The sky is the limit

Hiroki Fujimoto

Ando lab, Department of Physics, University of Tokyo

Contents

- How I joined Ando Lab
- My research history in Ando Lab
- My true curiosity
- After graduation

Contents

- How I joined Ando Lab
- My research history in Ando Lab
- My true curiosity
- After graduation

The origin of my interest

- Comic: “Discoveries and Inventions of Great Scientists ”

【収録人物】

■宇宙のなぞに挑戦した人たち

ニコラス・コペルニクス/ティコ・ブラーエ/ガリレオ・ガリレイ/ヨハネス・ケプラー/アイザック・ニュートン/ウィリアム・ハーシェル/アルバート・アインシュタイン

■生命のなぞに挑戦した人たち

アリストテレス/アントニー・レーウェンフック/ラマルク/チャールズ・ダーウィン/グレゴール・ヨハン・メンデル/トーマス・ハント・モーガン/ジェームズ・ワトソンとフランシス・クリック/

■原子なぞに挑戦した人たち

デモクリトス/ロバート・ボイル/ジョン・ドルトン/ ジャン・ペラン/マリー・キュリー/長岡半太郎/湯川秀樹/ エンリコ・フェルミ/フェルミ以降の科学者たち

■空を飛ぶゆめに挑戦した人たち

レオナルド・ダ・ヴィンチ/モンゴルフィエ兄弟とシャルル/ ジョージ・ケイレー/オットー・リリエンタール/ フェルナンド・フォン・ツェッペリン/ヘンスンからラングレーまで/ ライト兄弟/ライト兄弟以降の発明家たち

■宇宙のゆめに挑戦した人たち

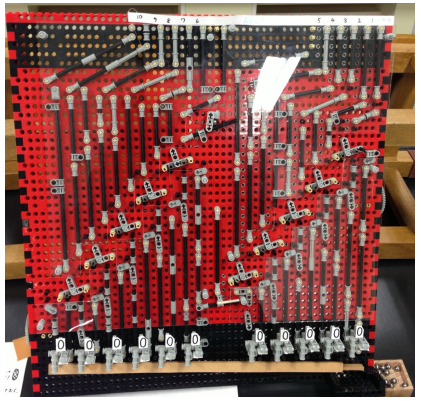
ジュール・ベルヌ/ロバート・ハッチンス・ゴダード/ コンスタンチン・エドアルドビッチ・チオルコフスキー/ ヘルマン・オーベルト/ウェルナー・フォン・ブラウン

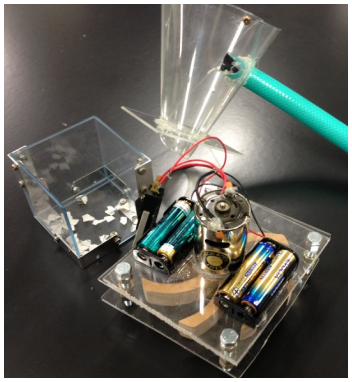
■日本の科学のさきがけとなった人たち

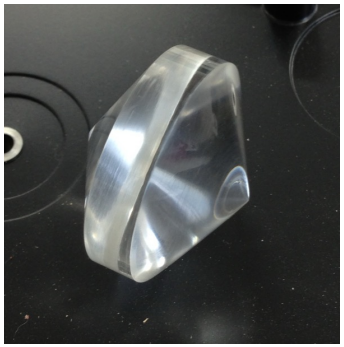
関孝和/平賀源内/杉田玄白/伊能忠敬/華岡青洲/田中久重/ 二宮忠八

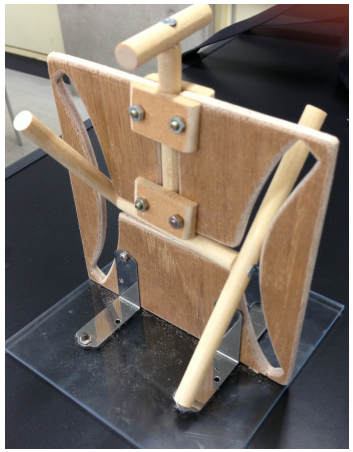
In my high school

- Shuyukan (修猷館) high school in Fukuoka
- I belonged to physics club, math club and swimming club
- Physics was the most interesting subject







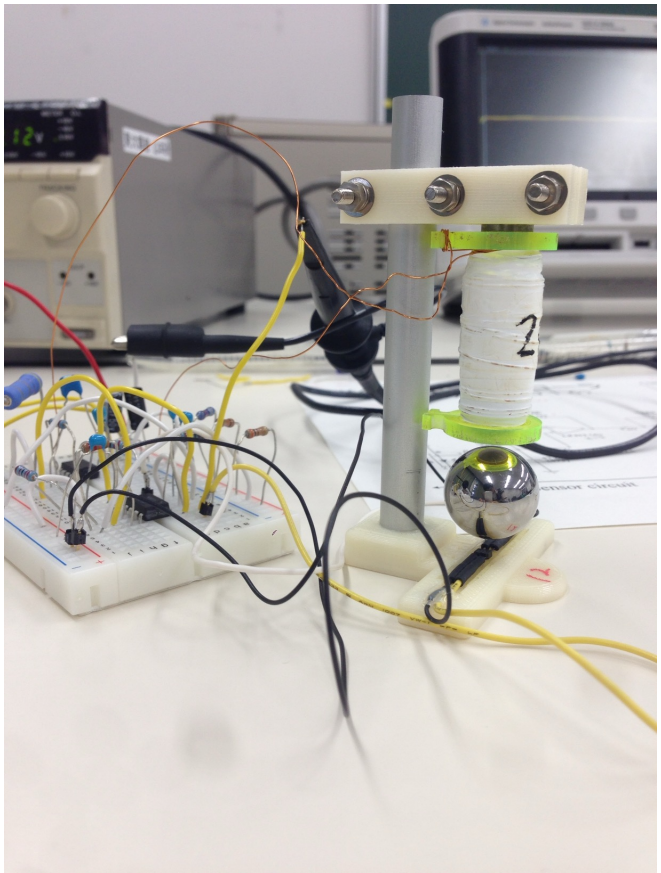


Engineering or Physics in U-Tokyo

- Interesting Course in B2: Special relativity
- Interesting intensive Course: Magnetic levitation (Dept. of Precision Engineering, 精密工学科)

- I had difficulty in choosing physics or engineering for my major

- I chose physics in pursuit of scientific aspects



My encounter with Ando Lab

- While B2 and B3, I was not interested in quantum physics, statistical physics and condensed matter physics

