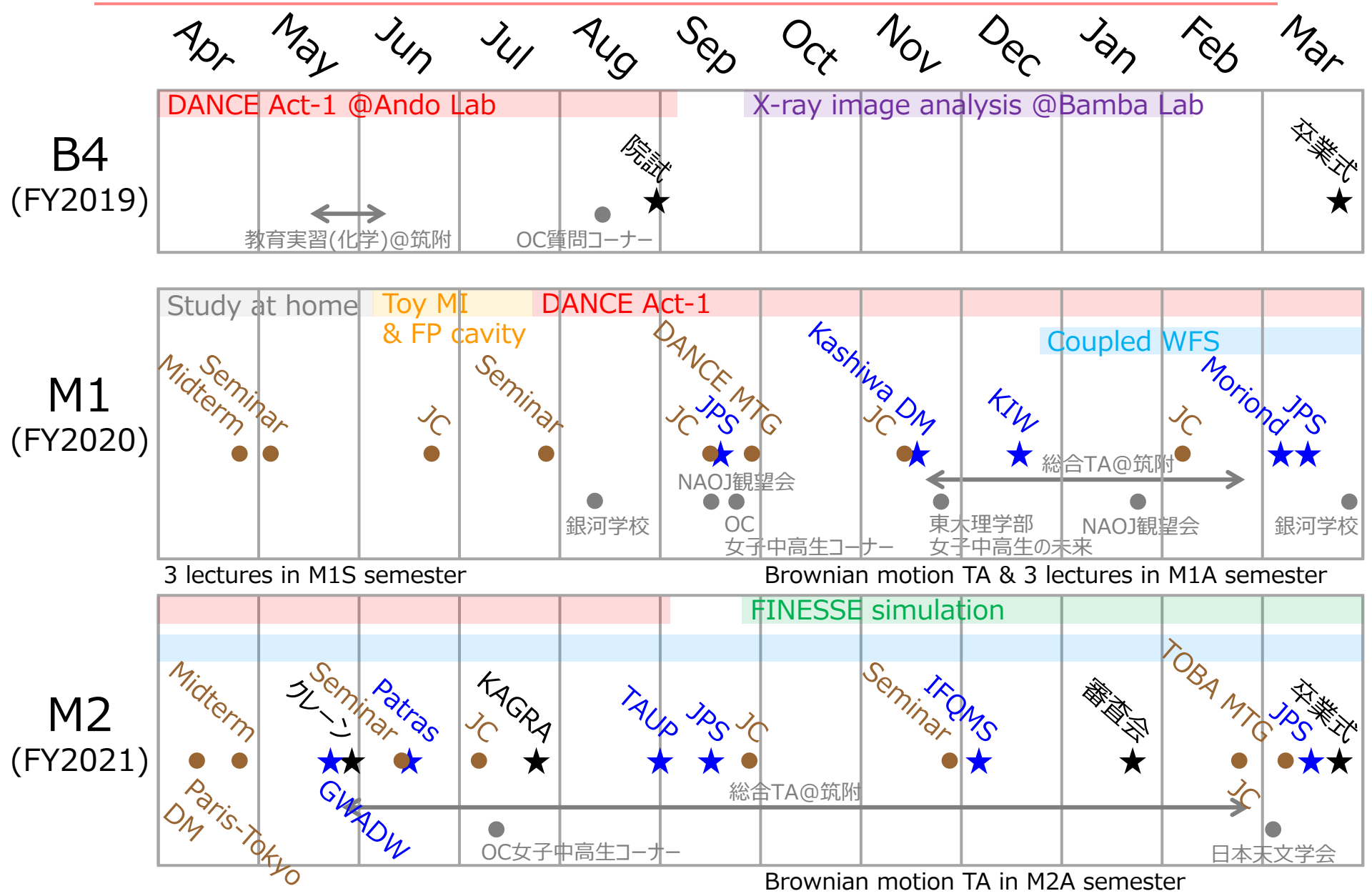
DANCE Act-1, Phase-III TOBA and FINESSE simulation

Yuka Oshima (D1)

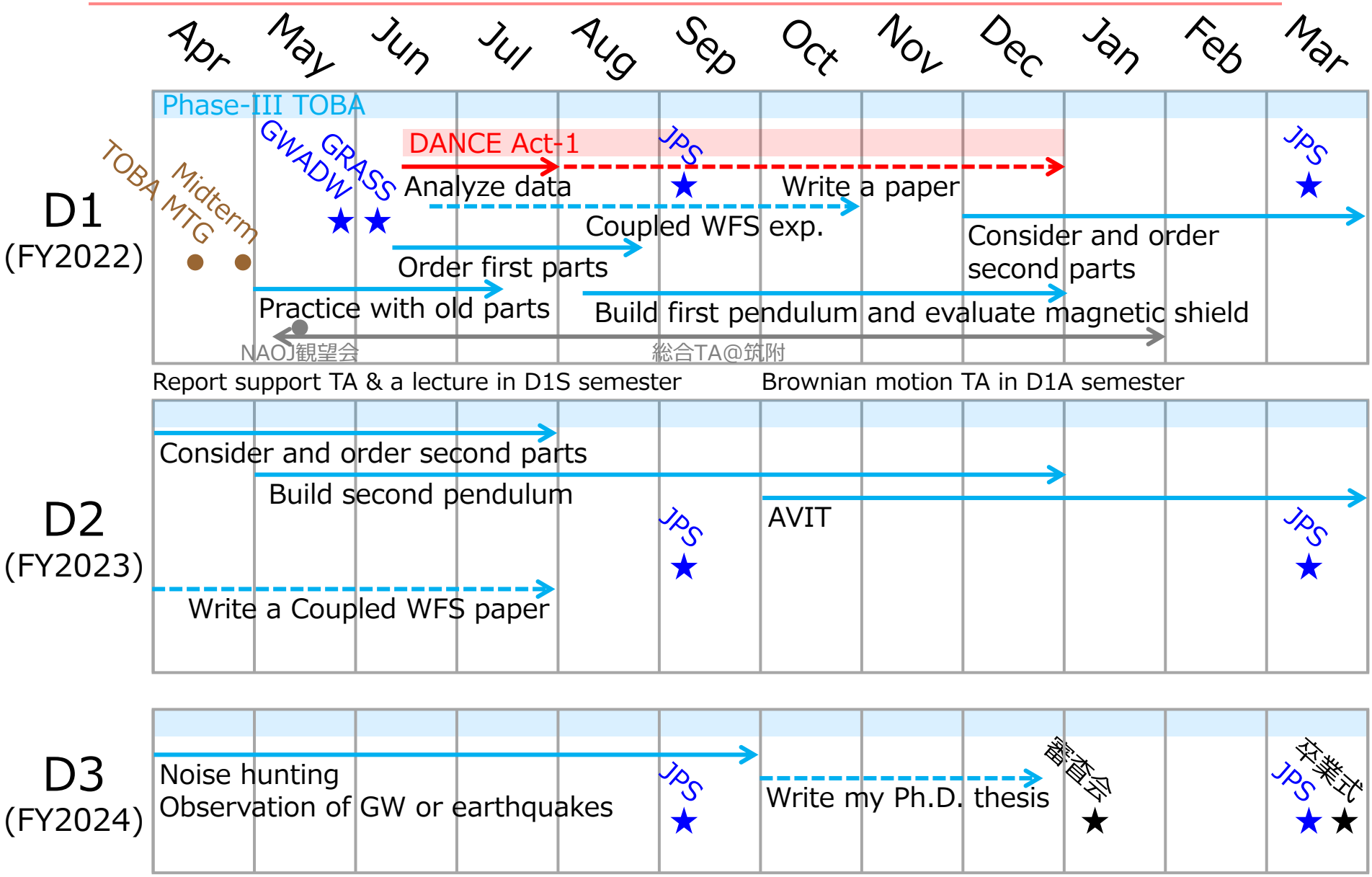
Department of Physics, University of Tokyo

What I did so far

★: Big event
★: Conference
●: Seminar & Journal club
●: Educational activities



Plans of my Ph.D. course



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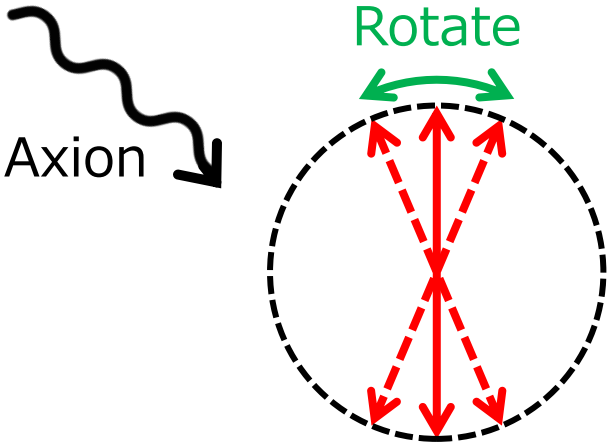
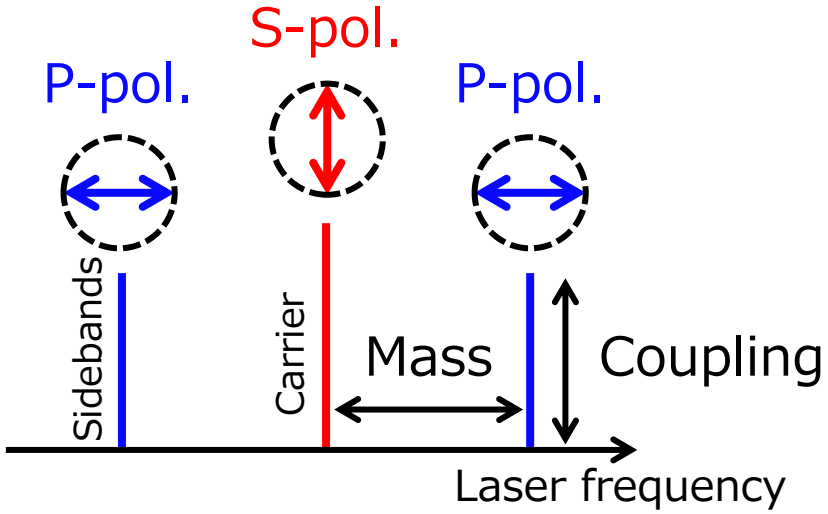
Contents

Fujimo-to kun already explained, so a quick review with two slides

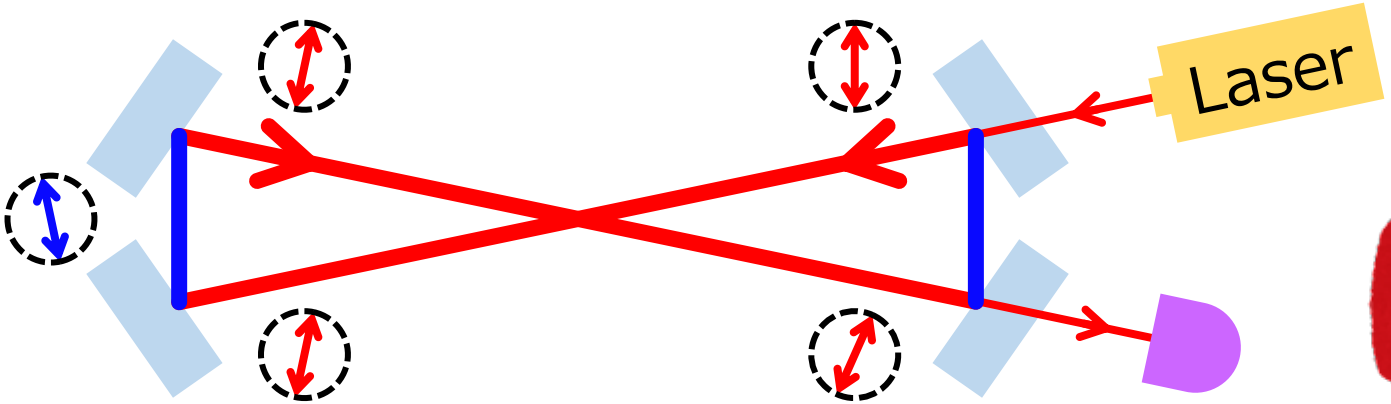
Principle of DANCE

- Axion-photon coupling makes linear polarization rotate

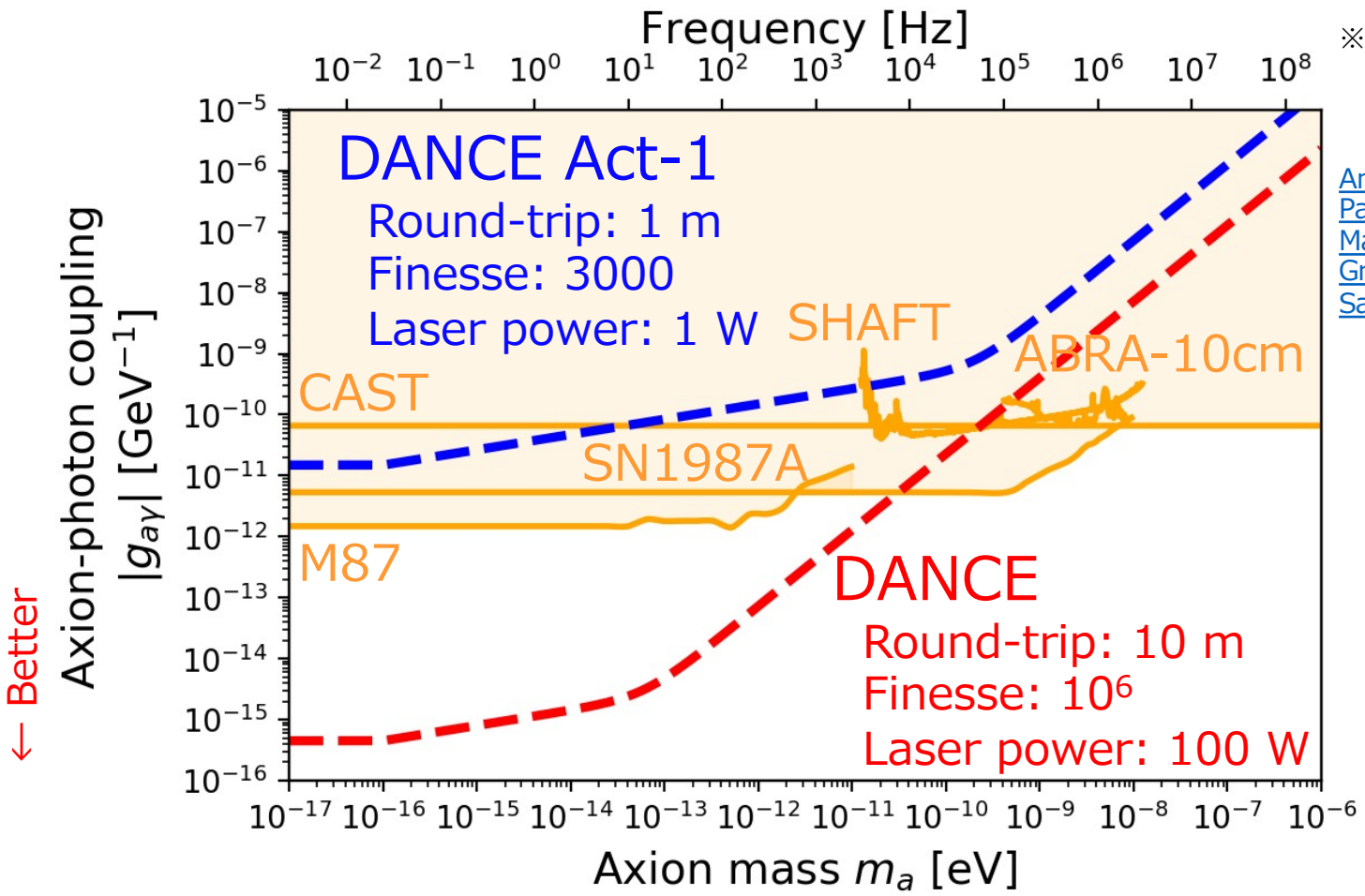




- A bow-tie ring cavity can amplify the rotation angle of linear polarization without inverting the rotated direction



Design sensitivity of DANCE



← Better

※ If one-year observation
If only shot noise
If DM is all composed of axion

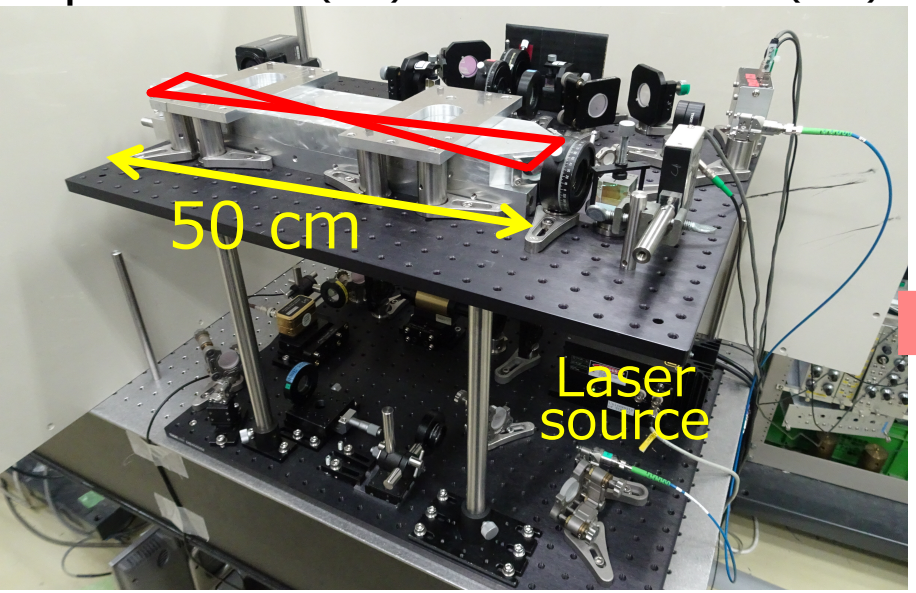
Anastassopoulos+ (2017)
Payez+ (2015)
Marsh+ (2017)
Gramolin+ (2021)
Salemi+ (2021)

- DANCE can improve the current best upper limits by several orders of magnitude
- DANCE Act-1 has moderate parameters but can go beyond CAST limits

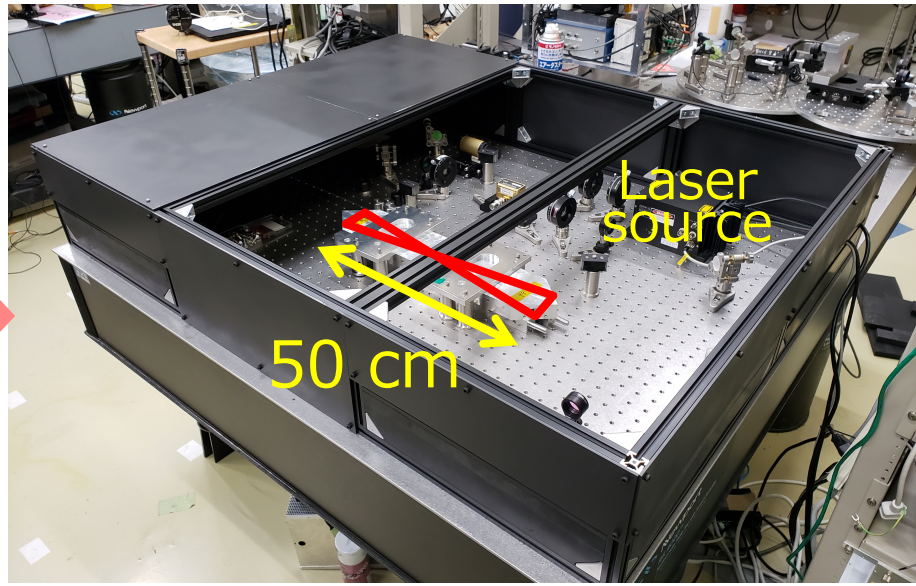
Contents

DANCE Act-1 at B207

Apr. 2019 (B4) – Nov. 2020 (M1)



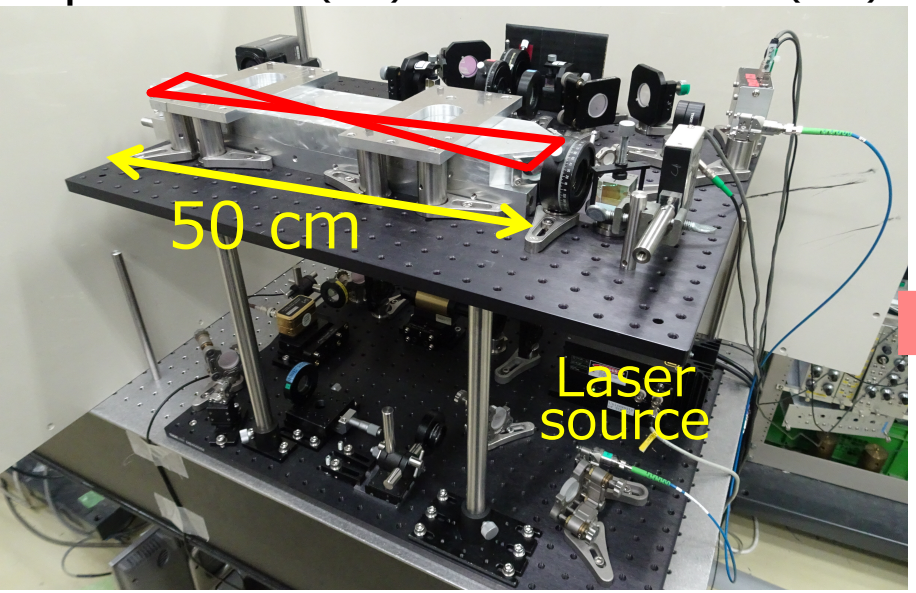
Dec. 2020 (M1) – Today (D1)



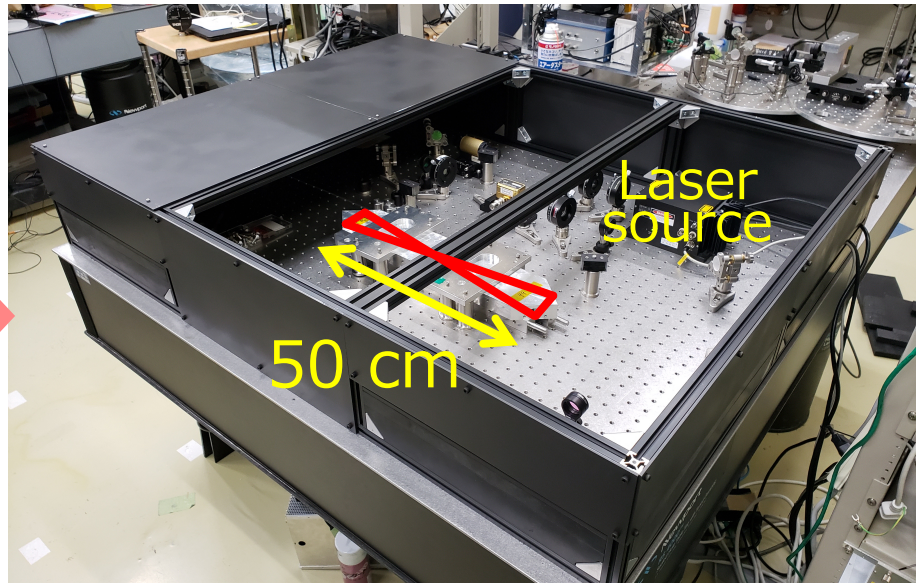
- Points for improvement
  - Constructed without an optical fiber
    → Laser intensity noise reduced
  - Changed mirrors and holding jigs
    → Finesse and alignment were improved
  - Build an optical table cover
    → Air turbulence reduced

DANCE Act-1 at B207

Apr. 2019 (B4) – Nov. 2020 (M1)

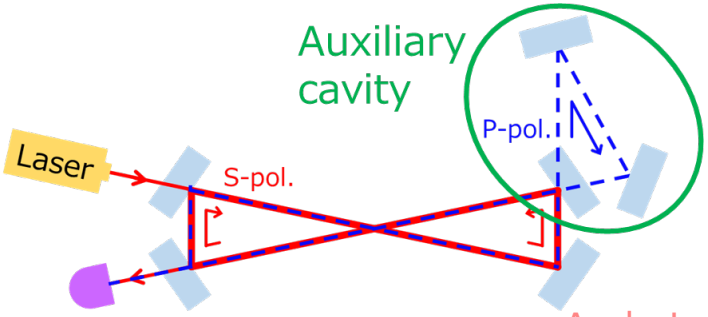


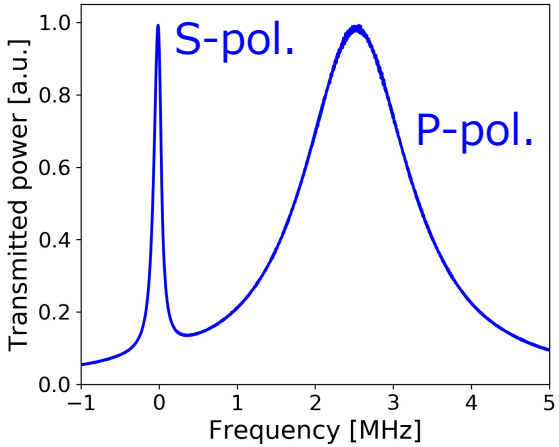
Dec. 2020 (M1) – Today (D1)



