First observation and analysis of DANCE: Dark matter Axion search with riNg Cavity Experiment

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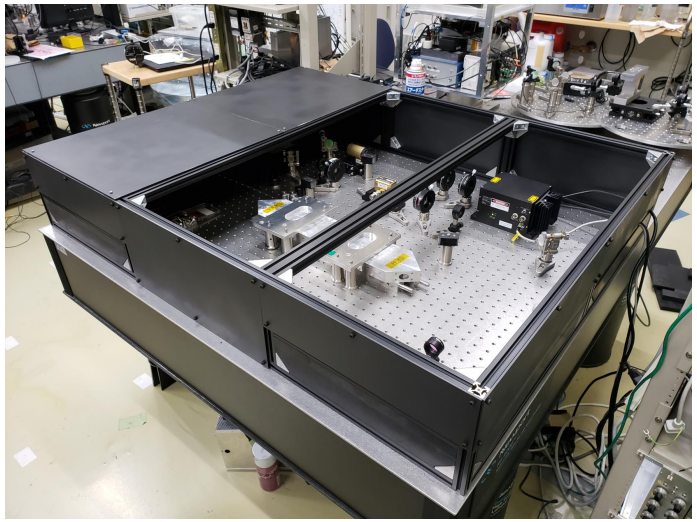
Overview

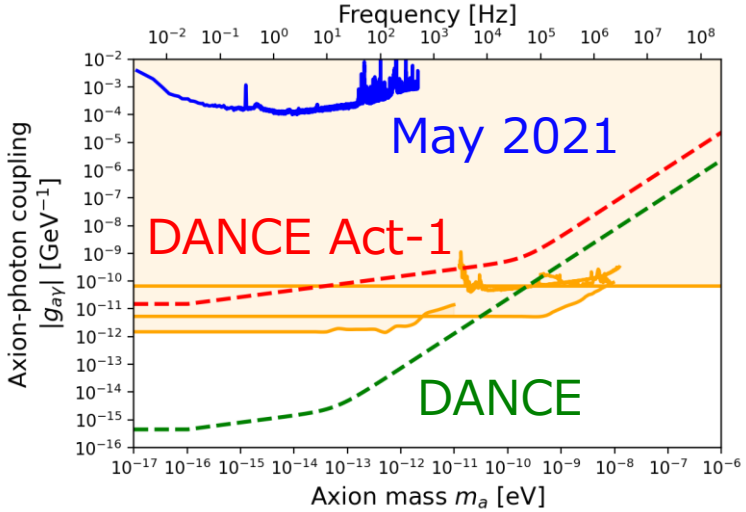
- We proposed a new experiment to search for axion dark matter with a ring cavity

  DANCE: Dark matter Axion search with riNg Cavity Experiment

  I. Obata, T. Fujita, Y. Michimura, PRL 121, 161301 (2018)

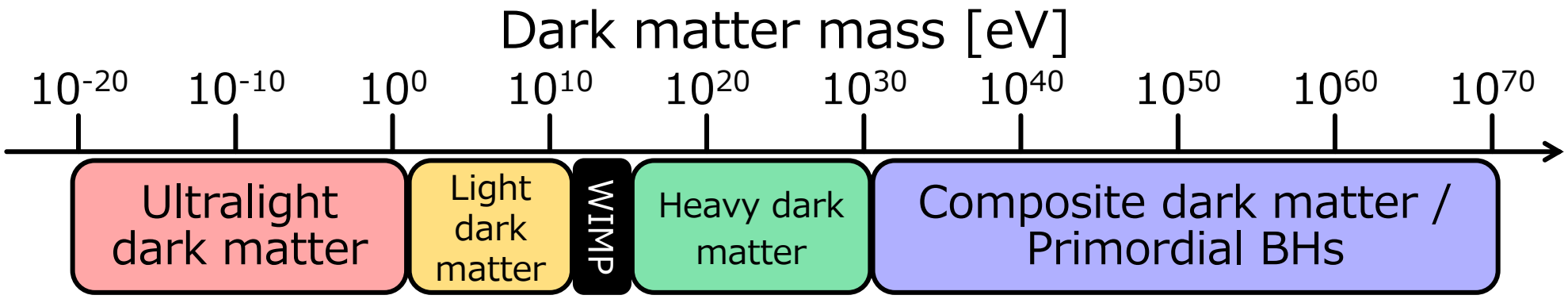
- Prototype experiment DANCE Act-1 is ongoing
  - Assembled and evaluated the optics
  - Obtained the first data for 12 days
  - Data analysis is underway





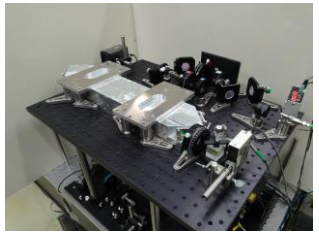
Axion search with laser interferometers

- Need to search for dark matter in wider mass range
- Ultralight dark matter can be searched with laser interferometers
- DANCE focuses on axion dark matter



Laser interferometers

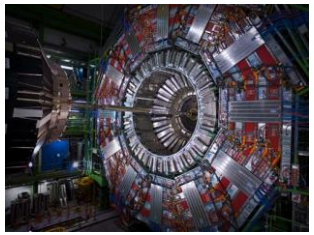
DANCE



KAGRA

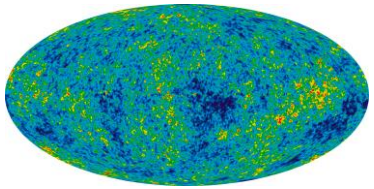
XENON1T

LHC



Subaru Telescope

CMB



→ **Yuta's talk**
(Dark Matter 4, No. 337)

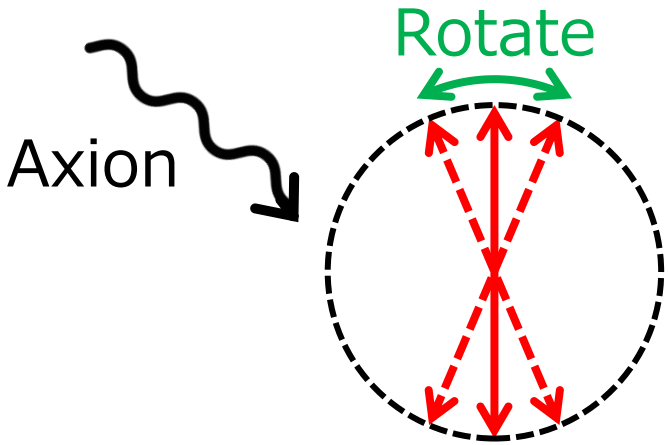
Polarization rotation from axions

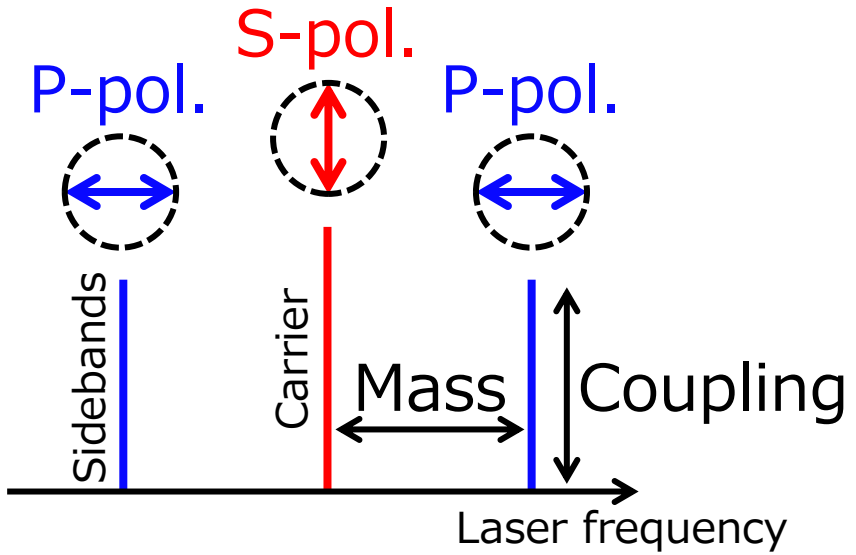
- Axion-photon coupling causes phase velocity difference between left- and right-handed photons

$$c_{\mathrm{L/R}} = \sqrt{1 \pm \frac{g_{a\gamma} a_0 m_a}{k} \sin(m_a t + \delta_\tau)}$$

