Dark matter Axion search with riNg Cavity Experiment DANCE: Latest Optical System and Sensitivity

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Abstract:

Researches on cosmology and astrophysics have revealed that more than 80% of the matter in the universe consists of an unknown substance, or dark matter. Axion-like particles (ALPs) are promising candidates for ultralight dark matter, which are motivated by string theory. ALPs can slightly cause the rotational oscillation of linearly polarized light, and thus ALP dark matter can be searched through polarization rotation measurements.

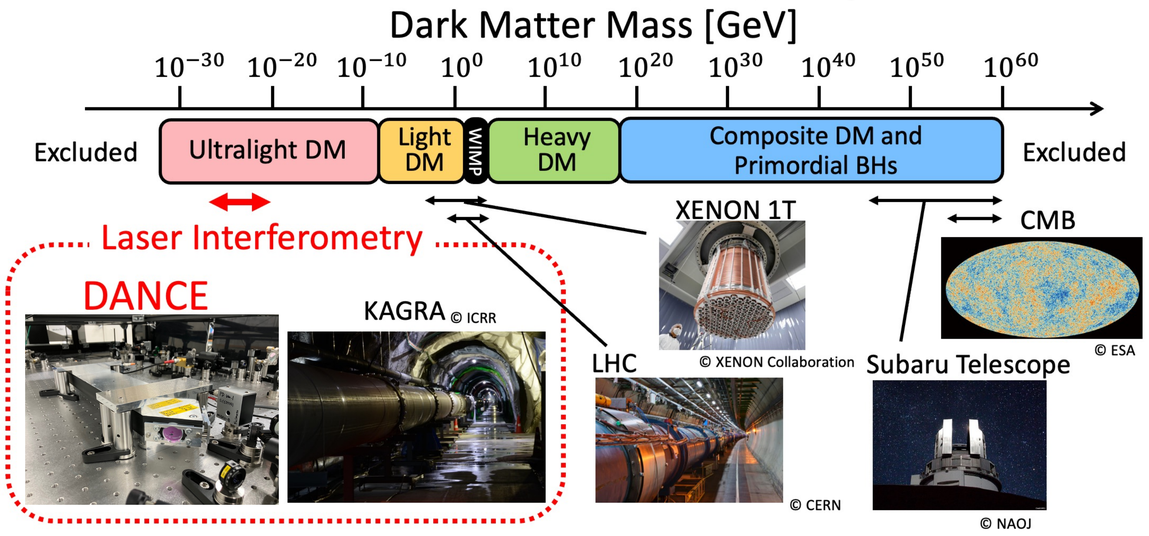
Recently, some ALP dark matter search experiments using the laser interferometers have been proposed. The basic idea is to use an optical cavity, which can enhance the effective light path and also the duration of the interaction. With this technique, the polarization rotation can be amplified and high-sensitive ALP dark matter search can be conducted.

In this workshop, we will introduce our interferometric ALP dark matter search experiment: DANCE and will report its latest sensitivity.

1. Introduction

Dark Matter Search

- Dark matter search experiments are ongoing in wide range of mass
- DANCE focuses on Axion-Like Particles (ALPs) using laser interferometry



[1] G. Bertone, *et al.*, *Nature* **562**, 51-56 (2018).

ALPs

- Pseudo-scalar particles that are ultralight dark matter candidates
- Predicted by string theory