- Discovering critical issue
  - Found resonant freq. difference on Feb. 2021

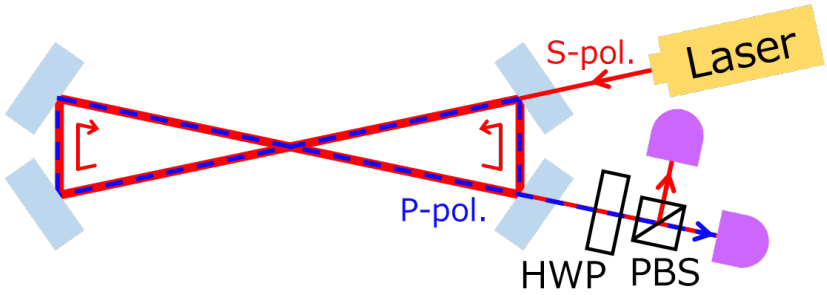
    → Fujimoto-kun's DANCE Act-1 with an auxiliary cavity at B111

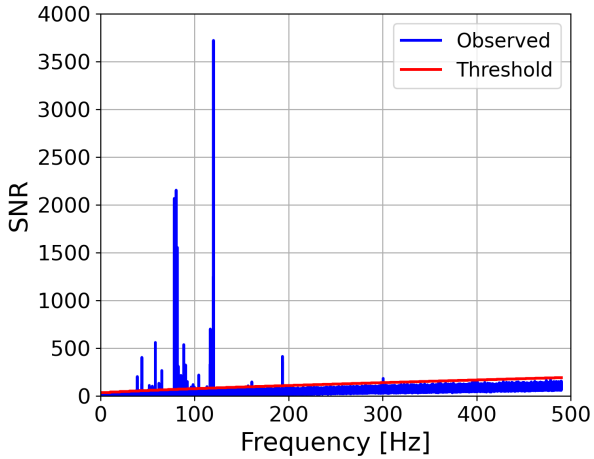


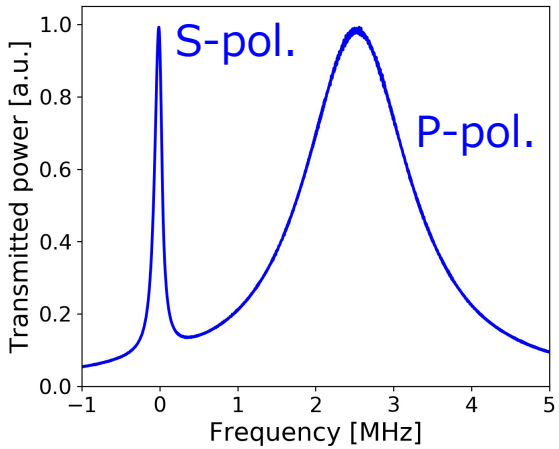


What I did for DANCE in 2021

1. Data acquisition for 12 days
2. Data analysis
3. Observation of resonant freq. difference





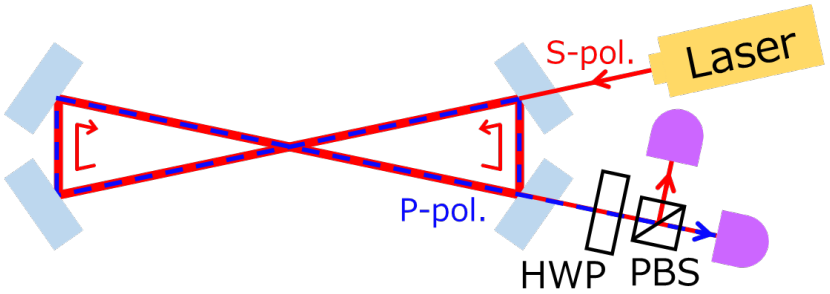


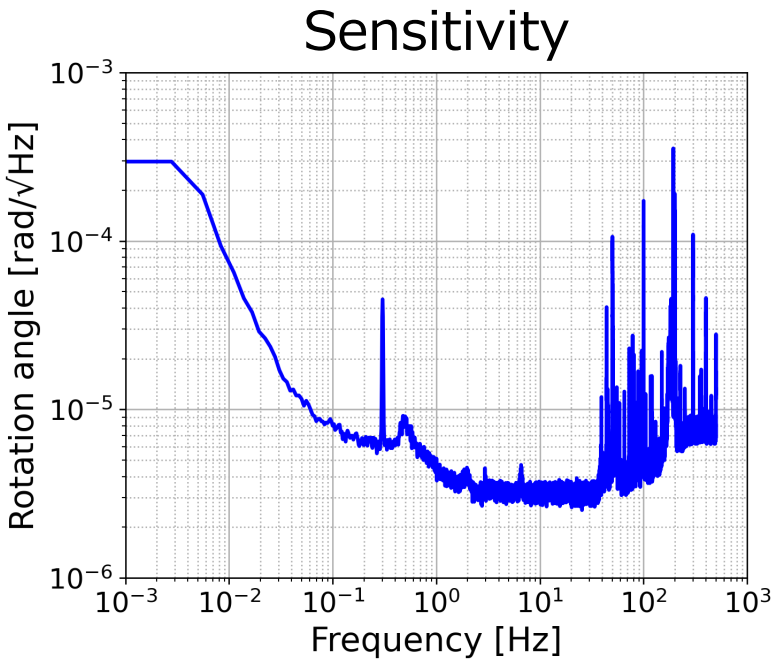
Data acquisition for 12 days

- Took data for 12 days (May 18-30, 2021) with sampling rate of 1 kHz

  → Estimated the current sensitivity

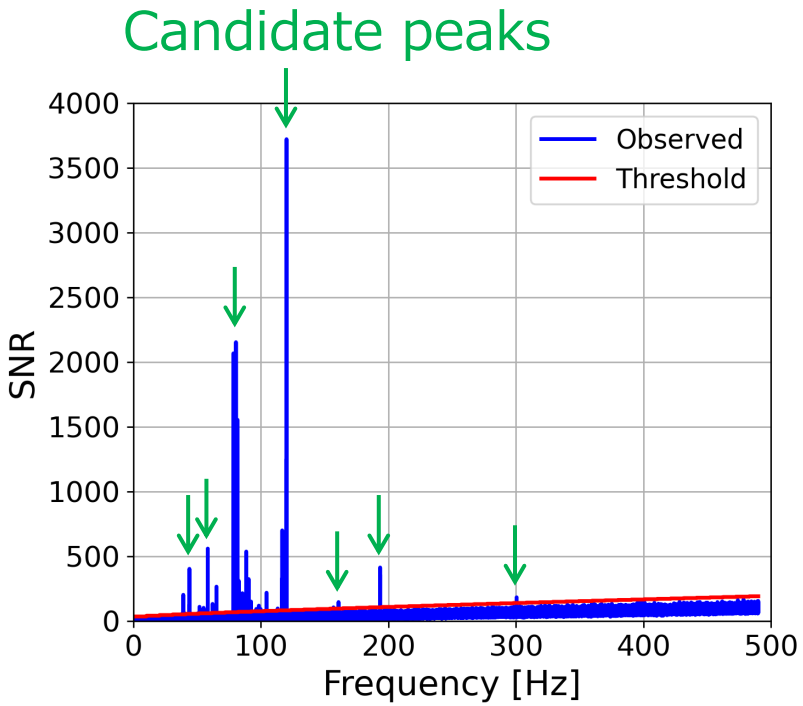
  - Long-term control system was developed by Fujimoto-kun





Data analysis

- Analyzed 10 hours of data
  → Found 55 candidate peaks
  → Candidate peaks were reduced to 33 by Q-factor veto
  → Then reduced to 9 by consistency veto
  - Data analysis pipeline was developed by Kume-san and Morisaki-san



Obs. of resonant freq. difference

- Measured resonant freq. difference between s- and p-pol.

elog #6378

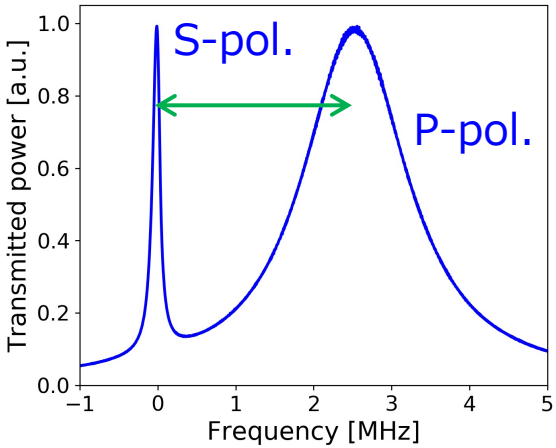
Date	Finesse for s-pol.	Finesse for p-pol.	Resonant freq. difference [MHz]
Feb. 18, 2021	2.80(34) x 10^3	193(10)	3.92(16)
Mar. 25, 2021	3.19(66) x 10^3	202(8)	2.50(4)
May 18, 2021	2.85(5) x 10^3	195(3)	2.52(2)
Jun. 7, 2021	2.86(5) x 10^3	195(3)	0.50(2)
Aug. 3, 2021	2.84(3) x 10^3	195(2)	0.64(2)
Feb. 2, 2022	~3000	~200	~0.8

Data acquisition

Does it change by day?

→ Resonant freq. difference is drifted

→ But we couldn't identify the cause



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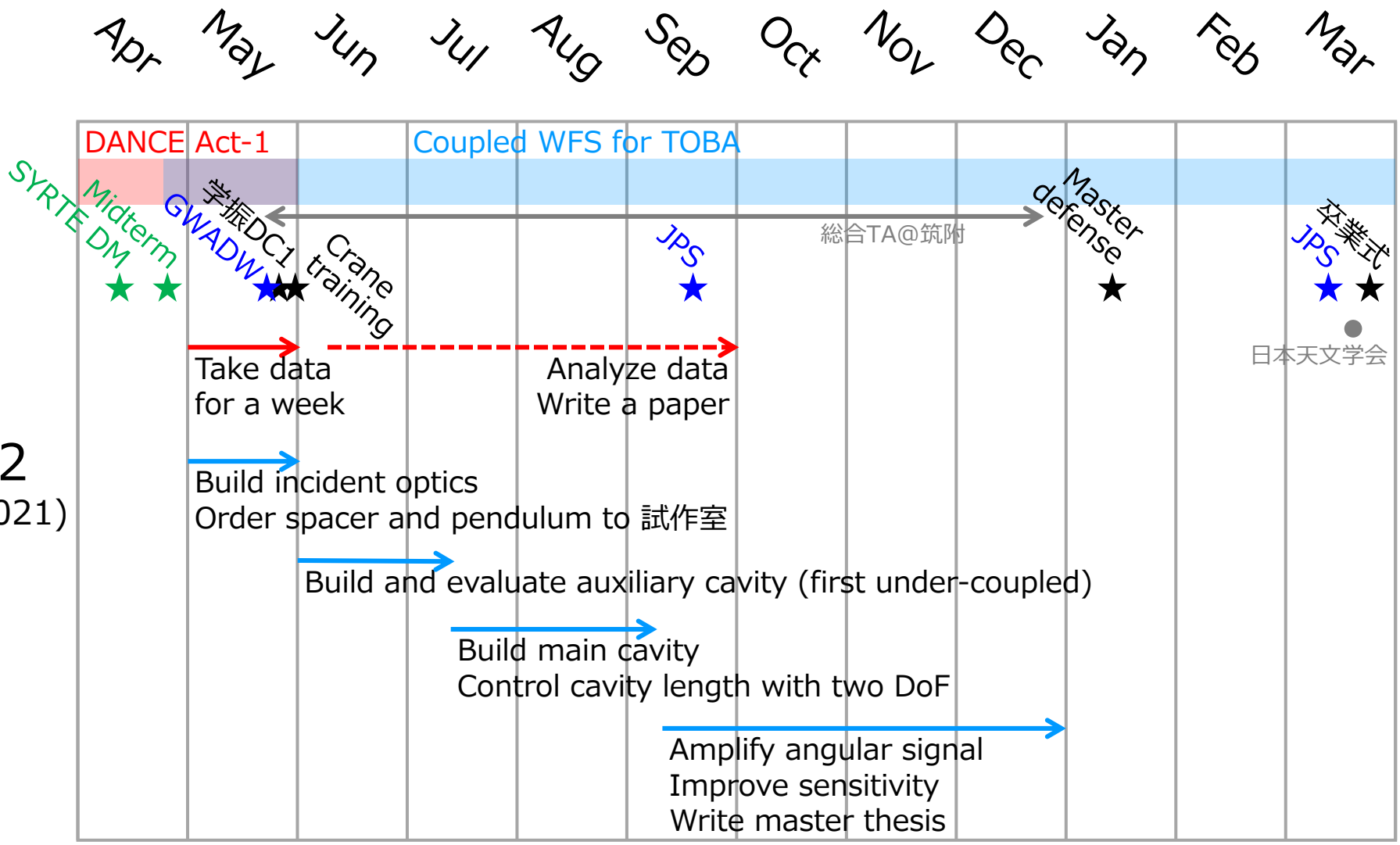
Reflections on DANCE Act-1

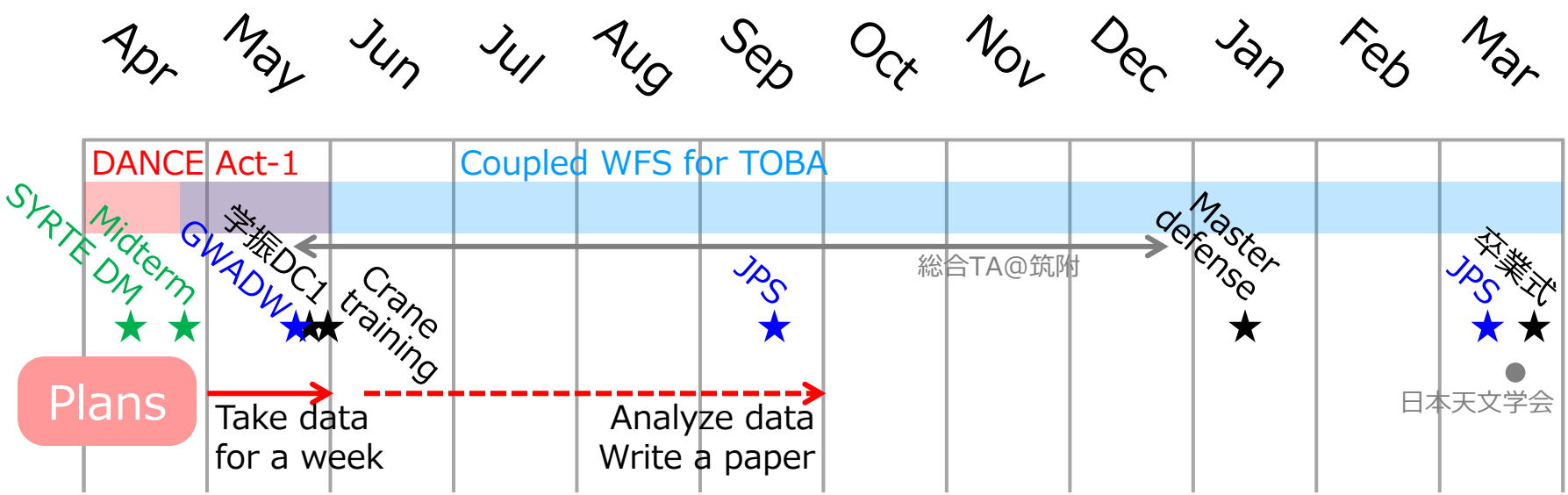
Re-post last year's slides



No lecture in M2S semester

Reflections on DANCE Act-1

Re-post last year's slides



M2
(FY2021)

In actuality

Took data for **two** weeks

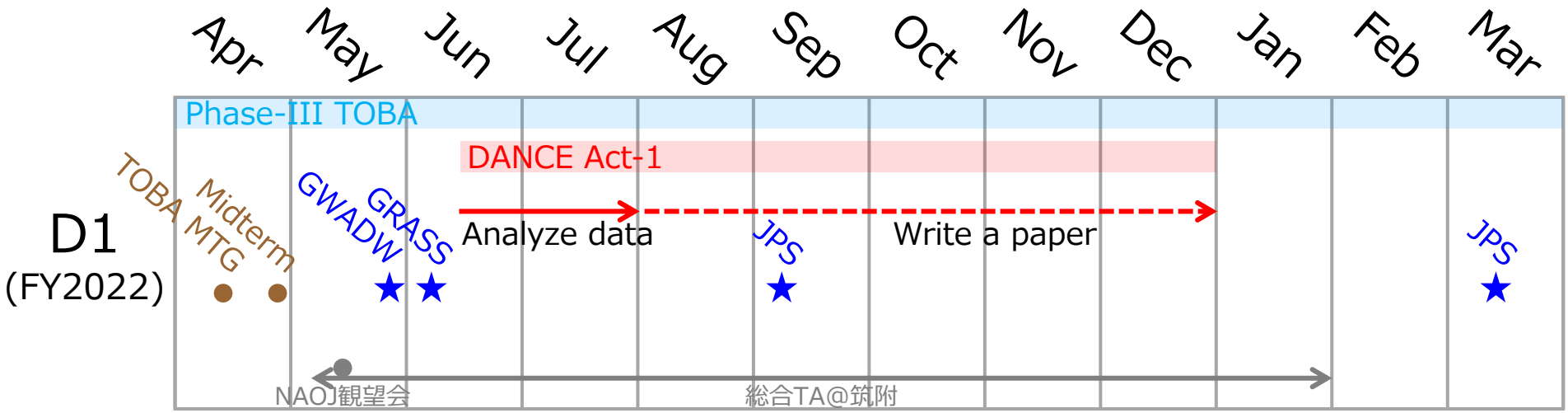
Analyzed data

Did not write a paper

- Goals for DANCE
  - Finish data analysis
  - Write a paper

What I will do for DANCE in 2022

- Finish data analysis by July 2022
  - Reduce common-mode noise
    - $\phi(t) = \sqrt{P_{\rm P}(t)/P_{\rm tot}} \quad \rightarrow \quad V_r(t) \equiv V_{\rm PDp}(t) - H_{ps} V_{\rm PDs}(t)$
  - Finish veto procedures
    - Compare p-pol. and total (p+s pol.)
  - Set the upper limits
- Write my paper by Dec. 2022
  - I want to talk with Michimura-san once every two weeks at a meeting and work on my paper



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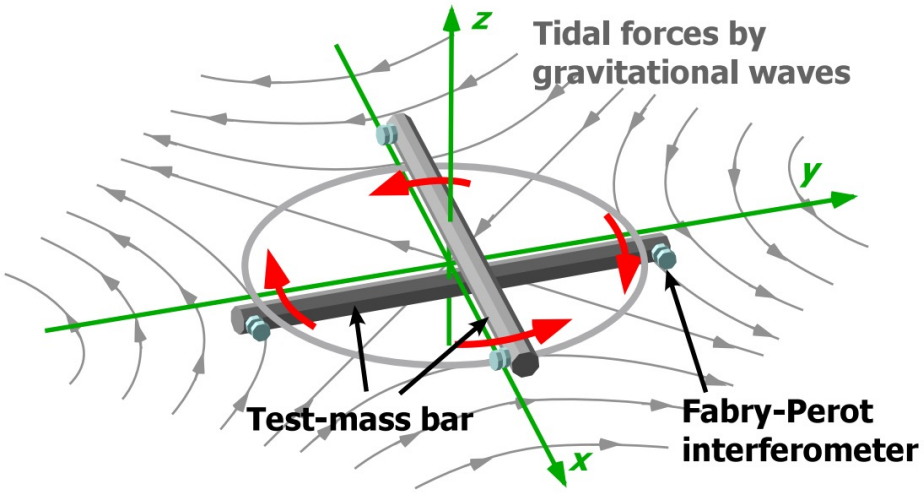
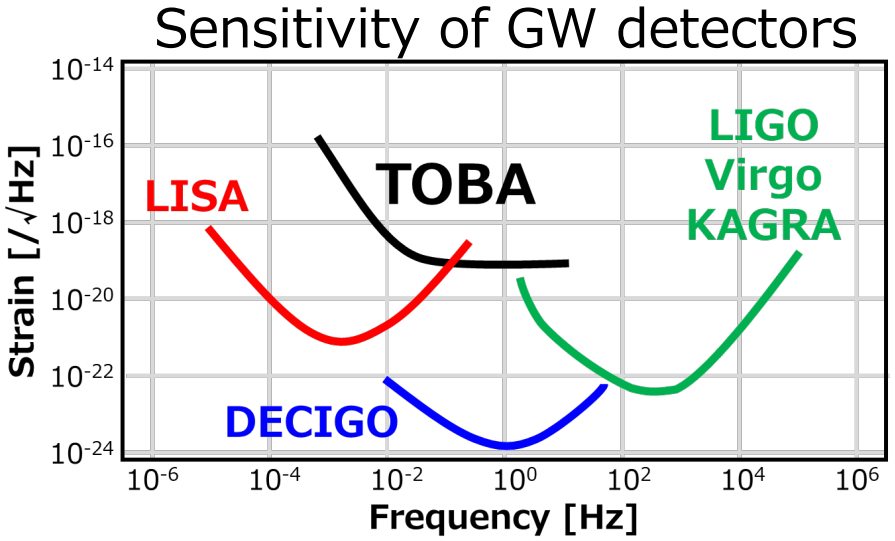
TOBA: TOrsion-Bar Antenna

- Originally proposed by Ando-sensei in 2010
  - Developed over many years at Ando Lab
- Use torsion pendulums
- Aim to detect GW at low frequency (0.1 – 10 Hz)
- Ground-based GW detector
  - No need for space launch technology and money
  - Easy maintenance
  - Science unique to the ground



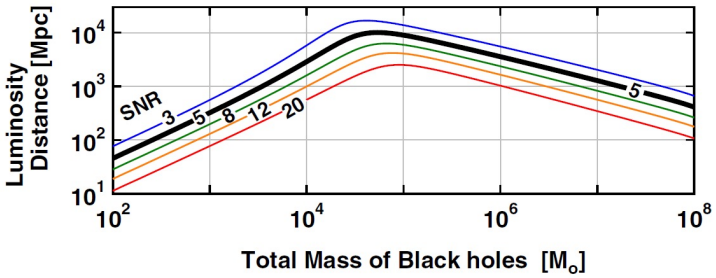
M. Ando+ (2010)



Science of TOBA

Astrophysics

- Intermediate mass BH binary merger
  - Within ~1 Mpc (Phase-III)
  - Within ~10 Gpc (Final)
    → Formation process of super massive BH

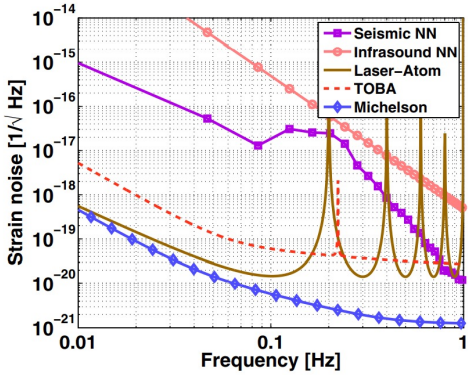


M. Ando+ (2010)

- Stochastic GW background
  - Ω_{GW} ~10^{-7} (Final)
    → Early universe

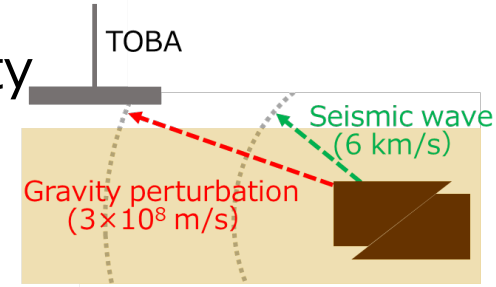
Geophysics

- Newtonian noise
  - First detection
    → Noise reduction for ET・CE



J. Harms+ (2013)

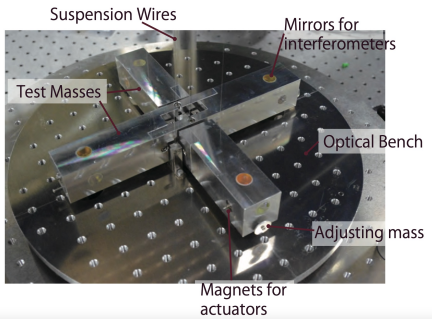
- Earthquake early warning
  - More than 10 sec earlier than now
    → Our safety



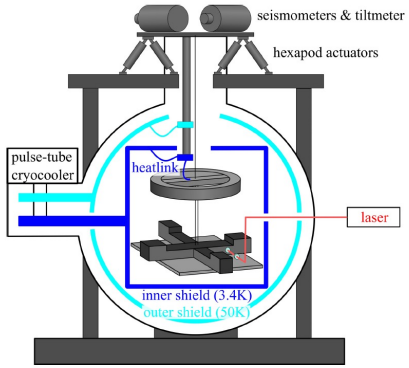
Road map of developing TOBA

Phase-I → Phase-II → Phase-III (Now) → Final

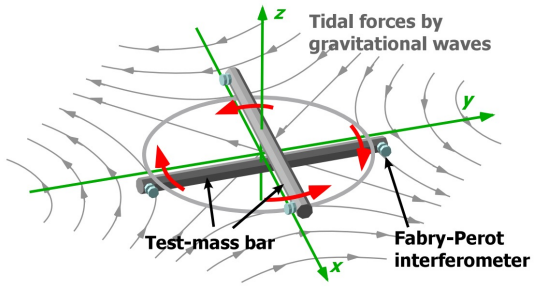
Phase-I	Phase-II	Phase-III	Final
Principle test		Technical demonstration	GW observation
10^{-8} /√Hz (Established)		10^{-15} /√Hz (Target)	10^{-19} /√Hz (Target)
20 cm bar		35 cm bar	10 m bar
Room temp.		Cryo. temp. (4 K)	Cryo. temp. (4 K)



