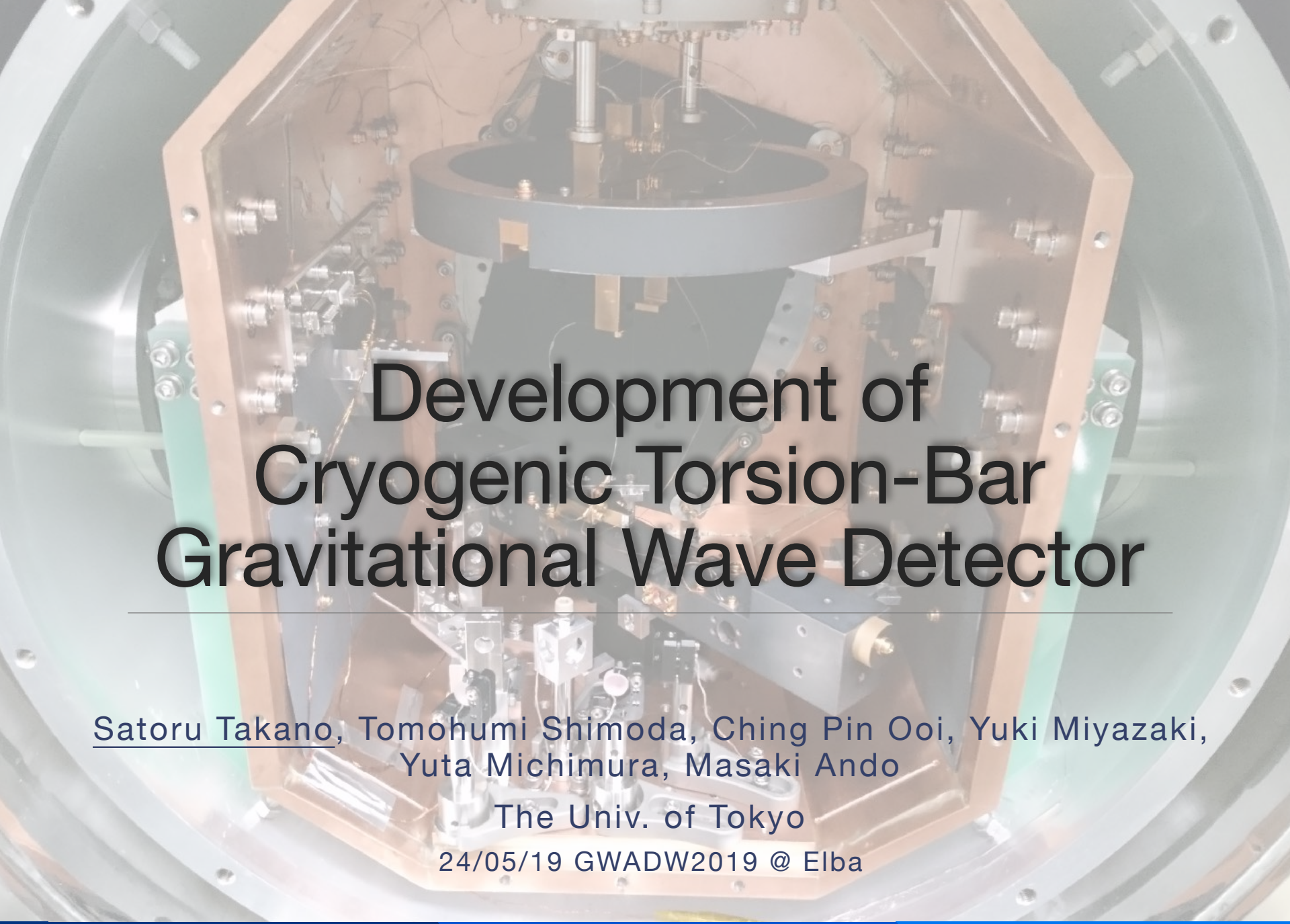


Development of Cryogenic Torsion-Bar Gravitational Wave Detector

Satoru Takano, Tomohumi Shimoda, Ching Pin Ooi, Yuki Miyazaki, Yuta Michimura, Masaki Ando

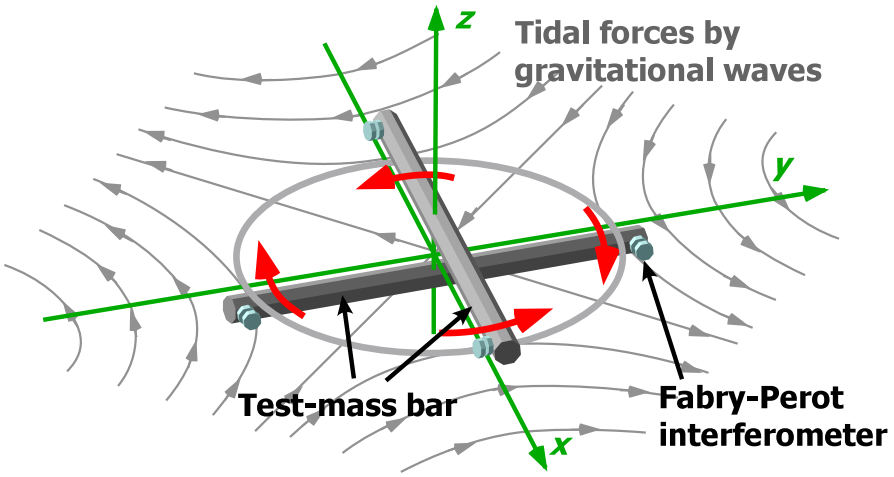
The Univ. of Tokyo

24/05/19 GWADW2019 @ Elba

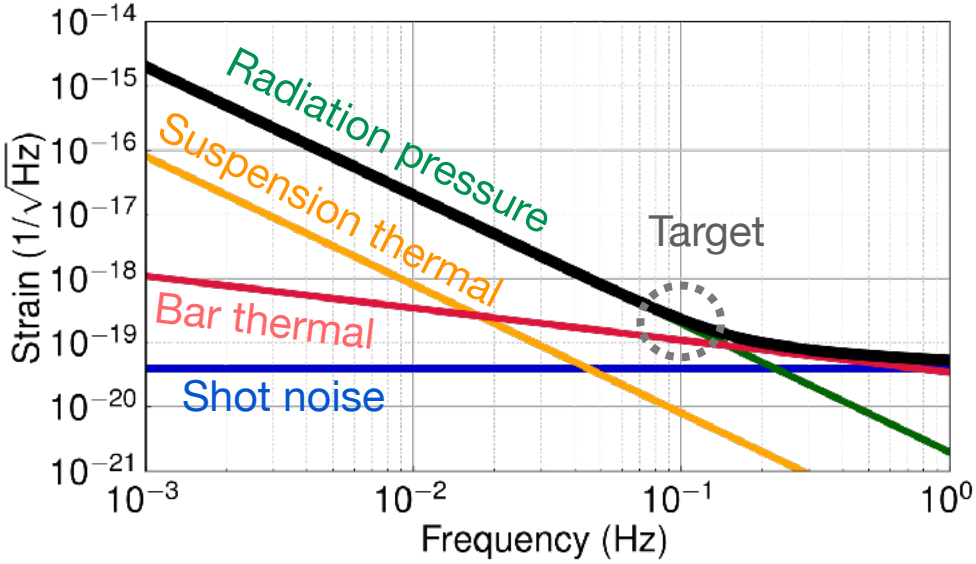
Torsion Bar Antenna (TOBA)

TOBA : TOrsion-Bar Antenna

- Gravitational wave detector using two torsion pendulums
- Resonant frequency of torsion pendulum ~ mHz
- → Sensitive to **low frequency** (~ 0.1Hz)
- Target sensitivity **h ~ 10^{-19} / √Hz** @ 0.1 Hz with **10 m** bars



