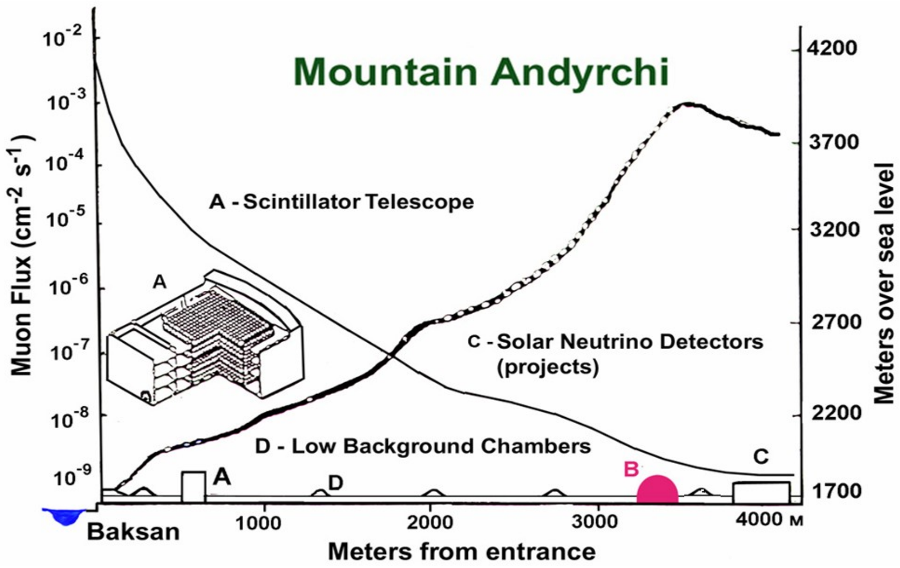
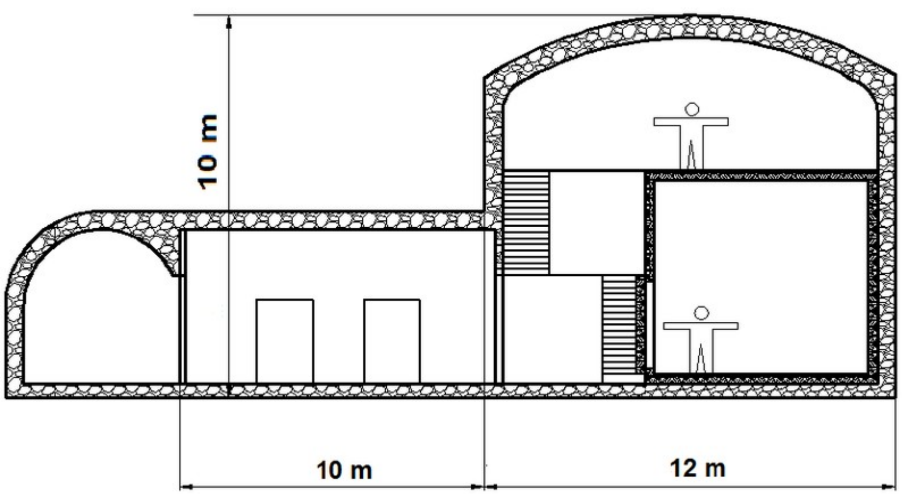
Новые перспективы при создании Криогенной низкофоновой лаборатории в БНО ИЯИ РАН

А.М. Гангапшев





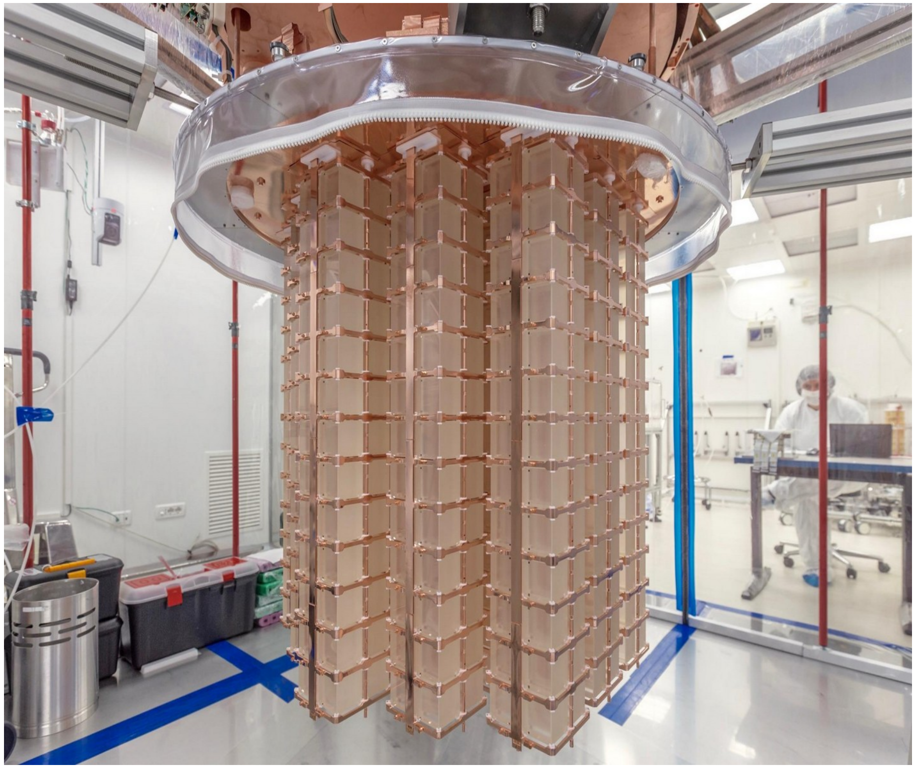
На данный момент наблюдается отставание России в области проведения экспериментов с использованием болометров при сверхнизких температурах ~10мК таких как:

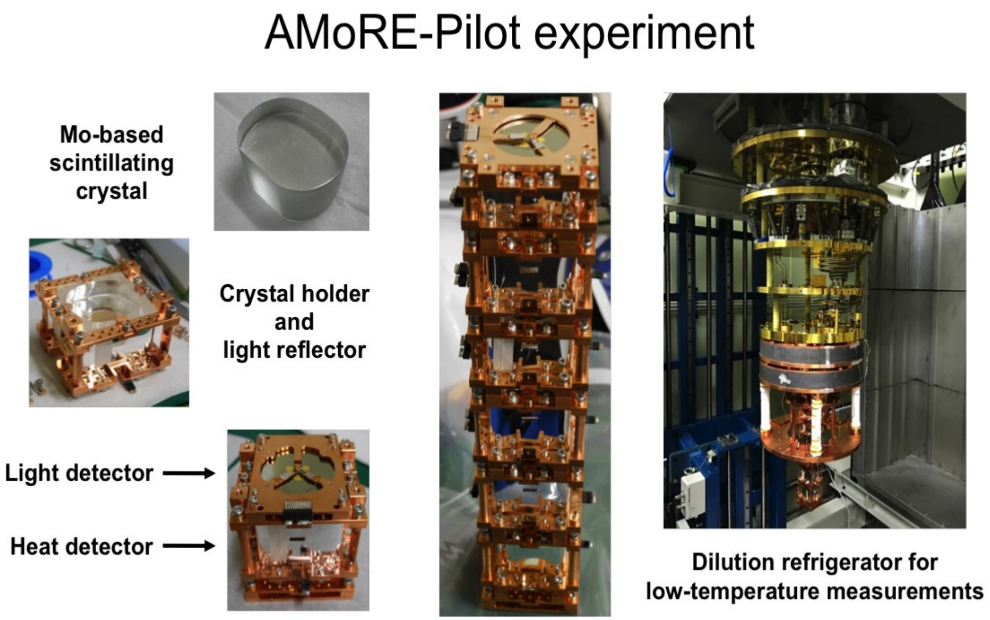
CRESST (https://www.cresst.de/exp_overview.php),
CUORE (https://cuore.lngs.infn.it/),
AMORE (https://amore.ibs.re.kr/about/amore-experiment/),
EDELWEISS (http://edelweiss.in2p3.fr/),
CUPID-MO (https://cupid-mo.mit.edu/)
и др.

Во всех этих экспериментах участвуют ученые из России, в том числе из ИЯИ РАН.

CUORE

AMORE





https://amore.ibs.re.kr/about/status/

https://cuore.lngs.infn.it/en/images

988 TeO_2 bolometers for a total mass of 741 kg (206 kg of ^{130}Te).

200 kg of $XMoO_4$ crystals at about 10 mK temperature

«Низкофоновая криогенная лаборатория» в БНО ИЯИ РАН

В России существует база для производства кристаллов с низким содержанием радиоактивных изотопов. Например Фомос Материалс (https://newpiezo.com/) поставляет кристаллы $CaMoO_4$ для международного эксперимента AMORE в Юж. Корее, ИНХ СО РАН выращивает кристаллы Li_2MoO_4 для эксперимента CUPID-Mo. Неполный перечень экспериментов которые можно осуществить при наличии низкофоновой криогенной лаборатории состоит из следующих пунктов:

1. поиск частиц темной материи;
2. поиск солнечных аксионов;
3. поиск безнейтринного двойного бета распада;
4. работы в области ЯМР;
5. разработка детекторов аксионов в с частотой ~ 1 ГГц на основе топологических изоляторов.

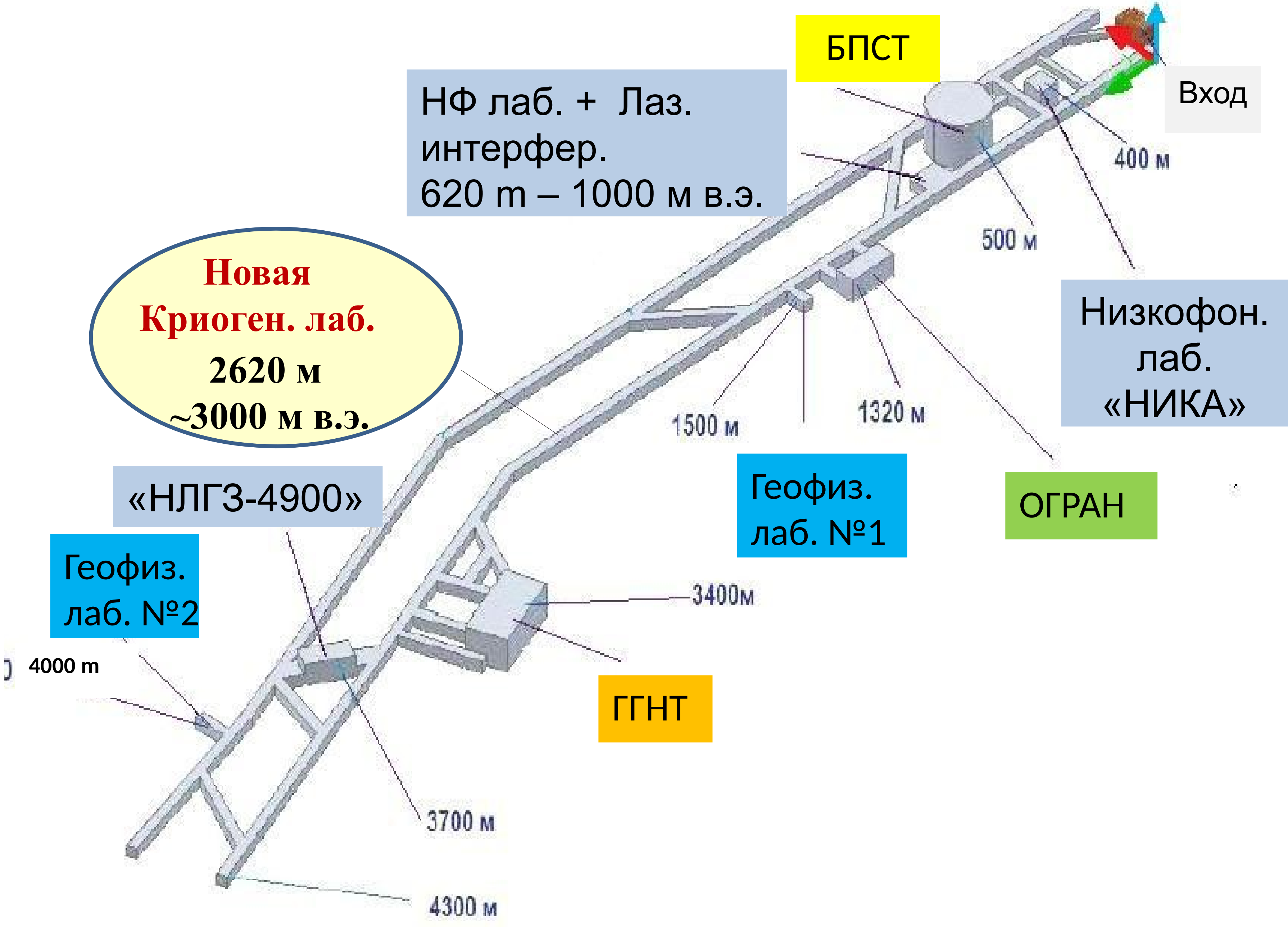
Возможный состав оборудования лаборатории (цены указаны на 2020г.):

1. Криостат растворения (например XLD400 от компании Bluefors Oy, Финляндия, https://bluefors.com/products/xld-series-dilution-refrigerator/) – ~60 млн. руб.

2. Пассивная низкофоновая защита состоящая из трех слоев: 15 см борированного полиэтилена, 15 см свинца и 15 см меди (~ 10 млн. руб.).

3. Компактный гелиевый ожижитель с системой сбора и очистки газа (например CryoMech LheP, Подробнее на сайте «ООО Криотрейд инжиниринг»: http://www.cryotrade.ru/heplants.html) – ~35 млн. руб.

