This talk is based on arXiv:2303.03594

First Results of DANCE from Long-Term Observation

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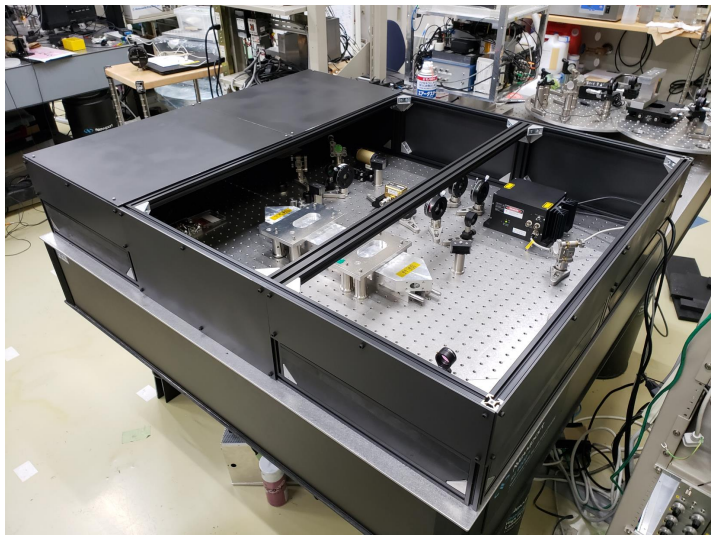
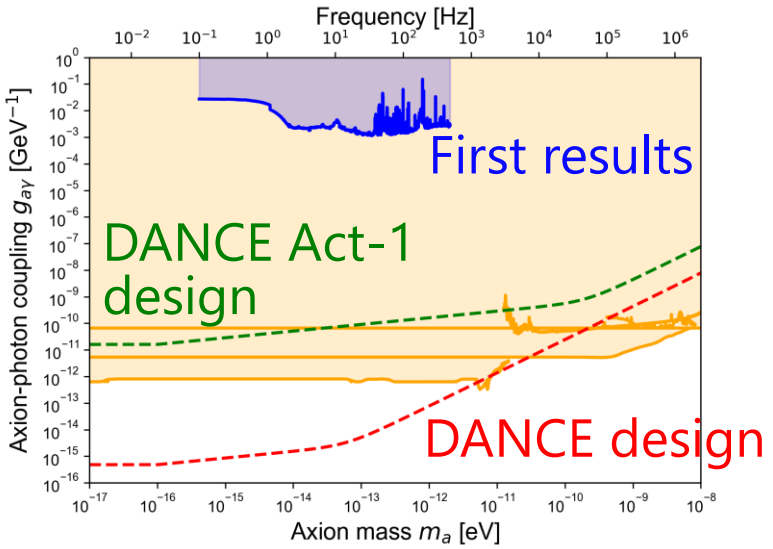
Overview

- New experimental project to search for axion DM with an optical cavity
  I. Obata, T. Fujita, Y. Michimura
  PRL 121, 161301 (2018)

  DANCE: Dark matter Axion search with riNg Cavity Experiment

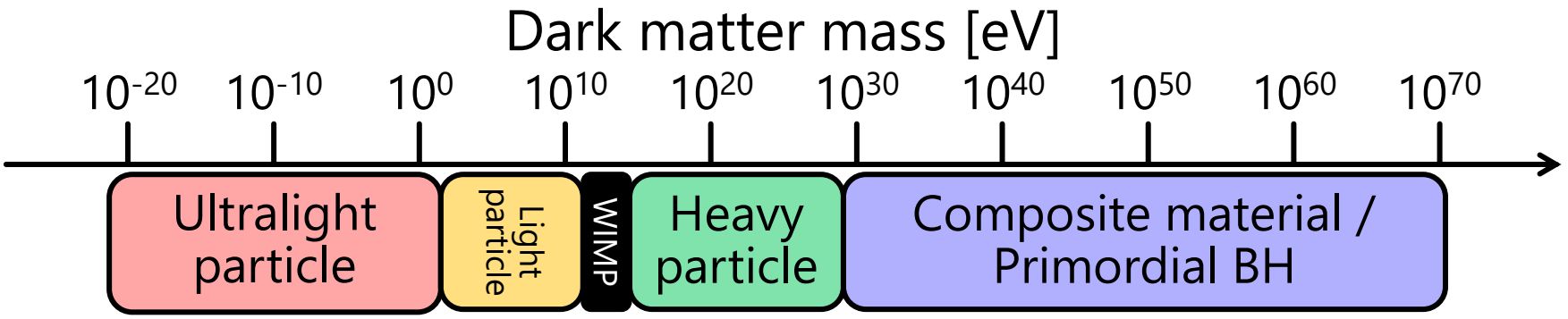
- First results of prototype experiment DANCE Act-1 from long-term observation
  YO, H. Fujimoto+, arXiv:2303.03594





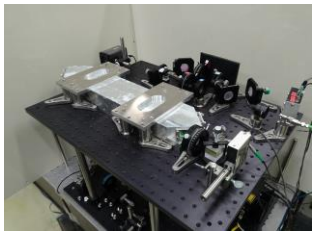
Axion search with laser interferometers

- We need to search for DM in a wider mass range
- Laser interferometers are useful
  to search for ultralight DM
- DANCE focuses on axion-like particle DM



