Sleepless 2021

Yuta Michimura
Department of Physics, University of Tokyo

Contents

- Looking back on the year 2020
- My research timeline over the past >10 years
- My plans and expectations for the year 2021
- Hot topics
  - Vector dark matter search with KAGRA
  - DANCE
  - Optical levitation mirrors
  - SILVIA

Review: My Plans JFY2020

Working on this, but not others yet…

KAGRA+ paper published

Birefringence paper not written yet

Not much as I had anticipated

Not yet

Not yet

We are about to do so

Not yet. Cover first

We are working on this

My Plans JFY2020

- Remaining things for O4
  - OMC, beam shutter
  - Optical table cover for TRX and TRY
  - upgraded MZM? In-vac RF PDs and RF/DC QPDs?
- Finish KAGRA+ paper, write birefringence paper
- More concrete planning of SILVIA and DECIGO
- Write SILVIA and DECIGO paper
- Absorption calculations for optical levitation mirror
- Start DANCE Act-1 observation
- Introduce polarization optics to TRX and TRY of KAGRA
- Search for ultralight dark matter with KAGRA data

Review: My Expectations JFY2020

Takeda-kun did it!

Aritomi-kun did it!

Chiyoda-kun did it!
And we are on the way of making better ones

Paper published!

Ching Pin-kun did it!

Not yet

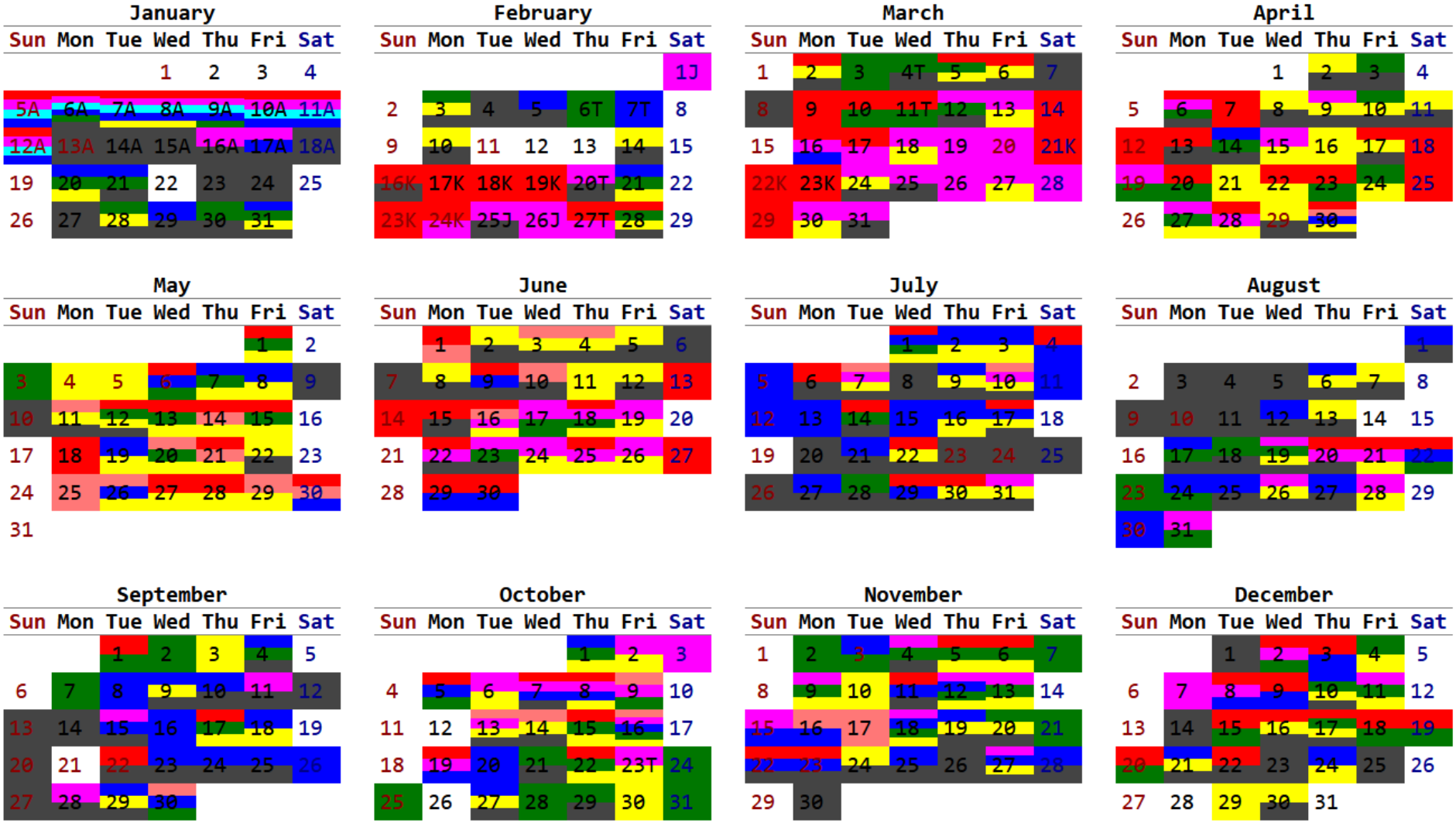
Finally, from July!

My Expectations JFY2020

- New data analysis on GW polarization
- Better control of filter cavity and more clear squeezing angle rotation
- Pave the way to optical levitation mirror (photonic crystal or curvature from coating stress)
- Stability confirmation paper for optical levitation
- Start Lorentz violation search with upgraded setup
- Q measurement at cryogenic temperatures
- Coil-coil actuator paper
- New people in our group

Effort Report for 2020

2020



Effort Report for 2020

- Almost no visits

00	KAGRA	47.9 days	15.8%	K Kamioka	9 days
00	KAGRA+	9.1 days	3.0%	T Tokyo-area	7 days
00	Quantum	33.6 days	11.1%	J Japan	3 days
00	Lorentz	1.8 days	0.6%	A Abroad	14 days
00	DM	40.8 days	13.4%	Home	333 days
00	DECIGO	39.7 days	13.1%		
00	Duties	50.3 days	16.6%		
00	Others	79.9 days	26.4%		

- Effort Report for 2021 upto March

2021

January

Sun	Mon	Tue	Wed	Thu	Fri	Sat
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

February

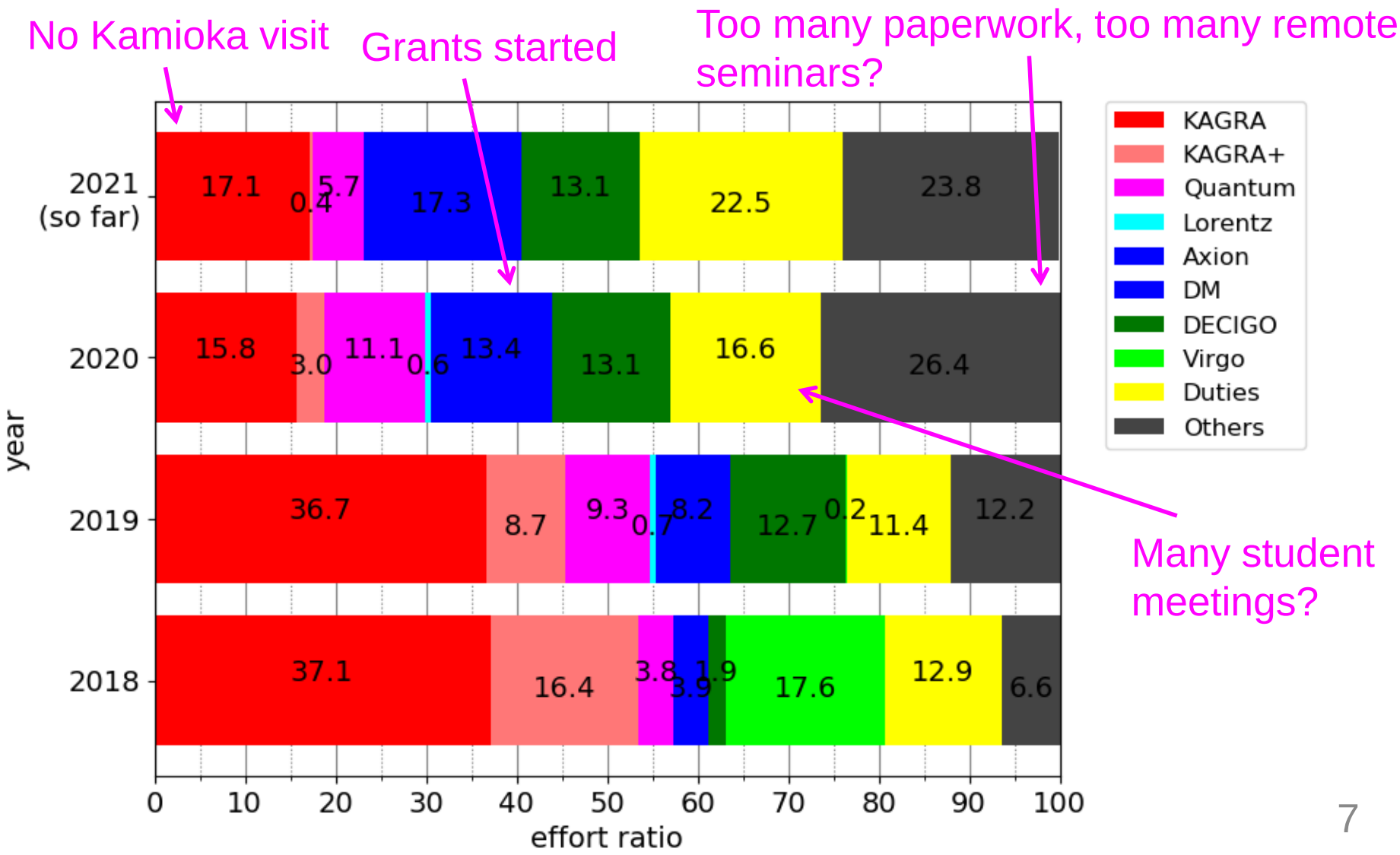
Sun	Mon	Tue	Wed	Thu	Fri	Sat
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28						

March

Sun	Mon	Tue	Wed	Thu	Fri	Sat
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