2. Principle of DANCE

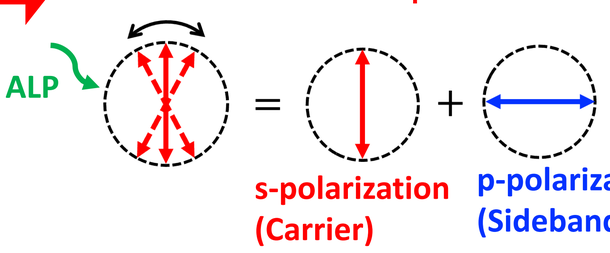
Axion-photon interaction

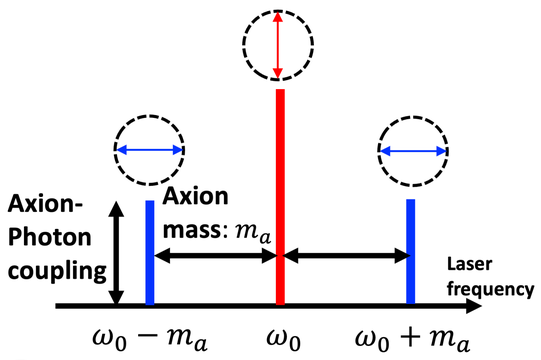
- Axion-photon interaction causes phase velocity difference between right- and left-handed circularly polarized light [2,3]

$$c_{L/R} = 1 \pm \frac{g_{a\gamma} a_0 m_a}{2k} \sin(m_a t + \delta_\tau)$$

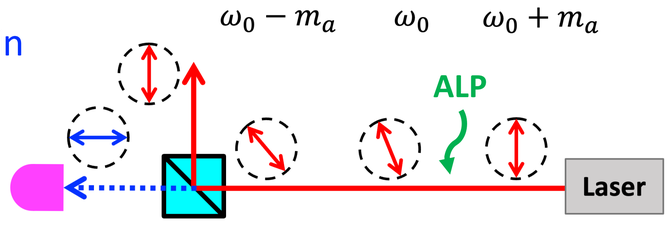
Axion-photon coupling constant; Axion field; Axion mass

ALPs rotate linear polarization



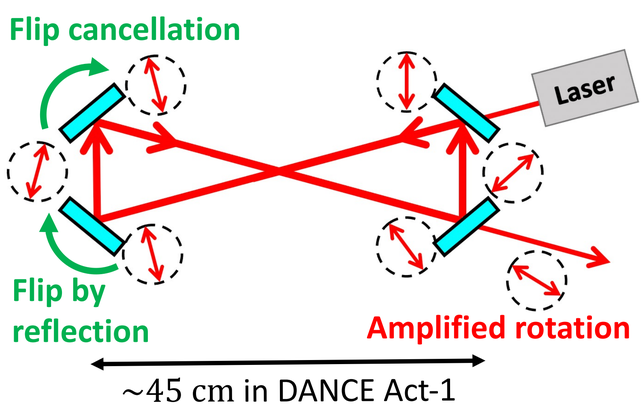


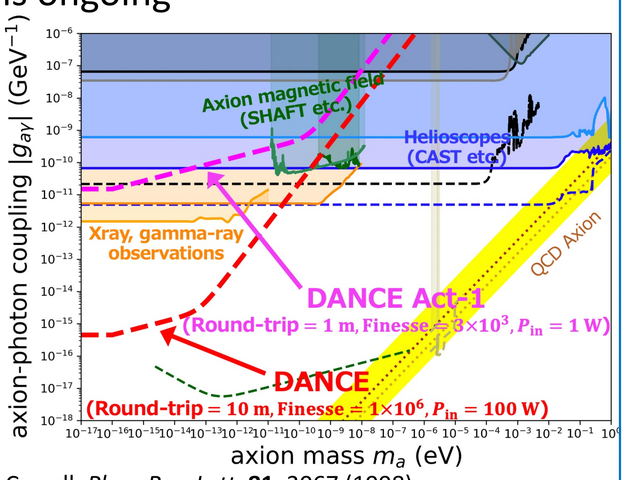
- Axion signal: p-pol. sidebands in amplitude quadrature
- Longer light path can enhance the polarization rotation



DANCE [4]

- enhances light path and rotational amplitude by using a bow-tie ring cavity [5]
- Bow-tie shape prevents polarization flips at the ends of the cavity
- Sensitive in low-mass region
- Prototype experiment: DANCE Act-1 is ongoing