⇒ I thought I might have chosen the wrong major

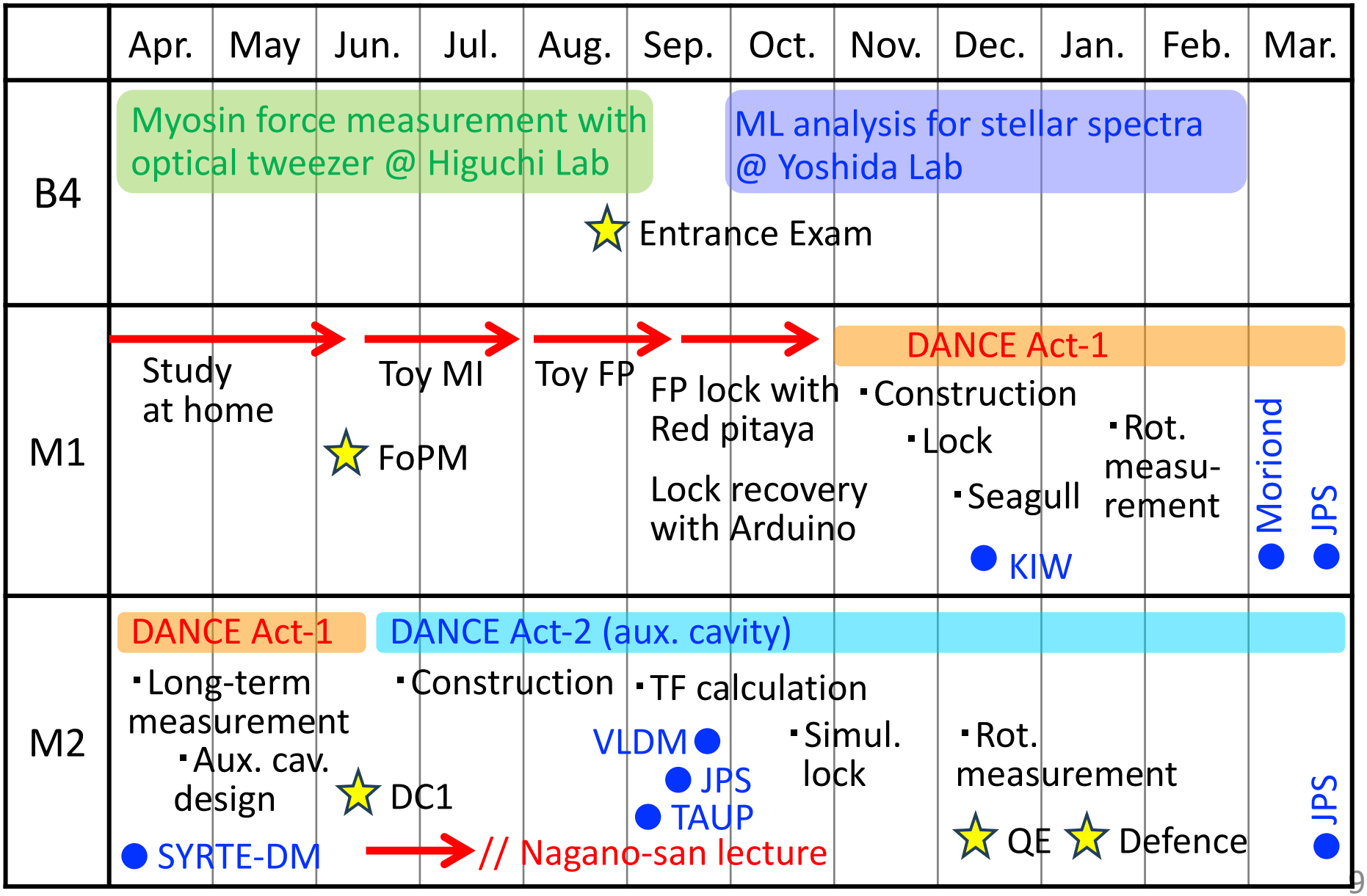
- I visited Ando Lab during spring vacation of B3 and I was so amazed
  - ➢Test General Relativity and Astrophysics
  - ➢Construct and control experimental setup by ourselves
- Ando Lab is the best place where I can do both of what I want!!

⇒ Joined Ando Lab from graduate school

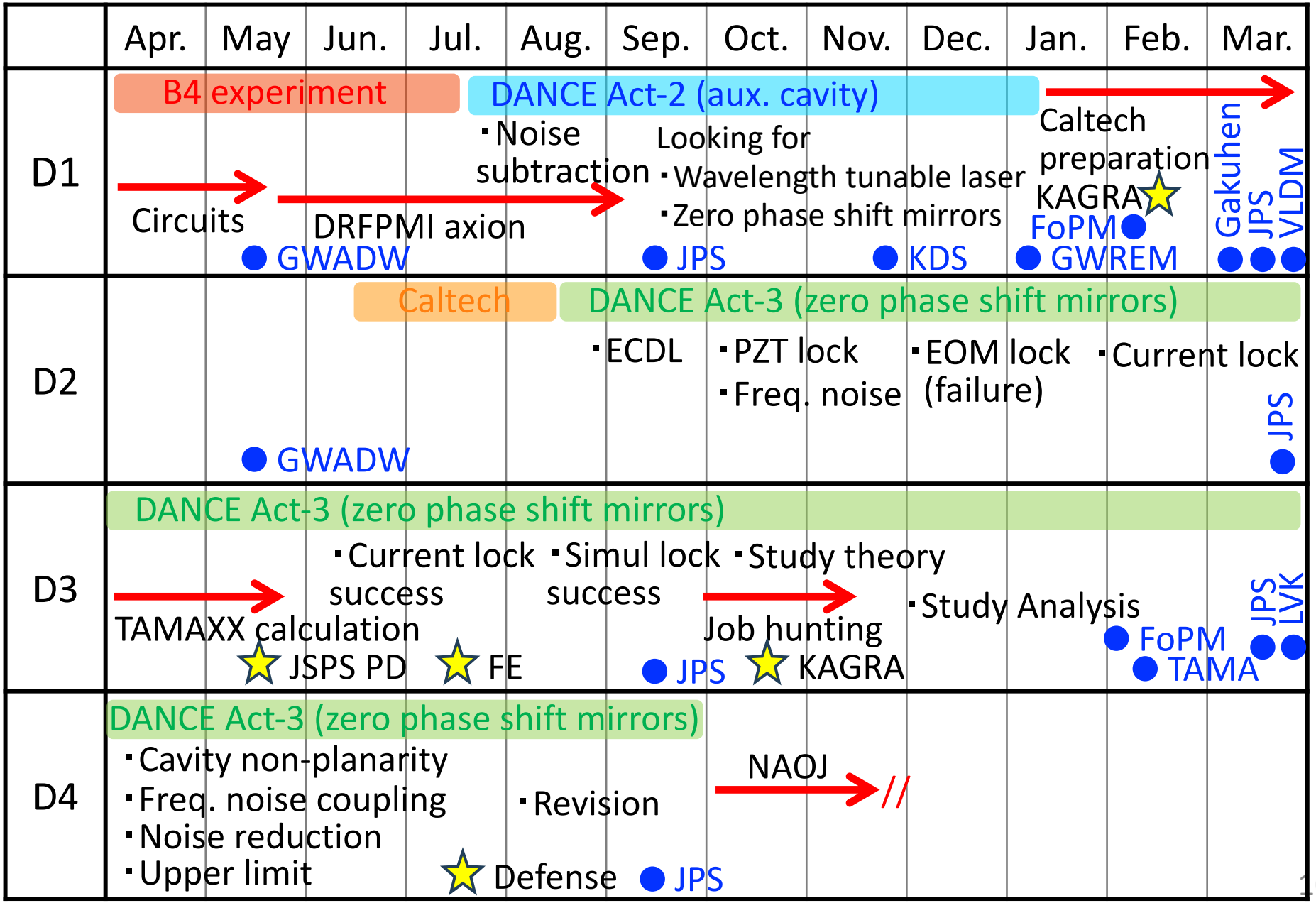
Contents

- How I joined Ando Lab
- My research history in Ando Lab
- My true curiosity
- After graduation

Rough schedule toward Ph.D.

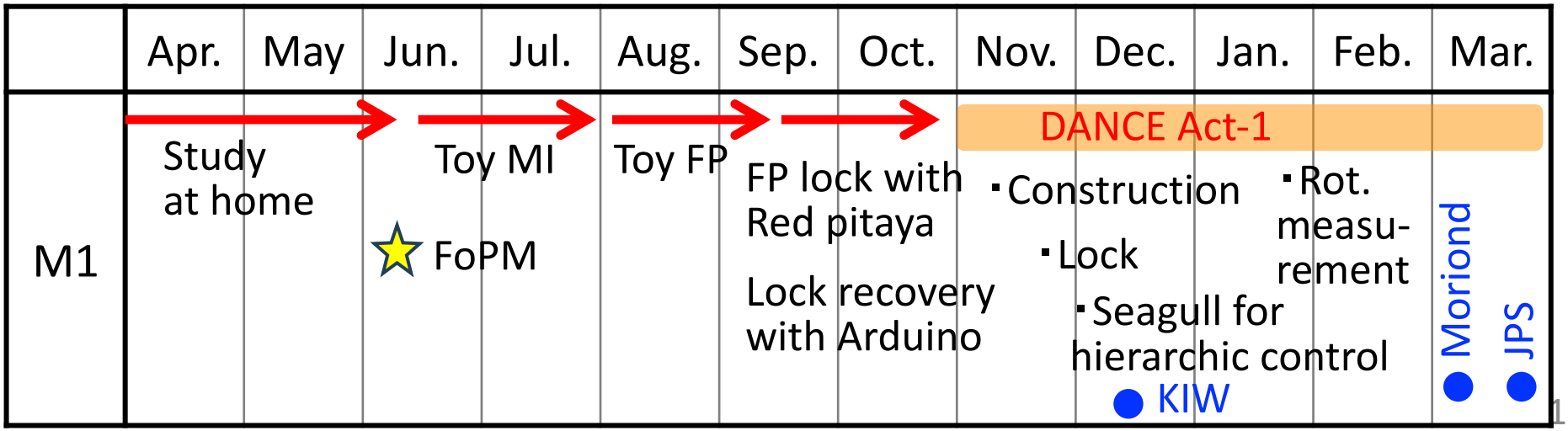


Rough schedule toward Ph.D.