Effort Ratio Over Time

- Getting harder to say what is my main work



In Reality…


WE'RE HAVING A MEETING TO DISCUSS EMPLOYEE RETENTION.
TELL THEM THAT EMPLOYEES QUIT BECAUSE THERE ARE TOO MANY USELESS MEETINGS.
WE WON'T BE GETTING INTO REASONS AT THE FIRST MEETING.
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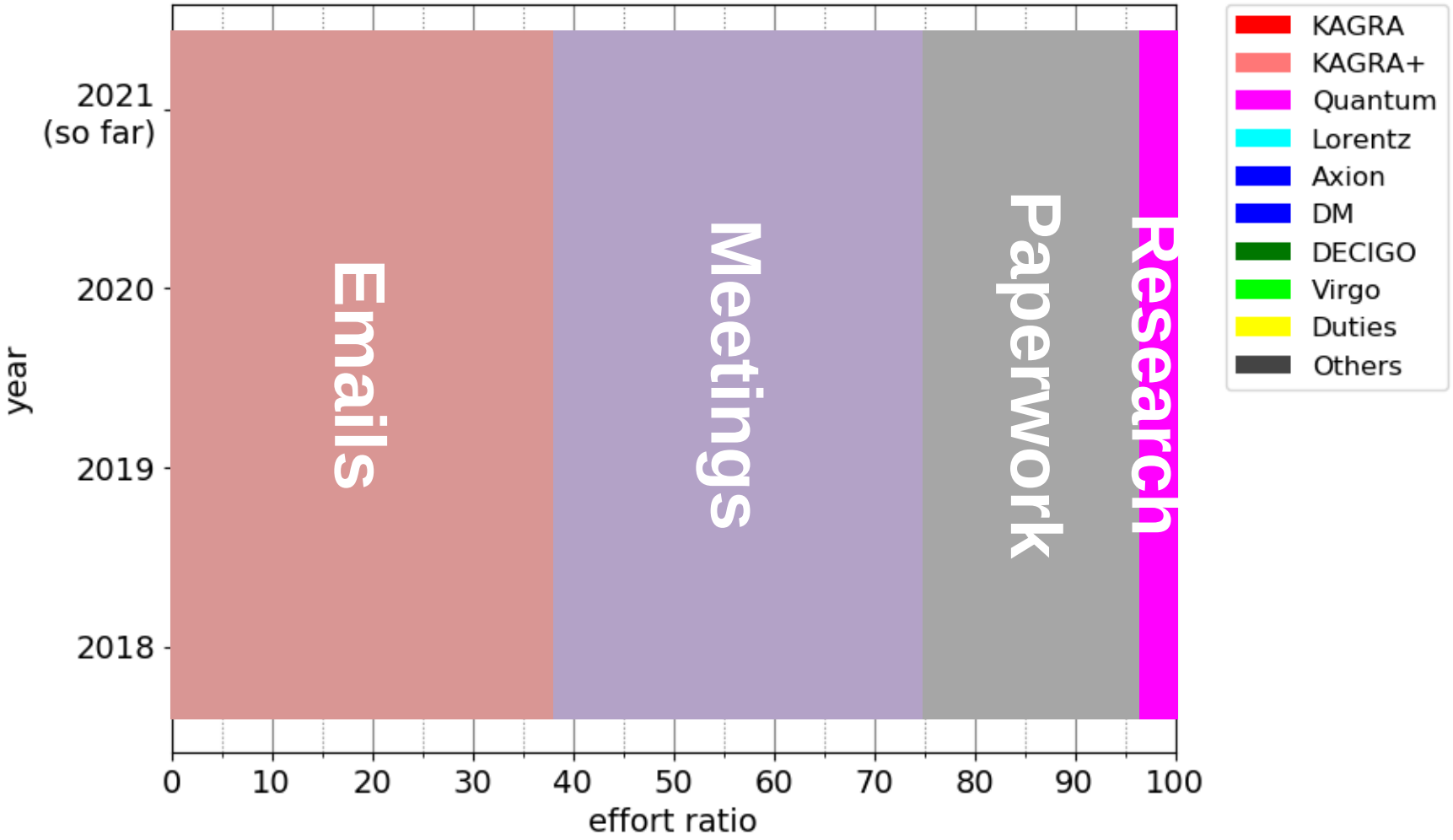
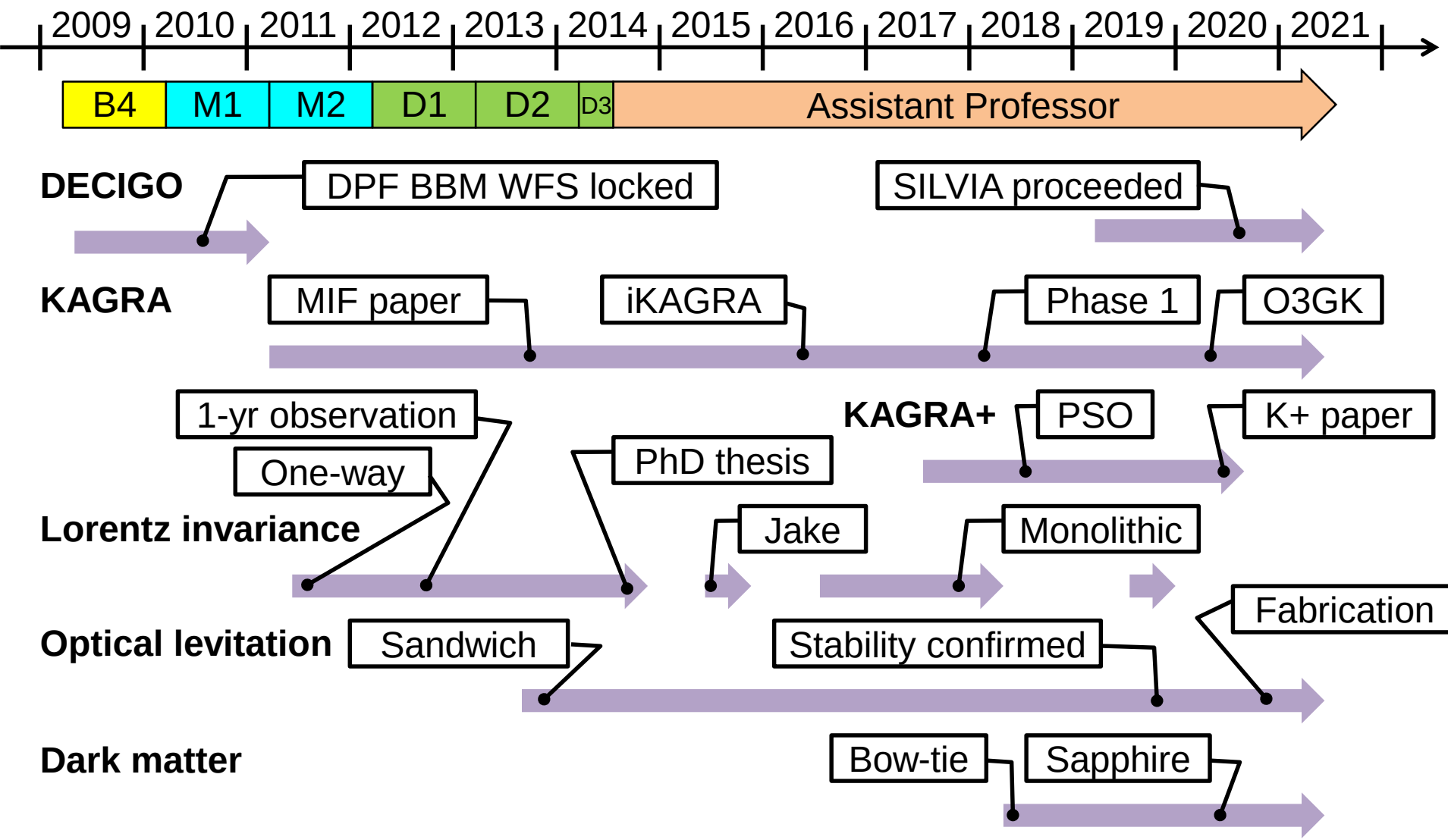

Emails
Meetings
Paperwork
Research
2021 (so far)
2020
2019
2018
year
0
10
20
30
40
50
60
70
80
90
100
effort ratio
KAGRA
KAGRA+
Quantum
Lorentz
Axion
DM
DECIGO
Virgo
Duties
Others

Summary and News from JFY2020

- New collaboration with Iwamoto Group at IIS
- 学術変革A and さきがけ started
  Met with new people (online…)
  New postdoc !
- Drastically increased number of meetings (student meetings, SILVIA meetings)
- Wrote many applications, prepared for number of hearings (5 positions, 2 grants (+2 as Co-I and +2 as 研究協力者) and SILVIA)
- Totally new lifestyle: COVID-19 and baby
- Too many meetings and not very productive research-wise?
- As a group, outcomes are almost as expected, although COVID-19 situation was completely unexpected

Research Timeline



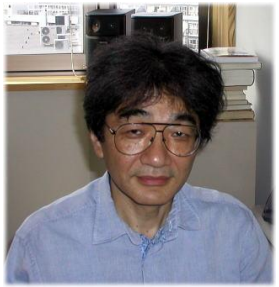
Undergraduate "Research"

- 2006 (B1)
  Fukutani Wilde Group at ISS, UTokyo
  - Optical characterization of Yttrium Hydride

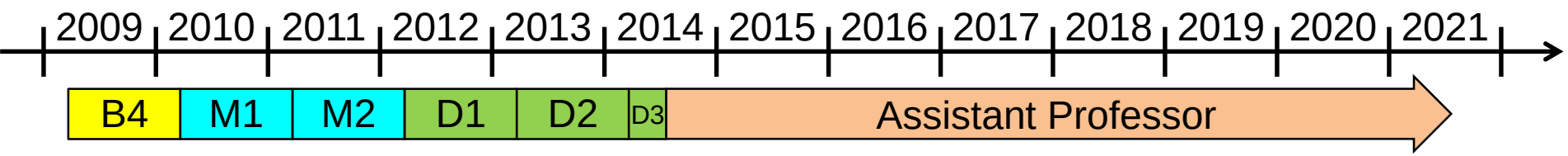
- 2007 (B2)
  Yoshie Group at ISS, UTokyo
  - Recyclable polymer

- 2008 (B3)
  サマーチャレンジ @ KEK
  - Test of gravitational inverse square law
  電波天文観測実習 @ Nobeyama Radio Observatory
  - Observation of infrared dark cloud G28.34+0.06
  物理学ゼミナール
  - 素粒子標準模型入門 textbook, visit to Kamioka

- 2009 (B4)
  Tsubono Lab
  - Digital control of
    DECIGO Pathfinder test mass
  Suto Lab
  - Maggoire textbook



