# 18th Patras Workshop on Axions, WIMPs and WISPs

Monday, 3 July 2023 - Friday, 7 July 2023

# Book of Abstracts

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**Wednesday Session 3 / 2**

## Electron Trap as a Dark-Photon Detector

**Authors:** Xing Fan[1]; Gerald Gabrielse[2]; Peter W. Graham[3]; Roni Harnik[4]; Thomas G. Myers[2]; Harikrishnan Ramani[3]; Benedict A. D. Sukra[2]; Samuel S. Y. Wong[3]; Yawen Xiao[3]

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Dark photon dark matter in the milli-eV mass range is notoriously difficult to detect, being too high in frequency for high-Q cavity resonators yet below the energy threshold of single-photon detectors. I will present a new method that overcomes this difficulty, based on recent work (arXiv:2208.06519) with Peter Graham and Gerald Gabrielse et al. We propose to use trapped electrons as high-Q resonators to detect dark photon dark matter. Initially cooled to its cyclotron ground state, the trapped electron's first excited state can be resonantly driven if the cyclotron frequency matches the dark photon mass. A proof-of-principle measurement demonstrates that the method is background free over a 7.4-day search, setting a limit on dark photon dark matter at 148 GHz (0.6 meV), which is around 75 times better than previous constraints. Dark photon dark matter in the 0.1–1 meV mass range (20–200 GHz) could likely be detected at a similar sensitivity in an apparatus designed for dark photon detection.

**Wednesday Session 3 / 3**

## The QCD axion sum rule

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We demonstrate that the true QCD axion that solves the strong CP problem can be found in all generality outside the customary standard QCD band, with QCD being the sole source of Peccei-Quinn breaking. The essential reason is that the basis of axion-gluon interactions does not need to coincide with the mass basis, namely the QCD axion can mix with other scalar fields in Nature. We determine in all generality the condition for an arbitrary N-scalar potential to be PQ invariant, together with a precise sum rule for the multiple QCD axion and other exact results.

**Tuesday Session 3 / 4**

## Discovery prospects with the DALI Experiment

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We will discuss the discovery potential of the Dark-photons & Axion-Like particles Interferometer (DALI), a new-generation haloscope that has been proposed, primarily, for the purpose of probing for Galactic dark matter in a post-inflationary Universe. Thus, the apparatus will search for axion-like particles in the, poorly explored, 25 to 250 $\mu$eV mass range, reaching Dine-Fischler-Srednicki-Zhitnitsky axion sensitivity; with a capacity to detect also paraphotons of a kinetic mixing strength to ordinary photons larger than some $10^{-16}$. To be sited at the Teide Observatory, in the Canary Islands, an ideal environment protected from terrestrial microwave sources, the project presents some peripheral objectives which will, of course, also be addressed on the basis of simulation results, as well as an overview of the experimental approach.

**Poster Session / 5**

## Axion-Photon Coupling Distributions for Non-Minimal DFSZ-type Axion Models

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We present a first combined theory prediction for the distribution of axion-photon couplings for non-minimal DFSZ and KSVZ models. Couplings of DFSZ models with more than one additional Higgs doublet are comparable to the non-minimal KSVZ literature values. They extend over a large range of parameters, reaching values up to almost three orders of magnitude larger than the ones observed in minimal models. The distributions of both DFSZ- and KSVZ-types of models display similar, very specific patterns. For the subset of DFSZ models with domain wall number of unity we find significantly enhanced axion-photon couplings. Our findings are relevant for axion searches like haloscopes, helioscopes, or light-shining-through-a-wall experiments.

**Monday Session 4 / 6**

## Discovering the QCD Axion with Polarization Haloscopes

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The QCD axion is a well-motivated extension of the Standard Model which dynamically relaxes away strong CP violation. However, to date most searches for the axion have instead focused on its model-dependent coupling to photons. I will present a new idea for axion detection that directly targets its defining coupling to gluons, by resonantly amplifying the oscillating currents from time-varying atomic electric dipole moments. If these effects are enhanced by large nuclear Schiff moments, such as in octupole-deformed nuclei, our proposal could be sensitive to the QCD axion's defining coupling at the most motivated GHz frequencies.

**Wednesday Session 2 / 7**

## Demonstration of a High-Volume Tunable Haloscope Above 7 GHz

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We present results from a first experimental demonstration of a tunable thin-shell axion haloscope, as proposed in [JCAP02(2021)018]. This novel geometry decouples the overall volume of the haloscope from its resonant frequency, thereby evading the steep sensitivity degradation in scaled high-frequency haloscopes. An aluminum 4 L pathfinder (designed for 6.8-8.2 GHz) has been fabricated and measured at room temperature. A singly polarized, axion-sensitive, $TM_{010}$-like mode is clearly identified against a background of spurious resonances. The on-resonance $E$-field distribution is mapped, verifying results from numerical calculations. With high-precision alignments, we achieve robust tuning over a representative frequency range. Anticipating future cryogenic operations, we demonstrate successful cavity alignments relying only on microwave reflection measurements, achieving a form factor of 0.57 and a room temperature $Q$ of 5,000

**Poster Session / 8**

## Axion quality from the symmetric of SU(N)

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The Peccei-Quinn solution to the strong CP problem has a problematic aspect: it relies on a global U(1) symmetry which, although broken at low energy by the QCD anomaly, must be an extremely good symmetry of high-energy physics. This issue is known as the Peccei-Quinn quality problem. We propose a model where the Peccei-Quinn symmetry arises accidentally and is respected up to high-dimensional Planck-suppressed operators. The model is a SU(N) dark gauge theory with fermions in the fundamental and a scalar in the symmetric. The axion arises from the spontaneous symmetry breaking of the gauge group and the quality problem is successfully solved for large enough number of dark colors N. The model includes additional accidentally stable bound states which provide extra Dark Matter candidates beyond the axion.

**Thursday Session 2 / 9**

## Results on dark matter search with XENONnT

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The XENONnT detector is currently running at the Gran Sasso underground laboratories and has recently set a new limit on direct WIMP search. The performances of this new detector and the recent results will be discussed. The near future perspectives for WIMP search and the sensitivity to other fundamental science channels (solar axions, ALPs, anomalous neutrino magnetic moment, solar neutrinos, neutrinoless double beta decay) will be reviewed.

**Thursday Session 2 / 10**

## Search for dark photon DM in 6-8 eV energy range with URIDA Experiment.

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The dark photon emerges as an additional gauge boson in a U(1) Standard Model extension and is coupled to the ordinary photon via kinetic mixing. To investigate the energy band from 6-8 eV, where photons are highly absorbent due to molecular oxygen with an absorption length on the order of cm at atmospheric pressure, we developed the Ultraviolet Range Initiated photons from Dark-photons in Ambient (URIDA) Experiment, motivated by other work. In order to minimize attenuation, the detection system was housed in a vacuum chamber. We constructed our detector system using low dark rate photo-multipliers that are sensitive at these energies and included an aluminum reflector similar to the FUNK experiment to enhance collection. Results on performance and preliminary sensitivity will be reported.

**Poster Session / 11**

## Electric dipole moments, new forces and dark matter

**Author:** Alexis David Plascencia Contreras[1]

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I will discuss minimal gauge extensions of the Standard Model where a new sector is predicted from the cancellation of gauge anomalies. As part of this new sector, there is a dark matter candidate and new sources of CP violation. I will discuss the dark matter phenomenology and the prediction of large electric dipole moments for the electron and the neutron.

**Wednesday Session 3 / 12**

## How axions change stars

**Author:** Konstantin Springmann[1]

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Lighter than expected QCD axions can get destabilized in sufficiently dense and large objects such as white dwarfs and neutron stars. Once the axion is sourced the mass of nucleons within the star is reduced, leading to a new ground state of nuclear matter. I will show that white dwarfs in this absolutely stable phase would look very different from what is observed, allowing to set novel and strong constraints in unexplored axion parameter space. Furthermore, I will show how this new ground state modifies the stellar composition of neutron stars.

**Friday Session 1 / 13**

## New axion haloscopes techniques to search for axion dark matter, high frequency gravitational waves and monopoles

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We introduce a systematic way to calculate the spectral sensitivity of an electromagnetic axion dark matter haloscope, so instrument comparison may be achieved independent of signal assumptions and only depends on the axion to signal transduction sensitivity and noise in the instrument [1]. Furthermore, it has been shown that electromagnetic axion haloscopes have proportional sensitivity to high-frequency gravitational waves based on the inverse Gertsenshtein effect. Thus, the calculation of the spectral sensitivity not only allows the comparison of dissimilar axion detectors independent of signal but also allows us to compare the order of magnitude gravitational wave sensitivity in terms of spectral strain sensitivity allowing comparisons to standard gravitational wave detectors based on optical interferometers and resonant-mass technology.

To calculate the sensitivity of axion haloscopes, we show Poynting theorem provides a systematic way of understanding power generation in a resonant haloscope [2]. For resonant haloscopes, it is optimum to impedance match, and the sensitivity is dictated by the real power flow in the system. In the quasi-static limit, the impedance must be mismatched to gain broadband sensitivity at the expense of resonant enhancement. In the quasi-static broadband case, we show the sensitivity may be calculated from the reactive power flow in the system.

Recently interactions between putative axions and magnetic monopoles have been revisited [3,4]. It has been shown that significant modifications to conventional axion electrodynamics arise due to these interactions so that the axion-photon coupling parameter space is expanded from one parameter g_{aγγ} to three (g_{aγγ}, g_{aEM}, g_{aMM}). We implement Poynting theorem in the resonant and quasi-static limits to determine how to exhibit sensitivity to g_{aEM} and g_{aMM} using various electromagnetic haloscopes techniques [5,6], allowing new ways to search for axions and a possible indirect way to determine if magnetically charged matter exists.