M1

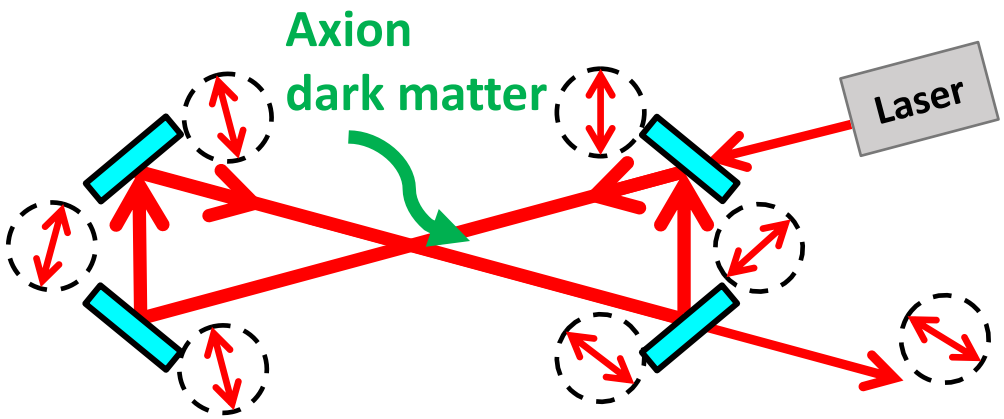
- Study at home while COVID-19
  - ➢Good opportunity for learning basic theory
- Toy MI, Toy FP and DANCE with Oshima-san
  - ➢Takano-san taught us how we conduct experiments so much
  - ➢Takano-san also suggested use of some devices (Red pitaya etc.)
- First talk at KIW
  - ➢Preparation in 1 week

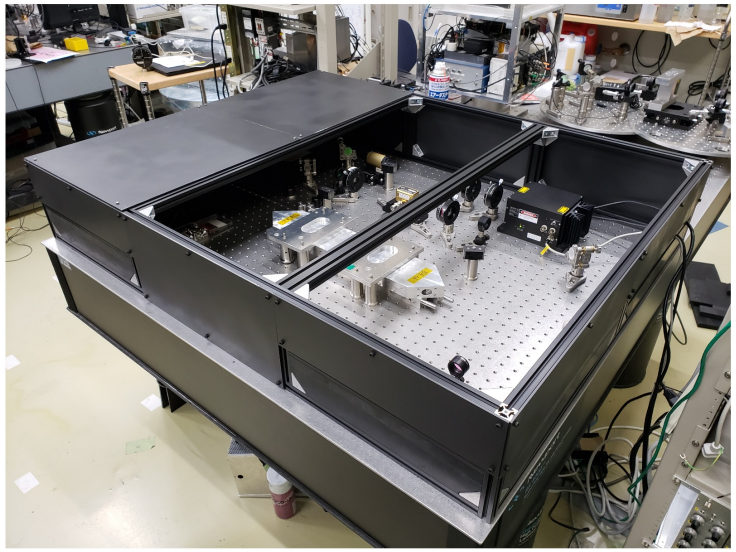


M1: DANCE Act-1

- Chose DANCE for FoPM application
- I wanted to work on the experiment from the very beginning
- Relatively easy setup for M1 student
- Know-how on polarization was not sufficient in Ando Lab?

  - ➢Construction, cavity lock and polarization rotation measurement
  - ➢Automated locking
  - ➢Noticed the presence of resonant frequency difference

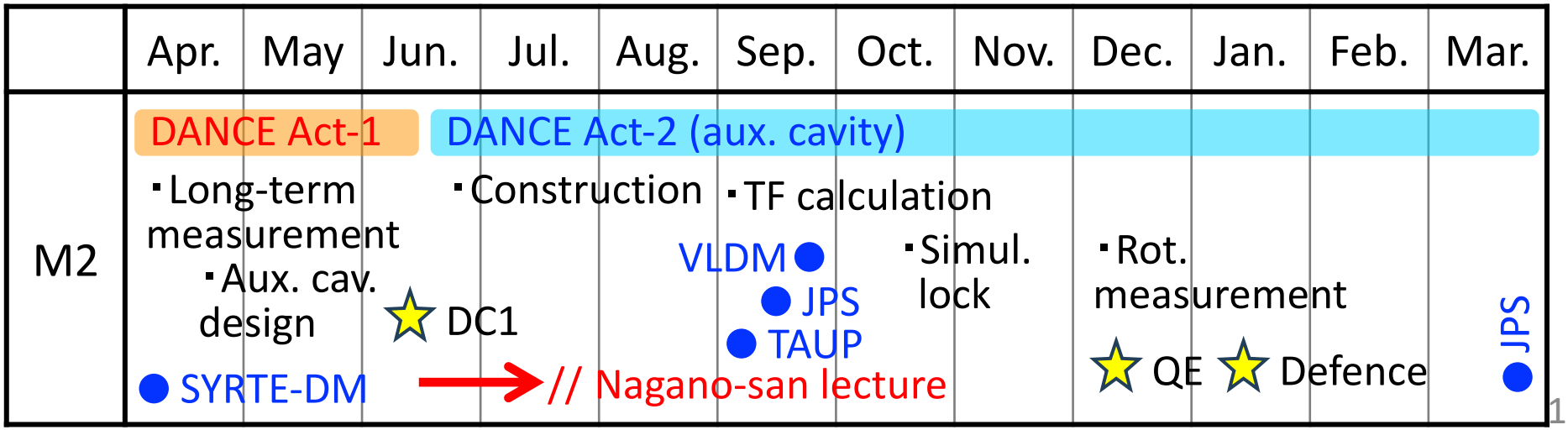




M2

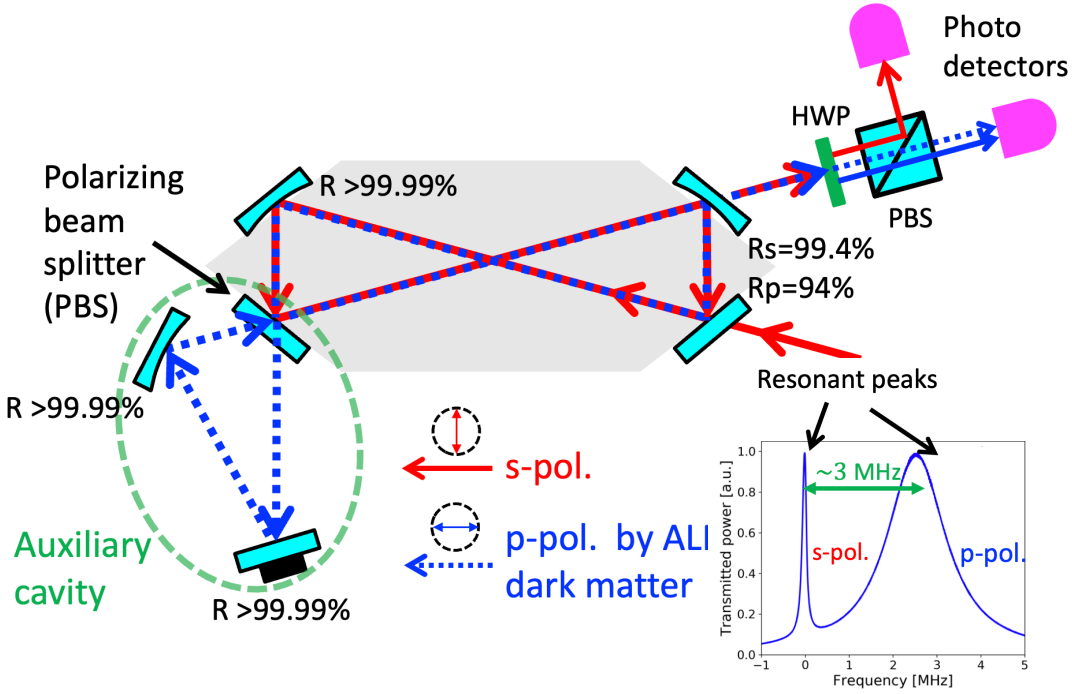
- Long-term observation of DANCE Act-1 with Oshima-san
  - ➢First result of DANCE Act-1

