Axion dark matter search with interferometric gravitational wave detectors

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Abstract

Axion dark matter differentiates the phase velocities of the circular-polarized photons. In this poster, a scheme to measure the phase difference by using a linear optical cavity is proposed. If the scheme is applied to the Fabry-Perot arm of KAGRA-like (Cosmic-Explorer-like) gravitational wave detector, the potential sensitivity to the axion-photon coupling constant, $g_{a\gamma}$, reaches $g_{a\gamma} \cong 2\times10^{-12}$ GeV^{-1} (4×10^{-14} GeV^{-1}) at the axion mass $m \cong 1\times10^{-13}$ eV (2×10^{-15} eV) and remains at around this sensitivity for 3 orders of magnitude in mass. Furthermore, its sensitivity has a sharp peak reaching $g_{a\gamma} \cong 10^{-14}$ GeV^{-1} (8×10^{-17} GeV^{-1}) at m=2.084×10^{-10} eV (1.563×10^{-11} eV). This sensitivity can be achieved without loosing any sensitivity to gravitational waves even during gravitational wave observation run.

1. Introduction

- Axion is a pseudo-scalar field originally proposed by Peccei and Quinn to solve the strong CP problem in QCD physics, known as “QCD axion” [1]. Recently, some high energy physics such as string theory also predict a number of axion-like particles from the compactification of extra dimensions.
- Since axion typically has a small mass and weakly interacts with the matter, **axion is a cosmologically well-motivated candidate for dark matter**.
- The conventional way to search axion is to look for axion-photon conversion under the strong magnetic field [2]. Recently, a new experimental approach to search for axion dark matter using optical cavities without a strong magnetic field that could drive large cost and/or be a major noise source was proposed [3-5].
- Here, **we show a new scheme to search for coupling of axion dark matter to photon by using a linear Fabry-Perot cavity, especially in the current and future gravitational wave detectors, such as KAGRA, Cosmic Explorer, and DECIGO.**

2. Phase velocity modulation due to axion-photon coupling

- Axion-photon coupling ($\frac{g_{a\gamma}}{4}a(t)F_{\mu\nu}\tilde{F}_{\mu\nu}$) varies phase velocity between two circular-polarized photons,

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

Coupling factor; Axion mass; Axion field amplitude; Photon wave number

- This leads to the **polarization-modulation of the linearly polarized light**.