Service Timeline



DECIGO

KAGRA

Steering Committee

MIF sub-chief

MIF chief

FPC

KSC Board

CPC

Joint Editorial Board

Service Timeline

2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021

B4 M1 M2 D1 D2 D3 Assistant Professor

DECIGO

Steering Committee

KAGRA

MIF sub-chief MIF chief

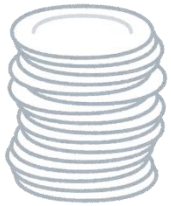
FPC

KSC Board CPC

Joint Editorial Board

Husband

Father



Applications Timeline

2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021

B4 M1 M2 D1 D2 D3 Assistant Professor

DC1 DC2 Wakate A Gakuhen A

ALPS Houga Sumitomo

Kiban B

Houga

CREST Co-I

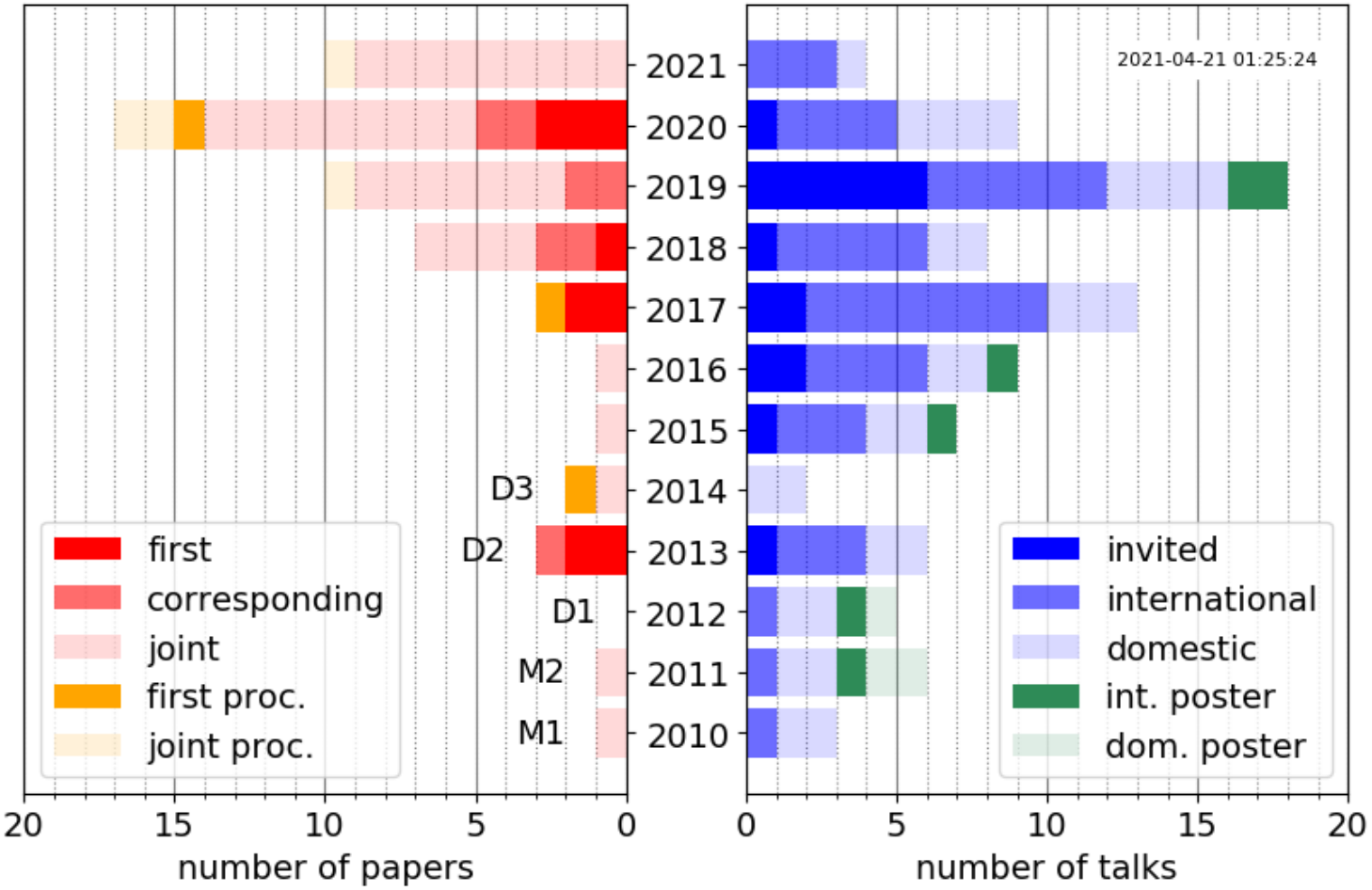
PRESTO

Kiban S Co-I

Kiban A Co-I

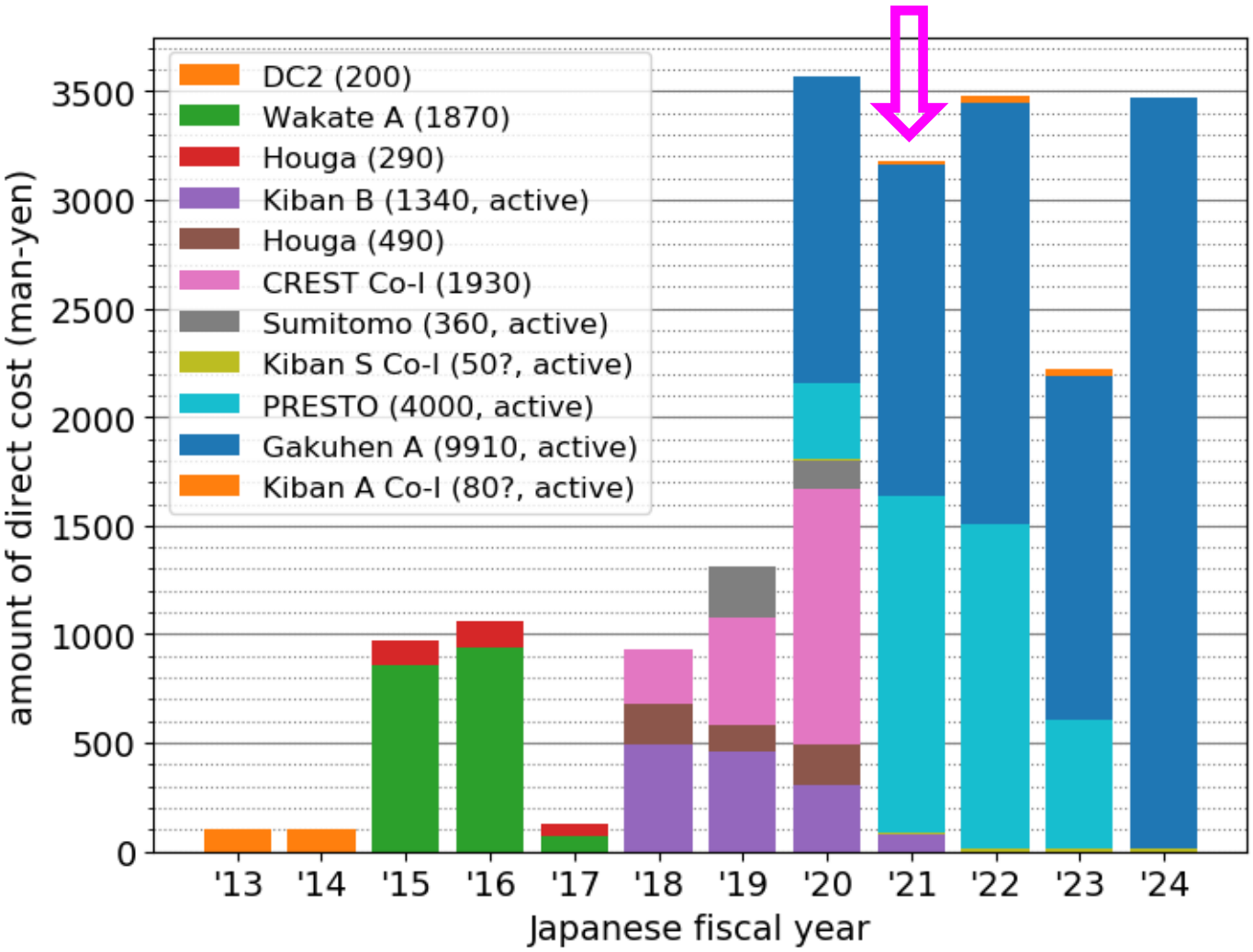
Productivity

- Pandemic probably forced people to write papers (based on past activities! Will be tough for 2021?)
- Number of presentations decreased (as expected)



Grants for JFY2021

- Crucial year to move projects forward in this tough moment



※直接経費のみ

My Plans JFY2021

- Remaining optical table covers and some optics for KAGRA
- Write O3 commissioning paper, birefringence paper and parametric instability paper
- Write SILVIA and DECIGO paper
- Development and characterization of optical levitation mirrors
- Start DANCE Act-1 observation and get the first results
- Polarization studies for DANCE
- Introduce polarization optics to TRX and TRY of KAGRA
- Search for vector boson dark matter with KAGRA data
- Papers on axion search with TMS, stochastic effects

My Expectations JFY2021

- Q measurement at cryogenic temperatures, with some interesting results
- Observation of radiation pressure noise
- Operation of (fixed) TOBA at cryogenic temperatures, with a monolithic optical bench
- Full characterization of coupled WFS
- First DANCE observation and data analysis
- Realization of s-pol and p-pol simultaneous resonance
- Write axion sensitivity calculation paper

Vector DM

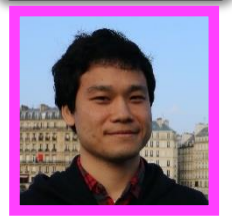
学術変革 ダークマター

- From November 2020 to March 2025
- https://member.ipmu.jp/DarkMatter/

Dark matter mass [GeV/c^2]

10^{-40} 10^{-30} 10^{-20} 10^{-10} 10^{0} 10^{10} 10^{20} 10^{30} 10^{40} 10^{50} 10^{60} 10^{70}

Excluded | Ultralight field | Light particle | WIMP | Heavy particle | Macroscopic | Excluded

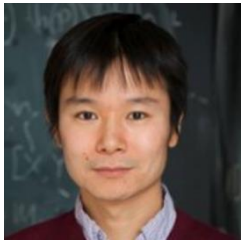


Particle

X-ray X-ray CMB Neutrino experiments X-ray CMB

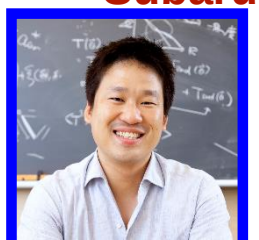
Laser interferometers e^+e^- Cosmic rays

Gravitational lensing



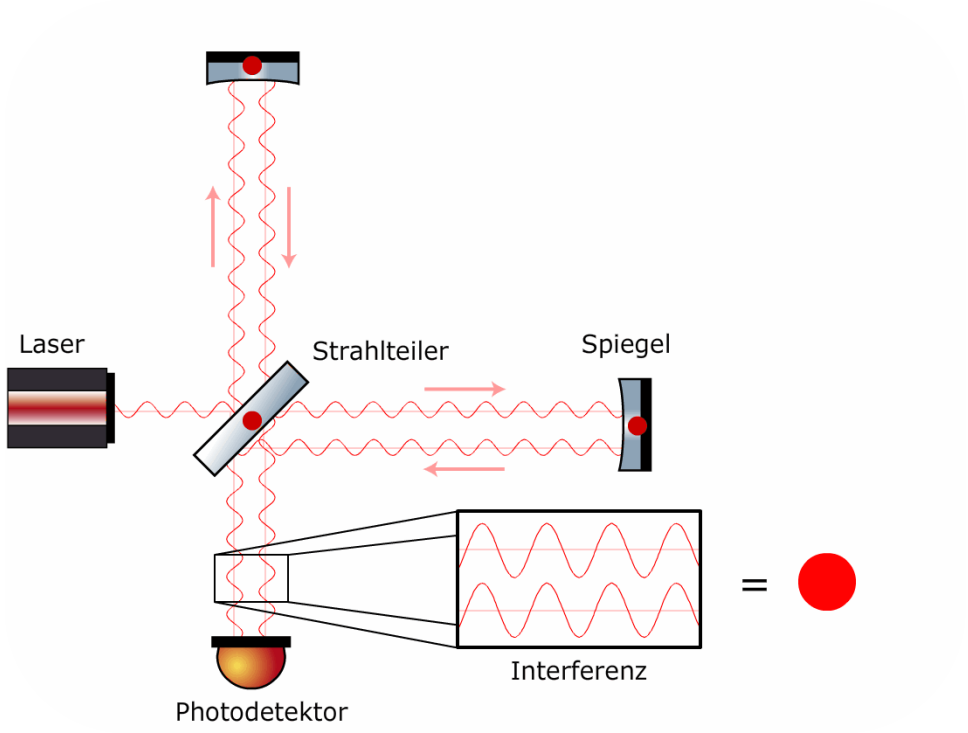
Subaru imaging / spectroscopy

Subaru spectroscopy



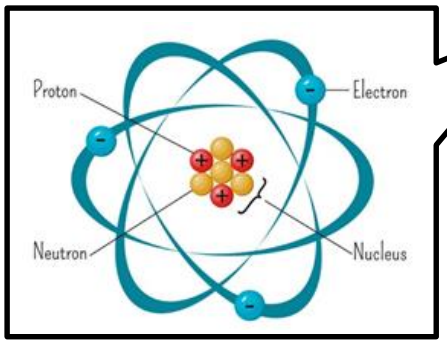
Ultralight Dark Matter

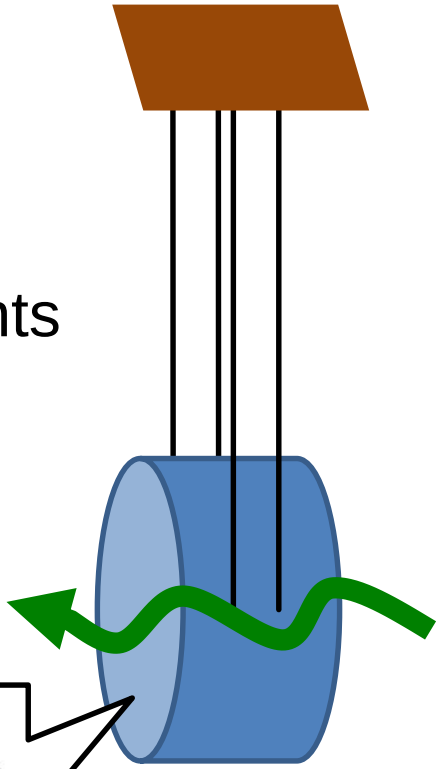
- Ultralight DM (<~1 eV) behaves as classical wave fields $f = 242\ \mathrm{Hz} \left(\frac{m_{\mathrm{DM}}}{10^{-12}\ \mathrm{eV}} \right)$
- Laser interferometers are sensitive to tiny length changes from such oscillations



Gauge Bosons

- Possible new physics beyond the standard model:
  New gauge symmetry and gauge boson
- New gauge boson can be dark matter
- B-L (baryon minus lepton number)
  - Conserved in the standard model
  - Can be gauged without additional ingredients
  - Equals to the number of neutrons
  - Roughly 0.5 per neutron mass,
    but slightly different between materials
    Fused silica: 0.501
    Sapphire: 0.510
- Gauge boson DM
  gives oscillating force

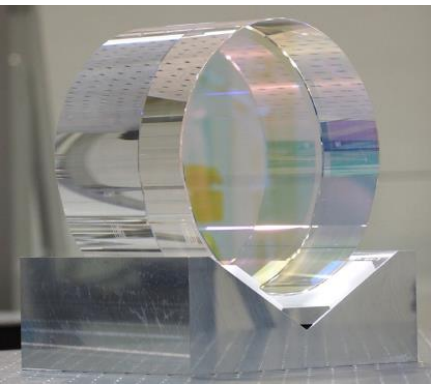




gauge field

Search with KAGRA

- KAGRA uses cryogenic sapphire mirrors for arm cavities, and fused silica mirrors for others
  (LIGO/Virgo uses fused silica for all mirrors)



