# Development of Torsion Pendulums and Readout Optics for Gravity Gradient Observation

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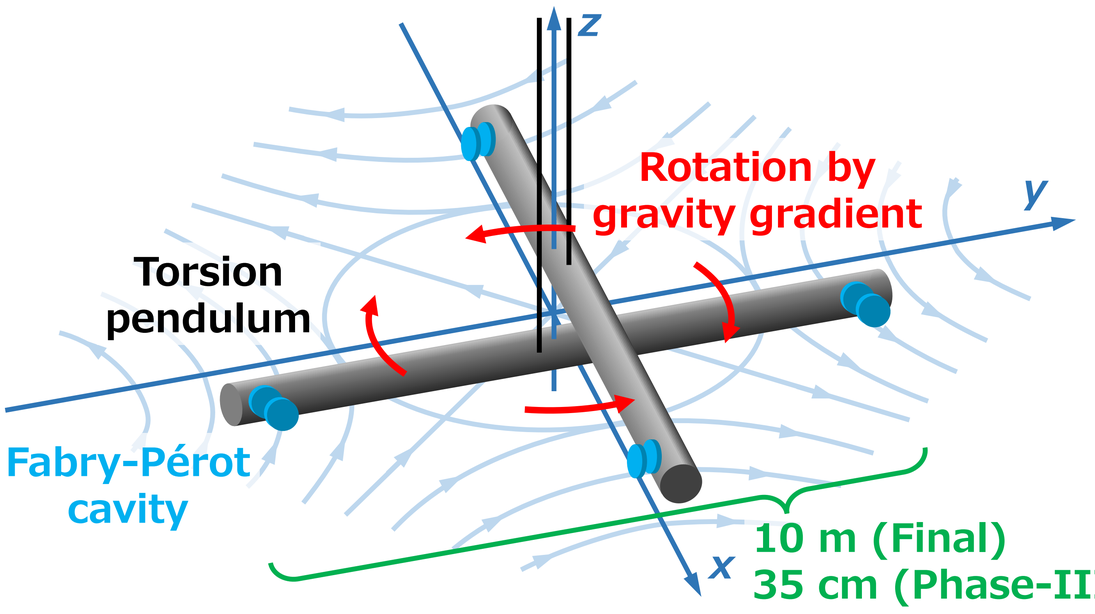
## Abstract

Torsion-Bar Antenna (TOBA) is a low-frequency gravity gradient detector using torsion pendulums. Gravity gradient fluctuation is measured as the differential rotation of two horizontally suspended bars. The resonant frequency of torsional motion is low (~1 mHz) therefore TOBA has good design sensitivity, specifically $10^{-19}$ /√Hz between 0.1-10 Hz with 10 m-scale pendulums. TOBA can be used for gravitational-wave observation and earthquake early warning. A prototype detector Phase-III TOBA with 30 cm-scale pendulums at cryogenic temperature is under development to demonstrate noise reduction. The target sensitivity is set to $10^{-15}$ /√Hz at 0.1 Hz. Currently we are developing cryogenic torsion pendulums made of silicon and Fabry-Pérot cavities to detect the differential rotation of pendulums.

## 1. TOBA: Torsion-Bar Antenna

### Principle [1]

- Ground-based gravity gradient detector
- Composed of two torsion pendulums
  - The resonant frequency of torsional motion is low (~1 mHz)
    → Good sensitivity in 0.1−10 Hz even on the ground
- Detect the differential rotation of bars with Fabry-Pérot cavities

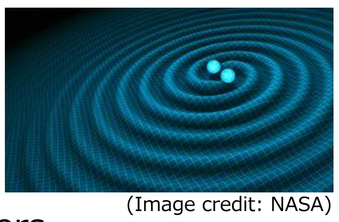



### Development plan [2]

| Phase-I (2009) | Phase-II (2015) | Phase-III (Now) | Final (Future) |
|---|---|---|---|
| Principle test | | Technical demonstration | 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) |