Расположение подземных объектов БНО ИЯИ РАН



На данный момент, например, есть задача по постановке эксперимента по поиску солнечных аксионов с помощью кристаллов $Tm_3Al_5O_{12}$ (методика описана в работе https://arxiv.org/pdf/2004.08121.pdf).

Этот эксперимент может быть выполнен в БНО ИЯИ РАН.

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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

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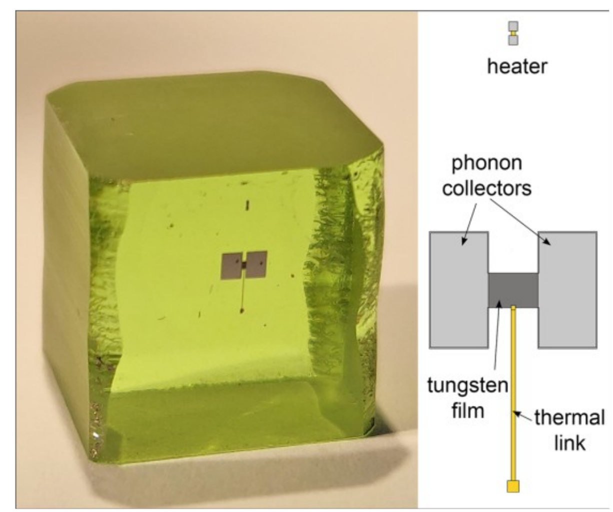

Fig. 2 **Left** $Tm_3Al_5O_{12}$ crystal after the TES deposition. It is possible to see two large aluminum phonon collectors (light gray) evaporated on top of a darker strip of tungsten. Closer to the upper edge of the crystal surface there is the heater made of a thin strip of gold with two aluminum pads deposited on top. **Right** A sketch of a similar TES design [37]

8.18 g $Tm_3Al_5O_{12}$ crystal

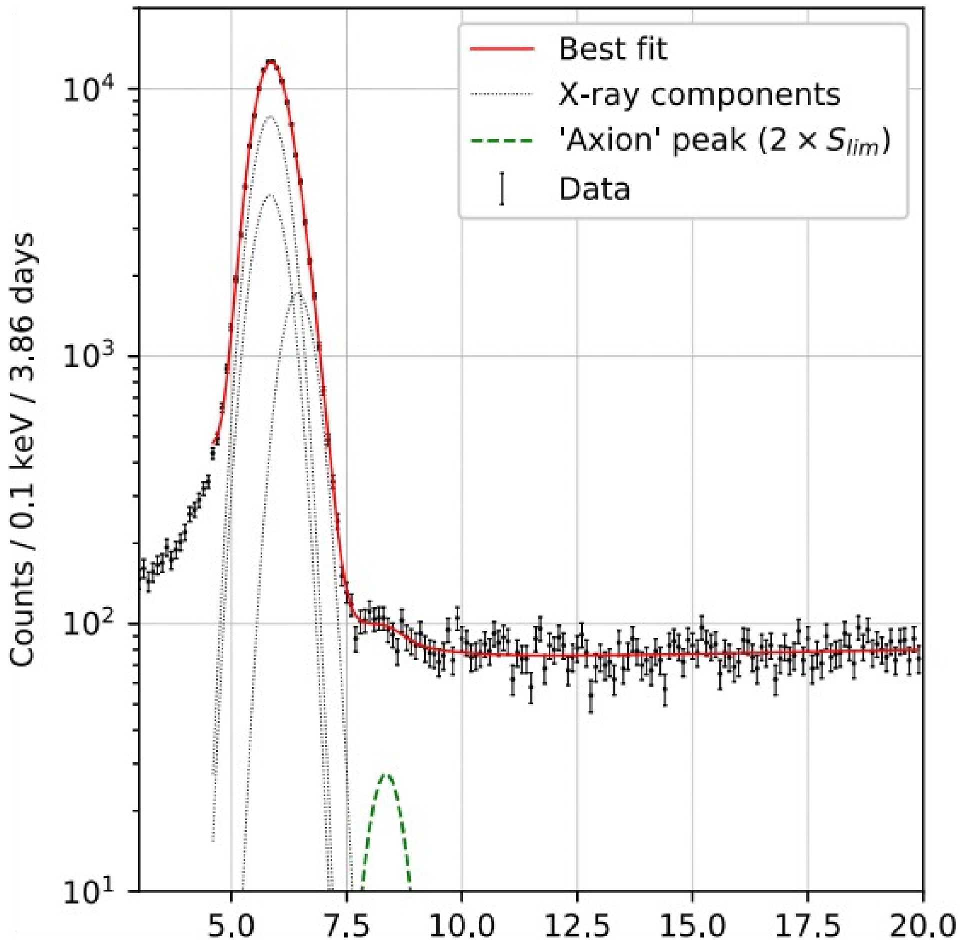

Fig. 3 Spectrum of events obtained during the live time of 3.9 days by $Tm_3Al_5O_{12}$ bolometer in 3 − 20 keV energy interval with 0.1 keV binning. The result of fitting by model (14) is presented by solid line. The presumed "axion" peak with area $S = 2 \times S_{lim}$ is shown by the dashed line (the area is increased to improve visibility)