K. Ishidoshiro+ (2011)
A. Shoda+ (2017)



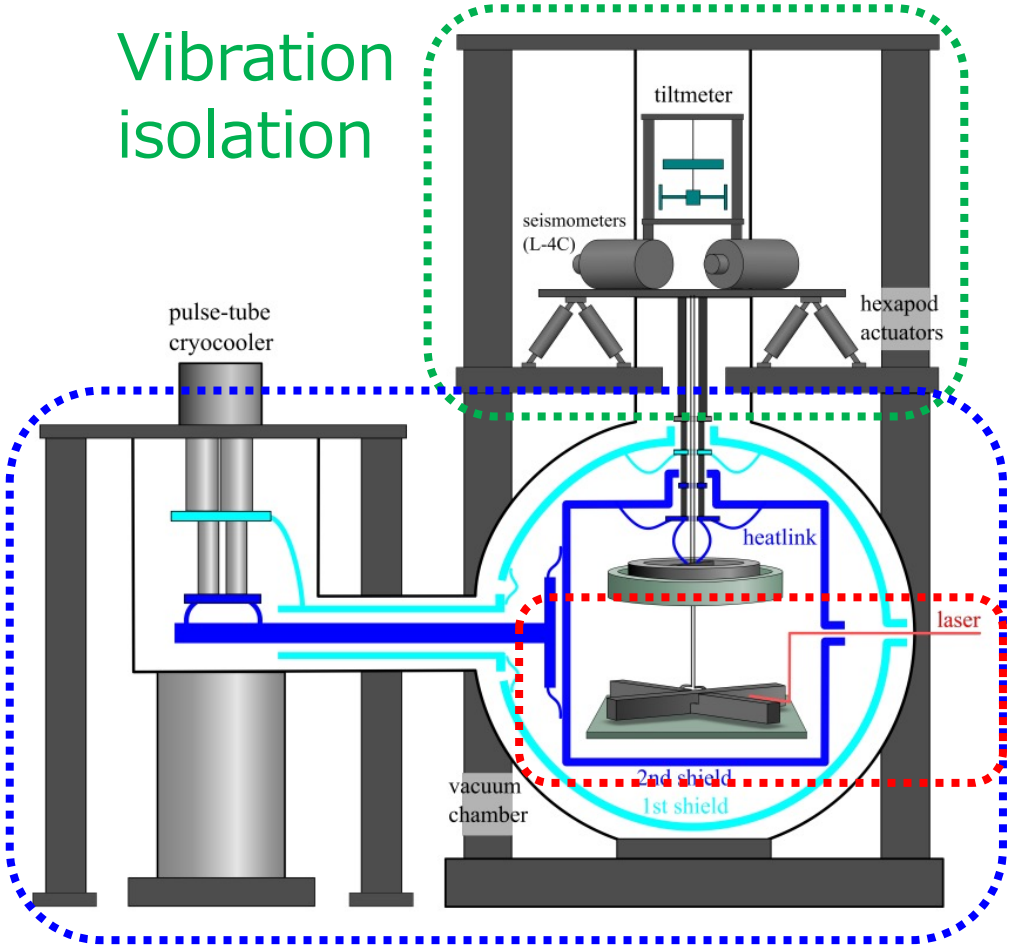
T. Shimoda+ (2020)

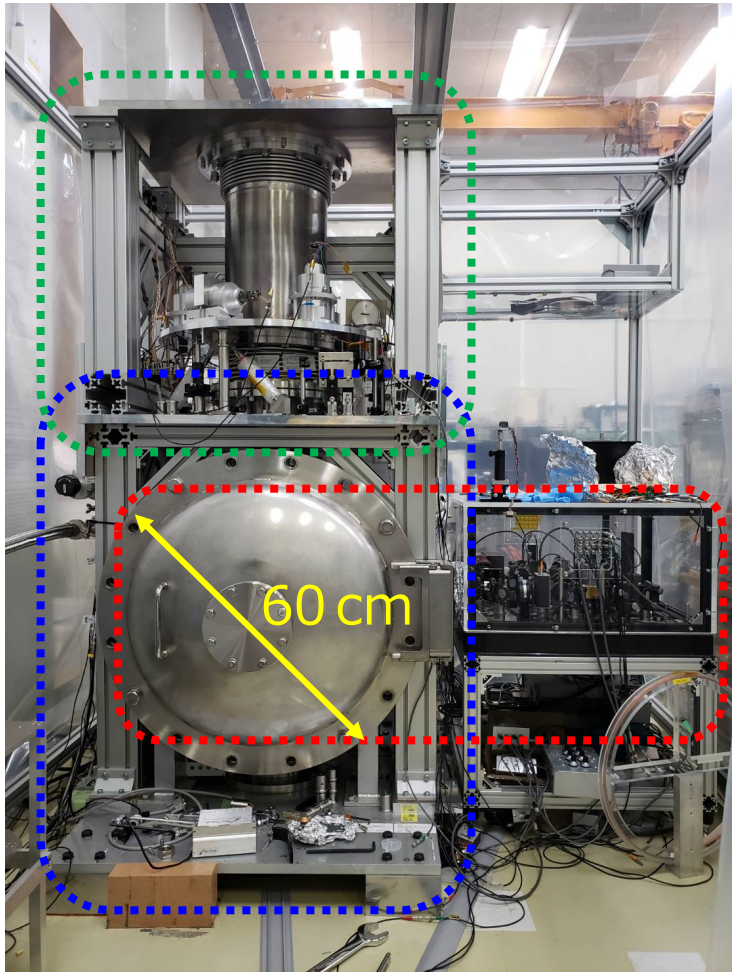


Configuration of Phase-III TOBA

Shimoda, Ph.D. thesis (2019)

Vibration isolation

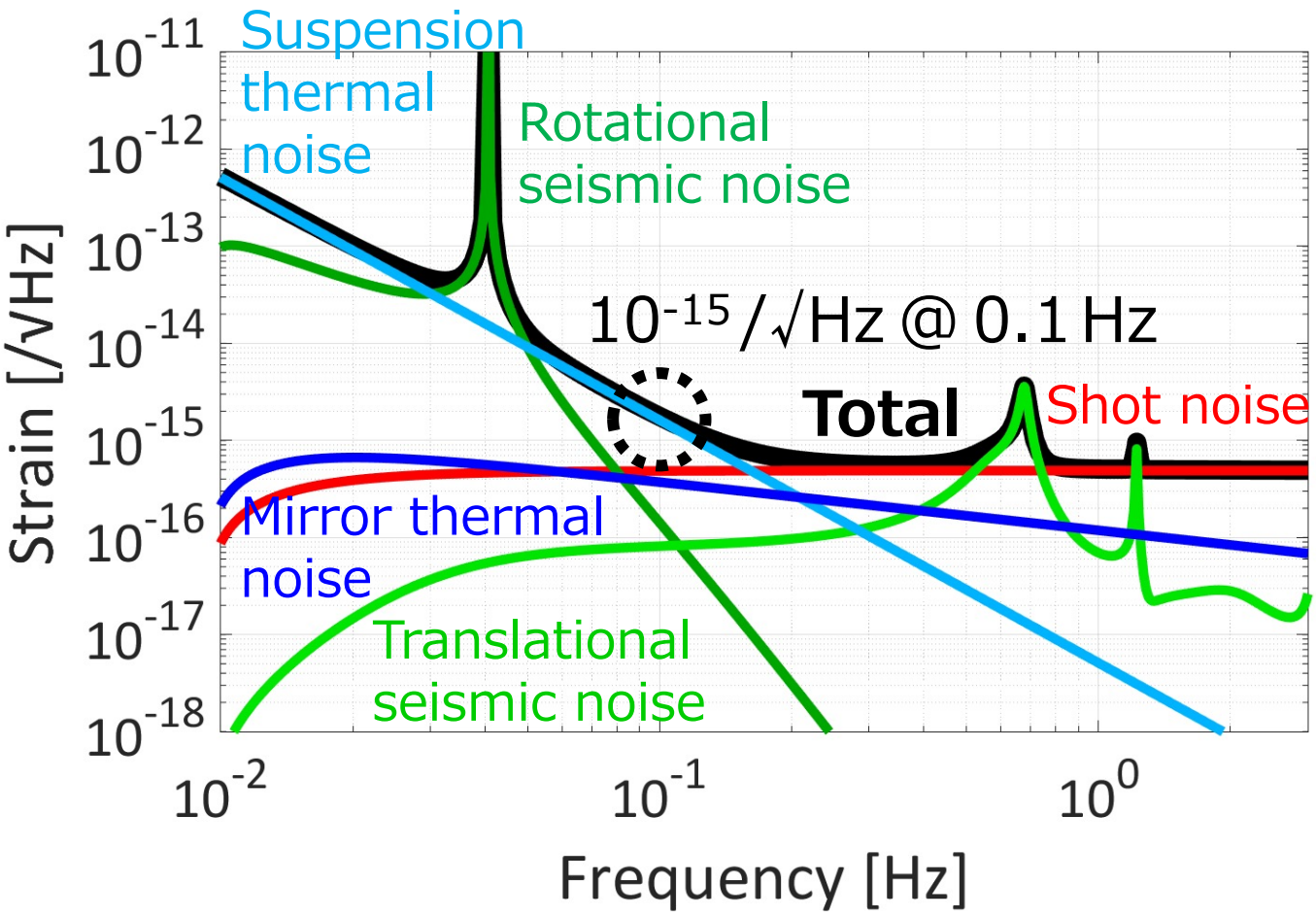


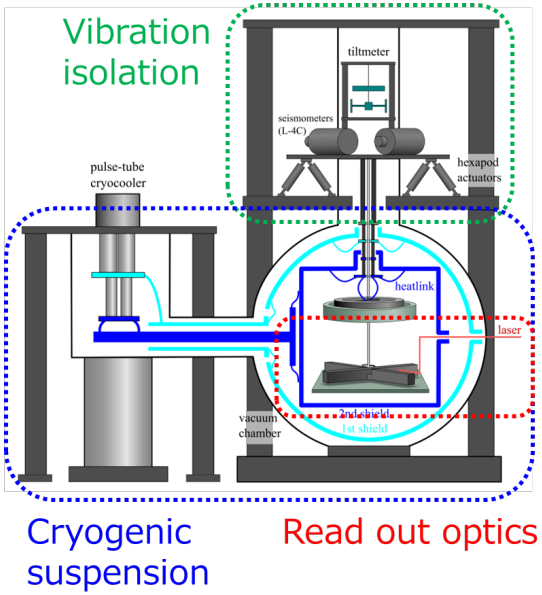


Cryogenic suspension

Read out optics

Target sensitivity of Phase–III TOBA





- Wire with high Q-value at 4 K → Ching Pin-san
- Cryogenic monolithic optics → Takano-san
- Coupled WFS → my master thesis

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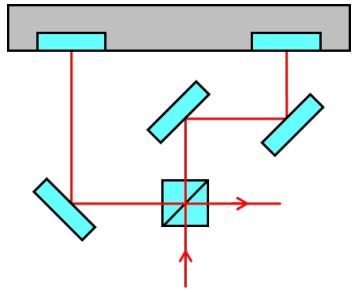
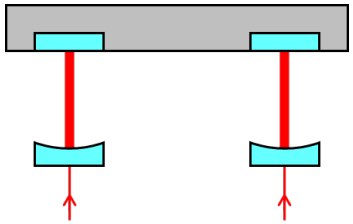
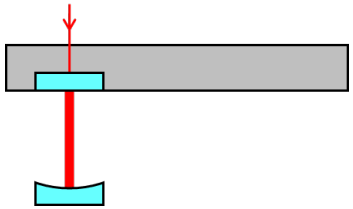
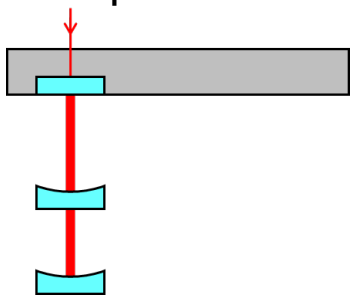
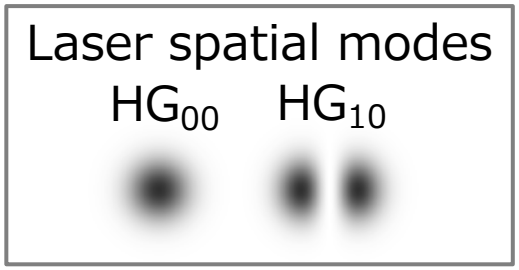
Candidates for readout optics

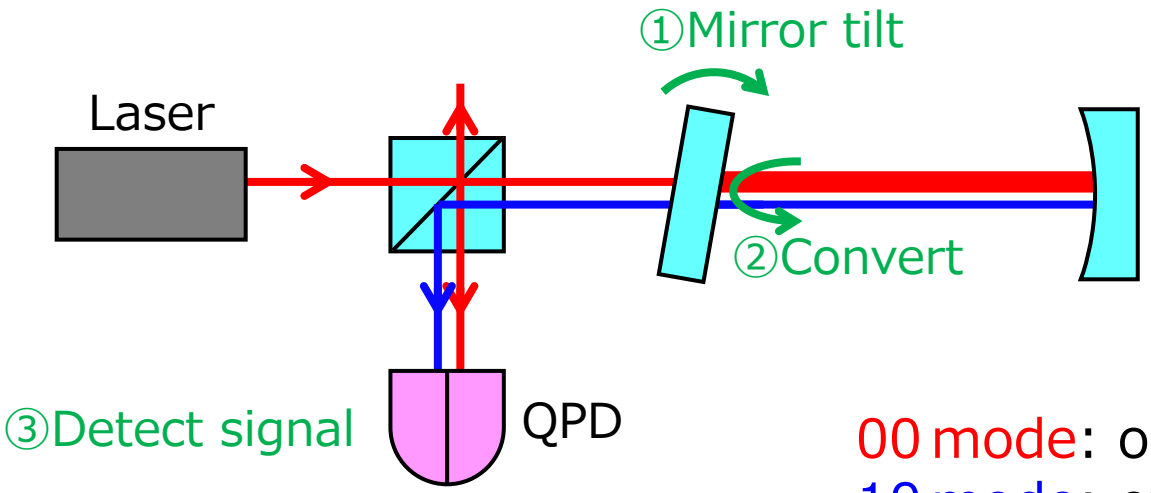
- Requirement for shot noise of Phase-III TOBA: 10^{-15} /√Hz

	Michelson	Differential FP cavity	WFS	Coupled WFS
				
Shot noise				
Freq. noise				
Trans-coupling				
Beam jitter				
Thermal noise				
Linear range				
Comments	Trans-coupling, beam jitter, and polarization noise in prototype TOBA	Difficult to operate, but I will try. Might utilize Komori-san's exp.	Cannot satisfy the requirement	**My master thesis.** Many good points, but difficult to build and control

Wavefront sensor

- WaveFront Sensor (WFS):
  angular sensor with an optical cavity



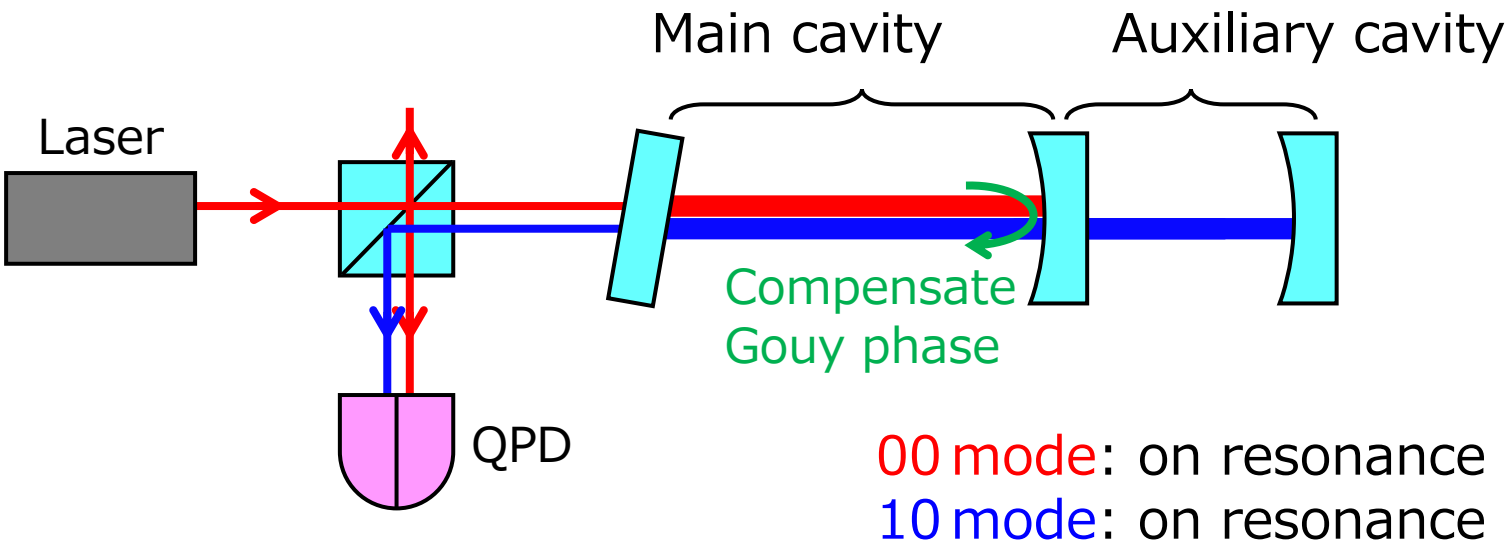


00 mode: on resonance
10 mode: off resonance

- 00 and 10 mode do not resonate simultaneously due to Gouy phase
  → 10 mode is not amplified in the cavity

Coupled wavefront sensor

- Coupled WFS:
  wavefront sensor with a coupled cavity



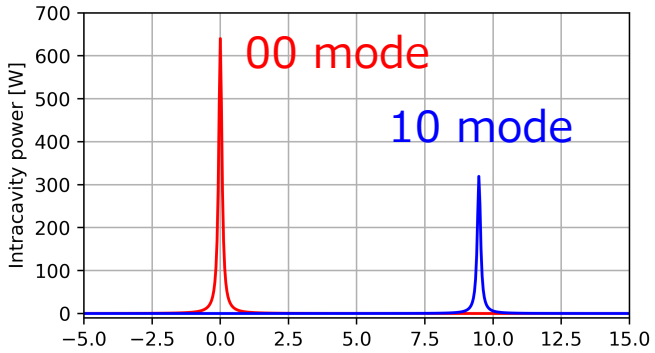
- Phase compensation by the auxiliary cavity can cancel Gouy phase of the main cavity

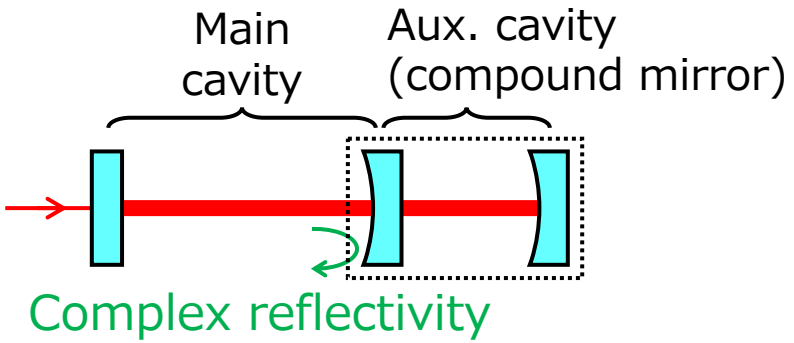
  → 00 and 10 mode resonate simultaneously

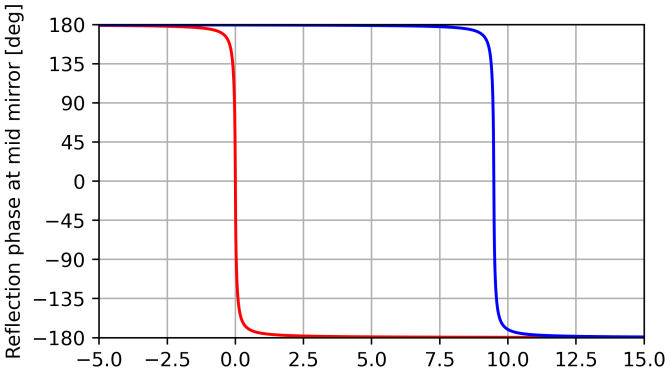
  → 10 mode is amplified in the main cavity

  → Coupled WFS is more sensitive than WFS

Phase compensation with aux. cavity

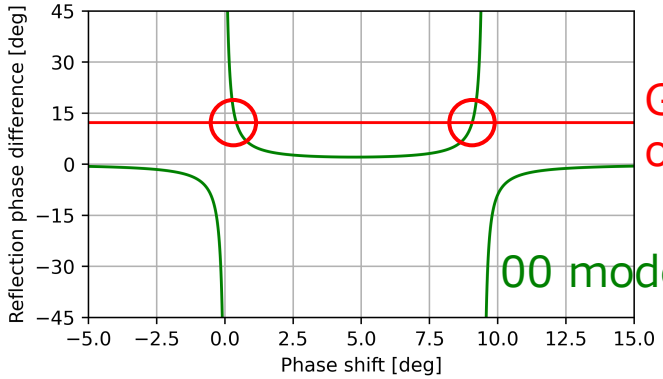






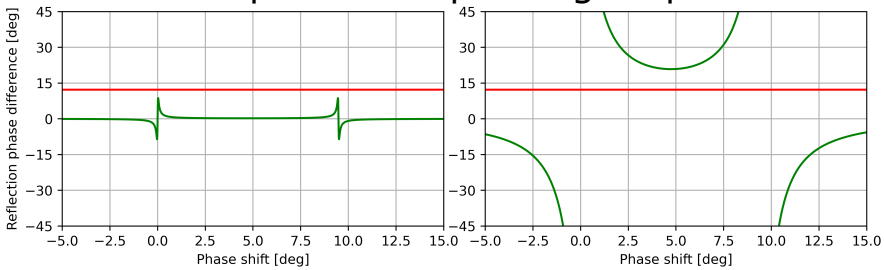
- 00 and 10 mode receive different phases when reflected at aux. cavity

  → Gouy phase of main cavity can be canceled



Aux. cavity length

Cannot compensate depending on parameters



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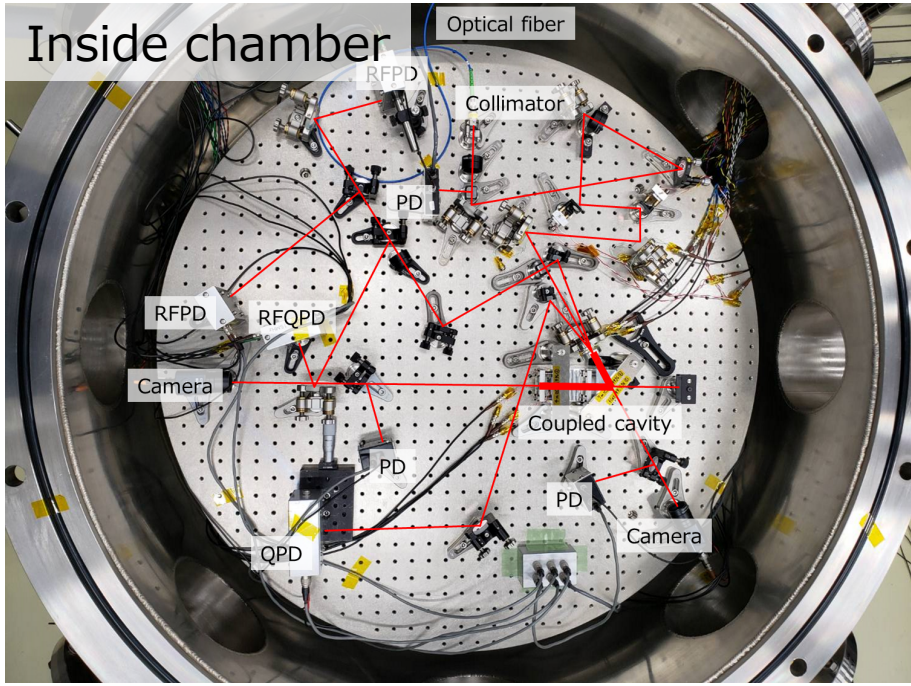
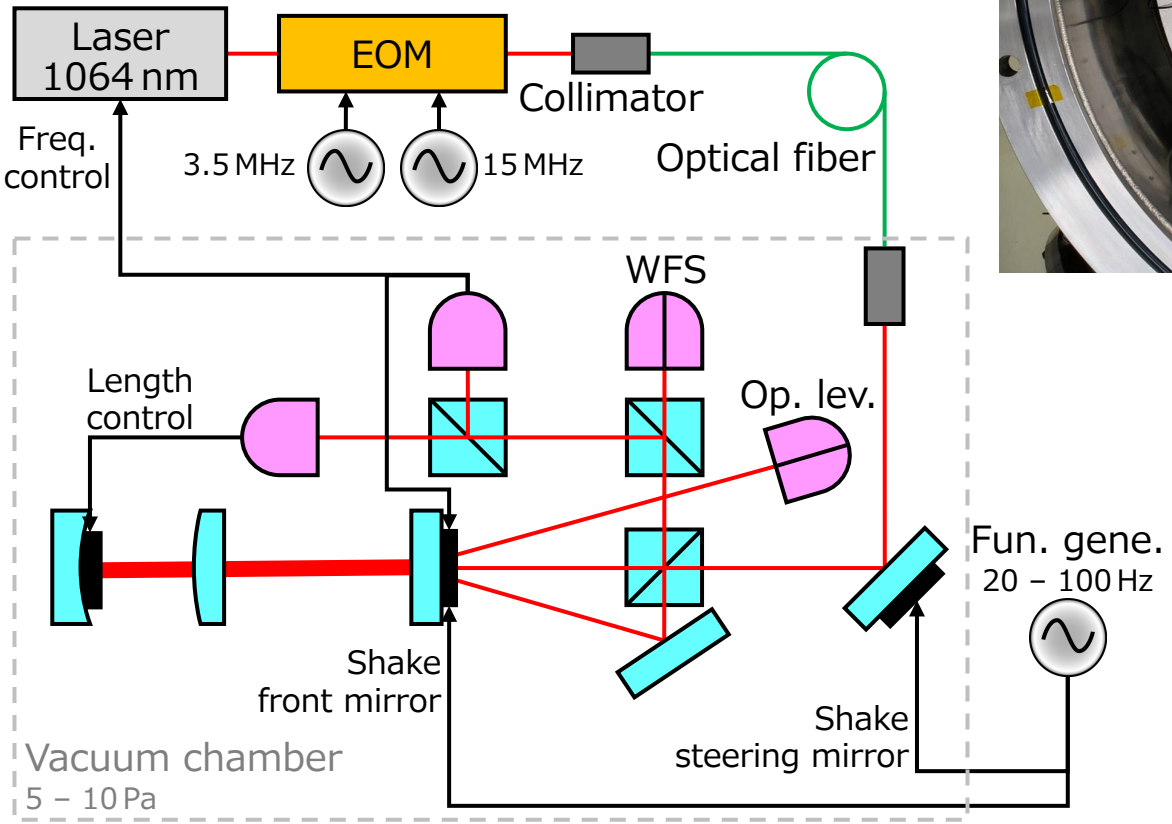
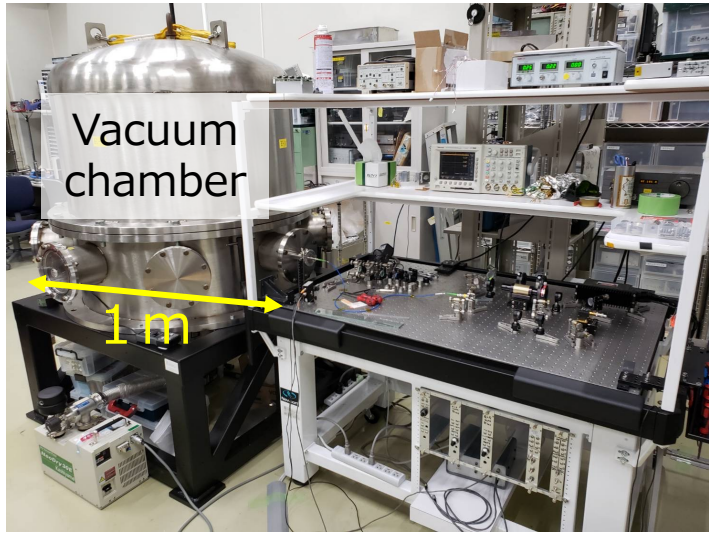
Overall experimental setup

