Solar axion search with TES microcalorimeters and an iron-57 absorber

International Center for Quantum-field Measurement System for Studies of the Universe and Particles

Tomonori Ikeda (ikedat@post.kek.jp)
High Energy Accelerator Research Organization

Japan Aerospace Exploration Agency

東京大学 THE UNIVERSITY OF TOKYO

国立天文台 NAOJ National Astronomical Observatory of Japan

WASEDA University

九州大学 KYUSHU UNIVERSITY

Yuta Yagi, Tasuku Hayashi, Keita Tanaka, Ryo Ota, Mikiko Saito, Takayuki Homma, Nao Yoshida, Fuminori Hirayama, Akira Sao, Takahiro Kikuchi, Satoshi Kohjiro, Yuki Nakashima, Noriko Y. Yamasaki, and Kazuhisa Mitsuda

1. Solar Axion search

✓ Axion can solve the strong CP-problem

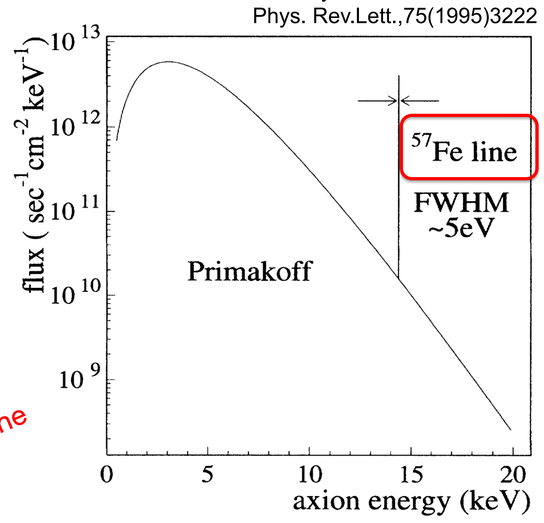
✓ Axion can be a part of dark matter

➢ **Axion search is a well-motivated experiment in both particle physics and astrophysics field**

✓ Sun is a good source of axion (kT ~ 1.3 keV)

- $\mathcal{L}_{a\gamma\gamma} = -\frac{g_{a\gamma}}{4} F_{\mu\nu}\tilde{F}^{\mu\nu}$
  → Primakoff effect (continuum)
- $\mathcal{L}_{aee} = C_e \frac{\partial_\mu a}{2f_a} \bar{f}_e \gamma_5 \gamma^\mu f_e$
  → Compton scattering (continuum)
  → Bremsstrahlung (continuum)
- $\mathcal{L}_{aee} = \sum_{N=p,n} \frac{g_{aN}}{2m_N} \bar{N}\gamma^\mu\gamma_5 N \partial_\mu a$
  → M1 transition in a nucleus (Line)

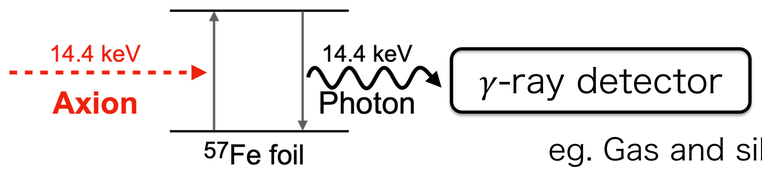
S. Moriyama
Phys. Rev.Lett.,75(1995)3222



➢ Line spectrum from ^{57}Fe, ^{7}Li, ^{83}Kr and ^{169}Tm are characteristic signals from solar axions

