Particle Production in the Early Universe

Report of Contributions

https://indico.cern.ch/e/1381302

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

The Open Effective Field Theory of Inflation

Tuesday 10 September 2024 10:10 (15 minutes)

There is an increasing interest in the interplay between Open Quantum Systems and Inflationary Physics. A time-dependent background and limited access to the degrees of freedom invites the use of Open Quantum systems. It provides a more general framework than the unitary time evolution of a pure state. In this talk, we develop a local EFT for the scalar curvature perturbations subject to the dynamics of an open quantum system. We focus on recovering the scale-invariant power spectrum and its amplitude as a function of the dissipation (among other EFT parameters). Our results largely generalize the setup of warm inflation to general non-equilibrium cases. We also explore the different shapes of the bispectrum and the dictionary between our formalism and the Langevin equation.

Author: AGUI SALCEDO, Santiago (University of Cambridge)

Presenter: AGUI SALCEDO, Santiago (University of Cambridge)

Session Classification: Short Talks

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

Unitarity, holomorphic cuts, and thermal effects in zero-temperature calculations

Tuesday 10 September 2024 14:55 (15 minutes)

When studying particle density evolution, within the classical Boltzmann approach, we must include all number-changing processes in which the particle participates, typically decays or scatterings. At higher orders, other types of reactions may become relevant as well. We formulate a diagrammatic unitarity-based algorithm to complete the set of contributing reactions. Initially, the particles are treated as classical point-like objects whose interactions are described through zero-temperature quantum field theory. In equilibrium, their phase space densities are the Maxwell-Boltzmann exponentials. Surprisingly, the algorithm automatically accounts for the effects of thermal corrections. The framework will be demonstrated through *CP* asymmetry calculations and higher-order corrections to particle decays in a thermal medium.

Author: Dr MATAK, Peter (Comenius University (SK))

Presenter: Dr MATAK, Peter (Comenius University (SK))

Session Classification: Short Talks

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

Non-Gaussianity from preheating with scale dependence

Tuesday 10 September 2024 10:25 (15 minutes)

Preheating involves the rapid production of daughter particles after the end of inflation. Combining lattice simulations with a non-perturbative delta N treatment, I will describe a general formalism to calculate the non-Gaussianity generated by preheating in the presence of a single light scalar field. When scale dependence during inflation is included, our results show that cosmic variance, i.e., the contribution from modes with wavelength longer than the size of the observable universe today, plays a key role in determining the non-Gaussianity. I will illustrate our formalism by applying it to an observationally-viable model of preheating that is motivated by non-minimal coupling to gravity, and present its full parameter dependence.

Authors: GHODERAO, Pulkit (Imperial College London); Prof. RAJANTIE, Arttu (Imperial College (GB))

Presenter: GHODERAO, Pulkit (Imperial College London)

Session Classification: Short Talks

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

Open quantum system dynamics of non-relativistic dark matter pairs

Tuesday 10 September 2024 12:05 (15 minutes)

For a quantitative investigation on the real-time evolution of heavy dark matter in the early universe, not only close-to-threshold effects but also key aspects such as decoherence and dissipation due to interactions with the thermal environment need to be taken into account. We employ the formalism of open quantum systems and determine the out-of-equilibrium evolution equations for non-relativistic dark matter pairs from first principles within the framework of potential non-relativistic effective field theories at finite temperature. For the considered hierarchy of energy scales, we eventually derive the coupled semiclassical Boltzmann equations from the quantum master equations and highlight their range of validity and consistency.

Author: QERIMI, Gramos (Technical University of Munich (TUM))

Presenter: QERIMI, Gramos (Technical University of Munich (TUM))

Session Classification: Short Talks

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

Upper Bound on Thermal Gravitational Wave Backgrounds from Hidden Sectors

Tuesday 10 September 2024 16:00 (15 minutes)

Hot viscous plasmas unavoidably emit a gravitational wave background, similar to the electromagnetic black body radiation. In this talk, based on arXiv:2312.13855, I will study the contribution from hidden particles to the GW background emitted by the early universe primordial plasma. While this contribution can easily dominate over that from Standard Model particles, we find that both backgrounds are capped by a generic upper bound that makes them difficult to detect in the foreseeable future. We illustrate our results for axions and heavy neutral leptons.