Coupling constant — Axion field — Axion mass

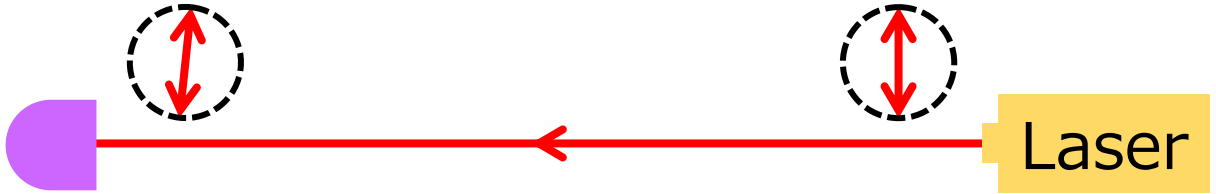
- Phase velocity difference of circular polarizations makes linear polarization rotate



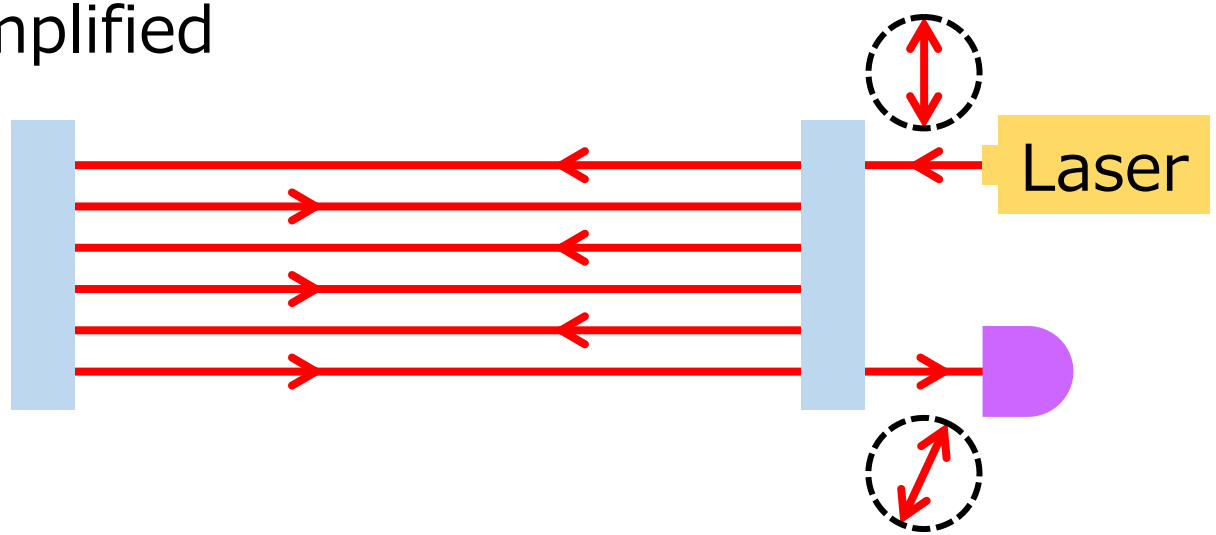


Signal amplification with cavities

- Rotation angle is too small to be observed without a cavity

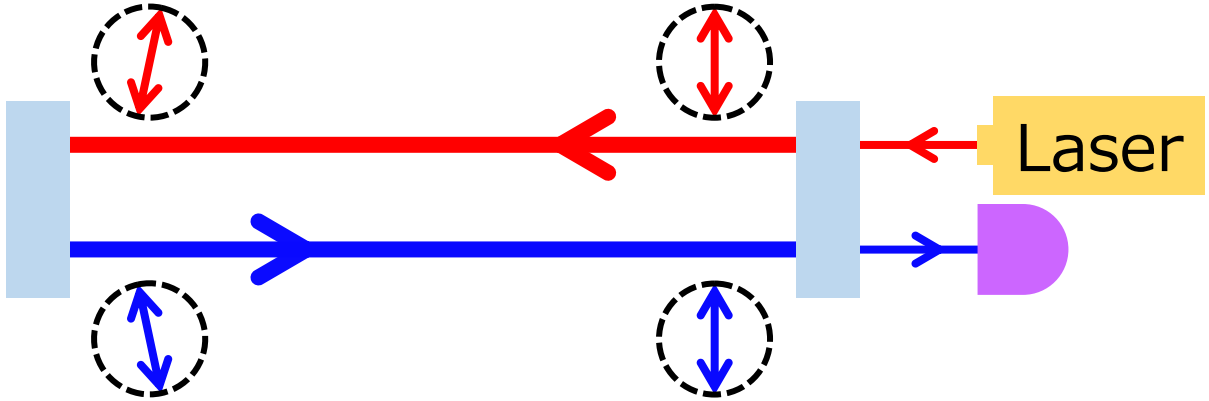


- Laser light runs between mirrors many times in a cavity
  → Rotation angle can be amplified

