Warsaw Workshop on Non-Standard Dark Matter: <br> multicomponent scenarios and beyond

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and CENT II (Faculty of Physics) buildings <br/> at the Ochota Campus of the University of

Book of abstracts

Table of contents

1

Self-interacting dark matter

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This is an abstract of a talk.

Session 2 / 7

The Self-Interacting Dark Matter Paradigm

Corresponding Author: haiboyu@gmail.com

Session 2 / 8

Direct Detection of Dark Matter with Electromagnetic Interactions

Corresponding Author: delnobile@cp3-origins.net

Session 2 / 9

Giant Monopoles

Corresponding Author: jarah@impcas.ac.cn

Session 3 / 11

Dark Matter Searches at the LHC

Corresponding Author: raman.khurana@cern.ch

Session 3 / 12

Particle dark matter: what it is and how to determine its properties

Corresponding Author: leszekr1@gmail.com

Session 3 / 13

Asymmetric Dark Matter and the LHC Diphoton Excess

Corresponding Author: frandsen@cp3.sdu.dk

Session 3 / 14

A smoking gun for dark matter self interactions?

Corresponding Author: kai.schmidt-hoberg@cern.ch

Session 4 / 15

Self-interactions of out-of-equilibrium Dark Matter

Corresponding Author: zaldivar@lapth.cnrs.fr

Session 4 / 16

Pseudoscalar portals into the dark sector

Corresponding Author: felix.kahlhoefer@desy.de

Session 4 / 17

WISPy Cold Dark Matter

Corresponding Author: jjaeckel@thphys.uni-heidelberg.de

Session 5 / 18

Direct Dark Matter Detection

Session 5 / 19

Indirect searches for particle dark matter

Corresponding Author: c.weniger@uva.nl

Session 5 / 20

tba

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Session 6 / 21

Cosmological Higgs-Axion Interplay for a naturally small Electroweak scale

Session 6 / 22

Gauge fields as dark matter

Corresponding Author: oleg.lebedev@helsinki.fi

Session 7 / 24

Axion Landscape

Corresponding Author: raffelt@mpp.mpg.de

Session 7 / 25

Cosmology of ultralight axions

Corresponding Author: david.marsh@kcl.ac.uk

Session 7 / 26

Axions, dark matter and all that MAD(MAX) stuff

Corresponding Author: jredondo@unizar.es

Session 7 / 27

Squeezing the last out of direct detection

Corresponding Author: josef.pradler@oeaw.ac.at

Session 8 / 28

Dark and Bright side of Fundamental Composite Dynamics

Corresponding Author: sannino@cp3-origins.net

Session 8 / 29

Inflatable Dark Matter

Corresponding Author: hooman@bnl.gov

Session 8 / 30

Bound states of symmetric and asymmetric dark matter

Corresponding Author: kalliopi.petraki@ens.fr

34

Signatures of sneutrino dark matter

Corresponding Author: belanger@lapth.cnrs.fr

35

Dark matter in a scale invariant bright hidden sector

Corresponding Author: mayumi@hep.s.kanazawa-u.ac.jp

Session 11 / 36

Observational tests of the composition of dark matter

Corresponding Author: dorr@asc.rssi.ru

Session 11 / 37

Flavor-Mixed Dark Matter in Cosmology

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Session 12 / 38

Multi-component dark matter with hidden SU(3) symmetry

Corresponding Author: takashi.toma@durham.ac.uk

Session 12 / 39

New effects of dark matter which are linear in the interaction strength

Corresponding Author: v.flambaum@unsw.edu.au

Session 12 / 40

Effective Operator Models for Semi-Annihilating Dark Matter

Corresponding Author: a.spray.work@gmail.com

Session 2 / 41

Super-Heavy Dark Matter from Inflation -- Towards Predictive Scenarios

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42

New effects of dark matter which are linear in the interaction strength

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Low-mass boson dark matter particles produced after Big Bang form classical field and/or topological defects. In contrast to traditional dark matter searches, effects produced by interaction of an ordinary matter with this field and defects may be first power in the underlying interaction strength rather than the second power or higher (which appears in a traditional search for the dark matter) [1-12]. This may give a huge advantage since the dark matter interaction constant is extremely small.
Interaction between the density of the dark matter particles and ordinary matter produces both 'slow' cosmological evolution and oscillating variations of the fundamental constants including the fine structure constant alpha and particle masses [4]. Recent atomic dysprosium spectroscopy measurements and the primordial helium abundance data allowed us to improve on existing constraints on the quadratic interactions of the scalar dark matter with the photon, electron and light quarks by up to 15 orders of magnitude. Limits on the linear and quadratic interactions of the dark matter with W and Z bosons have been obtained for the first time.

