Vision 2022

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Ando Lab Mid-term Seminar 2022

27.04.22.

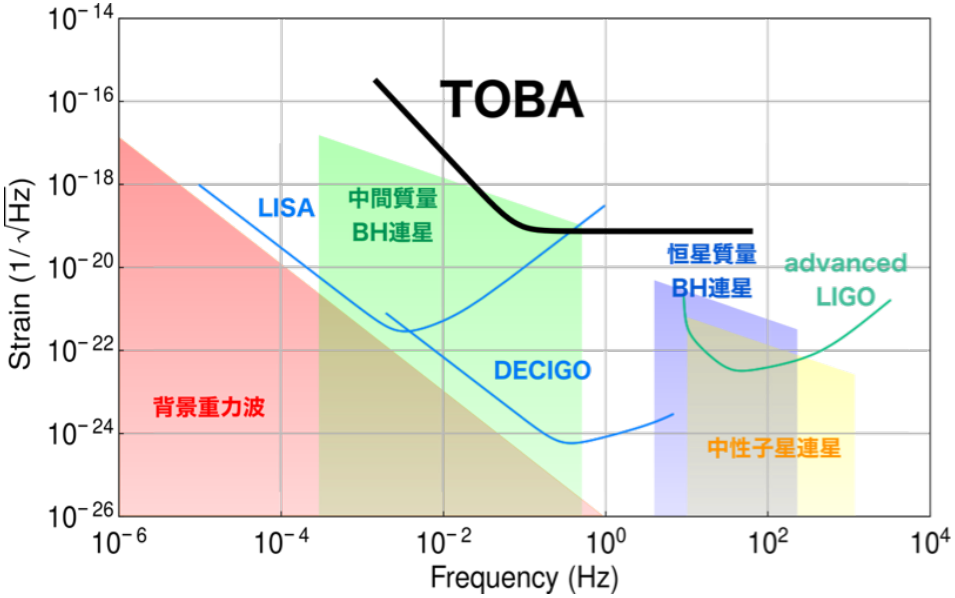
Contents

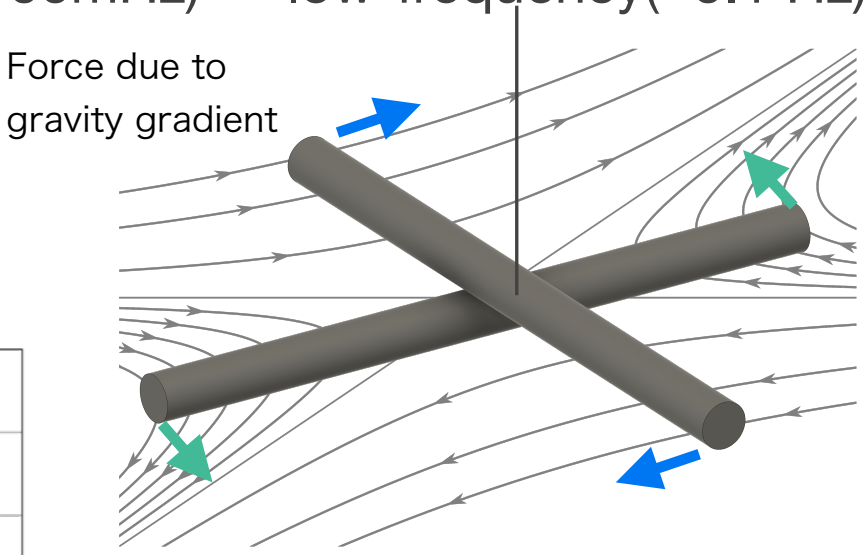
- Overview of TOBA
- Phase-III TOBA
- My Research Plan

Overview of TOBA

TOBA

- (Introduction for newcomers)
- TOrsion Bar Antenna: suspended torsion pendulum(s)
  - Low resonant frequency (<100mHz) → low-frequency(~0.1 Hz) detector
  - Detect gravity gradient
    - GWs (CBC, SGWB, etc.)
    - Local potential (NN, EEW)

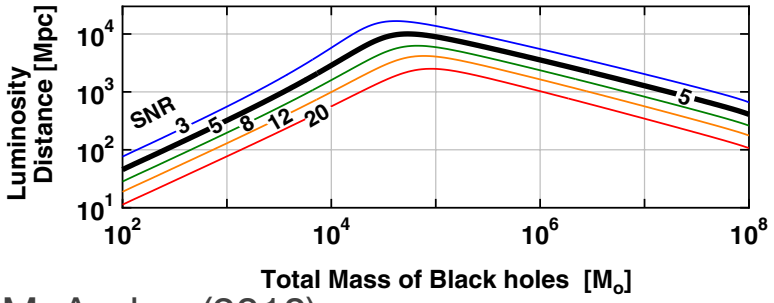




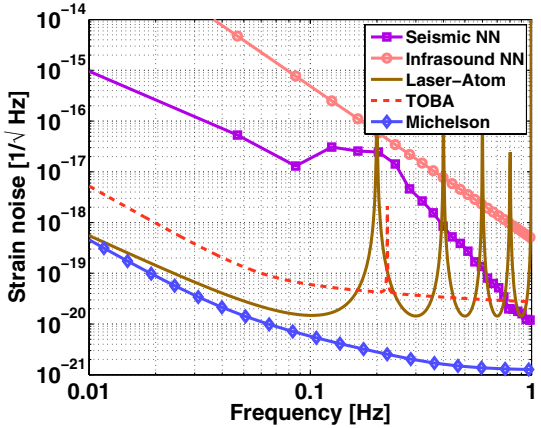
- Target Sensitivity @ 0.1Hz
  - GWs: 10^{-19} /√Hz
  - Local: 10^{-15} /√Hz

Science of TOBA

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



M. Ando+ (2010)

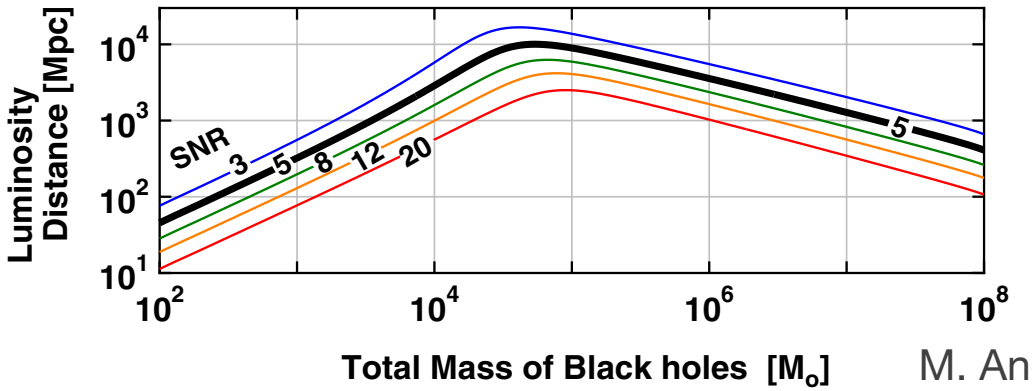


J. Harms+ (2012)

Astronomical Target

With sensitivity **$10^{-19}/\sqrt{Hz}$** …

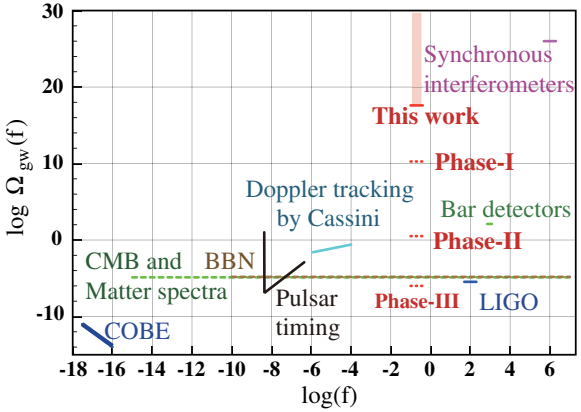
- Intermediate mass blackhole (IMBH) merger



