Development of Torsion-Bar Antenna for Low-Frequency Gravitational-Wave Observation

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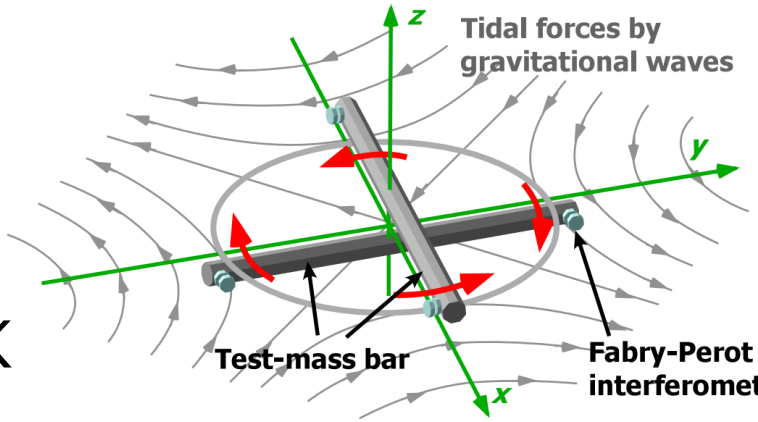
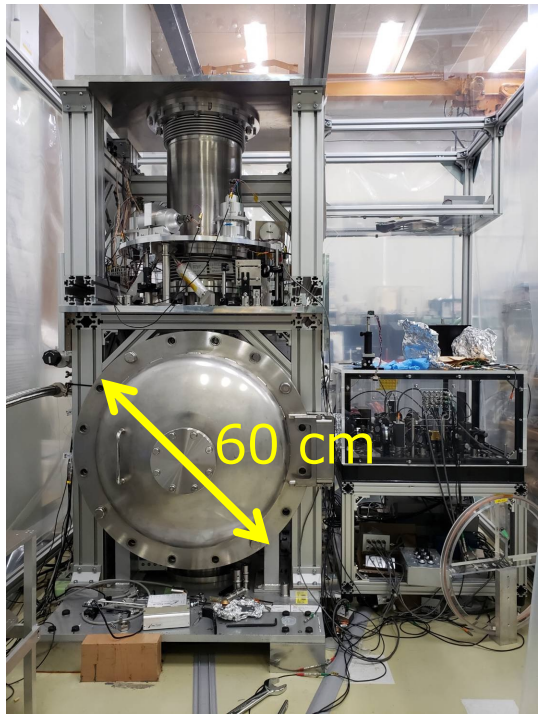
Overview

- Proposed Torsion-Bar Antenna (TOBA)
  to detect GW in 0.1-10 Hz
  - Target: 10^{-19} /√Hz
    with 10-m scale torsion pendulums at 4 K
  - Science: intermediate-mass BH binary merger
    within ~10 Gpc



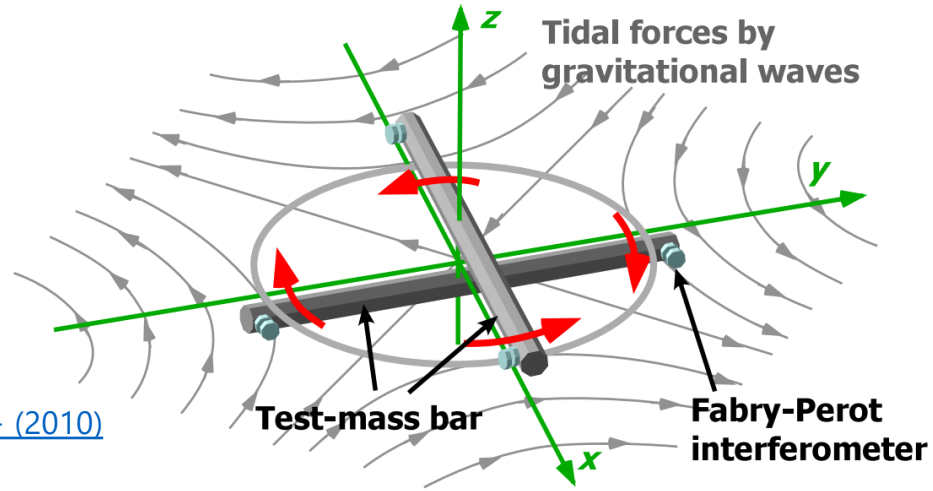
M. Ando+ (2010)

- Developing prototype detector Phase-III TOBA
  - Target: 10^{-15} /√Hz
    with 30-cm scale torsion pendulums at 4 K
  - Science: Newtonian noise, earthquake early warning
  - Some essential components are under development

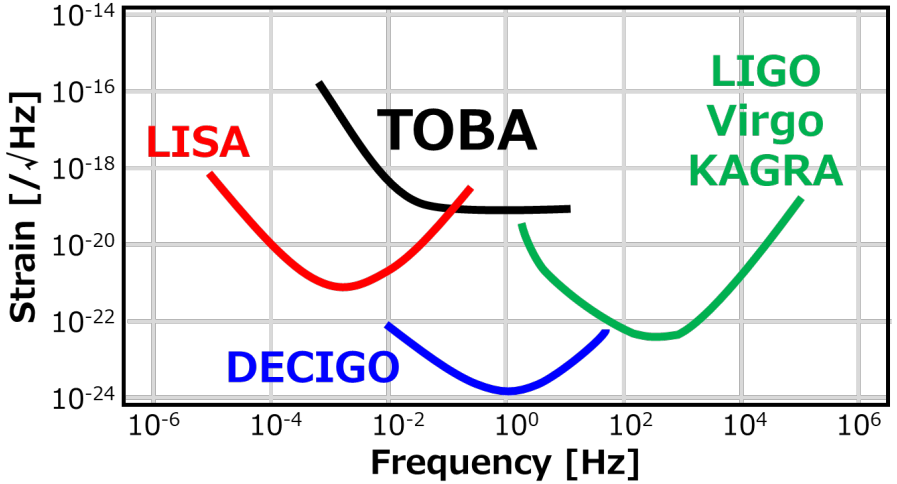


TOBA: TOrsion-Bar Antenna

- Ground-based GW detector for low freq. (0.1-10 Hz)
  - Final target: 10^{-19} /√Hz at 0.1 Hz
- Aim to detect the torsional rotation of test masses suspended horizontally
- The resonant frequency of torsional motion is low (~1 mHz)
  → Good sensitivity in low freq. even on the ground
  - Inexpensive to develop
  - Easy to maintain
  - Geophysical science



