New experiment searching for solar axions with Tm-containing cryogenic bolometer

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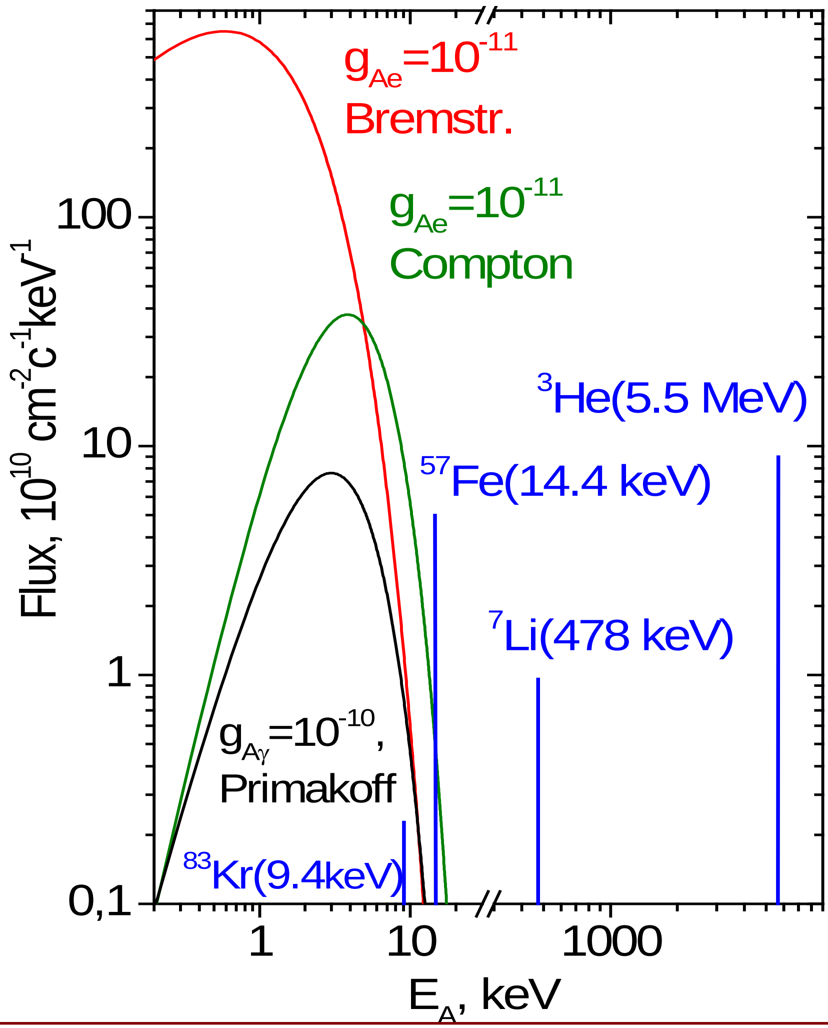
Solar axion spectra vs $g_{A\gamma}$, g_{Ae} u g_{AN}



The main sources of solar axions:

1. Reactions of main solar chain. *The most intensive fluxes are expected from M1-transitions in ^{7}Li and ^{3}He nuclei* (**g_{AN}**):

$^{7}Be + e^{-} \rightarrow {}^{7}Li^{*} + \gamma$; $^{7}Li^{*} \rightarrow {}^{7}Li + A$ (478 кэВ)

***p* + *d* → ^{3}He + A (5.5 MэВ).**

2. Magnetic type transitions *in nuclei whose low-lying levels are excited due to high temperature in the Sun* (**^{57}Fe,^{83}Kr**) (**g_{AN}**)

3. Primakoff conversion *of photons in the electric field of solar plasma* (**$g_{A\gamma}$**).

4. Bremsstrahlung: **e + Z(e) → Z + A.** (**g_{Ae}**)

5. Compton process: **γ + e → e + A.** (**g_{Ae}**)

6. axio-recombination: **e + I → I⁻ + A** and axio-deexcitation: **I* → I + A.**

7. *Plasmon-axion conversion. E<200 eV.*

If axion does exist, the Sun should be an intense source of axions. The expected energy spectrum of solar axions, like the spectrum of solar neutrinos, contains both continuous spectra and monochromatic lines. There are 6(7) main ***axion formation processes*** inside the stars:

Resonant excitation of nuclear levels

The axions can be produced when thermally excited nuclei (or excited due to nuclear reactions) in the Sun relaxes to its ground state and could be detected via resonant excitation of the same nuclide in a laboratory.

The monochromatic axions can excite the same nuclide in a laboratory, because the axions are Doppler broadened due to thermal motion of the axion emitter in the Sun, and thus some axions have suitable energy to excite the nuclide.

The axions from Primakoff, Compton and Bremsstrahlung processes with wide continues energy spectra can also excite low-lying levels of some nuclei.

^{169}Tm is more promising nucleus

Searches for solar axions were performed using reaction of resonant absorption by ^{7}Li-, ^{57}Fe-, ^{169}Tm- and ^{83}Kr-nuclei.

Resonant excitation of nuclear levels

Physics Letters B 678 (2009) 181–185

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Search for solar axions produced by Primakoff conversion using resonant absorption by ^{169}Tm nuclei

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Original Russian Text © Yu.M. Gavrilyuk, A.N. Gangapshev, A.V. Derbin, I.S. Drachnev, V.V. Kazalov, V.V. Kobychev, V.V. Kuzminov, V.N. Muratova, S.I. Panasenko, S.S. Ratkevich, D.A. Tekueva, E.V. Unzhakov, S.P. Yakimenko, 2018, published in Pis'ma v Zhurnal Eksperimental'noi i Teoreticheskoi Fiziki, 2018, Vol. 107, No. 10, pp. 617–622.

