Ultralight Dark Matter and observable phenomena

Report of Contributions

https://indico.sissa.it/e/165

Contribution ID: **1** Type: **not specified**

Cosmological perturbations with ultralight dark matter: spin 0 and 1

Monday, September 29, 2025 9:30 AM (45 minutes)

I will review models in which dark matter is described by an ultralight field. In particular, I will focus on the cosmological perturbations of spin-0 and spin-1 candidates. I will highlight the main differences in their predictions, and discuss the possibility for distinguishing the spin of dark matter using data from the matter power spectrum.

Presenter: FERREIRA CHASE, Tomas (DF-UBA/IFIBA)

Contribution ID: **2** Type: **not specified**

Early cosmology of ultralight dark matter

Monday, September 29, 2025 10:15 AM (45 minutes)

Ultralight dark matter (ULDM) has emerged as a compelling candidate to explain the dark sector, motivated not only by its potential to resolve small-scale structure issues but also by its natural appearance in high-energy theories such as string compactifications, as well as the coincidence of the observed abundance in the case of spin-0 scalar dark matter. In this talk, I will discuss the early cosmology of ULDM. I will review the misalignment mechanism for spin-0 scalar fields and its relation to inflationary dynamics, addressing constraints from isocurvature perturbations and possible resolutions. Building on this, I will then explore the case of spin-1 ULDM. In particular, I will analytically reinterpret some known numerical results for light dark photon production from spin-0 scalar by the stimulated scalar decay, and argue that the analytic formulation is independent of the particle spin. This suggests that the mechanism may provide a generic production channel for ULDM of arbitrary spin.

Presenter: YIN, Wen (Tokyo Metropolitan University)

Contribution ID: **3** Type: **not specified**

Production Mechanisms of Massive Spin-2 Dark Matter in the Early Universe

Monday, September 29, 2025 2:30 PM (45 minutes)

The possibility of additional spin-2 particles beyond the graviton has attracted growing interest in both cosmology and high-energy theory. In particular, massive spin-2 fields, or "dark gravitons" , have emerged as compelling dark matter candidates. Such states naturally arise in consistent ghost-free extensions of General Relativity, such as bigravity. The dynamics of these fields are constrained by the requirement of theoretical stability, with the most stringent condition provided by the Higuchi bound, which sets a lower mass limit to avoid negative-norm states. In this seminar, I will review the main mechanisms responsible for the production of spin-2 particles in the early Universe. I will show how, in all the cases, the Higuchi bound significantly restraints the available parameter space for dark gravitons as dark matter. I will then present how the effective mass of the spin-2 field can be dynamically lowered in chameleon-like extensions of bigravity. In the final part of my talk, I will introduce a novel, consistent mechanism to generate massive gravitons with masses in the ultralight regime, within the framework of chameleon bigravity. The aim is to provide a unified overview of production mechanisms and theoretical constraints, highlighting the role of spin-2 states as probes of the early Universe and as candidates for new physics beyond the Standard Model of cosmology.

Presenter: DANIELI, Valentina (CEICO - FZU, Czech Academy of Sciences)

Contribution ID: **4** Type: **not specified**

Ultralight DM and primordial density perturbations

Monday, September 29, 2025 3:15 PM (45 minutes)

I will give a pedagogical review on traces of ultralight dark matter in the cosmological perturbations. Specifically, I will discuss the suppression of small-scale structures due to their quantum pressure and the effects of isocurvature perturbations.

Presenter: KOBAYASHI, Takeshi (SISSA)

Contribution ID: **5** Type: **not specified**

Discussion/Collaboration

Contribution ID: **6** Type: **not specified**

Waves vs. particles in cosmological structure formation

Tuesday, September 30, 2025 9:30 AM (45 minutes)

Presenter: NIEMEYER, Jens (Georg-August-University Goettingen)

Contribution ID: **7** Type: **not specified**

Galaxy and star formation in Fuzzy Dark matter simulations

Tuesday, September 30, 2025 10:15 AM (45 minutes)

Presenter: FIALKOV, Anastasia (IoA, Cambridge University)

Contribution ID: **8** Type: **not specified**

The core-halo relation in the Scalar Field Dark Matter model

Tuesday, September 30, 2025 2:30 PM (45 minutes)

Scalar field dark matter (SFDM) is an alternative candidate to standard dark matter models, gaining attention due to the unique effects associated with its ultra-light mass. While its dynamics have been extensively studied across different scales, its full phenomenology remains under active investigation. In particular, the role of self-interactions and their impact on structure formation are still open questions. In this talk, I will explore the effects of both attractive and repulsive self-interactions in SFDM, with a focus on the evolution of the mass fraction and the core-halo relation. I will discuss analytical models proposed in the literature to describe dark matter halo cores and compare them with results from three-dimensional simulations. These findings will provide a basis for establishing comparisons between theoretical predictions and observational data, allowing us to impose constraints on the self-interaction term.