M. Ando+ (2010)

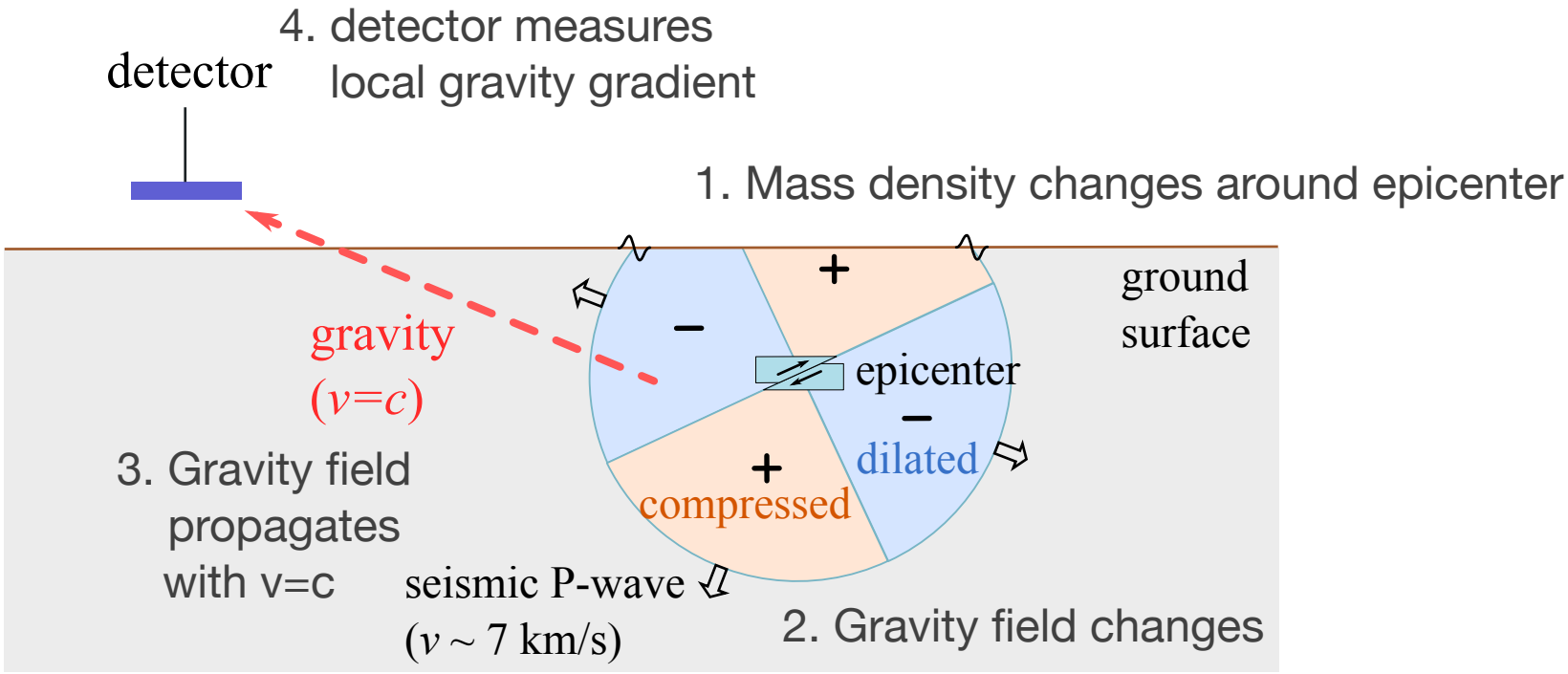
- 10^5 $M_\odot$ in 10 Gpc
- Hint for SMBH generation

- Stochastic GW background (SGWB)



- $\Omega_{GW} \sim 10^{-7}$ → Exceed BBN limit
- Insight for early universe

Earthquake Early Warning

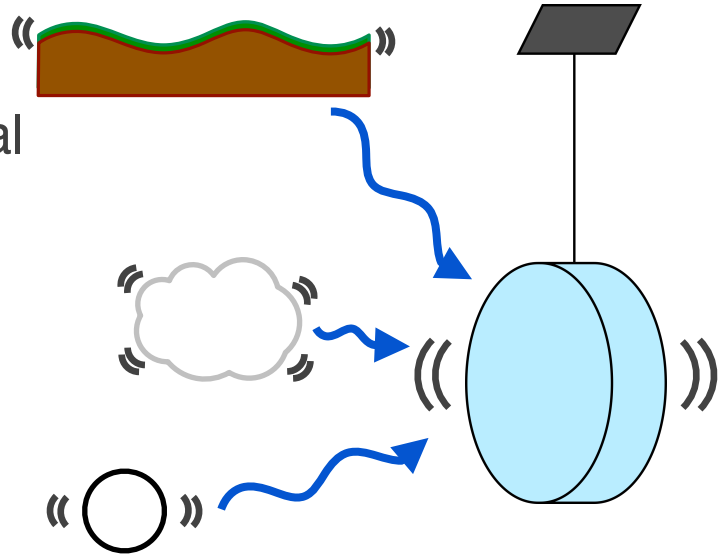


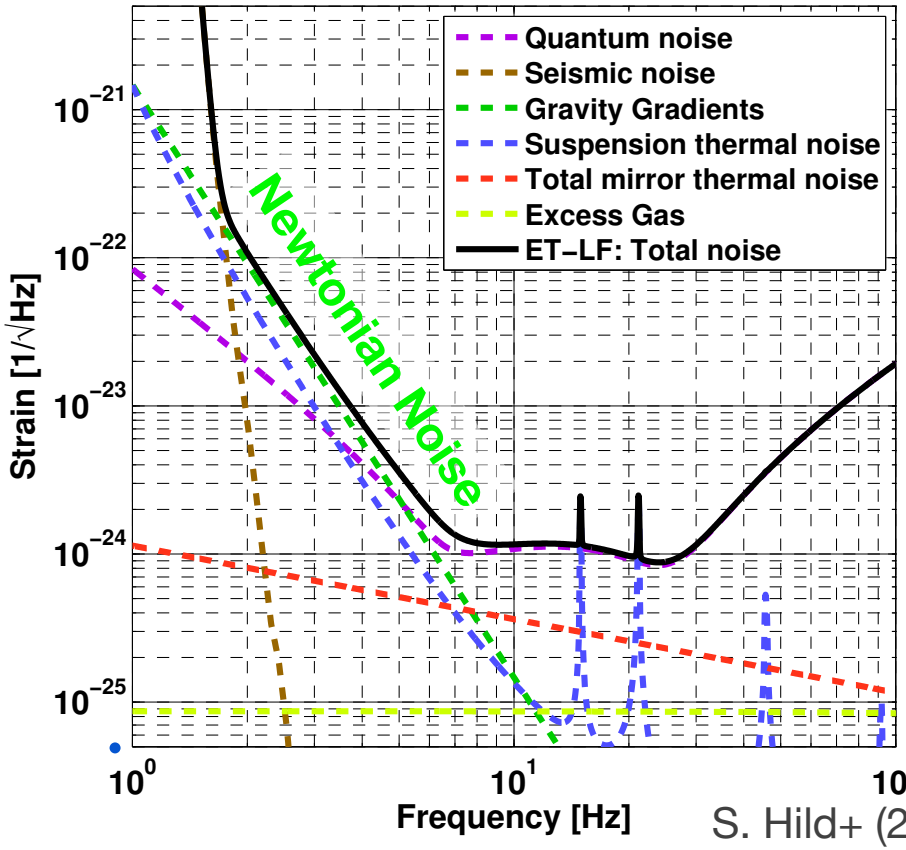
- Current warning: detect EQ by P-wave
  - Gravity field propagation is much faster than P-wave!
- With sensitivity $10^{-15}/\sqrt{\text{Hz}}$, TOBA can detect an M7 EQ 100 km away in 10 sec

Newtonian Noise

Newtonian Noise (Gravity Gradient Noise)

- Gravity gradient induce by local potential
  - Fundamental noise for GW detectors





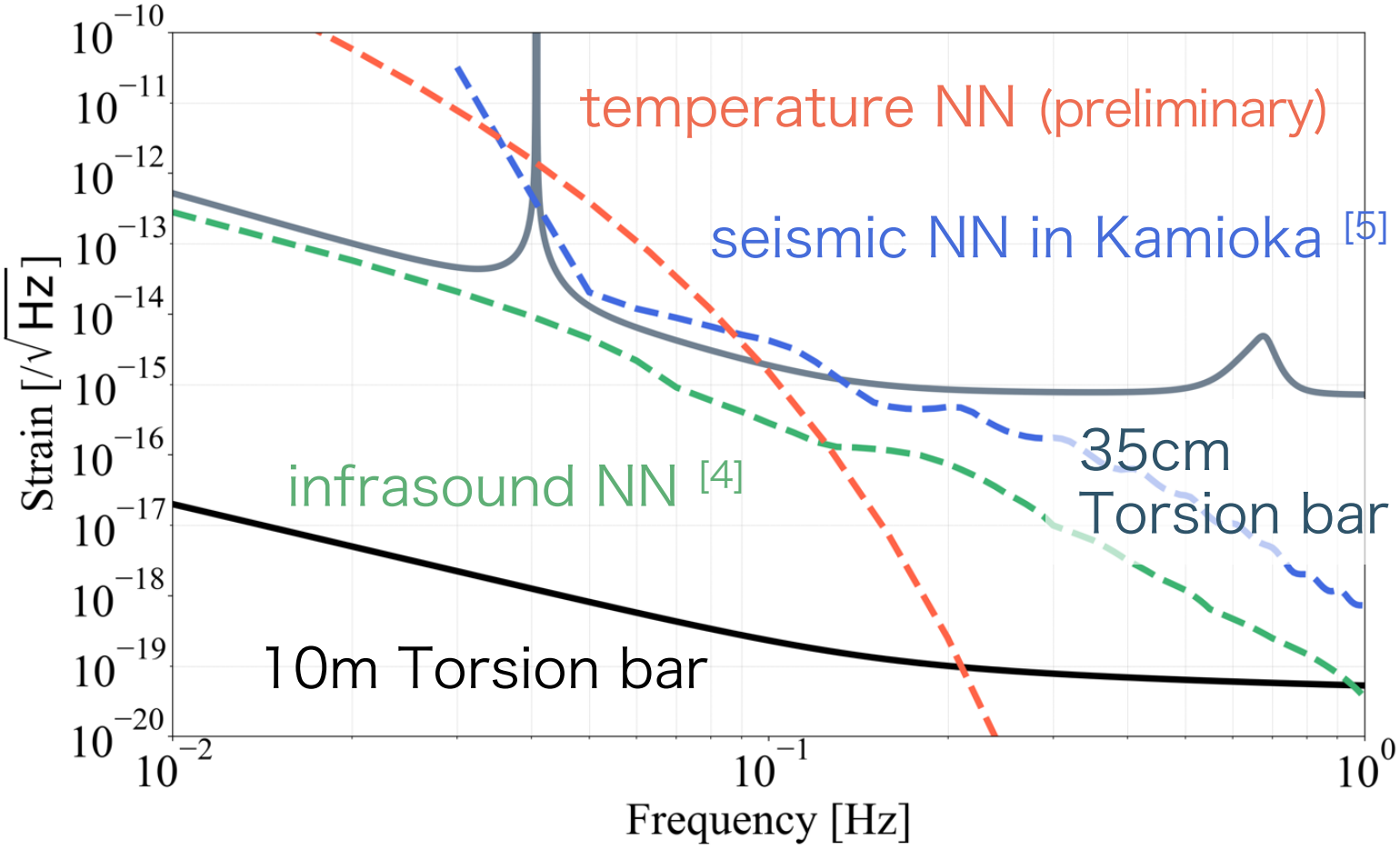
S. Hild+ (2011)