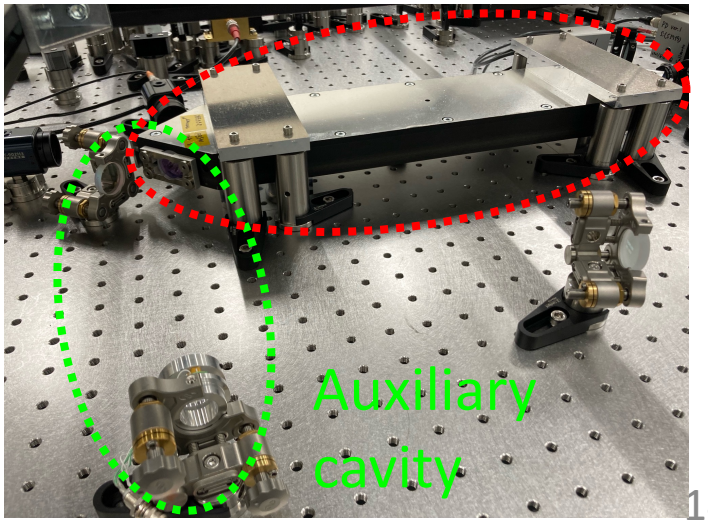
- Nagano-san lecture
  - ➢Learned the basics of interferometry and control
  - ➢I was so amazed at the control theory of FPMI



M2: DANCE Act-2 (aux. cavity)

- DANCE needed to simultaneous resonance of s- and p-pols
- Michimura-san told me about the Birmingham paper on aux. cavity
- Designed and constructed the aux. cavity for DANCE
- Ando-sensei suggested use of PBS for intermediate mirror
  ⇒ Reduced the loss and realized simultaneous resonance
- Calculated transfer function of DANCE cavity ($\delta c \rightarrow \delta\phi$)

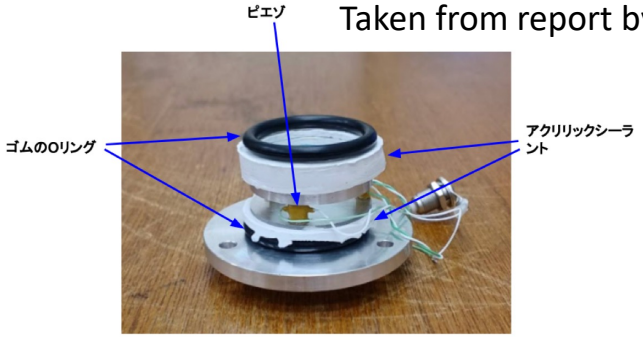


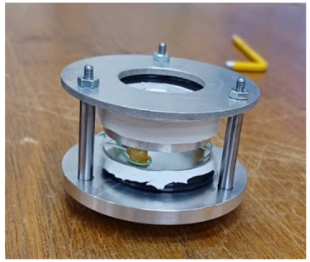


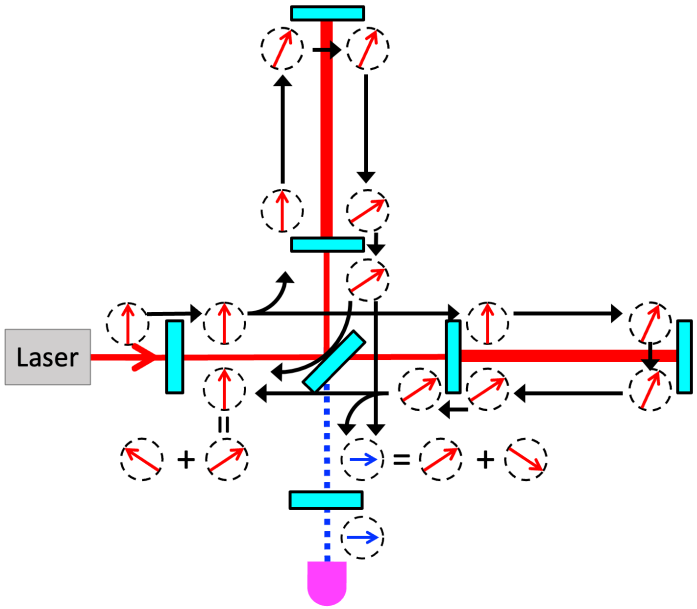
D1

- Helped B4 experiment by Okuma-kun and Sugawara-kun
  - ➢Removing parasitic resonance with soft material
- Calculation on DRFPMI axion search
- So many conferences (8)
- Preparation for Caltech visit

Taken from report by Okuma-kun



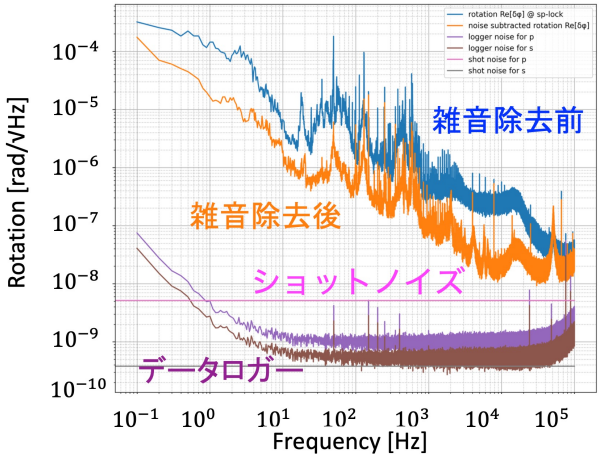


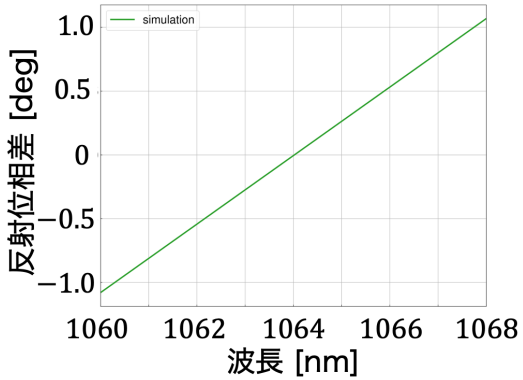


	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
D1	B4 experiment				DANCE Act-2 (aux. cavity)							
	Circuits →		DRFPMI axion →		▪Noise subtraction	Looking for ▪Wavelength tunable laser ▪Zero phase shift mirrors				Caltech preparation KAGRA☆		Gakuhen JPS VLDM
		● GWADW				● JPS			● KDS	FoPM● ● GWREM		●●●

D1: Toward DANCE Act-3

- Offline noise subtraction
- DANCE Act-3 with zero phase shift mirror
  - ➢Ordered Nakagawa laser
  - ➢Asked many manufacturers for zero phase shift mirror with large wavelength dependence (for NPRO)
    ⇒ Declined…Maybe impossible

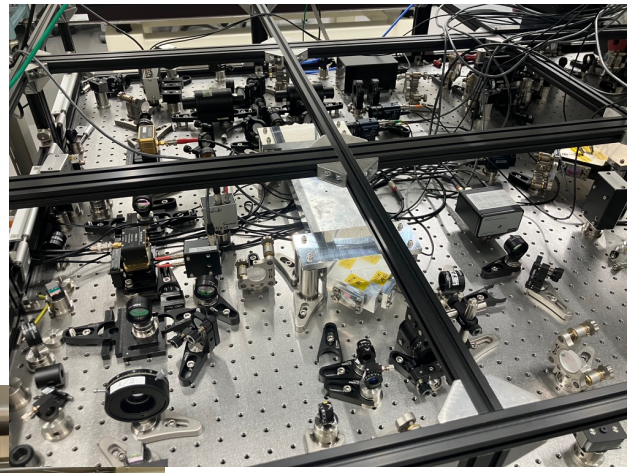


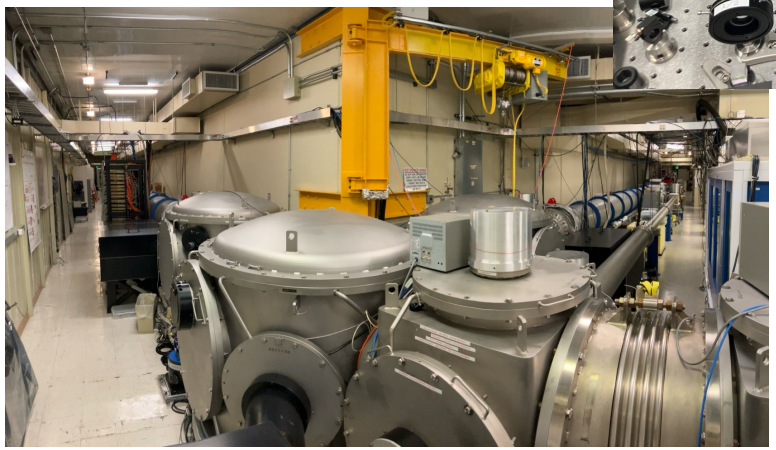


	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
D1	B4 experiment				DANCE Act-2 (aux. cavity)							
	Circuits →		DRFPMI axion →		・Noise subtraction	Looking for ・Wavelength tunable laser ・Zero phase shift mirrors				Caltech preparation KAGRA →		Gakuhen JPS VLDM
		● GWADW				● JPS		● KDS		FoPM ● ● GWREM		● ●

