Prospects of Search for Solar Axions with Mass over 1 eV and Hidden Sector Photons

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We present prospects of two experiments using the Tokyo Axion Helioscope. One is a search for solar axions. In the past measurements, axion masses from 0 to 0.27 eV and from 0.84 to 1.00 eV have been scanned and no positive evidence was seen. We are now actively preparing a new phase of the experiment aiming at axion masses above 1 eV. The other is a search for hidden sector photons from the Sun. We have been designing and testing some additional equipments, which have to be installed on the helioscope to search for hidden photons with mass of over 10^{-3} eV.

1 Introduction

The Sun could copiously emit weakly interacting particles, that could eventually be detected inside a sensitive detector at the Earth.

The axion is one of such particles. The existence of axions is implied by solutions to the strong CP problem [1]. Axions are expected to be produced in the solar core through their coupling to photons. This process is called Primakoff process. The outgoing axion has average energy of about 4 keV [2]. Sikivie proposed an ingenious experiment to detect such axions [3]. A detection schematic for solar axions is shown in Fig. 1. The detection device called axion helioscope is a system of a strong magnet and an X-ray detector, where the solar axions are transformed into X-ray photons through the inverse Primakoff process in the magnetic field. Conversion is coherently enhanced even for massive axions by filling the conversion region with light gas. If the axion mass m_a is at around a few eV, detection

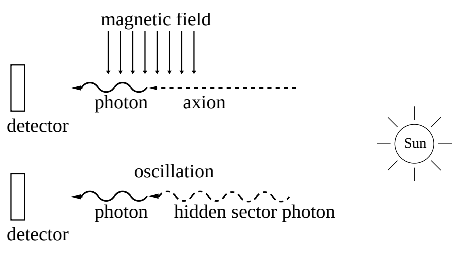

Figure 1: Detection schematics of solar axions and hidden photons from the Sun.

of the solar axion becomes feasible.

Hidden sector photons are another kind of weakly interacting particles. The existence of hidden photons is predicted by several extensions of Standard Model. If light hidden photons exist, they could be produced through kinetic mixing with solar photons [4, 5]. Therefore it is natural to consider the Sun as a source of low energy hidden photons. A schematic for the detection of hidden photons from the Sun is also shown in Fig. 1. Unlike the case of the axion, no magnetic field is required to transform photons into hidden photons.

In this paper we report the current status of two experiments. One is the search for solar axions and the other is the search for hidden photons from the Sun.

2 Tokyo Axion Helioscope

The schematic figure of the axion helioscope is illustrated in Fig. 2. It consists of a superconducting magnet, X-ray detectors, a gas container, and an altazimuth mounting. The magnet [6] consists of two 2.3-m long race-track shaped superconducting coils running parallel with a 20-mm wide gap between them. The transverse magnetic field in the gap is 4 T. The magnetic field can be maintained without an external power supply with a help of a persistent current switch. The magnet temperature is kept lower than 6 K by two Gifford-McMahon refrigerators. The container to hold dispersion-matching gas is inserted in the aperture of the magnet. It is made of four 2.3-m long stainless-steel square pipes and 5N high purity aluminium sheets wrapping around them to achieve high uniformity of temperature. The measured thermal conductance between both ends was 1×10^{-2} W/K at 6 K under 4 T. The one end of the gas container is suspended by three Kevlar cords. The other end at the opposite side is flanged to the magnet. This end is terminated with an X-ray window which is transparent above 2 keV and can hold gas up to 0.3 MPa. The gas introducing pipelines are also at this side and have an automated gas controlling system which enables us to scan wide range of axion mass. The generated X-rays are viewed by sixteen PIN photodiodes. Details on the X-ray detector are given in Ref. [7, 8]. Except for the gas controlling system, they are constructed in a vacuum vessel which is mounted on an altazimuth mount to track the Sun. It can track the Sun about a half of a day. During the other half of a day, background spectrum is measured.

Phase 1 of the solar observation was performed in December 1997 without the gas container [9]. Phase 2 was performed from July to September 2000 with the gas container and low density helium gas [10]. Phase 3 was performed from December 2007 to April 2008 with higher density helium gas than that of Phase 2 [11]. Since those measurements result in no positive signals of axion, upper limits on the axion-photon coupling constant $g_{a\gamma\gamma}$ were set to be $g_{a\gamma\gamma} < 6.0 - 10.4 \times 10^{-10}$ GeV^{-1} for $m_a < 0.27$ eV and $g_{a\gamma\gamma} < 5.6 - 13.4 \times 10^{-10}$ GeV^{-1} for $0.84 < m_a < 1.00$ eV. We are now preparing the search for solar axions with mass above 1 eV introducing higher density helium gas than that of last phase. Figure 3 shows the expected upper limit of next measurement. Our previous limits and the some other bounds are also plotted in the same figure. The SOLAX [12], COSME [13], DAMA [14] and CDMS [15] are solar axions experiments which exploit the coherent conversion on the crystalline plains in germanium and a NaI detector. The experiment by Lazarus et al. [16] and CAST [17, 18, 19] are the same kind of experiments as ours. The limits $g_{a\gamma\gamma} < 7 \times 10^{-10}$ GeV^{-1} is the solar limit inferred from the solar neutrino flux consideration [20]. Preferred axion models [21, 22, 23] are also shown by the shaded area in the Fig. 3.

