2nd Nordic Cosmology Meeting

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University of Helsinki

Book of Abstracts

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Invisible Higgs decay from dark matter freeze-in at stronger coupling

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We study the Higgs boson decay into dark matter (DM) in the framework of freeze-in at stronger coupling. Even though the Higgs-DM coupling is significant, up to order one, DM does not thermalize due to the Boltzmann suppression of its production at low temperatures. We find that this mechanism leads to observable Higgs decay into invisible final states with the branching fraction of 10% and below, while producing the correct DM relic abundance. This applies to the DM masses down to the MeV scale, which requires a careful treatment of the hadronic production modes. For DM masses below the muon threshold, the Boltzmann suppression is not operative and the freeze-in nature of the production mechanism is instead guaranteed by the smallness of the electron Yukawa coupling. As a result, MeV DM with a significant coupling to the Higgs boson remains non-thermal as long as the reheating temperature does not exceed $\mathcal{O}(100)$ MeV. Our findings indicate that there are good prospects for observing light non-thermal DM via invisible Higgs decay at the LHC and FCC.

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Symmetry-breaking inflation in non-minimal metric-affine gravity

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We study symmetry-breaking inflation within the framework of metric-affine gravity. By introducing a non-minimal coupling, $\beta(\phi) ca\tilde{l}R$, between the Holst invariant and the inflaton, both small-field and large-field inflationary predictions can be brought into agreement with the latest observational constraints. Remarkably, even for sub-Planckian vacuum expectation values, appropriately chosen values of $\beta(\phi)$ enable viable inflation, a scenario previously considered unattainable.

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Recovering a phase transition signal in simulated LISA data with a modulated galactic foreground

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First-order phase transitions at the electroweak scale are predicted by many Standard Model extensions. They could create a stochastic gravitational wave background observable in the millihertz range today. The next-generation spaceborne observatory LISA has the potential of observing these backgrounds. However, possible phase transition signals will be buried under instrument noises and a foreground signal from millions of galactic binary systems. Here we explore the detectability of different phase transition models. We use statistical methods to recover a phase transition signal from data that is simulated using the LISA Simulation Suite, which allows for the injection of realistic instrument noises and a modulated binary foreground. We find that, by accounting for the modulation of the foreground, we are better able to constrain the phase transition parameters.

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Revisiting butterfy effects for asymptotically Lifshitz black hole

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We explore connections between two salient chaotic
features, namely Lyapunov exponent and butterfly velocity, for the class of asymptotically Lifshitz black hole background with arbitrary critical exponent by implementing three different holographic approaches, namely,
entanglement wedge method, out of time-ordered correlators (OTOC) and pole-skipping. We present a comparative study where all of the above methods yield exactly similar results for the butterfly velocity and Lyapunov exponent. This establishes equivalence between all three
methods for probing chaos in the chosen gravity background. Explicit non-trivial dependencies of OTOC onthe arbitrary critical exponent has also been studied. We further derive the eikonal phase approximation and Lyapunov exponent at the turning point of the null geodesic of the background geometry using the classical approach. Eventually we uncover different scattering scenarios in the near-horizon and near-boundary regimes.

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Boosted Dark Matter Driven by Cosmic Rays and Diffuse Supernova Neutrinos

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Direct detection of light dark matter can be significantly enhanced by up-scattering of dark matter with energetic particles in the cosmic ambient. This boosted dark matter flux can reach kinetic energies up to tens of MeV, while the typical kinetic energies of GeV mass dark matter particles in the Milky Way halo are of the order of keV. Dark matter boosted by energetic diffuse supernova background neutrinos can be detected only through nuclear or electron scattering in ground-based detectors requiring a non-zero interaction of dark matter with nucleon or electron, in addition to its interaction with neutrino. However, in the presence of dark matter-nucleon (electron) interaction, the scattering of dark matter with cosmic rays is unavoidable. Thus, we consider boosted dark matter resulting from diffuse supernova neutrinos as well as cosmic protons (electrons) considering

both energy-dependent and energy-independent scattering cross-sections between dark matter and standard model particles. We explore this scenario in dark matter detectors such as XENONnT and neutrino detectors like Super-Kamiokande.

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Freeze-in at stronger coupling

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We study freeze-in production of dark matter (DM) at temperatures far below the dark matter mass. The temperature of the Standard Model (SM) thermal bath may have never been high such that dark matter production via thermal emission has been Boltzmann suppressed. This allows for a significant coupling between the SM and DM, which is being probed by the direct DM detection experiments and invisible Higgs decay searches at the LHC.