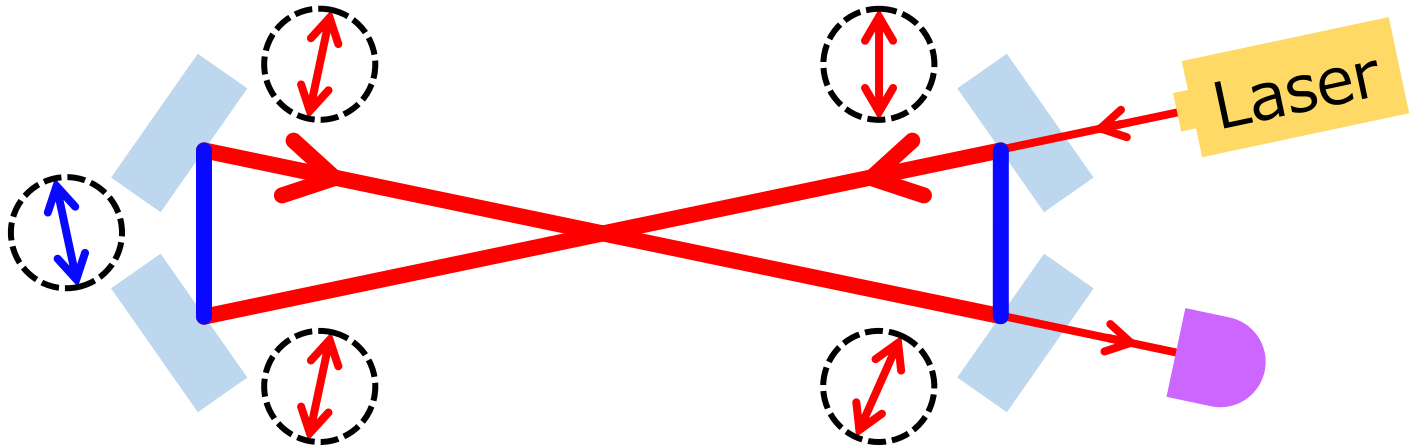


Bow-tie ring cavity

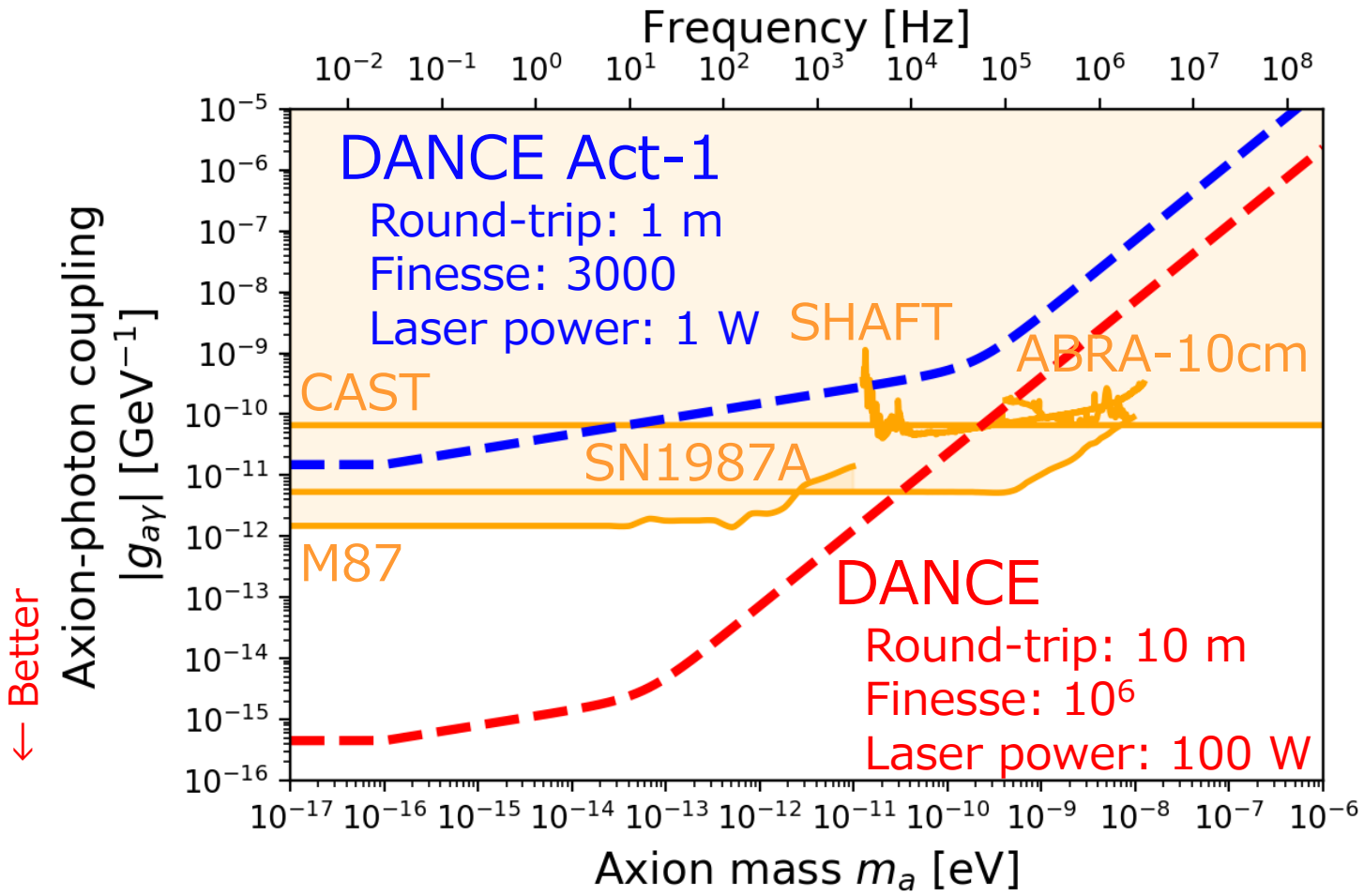
- Rotated direction is inverted in a linear cavity
  → Rotation effect is cancelled out



- A bow-tie ring cavity prevents linear polarization from inverting rotated direction



Design sensitivity of DANCE



※ 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)

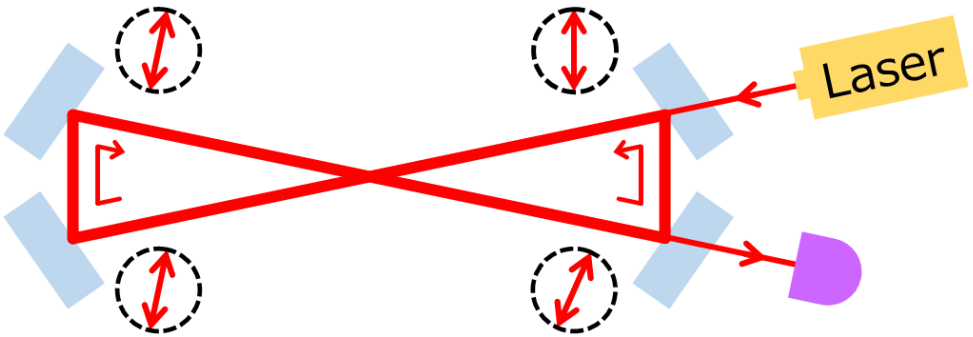
- Shot noise is caused by fluctuations of number of photons
- Need to minimize the other noises

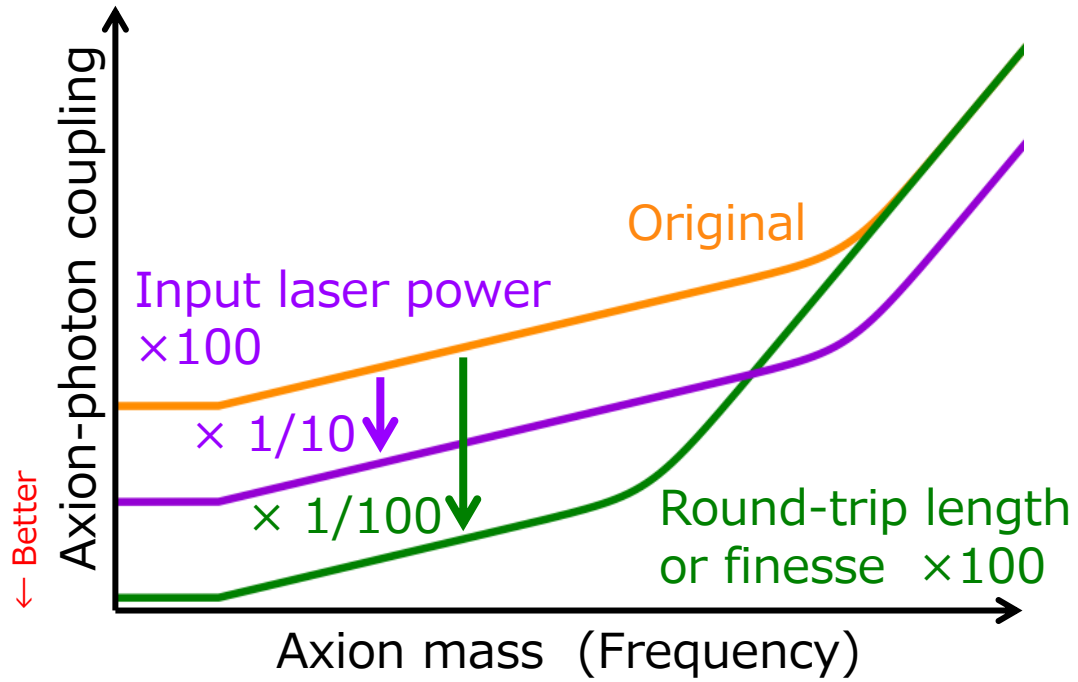
Important parameters (1)

