BSM^2 - Beyond the Standard Model BrainStorming Meeting: Particle Physics and Cosmology interface

Friday 12 July 2024 - Tuesday 16 July 2024

Escola Secundária José Régio

Book of Abstracts

Contents

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Gravitational particle production and freeze-in at stronger coupling

Author: Oleg Lebedev[None]

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I will discuss gravitational particle production in the early Universe and the consequent problems for the traditional concept of dark matter "freeze-in".

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Gravitational waves from cosmic superstrings and gauge strings

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We perform a phenomenological comparison of the gravitational wave (GW) spectrum expected from cosmic gauge string networks and superstring networks comprised of multiple string types. We show how violations of scaling behavior and the evolution of the number of relativistic degrees of freedom in the early Universe affect the GW spectrum. We derive simple analytical expressions for the GW spectrum from superstrings and gauge strings that are valid for all frequencies relevant to pulsar timing arrays (PTAs) and laser interferometers. We analyze the latest data from PTAs, and study correlations between GW signals at PTAs and laser interferometers.

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Conformal Majoron models with supercooled phase transitions at LIGO

Author: João Pedro Pino Gonçalves[1]

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Despite the shortcomings of the Standard Model (SM), all experimental observations so far have not indicated the existence of new physics (NP) at or near the TeV scale. The gravitational channel is another promising avenue to test NP and can potentially probe particles with masses far beyond those accessible at current collider experiments. With this in mind, we perform a phenomenological study of supercooled phase transitions within a conformal Majoron-like model in a generic U(1) charge assignment setting, where neutrino masses and mixings are generated through a type-I seesaw mechanism. Such transitions are extraordinary candidate scenarios to be tested at GW interferometers due to the significant amount of released latent heat and the long-lasting nature of the phase transition. This is expected to result in a SGWB with large energy density amplitude, well within the detection capabilities of existing and future experiments. Considering a broad range of masses from the TeV to the GUT-scale, we discuss the phenomenological implications for this class of models at current LIGO O5 run, as well as how current experimental measurements impact the parameter space.

Test / 6

Orbifold stability of asymptotic GUTs

Author: Anca Preda[None]

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In the realm of higher-dimensional grand unified theories (GUTs), the technique of orbifolding has emerged as a powerful tool to achieve spontaneous symmetry breaking by geometrical means. We use this tool to analyze the most general 5D GUT models based on the gauge groups SU(N), Sp(2N) and SO(N). We find a new physical consistency requirement, which these models have to satisfy in order to be phenomenologically viable, and which we call orbifold stability. Based on the criteria of orbifold stability, we can search for potentially interesting GUT candidates, and at the same time quickly discard any unrealistic scenario.

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Gravitational waves from a curvature induced phase transition of a Higgs-portal dark matter sector

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The study of interactions between dark matter and the Higgs field opens the interesting prospect of possible detection of dark matter (DM) through collider experiments. Naturally, this setup can have an impact on the features of DM itself, as well as to interfere with the spontaneous breaking of the electroweak symmetry. Furthermore, it is crucial that this Higgs-portal DM can be suitably harmonised with the various epochs of the early universe. In our latest study (2407.xxxxx), we examined whether Gravitational Waves (GW) can be generated from a curvature-induced phase transition of a non-minimally coupled scalar field DM with a portal to the Higgs field. This was investigated in the context of a dynamical spacetime during the transition from inflation to kination, while also considering the possibility for inducing the electroweak (EW) symmetry breaking in this manner. We explored a large range of inflationary scales and both cases of positive and negative values for the non-minimal coupling, while taking into account the phenomenological constraints imposed on the BSM model's couplings, when playing the role of DM. The resulting GW amplitudes are boosted by kination, but lie at high frequencies for the typically high inflationary scales.

