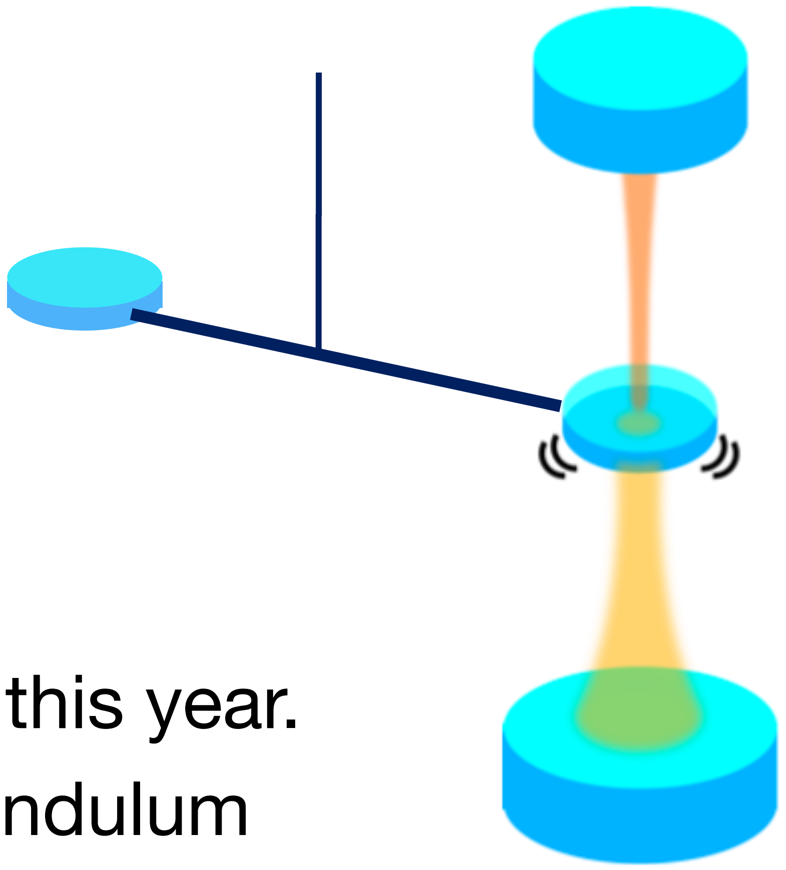
光学浮上のために頑張ること

安東研究室 修士2年
喜多直紀

安東研究室 中間報告会 2019/4/24

Abstract

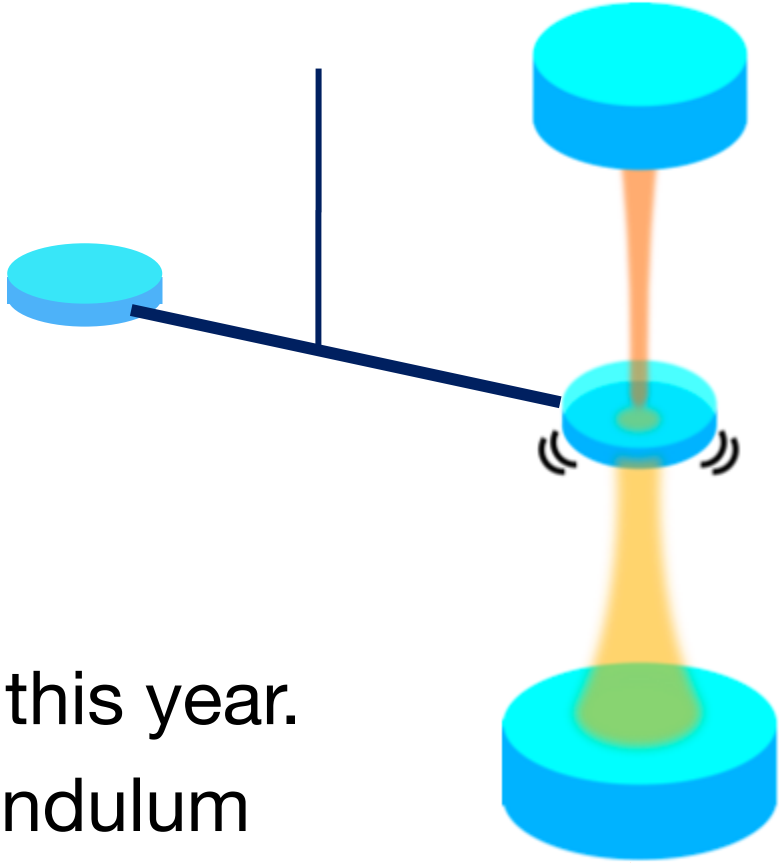


In this presentation, I talk about
My Road to Master Thesis.

I want to finish Torsional Pendulum experiment this year.

1. Replacing mirrors and installing a double pendulum
2. Locking the upper cavity and evaluating the frequency shift
3. Locking the two cavities and evaluating the frequency shift
4. Designing and Constructing the setup for Optical Levitation experiment

Abstract



In this presentation, I talk about
My Road to Master Thesis.

I want to finish Torsional Pendulum experiment this year.

1. Replacing mirrors and installing a double pendulum
2. Locking the upper cavity and evaluating the frequency shift
3. Locking the two cavities and evaluating the frequency shift
4. Designing and Constructing the setup for Optical Levitation experiment

Contents

- Introduction
  > Concept of Optical Levitation
- What we did last year
  > Experiment with the setup introduced PBSs
- What I will do this year

Contents

- Introduction
  > Concept of Optical Levitation

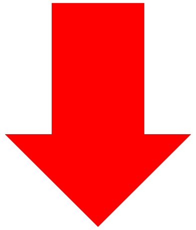
- What we did last year
  > Experiment with the setup introduced PBSs

- What I will do this year

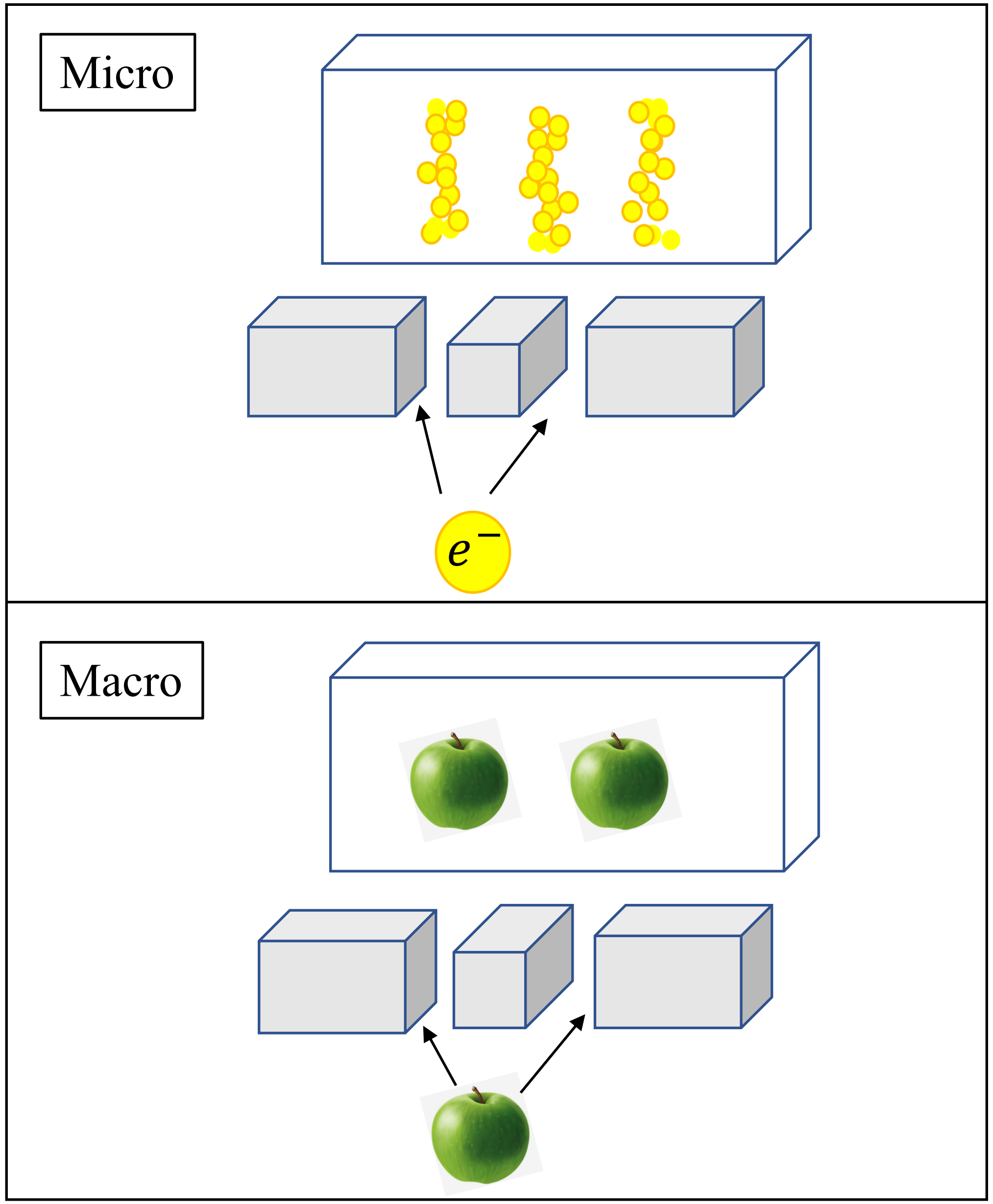
Background

In the macro scale, quantum effects have not been observed.

Ex. Superposition



Why can't we observe the effects in the macro scale??



Background

The reason is that

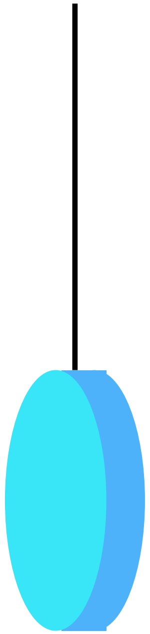
- the effects is buried under large classical noise?
- there is an upper limit mass for quantum mechanics?