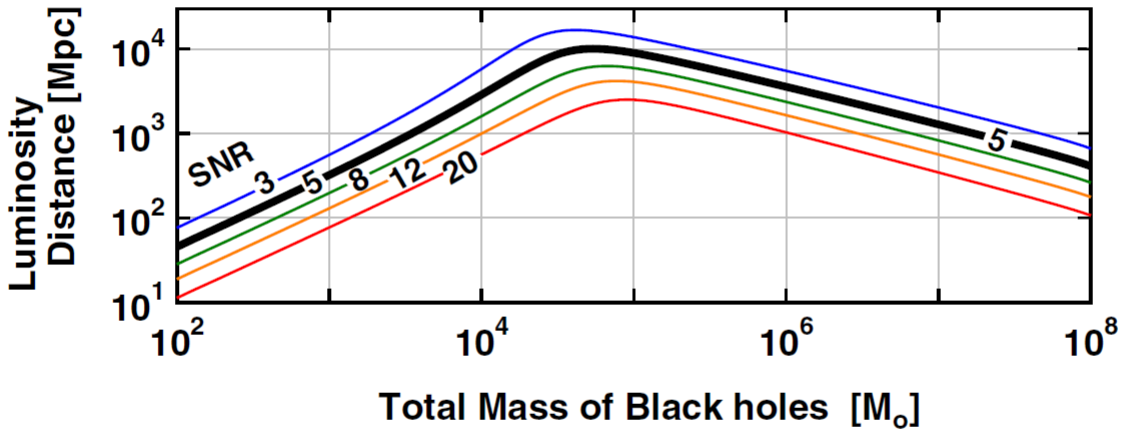
M. Ando+ (2010)



Science of TOBA (1)

Astrophysics

- Intermediate-mass BH binary merger
  - Within ~1 Mpc (Phase-III)
  - Within ~10 Gpc (Final)
    → Formation process of a supermassive black hole



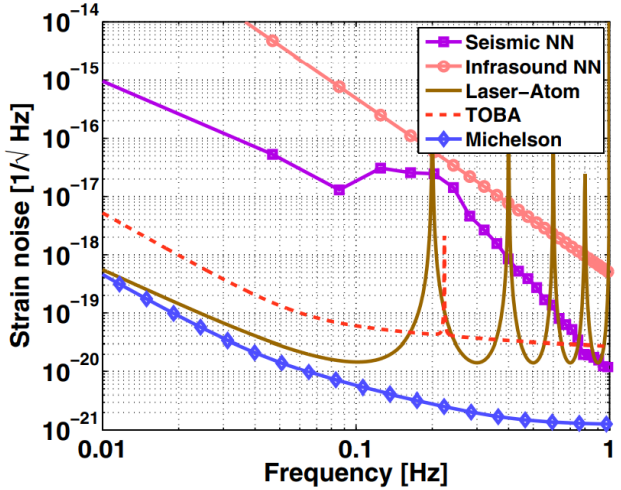
M. Ando+ (2010)

- GW stochastic background
  - Ω_{GW} ~10^{-7} (Final)
    → Direct exploration of the early universe

Science of TOBA (2)

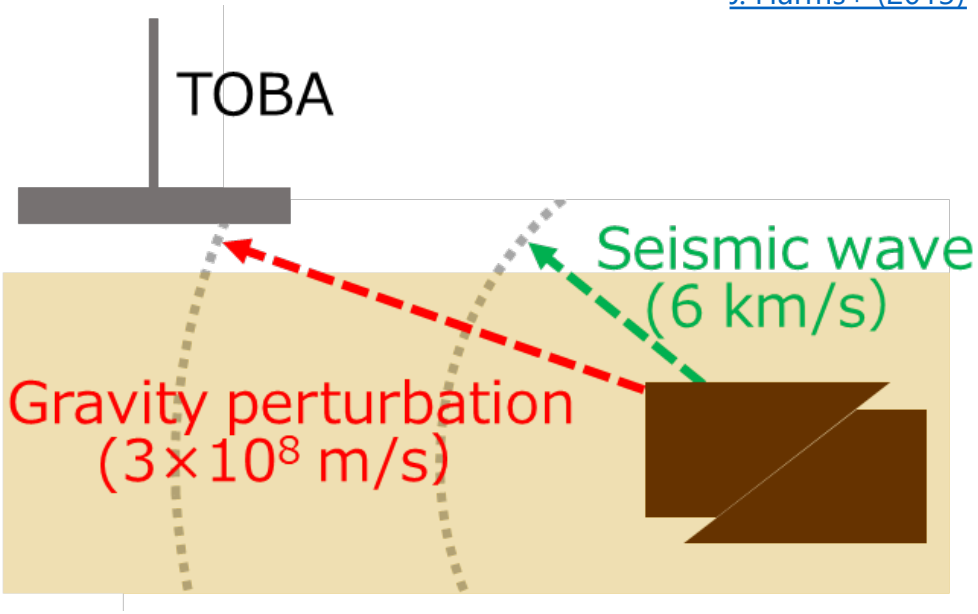
Geophysics

- Newtonian noise
  - First direct detection (Phase-III)
    → Noise reduction
    for the 3rd generation GW detectors