Laser interferometers

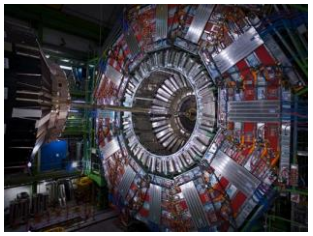
DANCE



KAGRA

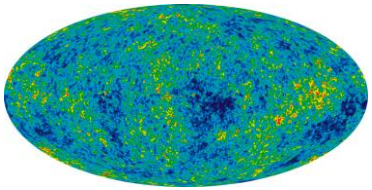
XENON1T

LHC



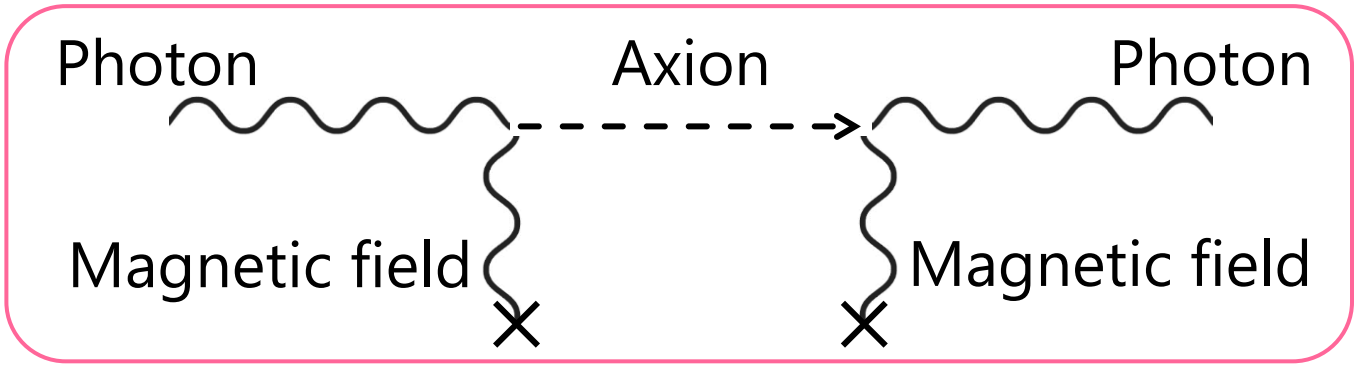
Subaru Telescope

CMB



Axions and ALPs

- QCD axions are hypothetical particles to solve the strong CP problem
- Various axion-like particles (ALPs) are predicted by string theory
  - One of the DM candidates
- Many experiments to search for ALPs through axion-photon coupling by using a strong magnetic field



Primakoff effect

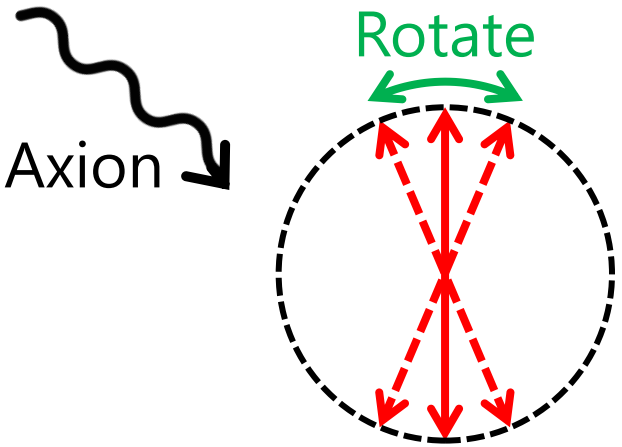
Polarization rotation from axions

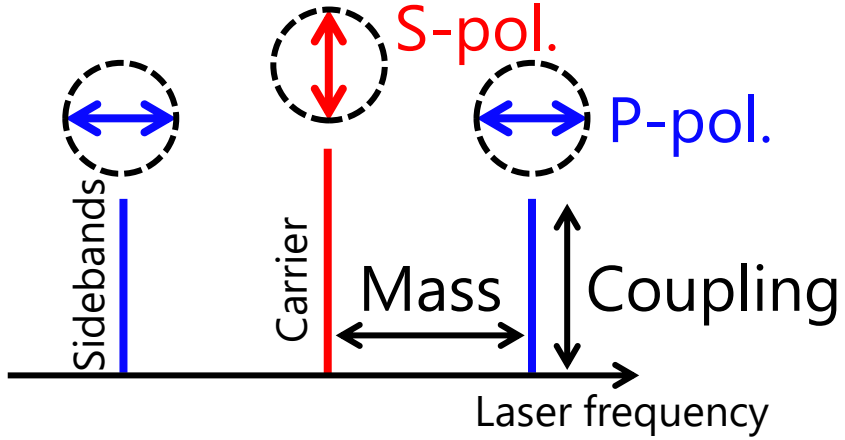
- Axion-photon coupling causes phase velocity difference between left- and right-handed photons

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

Coupling constant　Axion field　Axion mass

- Phase velocity difference of circular polarizations makes linear polarization rotate and oscillate
  - Axion search without magnetic field