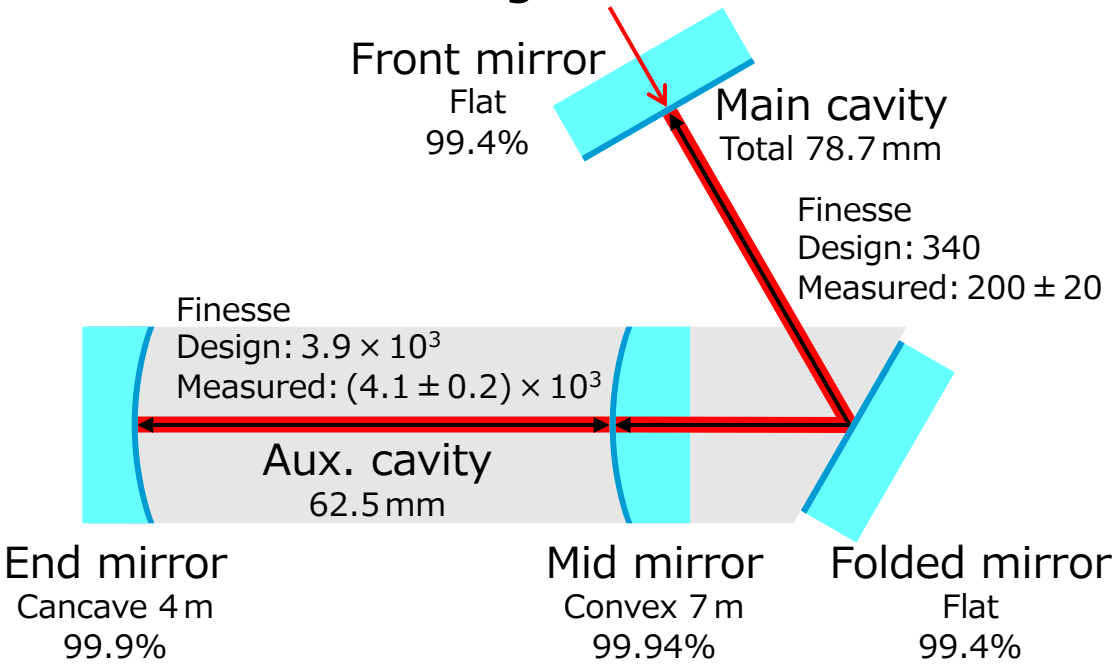


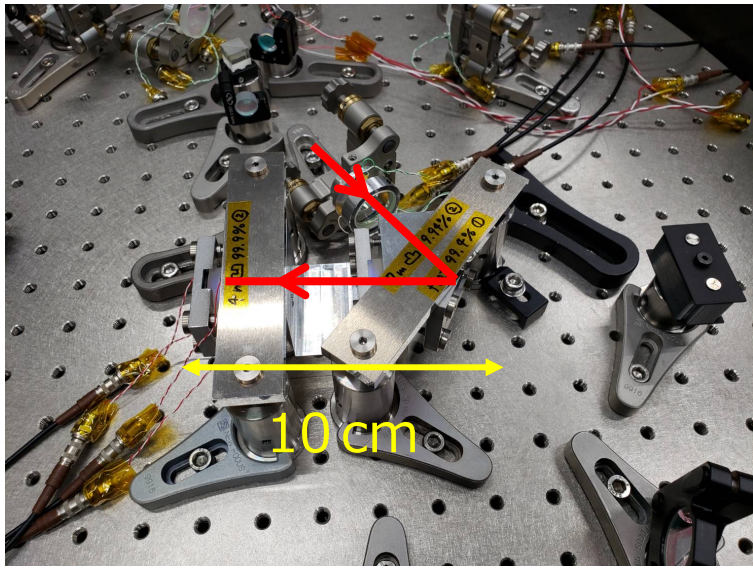




Cavity design

- Main cavity is folded to monitor transmitted light
- Reflectivity and loss of aux. cavity is important for phase compensation
  - HR coating is facing in aux. cavity
  - Designed parameters to doable phase compensation even with 0.1% loss in aux. cavity
- Fixed mirrors other than the front one rigidly to a spacer to stable alignment

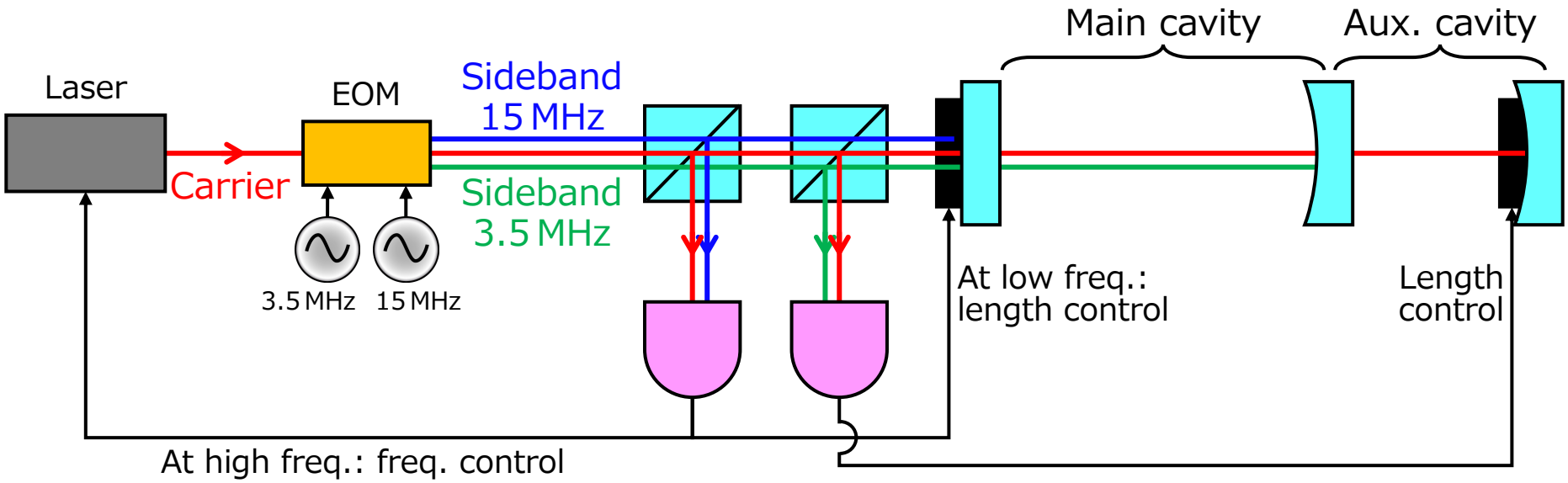




Control method of coupled cavity

- Used two modulated freq. for PDH technique
  - 15 MHz: for main cavity
  - 3.5 MHz: for aux. cavity

- Main cavity was controlled by a double loop
  - To prevent transmitting disturbances from main cavity to aux. cavity through laser freq.



Results of cavity control

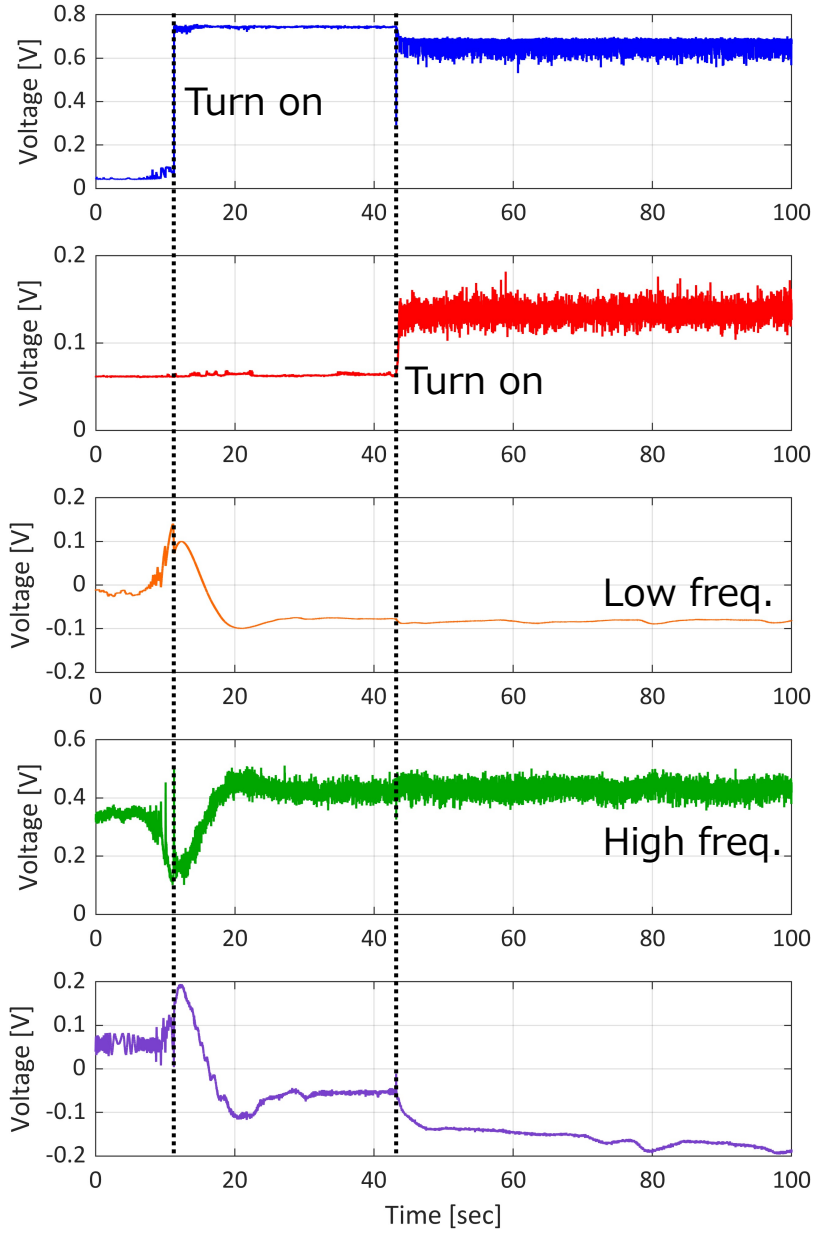
Trans. light of main cavity

Trans. light of aux. cavity

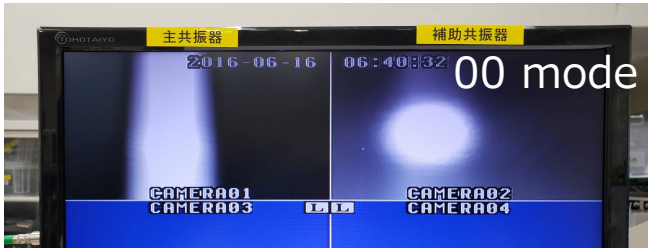
FB signal (front mirror)

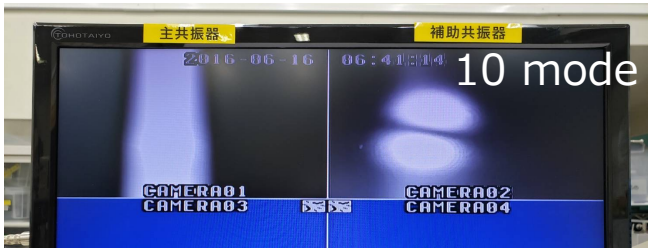
FB signal (laser freq.)

FB signal (end mirror)



Trans. light with CCD camera

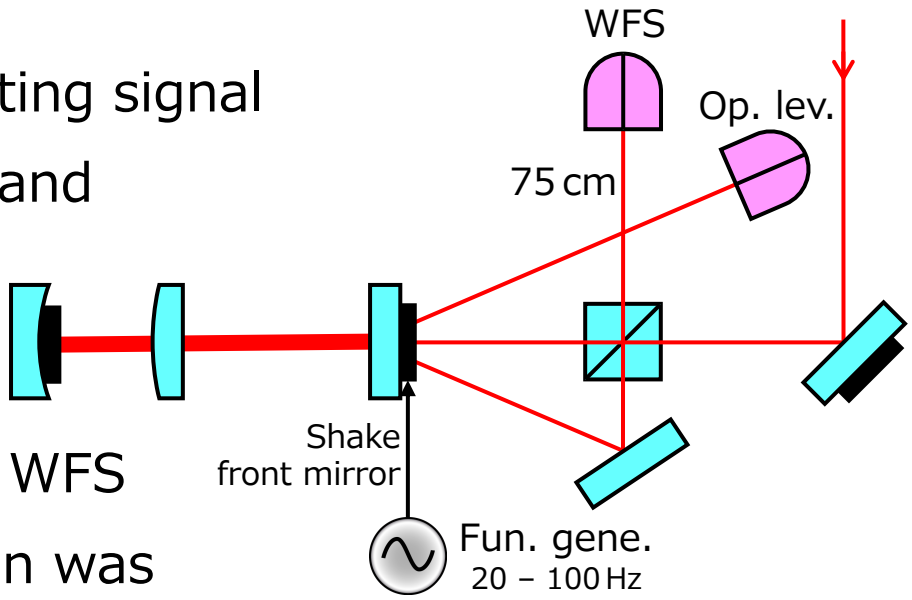




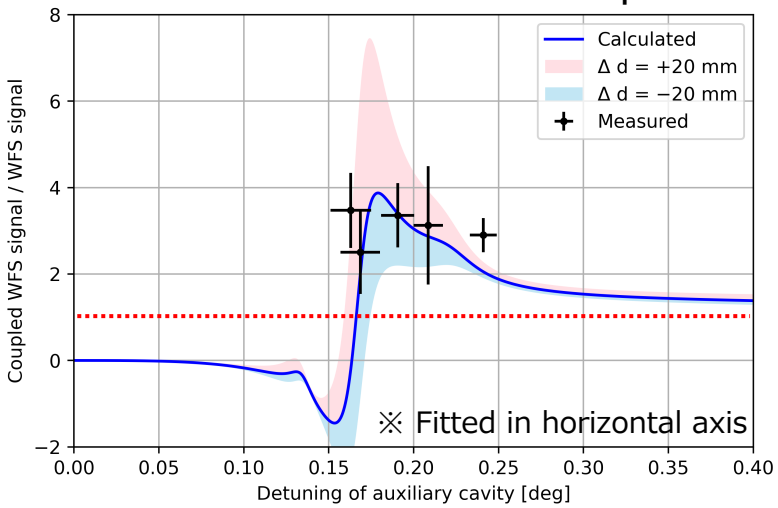
Results of signal amplification

- Shake front mirror with injecting signal
- Calibrate with op. lev. signal and trans. light of aux. cavity
- Compared WFS and Coupled WFS

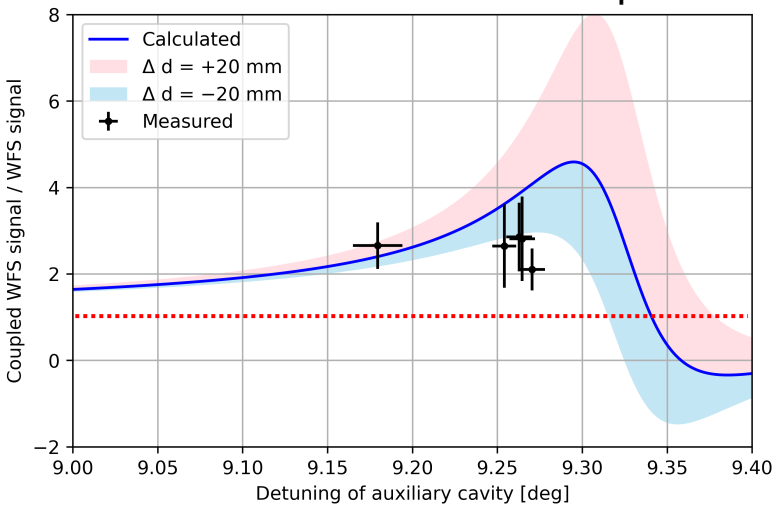
  → Angular signal amplification was confirmed



