Beyond General Relativity, Beyond Cosmological Standard Model

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Faculty of Physics, University of Warsaw

Book of Abstracts

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Gravitational Waves through the binary formation in Merging Galaxies

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Gravitational Waves through the binary formation in Merging Galaxies
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Gravitational waves: Violent events, such as the collision of two black holes, are thought to be able to create ripples in space-time known as gravitational waves. In 2016, the Laser Interferometer Gravitational-Wave Observatory (LIGO) announced that it found evidence of these tell-tale indicators. By the date, LIGO and LISA have observed 10 events of binary mergers along with the successful detection of Gravitational Waves in each case. With advanced interferometers coming in a row the detection rates will increase significantly and many unknown facts will be known.
Apart from the traditional sources of Gravitational waves like binary black holes, neutron stars including pulsars etc. the possibilities of generation of gravitational waves from supermassive black holes sitting in the heart of galaxies is still considered to be high. As the mergers of SMBH during galaxy collisions is a potential candidate of gravitational waves it also has a big drawback that we need to wait for millions of years for these mergers to take place for direct observation by presently available technology. In this context here we propose the work done in the field of the simulations of mergers and the detection of GWs and its broad scope even apply for any forthcoming merging even to be observed in near future.
GW & Galaxy Mergers: By the advancement of technology we have now been succeeded for direct observations of many galaxy mergers events. This astrophysical event is important in the sense of merger of supermassive black holes as well. Thus these are strong candidates of gravitational waves. I hereby present a detailed correlation between mathematical relativity principles involved in Galaxy mergers and the resulting possible gravitational waves. The study includes the theoretical approach in the mathematical domain of relativity related to heavy masses collisions. A systematic study of gravitational waves from galaxy mergers, through N-body simulations, is studied. In particular, investigation for the relative importance of galaxy components (disk, bulge, and halo) and effects of initial relative velocity, relative angular momentum, and the mass ratio of the galaxies is proposed.

Beyond I / 2

Perturbatively renormalizable quantum gravity

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The Wilsonian renormalization group (RG) requires Euclidean signature. The conformal factor of the metric then has a wrong-sign kinetic term, which has a profound effect on its RG properties. In particular around the Gaussian fixed point, it supports a Hilbert space of renormalizable interactions involving arbitrarily high powers of the gravitational fluctuations. These interactions are characterised by being exponentially suppressed for large field amplitude, perturbative in Newton's constant but non-perturbative in Planck's constant. By taking a limit to the boundary of the Hilbert space, diffeomorphism invariance is recovered in the continuum quantum field theory. Thus the

so-called conformal factor instability is the key that allows the construction of a genuine continuum limit for quantum gravity.

[1] Tim R. Morris. Renormalization group properties in the conformal sector: towards perturbatively renormalizable quantum gravity. JHEP, 08:024, 2018, 1802.04281.
[2] Matthew P. Kellett and Tim R. Morris. Renormalization group properties of the conformal mode of a torus. Class. Quant. Grav., 35(17):175002, 2018, 1803.00859.
[3] Tim R. Morris. Perturbatively renormalizable quantum gravity. Int. J. Mod. Phys., D27(14):1847003, 2018, 1804.03834.
[4] Tim R. Morris. Quantum gravity, renormalizability and dieomorphism invariance. SciPost Phys., 5:040, 2018, 1806.02206.
[5] Tim R. Morris. to appear.

Beyond V / 3

Nonlocal Quantum Gravity

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We present a weakly nonlocal gravitational theory unitary and finite at quantum level in the quantum field theory framework. As a consequence of finiteness, there is no Weyl anomaly and the theory turns out to be conformal invariant at classical as well at quantum level. Therefore, nonlocal quantum gravity is a conformal invariant theory in the spontaneously broken phase of the Weyl symmetry. As an application, Weyl conformal symmetry solves the black hole's singularity issue and cosmological singularity problem, otherwise unavoidable in a generally covariant local or nonlocal gravitational theory. Following and extending the seminal paper by Narlikar and Kembhavi, we provide explicit examples of singularity-free black hole exact solutions. The absence of divergences is based on the finiteness of the curvature invariants and on showing that the new types of black holes are geodesically complete. Indeed, no massive or massless particle can reach the former singularity in a finite amount of proper time or of affine parameter.