- Input laser power ··· Shot noise

- Round-trip length ··· Optical length
- Finesse ··· Number of round trip

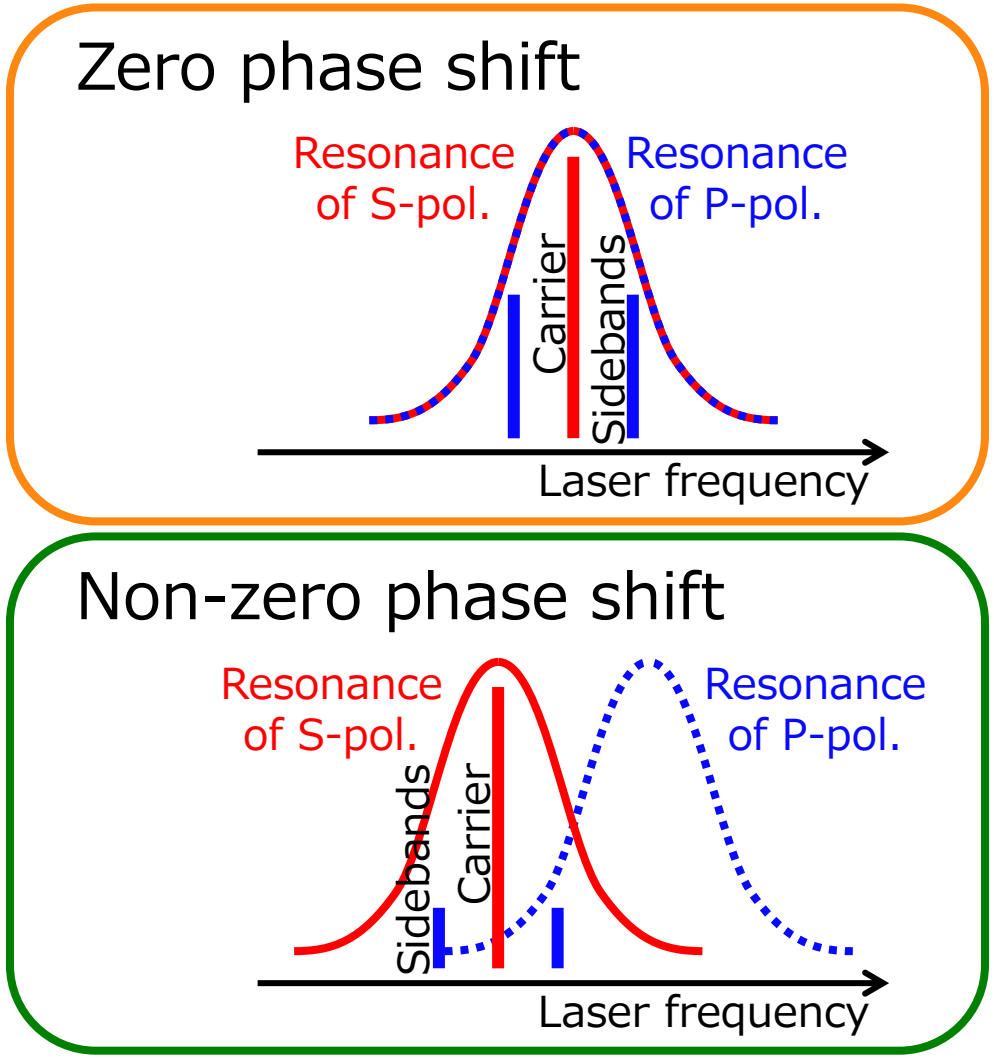
} Effective pass length

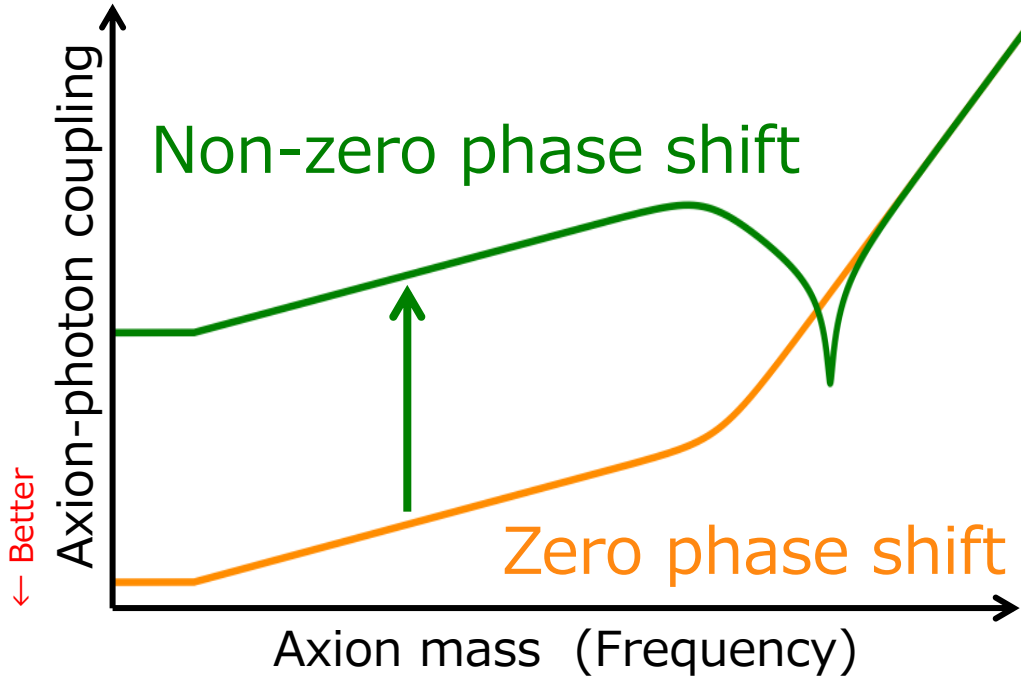




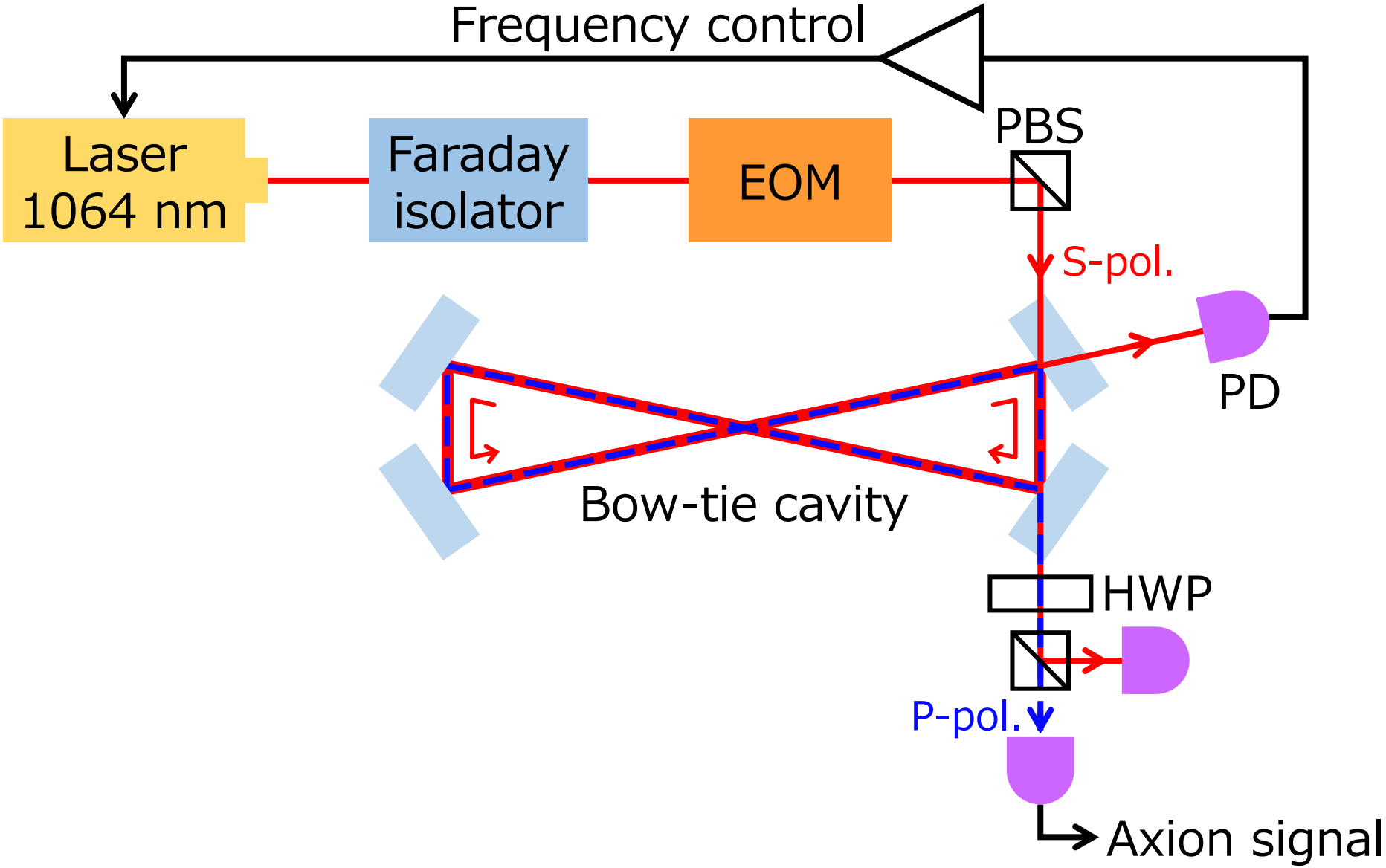
Important parameters (2)

- Resonant frequency difference between S- and P-polarizations
  ・・・ From non-zero phase shift by mirror coating at reflections