Near 00 mode resonant point



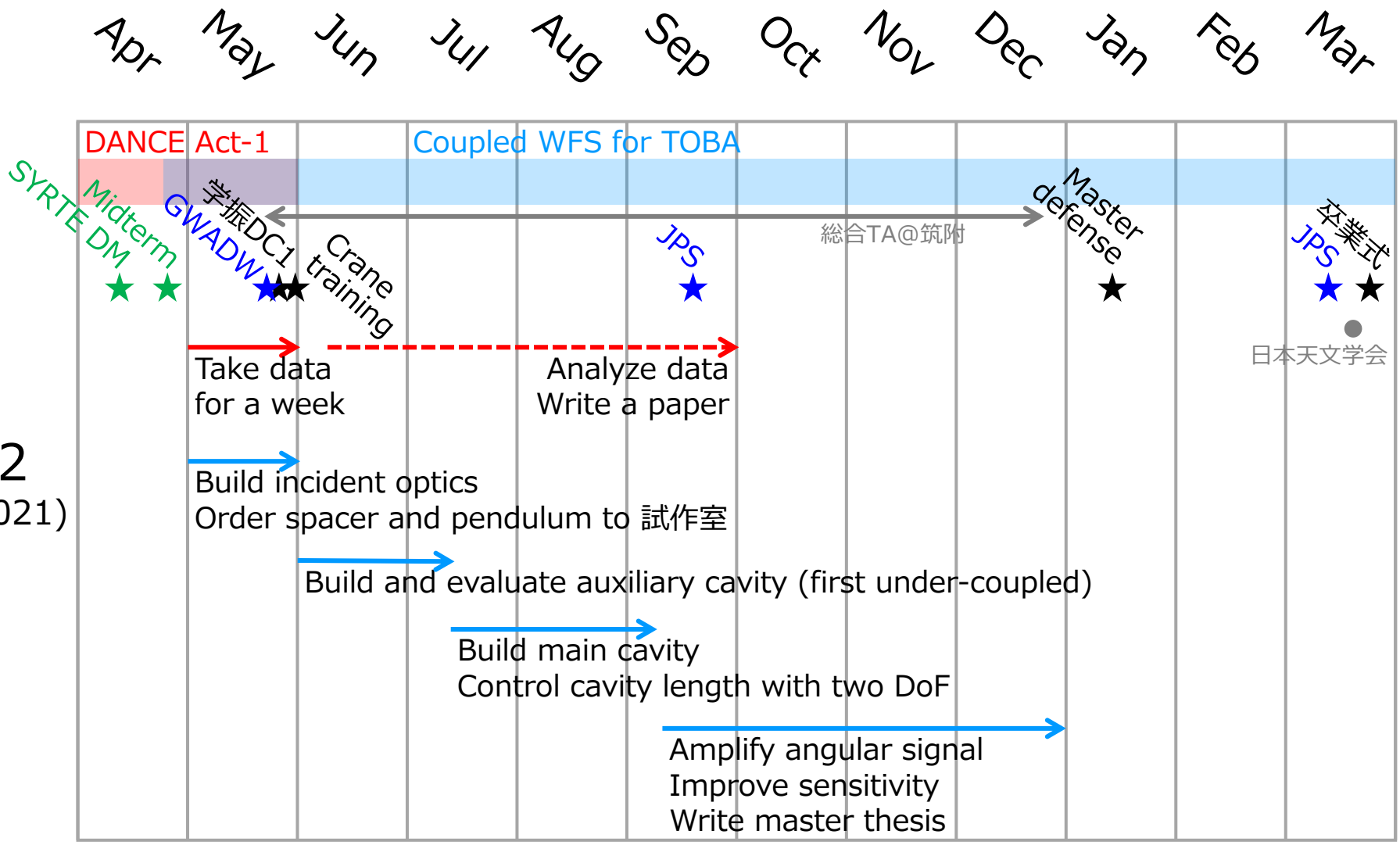
Near 10 mode resonant point



Contents

Reflections on Coupled WFS

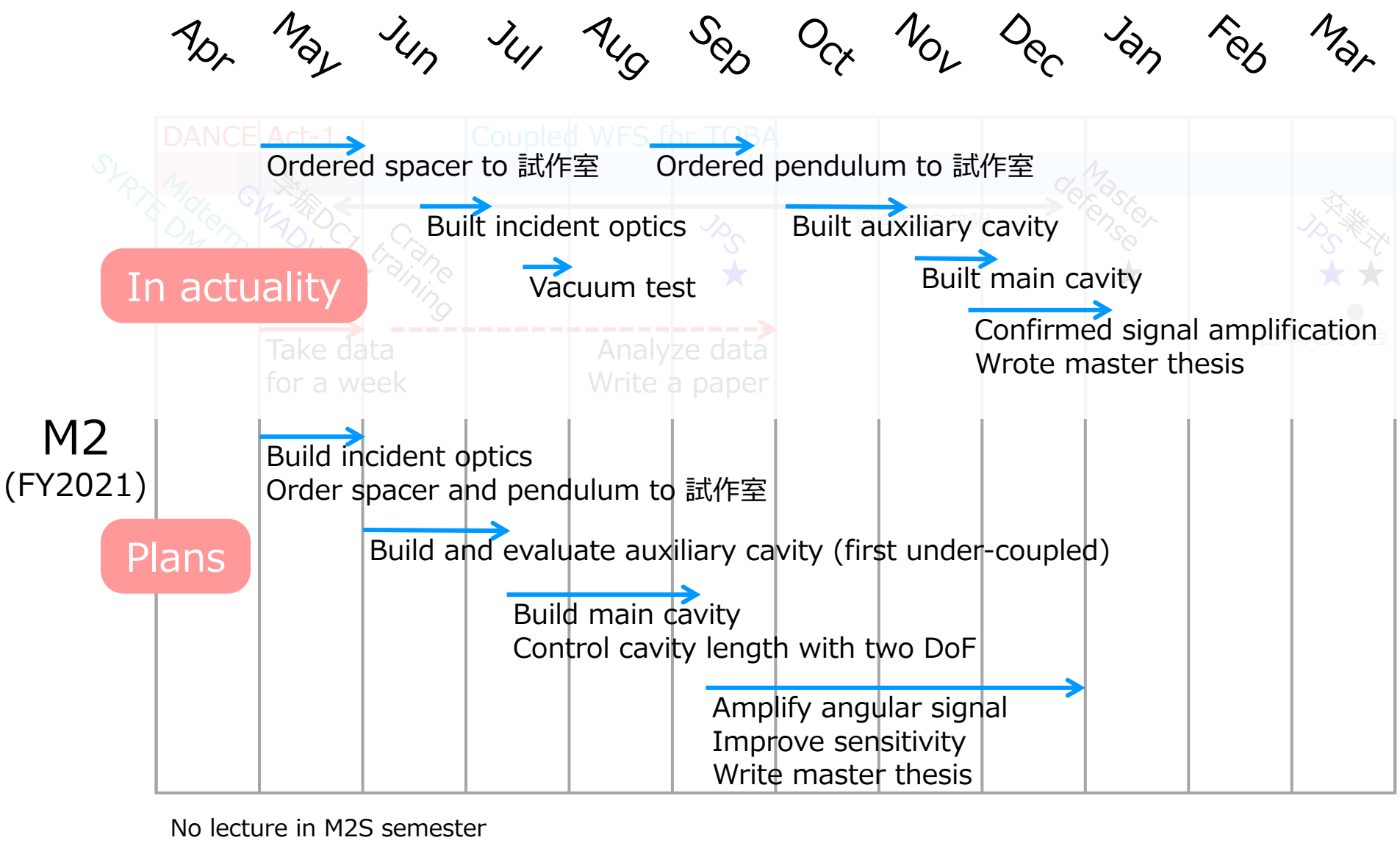
Re-post last year's slides



No lecture in M2S semester

Reflections on Coupled WFS

Re-post last year's slides



No lecture in M2S semester

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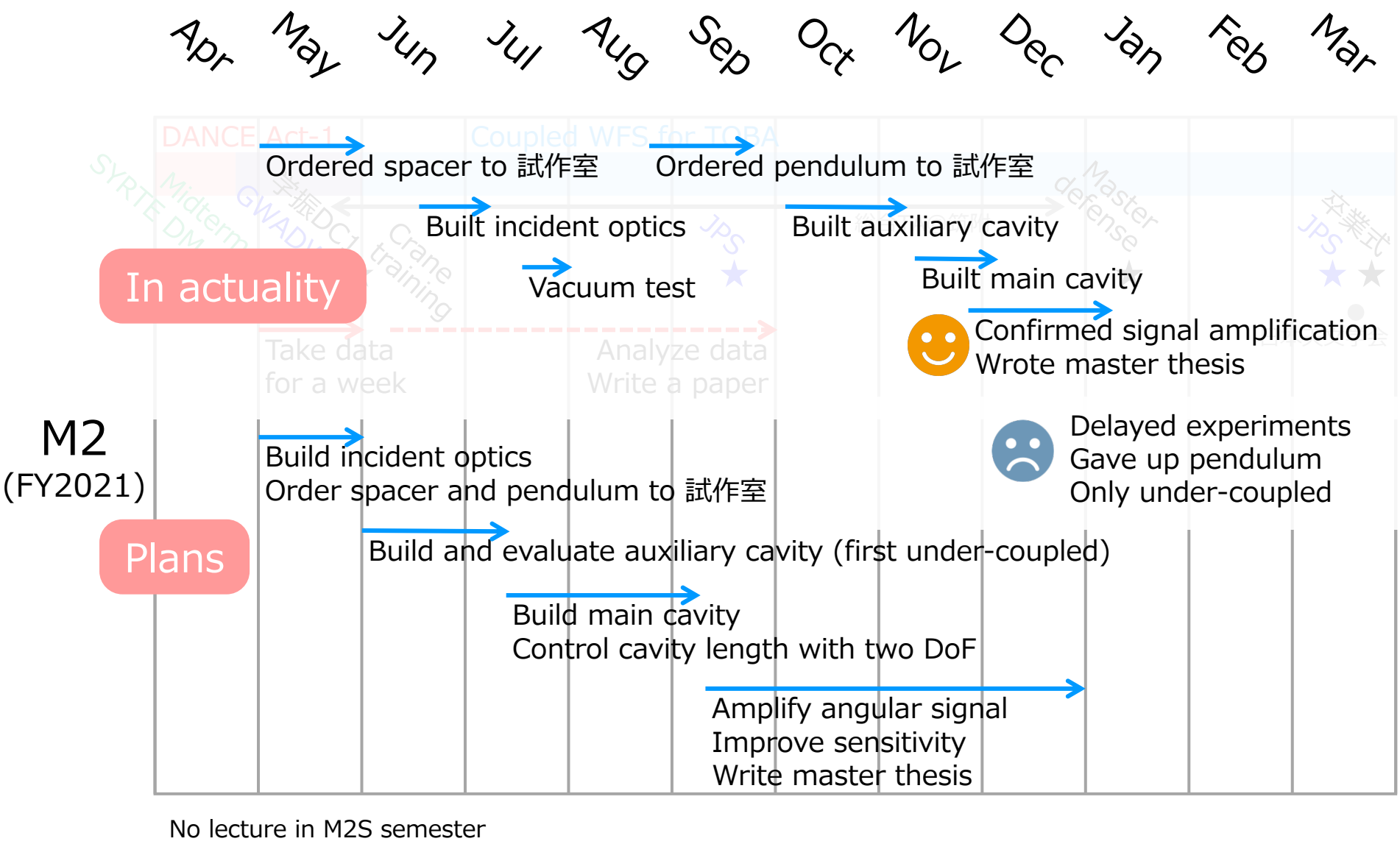
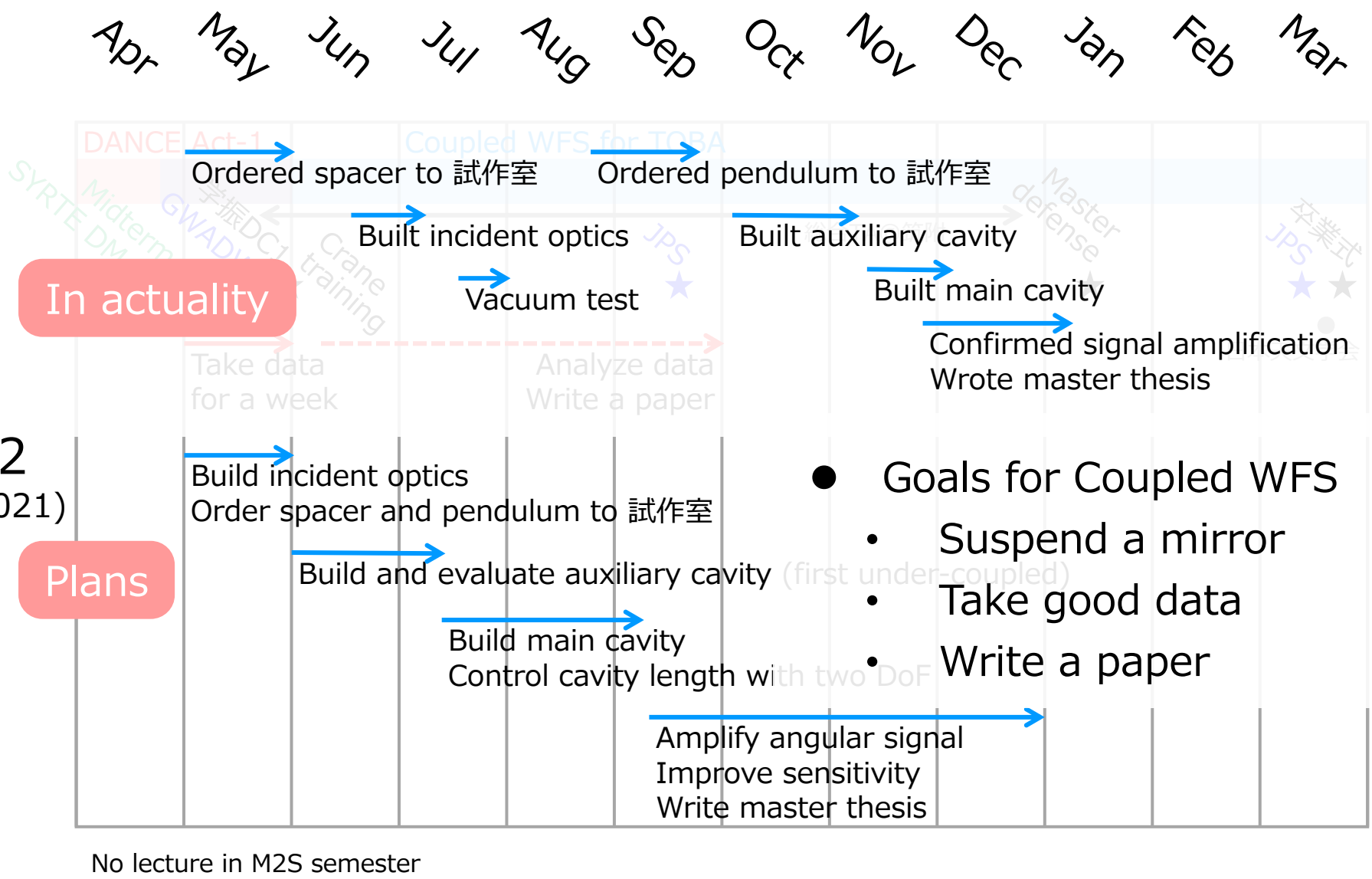


No lecture in M2S semester

Reflections on Coupled WFS

Re-post last year's slides



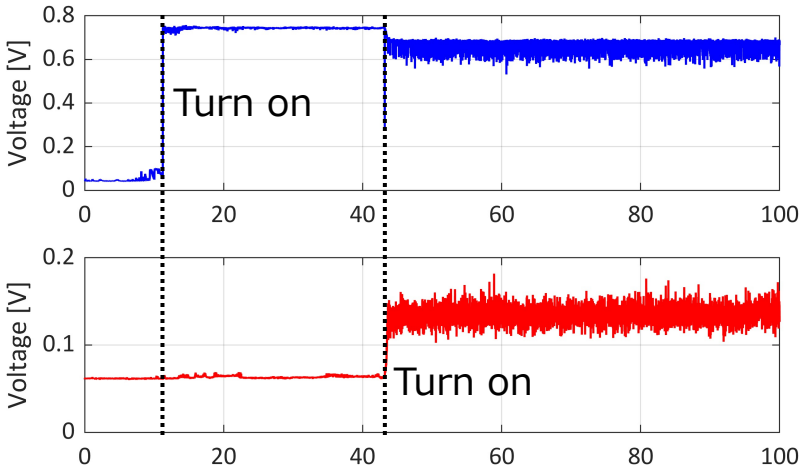
- Goals for Coupled WFS
  - Suspend a mirror
  - Take good data
  - Write a paper

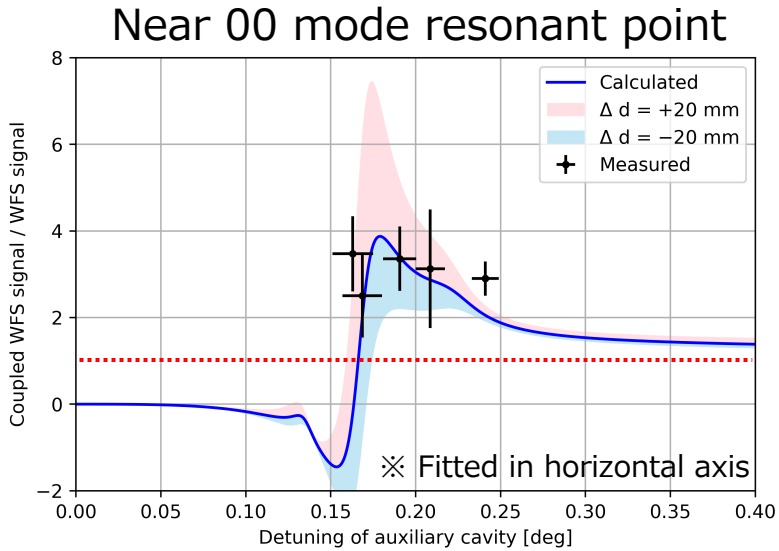
Current issues of Coupled WFS

- Current issues
  - Turning on the control of aux. cavity makes it unstable
  - Too large error bar

Trans. light of main cavity

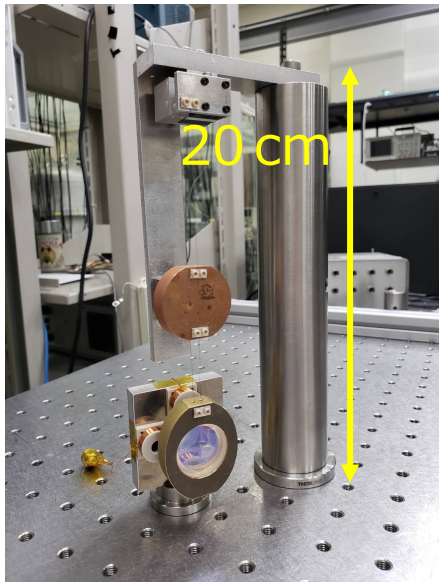
Trans. light of aux. cavity





What I will do for Coupled WFS

- Current issues
  - Turning on the control of aux. cavity makes it unstable
  - Too large error bar



- How to solve the first issue
  - Suspend a front mirror
    - Masses were already delivered
    - I will make a jig to suspend
    - I will put on picomotor to roof
  - Improve the mode-match coupling between main and aux. cavity
    - Try to align more

- The issue of large error bars might also be solved if the control becomes more stable?

Contents

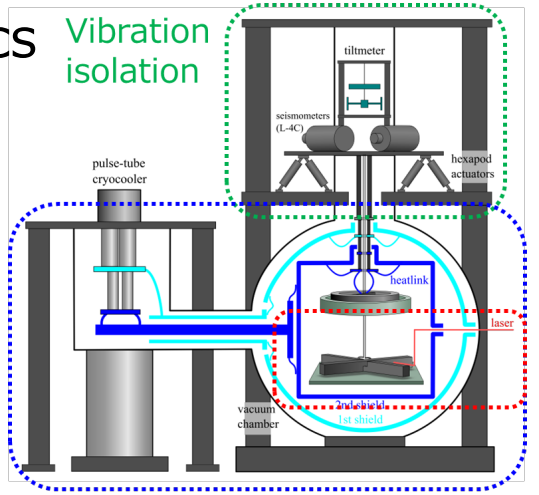
What I will talk today

- I got a master's degree with Coupled WFS
- What I will do for my Ph.D. thesis
  - Combine all components to complete Phase-III TOBA
  - TOBA has many components, so I will proceed step by step

Not new for Ando Lab, but I have never built a torsion pendulum

- What I will talk today
  - Rough design of the pendulum and optics
  - Moving mass
  - Magnetic shield

New for Ando Lab



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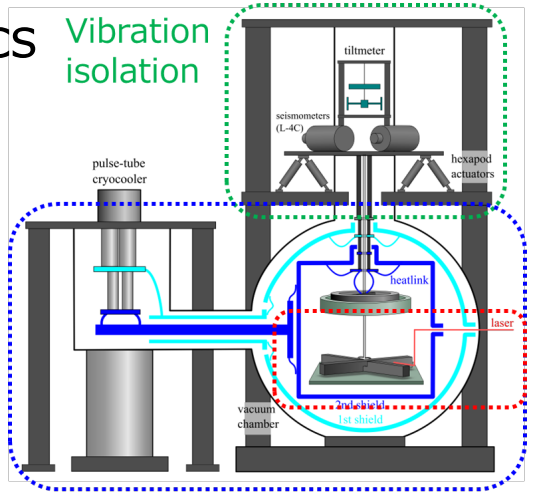
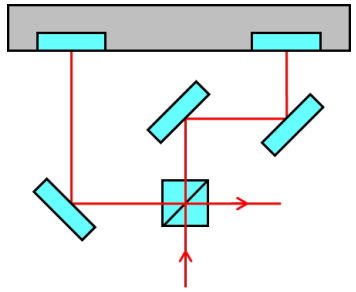
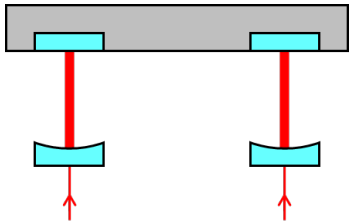
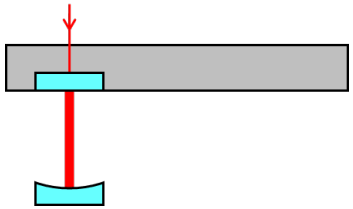
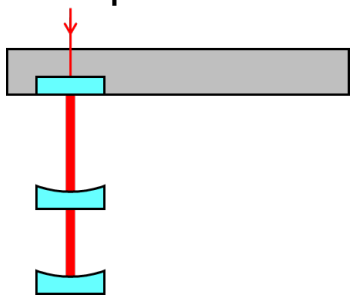
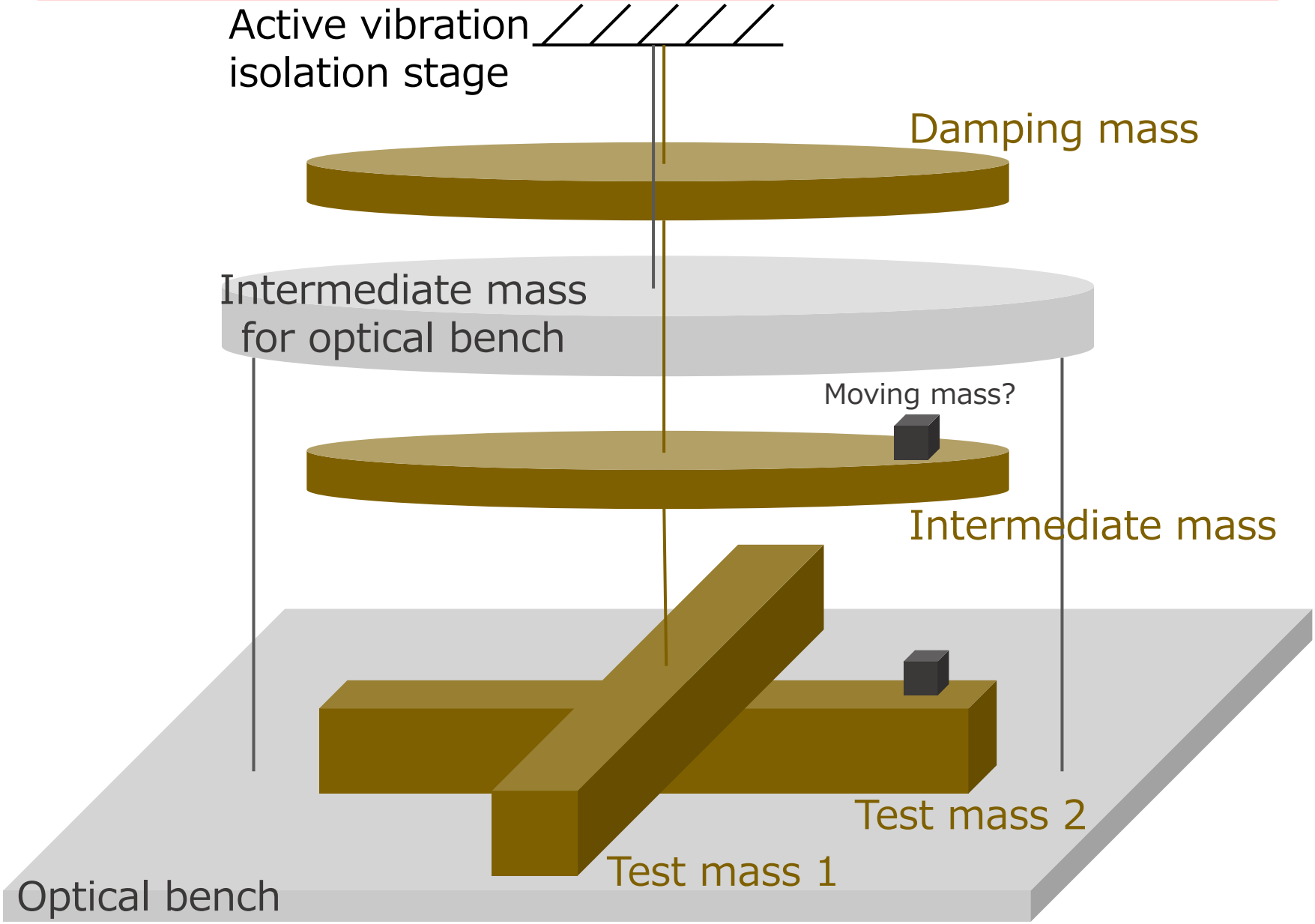


Candidates for readout optics

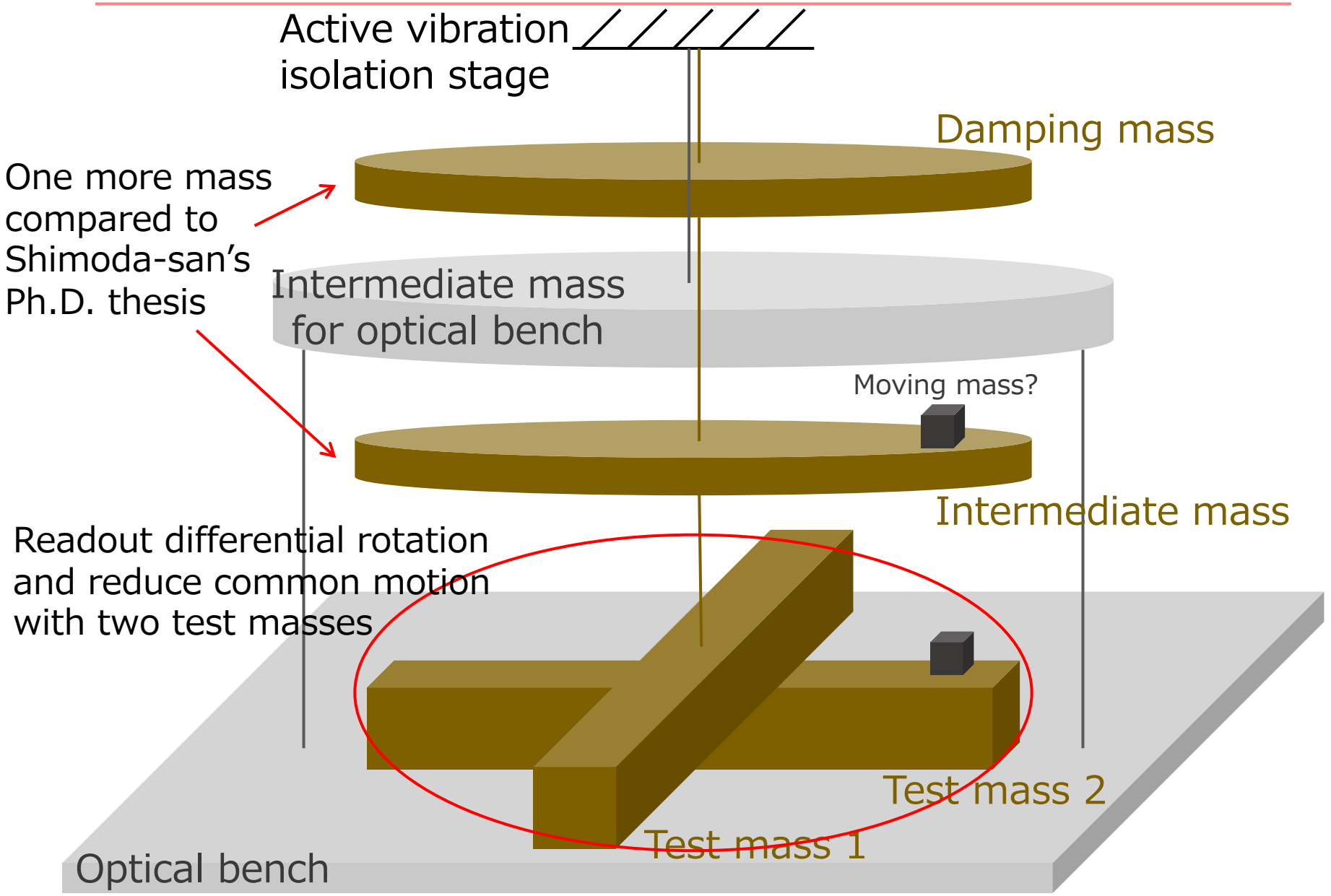
- Requirement for shot noise of Phase-III TOBA: 10^{-15} /√Hz

	Michelson	Differential FP cavity	WFS	Coupled WFS
				
Shot noise	🙂	🙂	☹	🙂
Freq. noise	☹	🙂	🙂	🙂
Trans-coupling	☹	☹	🙂	🙂
Beam jitter	☹	🙂	☹	🙂
Thermal noise	🙂	🙂	😐	😐
Linear range	🙂	🙂	🙂	☹
Comments	Trans-coupling, beam jitter, and polarization noise in prototype TOBA	Difficult to operate, but **I will try**. Might utilize Komori-san's exp.	Cannot satisfy the requirement	My master thesis. Many good points, but difficult to build and control