Presenter: LOPEZ SANCHEZ, Jessica Nayely (CEICO - FZU, Czech Academy of Sciences)

Contribution ID: **9** Type: **not specified**

Randomness, Warmth and Spin in Wave Dark Matter

Tuesday, September 30, 2025 3:15 PM (45 minutes)

I will describe how post inflationary production mechanisms (and even some inflationary ones) of ultralight dark fields, naturally lead to a free-streaming/Jeans suppression as well as a Poisson fluctuation related enhancement in the matter power spectrum. The lack of observation of these features can provide relatively model independent bound on the mass of dark matter particles. In general there is scale dependent growth of the power spectrum which can lead to suppressions on some scales and also enhanced early structure formation, including ubiquitous soliton formation on other scales. When such signatures are detected/constrained observationally, they provide insights into the production mechanisms as well as the mass and spin of such dark matter fields. Time permitting, I will discuss a general analytic framework for calculating the growth of structure in single and multi-species wave or particle dark matter with arbitrary density fractions and initial phase space distributions/field spectra, and their comparisons with N-body and Schrödinger Poisson simulations.

Presenter: AMIN, Mustafa (Rice University)

Contribution ID: **10** Type: **not specified**

Ultralight DM constraints with Pulsar Timing Arrays

Wednesday, October 1, 2025 9:30 AM (45 minutes)

Compact objects provide unique laboratories to probe the nature of dark matter. Millisecond pulsars, with their extraordinary timing precision and extreme densities, allow one to search for oscillatory signatures of ultralight dark matter fields, both through purely gravitational effects and via possible couplings to Standard Model particles. Pulsar timing arrays already constrain ultralight dark matter at masses near 1e-22 eV. Black holes, through superradiant instabilities and the formation of boson clouds, offer complementary constraints extending up boson masses of 1e-12 eV. I will review recent progress, including limits from pulsar timing and black hole spin measurements, and discuss prospects for future probes of dark matter with compact objects.

Presenter: BARAUSSE, Enrico (SISSA)

Contribution ID: **11** Type: **not specified**

Stellar Heating Induced by ULDM Halos

Wednesday, October 1, 2025 10:15 AM (45 minutes)

Ultralight Dark Matter (ULDM) has emerged as a compelling alternative to the Cold Dark Matter paradigm at small scales, naturally producing solitonic cores at the center of halos and granular structures arising from wave interference. These features lead to distinctive dynamical effects, including the random motion of the core and dynamical heating of stars in galactic systems. In this work we explore dynamical heating in the context of spin-s ULDM models, which predict broader solitonic cores and modified transition radii compared to the scalar case. We discuss how interference, subhalo encounters, and wavelets inject kinetic energy into stellar populations, driving observable signatures such as size–age relations in dwarf galaxies and thickening of galactic discs. At large scales, spin-s ULDM converges to the standard ΛCDM behavior, preserving cosmological consistency while offering testable predictions at galactic scales. Our results highlight the importance of stellar dynamics as a probe of the ULDM framework and its higher-spin generalizations.

Presenter: MUNIVE VILLA, Erick (CEICO - FZU, Czech Academy of Sciences)

Contribution ID: **12** Type: **not specified**

Searches of GWs and ULDM though binary resonances

Wednesday, October 1, 2025 2:30 PM (45 minutes)

In this talk, I will show how orbital resonances offer a new handle in the searches of GWs and ULDM. I will mainly focus on satellite and lunar laser ranging and binary pulsars.

Presenter: BLAS, Diego (ICREA/IFAE, Barcelona)

Contribution ID: **13** Type: **not specified**

Search for ULDM from the lab to our Galactic Center.

Wednesday, October 1, 2025 3:15 PM (45 minutes)

The microscopic nature of dark matter remains one of the major open mysteries in modern physics. Over the past decade, ultra-light dark matter (ULDM) candidates have attracted growing interest. In this talk, I will provide a brief overview of strategies aimed at the direct detection of ULDM. I will discuss the different signatures that ULDM may induce and highlight recent experimental results, both from laboratory setups and experiments in Earth's orbit. Finally, I will outline possible directions for future efforts, ranging from new laboratory experiments to astronomical observations of our Galactic Center.