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Networks of Axion Strings - Scaling

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In the post-inflationary scenario, if PQ symmetry breaking occurs, a network of global cosmic strings are expected to form. At the time of the QCD phase transition, the previously scaling network of such defects will collapse by forming domain walls attached to strings. Given that all of the energy density of the string network is left behind into axion waves, in order to improve current estimates of axion dark matter density, estimates of the scaling density of axion strings are required. In this talk, I will review recent work on the dynamics of axion strings which uses extreme scale computing resources for simulating 16384ˆ3 lattices. I will address and comment on the recent claims of logarithmic violations of scaling

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Kinetic Gauge Friction in Natural Inflation

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In this talk I will discuss a recently studied extension of the natural inflation model comprising a non - Abelian gauge sector coupled to the axion - inflaton kinetic term . I will show how such non - minimal coupling serves as a source of friction for the rolling inflaton granting at least sixty e - folds of accelerated expansion for sub - Planckian values of the axion decay constant . The analysis of perturbations reveals a negative sound speed, thus signaling an instability . Implementing a Chern - Simons - type coupling between the inflaton and gauge sectors cures the instability by delivering a positive speed . We finalize by presenting a numerical study of scalar and tensor perturbations for a fiducial set of parameters finding that the corresponding observables are compatible with current CMB bounds .

Contributed talks / 12

Holography for phase transitions

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First-order phase transitions represent a golden opportunity into uncovering new physics as well as into the QCD phase diagram. These transitions typically proceed through nucleation, expansion and collision of bubbles. As a consequence, the spectrum depends on out-of-equilibrium properties that are challenging to obtain, such as the wall speed. In this talk I will review recent progress in studying bubble dynamics in strongly coupled theories using holography, which is highly suited to study dynamical situations as it maps QFT problems to classical dynamics of black hole horizons. I will further present results for superheated transitions in a theory whose phase diagram mirrors that of QCD, relevant for neutron stars.

Contributed talks / 13

Gravitational Waves and Dark Matter from Scale Symmetry Breaking

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We present an updated analysis of the first-order phase transition associated with symmetry breaking in the early Universe in a classically scale-invariant model extended with a new SU(2) gauge group. Including recent developments in understanding supercooled phase transitions, we compute all of the model's characteristics and significantly constrain the parameter space. We then predict gravitational wave spectra generated during this phase transition. By computing the signal-to-noise ratio we conclude that this model is well-testable (and falsifiable) with LISA. We also provide predictions for the relic dark matter abundance. It is consistent with observations in a rather narrow part of the parameter space since we exclude the so-called supercool dark matter scenario based on an improved description of percolation and reheating after the phase transition as well as the inclusion

of the running of couplings. Finally, we devote attention to the renormalisation-scale dependence of the results.

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Constraining axions by neutron star superradiance

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In the phenomenon of black hole superradiance a rotating black hole loses its angular momentum to a growing cloud of particles. It has been successfully used to place limits on ultralight particles, such as axions and dark photons, with masses $\mu \sim 10^{-20} - 10^{-18}$ eV and $\mu \sim 10^{-12} - 10^{-11}$ eV. However, measurements of black hole spins are statistical in nature and have large uncertainties. On the other hand, it has been shown that superradiance occurs also in neutron stars due to an instability in the magnetosphere. A proper treatment has however been lacking, and no bounds analogous to those of black holes have been placed yet. In our work we calculate, for the first time, the superradiance rate and use it to place new bounds on axions of masses $\mu \sim 10^{-12} - 10^{-11}$ eV. This is done by requiring that the superradiance-induced spindown not be faster than that observed by pulsar timing arrays. We compare bounds obtained from several millisecond pulsars, including the newly found supermassive pulsar PSR J0952–0607. Finally, we suggest the possibility of other signals from superradiant axion clouds around neutron stars.

Contributed talks / 15

Axion inflation with non-Abelian gauge fields

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Currently, the search for primordial gravitational waves is largely focused on detecting the parity-odd polarization pattern in the Cosmic Microwave Background—the B-modes. Accurately interpreting B-mode measurements depends heavily on understanding their production mechanisms. A particularly compelling scenario involves gravitational wave generation through the interaction of axion with gauge fields. I will discuss recent advances in axion inflation incorporating non-Abelian gauge fields, highlighting primordial gravitational wave background signatures and implications for primordial magnetogenesis.