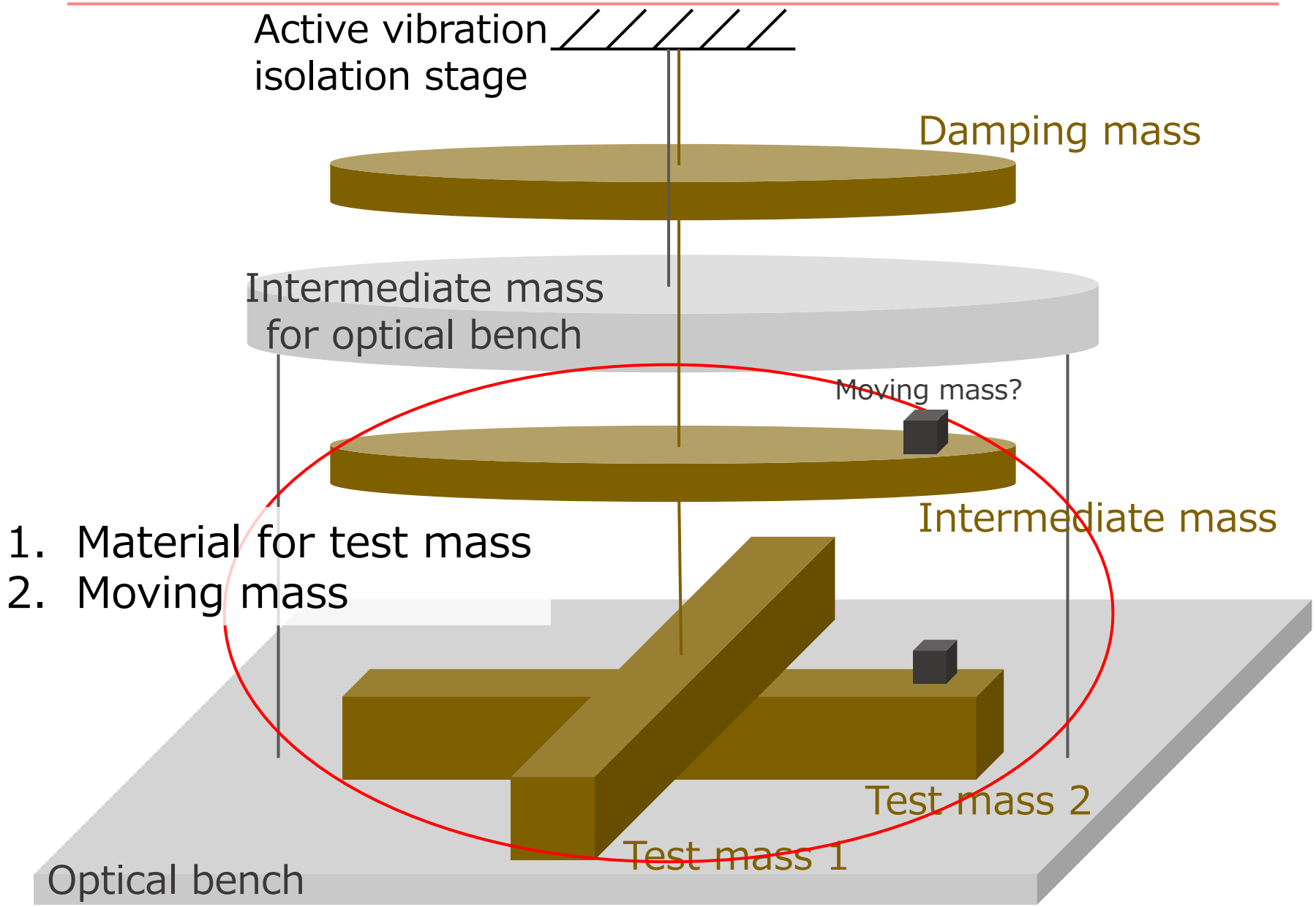
Overall view of torsion pendulum



Overall view of torsion pendulum



Overall view of torsion pendulum



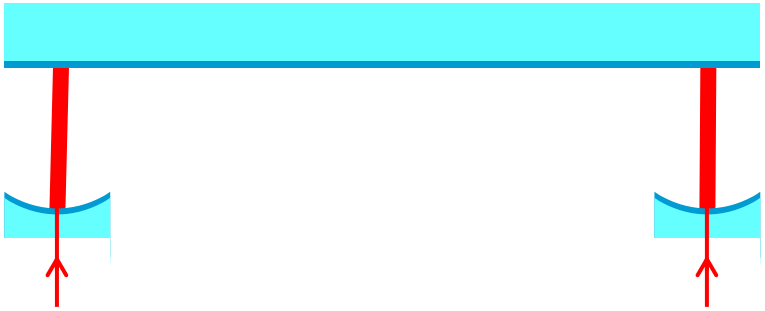
1. Material for test mass
2. Moving mass

Material for test mass

↓ I want to do this one

For simplicity, one test mass

- Fused silica bar with HR coating

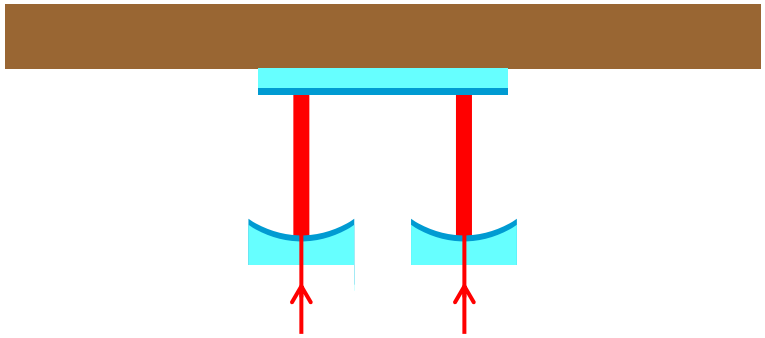


  - Surface roughness λ/10
  - Bar length 20 cm
    → Flatness 5 x 10^{-7} rad

Easy to put on optics because two cavities are far from each other

Difficult to attach many parts (actuators, moving mass) because made of fused silica

- 2-inch mirror on a metal bar



  - Surface roughness λ/100
  - Mirror diameter 5 cm
    → Flatness 2 x 10^{-6} rad

Easy to attach many parts because made of metal

Difficult to put on optics because two cavities are close

What I will talk today

- I got a master's degree with Coupled WFS
- What I will do for my Ph.D. thesis
  - Combine all components to complete Phase-III TOBA
  - TOBA has many components, so I will proceed step by step

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  - Rough design of the pendulum and optics
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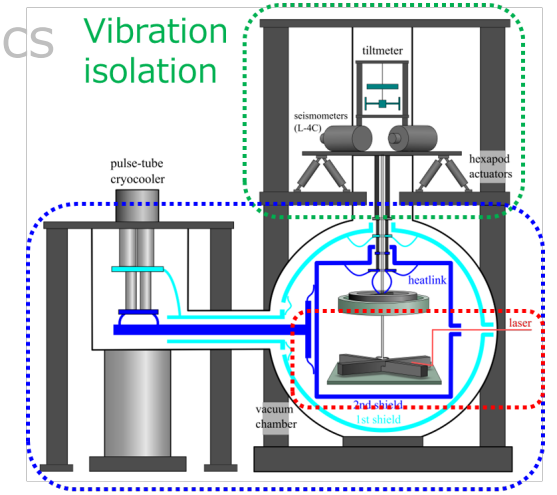
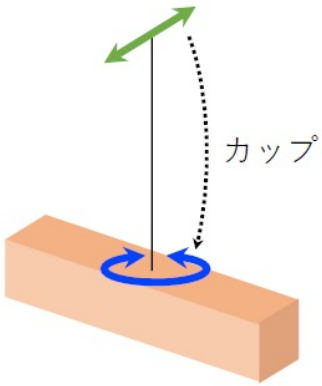
  - Magnetic shield



Motivation of moving mass

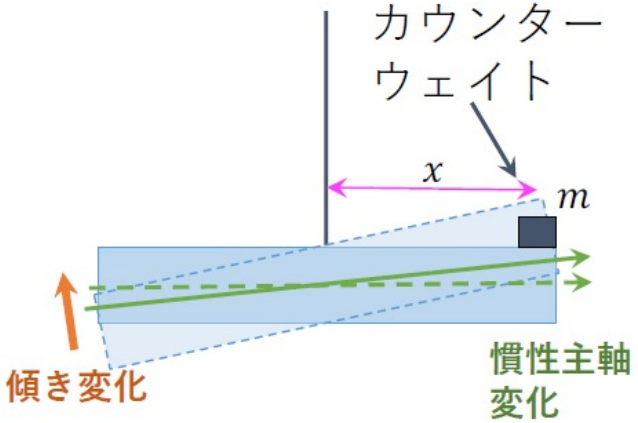
- Introduce moving mass to a torsion pendulum
  in order to compensate for the tilt of test mass
  and to reduce coupling from translational seismic vibration

- 並進振動からのカップリング雑音



- 理想的には伝達されないがさまざまな非対称性によって導入
- 低減方法が未確立

- カウンターウェイトによる調整
  - 重心位置変化による傾き変化
  - 質量バランス変化による慣性主軸変化

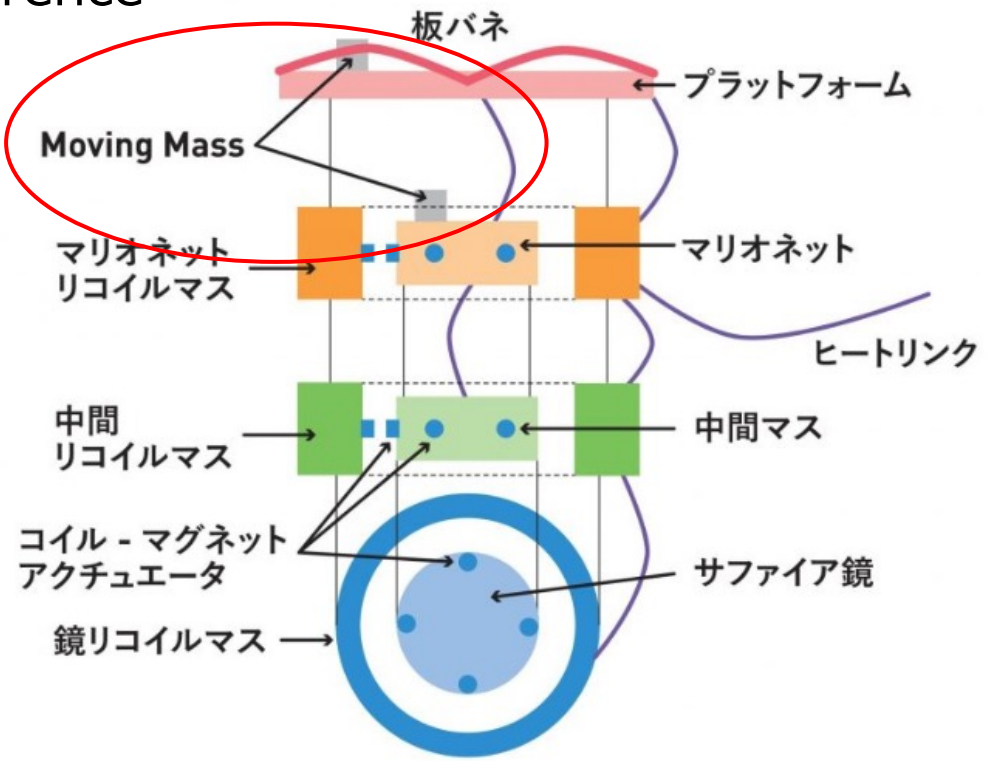


Shimoda-san's JPS slides

Motivation of moving mass

- TOBA is operated under vacuum and low temperature
  → We want to compensate for the tilt
  without touching the pendulum
- Moving mass is developed in KAGRA
  → We can use it as a reference

Suspension of KAGRA



日本機械学会誌

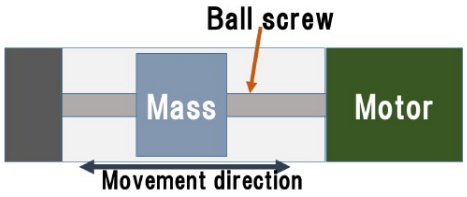
図 5　低温懸架システムの構成

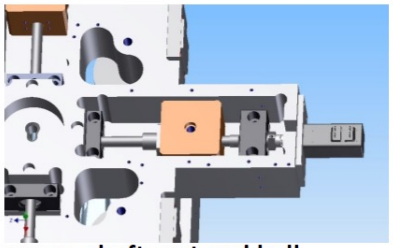
Old moving mass of KAGRA

Development of control system of mirror

JGW-G1605005-v1

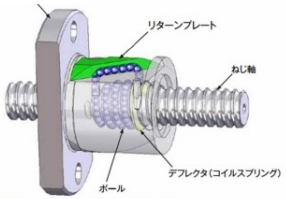
Moving Mass



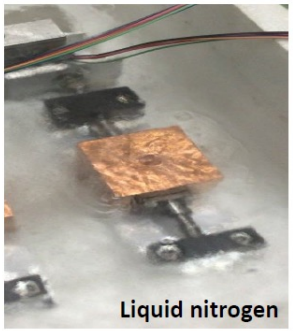


Ball Screw system : This system is composed by screw shaft, nut and ball. This is able to transform rotation of motor into liner motion of Mass.

Ball screw



Since the ball enter between screw shaft and nut, it is smooth that transform rotation of motor into liner motion of mass.



↑ Size of the moving mass: 10 cm?

Found issue ↓

Motivation

JGW-G2012151-v1

- Current moving mass is often stack when we use it several time
- Moving mass is important for compensation of pitch drift due to thermal contraction.
- If moving mass doesn't move, we cannot perform initial alignment.
- So, we have to design new moving mass and install before O4.

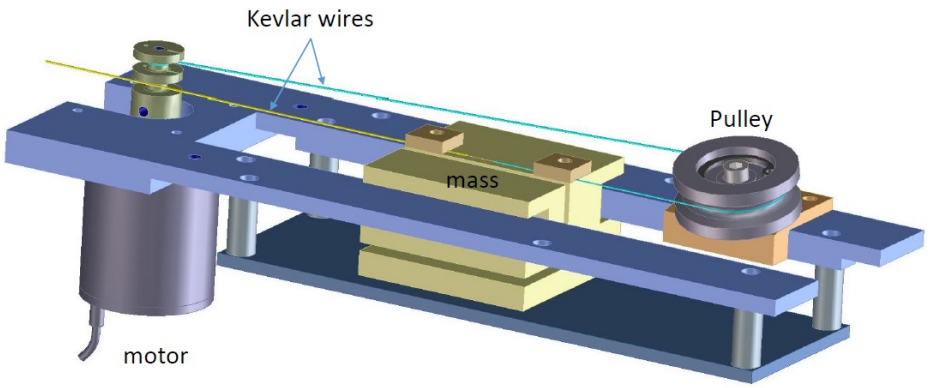
Requirement for moving mass:

- Range： ± 10 mrad (not strict requirement)
- Resolution：4 urad (not strict requirement)
- Reliability after moving many times ← new requirement

New moving mass of KAGRA

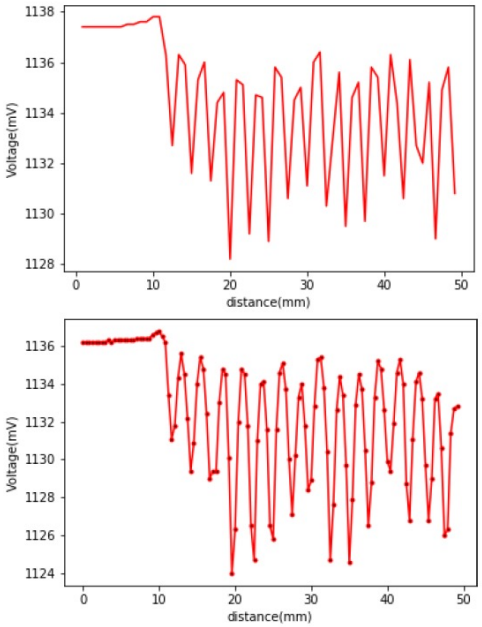
Design

JGW-G2012151-v1



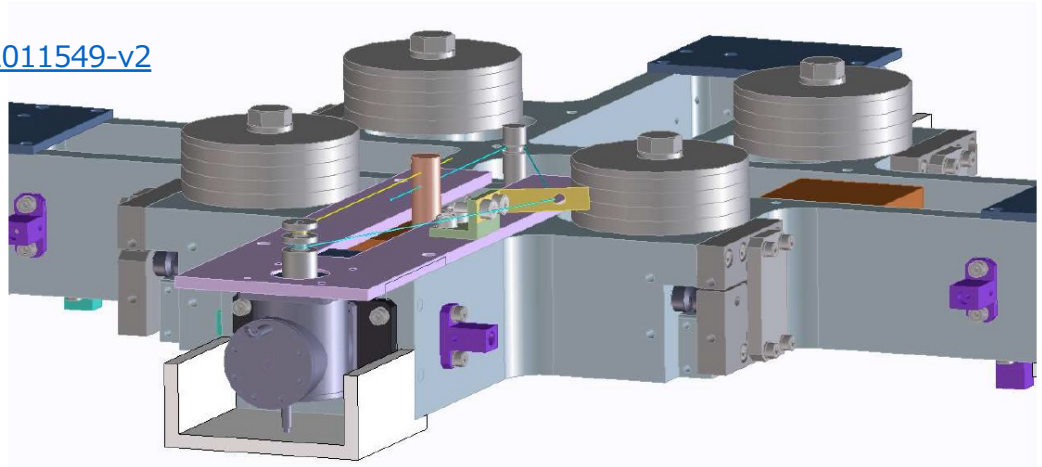
Rope way like system

Reliability check



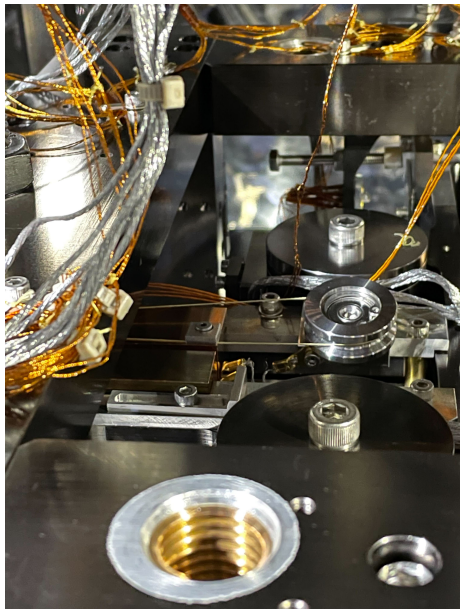
We checked performance just after cooling and after moving 6000 times in full range.
Both results are consistent each other and looks to be moved properly.

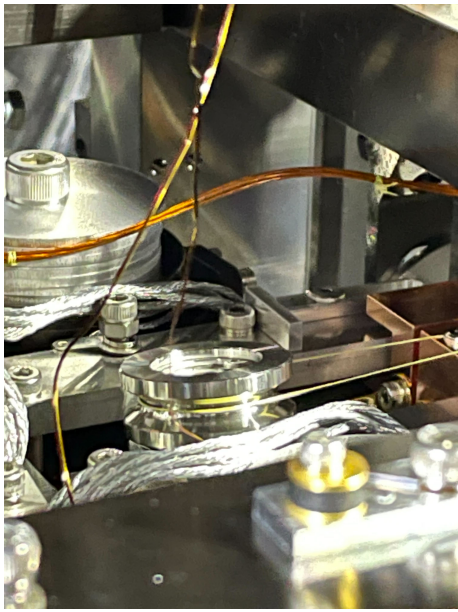
JGW-D2011549-v2



Moving mass for TOBA

- Moving mass of KAGRA is too large for TOBA
  → I will send an e-mail to Ushiba-san
  → I will order parts by June 2022