[1] ME Tobar, CA Thomson, WM Campbell, A Quiskamp, JF Bourhill, BT McAllister, EN Ivanov, M Goryachev, Comparing Instrument Spectral Sensitivity of Dissimilar Electromagnetic Haloscopes to Axion Dark Matter and High-Frequency Gravitational Waves, Symmetry, vol. 14, no. 10, 2165, 2022.
[2] ME Tobar, BT McAllister, M Goryachev, Poynting vector controversy in axion modified electrodynamics, Phys. Rev. D, vol. 105, 045009, 2022.
[3] AV Sokolov, A Ringwald, Generic axion Maxwell equations: path integral approach, arXiv:2303.10170
[4]AV Sokolov, A Ringwald, Electromagnetic Couplings of Axions,
[5] ME Tobar, CA Thomson, BT McAllister, M Goryachev, AV Sokolov, A Ringwald, Sensitivity of Resonant Axion Haloscopes to Quantum Electromagnetodynamics, Ann. Phys. (Berlin) 2200594, 2023.
[6] BT McAllister, A Quiskamp, C O'Hare, P Altin, EN Ivanov, M Goryachev, ME Tobar, "Limits on Dark Photons, Scalars, and Axion-Electromagnetodynamics with The ORGAN Experiment", arXiv:2212.01971

**Thursday Session 3 / 14**

## New results of the DOSUE-RR experiment and future

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Dark photon dark matter (DP-DM) is one of the dark matter candidates. The DP-DM is theoretically predicted to have a weak coupling $\chi$ to ordinary photons. This results in the emission of the conversion photon at the electromagnetic boundary such as a metal surface when the DP-DM passes through.
The DOSUE-RR (Dark-photon dark-matter Observing System for Un-Explored Radio-Range) is a series of multiple experiments. We aim to detect the conversion photons from the DP-DM using millimeter-wave receivers. The frequency of the conversion photon corresponds to the mass of dark matter by energy conservation, and the intensity of the conversion photon corresponds to the square of the coupling $\chi$. Since there is no obvious prediction for the dark matter mass, we should search in a wide frequency(=mass) range. A millimeter-wave receiver can cover a relatively wider frequency range rather than the haloscope experiments. The target frequency range of the DOSUE-RR is 10–300 GHz. To cover such a wide range, we are performing or planning multiple experiments.
We published our first results last year. We achieved the world's best exploration in the 18–26.5 GHz frequency range (74–110 $\mu$eV mass range) and set an upper limit ($\chi \sim< 10^{-10}$). We have been expanding our exploring range to both lower and higher frequency ranges. In this talk, we will present our latest results as well as the development status for the future.

**Poster Session / 15**

## Birefringence in CMB anisotropies due to cosmological pseudoscalar fields

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We study the imprints of a cosmological redshift-dependent pseudoscalar field on the rotation of cosmic microwave background.
We show how either phenomenological or theoretically motivated redshift dependence of the pseudoscalar field, such as those in models of Early Dark Energy, Quintessence or axion-like dark matter, lead to CMB polarization and temperature-polarization power spectra which exhibit a multipole dependence which goes beyond the widely adopted approximation in which the redshift dependence of the linear polarization angle is neglected.

By taking this multipole dependence into account, we calculate the parameters of these phenomenological and theoretical redshift dependence of the pseudoscalar field which can be detected by future CMB polarization experiments on the basis of a $\chi^2$ analysis for a Wishart likelihood.

Based on:
https://arxiv.org/abs/2301.07971
PRD accepted:
https://journals.aps.org/prd/accepted/06078Q7fNd11c43753909b613ecf12ab5f48958ef

**Friday Session 1 / 16**

## QCD axion mass prediction from Adaptive Mesh Refinement simulations

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If the PQ symmetry is broken after inflation then the QCD axion mass that gives rise to the observed dark matter (DM) abundance can in principle be calculated precisely. In practice it remains a computational challenge to accurately predict the DM contribution from nonlinear features of the PQ field such as axion strings, which introduce a large hierarchy of scales between their width and the Hubble length. In this work we employ adaptive mesh refinement (AMR) to simulate the post-inflationary axion field beginning before the PQ phase transition and into the scaling regime, building off of the framework of Buschmann et al. Nature Commun. 2022, which predicted the axion mass to be in the range (40,180) microelectronvolts. We improve the accuracy and precision of the mass prediction by running larger simulations further into the scaling regime and by closely examining sources of systematic uncertainty. For example, for the first time we account for axions produced during domain wall formation and string-network collapse using the AMR simulation framework. Our work leads to a narrow axion mass prediction that directly informs experiments such as ADMX, HAYSTAC, MADMAX, and ALPHA, which target axion DM in the mass range of interest. Moreover, our work helps determine the relevant initial conditions for investigating small-scale structure formation in the post-inflationary scenario.

**Wednesday Session 3 / 17**

## Search for the Cosmic Axion Background with ADMX

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The Cosmic axion Background (CaB), a relativistic background of axions that is not dark matter, could be produced in the late Universe from the decay of another dark matter candidate.
In this talk, we show the first result of the direct search for CaB performed with the axion haloscope, the Axion Dark Matter eXperiment.
Conventional haloscope analyses search for a signal with a narrow bandwidth, as predicted for dark matter, whereas the CaB will be broad. We introduce a novel analysis strategy, which searches

for a CaB-induced daily modulation in the power measured by the haloscope. Using this, we repurpose data collected to search for dark matter to set a limit on the axion photon coupling of the CaB originating from dark matter decay in the 800-995 MHz frequency range. We also show the extensibility of this analysis combined with possible single photon counters like the superconducting qubit.

**Tuesday Session 1 / 18**

## Constraints on axion dark matter from corrections to g-2 of the electron

**Authors:** Ariel Arza[1]; Jason Evans[1]

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We employ finite temperature QFT techniques to calculate corrections to g-2 of the electron in the presence of axion-like particles as a local dark matter background. The precise measurements of g-2 allows us to put competitive constraints on the axion-electron coupling.

**Thursday Session 3 / 19**

## WISPFI: WISP Searches on a Fiber Interferometer

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WISP Searches on a Fiber Interferometer (WISPFI) is a novel tabletop experiment using interferometric techniques applied to photonic crystal fibers searching for a resonant photon-axion conversion. It is independent of the local dark matter density which can highly reduce the sensitivity of axion experiments and could as well be the reason behind the null results of dark matter searches so far. The experimental setup consists of a partial fiber, partial free-space Mach-Zehnder-type interferometer. In the sensing arm, the fiber is coiled and placed inside the bore of a superconducting solenoid magnet (14T, 140mm diameter warm bore), where photon-axion mixing occurs. The photon-axion oscillations would then be detected by measuring changes in phase/amplitude. For the detection at resonant mixing, hollow-core photonic crystal fibers (HC-PCF) will be used, while regulation of the gas pressure inside the fiber will allow probing a wide range of axion masses. WISPFI's unique setup focuses on large axion masses around 100meV while reaching the QCD band so far unexplored by other experiments. A scalability of the experiment together with the involvement of state-of-the-art photonic techniques allow even a DFSZ sensitivity while probing dark matter axions in a very wide and unexplored mass range.

**Thursday Session 3 / 20**

## The ALPS II First Science Run

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The Any Light Particle Search II (ALPS II) is a light-shining-through-a-wall (LSW) experiment located at DESY in Hamburg, Germany, that is searching for axions and axion-like particles in the mass range below 0.1 meV. LSW experiments take advantage of the potential interaction between axions and two photons by shining a laser through a region of high magnetic field. This creates an axion field that travels through a wall, which blocks the laser light. On the other side of the wall, the axion field travels through another region with a high magnetic field where a portion of its power converts back to an electromagnetic field that can then be measured. The experiment is hosted by DESY to utilize the superconducting magnets, tunnels, and cryogenic infrastructure that were formerly part of the HERA accelerator. To enhance the sensitivity of the experiment, ALPS II employs a sophisticated optical system with 100 m optical cavities, a control architecture relying on precision interferometry, and a heterodyne detection system capable of measuring powers on the order of single photons per day. Now, nearly 10 years since the publication of the ALPS II TDR, the experiment has begun the first science run. This talk will give a brief overview of the experiment, discuss the lessons learned during the commissioning phase, and present the first results from the science run.

**Wednesday Session 3 / 21**

## Search for topological defect dark matter with a global network of optical magnetometers (GNOME)

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Ultralight axion-like particles are well-motivated dark matter candidates which can feature topological defects. If Earth encounters such structures, a global pattern of transient signals would be detectable with terrestrial experiments. Here, we report the analysis of three months of data from the Global Network of Optical Magnetometers for Exotic physics searches (GNOME). The data collected consist of correlated measurements from optical atomic magnetometers located in laboratories all over the world. A novel analysis method and improved sensors allowed to expand the search to short duration events (up to $10^{-3}$ seconds). No statistically significant signal was found in the data, placing new constraints that supersede current bounds in the interaction scale by three orders of magnitude.

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## Superradiance in stars

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Superradiance in black holes is reasonably well-understood but superradiance in stars has received comparatively little attention. This is surprising given the ease with which we can observe isolated neutron stars and the array of signatures which would result from stellar superradiance. I will discuss

the opportunities and challenges of stellar superradiance for detecting axions and other light bosons, and present the first systematic pipeline for computing superradiance rates in rotating stars.

**Thursday Session 4 / 23**

## SERAPH: Wavelike Dark Matter Searches with SRF Cavities

**Author:** Raphael Cervantes[None]

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Haloscopes consisting of a microwave cavity with a high quality factor (Q) connected to low-noise electronics have been deployed to detect wavelike axions and dark photons. But the dark matter mass is unknown, so haloscopes must be tunable to search through the photon coupling vs. mass parameter space. Therefore, the scan rate for haloscope experiments is a crucial figure of merit and is proportional to the cavity's quality factor. State-of-the-art experiments like ADMX currently use copper cavities with ⍰~80000. However, implementing superconducting cavities with ⍰~$10^{10}$ can increase the instantaneous scan rate by possibly a factor of $10^5$.

This presentation will report progress on the SERAPH experiment, a family of superconducting haloscopes being developed by the Superconducting Quantum Materials and Systems (SQMS) Center. In this presentation, I will first discuss the principles behind operating a haloscope whose bandwidth is much narrower than the dark matter halo energy distribution. I will then describe the first SERAPH experiments implementing a 1.3 GHz Niobium cavity with an ultra-high quality factor (Q~$10^{10}$) that has achieved the best sensitivity and deepest exclusion to wavelike dark photon dark matter by almost an order of magnitude. Next, I will discuss progress on the next phase of SERAPH, which will search dark photon dark matter using a widely-tunable SRF cavity (4-7 GHz). I will finally describe plans for subsequent SERAPH experiments to search for dark photons and axions with tunable SRF cavities tolerant to multi-Tesla magnetic fields and quantum sensors that subvert the Standard Quantum Limit.

**Poster Session / 24**

## Wide-Band Haloscope Read-Out Using Flux-Driven Josephson Parametric Amplifier

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This article presents the development of a broadband haloscope read-out based on a flux-driven Josephson Parametric Amplifier (JPA). While the JPA offers extremely low noise close to the quantum noise limit, initial devices had a tunable frequency range of 30 MHz, which required frequent warm-up and replacement. This results in a significant loss of time and the use of large amounts of liquid helium. To match the haloscope resonator's 200-300 MHz frequency range, we devised methods to extend the JPA's bandwidth to 300 MHz. These methods involve improvements to the JPA design by optimizing the inductance and critical current of the Josephson junction, as well as the creation of new JPA designs. In addition, we tested the implementation of multiple JPAs in a single read-out line. We tested using a switch to multiplex multiple amplifiers, and combining the amplifiers by connecting them in parallel, in series, and series-parallel combinations. This made it possible to achieve a bandwidth of up to 300 MHz without increasing the added noise due to the amplifiers. This article presents design details and test techniques for these multi-channel circuits.