Sources

- Seismic motion
- Pressure fluctuation
- Temperature fluctuation
- Moving object

Newtonian Noise Measurement

- TOBA has potential for measurement of some types of NN
  - Test models, establish mitigation scheme, …



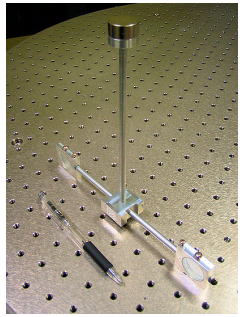
Development Plan

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

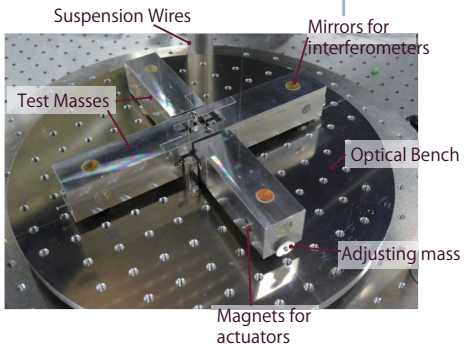
Principle Test

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

- Room Temp.
- 25cm TM(s)



M. Okada
Master Thesis

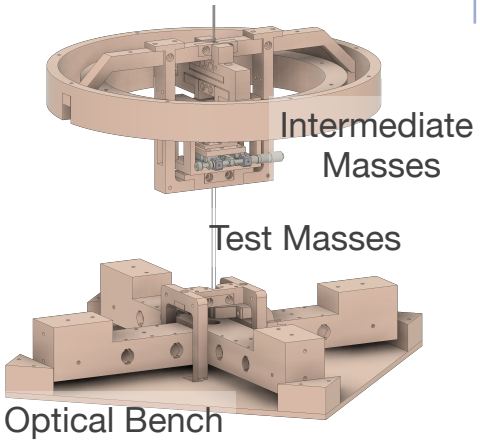


A. Shoda
Ph.D Thesis

Cryogenic Test

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

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

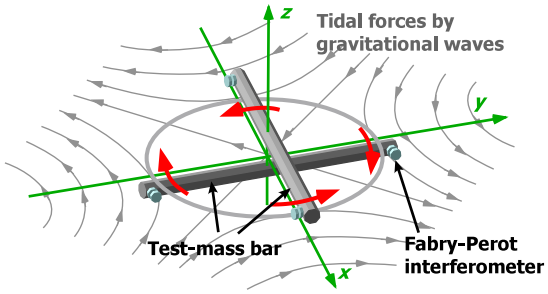


Optical Bench

Goal

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

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

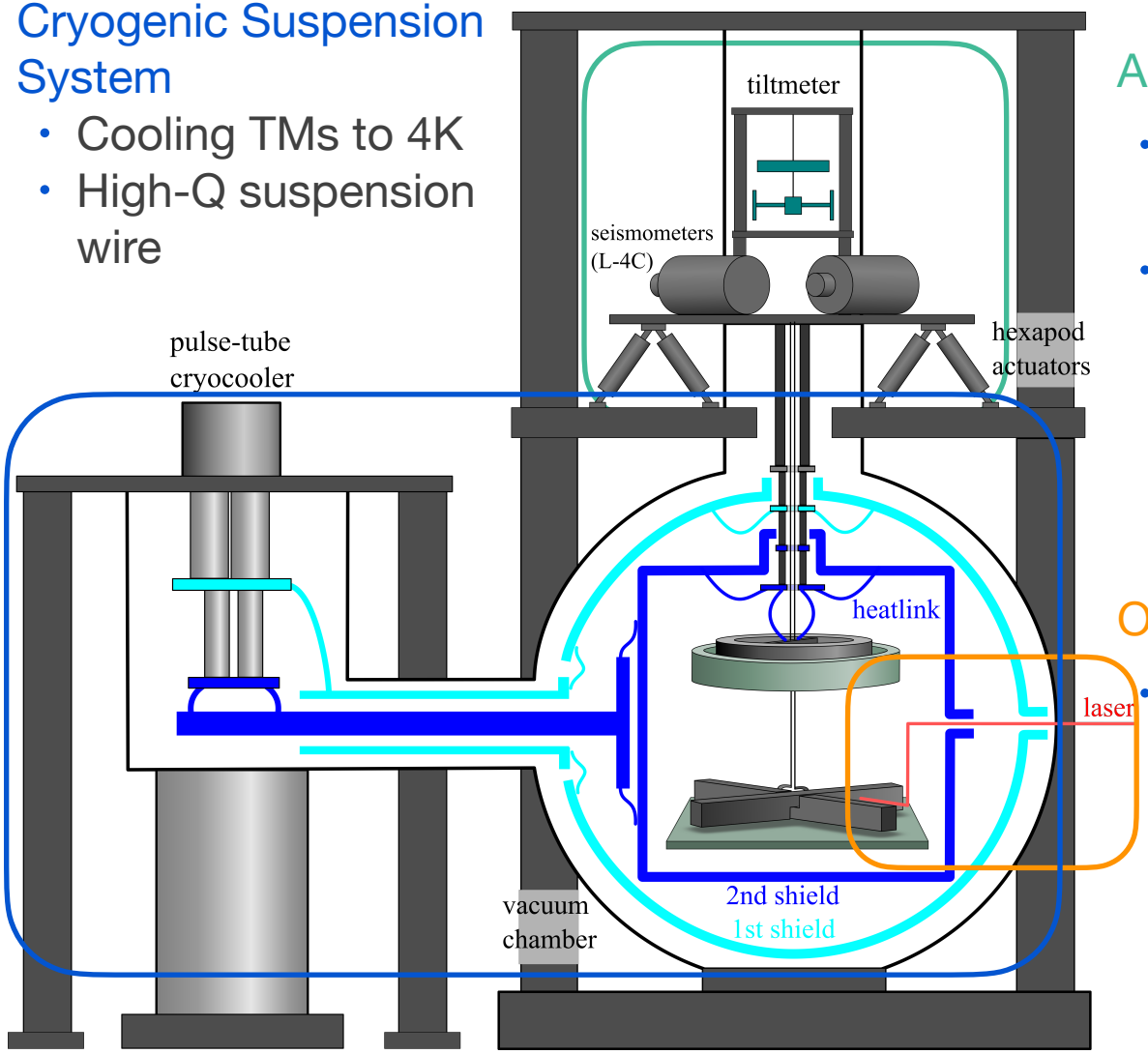


Phase-III TOBA

Setup of Phase-III TOBA

Cryogenic Suspension System

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



Active Vibration Isolation System

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

Optical System

- Rotation measurement by interferometers with high-sensitive

Development Items (Designed)

- Cryogenic Suspension System
  - Cooling System (Shimoda)
  - High-Q suspension wire (Ching Pin)
- Optical System
  - New WFS with higher sensitivity (Miyazaki, Oshima)
- Active Vibration Isolation
  - Reduction of translational seismic noise (Takano)
  - Reduction of vibration induced by cooler (Takano)

Development Items (Designed)

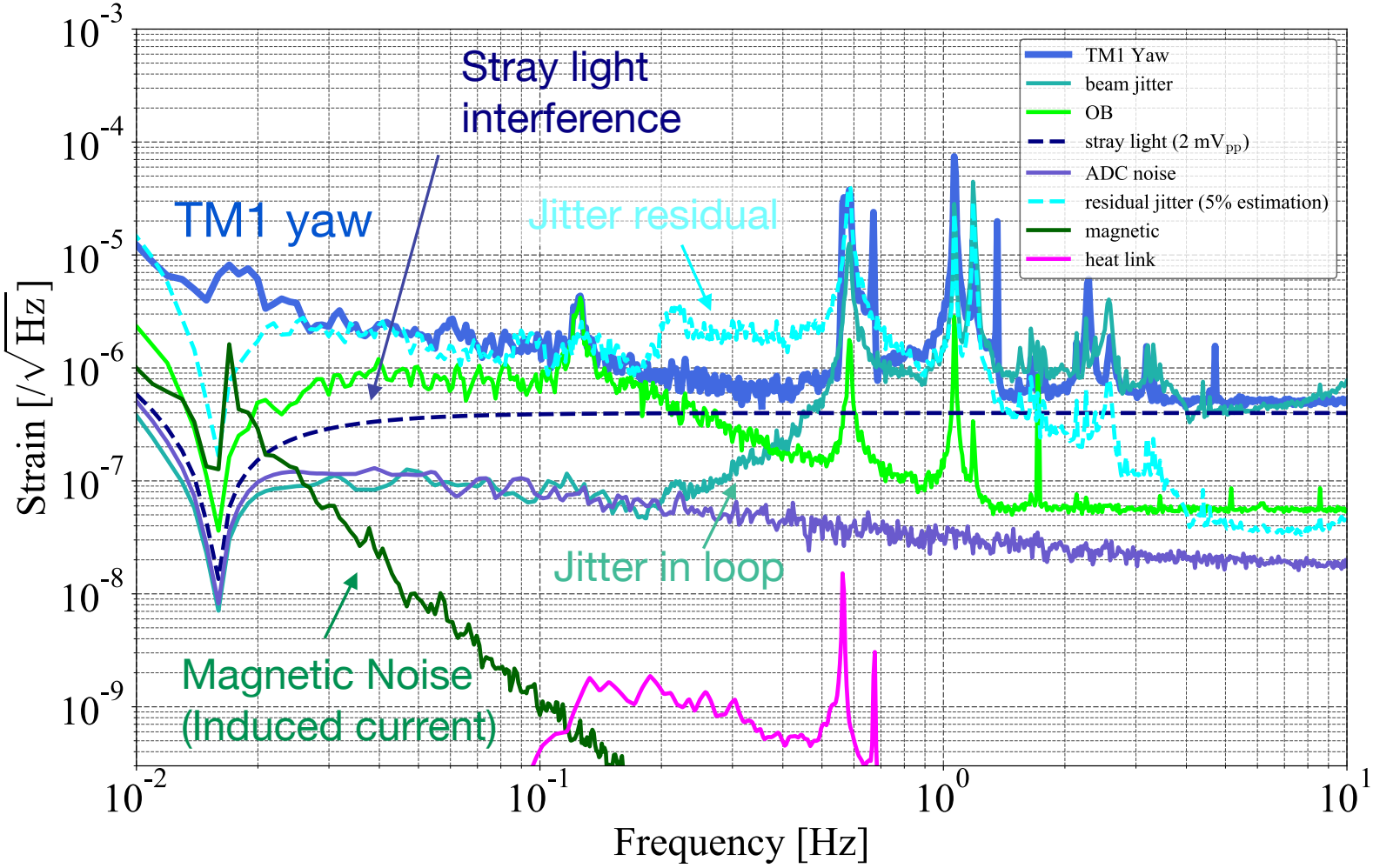
- Cryogenic Suspension System
  - Cooling System (Shimoda) → Cooled to 6.1 K
  - High-Q suspension wire (Ching Pin)
- Optical System
  - New WFS with higher sensitivity (Miyazaki, Oshima)