J. Harms+ (2013)

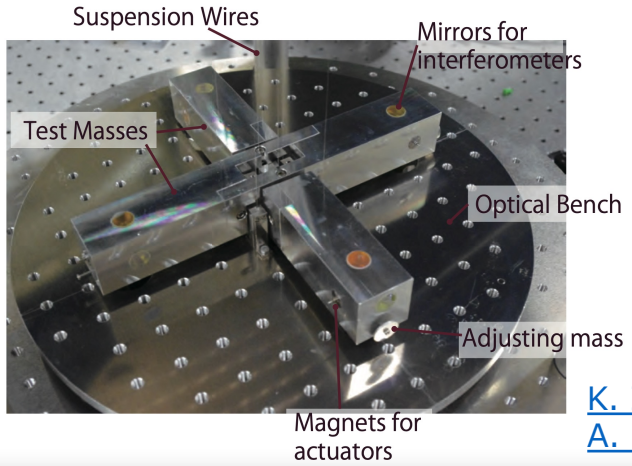
- Earthquake early warning
  - M7 earthquake apart from 100 km within 10 sec (Phase-III)
    → Reduction of disaster damage



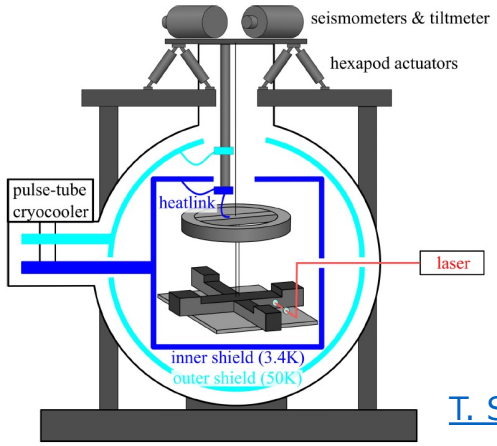
Development roadmap of TOBA

Phase-I → Phase-II → Phase-III (Now) → Final

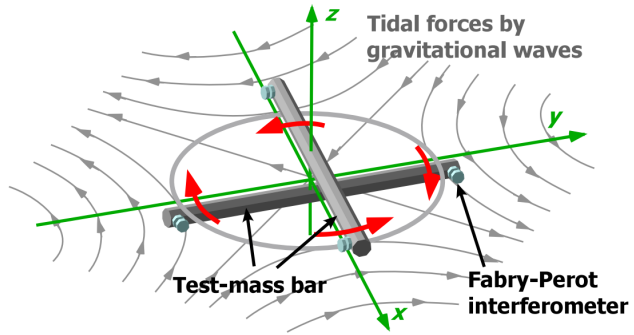
Phase-I	Phase-II	Phase-III (Now)	Final
Principle test		Technical demonstration Geophysical observation	GW observation
10^{-8} /√Hz (Established)		10^{-15} /√Hz (Target)	10^{-19} /√Hz (Target)
~20 cm bars		30 cm bars	10 m bars
Room temp.		Cryo. temp. (4 K)	Cryo. temp. (4 K)