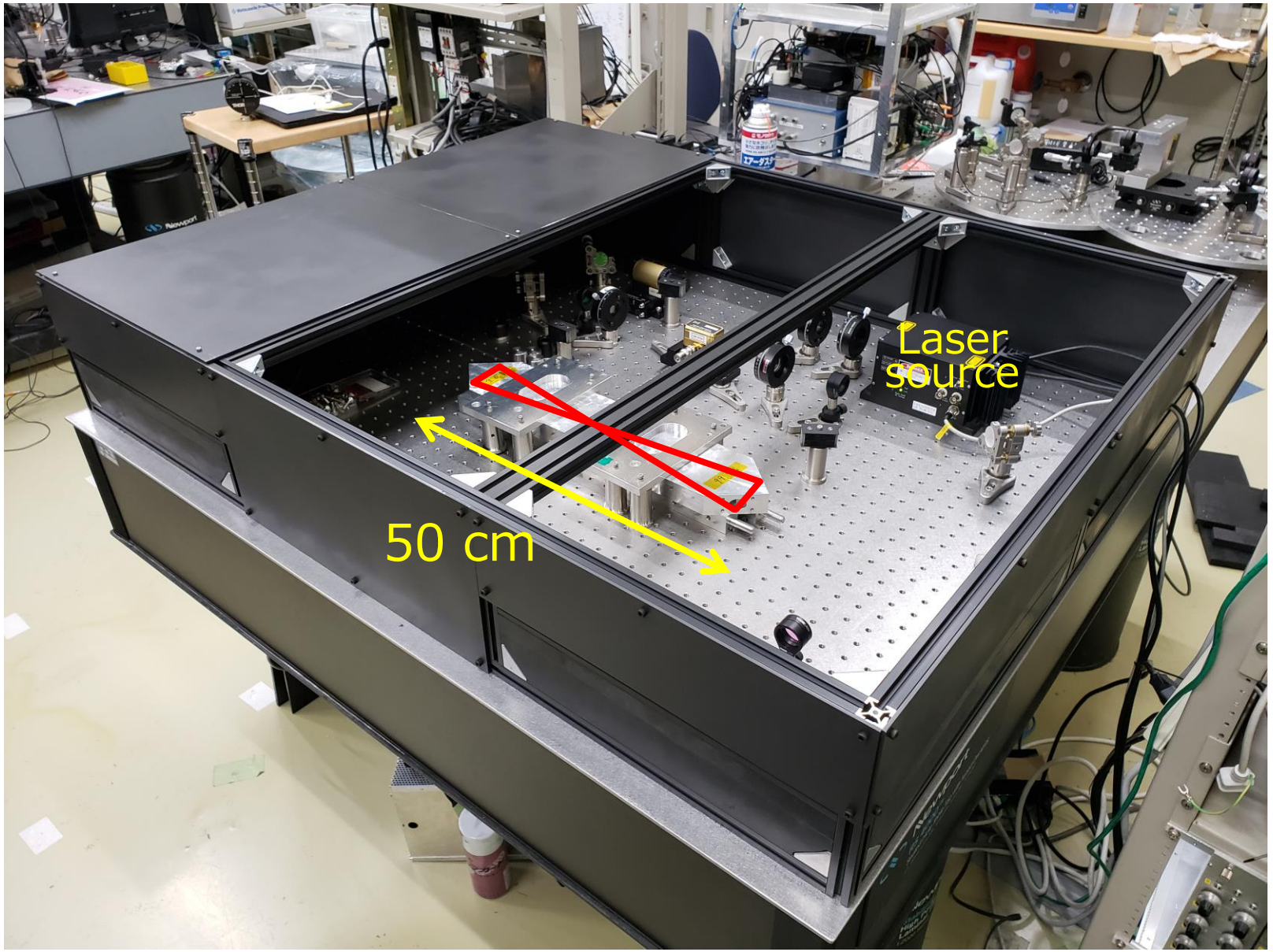




Experimental setup of DANCE

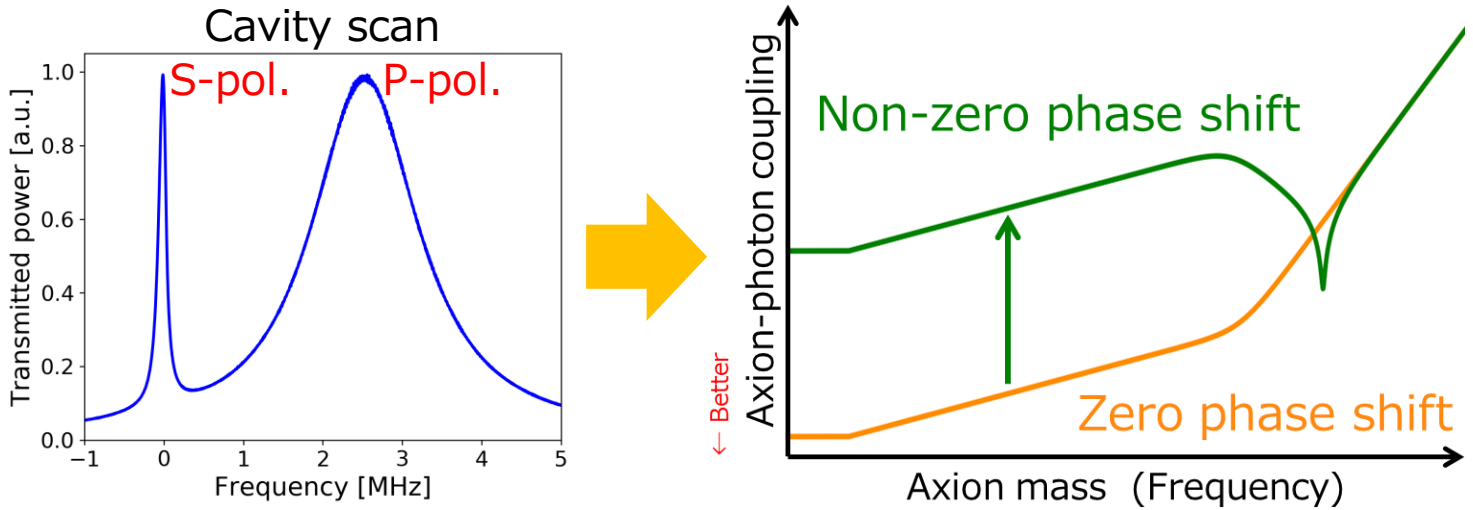


Picture of DANCE Act-1



Performance evaluation of the cavity

	Designed values	Measured values
Input laser power	1 W	242(12) mW
Transmitted laser power	1 W	153(8) mW
Finesse for carrier	3×10^3	$2.85(5)\times10^3$ (S-pol.)
Finesse for sidebands	3×10^3	195(3) (P-pol.)