In addition to traditional methods to search for the variation of the fundamental constants (atomic clocks, quasar spectra, Big Bang Nucleosynthesis, etc) we discuss variations in phase shifts produced in laser/maser interferometers (such as giant LIGO, Virgo, GEO600 and TAMA300, and the table-top silicon cavity and sapphire interferometers) [5,6], changes in pulsar rotational frequencies (which may have been observed already in pulsar glitches), non-gravitational lensing of cosmic radiation and the time-delay of pulsar signals [7]. Other effects of dark matter and dark energy include apparent violation of the fundamental symmetries: oscillating or transient atomic electric dipole moments, precession of electron and nuclear spins about the direction of Earth's motion through an axion condensate (the axion wind effect), and axion-mediated spin-gravity couplings [8-10], violation of Lorentz symmetry and Einstein equivalence principle [11,12].

Finally, we explore a possibility to explain the DAMA collaboration claim of dark matter detection by the dark matter scattering on electrons. We have shown that the electron relativistic effects increase the ionization differential cross section up to 3 orders of magnitude [13].
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43

General approach to dark matter coannihilation

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I will present a general classification of simplified models of dark matter coannihilation. Main phenomenological features of these models will be discussed by introducing general classes of LHC signatures. Several novel signatures that are not covered in current LHC searches will be emphasized. The class of models with a QCD charged coannihilation partner, highly relevant for LHC studies and interesting from the point of view of relic density predictions will be considered in detail.

44

Cosmology of ultralight axions

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Axions (and other light bosons) with masses in the range $10^{-33}\text{ eV}\lesssim m\lesssim 10^{-18}\text{ eV}$ have distinctive effects on cosmology. These effects allow one to observationally distinguish ultralight axions from the other major cosmological components of dark energy, cold dark matter, warm dark matter, and neutrinos. Current observations of the cosmic microwave background and large scale structure place percent-level constraints on the axion energy density, and limit them to be sub-dominant to cold dark matter for $m\lesssim 10^{-24}\text{ eV}$. Future observations with CMB-S4 will improve these constraints by up to two orders of magnitude and allow one to distinguish the effects of axions from those of massive standard model neutrinos. This allows sub-percent level tests of the one-species cold dark matter paradigm over a vast range of cosmic scales. Furthermore, axions with $m\approx 10^{-22}\text{ eV}$ could play a role in resolving issues of small-scale structure formation with cold dark matter, and are also distinct from warm dark matter. Efforts to probe this mass range (and higher) observationally include using high redshift galaxy formation, cosmic reionization, the Lyman-alpha forest flux power spectrum, CMB lensing, galaxy weak lensing, the 21cm power spectrum, and galactic substructure. In the lab, such axions and other bosons induce effects with long time scale oscillations, which could be probed with upcoming experiments such as CASPEr.

45

News from NEWS Experiment

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Nowadays there is compelling evidence for the existence of dark matter in the Universe. A general consensus has been expressed on the need for a directional sensitive detector to confirm, with a complementary approach, the candidates found in "conventional" searches and to finally extend their sensitivity beyond the limit of neutrino-induced background. We propose here the use of a detector based on nuclear emulsions to measure the direction of WIMP-induced nuclear recoils. The production of nuclear emulsion films with nanometric grains has been recently established. Several measurement campaigns have demonstrated the capability of detecting sub-micrometric tracks left by low energy ions in such emulsion films with nanometric grains. Innovative analysis technologies with fully automated optical microscopes have made it possible to achieve the track reconstruction for path lengths down to one hundred nanometres and there are good prospects to further exceed this limit. The detector concept we propose foresees the use of a bulk of nuclear emulsion films surrounded by a shield from environmental radioactivity, to be placed on an equatorial telescope in order to cancel out the effect of the Earth rotation, thus keeping the detector at a fixed orientation toward the expected direction of galactic WIMPs. We report the performances and the schedule of the NEWS experiment, with its one-kilogram mass pilot experiment, aiming at delivering the first results on the time scale of five years.

