9th Patras Workshop on Axions, WIMPs and WISPs

Schloß Waldthausen

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Search for solar axions produced by Compton process and bremsstrahlung

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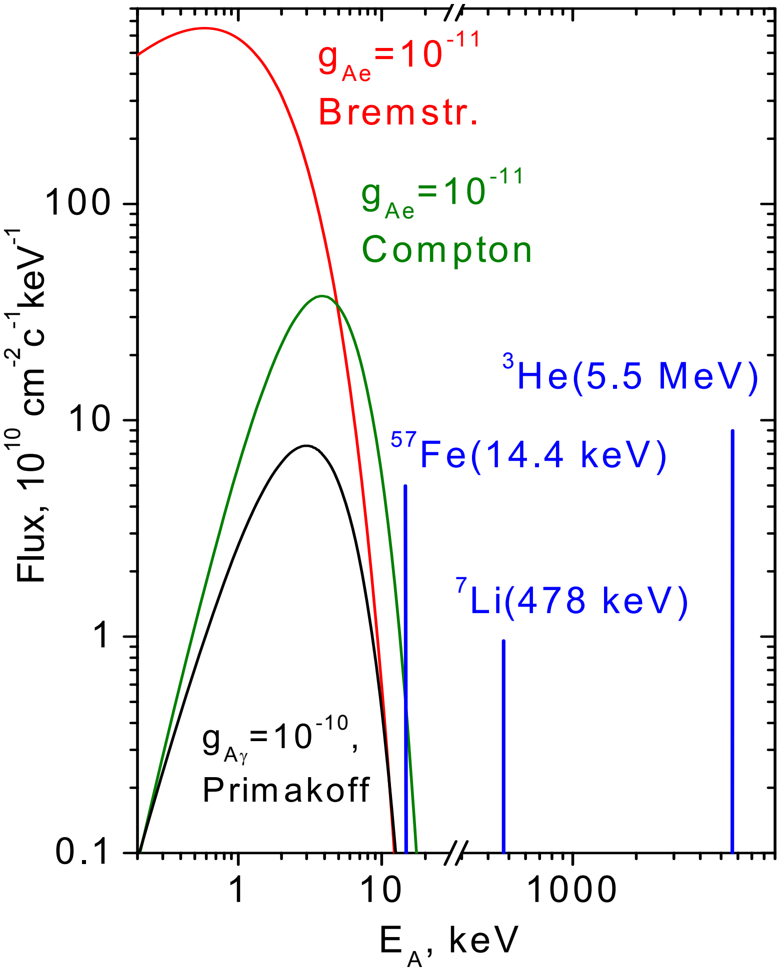
Solar axions spectra vs $g_{A\gamma}$, g_{Ae} and g_{AN}