M. Ando+ (2010)

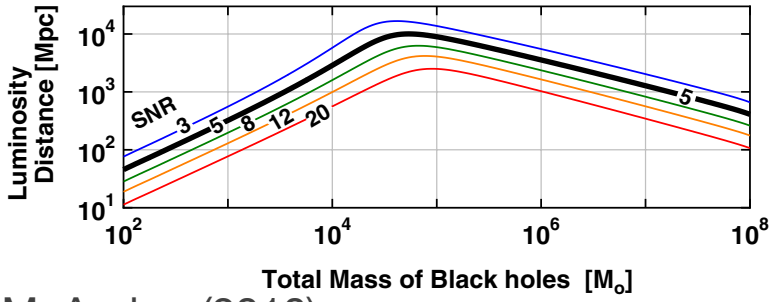


Design sensitivity of TOBA

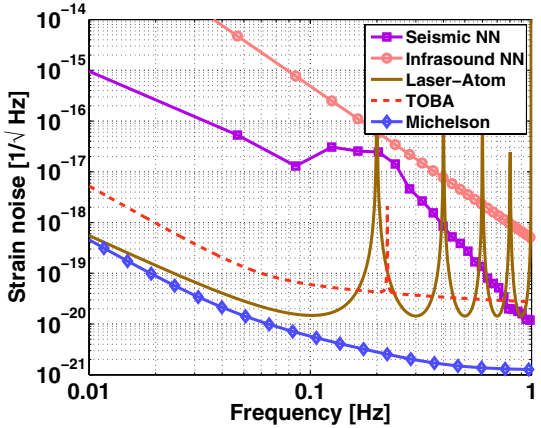
Science of TOBA

- TOBA
  - Astrophysics
    - IMBH Binary Merger
    - GW Stochastic Background
  - Geophysics
    - Newtonian Noise
    - Earthquake Alert

10 Gpc for 10^5 $M_\odot$



M. Ando+ (2010)



J. Harms+ (2012)

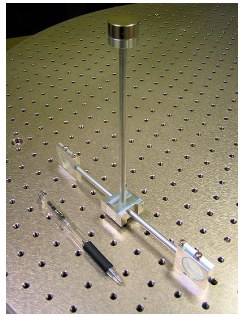
Development Plan

Phase-I (2009) → Phase-II (2015) → **Phase-III (Now)** → Final (Target)

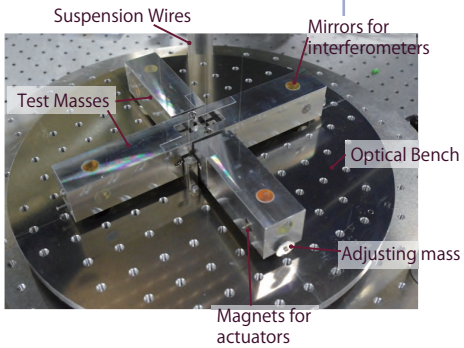
Principle Test

$10^{-8}/\sqrt{Hz}$ @ 0.1 Hz
(Established)

- Room Temp.
- 25cm TM(s)



M. Okada
Master Thesis

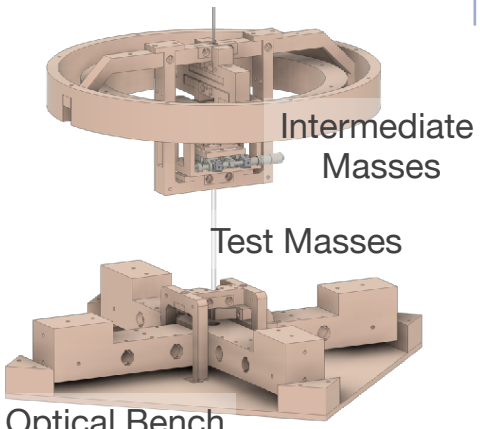


A. Shoda
Ph.D Thesis

Cryogenic Test

$10^{-15}/\sqrt{Hz}$ @ 0.1 Hz
(Design)

- **Cryo. Temp.** (4K)
- 35cm TMs

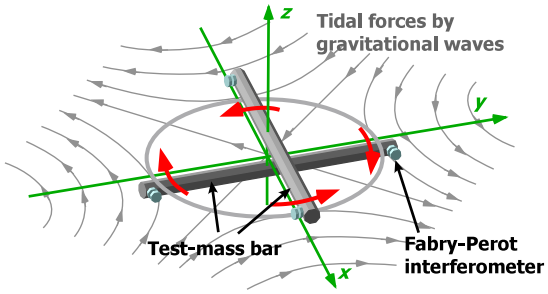


Optical Bench

Goal

$10^{-19}/\sqrt{Hz}$ @ 0.1 Hz
(Target)

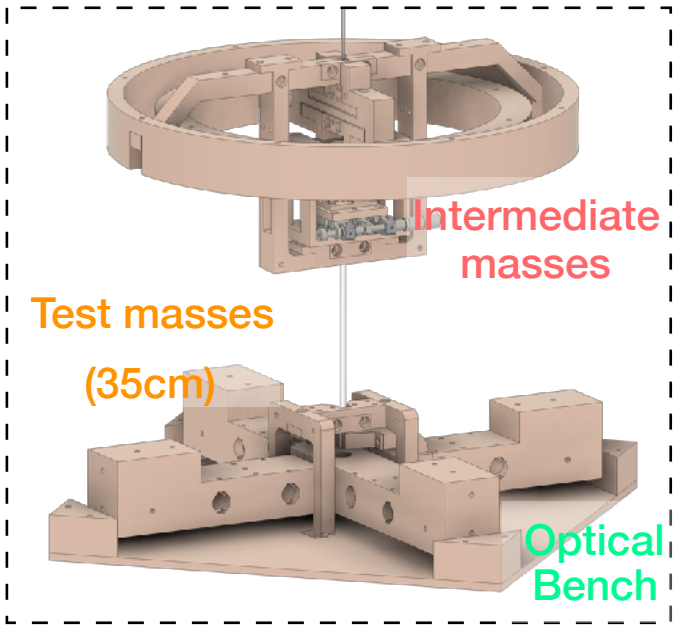
- **Cryo. Temp.** (4K)
- **10m** TMs

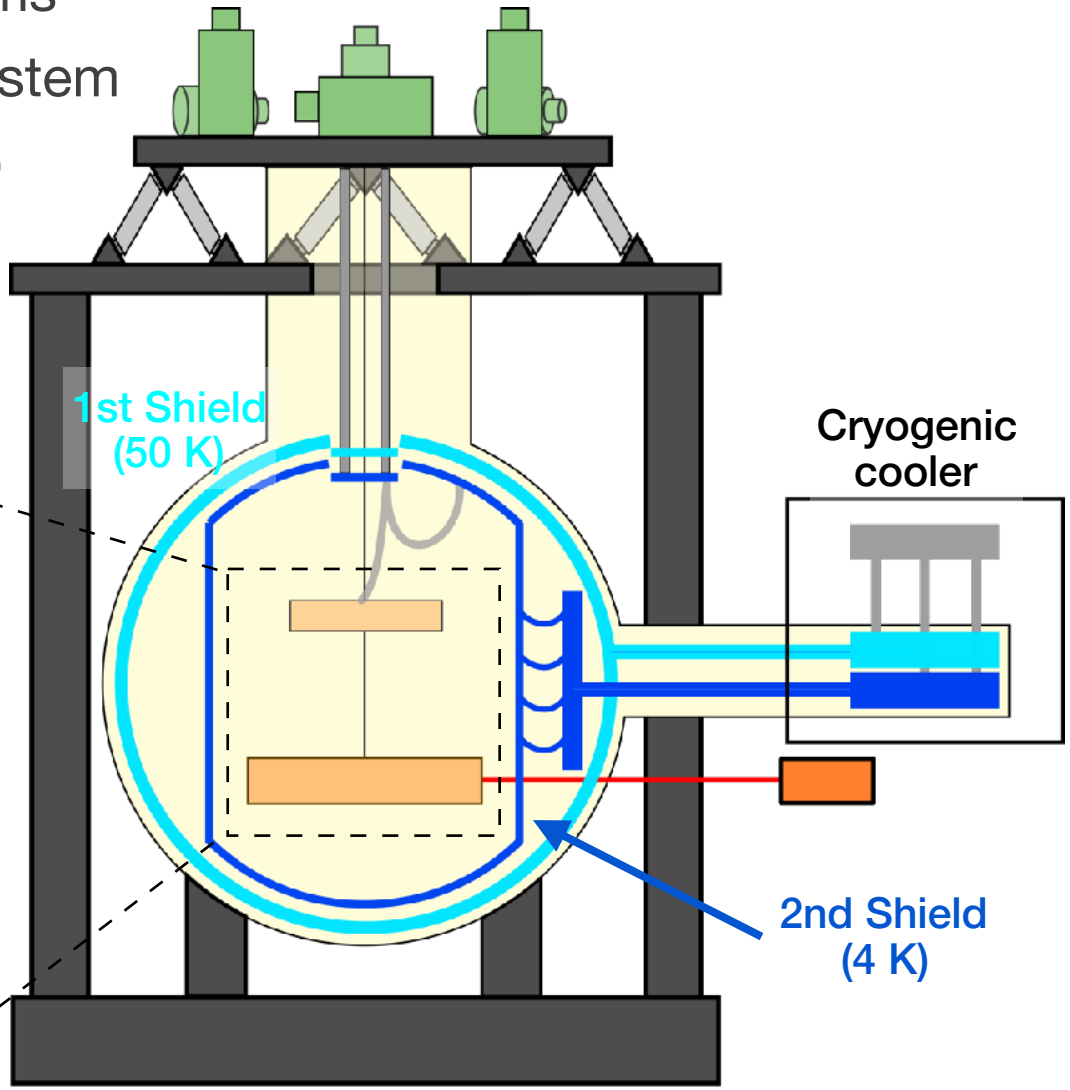


Phase-III TOBA

Overviews of Phase-III TOBA

- Two-stage torsion pendulums
- Active vibration isolation system
- Cryogenic temperature (4K)





