論文内容の要旨

Search for solar axions with mass around 1eV using coherent conversion of axions into photons
—(光子へのコヒーレント転換による
質量1eV前後の太陽アクシオンの探索)—

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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 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, $f_{\rm PQ} \sim 250$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 an axion exists, 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 the solar axions into photons and X-ray detectors detect 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 around 1 eV using coherent conversion of axions into photons. In order to detect axions with mass around 1eV, we need to make momentum transfer between axions and photons minimum. So that, we fill conversive region with dispersion-matching helium gas to give the photon effective mass of around 1 eV.

We measured with 10 sets of the density of helium that has the highest probabilities when the axion mass is around 1 eV.

As a result, we found the axion signal is consistent with zero within statistical errors in each mass region. We set 95% confidence limits on photon-axion coupling constant, $g_{a\gamma\gamma}$;

$$g_{a\gamma\gamma} < (4.7 - 10.7) \times 10^{-10}\ \mathrm{GeV}^{-1} \tag{1}$$

for the axion mass of

$$0.96\ \mathrm{eV} < m_a < 1.00\ \mathrm{eV}. \tag{2}$$

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

We shall keep searching solar axions with a wider region of the helium density. At the end of this experiment, we should have similar limits on $g_{a\gamma\gamma}$ in the mass range

$$0.27\ \mathrm{eV} < m_a < 1.13\ \mathrm{eV}. \tag{3}$$

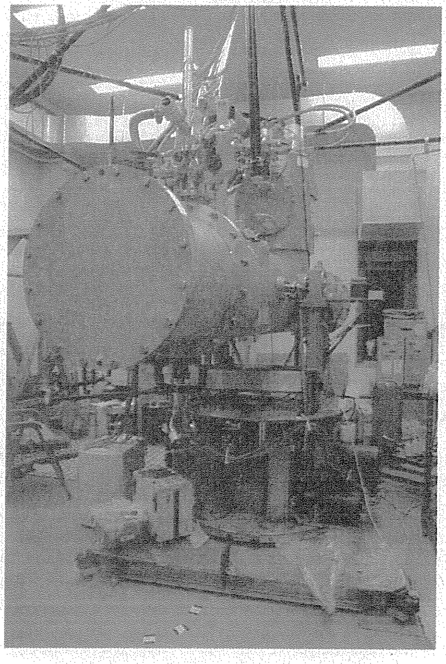

Figure 1: Tokyo Axion Helioscope.

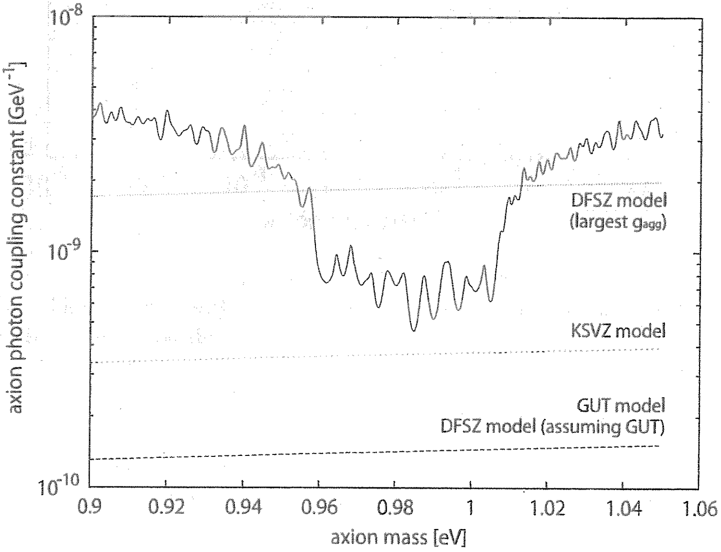

Figure 2: The exclusion plot on $g_{a\gamma\gamma}$ to m_a is plotted.

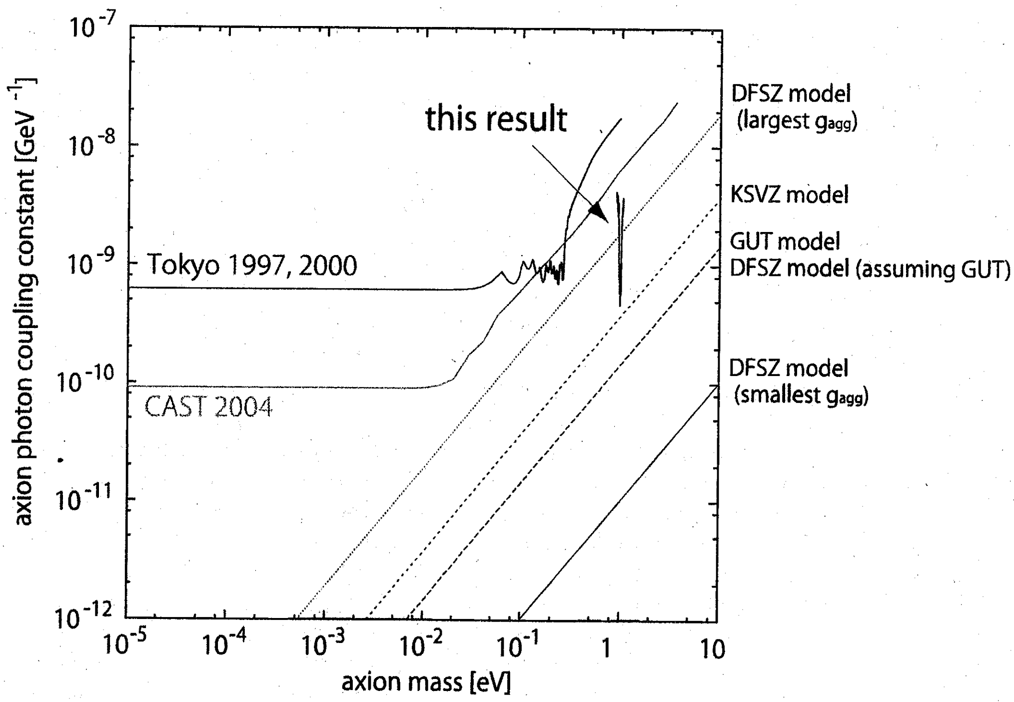

Figure 3: The upper limit of the axion to photon coupling constant, $g_{a\gamma\gamma}$, obtained by solar axion detect experiments.