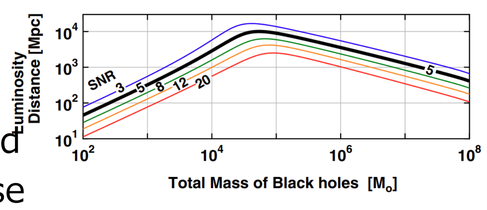
## 2. Science of TOBA

### Astrophysics



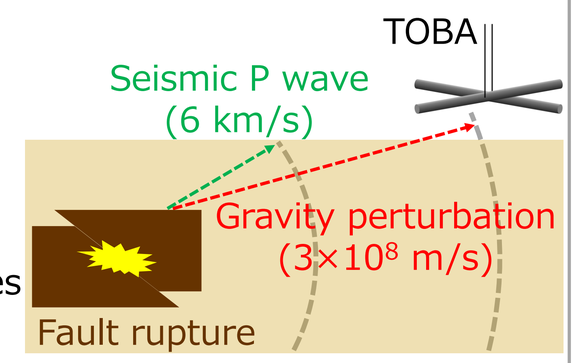
(Image credit: NASA)

- Gravitational waves
  from intermediate-mass black hole binary mergers
  - Within ~1 Mpc (Phase-III TOBA)
  - Within ~10 Gpc (Final TOBA) [1]




- Gravitational wave stochastic background
  → Direct exploration of the early universe
  - $\Omega_{GW}$ ~$10^{-7}$ (Final TOBA)

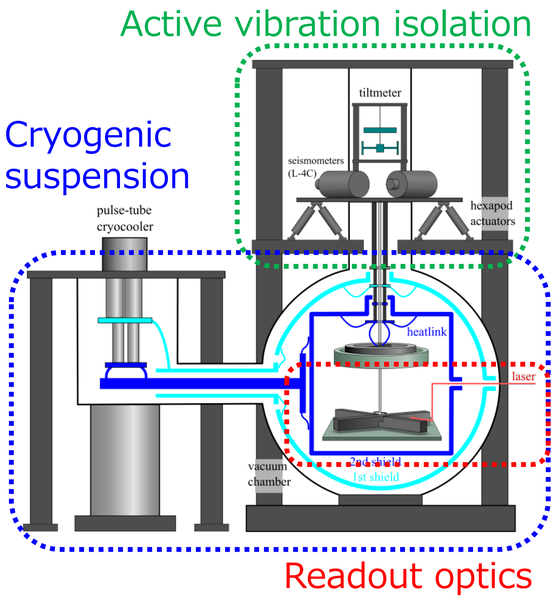
### Geophysics

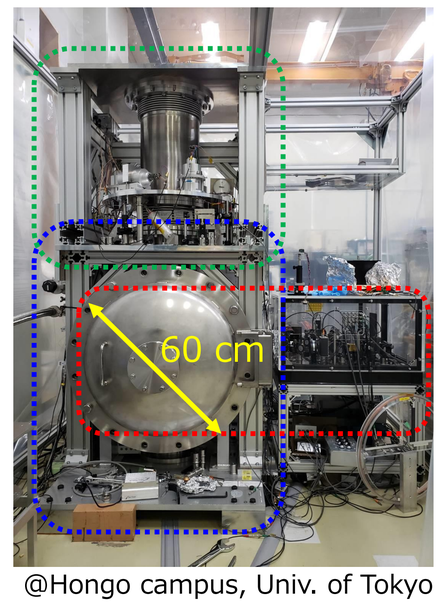



- Earthquake early warning
  - Within 10 sec for M7 earthquakes far from 100 km (Phase-III) [3]
- Newtonian noise: the fluctuations of the gravitational field by seismic and atmospheric perturbations
  - First direct detection (Final) [4]