2. Principle of Detection

✓ Induce an inverse reaction at the laboratory



eg. Gas and silicon detectors

✓ Catching the mono-energy γ-ray using detectors with a high-energy resolution

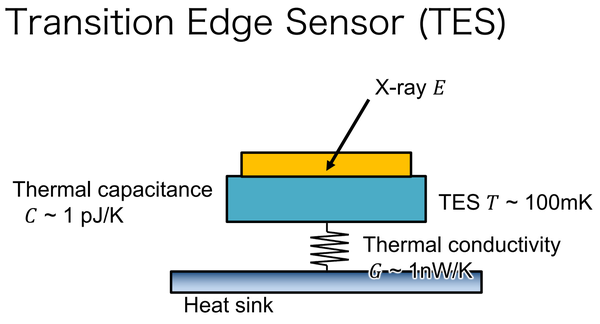
✓ We can investigate the interaction term of axion-nucleon coupling independently

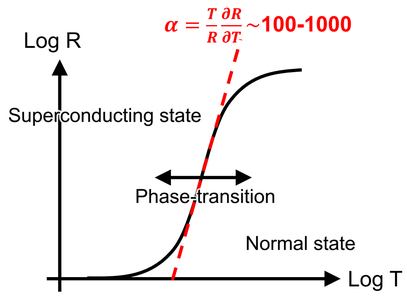
But…
- Branching ratio emitting γ-rays of 14.4 keV: ~10%
  - 90% convert to Auger electron or lower energy X-ray
- Self-absorption by an Iron foil: ~80%

→ Overall efficiency, including detector acceptance: only 1%(T. Namba, 2007) or 9%(A. V. Derbin, et al., 2011)

3. TES microcalorimeter

◆Transition Edge Sensor (TES)





- TES, which consists of a superconducting film, is operated in the narrow temperature region between the normal and superconducting state
- The logarithmic sensitivity of a superconducting transition α can be two orders of magnitude more sensitive than that of semiconductor thermistors

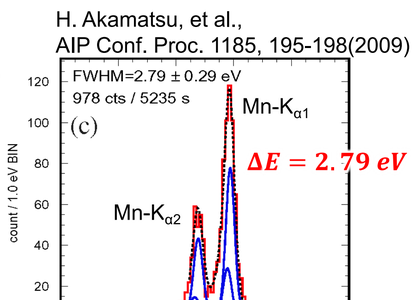
- Energy resolution

$$\Delta E \propto \sqrt{\frac{k_B T^2 C}{\alpha}}$$

$\alpha = \frac{T}{R}\frac{\partial R}{\partial T}$: dimensionless sensitivity
C: thermal capacitance
T: temperature

Y. Ezoe, et al.,
AIP Conf. Proc. 1185, 60-63(2009)

H. Akamatsu, et al.,
AIP Conf. Proc. 1185, 195-198(2009)



4. Design using iron-57 absorbers

✓ TES and iron converter/absorber are integrated

➢ More than 70% efficiency is expected

✓ The ferromagnetization of iron degrades on the spectroscopic performance

➢ Place the absorber at an optimized distance from the TES and connect it with a thermal strap

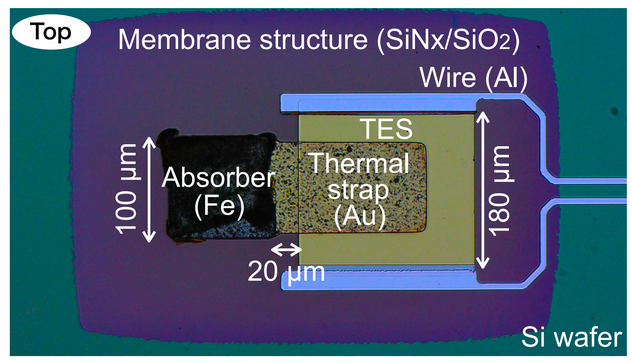
➢ **Succeeded in the operation of the TES microcalorimeter under iron magnetization for the first time (Y. Yagi, et al., 2023)**