➡ We need to reduce classical noise in “mg” scale in order to solve this problem.

Seismic noise, gas noise, thermal noise and so on.

Avoiding suspension thermal noise

By suspension with
a wire, there is
suspension thermal noise



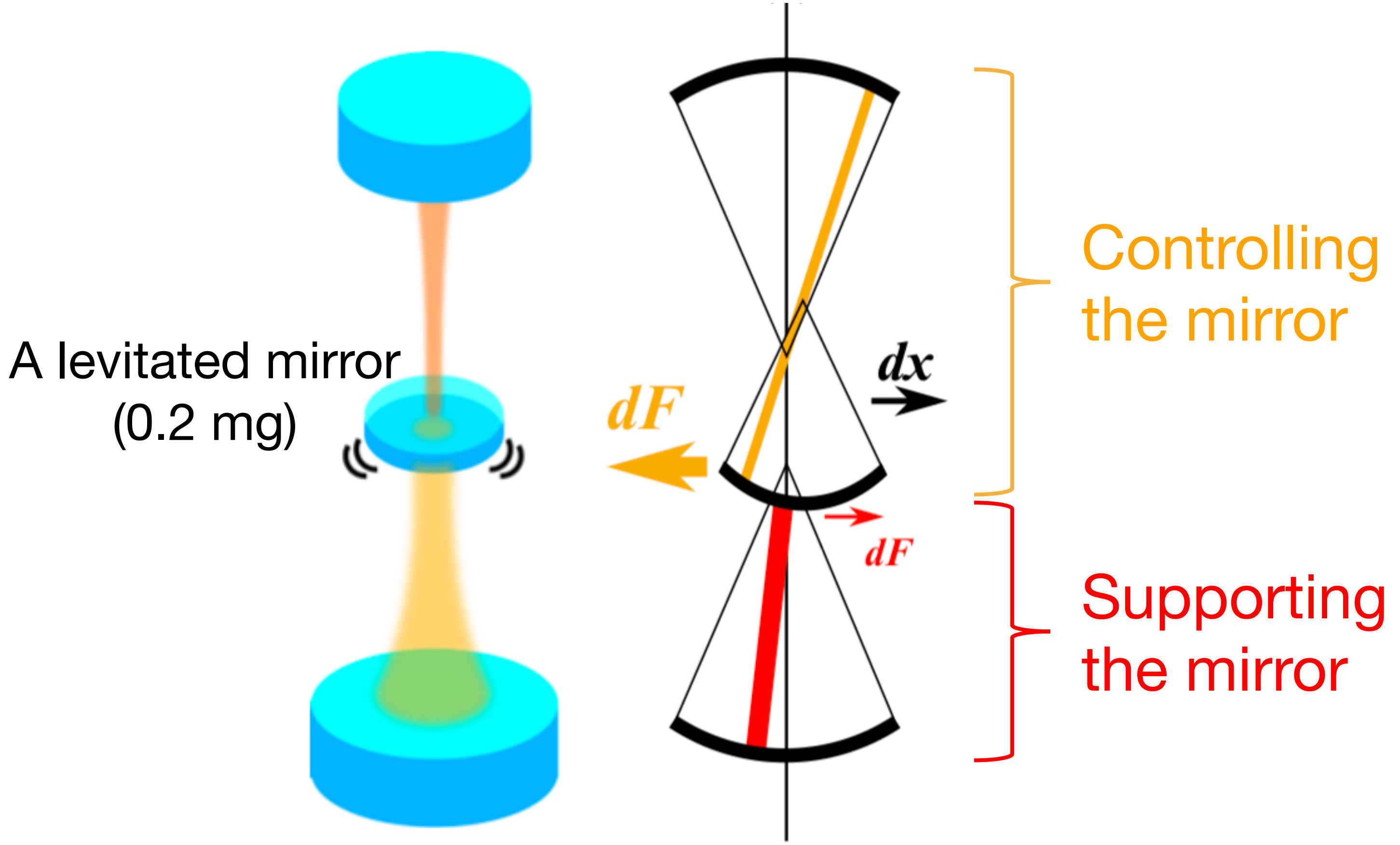
Pendulum

Optical Levitation

Because a mirror is
supported just by
radiation pressure,
there is no thermal noise

Optical Levitation

Optical Levitation is a method which can avoid thermal noise.



A restoring force works by tilting of the optical axis with a mirror's infinitesimal displacement

Theoretically stable

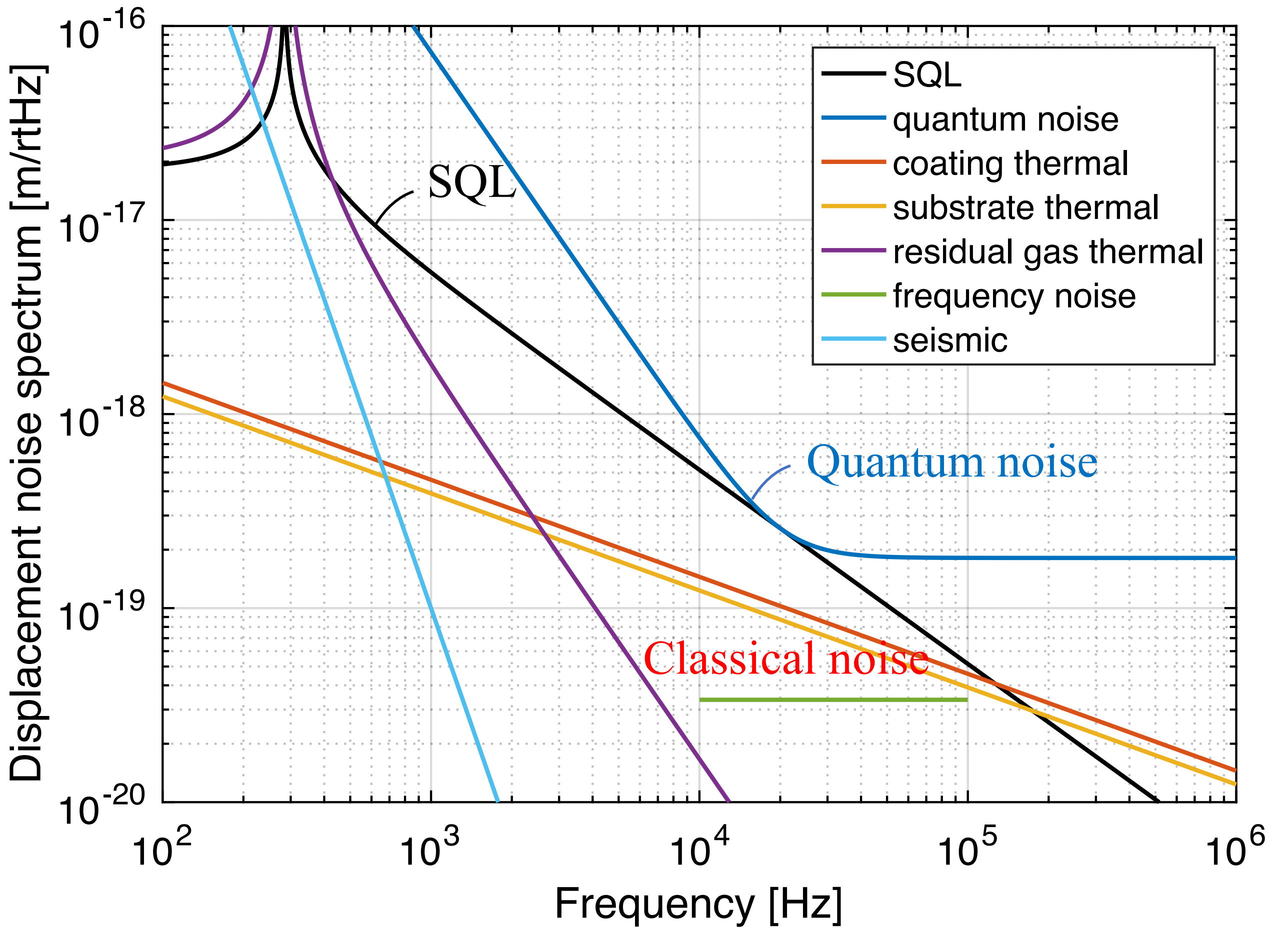
(Y. Michimura+ 2017)

SQL (Standard Quantum Limit)

SQL is the lower limit of measurement sensitivity which is determined by quantum noise.

Shot noise & Radiation pressure noise

With optical levitation method, we can reach SQL @23 kHz.

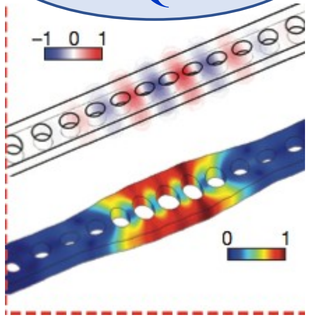


An example of sensitivity of Optical Levitation experiment

Previous research

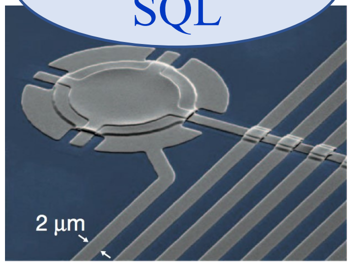
Our research is for mg scale.

