17. Kosmologietag

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ZiF | Bielefeld University

UNIVERSITÄT BIELEFELD

Faculty of Physics

Book of Abstracts

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FIMP 3/2 DM @ direct detection and collider experiments

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We present a Spin 3/2 FIMP dark matter (DM) candidate. FIMP dark matter is produced via the freeze-in mechanism that
generally implies tiny coupling between the DM and the standard model particles, making DM direct detection and
collider searches almost hopeless. This is not the case for a spin 3/2 DM at low reheating temperature, where direct
detection and collider bounds play a fundamental role in constraining the parameter space. We show the viability of the
model and discuss the details of the production mechanism and future experiments that can test it.

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Gravitational wave background from vacuum and thermal fluctuations during axion-like inflation

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We revisit the framework of axion-like inflation and consider a warm inflation scenario in which the inflaton couples to the topological charge density of non-Abelian gauge bosons whose self-interactions result in a rapidly thermalizing heat bath. Including both dispersive (mass) and absorptive (friction) effects, we find that the system remains in a weak regime of warm inflation (thermal friction ≪ Hubble rate) for phenomenologically viable parameters. We derive an interpolating formula for vacuum and thermal production of tensor perturbations in generic warm inflation scenarios, and find that the perturbations exhibit a model-independent f^3 frequency shape in the LISA window, with a coefficient that measures the maximal shear viscosity of the thermal epoch.

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Black holes from Yukawa forces in the very early universe?

Author: Guillem Domenech[None]

Primordial black holes are often assumed to form by the collapse of large primordial fluctuations. However, it might not be the only channel. Yukawa forces are attractive, and they can be much stronger than gravity, leading to an instability similar to gravitational collapse in the early universe. I will present recent advancements on the growth of fluctuations in the very early universe from Yukawa forces, from exact analytical solutions to the very first N-body simulations. I will focus on a simple model: heavy fermions interacting via a Yukawa coupling with a scalar field in a quartic potential. I will end with a discussion on how this mechanism may lead to black hole formation.

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Effects of flavour and CP symmetries on low-scale leptogenesis.

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While the Standard Model (SM) has been extremely successful, it fails to explain the origin of neutrino masses and of the baryon asymmetry of the universe. Extending the SM with right-handed neutrinos in the type-I seesaw framework provides the necessary ingredients to solve both of these problems. In addition, one can predict the PMNS angles and other low-energy parameters if we endow the model with a flavour symmetry from the series of non-abelian groups $(3n^2)$ and $(6n^2)$ and a CP symmetry. In this work, we study the impact of these symmetries on the predictions for neutrino oscillation data, low-scale leptogenesis and the testability prospects of the model. Based on 2203.08538 and some upcoming work.

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Reviewing the prospect of fermion triplets as dark matter and source of baryon asymmetry in non-standard cosmology

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The indirect searches of Dark Matter (DM), in conjugation with the so called 'missing track searches' at the collider seems to confine fermion triplet DM mass within a narrow range around 1 TeV. The canonical picture of pure triplet fermionic dark matter is in tension since it is under-abundant for the said mass range. Several preceding studies have shown that the existence of an extra species over the radiation background composed of the Standard Model particles, prior to the Big Bang Nucleosynthesis, leads to a fast expanding Universe driven by an enhanced Hubble parameter. This faster (than radiation) expansion has the potential to revive the under-abundant fermion triplet ($\mathbb{Z}_2$ odd, lightest generation) WIMP dark matter scenario by causing freeze-out earlier without modifying the interaction strength between dark matter and thermal bath. Although the CP asymmetry, produced due to the decay of $\mathbb{Z}_2$ even heavier generations of the triplet, remains unaffected by

the modification of cosmology, the evolution of the same receives significant non-trivial effect. It has been observed through numerical estimations that the minimum mass of the decaying triplet, required to produce sufficient baryon asymmetry, can be lowered up to two orders (compared to the standard cosmology) in this fast expansion scenario. The non-standard parameters n and T_r, which simultaneously control the dark matter relic abundance as well the frozen value of baryon asymmetry, are tightly constrained due to consecutive imposition of experimental bounds on relic density followed by observed value of baryon asymmetry of the Universe. It has been found that n is strictly bounded within the interval 0.4
$lesssim n$
$lesssim 1.8$. The upper bound is imposed by the baryon asymmetry constraint whereas the lower bound arises to satisfy the correct relic abundance of the DM. The restriction on the other non-standard parameter T_r is not so stringent as it can vary from sub GeV to few tens of GeV.