46

Super-Heavy Dark Matter from Inflation -- Towards Predictive Scenarios

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A generic prediction of Coleman-Weinberg inflation is the existence of a heavy particle sector whose interactions with the inflaton generate the inflaton potential at loop level. If the heavy sector contains stable states, a relic abundance of those is generated at the end of inflation by gravity alone. This general feature, and the absence of any particle physics signal of dark matter so far, call for a paradigm shift in dark sector physics. Thus, the dark matter is super-heavy, it originates from the inflaton dynamics and its abundance today is naturally explained by the weakness of gravitational production. Such dark matter can be tested via the measurements of CMB isocurvature perturbations and non-Gaussianities, or through its peculiar signatures in the ultra high energy cosmic rays flux.

47

Direct detection of self-interacting dark matter

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I will outline the unique direct detection phenomenology which arises if dark matter is self-interacting. The crucial point is that, in the Earth frame, the halo wind interaction with Earth-captured dark matter generically results in a spatially dependent near-Earth dark matter environment. This implies distinctive signatures in the direct detection signal, including latitudinal dependence, and modulation with sidereal day. The sidereal modulation is particularly interesting, since it can only have a cosmological origin. Some examples will be shown from dark matter simulations with dark photon self-interactions. I will then describe some model-independent search strategies for sidereal modulation signals of unknown shape, in the hope of encouraging experimental colleagues to perform such searches.

48

Effective Operator Models for Semi-Annihilating Dark Matter

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Semi-annihilation is a generic feature of dark matter which is stabilized by a symmetry group larger than Z2. We systematically classify and enumerate effective operators up to dimension 6 for scalar and/or fermionic dark matter, with a focus on models where annihilation is suppressed. We show when and how different two-to-two processes are generated from a single effective operator. We additionally use searches for high energy gamma rays, positrons and neutrinos to set limits on the Wilson coefficients of these operators for models with a unique dark matter candidate. Finally we briefly discuss complete models inspired by this framework.

49

Giant Monopoles as a Dark Matter Candidate

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I will review recent challenges to WIMP dark matter models and describe how some of them are addressed by giant monopole models. These models exist in theories with a dark sector including a dark SU(2) gauge symmetry coupled to an adjoint Higgs and two fundamental fermions. Several consistency checks of such models will be described, including consistency with MACHO bounds and the CMB power spectrum. The main prediction of such models, which can soon be tested using GAIA astrometry data, is that dwarf galaxies are embedded in halos which extend for tens of kpc, often beyond their tidal radii, which would be impossible for gravitationally bound particulate dark matter. This may explain the anomalously high abundance and relative velocities of dwarf galaxy pairs recently observed by Fattahi, Navarro, et al.

50

From dark particle physics to the matter distribution of the Universe

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The effective theory of structure formation (ETHOS) allows the classification of dark matter theories according to their structure formation properties rather than their intrinsic particle properties. This makes ETHOS a particularly useful framework for comparing theoretical predictions of extended dark matter scenarios to actual cosmological and astrophysical observations. Using this effective theory, we describe how the details of the dark matter physics actually affect the shape of the linear matter power spectrum, hence clarifying the link between dark matter microphysics and structure formation. We then use the ETHOS framework to put cosmological and astrophysical constraints on broad classes of dark matter microphysics. We finally discuss how non-minimal dark matter theories can be used to remove apparent tension between various cosmological probes.

51

Looking beyond the paradigm: an experimental example from the ultra-high energy cosmic-ray physics