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Quasi-Palatini Gravity and Scalar-Tensor Theories

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The Palatini formulation of gravity has been successfully used to motivate several observationally viable models of inflationary expansion. While the Palatini and metric formulations are equivalent in minimally coupled gravity, non-minimal scalar models are phenomenologically distinct depending on which formulation is used. At the same time, the recent hybrid approach to metric and Palatini gravity, featuring both the metric and Palatini scalar curvature, has been a productive avenue for model building. However, in practice, the distinction between metric and Palatini appears as a choice applied to an already existing model, rather than the introduction of a novel coupling function. This raises the interesting question of whether a continuous deformation between the metric and Palatini formulations is possible. To this end, we delineate between theories with distinct physical content and different formulations of the same theory, and we introduce the "quasi-Palatini" formulation. We demonstrate how this novel formulation can be used to modify already existing models without introducing new degrees of freedom. We study established models such as the Higgs model of inflation, F(R) gravity, and higher-order modified gravity, and we determine the relative presence of the Palatini variation by making contact with observations without parameter fine-tuning. We discuss how this approach may be further incorporated into the geometric trinity of gravity and metric-affine theories in general.

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Preparing for LISA with the Cosmology Data Centre Finland

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The Laser Interferometer Space Antenna (LISA) mission is a space-based gravitational wave interferometer set to launch in 2035, and which has now formally been adopted by ESA. LISA will search for gravitational waves in the millihertz frequency range, which is expected to contain gravitational waves of both astrophysical and cosmological origin. To prepare for the future launch of LISA and the wealth of data we expect it to provide, data analysis tools and pipelines need to be developed and tested. In this talk I will present the LISA activities of the recently established Cosmology Data Centre Finland (CDC-FI), which will handle some of the code prototyping and development necessary to prepare for the LISA mission. CDC-FI will also host the production of the next major LISA mock dataset, which will be used by the LISA community to test these codes. These efforts will constitute Finland's main contribution to LISA operations.

Contributed talks / 18

Black holes and gravitational waves from slow phase transitions

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Cosmological first-order phase transitions may have played a significant role in the formation of baryon asymmetry and dark matter, potentially leaving an observable gravitational wave signature. In this talk, I will focus on the possibility of primordial black hole formation from slow and strongly supercooled transitions. I will describe how the stochastic nature of the bubble nucleation process

generates large inhomogeneities that can collapse into primordial black holes after the transition. Additionally, I will show that for such transitions, the low-frequency part of the gravitational wave spectrum is sourced by the large fluctuations and the resulting spectrum has a distinguishable double-peak shape.

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Gravitational waves with the Pencil Code

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The gravitational wave module in the Pencil Code is a versatile tool for computing the time-dependent three-dimensional strain field from a range of different sources in the early universe ranging from phase-transitional hydrodynamic and magnetohydrodynamic stresses to inflationary ones involving electromagnetic and axion pseudoscalar stresses. The solver utilizes the analytic solution for stresses that change linearly between two time steps. The accuracy of the strain field scales quadratically with the time step and has a low prefactor, making the relative error of the scheme comparable to that of the other variables that scale cubicly with the time step. In my talk, I will explain this in more detail and give examples of the by now 15 different published applications.

Lightning talks / 20

Quintessential inflation in Palatini F(R,X) gravity

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Palatini F(R,X) gravity, with X the inflaton kinetic term, proved to be a powerful framework for generating asymptotically flat inflaton potentials. Here we show that the general form of the F(R,X) potential also provides a tail that generates, in principle, quintessential behavior for dark energy. We describe a few examples that fit the observed value of the cosmological constant and discuss the pros and cons of those models.

Lightning talks / 21

Tachyonic production of dark relics: classical lattice vs quantum 2PI in Hartree truncation

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An oscillating curvature of the spacetime can drive the production of dark matter during reheating, and accurately quantifying this requires the use of both non-perturbative and non-equilibrium methods. In our work, we compare the particle production on a non-minimally coupled scalar field when computed using a classical lattice approach to previous work utilizing Hartree-level 2PI-methods. Both approaches find two distinct phases of particle production, an initial tachyonic growth and a subsequent period of parametric resonance. In the range of scalar self-couplings considered, the lattice and the 2PI-approaches were also in agreement on average quantities such as the final scalar field variance up to a factor of less than 5. However, we also find that mode-mixing lacking in the Hartree-truncation plays a significant role in the lattice solution, leading to considerable differences in the resulting scalar power spectra. Our results indicate that a beyond-Hartree computation of 2PI-collision terms is necessary for accurate modelling of the particle production at a quantum level.