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Observing a compressed wave DM halo with gravitational waves

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The adiabatic growth of a central massive black hole could compress the surrounding dark matter halo, leading to a steeper profile of the dark matter halo. This phenomenon is called adiabatic compression. We investigate the adiabatic compression of wave dark matter - a light bosonic dark matter candidate with its mass smaller than a few eV. Using the adiabatic theorem, we show that the adiabatic compression leads to a much denser wave dark matter halo similar to the particle dark matter halo in the semiclassical limit. The compressed wave halo differs from that of the particle halo near the center where the semiclassical approximation breaks down, and the central profile depends on dark matter and the central black hole mass as they determine whether the soliton and low angular momentum modes can survive over the astrophysical time scale without being absorbed by the black hole. Such a compressed profile has several astrophysical implications. As one example, we study the gravitational waves from the inspiral between a central intermediate-mass black hole and a compact solar-mass object within the wave dark matter halo. Due to the enhanced mass density, the compressed wave dark matter halo exerts stronger dynamical friction on the orbiting object, leading to the dephasing of the gravitational waves. The pattern of dephasing is distinctive from that of inspirals in the particle dark matter halo because of the difference in density profile and because of the relatively suppressed dynamical friction force, originating from the wave nature of dark matter. We investigate the prospects of future gravitational wave detectors, such as Laser Interferometer Space Antenna, and identify physics scenarios where the wave dark matter halo can be reconstructed from gravitational wave observations.

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Axion inflation in the strong-backreaction regime: Lifetime of the Anber-Sorbo solution

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Axion inflation is an attractive particle physics model of inflation with a rich phenomenology, due to the parity violating production of gauge-fields in this model, which may have implications for the production of gravitational waves, scalar perturbations and the baryon asymmetry. In recent years, a scenario with strong back-reaction of the gauge fields onto the inflaton in this model has been studied extensively, using different methods such as lattice simulations, solving the system numerically in Fourier space, or a novel technique called the gradient expansion formalism. Additionally, a well known analytical solution to Axion inflation exists. In this so-called Anber-Sorbo solution, the gauge field production counter-acts the scalar potential gradient, which may be too steep to allow for traditional slow-roll inflation. Our aim is to study the lifetime of the Anber-Sorbo solution using the gradient expansion formalism, motivated by a recent analytical calculation based on this solution. We initially rely on the approximation of a constant Hubble parameter used in the analytical study, but then make use of the full power of the gradient expansion formalism to examine the impact of a varying Hubble-rate. We find that the lifetime of the Anber-Sorbo solution can be extended to several e-folds at the cost of a high degree of fine tuning of the initial conditions.

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Strong electroweak phase transition and simplified dark matter models

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Beyond the Standard Model (SM) physics is required to explain both dark matter (DM) and the baryon asymmetry of the universe, the latter possibly generated during a strong first-order electroweak phase transition. While many proposed models tackle these problems independently, it is interesting to inquire whether the same model can explain both. Here, I focus on a DM model featuring an inert Majorana fermion that is coupled to SM leptons via a scalar mediator, which in turn interacts directly with the Higgs boson [1].

To link precision phase transition thermodynamics with extracting the DM energy density, I construct the corresponding three-dimensional effective theory, that systematically includes thermal resummations to all orders, using the in-house software package DRalgo [2]. Finally, I discern regions of the model parameter space that reproduce the observed DM energy density and allow for a first-order phase transition, while evading the most stringent collider constraints.

[1] S. Biondini, P. Schicho, and T. V. I. Tenkanen, Strong electroweak phase transition in t-channel simplified dark matter models, JCAP 10, 044 (2022), [2207.12207].

[2] A. Ekstedt, P. Schicho, and T. V. I. Tenkanen, DRalgo: A package for effective field theory approach for thermal phase transitions, Comput. Phys. Commun. 288, 108725 (2023), [2205.08815].

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On Stellar Migration from the Andromeda Galaxy

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Recent *Gaia* observations suggest that some hypervelocity stars (HVSs) might originate from outside the Galaxy. We ask if these HVSs could come from as far as Andromeda. Therefore, we simulate HVSs originating in Andromeda with initial conditions based on attributes of high velocity stars measured in the Milky Way and a simple model for the gravitational potential of Andromeda and the Milky Way. We evaluate the validity of this scenario based on the simulation results. We find that the scenario is possible according to the simulation results, but unlikely to be responsible for the majority of presumably extragalactic HVSs observed in the Milky Way. Further, we analyse the properties of HVSs that are able to reach the Milky Way and discuss whether they could be detected experimentally.

