

Cryogenic Monolithic Interferometer for Sensing Gravity Gradient

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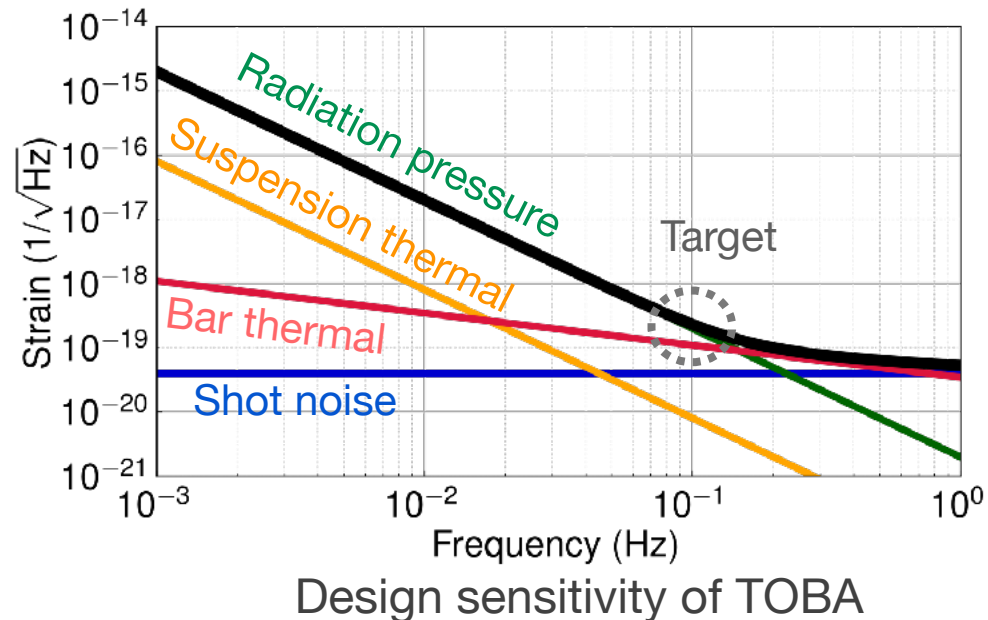
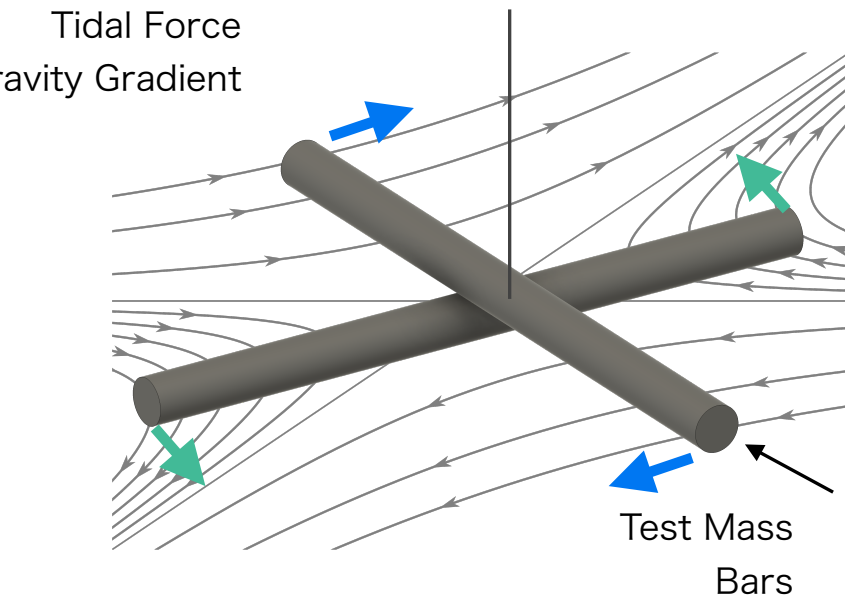
08/12/21 4th IFQMS



Torsion Bar Antenna (TOBA)

TOBA : TORSion-Bar Antenna

- Gravity gradiometer using two torsion pendulums
- Resonant frequency of torsion pendulum \sim mHz
 - ▶ Sensitive to low frequency (\sim 0.1 Hz)
- Target sensitivity $h \sim 10^{-19} / \sqrt{\text{Hz}}$ @ 0.1 Hz with **10 m** bars
 - ▶ Limited by noises coming from quantumness of laser light