Resonant frequency difference between S- and P-pol.	0 Hz	2.52(2) MHz

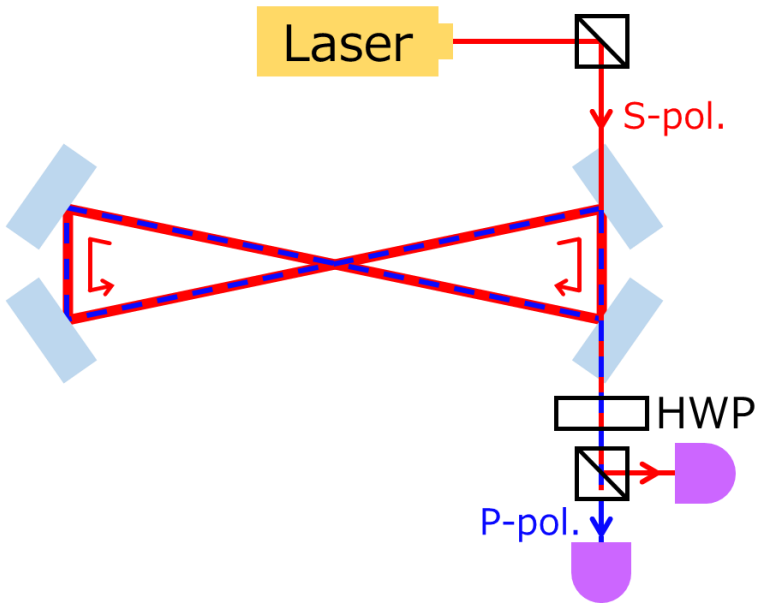


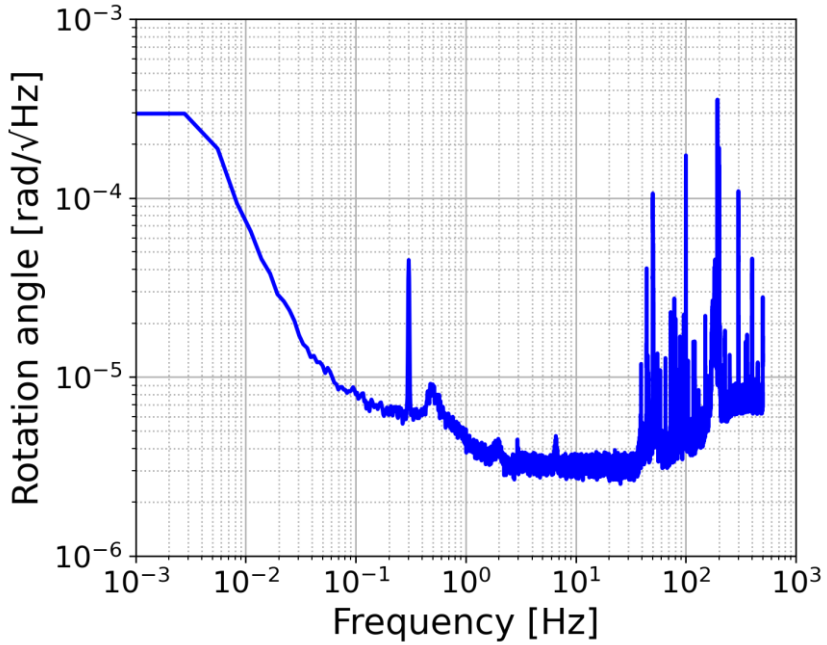
Data acquisition and calibration

- Recorded amount of P-pol. $P_{\mathrm{P}}(t)$ and total transmitted light $P_{\mathrm{tot}}(t)$ for 12 days (May 18-30, 2021) with 1 kHz sampling

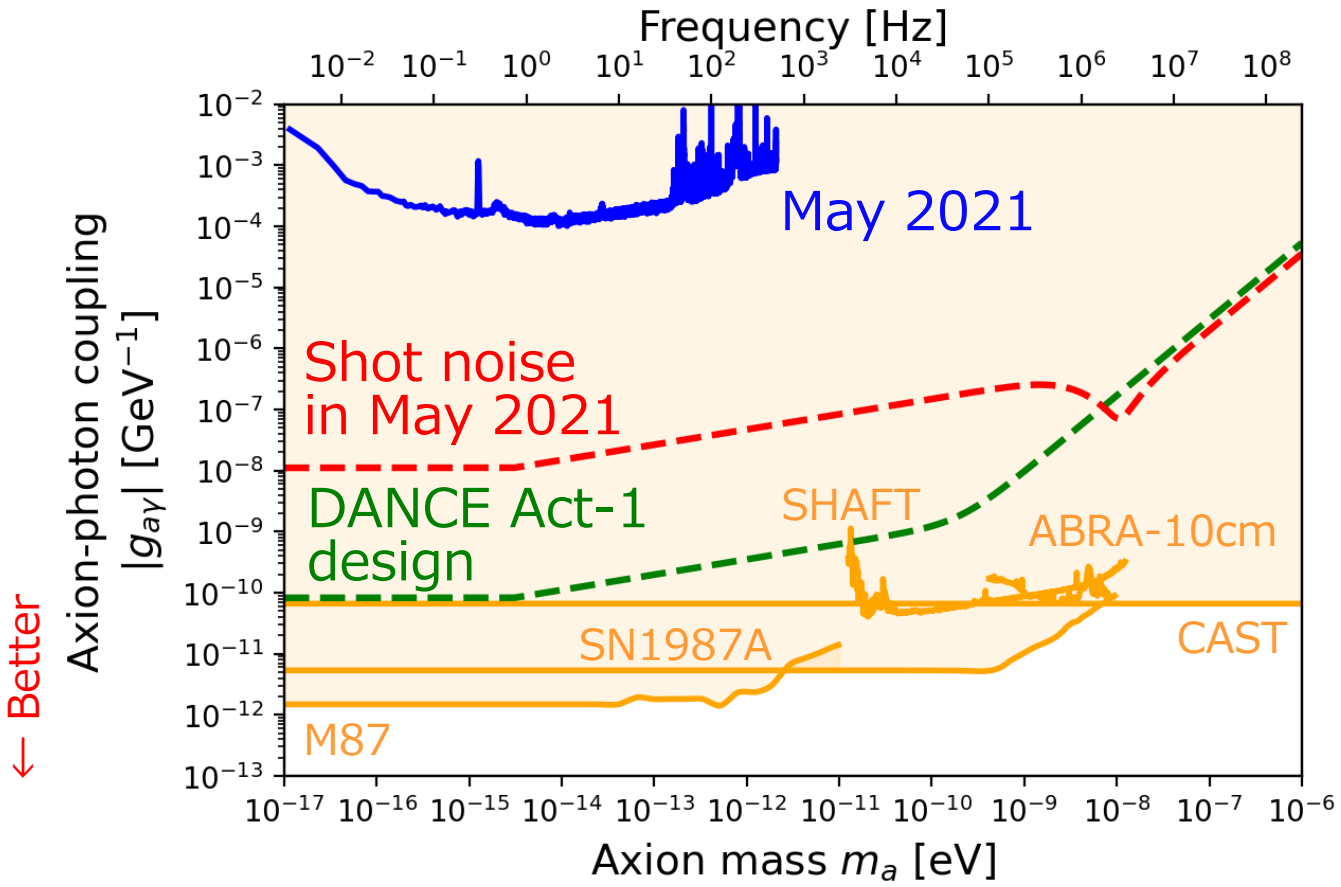
- Calibrated to rotation angle of linear polarization