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# Search for the Sagittarius Tidal Stream of Axion Dark Matter around 4.55 μeV

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We report the first search for the Sagittarius tidal stream of axion dark matter around 4.55 μeV using CAPP-12TB haloscope data acquired in March of 2022. Our result excluded the Sagittarius tidal stream of Dine-Fischler-Srednicki-Zhitnitskii and Kim-Shifman-Vainshtein-Zakharov axion dark matter densities of ρa >~ 0.184 and >~ 0.025 GeV/cm3, respectively, over a mass range from 4.51 to 4.59 μeV at a 90% confidence level.

**Monday Session 3 / 26**

# Novel designs and schemes for high-mass axion haloscopes

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The axion is a hypothetical particle resulting from the PQ mechanism that resolves the strong CP problem, and is one of the strong candidates for dark matter. The cavity haloscope is a highly sensitive method for detecting dark matter axions. The Center for Axion and Precision Physics Research of the Institute for Basic Science (IBS-CAPP) has recently developed various detector designs suitable for high-mass dark matter axion searches, such as multiple-cell cavities, wheel tuning mechanism, and photonic crystal cavities. In addition, we have developed a new detection scheme based on heterodyne interferometry that amplifies and detects the variance of weak signals with known coherence. This presentation reviews the newly developed detector designs and introduces the proposed variance detection method. We also discuss CAPP's plans for high-mass axion searches using these detectors.

**Monday Session 2 / 27**

## Search for KSVZ axion dark matter around 24.5 $\mu$eV

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The axion is a well-motivated hypothetical particle resulting from the Peccei-Quinn mechanism, which is an elegant solution to the strong $CP$ problem of quantum chromodynamics. Because of its hypothetical abundance and weak coupling, it is also considered a promising candidate for dark matter, another big mystery of the universe. The Center for Axion and Precision Physics Research (CAPP) of the Institute for Basic Science (IBS) is searching for axions in various mass ranges using several experimental configurations based on the axion haloscope. This talk presents one of the experiments conducted in IBS-CAPP that focuses on the mass around 24.5 $\mu$eV at the Kim-Shifman-Vainshtein-Zakharov (KSVZ) sensitivity. The experiment employs an 8-cell microwave resonant cavity to maximally utilize a given volume, and a flux-driven Josephson parametric amplifier to achieve a low system noise temperature. In this talk, the first data from the experiment that scanned 100 MHz at near KSVZ sensitivity is presented. The current status and prospects are also discussed.

**Thursday Session 4 / 28**

## High-temperature superconducting cavities: current progress and future plans for axion searches at CAPP

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Superconducting radiofrequency technology has been essential for advancing the performance in particle physics experiments over the past decades. In particular, axion haloscopes require high-quality factor (Q) superconducting cavities working in multi-tesla magnetic fields to enhance scanning speeds, which can be accomplished using high-temperature superconducting (HTS) tapes. Biaxially-textured rare-earth barium copper oxide (ReBCO) tapes, with robust vortex pinning capabilities in high magnetic fields, are ideal materials for creating high Q cavities in a strong magnetic field. The Center for Axion and Precision Physics Research (CAPP) has successfully fabricated cavities utilizing ReBCO tapes, which boast a Q factor up to two orders of magnitude greater than copper. In this presentation, we discuss the first axion dark matter search results using a high-temperature superconducting cavity with a sapphire tuning mechanism. The experiment demonstrated an order-of-magnitude increase in scanning speed compared to previous laboratory setups. Furthermore, we will cover the development and characterization status of HTS cavities for various experiments at CAPP.

**Friday Session 2 / 29**

## Dark Matter detection with Qubits

Dark Matter searches utilizing single-photon and phonon excitations have been broadly accepted as effective methods of harnessing the miniscule energies transferred from Ultra-light and Light Dark Matter. Qubits are highly sensitive to sub-eV energy phonons and photons which make them a compelling detection technology for light and Ultralight Dark Matter. We will discuss the potential of this novel idea while providing a proof-of-principle demonstration of this technology and an overview of a brand-new R&D program at Fermilab.

**Thursday Session 2 / 30**

## The first axion quark nugget experiment using a haloscope at CAPP

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Axions are hypothetical particles arising from the Peccei-Quinn mechanism, which solves the strong charge-parity problem, a significant puzzle in the Standard Model. In this study, we focus on an alternative axion production mechanism compared to conventional dark matter axions, known as the axion quark nugget (AQN) dark matter model. The model suggests that anti-AQNs predominantly constitute the dark matter component, and upon colliding with ordinary matter, they can annihilate to produce broad-band relativistic axions. Although the resulting axion frequency distribution differs from the conventional model, cavity haloscopes can detect axions produced through the interaction of anti-AQNs and the Earth's surface. Based on this concept, the Center for Axion and Precision Physics research initiated an AQN-based experiment utilizing a haloscope, which incorporates a flux-driven Josephson parametric amplifier and a newly developed superconducting cavity. With the cavity resonant frequency fixed at 2.2685 GHz, the experiment aims to explore the 4 μeV –9 μeV axion rest mass region, seeking the daily modulation of the axion signal predicted by the model. This experiment is currently underway, and the results will be presented during the workshop.

**Thursday Session 1 / 31**

## The ORGAN Experiment: Results, Status, and Future Plans

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We present the current status and future plans of the various experiments within The Oscillating Resonant Group AxioN (ORGAN) Collaboration, which develops microwave cavity axion haloscopes. ORGAN is a collaboration of various nodes of the ARC Centres of Excellence for Engineered Quantum Systems, and Dark Matter Particle Physics.

The ORGAN Experiment is a high mass haloscope (~60-200 micro-eV) broken down into various phases, having commenced in 2021, and running until 2026 [1]. Phase 1 recently concluded, excluding ALP Cogenesis models of dark matter in the relevant mass ranges [2,3], along with scalar dark matter and dark photon limits. Phase 2 is in research and development, expected to commence in 2024 and achieve deeper sensitivity. Active avenues of research and development for ORGAN include novel high frequency cavity design [4,5], superconducting materials, and single photon counting.

ORGAN-Q is a pathfinder experiment (~25 micro-eV), designed as a testbed for various techniques to be integrated into the main ORGAN Experiment in Phase 2, such as quantum-limited amplification, and other improvements. It is currently in commissioning, expected to commence in late 2023.

ORGAN-Low Frequency is a lower-mass experiment designed to utilise an MRI magnet, and novel cavities to push into the low frequency regime, and search for different models of dark matter. It is currently in development, expected to commence in late 2023-early 2024.

We will summarize each experiment in terms of the relevant experimental details, current status, run plans, and projected reach.

1. Ben T. McAllister, Graeme Flower, Eugene N. Ivanov, Maxim Goryachev, Jeremy Bourhill, Michael E. Tobar, 'The ORGAN experiment: An axion haloscope above 15 GHz', Physics of the Dark Universe 18, 67-72
2. Aaron P. Quiskamp, Ben T. McAllister, Paul Altin, Eugene N. Ivanov, Maxim Goryachev, Michael E. Tobar, 'Direct Search for Dark Matter Axions Excluding ALP Cogenesis in the 63-67 micro-eV Range, with The ORGAN Experiment', Science Advances 8, Issue 27
3. ORGAN 1b results to be released soon
4. Ben T. McAllister, Graeme Flower, Lucas E. Tobar, and Michael E. Tobar, 'Tunable Supermode Dielectric Resonators for Axion Dark-Matter Haloscopes, Phys. Rev. Applied 9, 014028
5. Aaron P. Quiskamp, Ben T. McAllister, Gray Rybka, and Michael E. Tobar, 'Dielectric-Boosted Sensitivity to Cylindrical Azimuthally Varying Transverse-Magnetic Resonant Modes in an Axion Haloscope', Phys. Rev. Applied 14, 044051

**Monday Session 1 / 32**

## Recent Progress on CAPP's Main eXperiment (CAPP-MAX)

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IBS-CAPP has established the state-of-the-art axion detector facility in Korea with multiple dilution refrigerator systems. The recent addition was 12 T big bore (32 cm) Nb3Sn superconducting magnet to the line-up with quantum noise-limited amplifiers to collect the axion dark matter physics data with a DFSZ level sensitivity. Achieving around 200 mK of total system noise temperature made it possible to scan more than 1 GHz per year. This milestone reflects the CAPP's effort of successfully applying cutting-edge technologies and innovative R&Ds to building a top-notch axion dark matter search experiment. The other critical R&D focus has been on the development of the high temperature superconducting cavity that sustains high Q-factor (> 10 million) even at 12T. A 36-liter superconducting cavity with HTS will be added to the CAPP-MAX experiment this year to enhance the scanning speed even further. We will present the status of CAPP's axion search and R&D efforts, including future plans.

**Friday Session 1** / **33**

## Employing Radio Telescopes to Search for Ultralight Dark Matter

**Author:** Shuailiang Ge[None]

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Ultralight axions and dark photons are compelling candidates for dark matter. In this talk, I will provide an overview of my recent work (arXiv:2207.05767, 2301.03622) on detecting radio-frequency axions and dark photons using radio telescopes. The detectability relies on two distinct underlying mechanisms. One mechanism involves local dark photon dark matter inducing harmonic oscillations of electrons within the antenna of radio telescopes. This process results in a local radio electromagnetic (EM) signal that can be captured by telescope receivers. The other mechanism is the resonant conversion of dark photons into EM waves in the solar corona when their mass matches the solar plasma frequency. This mechanism is also applicable to axions due to the presence of the solar magnetic field. The resulting radio EM waves can be detected by radio telescopes designed for solar observations, although the detectability for axions is suppressed due to the relatively weak solar magnetic field. By analyzing data from radio telescopes such as FAST and LOFAR, we have obtained constraints on the kinetic mixing constant between dark photons and photons, surpassing existing bounds in multiple radio-frequency ranges.

**Poster Session** / **34**

## Ultra-light cavities for CAPP-MAX

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The Main AXion Experiment (MAX) of the center for axion and precision physics research (CAPP) has achieved the DFSZ sensitivity in axion dark matter search by employing cutting-edge technology. The ultra-light cavity (ULC) of the experiment has a total weight of less than 5kg, even with a volume of 37 liters, and can achieve cavity temperatures below 30mK due to the use of a 0.5mm thick Oxygen-Free High-thermal Conductivity (OFHC) copper sheet for the cavity body and frequency tuning rod.

CAPP has been gradually applying its advanced High-Temperature Superconducting (HTS) cavity fabrication techniques to the production of ULCs in order to expand the axion search range in CAPP-MAX. First, a cavity with a Q factor averaging 150k was produced by attaching HTS tape to the side of the tuning rod, and axion search experiments are currently underway at 1.18-1.53GHz. Next, a cavity with a Q factor of over 10^6 will be produced by internally coating the ULC with HTS tape, allowing for even better sensitivity in searching for axions at >1.5GHz compared to the DFSZ.