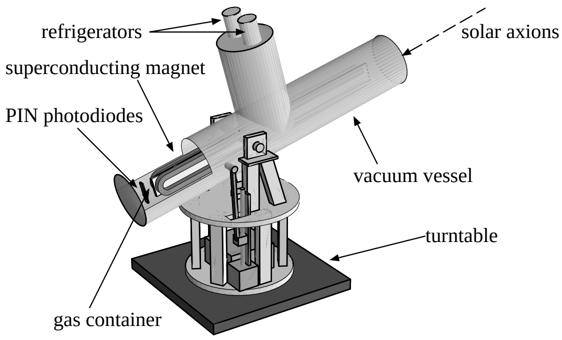

Figure 2: The schematic view of the axion helioscope.

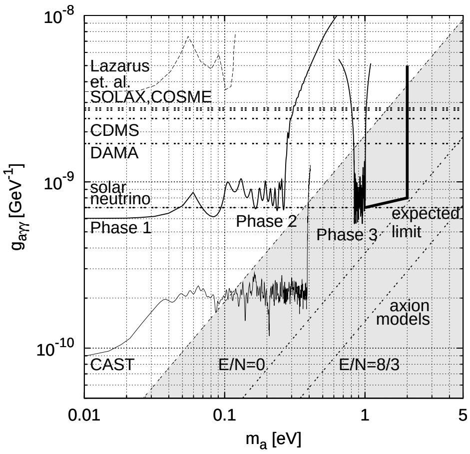

Figure 3: Exclusion limit on $g_{a\gamma\gamma}$ versus m_a at 95% confidence level.

3 Search for hidden photon

To search for hidden photons from the Sun, we plan to add an additional apparatus on the cylinder of the helioscope. A schematic design of the apparatus is illustrated in Fig. 4. It mainly consists of a vacuum vessel as a conversion region, a parabolic mirror, and a photomultiplier (PMT). In one side of the vessel, the parabolic mirror is attached to collect photons produced from the hidden photon - photon oscillation and the focal point of the mirror is set at the other side of the vessel. The mirror has a diameter of 50 cm, and a focal length of 1 m. On the focal point, the PMT is attached to detect collected photons. In addition, we plan to cool the PMT to reduce the dark count rate. As a preliminary experiment, we have cooled R329-02, a product of Hamamatsu photonics, and measured its dark count rate. The measured rate at -30 ^{o}C was about 10 Hz. This rate is several times lower than the dark count rate at room temperature. For the actual experiment, we plan to use a more suitable one than R329-02.

If we suppose the dark count rate is 10 Hz, pressure in the vessel is much less than 10 Pa, the length of conversion region is 1 m, the diameter of the mirror is 0.5 m, reflectivity of

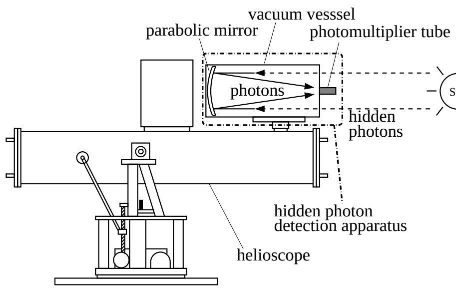

Figure 4: The schematic view of the apparatus to search for hidden photon from the Sun.

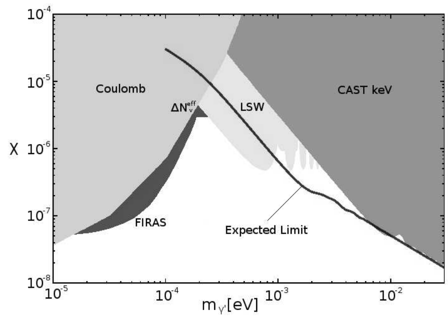

Figure 5: Exclusion limit on mixing strength between photon and hidden photon χ versus hidden photon mass $m_{\gamma'}$. The solid line shows our expected limit.

the mirror is 90 %, and measuring time is 10^6 s, we expect an exclusion region above the solid line shown in Fig. 5. The limits from other experiments and observations: Coulomb's law tests [24, 25], "light shining through walls" experiments [26, 27], CAST [4] and exclusion from CMB observation [28, 29] are also shown in Fig. 5.

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