Contributed talks / 22

Absence of propagating gravitational-wave polarisations in degenerate f(R) models

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In the context of $f(R)$ gravity, as well as other extended theories of gravity, the correct counting of globally well-defined linear dynamical modes (i.e. gravitational-wave polarisations) has recently drawn a vivid interest. In this talk, we present a consistent approach shedding light on such issues for both so-called degenerate and non-degenerate $f(R)$ models embedded in Minkowski and de Sitter backgrounds. We find that the linearised spectrum of degenerate models on these backgrounds is empty, lacking both the graviton and scalaron modes which appear in generic non-degenerate models. Our work generalises previous results in the literature applicable only to the specific (degenerate) model $f(R) = \alpha R^2$; in fact, we find that the same pathologies discovered therein emerge for all choices of $f(R)$ belonging to the wide class of degenerate models.

Lightning talks / 23

Cosmology in metric affine theories of gravity

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The stress energy tensor we all know is related to the existence of a metric. But the metric is not the only character we can take into account when studying a theory of gravity. We can also consider an independent connection. If we do so we will have the hypermomentum tensor in the game too. This can be related to quantities such as torsion and non metricity. What is the role of these quantities in cosmology? Can we explain some kind of accelerated expansion without relying necessarily on a cosmological constant?

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Euclid

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Euclid is the cosmology satellite of the European Space Agency (ESA). Its main goal is to solve the mystery of dark energy: what is causing the accelerated expansion of the universe. Euclid was launched in July 2023, and it has been collecting data since February 2024. One of the nine Euclid data processing centers is operating in Finland.

The first major public data release, the so-called Quick Release 1 (QR1) will take place on March 19th this year. The first cosmological results are expected in October 2026. I will give a brief review of the status of the project, and what we can expect from the coming Q1 release.

Contributed talks / 25

Evolution of black hole-string networks

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Primordial black holes (PBHs), potentially formed in the early universe, may play a crucial role in cosmology, serving as seeds for supermassive black holes and contributing to the formation of merging black hole binaries observed by LIGO/VIRGO. They have also been proposed as candidates for dark matter. Another scenario involves cosmic strings, hypothetical linear defects predicted by various particle physics models. Recent studies suggest that PBHs and cosmic strings could coexist, forming an interconnected BH-string network that influences their evolution. Depending on how efficiently BHs detach from the network, two scenarios emerge: a "frozen network" where BHs remain connected by stretched strings, or a scenario where BHs detach efficiently and become isolated, potentially leading to detectable gravitational radiation from oscillating string loops. This study aims to simulate the evolution of BH-string networks, particularly their early stages, to determine under what conditions a frozen network forms and how it impacts gravitational wave signals, which could differ from those of standard cosmic strings.

Contributed talks / 26

Cosmological Implications of a New Dark Sector Phase Transition after BBN

Author: Florian Niedermann[None]

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In this talk, I will discuss the phenomenology of a first-order phase transition that occurs after Big Bang nucleosynthesis (BBN) but before recombination in a sector that is secluded from the standard model. Such a rather late phase transition impacts curvature perturbations at a time when some of them have already re-entered the cosmological horizon. In particular, the trigger dynamics of the phase transition induces acoustic oscillations in the post-phase transition fluid, leading to observable signatures in the cosmic microwave background and the large-scale structure of the Universe. Following this general discussion, I will present a simple dark sector Higgs model where an SU(N) gauge symmetry undergoes spontaneous breaking to SU(N-1) via a supercooled first-order phase

transition à la Coleman-Weinberg. The latent heat released in the phase transition acts as an early phase of dark energy before it is converted into strongly interacting dark radiation. This scenario, termed Hot New Early Dark Energy, can alleviate the Hubble tension while remaining consistent with Big Bang nucleosynthesis constraints.

