The Current Status of TOrsion-Bar Antenna (TOBA) Experiment

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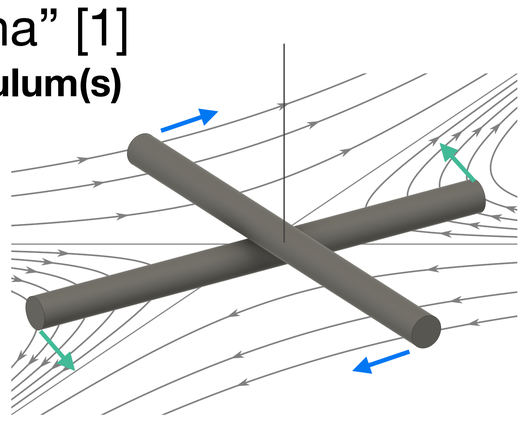
Abstract

Torsion-bar antenna (TOBA) is a ground-based gravity gradiometer proposed for measurement of gravity gradient fluctuations such as gravitational waves and gravity gradient noise. TOBA consists of two perpendicular torsion pendulum, and the low mechanical resonant frequency of torsion pendulums enables us to measure gravity gradient of frequencies around 0.1 Hz. TOBA aims to achieve the sensitivity 10^{-19} / √Hz at 0.1 Hz. For the final sensitivity goal we are developing a prototype Phase-III TOBA in order to investigate technical issues and establish noise reduction scheme. One of the key topic of Phase-III TOBA is cryogenic suspension system for the reduction of the thermal noise. Another key point is the readout system with monolithic interferometer. We will show the current situation of the developments and future upgrade plans for further improvement.

1. Introduction

TOBA = "TOrsion-Bar Antenna" [1]



- GW detector using (a) **torsion pendulum(s)**
- Low resonant frequency (~ mHz)
  - Target range: **0.1Hz ~ 10 Hz**
- Ground-based
  - Inexpensive, Easy to maintenance
- Our goal: **10^{-19}/√Hz @ 0.1 Hz**

Scientific Target

Astrophysical
- IMBH merger: **10 Gpc** for **10^5 $M_\odot$ BHs** [1]
- Gravitational Wave Stochastic Background: **$\Omega_{GW} \leq 10^{-7}$** [1]

Geophysical
- Newtonian Noise: **Detection, model test**
- Earthquake Early alert: < **10 sec** for **M7** in **100 km**