    → Partially demonstrated
- Active Vibration Isolation
  - Reduction of translational seismic noise (Takano)
  - Reduction of vibration induced by cooler (Takano)

    → Limited Performance

Current Sensitivity (of one TM)

- Measured by Shimoda-san in 2019



Development Items (Uploaded)

- Cryogenic Suspension System
  - Cooling System → Improvement down to **4 K**
  - High-Q suspension wire (Ching Pin)
- Optical System
  - New WFS with higher sensitivity (Oshima) →Further test
  - **Reduction of Readout Noise (Takano)** →Monolithic
- Active Vibration Isolation
  - Reduction of translational seismic noise (Takano)
  - Reduction of vibration induced by cooler (Takano)
- **Magnetic Noise**
  - Shield of ambient magnetic field
  - Less conductive material

My Research Plan

My Research Target

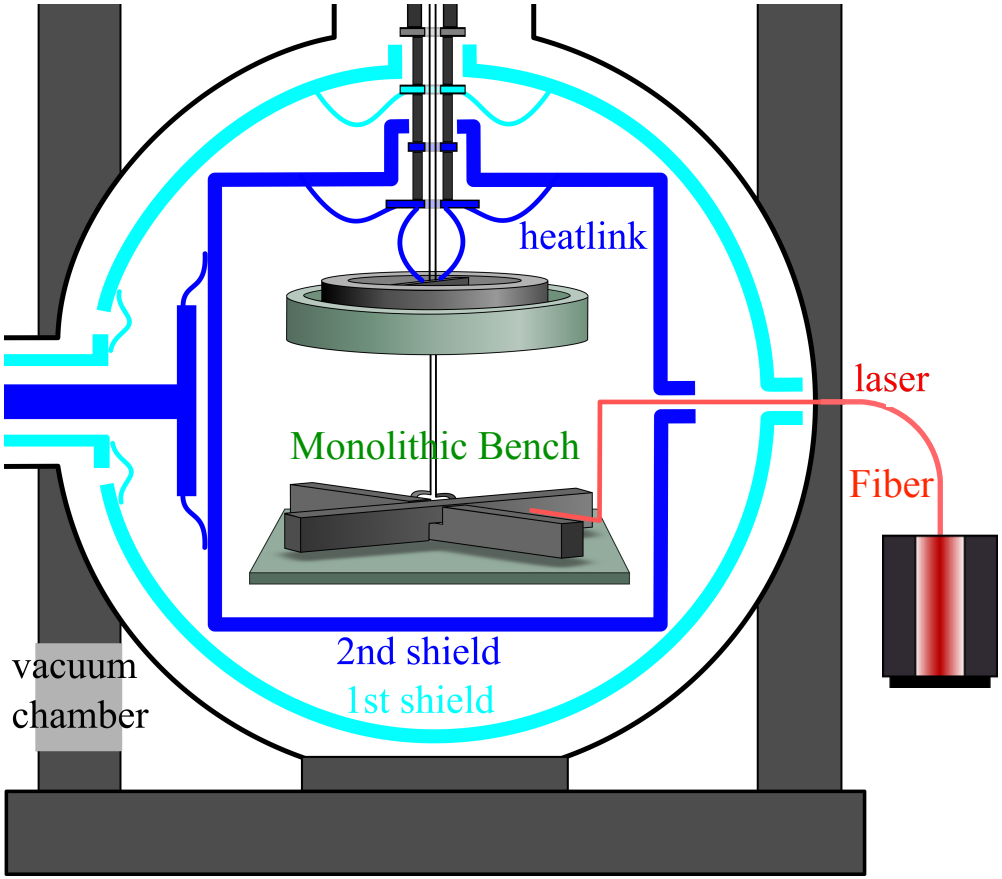
- **Introduce monolithic optical bench**
  - Motivation: reduction of readout noise to the shot-noise level
  - What's new?
    - Cryogenic
    - Silicon

- Make TM of silicon
  - Motivation: reduction of magnetic noise due to induced current

- Option
  - Improve AVIT
  - Calculation (or design) of interferometer design of future TOBA

Monolithic Interferometer

- Previously, lasers injected from in air to a suspended OB
  - ✗ Jitter is terrible
    - Introduce light by optical fiber
- At cryogenic temp. silicon is one of promising material
  - Silicon-made optics

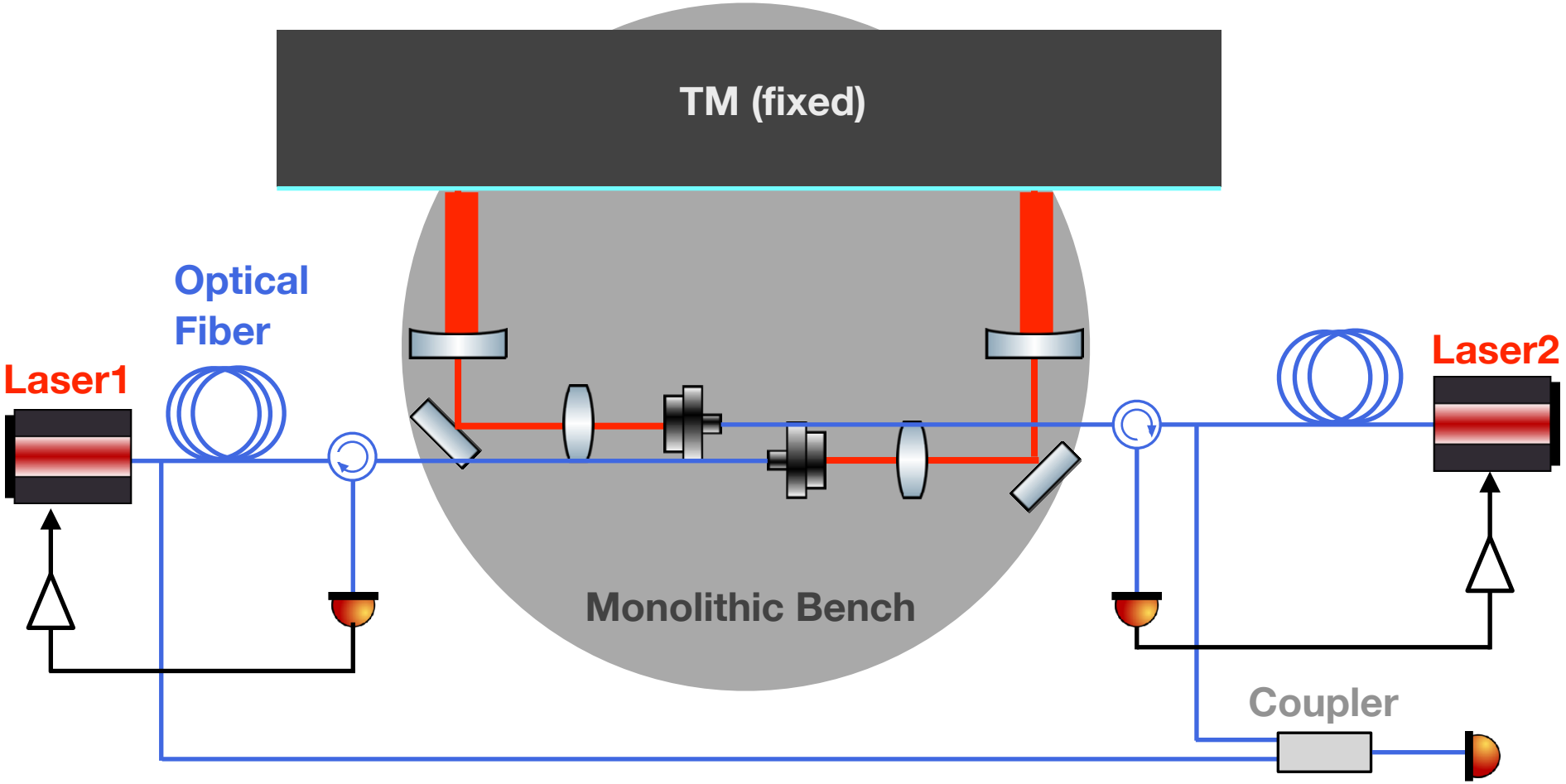


Action Item

- Establish construction scheme of the monolithic bench
  - How to fix optics?
  - How stable?
  - Usable at cryo temp.?
- Evaluate these point