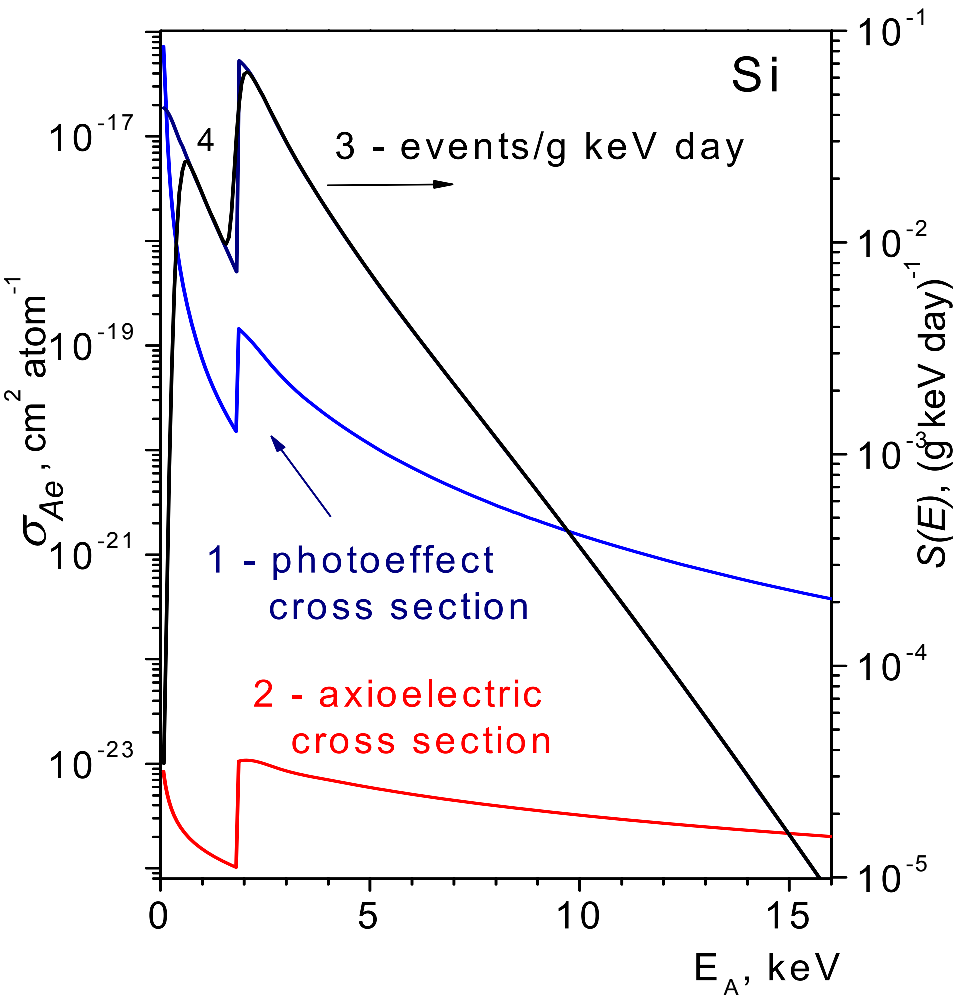


The main sources of solar axions:

1. Reactions of main solar chain. The most intensive fluxes are expected from M1-transitions in ^{7}Li and ^{3}He nuclei (**g_{AN}**):
$^7Be + e^- \rightarrow {}^7Li^* + \gamma$; $^7Li^* \rightarrow {}^7Li + A$ (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,14.4 кэВ)** (**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.** CAST coll. arXiv:1302.6283

Searches for solar axions were performed using reactions of axioelectric effect in atoms and resonant absorption by nuclei.

Cross section for axioelectric effect



Axioelectric effect is analogue of photoeffect. The cross sections for relativistic and non-relativistic axions were obtained in:

M. Pospelov, A. Ritz, and M. B. Voloshin, Phys. Rev. D **78**, 115012 (2008).
A. Derevianko, V. A. Dzuba, V. V. Flambaum, and M. Pospelov, Phys. Rev. D **82**, 065006 (2010).

$$\sigma_{Ae}\Big|_{\beta\to 0} \simeq \sigma_{pe}(m_A)\frac{3m_A^2}{4\pi\alpha f_A^2\beta}$$

$$\sigma_{Ae}\Big|_{\beta\to 1} \simeq \sigma_{pe}(E)\frac{E^2}{2\pi\alpha f_A^2} ,$$

