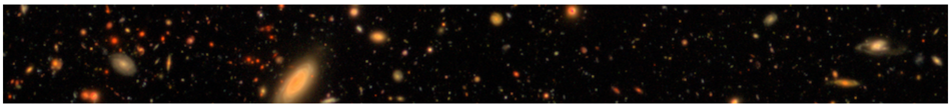
Workshop on Very Light Dark Matter 2023

Tuesday 28 March 2023 - Thursday 30 March 2023

Mario Royal Kaikan (Chino, Nagano) + Online



Book of Abstracts

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Gravitational impact of Supernovae in Ultra-light Axion Dark Matter halos

One of the viable dark matter models is the Ultra-light Scalar field Dark Matter where it assumes an ultra-light axion-like particle of mass 10^(-22)eV. Current cosmological (dark matter only) simulations reveal that the dark matter halos formed in this model have a unique wave-like structure and a characteristic soliton at their centers. In this talk, I will discuss how these inners solitons are modified when we account for some violent baryonic feedback effects using a semi-anlytical model to describe Supernovae feedback. I will then show how constraints from local dwarf galaxy observations may be affected.

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The viability of ultralight bosonic dark matter in dwarf galaxies

Author: Isabelle Goldstein[None]

Co-author: Savvas Koushiappas

The dark matter distribution in dwarf galaxies holds a wealth of information on the fundamental properties and interactions of the dark matter particle. We study whether ultralight boson dark matter is consistent with the gravitational potential extracted from stellar kinematics. We use velocity dispersion measurements from six classical dwarf galaxies to show that axion-like particles with masses of order m ~ 10^−22eV are inconsistent with the potential distribution in classical dwarf galaxies unless the hierarchical assembly of the Milky Way did not trace the mean evolution of Milky Way size halos.

Morning session-1 / 3

Tidal Love numbers for environmental black-hole mergers

Tidal Love numbers describe the deformability of compact objects under the presence of external tidal perturbations, and are found to be exactly zero for black holes. We discuss about the scenario of black holes dressed with an ultralight scalar field, addressing their detectability at future gravitational wave experiments.

Morning session-2 / 4

Continuous gravitational waves from self-interacting axion condensate

Ultra-light particles, such as axions, form a macroscopic condensate around a highly spinning black hole by the superradiant instability. The condensate emits characteristic gravitational waves, such as a monochromatic gravitational wave. The characteristic gravitational waves open the possibility of detecting the axion through gravitational wave search. However, the precise evolution of the condensate must be known for the actual detection. In this talk, we consider the effect of the self-interaction and the black hole spin-down on the evolution of the condensate and the resulting gravitational waves from the condensate. We discuss that the self-interaction will excite various modes, and thus, the condensate emits continuous gravitational waves in several frequencies.

Morning session-1 / 5

Production of very light dark photon dark matter

In this talk, I will show several production mechanisms of light dark photon dark matter in the early universe. It contains (i) resonant dark production from axion oscillation, (ii) dark photon emission form the collapse of cosmic string loops, (iii) misalignment production of coherently oscillating dark photons. Observational implications will also be discussed.

Morning session-1 / 6

Stability of domain wall network with initial inflationary fluctuations, and its implications for cosmic birefringence

We study the formation and evolution of domain walls with initial inflationary fluctuations by numerical lattice calculations, correctly taking into account correlations on superhorizon scales. We find that, contrary to the widely-held claim, the domain wall network exhibits remarkable stability even when the initial distribution is largely biased toward one of the minima. This is due to the fact that the domain wall network retains information about initial conditions on superhorizon scales, and the scaling solution is not a local attractor in this sense. Applying this result to the axion-like particle domain wall, we show that it not only explains the isotropic cosmic birefringence suggested by the recent analysis but also predicts anisotropic cosmic birefringence that is nearly scale-invariant on large scales and can be probed by future CMB observations.

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Search for vector dark matter in microwave cavities with Rydberg atoms

In this talk, I present a proposal of an experiment based on 1) the application of a strong electric field inside a microwave cavity and 2) electrometry using Rydberg atoms. This kind of experiment could be extremely useful at detecting dark photons through the stationary electric field filling the whole space it induces. The sensitivity of this experiment is quite constant over a significant frequency range, and looks overall independent of the mode of the cavity. We show that this experiment could improve the current constraint on the coupling constant of the dark photons to Standard Model photons around the tenth of μeV mass range. The main limiting factor on the sensitivity of the experiment is surprisingly not the quality factor of the cavity but mainly the amplitude stability of the applied field.