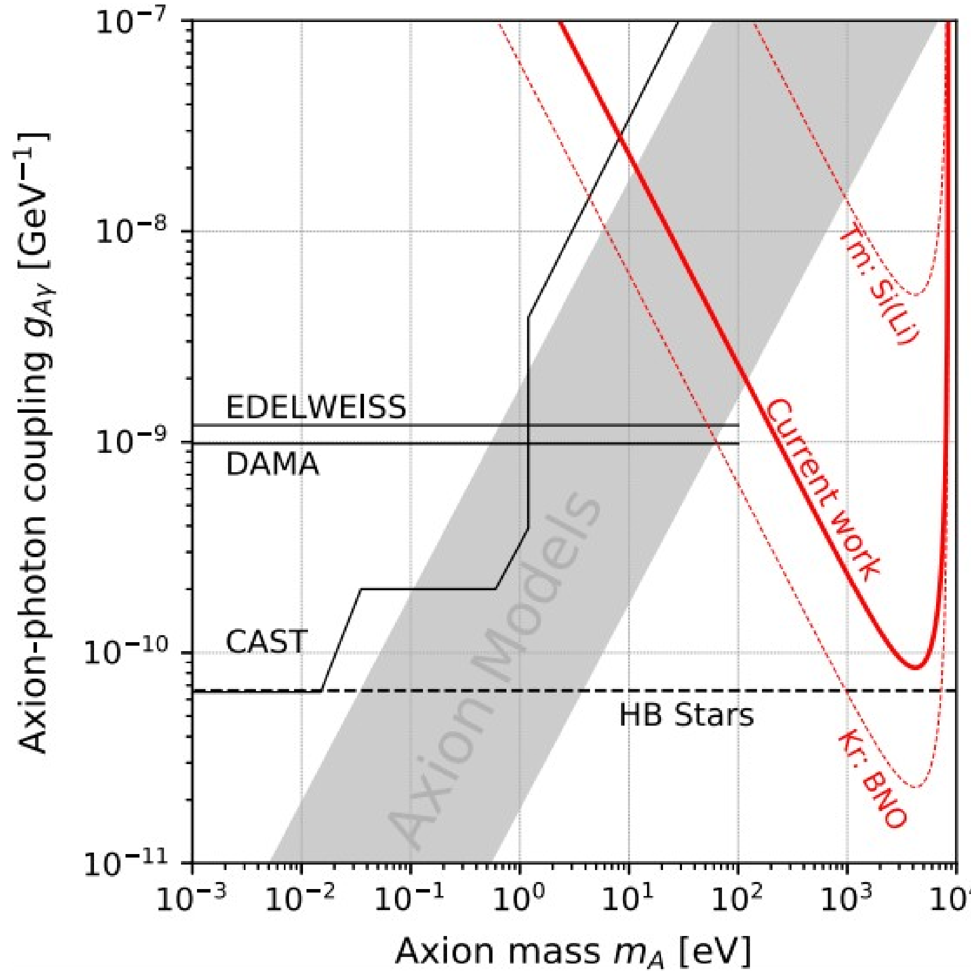

Fig. 4 Axion–photon coupling $g_{A\gamma}$ limits obtained in current work in comparison with other experiments (DAMA [39], EDELWEISS [40], CAST [41], ^{169}Tm-Si(Li) [15], ^{83}Kr-gas counter [18]) and astrophysical bounds (horizontal branch stars lifetime [42])

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A Lab-Scale Experiment for keV Sterile Neutrino Search

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Abstract

We developed a simple small-scale experiment to measure the beta decay spectrum of ^{3}H. The aim of this research is to investigate the presence of sterile neutrinos in the keV region. Tritium nuclei were embedded in a 1×1×1 cm^3 LiF crystal from the ^{6}Li(n,α)^{3}H reaction. The energy of the beta electrons absorbed in the LiF crystal was measured with a magnetic microcalorimeter at 40 mK. We report a new method of sample preparation, experiments, and analysis of ^{3}H beta measurements. The spectrum of a 10-hour measurement agrees well with the expected spectrum of ^{3}H beta decay. The analysis results indicate that this method can be used to search for keV-scale sterile neutrinos.

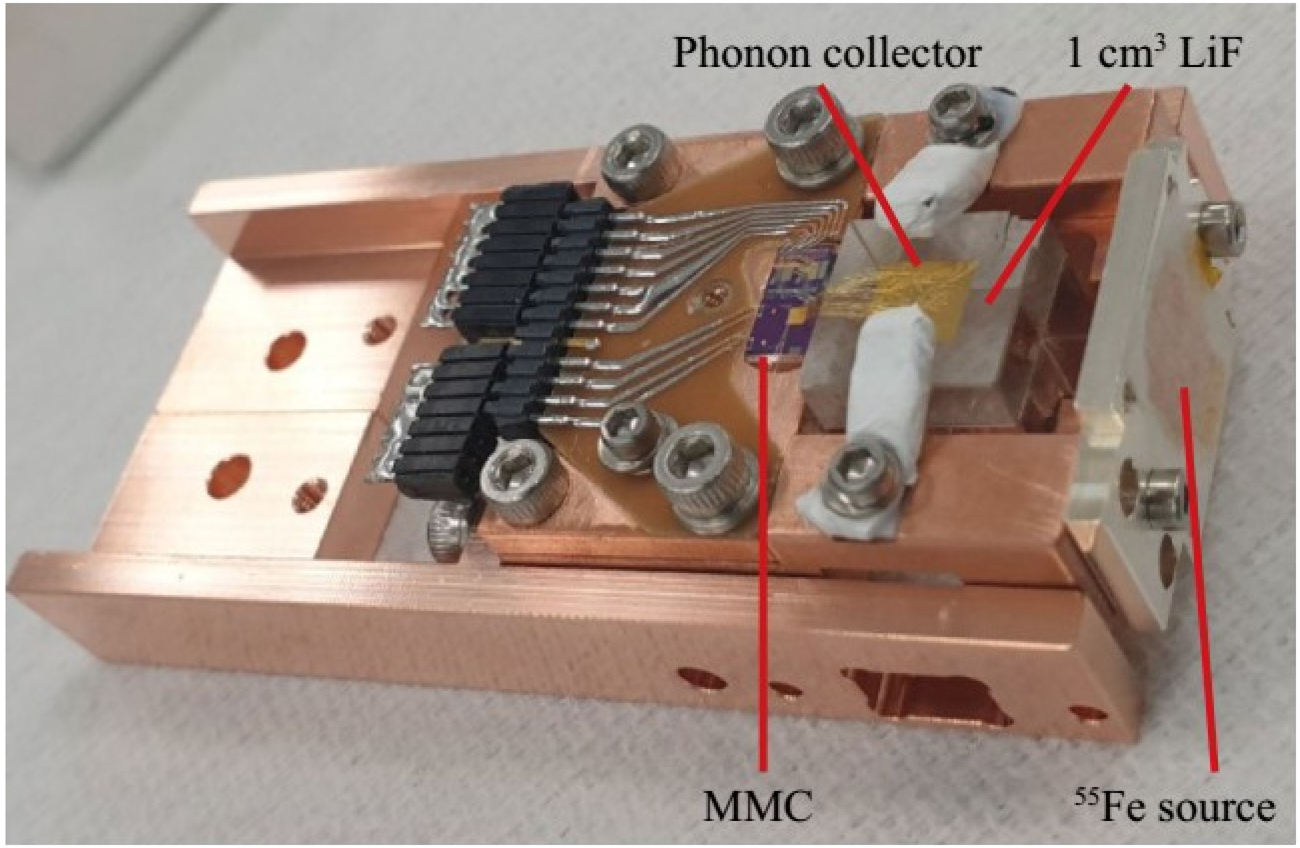

Fig. 1 Experimental setup with a 1×1×1 cm^3 LiF crystal. ^3H ions are produced in the crystal from the $^6Li(n,\alpha)^3H$ reaction in the bulk. An MMC placed to the next to the crystal is thermally connected to the crystal via gold bonding wires and a phonon collection film. (Color figure online)