K. Ishidoshiro+ (2011)
A. Shoda+ (2017)



T. Shimoda+ (2020)

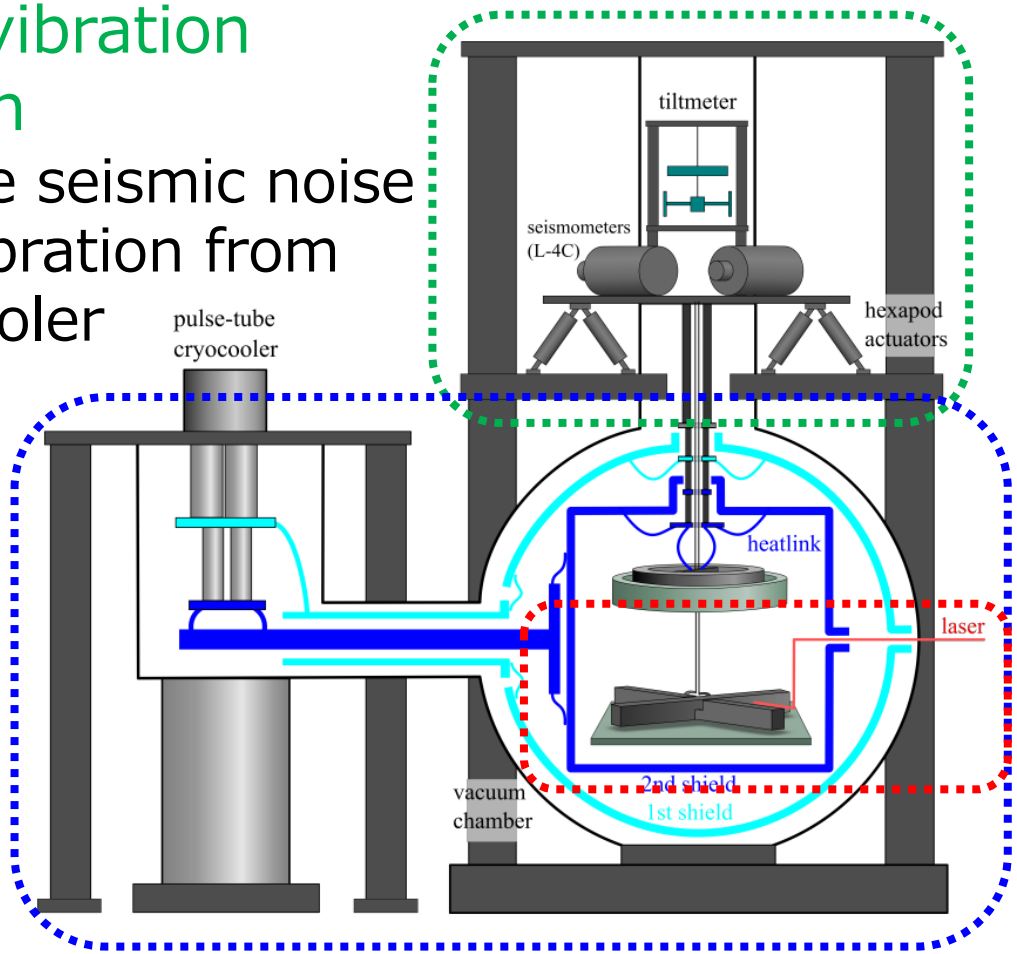


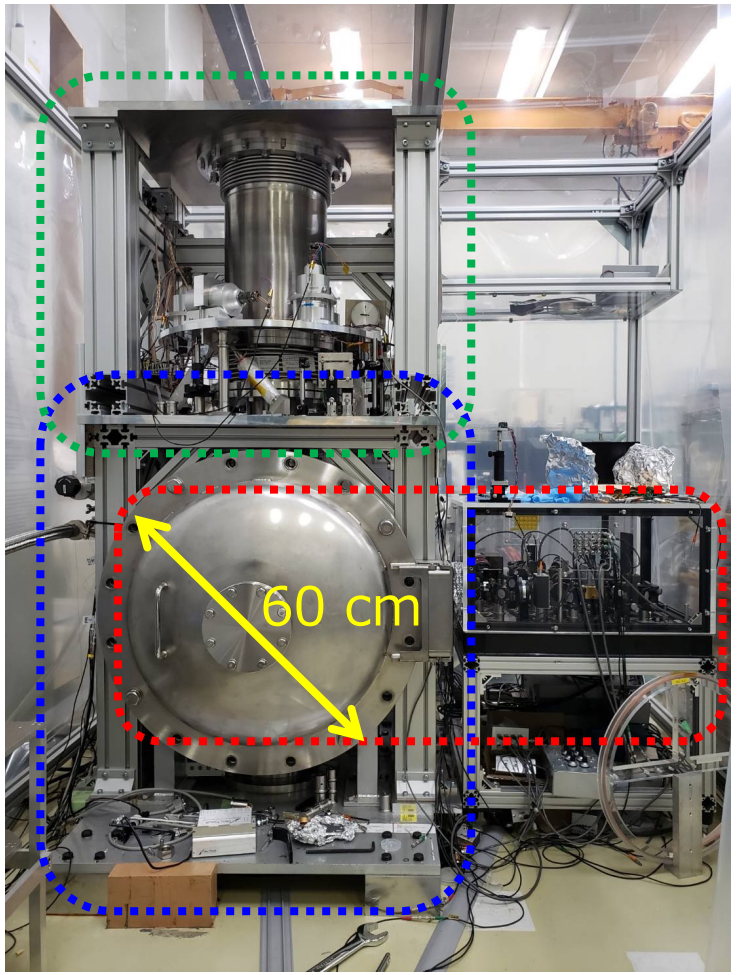
Configuration of Phase-III TOBA

T. Shimoda, Ph.D. thesis (2019)

Active vibration isolation

Reduce seismic noise and vibration from cryocooler





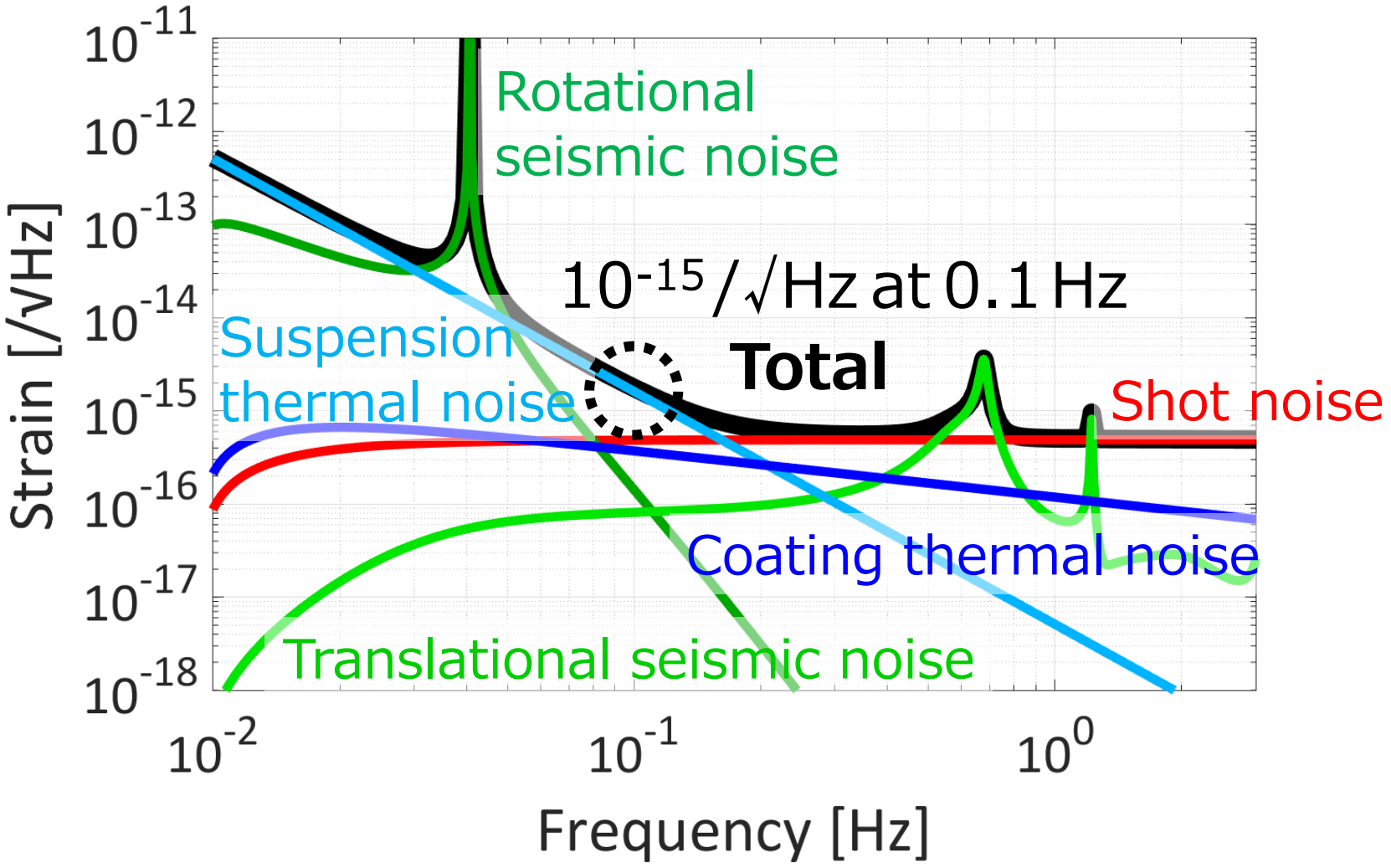
Cryogenic suspension

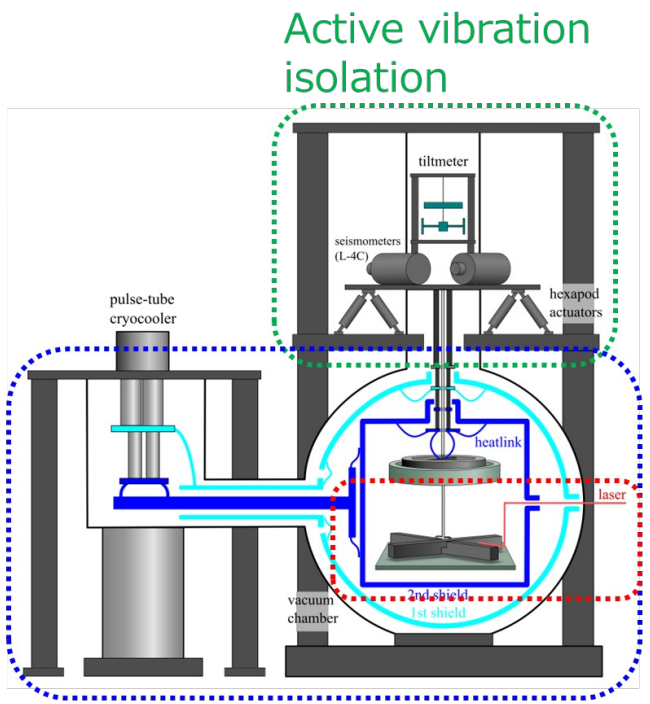
Torsion pendulums at 4 K

Optical readout

Detect the rotation of the pendulums