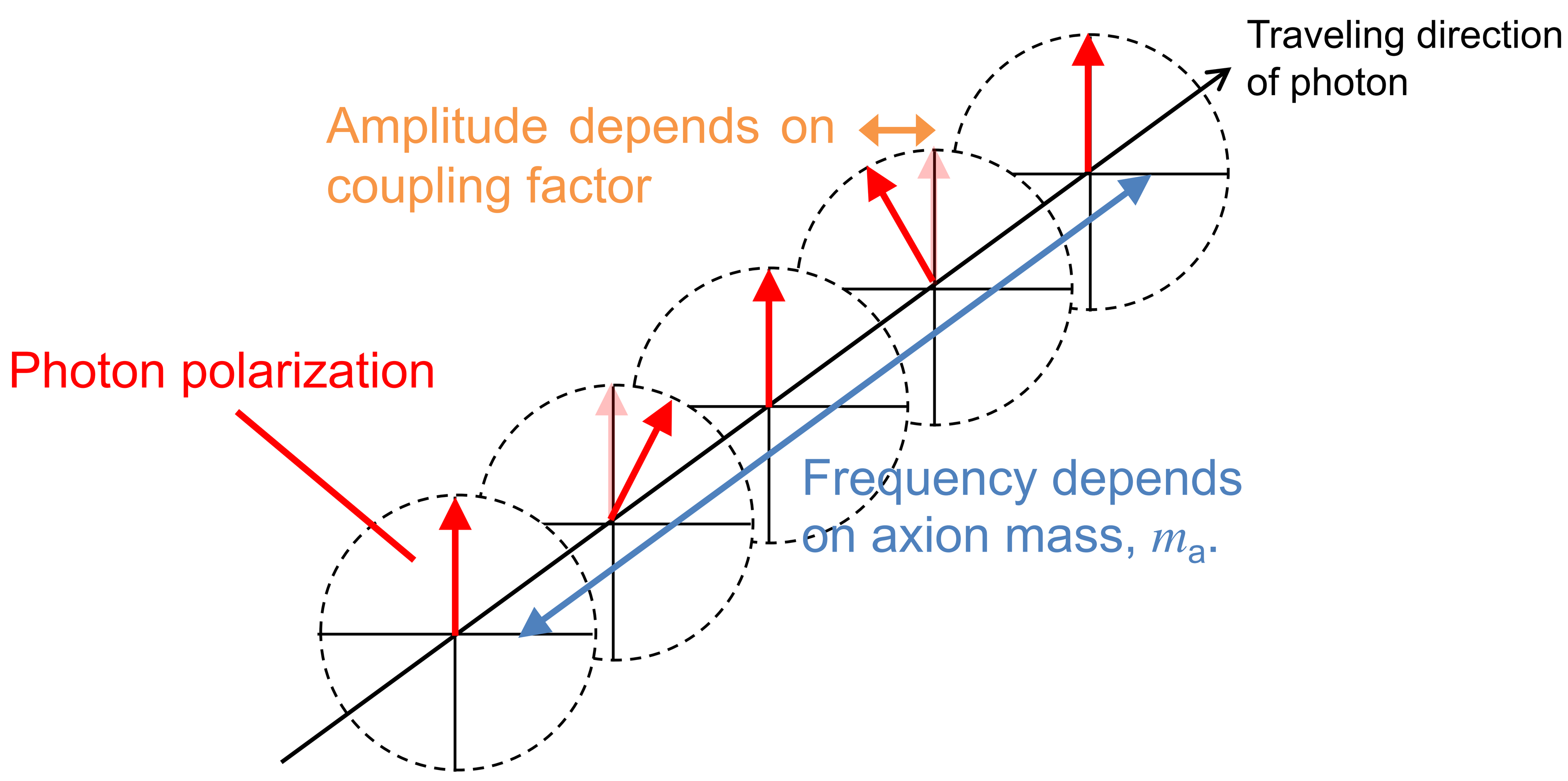

Fig. 1: Polarization modulation caused by axion-photon coupling.

3. Axion search with a linear optical cavity

- The schematic setup of our proposed scheme is shown in figure 2.
- **The signal, i.e. polarization-modulation, is enhanced inside the cavity.** Especially, if the modulation frequency and photon round trip frequency, i.e. free spectral range, is consistent, the signal will resonate in the cavity.

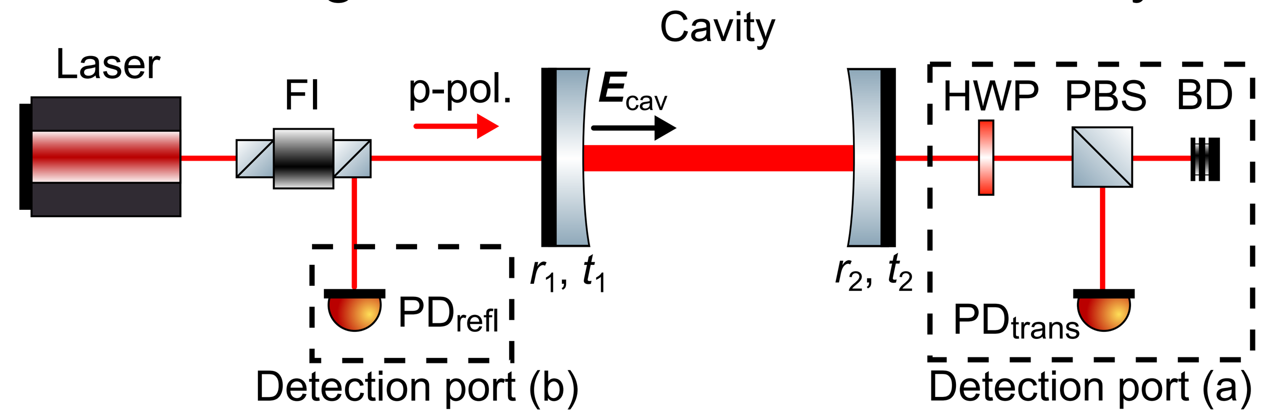

Fig. 2: Schematic of experimental setup for axion search with a linear optical cavity. Signal is detected in detection port (a) and (b). Components for phase measurement are not shown. The polarization of incident light is arbitrary if only it is linear polarization.

4. Sensitivity to the axion-photon coupling

- The sensitivity is limited by shot noise, in principle.
- Thus, long arm and high power are necessary.
  →**Gravitational wave detector can be used.**
- Figure 3 shows the shotnoise limited sensitivities to $g_{a\gamma}$ with 1 year observation. Here, we adopted the experimental parameter sets of KAGRA, Cosmic Explorer, and DECIGO.
- In our scheme the displacement noise such as the vibration of mirrors or the gravitational wave signal is not a problem.