**Monday Session 3 / 35**

## BRASS-p Search for Exotic WISPy Phenomenon

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The Broadband Radiometric Axion Search (BRASS-p) prototype is a state-of-the-art radio telescope with exceptional sensitivity for searching WISPy dark matter within the 12-18 GHz mass range. Its analog receiver provides dual polarization sensitivity at low system temperature, and the digital back-end of BRASS-p delivers high resolution ($\frac{\delta\nu}{\nu} = 10^{-8}$) over the broadband intermediate frequency of 4 GHz. As such, BRASS-p is well-suited to detect exotic WISPy dark matter phenomena beyond the thermalized halo of the axion/ALPS or unpolarized hidden photon. In this presentation, we will provide a quick update on the current status and sensitivity of BRASS-p in detecting standard halo model WISPs, and addressing the spectral standing wave issue in dish antenna experiment. Finally, we will discuss its ability to resolve the sidereal modulated signal from polarised hidden photons and search for electromagnetic transients from axion mini-clusters or streams.

**Monday Session 3 / 36**

## Detecting axions from SNe using underground neutrino detectors.

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In this talk I will characterize the unexplored sensitivity of current and future neutrino experiments to an axion burst from a galactic SN. In particular I will focus on water Cherenkov detectors like Super- and Hyper-Kamiokande showing that axion interactions with oxygen nuclei in the detector can give an observable gamma-ray signal. This possibility would open a new way to detect axions in an unexplored range of their parameter space.
This talk is based on a collaboration with Pierluca Carenza, Giampaolo Co', Maurizio Giannotti, Giuseppe Lucente, Alessandro Mirizzi and Thomas Rauscher.

**Poster Session / 37**

## Study of axion-like particles with Perseus data of MAGIC

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We present constraints on Axion-Like Particles using very-high-energy gamma-ray data from the MAGIC telescopes in the direction of the Perseus Galaxy Cluster. Axion is envisioned and theorized as a solution to the Strong CP problem of the Standard Model. As a generalization of the axion, axion-like particles are introduced. Depending on the specifics of their production mechanisms in the Early Universe, their properties make them viable candidates for Dark Matter particles. Traveling through the astrophysical environments embedded in magnetic fields, axion-like particles can interact with high-energy gamma rays. Depending on their coupling and mass, this would leave a distinctive signature in their spectra in the form of hardening, softening, or spectral distortions. Using the MAGIC dataset of two sources located in the Perseus cluster, we set constraints on the ALPs mass, reaching several hundred neV and improving the current limits on the strength of their coupling to photons.

**Poster Session / 38**

## WIMPs during reheating

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Weakly Interacting Massive Particles (WIMPs) are among the best-motivated dark matter candidates. In the standard scenario where the freeze-out happens well after the end of inflationary reheating, they are in tension with severe experimental constraints. Here, we investigate the thermal freeze-out of WIMPs occurring during reheating, while the inflaton $\phi$ coherently oscillates in a generic potential $\propto \phi^n$. Depending on the value of n and the spin of the inflaton decay products, the evolution of the radiation and inflaton energy densities can show distinct features, therefore, having a considerable impact on the freeze-out behavior of WIMPs. As a result of the injection of entropy during reheating, the parameter space compatible with the observed DM relic abundance is enlarged. In particular, the WIMP thermally averaged annihilation cross-section can be several magnitudes lower than that in the standard case. Finally, we discuss the current bounds from dark matter indirect detection experiments and explore future challenges and opportunities.

**Poster Session / 39**

## A Cryogenic Single-Photon Detector for ALPS II

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The Any Light Particle Search II (ALPS II) experiment searches for axions and axion-like particles (ALPs) in an important parameter space that is relevant in understanding anomalous astrophysical phenomena, including stellar evolution. ALPS II takes advantage of the axion coupling to photons using a resonantly enhanced Light-Shining-through-a-Wall (LSW) technique. Photons created using a strong laser may convert into axions or ALPs in the presence of a strong magnetic field, traverse a light-tight barrier, reconvert into photons in another strong magnetic field, and be subsequently detected. Fabry-Perot resonators before and after the light-tight barrier lead to an enhancement of the electromagnetic fields, providing an extra boost in the conversion probability as compared to traditional LSW experiments. At the sensitivity goal for ALPS II we expect only 1 reconverted photon per day, which necessitates sensitive photon detectors with high efficiency and low backgrounds. The first stage of ALPS II, currently running at DESY, Hamburg, will use a heterodyne (HET) detection method. Because there are no other LSW experiments operating at the ALPS II sensitivity, an independent detector technology would be needed to confirm the results from the HET run, especially in the case of a discovery. For this purpose, ALPS II can utilize advances in cryogenic single-photon detection by employing superconducting Transition Edge Sensors (TESs). We are currently developing a TES-based detector system that can meet the requirements for ALPS II, offering single-photon detection with high efficiency and low-backgrounds at the 1064 nm (1.165 eV) energy of interest. In this work, we present the current status of the ALPS II TES detector characterization efforts.

**Tuesday Session 2 / 40**

## Axion relics in non-standard cosmologies

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I will review our recent findings in axion production by considering a period before the onset of Big Bang nucleosynthesis that experimented a non-standard expansion. I will start with cold dark matter production through the misalignment mechanism, firstly assuming the energy density of the universe is dominated by a particle field described by a general equation of state. Secondly, I will refer to the case involving early matter domination by a scalar field with a time-dependent decay rate. In both scenarios, I will show the parameter space where the QCD axion is a dark matter candidate.
Finally, I will refer to axion thermal production during early matter domination or a late reheating era.

**Friday Session 2 / 41**

## SUPAX - A Superconducting Axion Search Experiment

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SUPAX is one of the first RF cavity based experiments in Germany to search for axions. Axions could solve the well known strong CP problem and may explain the dark matter content of the universe.
Axions are expected to convert to photons in the presence of a strong magnetic field, where the photon frequency depends on the axions mass. For wavelengths in the microwave regime resonators are typically used to enhance the axion signal.

SUPAX is using such a resonator in form of an RF cavity. A cavity made of copper has already been produced and successfully tested at room and LHe temperatures, probing for Dark Photons in the absence of a magnetic field, whilst tunable and superconducting RF cavities are currently being developed to improve the quality factor. We are planning to coat the inside of the cavity with a superconductor which can maintain superconductivity in magnetic fields up to 14 T and has not been used in this context. With this innovative approach and by using an existing 14 T magnet at the Helmholtz Institute at the Johannes Gutenberg University in Mainz, the largely unexplored mass region between 20 $\mu$eV to 50 $\mu$eV could be tested.

In this talk I will cover the experimental setup, data acquisition, analysis and current results of the experiment as well as future ideas of the experiment beside the search for Dark Matter candidates like axions and dark photons.

**Tuesday Session 2 / 42**

# MADMAX

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MADMAX, the MAgnetized Disc and Mirror Axion eXperiment, is a dielectric haloscope concept with the aim to detect the axion in the mass range 40-400 ueV through axion-photon conversion in the presence of a strong magnetic field.
In this talk I will review the MADMAX design concept, and discuss the status of ongoing research into booster systems for enhancing the weak axion signal.
Preliminary results will be presented from a prototype Closed Booster with 100 mm diameter disks, which was operated at room temperature in CERN's 1.6T MORPURGO magnet. The data provide the first limits on ALPs using a dielectric haloscope.
Significant progress has been made on the realization and calibration of an Open Booster prototype with three movable disks. These necessary steps towards the full scale dielectric haloscope will be presented, together with the outlook towards first ALPs run at cryogenic temperature.

**Monday Session 4 / 43**

# Probing the blue axion with cosmic optical background anisotropies

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A radiative decaying big bang relic with a mass at the eV scale, which we dub "blue axion,"can be probed with direct and indirect observations of the cosmic optical background (COB). The strongest bounds on blue-axion cold dark matter come from the Hubble Space Telescope (HST) measurements of COB anisotropies at 606 nm. We suggest that new HST measurements at higher frequencies (336 nm and 438 nm) can improve current constraints on the lifetime up to one order of magnitude, and we show that also thermally produced and hot relic blue axions can be competitively probed by COB anisotropies. We exclude the simple interpretation of the excess in the diffuse COB detected by the Long Range Reconnaissance Imager (LORRI) as photons produced by a decaying hot relic. Finally, we comment on the reach of upcoming line intensity mapping experiments, that could detect blue axions in a large portion of the parameter space for either cold or hot dark matter.

**44**

## On Discrete Goldstone bosons

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Exact discrete symmetries, if non-linearly realized, can reduce the ultraviolet sensitivity of a given theory. The scalars stemming from spontaneous symmetry breaking are massive without breaking the discrete symmetry, and those masses are protected from divergent quadratic corrections. This is in contrast to non-linearly realized continuous symmetries. In this talk we use invariant theory to develop the specific case of a scalar in a triplet of $A_4$, showcasing the substantial improvements and compelling phenomenological consequences of this setup.

**Tuesday Session 1 / 45**

## First Results of BREAD: Broadband Reflector Experiment for Axion Detection

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We report R&D progress, as well as first dark photon search results with BREAD - a novel dish antenna for broadband ~$\mu$eV-eV wave-dark matter detection, which allows to utilize state-of-the-art high-field solenoidal magnets. Axions are converted non-resonantly to photons on a cylindrical metallic wall parallel to an external magnetic field. These photons are then focused using a novel reflector geometry onto a state-of-the-art high-sensitive photon detector. We recently demonstrated [PRL 128 (2022) 131801] that this concept using a $\sim 10\,\mathrm{m}^2$ conversion area in a $\sim 10\,\mathrm{T}$ solenoidal magnet has the potential to discover QCD axions spanning multiple decades in mass range. In this talk we discuss progress of our first stage pilot experiments - GigaBREAD and InfraBREAD - covering different mass ranges. We show first results of a room-temperature GigaBREAD prototype and discuss upscaling to larger, cryogenic and magnetized versions.

**Poster Session / 46**

## ANHARMONIC EFFECTS ON THE SQUEEZING OF AXION PERTURBATIONS

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It is well known in cosmology that the history of the Universe undergoes a period of quasi exponential expansion. The fluctuations of the inflaton field are believed to have a quantum origin, however the CMB sky we observe today is classical. Therefore the questions whether the initial perturbations have a quantum or classical origin and how to discriminate them arise. Actually inflation itself provides an explanation for the "classicalization" of the originally quantum perturbations. They are squeezed due to the fast expansion of the universe. A squeezed state is a special quantum state for which one variable is allowed to have an arbitrarily small uncertainty, while its conjugate counterpart has a very big uncertainty correspondingly. This is indeed the most quantum state we could think about, however, from an observational point of view, it is indistinguishable from a classical phase-space distribution. In this talk, I will present the evolution in time of the perturbations of axion-like particles, introducing the notion of Bogoliubov coefficients and squeezing parameters. I will also present the link between these mathematical notions and physical observables, in order to address the question about the observability of the quantum nature of these perturbations. Moreover I will study the modification of the squeezing parameters due to anharmonic effects. An exponential increase in the Bogoliubov coefficients, i.e. in the average energy density of the perturbations, is observed.