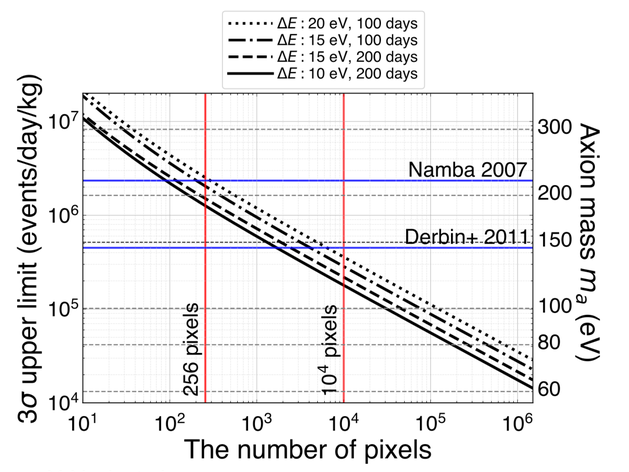
✓ The first science run on the ground was done in 2024

➢ Please wait for the publication

➢ Sensitivity was dominated by the photon limit

➢ The next step is to increase the target mass (need to multi-pixel readout)

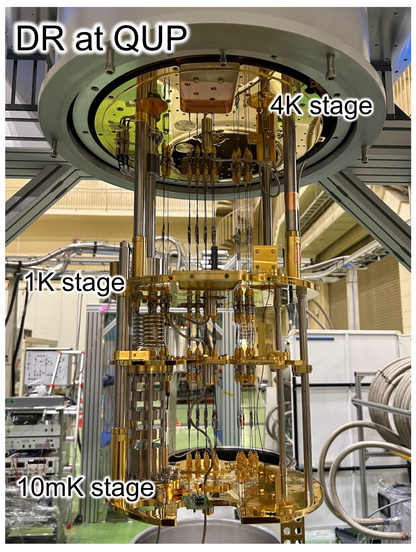




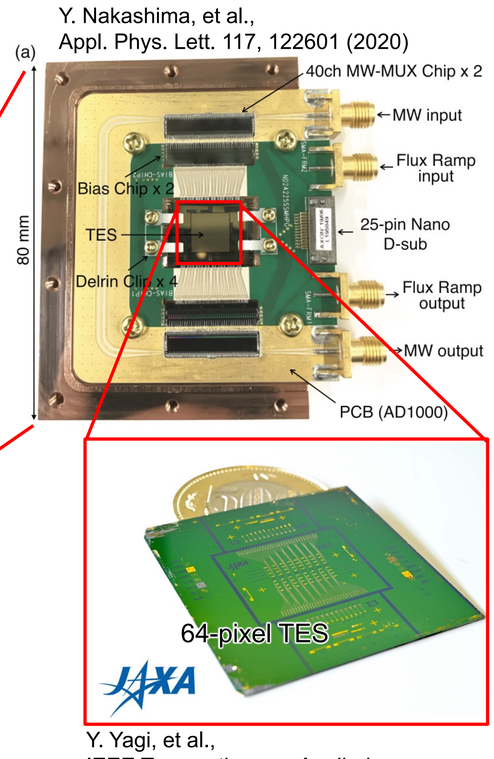
Y. Yagi, et al.,
Journal of Low Temperature Physics (2023) 211:255-264

5. Development of 64-pixel TES array

✓ We are planning to install a 64-pixel TES array into the dilution refrigerator at QUP (High Energy Accelerator Research Organization)



Y. Nakashima, et al.,
Appl. Phys. Lett. 117, 122601 (2020)



✓ Fabrication of a 64-pixel TES array was already done (Y. Yagi, et al, 2023)

✓ The microwave SQUID multiplexer (MW-Mux) can multiplex 40 TESs per chip(Y. Nakashima, et al., 2020)

Y. Yagi, et al.,
IEEE Transactions on Applied Superconductivity 33(5) 2100805, 2023

6. Conclusion

✓ Detection of the 14.4 keV line signal using TES calorimeter is a promising way to investigate the solar axion

✓ Key components of the experiment (iron absorber and MW-Mux) were already developed

✓ We are developing a 64-pixel TES array for solar axion search at QUP