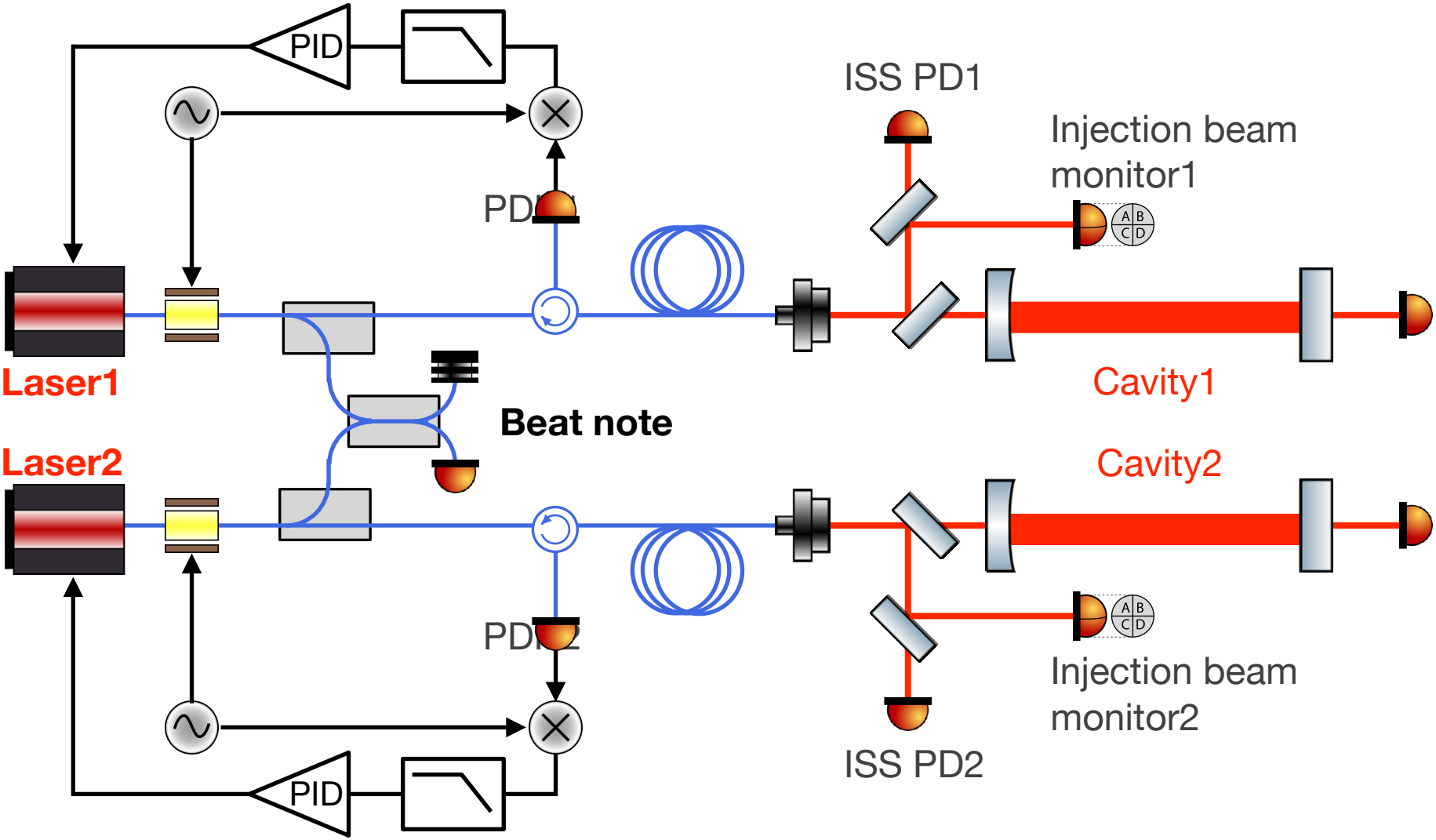
- Achieve shot noise level sensitivity with fixed mirrors
  - Interferometer configuration
  - Sensing scheme

Basic Optical Design

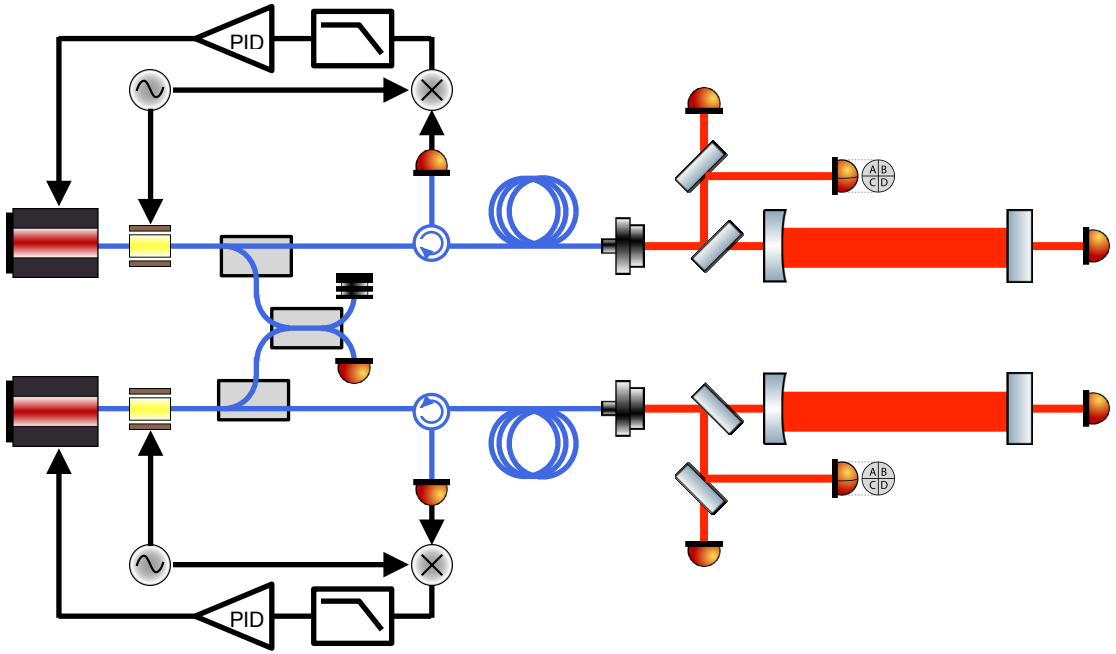


- Read displacement of each arm cavity independently (2 laser)
- Feedback to each laser's frequency
- Measure beat frequency to read differential motion

Optical Layout



Parameters



- Target: 10^{-16} m/√Hz @ 0.1Hz (differential)
- Would be limited by shot noise

Power	10 mW
Length	5 cm
Front Mirror Curvature	20 cm
End Mirror Curvature	∞
Front Mirror Reflectivity	99.5%
End Mirror Reflectivity	99.9%
Finesse	1045
FSR	3 GHz
FWHM	3 MHz

Bonding Test

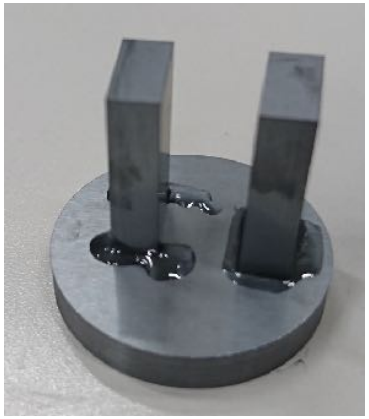
Fixed silicon blocks with

- Stycast 1266
- DP190

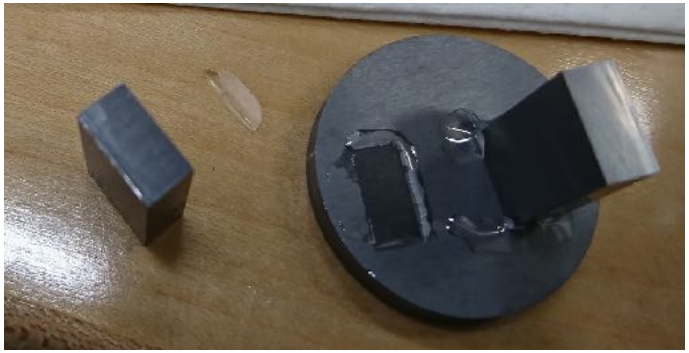
] Epoxy

- NOA63
- NOA81

] UV cure



Cooling & Heating



After cooling to 4K…

- UV cure: broken
- Epoxy
  - Stycast: OK after many cycles
  - DP190: Broken after a few cycles