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Insight into the thermodynamic phase transition of RN-AdS black holes in massive gravity via Quasinormal modes and unstable circular photon orbits

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We use the quasinormal modes of a massless scalar perturbation to probe the phase transition of the high dimension charged AdS black holes. As a result, the signature of the critical behavior of this black hole solution is detected \[[1] , [2] \]. As an alternative, we can use also the unstable circular photon orbits around a $RN - AdS_4$ BH in massive gravity to establish a direct link between the null geodesics and the critical behavior thermodynamic of such black hole solution. The analysis shows that the unstable circular radius r_0 and the minimal impact parameter ξ_0 corresponding to

the unstable circular orbits are a good tool to reveal the thermodynamic phase structure \[[3] \].
1 https://arxiv.org/abs/1606.08524
2 https://arxiv.org/abs/1701.00872
3 https://arxiv.org/abs/1902.00557

Beyond I / 6

Strong gravitational radiation from a simple dark matter model

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A rather minimal possibility is that dark matter consists of the gauge bosons of a spontaneously broken symmetry. I will discuss the possibility of detecting the gravitational waves produced by the phase transition associated with such breaking. Concretely, I will focus on the scenario based on an ⬚(2)_D group and argue that it is a case study for the sensitivity of future gravitational wave observatories to phase transitions associated with dark matter. This is because there are few parameters and those fixing the relic density also determine the effective potential establishing the strength of the phase transition. Particularly promising for LISA is the super-cool dark matter regime, with DM masses above 100 TeV, for which the gravitational wave signal is notably strong.

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Cosmological constraints on $\Lambda(\alpha)$CDM models with time-varying fine structure constant

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We study the $\Lambda(\alpha)$CDM models with $\Lambda(\alpha)$ being a function of the time-varying fine structure constant α. We give a close look at the constraints on two specific $\Lambda(\alpha)$CDM models with one and two model parameters, respectively, based on the cosmological observational measurements along with 313 data points for the time-varying α. We find that the model parameters are constrained to be around $10\hat{}-4$, which are similar to the results discussed previously but more accurately.

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Hidden cosmological dynamics in teleparallel gravity

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The cosmology of modified teleparallel gravity theories, such as $f(T)$ or scalar-torsion gravity, is a widely studied field. Most often one considers flat ($k = 0$) cosmology, while the non-flat case

($k = \pm 1$) is less well studied. While in the former it is easy to find a combination of tetrad and spin connection that solves the antisymmetric part of the field equations, thus leaving only the Friedmann equations, this task is less obvious in the non-flat case. In a recent work we have shown how to find such tetrads and spin connections and that they are not unique.

In my talk I will briefly show how it is possible to solve the antisymmetric part of **any** generic teleparallel gravity theory by solving a few simple equations and show their non-unique solutions. I will then use these different solutions and show how they lead to different Friedmann equations in $f(T)$ and scalar-torsion cosmology, and thus different cosmological dynamics. The remarkable fact about these solutions is that on some initial Cauchy hypersurface they have the same metric, and differ only in their tetrad / spin connection, so that they cannot be distinguished initially by observations. However, due to the different Friedmann equations, the metrics will evolve differently, and so the observable dynamics depends on these "hidden" dynamical variables.

My talk is based on the article arXiv:1901.05472.

Beyond V / 9

Information Missing Puzzle, Where Is Hawking's Error?

Author: Ding-Fang Zeng[None]

We will discuss in our talk a picture for blackholes' inner structure and microscopic state in which matters falling into the horizon or consisting of them are oscillating around instead of accumulating statically on their central point, thus resolving the Schwarzschild singularity naturally. After quantizing, this picture not only blurs the horizon remarkably, but also provides an interpretation for the Bekenstein-Hawking entropy as measures of the number of consisting matters' oscillation modes. Since each microscopic blackhole has its own dynamic mass distribution and special r_h-t curve when evaporating and distinguishable from each other, thermal features of the Hawking radiation are only averaged description of many such objects with equal mass and symmetry. As conclusion, we claim that Hawking' error in the information missing puzzle lies in taking the averaged ensemble behavior of many microscopic blackholes with equal mass and symmetry as features of a special microscopic one.

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A new mathematical approximation for the equation of state of unified dark matter and dark energy

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In this talk, I investigate the new mathematical approximation for the equation of state of unified dark matter and dark energy. This approximation provides well-behaving evolution of state for both small and high redshifts. In particular, the dark fluid composed by dark matter and dark energy described by our approximation behaves like dark matter for big redshifts and like dark energy at low redshifts. Hence in our approximation, one can parameterize dark energy and dark matter using a single dark fluid, like in the case of the Chaplygin gas. Within this approximation, we consider two different cases: one with dark energy equation of state parameter fixed to −1 and the second one, where w≠−1 is chosen to match the best fit to the data. We study main cosmological properties of these cases at the expansion and perturbation levels. Based on Markov chain Monte Carlo method with currently available cosmic observational data sets, we constrain these models to determine

the cosmological parameters at the level of background and clustering of matter. We consider the interaction between dark matter and dark energy which directly affects the evolution of matter and its clustering. Our model appears to be perfectly consistent with the concordance ΛCDM universe, while providing unification of dark energy and dark matter.