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Analytically "Solving" the N-Body Problem

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It is common physics knowledge that the N-body problem cannot be solved analytically for $N > 2$. Indeed, it has been proven that for general initial conditions the particle trajectories can not be expressed in terms of elementary functions. However, if we consider different observables, e.g., density n-point functions, this theorem does not directly apply. Moreover, when working with such collective quantities it is natural to work with statistical initial conditions, rather than explicit ones. As it turns out, the integration over such a probability distribution of initial conditions can yield a significant simplification.

Putting these two ideas together in the framework of Kinetic Field Theory, we "solve" the N-Body Problem for $N \to \infty$ for initial conditions resembling those of cosmic matter at recombination. Utilizing a new diagramatic approach to perturbative calculations within Kinetic Field Theory, we expand the expression for the matter fluctuation power spectrum in the particle interactions and the initial particle correlations. This double-expansion allows us to obtain expressions which can be evaluated reasonably easily. Keeping only linear initial particle correlations and going to high order in the particle interactions, we reproduce the linear growth of the matter fluctuation power spectrum on all scales from microscopic Newtonian particle dynamics alone. Contributions from second and higher order initial particle correlations are currently being investigated and it is expected that these non-linear initial correlations yield non-linear structure growth.

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Asymptotic Symmetries and Memories of Electrodynamics in FLRW Spacetimes

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In recent years, the asymptotic structure of gravity and gauge theories has been studied extensively. This was, however, done almost exclusively for (asymptotically) flat spacetimes with a few exceptions.
In this talk, I will give an overview of the asymptotic structure of electrodynamics in certain FLRW spacetimes. I will first introduce asymptotic symmetries and then show their relation to the associated memory effects. Furthermore, I will discuss differences with respect to the flat spacetime counterpart. Most of the presented results extend directly to other gauge theories.

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The Stochastic Relaxion

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Light scalar fields, such as axions, can play an important role in cosmology. In this talk I will discuss the mechanism of cosmological relaxation of the electroweak scale, which provides a dynamical solution to the Higgs mass hierarchy problem. In the simplest model, the Higgs mass is scanned during inflation by a light field, the relaxion, whose slow-roll dynamics selects a naturally small Higgs vev. We revisit the original proposal and investigate the mechanism in a regime where the relaxion is subject to large fluctuations during inflation, including the "quantum-beats-classical" regime. The stochastic dynamics of the field is described by means of the Fokker-Planck formalism. We derive a new stopping condition for the relaxion taking into account the transitions between the local minima of its potential. We investigate the consequences both for the QCD relaxion and the strong CP problem, as well as for non-QCD models. We identify a new region of the parameter space where the stochastic misalignment of the relaxion from its local minimum due to fluctuations can naturally explain the observed dark matter density in the universe.

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Scalar fields damping in a thermal plasma

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The behavior of scalar fields in a thermal plasma plays an important role in the study of the early universe, and it is relevant for addressing problems in astrophysics and cosmology. In this talk, we present a calculation of the dissipation rate in a simple scalar model at a finite temperature. We discuss the impact of thermal masses on the quasi-particle kinematics and show the different allowed regimes for different processes, such as decay, inverse decay, and Landau damping. We point out and correct an error in an earlier computation in [1]. For some parameter choices, our correction can significantly change the evolution of the system. These results could be implemented in models of inflation, and have implications for reheating, baryogenesis, and dark matter, among others.

[1] M. Drewes, J. U. Kang, Nucl. Phys. B 875 (2013) 315–350, arXiv.1305.0267 [hep-ph]

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Higgsless simulations - A modern tool in the numerical exploration of first-order phase transitions and stochastic backgrounds of gravitational waves

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A stochastic gravitational wave background of cosmological origin is an intriguing possibility to be probed by gravitational wave detectors such as pulsar timing arrays and LISA in the near future. In this talk, I will present a novel "Higgsless"simulation to predict the stochastic gravitational wave spectrum from first-order phase transitions in the early universe. I will present results for weak-to-intermediate phase transitions, and demonstrate an application to phase transitions seeded by domain walls. Being numerically efficient and fully nonlinear, the "Higgsless"approach will pave the way for exploring previously uncharted regimes of strong phase transitions and relativistic wall velocities.

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Recent advances in Dirac Leptogenesis

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Dirac Leptogenesis is a viable scenario that connects the observed baryon asymmetry of our universe to the possibility that neutrinos are Dirac fermions. After reviewing the basic ingredients of this approach we present two models for parametrically small Dirac neutrino masses. Both constructions also allow for the generation of a lepton asymmetry from out-of-equilibrium particle decays, that gets reprocessed into a baryon asymmetry via the electroweak sphaleron process. The first model relies on a scalar decaying during reheating and requires a strong resonant enhancement to produce enough CP violation. Our second model with decaying fermions offers a novel non-resonant enhancement of the required CP violation together with a way to make the asymmetry generation more efficient, that was previously only known for Majorana scenarios.