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The theoretical effort towards explaining the nature of Dark Matter must well recognize and assimilate the experimental results. However, if these results are taken without an appropriate care and criticism, whole classes of theoretical scenarios might be ruled out prematurely. I'll present an example of such an efficient experimental thinking-blocker: the apparent lack of photons in the flux of ultra-high energy cosmic rays (UHECR), i.e. those above 10^19 eV, observed at the Earth. It has been confirmed by the key observatories (Pierre Auger Observatory, Telescope Array) that the contribution of ultra-high energy photons to the observed flux of cosmic rays is not larger than 1%. Such a limit severely constrains exotic scenarios of the origin of UHECR. These scenarios predict eg. decays or annihilation of hypothetical super-massive particles leading to the significantly increased presence of photons in the observed flux of UHECR which is practically ruled out by the present photon limits. The upper limits on the UHE photon flux constrain also violation of fundamental physics laws like Lorentz invariance. While theoretical implications of non-observation of UHE photons appear serious, it is not commonly understood that the present experimental limits are determined without considering all the thinkable standard or non-standard physics effects leading to the suppression or worse traceability of UHE photons. I'll discuss a simple scenario capable of explaining the non-observation of UHE photons without ruling out the exotic predictions of high photon fractions. The example concerns a hypothetical, frequent interactions of UHE photons initiating large electromagnetic cascades above the Earth atmosphere. Emerging of such a cascade would dramatically affect the development of the corresponding air shower in the atmosphere. I'll demonstrate that air showers induced by large electromagnetic cascades might be hardly distinguishable from air showers initiated by nuclei. If this is the case then we might heavily underestimate the photon component in the observed UHECR flux and the corresponding theoretical predictions should be revised. Although there are no hints about the nature of the mechanism leading to the creation of very large electromagnetic cascades, there is a number of non-trivial possibilities, including both standard and non-standard physics, that have never been discussed in the literature. It therefore seems appropriate to conclude that taking a full scientific advantage of the unprecedented statistics and precision of the UHECR data collected by the top observatories, in particular by the Pierre Auger Observatory, might require more intense and deeper interactions between the experimentalists and theorists. This talk will be an effort towards facilitating these interactions.

52

Self-interactions of out-of-equilibrium Dark Matter

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Self-Interacting Dark Matter is a popular solution to the small-scale problems of cold dark matter. In this talk, it will be shown how it is possible to obtain the desired amount of self-interactions from dark matter candidates which have never been in equilibrium with the visible sector, while at the same time avoiding all the phenomenological issues present in a large variety of models proposed in the literature, relying on dark-visible equilibrium.

53

Twin Universe

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1. Predictions of our model and especially fittings with measured data indicate a possible presence of an other universe in our known one. In our previous publication we have reported about our finding that possibly a smaller twin Universe was born in the Big Bang and passing through our Universe it left to the multiverse space. Taking this seriously we can start describe such a double event and try to give the equations, possible solutions and effects which can be predicted. We will describe the case on the base of a traditional picture.
2. The system of coupled equations describing the double universe case
H_1^2≈ V_1 (ϕ_1)/3〖m_p〗^2+V_int (t,L,ϱ_i,T_i,ϕ_i,…)
3H_1 ϕ˙_1≈-V_1^' (ϕ_1)
H_2^2≈V_2 (ϕ_2)/3〖m_p〗^2+V_int (t,L,ϱ_i,T,ϕ_i,…)
3H_2 ϕ˙_2≈-V_2^' (ϕ_2)
L^2≈V(ϕ)/3〖m_p〗^2
3Lϕ˙≈-V^' (ϕ)
where L – measure of the overlap of U1 and U2, φ – inflaton in multiverse, V – potential in multiverse
3. Analysis
Our EQP/DWT model [4,5,6,7,8]provides in case of the universe the measurable baryonic, dark matter, total matter and dark energy rates. These deviate significantly from the measurable ones by WMAP and Planck and rise the possibility of a double Big Bang. Supposing this the prediction fit well for the recently measurable ratios. On this base we can suppose that an other (with about 1/3 expected total energy) universe has been created probably yet in the epoch of inflation [2,3]. Such a double event can have numerous important, measurable outcomes.
4. Important experimental fields
The measurements of WMAP yielded power spectra and temperature fluctuation map. The Planck Mission similar measurements provided more characteristic asymmetries for the dark matter content of the measured sky. The Eridanus Cold spot and super Void investigations in the background of a measurements, the Quark Gluon plasma Heavy ion reactions [1] and also the double Black Hole measurements are very important related fields. Double galaxies and galaxy collisions can provide important knowledge [9,10,11,12].
5. Conclusions
Many interesting questions arise and many interesting predictions can be made on the base of this model and scenario. In case of two universes their dark matter content and dark matter interactions can be important.