Author: GEORIS, Yannis

Co-authors: KLARIC, Juraj (Universiteit van Amsterdam, Nikhef); DREWES, Marco; KLOSE, Philipp (Bielefeld University)

Presenter: GEORIS, Yannis

Session Classification: Short Talks

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

CMB signature of non thermal dark matter production from self interacting dark sector

Tuesday 10 September 2024 17:00 (15 minutes)

The fundamental nature of dark matter (DM) and its production mechanism is yet unknown. Non thermal or freeze in DM scenarios are currently being widely explored. In this work we explore the production of non-thermal DM and its connection with Cosmic Microwave Background (CMB) via additional relativistic degrees of freedom which are simultaneously generated during the period $T_{\rm BBN}$ to $T_{\rm CMB}$ from a long-lived dark sector particle. To realize this phenomena we minimally extend the type-I seesaw scenario with a Dirac fermion singlet(χ) and a complex scalar singlet (ϕ) which transform non-trivially under an unbroken symmetry Z_3. χ being the lightest stable particle in the dark sector, acts as a stable dark matter candidate while the next to lightest state ϕ operates like a long lived dark scalar particle. The initial density of ϕ is thermally generated through either self-interacting number
changing processes ($3\phi \rightarrow 2\phi$) within dark sector or the standard annihilation to SM particles ($2\phi \rightarrow$ 2 SM). The late time (after neutrino decoupling) non-thermal decay of ϕ can produce dark matter in association with active neutrinos. The presence of extra relativistic neutrino degrees of freedom at the time of CMB can have a significant impact on $\Delta N_{\rm eff}$. Thus the precise measurement of $\Delta N_{\rm eff}$ by current PLANCK 2018 collaboration and future experiments like SPT-3G and CMB-S4 can indirectly probe this non-thermal dark matter scenario which is otherwise completely secluded due to its tiny coupling with the standard model

Authors: Prof. GHOSH, Dilip Kumar (Indian Association for the Cultivation of Science); Dr GHOSH, Purusottam (Institute of Physics); Mr JEESUN, Sk (Indian Association for the Cultivation of Science)

Presenter: Mr JEESUN, Sk (Indian Association for the Cultivation of Science)

Session Classification: Short Talks

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

Signatures of inflaton fragmentation during reheating

The exponential expansion of the early Universe driven by inflation leaves it in a cold, empty state. When inflation ends, the energy density of the inflaton field must then be transfered into visible and dark matter and radiation, during the stage known as reheating. In this talk I will review the formalism necessary to determine particle production rates, and the instantaneous temperature during reheating, in the presence of a transient epoch of resonant growth of fluctuations (preheating), sourced by inflaton-inflaton or inflaton-dark matter interactions, which can fragment the classical inflaton condensate. I will discuss the impact that these dynamics can have in the duration of reheating, and in some cosmological observables.

Author: Prof. GARCIA GARCIA, Marcos A. (Instituto de Fisica, UNAM)

Presenter: Prof. GARCIA GARCIA, Marcos A. (Instituto de Fisica, UNAM)

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

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

Tuesday 10 September 2024 16:15 (15 minutes)

We revisit the framework of axion-like inflation, considering 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.

Authors: LAINE, Mikko Sakari (Universitaet Bern (CH)); KLOSE, Philipp (Universität Bielefeld); PROCACCI, Simona (University of Geneva (CH))

Presenter: KLOSE, Philipp (Universität Bielefeld)

Session Classification: Short Talks

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

Exploring General Vector Mediators in Inelastic Dark Matter Models

Tuesday 10 September 2024 16:45 (15 minutes)

Despite the robust cosmological and astrophysical evidence confirming the existence of a non-baryonic matter component in the Universe, the underlying nature of Dark Matter (DM) remains a mystery. Among the several possible scenarios, light DM candidates thermally produced in the early Universe are especially interesting, since their abundance could be set via the standard freeze-out mechanism. Additionally, new light states can present a rich phenomenology and are attracting increasing attention due to recent experimental capabilities to probe dark sectors with feeble interactions. In particular, inelastic DM (iDM) candidates are an appealing option, since they can avoid CMB bounds as well as indirect and direct detection searches. Although such models have been intensively studied in the literature, the usual scenario is to consider a secluded dark photon mediator. In this work, we consider the case of iDM with general vector mediators and explore the consequences of such a choice in the relic density computation, as well as for the cosmological and experimental bounds. We also provide a numerical Python library to compute the relic densities for user-defined gauge charges.