ASTROPHYSICS AND COSMOLOGY

New Constraints on the Axion–Photon Coupling Constant for Solar Axions

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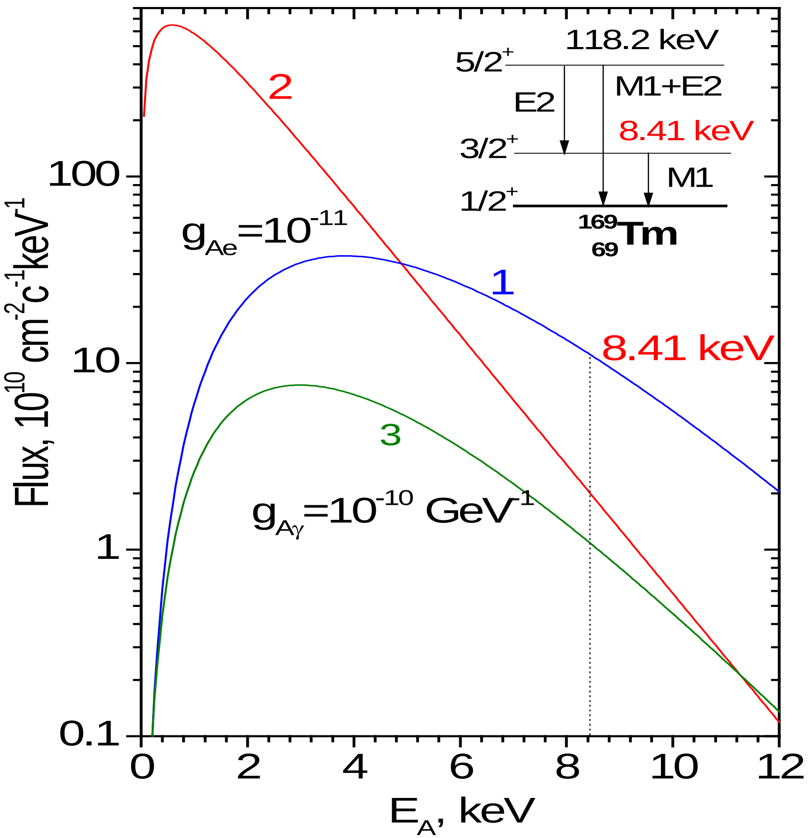
Resonant absorption by ^{169}Tm nucleus



1,2—the spectra of the axions produced by the Compton process and the bremsstrahlung ($g_{Ae}=10^{-11}$). 3—spectrum of the axions produced by the Primakoff effect ($g_{A\gamma}=10^{-10}$ GeV^{-1}). The level scheme of the ^{169}Tm nucleus is shown in the inset.

The rate of solar axion absorption by the ^{169}Tm:

$$R_A = \pi\sigma_{0\gamma}\Gamma\frac{d\Phi_A}{dE_A}(E_A = 8.4)\left(\frac{\omega_A}{\omega_\gamma}\right),$$

where $\sigma_{0\gamma}$ is a maximum cross section of γ-ray absorption. The experimentally derived value of $\sigma_{0\gamma}$ for ^{169}Tm nucleus is 2.56×10^{-19} cm^2. Width of energy level $\Gamma = 1.13\times10^{-10}$ keV.

$$\frac{\omega_A}{\omega_\gamma} = \frac{1}{2\pi\alpha}\frac{1}{1+\delta^2}\left[\frac{g^0_{AN}\beta + g^3_{AN}}{(\mu_0-0.5)\beta+\mu_3-\eta}\right]^2\left(\frac{p_A}{p_\gamma}\right)^3$$

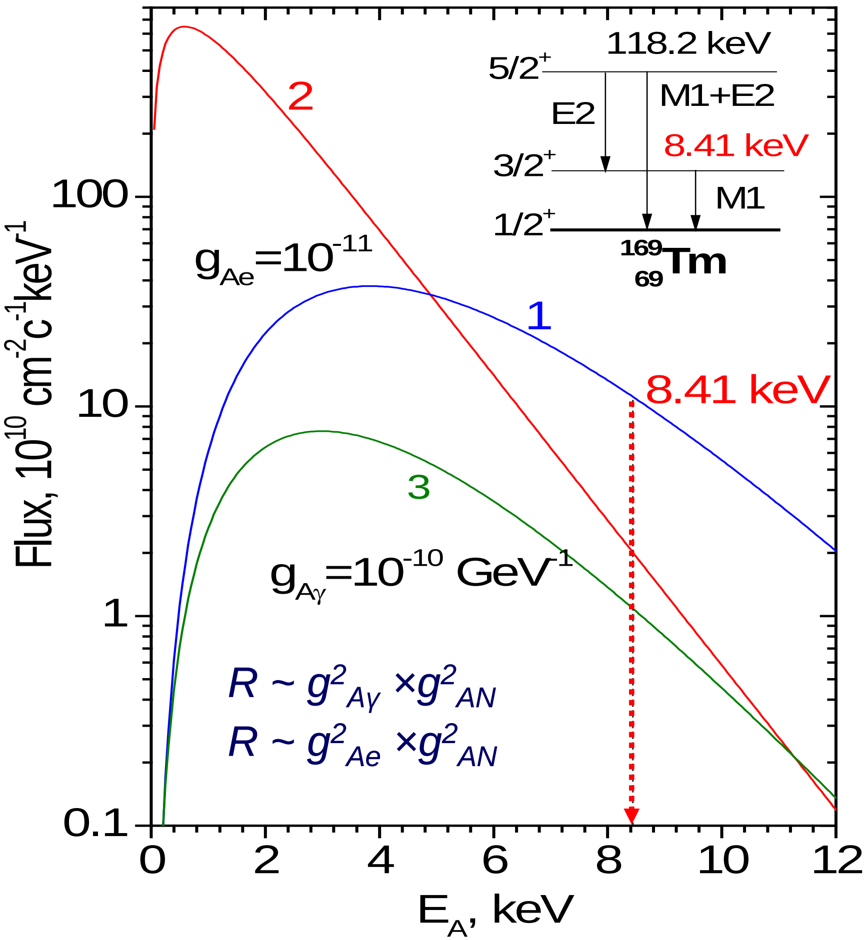
The ratio of the nuclear transition probability with the emission of an axion ω_A to the probability of magnetic type transition ω_γ.