**Tuesday Session 2 / 47**

## New results for searches of exotic decays with NA62 in beam-dump mode

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We report on the search for visible decays of exotic mediators from data taken in "beam-dump" mode with the NA62 experiment.
The NA62 experiment can be run as a "beam-dump experiment" by removing the Kaon production target and moving the upstream collimators into a "closed" position. More than $10^{17}$ protons on target have been collected in this way during a week-long data-taking campaign by the NA62 experiment. We report on new results from analysis of this data, with a particular emphasis on Dark Photon and Axion-like particle Models.

**Poster Session / 48**

## dSpec, dead-time free spectrometer for WISP searches using 5G telecommunication technologies

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In the WISP search, the broad coverage of the mass region is crucial because we know neither dark matter mass nor coupling to standard model particles. In particular, many Axion or dark photon experiments search the conversion photon signal in radio wave range (O(1 GHz) - O(100 GHz)), and the signal is expected to be observed as a narrow peak. Therefore, ideal specifications of the spectrometer are wide frequency coverage (e.g., 4 GHz bandwidth) as well as dead-time-free. However, in the

case of commercially available spectrometers, they have ~1% efficiency in time (i.e., time fraction of measurement) or only a few MHz bandwidth typically. We solved this situation by developing a spectrometer, "dSpec", which is optimized for the WISP search (i.e., optimized for measuring the narrow frequency peak over a wide range). dSpec is built on a single RFSoC 2x2 board (AMD Xilinx), which has a CPU, an FPGA, two DACs, and two high-speed ADCs. This board has made for 5G telecommunications. We developed 16 paralleled FFT architecture on the FPGA. It allows us to construct the spectrometer with a wide bandwidth (4 GHz) and fine frequency resolution (31kHz). We evaluated the performance of dSpec, and we confirmed the good performance for the WISP search, e.g., nonlinearity < 0.5%, time efficiency > 99.9%. We will present the design of the dSpec as well as its performance test results.

**Friday Session 2 / 49**

# Ultra-high Q cavity-based search for the Dark Photon: new exclusion limit from Dark SRF phase 1 and steps forward for phase 2

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We present here the first results of Dark SRF, a light-shining-through-wall (LSW) experiment that leverages ultra-high quality factor superconducting radio frequency (SRF) cavities to search for dark photons. The use of Nb SRF cavities combined with a strict calibration and measurement protocol increased sensitivity to dark photons by several orders of magnitude compared to other LSW experiments, as demonstrated by our new limit that excluded a broad range of previously unstudied dark photon mass and mixing angle.
In addition to the results of the search conducted in liquid helium using 1.3GHz SRF cavities, we also present the first steps of the second phase of the experiment, which will take place in a dilution refrigerator using 2.6GHz SRF cavities. These experiments are part of a wider effort of the Superconducting Quantum Materials and Systems (SQMS) Center to employ ultra-high Q SRF cavities to search for Beyond the SM particles and wavelike dark matter.

**Tuesday Session 3 / 50**

# Results from ADMX: Searching for Axon Dark Matter in the 3.3-4.2 μeV Mass Range

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Axions are a well-motivated theoretical particle that solve the Strong CP problem of quantum chromodynamics. The properties of the axion make it a compelling dark matter candidate. The Axion Dark Matter eXperiment (ADMX) searches for axion dark matter within the local Milky Way halo using an axion haloscope. This presentation will discuss results from the most recent run of ADMX

which searched for axions between 3.3-4.3 μeV. In addition, we will also provide updates on future searches with ADMX that will search for axions at higher frequencies using a multi-cavity array.

**Wednesday Session 3 / 51**

## Haloscope searches for axion dark matter with CAPP

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Significant experimental efforts to search for QCD axions have been made at the Center for Axion and Precision Physics Research (CAPP) in order to address the fundamental questions in physics: the strong CP problem and the dark matter mystery. The Center has established a world-class facility dedicated for cavity haloscope searches relying on the axion-photon coupling. By leveraging powerful equipment such as high-field superconducting magnets and high-performance refrigerators, as well as sensitive quantum devices such as a series of Josephson parametric amplifiers, CAPP has begun to explore the theoretically interesting territory represented by the KSVZ and DFSZ models. CAPP has also developed state-of-the-art technologies in various areas to enhance experimental performance over wider frequency ranges. In this presentation, the recent search results and several novel R&D developments are highlighted and future plans are discussed.

**Wednesday Session 2 / 52**

## Superfluid Frequency Tuning of Superconducting Cavities for Axion Dark Matter Search

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The Center for Axion and Precision Physics Research (CAPP) has introduced a new generation of axion haloscopes by developing high quality factor ($> 10^7$) superconducting cavities even in the high magnetic field, utilizing high-temperature superconducting (HTS) tapes. In order to practically utilize superconducting cavities in axion haloscopes, the tuning mechanism should not compromise the cavity's quality factor or the geometrical factor. CAPP has developed an advanced frequency tuning mechanism that uses superfluid liquid helium (SLHe) to precisely control the amount of liquid helium in the cavity at the nanoscale level. This tuning method can adjust the resonant frequency of the cavity by up to 3\%, while maintaining the quality and form factors within 10\%, even when the quality factor is much larger than the axion quality factor. In addition, the use of SLHe eliminates the need for mechanical movement, resulting in thermally stable frequency tuning. A commissioning axion search experiment is underway utilizing a HTS cavity with an ultra-high quality factor ($> 10^7$) and a SLHe tuning method. We aim to present our preliminary findings at the upcoming workshop.

**Poster Session / 53**

## Spectrum of dark matter axions from strings

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Understanding of the production of axions from global string decays in the early universe is indispensable for the precise estimation of the relic axion abundance and for a sharp prediction of the axion dark matter mass. In this contribution, we present the state-of-the-art results on the analysis of the spectrum of dark matter axions radiated by strings based on the large scale numerical simulations of the Peccei-Quinn field in the expanding background. We discuss several systematic effects that can bias the numerical results, and point out that some of them could be regarded as possible sources of discrepancy in the literature. It turns out that the spectrum is highly distorted at large string tension due to discretization effects, which highlights the need for further improvement in the dynamical range to resolve the discrepancy. By extrapolating the numerical results, we also quantify the predicted values of the axion dark matter mass and its uncertainty.

**Poster Session / 54**

## Measuring the Electric Dipole Moment of the electron using polar molecules in a parahydrogen matrix

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The electric dipole moment of the electron (eEDM) is a sensitive probe for new physics beyond the Standard Model that can also provide indirect evidence for the existence of dark matter. We propose an experiment to measure the eEDM using diatomic polar molecules (BaF) embedded in a cryogenic matrix of parahydrogen. By exploiting the large internal molecular field available in BaF molecules and the efficient cooling and large concentrations of molecules enabled by the parahydrogen matrix, the proposed experiment has the potential to improve the current eEDM limits by over an order of magnitude, down to around $10^{-31}\ e{\cdot}\mathrm{cm}$. Such an improvement could provide important information about the sources of CP violation and help understand the origin of the matter-antimatter asymmetry in the universe. Furthermore, our measurements could indirectly offer insights into the nature of dark matter since many extensions of the Standard Model that account for dark matter predict an eEDM large enough to be within the measurement range of planned experiments.

**Poster Session / 55**

## WISPFI-E: WISP searches on a Fiber Interferometer under the application of an Electric field

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The search for dark matter axions is an ongoing challenge for modern physics, and conventional searches typically involve the use of external magnetic fields to detect axions. However, these experiments are not sensitive to the axion-photon couplings $g_{aAB}$ and $g_{aBB}$ predicted in scenarios based upon modified Quantum-Electromagnetodynamics. We propose here a novel approach to search for resonant photon-axion conversion by integrating hollow-core photonic crystal fibers (HC-PCF) in a Mach-Zehnder interferometer and measuring changes in amplitude/phase. By attaching electrode strips to the HC-PCF, it is possible to probe the photon-axion conversion under the application and

modulation of strong electric fields. The application of an electric field of $\sim 5\ MV/m$ or higher will allow us to achieve sensitivity levels comparable to those of conventional searches conducted with external magnetic fields of the order of $\sim 14T$. This can significantly decrease the experimental cost and can also allow for a much higher sensitivity. By overcoming the technological challenges of generating such high electric fields, this approach can open up additional unique opportunities in direct dark matter searches.

**Poster Session / 56**

## Intensity Interferometry Search for Ultralight Bosonic Dark Matter in GNOME Data

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The Global Network of Optical Magnetometers for Exotic physics searches (GNOME) [1] uses precise atomic spin-based sensors (magnetometers and comagnetometers) to search for ultralight dark matter (e.g., axions and axion-like particles). GNOME searches for the global exotic spin perturbations that could be simultaneously observed in distant laboratories. It was recently proposed to use GNOME to search for ultralight bosonic dark matter virialized in the galactic halo by possible quadratic coupling to fermion spins [2]. This so-called intensity interferometry approach is based on searches for correlations in stochastically fluctuating signals recorded in different GNOME stations. Compared to the resonant searches aiming at a direct detection of oscillations in signals arising at the dark matter Compton frequency, this approach allows us to extend the probed Compton frequency range by around six orders of magnitude (corresponding to the ratio of carrier Compton frequency to the frequency dispersion caused by the relativistic Doppler effect). With a bandwidth of around 100 Hz, GNOME is expected to probe quadratic coupling in a mass range $10^{-14}$-$10^{-9}$ eV. Working progress and analysis prospects will be discussed during the presentation.

[1] S. Pustelny, et al., The global network of optical magnetometers for exotic physics (gnome): A novel scheme to search for physics beyond the standard model, Annalen der Physik 525, 659 (2013).

[2] H. Masia-Roig, et al., Intensity interferometry for ultralight bosonic dark matter detection, arXiv:2202.0264510.48550/arXiv.2
(2022).

**Tuesday Session 3 / 57**

## Light Dark Matter search with the NA64-e Experiment at Cern SPS

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The Dark Matter (DM) puzzle is one the major topics of modern physics. Several astrophysical and cosmological observations suggest that DM makes the vast majority of the mass of the Universe but, to date, its elementary properties remain unknown. In addition to gravity, DM could interact with ordinary matter through a new force, mediated by a new vector boson (Dark Photon, Heavy Photon or A'), kinetically mixed with the Standard Model (SM) photon. The NA64-e experiment at Cern SPS explores this theoretical scenario, using a 100 GeV electron beam impinging on a thick active target (electromagnetic calorimeter, ECAL). The interaction of the beam with the target may produce a Dark Photon, subsequently decaying in a pair of DM particles, flying away from the detector carrying a significant part of the primary electron energy. The signature of the A' production is a significant missing energy, defined as the difference between the energy of the incoming electron of the beam and the energy deposited in the ECAL. In order to reject events were SM processes result in the production of highly penetrating particles (such as muons, pions, neutrons…) escaping the active target and mimicking the signal signature, NA64-e features a large hadronic calorimeter, used as an active veto, placed downstream the ECAL.
With no positive DM evidence in $2.84 \times 10^{11}$ electrons on target, the NA64-e experiment set the most competitive limits in a significant portion of the A' parameter space. During fall 2022, together with the electron-beam data-taking, NA64-e collected data with a positron beam, in order to exploit the intense positron annihilation mechanism for DM production. This talk will present the NA64-e status and its future prospects, reporting on the progresses on the analysis of data collected in 2022 in both electron and positron mode.