Contributed talks / 27

Primordial Black Holes from the Running-Mass-Inflation

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The running-mass inflation model generates the primordial curvature perturbation spectrum that is consistent with observations at the pivot scale but exhibits a very large running at smaller scales. This creates favourable conditions for the formation of primordial black holes. In the current work we analyse a novel mechanism that provides the graceful exit for this model and enables us to compute the shape of the full spectrum. Moreover, the created black holes are of the right mass and abundance to explain Dark Matter.

Lightning talks / 28

Numerical study of the scaling of magnetic monopoles

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Magnetic monopoles are a common prediction of early universe phase transitions. In particular, any type of a grand unified theory phase transition will produce magnetic monopoles, and it is thought that these monopoles would come to dominate the energy density of the universe. This consitutes the 'monopole problem' of grand unification, which theories of inflation solve by diluting the energy density of monopoles sufficiently.
We study the evolution of a system of monopoles numerically, in a case where the monopoles do not interact with other matter. During radiation era, we find evidence that the monopoles annihilate sufficiently fast to maintain a constant energy fraction, while in matter era the density fraction decreases slowly. While our results suggest that a gas of monopoles after a phase transition will not come to dominate the energy density of the universe, further work is needed to see if thermal velocities reduce the annihilation frequency.

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The NANOGrav 15 yr Data Set: Running of the Spectral Index

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In this talk I will review the succesful search for Hellings-Downs correlations by the NANOGrav collaboration and the search for new physics with pulsar timing data. In particular, I will show the first model-independent search going beyond the simple power-law fit to characterise the frequency spectrum of the signal observed by the collaboration, allowing for a running of the spectral index. We can also interpret the model as a description of primordial GWs from cosmic inflation. Based on work published in ApJL 978 L29 (2025).

Lightning talks / 30

Generating gravitational wave spectra from equations of state for phase transitions in the early universe

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The frequency range of gravitational waves from first-order cosmological phase transitions will be investigated by the upcoming space-based gravitational wave observatory LISA. If we see a signal of cosmological origin, we need to be able to deduce the parameters of the phase transition from the gravitational wave signal to understand the physics behind it. This requires simulations of the gravitational wave spectra with various parameters. Many of the existing simulations have been based on 3D lattices, which is computationally expensive and therefore infeasible for a large parameter space. A significantly faster alternative is provided by the Sound Shell Model, which provides a computationally efficient way of calculating the gravitational wave spectra, reproducing the results of numerical simulations for intermediate strength transitions. The Sound Shell Model is encapsulated in the simulation framework PTtools developed by our research group. We have also developed the web-based plotting utility PTPlot to visualise these gravitational wave spectra.

The vast majority of existing simulations have been based on the bag model equation of state, which assumes the ultrarelativistic sound speed $c_s = \frac{1}{\sqrt{3}}$. As the latest addition, PTtools has been extended to include support for arbitrary equations of state and therefore for a temperature- and phase-dependent sound speed $c_s(T, \phi)$, extending the simulations beyond the ultrarelativistic assumption of the bag model.

Lightning talks / 31

Cosmology based on gauge theories of gravity

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Lorentz gauge theory of gravity with spontaneous symmetry breaking field provides successful description of ΛCDM model, as well as generalised black hole solutions compared to those in General Relativity. This talk summarises these extensions provided by such theory and explores whether this can be realised with different symmetry group, Euclidean gauge for example, and how this will affect further applications in cosmology, such as cosmological perturbation and gravitational waves.

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ΛCDM theory of cosmology

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The bulk action of the Yang-Mills theory based on the compact Lorentz group Spin(4)=SU(2)xSU(2) is determined by one parameter c_T. When c_T=1, the theory is right-handed and predicts a spin-2 field with the dynamics of the metric tensor in general relativity in the presence of dust. When c_T=0, the theory is achiral and has no local degrees of freedom. A transition from the latter to the former phase could thus generate the ΛCDM cosmology without the need of inflation, dark energy or dark matter.

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Global portraits of inflation in nonsingular variables

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In the phase space perspective, scalar field slow roll inflation is described by a heteroclinic orbit from a saddle type fixed point to a final attractive point. In many models the saddle point resides in the scalar field asymptotics, thus for a comprehensive view of the dynamics a global phase portrait is necessary. For this task in the literature one encounters dynamical variables that either render the initial or the final state singular, thus obscuring the full picture. In this work we construct a hybrid set of variables which allow the depiction of both the initial and final states distinctly in nonsingular manner. To illustrate the method, we apply these variables to portray various interesting types of nonminimal scalar field inflationary models in metric and Palatini formalism.

