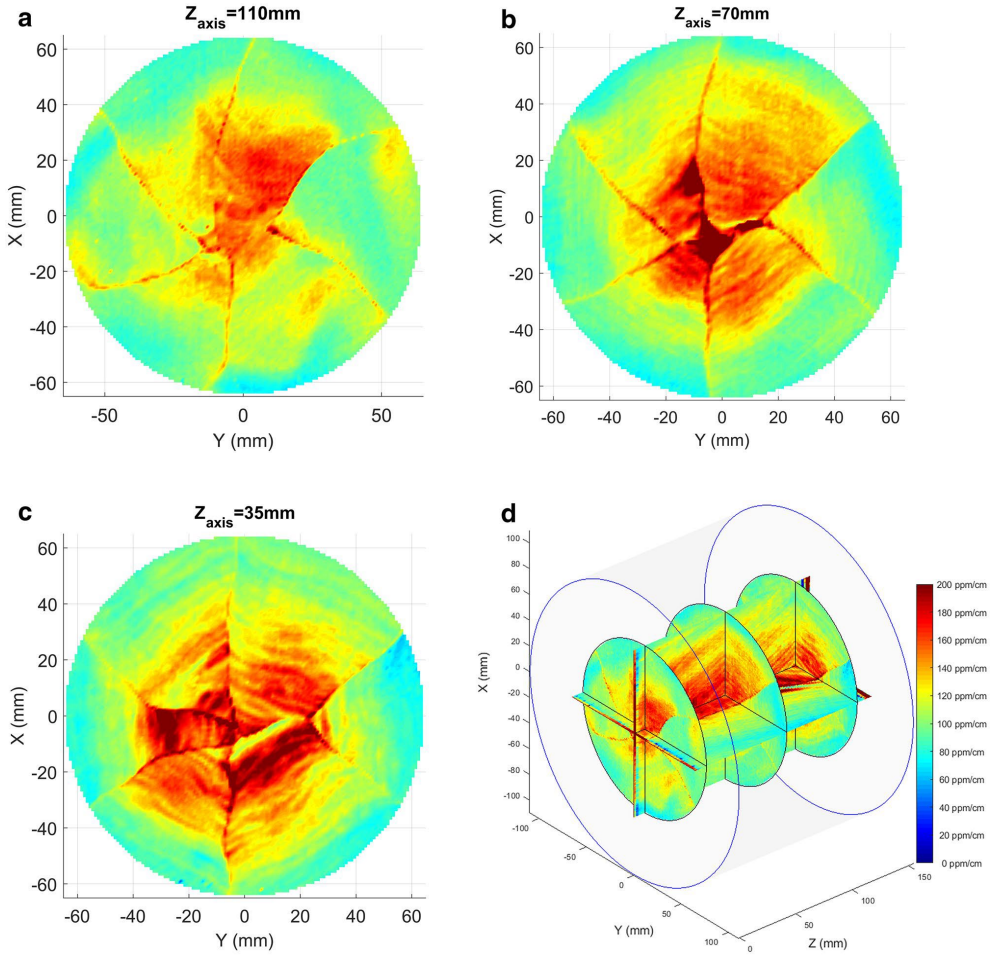
3D Absorption Map of a Sapphire Crystal



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Birefringence Map of a Sapphire Crystal