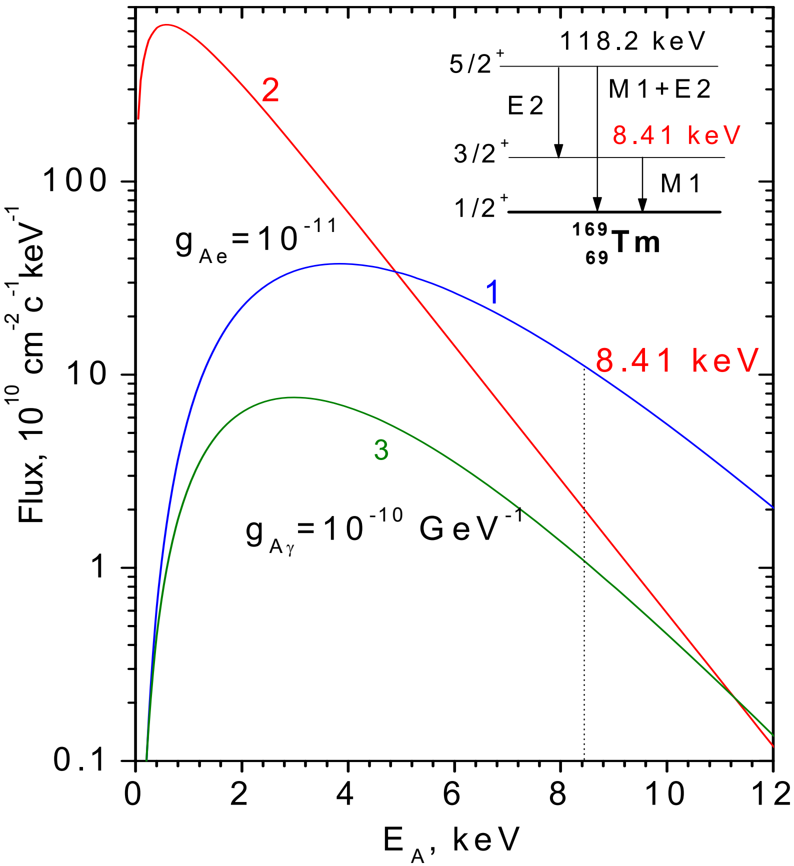
We proposed the approximation for all β values and $g_{Ae}=2m_e/f_A$:

$$\sigma_{abs} = \frac{g_{Ae}^2}{\beta}\frac{3}{16}\frac{E_A^2}{\pi\alpha m_e^2}\sigma_{ph}(E_A)(1-\frac{\beta}{3})$$

JETP Lett., 95, 379 (2012) arXiv:1206.4142

Cross sections for the (1) photoelectric effect for Si atom and (2) axioelectric effect for gAe = 1 and mA = 0, (3) the expected spectrum of events detected per day in 1 g of Si in 1 keV interval, and (4) the spectrum taking into account the resolution of the detector (right scale).

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 Γ = 1.13×10^{-10} keV.

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

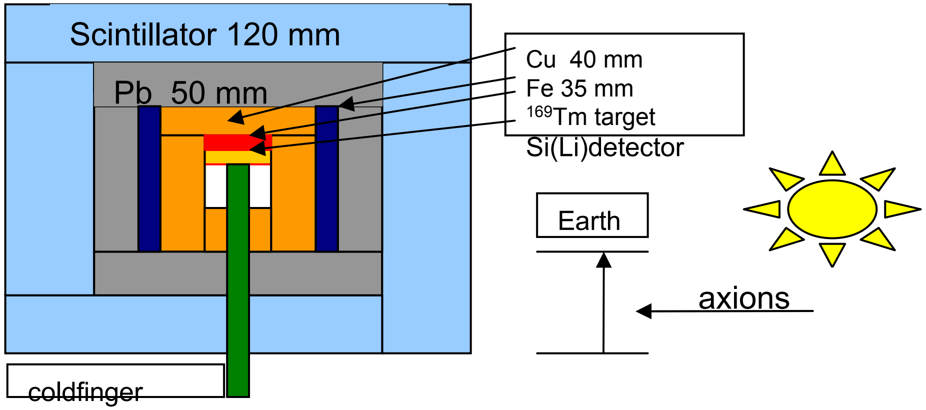
The ratio of the nuclear transition probability with the emission of an axion ω_A to the probability of magnetic type transition ω_γ.