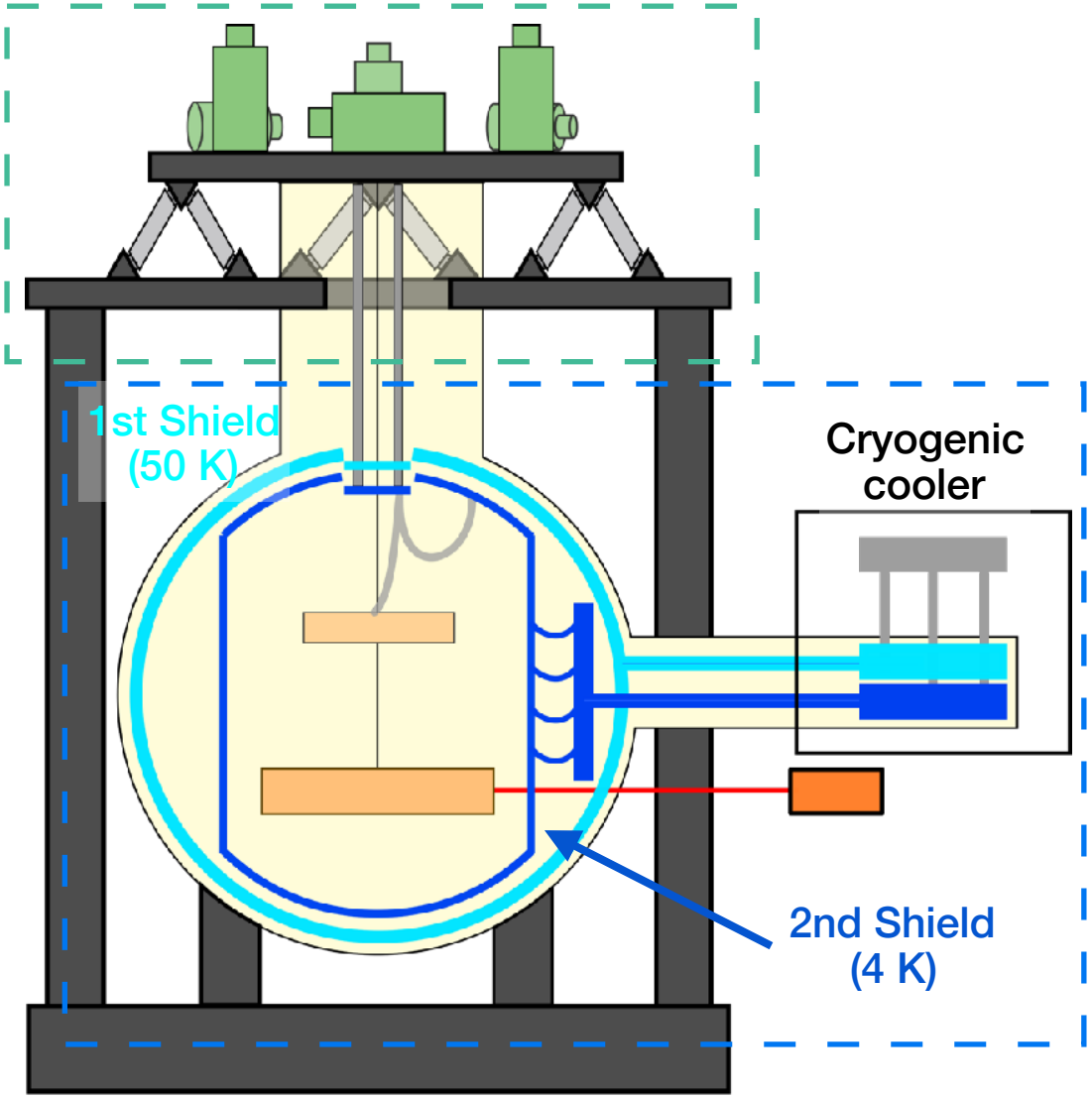
Overviews of Phase-III TOBA

Active vibration isolation (AVIS)

- Isolation ratio ~ 10^2 @ 0.1 - 1 Hz
- Reducing vibration caused by the cooler via heatlinks

Cryogenic System

- Cooled down to 4 K
- Silicon/Sapphire wire with High Q (Q ~ 10^8)



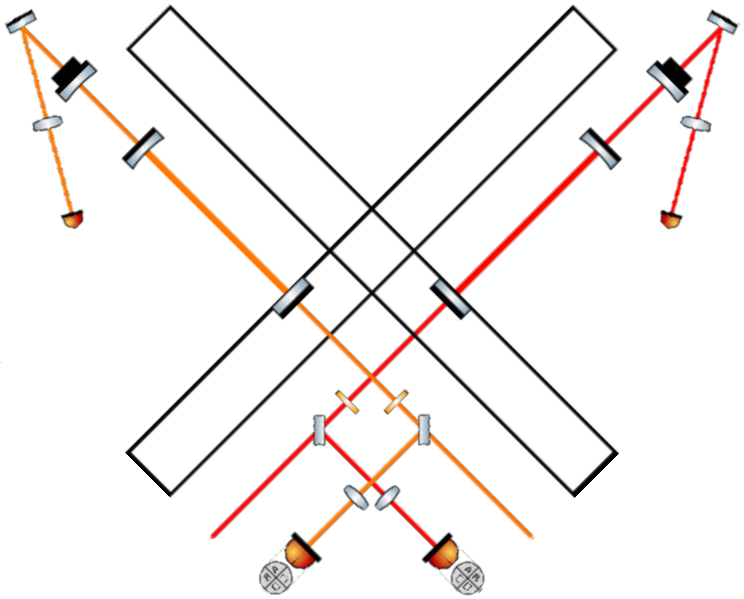
Readout Scheme

Coupled-cavity wave front sensor (new idea)

- Compensate Gouy phase by auxiliary cavity
  - HG10 mode resonates as well as HG00
  - Induced HG10 is enhanced
  - Higher sensitivity than normal WFS

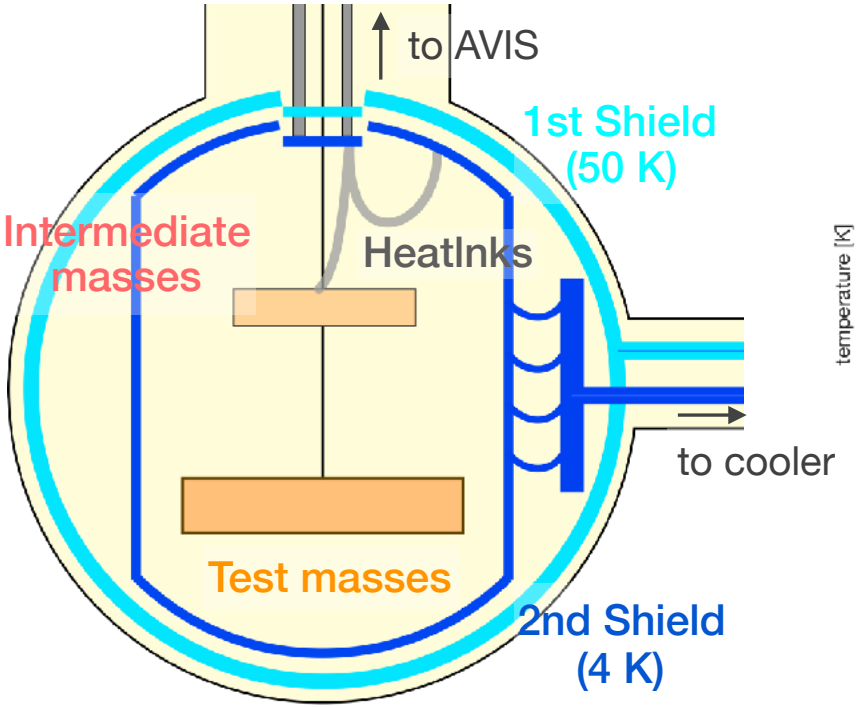
    5×10^{-16} rad/$\sqrt{\text{Hz}}$ @ 0.1 Hz