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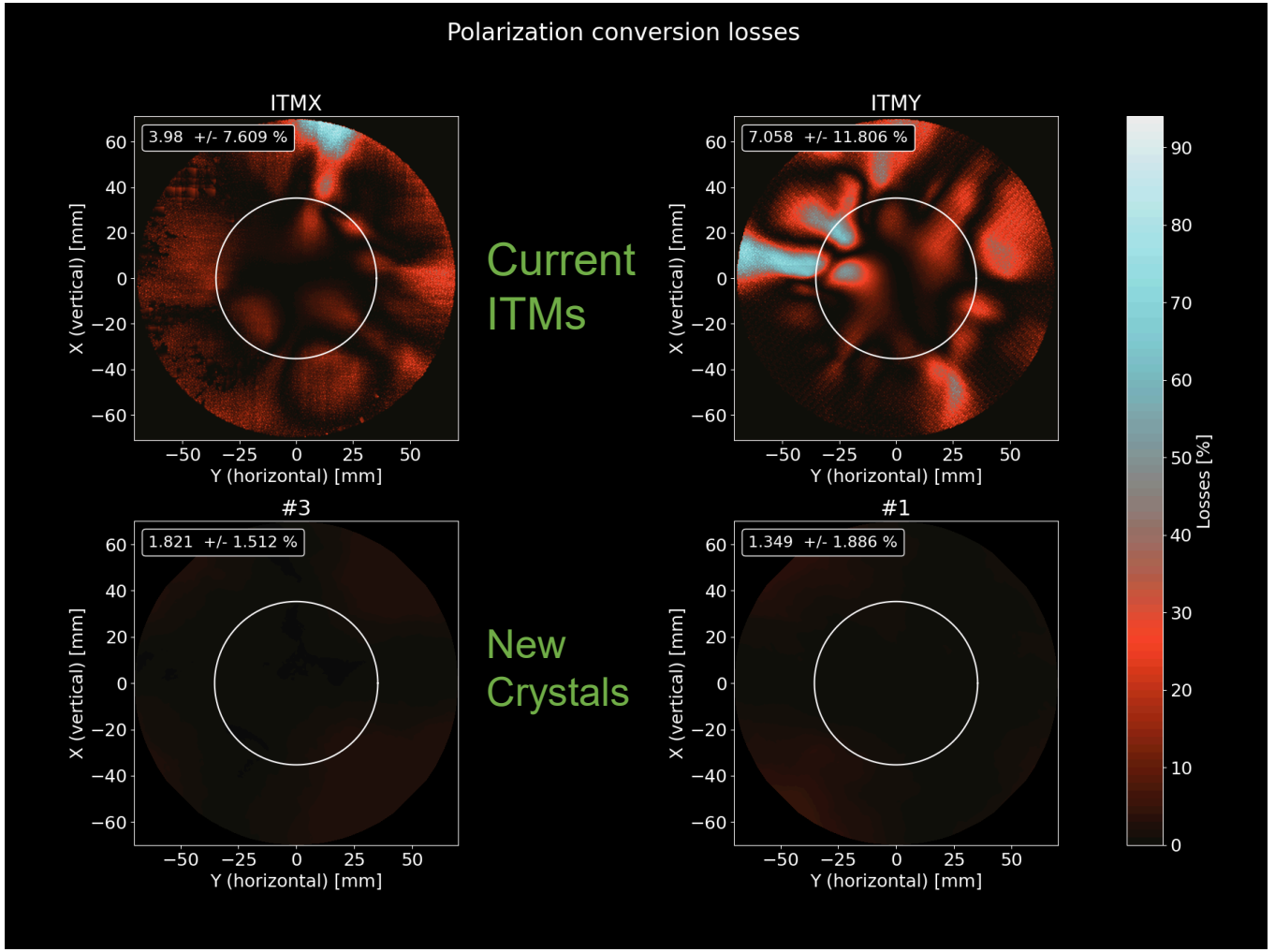