D2

- GWADW @ Elba: Best conference ever
- Visit to Caltech
- Started DANCE Act-3 after Caltech



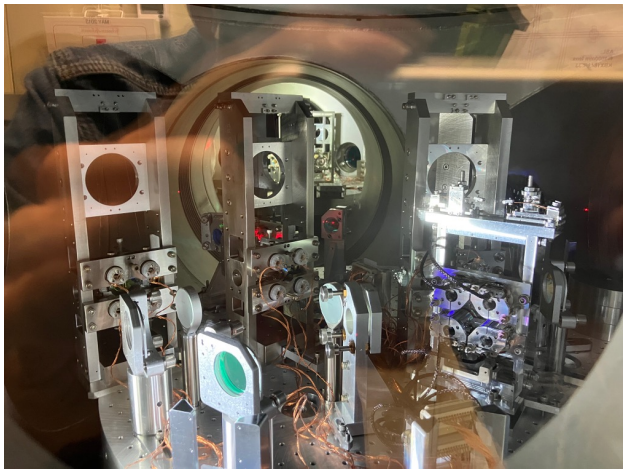


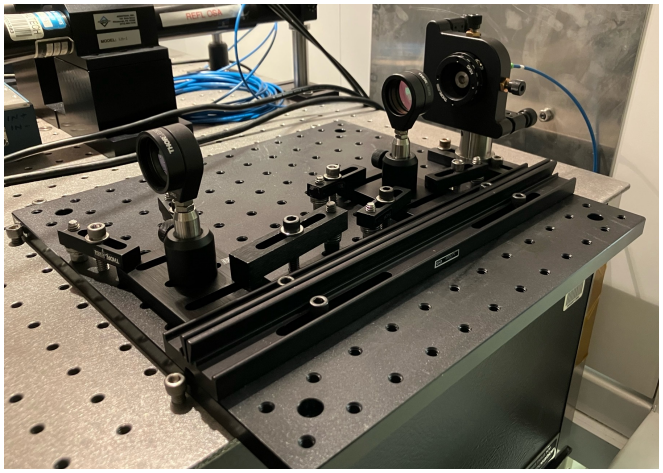
	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
D2			Caltech			DANCE Act-3 (zero phase shift mirrors)						
						▪ ECDL	▪ PZT lock ▪ Freq. noise		▪ EOM lock (failure)		▪ Current lock	
		● GWADW										● JPS

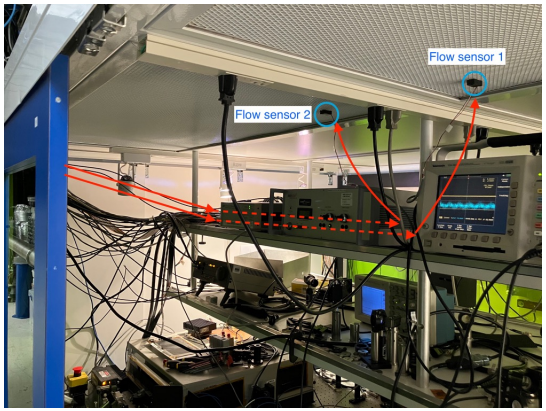
D2: Caltech

- I was supposed to help 40m BHD experiment, but PRFPMI had not been recovered
  - ➢Helping 40m recovery (FPMI lock, PRMI lock) was so exciting
  - ➢Constructed mode-matching breadboard for OMC
  - ➢Installed flow sensor for HEPA filter, etc.

- Good foods and many dangerous areas
- One of my best memories in my Ph.D. course

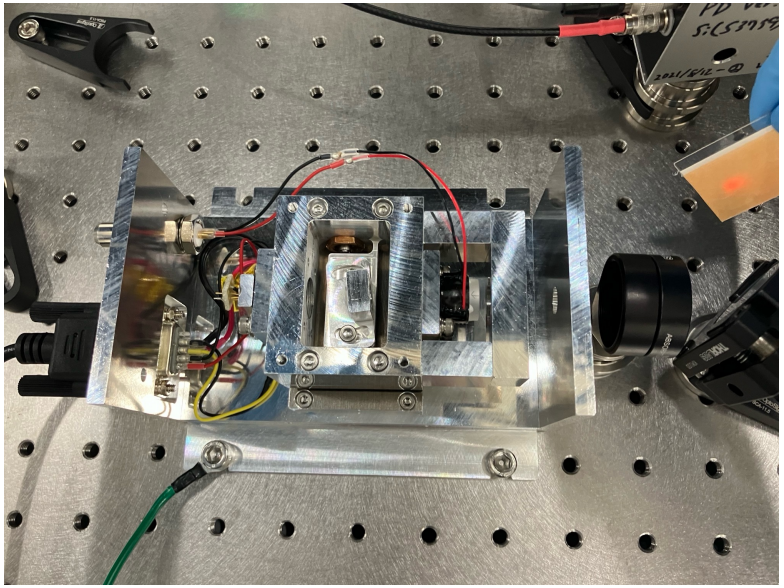


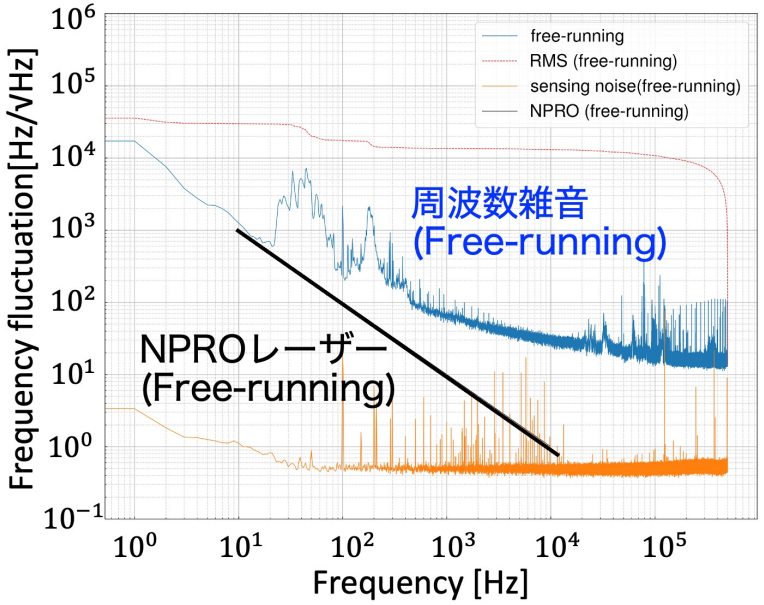




D2: DANCE Act-3 (zero phase shift mirror)

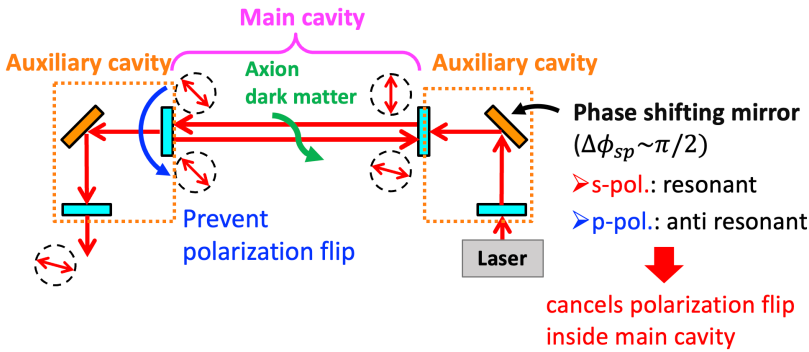
- Act-3 tries to realize simultaneous resonance with zero phase shift mirrors and wavelength tunable laser
  - ➢Installed Nakagawa ECDL with great help by Takidera-kun
  - ➢Locked to low finesse cavity and measured frequency noise
    ⇒ Large noise at high frequency.
    Fast control was needed for high finesse cavity
  - ➢Tried EOM but failed for its small actuation
  - ➢Started trying current lock from February