Contributed talks / 35

Thermal nucleation in perturbation theory

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Cosmological first-order phase transitions may have generated an observable gravitational wave background, offering a unique probe of beyond-Standard-Model physics. A crucial step in predicting this background is the reliable computation of bubble nucleation rates. In this talk, I will give an overview of recent advancements in perturbative high-temperature nucleation rate calculations. These include the application of effective field theory, which enhances our understanding of the equilibrium part of the computation, and the use of Boltzmann equations to account for the off-equilibrium effects of the primordial plasma onto nucleation. I will also discuss some open challenges that remain in perturbative approaches, paving the way for future developments.

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Signatures of the speed of sound on the gravitational wave power spectrum from sound waves

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Future space-based interferometers offer an unprecedented opportunity to detect signals from the stochastic gravitational wave background originating from a first-order phase transition at the electroweak scale. The phase transition is accompanied by a change of the equation of state from that of pure radiation. In this work we study the effect of this change on the power spectrum of gravitational waves generated by the sound waves in the plasma during the acoustic phase of the transition. We carry out an analytic calculation assuming that the sound speed and the fluid shear-stress that sources tensor perturbations remain approximately constant during the acoustic phase. The effect of a softer equation of state is twofold:
(i) a scale-independent suppression of the power spectrum at all scales, due to the modified propagation of both sound and gravitational waves and
(ii) the peak of the spectrum moves to smaller frequencies as the equation of state becomes softer.
The power-law indices of the spectrum at small and large scales are unaffected by the softening of the equation of state. Our work improves the current estimation of the gravitational waves power spectrum from first order phase transitions and expands the possible scenarios of transitions that can be tested by gravitational wave detectors.

Contributed talks / 37

New early dark energy and its equation of state

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The Hubble Tension is the discrepancy between the measured value of the Hubble parameter H_0 and its ΛCDM model prediction using CMB data. New Early Dark Energy (NEDE) addresses this tension using a triggered phase transition in the dark sector. In this work we constrain the properties of NEDE using recent CMB and supernovae datasets, as well as the new BAO data from the DESI survey.

We study the equation of state parameter, characterizing the post-phase transition fluid, allowing it to evolve in time. Our results indicate that data is compatible with a simple time dependence that could arise from a mixture of radiation and a stiff fluid. Our model shows a significant reduction of the tension down to below 3σ.

Invited talk / 38

Nonlinear Cosmological probes of gravity theories beyond General Relativity

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Several modifications to general relativity have been proposed to explain the nature of dark energy and the accelerated expansion of the Universe. In this talk, I will review the present status of modified theories of gravity in the light of astrophysical probes of gravity in the weak-field regime, ranging from stars to cosmological scales. I begin by setting the scene for how theories beyond General Relativity are expected to behave in the different astrophysical systems and their cosmological signatures. With these in hand, I present a range of observational tests intending to use the current and next generation of observations for tests of gravity. In particular, I will show how physical observables of the non-linear regime of structure formation are promising probes to constraining theoretical models in the nonlinear dynamics of galaxies, clusters and large-scale structures.

Invited talk / 39

Quantum Tachyonic Preheating Revisited.

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Tachyonic preheating is one of a few compelling mechanisms for transitioning from an inflationary, empty Universe to a hot radiation dominated Universe. The 2PI formalism allows for a correct quantum treatment of particle production and thermalisation, and is well suited for numerical implementation on the lattice. I will present an investigation of tachyonic preheating, aimed at updating similar simulations performed two decades(!) ago, and exploring the limitations of the classical-statistical approximation in this context.

Invited talk / 40

The bubble wall velocity in cosmological phase transitions

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Cosmological first order phase transitions are a promising source of gravitational waves, and a possible explanation of the baryon asymmetry and dark matter abundance. Predicting the phenomenological consequences of such phase transitions requires knowledge of the expansion velocity of the bubbles formed in a phase transition. In this talk, I will present WallGo, a software package for the computation of bubble wall velocities. WallGo is the first publicly available code that computes the matrix elements, collision integrals Boltzmann equation and scalar field equation of motion for user-defined models. I will present results obtained with WallGo, and discuss its limitations. Lastly, I will discuss several simplifying regimes in the computation of the wall velocity, such as the ballistic limit and a large jump in degrees of freedom.