Development Plan

Phase-I
(2009)

Phase-II
(2015)

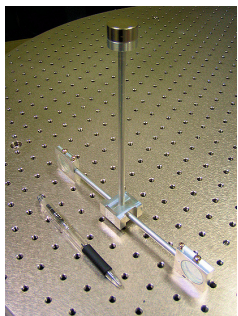
Phase-III
(Now)

Final
(Target)

Principle Test

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

- Room Temp.
- 25cm TM(s)

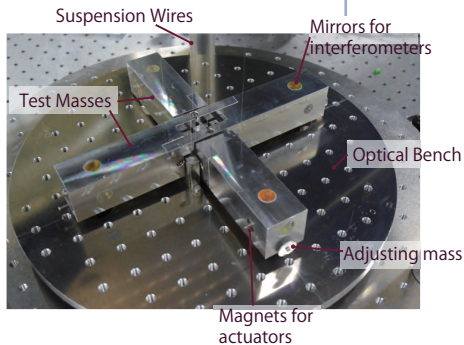


K. Ishidoshiro
Ph.D Thesis

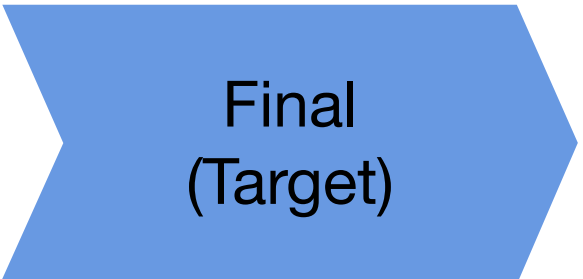
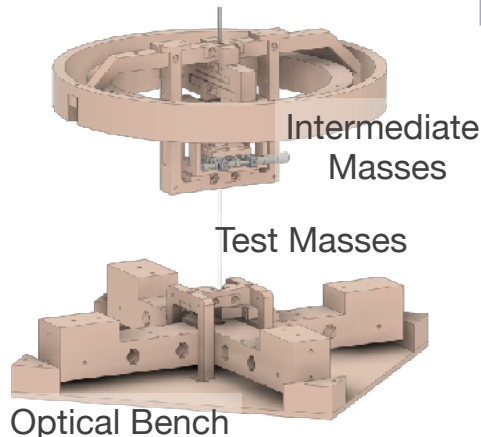
Cryogenic Test