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54

Observational Constraints on Decoupled Hidden Sectors

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Can dark matter properties be constrained if dark matter particles interact only very feebly with the Standard Model fields? The answer is yes. By studying both cosmological and astrophysical constraints, we show that stringent constraints on dark matter properties can be derived even if the dark matter sector is practically uncoupled from the Standard Model sector. By taking the Higgs portal model as a representative example, we study in detail scenarios where the hidden sector does not thermalize with the Standard Model sector but within itself, resulting in dark matter abundance determined by the freeze-out mechanism operating within the hidden sector.

55

Detecting Asymmetric Dark Matter via Neutron Star Collapse

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Asymmetric dark matter forms a well motivated class of dark matter models with unique detection characteristics. In particular, if asymmetric dark matter has a non-negligible nuclear scattering cross-section, it will accumulate efficiently in neutron star cores, potentially causing neutron star collapse. Due to the extremely high mass and detailed modeling of neutron star populations, observations can probe parameter spaces far below current direct detection bounds. In this talk, I will discuss the current state of astrophysical constraints on this model space, as well as three intriguing anomalies (the missing pulsar problem, Fast radio bursts, and r-process production in Ultra-faint dwarf galaxies) that may potentially be explained by dark matter accumulation in neutron star interiors.

56

Z_2 SIMP Dark Matter

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Dark matter with strong self-interactions provides a compelling solution to several small-scale structure puzzles. Under the assumption that the coupling between dark matter and the Standard Model particles is suppressed, such strongly interacting massive particles (SIMPs) allow for a successful thermal freeze-out through N-to-N' processes, where N dark matter particles annihilate to N' of them. In the most common scenarios, where dark matter stability is guaranteed by a Z_2 symmetry, the seemingly leading annihilating channel, i.e. 3-to-2 process, is forbidden, so the 4-to-2 one dominate the production of the dark matter relic density. Moreover, cosmological observations require that the dark matter sector is colder than the thermal bath of Standard Model particles, a condition that can be dynamically generated via a small portal between dark matter and Standard Model particles, à la freeze-in. This scenario is exemplified in the context of the Singlet Scalar dark matter model.

57

Radiative Generation of Neutrino Masses and Dark Matter

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Two major questions of the Standard are neutrino masses and dark matter.
The minimal model T12A addresses both by introducing new particles, scalars and fermions as singlets and doublets.

This allows for the radiative generation of neutrino masses but also leads to the occurrence of lepton flavor violating processes.

In our work we will study the parameter space of the model imposing the relic density constraint and constraints for neutrino masses.

Furthermore we will consider dark matter direct detection limits.

58

Dark matter serach with XMASS

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The XMASS program is implemented through a large volume of liquid Xe
scintillation expermeints at Kamioka in Japan. In the current stage,
we focus on the the direct detection of dark matter with 832 kg liquid Xe.
We have achieved the low energy threshold (~0.6keVee) thanks to the
high scintillation light yield that allows us the low mass WIMPs search
and a study of annual modulation due to dark matter.
Also the background level of electron recoil events is very low, especially in the ~40-100keVee region the level is O(10^-4count/keVee/kg/day) which
is world lowest level. Therefore we have searched for axion, super-WIMPs, inelastic scattering of dark matter as well.
In this talk, the latest dark matter search results are shown.
We are developing the next phase detector to increase the
sensitivity of dark matter search. The future plans of the XMASS
experiment are also presented.

60

Spectral features in the MeV gap

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Dark matter with mass of a few GeV can lead to observable signals in gamma rays with energies peaked at O(100 MeV). In such scenarios a significant part of the signal falls into the „MeV gap", a drop in sensitivity of current observational coverage with energies in the range 0.1-100 MeV. A gap that will soon be probed by new planned experiments. In this talk we point out the existence of novel spectral features in precisely this photon energy range. Such features are generic, as they depend on SM physics alone, although are clearly pronounced only in specific scenarios. We will discuss origin and importance of these features, as well as some implications for phenomenology.

61

Reheating the Standard Model from a hidden sector

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We consider a scenario where the inflaton decays to a hidden sector weakly coupled to the visible sector. Dark matter freezes out in the hidden sector and later a tiny portal coupling between the hidden and the visible sector heats the visible sector so that the Standard Model degrees of freedom dominate the energy density, before Big Bang Nucleosynthesis. We confront this scenario against different observational limits including dark matter abundance and primordial isocurvature perturbations and find that this scenario is viable though rather strictly constrained.