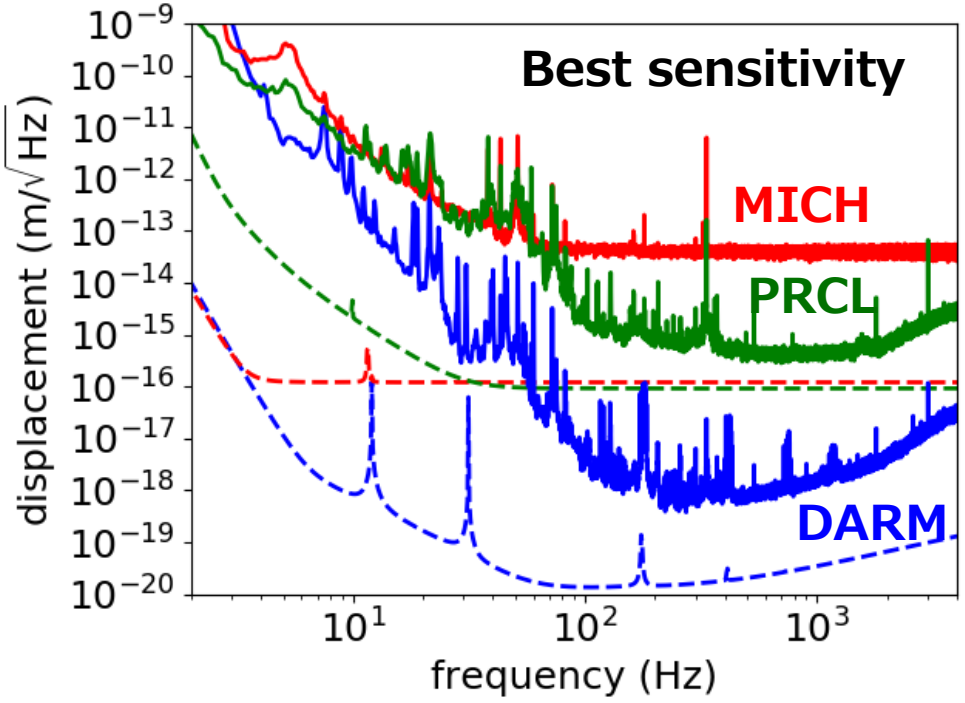
B-L charge
Fused silica: 0.501
Sapphire: 0.510

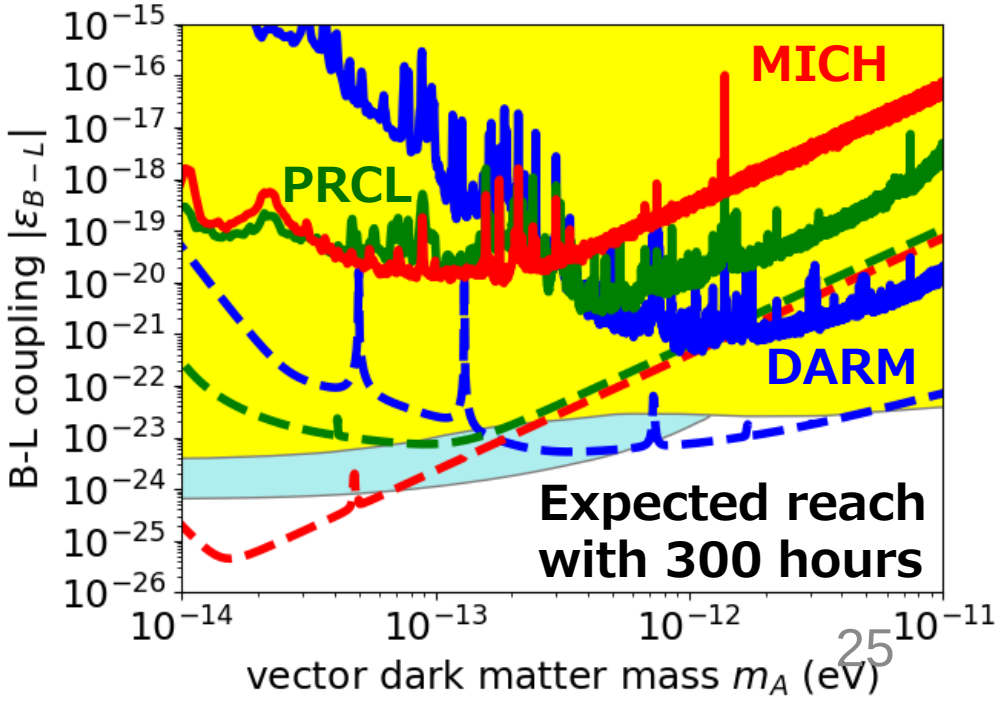
Search with KAGRA

- By measuring the lengths of auxiliary part of the interferometer, force difference between sapphire and fused silica can be measured

KAGRA O3GK Run in 2020

- 2020 Feb 25 - March 10, 2020 April 7 - 21
- Displacement sensitivities are not as good as the design (especially at low frequencies where auxiliary channels have good DM sensitivity)
- Good occasion to develop the pipeline to analyze multiple detector outputs



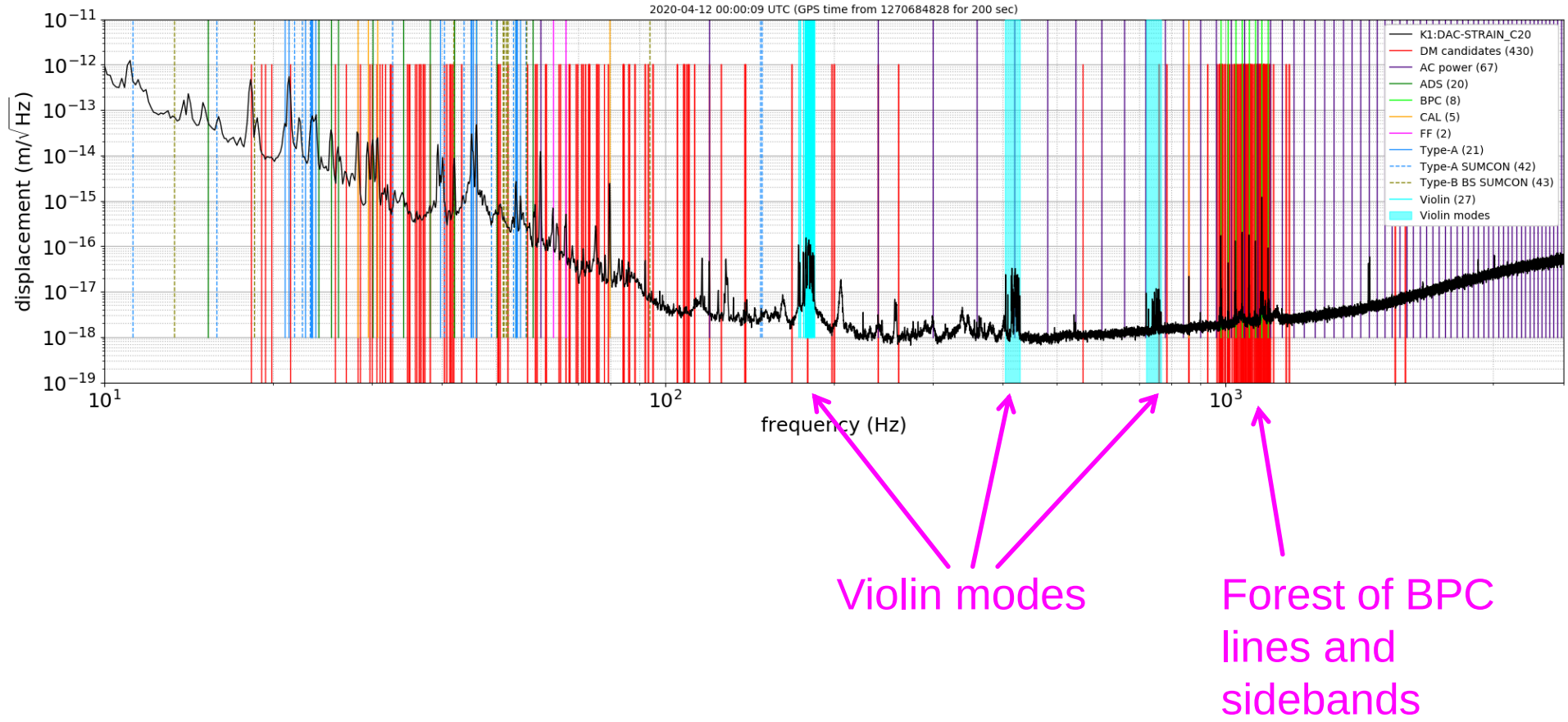


Data Analysis Flow

1. Calculate FFT of data
2. Calculate SNR and find frequency bins above threshold
   - Parameter tuning of spectrum smoothing on-going
3. Veto based on the linewidth of the peak
4. Veto by checking consistency between multiple series of data at different times
   - Now using two series. Maybe better to use more?
5. Veto by comparing the candidate frequencies and known line noises
   - List of known lines made
6. Veto using multiple detector outputs (DARM, PRCL, MICH)
   - Studies on the effect of DM field polarization on-going
7. Put upper limits (or claim outliers)
   - Studies on stochastic effects on-going

