Status report of the Tokyo axion helioscope experiment

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Abstract. We have searched for solar axions with a detector which consists of a 4 T × 2.3 m superconducting magnet, PIN-photodiode X-ray detectors, and an altazimuth mount to track the sun. The conversion region is filled with cold helium gas which modifies the axion mass at which coherent conversion occurs. In the past measurements, axion mass from 0 to 0.27 eV have been scanned. Since no positive evidence was seen, an upper limit to the axion-photon coupling constant was set to be $g_{a\gamma} < 6–10 \times 10^{-10}/\text{GeV (95\% CL)}$ depending on the axion masses. We are now actively preparing for a new stage of the experiment aiming at one to a few eV solar axions. In this mass region, our detector might be able to check parameter regions which are preferable to the axion models.

1. Introduction

Axions [¹] that are thermally produced in the core of the sun through the Primakoff process (Fig. 1) are called the solar axions. Sikivie [²] proposed an ingenious experiment to detect such axions. The detection device called axion helioscope is a system of a strong magnet and an X-ray detector, where the solar axions is converted into X-ray photons through the inverse Primakoff process (Fig. 1) 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 of the solar axions becomes feasible.

We have constructed an axion helioscope with a dedicated superconducting magnet. Cold helium gas was used as the conversion medium, and the highest axion mass was targeted at 2.6 eV. We report the current status of this experiment.

2. The Sumico V detector

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 [³] 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
In the solar core

\[ \gamma \rightarrow a \rightarrow \gamma \]

In the magnet

\[ a \rightarrow \gamma \rightarrow \text{PIN photodiodes} \]

Figure 1. The solar axions produced via the Primakoff process in the solar core are, then, converted into X-rays via the reverse process in the magnet.

Figure 2. The schematic view of the axion helioscope.

of a persistent current switch. The magnet 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 the both ends was \( 1 \times 10^{-2} \) W/K at 6 K under 4 T. The “solar” end of the gas container is suspended by three Kevlar cords. The “detector” end at the opposite side is flanged to be fixed 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. The converted X-ray is viewed by sixteen PIN photodiodes. Details on the X-ray detector are given in Ref. [4]. 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.

3. Past and future measurements

3.1. Phase I — the first measurement

Phase I of the solar observation was performed from 26th till 31st December 1997 without the gas container [5]. Since the conversion region was vacuum, the sensitivity was limited below \( m_a < 0.03 \) eV. From the absence of an axion signal, an upper limit on the axion-photon coupling is given to be \( g_{a\gamma} < 6.0 \times 10^{-10} \text{GeV}^{-1} \) (95% CL).

3.2. Phase II — with low density helium gas

Phase II was performed from July to September 2000, where low density helium was introduced [6]. The sensitive mass region was brought up by an order of magnitude. Again, no signature of axions was seen, restricting the axion-photon coupling to be \( g_{a\gamma} < (6.2-10.4) \times 10^{-10} \text{GeV}^{-1} \) for \( 0.05 < m_a < 0.27 \) eV. The exclusion limit at 95% confidence level obtained from Phase I and II are shown together in Fig. 3.

3.3. Phase III — the next stage

At present, we are preparing for the next stage. In Phase III, high density helium will be introduced aiming at more massive axions up to \( m_a \lesssim 2.2-2.6 \) eV. To achieve this goal, several developments have been made. When the superconducting magnet quenches, the high-density helium should be relieved safely before the gas container would burst. The gas introducing pipeline was completely reworked based on the measured pressure change after a forced quench with a safely low pressure helium. In addition, a cryogenic rupture disk was installed as a last resort. Another challenge is that the higher the axion mass becomes, the narrower the resonance...
width of the conversion becomes. The gas density should be controlled with an extreme accuracy typically of the order of 0.1% at \( m_a = 2.6 \text{ eV} \), and many data points should be measured to scan a range. For this purpose, an automated gas controlling system was developed. It has successfully demonstrated to stabilize the temperature and to control the pressure of helium gas with a good accuracy.

4. Conclusions
We have searched for solar axions with an axion helioscope, and axion mass from 0 to 0.27 eV have been scanned. No evidence of axion signal has been seen so far, implying an exclusion limit to the axion-photon coupling as shown in Fig. 3. In the lower mass region, the above limit has been renewed by CAST. However, we are preparing for the next stage aiming at a higher mass region where our detector might be able to check the parameter regions preferred by theory. In December 2007, a preliminary measurement started at \( m_a \approx 1 \text{ eV} \). Remaining problems are being resolved one by one. The ultimate density will be reached in 2008, although a full range scan will take years.

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