Authors: LUISA FOGUEL DA SILVA, Ana (Universidade de São Paulo); REIMITZ, Peter; ZUKANOVICH FUNCHAL, renata (Universidade de São Paulo)

Presenter: LUISA FOGUEL DA SILVA, Ana (Universidade de São Paulo)

Session Classification: Short Talks

Contribution ID: **23** Type: **not specified**

Neutrino Decoupling at NLO: Methods and Rates

Tuesday 10 September 2024 16:30 (15 minutes)

Author: ESCUDERO ABENZA, Miguel (CERN)

Presenter: ESCUDERO ABENZA, Miguel (CERN)

Session Classification: Short Talks

Contribution ID: **24** Type: **not specified**

Adiabatic renormalization without infrared distortions in cosmological spacetimes

Tuesday 10 September 2024 14:40 (15 minutes)

Particle creation in cosmological spacetimes leads to new ultraviolet divergences in the expectation values of field operators (such as the stress-energy tensor) not present in Minkowski spacetime. Adiabatic renormalization is an extensively used method to renormalize these, but it may lead to unwanted distortions at infrared scales. In my talk I will present a new renormalization method for free quantum scalar fields propagating in cosmological spacetimes, which generalizes the standard adiabatic scheme with the introduction of arbitrary mass scales not present in the standard program. By setting them to the physical scale of the problem, we obtain ultraviolet-regularized quantities that do not distort the amplitude of the power spectra at the infrared momenta scales amplified by the non-adiabatic expansion of the universe. I will illustrate our method in two examples of cosmological interest: de Sitter inflation and geometric reheating. Talk based on 2212.01078 and 2311.08986.

Author: Dr TORRENTI, Francisco (ICCUB, U. Barcelona)

Presenter: Dr TORRENTI, Francisco (ICCUB, U. Barcelona)

Session Classification: Short Talks

Contribution ID: **26** Type: **not specified**

Consistent EFTs in the Schwinger-Keldysh formalism

Tuesday 10 September 2024 12:20 (15 minutes)

We compare the evolution equations for a particle species in a thermal bath for a toy model obtained first by solving the full system and second by constructing an EFT in vacuum and solving the von Neumann equation for the subsystem. We find that the second approach clearly fails to account for particle production and decay due to the inability of the von Neumann equation to describe dissipative dynamics. We then attempt to embed the vacuum effective Lagrangian into the Schwinger-Keldysh formalism and obtain the evolution equation, but still miss some terms. Finally, we move on to construct a consistent EFT in the Schwinger-Keldysh formalism directly and show that it exactly matches the full solution.

Authors: WANG, Edward (Technical University of Munich (TUM)); BINDER, Tobias

Presenter: WANG, Edward (Technical University of Munich (TUM))

Session Classification: Short Talks

Contribution ID: **31** Type: **not specified**

Excited bound states and their role in dark matter production

Tuesday 10 September 2024 11:45 (20 minutes)

We explore the impact of highly excited bound states on the evolution of number densities of new physics particles, specifically dark matter, in the early Universe. Focusing on dipole transitions within perturbative, unbroken gauge theories, we develop an efficient method for including around a million bound state formation and bound-to-bound transition processes. This enables us to examine partial-wave unitarity and accurately describe the freeze-out dynamics down to very low temperatures. In the non-Abelian case, we find that highly excited states can prevent the particles from freezing out, supporting a continuous depletion in the regime consistent with perturbativity and unitarity. We apply our formalism to a simplified dark matter model featuring a colored and electrically charged t-channel mediator. Our focus is on the regime of superWIMP production which is commonly characterized by a mediator freeze-out followed by its late decay into dark matter. In contrast, we find that excited states render mediator depletion efficient all the way until its decay, introducing a dependence of the dark matter density on the mediator lifetime as a novel feature. The impact of bound states on the viable dark matter mass can amount to an order of magnitude, relaxing constraints from Lyman-alpha observations.