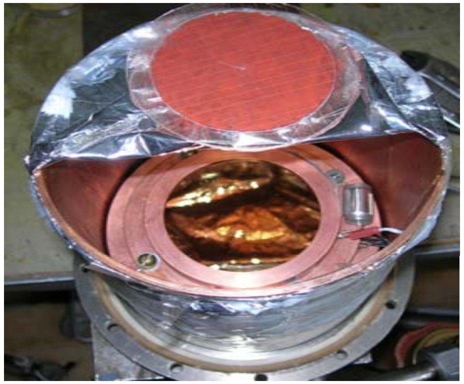
$$\frac{\omega_A}{\omega_\gamma} = 1.03(g_{AN}^0 + g_{AN}^3)^2(p_A/p_\gamma)^3$$

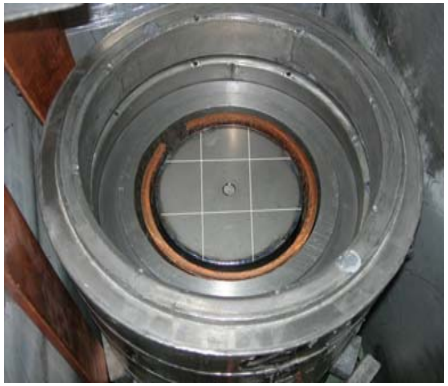
The detection probability of the axions is determined by the product $g^2_{A\gamma} \cdot g^2_{AN}$ which is preferable for small $g_{A\gamma}$ values.