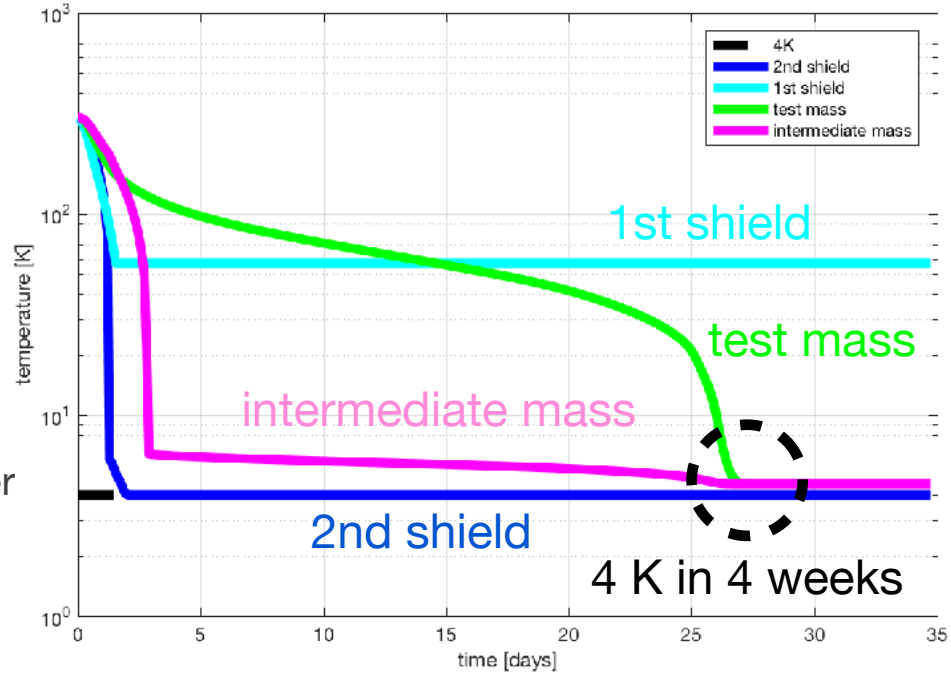
Optical configuration →



Cryogenic System

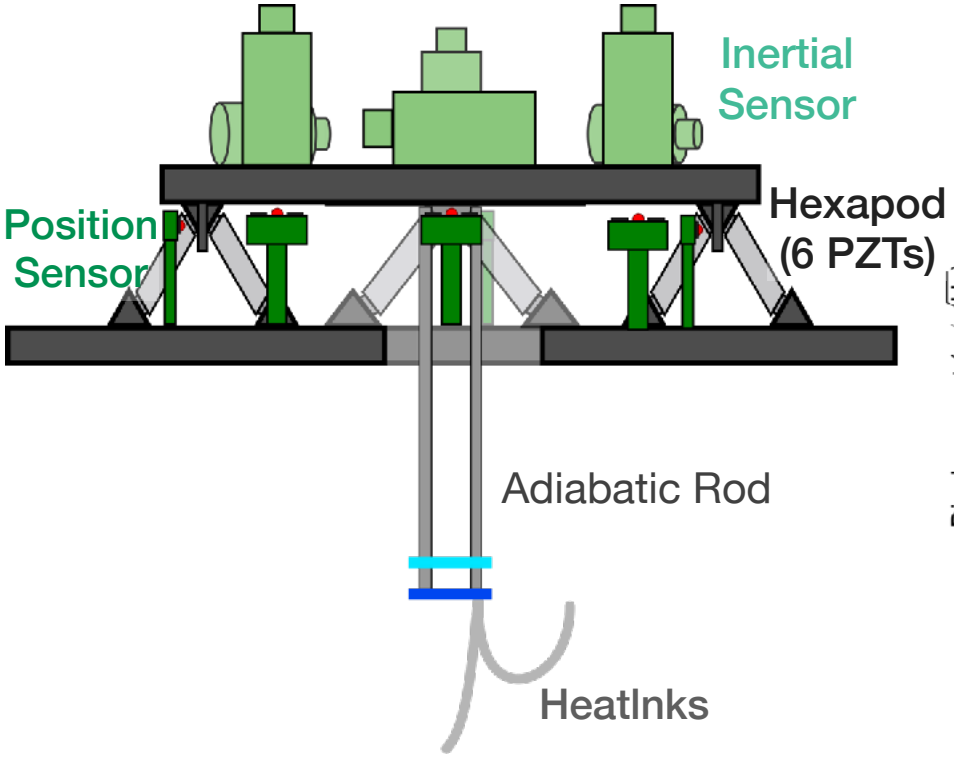
- Two shields:
  - 1st shield: Aluminum, cooled to 50 K
  - 2st shield: Cupper, cooled to 4 K
- Intermediate masses: cooled via heatlinks
- Test masses: cooled via suspension wires