R&D Plan

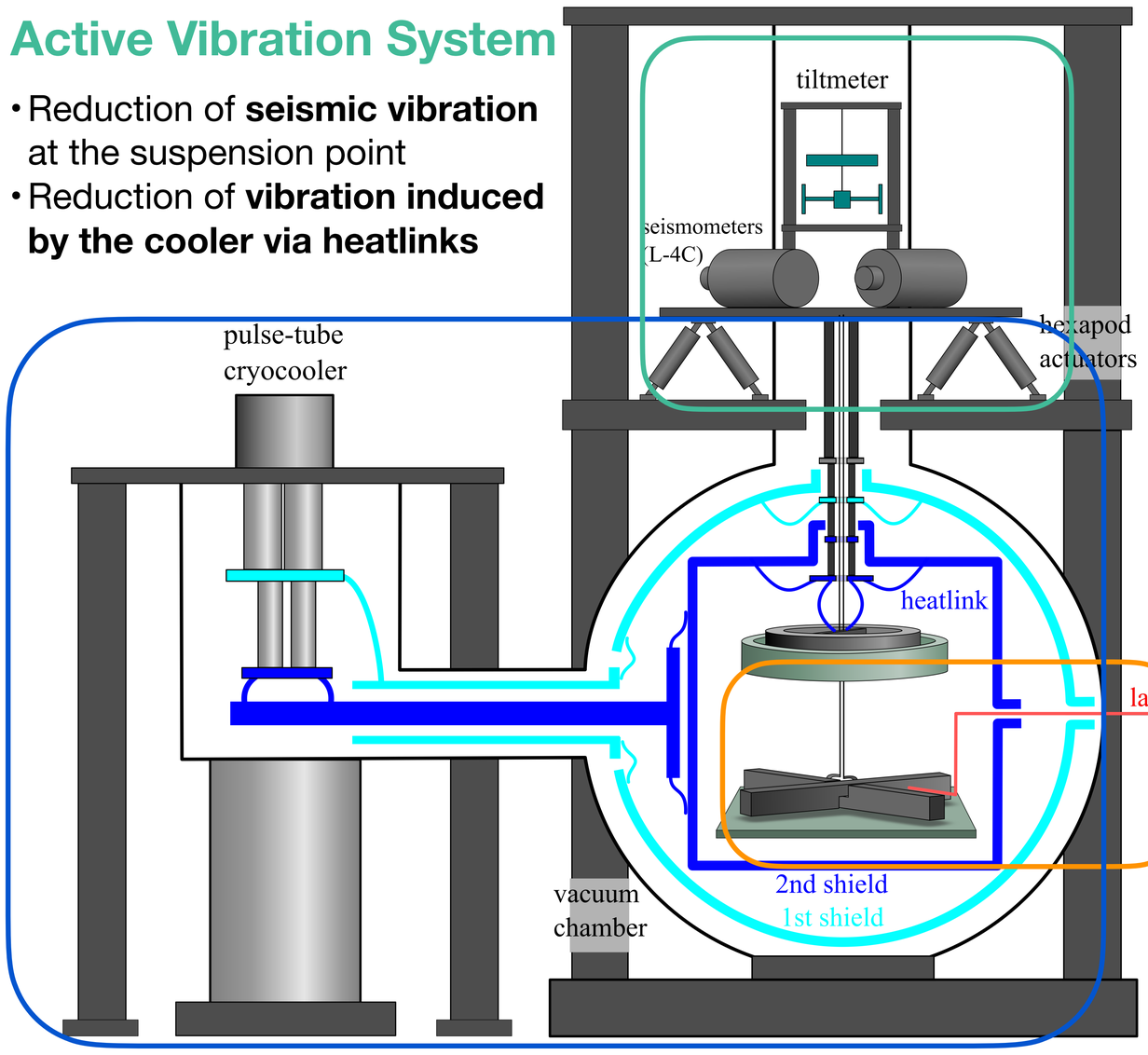
Phase-I (2009)	Phase-II (2015)	**Phase-III (Now)**	Final (Future)
Principle Test		Cryogenic Test	Goal
10^{-8}/√Hz @ 0.1 Hz (Established)		**10^{-15}/√Hz @ 0.1 Hz** (Design)	**10^{-19}/√Hz @ 0.1 Hz** (Target)
- Room Temp. - 25cm TM(s)		- **Cryo. Temp.** (4K) - 35cm TMs	- **Cryo. Temp.** (4K) - **10m** TMs

[1] Ando +, Phys. Rev. Let. **105**, 161101(2010)

2. Phase-III TOBA

Active Vibration System

- Reduction of **seismic vibration** at the suspension point
- Reduction of **vibration induced by the cooler via heatlinks**



Cryogenic Suspension

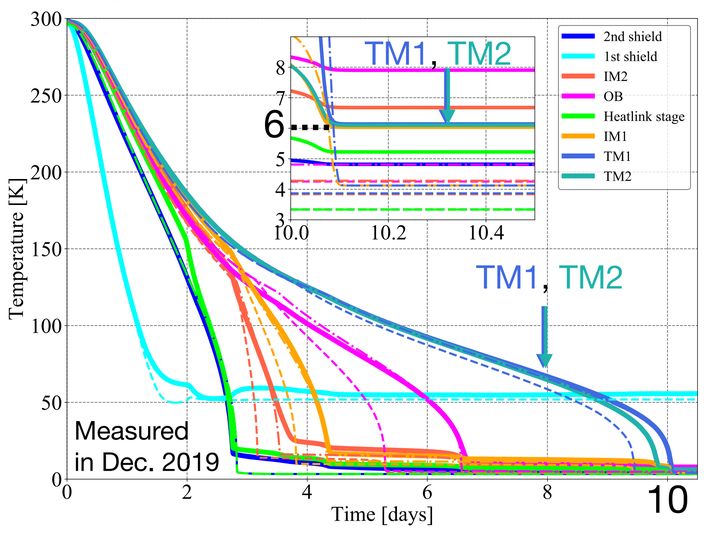
- Cool two TMs down to **4 K**
- High-Q suspension fiber