Beyond I / 12

Echoes from Quantum Black Holes

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Exotic compact objects (ECOs) produce the same initial event detected by LIGO-Virgo collabo-ration as classical black holes (BHs), but various quantum gravity models feature the different following echoes. In particular, we investigate the echoes from the fluctuation-dissipation theorem [1, 2], which changes the dispersion relationship near the (would-be) horizon and results in a Boltzmann reflective boundary. We derive correspondent quasi-normal modes (QNMs) analytically. Further, we model the analytical and numerical echoes in the real time, which are consistent with each other. Last, we show that the superradiance is highly suppressed in the theorem.

Based on: Echoes from Quantum Black Holes(in prep.)
Fluctuation Dissipation theorem for Quantum Black Holes (in prep.)
Black Hole Echology arXiv:1803.02845v2

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Affine quantization of the Brans-Dicke theory: Smooth bouncing and the equivalence between the Einstein and Jordan frames

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In this talk, we present a complete analysis of the quantization of the classical Brans-Dicke theory using the method of affine quantization in the Hamiltonian description of the theory. The affine quantization method is based on the symmetry of the phase space of the system, in this case the (positive) half-plane, which is identified with the affine group. We consider a Friedmann-Lemaître-Robertson-Walker type spacetime, and since the scale factor is always positive, the affine method seems to be more suited than the canonical quantization for our quantum cosmology. We find the wave function of the Brans-Dicke universe and its energy spectrum. A smooth bounce is expected at the semiclassical level in the quantum phase-space portrait. We also address the problem of equivalence between the Jordan and Einstein frames. ArXiv:1810.00707

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Stochastic formalism applied to a collapsing universe

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Contracting cosmologies give rise to quantum vacuum fluctuations from which the primordial perturbations present in our universe could be generated. The existence of a cosmological phase before the Big Bang leads to a different perspective regarding the initial conditions for the universe. In this talk I will describe a collapsing universe, based on a scalar field and an exponential potential, and apply the stochastic formalism, which allows us to study how quantum fluctuations give rise to stochastic noise which modifies the classical dynamics of the scalar field at large scales, above a coarse-graining scale. In particular I will explore how quantum fluctuations can perturb the equation of state on large scales leading to the break down of the classical collapse solution.

Beyond IV / 15

Cosmic Inflation and Dark Energy from the Electroweak Phase Transition

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Cosmic inflation is a period of accelerated expansion in the Early Universe. Inflation is the most compelling proposal for the formation of of the observed structures in the Universe like galaxies and galactic clusters. It also makes the Universe uniform and spatially flat in agreement with observations. To drive inflation an exotic substance is needed, with pressure negative enough to cause the expansion of the Universe to accelerate, when this substance is dominant. Observations suggest that the late Universe is also undergoing accelerated expansion, which is assumed to be due to another exotic substance called dark energy. Can this be the one and the same with the substance behind inflation? In this talk I present a novel idea, in which inflation leaves behind a minute potential density, which can become the dark energy observed today. The field responsible for inflation (inflaton), is trapped in a local minimum of its scalar potential until the electroweak phase transition. The transition releases the field and allows it to vary slowly down a shallow potential tail, becoming dark energy. This behaviour is facilitated by a suitable coupling between the inflaton field and the electroweak Higgs field. The model is successful without fine-tuning, because it makes use of the curious fact that the electroweak energy scale is roughly the geometric mean of the Planck scale and the dark energy scale.

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On the gauge fixing in the Hamiltonian in general teleparallel theories

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To gauge fix, or not to gauge fix: that is the question I address in my talk. The covariant formulation of teleparallel gravity theories must be formulated with a spin connection. However, one can always choose a gauge which puts the spin connection to zero. This is not always preferred, though it definitely makes the Hamiltonian analysis easier. There are two ways to avoid gauge fixing. One way is

to work in a more general Poincaré gauge theory where both curvature and torsion are present, and impose flatness buy Lagrange multipliers. This method is already quite involved and will be even more cumbersome when one consider more complicated teleparallel gravity theories. The second way is to do the Hamiltonian analysis with tetrad (or vierbein) fields and Lorentz matrices, and their velocities as canonical fields for the Hamiltonian analysis. In this talk I show, for general teleparallel gravity theories, that putting the spin connection to zero is indeed consistent with the Hamiltonian analysis in the covariant formulation, and can not change the count of degrees of freedom.
The contribution is based on an generalization of arXiv:1802.02130 [gr-qc] to appear in the proceedings of Teleparallel Universes in Salamanca (2018).