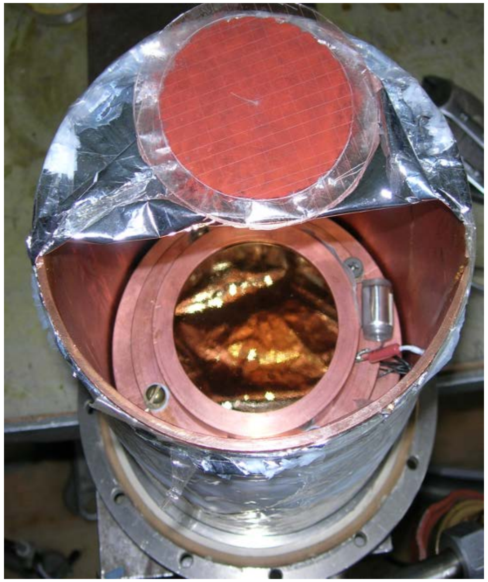
$$\frac{\omega_A}{\omega_\gamma} = 1.03(g^0_{AN} + g^3_{AN})^2(p_A/p_\gamma)^3$$

The detection probability of the axions is determined by the product $g^2_{A\gamma}\cdot g^2_{AN}$ which is preferable for small $g_{A\gamma}$ values.

Phys. Lett. B 678 181 (2009) Phys.Rev.D83, 023505 (2011)

Resonant absorption by ^{169}Tm nuclei





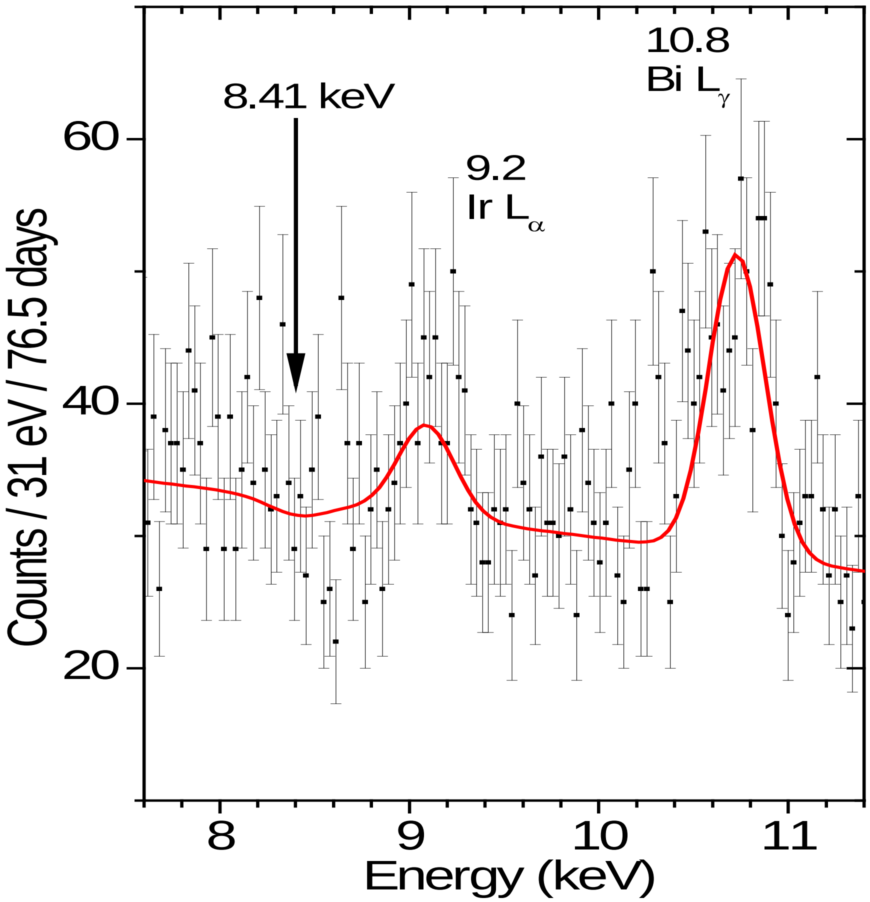
To search for 8.41 keV γ's the planar Si(Li) detector with a sensitive area diameter of 66 mm and a thickness of 5 mm was used.

The detection probability of the axions is determined by the product $g^2_{A\gamma} \times g^2_{AN}$ and $g^2_{Ae} \times g^2_{AN}$ which is preferable for small $g_{A\gamma e}$ values.