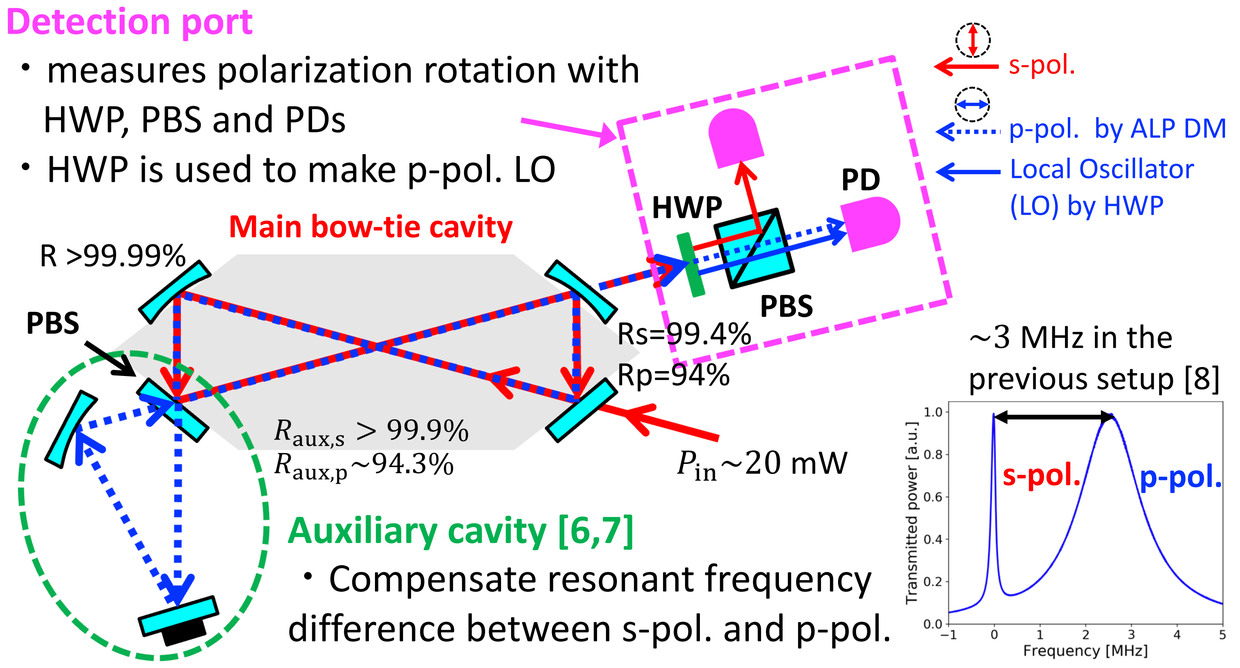


[2] S. M. Carroll *et al.*, *Phys. Rev.* D **41**, 1231 (1990). [3] S. M. Carroll, *Phys. Rev. Lett.* **81**, 3067 (1998).
[4] I. Obata *et al.*, *Phys. Rev. Lett.* **121**, 161301 (2018). [5] H. Liu, *et al., Phys. Rev.* D **100**, 023548 (2019).

3. Current experimental setup

Detection port

- measures polarization rotation with HWP, PBS and PDs
- HWP is used to make p-pol. LO



Auxiliary cavity [6,7]

- Compensate resonant frequency difference between s-pol. and p-pol.