Design sensitivity of Phase-III TOBA

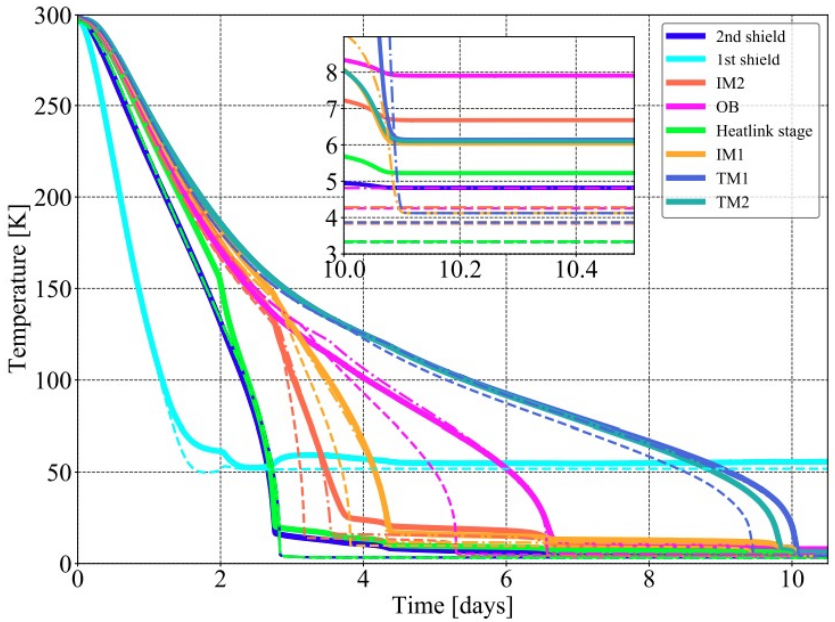




Current status of Phase-III TOBA (1)

Cryogenic suspension

- ✓ Cryogenic test was successfully done to 6 K
- Developing suspension wire made of sapphire for high Q value (~10^8)
- Designing torsion pendulums to reduce coupling from translational seismic noise



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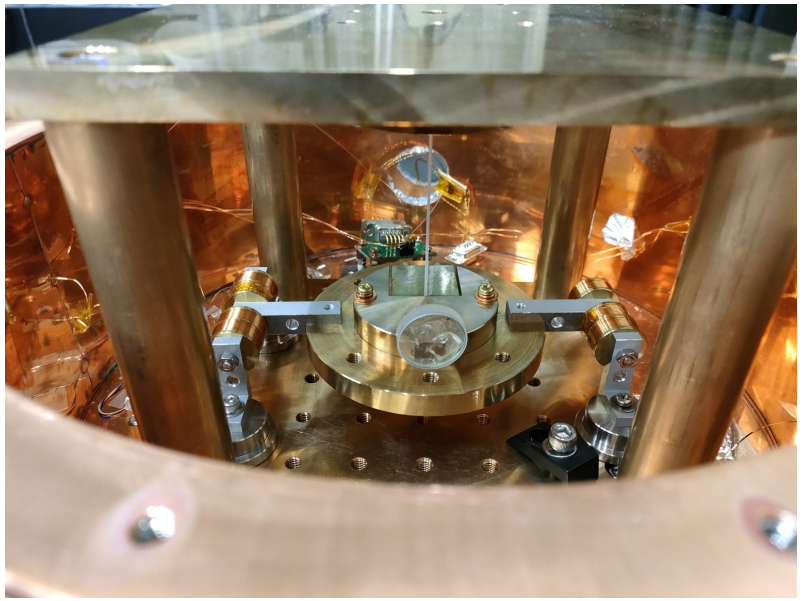
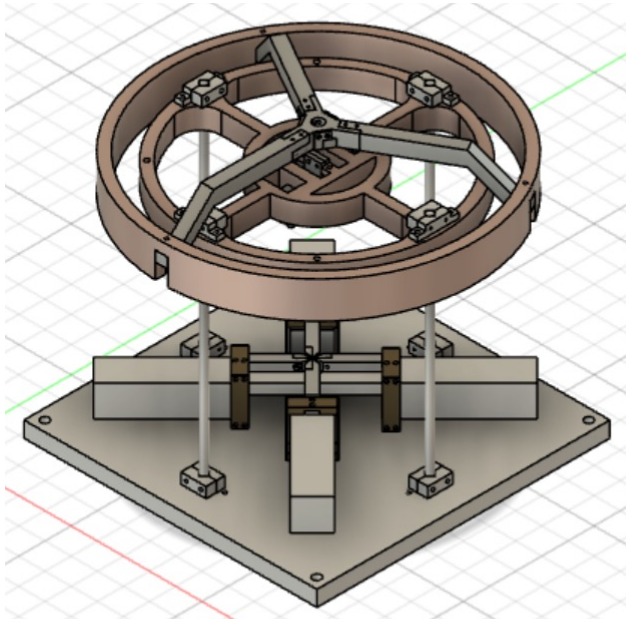