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Implications of the possible 21-cm line excess at cosmic dawn on dynamics of interacting dark energy

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arXiv:1904.02458v1 [astro-ph.CO]
In this paper we study implications of the possible excess of 21-cm line global signal at the epoch of cosmic dawn on the evolutions of a class of dynamically interacting dark energy (IDE) models. We firstly summarize two dynamical mechanisms in which different background evolutions can exert considerable effects on the 21-cm line global signal. One is the decoupling time of Compton scattering heating, the other stems from the direct change of optical depth due to the different expansion rate of the Universe. After that, we investigate the IDE models to illustrate the tension between the results of Experiment to Detect the Global Epoch of reionization Signature (EDGES) and other experiments. To apply the analyses of these two mechanisms to IDE models, we find that only the optical depth can be significantly changed. Accordingly, in order to relieve the tension by including the effects of the decoupling time of Compton scattering heating, we deduce a possible evolution form for the Hubble parameter within IDE that begins at an early stage around z~100 and then smoothly evolves to a value at z~17 which is smaller than that obtained in the standard paradigm. Eventually, we fulfill this scenario by adding an early dark energy dominated stage to the cosmological paradigm described by IDE models, which can alleviate the tension between EDGES and other cosmological observations but cannot completely solve it.

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Homogeneous black strings in Einstein–Gauss–Bonnet with Horndeski hair and beyond

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In this talk we construct new exact solutions in Einstein-Gauss-Bonnet and Lovelock gravity, describing asymptotically flat black strings. The solutions exist also under the inclusion of a cosmological term in the action, and are supported by scalar fields with finite energy density, which are linear along the extended direction and have kinetic terms constructed out from Lovelock tensors. The divergenceless nature of the Lovelock tensors in the kinetic terms ensures that the whole theory is second order. For spherically, hyperbolic and planar symmetric spacetimes on the string, we obtain an effective Wheeler's polynomial which determines the lapse function up to an algebraic equation.

For the sake of concreteness, we explicitly show the existence of a family of asymptotically flat black strings in six dimensions, as well as asymptotically AdS5 × R black string solutions and compute the temperature, mass density and entropy density. We compute the latter by Wald's formula and show that it receives a contribution from the non-minimal kinetic coupling of the matter part, shifting the one-quarter factor coming from the Einstein term, on top of the usual non areal contribution arising from the quadratic Gauss-Bonnet term. Finally, for a special value of the couplings of the theory in six dimensions, we construct strings that contain asymptotically AdS wormholes as well as rotating solutions on the transverse section. By including more scalars the strings can be extended to p-branes, in arbitrary dimensions.

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New constraints on the most general scalar-tensor theories

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In this talk, I will discuss the key imprints of the most general scalar tensor theories at stellar scales, and explain how solar observations can significantly improve previous constraints on their theory space. Finally, I will discuss the relevant consequences at cosmological scales.

Beyond V / 20

Hamiltonians & degrees of freedom in "Lorentz-violating" field theories

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Many classical field models which "violate Lorentz symmetry" do so via a vector or tensor field which takes on a vacuum expectation value, thereby spontaneously breaking the underlying Lorentz symmetry of the Lagrangian. To obtain a tensor field with this behavior, one can posit a smooth potential for this field, or one can enforce a non-zero tensor value via a Lagrange multiplier. In this talk, I will discuss the unexpected effects that can arise when one tries to construct a field model in this way. In particular, the number of degrees of freedom of the model is not necessarily reduced, compared to a theory with a smooth potential, when one "constrains" the field via a Lagrange multiplier; and for certain field theories with a potential, the equations of motion do not allow the field to evolve smoothly on and off of the vacuum manifold.

Beyond V / 21

Primordial Kerr Black Holes

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Primordial Black Holes (PBHs) are appealing candidates for dark matter in the universe but are severely constrained by theoretical and observational constraints. I will focus on the Hawking evaporation limits extended to Kerr Black Holes. These results have been obtained with a new to-be-published code entitled BlackHawk that I will briefly present. In particular, I will review the isotropic extragalactic gamma ray background constraint and show that the "window" in which PBHs can constitute all of the dark matter depends strongly on the PBH spin. Finally, I will give some tools that could be used to distinguish between Black Holes of primordial or stellar origin based on the Thorne limit on their spin.

Beyond I / 22

Is Vacuum Decay During Inflation Fatal?

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If the Standard Model vacuum is metastable, bubbles that form expand and convert the entire vacuum into a true vacuum state incompatible with observations. It is sometimes argued, however, that true vacuum bubbles forming during inflation are 'inflated away' and thus pose no danger to the present day universe, even if they form. I will argue that this point of view is incorrect - while the exponential expansion of spacetime does affect the evolution of true vacuum bubbles, they do not, in fact, collapse to nothing and can in fact survive to the present day. Consequently, the electroweak vacuum instability must be fixed or circumvented if high scale inflation is to take place, providing strong hints that there must be new physics before the Planck scale.

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Can Horndeski gravity be recast in the Teleparallel framework?