Afternoon session-2 / 8

Probing Axions through Tomography of Anisotropic Cosmic Birefringence

Cosmic birefringence is the in-vacuo rotation of the linear polarization plane experienced by photons of the Cosmic Microwave Background (CMB) radiation when theoretically well-motivated parity-violating extensions of Maxwell electromagnetism are considered. If the angle parametrizing such a rotation is dependent on the photon's direction, then this phenomenon is called Anisotropic Cosmic Birefringence (ACB). We have performed for the first time a tomographic treatment of the ACB, by considering photons emitted both at the recombination and reionization epoch. This allows one to extract additional and complementary information about the physical source of cosmic birefringence with respect to the isotropic case. We have focused on the case of an axion-like field, whose coupling with the electromagnetic sector induces such a phenomenon, by using an analytical and numerical approach (which involves a modification of the CLASS code). We have found that the anisotropic component of cosmic birefringence exhibits a peculiar behavior: an increase of the axion mass implies an enhancement of the anisotropic amplitude, allowing to probe a wider range of masses with respect to the purely isotropic case. Moreover, have we shown that at large angular scales, the interplay between the reionization and recombination contributions to ACB is sensitive to the axion mass, so that at sufficiently low multipoles, for sufficiently light masses, the reionization contribution overtakes the recombination one, making the tomographic approach to cosmic birefringence a promising tool for investigating the properties of this axion-like field.

Afternoon session-3 / 9

Probing ultra-light dark matter with lensed gravitational waves

Probing cosmic structures with gravitational wave lensing Just like light, gravitational waves (GWs) are deflected and magnified by the large-scale structure of the Universe. Their low frequency, phase coherence and capacity to propagate with no absorption make GW lensing highly complementary to gravitational lensing of electromagnetic radiation. I will discuss the framework of lensing in the wave optics regime and describe some of the opportunities that strong lensing of GWs will open to probe the matter distribution, including novel tests for ultra-light dark matter. The rich phenomenology of GW lensing will greatly benefit with the rapidly increasing rate of GW detections.

Afternoon session-3 / 10

Motion of S2 and bounds on scalar clouds around SgrA*

The motion of S2, one of the stars closest to the Galactic Centre, has been measured accurately and used to study the compact object at the centre of the Milky Way. It is commonly accepted that this object is a supermassive black hole but the nature of its environment is open to discussion. Here, we investigate the possibility that dark matter in the form of an ultralight scalar field "cloud"clusters around Sgr A*. We use the available data for S2 to perform a Markov Chain Monte Carlo analysis and find the best-fit estimates for a scalar cloud structure. Our results show no substantial evidence for such structures. When the cloud size is of the order of the size of the orbit of S2, we are able to constrain its mass to be smaller than 0.1% of the central mass, setting a strong bound on the presence of new fields in the galactic centre.

Afternoon session-1 / 11

Weak lensing and cosmic birefringence

Cosmic birefringence a newly reported signal from CMB and promising probe for new physics. In this talk, I am going to talk about weak lensing correction to Cosmic Birefringence signal. It will be important to use highly improved data by next generated CMB observations in the near future.

Afternoon session-1 / 12

The evolution of domain wall network with inflationary fluctuations under the asymmetric potential

Domain wall networks can induce cosmological problems. Previous work has shown that networks with initial inflationary fluctuations are long-lived despite being under population bias. This is due to large scale correlations, which cannot be seen in white noise case. However, the fate of these networks under potential bias is not well-understood. In our research, we investigate the time evolution of such networks under the linear potential bias using 2 dimensional lattice simulations. We show that the networks have a finite lifespan and collapse when the pressure becomes comparable to the tension they experience. Specifically, we find the relation between the lifetime and the bias strength. This implies that the cosmic domain wall problem is avoidable in certain scenarios.