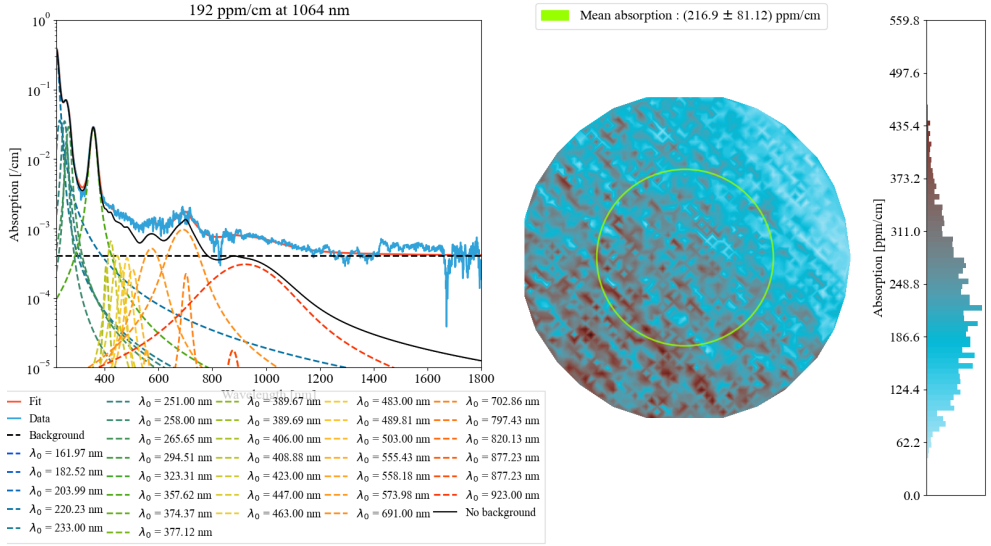
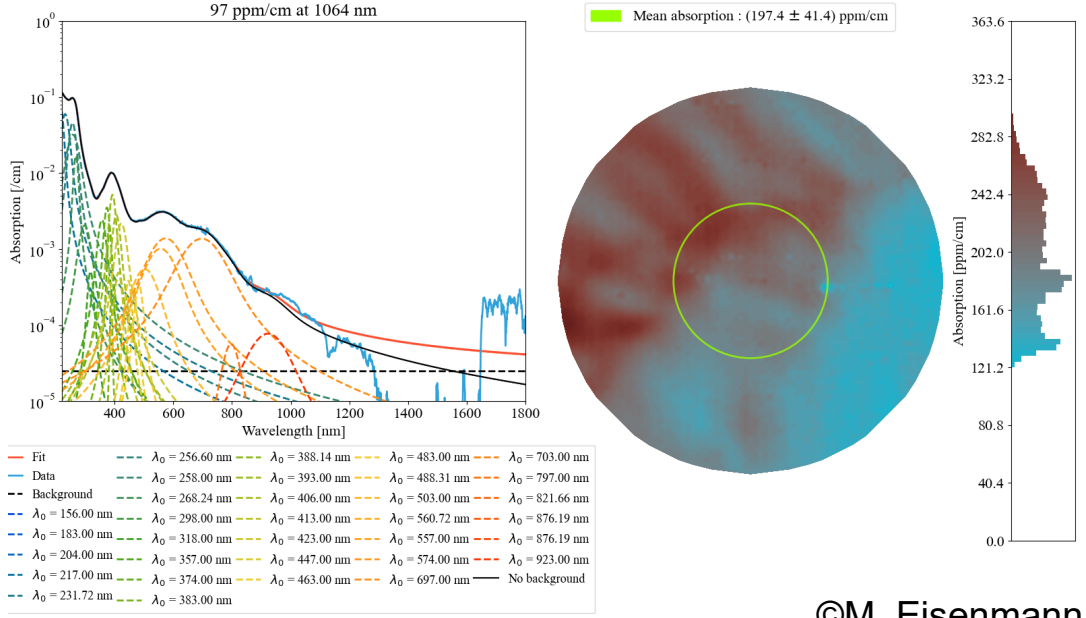