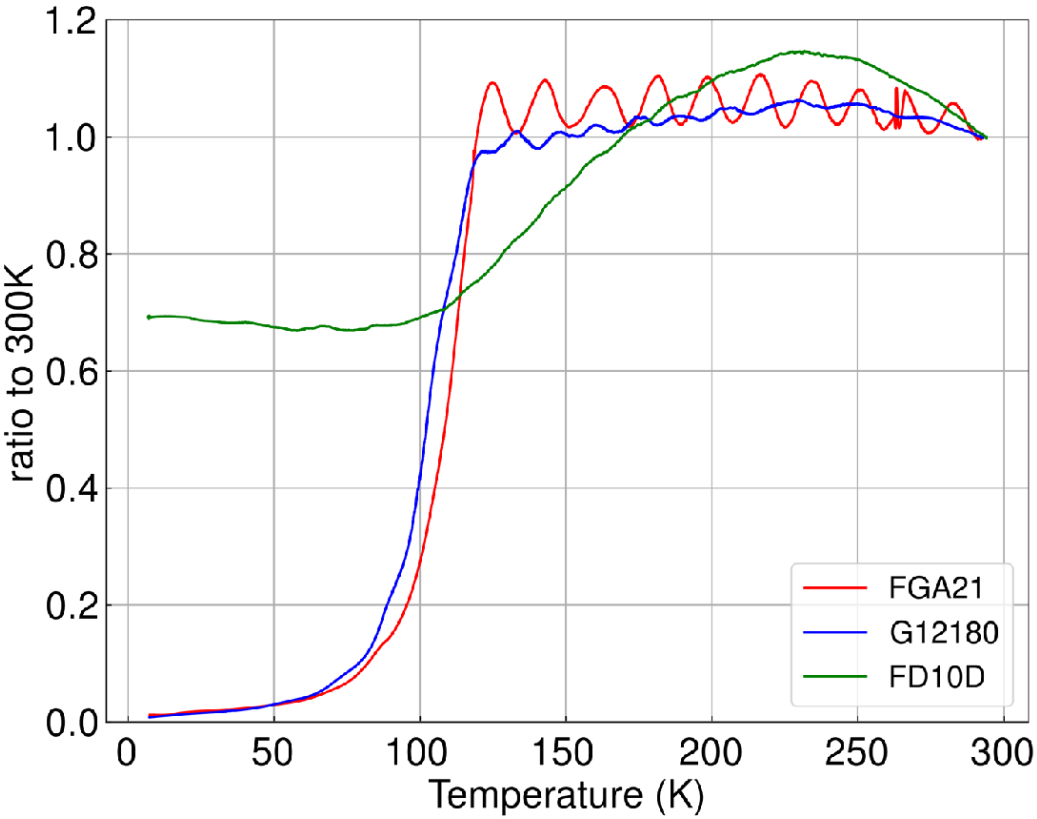
→ **Stycast is suitable**

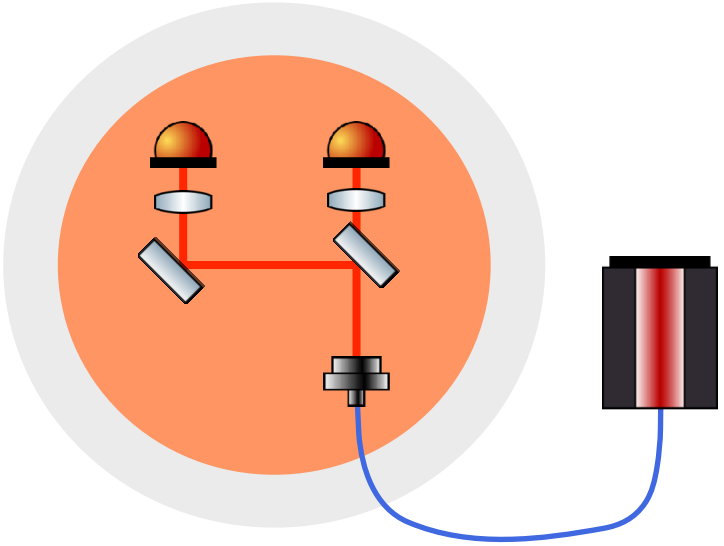
PD Selection

- Test response of 3 PDs
- FGA21 (Thorlabs)
- G12180-010A (Hamamatsu)

→ unusable

- FD10D (Thorlabs) → survive

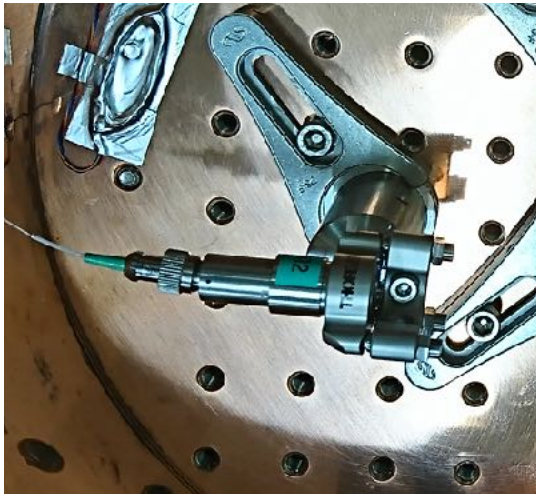


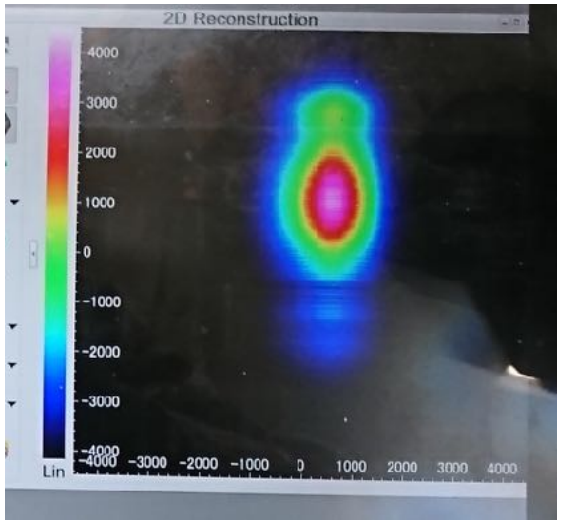


Measurement Setup

Collimator Test

- After some cooling & heating cycles, beam shape got ugly





- Changed the collimator from **F260APC-1550** (Thorlabs) to **F-COL-9-15** (Newport)
  - Seems surviving after a few cycles

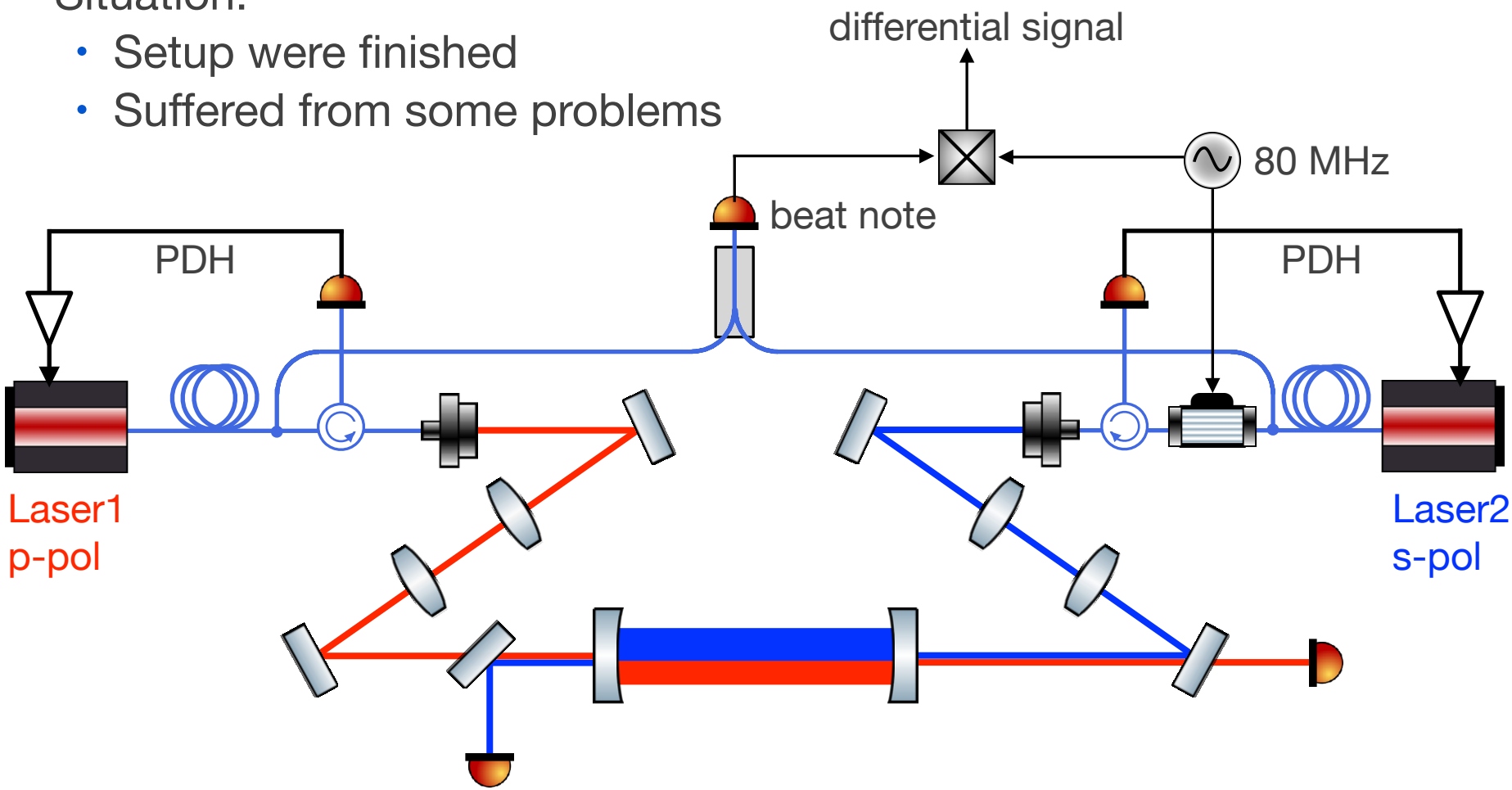
- Now I'm using CFP5-1550A (Thorlabs), but not have tested at cryo temperature…

Table Top Test

Test for beat note measurement with a dual-path FP cavity

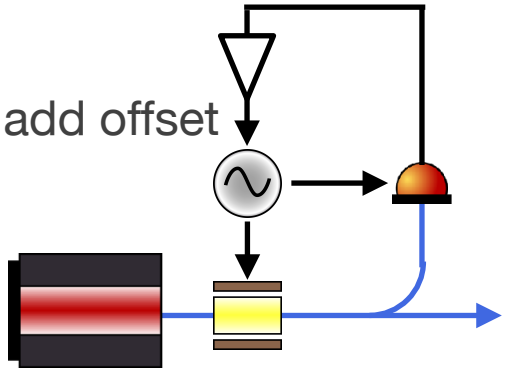
Situation:

- Setup were finished
- Suffered from some problems



Problems

- Residual Amplitude Modulation
  - Offset in PDH signal
  - Inevitable for fiber EOM (ref. [1])
  - Controls
    - Passive: Foam box
    - Active: Offset voltage on EOM



- Parasitic Interference
  - Reflection at fiber connectors
  - Noises on PDH signal
  - Sometimes large, sometimes small, I totally don't know why…
  - Splicing all the fiber may solve this?