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BSMPT v3 A Tool for Phase Transitions and Primordial Gravitational Waves in Extended Higgs Sectors

Authors: Jonas Muller[None]; João Viana[None]; Lisa Biermann[1]; Margarete Muhlleitner[None]; Philipp Basler[None]; Rui Santos[2]

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Strong first-order phase transitions (SFOPT) during the evolution of the Higgs potential in the early universe not only allow for the dynamical generation of the observed matter-antimatter asymmetry, they can also source a stochastic gravitational wave (GW) background possibly detectable with

future space-based gravitational waves interferometers. As SFOPTs are phenomenologically incompatible with the Standard Model (SM) Higgs sector, the observation of GWs from SFOPTs provides an exciting interplay between cosmology and particle physics in the search for new physics. With the C++ code BSMPTv3, we present for the first time a tool that performs the whole chain from the particle physics model to the gravitational wave spectrum. Extending the previous versions BSMPTv1 and v2, it traces the phases of beyond-SM (BSM) Higgs potentials and is capable of treating multiple vacuum directions and multi-step phase transitions. During the tracing, it checks for discrete symmetries, flat directions, and electroweak symmetry restoration, and finally reports the transition history. The transition probability from the false to the true vacuum is obtained from the solution of the bounce equation which allows for the calculation of the nucleation, percolation and completion temperatures. The peak amplitude and frequency of the GWs originating from sound waves and turbulence, are evaluated after the calculation of the thermal parameters at the transition temperature, and finally the signal-to-noise ratio at LISA is provided. The code BSMPTv3 is a powerful self-contained tool that comes more than timely and will be of great benefit for investigations of the vacuum structure of the early universe of not only simple but also complicated Higgs potentials involving several vacuum directions, with exciting applications in the search for new physics.

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Probing freeze-in via invisible Higgs decay

Authors: Oleg Lebedev[None]; António Morais[1]; Vinicius Oliveira[None]; Roman Pasechnik[2]

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We explore the implications of low reheating temperatures in the early Universe, focusing on scenarios where a minimal threshold of 4 MeV is crucial to preserve the accuracy of Big Bang Nucleosynthesis (BBN) predictions. We specifically investigate the freeze-in mechanism, wherein scalar Dark Matter (DM) candidates are Boltzmann suppressed due to their mass exceeding the reheating temperature. Building upon previous research demonstrating the efficacy of this approach, particularly in achieving the correct abundance of DM, our exploration extends to lower reheating temperatures, necessitating a lighter DM mass (at MeV scale). Furthermore, we will incorporate the contribution of mesons post-Quantum Chromodynamics (QCD) phase transition, wherein quarks transition into bound states, facilitating DM production via the Higgs portal. Our findings shed light on the viability of such scenarios and their implications for understanding the early Universe and the nature of dark matter.

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The many faces of Higgs CP-violation

Author: Rui Santos[1]

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The Large Hadron Collider is now running at a centre of mass energy of 13.6 TeV. I will present benchmark scenarios for a simple extension of the Standard Model: the complex two-Higgs doublet model (C2HDM) which allows for CP-violation in the scalar sector. I will present a number of benchmarks that show that in this model there are several ways to probe CP-violation in the different sectors of the model.

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Direct detection of pNG dark matter in the S2HDM

Author: Pedro Gabriel[None]

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Pseudo-Nambu-Goldstone (pNG) dark matter models are popular for having a rich phenomenology and for being compatible with many existing observations. These models have the distinct feature of having negligible DM direct detection cross section at leading order, being that the first relevant contribution to the cross section comes from the one-loop electroweak corrections. These one-loop corrected cross sections can be of the order of present experimental limits and even more so of future DM detection experiments. In this presentation, we look into the direct detection of pNG DM in the context of the S2HDM and we explore the possibility of current and future direct detection experiments being able to probe the parameter space of this model.

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Hubble tension in a nonminimally coupled curvature-matter gravity model

Author: Miguel Barroso Varela[None]

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The presently open problem of the Hubble tension is shown to be removed in the context of a modified theory of gravity with a non-minimal coupling between curvature and matter. By evolving the cosmological parameters that match the cosmic microwave background data until their values from direct late-time measurements, we will show how to obtain an agreement between different experimental methods without disrupting their individual validity. These modified gravity models are shown to provide adequate fits for other observational data from recent astrophysical surveys and to reproduce the late-time accelerated expansion of the Universe without the inclusion of a cosmological constant. This talk is based on the work conducted in JCAP06(2024)025 (arXiv:2403.11683).