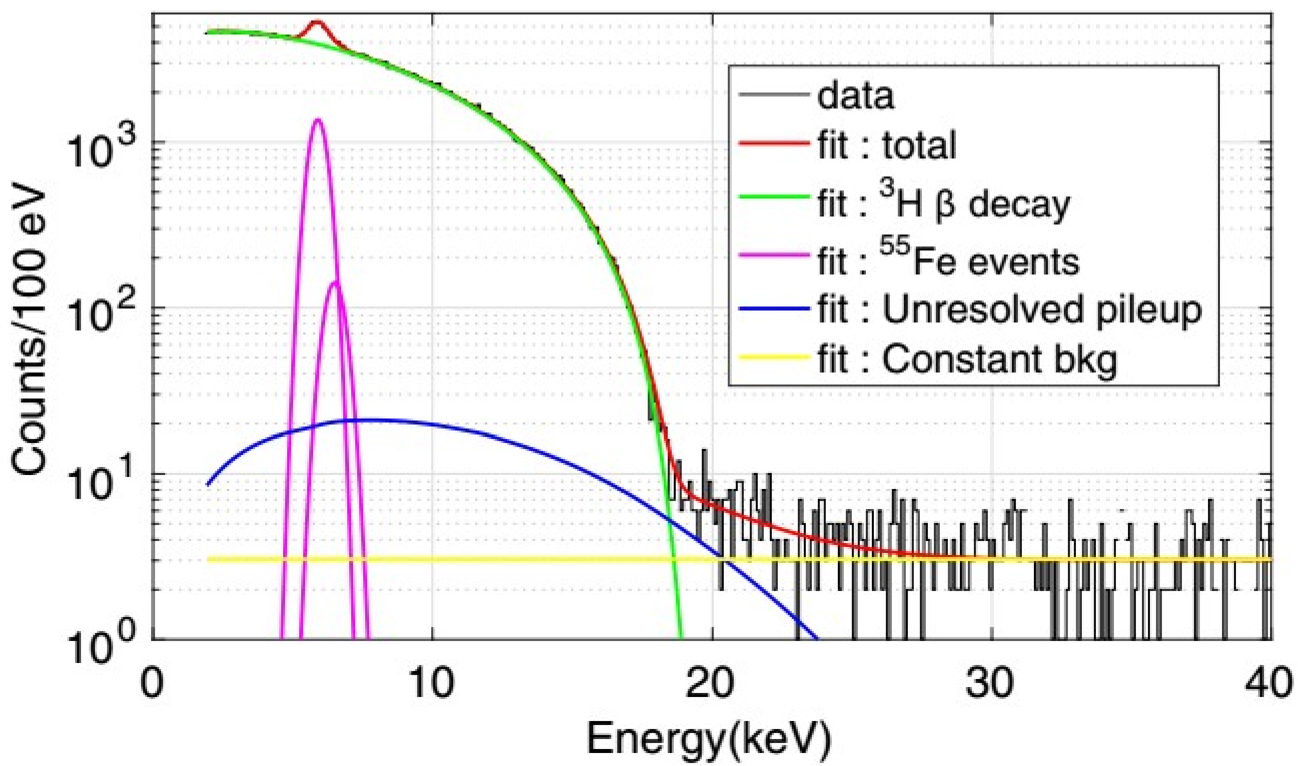

Fig. 4 The measured and fit spectra. The fit total is the sum of the listed events. (Color figure online)

Direct Detection of Axion-Like Particles in Bismuth-Based Topological Insulators

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In recent years a new field emerged in dark matter community and immediately attracted a multitude of theoriests and experimentalists, that of light dark matter direct detection in electronic systems. The phenomenon is similar with nuclear recoil in elastic scattering between dark matter and nucleus but with different kinematics. Due to the small energy gap, the electronic system can probe sub-GeV dark matter rather than nucleus target. In particular the absorption into materials can even detect ultra-light dark matter within mass around meV. In terms of the equivalence between optical conductivity and absorption cross section, axion detection can be computed in Bismuth-based topological insulators. It is found that topological insulator has strong sensitivity on axion and provides a complementary direct detection to superconductor and semiconductors. The novelty of topological insulator is that the thin film could even obtain the same sensitivity as superconductor.

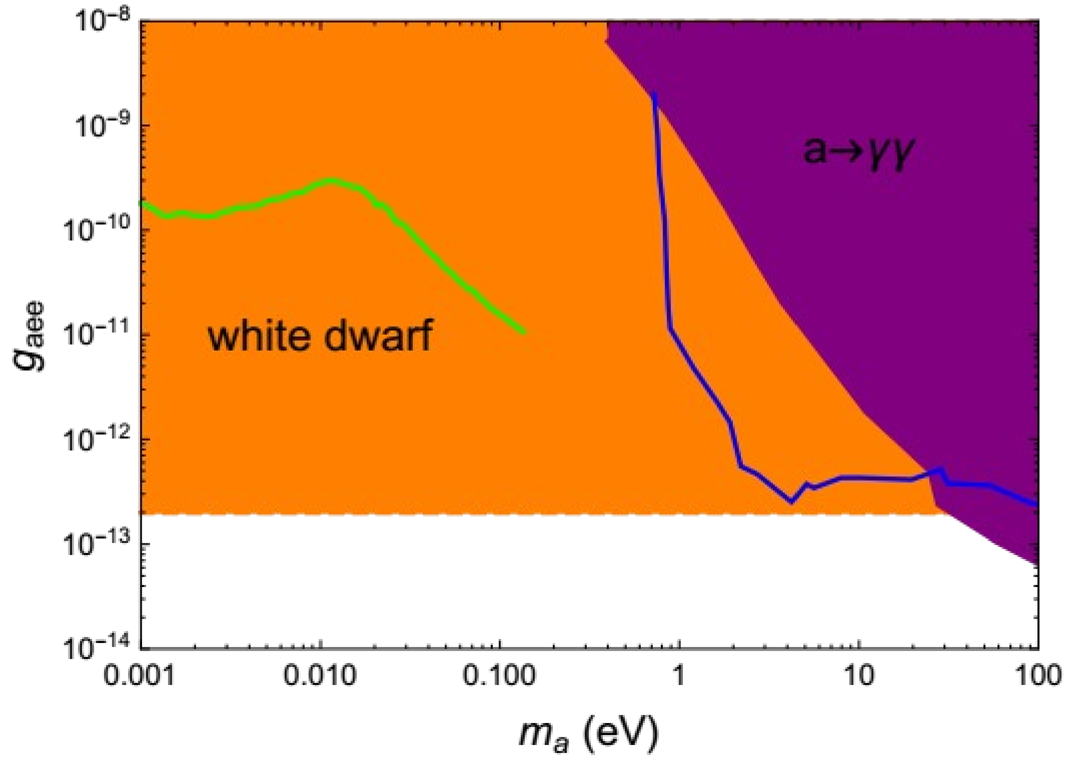

FIG. 2. The projected sensitivity is given explicitly with green line. In comparison with semi-conductor, we show the projected sensitivity of Ge with blue line. The shaded regions correspond to various constraints from astrophysics and particle physics.