**Wednesday Session 2 / 59**

## Axion dark matter search with DFSZ sensitivity at CAPP

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The axion is a solution to two distinct puzzles in the universe. It was originally proposed by Peccei and Quinn to explain the CP conservation in strong interactions, and in a specific mass range it naturally becomes a dark matter candidate. The CAPP-12T experiment conducted at the Center for Axion and Precision Physics Research (CAPP) searches for axions in the mass range equivalent to 1 –2 GHz with Dine-Fischler-Srednicki-Zhitniskii sensitivity. The experimental setup includes a wet-type dilution refrigerator, a 12 T superconducting solenoid with 320 mm diameter, nearly quantum-limited noise Josephson parametric amplifiers, and a large volume (36.8 L) thin copper cavity. Following the first successful search in 2022, the second phase of the experiment with improvements including the readout circuit by three JPAs in series
has successfully finished scanning up to 1.18 GHz. I will discuss the results from the first and second phases of this experiment, as well as our plans for the future.

**Poster Session / 60**

## Detection of hidden photon dark matter using the direct excitation of transmon qubits

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We propose a new dark matter detection method utilizing the excitation of superconducting qubits [1]. Assuming the hidden photon dark matter of a mass of $O(10)$ $\mu$eV, the classical wave-matter oscillation induces an effective ac electric field via the small kinetic mixing with the ordinary photon. This serves as a coherent drive field for a qubit when it is resonant, evolving it from the ground state towards the first-excited state. We evaluate the rate of such evolution and observable excitations in the measurements, as well as the search sensitivity to the hidden photon dark matter. For a selected mass, one can reach $\epsilon \sim 10^{-12} - 10^{-13}$ (where $\epsilon$ is the kinetic mixing parameter of the hidden photon) with a few tens of seconds using a single standard transmon qubit. While the absolute expected sensitivity does not surpass the conventional haloscope experiments, it has a significant advantage in the frequency tunability using the SQUID-based qubit, with which a mass scan over 1-10 GHz can be achieved. The volume-independent nature of the sensitivity is also promising for searches in the high frequency regime (>10 GHz). The sensitivity scalability along the number of qubits also makes it a promising scheme in accord to the rapid evolution of the superconducting quantum computer technology.

[1] arXiv: 2212.03884

**Poster Session / 61**

## Dark matter and axion dark radiation properties from energy cascade in dark matter flow

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We present a new theory to predict dark matter (DM) particle mass, size, lifetime, and properties of possible dark radiation from DM particle decay. In self-gravitating collisionless dark matter, the existence of inverse mass and energy cascade from small to large scales facilitates the hierarchical structure formation. A scale-independent constant rate of energy cascade $\varepsilon_u \approx -4.6 \times 10^{-7} m^2/s^3$ can be identified. The energy cascade leads to a two-thirds law for pairwise velocity and a four-thirds law for halo density profile. Both scaling laws can be directly confirmed by N-body simulations and galaxy rotation curves. For collisionless dark matter with only gravity involved, scaling laws can be extended down to the smallest scale, where quantum effects become important. Combining $\varepsilon_u$, Planck constant $\hbar$, and gravitational constant $G$ on that scale, we predict DM particles have a mass $m_X = (\varepsilon_u \hbar^5 G^{-4})^{1/9} = 0.9 \times 10^{12}$GeV, a size $l_X = (\varepsilon_u^{-1} \hbar G)^{1/3} = 3 \times 10^{-13}$m, and a lifetime $\tau_X = c^2/\varepsilon_u = 10^{16}$yrs, where $c$ is the speed of light. The energy scale $E_X = (\varepsilon_u^5 \hbar^7 G^{-2})^{1/9} = 10^{-9}$eV strongly suggests a dark "radiation" field to provide a viable energy dissipation mechanism. If existing, the dark "radiation" should be produced by DM decay at early time $t_X = (\varepsilon_u^{-5} \hbar^2 G^2)^{1/9} = 10^{-6}$s (quark epoch) with a mass of $10^{-9}$eV such that axion can be a very promising candidate. If axion is the dark "radiation" responsible for the energy dissipation, it should have a mass around $10^{-9}$eV with a GUT scale decay constant $10^{16}$GeV and an effective axion-photon coupling constant $10^{-18}$GeV$^{-1}$. The dark radiation energy density is around $\Omega_a h^2 \approx 2.6 \times 10^{-7}$, which is about 1 percent of the photon energy in CMB. Parameterized by the increase in the effective number of neutrino, $\Delta N_{eff} = 0.02$ can be obtained. Since the DM particle mass $m_X$ is only weakly dependent on $\varepsilon_u$ as $m_X \propto \varepsilon_u^{1/9}$, the estimation of $m_X$ should be pretty robust for a wide range of possible values of $\varepsilon_u$. If gravity is the only interaction and dark matter is fully collisionless, mass of $10^{12}$GeV seems required to produce the given rate of energy cascade $\varepsilon_u$. In other words, if DM particle mass has a different value, there must be some new interactions beyond gravity. This work suggests a heavy dark matter scenario with a mass much greater than WIMPs. Potential extension to self-interacting dark matter is also presented. More details can be found at arXiv:2202.07240.

**Friday Session 1 / 62**

## Dark Matter searches with the MAGIC telescopes

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The MAGIC (Major Atmospheric Gamma ray Imaging Cherenkov) telescopes are a system of two Imaging Cherenkov telescopes located on the Canary island of La Palma. They detect very high energy (VHE, E>100GeV) gamma rays by capturing the Cherenkov light released from charged particles in the gamma-ray-induced particle showers. For many years MAGIC devoted a consistent part of the observation to the collection of data which can be used for Dark Matter searches. Processes like Dark Matter annihilation and decay have been explored on several targets: clusters of galaxies such as the Perseus cluster, Dwarf Spheroidal galaxies, the Galactic center and even globular clusters. We are presenting the most important results published by MAGIC in Dark Matter searches, some of them being very important for the field of high energy astrophysics.

**Wednesday Session 3 / 63**

## DMRadio-50L Overview and Status Update

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The axion is one of the most compelling dark matter (DM) candidates and a solution to the strong charge-parity problem. DMRadio-50L is a resonant lumped-element detector with a toroidal magnet searching for axions in the range 5 kHz - 5 MHz (20 peV - 20 neV) with a target sensitivity to axion-photon-photon coupling $5 \times 10^{-15}$ GeV$^{-1}$. DMRadio-50L also acts as an innovation platform and technology test bed for quantum sensors that will enable a next-generation search for GUT-scale axions in this mass region (DMRadio-GUT). This talk will provide an overview of the DMRadio-50L experiment as well as an update of its ongoing construction.

**Monday Session 2 / 64**

## Searches for daily modulations with the CAST-CAPP detector

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Despite the overwhelming observational evidence, dark matter has so far been elusive to all experimental searches. As an example, haloscope experiments, which are the most sensitive ones, are focusing on narrow resonant searches while trying to minimize the noise and increase the signal power. However, a broadband approach might be the key to the discovery of the axion. Axion Quark Nuggets (AQN) were originally proposed to explain the similarity of the dark and visible cosmological matter densities. Relativistic axions (~0.6c) are then emitted from AQNs when they propagate through the Earth's atmosphere and interior. AQN production mechanism should manifest itself in (i) a daily modulation of flux up to 20% and (ii) a seasonal phase shift. These features, together with a broadband detection strategy could provide a novel tool in the search for axions.

In this talk, we will present the preliminary analysis results of selected data from the CAST-CAPP detector that were used as a proof of principle and were compared with the B=OFF data where no signal should be present. The applied analysis sets the ground for future analyses also with other haloscope experiments and has the potential to re-shape direct axion searches.

**Monday Session 3 / 65**

## From Black Holes into the Voids: What TeV Astrophysics Tells Us about Axion-like Particles

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TeV blazars, ubiquitous in the extragalactic gamma-ray sky, produce pair beams that inverse-Compton cascades into GeV gamma rays. However, the non-observation of such cascades indicates that non-thermal energy loss processes such as interactions with heavy axion-like particles (ALPs) can play a role in alleviating this GeV-TeV tension, in addition to space plasma instabilities that drain energy into the intergalactic medium plasma as well as the deflection and diffusion of the pair beam due to the intergalactic magnetic field. A direct consequence of the instability losses and heating of the IGM plasma is the modification of the thermal history at late times, which suppresses structure formation particularly in baryonically underdense regions, potentially holding a clue towards resolving the small-scale crisis in cosmology. Depending on the resonant modes and degree of heating, constraints on lighter ALPs are further tightened.

**Poster Session / 66**

## Axions as solar thermometers

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The upcoming helioscope experiment IAXO is sensitive to realistic QCD axion models, making it one of the most exciting future axion searches. Indeed, in case of a discovery, IAXO may even determine the axion mass in the multi-meV range and allow us to study solar metallicities, magnetic fields, and distinguish different solar or axion models.
This talk further explores that scenario. In particular, I will show how the helioscope's solar "axion image"can be inverted to infer the solar temperature and Debye scale at different points inside the entire Sun. Apart from laying out the necessary computational steps, I will explicitly demonstrate the viability of this approach for IAXO and comment on the relationship of our method with similar techniques, neutrino observatories, and related efforts within my MSCA fellowship "AxiTools."

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## Testing universal dark-matter caustic rings with galactic rotation curves

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Infall of cold dark matter on a galaxy may result in caustic rings where the particle density is enhanced. They may be searched
for as features in the galactic rotation curves. Previous studies suggested the evidence for these caustic rings with universal, that is
common for different galaxies, parameters. Here we test this hypothesis with a large independent set of rotation curves by means
of an improved statistical method. No evidence for universal caustic rings is found in the new analysis.

**Poster Session / 68**

## Axion-like particle emission from type Ia supernovae

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Axion-like particles (ALPs) are a class of hypothetical bosons beyond the standard model of particle physis, which are very weakly-interacting and long-lived. Since many ALPs may be produced in hot plasma in supernovae (SNe), a nearby SNe Ia can be used as a probe of ALPs. It is desirable to predict the ALP emission from SNe Ia to discuss a possible constraint that can be obtained from the event. ALPs may convert into photons and back in the magnetic field in the intergalactic space and galaxies. It is hence possible to constrain the ALP parameters by γ-ray observations of a nearby astronomical object which emits a lot of ALPs. Here, we calculate the ALP emission from type Ia SNe and take into the account the light range of ALPs mass. Using the SN Ia model, we consider the issue of detection a photon flash from SNe Ia.