Author: BINDER, Tobias

Presenter: BINDER, Tobias

Session Classification: Short Talks

Contribution ID: **32** Type: **not specified**

No Warm Inflation From a Vanilla Axion

Tuesday 10 September 2024 09:50 (20 minutes)

At finite temperature, the coupling of an axion to non-Abelian gauge fields causes dissipation due to sphaleron heating. This mechanism is ideally suited for realizing warm inflation since it can lead to large thermal friction while preserving the flatness of the potential. We show, however, that requiring standard properties of an axion – in particular a discrete shift symmetry and a potential generated non-perturbatively by instanton effects – excludes the strong regime of warm slow-roll inflation, in which thermal friction dominates. The derivation of this result does not require any phenomenological input. While non-minimal (axion-like) models provide a way out, the present argument also leaves room for the weak regime of warm axion inflation, albeit in the latter case a super-Planckian decay constant represents a well-known issue.

Based on:
S. Zell, No Warm Inflation From Sphaleron Heating With a Vanilla Axion, arXiv:2408.07746.

Author: ZELL, Sebastian (EPFL - Ecole Polytechnique Federale Lausanne (CH))

Presenter: ZELL, Sebastian (EPFL - Ecole Polytechnique Federale Lausanne (CH))

Session Classification: Short Talks

Contribution ID: **33** Type: **not specified**

Minimal Warm Inflation with the heavy QCD axion

Tuesday 10 September 2024 09:30 (20 minutes)

Slow-roll inflation is a successful paradigm. However, even small couplings of the inflaton to other light fields can dramatically alter the dynamics and predictions of inflation. As an example, the inflaton can generically have an axion-like coupling to gauge bosons. Even relatively small couplings will automatically induce a thermal bath during inflation. The thermal friction from this bath can easily be stronger than Hubble friction, altering the usual predictions of any particular inflaton potential. Thermal effects suppress the tensor-to-scalar ratio, r, significantly, and predict unique non-gaussianities. This axion-like coupling provides a minimal model of warm inflation which avoids the usual problem of thermal back-reaction on the inflaton potential. I will discuss a realization of these dynamics in which a heavy QCD axion takes the role of the minimal warm inflaton, and QCD gluons in their unconfined phase comprise the thermal bath, introducing the first model of warm inflation in which the thermal friction emerges directly form coupling the inflaton to Standard Model particles. Exploring hybrid warm inflation as specific example that can fit the current cosmological data, I will show that future collider and beam dump experiments have discovery potential for a heavy QCD axion compatible with the minimal warm inflaton.

Author: BERGHAUS, Kim (California Institute of Technology)

Presenter: BERGHAUS, Kim (California Institute of Technology)

Session Classification: Short Talks

Contribution ID: **34** Type: **not specified**

Real dynamics of thermal false vacuum decay

Tuesday 10 September 2024 11:25 (20 minutes)

We revisit false vacuum decay in relativistic field theory and with a heat bath. We find the decay rate due to classical thermal fluctuations of the field. We do this numerically, by performing real-time simulations of the field evolution from the initial state in thermal equilibrium. We compare our findings with predictions of the well-known Euclidean formalism. We find agreement at the level of leading semiclassical exponent and corresponding Euclidean solution (sphaleron). However, we find the discrepancy at the level of prefactor, and the measured decay rate significantly lower than the Euclidean prediction. We identify physical effects leading to this discrepancy and pointing to limitations of the Euclidean formalism to describe the thermal decay rate. We discuss implications of our findings for cosmology and quantum matter.

Author: Dr SHKERIN, Andrey (University of Minnesota)

Presenter: Dr SHKERIN, Andrey (University of Minnesota)

Session Classification: Short Talks

Contribution ID: **35** Type: **not specified**

Gravitational production of dark particles

Tuesday 10 September 2024 14:00 (20 minutes)

The phenomenon of cosmological gravitational particle production (CGPP) occurs during and after inflation as quantum fields "feel"the cosmological expansion are excited out of their ground state. CGPP is a compelling and minimal explanation for the origin of dark matter, which might only interact gravitationally, as well as other cosmological relics. In this talk, I'll discuss some recent developments in the study of dark matter from CGPP. This includes: interference fringes in the dark matter energy spectrum, a recent study of CGPP for massive spin-2 particles, and observational probes.