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Teleparallel gravity is an alternative, but equivalent (in field equations) to General Relativity description of gravitational interactions where gravity is mediated through torsion instead of curvature. Horndeski gravity is the most general scalar-tensor theory, with a single scalar field, leading to second-order field equations and after the GW170817 it has been severely constrained. In this talk, I will introduce the analogue of Horndeski's theory in the teleparallel gravity framework. I will show that, even though, many terms are the same as in the curvature case, there is a much richer phenomenology in the teleparallel setting because of the nature of the torsion tensor. Moreover, Teleparallel Horndenski contains the standard Horndenski gravity as a subcase and also contains many modified Teleparallel theories considered in the past, such as f(T) gravity or Teleparallel Dark energy. Thus, due to the appearing of a new term in the Lagrangian, this theory can explain dark energy without a cosmological constant, may describe a crossing of the phantom barrier, explain inflation and also solve the tension for H0, making it a good candidate for a correct modified theory of gravity.

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Constraining the interacting vacuum scenario

Author: Natalie Hogg[1]

Co-authors: Matteo Martinelli ; Simone Peirone ; Marco Bruni ; David Wands

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It is well-known that there are problems with the standard model of cosmology that hint at possible physics beyond the ΛCDM paradigm. In particular, the 4σ tension in the values of H_0 coming from CMB and supernovae measurements is motivation enough to consider alternative cosmological models.

In this talk, I will introduce one such model, the interacting vacuum scenario. Beginning with the covariant theory of the interaction, I will show the linear theory of perturbations in the scenario before specialising to the spatially flat FLRW background. I will describe how the interaction parameter can be constrained using MCMC methods and show the results of our investigation for both a constant and a dynamical interaction, focusing on the effects of the interaction on the cosmological tensions.

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Viability of Bigravity Cosmology

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Bigravity is an extension of dRGT (de Rham, Gabadadze, Tolley) massive gravity, which arises by having two dynamical metric tensors. Massive gravity has recently had a flurry of interest in the last decade due to the self-accelerating properties of a massive graviton, leading to possible solutions for dark energy. Bigravity has been studied as an alternative dark energy model due to the lack of stable cosmological solutions of pure dRGT massive gravity. In this talk we investigate the low energy limit of bigravity, a viable and testable model that is distinguishable from GR and study how viable this model is for dark energy.

Beyond IV / **26**

Constant roll warm inflation

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I will present the idea of combinig the constant roll inflation with the warm inflationary paradigm, which comes from the strong particle production during inflation. I will show how to solve such a system and I will rpesent fundamental applications of this theory: from inflation to primordial black holes production

Beyond III / 27

Beyond Standard Model and Asymptotically Safe Gravity

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Einstein gravity cannot be quantised using standard Quantum Field Theory techniques. Hence to describe gravity on quantum level then either a new, special quantisation prescription should be proposed or General Relativity should be replaced by another theory which can be properly quantised. If the first option is true, then General Relativity should possess an interacting UV fixed point (as an asymptotically safe theory) and then GR becomes a fundamental Quantum Field Theory to arbitrary scales. There are many hints that indeed it is so.

On the other hand there are many proposals on how to extend the Standard Model, designed to deal with its fundamental inconsistencies. Since no new particles have been detected experimentally so far, the models which add only one more scalar particle and possibly right-chiral neutrinos are favoured. One of such models is the Conformal Standard Model.

If there are no intermediate scales between electroweak and Planck scale then these type of models supplemented with asymptotically safe gravity can be valid up to arbitrarily high energies and give a complete description of particle physics and gravitational phenomena.

This assumption restricts the mass of the second scalar particle to 300 +/-28 GeV and the mass of Higgs boson at 125 +/- few GeV. This has also impact on the multiple Higgs inflation scenarios.

Whats more various theories of gravity gives various predictions for the Higgs boson masses. Hence then by accurate measurements we can investigate the quantum gravity in LHC.

Talk based on the articles: https://arxiv.org/abs/1810.08461, arXiv:1712.03778 and unpublished results in collaboration with Frederic Grabowski and prof. Krzysztof A. Meissner.

Beyond IV / 28

Shift-symmetric orbital inflation: single field or multi-field?

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Multi-field inflation with curved field manifold attracts a lot of attention recently. From theoretical aspect, this class of models may be more naturally realized in the UV completion of inflation. From observational point of view, however, the current constraints on primordial non-Gaussianity and isocurvature perturbation already/marginally ruled out many of these models. In this talk I will introduce a new class of two-field inflationary attractors, known as 'shift-symmetric orbital inflation'. It is strongly multi-field, but the phenomenology still mimics single-field inflation, since in the end only one degree of freedom (the one with isocurvature origin) is responsible for the prediction of primordial perturbations. This new regime of multi-field attractors provides a different

perspective to explore UV completion of inflation, which is free from the problems faced by single field models.