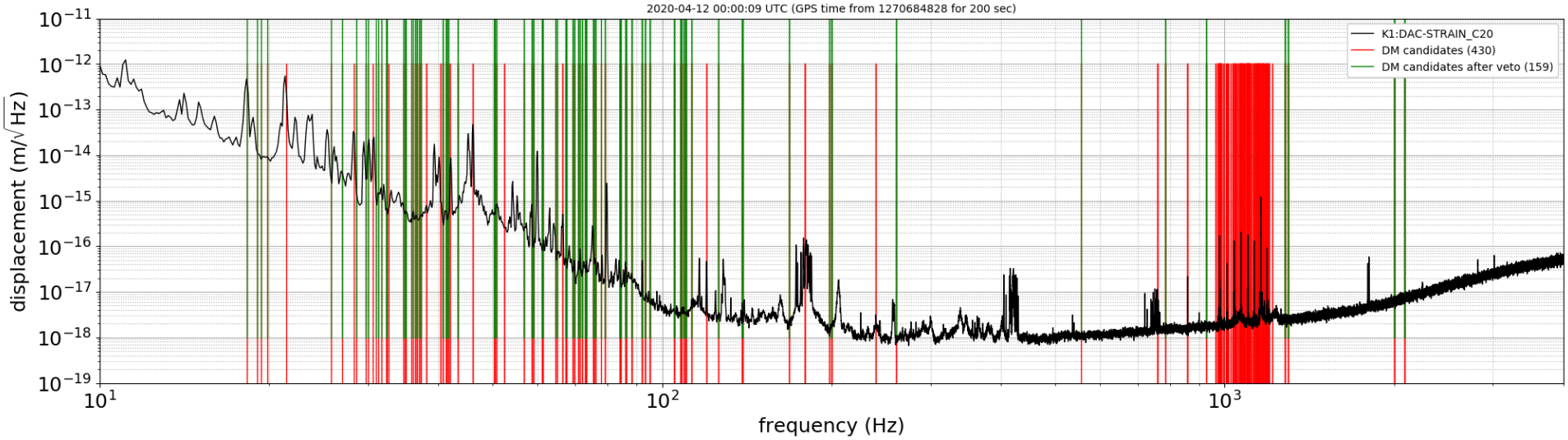
PRELIMINARY Candidates

- After step 4



PRELIMINARY Candidates

- After step 5

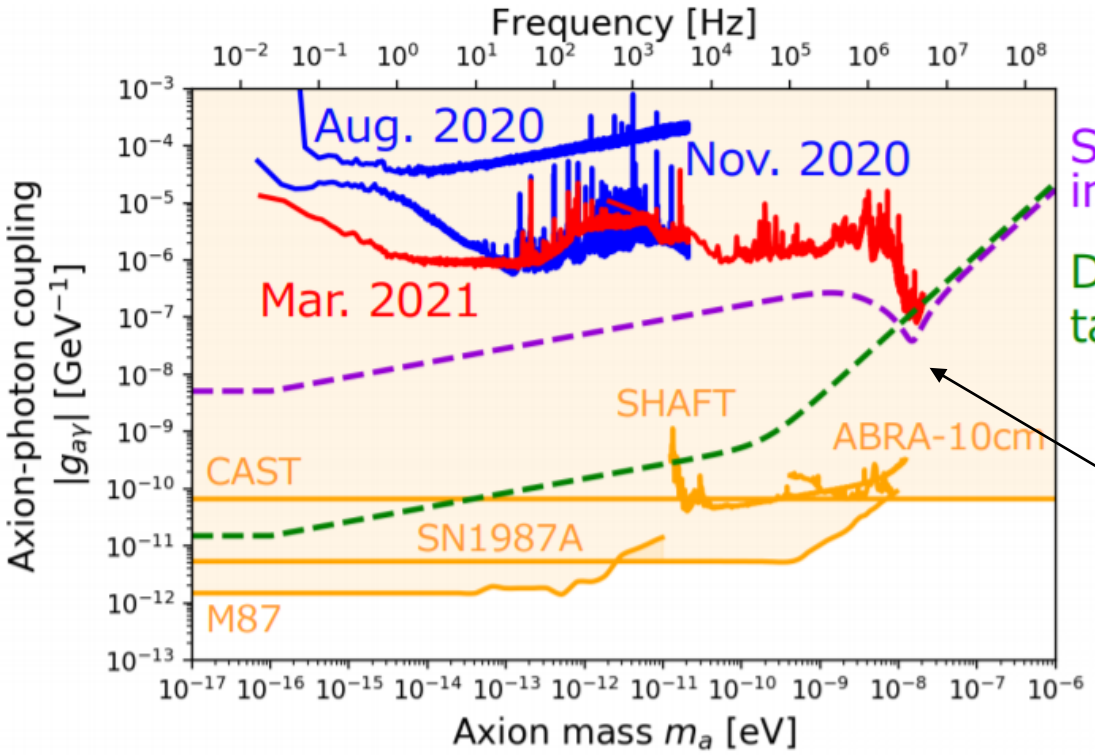


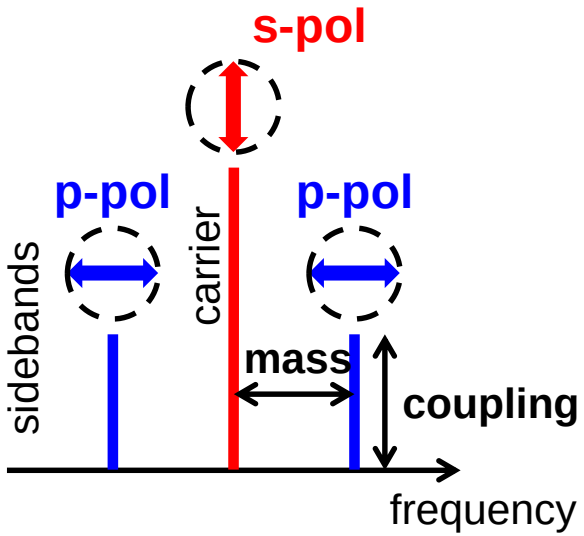
- Low frequency candidates could be investigated further using PRCL and MICH
  - DARM is more sensitive in terms of displacement, but less sensitive in terms of vector DM coupling

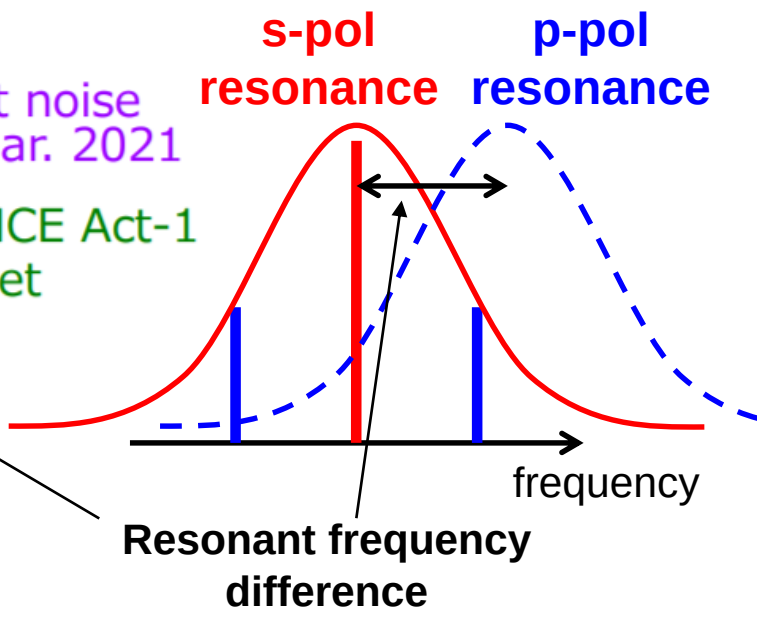
DANCE

Current Estimated Reach

- Sensitivity largely degraded due to resonant frequency difference between polarizations
  - p-pol generated by axion-photon coupling also needs to be amplified inside the cavity



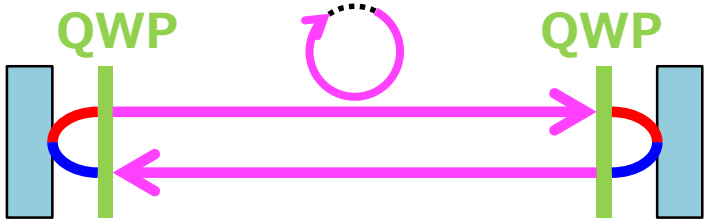




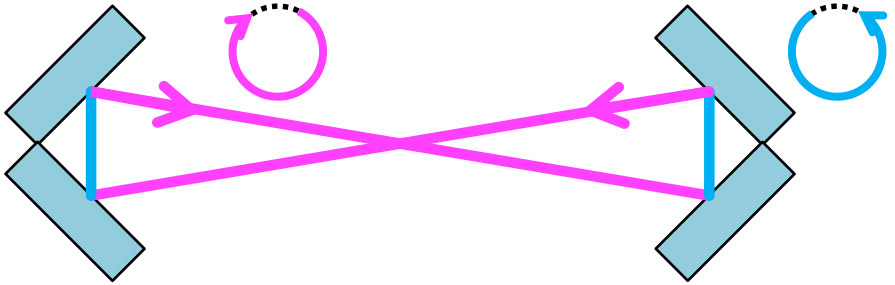
Plot by Y. Oshima

Past Proposals

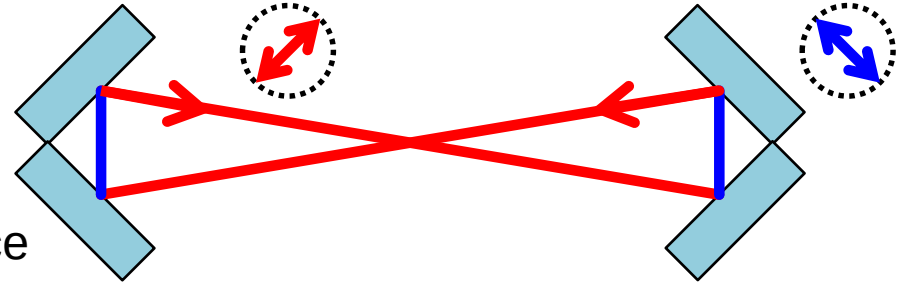
- W. DeRocco & A. Hook,
  PRD **98**, 035021 (2018)
  use of QWP to keep polarization



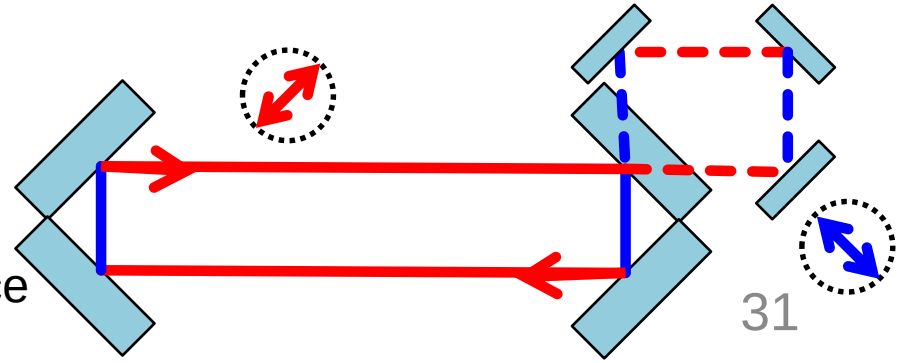
- I. Obata, T. Fujita, YM,
  PRL **121**, 161301 (2018)
  bow-tie cavity to keep polarization



- H. Liu+,
  PRD **100**, 023548 (2019)
  tune incident angles to tune s-pol
  and p-pol resonant frequency difference

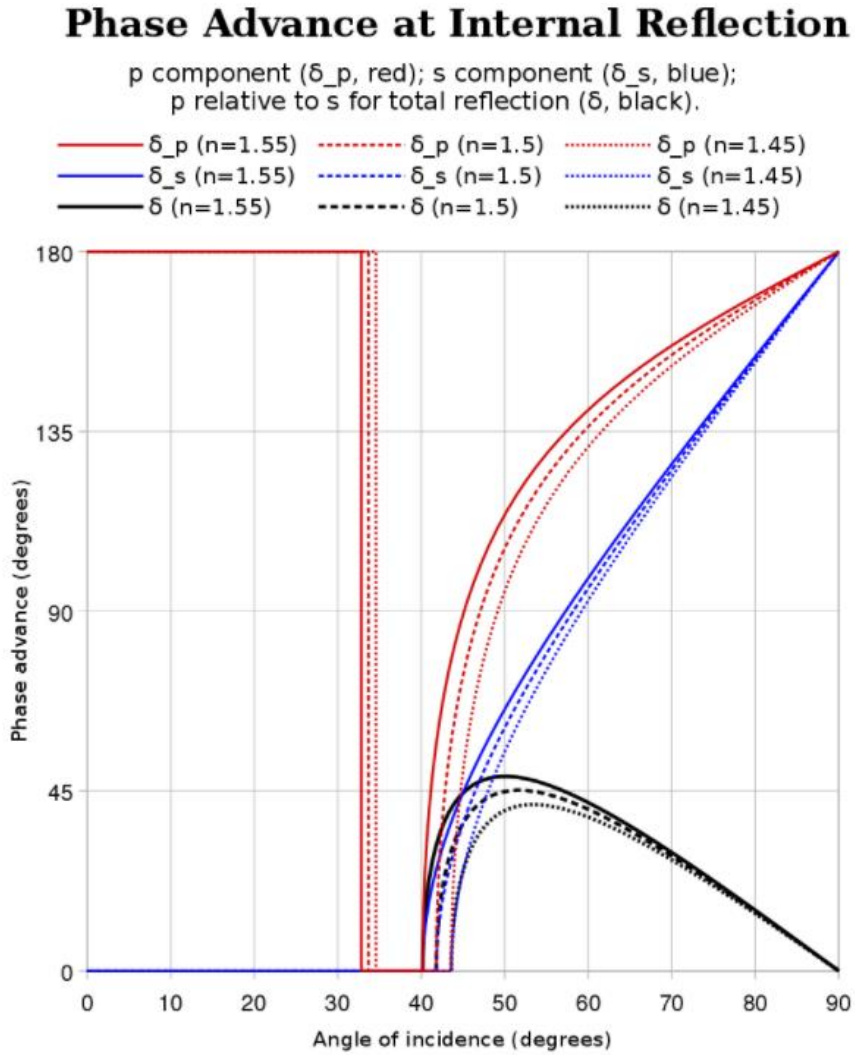


- D. Martynov & H. Miao,
  PRD **101**, 095034 (2020)
  use auxiliary cavity to tune s-pol
  and p-pol resonant frequency difference



Resonant Frequency Difference

- Caused by reflected phase difference in Fresnel reflection with non-zero incidence
- Coating also has birefringence



[Applied Physics B 97, 457 (2009)]

Birefringence of interferential mirrors at normal incidence

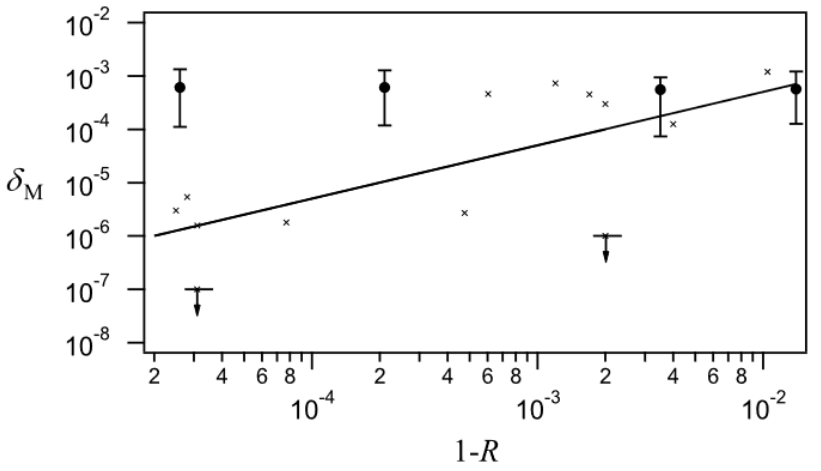
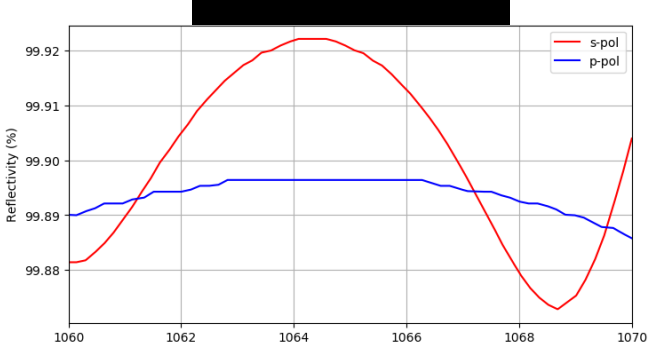