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

3 Si(Li)-detectors inside low background setups





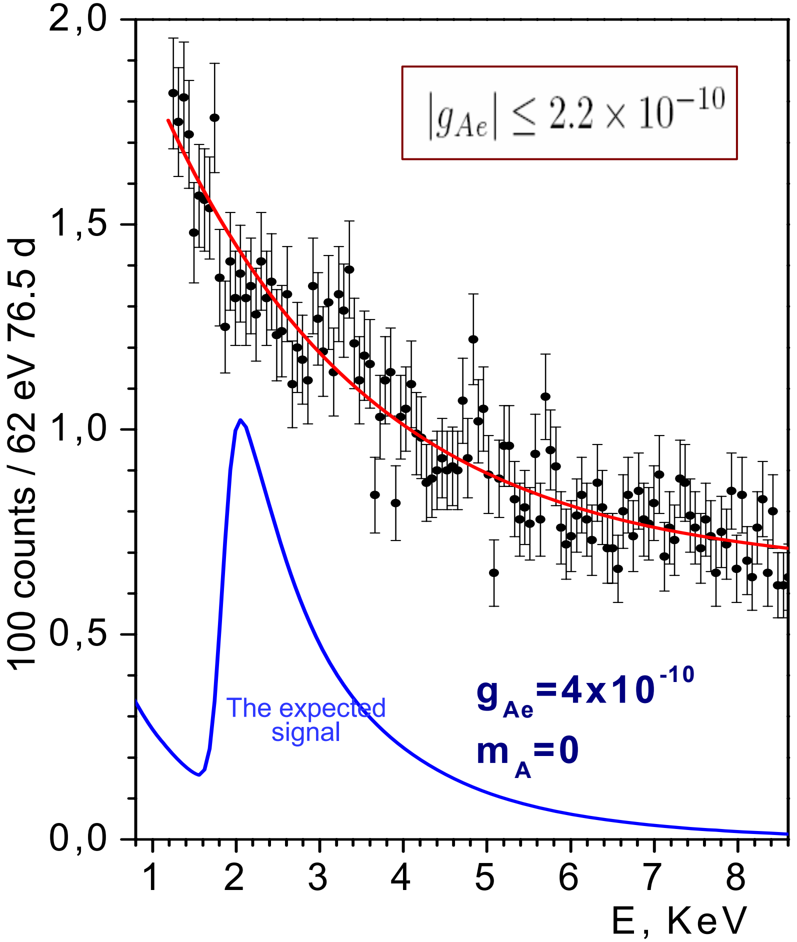


I. S=0.35 cm^2
FWHM=150 eV
background=30 cm^{-2}day^{-1}keV^{-1} at 14.4 keV

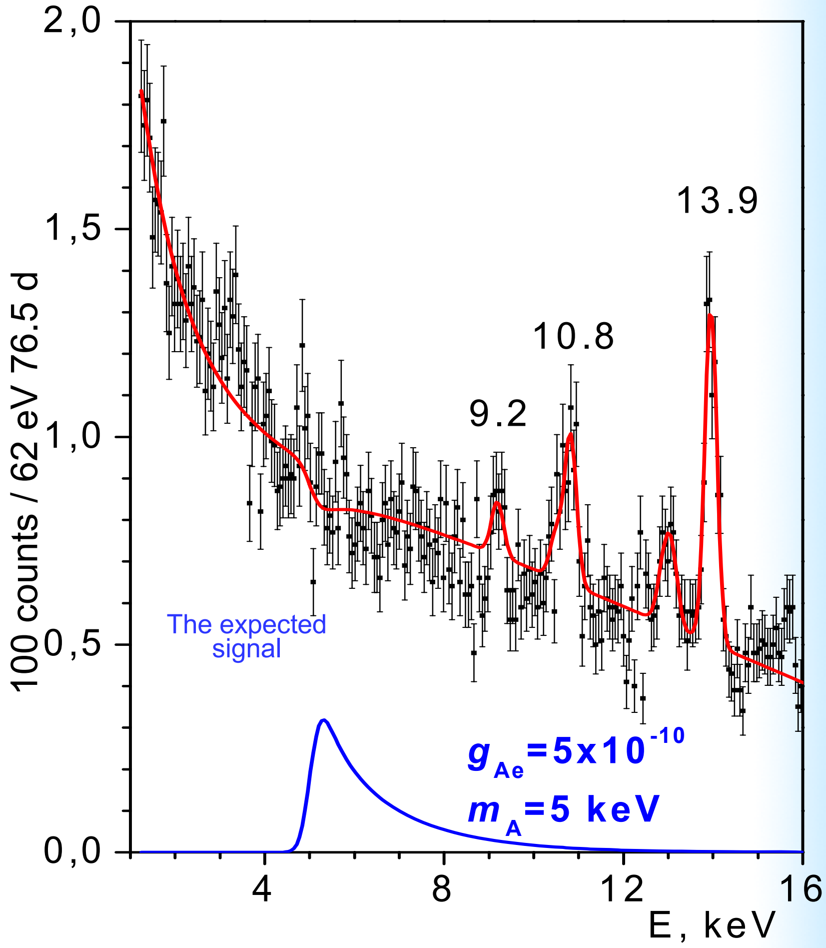
II. 2.0 cm^2
300 eV
5
cm^{-2}day^{-1}keV^{-1}