Photo by C. P. Ooi

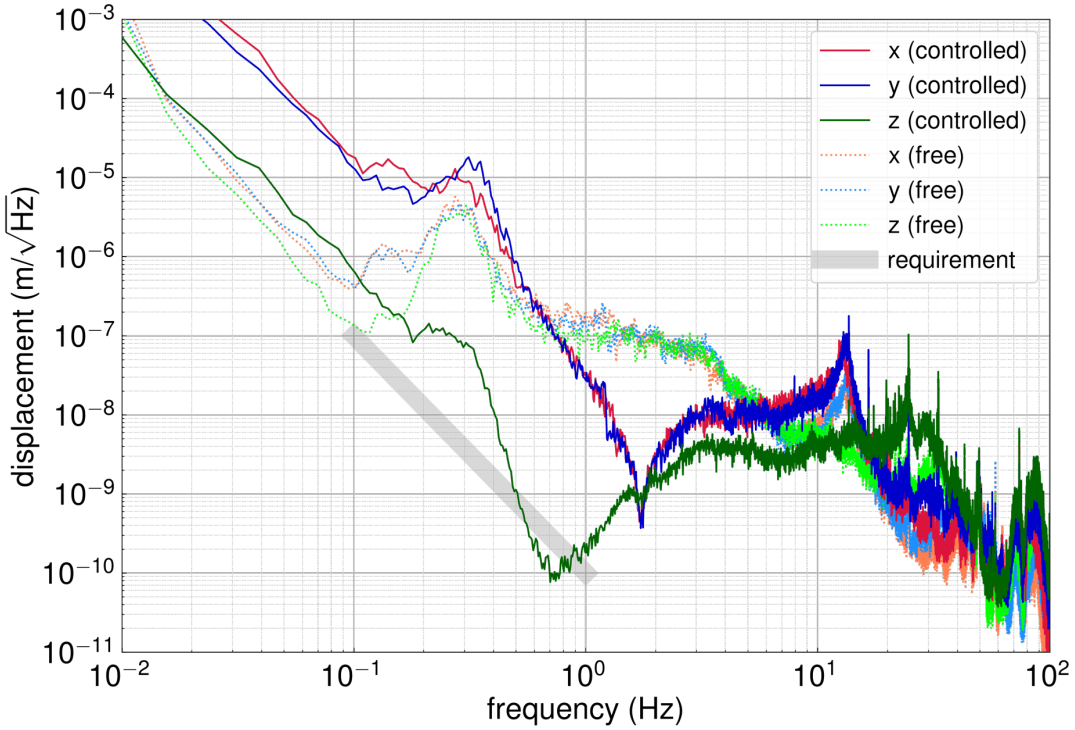


Drawn by YO

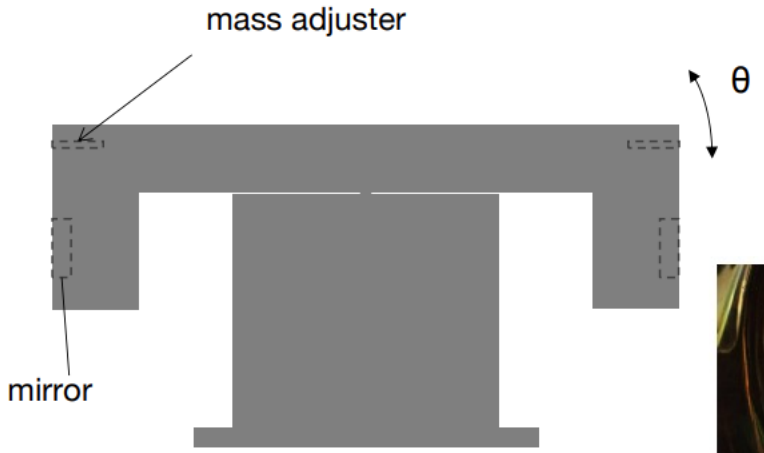
Current status of Phase-III TOBA (2)

Active vibration isolation

- ✓ 3 DoF was successfully controlled with geophones and piezo actuators
- ● Developing a tiltmeter to reduce tilt-horizontal coupling