Optical Readuout

- Rotation measurement by high-sensitive interferometer
  → See Yuka's poster (B3)
- Cryogenic monolithic interferometer

3. The Current Status

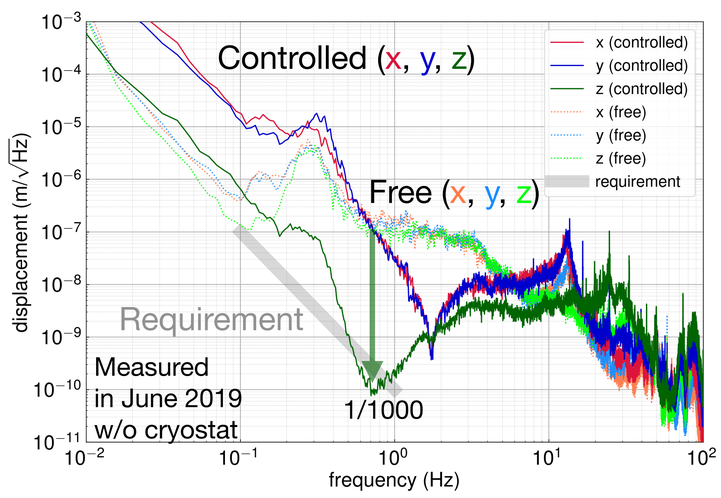
Cryogenic Suspension



- Cooled to **6.1 K** in **10 days** [2]
- High-Q suspension: under development

[2] T. Shimoda, Ph.D Thesis (2020)

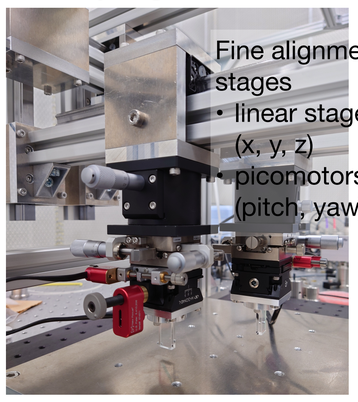
Active Vibration Isolation

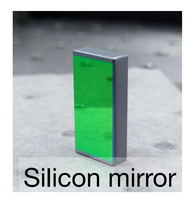


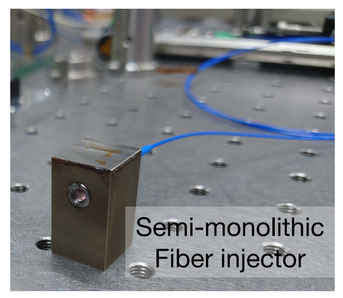
- **1/1000** suppression at maximum at 0.7 Hz
- Limited by
  - < 0.5 Hz: tilt-horizontal coupling
  - > 5 Hz: resonances of the support structure

Optical Readout

- New rotational sensor
  - See Yuka's poster (B3)
- Monolithic interferometer
  - Selected components
  - Monoithic interferometer assembly
    → Trying with a setup below







5. Summary & Future Plan

- We are developing TOBA to detect gravity gradient below 0.1 Hz
- Target is IMBH mergers, GWSB, newtonian noise, earthquakes, etc.
- Currently developing Phase-III TOBA
  - Successfully cooled TMs to 6.1 K
  - Reduced seismic vibration by 1/1000 at 0.7 Hz

Future Plan

- Development of high-Q suspension fiber
- Improvement of active vibration isolation system
- Demonstration of new rotationanl sensor
- Assembly of monolithic interferometer