Thulium-containing bolometer for solar axion resonant absorption search

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Abstract

Axion is a hypothetical pseudoscalar Nambu-Goldstone boson that was introduced as an extension to the Standard Model intended to solve the strong CP problem. It also could be a possible solution for a series of other fundamental physics problems such as the the dark matter or photon ultratransparency of the Universe. In this work we describe a novice technique of axion search with Tm-containing crystal $Tm_3Al_5O_{12}$, a garnet that could be operated in the bolometric regime. A small sample of this crystal of 8.18 g has been already applied for axion search producing a new limit of the coupling constants: $|g_{A\gamma}(g^0_{AN} + g^3 AN)| \leq 1.44 \times 10^{-14} GeV^{-1}$ and $|g_{Ae}((g^0_{AN} + g^3 AN)| \leq 2.81 \times 10^{-16}$.

What is an axion

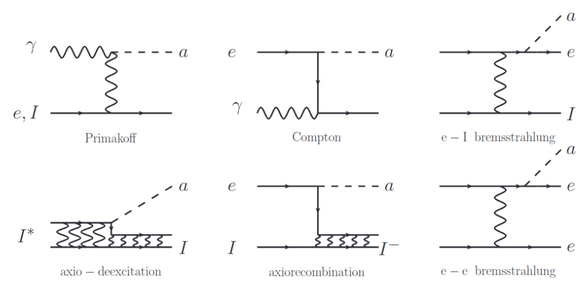
In order to solve the strong CP problem R. D. Peccei and H. R. Quinn in 1977 proposed the concept of the new chiral symmetry $U(1)_{PQ}$ [1].

$$L_\Theta = (\Theta - \frac{A}{f_A}) \frac{g_s^2}{32\pi^2} G_a^{\mu\nu} \tilde{G}_{a\mu\nu}$$

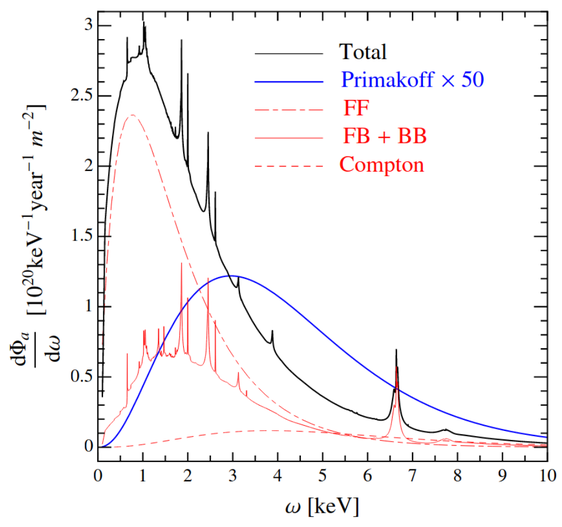
The spontaneous breaking of this symmetry at the energy f_A allows one to compensate CP-violating term of the QCD Lagrangian completely. S. Weinberg and F. Wilczek have shown (1978) that the introduced PQ-model should lead to the existence of a new neutral pseudoscalar particle. The later expecrimenst have closed the classic PQWW axion with symmetry breaking scale $f_A \approx 250$ GeV, but the concept itself has survived with DFSZ and KSVZ model classes.

Solar axions

If an axion exists, the Sun would be a strong source of it. The main reactions responsible for it are the so-called ABC-processes



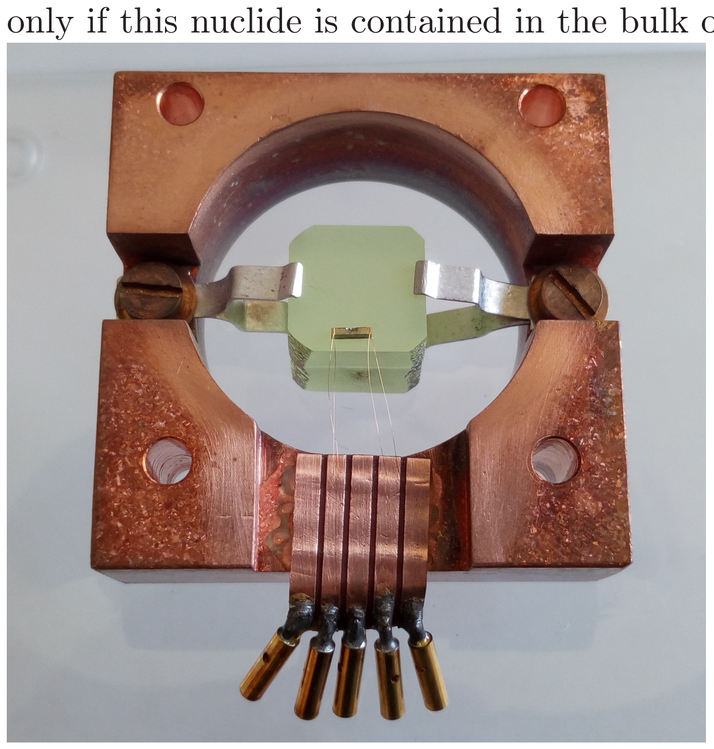
The ABC stands for Atomic axio-recombination and Atomic axio-deexcitation, axio-Bremsstrahlung in electron- Ion or electron-electron collisions and Compton scattering, see [2,3]