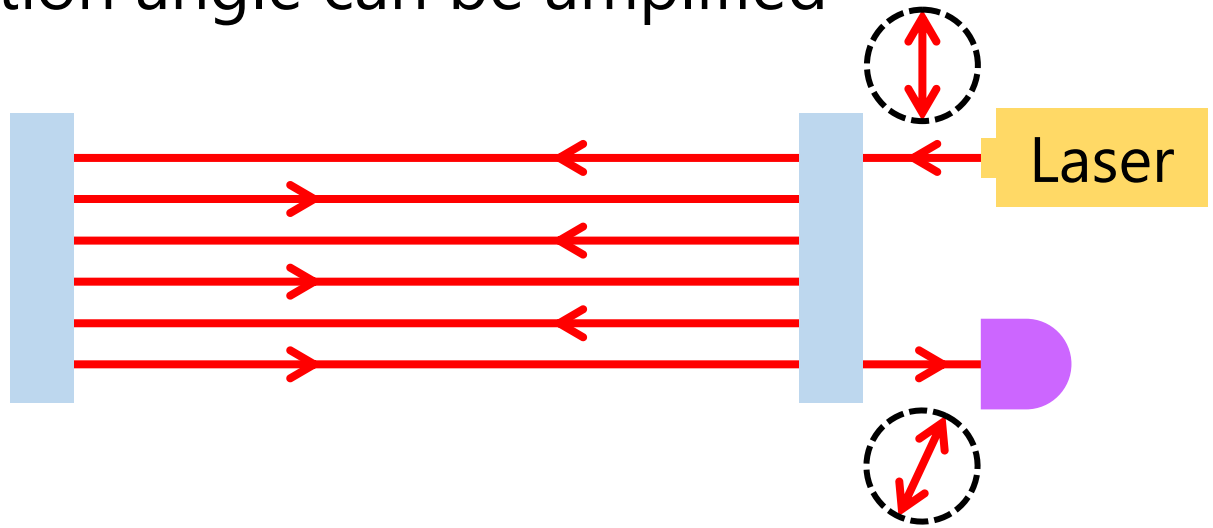




Signal amplification with cavities

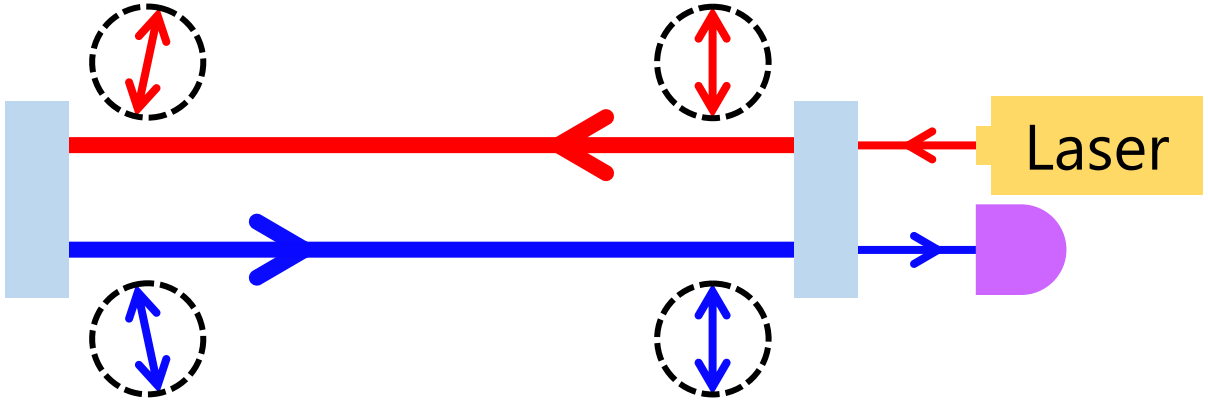
- Rotation angle is too small to be observed without a cavity