A Proposal to Detect Dark Matter Using Axionic Topological Antiferromagnets

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Antiferromagnetically doped topological insulators (A-TI) are among the candidates to host dynamical axion fields and axion-polaritons; weakly interacting quasiparticles that are analogous to the dark axion, a long sought after candidate dark matter particle. Here we demonstrate that using the axion quasiparticle antiferromagnetic resonance in A-TI's in conjunction with low-noise methods of detecting THz photons presents a viable route to detect axion dark matter with mass 0.7 to 3.5 meV, a range currently inaccessible to other dark matter detection experiments and proposals. The benefits of this method at high frequency are the tunability of the resonance with applied magnetic field, and the use of A-TI samples with volumes much larger than 1 mm^3.

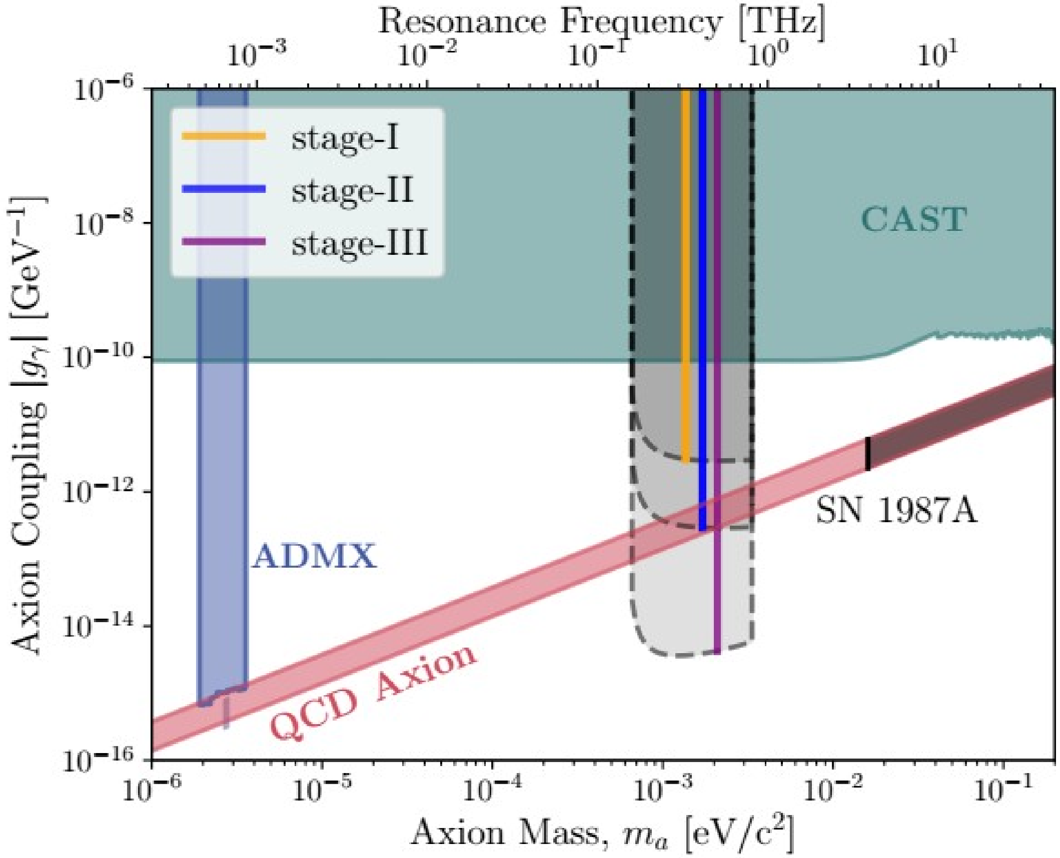
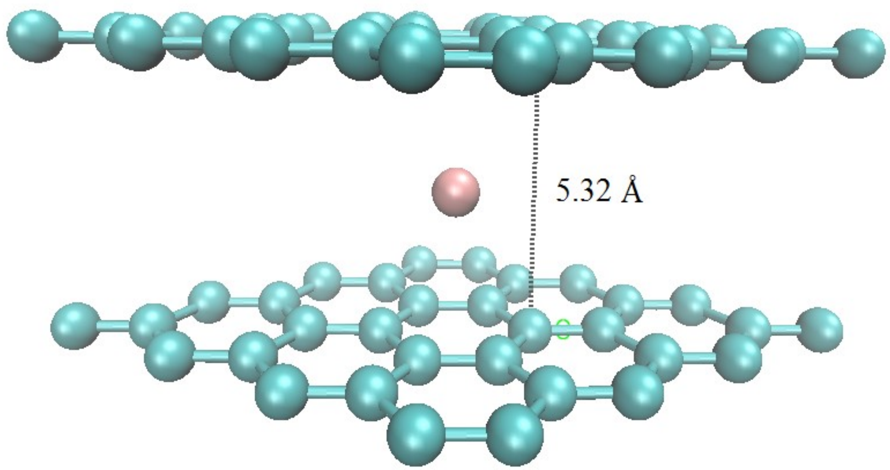
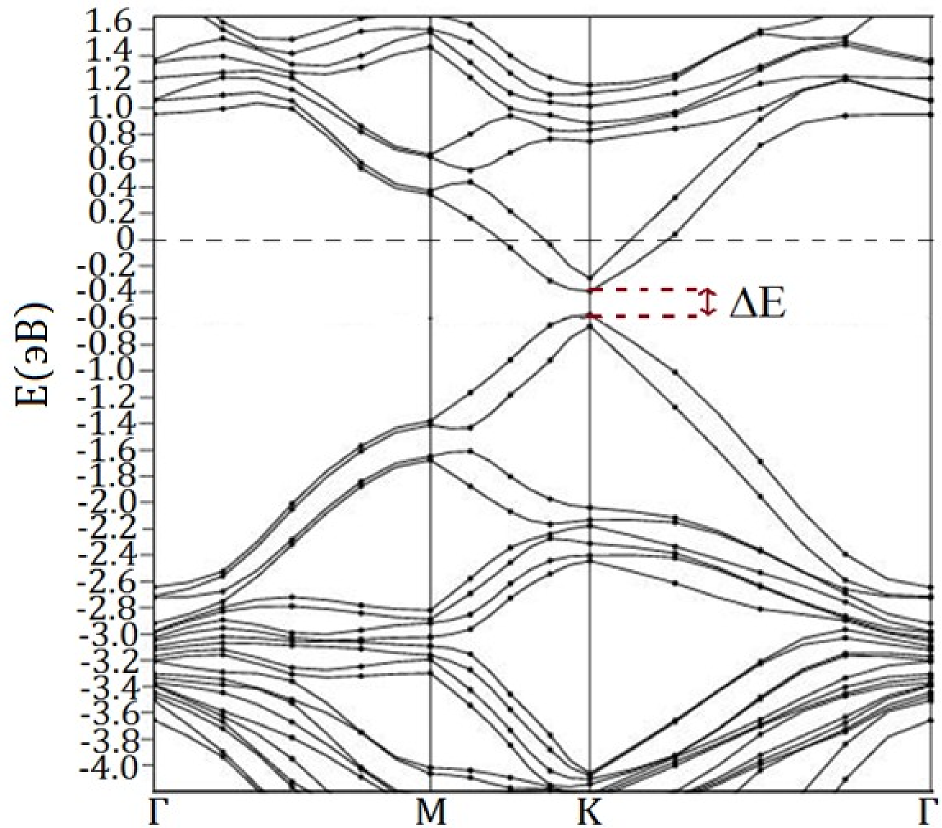


FIG. 4. Axion parameter space. Vertical lines lines show the projected sensitivity of our proposal using Fe doped Bi_2Se_3 at $\sim$5T applied field for 10^2 s integration time with dark count rate $\Gamma_d = 0.001$ Hz. Staged designs are described in the text. Gray shaded regions assume scanning $1\ \mathrm{T} \leq B_0 \leq 10\ \mathrm{T}$. The KSVZ and DFSZ axion models are shown as the red band. Existing exclusions from ADMX [17, 18], CAST [27], and supernova 1987A [23] are shown as coloured regions.