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Dratopi: DRalgo to python interfacer

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Dratopi is a helper tool under development for interfacing with python the recent Mathematica package DRalgo, by Ekstedt, Schicho and Tenkanen. The purpose is to provide a tool for studying phase transitions in the dimensional reduction formalism by combining DRalgo with phase transition packages (or modified versions thereof) like CosmoTransitions, by Carroll Wainwright. I will give an overview/tutorial of Dratopi in its current state of development.

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Freeze-in Complements Freeze-out

Author: Rodrigo Capucha[1]

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There are many extensions of the Standard Model with a dark matter (DM) candidate obtained via the freeze-out mechanism. It can happen that after all experimental and theoretical constraints are taken into account, all parameter points have a relic density below the experimentally measured value. This means that the models solve only partially the DM problem, and at least one more candidate is needed. In this work we show that it is possible to further extend the model with a DM candidate obtained via the freeze-in mechanism to be in agreement with the relic density experimental measurement. Once the relic density problem is solved with this addition, new questions are raised. This new model with at least two DM candidates could have a freeze-out undetectable DM particle both in direct and indirect detection. This could happen if the freeze-out DM particle would have a very low density. Hence, a collider DM hint via excess in the missing energy with no correspondence in direct and indirect detection experiments, could signal the existence of a Feebly Interacting Massive Particle (FIMP). Conversely, if a DM particle is found and a particular model can explain all observables except the correct relic density, an extension with an extra FIMP would solve the problem. The freeze-in DM candidate, due to the small portal couplings, will evade most experimental constraints.

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The de Sitter Swampland Conjectures test of some interesting inflationary models

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We use the de Sitter Swampland Conjectures to test some inflationary models compatible with CMB data. We find that warm inflationary models, with one or more scalar fields, and the Claplygin-inspired models for some class of potentials satisfy the de Sitter Swampland Conjectures, Inflationary models in the context of theories of gravity that couple nonminimally curvature and matter are shown to be incompatible with the de Sitter Swampland Conjectures.

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Opening

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Color restoration in the early Universe: A minimal leptoquark model

Authors: Andreas Ekstedt[None]; António Morais[1]; Johan Rathsman[2]; Marco Finetti[3]; Mårten Bertenstam[2]; Roman Pasechnik[4]

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The electroweak phase transition is a promising explanation for the origin of baryon asymmetry in the universe, a core problem in cosmology and particle physics.

An extension of the Standard Model is necessary to generate a strong first-order phase transition. Besides representing a target for several future-generation colliders, such Beyond the Standard Model (BSM) theories can generate - through a thermal phase transition - gravitational waves (GWs) potentially detectable by future space-based detectors, such as LISA [1], DECIGO, and BBO.

As a result, the interplay between BSM phenomenology and GWs is among the most active areas in the field of high-energy physics. Of particular interest are leptoquark (LQ) models, offering an alternative to conventional seesaw scenarios for the generation of Majorana neutrino masses at TeV scale. The presence of LQs can induce first order phase transitions with a temporary colour-breaking phase in the early universe.

With this talk, I intend to present results from the analysis of a minimal leptoquark model. In a dimensionally reduced effective theory approach [3], the model presents strong first order transitions, producing - in some scenarios - gravitational waves detectable by LISA. To our knowledge, these results provide the first evidence for the potential detection of color-breaking and color-restoration features in the above mentioned detectors.

I will conclude with a discussion on the intersection between collider and cosmological observables, pointing to the Higgs cubic self-coupling as a relevant quantity for this purpose, both in the current and in future studies.

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[1] Amaro-Seoane, P., Audley, H., Babak, S., Baker, J., Barausse, E., Bender, P., … & Zweifel, P. (2017). Laser interferometer space antenna. arXiv preprint arXiv:1702.00786.

[2] Felipe F. Freitas, João Gonçalves, António P. Morais, Roman Pasechnik, Werner Porod,

Phys.Rev.D 108 (2023) 11, 115002. On interplay between flavour anomalies and neutrino properties.