Afternoon session-1 / 13

Cosmic birefringence tomography with late-time polarization signals

In this presentation, I consider polarization signals after the reionization epoch to constrain rotation angles of CMB polarization plane for the cosmic birefringence tomography. The late-time polarization signals, the so-called polarized SZ (pSZ) effect, arises in the process of the scattering of the cosmic microwave background (CMB) photons off the electrons. The pSZ signals can be reconstructed by combining CMB and galaxy surveys. I will present expected constraints on the rotation angles with future CMB experiments from pSZ signals and discuss potential application for constraining late-time cosmic birefringence.

Morning session-1 / 14

Fuzzy Vector Dark Matter

We will review the recent progress in the understanding of the non-relativistic weak-gravity dynamics of massive dark vector fields and whether they can play the role of dark matter in the late universe. We will also discuss different production mechanisms of vector dark matter in the primordial universe.

Morning session-1 / 15

Dark photon superradiance

I will describe the electrodynamics of a kinetically mixed dark photon cloud that forms through superradiance around a spinning black hole, and outline strategies to search for the resulting multi-messenger signals. A dark photon superradiance cloud sources a rotating dark electromagnetic field which, through kinetic mixing, induces a rotating visible electromagnetic field. Standard model charged particles entering this field initiate a transient phase of particle production that populates a plasma inside the cloud, which ultimately powers strong electromagnetic emissions. These emissions are expected to have a significant X-ray component and potentially be periodic, with period set by the dark photon mass. The luminosity is comparable to the brightest X-ray sources in the Universe, allowing for searches at distances of up to hundreds of Mpc with existing telescopes.

Morning session-2 / 16

Evolution of binary systems accompanying axion clouds in extreme mass ratio inspirals

Axions can form a cloud around a rotating black hole (BH) by the superradiant instability. We expect to be able to explore axions from gravitational waves (GWs) from binary BHs. In particular, when the BH with a cloud belongs to a binary system, the resonant phenomenon occurs during the inspiral phase. We study the evolution of binary systems accompanying the axion cloud around the resonance frequency, focusing on small mass ratio cases. We also discuss the implication to the observational signatures and show that the modification of the GW frequency evolution can be a signature of the presence of axions.

Morning session-2 / 17

Quantum Nucleation of Chiral Soliton Lattice

The Chiral Soliton Lattice (CSL) is a lattice structure composed of pion or axion domain walls aligned in parallel at equal intervals, which is energetically stable in the presence of a background magnetic field and a finite (baryon) chemical potential due to the topological term originated from the chiral anomaly. In this talk, I will discuss how to describe its formation by the quantum tunneling. I will show that CSL formation is promoted when the magnetic field strength and the chemical potential of the system is slightly larger than the scale of the axion decay constant.

Afternoon session-2 / 18

Complementarity Probes of light dark sector via Gravitational Waves and Laboratories

The non-thermal production of dark matter (DM) usually requires very tiny couplings of the dark sector with the visible sector and therefore is notoriously challenging to hunt in laboratory experiments. Here we propose a novel pathway to test such a production in the context of a non-standard cosmological history, using both gravitational wave (GW) and laboratory searches. We investigate the formation of DM from the decay of a scalar field that we dub as the reheaton, as it also reheats the Universe when it decays. We consider the possibility that the Universe undergoes a phase %of kination with \textit{kination-like} stiff equation-of-state (wkin>1/3) before the reheaton dominates the energy density of the Universe and eventually decays into Standard Model and DM particles. We then study how first-order tensor perturbations generated during inflation, the amplitude of which may get amplified during the kination era and lead to detectable GW signals. Demanding that the reheaton produces the observed DM relic density, we show that the reheaton's lifetime and branching fractions are dictated by the cosmological scenario. In particular, we show that it is long-lived and can be searched by various experiments such as DUNE, FASER, FASER-II, MATHUSLA, SHiP, etc. We also identify the parameter space which leads to complementary observables for GW detectors such as LISA and u-DECIGO. In particular we find that a kination-like period with an equation-of-state parameter wkin≈0.5 and a reheaton mass O(0.5−5) GeV and a DM mass of O(10−100) keV may lead to sizeable imprints in both kinds of searches. Based on: Journal of High Energy Physics volume 2022, Article number: 105 (2022)

Afternoon session-2 / 19

Cosmic evolution and thermal stability of Barrow holographic dark energy in a nonflat Friedmann-Robertson-Walker Universe