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Minimal FIMP models during reheating and inflationary constraints

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We study the production of Dark Matter (DM) in a minimal freeze-in model during inflationary reheating. We analyze the case where a heavier parent particle decays into DM and a Standard Model fermion in two reheating scenarios: bosonic reheating (BR) and fermionic reheating (FR). We show that for a low reheating temperature, BR and FR scenarios predict different lifetimes and masses for the parent particle when considering potentials with power-law behavior. We highlight how different treatments of the reheating phase and definitions of the reheating temperature in the literature can lead to conflicting conclusions about the relevance of long-lived particle (LLP) searches in testing the freeze-in model. Additionally, we investigate the interplay between LLP searches and

cosmological constraints on inflationary models, specifically α-attractor E- and T-models. We find that the inflaton potential and the reheating temperature significantly affect the relic density of DM and have implications for interpreting collider signatures and understanding the dynamics of inflationary reheating.

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Leptogenesis: An Overview from the Low to the High

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Leptogenesis: An Overview from the Low to the High

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Squeezing data with model-independent approaches to constrain LCDM model and beyond

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Constraints on LCDM and beyond are usually obtained assuming, with different degrees, an underlying model, and that either on the level of the measurements or on the modeling of the systematics or when calculating parts of the theoretical outcomes for models beyond the fiducial one. In this talk we present some of our attempts to extract from the cosmological data information that are as much model-independent as possible, in order to constrain LCDM model parameters, such as the Hubble constant, the matter density and the matter fluctuation parameter sigma8; or models beyond LCDM such as those with extensions inducing effects on the background or on the large scale structures formation and growth level. We then show results and consequences from adopting these approaches with respect to ones obtained with more model dependent assumptions.

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New Approaches to Cosmology Inference from Galaxy Clustering

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Cosmology results of LOFAR

LoTSS (LOFAR Two-meter Sky Survey) is one of the major surveys conducted by the LOFAR(Low Frequency Array) network. It is a large-scale project aimed at creating deep, high-resolution radio maps of the northern sky at low frequencies. We present the work of the cosmology group in the LOFAR Surveys Key Science Projects: the count-in-cell statistics of the LoTSS sources(Pashapourahmadabad et al.); the redshift distribution from LoTSS deep fields(Bhardwaj el al.); the radio dipole from LoTSS DR2(Böhme et al); the auto-correlation and angular power spectrum of LoTSS (Hale et al.); the cross-correlation with CMB lensing and the Integrated Sache-Wolfe effect (Nakoneczny et al.); the cross-correlation with the optical spectroscopic survey eBOSS (Zheng et al.); and the joint cosmological parameter estimation with LoTSS combining auto and cross-correlation with CMB and eBOSS and

other surveys (Heneka et al.). We provide competitive constraints on the bias and redshift distribution of radio sources, BAO constraints and cosmological parameter constraints.

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The cosmic radio dipole: Bayesian estimators on new and old radio surveys

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The cosmic radio dipole is an anisotropy in the number counts of radio sources, analogous to the dipole seen in the cosmic microwave background (CMB). Measurements of the radio dipole with large radio surveys have shown that though the radio dipole is aligned in direction with the CMB dipole, the amplitudes are in tension. These observations present an intriguing puzzle as to the cause of this discrepancy, with a true anisotropy having large repercussions for cosmology as a whole. We present a novel set of Bayesian estimators to determine the cosmic radio dipole and compare the results with commonly used methods on the Rapid ASKAP Continuum Survey (RACS) and the NRAO VLA Sky Survey (NVSS) radio surveys. In addition, we enhanced the Baysian estimators in various ways to take into account systematic effects known to affect such large radio surveys, i.e. folding information such as the local noise floor or array configuration directly into the parameter estimation. The enhancement of these estimators allows us to greatly increase the amount of sources used in the parameter estimation, yielding tighter constraints on the cosmic radio dipole estimation than previously achieved with NVSS and RACS. We extend the estimators further to work on multiple catalogues simultaneously, leading to a combined parameter estimation using both NVSS and RACS. The result is a dipole estimate that perfectly aligns with the CMB dipole in terms of direction but with an amplitude that is three times as large, and a significance of 4.8σ. This new dipole measurement is made to an unprecedented level of precision for radio sources, which is only matched by recent results using infrared AGN.