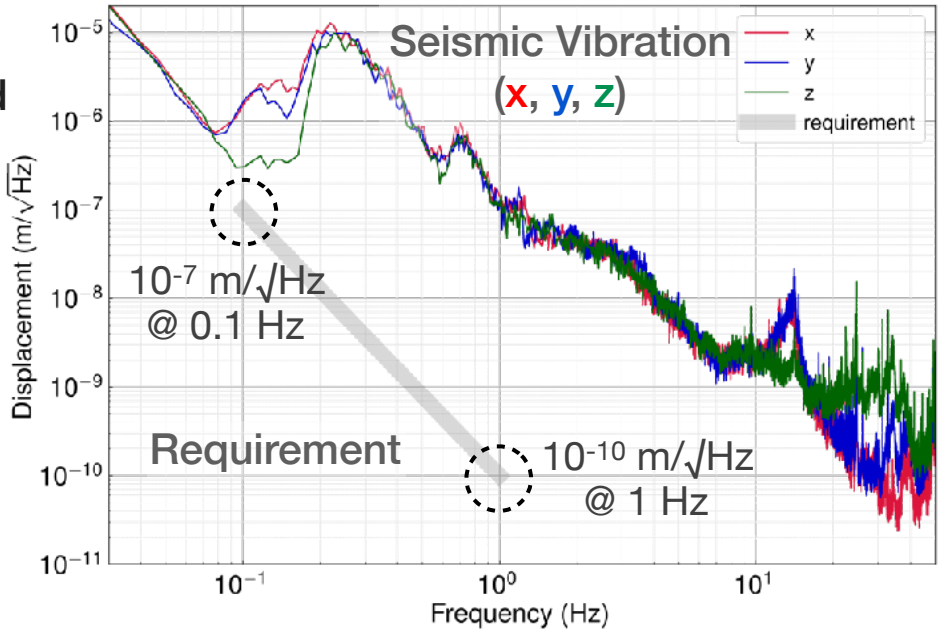




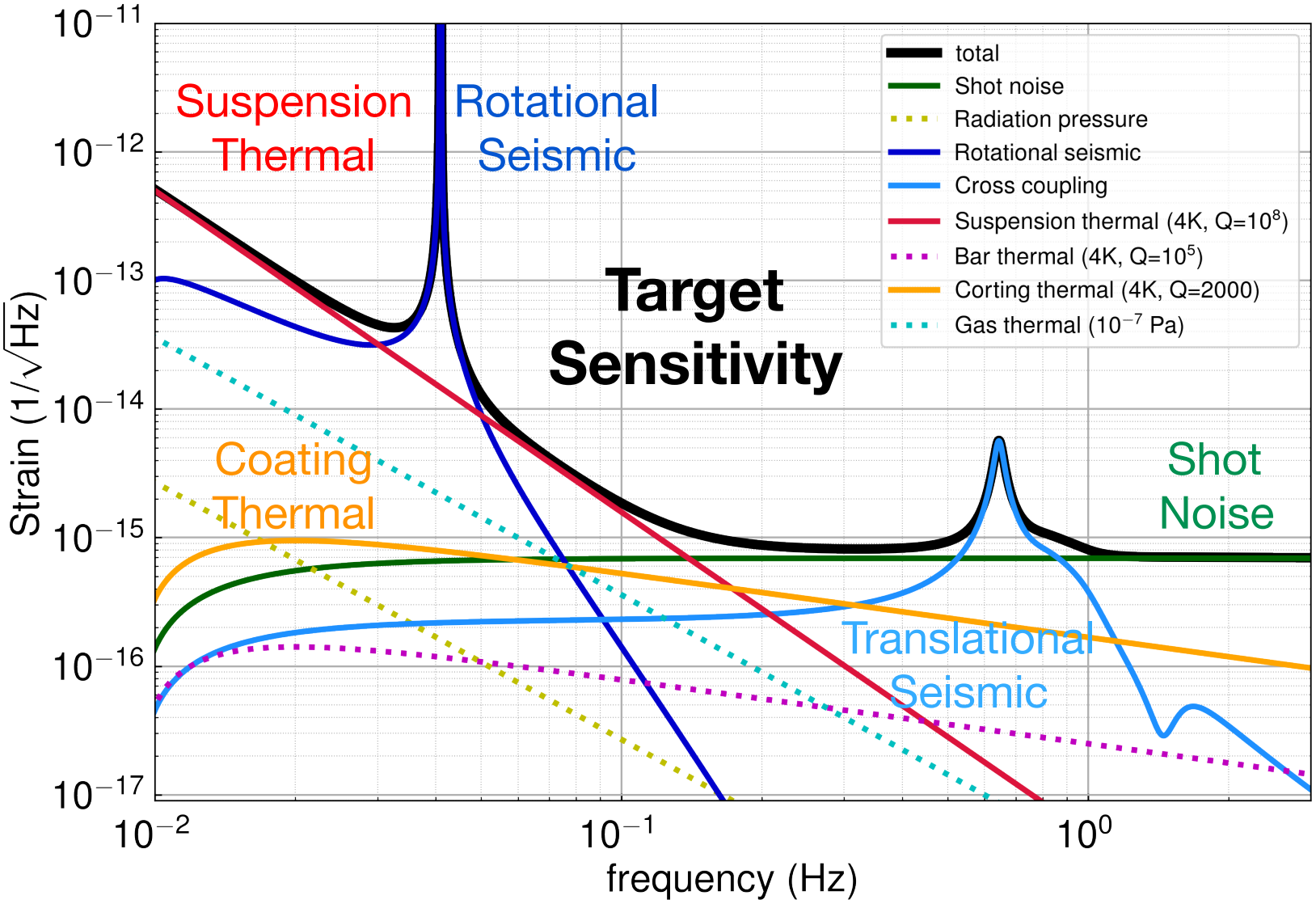
Active Vibration Isolation

- Inertial sensor + Position sensor + Hexapod actuator (PZTs)
- Function
  - Reduce translational vibration @ the suspension point
  - Reduce the vibration introduced by the cooler via the heatlinks