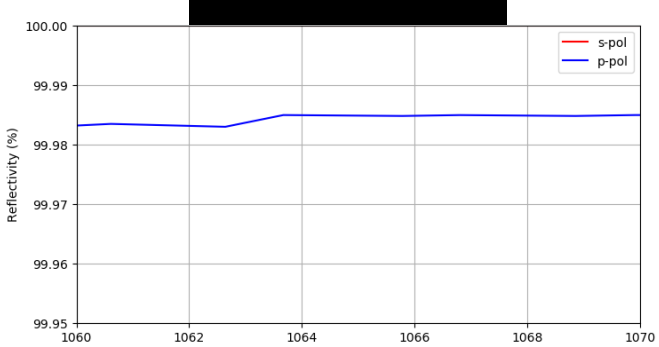
Fig. 6 Two different numerical calculations for the induced phase retardation per reflection as a function of $(1 - R)$. *Solid curve*: birefringence only for the first layer just after the substrate. *Dots with error bars*: calculation with random birefringence per each layer. *Crosses*: measurements plotted in Fig. 3

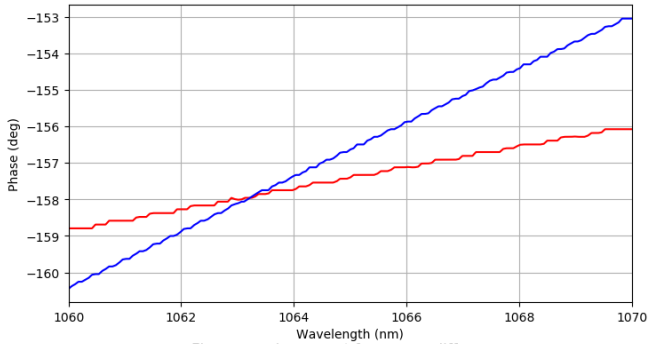
https://en.wikipedia.org/wiki/Fresnel_rhomb

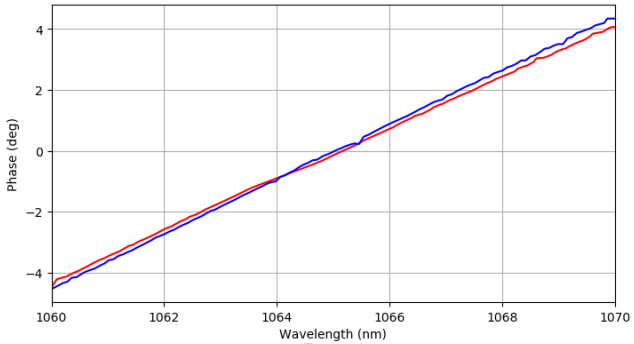
Zero Phase Shift Mirrors

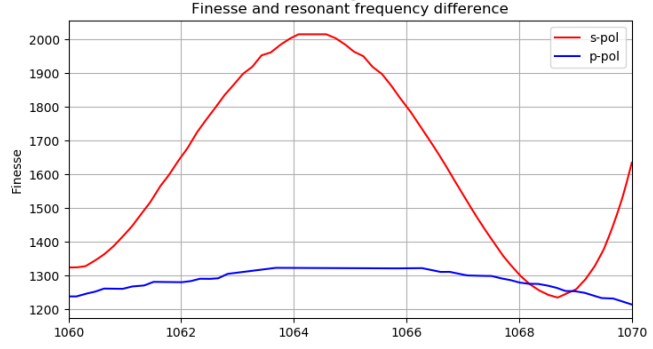
Phase shift needs to be less than O(0.01) deg to have simultaneous resonance within the linewidth

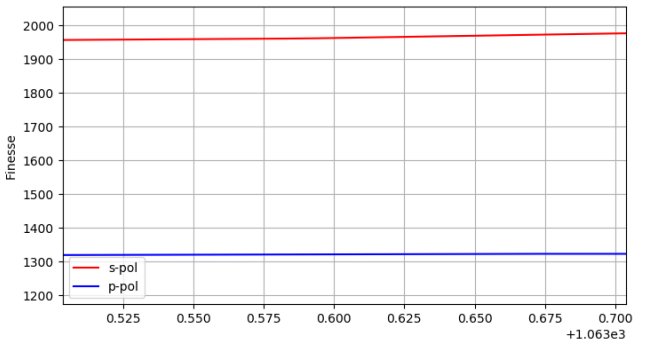


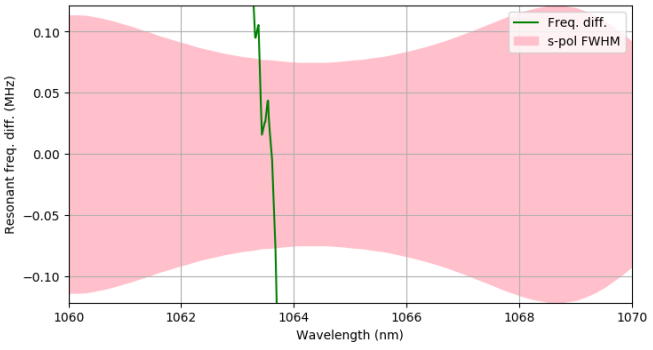


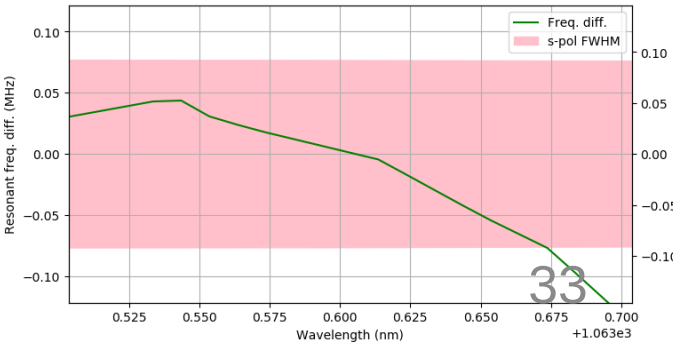












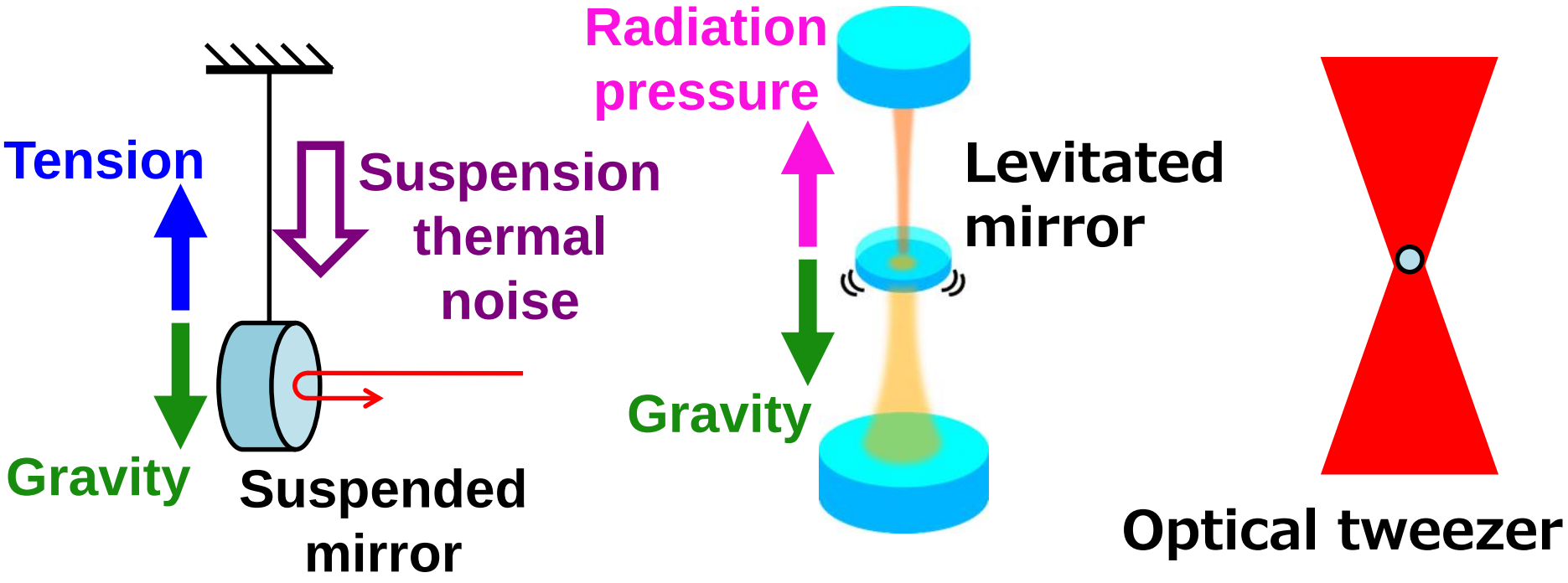
Comparison of Tuning Methods

	Auxiliary cavity	**Incident angle**	**Wavelength**
Finesse	Limitations (mode mismatch, AR losses)	Can make high	Can make high
Power	Can make high	Can make high	Could be tough (amp for certain wavelength)
Cavity controls	Complicated (additional beam necessary to control aux. cavity)	Simple	Simple (could require frequency actuator if not equipped to laser source)
Sweeping the observation band	Easy (can be done without unlocking)	Requires mechanical system	Could be tough (need for unlocking)
Coating error tolerance	Not much (not good if phase shift too small)	Depends much (cannot make it if no zero crossing)	Depends much (cannot make it if no zero crossing)

Optical Levitation

Optical Levitation of Mirror

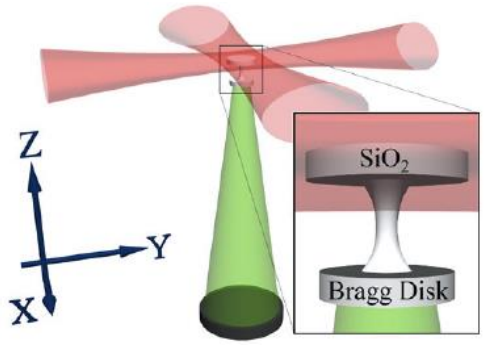
- Support a mirror with radiation pressure alone
- Free from suspension thermal noise
- Large coupling compared with optical tweezers



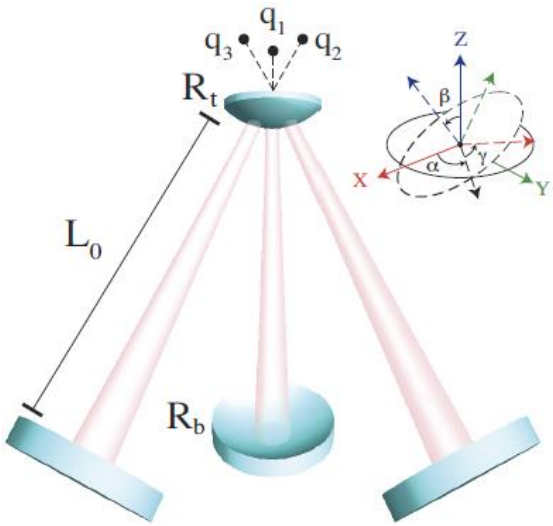
Sandwich Configuration

- Mirror levitation has never been realized
- Simpler configuration than previous proposals

  YM, Y. Kuwahara+, Optics Express 25, 13799 (2017)
- Proved that stable levitation is possible and SQL can be reached with 0.2 mg mirror