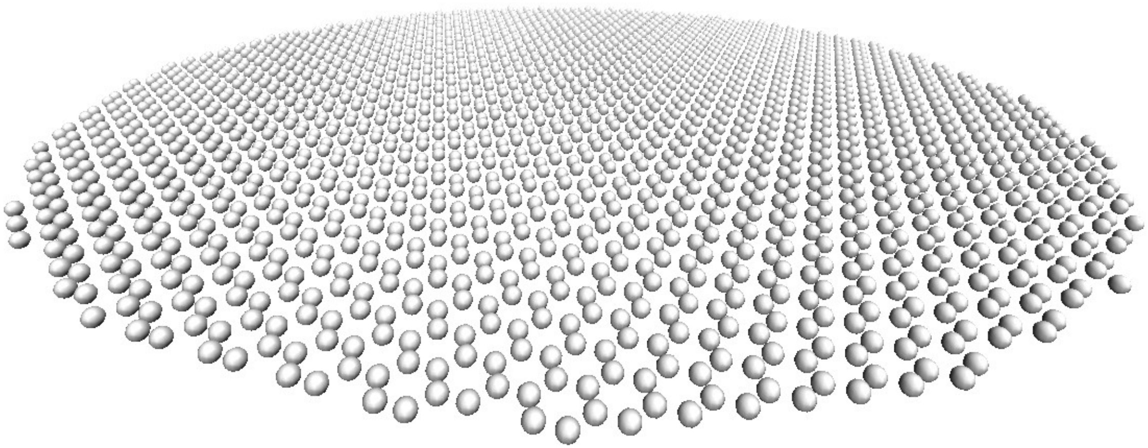
Использование графена как топологического изолятора
В качестве составной части детектора аксионов



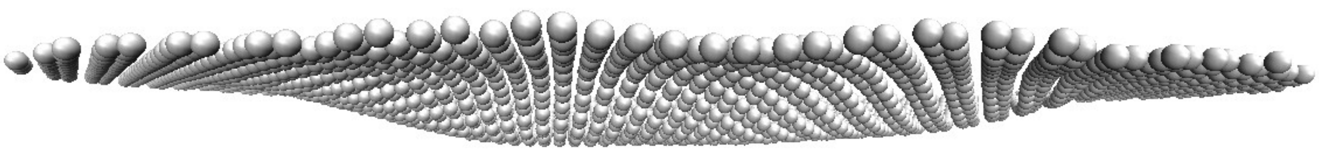
Электронная зонная структура двухслойного графена, интеркалированного атомом калия



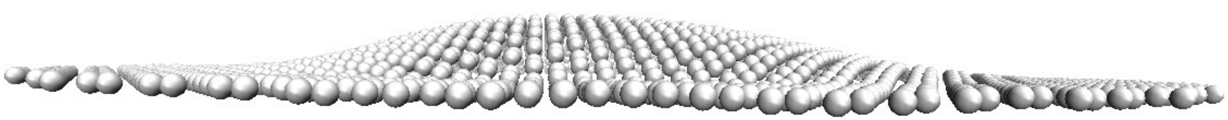
Колебания графенового листа в терагерцовом диапазоне ($\boldsymbol{\nu}$ = 0.15 THz)