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

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



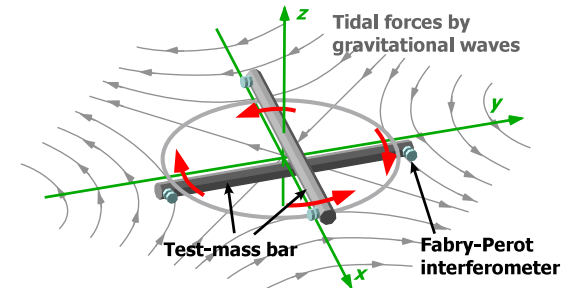
A. Shoda
Ph.D Thesis



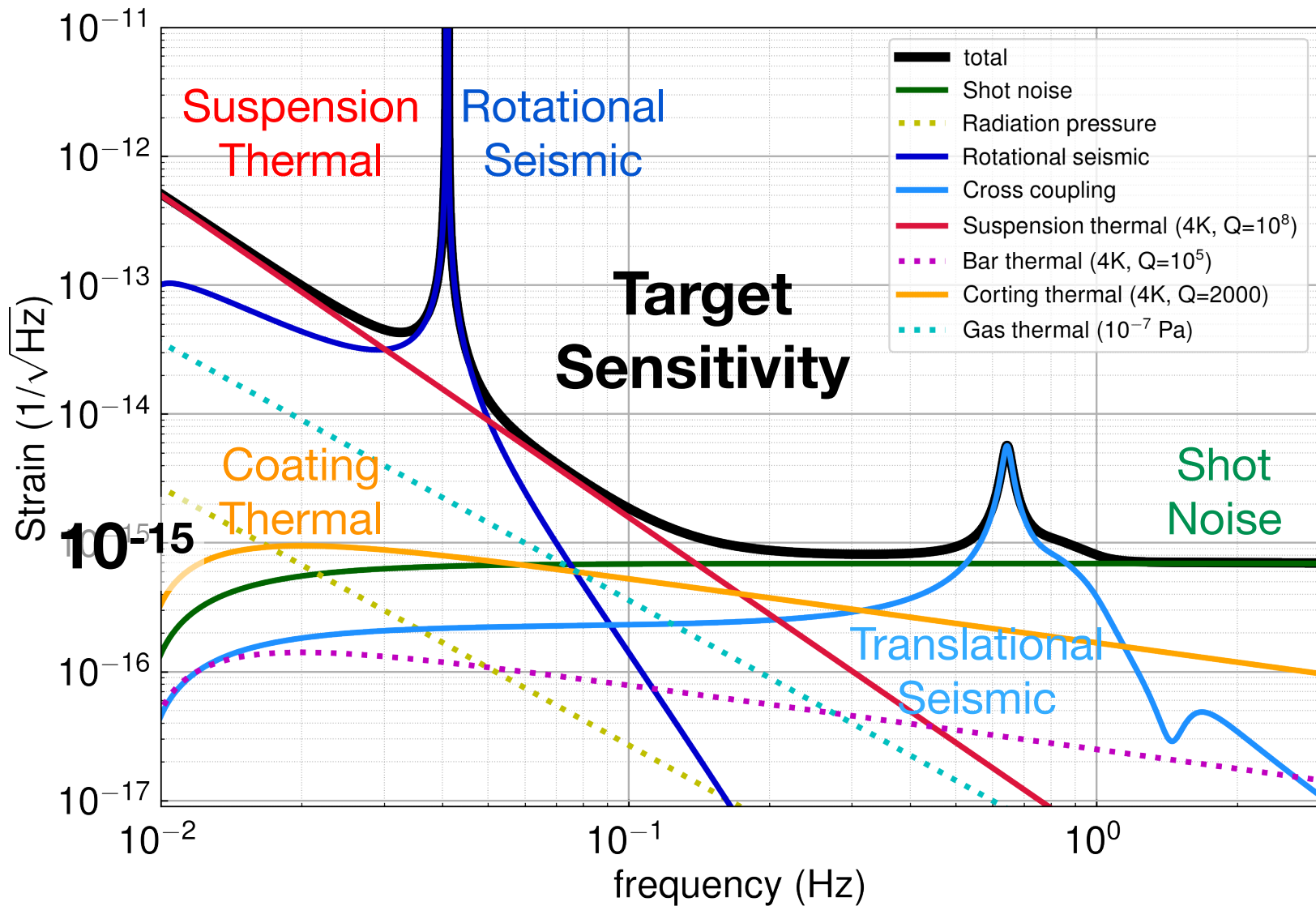
Goal

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

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



Design Sensitivity

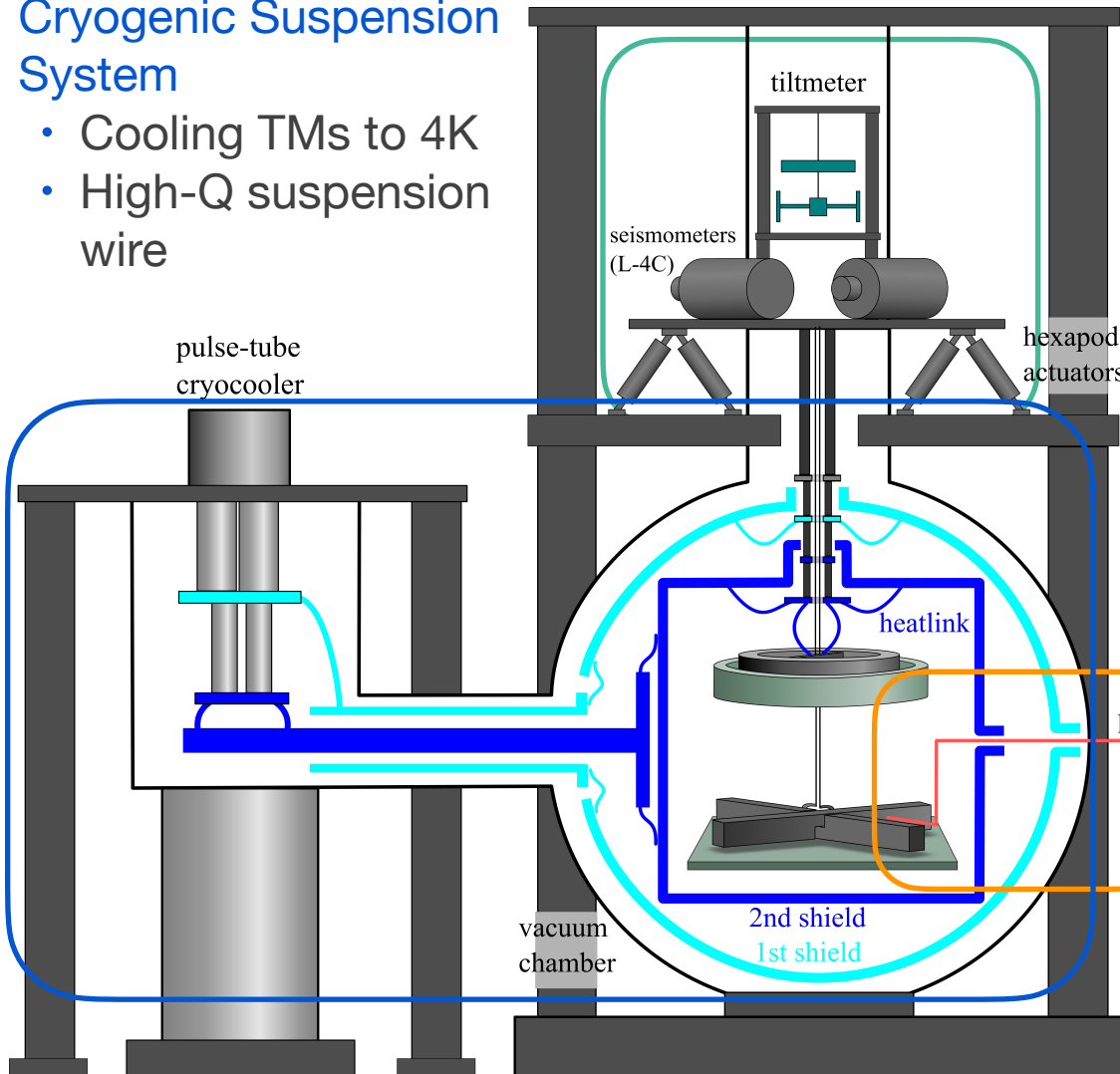


Setup of Phase-III TOBA

Cryogenic Suspension System

- Cooling TMs to 4K
- High-Q suspension wire

pulse-tube cryocooler



Active Vibration Isolation System