Reached
SQL



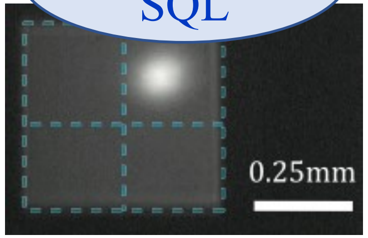
nanomechanical
oscillator, 311fg
Chan+(2011)

Reached
SQL



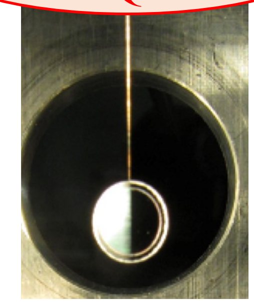
membrane, 48pg
Teufel+(2011)

Reached
SQL



membrane, 7ng
Peterson+(2016)

Not reached
SQL

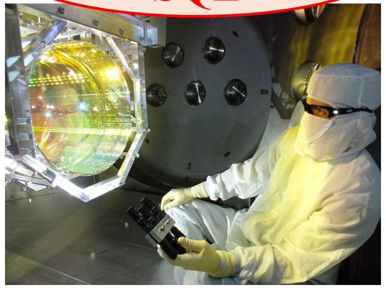


suspended mirror, 5mg
Matsumoto+(2014)

Not reached
SQL

Suspended mirror, 1g
Neben+(2012)

Not reached
SQL



suspended mirror, 40kg
GW detector
(LIGO, Virgo, KAGRA)

fg pg ng mg g kg

Mass

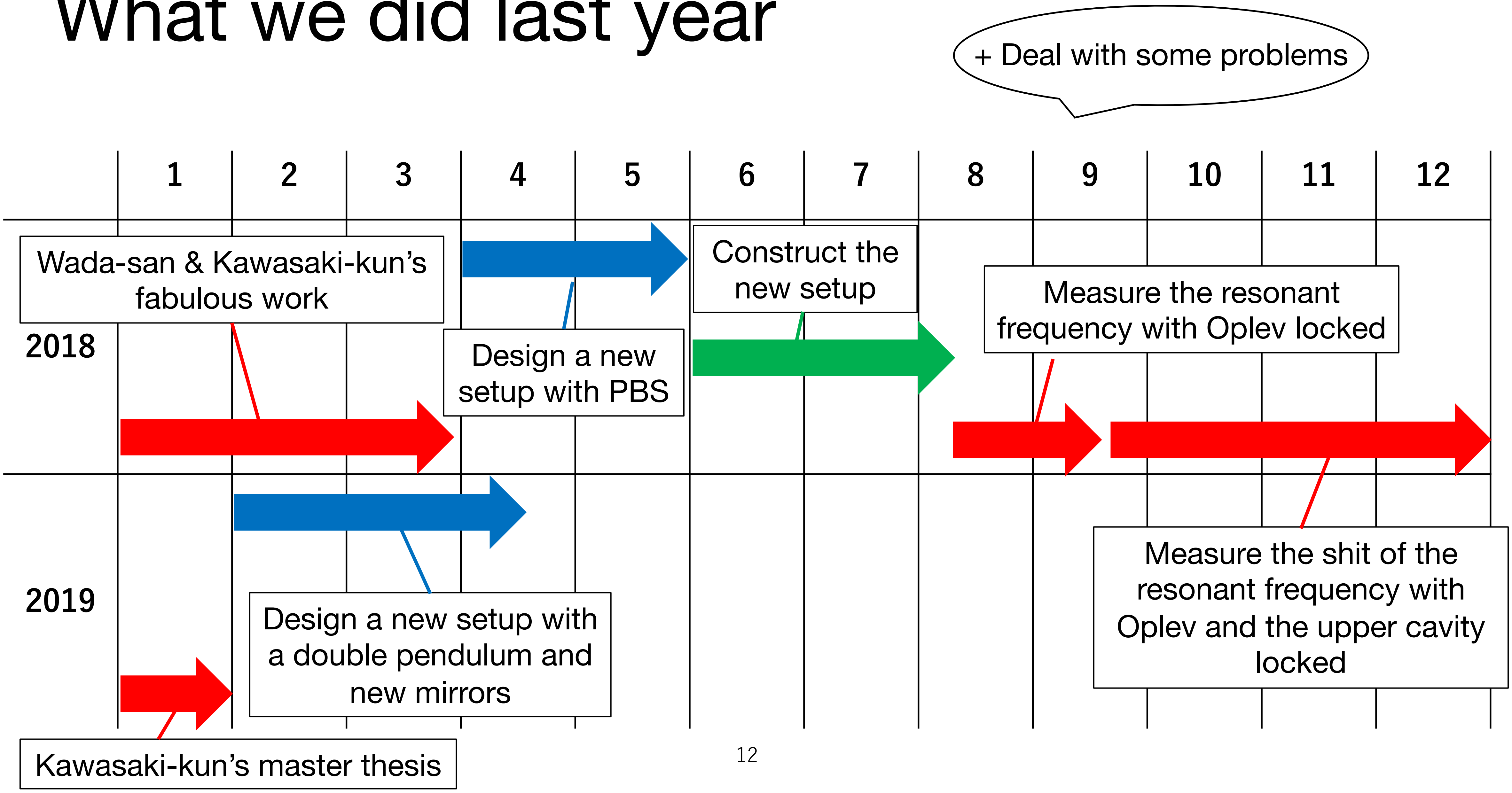
Contents

- Introduction
  > Concept of Optical Levitation

- What we did last year
  > Experiment with the setup introduced PBSs

- What I will do this year

What we did last year



Kawasaki-kun's setup with PBSs

Kawasaki-kun designed a new setup with PBSs so as to measure intra-cavity power directly.

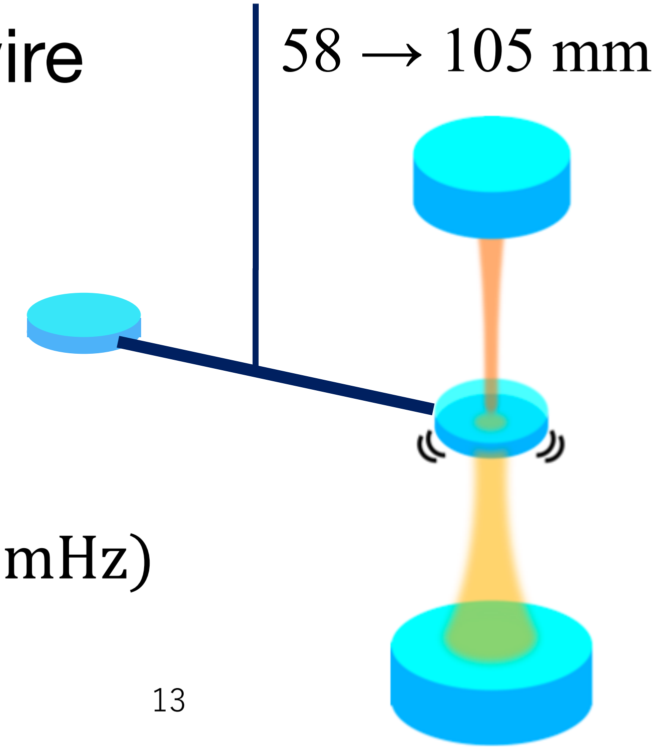
And made the length of a wire longer than Wada-san's.

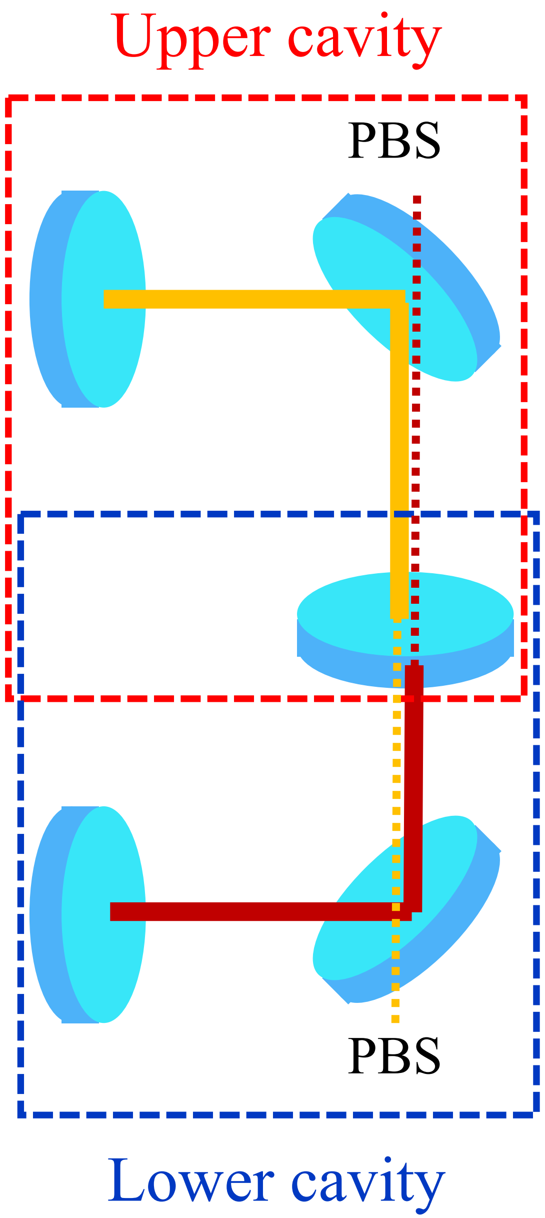
$$f_{yaw} = \frac{1}{2\pi}\sqrt{\frac{\pi n r^4}{2lI_{yaw}}} = 17.0\ \mathrm{mHz}$$