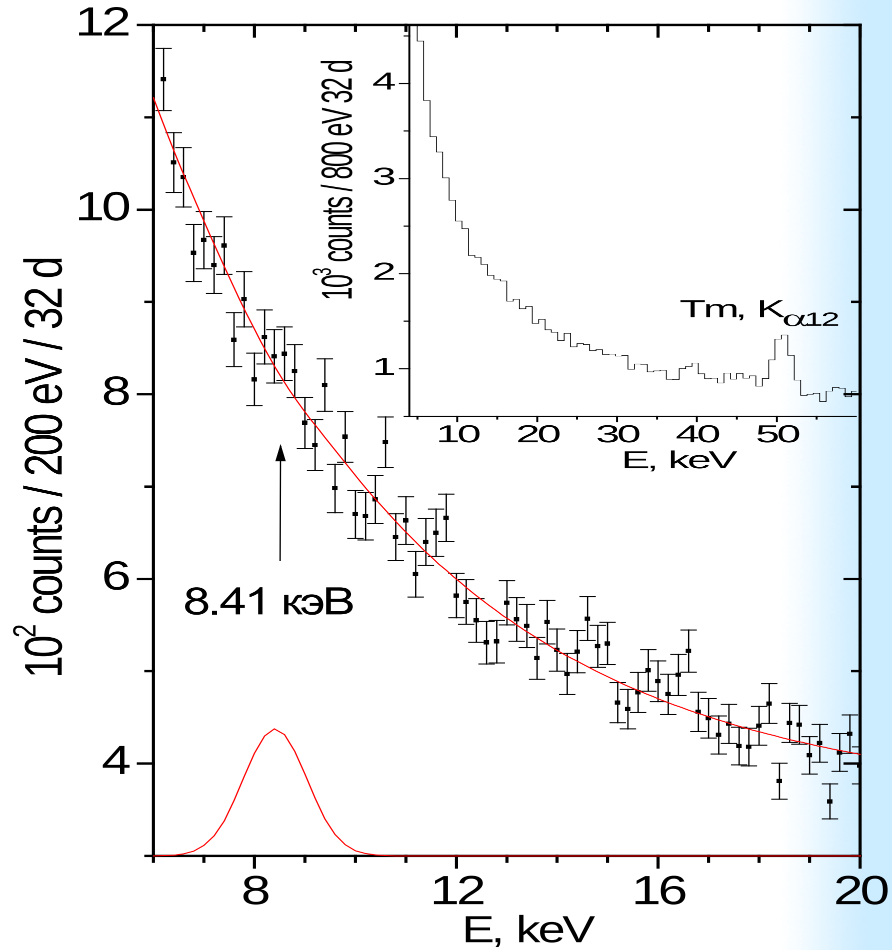
The search for resonant absorption of Primakoff, Compton and Bremsstrahlung solar axions by 169Tm nuclei have been performed using Si(Li) detector and Tm target. The expected axion count rate is proportional $R \sim g^2_{A\gamma} \times g^2_{AN}$ for Primakoff axions and $R \sim g^2_{Ae} \times g^2_{AN}$ for Bremsstrahlung and Compton axions.

PL B 678 181 (2009) PRD83, 023505 (2011)

Results of search for 8.41 keV peak



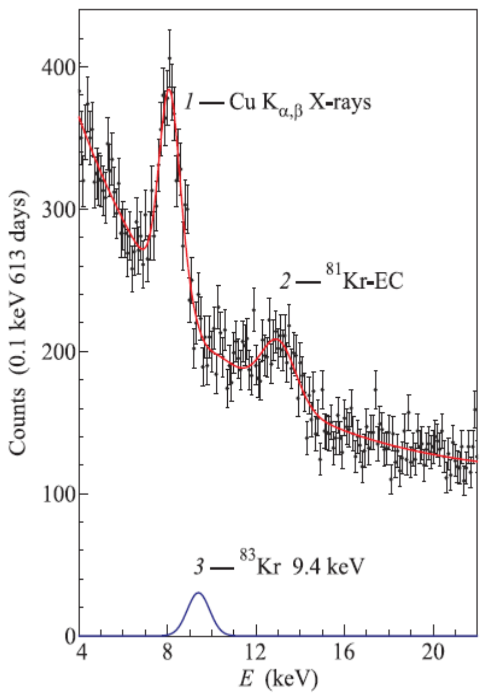
Spectrum measured with 2 cm² Si(Li)-detector in the region 7.6-11.4 keV.

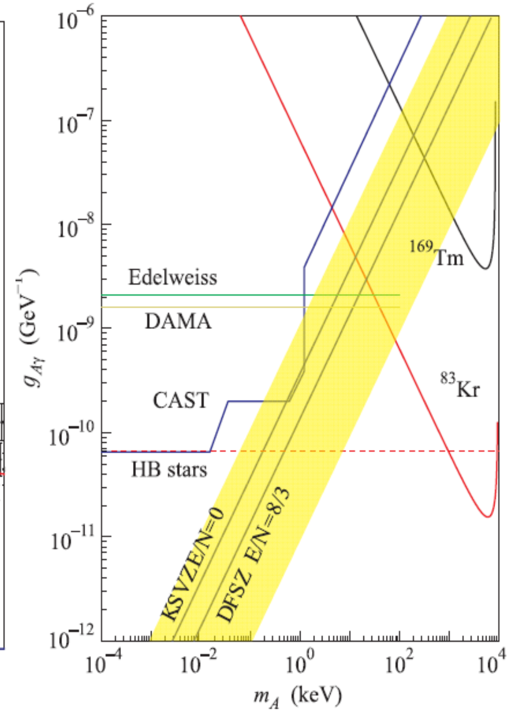


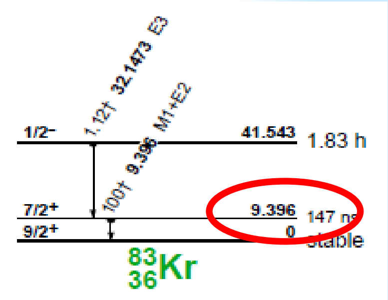
Spectrum of 34 cm² Si(Li)-detector measured with 169Tm target.