S. Singh+: PRL 105, 213602 (2010)

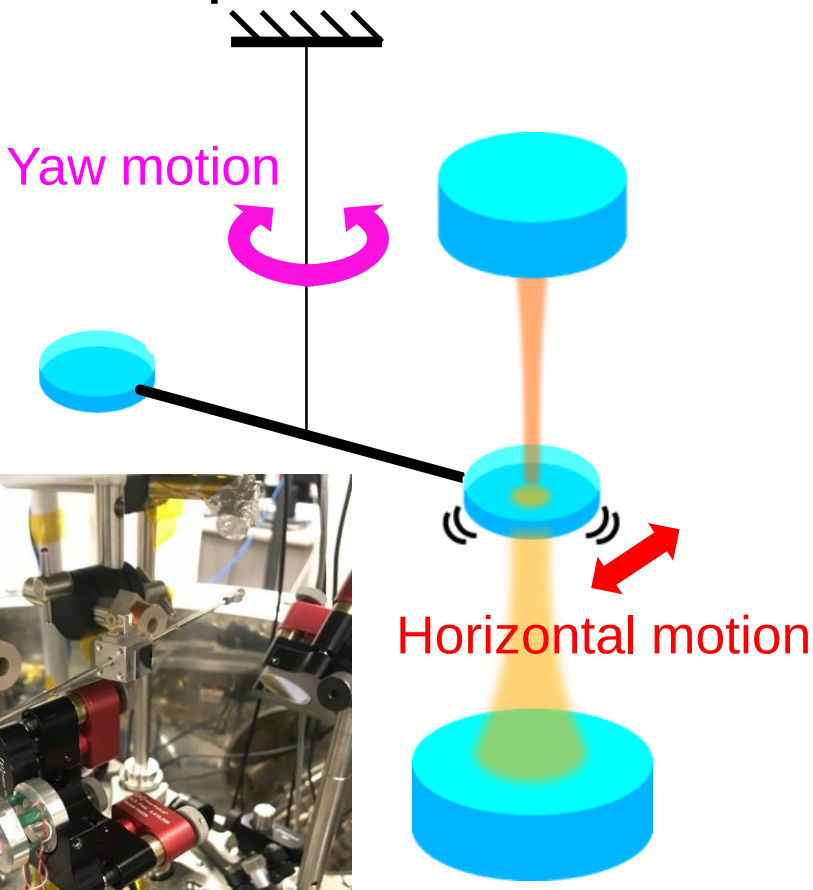


G. Guccione+: PRL 111, 183001 (2013)

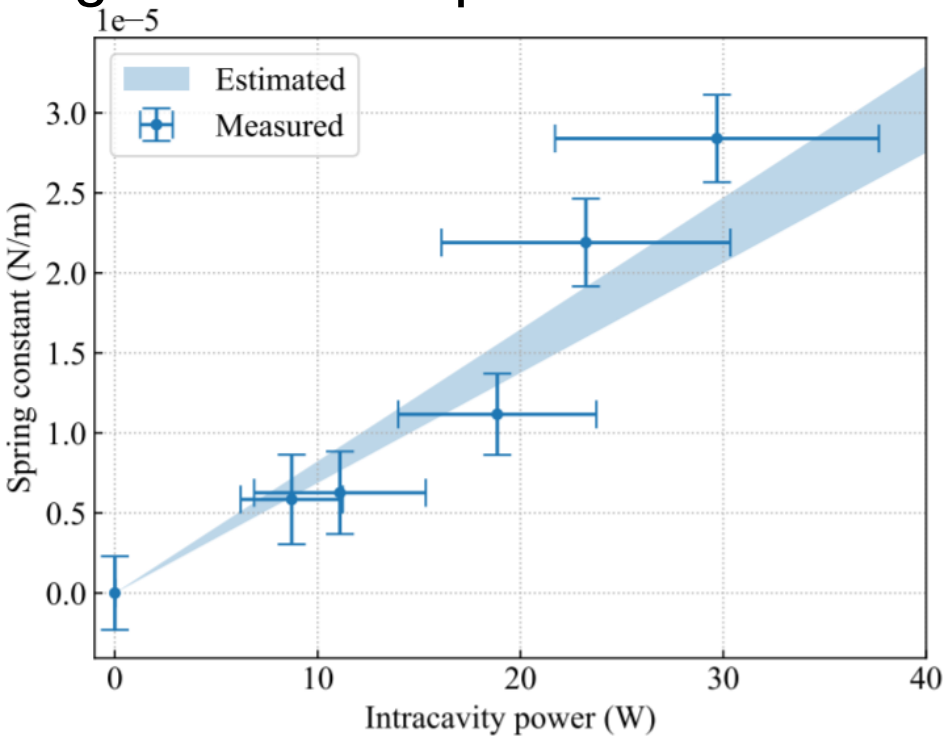
Experiment to Verify the Stability

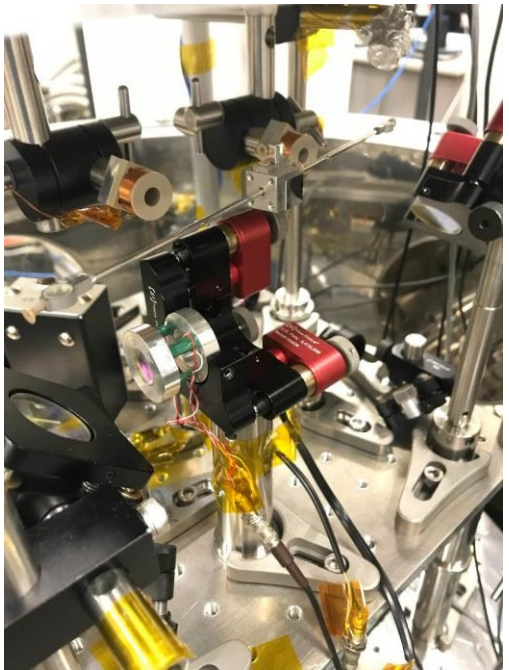
- Verified the stability with a torsion pendulum and a dummy mirror

  T. Kawasaki, …, YM,
  PRA 102, 053520 (2020)



Measured optical geometrical spring agreed with expectation





Fabrication of Levitation Mirrors

- mg and mm-scale curved mirror necessary
  e.g. For levitation demonstration
  φ 3 mm, 0.1 mm thick (~1.6 mg for fused silica)
  RoC = ~30 mm convex
  R > 99.95 %
- Two approaches
  1. Coat thin fused silica mirror to bend the mirror
  2. Photonic crystal mirror to create effective curvature

Supported by ANR-JST
QFilter project

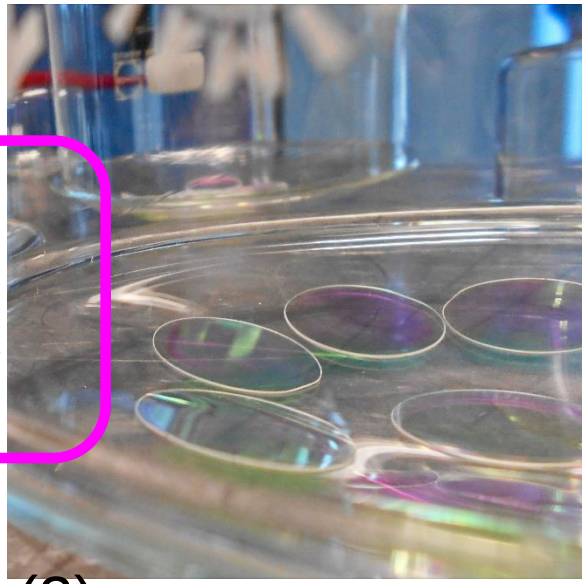
New Approach for Fused Silica

2014 Approach

(1) Make 3 mm dia. lens → (2) Coat → CRACKED!

2020-2021 Approach

(1) Make 1 inch dia. 0.1 mm thick disk → (2) Coat (bend due to stress) → (3) Cut into 3 mm dia.



Somehow concave instead of convex
Coating thickness x2
-> RoC x~1/2
Substrate thickness x1/2
-> RoC x~1/4

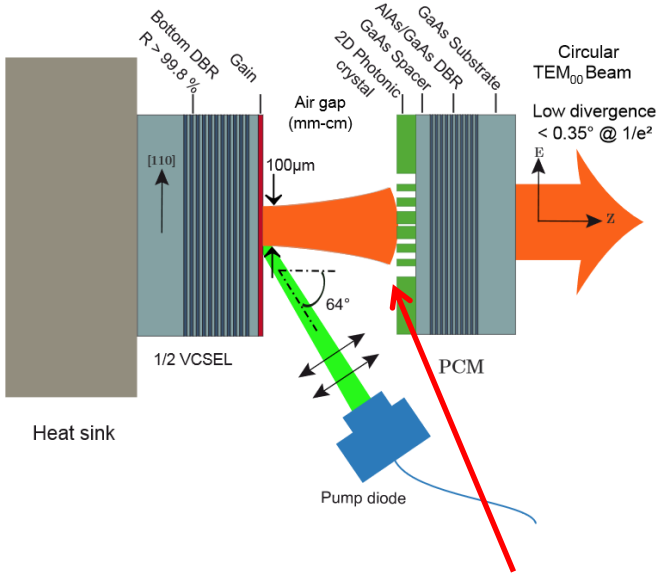
So far successful upto (2)
- R=92(1)%, RoC=500^{+2000}_{-200} mm
- R=88(1)%, RoC=400^{+800}_{-200} mm

Trying (3) and thicker coating (would try thinner substrate)

Photonic Crystal Mirror

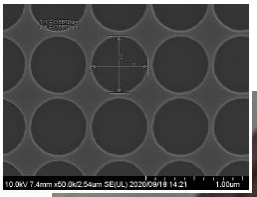
- Effective curvature possible by modulating the filling factor

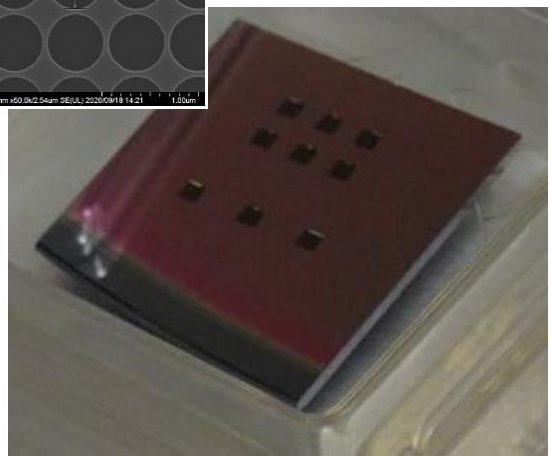
  M. S. Seghilani+,
  Optics Express 22, 5962 (2014)

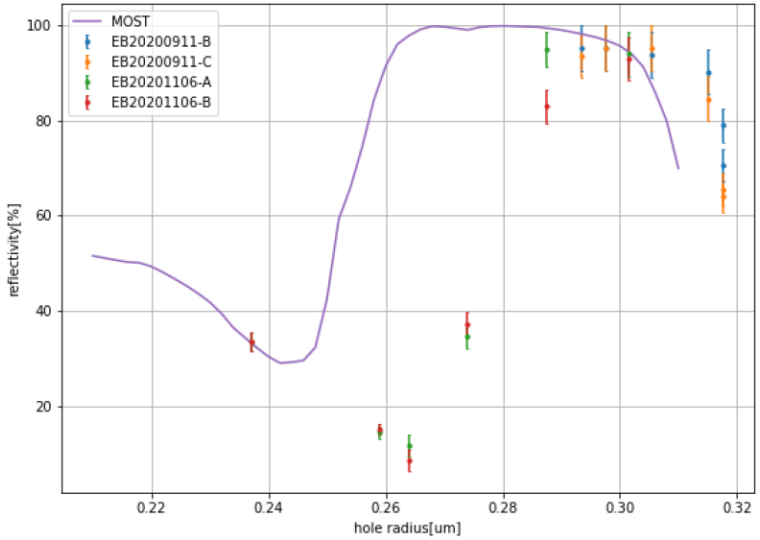


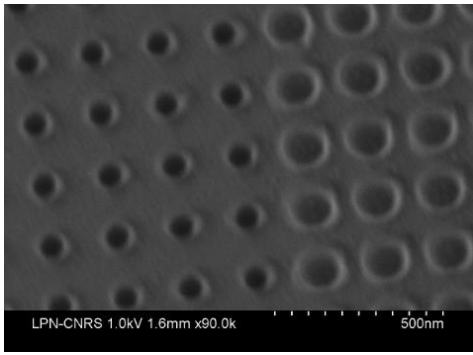
- Currently trying Si photonic crystal mirror without modulation