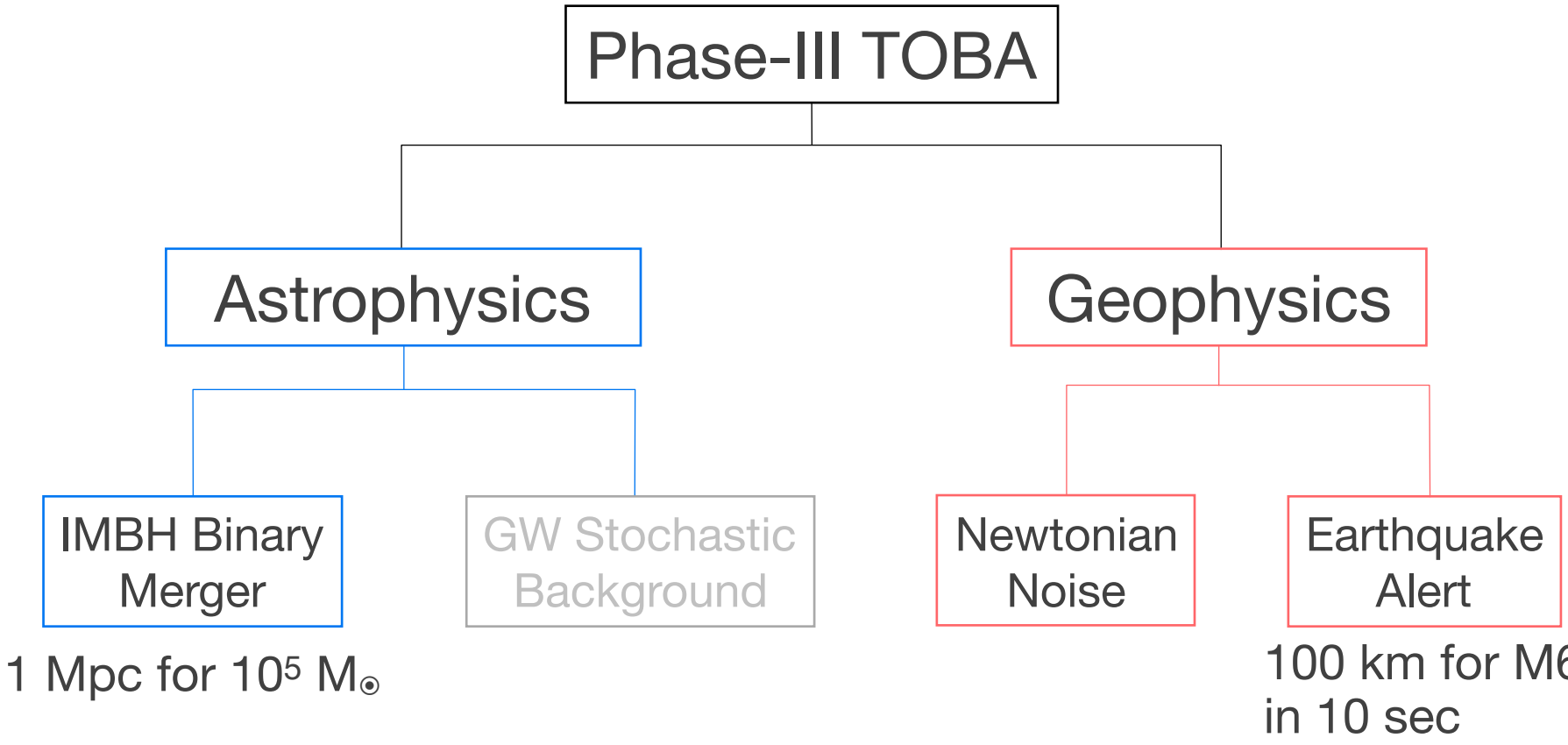




Target Sensitivity of Phase-III TOBA



Science of Phase-III TOBA



Current Status

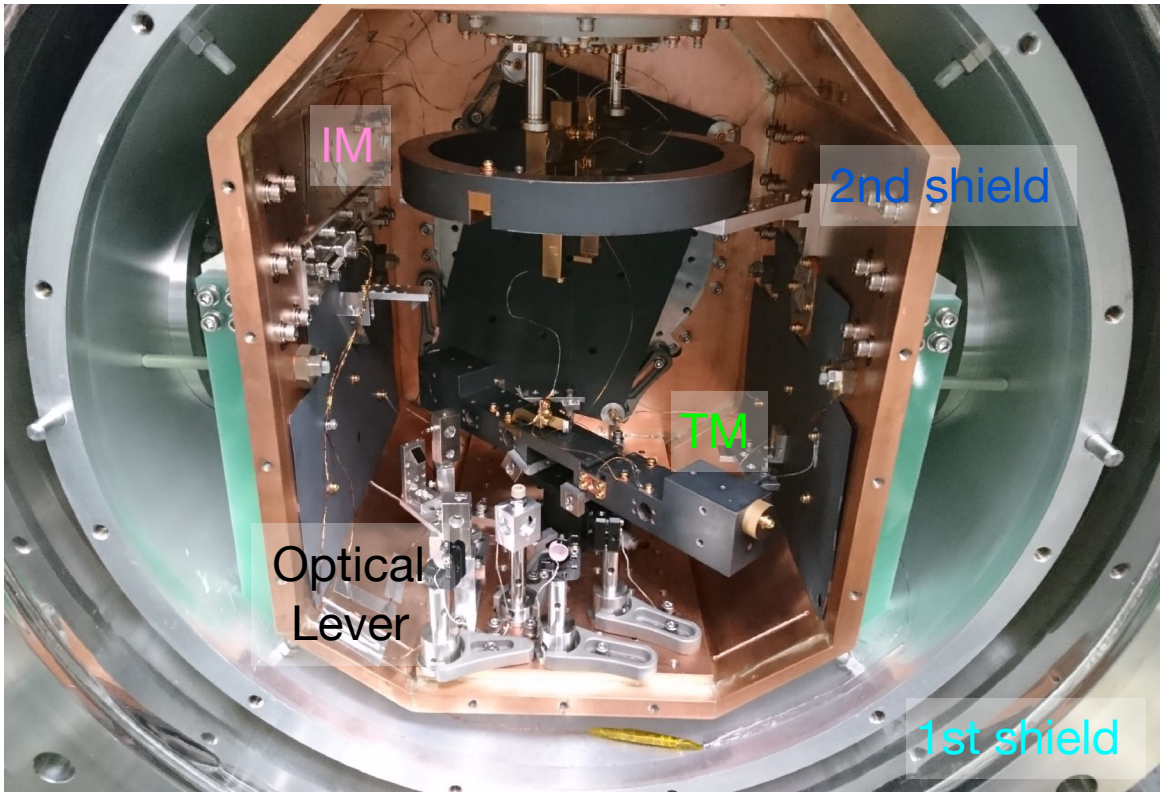
Current Status

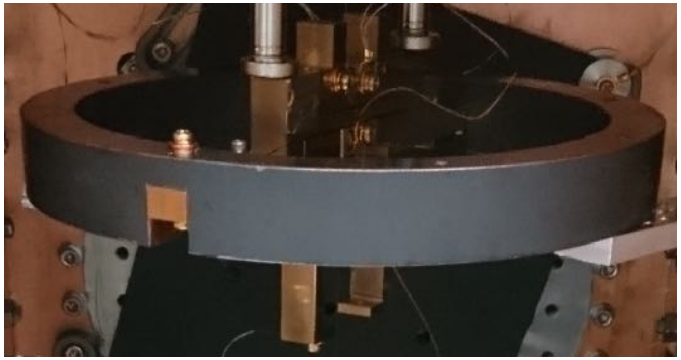
- Cryogenic System
  - 2 shields were installed
  - 1st cryogenic torsion pendulum test
  - Some problems about cooling

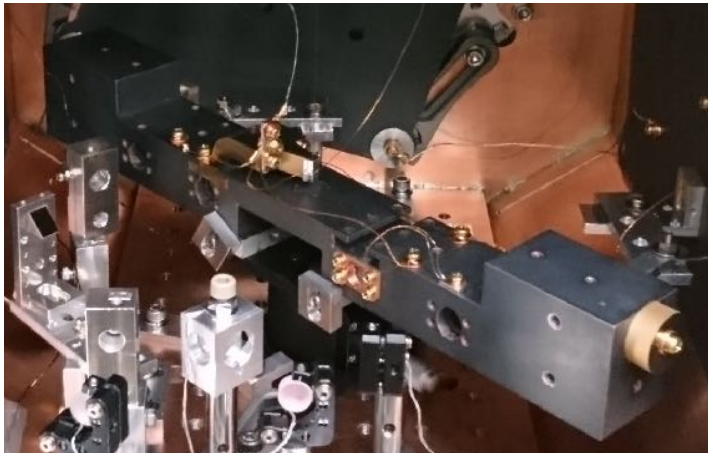
- AVIS
  - Construction were done
  - Seismic vibration isolation were tested
  - Tilt-horizontal coupling limits the performance

Cryogenic System

- Shields and suspension system were installed (2019 Feb.)
- Suspension is a temporary setup to test cooling
  - Suspension wire: CuBe
  - Heatlinks are connected to both IM and TM