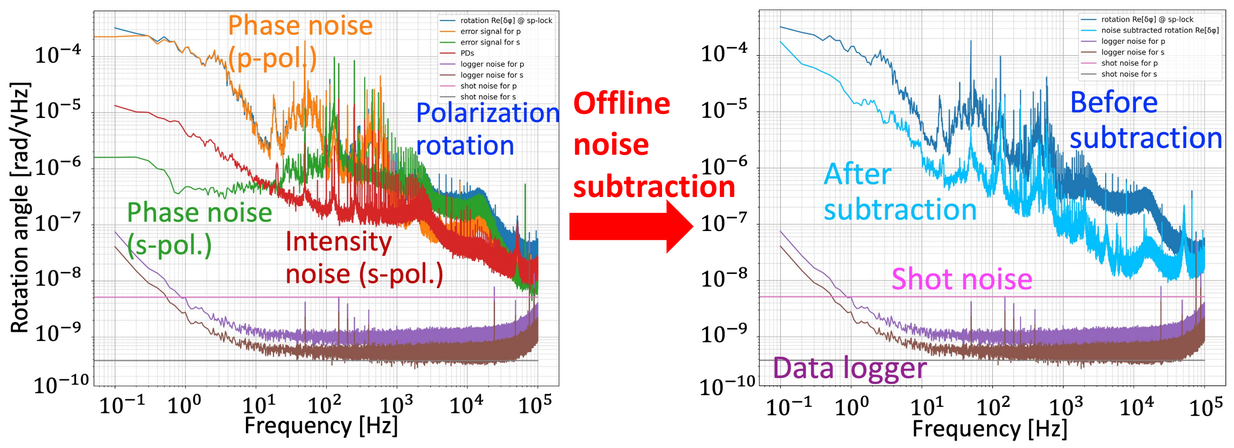
	s-pol.	p-pol.
Finesse	549(3)	36.8(2)

- Finesse for p-pol. is limited by the AR coating of the PBS used in the auxiliary cavity

[6] D. Martynov and H. Miao: *Phys. Rev. D* **101**, 095034 (2020) [7] H. Fujimoto *et al.*: arXiv:2110.12023
[8] Y. Oshima *et al.*: arXiv:2110.10607

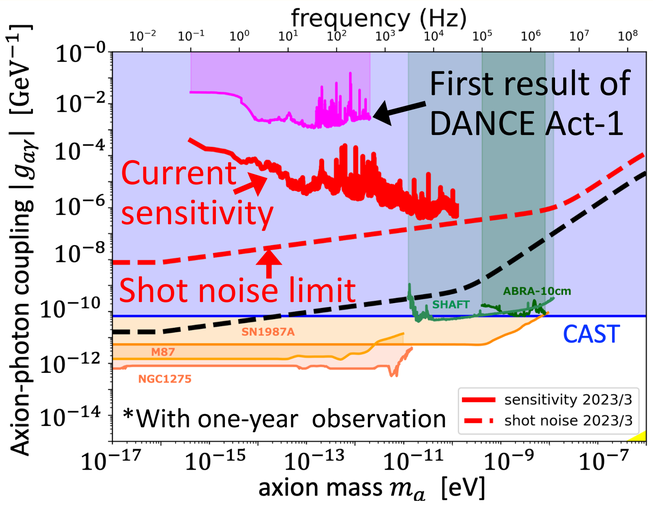
4. Noise hunting and Offline noise reduction

- Phase noise (cavity vibration, laser frequency noise) is limiting
- Phase noise couples to the p-pol. generated by birefringence of cavity mirrors or polarization mismatch at injection port
- Offline noise subtraction in time-series data succeeded in reducing noise by ~1 order of magnitude



5. Estimated current sensitivity

- Estimated the current sensitivity with the measured spectrum
- > 2 orders of magnitude better than the first result of DANCE Act-1 [9]
- Need for the improvement of ~4 orders of magnitude to reach the CAST limit



[9] Y. Oshima *et al.*: arXiv:2303.03594

6. Summary

- DANCE searches for axion dark matter with ring cavity by enhancing the rotation of linear polarization
- Prototype experiment: DANCE Act-1 is underway:
  - Development of optical systems for simultaneous resonance of s/p-pol.
  - Noise hunting and offline noise reduction
- Further commissioning is needed to reach the CAST limit