We study the cosmological evolution of a nonflat Friedmann-Robertson-Walker Universe filled by pressureless dark matter and Barrow holographic dark energy (BHDE). The latter is a dark energy model based on the holographic principle with Barrow entropy instead of the standard Bekenstein-Hawking one. By assuming the apparent horizon of the Universe as IR cutoff, we explore both the cases where a mutual interaction between the dark components of the cosmos is absent/present. We analyze the behavior of various model parameters, such as the BHDE density parameter, the equation of state parameter, the deceleration parameter, the jerk parameter, and the square of sound speed. We also comment on the observational consistency of our predictions, showing that the interacting model turns out to be favored by recent experimental constraints from Planck+WP+BAO, SNIa+CMB+LSS and Union2 SNIa joint analysis over the noninteracting one. The thermal stability of our framework is finally discussed by demanding the positivity of the heat capacities and compressibilities of the cosmic fluid.

Morning session-1 / 20

Bounds on Long-lived Dark Matter Mediators from Neutron Stars

Neutron stars close to the Galactic center are expected to swim in a dense background of dark matter. For models in which the dark matter has efficient interactions with neutrons, they are expected to accumulate their own local cloud of dark matter, making them appealing targets for observations seeking signs of dark matter annihilation. For theories with very light mediators, the dark matter may annihilate into pairs of mediators which are sufficiently long-lived to escape the star and decay outside it into neutrinos. We examine the bounds on the parameter space of heavy (\sim~TeV to \sim~PeV) dark matter theories with long-lived mediators decaying into neutrinos based on observations of high energy neutrino observatories, and make projections for the future. We find that these observations provide information that is complementary to terrestrial searches, and probe otherwise inaccessible regimes of dark matter parameter space.

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Sub-GeV dark matter search at ILC beam dumps

Light dark matter particles may be produced in electron and positron beam dumps of the International Linear Collider (ILC). We propose an experimental setup to search for such events, the Beam-Dump eXperiment at the ILC (ILC-BDX). The setup consists of a muon shield placed behind the beam dump, followed by a multi- layer tracker and an electromagnetic calorimeter. The calorimeter can detect electron recoils due to elastic scattering of dark matter particles produced in the dump, while the tracker is sensitive to decays of excited dark-sector states into the dark matter particle. We study the production, decay and scattering of sub-GeV dark matter particles in this setup in several models with a dark photon mediator. Taking into account beam-related backgrounds due to neutrinos produced in the beam dump as well as the cosmic-ray background, we evaluate the sensitivity reach of the ILC-BDX experiment. We find that the ILC-BDX will be able to probe interesting regions of the model parameter space and, in many cases, reach well below the relic target.

Afternoon session-1 / **22**

Hybrid inflation driven by QCD axion

Inflation plays a central role in modern cosmology. In order to reheat the Universe, inflaton must couple to the Standard Model particles, including gluons. Meanwhile, the QCD axion may couple to gluons to solve the strong CP problem. In this study, we investigate the inflationary scenario involving a QCD axion and a scalar field coupled to gluons. We find that this scenario can solve the isocurvature and quality problems associated with the QCD axion. We also discuss the possibility of QCD axion dark matter. Interestingly, the QCD axion can serve as the inflaton.

Afternoon session-2 / **23**

Probing Virtual ALPs Using Precision Phase Measurement

We propose an experimental scheme for detecting the effects of off-shell axion-like particles (ALPs) through optical cavities. In this proposed experiment, linearly polarized photons are pumped into an optical cavity where an external time-periodic or space-periodic magnetic field is present. The magnetic field mediates an interaction between the cavity photons and ALPs giving rise to a modification in the phase of the cavity photons. The time-dependent nature of the external magnetic field prompts a novel amplification effect which significantly enhances this phase modification. A detection scheme is then proposed to identify such axion-induced phase shifts. We find that the phase modification is considerably sensitive to the photon-ALPs coupling constants for the range of ALPs mass 3e-6 eV to 44e-6 eV for time-periodic and 6e-4 eV to 6e-3 eV for space-periodic magnetic fields.

Morning session-2 / **24**

Light dark matter around eV mass range

I will talk about dark matter in eV mass range such as the experimental hints, future reaches, and dark matter theory.