Beyond IV / 29

Stability of de Sitter spacetime against the backreaction of the infrared modes of scalar fields

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We study the back-reaction of the infrared modes of an O(N) scalar theory in a classical de Sitter background. We use the nonperturbative renormalization group methods to extract analytically the flow of the Hubble constant as the gravitationally enhanced long wavelength modes are integrated out. For a massless theory, the interactions tend to renormalize negatively the Hubble constant, thus drawing energy from the classical gravitational field. This phenomenon saturates however, and unbounded loop corrections are screened by nonperturbative effects which stabilise the geometry.

Based on : G. Moreau and J. Serreau, Phys. Rev. Lett. **122** (2019) no.1, 011302, Phys. Rev. D **99** (2019) no.2, 025011

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Stochastic inflation beyond slow roll

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I will begin by introducing the stochastic formalism for inflation. I will give some motivation for using the stochastic approach and then explain why we may want to consider situations that violate slow roll. I will explain the requirements for stochastic inflation to be a valid approach and discuss whether they are still appropriate when we are away from slow roll. The two requirements that I will consider in detail are the separate universe approach and the choice of gauge that our stochastic equations are written in. I will show that the stochastic formalism is safe to be used, even when slow roll is violated.

arXiv number: 1905.06300 (https://arxiv.org/pdf/1905.06300.pdf)

Beyond V / 31

Scalar-tensor theories beyond Riemannian

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We discuss scalar-tensor theories based on a non-Riemannian geometry, called the metric-affine geometry, where the metric and the connection are treated as independent variables. In the metric-affine formalism, the Einstein-Hilbert action enjoys an additional local symmetry, the projective symmetry, under a shift of the connection. We find that the projective symmetry can provide an Ostrogradky ghost-free structure of general scalar-tensor theories. The ghostly sector of the second-order derivative of the scalar is absorbed into the projective gauge mode when the unitary gauge can be imposed. We also find that, up to the quadratic order of the connection, the most general projective invariant theory is equivalent to the U-degenerate theory when the connection is integrated out and, if we further assume the Galileon-type self-interactions, the theory is equivalent to DHOST theory.

1 Katsuki Aoki and Keigo Shimada, Galileon and generalized Galileon with projective invariance in a metric-affine formalism, 1806.02589.
2 Katsuki Aoki and Keigo Shimada, Scalar-metric-affine theories: Can we get ghost-free theories from symmetry?, 1904.10175.

32

Dark sector evolution in Horndeski models

Author: Francesco Pace[1]

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Despite the good agreement between theoretical predictions and observational results, the cosmological constant is not a satisfactory explanation for the accelerated expansion of the universe. Hence an intense theoretical effort has been devoted to the study of models beyond General Relativity plus a cosmological constant.

In this talk, I will present ongoing work on the study of the properties of the dark sector to describe Horndeski models in terms of a non-trivial fluid within the Equation of State formalism. I will apply the framework to derive approximate expressions which give a simple physical intuition of the problem at hand and to understand theoretically modified gravity parameters and effects on observables.

I will show how under certain approximations, the Equation of State formalism naturally leads to the definition of phenomenologically modified gravity functions such as effective gravitational constant G_{eff} and the slip η. these new expressions will be linked to results from other perturbative approaches used in the literature.

The work here presented is discussed in the following work "Dark sector evolution in Horndeski models", with reference number arXiv:1905.06795

Beyond V / **33**

Current status of smooth quantum gravity

Authors: Jerzy Krol[1]; Torsten Asselmeyer-Maluga[2]

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Smooth QG is the attempt to use findings and infinite geometric constructions of differential geometry and topology in dimensions 3 and 4, to solve problems in physics, especially gravitational physics. The relation between general relativity and quantum mechanics is of particular interest. We report the recent result of G. Etesi that large exotic R4's are Ricci-flat and Koehler so that they are gravitational instantons. Also exotic smoothness structure of certain R4 determines realistic value of the cosmological constant, neutrino masses and some parameters of inflation. The smoothness is used to explore quantum regime of gravity via operator algebras and Riemannian curvature it generates.

https://arxiv.org/abs/1601.06436
https://arxiv.org/abs/1709.03314
https://arxiv.org/abs/1811.04464

Beyond IV / 34

Probing the Inflationary Field Content with Primordial Gravitational Waves and more.

Author: Matteo Fasiello[1]

[1] *ICG Portsmouth*

The inflationary paradigm, already in its simplest disguises, has been spectacularly successful when it comes to agreement with observations. However, there's a lot we do not yet know about inflation:
- what is its energy scale?
- how about its particle content?
- how did inflation begin?
...