Search for solar axions emitted in M1-transition of ^{83}Kr nuclei (INR BNO + PNPI)

A search was carried out for 9.4 keV axions emitted in the M1 transition of 83Kr nuclei on the Sun, using the resonance absorption reaction : **$A + {}^{83}Kr \rightarrow {}^{83}Kr^* \rightarrow {}^{83}Kr + \gamma$ (9.4 keV).** To register γ-quanta and electrons arising from the discharge of the nuclear level, a proportional gas chamber filled with 99.9% enriched krypton-83 and located in a low-background installation in the underground laboratory of the **Baksan Neutrino Observatory** was used**.**







Two proportional Kr-chambers with the first layer of passive protection. Spectrum of the Kr camera measured over 613 days. Limits on gAγ. Decay scheme and the Andyrchi mountain, under which the BNO INR is located at a depth of 4800 m.

Two recent papers about $Tm_3Al_5O_{12}$-bolometer

Nuclear Inst. and Methods in Physics Research, A 949 (2020) 162924

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

ELSEVIER

A test of bolometric properties of Tm-containing crystals as a perspective detector for a solar axion search

E. Bertoldo [a], A.V. Derbin [b], I.S. Drachnev [b], M. Laubenstein [c], D.A. Lis [d], M. Mancuso [a], V.N. Muratova [b], S. Nagorny [e], S. Nisi [c], F. Petricca [a], V.V. Ryabchenkov [f], S.E. Sarkisov [f], D.A. Semenov [b], K.A. Subbotin [d], E.V. Unzhakov [b,*], E.V. Zharikov [d]

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THE EUROPEAN PHYSICAL JOURNAL C

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Regular Article - Experimental Physics

New limits on the resonant absorption of solar axions obtained with a ^{169}Tm-containing cryogenic detector

A. H. Abdelhameed[1], S. V. Bakhlanov[2], P. Bauer[1], A. Bento[1,7], E. Bertoldo[1], L. Canonica[1], A. V. Derbin[2], I. S. Drachnev[2], N. Ferreiro Iachellini[1], D. Fuchs[1], D. Hauff[1], M. Laubenstein[3], D. A. Lis[4], I. S. Lomskaya[2], M. Mancuso[1], V. N. Muratova[2], S. Nagorny[5], S. Nisi[3], F. Petricca[1], F. Proebst[1], J. Rothe[1], V. V. Ryabchenkov[6], S. E. Sarkisov[6], D. A. Semenov[2], K. A. Subbotin[4], M. V. Trushin[2], E. V. Unzhakov[2,a], E. V. Zharikov[4]

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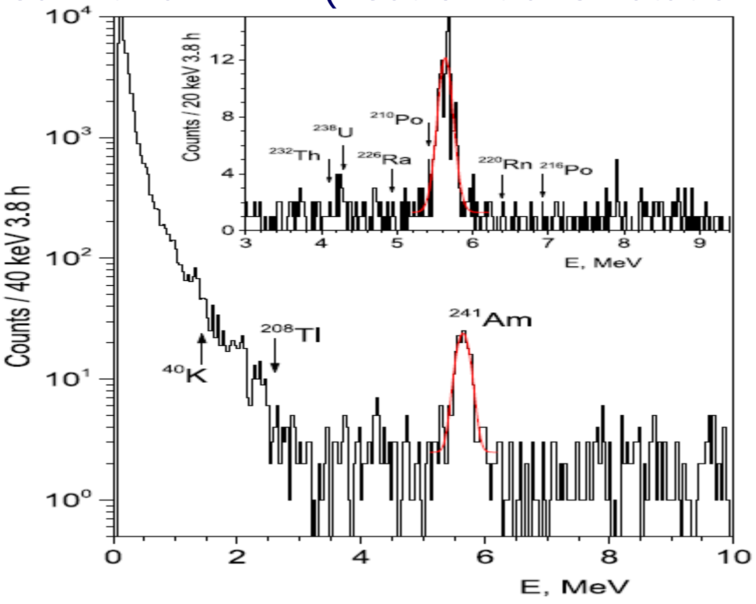
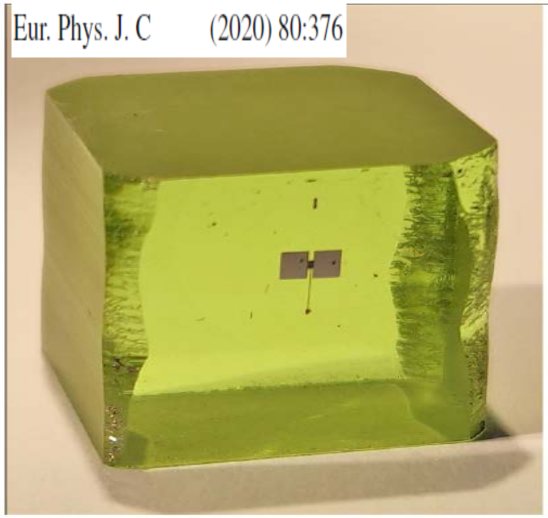
$Tm_3Al_5O_{12}$ crystal is a new promising bolometer.