- Reduction of vibration at the suspension point
- Reduction of vibration induced cryocooler

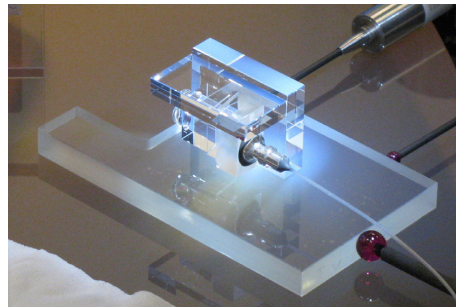
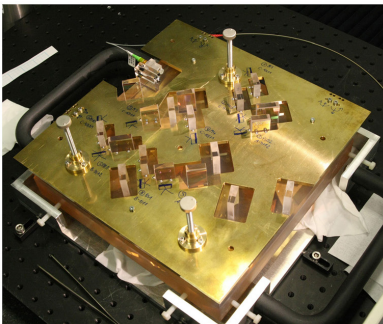
Optical System

- Rotation measurement by high-sensitive wave front sensor
- Monolithic interferometer for reducing readout noise

This Talk

Monolithic Interferometer

- Monolithic interferometer (MI)
 - ◉ Glued optics on a base plate
 - ◉ Adopted in the field of GW detectors
 - ◉ **Good sensitivity** around 0.1 Hz (e.g. $3.5 \times 10^{-14} \text{m}/\sqrt{\text{Hz}}$ for LPF [1])
 - ◉ Need to special care for alignment