$$\downarrow$$

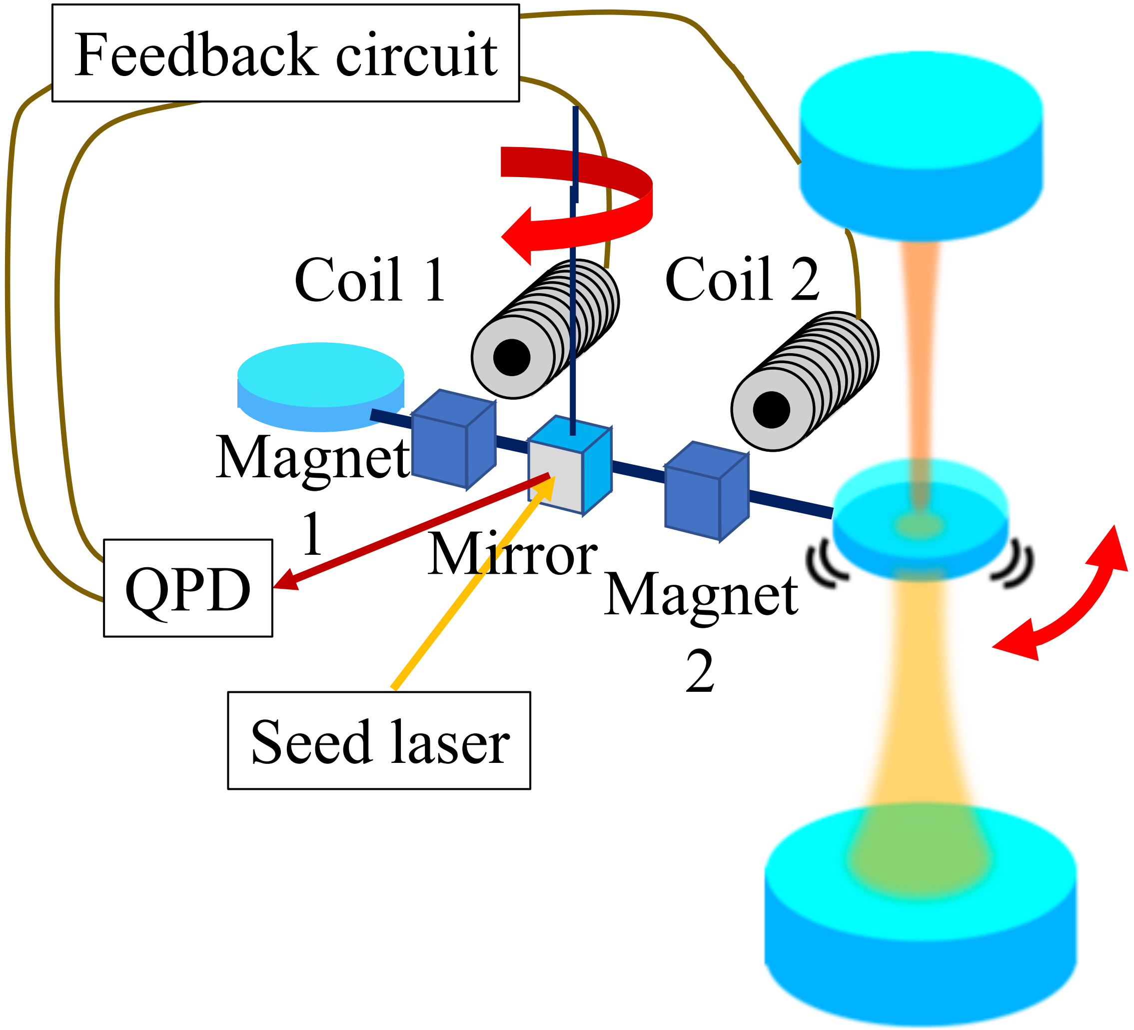
$$15.0\ \mathrm{mHz}$$

$$(\mathrm{measured}: 21.2 \pm 0.2\ \mathrm{mHz})$$





Evaluating the stability in YAW direction



<How to>

- We adopt a resonant frequency as a quantitative value for a restoring force.
- With optical lever locked, we measure the open-loop transfer function.

<Why use a torsional pendulum?>

- We can measure the restoring force directly because it is sensitive to a weak force.

Evaluating the stability in YAW direction

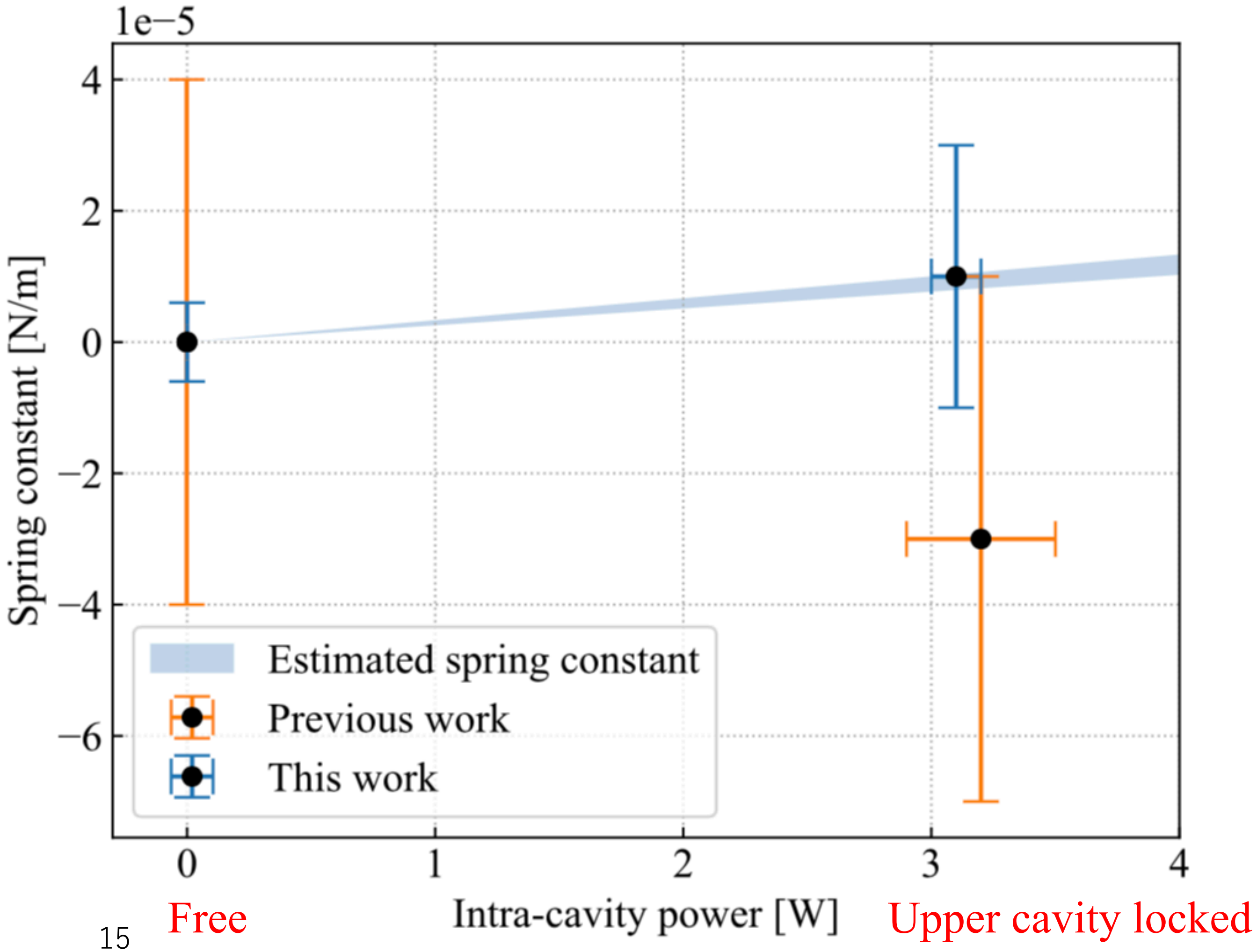
Free

▶ resonance : 21.2±0.2 mHz

Upper cavity locked

▶ resonance : 21.6±0.6 mHz

The shift is not valid because error of the resonant frequency is large.



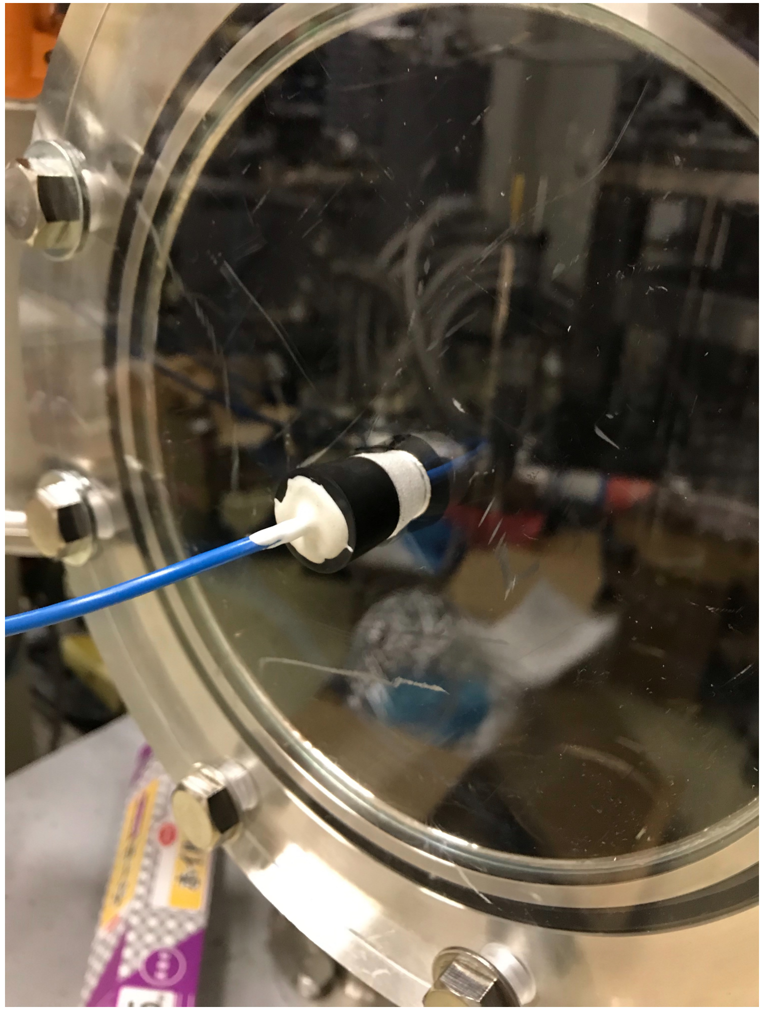
Dealing with problems

- Feed through

With conventional feed through, we can't introduce high power laser into the chamber.