[1] https://arxiv.org/pdf/2201.07470.pdf

Remained Tasks

- Construction
  - Assembly setup: constructed, now practicing
  - Alignment: template designing, order as soon as possible
  - Considering thermal stress: designed flexures

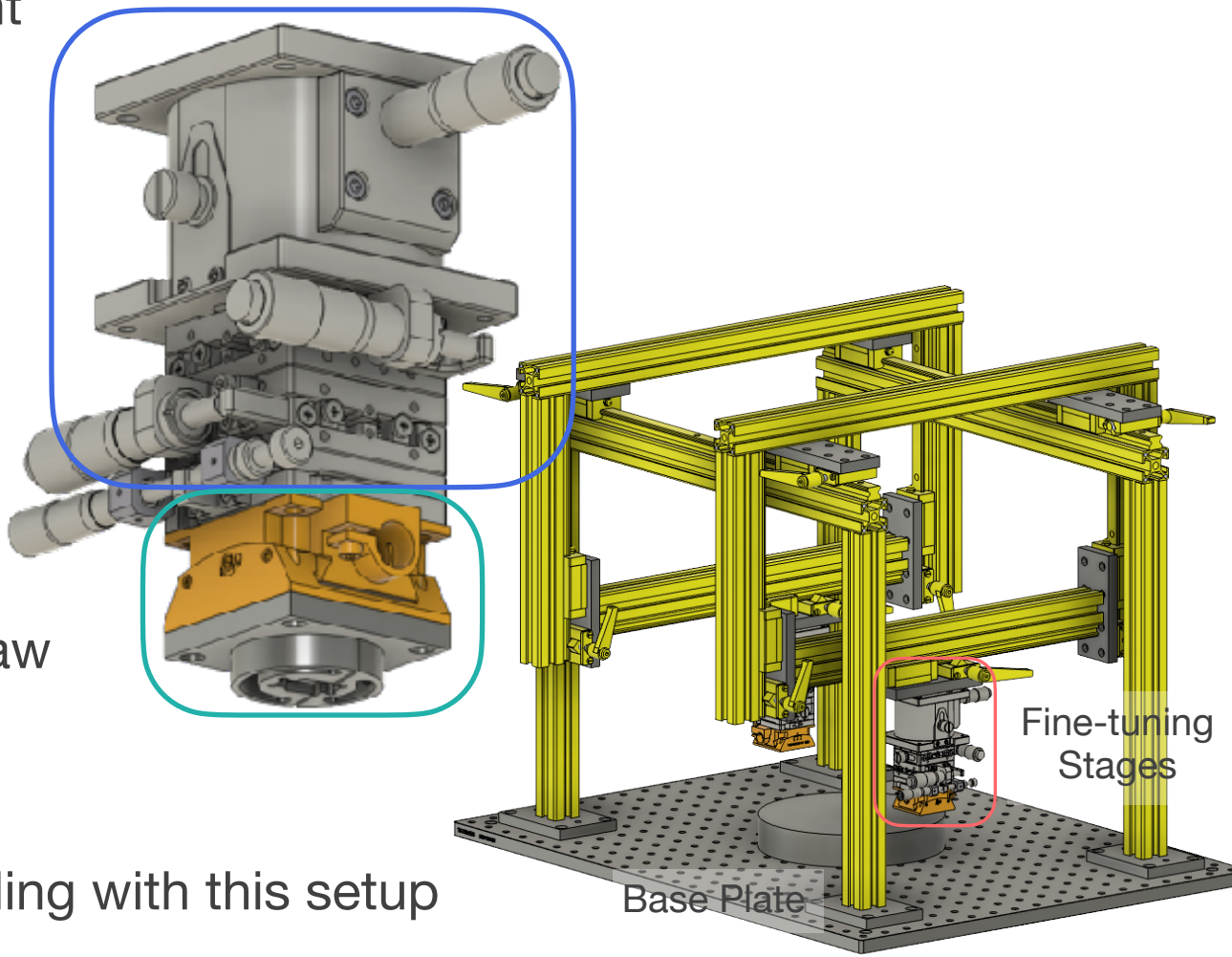
- Cooling
  - Cryostat have not operated > 2yr → need to check

- Install
  - Install monolithic interferometer
  - Check stability, acquire the champion data

Assembly Setup

5 axis movable

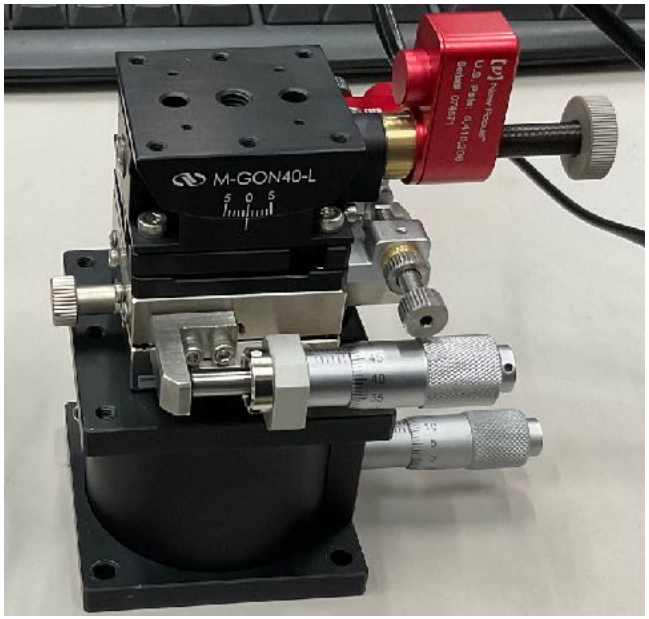
- Coarse adjustment
  - Linear guide
  - 3 axis: x, y, z
- Fine adjustment
  - Linear stage
  - 3 axis: x, y, z
- Alignment
  - Picomotor
  - 2 axis: pitch, yaw