  So far achieved 95(5) % reflectivity



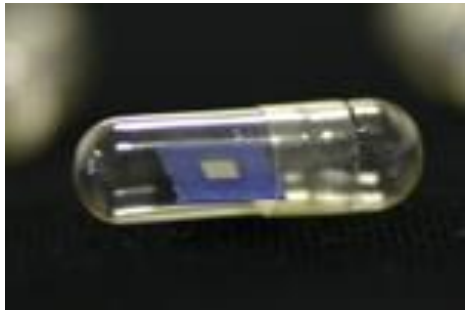






Next Steps

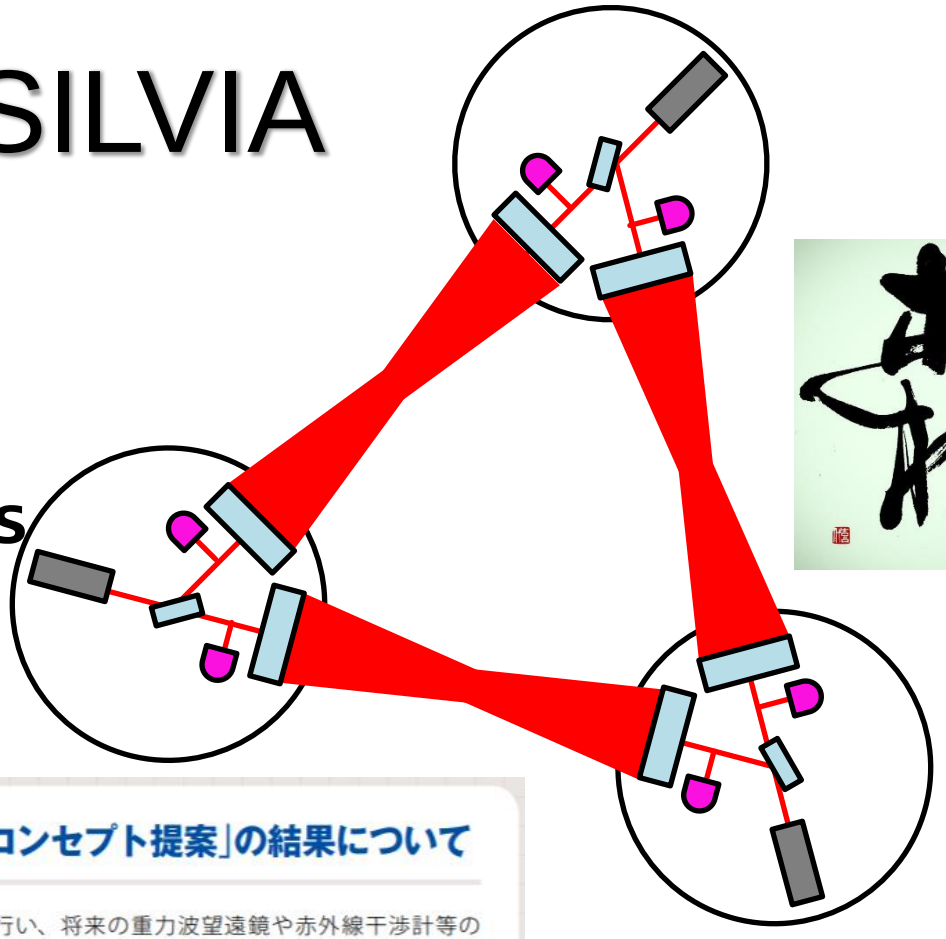
- **Thin fused silica mirror**
  - Measure T=10ppm mirrors
    We already have them (RoC~500 mm by LMA)
  - Measure the RoC after cutting
  - Try thicker coating and thinner substrate to get more curve
- **Photonic crystal mirror**
  - Measure reflected phase (how?)
  - Make PhC mirror with modulation
  - Measure with different wavelengths
  - Make PhC with Si_3N_4 membrane
    We already have a raw sample
    (Norcada NX5100DS)
    Could be made at 京都大学ナノテクノロジーハブ拠点



SILVIA

SILVIA

- **S**pace
  Interferometer
  Laboratory
  Voyaging towards
  Innovative
  Applications



「2019年度公募型小型計画・宇宙科学ミッションコンセプト提案」の結果について

2019年10月10日に公募を開始した「2019年度公募型小型計画・宇宙科学ミッションコンセプト提案」は、2020年2月5日の締切までに7件の応募がありました。宇宙科学研究所は提案の評価を宇宙理学委員会と宇宙工学委員会に依頼し、2つの委員会は合同で「公募型小型・評価審査小委員会」を設置しました。

宇宙科学プログラム室は、希望のあったワーキンググループに対し、提案書作成に向けた調整、支援を行いました。小委員会では、応募のあった全テーマについて2020年3月に一次ヒアリングを行った後、4テーマについて2020年5月に二次ヒアリングを実施し、最終的に1テーマを選定しました。小委員会の選定結果は2020年8月3日の臨時宇宙理工学合同委員会に報告され、そこでの審議を経て承認されました。

次のフェーズに進むことのできる提案は、新時代の高精度天体観測手法である宇宙干渉計の実現に必須となる、超高精度フォーメーションフライト技術とドラッグフリー技術の軌道上実証を行い、将来の重力波望遠鏡や赤外線干渉計等のミッション実現に向けた技術を獲得することを目指すSILVIA (Space Interferometer Laboratory Voyaging towards Innovative Applications) 計画の1件であります。

今後、この提案に対してアイデア実現加速プロセス (Pre-PhaseA1b) を実施し、適切な時期にミッション定義フェーズ (Pre-Phase A2) に進むための審査(プリプロジェクト候補選定審査) を実施していく予定です。その後本提案は、公募型小型計画5号機あるいは6号機の候補の一つとして活動していくことになります。

公募型小型・評価審査小委員会および木村 真一委員長には、大変な労力をかけて厳正なる審査をしていただきました。小委員会委員および小委員会から評価を委託された外部委員の皆様に深く感謝いたします。

(佐藤 英一)

JAXA宇宙科学研究所 ISAS News
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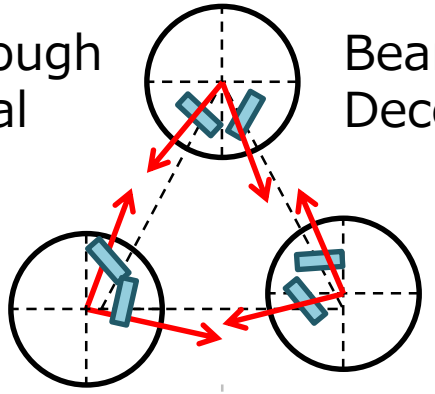
2020年8月号

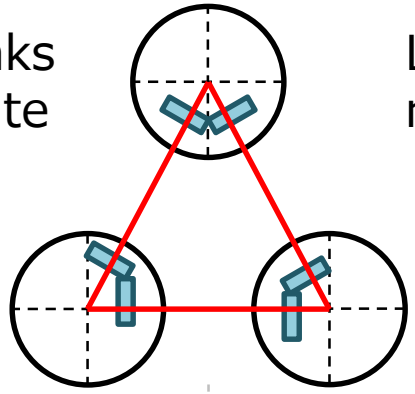
Initial Acquisition Sequence

Deployment	Link acquisition	Lock acquisition	Obs.

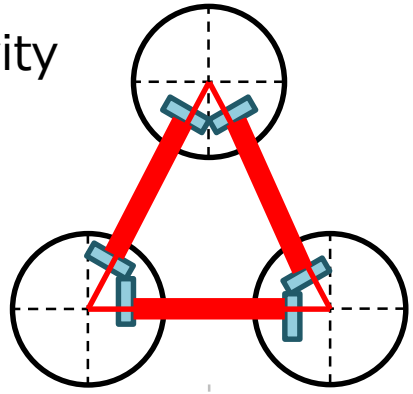
Make a rough equilateral triangle (100 m)



Beam links Decelerate



Lock on cavity resonance



Triangle <0.4 m
GPS(-like)
Thrusters

Relative distance between TMs <34 um
Some sensors
TM, Thrusters

<1 nm
PDH
TM

Relative speed between TMs <1.3 cm/sec
GPS(-like)
Thrusters

<0.12 mm/sec
PDH
Laser freq.

<3.4 um/sec
PDH
TM

<51 nm/sec

Relative angle <3 mrad
STT
Thrusters

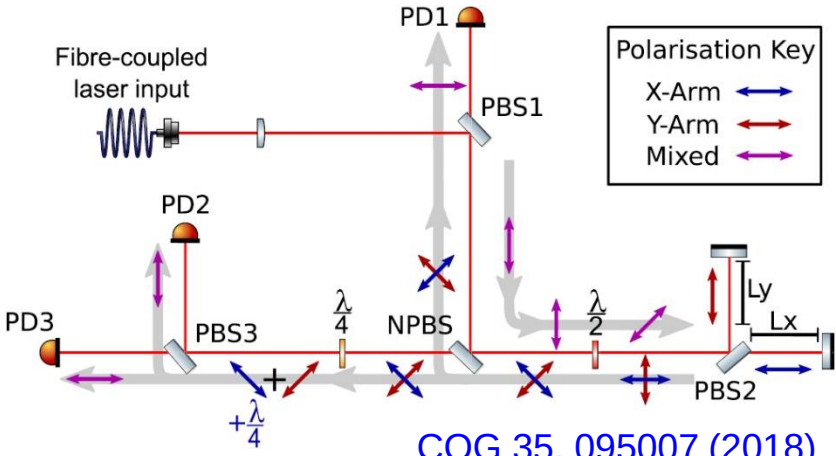
<21 urad
AOD?
Steering, TM

QPD ?

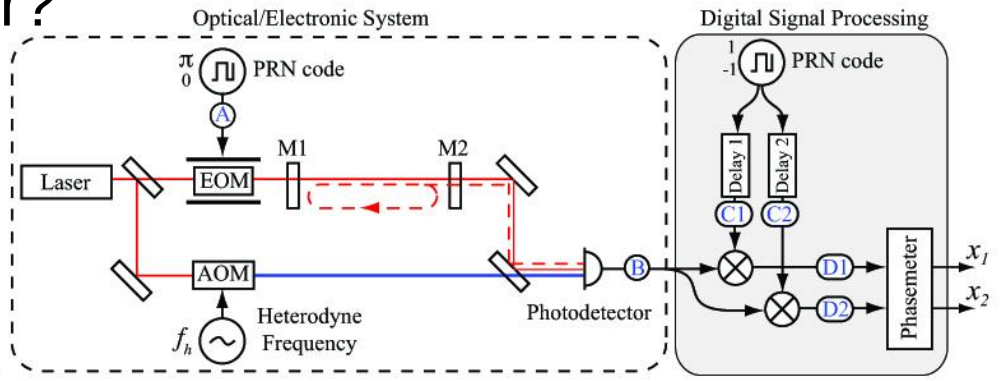
<0.7 urad
WFS
TM

Bridging Sensors Before PDH

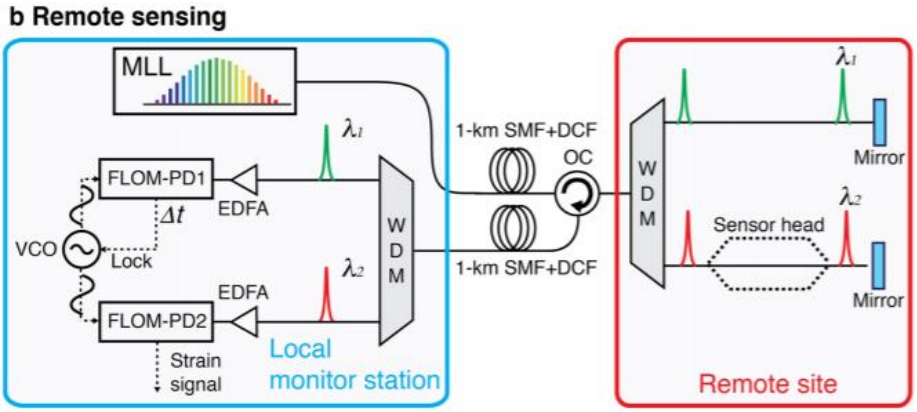
- O(cm) range, O(um) resolution
- FSR counting?
- Kalman filter or something to estimate the TM speed?
- Quadrature interferometer?
- Heterodyne interferometer?
- Digital interferometry?
- Time-of-flight measurement of pulses?



CQG 35, 095007 (2018)



Optics Express 17, 828 (2009)



Scientific Reports 7, 13305 (2017)

Don't Forget...

- Birefringence studies for KAGRA
- Mitigation of parametric instabilities in KAGRA
- Machine learning and modern controls for suspension controls and interferometer alignment
- Observing run for Lorentz invariance test
- Lorentz invariance test in space
- Rotating TOBA
- Coil-coil actuator
- Optical trapping of micro-particles and doughnuts
- Control of rotational mode of optically levitated mirror using LG beams

SUMMARY

- **We are at a very exciting stage!**

Vector DM

- Very first data analysis with multiple detector outputs

DANCE

- Very first data taking and data analysis
- New ideas for the optical configuration

Optical levitation

- New approaches for the fabrication with promising first results and cooperative partners

SILVIA

- Proceeded to the next step, many things to contribute