New cosmological probes (at all scales, from CMB to interferometers) will soon put some of our best ideas to the test.
The answers to these questions are bound to be transformative of our understanding of cosmology and, possibly, also particle physics. A high-scale inflation, for example, would automatically be a portal to otherwise unaccessible energy scales.
In this talk I will review some recent work on the inflationary particle content and then focus on a model that includes a pseudo scalar field coupled with SU(2) gauge fields. This setup can generate a chiral gravitational waves signal. I will then detail on how the parameter space of the theory supports a blue tensor spectrum and large tensor as well as mixed non-Gaussianities.

Beyond I / 35

Gravitational Wave Cosmology -The Dawn has Arrived!

Beyond I / 36

Observing the Universe with Gravitational Waves

Detection of gravitational wave signals from mergers of black holes and neutron stars is one the most important discoveries of this century. I shall briefly present the phenomenon of gravitational

radiation as predicted by Einstein's general relativity. I shall describe gravitational wave detectors and

methods of analyzing gravitational wave data. I shall review the observations made during the two observational runs of advanced LIGO and Virgo detector projects. I shall present the physical and astrophysical significance of these observations. I shall summarize the most recent observations of gravitational wave signals made during the third observational run of LIGO and Virgo detectors that is currently underway.

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Decaying Massive Scalar in Expanding FRW-universes

Author: Juho Lankinen[1]

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Particle decay processes in the early Universe have deep and profound implications in cosmology. In a regime where curvature cannot be neglected anymore, the Minkowskian quantum field theory is ultimately only an approximation and of limited applicability. Because the energy conservation law is violated, the particle decay rates, cross sections and lifetimes are modified compared to usual flat space results. New particle processes, forbidden in Minkowski space, are to be considered leading to new Feynman diagrams even at first order.

Using quantum field theory in curved spacetime, we calculate the transition probabilities for a massive scalar decaying into massless fermions and into massless scalars. This is done using the method of added-up probability. It is found that the usual Minkowskian decay rates are considerably modified for early times and in long-time limit approach the Minkowskian result. For conformally coupled scalars the decay rate is modified by an additive term and the decay into fermionic channel is enchanced and decay into scalar channel diminished. Comparisons of the decay rates show that a decay channel into fermions is the dominant channel of decay in the very early Universe.

Based on:
J. Lankinen and I. Vilja, Particle decay in expanding Friedmann-Robertson-Walker universes, Phys. Rev. D 98, 045010, arXiv:1805.09620
J. Lankinen, J. Malmi and I. Vilja, Fermionic decay of a massive scalar in the early Universe, arXiv:1904.05084

Beyond V / 38

Electroweak baryogenesis and dark matter from a complex singlet scalar

Author: Da Huang[1]

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We connect the electroweak (EW) baryogenesis and the dark matter physics in a complex singlet scalar S extension of the Standard Model. We impose the additional CP and Z_2 symmetries on the scalar potential. With the complex vacuum expectation value of S at the temperature higher than the EW phase transition, the CP symmetry is spontaneously broken and a strong first-order EW phase

transition is easily realized. Together with a dimension-6 effective operator that gives new complex contributions to the top quark mass, we show that it is easy to yield the observed baryon asymmetry in our Universe. On the other hand, the CP and Z_2 symmetries are recovered after the EW phase transition. The lighter real state in S can be the dark matter candidate, and the strong constraints of CP violations can be avoided. With the scan of parameter space, we can find models which can explain the dark matter relic abundance and the baryon asymmetry simultaneously while satisfying all constraints.

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Constraining the inflationary field content

Author: Laura Iacconi[1]

Co-authors: David Wands [1]; Matteo Fasiello [2]

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Understanding the laws of inflation can shed light on the processes that govern physics at very high energy scales, beyond current experimental limits. In particular, the characterisation and detection of primordial gravitational waves produced during inflation can be an excellent test for the particle content of the very early universe. We consider an inflationary realisation whose tensor spectrum is sourced already at linear order. We show how this set-up supports a sufficient production of primordial gravitational waves to make the signal detectable at interferometer scales. We complement theoretical consistency checks on the model with stringent observational bounds on its parameter space stemming from CMB measurements, LIGO and Big Bang Nucleosynthesis bounds, as well as constraints from Primordial Black Holes production and UltraCompact MiniHalos.

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On Running couplings from adiabatic regularization

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We extend the adiabatic regularization method by introducing an arbitrary mass scale μ in the construction of the subtraction terms. This allows us to obtain, in a very robust way, the running of the coupling constants by demanding μ-invariance of the effective semiclassical (Maxwell-Einstein) equations. In particular, we get the running of the electric charge of perturbative quantum electrodynamics. Furthermore, the method brings about a renormalization of the cosmological constant and the Newtonian gravitational constant. The running obtained for these dimensionful coupling constants has new relevant contributions, not predicted by previous analysis. We point out that the running of the couplings has to be taken into account when solving the renormalized backreaction equations, for example in the case of the Schwinger pair creation effect in de Sitter space or in preheating of fermions after inflation.