➡ So we made an original feed through for high power.

		conventional	Hand-made
Pre-feed through power	P_{pre}	~1.0 W	~1.0 W
Post-feed through power	P_{post}	~0.1 W	~0.5 W

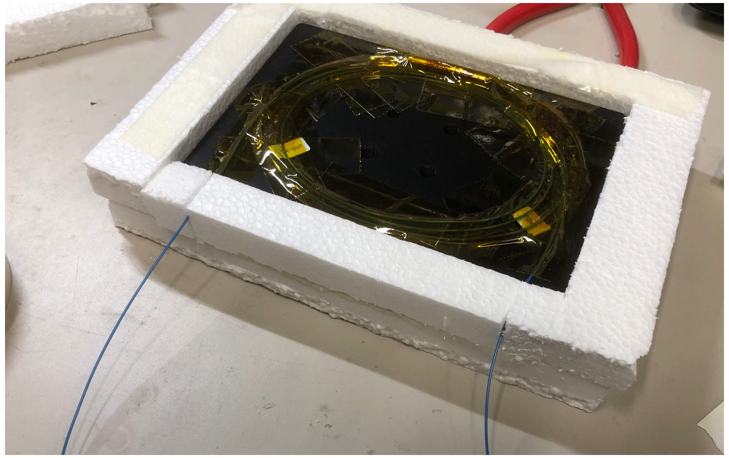


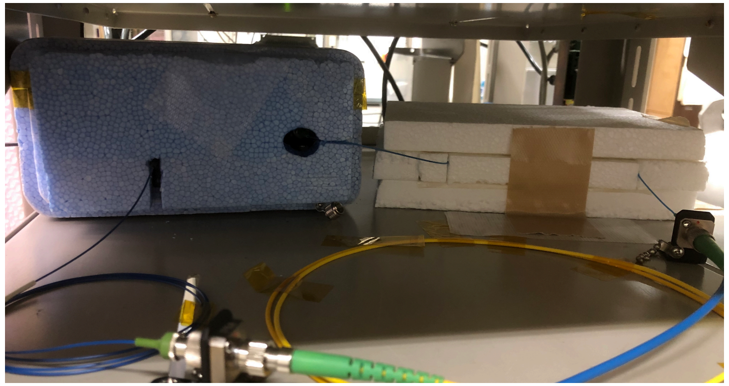
Dealing with problems

- Fluctuation of PDH signal

  The temperature in lab is fluctuating by air conditioning and the polarization of laser is rotating.
  = Unstable cavity lock

We cover the EOM and the isolator with styrofoam boxes.
Then we can reduce it and lock the upper cavity for a few hours.

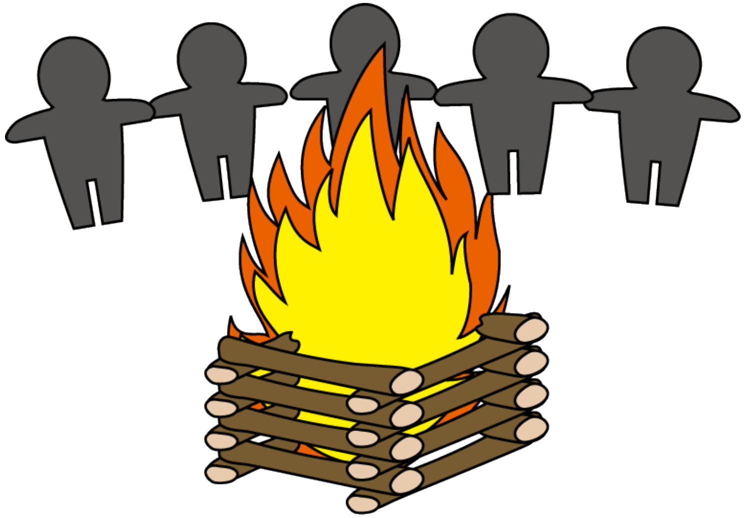




From the next slide, I talk about today’s main theme

“What I will do this year”

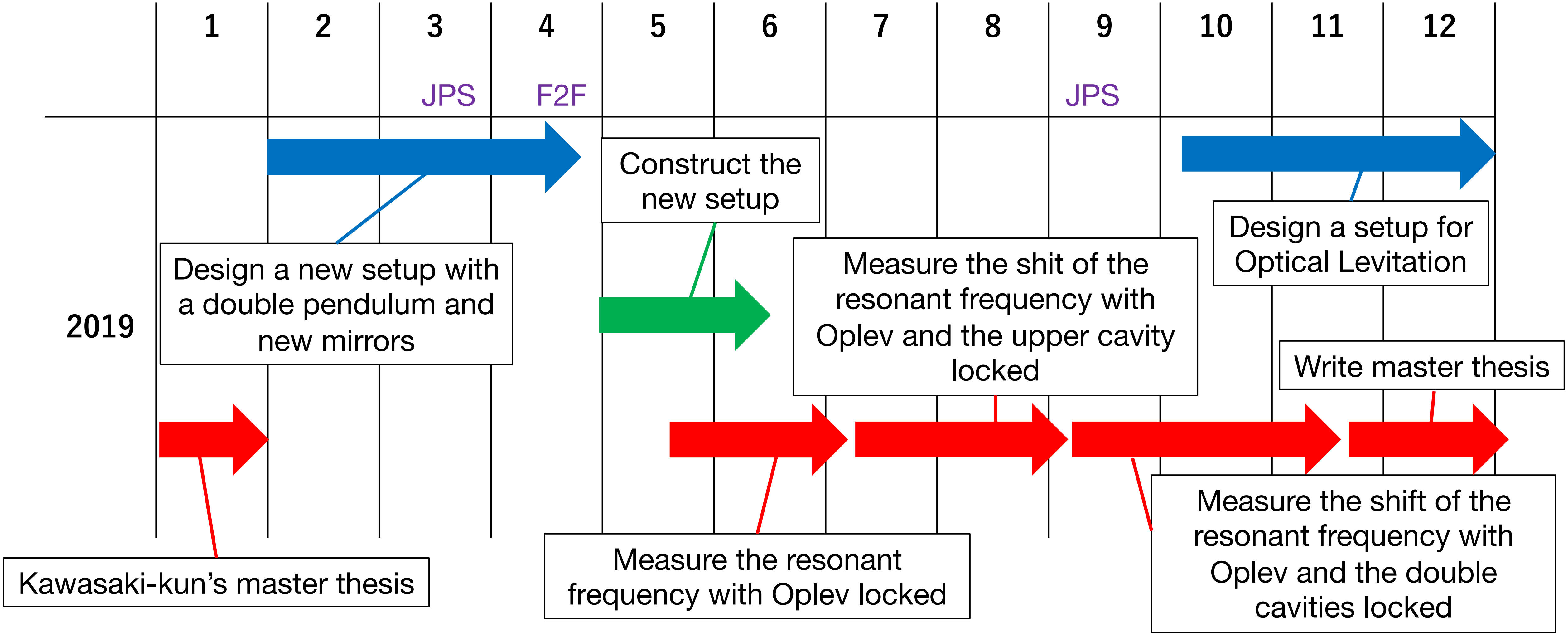
If you have ideas and advices, please tell me.



Contents

- Introduction
  > Concept of Optical Levitation
- What we did last year
  > Experiment with the setup introduced PBSs
- What I will do this year

What I will do this year



Problems of the current setup

Humanly

- How to share the work with Kawasaki-san?

Can't see a shift of the resonant frequency

Optical

- Intra-cavity power is very small.

- The polarization of laser is still rotating.

mechanical

- Inertial momentum of the torsional pendulum is large.

- Actuator coupling(Yaw→Roll) is large and the cavity lock is unstable.
- Mode matching rate is wrong during measurements because we need to introduce large signal.

Problems of the current setup

Humanly

- How to share the work with Kawasaki-san?

Can't see a shift of the resonant frequency

Optical

- Intra-cavity power is very small.

- The polarization of laser is still rotating.

mechanical

- Inertial momentum of the torsional pendulum is large.

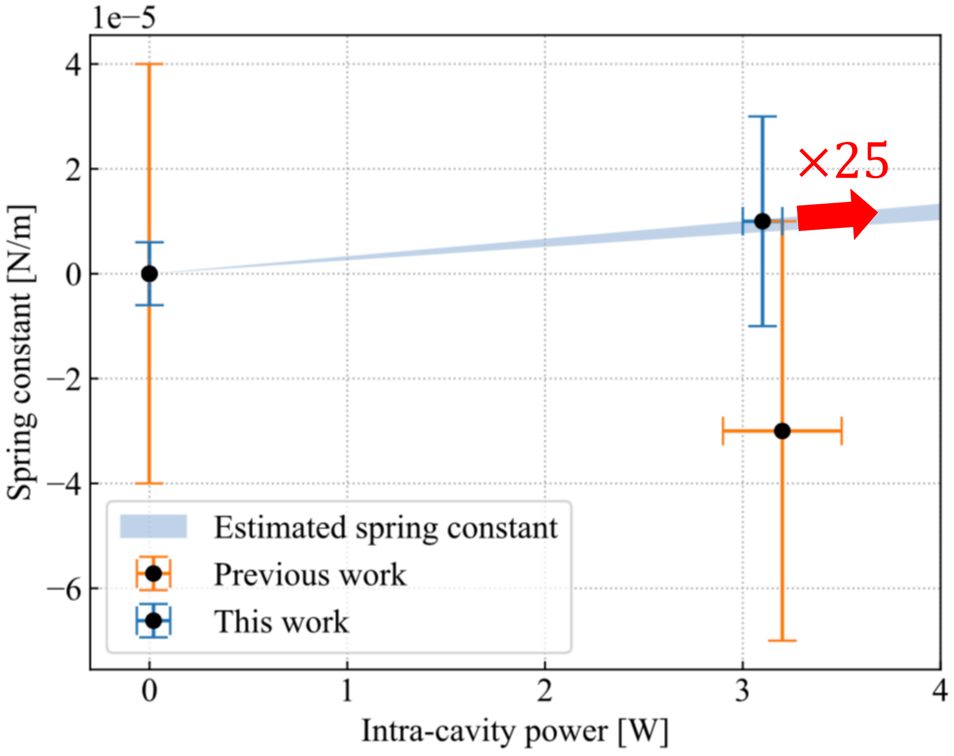
- Actuator coupling(Yaw→Roll) is large and the cavity lock is unstable.
- Mode matching rate is wrong during measurements because we need to introduce large signal.