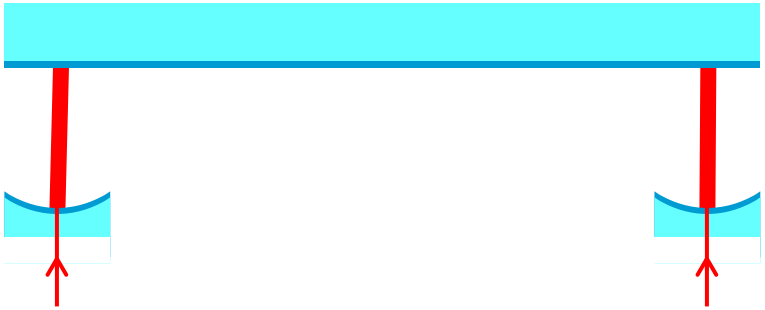





klog #20187

Where to put moving mass

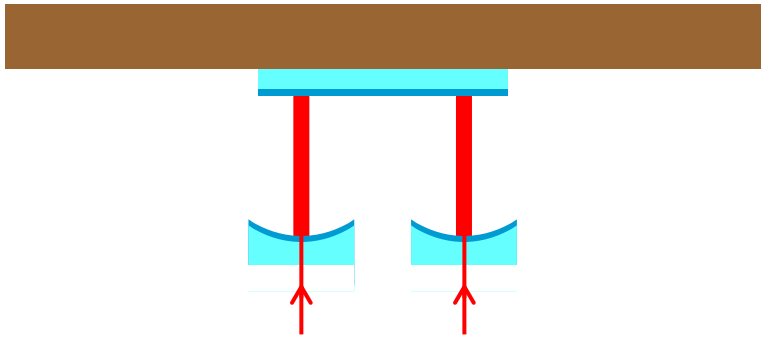
- Fused silica bar with HR coating



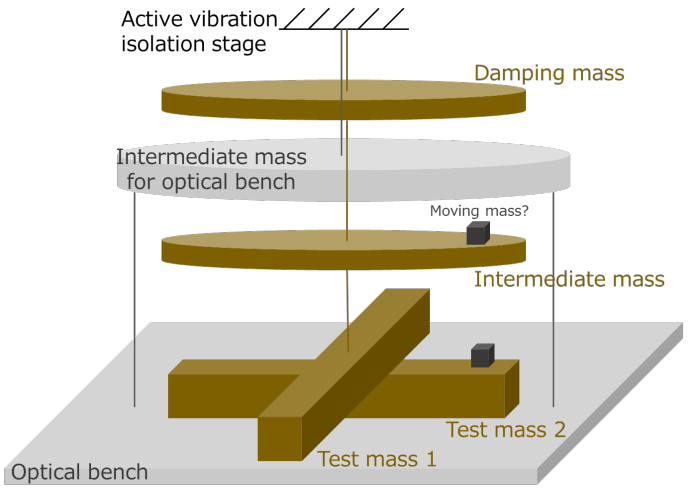
  - Only on intermediate mass

  ↑ I want to do this one

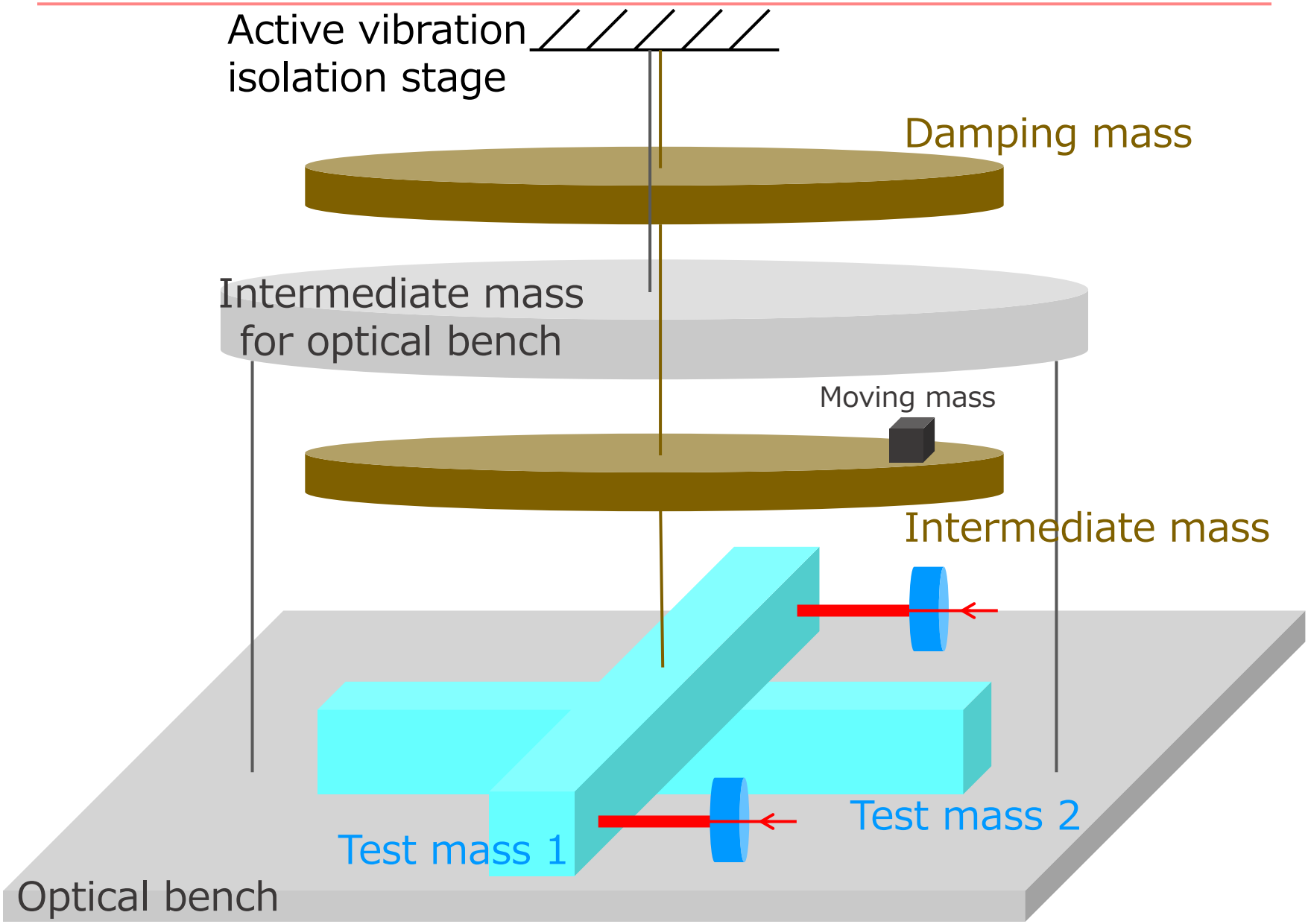
- 2-inch mirror on a metal bar



  - Both on test mass and intermediate mass

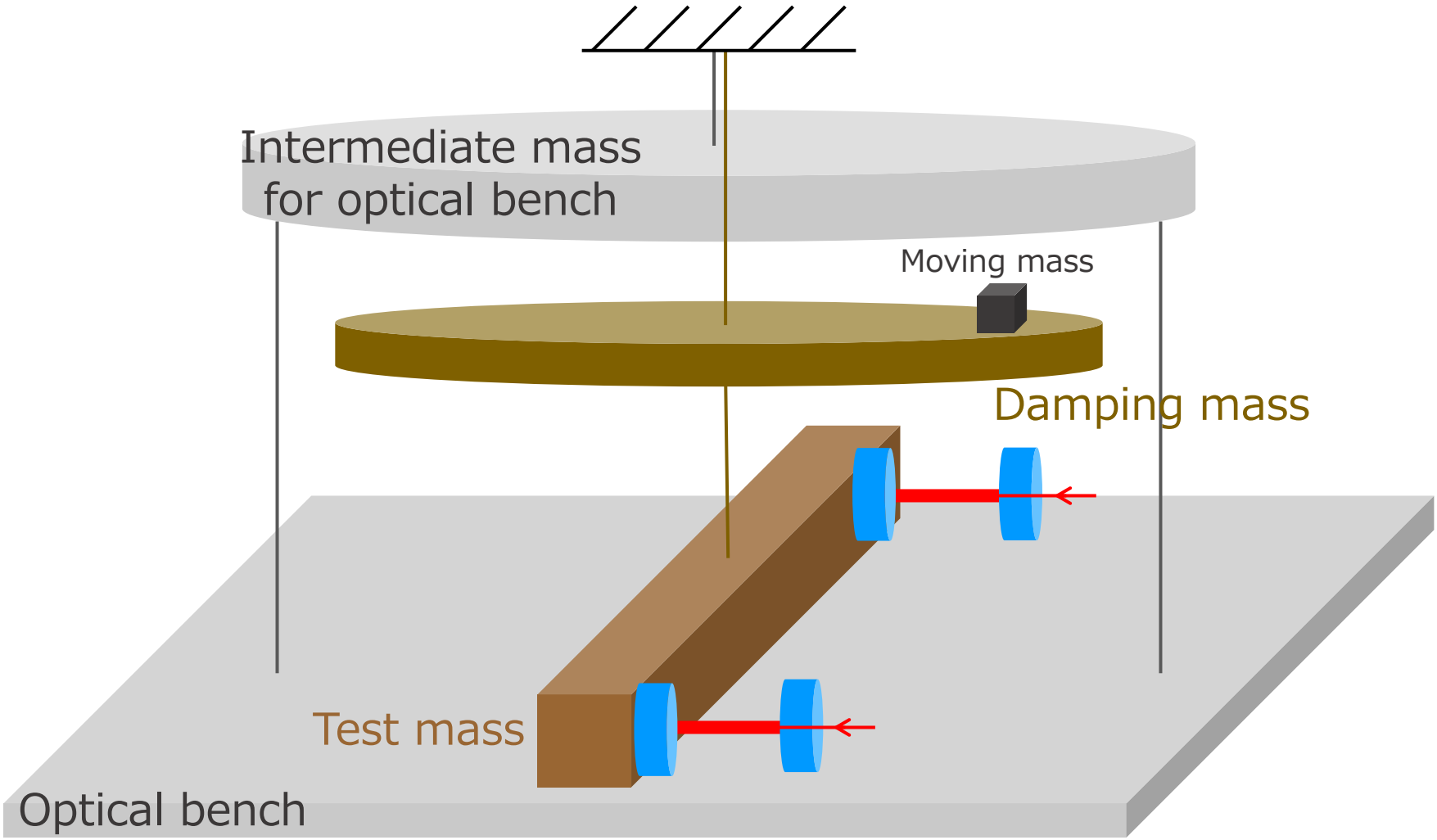


My plans of torsion pendulum



First step of torsion pendulum

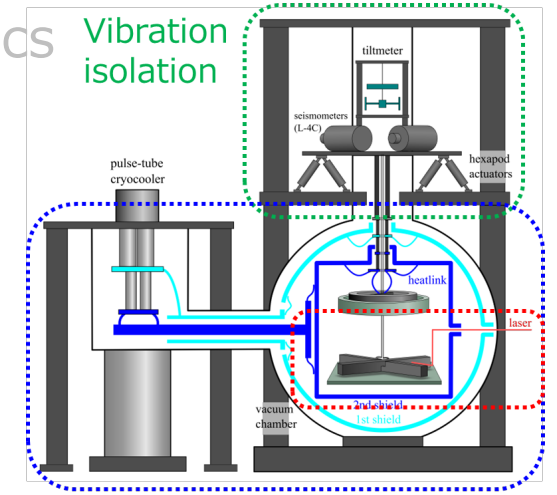
- I have never built a torsion pendulum
  → I will start an easier step



What I will talk today

- I got a master's degree with Coupled WFS
- What I will do for my Ph.D. thesis
  - Combine all components to complete Phase-III TOBA
  - TOBA has many components, so I will proceed step by step

- What I will talk today
  - Rough design of the pendulum and optics
  - Moving mass
  - Magnetic shield



Origin of magnetic noise

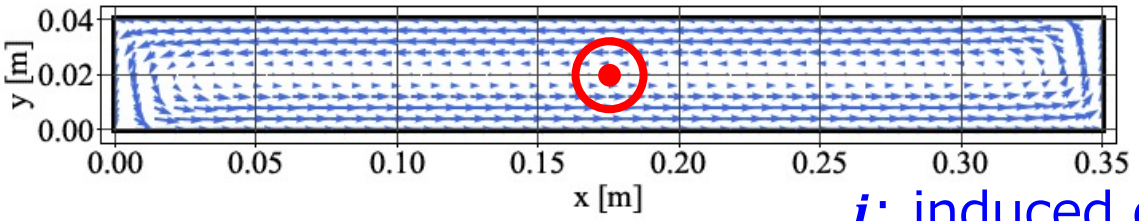
Shimoda, Ph.D. thesis (2019)

Top view of the test mass

$\boldsymbol{B}$: DC geomagnetic field

$\boldsymbol{\mu}$: magnetic moment

$\boldsymbol{N}$: torque



$\boldsymbol{i}$: induced eddy current

Figure 7.1: Distribution of induced eddy current in the bar.

External magnetic field fluctuation

↓

$\boldsymbol{i}$: induced eddy current

↓

$\boldsymbol{\mu}$: magnetic moment

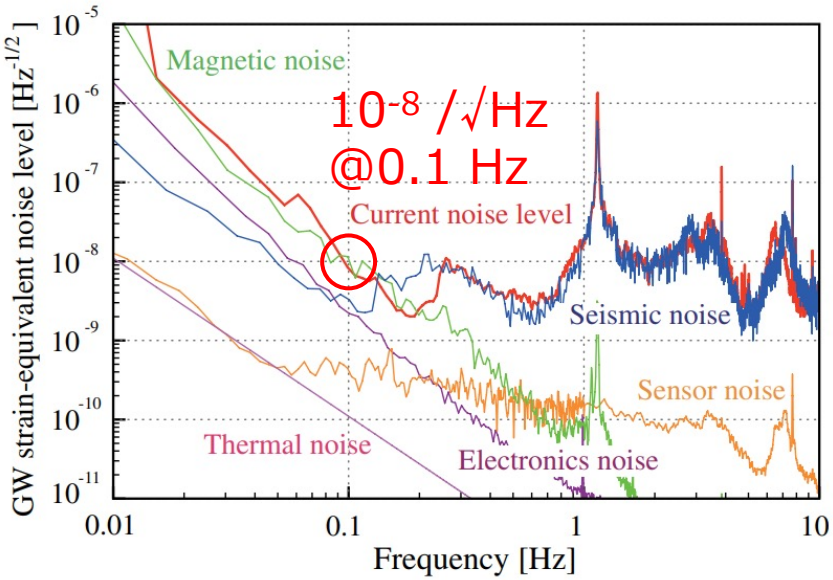
$\boldsymbol{B}$: DC geomagnetic field

↓

$\boldsymbol{N}$: torque (noise for TOBA)

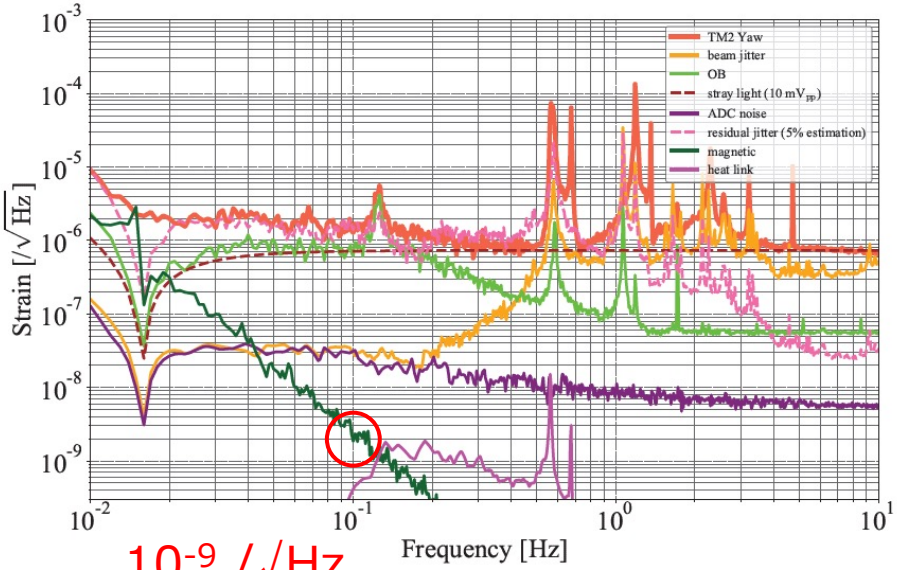
Magnetic noise level so far

Phase-I TOBA



Ishidoshiro+ (2011)

Phase-III TOBA



10^{-9} /√Hz
@0.1 Hz

Shimoda, Ph.D. thesis (2019)

- Magnetic noise is one of the dominant noises for TOBA
- We need to reduce 6 orders of magnitude to achieve the target sensitivity of Phase-III TOBA (10^{-15} /√Hz)

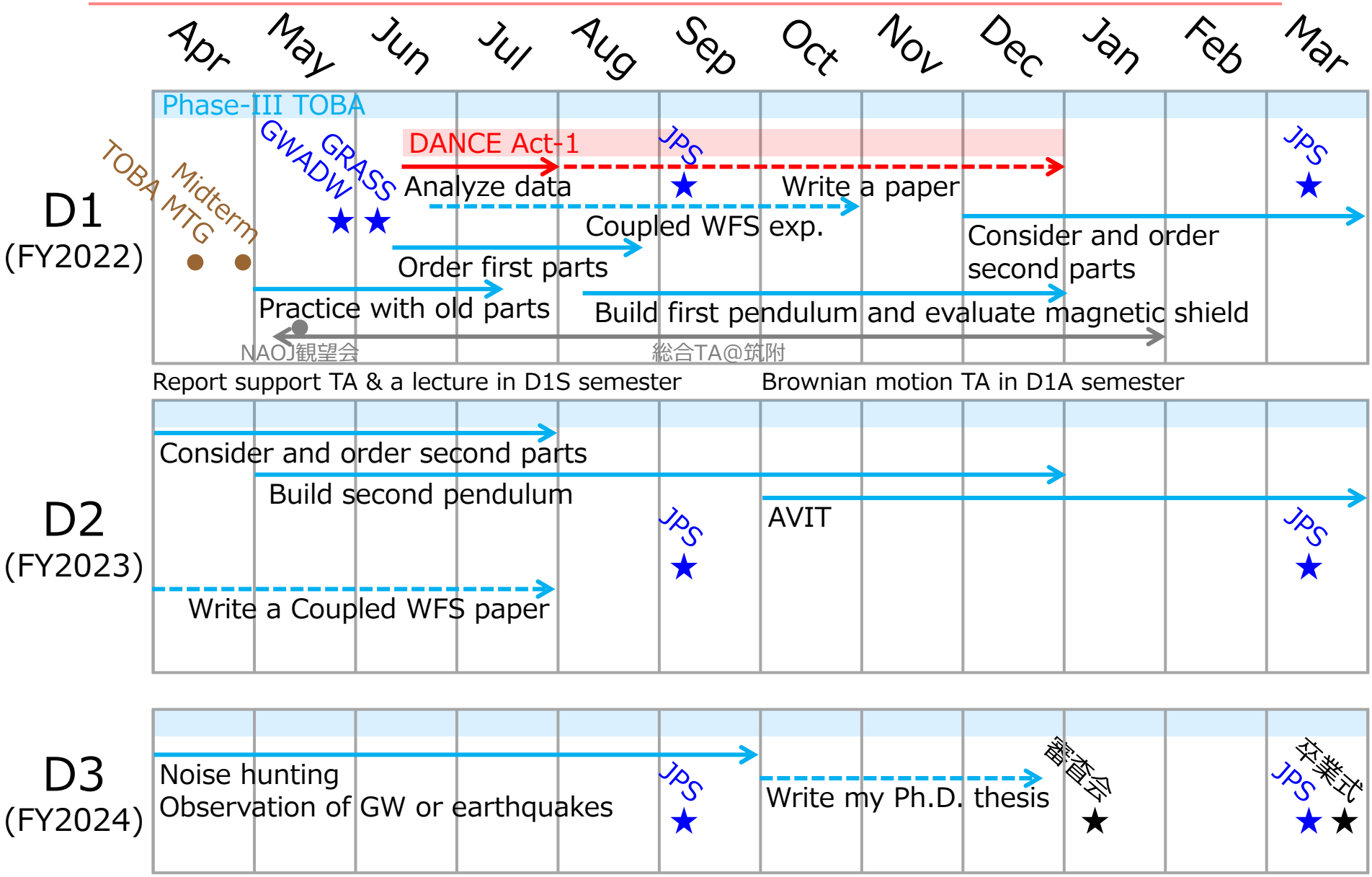
Magnetic shield

- How to reduce magnetic noise?
  - Choose a material of test mass to a non-conducting one
    → Difficult because a non-conducting mass
    will be suffered from the electrostatic force
  - Introduce magnetic shield
    → Ando Lab doesn't have know-how
    → Consult with Sekino-sensei (Q-LEAP member) on May 9

東大 工学部 関野研究室 HP

Sekino Lab is developing medical devices
using electromagnetic fields and superconductivity

Plans of my Ph.D. course



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FINESSE simulation

- Introduction of FINESSE
- Current status of Coupled WFS simulation
- Plans for KAGRA simulation

FINESSE

- One of interferometer simulation tools
- Frequency domain INterfErometer Simulation SotfwarE

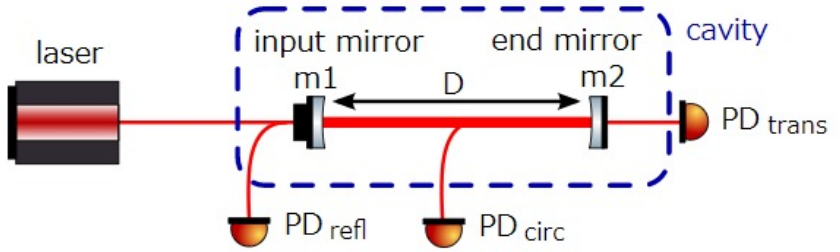
My seminar's slides

Write codes with Python

```
import numpy as np                          # Importing numpy
import matplotlib                           # For plotting
import matplotlib.pyplot as plt
from pykat import finesse                   # Importing the pykat.finesse package
from pykat.commands import *                # Importing all packages in pykat.commands.
from IPython.display import display, HTML   # Allows us to display HTML.

# Telling the notebook to make plots inline.
%matplotlib inline
# Initialises the PyKat plotting tool. Change the dpi-value to
# make plots appear smaller/bigger on your screen.
pykat.init_pykat_plotting(dpi=90)

basekat=finesse.kat() # initialising Finesse
basecode = """
l laser 1 0 n0   # Laser (Power = 1 W, wavelength offset = 0)
s s1 1 n0 nc1    # Space (Length = 1 m)

## The cavity ##
m m1 0.7 0.3 0 nc1 nc2  # Mirror  (R = 0.7, T = 0.3, phi = 0)
s sL 4000 nc2 nc3       # Space (Length = 4 km)
m m2 0.8 0.2 0 nc3 nc4  # Mirror  (R = 0.8, T = 0.2, phi = 0)
"""
basekat.parse(basecode) # Parsing the FINESSE-code

kat1 = deepcopy(basekat)
code = """
## Detectors ##

# Photo diodes measureing DC-power
pd refl nc1          # Reflected field
pd circ nc2          # Circulating field
pd tran nc4          # Transmitted field

## Simulation instructions ##
xaxis m1 phi lin -450 90 2000   # Varying tuning of input mirror m1.
yaxis abs                       # Plotting the amplitude of the detector measurements.
"""
kat1.parse(code) # Parsing the FINESSE-code
out1 = kat1.run()       # Running the FINESSE-simulation, storing output in out1.
```

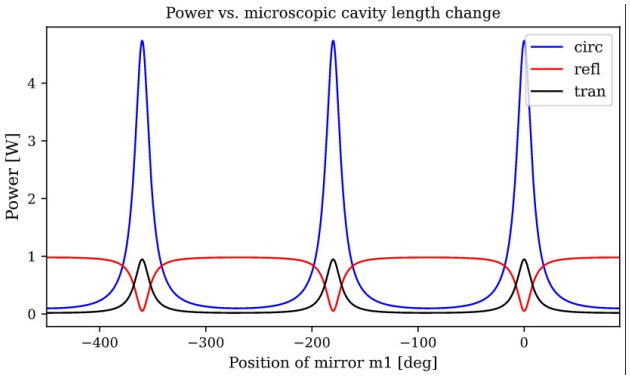
Please note that
FINESSE: software
finesse: physical quantity

Build interferometers in our mind



Run codes

Plot results



JGW-G1301720: FINESSE lecture slides

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FINESSE simulation

- Introduction of FINESSE
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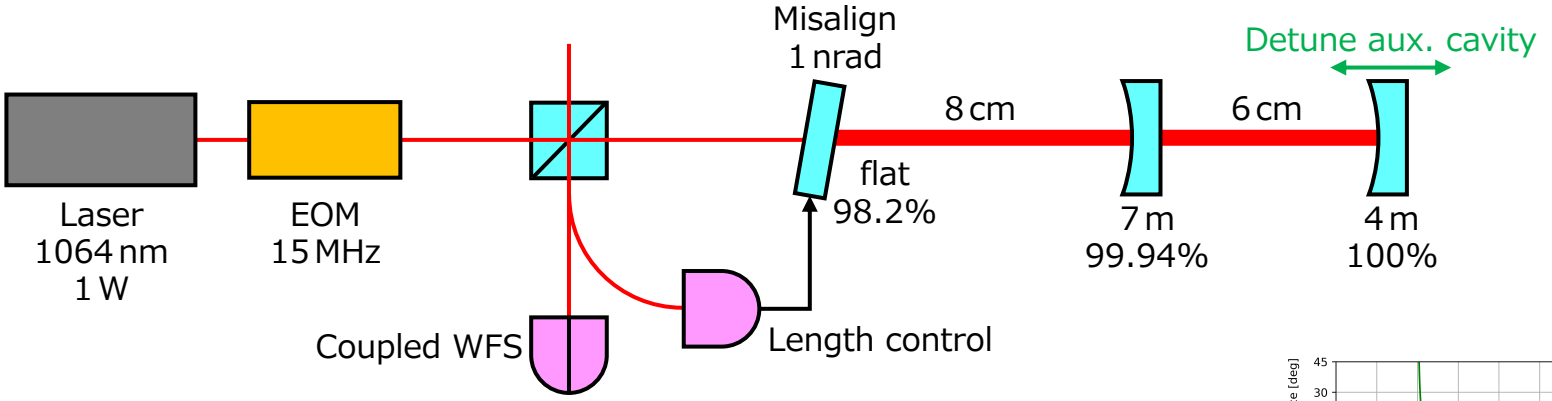
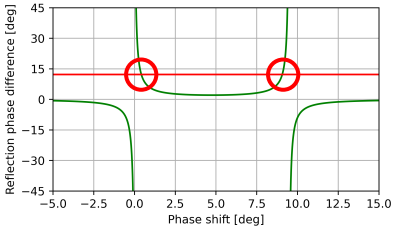
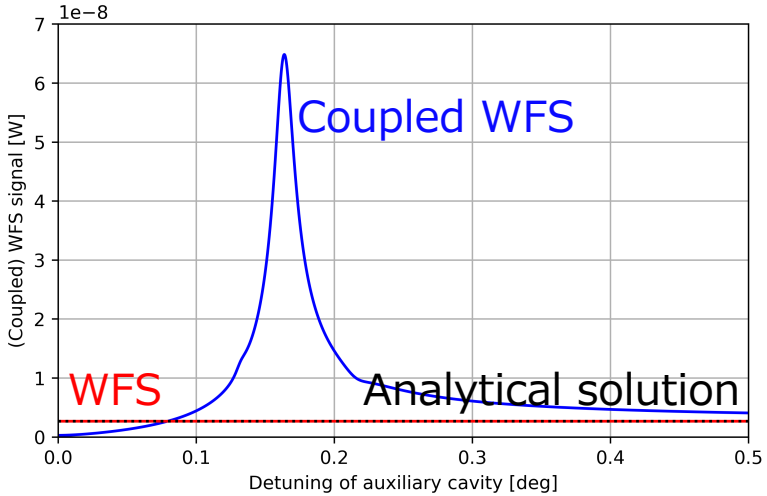
Signal amplification of Coupled WFS



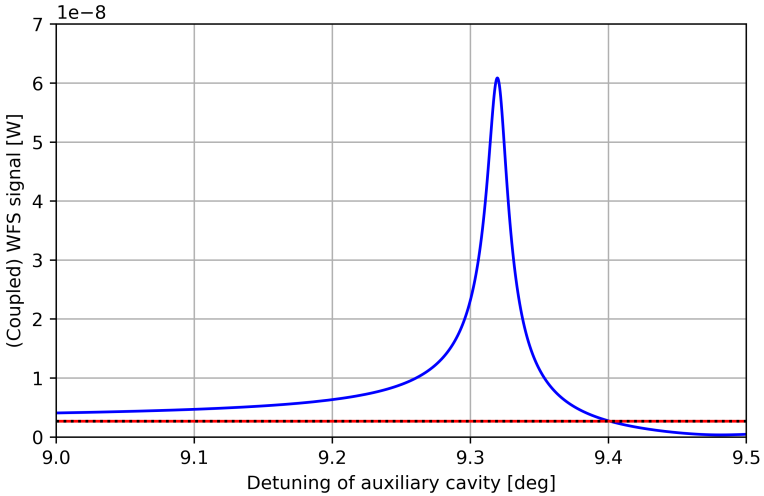


- Angular signal amplification was confirmed with simulation

Near 00 mode resonant point

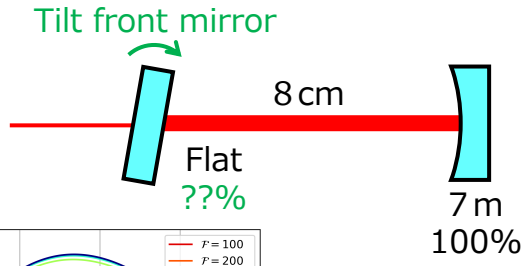


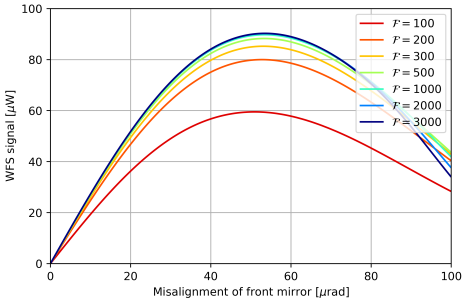
Near 10 mode resonant point

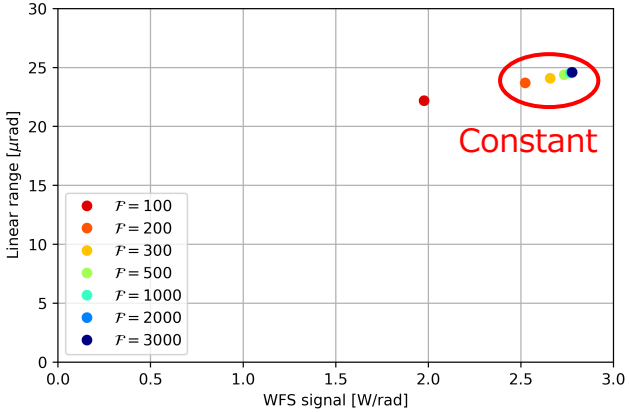


Linear range of WFS・Coupled WFS

WFS

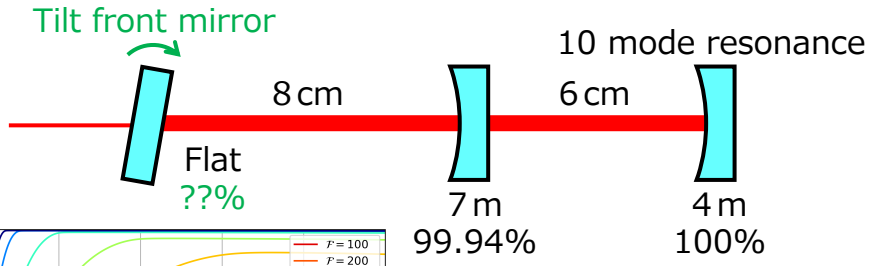


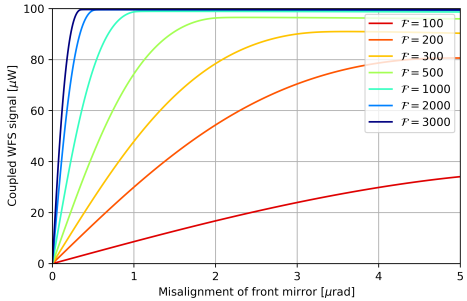


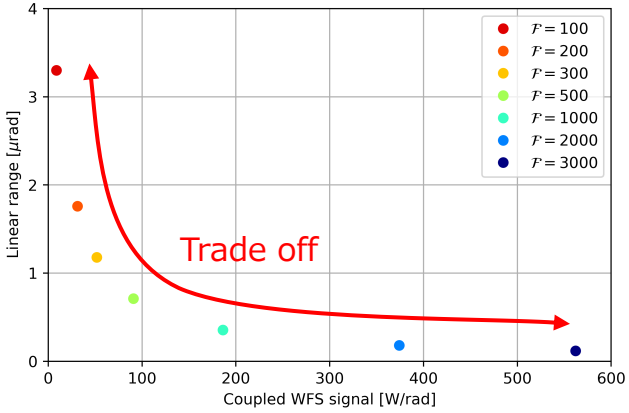


- Signal intensity and linear range do not depend on finesse

Coupled WFS







- The larger the finesse, the greater the signal intensity, and the smaller the linear range