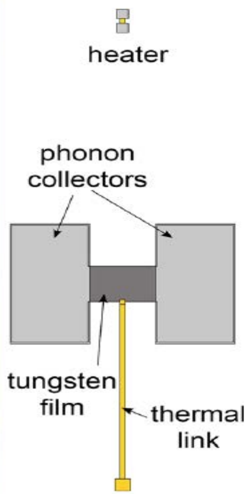
The properties of thulium garnet $Tm_3Al_5O_{12}$ were studied with the aim of using it to search for resonance excitation of the first nuclear level of ^{169}Tm (8.4 keV) isotope by solar axions: $A + {}^{169}Tm \rightarrow {}^{169}Tm^* \rightarrow {}^{169}Tm + \gamma$ (8.41 keV). X-rays and γ-quanta, conversion and Auger electrons that occur during the discharge of a level with an energy of 8.4 keV will be detected by the same crystal. It was established that $Tm_3Al_5O_{12}$ at a temperature of 10 mK can operate as a bolometric detector, the radiation purity of the crystal, its optical properties were studied, and the first spectrum of phonon signals was obtained with an NTD (neutron transmutation doped) sensor..

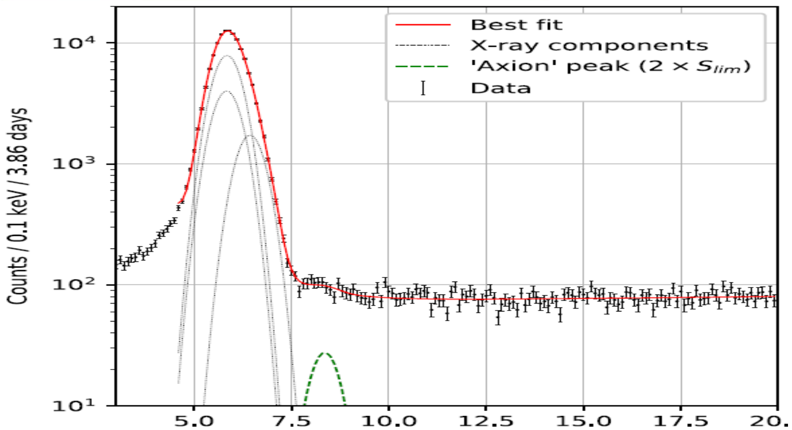


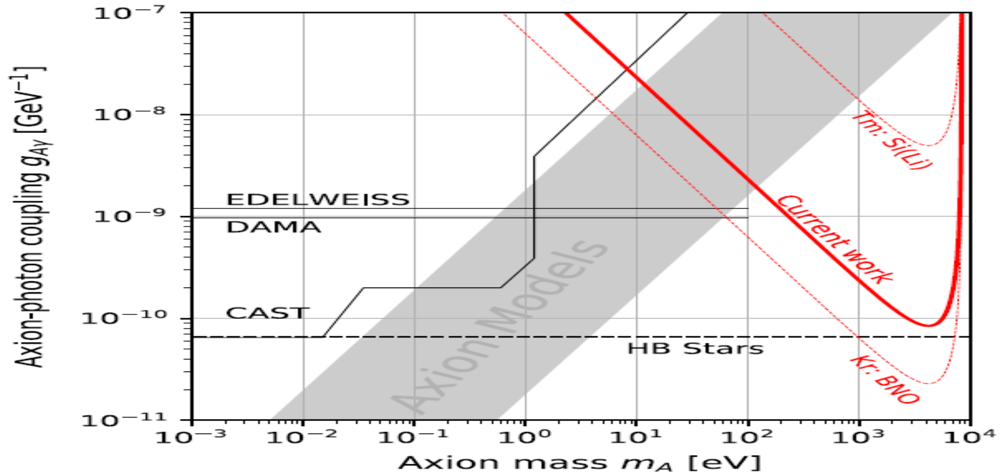
Left: $Tm_3Al_5O_{12}$ crystal inside a copper holder which was cooled to a temperature of 10 mK. Gold wires provide electrical contacts. Right: Spectrum of a Tm-bolometer, measured with NTD thermistor, and the results of 241Am α-peak fitting.

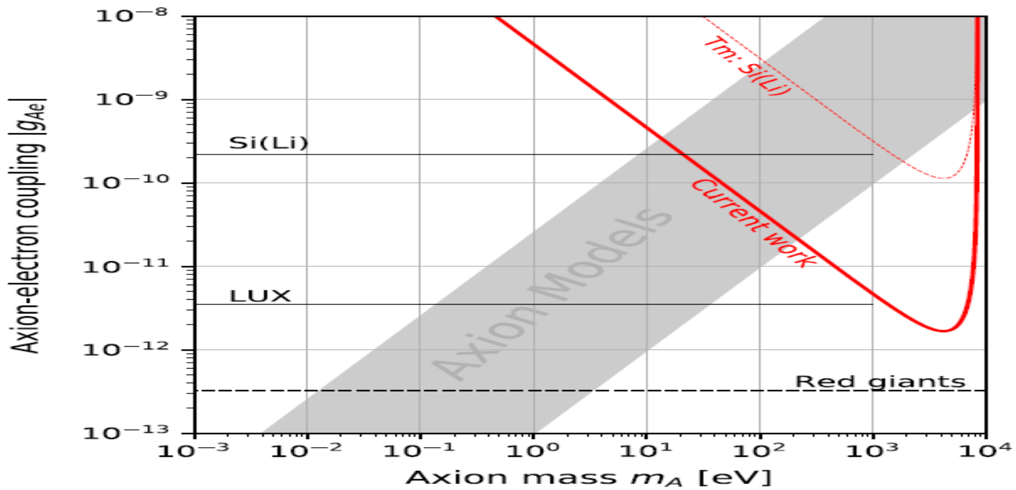
$Tm_3Al_5O_{12}$ cryogenic bolometer at 10 mK