Make intra-cavity power higher

- We want to make intra-cavity power much higher.

➡ Change the mirrors.

		Current(measured)	New(designed)
Input power	P_{in}	0.5 W	0.5 W
Finesse	$\mathcal{F}$	660 ± 50	1800
Intra-cavity power	P_{cavity}	3.1 ± 0.1 W	80 W
Shift of frequency	f_{shift}	0.3 ± 0.3 mHz	6.1 mHz



Make the pendulum's inertial momentum smaller

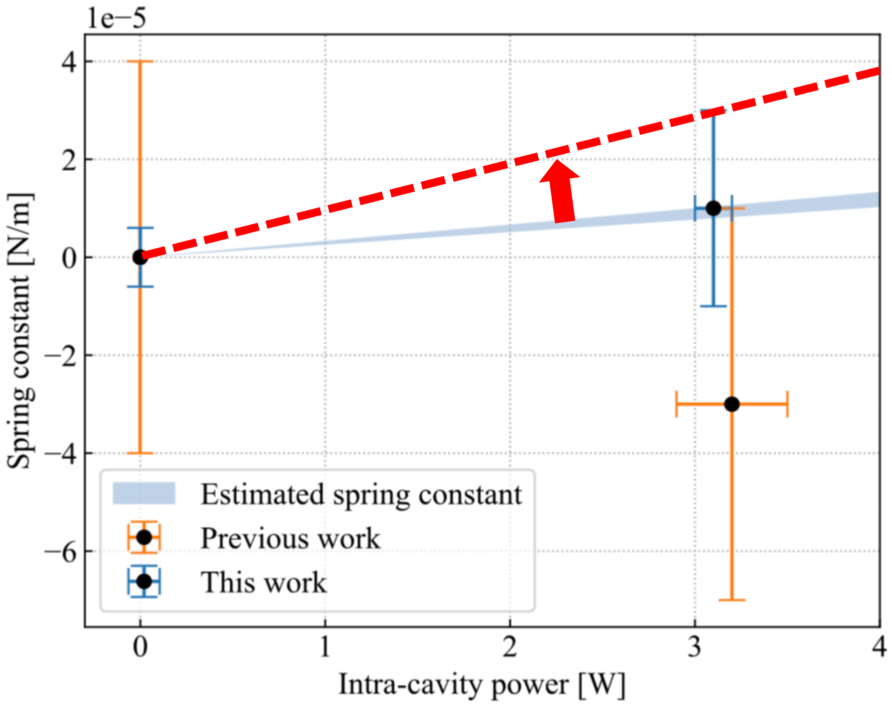
We want to make the inertial momentum of the torsional pendulum smaller.

Shift of the resonant frequency $$\frac{1}{2\pi}\sqrt{\frac{\pi n r^4}{2 l I_{yaw}} + \frac{1}{a}\frac{2P_{circ}}{c I_{yaw}}} - \frac{1}{2\pi}\sqrt{\frac{\pi n r^4}{2 l I_{yaw}}}$$

I_{yaw}: Inertial momentum in YAW
P_{circ}: Intra-cavity power

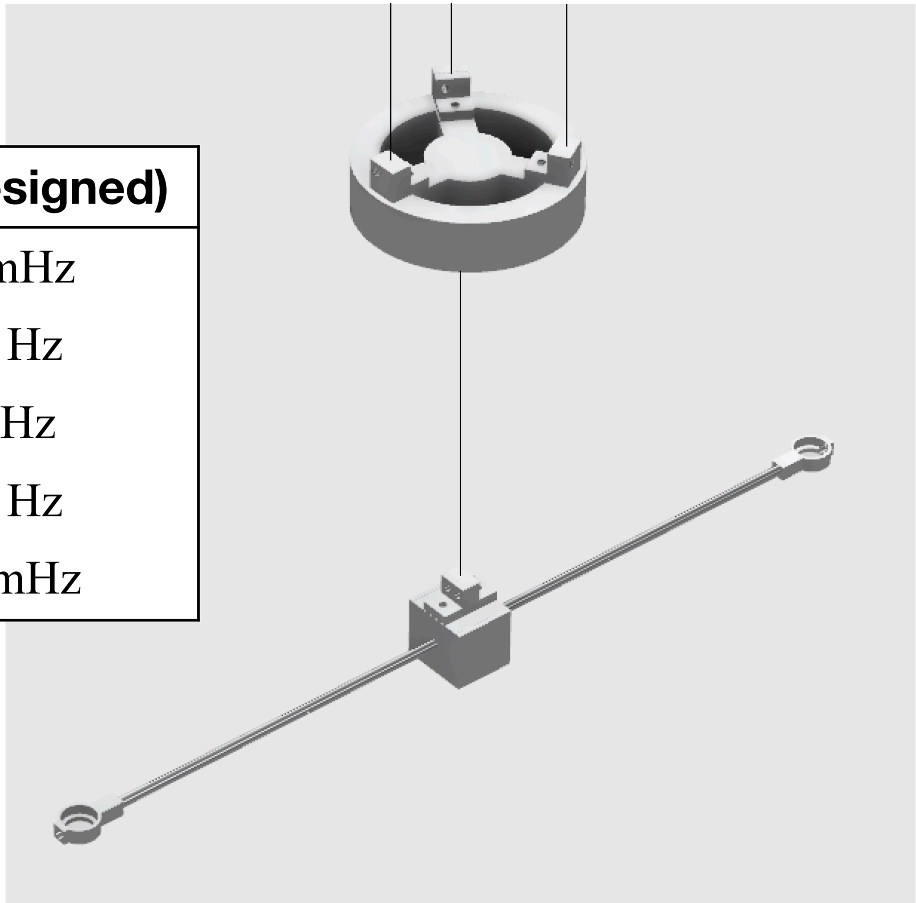
➡ Change the torsional pendulum.

		Current(measured)	**New(designed)**
Radius of a wire	a	25 um	20 um
Length of a wire	L	105 mm	mm
Inertial momentum	I_{YAW}	1.06×10^{-4} kg m^2	8.51×10^{-6} kg m^2
Shift of frequency	f_{shift}	0.3 ± 0.3 mHz	2.4 mHz



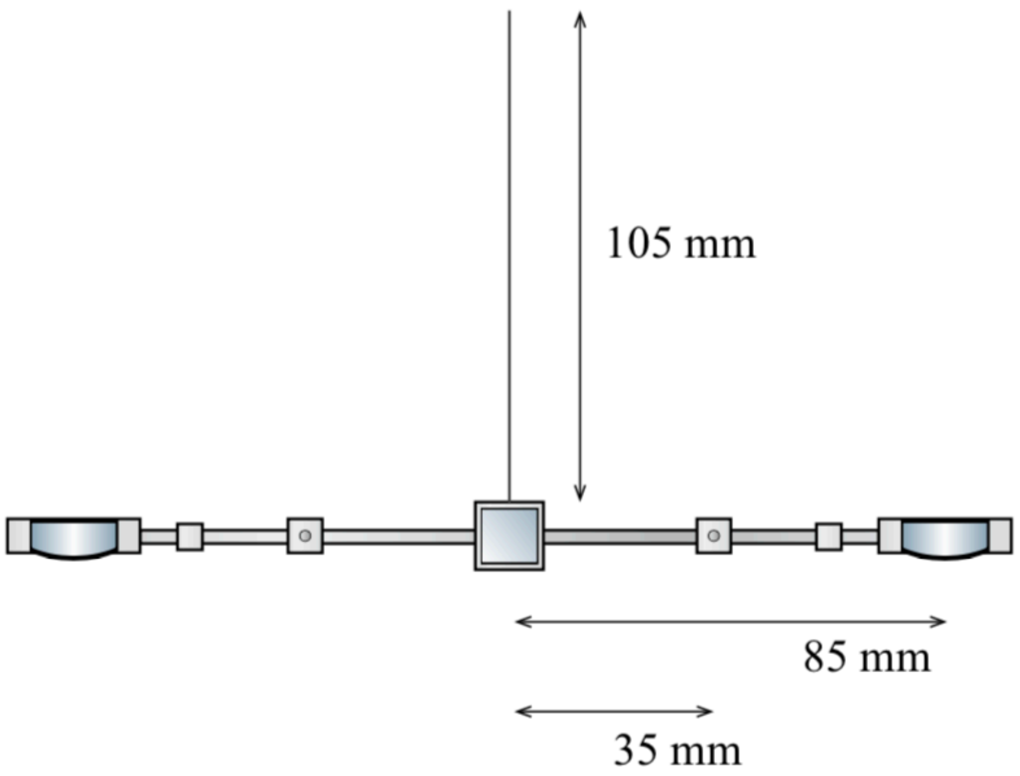
Design of new pendulum

		Current(designed)	New(designed)
Resonant frequency	f_{YAW}	15 mHz	38 mHz
	f_{ROLL}	0.88 Hz	1.7 Hz
	f_{Pitch}	11 Hz	11 Hz
	f_{LONG}	1.5 Hz	1.7 Hz
Shift of frequency	f_{shift}	0.3 ± 0.3 mHz	2.4 mHz