t = 0

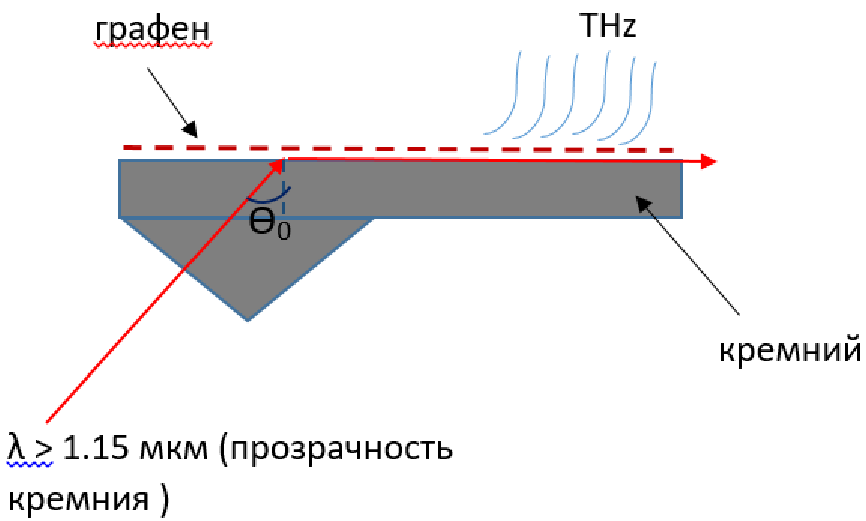


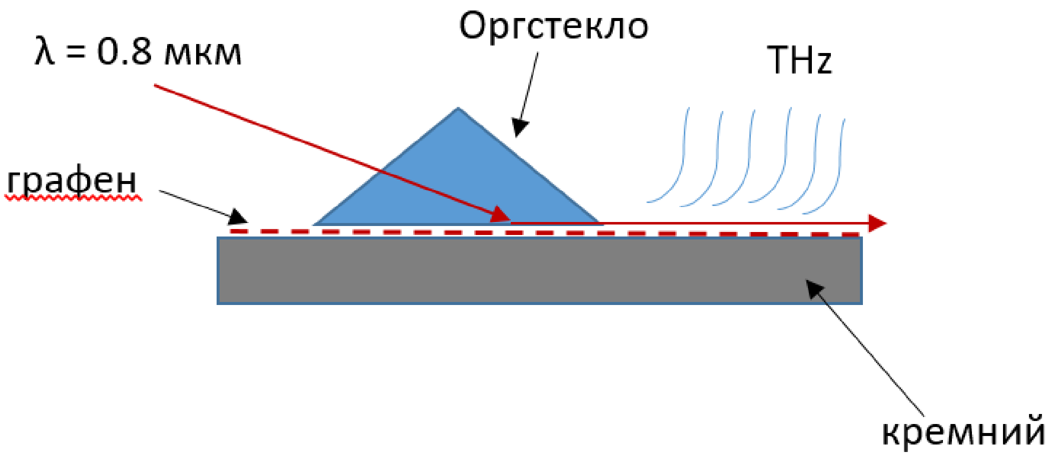
t = 100 t0



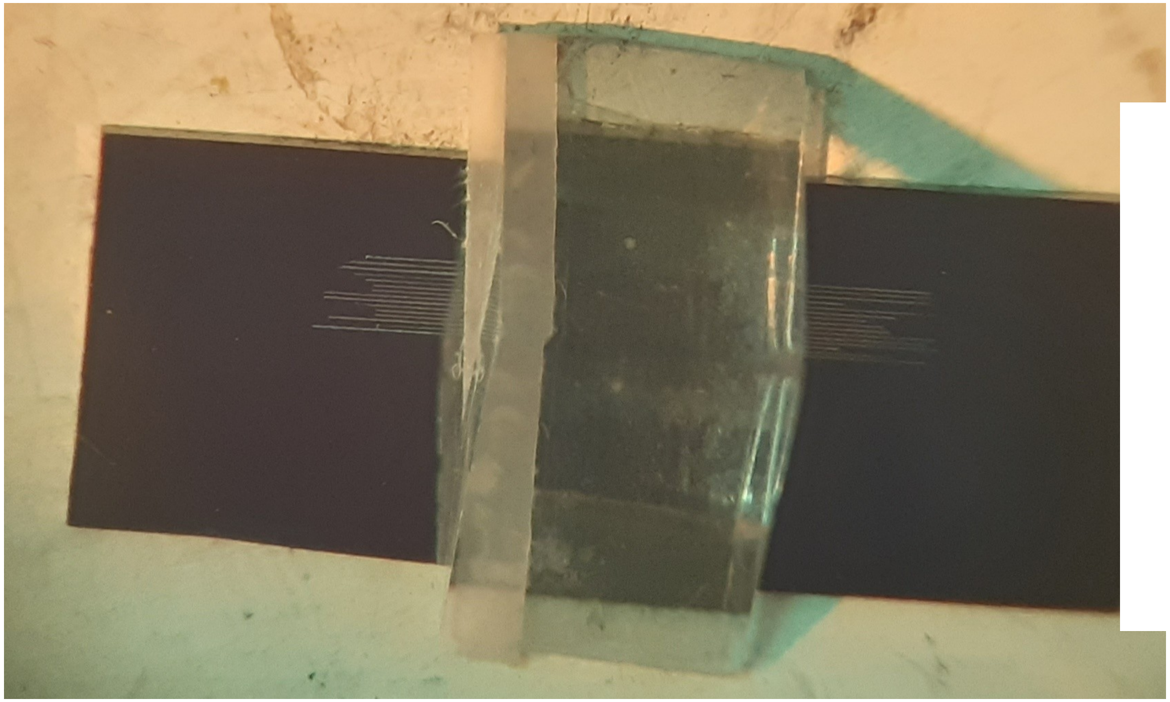
t = 200 t0

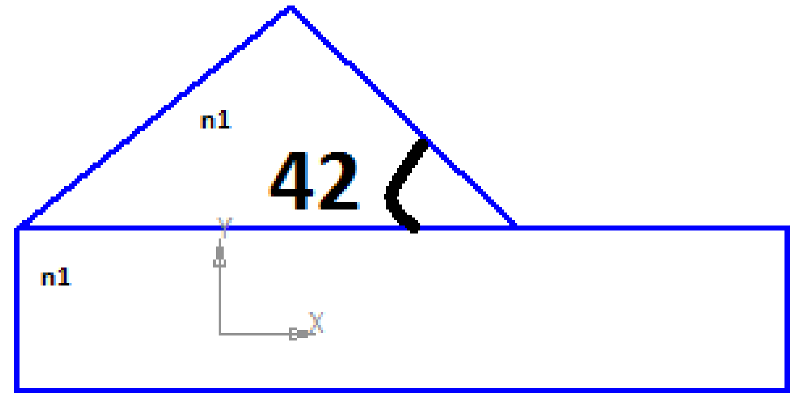
Схемы используемые для генерации терагерцового излучения





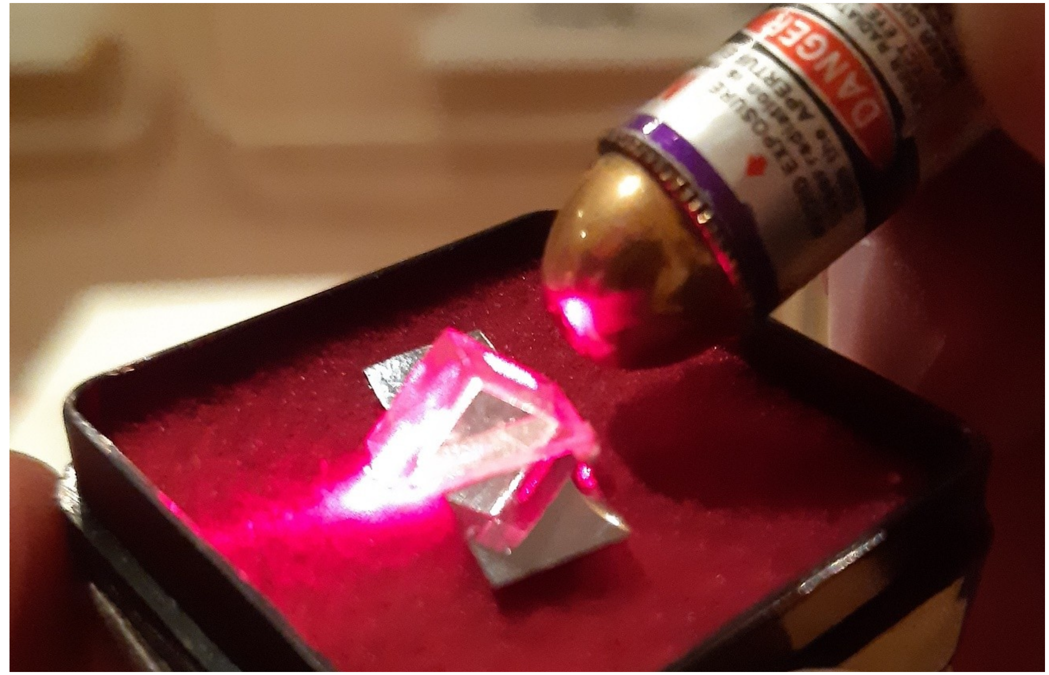
Создание прототипа





По расчетным формулам было получено приемлемое значение для условия полного внутреннего отражение. Объект состоит из 2 кусков оргстекла склеенных между собой. Призма имеет угол при основании 42 градуса.

Эксперемент с подложкой



В данном эксперименте были сделаны все модификации объекта, а детектор был заменен на другой. Регистрация излучения происходит с помощью микроволнового детектора.