Presenter: HEES, Aurélien (LTE, Paris)

Contribution ID: **14** Type: **not specified**

Screening of Scalar Fields - Challenges and Opportunities

Thursday, October 2, 2025 10:15 AM (45 minutes)

I will discuss the ways in which non-linear behaviour of scalar field theories, in particular variations of the mass of the scalar with the density of the local environment, can both hinder and help the detection of such scalars. To illustrate this I will discuss chameleon dark energy scalars, and quadratically coupled ultra-light dark matter.

Presenter: BURRAGE, Clare (University of Nottingham)

Contribution ID: **15** Type: **not specified**

Hidden Gravitons Phenomenology

Thursday, October 2, 2025 9:30 AM (45 minutes)

Ultralight bosonic fields are well-motivated candidates for explaining dark matter, dark energy, and other open problems in cosmology. While scalars are the standard approach, higher-spin fields—including vectors and spin-2 gravitons—can exhibit similar behavior with distinctive phenomenology. This talk explores the cosmological evolution of such fields, emphasizing the isotropy theorem that ensures an isotropic average energy–momentum tensor for rapidly evolving configurations. We focus on ultralight massive spin-2 fields ("hidden gravitons") as wave-like dark matter, discussing their background evolution, cosmological perturbations, and their impact on small-scale structure formation. We also review key experimental and observational constraints from fifth-force searches, astrophysical data, and collider analyses. Particular attention is given to the potential generation of stochastic gravitational wave backgrounds, which could serve as a powerful probe of these scenarios.

Presenter: CEMBRANOS, José (IPARCOS-UCM)

Contribution ID: **16** Type: **not specified**

Scalar field DM search in GW (and not only) experiments

Thursday, October 2, 2025 2:30 PM (45 minutes)

The nature of dark matter remains unknown to date, although several candidate particles are being considered in a dynamically changing research landscape. Scalar field dark matter is a prominent option that is being explored with precision instruments, such as atomic clocks and optical cavities.
In particular, low-mass (sub-eV) scalar field dark matter may induce apparent oscillations of fundamental constants, resulting in corresponding oscillations of the size and the index of refraction of solids. Laser interferometers are highly sensitive to changes in the size and index of refraction of the main beam splitter.
In this talk, I will focus on the experimental search for scalar field dark matter signature and what results have been obtained so far searching in different laser interferometric detectors.

Presenter: AIELLO, Lorenzo (Tor Vergata University of Rome)

Contribution ID: **17** Type: **not specified**

Laboratory Searches for Ultralight Dark Matter: Polarimetry, Interferometry, and Beyond

Thursday, October 2, 2025 3:15 PM (45 minutes)

Presenter: EJLLI, Aldo (Max-Planck-Institut für Gravitationsphysik, Hannover)

Contribution ID: **18** Type: **not specified**

Probing Ultralight Dark Matter with Levitated Sensors

Friday, October 3, 2025 9:30 AM (45 minutes)

In this talk I will explain how levitated sensors can be used to search for ultralight dark matter with different spins: scalar, vector, and tensor. I will focus on a magnetically levitated superconducting particle (maglev) and describe the experimental setup that creates the magnetic trap. I will then show how interactions with ultralight dark matter give rise to a force, leading to a measurable mechanical response of the superconducting particle. Finally, I will discuss the noise sources in the experiment and present the sensitivity curves for each ultralight dark matter spin case.

Presenter: DELGADO, Paola C. M. (CEICO - FZU, Czech Academy of Sciences)

Contribution ID: **19** Type: **not specified**

Ultra-light dark matter searches with gravitational wave detectors

Friday, October 3, 2025 10:15 AM (45 minutes)

Dark matter remains one of the most intriguing mysteries in our understanding of the universe. Recent theoretical advancements have motivated new experimental strategies to detect ultralight dark matter particles. This talk explores innovative methods for searching for these elusive particles using gravitational wave detectors. I will discuss how ultralight dark matter may generate detectable signals, either through direct interactions with detectors or through the emission of gravitational waves. Focusing on gravitational wave observatories such as LIGO, Virgo, and KAGRA, I will summarize recent observational efforts and highlight emerging possibilities for uncovering the nature of this fundamental component of the universe.

Presenter: PICCINNI, Ornella (Australian National University)

Contribution ID: **20** Type: **not specified**

Probing Ultra-Light Dark Matter with Gravitational Wave Frequency Modulation

Friday, October 3, 2025 2:30 PM (45 minutes)

Presenter: GASPAROTTO, Silvia (IFAE/UAB)

Contribution ID: **21** Type: **not specified**

ULDM searches with atom interferometry

Friday, October 3, 2025 3:15 PM (45 minutes)

Presenter: MCCABE, Christopher (King's College London)