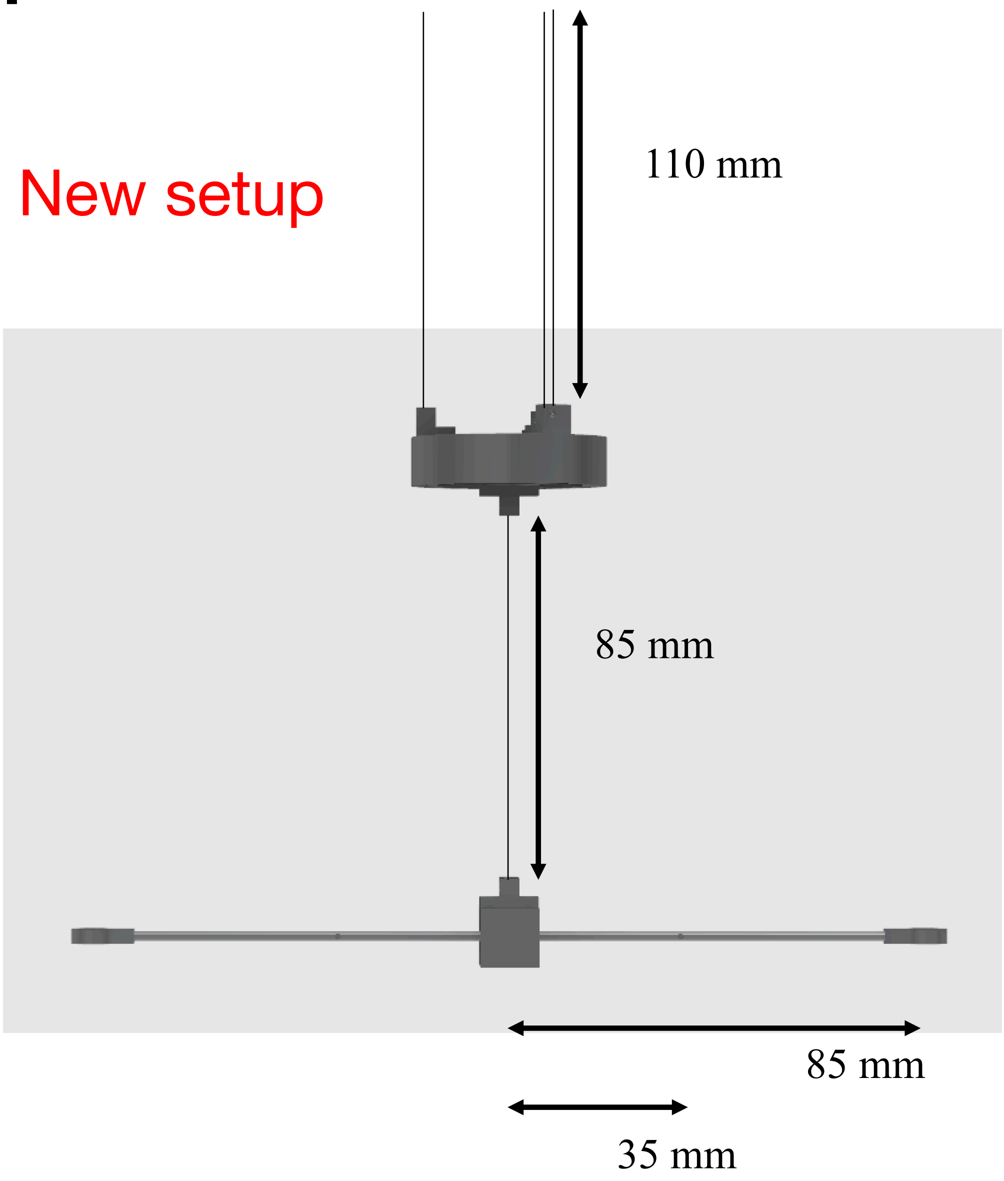


Design of new pendulum

Current setup

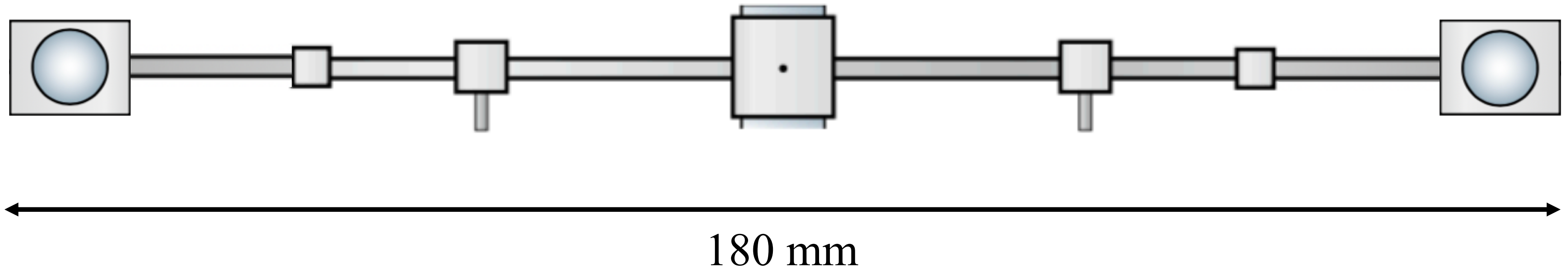


New setup

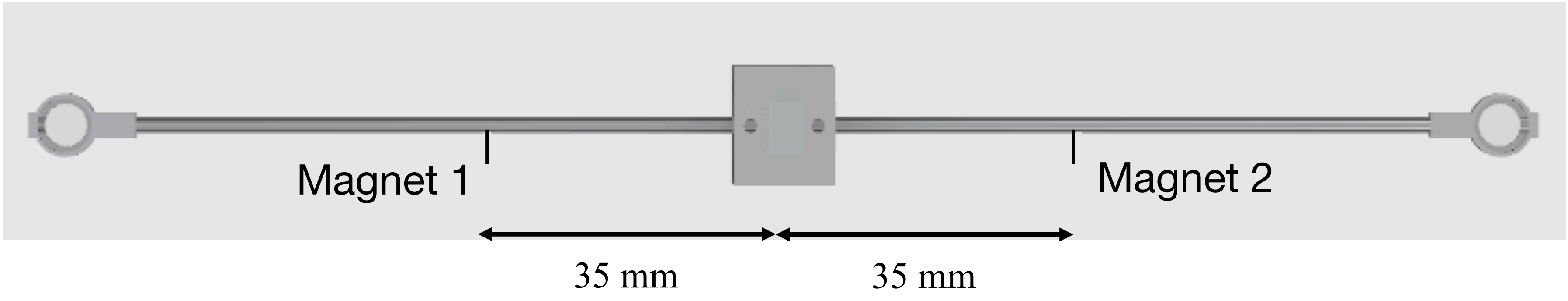


Design of new pendulum

Current setup

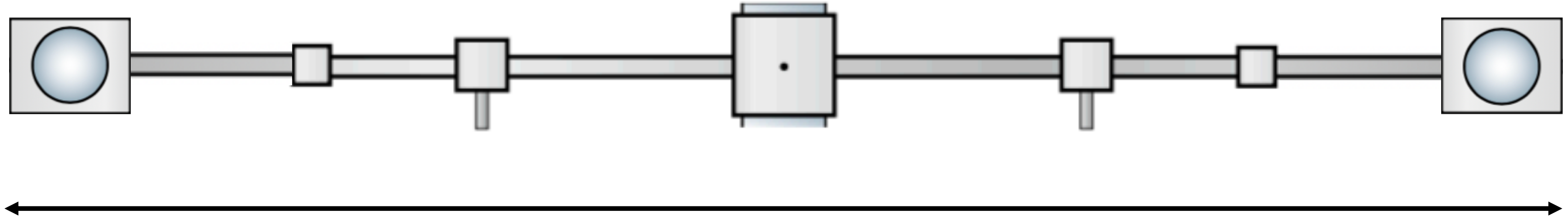


New setup

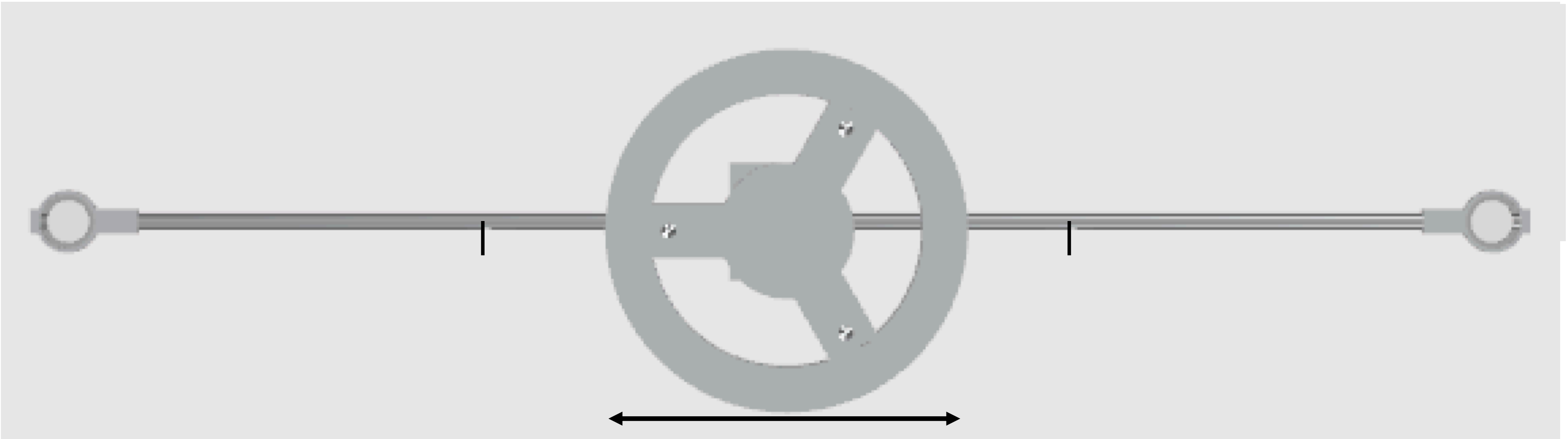


Design of new pendulum

Current setup



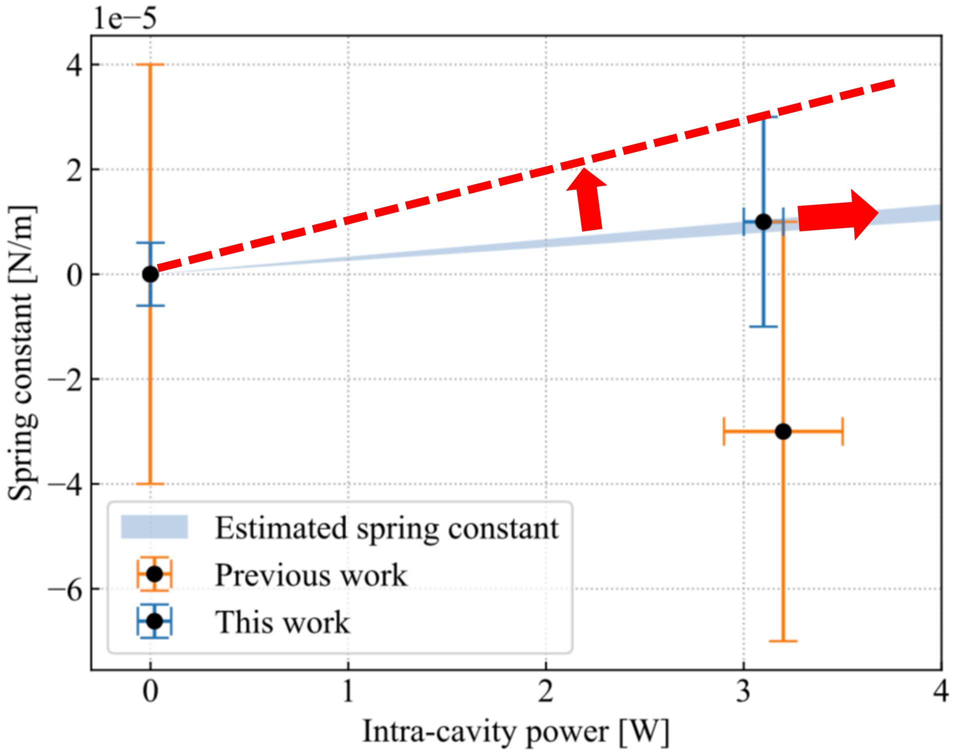
New setup



Higher power & smaller inertial momentum

If we can get higher power and smaller inertial momentum,
the shift of the resonant frequency is much larger.

		Current(measured)	New(designed)
Input power	P_{in}	0.5 W	0.5 W
Finesse	$\mathcal{F}$	660 ± 50	1800
Intra-cavity power	P_{cavity}	3.1 ± 0.1 W	80 W
Radius of a wire	a	25 um	20 um
Length of a wire	L	105 mm	85 mm
Inertial momentum	I_{YAW}	1.06×10^{-4} kg m^2	8.51×10^{-6} kg m^2
Shift of frequency	f_{shift}	0.3 ± 0.3 mHz	40.7 mHz



Problems of the current setup

Humanly

- How to share the work with Kawasaki-san?

Can’t see a shift of the resonant frequency

Optical

If we solve this two problems,

mechanical

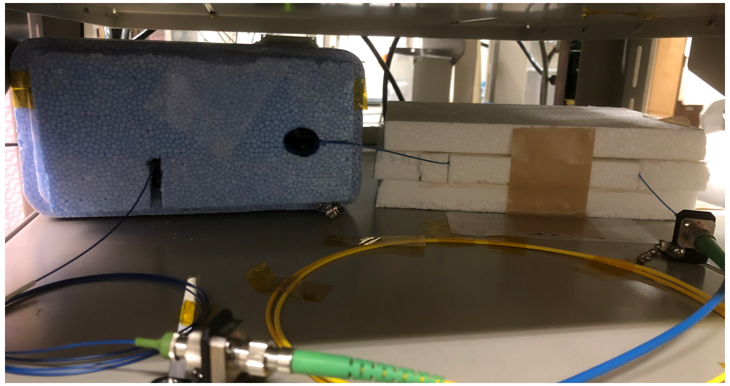
- Intra-cavity power is very small.
- The polarization of laser is still rotating.(PDH signal)

- Inertial momentum of the torsional pendulum is large.
- Actuator coupling(Yaw→Roll) is large and the cavity lock is unstable.
- Mode matching rate is wrong during measurements because we need to introduce large signal.