$$\phi(t) = \sqrt{P_{\mathrm{P}}(t)/P_{\mathrm{tot}}}$$





Estimated sensitivity



Assuming 12-day observation

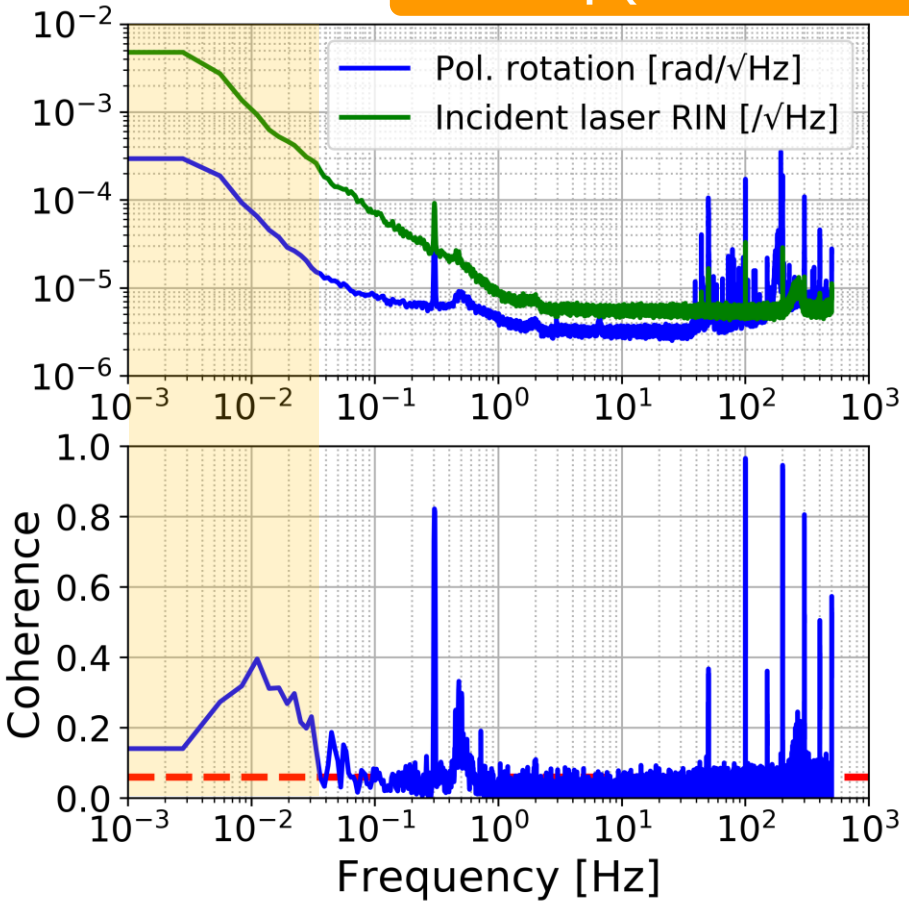
Preliminary

- Need to reduce noises to reach shot noise
- Need to reduce resonant frequency difference between polarizations and inject higher laser power to achieve DANCE Act-1 design

Discussion for noises

Correlation with incident light

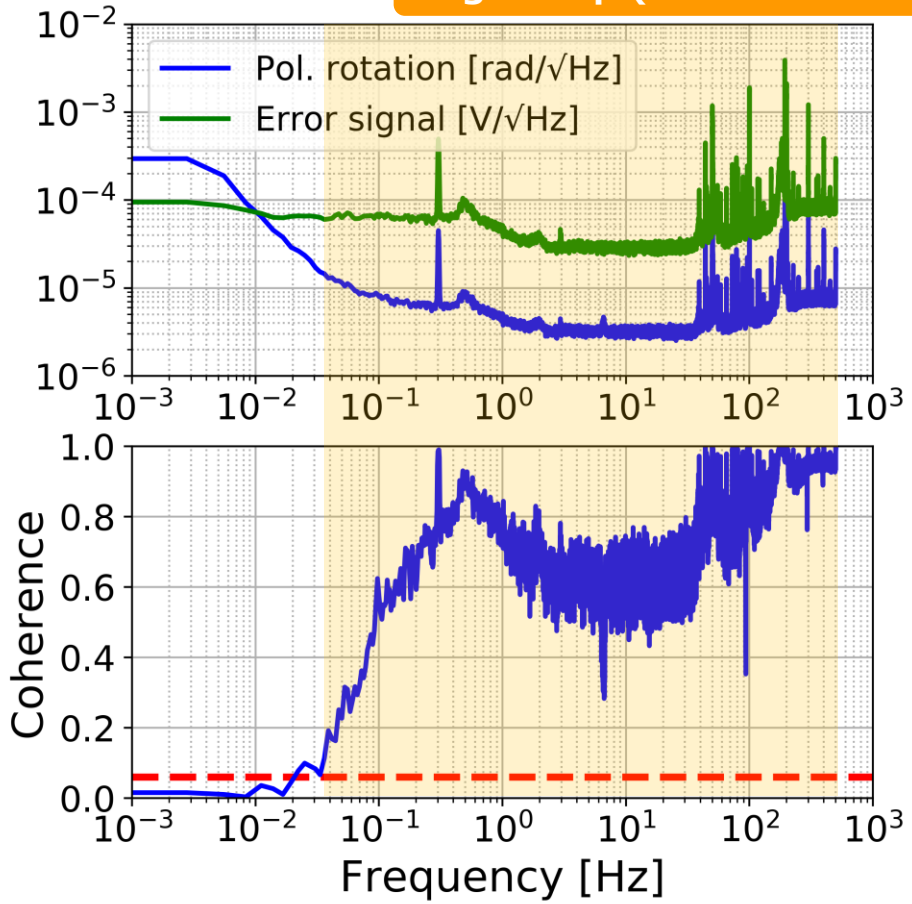
Low freq. (below 0.03 Hz)



