# The research of TOBA so far and my future plans

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#### Caution

- I will try to speak in English as possible
- ・でも時々日本語になります
- Discussion is welcomed whether in Japanese or English



#### Contents

- The current status of TOBA
  - The introduction of TOBA
  - The current setup
  - What we did last year

- Future prospects of me
  - Experiments about TOBA
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## **TOBA (Torsion Bar Antenna)**

#### **Torsion Bar Antenna (TOBA)**

- A gravitational detector using one/two torsion pendulums
- The resonant frequency of torsion mode is about mHz
  - $\rightarrow$  we can see GWs in low frequency (0.1-10Hz)
- Detectable on the ground  $\rightarrow$  no need to operate in space, low cost
- Goal:  $h \sim 10^{-19} / \sqrt{\text{Hz}}$  @0.1Hz by using 10m test mass(es)



## **Targets of TOBA**

#### **GWs in low frequency**

IMBH binary merger
 Hints for generation of SMBH



 Gravitational Wave Background
 Direct measurement for early universe



M. Ando et al., PRL, 105, 161101(2010)

https://physics.aps.org/articles/v11/36

K. Ishidoshiro et al., PRL 106, 161101 (2011)

## **Targets of TOBA**

#### **Gravitational gradients**

- Newtonian Noise
  - Testing modelsR&D for 3G detectors





Early alert for earthquakes
 Big social contributions

## R&D plan



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#### The current setup

- 20cm test mass, suspended by double pendulums
- Measuring differential motion of two arms by Michelson interferometer
- Using counter weights to reduce seismic cross-coupling



Hexapod

#### Readout system

Seismometers x6

### **Current sensitivity**



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#### What we did about TOBA

#### What I did was investigation of noises as we could

- PEM injection
  - Vertical vibrations on the optical bench
  - Magnetic fields on TOBA entirely
- Noise from the laser
  - Frequency noise
  - Polarization noise

#### Duty cycle of me



#### What we did about TOBA

What we did was investigation of noises as we could

- PEM injection
  - Vertical vibrations on the optical bench
  - Magnetic fields on TOBA entirely
- Noise from the laser
  - Frequency noise
  - Polarization noise

I did mainly

I did partially Shimoda-san did mainly

He will talk about this



## **Motivation**

The motivation:

- We assumed that if we lowered the actuation efficiency, the sensitivity would get improved
- But it didn't work!

There was another limiting noise (actually, the polarization noise was dominant)



#### **Vertical seismic noise**

Coupling to vertical seismic vibration via readout



Shake OB directly to measure the transfer function

## Setup of vertical vibration injection

- TM was fixed on OB
- Michelson interferometer on OB
- OB was supported by 3 PZTs, which shook OB directly
- OB motion invoked by PZTs was measured 3 photo sensors



#### **Measuring scheme**

- TM was fixed on OB
- Michelson interferometer on OB
- OB was supported by 3 PZTs, which shook OB directly
- OB motion invoked by PZTs was measured 3 photo sensors



#### Measurement

#### Transfer function from vertical motion of OB to MI signal



#### Calculation





Measured by the seismometers

#### Calculated by models

Measured by the injection

#### Result



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#### Result



- This readout noise is dominant around 5Hz 50Hz
- Which components induced this noise is yet unknown

#### **Frequency noise**

Measured by difference between symmetric and antisymmetric MI



#### Measurement

Measured by difference between symmetric and antisymmetric MI



#### Result

• Frequency noise is about 1 order smaller

than the sensitivity @ 0.1 Hz  $10^{-6}$ **Best sensitivity**  $10^{-7}$ strain (/ -01 (/ Hz) -10<sup>-10</sup>  $10^{-8}$ Frequency noise  $10^{-11}$  $10^{-12}$ 10<sup>0</sup>  $10^{-1}$ 10<sup>1</sup> Frequency (Hz)

## **Magnetic Noise**

Coupling path from variation of magnetic field to the interferometer

Uniform field
 Induced as torque directly



Nonuniform field
 Induced via force to torque



In both cases the variation of dipole moment was neglected I only considered the effect from uniform field

## **Injection setup**

Injected magnetic field in two directions

 The field was generated by two coils made by Okada-san









#### **Measurement 1**

Bx: 9.6 /  $f^2$  mrad  $\cdot$  (Hz)<sup>2</sup> / T By: 12 /  $f^2$  mrad  $\cdot$  (Hz)<sup>2</sup> / T

#### Dipole moment: $\mu = 6.27 \times 10^{-3} \,\text{A} \cdot \text{m}^2$



#### **Measurement 2**

Magnetic field in the vacuum chamber



#### Calculation



#### Result



#### Result



Almost the same level as the sensitivity
 This noise may limit the sensitivity below 10<sup>-2</sup> Hz

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#### From now, I just want to discuss about

#### what I will do for master thesis

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### **Phase-III TOBA**

• We are now planning Phase-III TOBA (detail: Shimoda-san's talk)



## Cryogenic

What we must do:

- Evaluation of cooling
- Evaluation of induced noise by the cooler, heatlinks, etc.
- Reduction of vibration via heatlinks
- and more



#### New readout system

What we must do:

- Principle test (table top, suspended)
  Table top was done by Shimoda-san
  If I do this, next target might be to test this scheme for suspended cavity
- Design, calculation
  Requirement value is 500 ppm
- Evaluation of a monolithic optical bench
  How rigid is it?



#### **Other topics about Phase-III TOBA**

- Improvement of AVIT
  Increasing the range of actuation (using longer PZTs)
  (modern control?)
- Test of other vibration isolation schemes
  Center of percussion
  VSPI
- Evaluation of coil-coil actuators
  Aritomi-san already did, but I heard from Shimoda-san that there is still something to investigate about them

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#### **Other experiment**

- Other possibilities:
- Following Komori-san's experiment
  Radiation-pressure experiment
  Measurmet of non-equilibrium thermal noise
  CSL experiment
- Joining Kawasaki-kun's experiment
  Axion!



## Discussion

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### Summary

- Last year I investigated some noises in TOBA
- What I will do is TBD
  - > I should decide it until the deadline of application of JPS meeting

# END

#### **Polarization noise**

Measuring the intensity of each polarization of the laser

- TM was fixed on the OB
- Both polarization were monitored by PDs



## **Old sensitivity**



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