論文内容の要旨

Search for solar axions with mass below 1 eV using coherent conversion of axions into photons
(アクシオンから光子へのコヒーレント転換を用いた質量 1eV 以下の太陽アクシオン探索)

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Quantum Chromodynamics (QCD) is the theory of the strong interactions. Although QCD has proven remarkably successful, there is a blemish called the strong CP problem. The strong CP problem is that the effective Lagrangian of QCD has CP violating term but it has not been observed in any experiment yet.

Peccei and Quinn proposed an attractive solution to solve this problem. They introduced new global $U(1)$ symmetry, Peccei-Quinn (PQ) symmetry. When PQ symmetry spontaneously breaks, a new effective term arises in QCD Lagrangian which cancels the CP violation term. The solution also predicts a new pseudo Nambu-Goldstone boson, axion.

It was originally thought that PQ symmetry breaking scale ($f_{\rm PQ}$) is at the weak interaction energy scale, $f_{\rm PQ} \sim 250\,\rm GeV$. But in this energy scale, axions have relatively strong couplings, and the original model was experimentally excluded. Since there are various experimental, astrophysical and cosmological considerations, axions survive as the invisible axions which have higher $f_{\rm PQ}$ and weaker couplings.

If axions exists and their coupling constant to photons is large enough, many celestial objects (stars, compact objects, supernovae, galactic centers, gamma-ray bursts, etc.) can be good axion sources. Needless to say, the Sun is the strongest source among them. The high energy thermal plasma like the Sun emits axions through the Primakoff effect and the axions reach the surface of the Earth. Our experiment, Tokyo Axion Helioscope (Fig.1), is one of the experiments to directly detect solar axions. To detect axions, Tokyo Axion Helioscope utilized a superconducting magnet. The magnetic field produced by it converts solar axions into photons and the X-ray detector detects the photons. In our past experiments, we obtained the upper limit of the axion to photon coupling constant, $g_{a\gamma\gamma}$.

In the present experiment, we searched for solar axions with mass below 1 eV using coherent conversion of axions into photons. In order to detect axions with mass below 1 eV, we need to keep the coherence between axions and photons. So that, we fill conversion region with dispersion-matching helium gas to give photons effective mass below 1 eV.

We measured with 9 sets of the density of helium that has the highest probabilities when the axion mass is below 1 eV.

As a result, we found no axion signal within statistical errors in the mass region $0.79\,\mathrm{eV} < m_a < 0.84\,\mathrm{eV}$. We set 95% confidence limits on axion-photon coupling constant, $g_{a\gamma\gamma}$;

$$g_{a\gamma\gamma} < (6.2 - 17.4) \times 10^{-10}\ \mathrm{GeV}^{-1} \qquad (1)$$

for the axion mass of

$$0.79\ \mathrm{eV} < m_a < 0.84\ \mathrm{eV}. \qquad (2)$$

This result gives currently the most stringent observational limit on the existence of solar axions in this mass region as shown in Figs. 2 and 3.

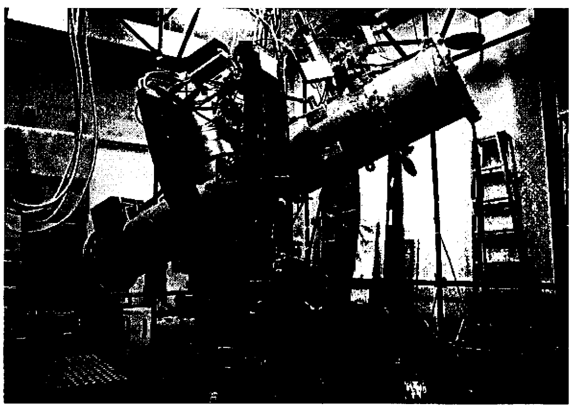

Figure 1: Tokyo Axion Helioscope.

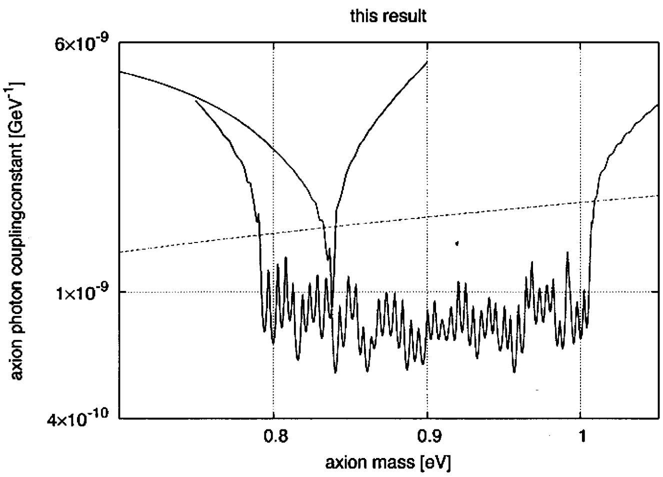

Figure 2: Exclusion plot on $g_{a\gamma\gamma}$ to m_a is plotted. Black line shows the result of this experiment.

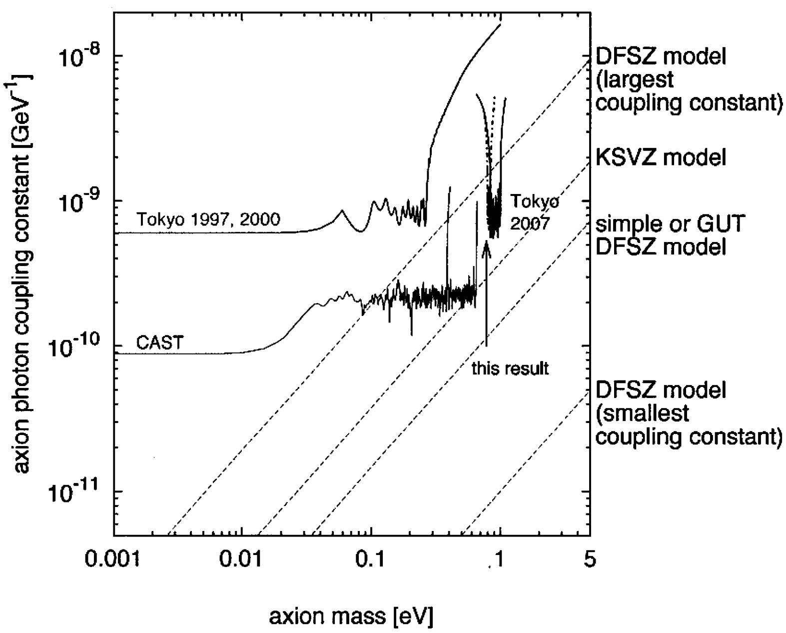

Figure 3: Upper limit of the axion to photon coupling constant, $g_{a\gamma\gamma}$, obtained by solar axion detect experiments. Black line shows the result of this experiment.