Plotted by S. Takano



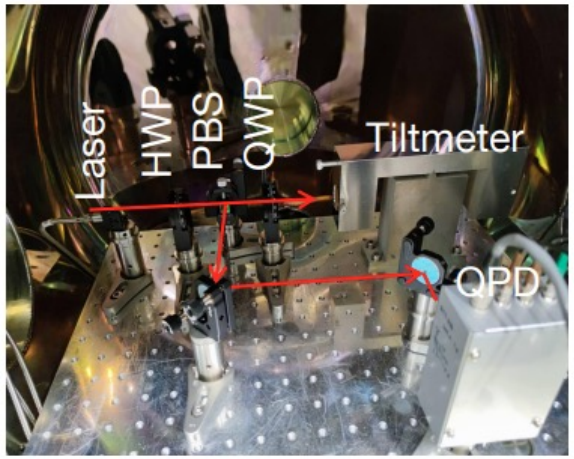
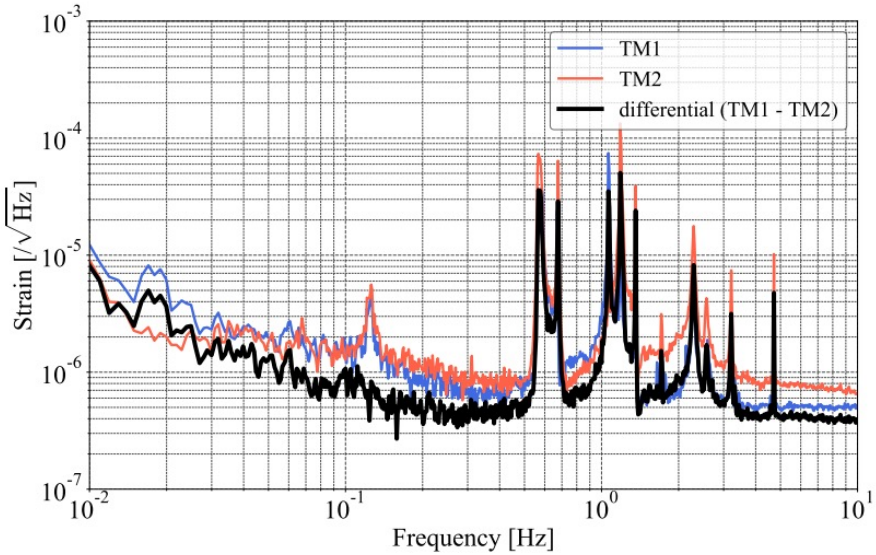


Photo by M. Cao

Current status of Phase-III TOBA (3)

Optical readout

- ✓ Torsional motion was successfully measured with an optical lever
- ● Developing improved-type wavefront sensor
- ● Developing monolithic differential Fabry–Pérot cavity made of silicon



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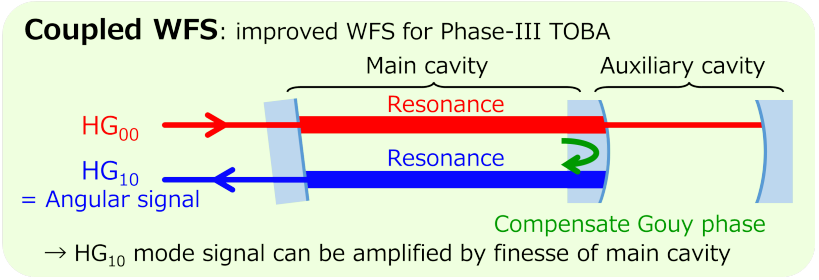

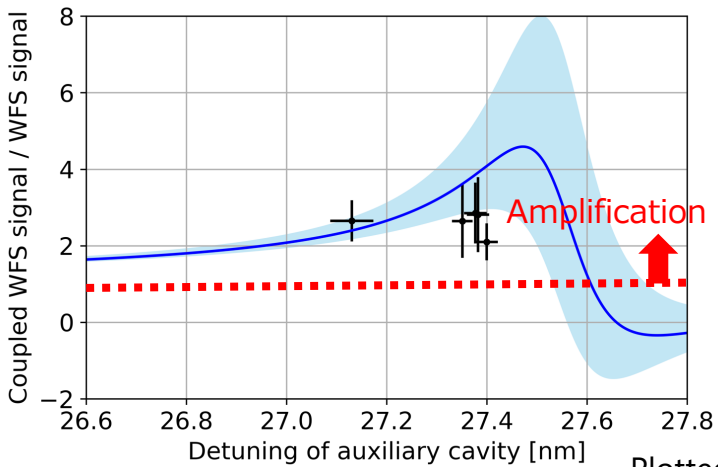

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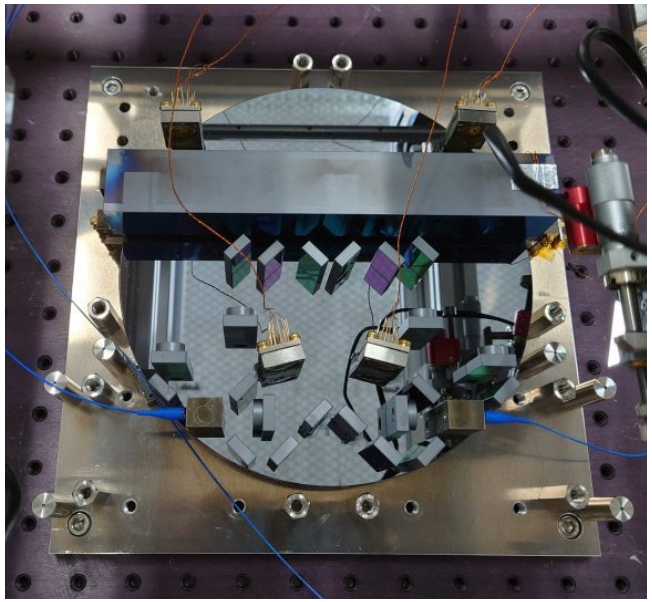

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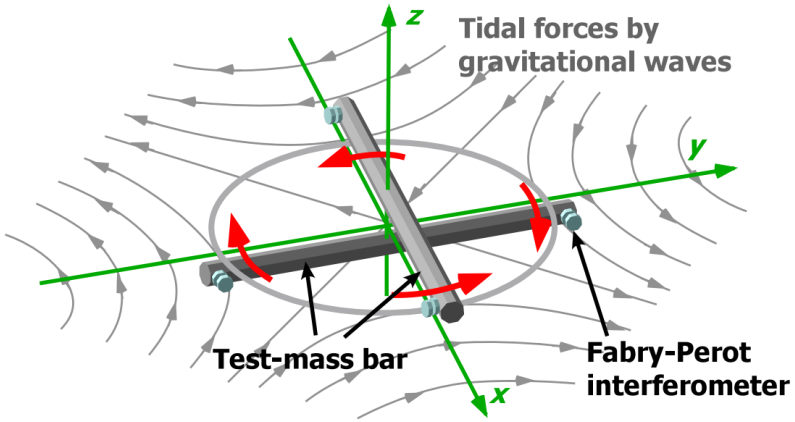