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FINESSE simulation

- Introduction of FINESSE
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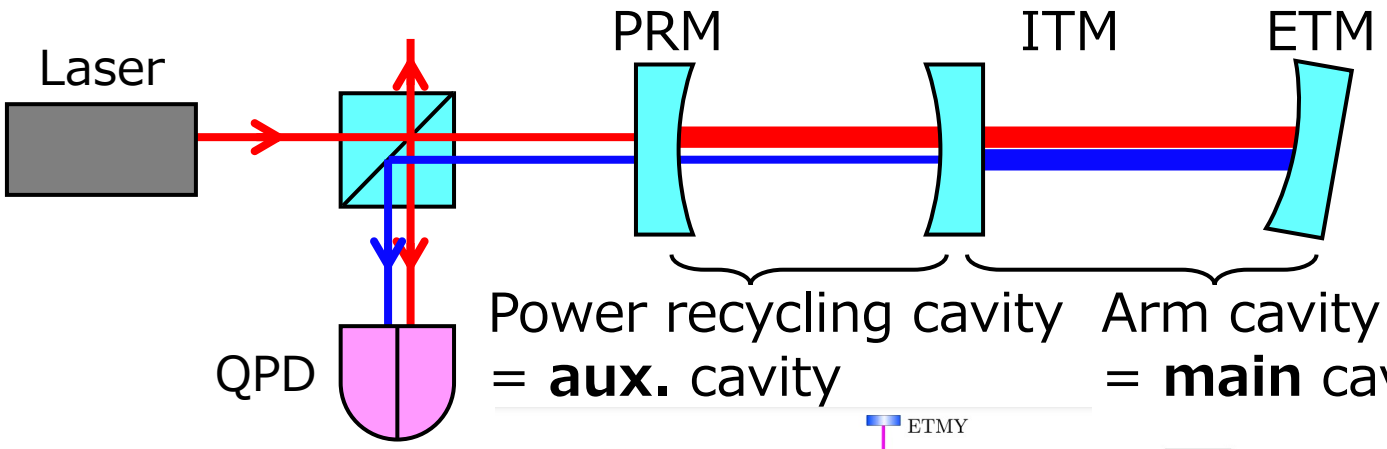
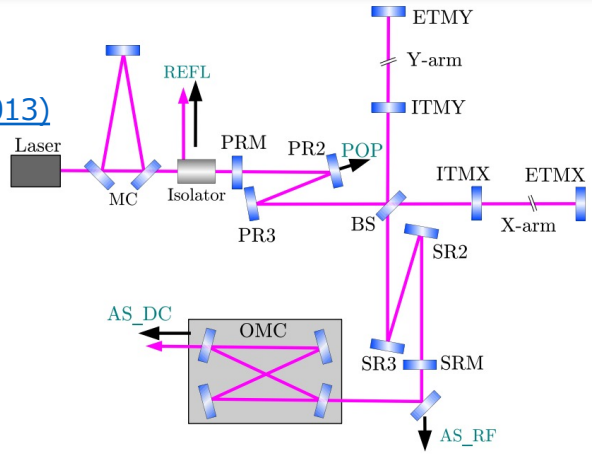
Coupled cavity in KAGRA

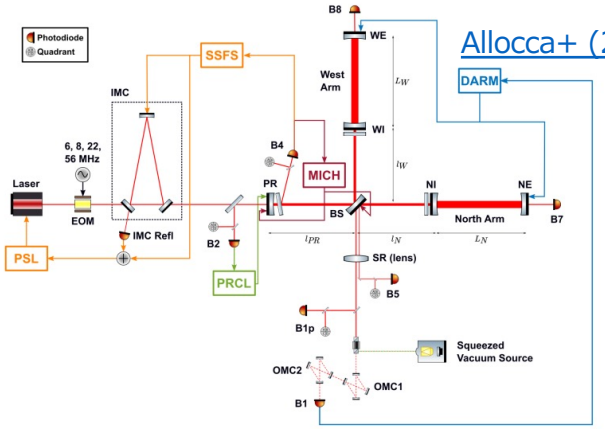
- KAGRA has a coupled cavity
  - → I want to calculate WFS signal amplification when PRC is detuned
  - → I want to compare with Virgo's configuration, or suggest the best PRC configuration



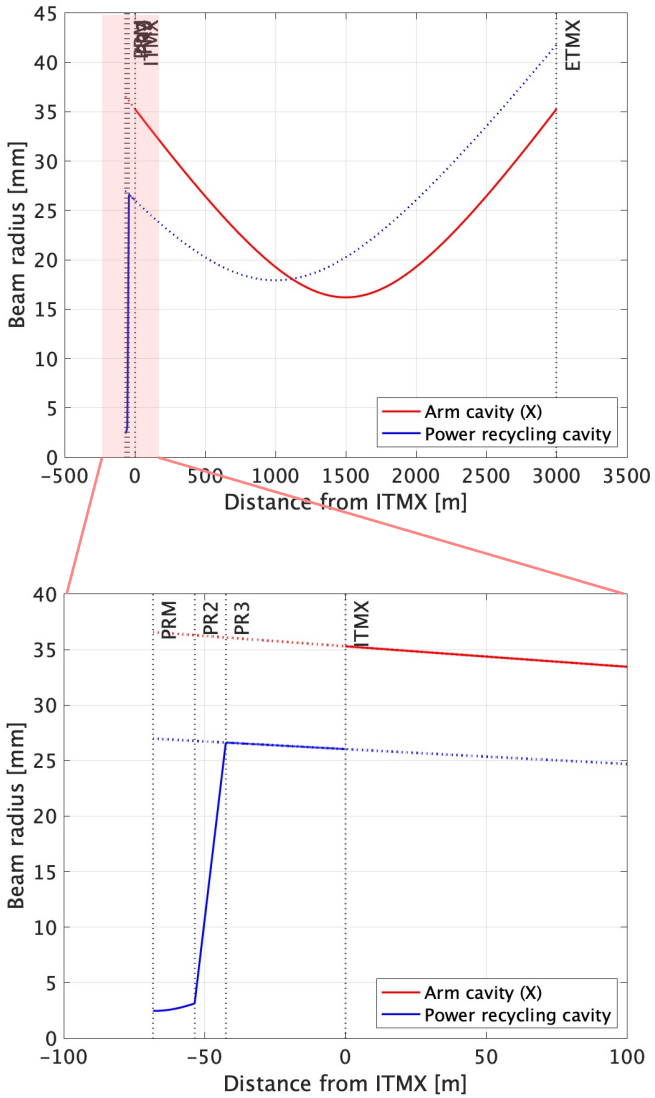
Aso+ (2013)

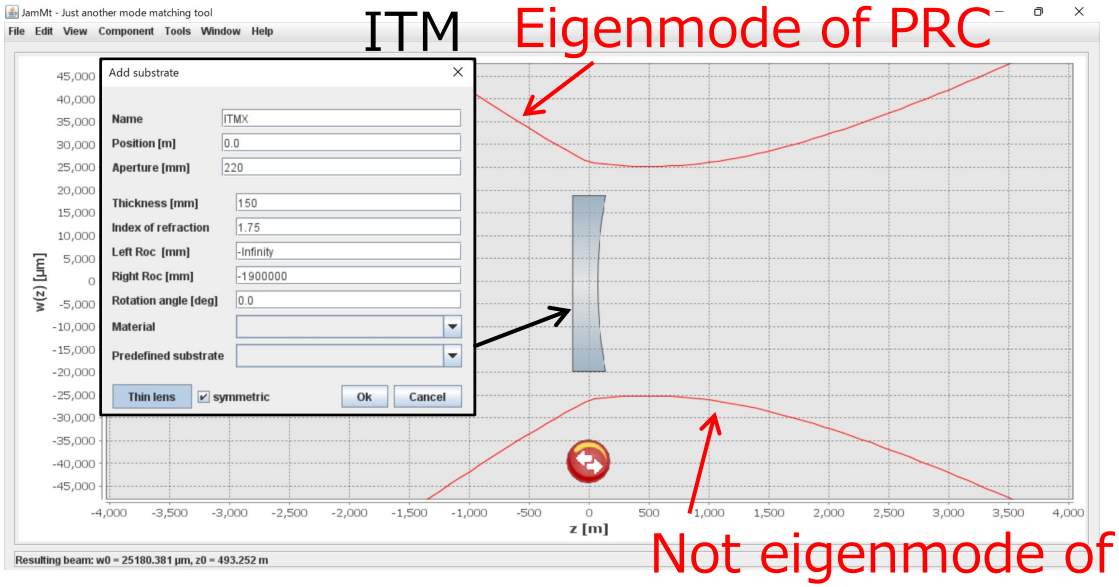


Allocca+ (2020)



Eigenmodes of KAGRA cavities





ITM

Eigenmode of PRC

Not eigenmode of arm cavity

- Seems that the eigenmodes of PRC and arm cavity in KAGRA do not match, even taking into account the effect of ITM

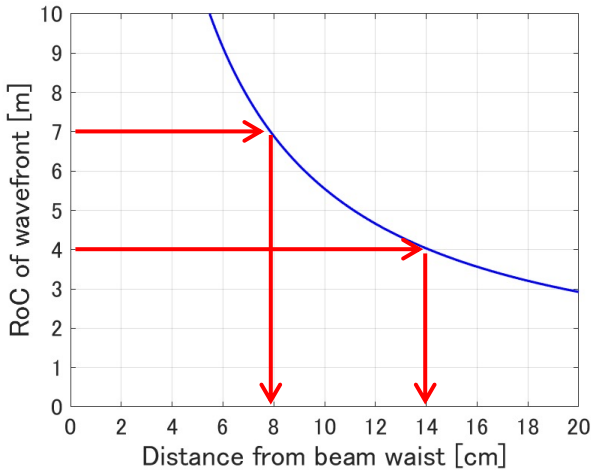
  → I want to ask someone and understand

JGW-T1100512-v2
JGW-G1200763-v1

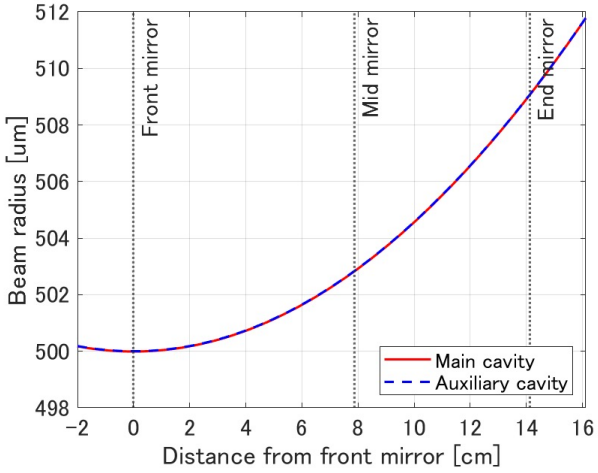
How to build coupled cavity

- Before calculating linear range of Coupled WFS, I have to build coupled cavity with FINESSE
- Eigenmode declared later is overwritten, so I have to calculate configuration of coupled cavity in advance
  - cav auxcav mid n7 end n8 ← Trace eigenmode for auxiliary cavity, but overwritten
  - cav maincav front n5 mid n6 ↑ Trace eigenmode for main cavity

RoC with beam radius of 500 um



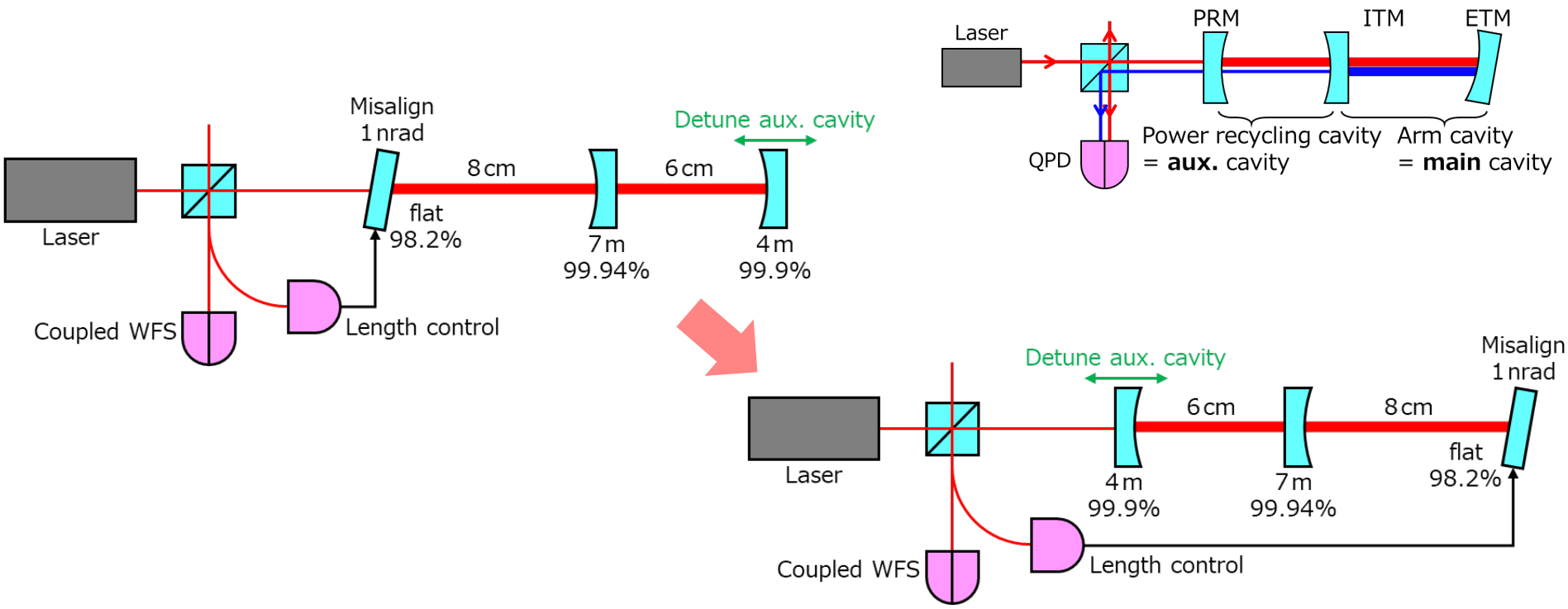
Eigenmodes of two cavities



RoC.m
Eigenmode.m

My try and error

- KAGRA is too long and too complicated
  - → I started with my master thesis's setup that swapped the front and back configurations
  - → Found that difficult to detune the front aux. cavity while keeping the back main cavity resonating
  - → I have to start with an easier situation. How?



Summary

DANCE Act-1

- Took and analyzed data in 2021
- Plan to finish data analysis and write a paper in 2022

Phase-III TOBA

- Demonstration of Coupled WFS in 2021
- Plan to suspend a mirror, take data, and finish the exp. of Coupled WFS in 2022
- Plan to start torsion pendulum exp. from easier step

FINESSE simulation

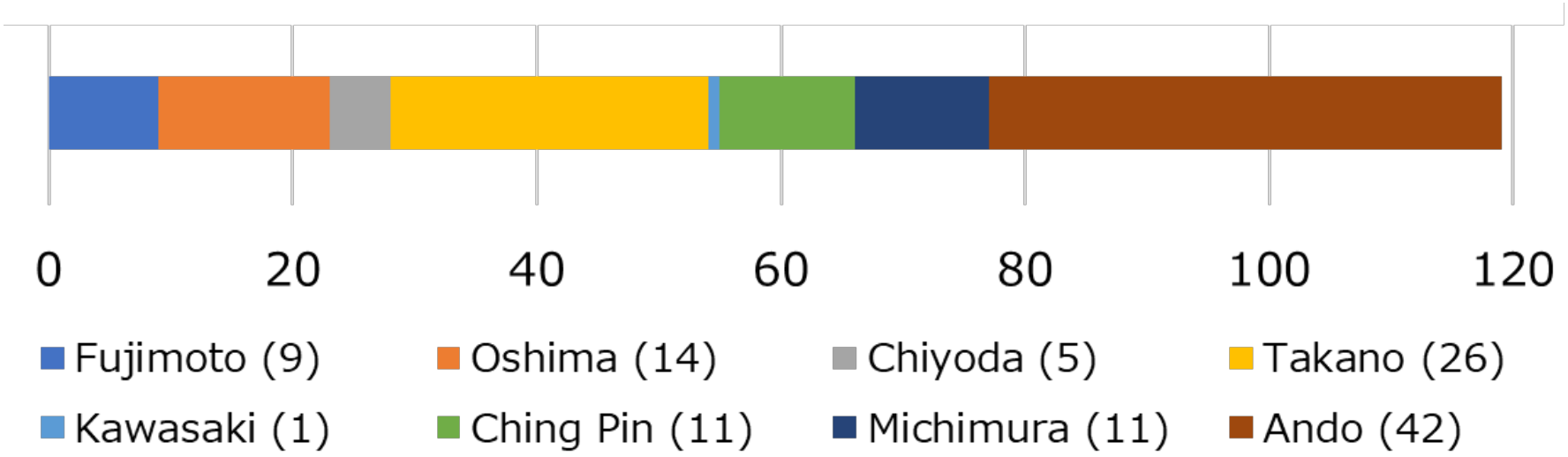
- Simulation of Coupled WFS in 2021
- Plant to start KAGRA simulation

また1年間よろしくお願いします

Bonus Slides

Ando Lab e-log analysis in 2021

- 119 e-log were posted in Apr. 1, 2020 – Mar. 31, 2021
- 40 meetings were held

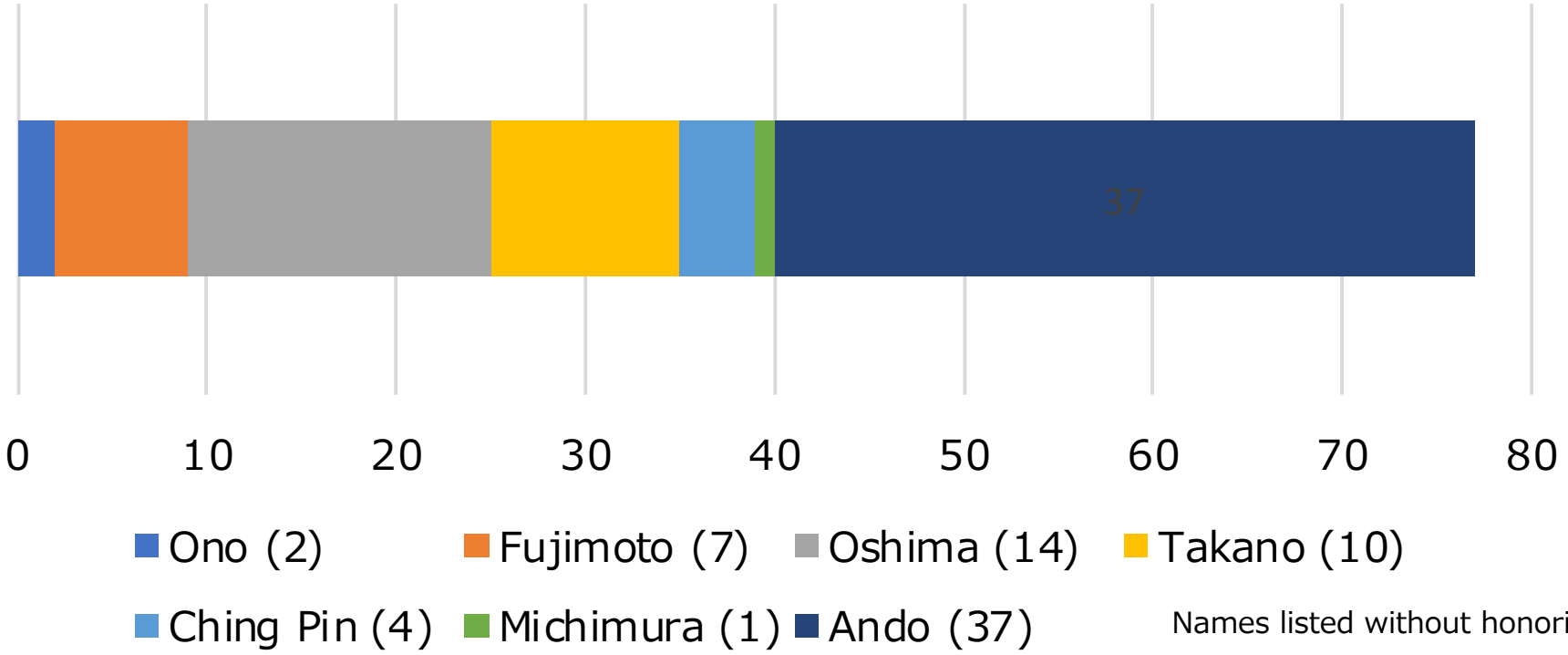


Names listed without honorifics

- Aritomi-san posted to NAOJ e-log
- Takeda-san wrote comments for meeting log

Ando Lab e-log analysis in 2022

- 77 e-log were posted in Apr. 1, 2021 – Mar. 31, 2022
- 37 meetings were held



- Kawasaki-san and Haoyu-san wrote comments for meeting log

List of e-log I posted

This page is just a memo for myself

- 2021/4/1 #5655 How to measure resonant frequency difference btw pol. accurately
- 2021/5/2 #5742 Frames of DANCE house at B111
- 2021/6/1 #5811 Design of Cavity Spacer
- 2021/7/16 #5927 Vacuum test of TOBA-WFS chamber
- 2021/7/30 #5953 Vacuum test of TOBA-WFS chamber (2)
- 2021/8/5 #5965 Water leakage issue of TOBA chiller
- 2021/8/6 #5981 Introducing laser beam into TOBA-WFS chamber
- 2021/9/4 #6015 Revision of Brownian Motion Text for FY2021
- 2021/10/1 #6049 Circuit Noise Inspection for Brownian Motion Experiment (2)

List of e-log I posted

This page is just a memo for myself

- 2021/11/3 #6112 Construction and Characterization of Auxiliary Cavity
- 2021/12/9 #6243 Calibration of Optical Lever
- 2021/12/10 #6251 Rough Characterization and Lock of Main Cavity
- 2021/12/17 #6279 Coupled cavity was locked by PDH technique
- 2021/12/17 #6297 Signal amplification was observed with Coupled WFS?
- 2022/2/14 #6378 History of resonant freq. difference of DANCE at B207
- 2022/2/14 #6394 Revision of Brownian Motion Text for FY2022

Extra Slides

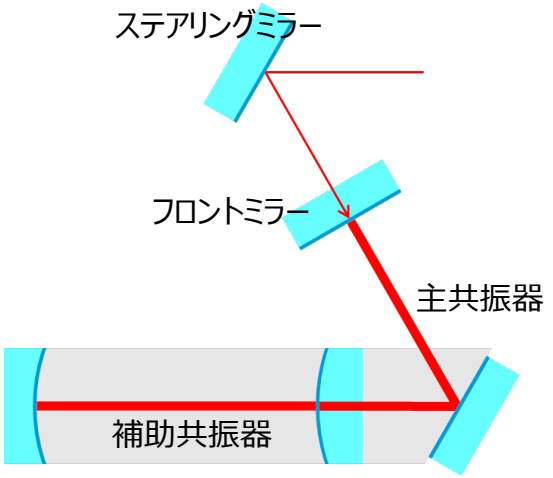
考察 1:共振器の固有モードのカップリング

- 現在の問題点
  - フロントミラーを置いた後は補助共振器のアラインメントを調整していない

    → 2 つの共振器の固有モードのカップリングが悪く
    補助共振器の 10 モードの光量が大きい

    → 主共振器内の光量が減少するため
    補助共振器の共振点に制御できない

    → 共振点から少しずれた点に制御がかかり
    透過光量が 1 次でふらついている



- 解決方法
  - ステアリングミラーとフロントミラーのアラインメントを調整して
    共振器の固有モードのカップリングを改善
    → 補助共振器の 10 モードの光量を減らす

考察 2: 補助共振器の制御の安定性

- 現在の問題点
  - 2 つの共振器の PDH 信号は 40 Hz 以上で相関をもっている
    → 高周波数帯までフィードバック信号を返せず制御が不安定
- 解決方法
  - フロントミラーを振り子で吊って防振し
    主共振器の高周波数帯での外乱を小さくする (設計・製作済み)
  - 主共振器のフィードバック信号をフロントミラーに返し
    PDH 信号の高周波数帯における相関を小さくする