**Monday Session 3 / 69**

## Cosmic Last Scattering Surface as an Axion Dark Matter Detector

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We derive the isotropic birefringence (all-sky rotation of linear polarization) of the cosmic microwave background (CMB) sourced by axion-like particles (ALPs) or 'axion'dark matter. We find distinct birefringence signals for oscillating ultra-light axions at recombination as well as from local dark matter. Using *Planck* upper limits while incorporating allowed axion fractions of dark matter, we find strong constraints on the axion-photon coupling which can improve over CAST limits by up to 5 and 2 orders, respectively for recombination and local dark matter axions.
Forecast constraints (*SO, CMB-S4, CMB-HD & PICO*) can tighten coupling constraints further by 1-2 orders, extending to higher axion mass.

The recent hints of a detection (at ~3σ) of isotropic CMB birefringence from a re-analysis of *Planck* and *WMAP* data are considered, in light of our new axion dark matter signals. We point out regions of interest in the parameter space for ultra-light axion dark matter which could explain this detection of isotropic cosmic birefringence, if confirmed.
CMB birefringence constraints scale only weakly with ALP fraction of dark matter. They are also unaffected by uncertainties common to other astrophysical ALP probes: strength and spectrum of magnetic fields, over- density of ALPs in structures or objects and the source's intrinsic polarization orientation.

**Monday Session 3 / 70**

## Astrophysical Searches for the String Axiverse

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Compactification in string theory generally gives rise to a large number of pseudoscalar, Axion Like Particles (ALPs). Remaining agnostic to the exact form of the resulting Lagrangian, we consider an $N \in [2, 30]$ axion model for which ALPs are mass mixed in the interaction basis. As a consequence, and akin to neutrinos, we find the ALPs flavours to oscillate amongst themselves during propagation. Within the interaction basis, coupling to the standard model is present only for one flavour of ALP with the remaining ALPs being "hidden". The capacity for interacting ALPs to oscillate into a hidden sector effectively dilutes their interactions with the standard model, thereby weakening the bounds on their coupling. We have recast existing astrophysical bounds, paying specific attention to those arising from Very High Energy (VHE) Blazar spectra as well as the CAST experiment. Recent observations have shown the intergalactic space to be more transparent to VHE gamma rays than is expected given the Extra-Galactic Background Light (EBL) density. The introduction of an ALP alleviates this discrepancy by providing a mode within which the VHE photons can propagate unimpeded by EBL. We have extended this to the non-trivial case of multiple axions, where the large inter-galactic distances allow ample time for oscillation to occur. The CAST experiment, in contrast, with its limiting propagation distance, provides a stage on which to consider the effect of a misaligned EM/Electronic ALP mixing on axion couplings in a multi axion scenario.

**Monday Session 2 / 71**

## First Results from the LUX-ZEPLIN Dark Matter Experiment

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The LUX-ZEPLIN (LZ) experiment is a multi-tonne dark matter direct detection experiment operating 4850 feet underground at the Sanford Underground Research Facility in Lead, South Dakota. At the heart of LZ is a liquid xenon time projection chamber (TPC) with an active mass of 7 tonnes that will search for the low energy signatures from interactions with WIMP dark matter in our galactic halo and other rare physics processes. It includes an active veto system consisting of an optically separated and instrumented xenon skin layer and a surrounding external liquid scintillator outer detector to provide rejection and characterisation of gamma-rays and neutrons from internal sources.

An extensive materials screening campaign and in-house purification of the liquid xenon has ensured that LZ meets the strict radioactivity constraints needed to explore new parameter space in the search for Dark Matter. In this talk, I will present dark matter search results from the first science run of LZ between December 2021 and May 2022, report on the experiment's status and discuss the next steps towards a global LXe rare-event search observatory.

**Poster Session / 72**

## Searching for photon-ALPs mixing effects in AGN gamma-ray energy spectra

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High energy gamma-rays propagating in external magnetic fields may convert into axion-like particles (ALPs). In this case, the observed gamma-ray spectra are modified by the resulting energy-dependent conversion probability. In this study, we use the energy spectra of 20 extra-galactic gamma-ray sources recorded during 10 years of \textit{Fermi}-LAT observations. We define a test statistics based upon the likelihood ratio to test the hypothesis for a spectral model without vs. a model with photon-ALPs coupling. The conversion probability is calculated for fixed values of the mass and two-photon coupling of the pseudo-scalar particle while the external magnetic field is characterized by the additional free parameters length scale $s$ and average field strength $B$. As a consistency check and in order to extend the analysis to include very high energy gamma-ray data, another test statistics is defined with the $\chi^2$ method. We find for 18 of the 20 sources a favorable fit, particularly for Markarian~421 and NGC~1275 a significant improvement, with the hypothesis of photon-ALPs coupling in likelihood analysis. The test statistics of the sources are combined and the significance has been estimated $5.3\ \sigma$ (test statistics summed in local maxima of all sources) and $6.0\ \sigma$ (global maxima). The significance is estimated from dedicated simulations under the null hypotheses. The locally best-fitting values of $B$ and $s$ fall into the range that is expected for large scale magnetic fields present in relevant astrophysical environments.

**Tuesday Session 2 / 73**

## Axion-like particle effects in high-energy astrophysics

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Abstract: Axion-like particles (ALPs) are very light neutral spin-zero bosons predicted by superstring theory and primarily interacting with two photons. In the presence of an external magnetic field they give rise to two effects: (i) photon-ALP oscillations, (ii) change of the photon polarization state. The former effect produces a modification of the photon transparency and irregularities in observed spectra. In addition, two hints at ALP existence have been discovered associated with photon-ALP oscillations. Observatories like ASTRI, CTA, LHAASO will likely provide us additional information. ALP-induced effects on photon polarization are also sizable in a wide energy band from the X-ray up to the MeV range when photons are produced in the central region of galaxy clusters or at the jet base of blazars. The ALP-induced features on photon polarization can give us additional hints at the ALP existence or further constrain the ALP parameter space. We expect observatories like IXPE in the X-ray band, and like COSI and AMEGO in the MeV range to be able to detect these possible effects.

**Thursday Session 1 / 74**

## WIMP direct detection experiments

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Direct dark matter detection experiments aim to observe interactions between dark matter particles and ordinary matter, in order to identify and study this elusive substance that makes up a significant fraction of the mass of the Universe.

Weakly interacting massive particles (WIMPs) are among the most popular dark matter candidates. In this talk, we will discuss the current status of direct detection experiments searching for WIMP dark matter and the different detection methods that have been used.

We will also discuss experimental challenges and explore future opportunities in direct WIMP detection, which may enable even more sensitive and precise measurements in the coming years.

**Thursday Session 1 / 75**

## The Dark Matter Radio Suite of Experiments

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DMRadio searches for QCD axions over a broad mass (frequency) range: 0.4neV to 0.8ueV (0.1MHz to 200MHz), with sensitivity down to the DFSZ model. To achieve this ambitious goal, DMRadio includes three axion detection experiments: DMRadio-50L is under construction and will begin operation in early 2024. It consists of a toroidal magnet with a superconducting sheath and solenoidal resonator pickup operating from 5kHz to 5MHz. The design of DMRadio-m3 is nearing completion. It consists of a solenoidal magnet with a copper coaxial resonant pickup, and will reach DFSZ from 30 MHz to 200 MHz. DMRadio-GUT is a future experiment to build on experience from both DMRadio-50L and DMRadio-m3. It uses a large detector volume with quantum enhancement to reach DFSZ from 0.1 MHz to 30 MHz. While readout with dc SQUIDs is sufficient for DMRadio-m3, quantum enhanced measurement through radio frequency quantum upconverters will be needed for DMRadio-GUT. To this end, quantum upconverters will be deployed on DMRadio-50L as a testbed for quantum enhancement. Experimental design and projected sensitivities for the DMRadio suite will be presented.

**Friday Session 2 / 76**

## Status and recent developments of the QUAX haloscope at Legnaro National Laboratories

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The QUaerere AXion (i.e. QUest for AXions, in short QUAX) experiment is an haloscope-based galactic axion search effort aiming to probe theoretically-relevant axion-photon couplings in the 8.5-11 GHz frequency window.
This frequency range will be covered by two haloscope setups, located at LNL- and LNF-INFN laboratories in Italy respectively. In this talk we will focus on the recent results obtained at LNL, starting with the detailed analysis of the summer 2022 data run. The proof-of-concept acquisition covered a 200 kHz frequency range around 10.35345 GHz, demonstrating the highest sensitivity yet obtained above 10 GHz.
The employed resonator was a TM030 dielectric cavity with loaded Q factor of $\sim$250000 in overcoupled conditions, while a Nb-Ti superconducting magnet provided an 8 T magnetic field. The run took advantage of the low temperatures provided by a dilution refrigerator, allowing the installation of a low noise Traveling Wave Parametric Amplifier (TWPA) developed by the group of N. Roch (Grenoble).
Total noise temperature of the setup was measured as 2.06 +/- 0.13 K, resulting in peak sensitivity of $g_{a\gamma\gamma} < 2.05 \cdot 10^{14}$ GeV$^{-1}$ at 95% C.L. We will also detail recent developments at LNL, such as testing of an easily tuning mechanism for empty cavities and of a high C-factor TM030 Bragg resonator. Additionally, we will present the results concerning a novel coaxial polygonal cavity, which promises both very high effective volumes and frequency tunability. Finally, we will give an overview of the near-future perspectives for the experiment, detailing the plans to upgrade the current setup to a fully operational haloscope.

**Thursday Session 2 / 77**

## Recent developments on axion searches at LNF

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The Low-Energy Frontier of Particle Physics 1 provided a well motivated case for physics at the subelectronvolt scale that inspired the design and realization of several experiments within the reach of small and medium laboratories.
At the National Laboratories of Frascati [2] (LNF), the interest in the dark sector first started at the KLOE experiment [3] with the search of light vector-mediators produced in e+e− collisions at 1 GeV, and continues today with the PADME experiment [4], that looks for dark photons with a positron-beam dump experiment, the second Sikivie's haloscope of the QUAX experiment, and a proposal for a large haloscope [5, 6], FLASH, for searches of axions, dark photons and high-frequency gravitational waves at 100 MHz.
We will discuss the commissioning of the second QUAX haloscope, operating at about 9 GHz, the perspectives for the next few years run and the results of the ongoing R&D, needed to increase the haloscope sensitivity, on quantum amplifiers, microwave-photon counters and superconducting cavities.
Then, we will discuss the status of the FLASH-haloscope proposal and present the updated sensitivities to axions, dark photons and HFGW. The proposal is based on the recycling of the FINUDA magnet, a superconducting solenoid of 1.4 m radius, 2.2 m length and 1.1 T field.
The refurbishing and commissioning of the magnet started and we expect to conduct a cooling test within the year.