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

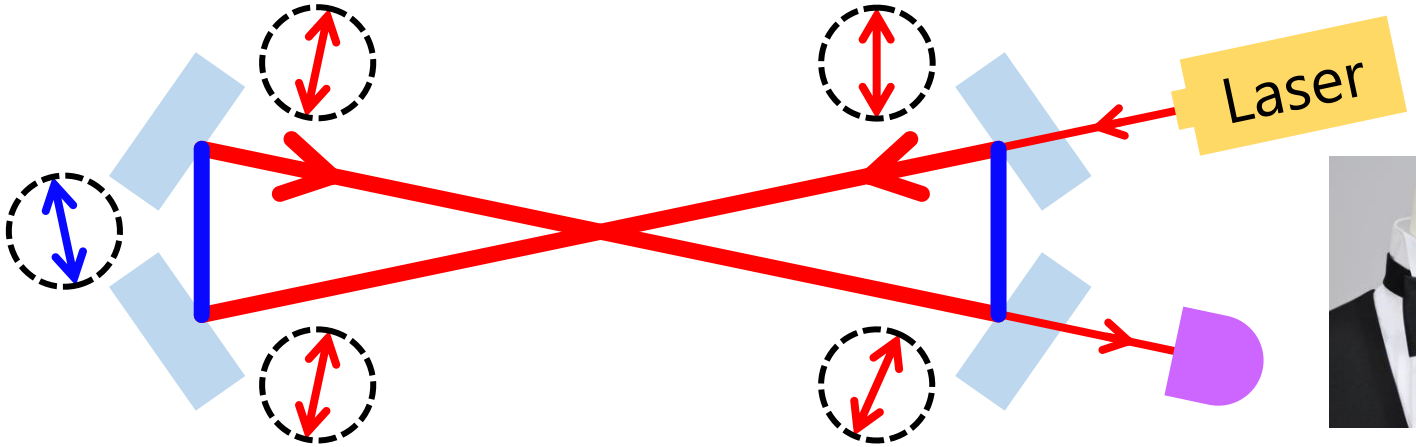


Bow-tie ring cavity

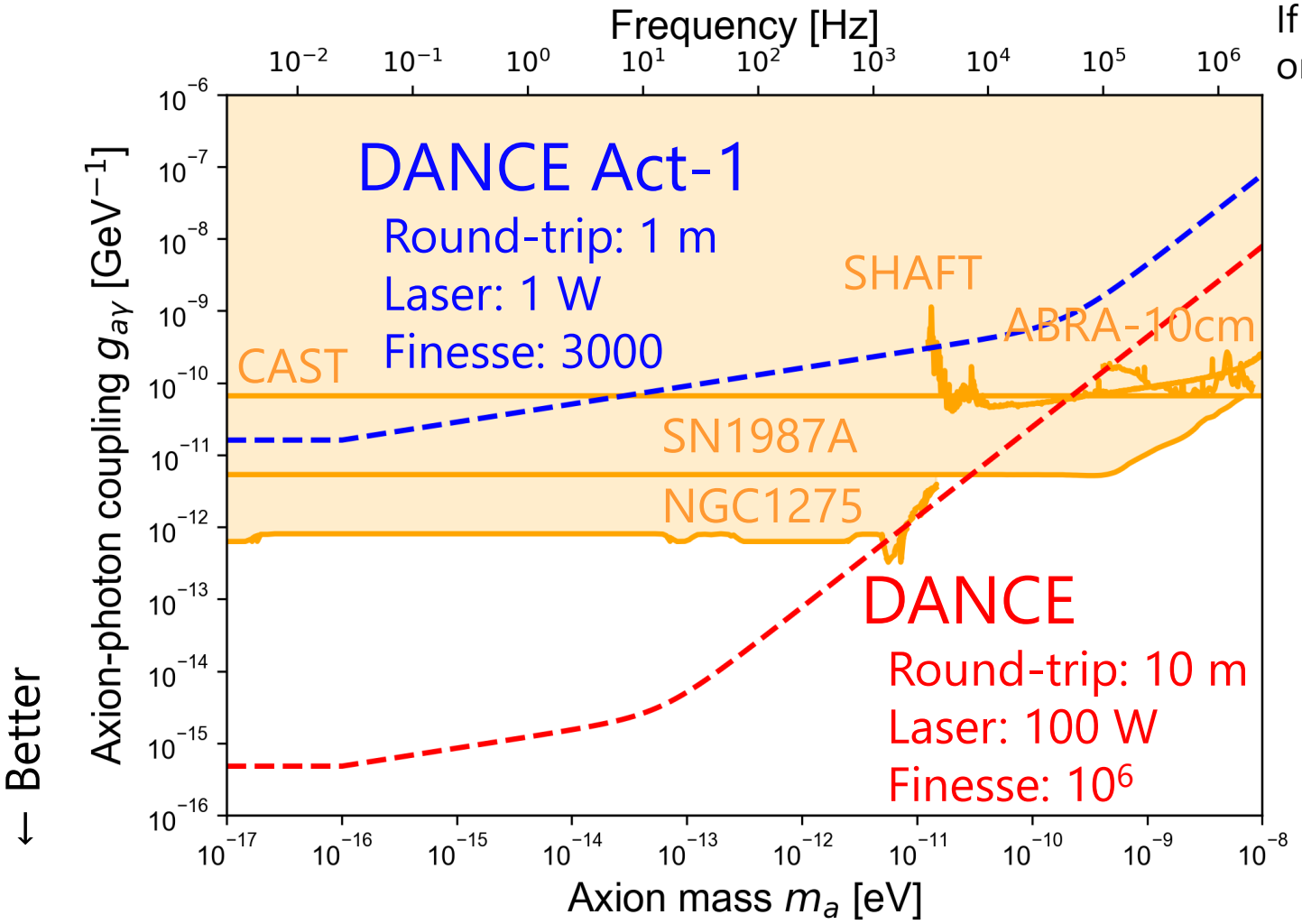
- Rotated direction is inverted by reflection on mirrors
  → Rotation effect is canceled out in a linear cavity