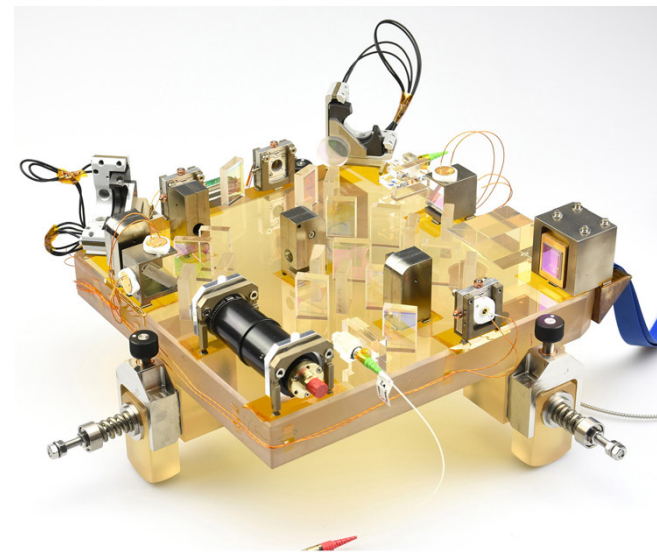


Previous cases: room temperature



TOBA: **cryogenic temperature**

- ▶ Test whether optics survive at 4 K or not
- ▶ Achieve **laser shot-noise limited sensitivity**



Example of MI [2]

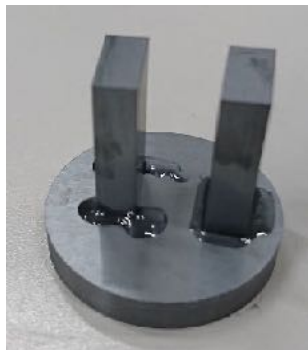
[1] [Armano et al., PRL 116, 231101 \(2016\)](#)

[2] [Chwalla et al., CQG 33, 245015 \(2016\)](#)