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[5] C. Gatti et al., arXiv:1811.06754 (2018).
[6] D. Alesini et al., arXiv:1911.02427 (2019).

**Monday Session 4 / 78**

## WIMP cross-section limits from radio observations of dwarf spheroidal galaxies

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Dark matter (DM) consisting of weakly interacting massive particles (WIMPs) self-annihilates into baryonic matter and provides a possibility for indirect detection. We observe dwarf spheroidal galaxies (dSph) because they are rich in DM but baryonic emissions are low. In the magnetic field of dSph, the particles produced in DM self-annihilation emit synchrotron radiation which peaks at low radio frequencies.

We use the non-detection of 150 MHz radio continuum emission from six dSph with the LOw-Frequency ARray (LOFAR) to derive constraints on the annihilation cross section of WIMPs where electron-positron pairs are produced. Our main underlying assumption is that the transport of the cosmic rays can be described by the diffusion approximation, requiring a non-zero magnetic field strength. We compute limits for multiple values of magnetic field and diffusion coefficient, taking the known measured values as the benchmark model.

The resulting limits exclude thermal WIMPs with masses below 20 GeV. Our limits are comparable to the limits set by FermiLAT using gamma-ray observations of multiple dSph and probe unique regions of low mass WIMPs. We also explore the improvement of the results with stacking and the potentially high uncertainty due to the choice of diffusion model parameters.

**Friday Session 2 / 79**

## JUNO's Quest: The Hunt for Solar Axions

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We shall discuss the 5.49 MeV solar axions flux produced in the $p(d,^3\mathrm{He})a$ reaction and analyze the potential to detect it with the forthcoming large underground neutrino oscillation experiment Jiangmen Underground Neutrino Observatory (JUNO). In doing so, we will consider axions through various processes such as Compton and inverse Primakoff conversion, as well as through their decay into two photons or electron-positron pairs inside the detector. In this talk, a detailed discussion to constrain the axion-electron ($g_{ae}$), axion-photon ($g_{a\gamma}$), and isovector axion-nucleon ($g_{3aN}$) couplings, using the expected JUNO data for different benchmark values of axion mass will be presented. For comparison, we shall also show bounds arising from other laboratory-based experiments.

**Poster Session / 80**

## Calibration of an open dielectric haloscope

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The \textbf{Ma}gnetized \textbf{D}isk and \textbf{M}irror \textbf{A}xion e\textbf{X}periment is a dielectric haloscope that aims to search for axionic dark matter. It utilizes a stack of movable dielectric disks, called a booster, to enhance the weak axion signal. The unique design enables a highly tunable resonator at frequencies inaccessible to traditional cavity haloscopes. However, the added complexity and open boundary conditions pose challenges for full 3D simulations. To gain a better understanding of the setup and identify relevant systematic effects, conducting 3D measurements of the electromagnetic field inside the booster proves to be a promising approach. Furthermore, reciprocity shows that measuring an electromagnetic test field, such as the one excited by a reflection measurement, enables direct calculation of the sensitivity to the axion signal.

In this talk, I will present measurements on the electromagnetic field of a small dielectric booster using non-resonant perturbation theory, commonly known as the bead pull method. This approach provides new insights into the electromagnetic properties of a dielectric haloscope and paves the way for a model-independent signal power calibration.

**Poster Session / 81**

## Running in the ALPs and beyond: the interplay between the SM and a singlet

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Axion-like particles or generalized pseudoscalar singlets are ubiquitous in BSM. Studying the evolution of their interactions with the SM is therefore of utmost importance.

I will discuss this interplay based on the derivation of the full set of renormalization group equations of the complete singlet EFT at one-loop accuracy, including shift-breaking and CP-violating interactions, and keeping trace of the mixing effects between the exotic and the Higgs particles. Our results are gathered in a new ALPRunner package, that we use to explore some phenomenological applications, such as EDM constraints for a generic singlet (including its mixing with the Higgs). We compare those constraints with the ones obtained in a more shift-symmeric scenario.

**Poster Session / 82**

## Dark Matter Searches with Qubits

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Dark Matter searches utilizing single-photon and phonon excitations have been broadly accepted as effective methods of harnessing the miniscule energies transferred from Ultra-light and Light Dark

Matter. Qubits are highly sensitive to sub-eV energy phonons and photons which make them a compelling detection technology for light and Ultralight Dark Matter. We will discuss the potential of this novel idea while providing a proof-of-principle demonstration of this technology and an overview of a brand-new R&D program at Fermilab.

**Thursday Session 4 / 83**

## Searching for Low-Mass Axions using Resonant Upconversion

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We present new results of a room temperature resonant AC haloscope, which searches for axions via photon upconversion. Traditional haloscopes require a strong applied DC magnetic background field surrounding the haloscope cavity resonator, the resonant frequency of which is limited by available bore dimensions. UPLOAD, the UPconversion Low-Noise Oscillator Axion Detection experiment, replaces this DC magnet with a second microwave background resonance within the detector cavity, which upconverts energy from the axion field into the readout mode, accessing axions around the beat frequency of the modes. Furthermore, unlike the DC case, the experiment is sensitive to a newly proposed quantum electromagnetodynamical axion coupling term $g_{aBB}$. Two experimental approaches are outlined - one using frequency metrology, and the other using power detection of a thermal readout mode. The results of the power detection experiment are presented, which allows exclusion of axions of masses between $1.12 - 1.20\ \mu eV$ above a coupling strength of both $g_{a\gamma\gamma}$ and $g_{aBB}$ at $3 \times 10^{-6}$ 1/GeV, after a measurement period of 30 days, which is a three order of magnitude improvement over our previous result.

**Monday Session 1 / 84**

## Welcome

**Monday Session 1 / 91**

## Axion Searches

The axion provides a solution to the Strong CP Problem of particle physics and is a candidate for the cold dark matter of the Universe I'll briefly review the constraints on the axion from particle physics, stellar evolution and cosmology. The constraints imply that its interactions are extremely weak, so much so that the axion was once thought "invisible". Nonetheless a number of methods have been proposed to detect so-called "invisible" axions and a world-wide campaign is under way to look for them. I'll describe these techniques, the experiments that implement them, and the results that have been obtained so far.

**Monday Session 2 / 92**

## Searches of Axions/ALPS with (Baby)IAXO

The InternaDonal Axion Observatory (IAXO) is a new generaDon axion helioscope aiming at a sensitivity to the axion-photon coupling of gaγ a few×10-12GeV-1, i.e. 1-1.5 orders of magnitude beyond the one achieved by CAST, currently the most sensitive axion helioscope. The main elements of IAXO are a large superconducting toroidal magnet with eight bores, x-ray focusing optics and low background detectors. An intermediate helioscope on the way to IAXO, called BabyIAXO, with the aim of testing the new technology for the full scale experiment, is now being designed and will be located at DESY. The design of all components and assembly procedures is quite advanced. Due to the socio-political problems worldwide a delay has been accumulated for the fabrication of the magnet. We will discuss the strategy to perform important tests in the final BabyIAXO location at DESY on different instrumentation and mechanics in preparation to BabyIAXO while waiting for the magnet to be in place. Once completed, BabyIAXO will be able to test gaγ down to 2×10-11 GeV-1 . In addition, already with babyIAXO it will be possible to search for evidence of axion-electron and axion-nucleon coupling in the Sun. Moreover, installing cavities or antennas in the magnet bores will turn BabyIAXO into an axion haloscope, sensitive to dark matter axions in different mass ranges. We will discuss the physics reach of BabyIAXO and present the enhanced sensitivity for axion discovery which will be possible to obtain with the full scale IAXO.

**Poster Session / 93**

## Dichroic Fabry-Perot Cavity

**Poster Session / 94**

## Enlightening the search for dark matter with atomic phenomena

**Poster Session / 95**

## Kinetic WISP detection with a network of optomechanical sensors

**Tuesday Session 1 / 96**

## Fundamental muon experiments and limits on the hidden sector

**Tuesday Session 3 / 97**

## Axion Quark Nuggets and Matter-Antimatter asymmetry as two sides of the same coin: theory, observations and future searches

In this talk I want to discuss the (unorthodox) scenario when the baryogenesis is replaced by a charge separation process in which the global baryon number of the Universe remains zero. In this, the so-called axion quark nugget (AQN) dark matter model the unobserved antibaryons come to comprise the dark matter in the form of dense nuggets. In this framework, both types of matter (dark and visible) have the same QCD origin, form at the same QCD epoch, and both proportional to one and the same fundamental dimensional parameter of the system, which explains how the two, naively distinct, problems could be intimately related, and could be solved simultaneously within the same framework. In particular, I discuss several recent papers suggesting that we have been witnessing of such kind DM for years (even centuries). I will also discuss the broadband search strategy of relativistic axions which always accompany AQNs when the they interacting with the Earth material. I will explain why a study of the daily modulations could be a powerful tool to discover such kind of relativistic axions.

**Wednesday Session 1 / 98**

## Axion astrophysical bounds

In this talk I will revise the current astrophysical bounds on axions ranging from energy-loss in stellar systems (globular clusters, supernovae) and from photon-axion conversions in cosmic magnetic fields.

**Wednesday Session 2 / 99**

## Search for dark matter with gravitational wave detectors

**Thursday Session 1 / 100**

## Latest insights on cosmology from ESA's Gaia space astrometry mission

The European Space Agency's Gaia satellite was launched in 2013 and continues to operate flawlessly today. It is measuring the distances and space motions of more than two billion stars with extreme accuracy. I will build on the talk that I gave to the 16th Patras Workshop in June 2021, and emphasise various applications to the study of the dynamics of our Galaxy, and in particular how this is related to our understanding of cosmological structure, and the existence of dark matter. I will explain how the latest data continue to demonstrate remarkable consistency with the predictions of structure formation in the Lambda CDM model. I will outline the status of the "plane-of-satellites" problem, the "core-cusp" problem, the continuing tension in estimates of the Hubble constant from the early and late Universe methods, observational evidence for the deceleration of our Galaxy's central bar due to its dark matter halo, and constraints on the time variation of the gravitational constant.

**Thursday Session 2 / 101**

## no title

**Thursday Session 3 / 102**

## Status of the BSM and FIPs experiments in PBC

During last years the Physics Beyond Colliders (PBC) study at CERN explored the scientific potential of the CERN accelerator complex and infrastructure to the projects complementary to LHC and other colliders. This talk presents the status of the proposals presented in the domains of Beyond Standard Model (BSM) physics, especially the search for Feebly Interacting Particles (FIPs) and dark matter candidates.

**Friday Session 1 / 103**

## test

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