Invited talk / 41

LISA and its synergy with particle physics colliders

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One of the primary objectives of the LISA mission is to measure and characterize the stochastic gravitational-wave background (SGWB). Achieving this goal will allow LISA to explore various domains, including astrophysics, cosmology, and particle physics. This talk focuses on the latter, specifically on physics beyond the Standard Model that involves strong first-order phase transitions. We demonstrate that LISA holds significant potential for advancing particle physics. Indeed, by searching and reconstructing (or imposing upper bounds on) the SGWB from first-order phase transitions, LISA can accurately constrain the parameter space of particle physics models, in synergy with current and future colliders.

Invited talk / 42

Fishing for light dark matter with pulsars (via Zoom)

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Pulsars, which are very rapidly spinning neutron stars, can be instrumental in solving the puzzle, which has perplexed the minds of the scientific community for almost a century –dark matter (DM). In the talk I will mainly focus on the light DM candidates that can be searched for in pulsar observables. The ultralight scalar field DM (also known as "fuzzy" DM), consisting of bosons with extremely low masses of m ~ 10^{-22} eV, solves some of the problems of the conventional cold DM hypothesis. It was shown by Khmelnitsky and Rubakov (2014) that such DM in the Milky Way induces oscillating gravitational potentials, leaving characteristic imprints in the time of arrivals of radio pulses from pulsars. In addition (Ivanov et al 2019, Castillo et al. 2022), the coupling of axion-like particles to photons alters the polarization properties of light, i.e. the plane of polarization of linearly polarized beam propagating through the axion field starts to oscillate with typical frequencies of 10^{-8} –10^{-5} Hz. Searches for these two effects were performed in the data of the European Pulsar Timing Array (EPTA), and stringent constraints on the DM density and coupling constant between photons and axion-like particles have been set. In addition, traces of QCD axions with masses of around ˜ μeV can be searched for with the spectroscopic observations of pulsars. We discuss the systematics and artifacts in pulsar data that can mimic the signal of interest and possible methods to avoid the existing biases.

Invited talk / 44

Direct detection of dark matter: overview

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Direct detection of scattering events of dark matter off ordinary atoms is a critical goal that would allow us to extract information about the nature of the dark matter particle. I will give an overview of the theory underlying the direct detection experiments and on the current status of these experiments. I will discuss some future prospects, focusing on the developments towards direct detection of light (sub-GeV) dark matter.

Contributed talks / 45

The Adiabaticity Condition Revisited: Necessary but not Sufficient

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We present a simple counterexample that illustrates the fact that a standard expression of the adiabaticity condition –
$abs\dot{\omega}/\omega^2$
$abs \ll 1$, where ω corresponds to the characteristic frequency of any given field mode – is a necessary but not sufficient condition for particle production. We further illustrate this via the example of a Mukhanov-Sasaki-like variable corresponding to a massless test scalar field on time dependent backgrounds where in and out states can be defined, and show that the trace log for the latter has no imaginary contributions, even as the adiabaticity condition is nominally violated for certain field modes at some time. To understand these examples, we first re-examine the equivalence of physical observables derived from in-out amplitudes under field redefinitions (otherwise known as the equivalence theorem) under general spacetime dependent field redefinitions, clarifying the conditions under which it fails to apply via functional methods and LSZ reduction. We then identify the insufficiency of the adiabaticity condition as a failure of the former to be an unconditional proxy for adiabatic evolution, and restate the general conditions for the latter. We conclude by discussing the ramifications and cautions that follow from this result to familiar applications in cosmology as well as regularization schemes that rely upon an adiabatic expansion.

Invited talk / 46

Primordial black holes and their gravitational wave signatures

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Primordial black holes (PBHs) are a compelling dark matter candidate that can be effectively probed through their gravitational wave (GW) signatures. In this talk, I will focus on standard scenarios in which PBHs form via the collapse of sizeable primordial curvature fluctuations. I will discuss what current pulsar timing array (PTA) measurements can tell us about stellar-mass PBHs and whether future GW detectors could confirm or rule out most scenarios for PBH dark matter. Non-Gaussianities in primordial density fluctuations may play a crucial role in this discussion. I will explore when and how they might affect GW signals from PBH binary mergers and scalar-induced GW backgrounds associated with PBH formation. Finally, I will outline some spectral features characteristic to PBH scenarios.

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Welcome and opening remarks

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