Spectro-photometry measurements





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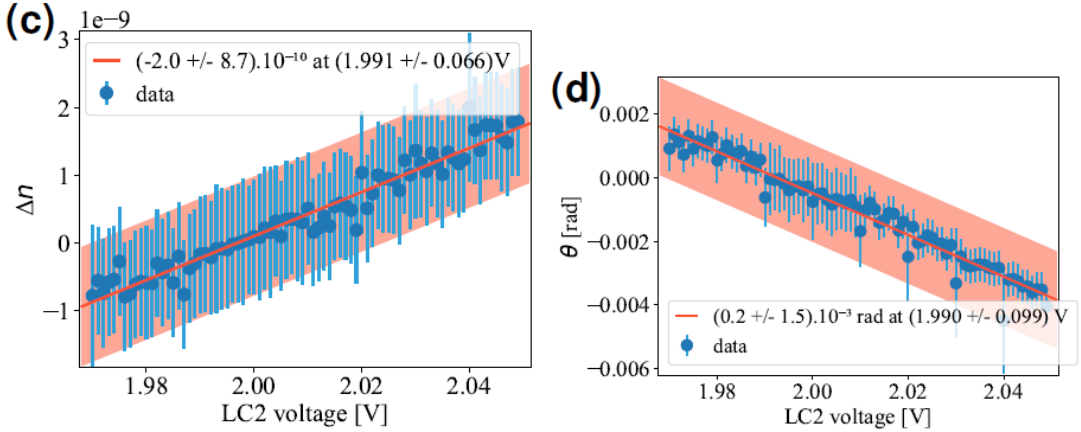
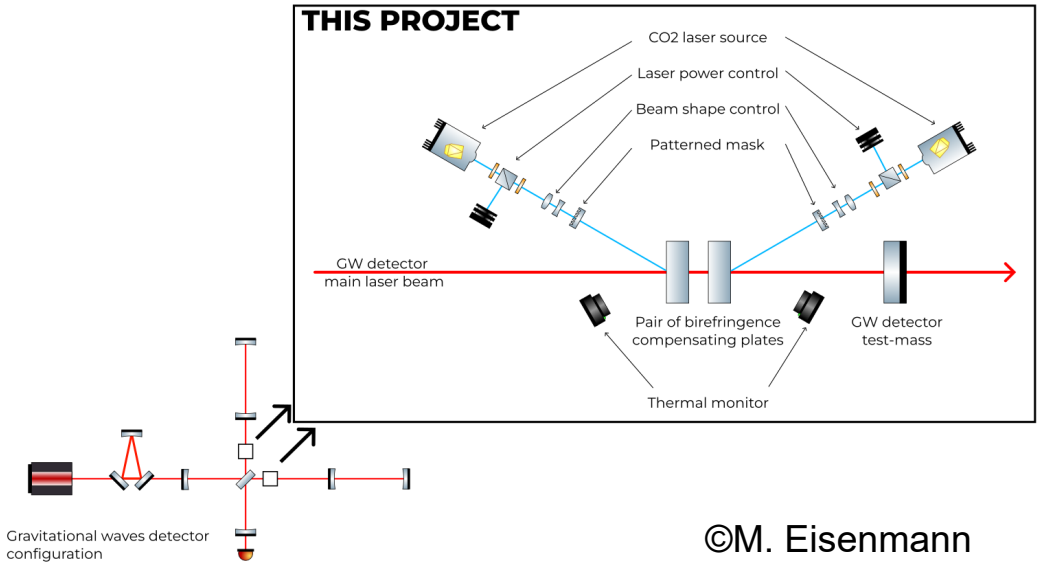
In-situ birefringence compensation