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  - Some essential components are under development:
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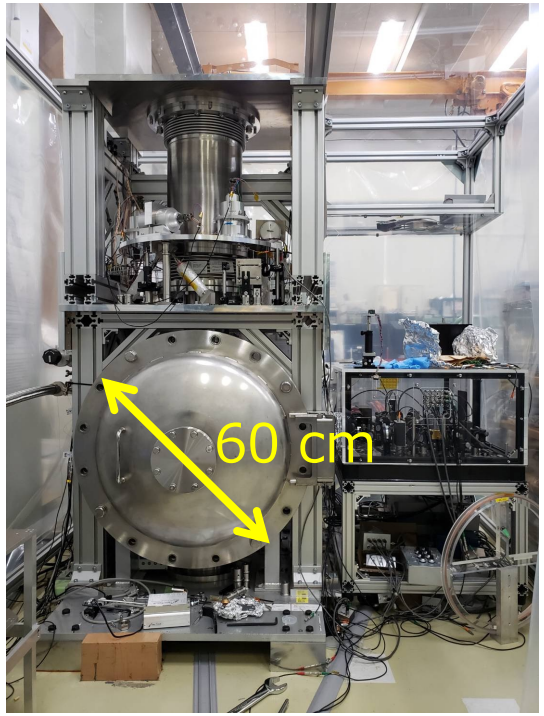
    improved WFS, monolithic silicon FP cavity



Extra Slides

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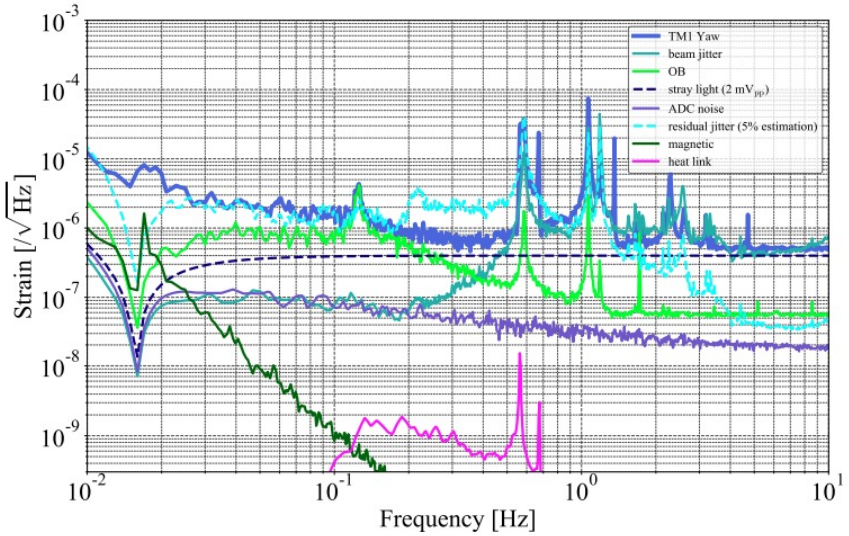

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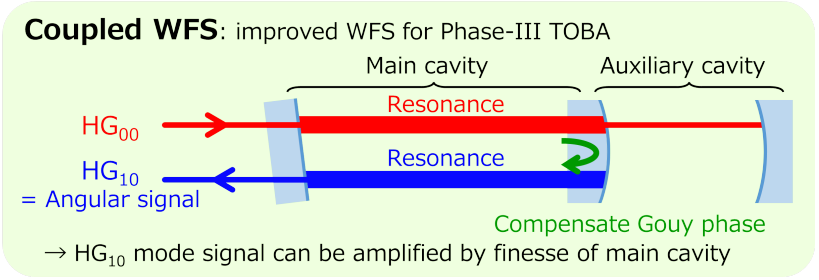

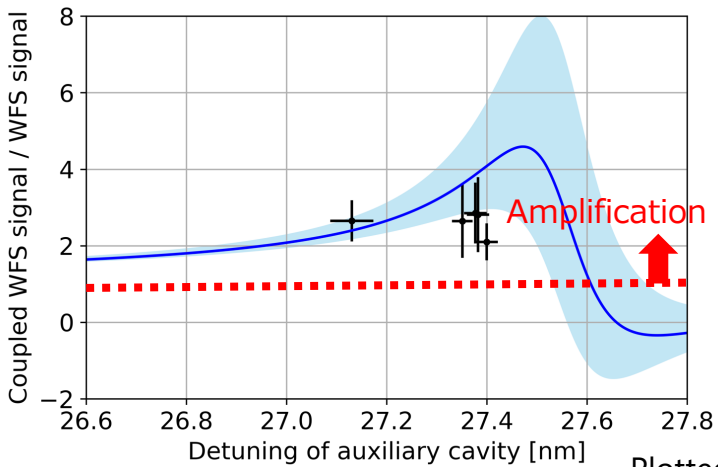

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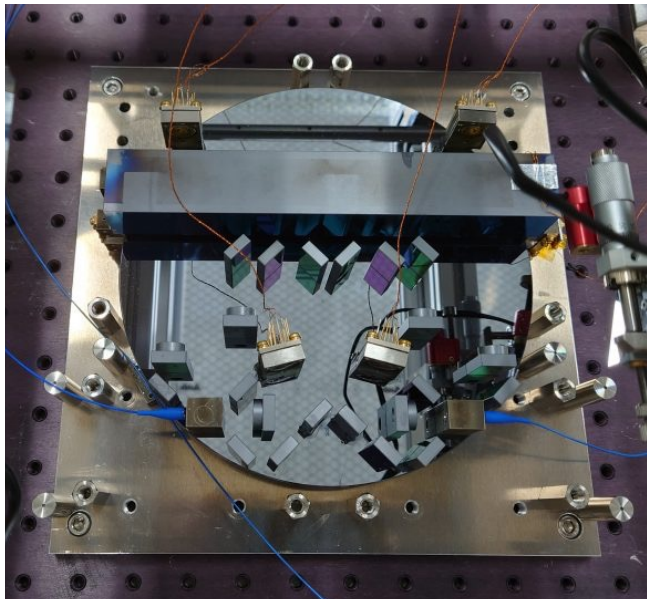

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