D3, D4

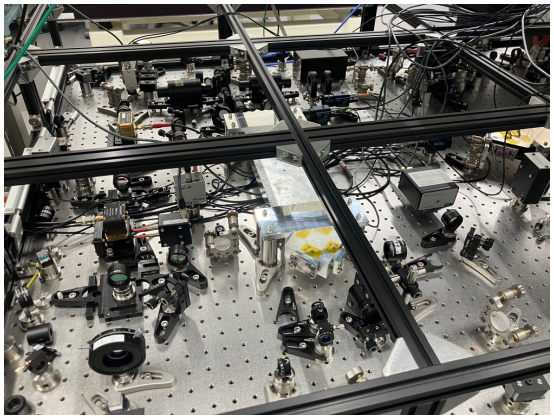
- Applied JSPS PD fellowship at NAOJ with TAMAXX proposal
- Failed the selection and started job hunting
  ⇒ Project researcher at NAOJ

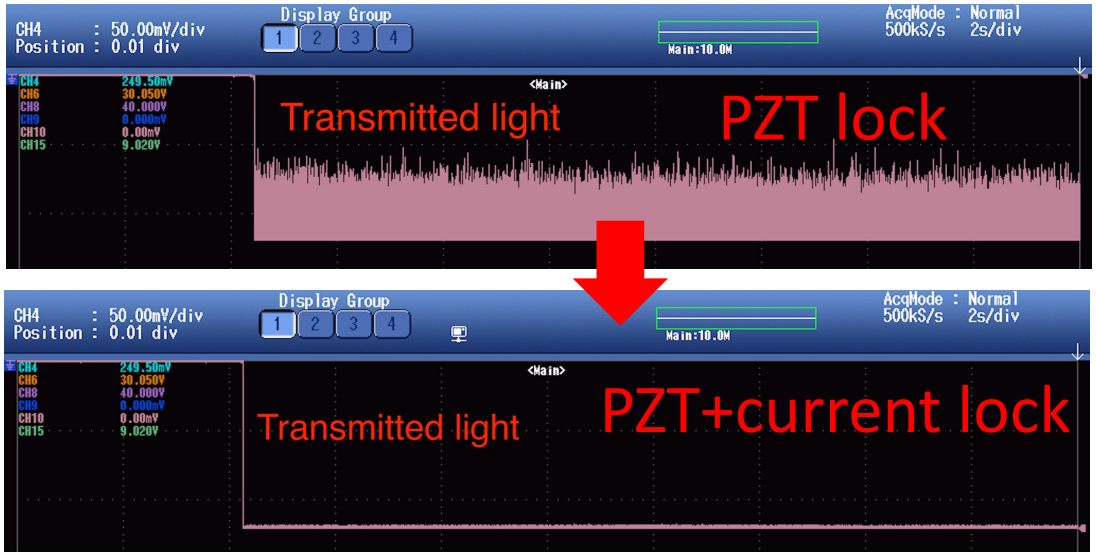


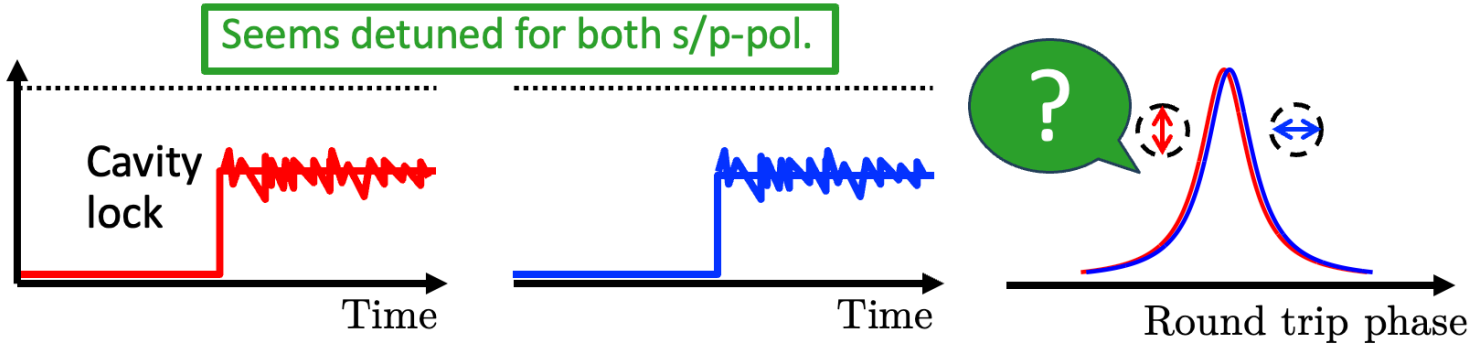
	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
D3	DANCE Act-3 (zero phase shift mirrors)											
	TAMAXX calculation		・Current lock success		・Simul lock success		・Study theory		・Study Analysis			
		★ JSPS PD		★ FE		● JPS	★ KAGRA				● FoPM ● TAMA	● JPS ● LVK
D4	DANCE Act-3 (zero phase shift mirrors)											
	・Cavity non-planarity ・Freq. noise coupling ・Noise reduction ・Upper limit			★ Defense	・Revision	● JPS	NAOJ → //					

D3,D4: DANCE Act-3 (zero phase shift mirror)

- Succeeded in current lock in June
- Tried simultaneous resonance by tuning wavelength but failed
  - ➢Mysterious detuning
- Found that this can be improved by touching the cavity mirrors and realized simultaneous resonance (August)







D3,D4: Why I extended my Ph.D. course

- I achieved simultaneous resonance by September but…
  - ➢I wasn't sure what is causing the mysterious detuning
  - ➢I wasn't sure why touching cavity mirrors can solve it
  - ➢Polarization rotation was not measured
  - ➢Noise hunting was not done
  - ➢Around this time, I was often scolded by not knowing the axion and DM theory well ⇒ needed to learn more
  - ➢Needed to learn upper limit analysis as well
  - ➢Failed JSPS PD fellowship and needed to start job hunting

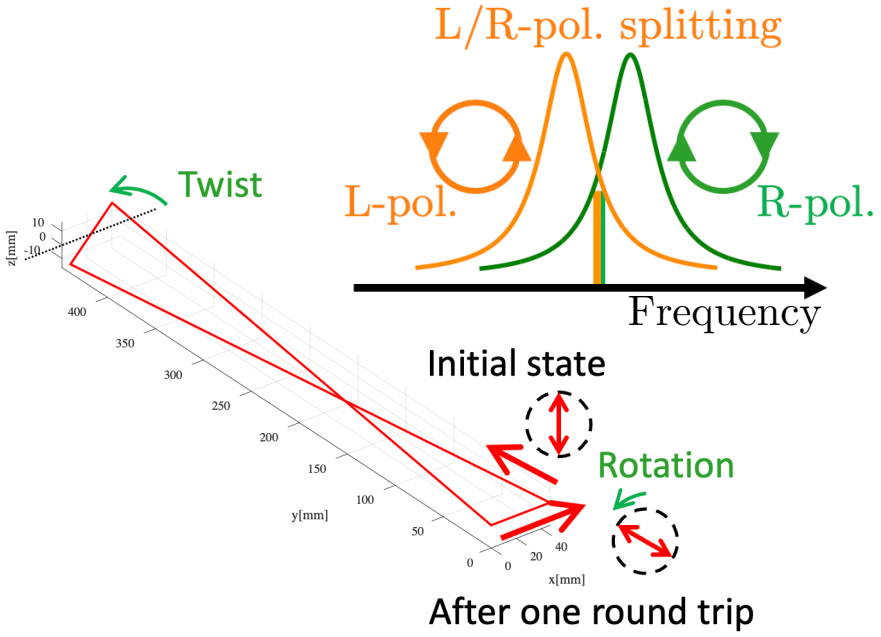
- I couldn't handle the pressure of finishing these tasks by December while writing my thesis
  ⇒ Extended my Ph.D. course