62

Searches for Non-Standard Dark Matter Interactions in the LUX and LZ Detectors

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Although the search for standard, moderate-mass WIMPs continues in earnest across the globe with different detection technologies, the continued lack of a conclusive discovery has encouraged the opening up of other pursuits. This talk will discuss the present capabilities of the world-leading LUX experiment, which has recently published new spin-independent as well as spin-dependent limits, and the future capabilities of its multi-ton-scale successor LZ, in terms of low-mass WIMP nuclear-recoil searches via the ionization channel (S2) in two-phase xenon TPCs. These are made possible through studies of signals of very few electrons, supported with robust new calibration techniques in vivo with DD neutrons, tritium betas, and cosmogenic xenon lines. Lastly, the status of the quest for an electron recoil spectrum or mono-energetic peak from either solar or galactic axions respectively, the axion being a well-motivated non-WIMP dark matter candidate in its own right, will be presented too.

63

A Superheated, Scintillating, Liquid Xenon Bubble Chamber for Expanding the Direct Search for Dark Matter

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The search for dark matter, which comprises ~25\% of the energy content of the universe, is today one of the most exciting fields in particle physics. As bigger detectors are being built to increase their sensitivity, background reduction is an ever more challenging issue. To this end, a new type of dark matter detector is being developed, a xenon bubble chamber, which would combine the strengths of liquid xenon TPCs, namely event by event energy reconstruction, with those of a bubble chamber, namely insensitivity to most electronic recoils. In addition, it would be the first time ever that a dark matter detector is active on all three detection channels, ionization and scintillation characteristic of xenon detectors, and heat through bubble formation in superheated fluids. Preliminary simulations have shown that, depending on the threshold, a discrimination of 99.99\% to 99.9999+\% can be achieved, which is on par or better than many current experiments. Such a detector, being both gaseous and liquid, could potentially punch through the neutrino floor using directionality, as well as be sensitive to ultra-relativistic light WIMPs through high-energy electron recoils observed as visible, directed bubble tracks, plus achieve ultra-low-, sub-keV thresholds, in order to look for low-mass WIMPs via low-energy nuclear recoils.

64

Multi-component dark matter with hidden SU(3) symmetry

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We consider an extended model with the hidden SU(3) symmetry.The SU(3) symmetry is broken by non-zero vacuum expectation values of two SU(3) triplets. After the symmetry breaking, the Z2xZ2 symmetry remains as an intrinsic symmetry of the original gauge symmetry. Because of the Z2xZ2 symmetry, this model includes multi-component dark matter particles. We discuss phenomenology of the multi-component dark matter and how to discriminate it from single-component dark matter.

Session 2 / 65

From dark particle physics to the matter distribution of the Universe

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Leopold Infeld Colloquium / 66

Current Perspectives on Dark Matter

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parallel session / 67

Self-interactions of out-of-equilibrium Dark Matter

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parallel session / 68

Self-interacting dark matter from a Breit-Wigner resonance

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parallel session / 69

Direct detection of self-interacting dark matter

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parallel session / 70

Z_2 SIMP Dark Matter

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parallel session / 71

Multi-component dark matter with hidden SU(3) symmetry

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parallel session / 72

Radiative Generation of Neutrino Masses and Dark Matter

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parallel session / 73

General approach to dark matter coannihilation

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parallel session / 74

Reheating the Standard Model from a hidden sector

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parallel session / 75

Observational Constraints on Decoupled Hidden Sectors

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parallel session / 76

Spectral features in the MeV gap

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parallel session / 77

Looking beyond the paradigm: an experimental example from the ultra-high energy cosmic-ray physics

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parallel session / 78

Detecting Asymmetric Dark Matter via Neutron Star Collapse

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parallel session / 79

Searches for Non-Standard Dark Matter Interactions in the LUX and LZ Detectors

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parallel session / 80

Dark matter serach with XMASS

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parallel session / 81

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parallel session / 82

C & X–Band observations of the peculiar cluster MACS J0417.5–1154 from ATCA

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parallel session / 83

A Superheated, Scintillating, Liquid Xenon Bubble Chamber for Expanding the Direct Search for Dark Matter

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parallel session / 84

Multi-Component Dark Matter: vector and fermion case

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Session 5 / 86

Signatures of sneutrino dark matter

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87

Welcome

Session 12 / 88

Closing remarks

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