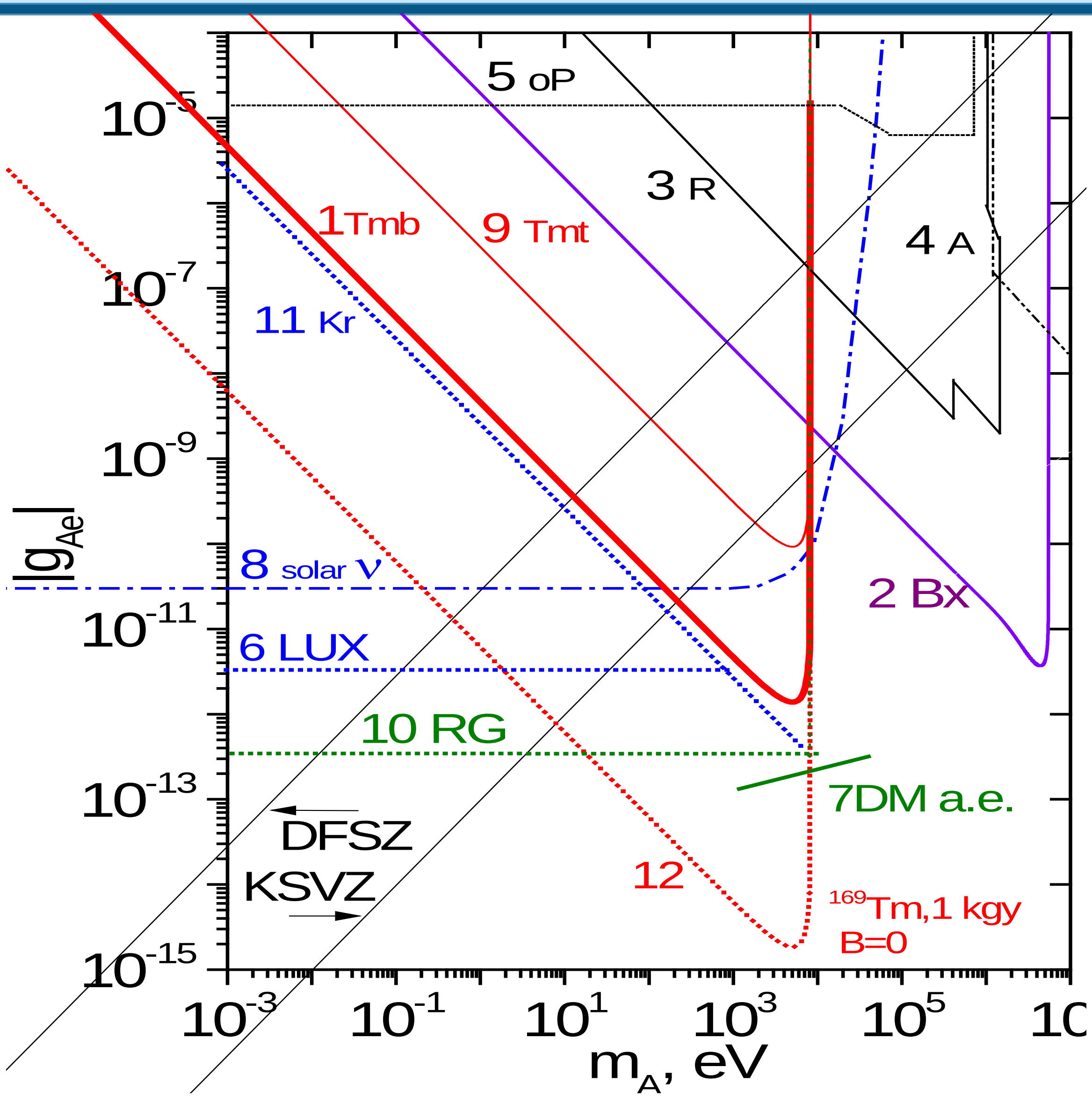






A search for resonant absorption of solar axions by ^{169}Tm nuclei was carried out. A newly developed approach involving low-background cryogenic bolometer based on $Tm_3Al_5O_{12}$ crystal was used that allowed for significant improvement of sensitivity in comparison with previous ^{169}Tm based experiments. The measurements performed with 8.18 g crystal during 3.9 days exposure yielded the following limits on axion couplings: $|g_{A\gamma}m_A| \leq 2.31\times10^{-7}$ and : $|g_{Ae}m_A| \leq 4.59\times10^{-9}$ eV.