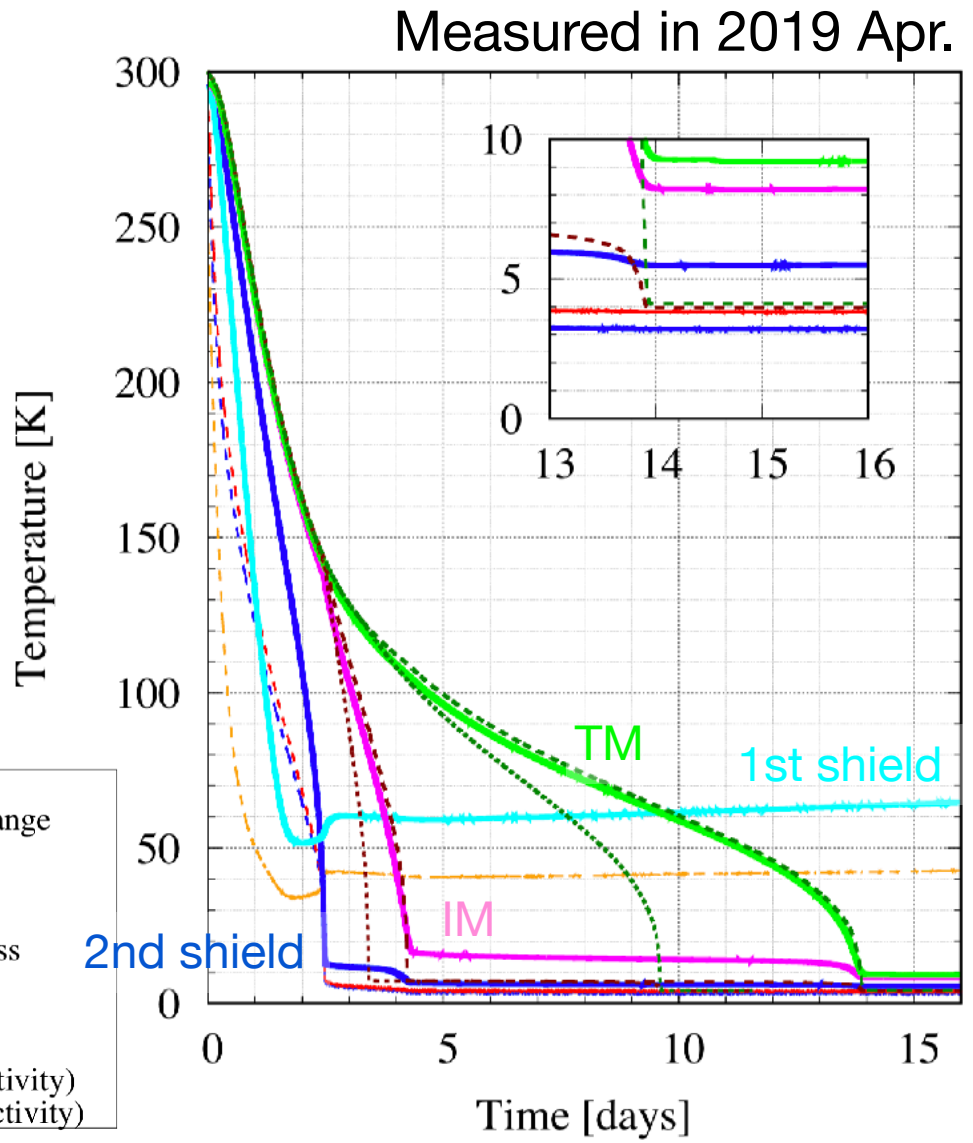


Result of Cooling

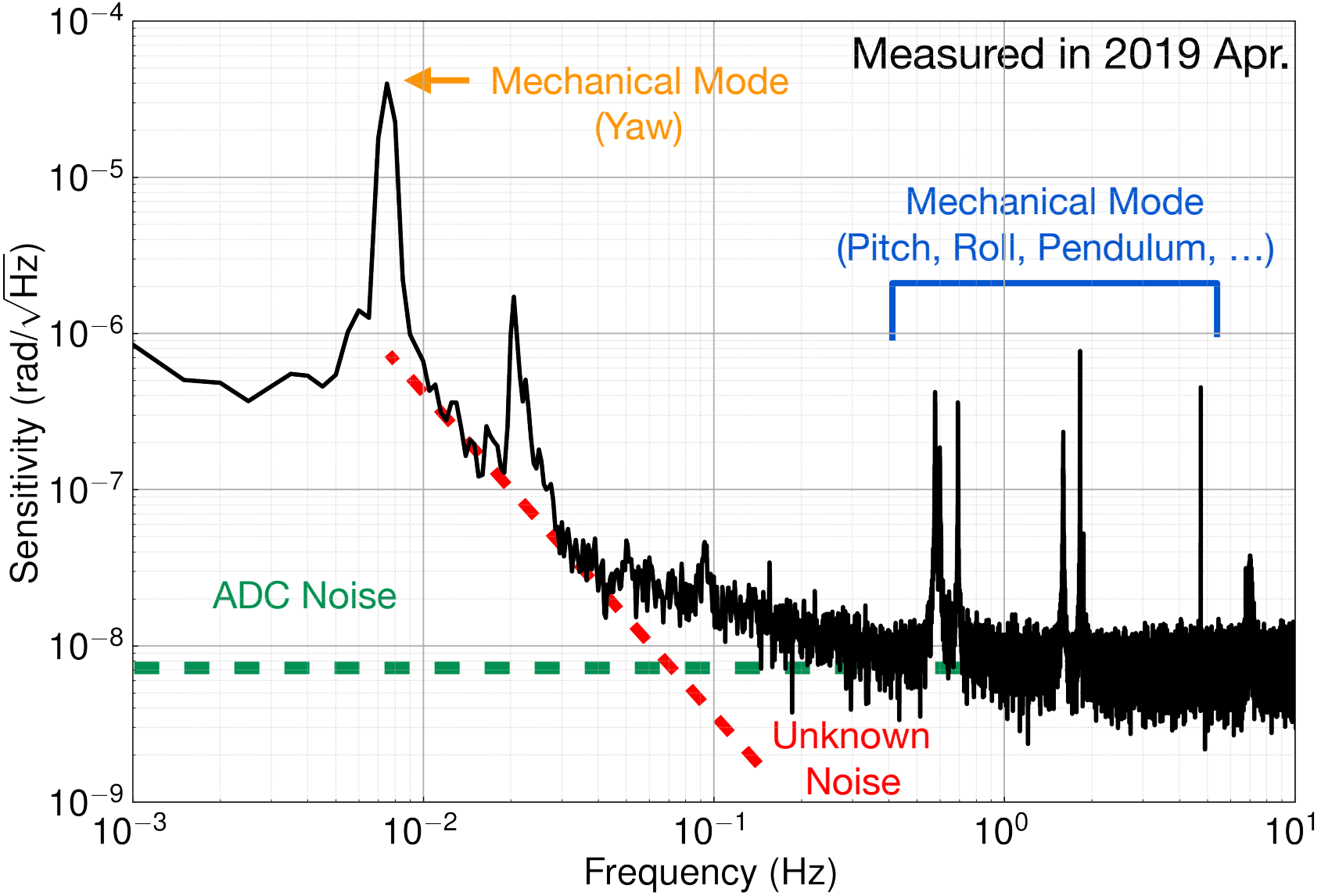
1st cryogenic torsion pendulum test

- Cooled down to **8.5K**
  - There exists some kind of heat injection
- It took ~ **2weks** to reach equilibrium
  - Cooling speed is twice slower as expected

Further investigation is needed

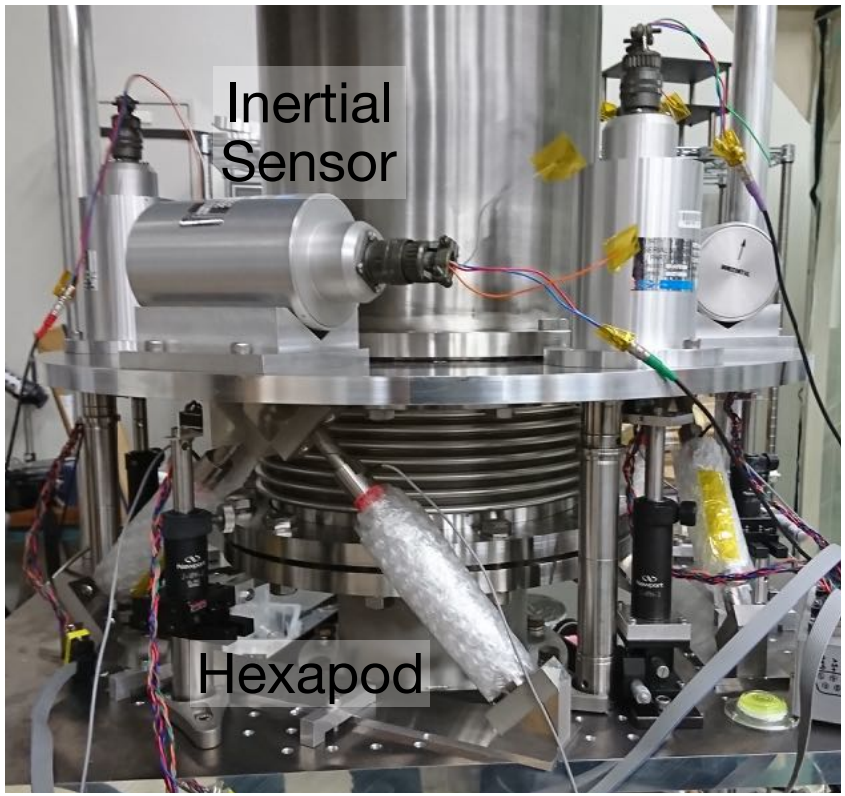


Sensitivity

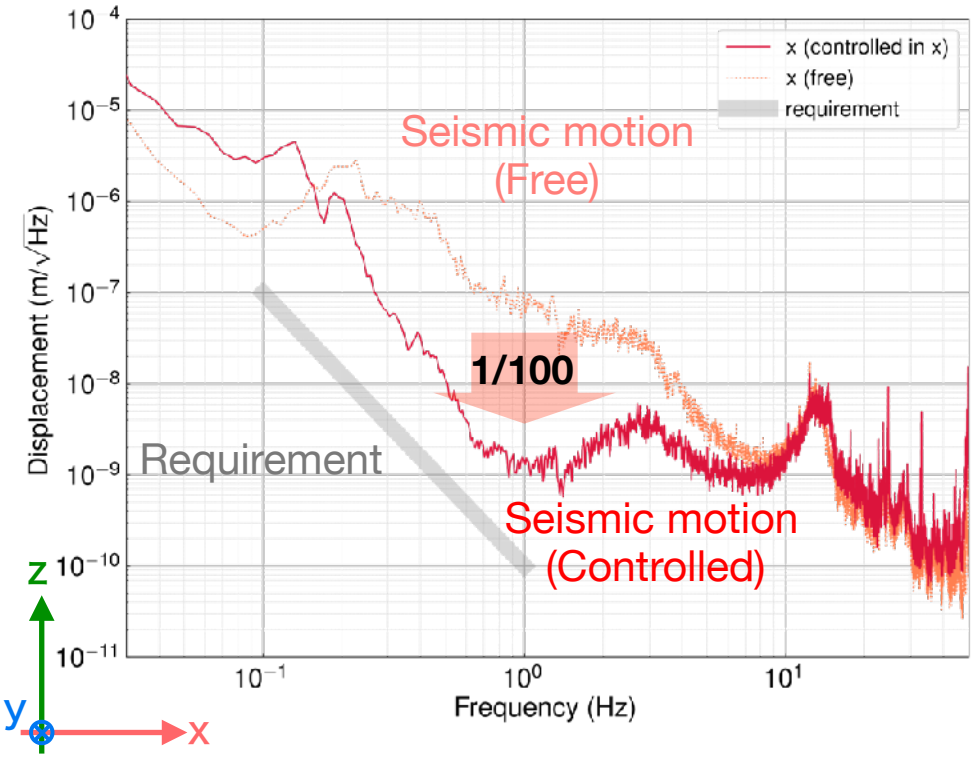


AVIS Performance

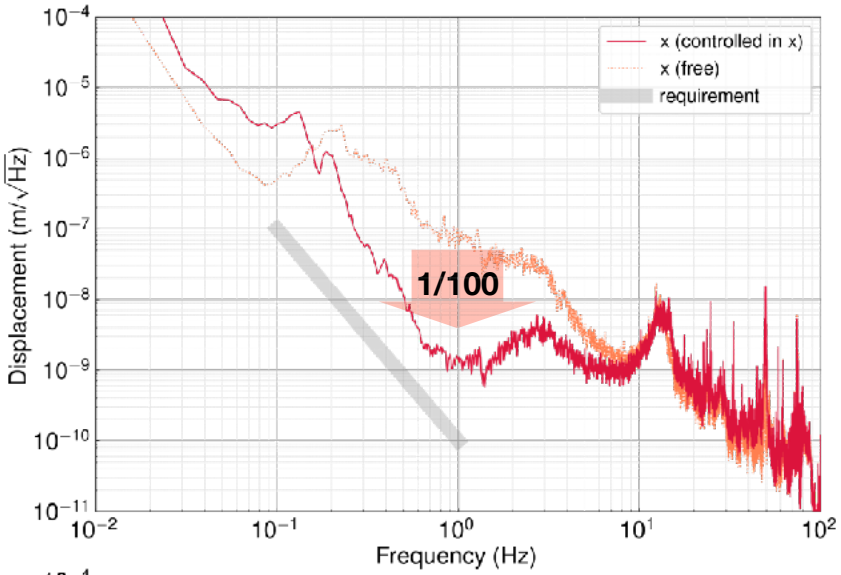
- Constructed separately from the cryogenic system
- Succeeded in reducing Seismic motion by 1/100 @ 1Hz
- Current problem: tilt-horizontal coupling of inertial sensor