- A bow-tie ring cavity prevents linear polarization from flipping

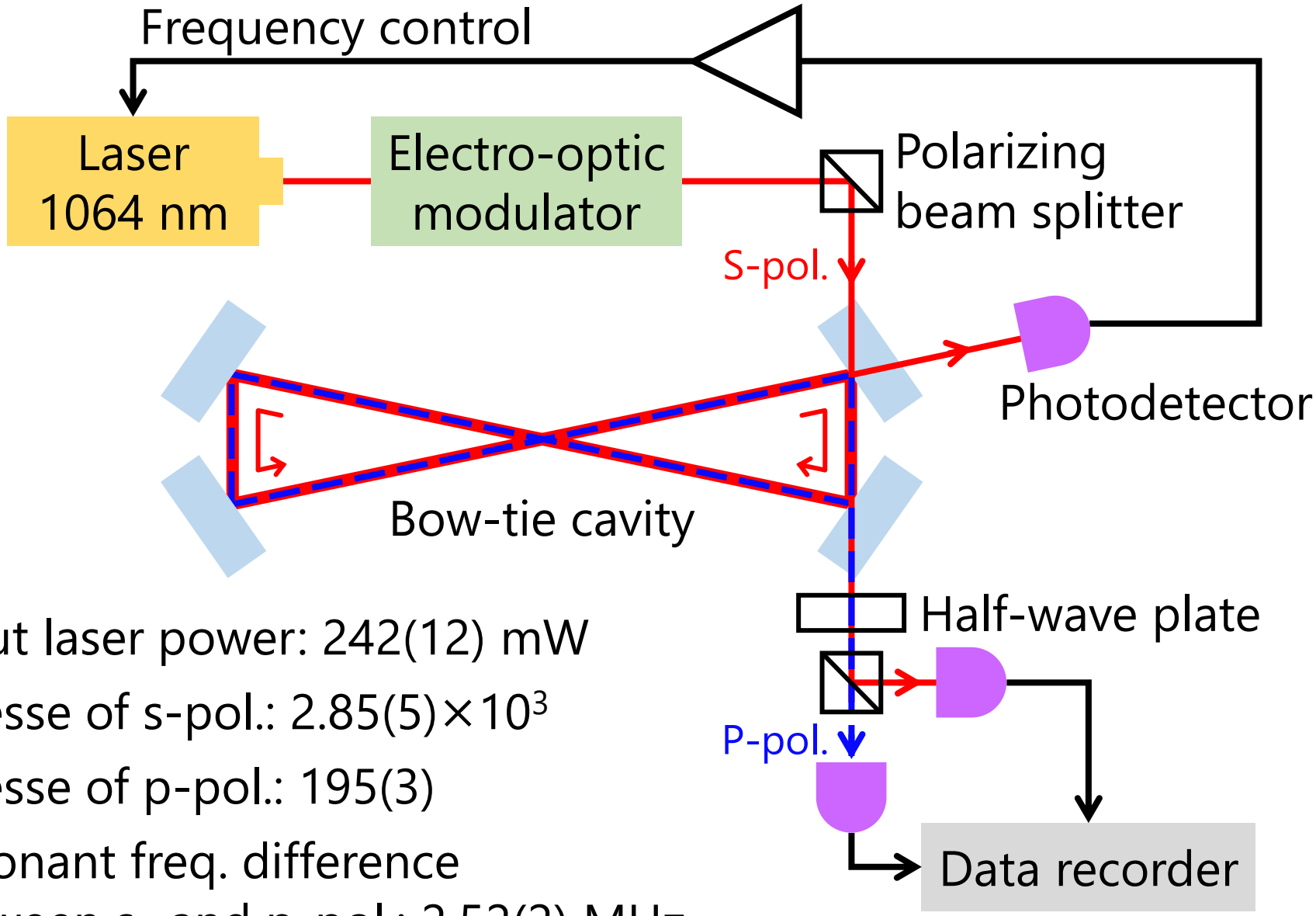


Design sensitivity of DANCE



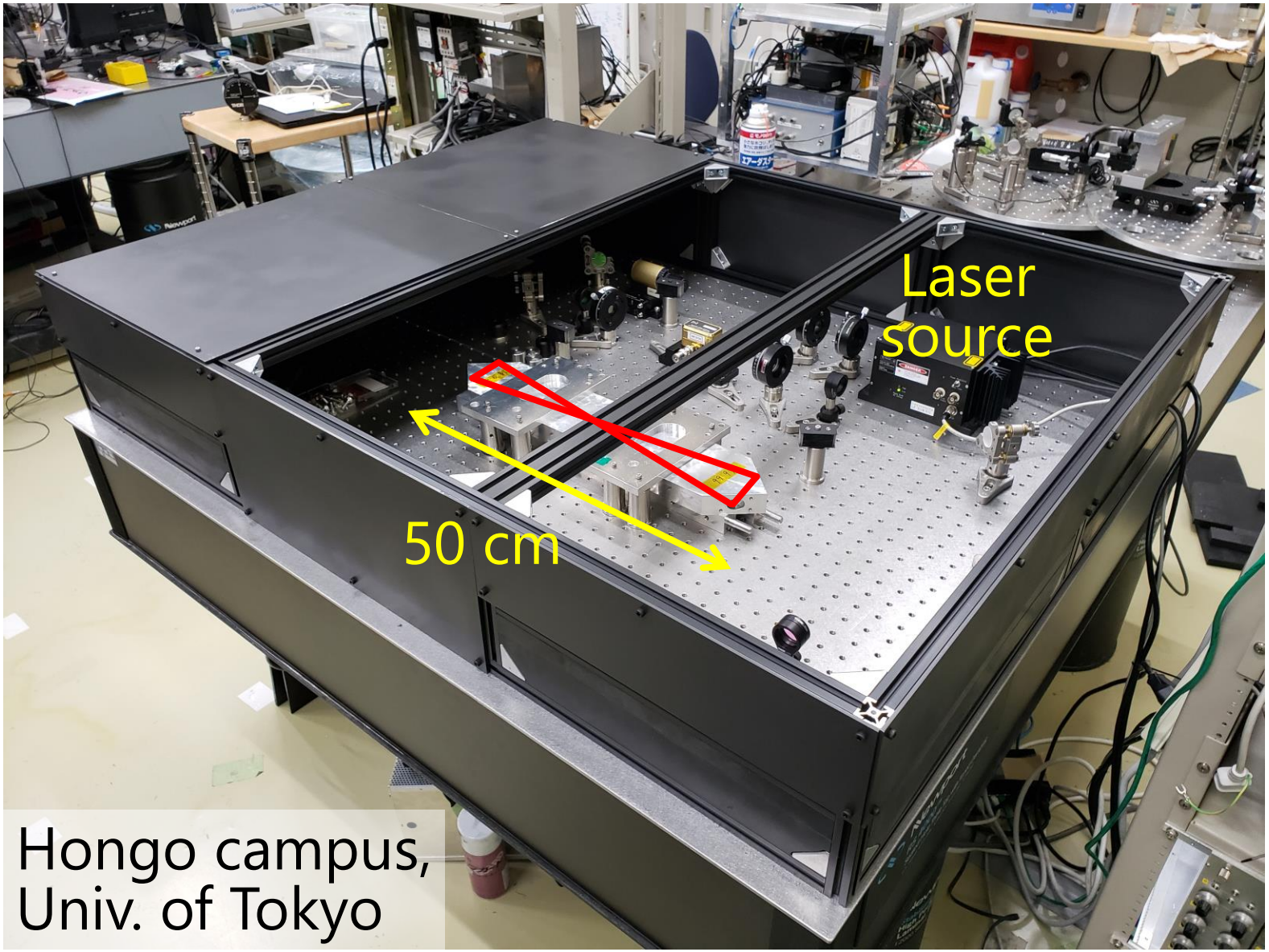
- Shot noise is caused by fluctuations in photons' number
- Need to minimize the other noise sources

Setup of DANCE Act-1



- Input laser power: 242(12) mW
- Finesse of s-pol.: $2.85(5)\times10^3$
- Finesse of p-pol.: 195(3)
- Resonant freq. difference between s- and p-pol.: 2.52(2) MHz