III. 34 cm^2
1.5 keV
2.6
cm^{-2}day^{-1}keV^{-1}

Results of search for axioelectric effect

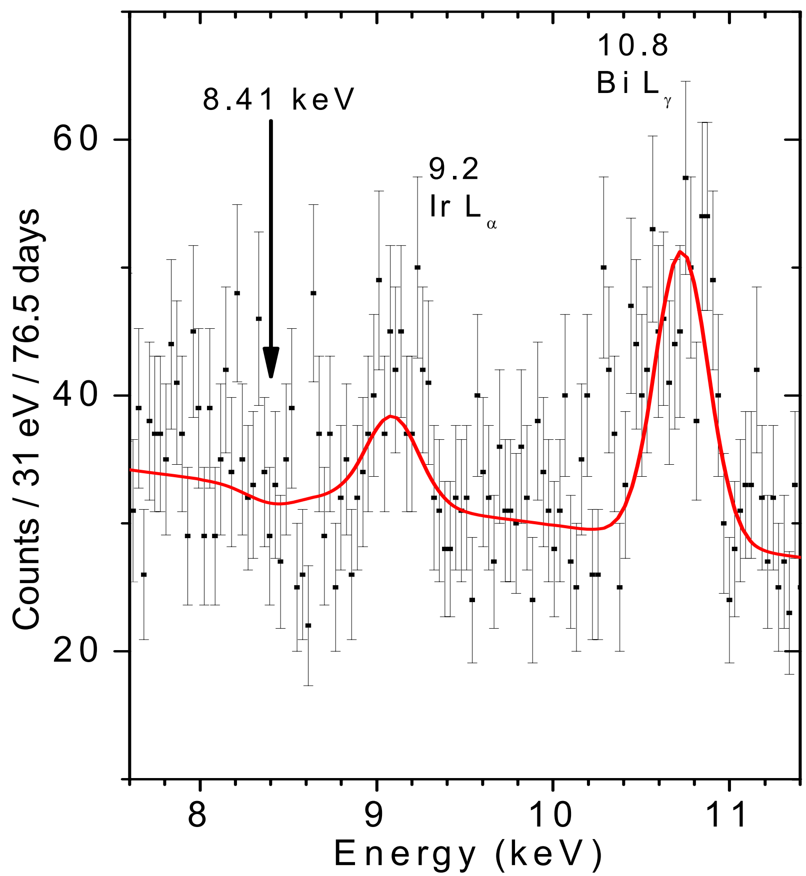


The spectrum measured by Si(Li) detector. Optimal fit and the expected spectrum in the case of axions with $m_A \approx 0$ and $g_{Ae} = 4 \times 10^{-10}$. The upper limit on g_{Ae}: $g_{Ae} < 2.2 \text{x} 10^{-10}$ (90% c.l.)



The spectrum in (1-16) keV range. Optimal fit for m_A = 5 keV. The expected spectrum is shown for m_A = 5 keV and $g_{Ae} = 5 \times 10^{-10}$.

Results of search for resonant absorption

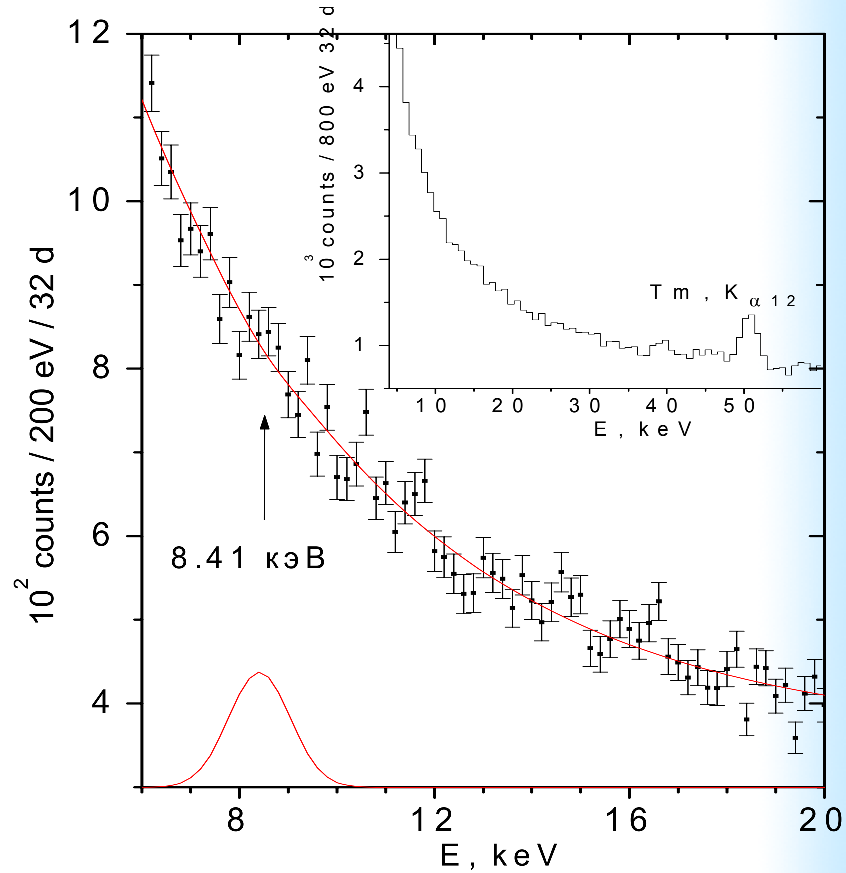


Spectrum measured with 2 cm² Si(Li)-detector in the region 7.6-11.4 keV.The limits on axion-photon (GeV⁻¹) and axion-nucleon couplings:

$g_{A\gamma} \cdot |(g_{AN}^0 + g_{AN}^3)| \leqslant 9.2 \times 10^{-13}$

$g_{A\gamma} m_A \leqslant 1.36 \times 10^{-14}$

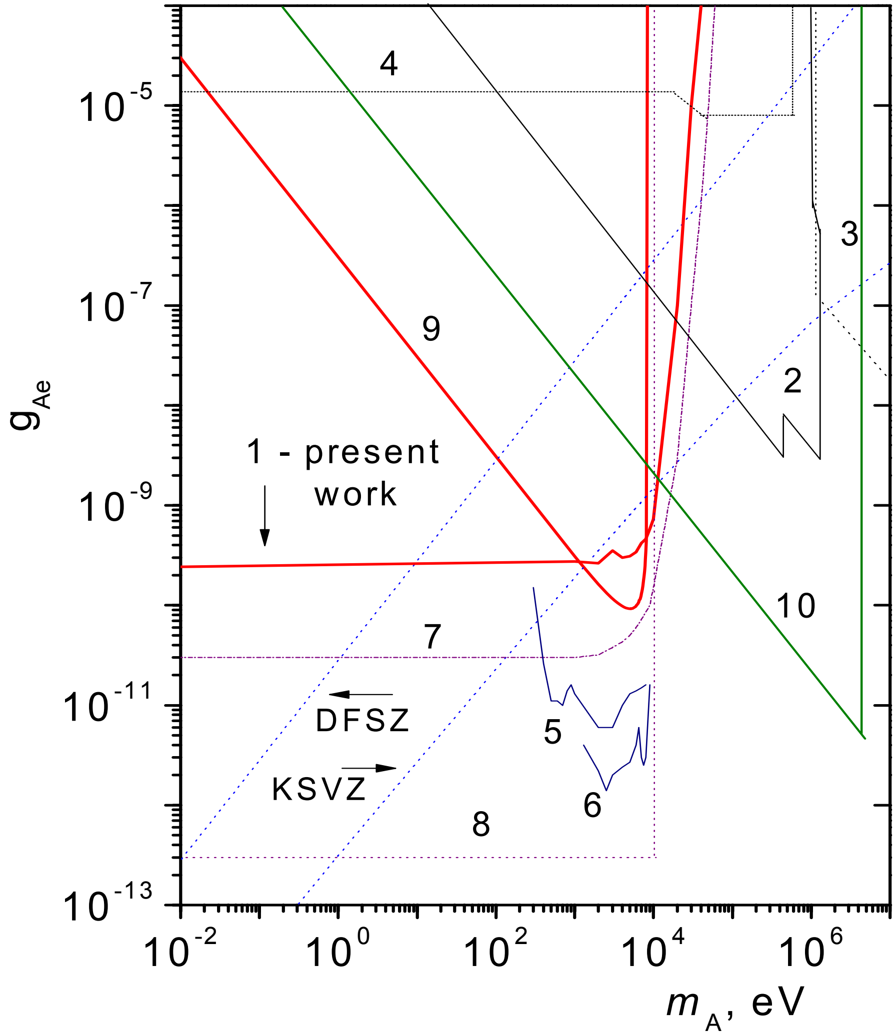
$m_A \leqslant 191$ eV



Spectrum of 34 cm² Si(Li)-detector measured with 169Tm target. The limits on axion-electron and axion-nucleon couplings:

$g_{Ae} \times |(g_{AN}^0 + g_{AN}^3)| \leq 2.1 \times 10^{-14}$

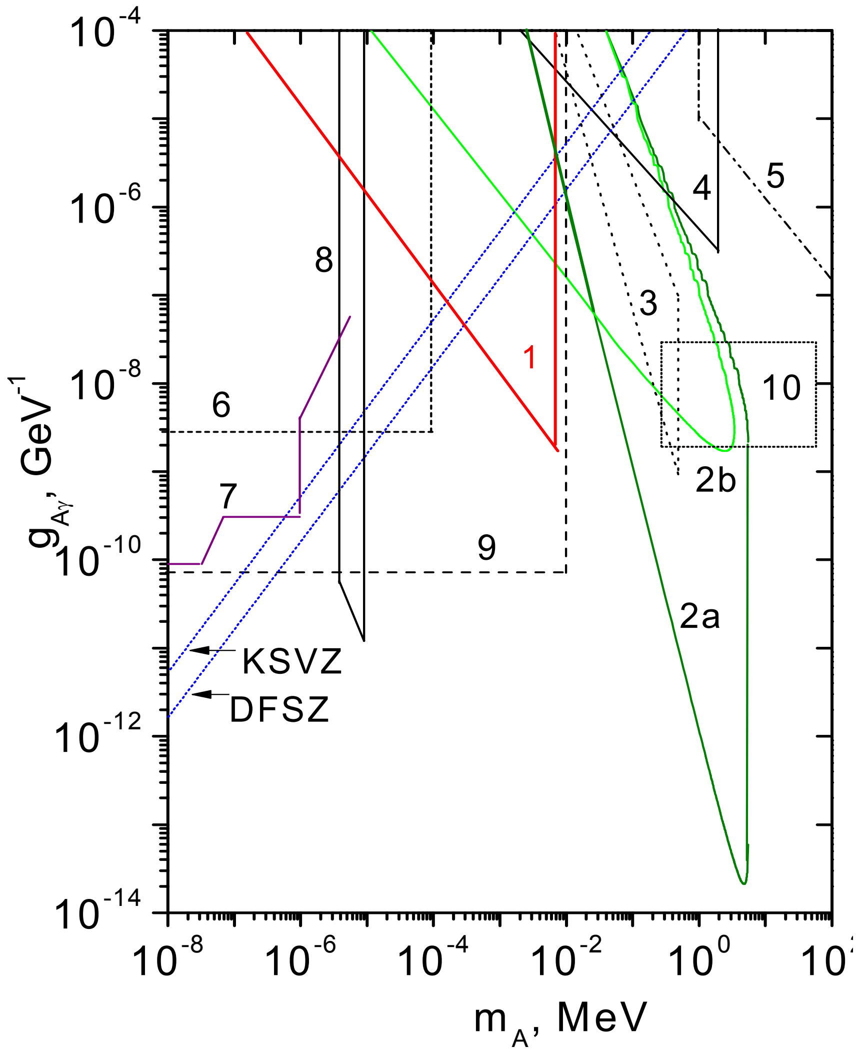
Limits on axion-electron coupling



1- *Axioelectric absorption*
2- *reactor experiments and 478 keV solar axions*
3- *beam dump experiments*
4- *decay of orthopositronium*
5- *CoGeNT*
6- *CDMS*
7- *axion luminosity of the Sun*
8- *red giants*
9- *^{169}Tm resonant absorption*
10- *Borexino 5.5 MeV axions*

The regions of excluded values lie above the corresponding lines. Two lines show the g_{Ae} values in the DFSZ and KSVZ (E/N = 8/3) models.

Limits on axion-photon coupling



1 – 169Tm resonant absorption
2 – Borexino, 5.5 MeV axions
3 – CTF, 478 keV axions
4 – Reactor experiments
5 – beam-dump experiments
6 – Cosme, Solax, DAMA
7 – CAST
8 – Tokyo telescope
9 – HB-stars
10 – predictions of SUSY and mirror heavy axion models

The regions of excluded values lie above and inside the corresponding lines.
Two lines show the $g_{A\gamma}$ values in the DFSZ and KSVZ models.