## 3. Development of Phase-III TOBA

### Configuration [3]

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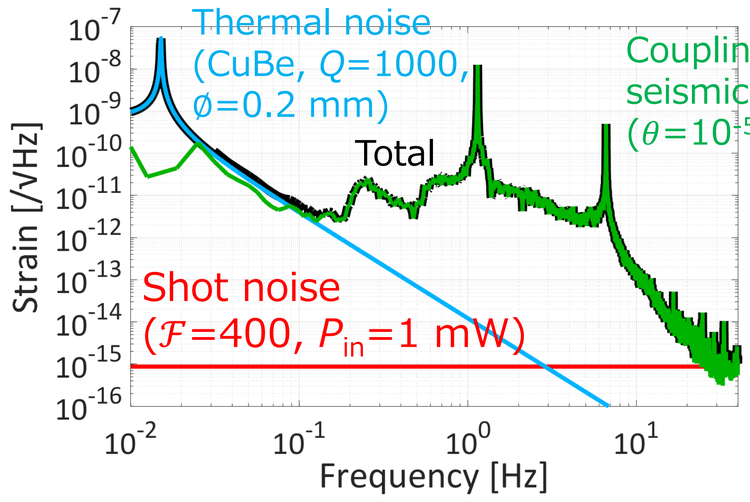
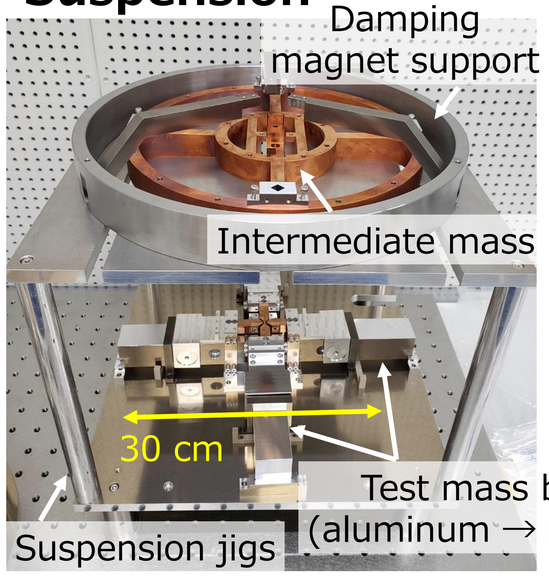
### Design sensitivity

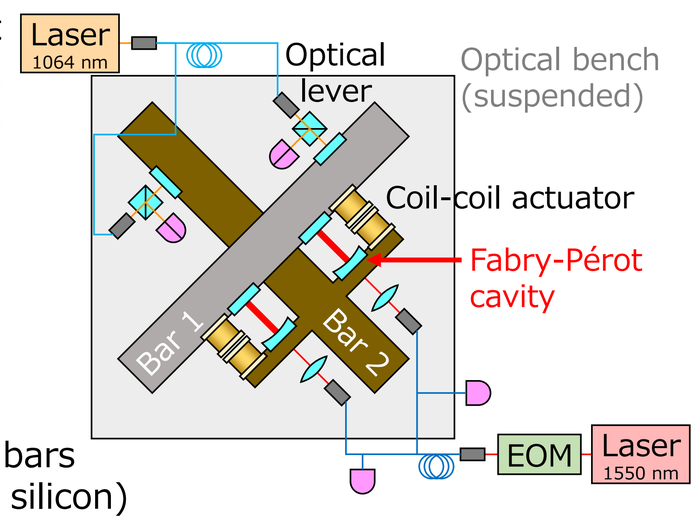



- Target sensitivity
  - $6\times10^{-12}$ /√Hz at 0.1 Hz
  - Limited by suspension thermal noise

### Suspension




### Readout optics




## 4. Summary & Future plans

- TOBA is a gravity gradient detector with torsion pendulums
  - TOBA can detect gravitational waves and earthquakes between 0.1−10 Hz
- We are developing Phase-III TOBA
  - We finished designing suspension and readout optics
  - We plan to build a setup

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### References

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