Author: LONG, Andrew (Rice University)

Presenter: LONG, Andrew (Rice University)

Session Classification: Short Talks

Contribution ID: **36** Type: **not specified**

On the anomalous gravitational fermion production in terms of level crossing

Tuesday 10 September 2024 14:20 (20 minutes)

Gravitational chiral anomaly connects the topological charge of spacetime and the chirality of fermions. It has been known that the chirality is carried by the particles (or the excited states) and also by vacuum. However, in the study of gravitational leptogenesis, for example, lepton asymmetry associated with the chiral gravitational waves sourced during inflation is conventionally evaluated only by integrating the anomaly equation. In this evaluation, no distinction between the excite states and vacuum contribution has been made. In this talk, I apply an analogy between U(1) electromagnetism and the weak gravity to the spacetime that resembles the one considered in the gravitational leptogenesis scenario. By assuming the emergence of Landau level-like dispersion relation in our setup, I suggest that level-crossing does not seem to be efficient while the charge accumulation in the vacuum likely takes place. Phenomenological implication is also discussed.

Author: KAMADA, Kohei (Institute for Basic Science)

Presenter: KAMADA, Kohei (Institute for Basic Science)

Session Classification: Short Talks

Contribution ID: **37** Type: **not specified**

Gravitational waves from preheating

Monday 9 September 2024 11:15 (30 minutes)

Presenter: TOKAREVA, Anna (Hangzhou Institute for Advanced Study & ICTP-AP Centre Beijing/Hangzhou)

Session Classification: Boltzman approximation and beyond

Contribution ID: **38** Type: **not specified**

Signatures of inflaton fragmentation during reheating

Monday 9 September 2024 14:45 (30 minutes)

Presenter: Prof. GARCIA GARCIA, Marcos A. (Instituto de Fisica, UNAM)

Session Classification: Boltzman approximation and beyond

Contribution ID: **39** Type: **not specified**

Electroweak baryogenesis

Monday 9 September 2024 15:30 (30 minutes)

Presenter: POSTMA, Marieke

Session Classification: Boltzman approximation and beyond

Contribution ID: **40** Type: **not specified**

Thermalization and dark matter production

Wednesday 11 September 2024 10:00 (30 minutes)

Presenter: MUKAIDA, Kyohei (DESY)

Session Classification: Thermal and non-thermal QFT

Contribution ID: **41** Type: **not specified**

TBA - CERN TH colloquium

Wednesday 11 September 2024 14:00 (1 hour)

Presenter: LAINE, Mikko Sakari (Universitaet Bern (CH))

Session Classification: Thermal and non-thermal QFT

Contribution ID: **42** Type: **not specified**

CosmoLattice: capabilities and limitations

Thursday 12 September 2024 09:30 (30 minutes)

Presenter: FIGUEROA, Daniel G. (Univ. of Valencia and CSIC (ES))

Session Classification: Numerical methods / lattice

Contribution ID: **43** Type: **not specified**

Thermal corrections to dark matter production

Wednesday 11 September 2024 10:45 (30 minutes)

Presenter: HARZ, Julia

Session Classification: Thermal and non-thermal QFT

Contribution ID: **44** Type: **not specified**

Axion dark matter: production and clustering

Thursday 12 September 2024 11:00 (30 minutes)

Presenter: GORGHETTO, Marco (DESY)

Session Classification: Numerical methods / lattice

Contribution ID: **45** Type: **not specified**

Gravitational wave from hidden sectors

Thursday 12 September 2024 14:45 (30 minutes)

Presenter: Dr MADGE, Eric (Weizmann Institute of Science)

Session Classification: Numerical methods / lattice

Contribution ID: **46** Type: **not specified**

CP-violating sources in electroweak baryogenesis

Thursday 12 September 2024 15:30 (30 minutes)

Presenter: TAMARIT, Carlos (Johannes Gutenberg University of Mainz)

Session Classification: Numerical methods / lattice

Contribution ID: **47** Type: **not specified**

Quantum kinetic equations

Friday 13 September 2024 09:45 (30 minutes)

Presenter: KAINULAINEN, Kimmo Juhani (University of Jyvaskyla (FI))

Session Classification: Novel methods

Contribution ID: **48** Type: **not specified**

The bubble wall velocity in first order phase transitions

Friday 13 September 2024 11:15 (30 minutes)

Presenter: VAN DE VIS, Jorinde Marjolein

Session Classification: Novel methods