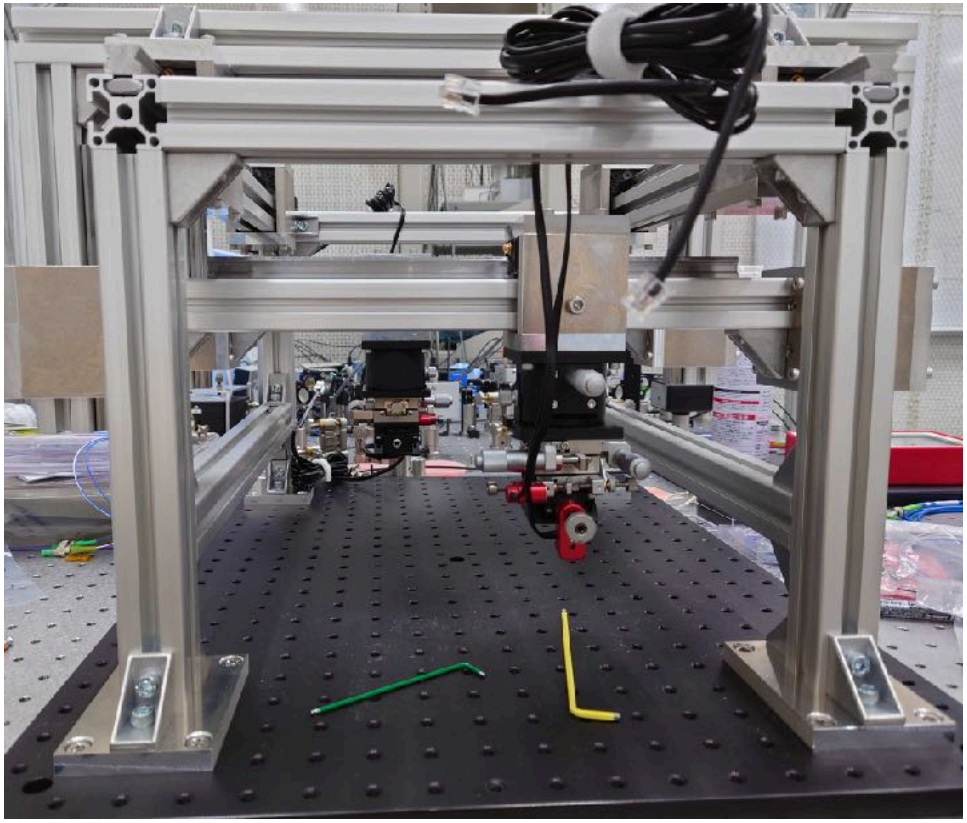


Now Practicing bonding with this setup

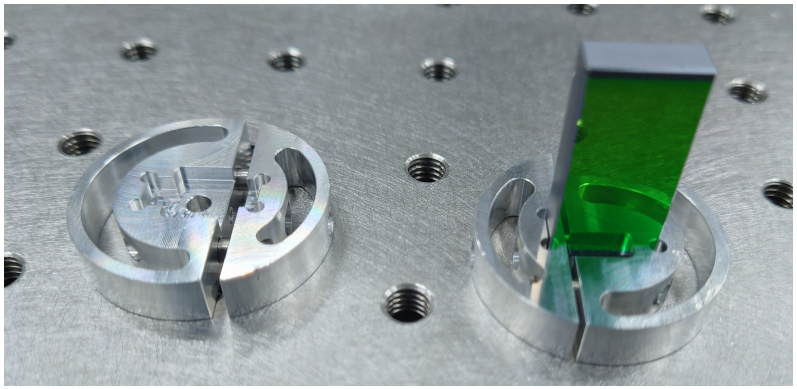
Assembly Setup

- Fine-tuning stages





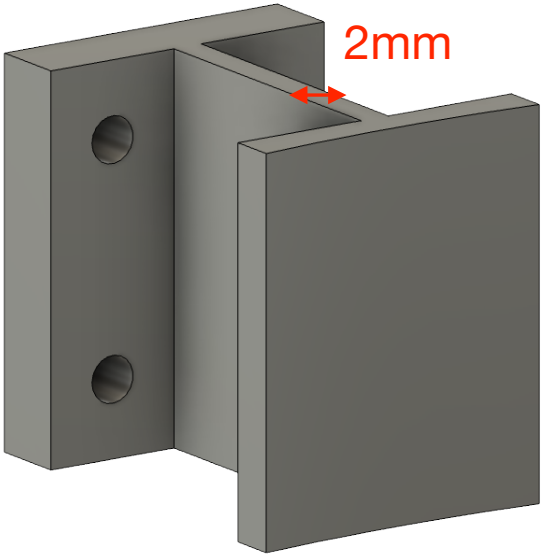
Overview

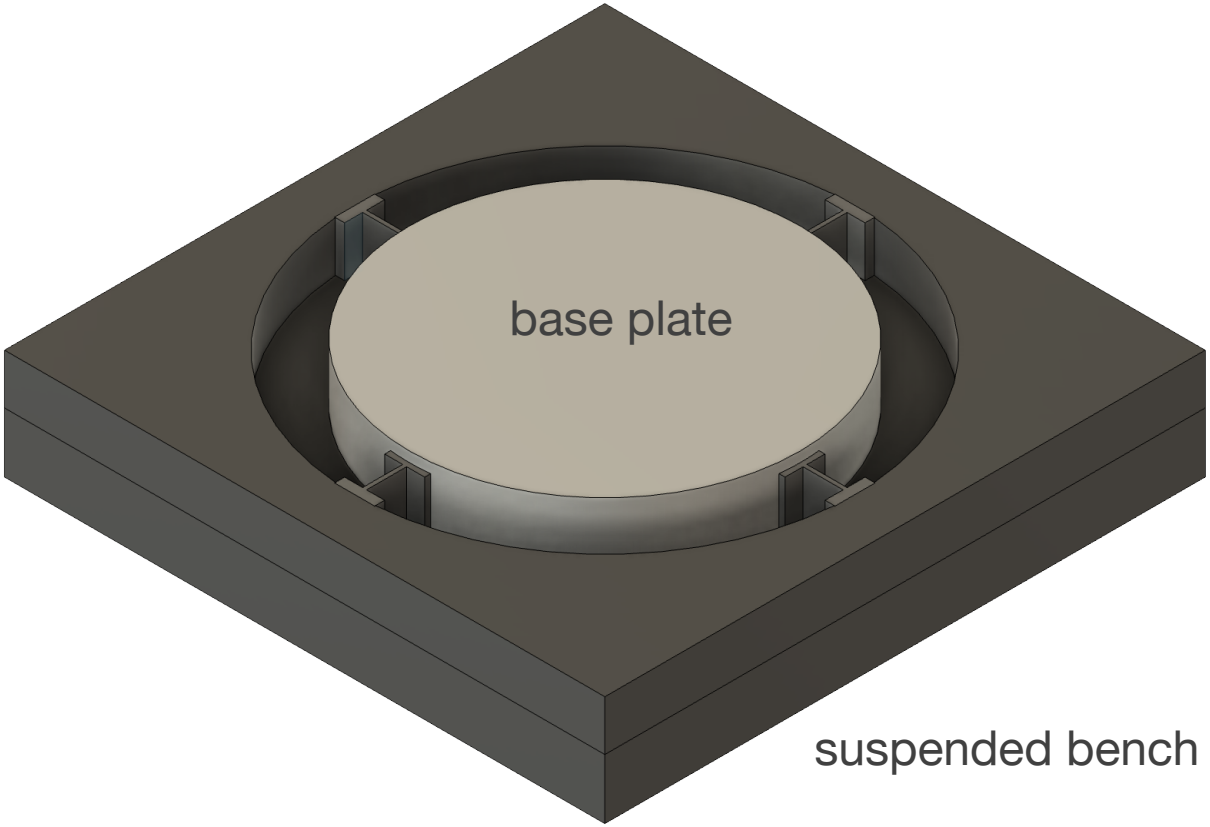


Optics on the holder

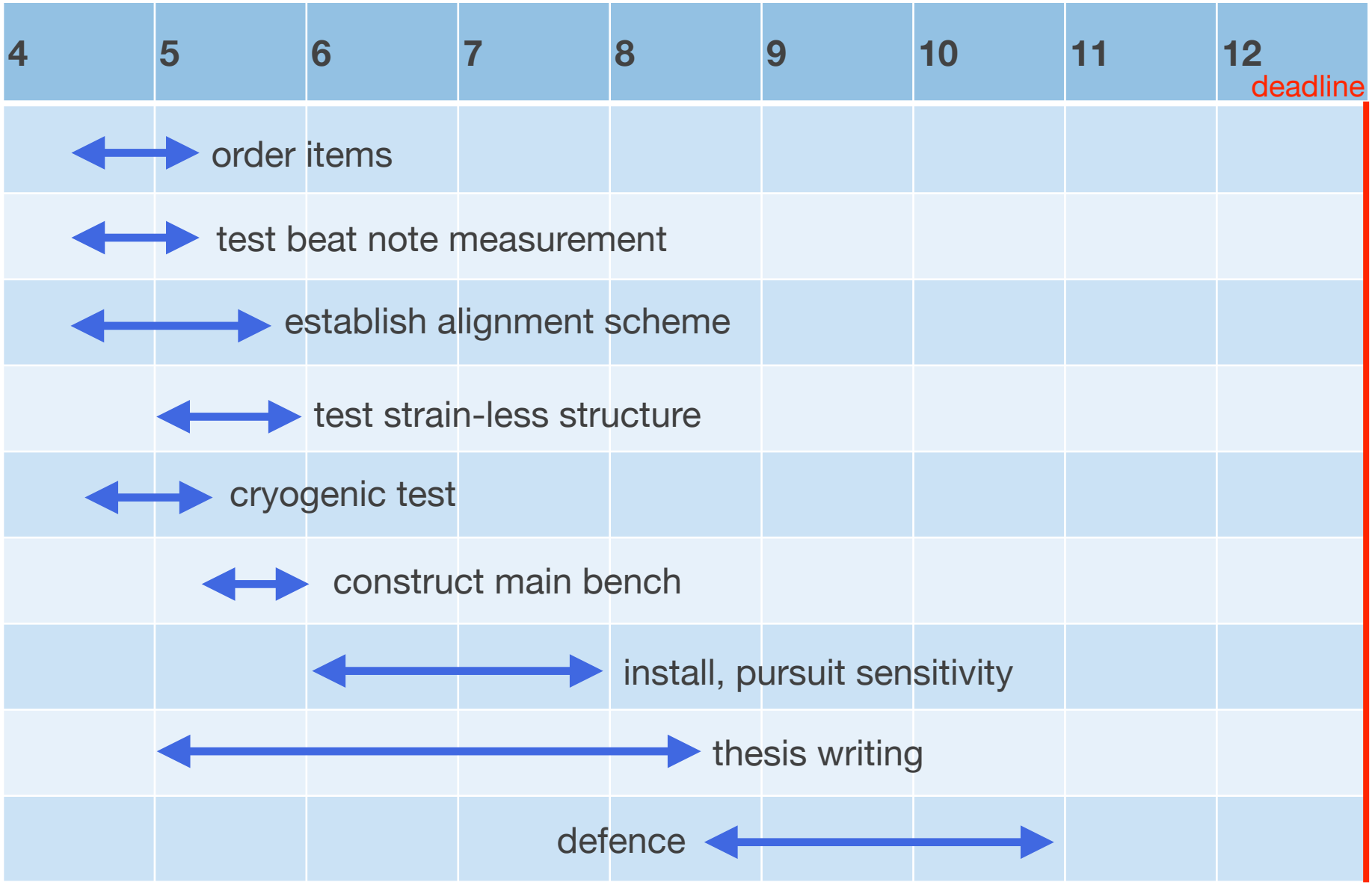
Flexure Design

- Compensate thermal stress due to thermal contraction during cooling
- To the base plate: bonded by stycast
- To the suspended bench: screws





Time Line


4
5
6
7
8
9
10
11
12
deadline
order items
test beat note measurement
establish alignment scheme
test strain-less structure
cryogenic test
construct main bench
install, pursuit sensitivity
thesis writing
defence

Summary

- Improvement of sensitivity of TOBA:
  - Readout noise reduction → monolithic interferometer
    - Test of components almost done
    - Starting construction

- Goal is close, but deadline is also close
- I'm rushing toward the goal, but I will go step by step

End