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contributed talk

Morning session-1 / 26

Stochastic Properties of Ultralight Scalar Fields

Ultralight axionlike particles are well-motivated dark matter candidates that are the target of numerous direct detection efforts. In the vicinity of the Solar System, such particles can be treated as oscillating scalar fields. The velocity dispersion of the Milky Way determines a coherence time of about 10^6 oscillations, beyond which the amplitude of the axion field fluctuates stochastically. Any analysis of data from an axion direct detection experiment must carefully account for this stochastic behavior to properly interpret the results. This is especially true for experiments sensitive to the gradient of the axion field that are unable to collect data for many coherence times. Indeed, the direction, in addition to the amplitude, of the axion field gradient fluctuates stochastically. I will present a stochastic treatment for the gradient of the axion field, which can be applied to any axion signal, regardless of coherence time. Additionally, I will show that ignoring the stochastic behavior of the gradient of the axion field can potentially result in failure to discover a true axion signal.

Morning session-1 / 27

Dark Matter and Quantum Gravity

Recent studies in the Swampland Program are pointing a possibility that quantum gravity constraints can be used to curve out the vast theory space of dark matters theoretically. In this talk, I will introduce our recent attempts to this direction based on unitarity of gravitational scattering amplitudes. In particular, I will discuss dark photon scenarios as an illustrative example and also provide prospects on applications to other dark matter scenarios.

Afternoon session-3 / 28

How axions change stars

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 us to set novel and strong constraints in unexplored axion parameter space. Furthermore, I will show how this new ground state changes the stellar composition of neutron stars.

Afternoon session-2 / 29

Impact of HWP systematics on the measurement of cosmic birefringence from CMB polarization

Employing an half-wave plate (HWP) as polarization modulator is a promising strategy to mitigate systematics in CMB experiments. However, if not calibrated well enough or accounted for correctly in the analysis, its non-idealities represent an additional source of systematics that can impact the science extracted from CMB. In this talk, I will show how their effect on the observed angular power spectra is partially degenerate with cosmic birefringence, according to both simulations and analytical computations.

Afternoon session-1 / 30

Axion Dark Matter from Frictional Misalignment

We study the impact of sphaleron-induced thermal friction on the axion dark-matter abundance due to the interaction of an axion-like particle (ALP) with a dark non-abelian gauge sector in a secluded thermal bath. Thermal friction can either enhance the axion relic density by delaying the onset of oscillations or suppress it by damping them. We derive an analytical formula for the frictional adiabatic invariant, which remains constant along the axion evolution and which allows us to compute the axion relic density in a general set-up. Even in the most minimal scenario, in which a single gauge group is responsible for both the generation of the ALP mass and the friction force, we find that the resulting dark-matter abundance from the misalignment mechanism deviates from the standard scenario for axion masses m⊠ 100 eV. We also generalize our analysis to the case where the gauge field that induces friction and the gauge sector responsible for the ALP mass are distinct and their couplings to the axion have a large hierarchy as can be justified by means of alignment or clockwork scenarios. We find that it is easy to open up the ALP parameter space where the resulting axion abundance matches the observed dark-matter relic density both in the traditionally over- and underabundant regimes. This conclusion also holds for the QCD axion.

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Multi-prong searches for light dark matter

Morning session-2 / 32

First Results of DANCE from Long-Term Observation

Axions are one of the well-motivated candidates for dark matter, originally proposed to solve the strong CP problem in particle physics. Dark matter Axion search with riNg Cavity Experiment (DANCE) is a new experimental project to search for axion dark matter. We aim to detect the rotation and oscillation of optical linear polarization caused by axion-photon coupling with a bow-tie cavity. DANCE can improve the sensitivity to the axion-photon coupling constant in the axion mass range of 10^{-17} eV < m_a < 10^{-11} eV by several orders of magnitude compared to the best upper limits at present. A prototype experiment DANCE Act-1 is ongoing to demonstrate the feasibility of our method. We will report the first results of DANCE Act-1 from 24-hour observation in this workshop. We found no evidence for axions and set 95% confidence level upper limits on the axion-photon coupling g_ag ⊠ 8 x 10^{-4} GeV^{-1} in 10^{-14} eV < m_a < 10^{-13} eV. Although the bounds did not exceed the current best limits, this work is the first demonstration of axion dark matter search with an optical ring cavity.

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Recent Upgrades of Optical System and Data Analysis in DANCE

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Information