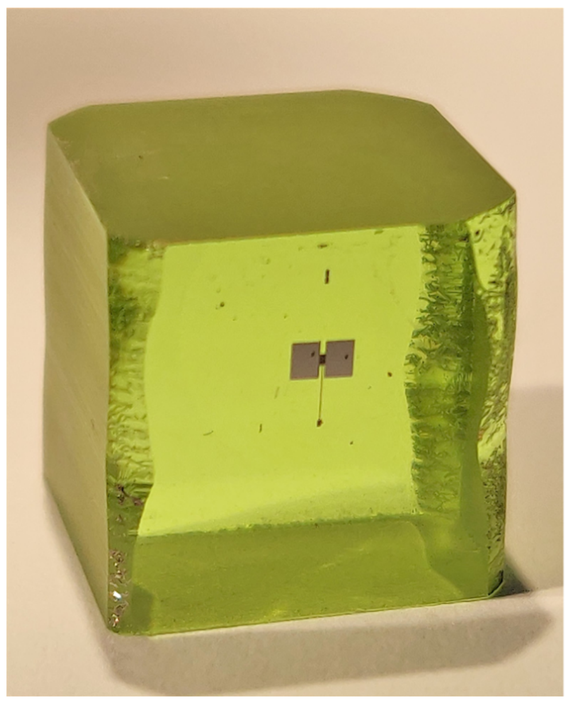


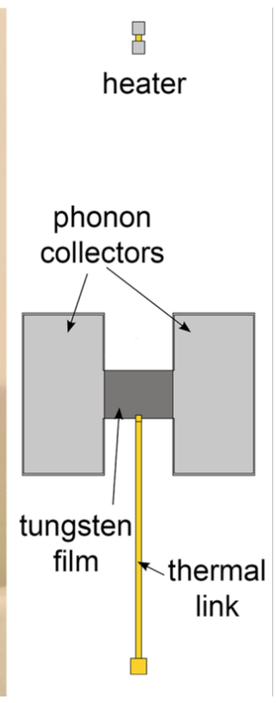
Another source of axions would be the Primakoff process, associated with axion-gamma interaction.
One should note, that energies of these axions lie in the keV region. The least model-dependent axion reaction is resonant absorption by atomic nuclei in magnetic type transitions, the cross section of which depends mainly of axion mass.

$Tm_3Al_5O_{12}$ Crystals

^{169}Tm has a low-lying M1 transition at 8.41 keV that makes it optimal for axion detection [4]. Since axion detection product is a low-energy gamma-radiation the best sensitivity could be obtained only if this nuclide is contained in the bulk of the detector.



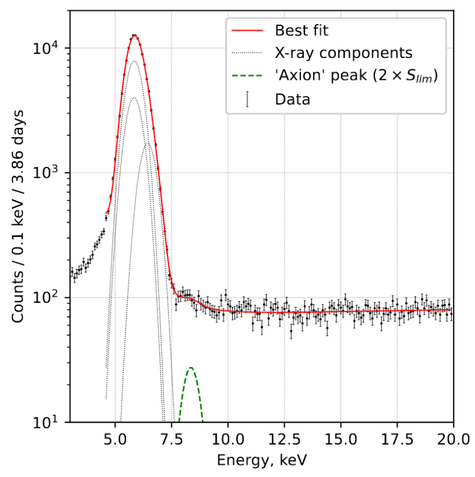


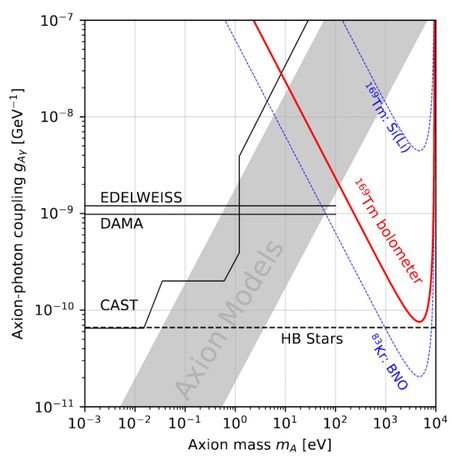


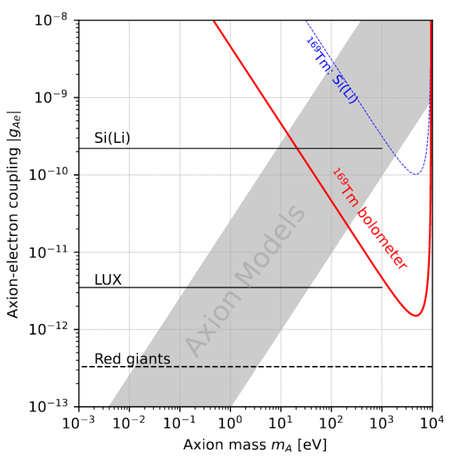
In order to fulfill this reqirement a series of $Tm_3Al_5O_{12}$ granate crystals were produced and tested to be valid for particle detection in blometric regime.
The readout was performed with Neutron Transmutation Doped (NTD) Ge sensor (left) and later with Transition Edge Sensor (TES, right).

Preliminatry bolometric results

The 8.18 g crystal with TES readout sensor was used for low-background spectral measurement in at the Max Plank Institute for Physics (MPP) in Munich, Germany for 3.86 days and has shown decent resolution as a bolometer. The facility was located above ground and had no shielding against environmental and cosmic radiation.
The spectrum obtained was fitted with consideration of x-ray background components, flat background and 8.41 keV expected axion peak (left figure)







As a result, new limits on axion couplings were obtained:

$$|g_{A\gamma}(g^0_{AN} + g^3 AN)| \leq 1.44 \times 10^{-14} GeV^{-1}$$
$$|g_{Ae}((g^0_{AN} + g^3 AN)| \leq 2.81 \times 10^{-16}$$

Better limits are expected for future experiments crystals with increased detector mass and lower enviromental background.

references

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Acknowledgements

The study was performed under support of Russian Science Foundation (projects № 21-12-00063 and № 22-22-00017)