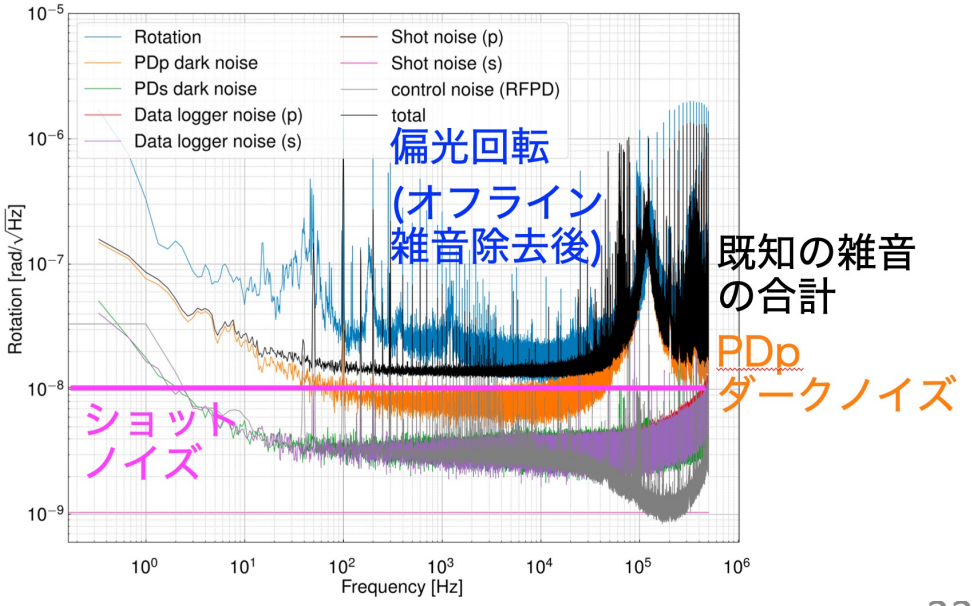
- I think I was too lazy, I could have tried harder…

D3, D4: During extension

- Learned axion theory, DM theory and upper limit analysis
- Identified the mysterious detuning was caused by cavity non-planarity
- Identified the model of the frequency noise coupling

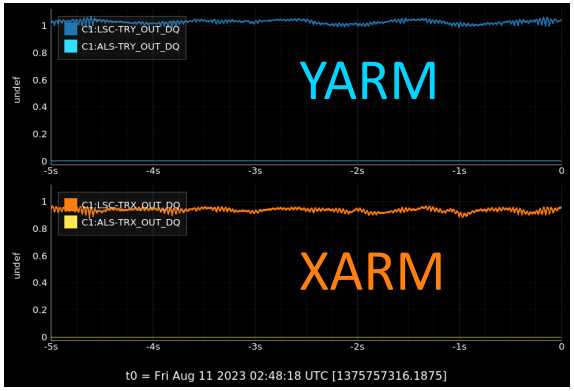
- Managed to pass the Ph.D. defense

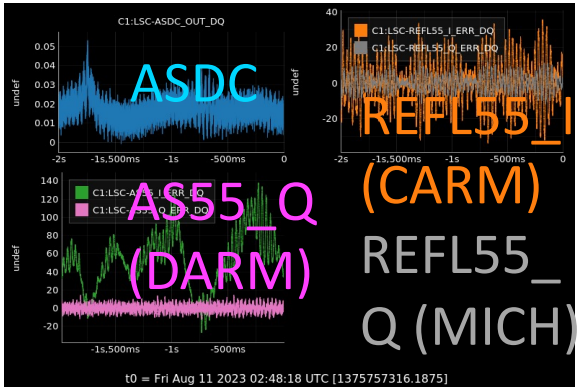


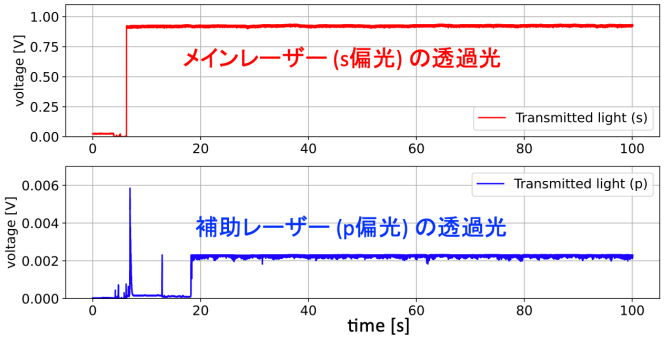


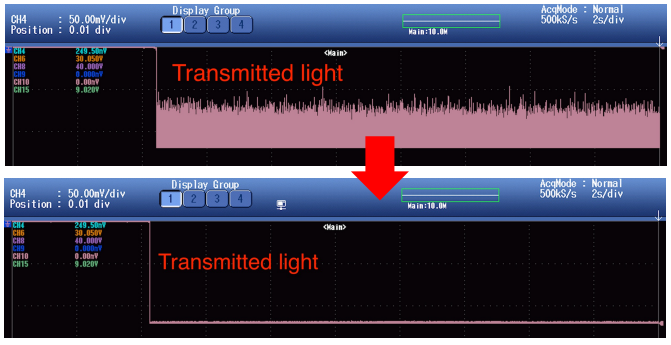
Happiest moments during experiments

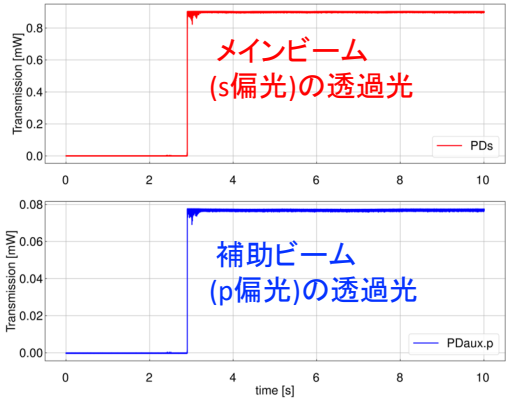
- Simultaneous resonance with aux. cavity
- Success in ECDL lock with current actuator
- Simultaneous resonance with zero phase shift mirrors
- Noise reduction in Act-3
- Success in FPMI lock at Caltech

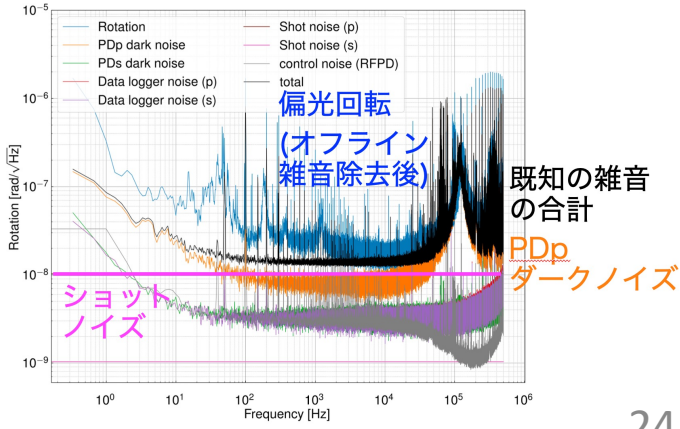












What I learned in Ando Lab

- There is always a reason behind even the smallest things. And if you don't give up, you can surely solve them.
  - In experiments, many "mysterious" things occur.
  - We may ignore them to go ahead if they seems not important.
  - But they are not mystery. They always occur with valid reason and can be identified if you want
  - The reason behind may be affecting the other big issues
- I learned the guts to never give up solving mysteries from Takano-san and Arai-san