Clear!

Other problems 1

今後の課題



- Fluctuation of PDH signal

  The temperature in lab is fluctuating by air conditioning and the polarization of laser is rotating.
  = Unstable cavity lock

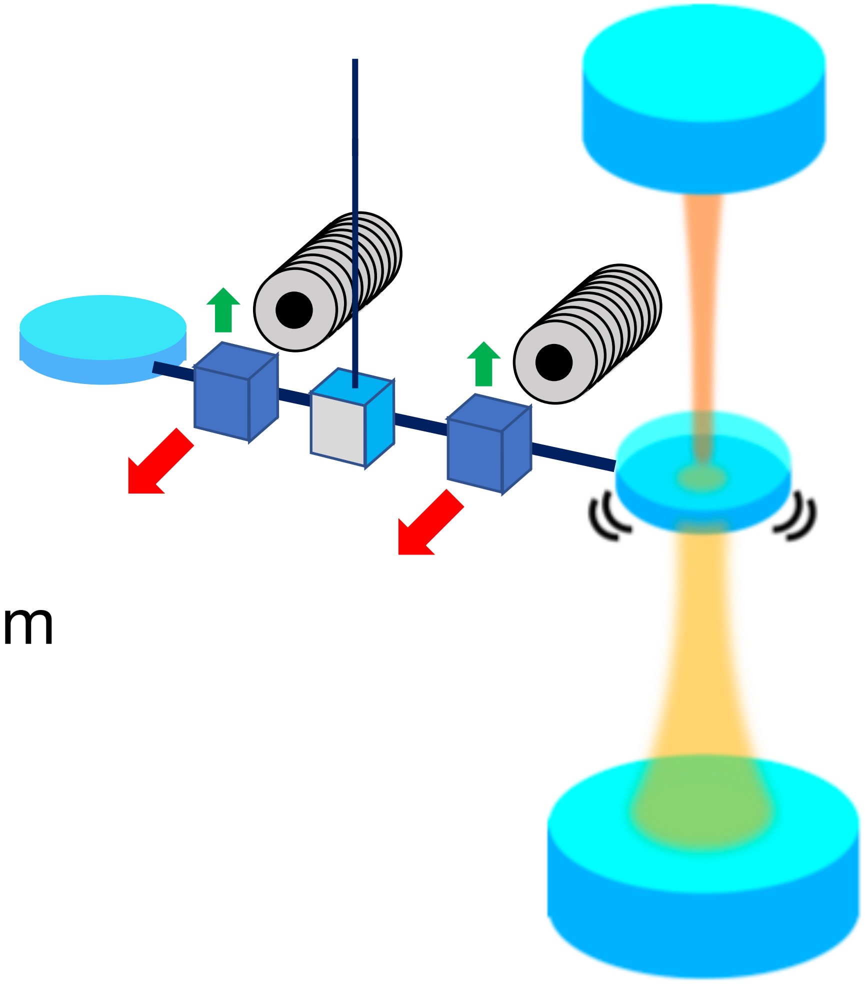
  It is still a problem for low intra-cavity power.

➡ We need to keep the temperature at constant.
・More styrofoam?
・Turn off the air conditioner during measurements?

Other problems 2

今後の課題

- Actuator coupling(Yaw→Roll) is large and the cavity lock is unstable.
  (With Oplev)



➡ We need to reduce the coupling.
  - Control the coils? Ex. piezo
  - Put the magnet under the center of the pendulum like the current setup?

Other problems 3

解決のはず

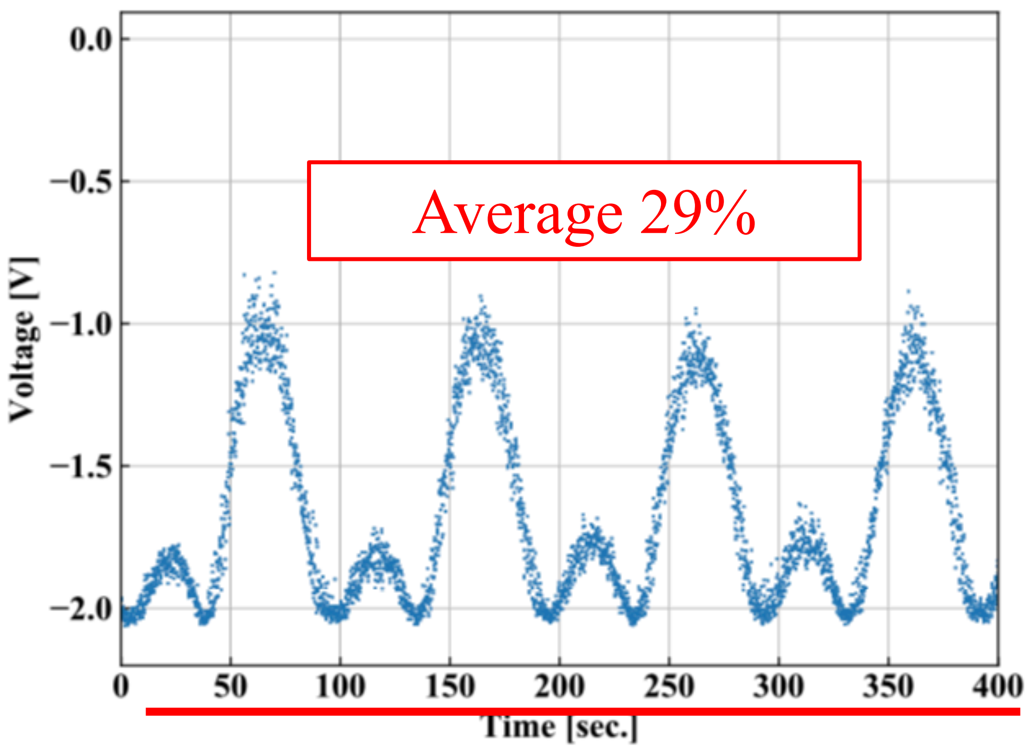
Amplitude of the transmitted beam is fluctuating during measurements of the open-loop gain because we had to introduce large signal.

Due to seismic noise

$$\left(\frac{\pi\omega_0}{\lambda}\frac{1}{a}\delta h\right)^2 \fallingdotseq 29\ \%$$

ω_0: Radius of beam weist, a: Distance between

δh: The displacement of the levitated mirror in YAW direction



➡ Seismic noise will be reduced due to a double pendulum, and this problem will be solved.

Summary

- For Torsional Pendulum experiment, there are some problems which to solve.
- We have to decide how to assign the work for Torsional Pendulum experiment to each of us this year.
- I will do my best for Optical Levitation and my Master Thesis !

おしまい