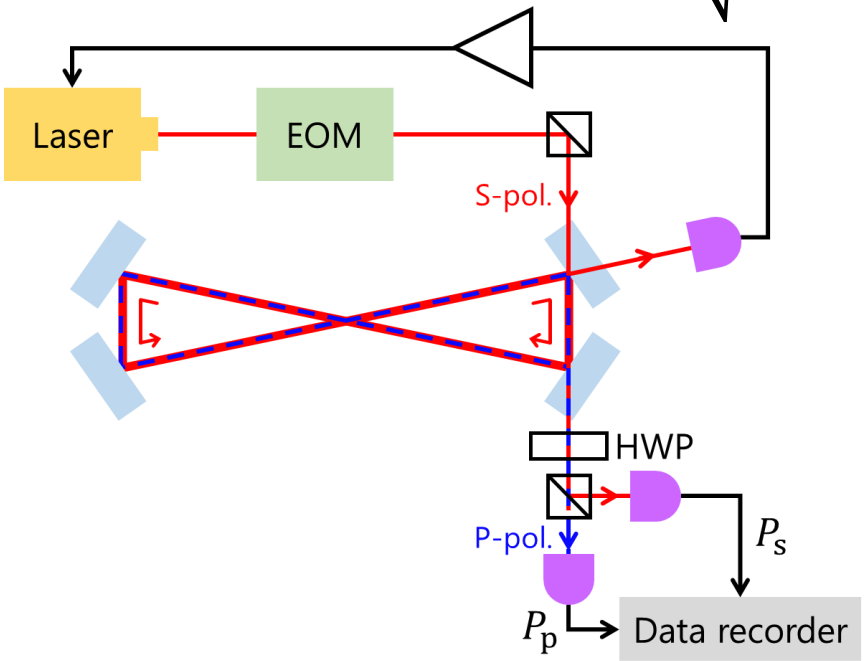
Picture of DANCE Act-1

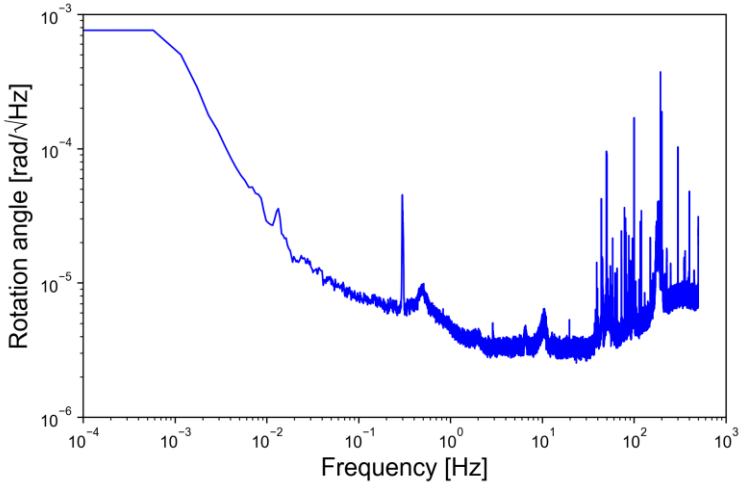


Data acquisition and calibration

- Recorded the data in May 18-30, 2021
- The first 86,400-second (24-hour) data was selected
- Amplitudes of s- and p-polarizations were calibrated to the rotation angle of linearly polarized light

$$\phi(t) = \sqrt{\frac{P_{\mathrm{p}}(t)}{P_{\mathrm{s}}(t) + P_{\mathrm{p}}(t)}} + 2\theta_{\mathrm{HWP}}$$