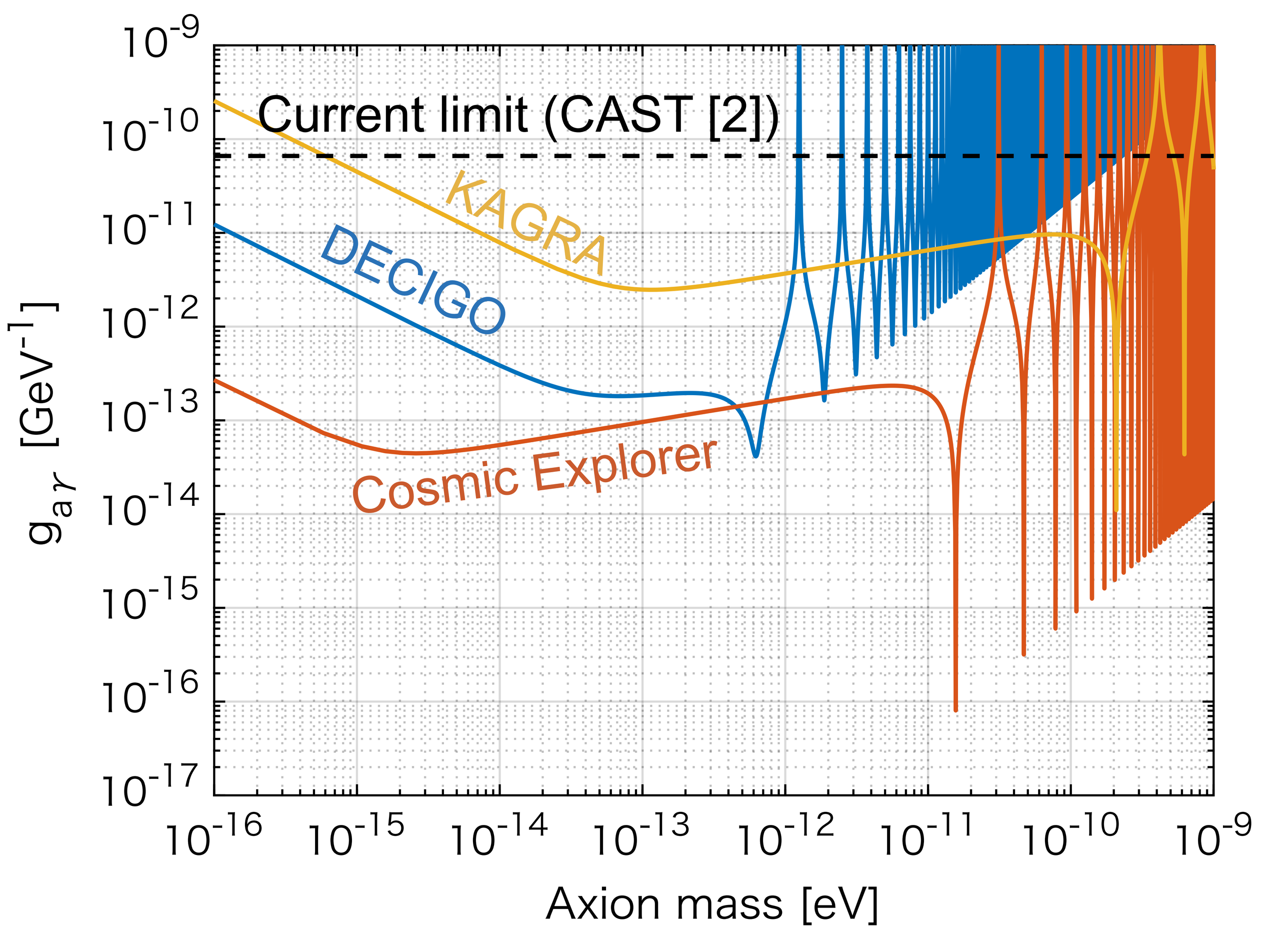

Fig. 3: Sensitivity comparison of some parameter sets. Although the higher mass range seems to be filled, they have sensitivity peaks at mass of $m = N\pi/L$ ($N \in \mathbb{N}$), i.e. free spectral range.

5. Discussion and conclusion

- We developed the experimental scheme to search for axion dark matter with the optical linear cavity used in gravitational wave detectors.
- Our scheme can be applied with minor modification of transmittion monitor system or anti-symmetric port.
- Their sensitivities can **overcome the current limit of CAST [2] by three (six) order of magnitude in broad (most sensitive) axion mass range.**
- Remarkably, our new scheme for axion dark matter search can be performed **without loosing gravitational wave detector sensitivity and coexist with its observation run for gravitational waves.**

References

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