Component Selection

Component selection is on going

Bonding



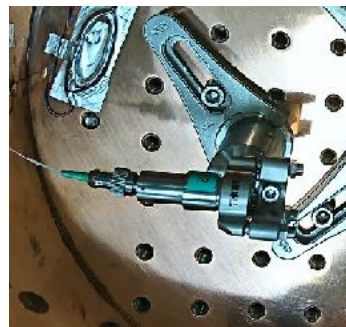
after
cooling



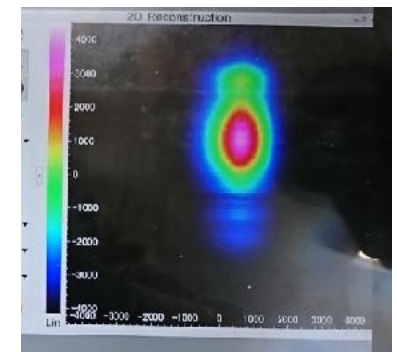
UV cured: dead



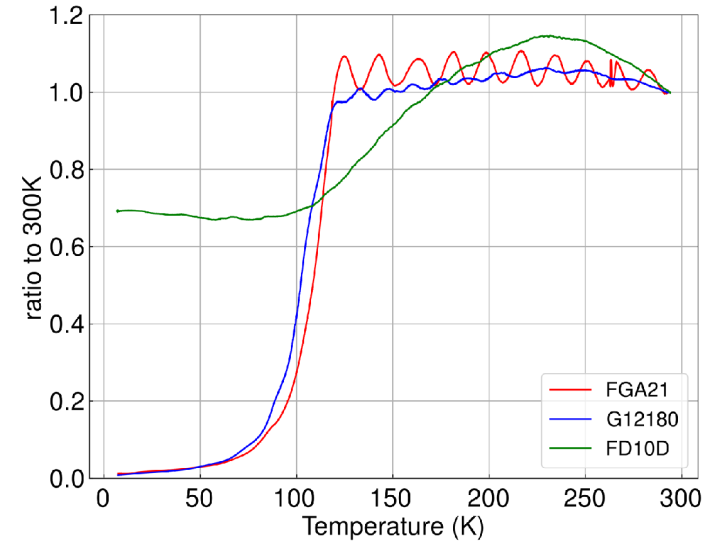
Epoxy-type: survived



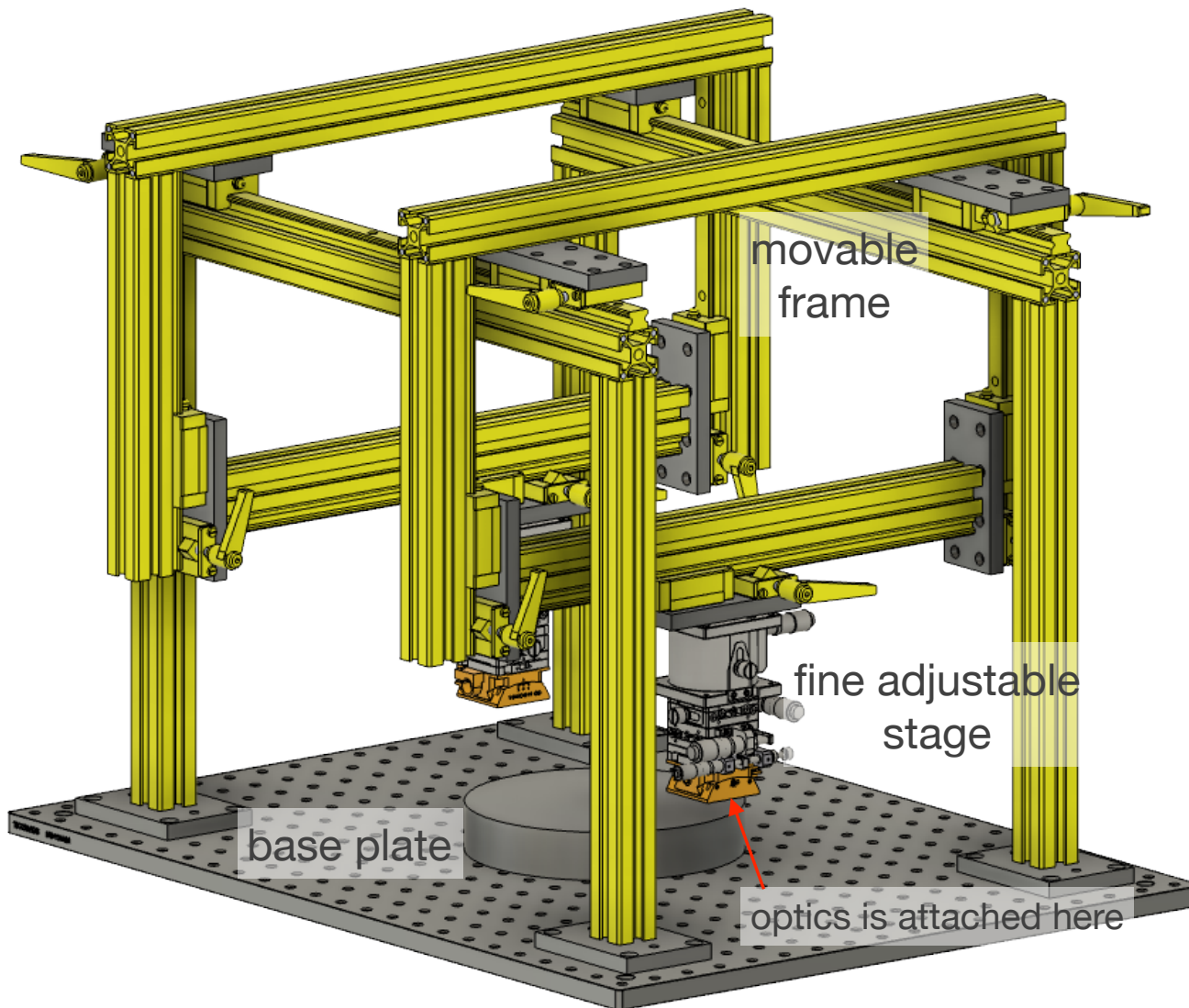
Collimator



PD

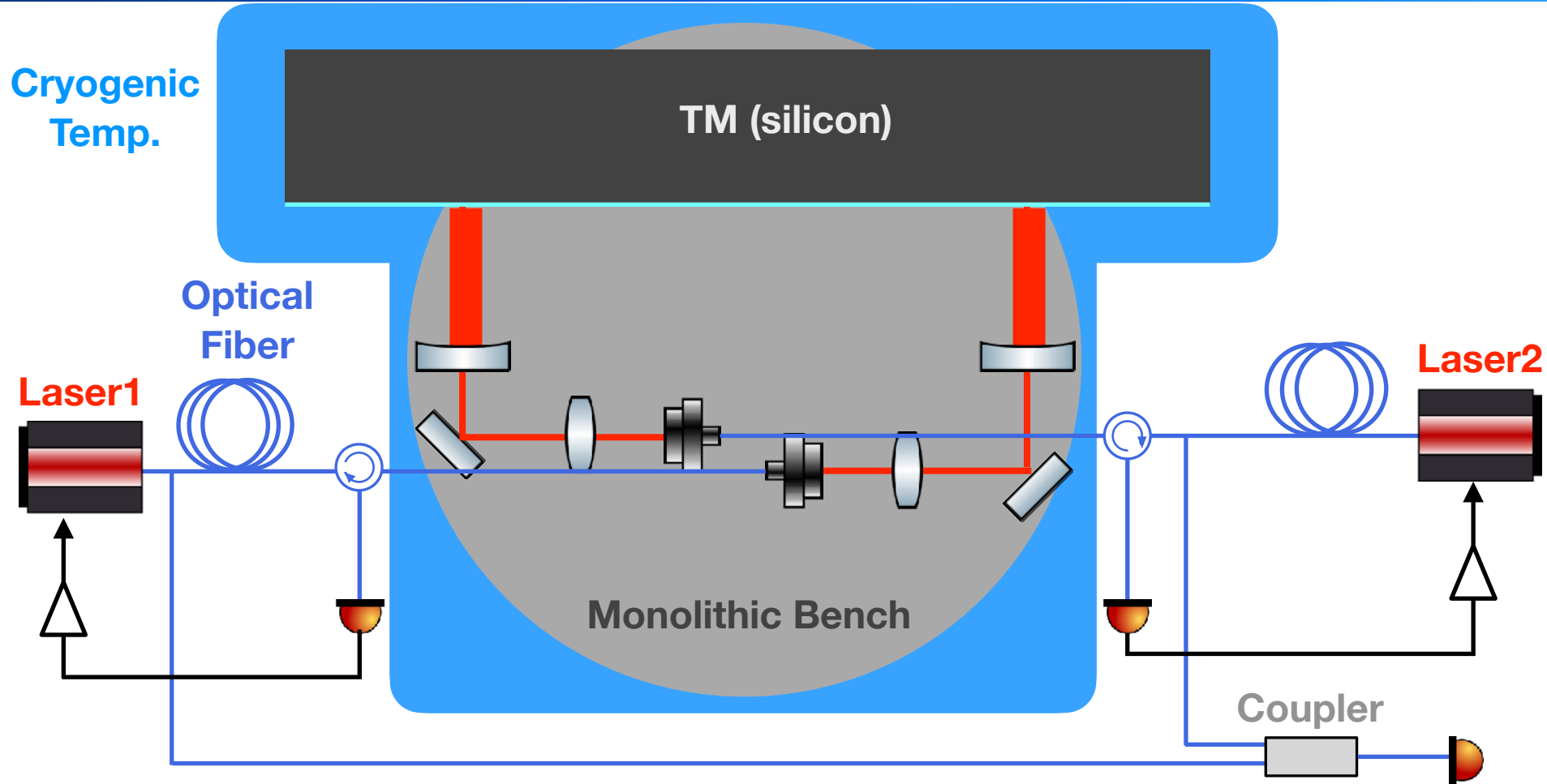


Construction Bench



Movable frame
(Coarse)
+
Adjustable stage
(Fine)

Basic Optical Design



- Read displacement of each arm cavity independently (2 laser)
- Feedback to each laser's frequency
- Measure beat frequency to read differential motion (= yaw rotation)

Summary

- TOBA is a gravity gradiometer using torsion pendulum(s)
 - ◉ Final goal is to achieve noise level limited by quantumness of light
- Monolithic interferometer has been developed to reduce readout noise
 - ✓ Component selection was done
 - ✓ Construction bench was designed
 - ▶ Construction test will be done in the near future