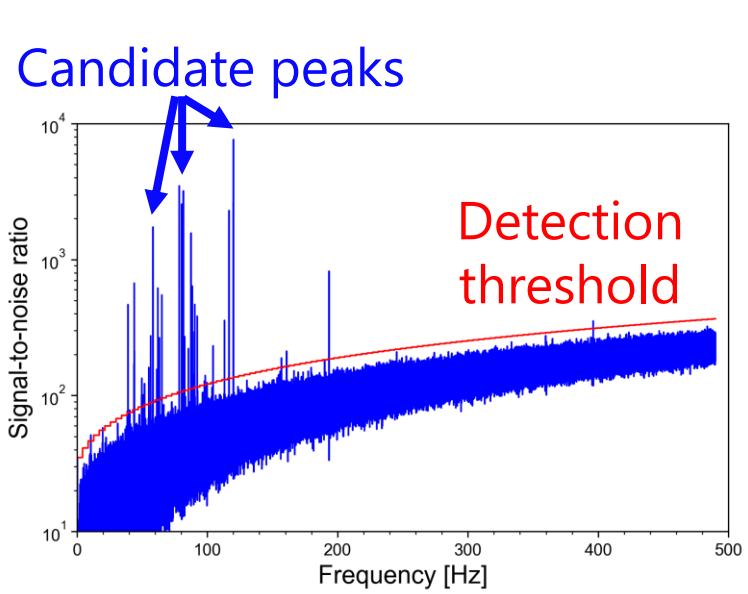


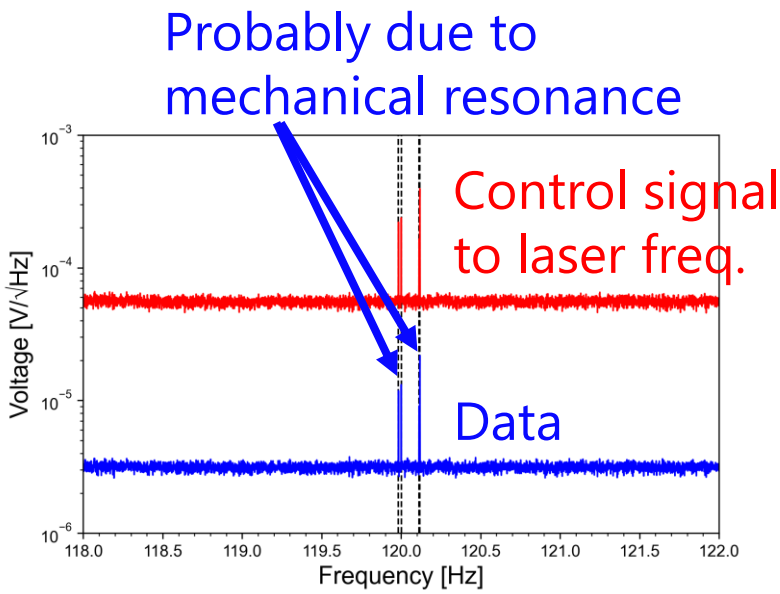


Data analysis

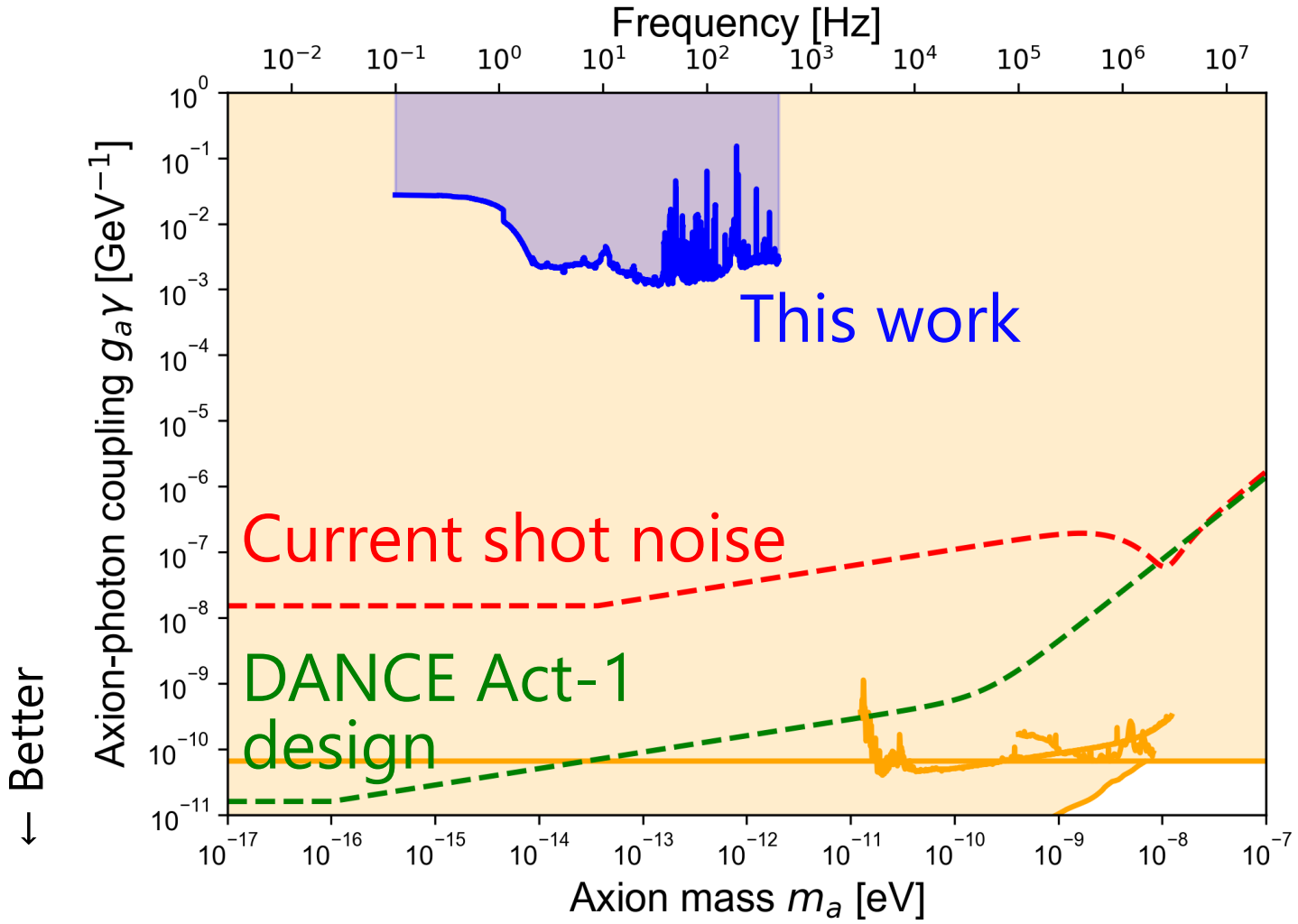
H. Nakatsuka+ (2022)
J. Kume+, in prep.

- Analysis pipeline for ultralight DM applied to the data
- 551 points exceeded the threshold
- All candidate peaks were rejected by 3 veto procedures
  - Consistency veto: 551 → 271
  - Linewidth veto: 271 → 7
  - Control signal veto: 7 → 0



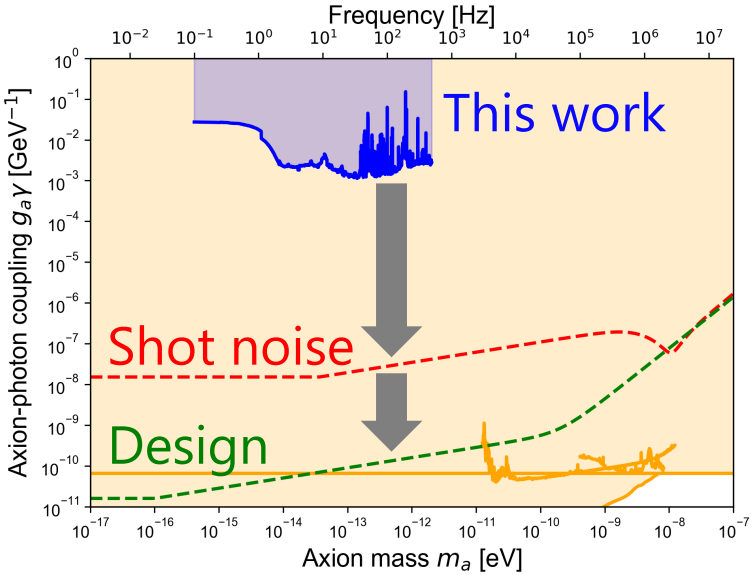


Results



- Worse than design sensitivity by 7 orders of magnitude
- First results of axion DM search with a ring cavity

Discussion to improve the sensitivity



1. This work to shot noise

- We need to reduce classical noises
  - Laser intensity noise
  - Laser frequency noise
  - Mechanical vibration

2. Shot noise to design sensitivity

- We need to improve the parameters
  - Input laser power: 0.2 W → 1 W
  - Observation time: 24 hours → 1 year
  - Resonant freq. difference between s- and p-pol.: 3 MHz → 0 Hz (simultaneous resonance)

We are installing an auxiliary cavity (H. Fujimoto's talk)

Summary

- New experimental project to search for axion DM with a bow-tie cavity: DANCE

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

- Prototype experiment DANCE Act-1 is ongoing
  - Long-term observation in May 2021
  - The first upper limit on $g_{a\gamma}$ with a ring cavity
  - We continue to improve the sensitivity

YO, H. Fujimoto+, arXiv:2303.03594
H. Fujimoto, YO+, JPCS 2156, 012182 (2021)