[3] Andreas Ekstedt, Philipp Schicho, Tuomas V.I. Tenkanen, Comput.Phys.Commun. 288 (2023) 108725. DRalgo: A package for effective field theory approach for thermal phase transitions.

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Discussion

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Cosmology of composite dynamics: dark matter, phase transitions and gravitational waves

Author: Roman Pasechnik[1]

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In this talk, I briefly overview recent progress in strong coupling dynamics at finite temperatures and its cosmological implications in SU(N) gauge theories, with and without fermions. In a confining pure Yang-Mills theory of dark sector, the scalar glueballs are considered as possible candidates for Dark Matter. To predict the relic abundance of glueballs for the various gauge groups and scenarios of thermalization of the dark gluon gas, we employ a thermal effective theory that accounts or the strong-coupling dynamics in agreement with lattice simulations. In a QCD-like theory with N_f flavours, the Polyakov-loop Improved Linear Sigma Model in the Cornwall-Jackiw-Tomboulis formulation is employed to investigate the chiral phase transition in regimes that can mimic QCD-like theories incorporating in addition composite dynamics associated with the effects of confinement-deconfinement phase transition. We show that strong first-order phase transitions occur for weak effective couplings of the composite sector leading to gravitational-wave signals potentially detectable at future experimental facilities.

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Axion paradigm with color-mediated neutrino masses

Authors: Aditya Batra[1]; Henrique Brito Câmara[None]; Filipe Rafael Joaquim[None]; Rahul Srivastava[2]; Jose WF Valle[3]

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I will discuss our recent paper Phys.Rev.Lett. 132 (2024) 5, 051801, where we propose a generalized KSVZ-type axion framework in which coloured fermions and scalars act as two-loop Majorana neutrino-mass mediators. The global Peccei-Quinn symmetry under which exotic fermions are charged solves the strong CP problem. Within our general proposal, various setups can be distinguished by probing the axion-to-photon coupling at helioscopes and haloscopes. We also comment on axion dark-matter production in the early Universe.

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The Physics of Fermionic Portal to Vector Dark Matter

Author: Alexander Belyaev[1]

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We suggest a new class of models - Fermionic Portal Vector Dark Matter (FPVDM) which extends the Standard Model (SM) with SU(2)_D dark gauge sector. While FPVDM does not require kinetic mixing and Higgs portal to explain Dark Matter (DM) phenomena. This framework is based on the Vector-Like (VL) fermionic doublet which couples the dark sector with the SM sector through the Yukawa interaction. The FPVDM framework provides a vector DM with Z_2 odd parity ensuring its stability. Multiple realisations are allowed depending on the VL partner and scalar potential, which explain not only DM but also could provide solution of various BSM hints, including (g-2)_mu, flavour anomalies as well as W-boson mass measurement by CDF. Moreover, the breaking of SU(2)_D can also provides the Graviational Wave signals from a specific regions of the parameter space, where the strong first-order phase transition takes place.

Two FPVDM examples will be discussed. One of them is the realisation with only a VL top partner, which provides interesting and promising implications for DM direct and indirect detection experiments, relic density and collider searches. Another realisation is th emodel with a doublet of new vector-like partners of muon can simultaneously explain DM relic density together with (g-2)_mu anomaly which has been in close focus of the HEP community over two decades. It predicts the mass of vector DM to be below GeV as well as the mass of the muon partner to be below 1 TeV, and provides novel
multi-lepton signatures at the LHC.

The talk is based on 2203.04681, 2204.03510 arXiv papers as well as the two new papers which are coming soon.