Suggested to be limited by laser intensity noise

Correlation with error signal

High freq. (above 0.03 Hz)

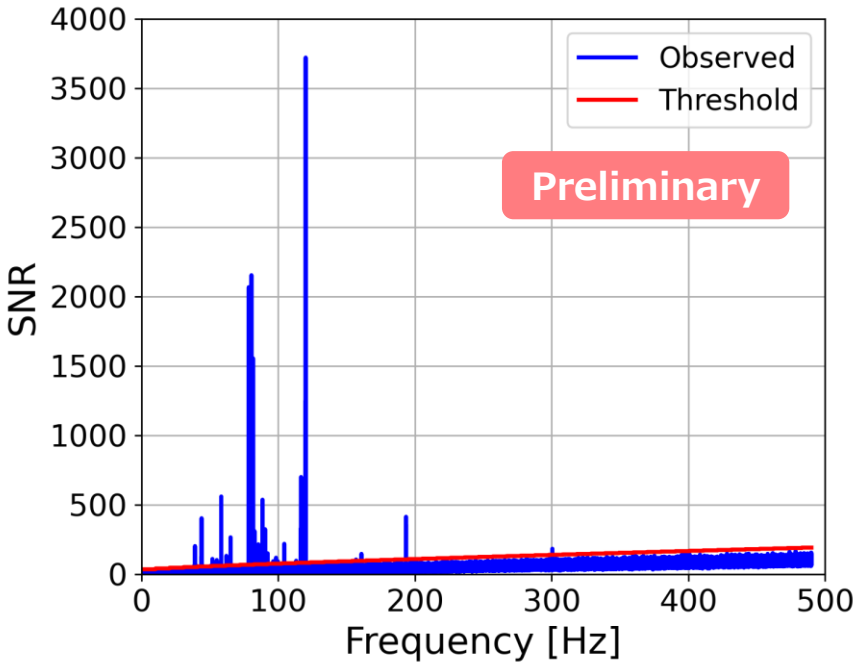


Suggested to be limited by external noises such as mechanical vibration

Data analysis

- Started analysis with 10-hour data due to high computational cost
- Applied the data analysis pipeline for ultralight dark matter

  → Found 55 candidate peaks



- Veto procedure

1. Q-factor veto

   (DM signal should have Q of ~10^6)

   → Candidate peaks were reduced to 33

2. Consistency veto

   (DM signal should have the same frequency in two segments of data)

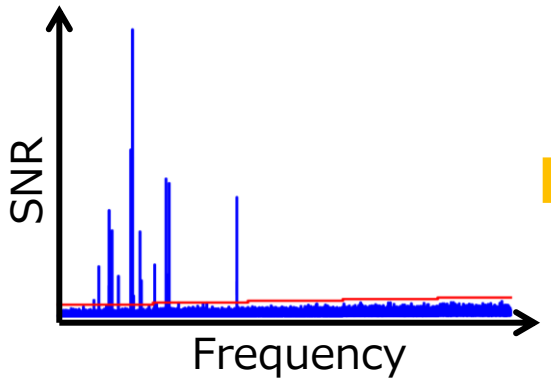
   → Candidate peaks were reduced to 8

   → Investigating the cause of the peaks

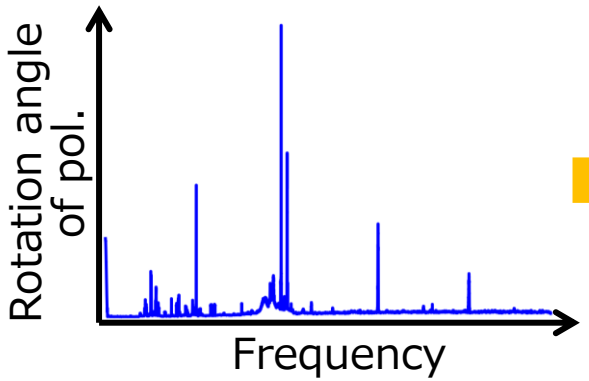
Future plans

- Further data analysis to set the upper limit

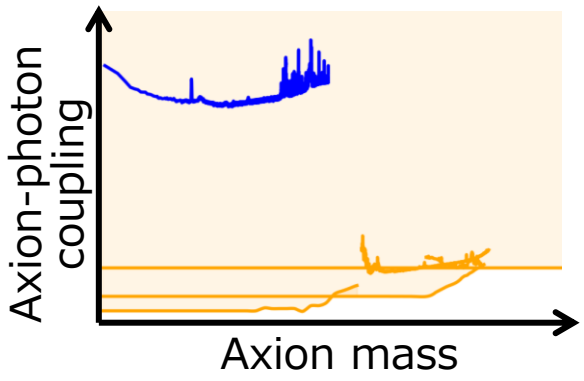
1. Find candidates
2. Veto noise peaks



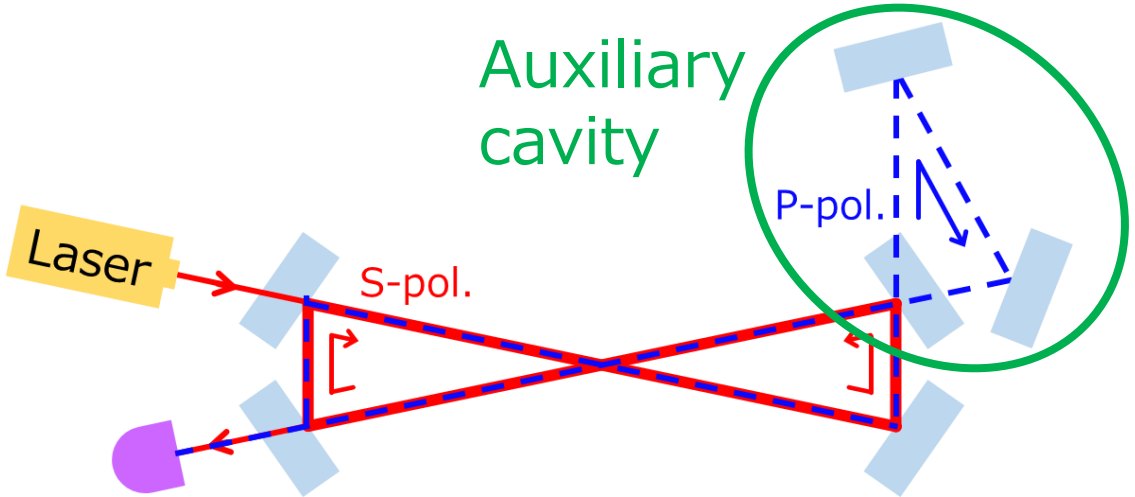
3. Set the upper limit to rotation angle of pol.



4. Convert to coupling constant



- New setup of DANCE Act-1 to improve the sensitivity



Cancel out resonant frequency difference between polarizations with an auxiliary cavity

D. Martynov, H. Miao, PRD 101, 095034 (2020)

→ **Hiroki's poster**
(Poster session 2, No. 363)

Summary

- DANCE: a new experiment to search for axion dark matter with a bow-tie ring cavity
  I. Obata, T. Fujita, Y. Michimura, PRL 121, 161301 (2018)
- Prototype experiment DANCE Act-1 is ongoing
  - Assembled and evaluated the optics
    - Found resonant frequency difference between polarizations
  - Obtained the first data for 12 days
    - Estimated the sensitivity and analyzing the data