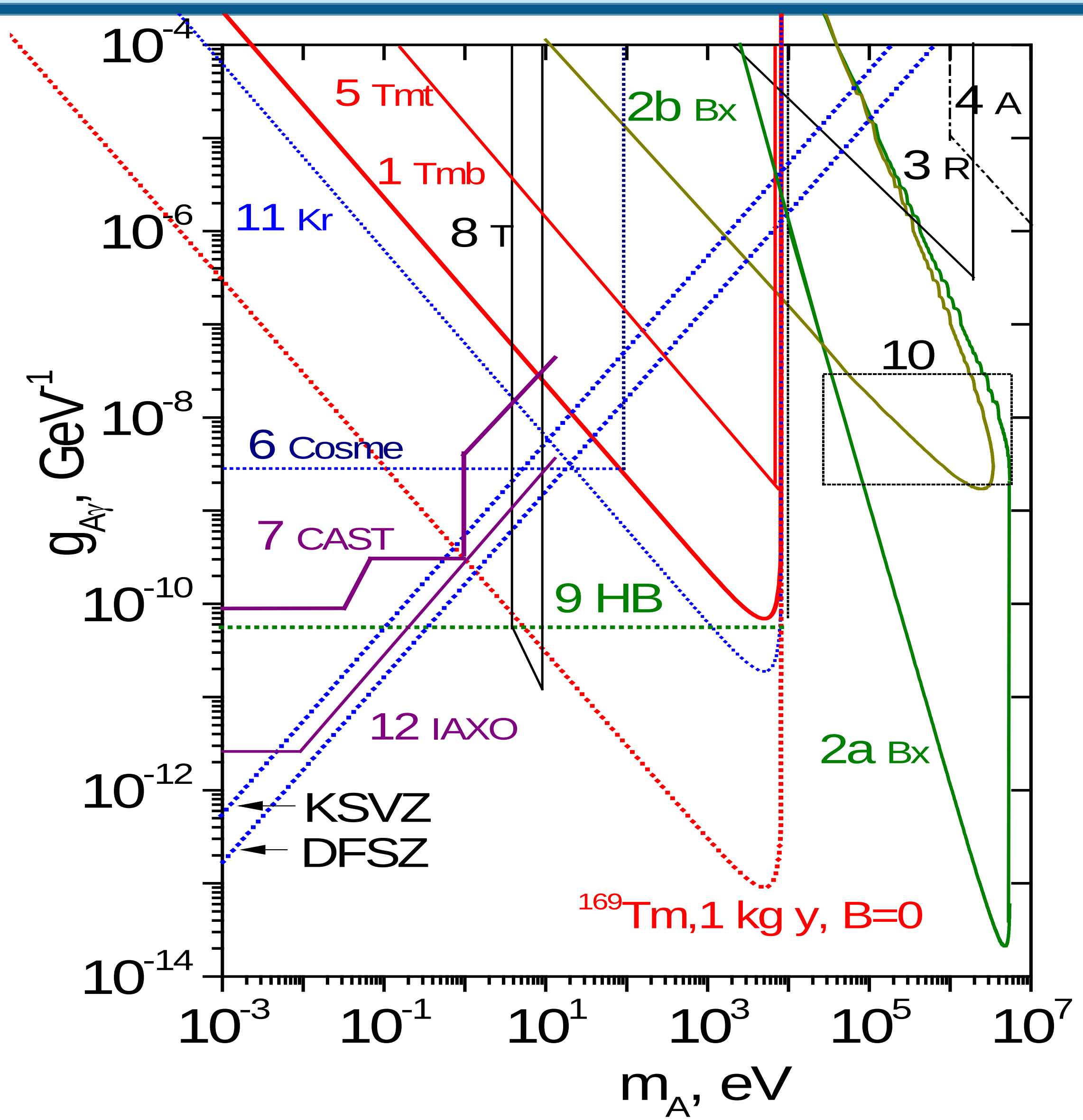
Limits on axion-electron coupling g_{Ae} and m_A



The existing upper limits on g_{Ae} (90% c.l.).

1. – $Tm_3Al_5O_{12}$ *bolometer;*
2. - *Borexino;*
3. - *reactor;*
4. - *accelerator;*
5. - *orthopositronium;*
6. - *LUX (solar);*
7. - *PANDA II (DM);*
8. - *0.1 from neutrinos;*
9. - ^{169}Tm *+ Si (Li) "target-detector";*
10. - *red giants;*
11. - *83Kr, Baksan (preliminary);*
12. - *Tm bolometer with an exposure of 1 kg per year in backgroundfree experiment.*
13. - g_{Ae} *values in DFSZ and KSVZ axion models.*

Limits on axion-photo coupling $g_{A\gamma}$ and m_A



The existing upper limits on $g_{A\gamma}$ (90% c.l.).
1 – $Tm_3Al_5O_{12}$ bolometer;
2 a,b - Borexino;
3 - reactor;
4 - accelerator;
5 - ^{169}Tm + Si (Li) “target-detector”;
6 – Cosme, Solax, Dama;
7 - CAST;
8 - telescopes;
9 - HB stars;
10 - red giants;
11 – SUSY and mirror models;
12 - IAXO (project)
13 – Tm-bolometer with an exposure of 1 kg per year in background free experiment.
14- $g_{A\gamma}$ values in DFSZ and KSVZ axion models.

Thank you for your attention!

Number of words neutrino and axion in a title of papers in arXiv.org during last 5 years:

	2016	2017	2018	2019	2020	2021
Neutrino	830	782	760	953	820	528
Axion	148	200	232	264	333	218
A / N	0.18	0.26	0.31	0.28	0.41	0.41