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Superradiant axion clouds around asteroid-mass primordial black holes

Authors: João Rosa[1]; Nuno Branco[1]; Ricardo Ferreira[1]

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We analyze the dynamics and observational signatures of axion clouds formed via the superradiant instability around primordial black holes, focusing on the mass range $10^{14} - 10^{18}$ kg where the latter may account for all the dark matter.
We take into account the leading effects of axion self-interactions, showing that, even though these limit the number of axions produced within each cloud,
a large number of superradiant axions become free of the black hole's gravitational potential and accumulate in the intergalactic medium or even in the host galaxy, depending on their escape velocity.
This means that primordial black hole dark matter may lead to a sizeable astrophysical population of non-relativistic axions, with masses ranging from 0.1 eV to 1 MeV, depending on the primordial black hole mass and spin.
We then show that if such axions couple to photons their contribution to the galactic and extragalactic background flux, mainly in the X-ray and gamma-ray band of the spectrum, is already beyond current observational limits for a large range of parameters that are, therefore, excluded. We finish by showing the prospects of the Athena X-ray telescope to further probe this co-existence of primordial black holes and axions.

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Multi-Higgs Doublet Models and symmetries

Author: Ivo de Medeiros Varzielas[1]

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I will talk about Beyond Standard Model scenario where there is more than 1 Higgs doublet, and also additional symmetries to control the proliferation of free parameters.

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TBA

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Direct detection of pNG dark matter in the S2HDM

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Pseudo-Nambu-Goldstone (pNG) dark matter models are popular for having a rich phenomenology and for being compatible with many existing observations. These models have the distinct feature of having negligible DM direct detection cross section at leading order, being that the first relevant contribution to the cross section comes from the one-loop electroweak corrections. These one-loop corrected cross sections can be of the order of present experimental limits and even more so of future DM detection experiments. In this presentation, we look into the direct detection of pNG DM in the context of the S2HDM and we explore the possibility of current and future direct detection experiments being able to probe the parameter space of this model.

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Opening

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Orbifold stability of asymptotic GUTs

Author: Anca Preda[None]

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In the realm of higher-dimensional grand unified theories (GUTs), the technique of orbifolding has emerged as a powerful tool to achieve spontaneous symmetry breaking by geometrical means. We use this tool to analyze the most general 5D GUT models based on the gauge groups SU(N), Sp(2N) and SO(N). We find a new physical consistency requirement, which these models have to satisfy in order to be phenomenologically viable, and which we call orbifold stability. Based on the criteria of orbifold stability, we can search for potentially interesting GUT candidates, and at the same time quickly discard any unrealistic scenario.

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Hubble tension in a nonminimally coupled curvature-matter gravity model

Author: Miguel Barroso Varela[None]

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The presently open problem of the Hubble tension is shown to be removed in the context of a modified theory of gravity with a non-minimal coupling between curvature and matter. By evolving

the cosmological parameters that match the cosmic microwave background data until their values from direct late-time measurements, we will show how to obtain an agreement between different experimental methods without disrupting their individual validity. These modified gravity models are shown to provide adequate fits for other observational data from recent astrophysical surveys and to reproduce the late-time accelerated expansion of the Universe without the inclusion of a cosmological constant. This talk is based on the work conducted in JCAP06(2024)025 (arXiv:2403.11683).

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Gravitational waves from cosmic strings with friction

Authors: Lara Sousa[None]; Sergei Mukovnikov[1]

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Cosmic strings can be produced during phase transitions in the very early universe. They are particularly interesting objects since they emit gravitational waves contributing to the stochastic gravitational wave background. This gives us possibility to connect gravitational waves experiments to unknown physics scenarios of the very distant past. In the early stages of cosmic string network evolution we expect frequent interactions of cosmic strings with particles of the surrounding plasma. Usually in the literature the contribution to the stochastic gravitational wave background from these friction-dominated regimes is neglected. In our work, however, we show that, for a significant part of parameter space, the inclusion of friction leads to a prominent signature in the ultra high frequency range of the spectrum. More than that, this signature should be sensitive to the particular underlying high energy physics scenarios, depending not only on the fields that constitute the string but also on the particle contents of the early universe.

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Exploring de Dark Universe @ the LHC using top quarks

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In this talk we will present our recent work on the studies of the LHC sensitivity to the detection of potential new boson mediators that couple to Dark Matter by looking into angular distributions in ttbar production at the LHC. We will show that no matter how hard and challenging the discover of New Physics is at the LHC, it is equally hard to remove the New Physics events in ttbar classical measurements, if indeed this New Physics exist!