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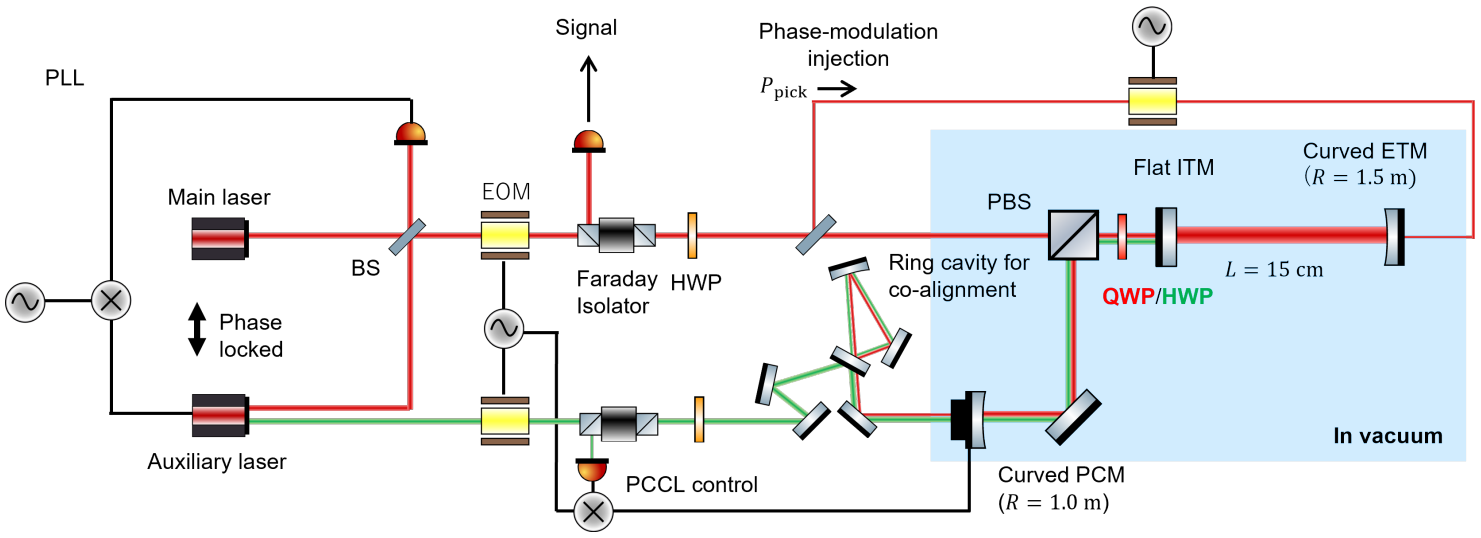
Speed meter for eliminating radiation pressure noise

- Change the measurement variable from position to momentum (speed)
- Elimination of quantum radiation pressure noise
- Improvement of low frequency sensitivity



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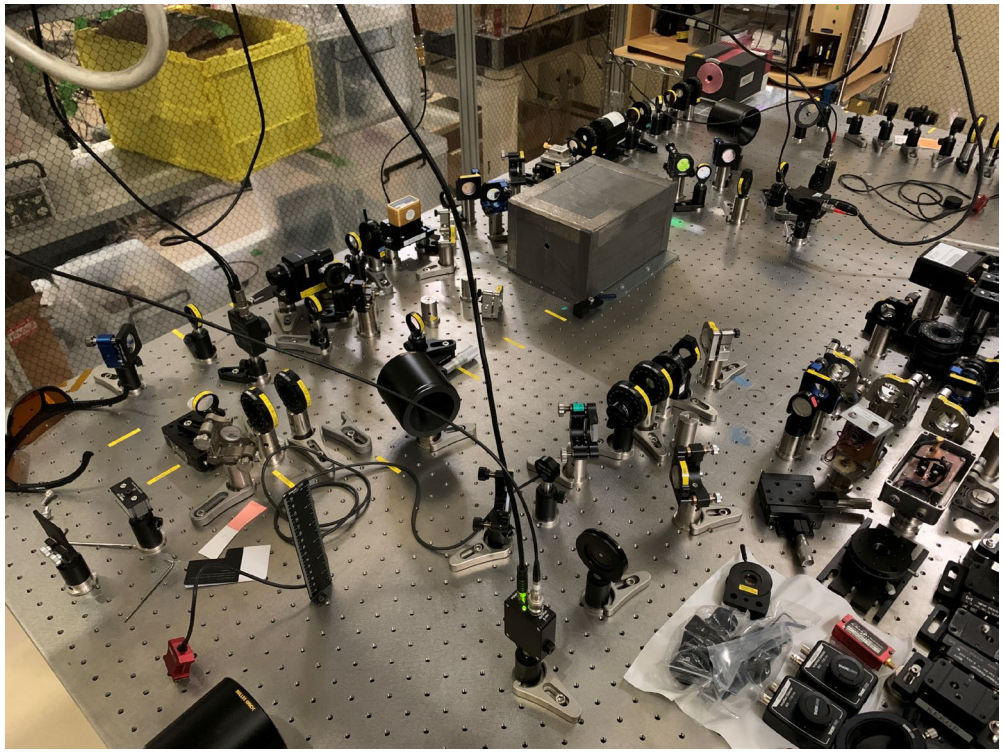