What I learned in Ando Lab

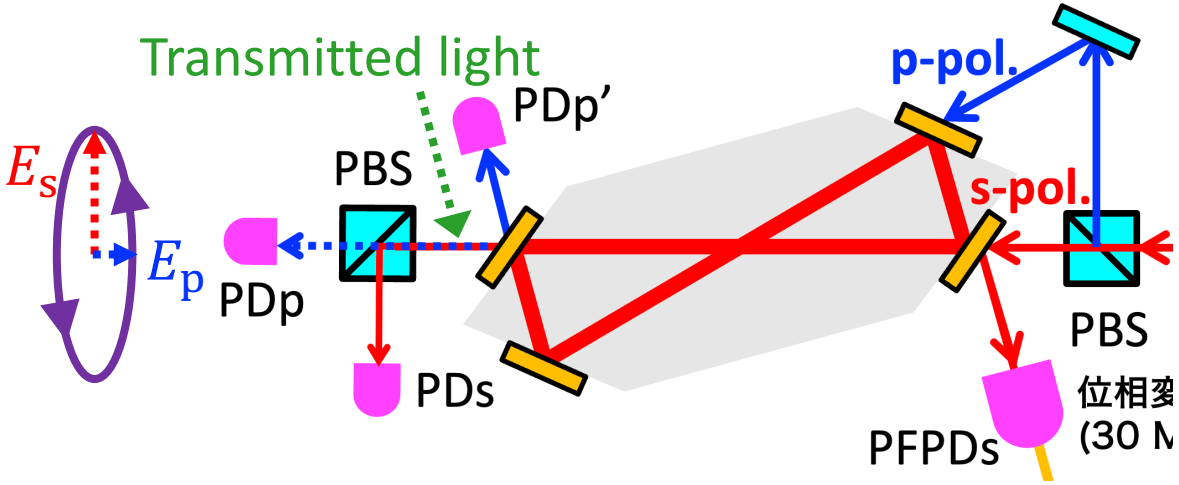
- Example: Mysterious ellipticity of transmitted light from non-simultaneous resonant DANCE cavity

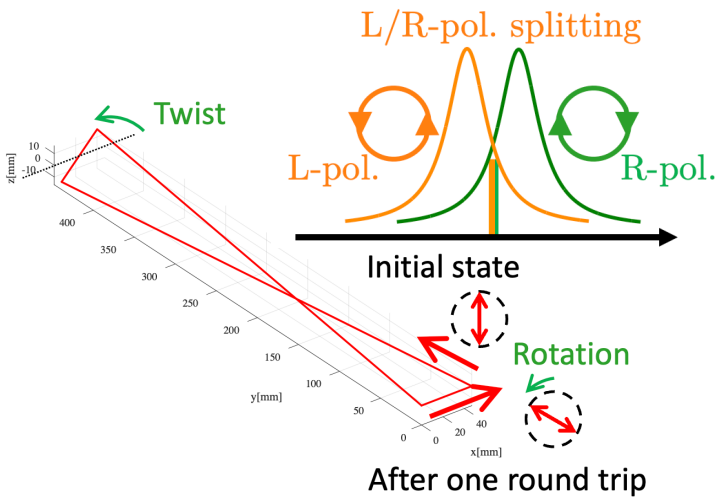
➢Transmitted polarization from DANCE cavity was elliptical under non-simultaneous resonance

➢The effect was small ($E_p/E_s = 0.016(2)$), so I ignored first

➢In fact, this was caused by the cavity non-planarity

➢Cavity non-planarity was also preventing the simultaneous resonance as the mysterious detuning





Contents

- How I joined Ando Lab
- My research history in Ando Lab
- My true curiosity
- After graduation

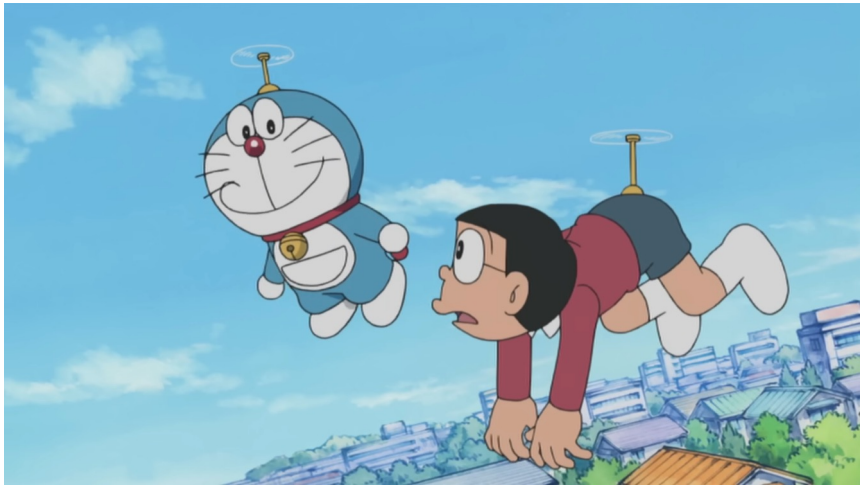
My true curiosity

- The sky is the limit
  - The sky had been thought to be unreachable like this saying
  - Humanity developed airplanes and rockets, breaking the limit of the sky
  - The detection of GW was once thought to be impossible, but LIGO detected it 100 years after the prediction

- What's next? How far can we go?
- Will my hidden curiosity be satisfied in the future?

Can we fly freely?

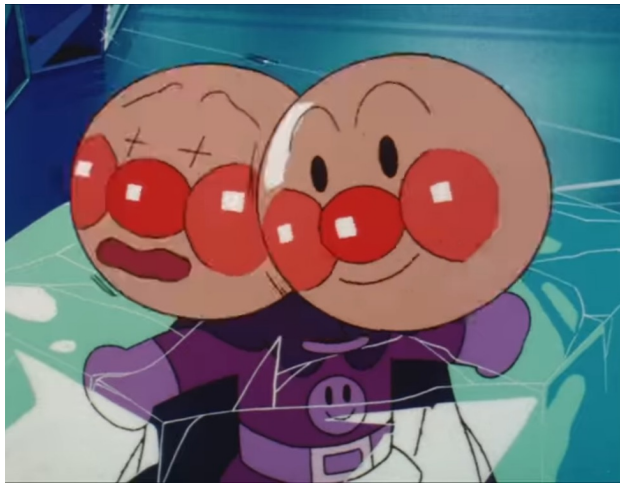
- We can now fly by airplanes but it's not easy for an individual to fly freely in the sky
- I really want a device that would let me fly as easy as riding a bicycle
- Negative mass seems difficult…
- Can we develop wings like the ones pterosaurs (翼竜) once used?



What is human consciousness?

- What's the true nature of human consciousness?
- Is what I'm thinking now governed by physics?

- I really want to know the theory that defines our consciousness
- Simpler problem: Can we predict what you make in rock-paper-scissors by physics?
  - Dice: Deterministic
  - Spin: Stochastic
  - Rock-paper-scissors: ?



Do you have hidden curiosity?

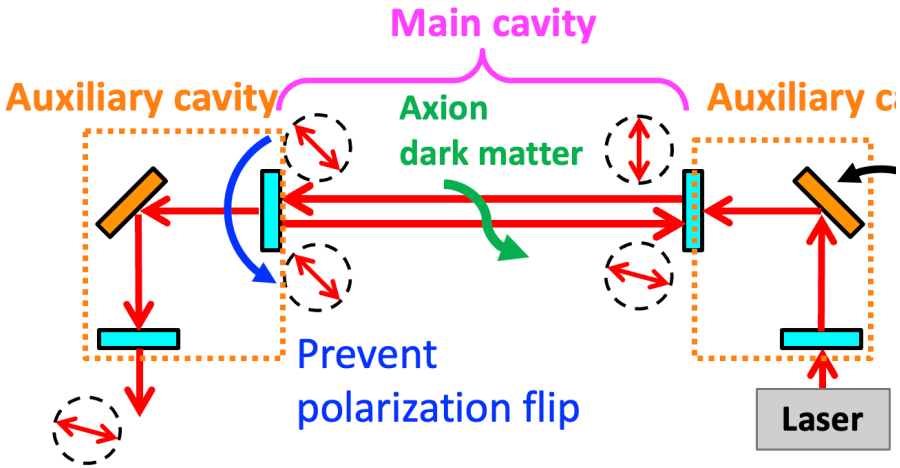
- I want to ask some of you

Contents

- How I joined Ando Lab
- My research history in Ando Lab
- My true curiosity
- After graduation

After graduation

- Project researcher at NAOJ
  - ➢Will join the KAGRA squeezer group
  - ➢Want to work on the KAGRA RSE as well
  - ➢May develop axion search experiment: TAMAXX?



Summary

- I believe Ando Lab is the best for me
- Not only the research topic and environment, people here are all wonderful
- Thank you all for everything so far