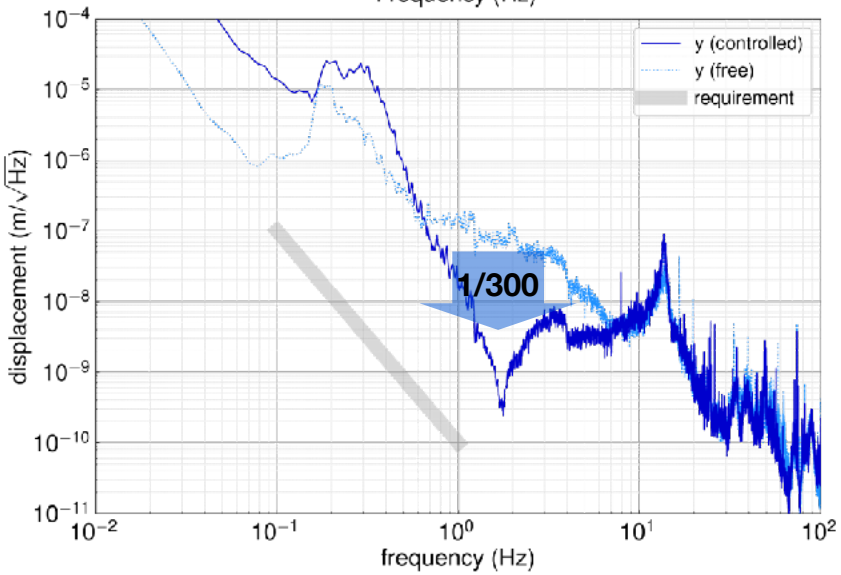


Measured in 2019 Apr.

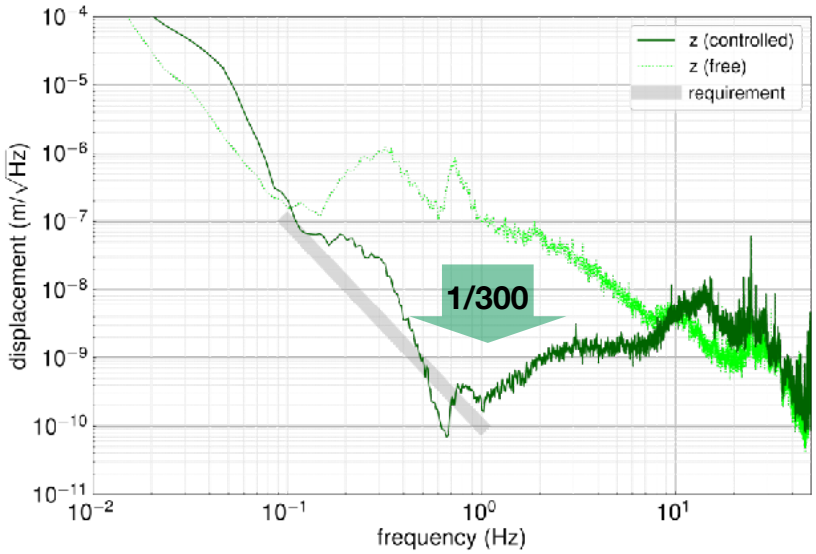


AVI Performance





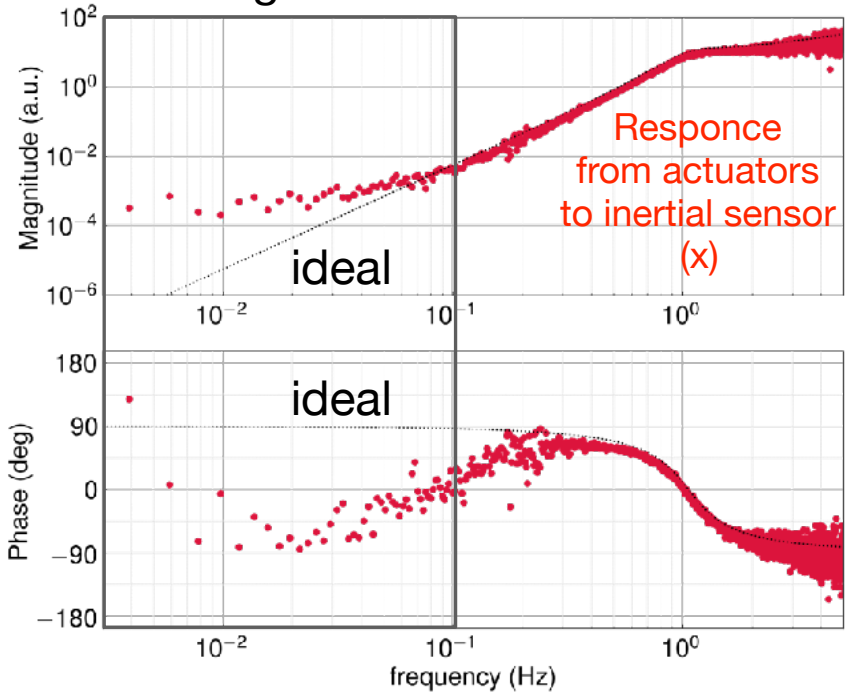
- Controlled in each DoF independently

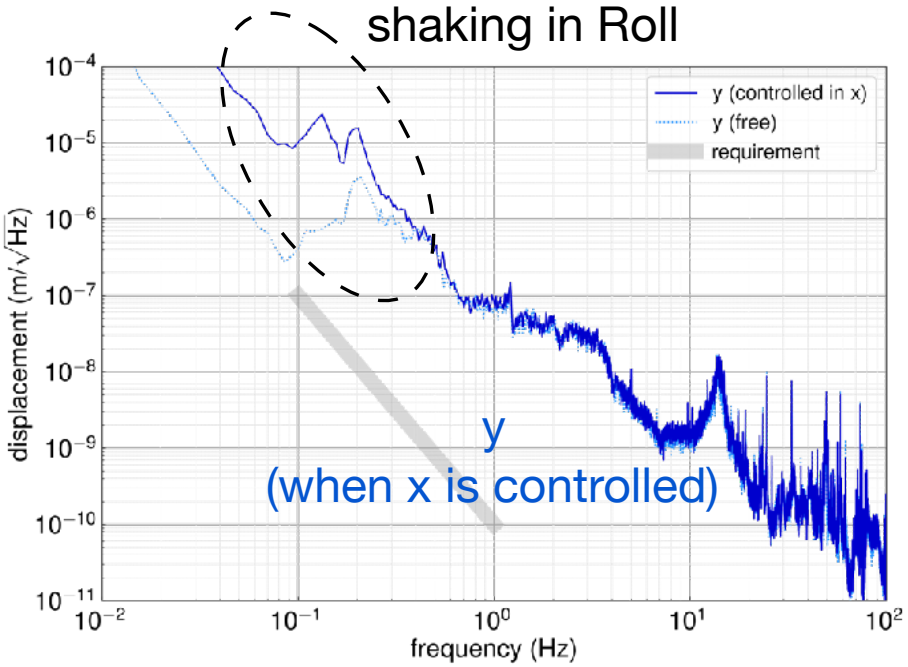


Tilt-Horizontal Coupling

- When controlling one translational direction, we also shake in Pitch/Roll rotation
- Below 0.1 Hz tilt signal exceeds true translational signal
  - Cannot put blend frequency below than 0.1 Hz
  - Cannot control at the same time

Shaking in Pitch





Future Works

AVIS

- Combine with cryogenic system
- Test the reduction of the vibration introduce from heatlinks
- Introduce tilt meter to reduce tilt-horizontal coupling by controlling tilt motion

Cryogenic system

- Check why the cooling speed is slower than expected
- Develop high Q wire at 4K

Others

- Construct optical system
- Measure how the cooling affects components (how much they drift)

Summary

- Phase-III TOBA is under development
  - Target sensitivity: 10-15/√Hz @ 0.1 Hz
  - Science target: Newtonian noise, earthquake alert, IMBH

- Main Issue:
  - Active vibration isolation system
  - Cryogenic system

  both system are constructed and evaluated

- Future works
  - Develop high Q value wire
  - Improve cooling speed and reduce heat injection
  - Introduce tiltmeter to avoid tilt-horizontal coupling
  - Combine AVIS and cryogenic system together