Next R&D ideas with TAMA

Science Investigations/
Instruments and data to be returned

EPR squeezing

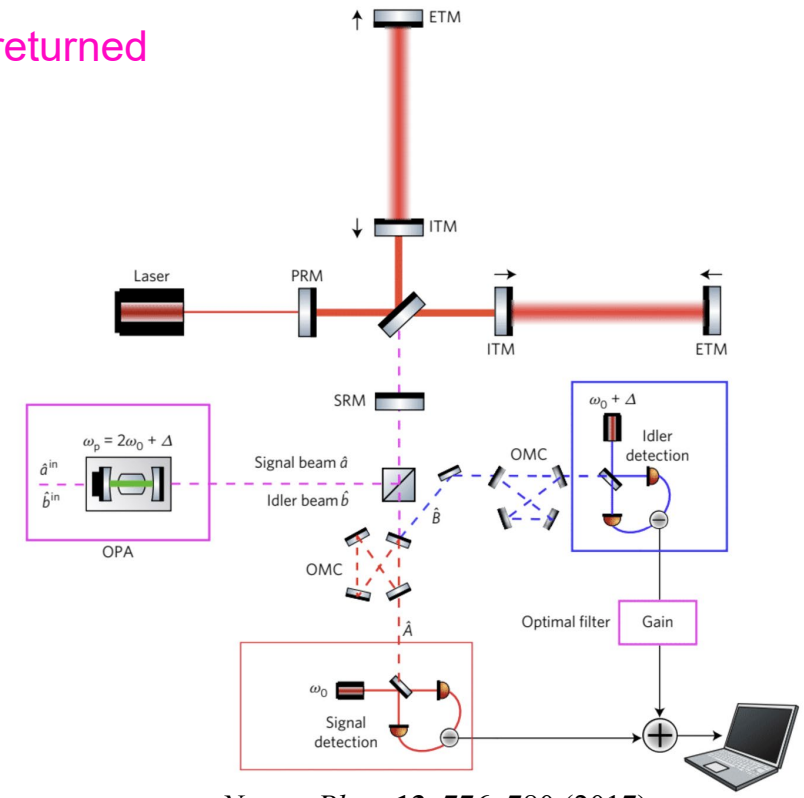
- Frequency dependent squeezing without the need of long filter cavity
- A pair of entangled photons to induce frequency dependency

Dark matter search

- Search for Axion like particle
- Detect polarization rotation in TAMA's arm cavity
- Novel configuration to allow the use of a linear cavity

High-frequency GW detector technologies

- KAGRA may focus on high frequency GW in the future upgrade
- Necessary R&Ds: high-power compatible cooling and parametric instability mitigation



Nature Phys. **13**, 776–780 (2017)

GWSP future strategy meeting: Feb. 18-20, 2025

Originality and international competitiveness, Why NAOJ

- Unique position of the TAMA300 facility
  - Fully equipped 100m class prototype interferometer for R&D use
  - Filling the gap between tabletop experiments and large observatories
  - Still small enough to be managed by small number of researchers
  - Able to try ideas freely

Current Status

- Several research themes are on going
  (filter cavity, sapphire development, etc)

Cost assessments, budget line and status

- Kakenhi for each research topic
- Facility maintenance support from NAOJ (10MJPY/year?)

Project Organization

- TBD

Answers to the questions for the LoI

(Q1) Is the money for hiring people included in the estimated budget?

(A1) Budget for postdocs is not included in the 10MJYP/year request to NAOJ. We plan to hire postdocs with Kakenhi.

(Q2) Is the maintenance cost of TAMA facility included in the estimated budget?

(A2) Yes, the large part of the 10MJPY/year request to NAOJ is the maintenance cost of the TAMA facility.