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Nonthermal dark matter from modified early matter domination

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Thermal freeze-out or freeze-in during a period of early matter domination can give rise to the correct dark matter abundance for an annihilation rate of $\left\langle \sigma_{ann} v \right\rangle_f < 3 \times 10^{-26} \mathrm{cm}^3 \mathrm{s}^{-1}$. In the standard scenario, a single field that behaves like matter drives the early matter dominated era and decays to radiation before big bang nucleosynthesis. However, in more realistic models, this epoch may involve more than one field which can result in a complex thermal history. As a simple extension to the standard scenario, we will consider dark matter production via freeze-in/out in the presence of two fields and demonstrate that the allowed parameter space to obtain the correct dark matter abundance can be significantly enlarged to accommodate a wide range of dark matter masses and annihilation rates. In doing so, we will also consider the onset of early matter domination and the effects of a period of either matter or radiation domination preceding a single-field scenario.

arXiv:1812.10522 [hep-ph]
R. Allahverdi and J. Osinski 2019 in preparation

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Power-law Inflation with a Nondynamical Scalar Field

Authors: Asuka Ito[1]; AYA IYONAGA[None]; Suro Kim[1]; Jiro Soda[1]

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Many scalar-tensor theories have more than 2 degrees of freedom because of additional scalar fields. However, there is a theory named "cuscuton" whose number of degrees of freedom is only 2 on a cosmological background. This theory has a nondynamical scalar field, which is called "cuscuton field." In this talk, we consider inflation in the context of cuscuton gravity. We find a new exact power-law solution and show that this can be reconciled with the CMB data in the presence of the cuscuton field. We believe the result would be general in any dressed inflationary scenario.

arXiv: 1902.08663 [astro-ph.CO]

Beyond V / 44

Metric Optical Geometry and Beyond

Optical geometry is a spatial formalism for light propagation in Lorentzian spacetimes. This provides a geometrically interesting and useful framework for gravitational lensing, which is usually treated in terms of the quasi-Euclidean standard approximation instead. In this talk, I will first consider Riemannian optical geometry, and review basic results as well as recent work using the Gauss-Bonnet theorem and curve-shortening flow. In particular, the first isoperimetric inequality in this context will be presented. Then going beyond metric geometry, I will consider possible extensions to Randers-Finsler optical geometry, which arises for stationary spacetimes, and show a connection with the magnetoelectric effect. Finally, a framework for optics in non-metric spacetimes will be discussed.

Beyond I / 45

TBA

Beyond I / 46

TBA

Beyond I / 47

TBA

Beyond I / 48

Stochastic inflation: slow roll and beyond

Quantum fluctuations play an essential role in the dynamics and phenomenology of inflation in the very early universe. Usually quantum fluctuations during inflation are studied perturbatively (often linearly) about a fixed classical background, but in the stochastic approach quantum fluctuations on small scales provide a stochastic contribution to the non-perturbative classical evolution on large (super-Hubble) scales. In particular the stochastic delta-N formalism can be used to study large density perturbations required to form primordial black holes. This relies on the separate universe viewpoint but does not necessarily require slow roll (though the system is particularly simple in slow roll). I will discuss some of the issues when applying the stochastic approach beyond slow-roll.

Beyond I / 49

Testing the Particle Dark Matter paradigm with future cosmological and astronomy surveys.

The presence of dark matter strongly suggests that the laws of Physics as we know them are incomplete. In this talk I will summarise the directions which have been explored to determine the nature of dark matter (as well as their motivations), and discuss how future cosmological and astronomy surveys will help us to progress in this field.

Beyond I / 50

Cosmological implications of the electroweak vacuum instability

When extrapolated to high energies, the Standard Model of particle physics predicts that the current vacuum state is metastable. Its predicted decay rate is currently extremely low, but it would have been much higher in the early Universe. Therefore the fact that the Universe survived its first moments places constraints on both the cosmological history and on particle physics. I will discuss and review these constraints, focussing particularly on the bounds that can be obtained for the non-minimal couplings between the Higgs field and spacetime curvature.

Beyond II / 51

Dark Matter Indirect Detection

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Beyond III / 52

Neutrino Cosmology - Weighing the Ghost Particle with the Universe

Over the past decades, the high-precision cosmological data have significantly improved our understanding of the Universe, contributing greatly to the establishment of the standard model of cosmology. However these results have also opened new questions in both fundamental physics and astrophysics. One of the great mystery of the universe is that more than 80% of the matter in our Universe is made up of material that is invisible (dark matter). This component has important consequences in the evolution of the Universe and in the structure formation processes. While the major contribution to the dark matter should arise from cold dark matter (CDM), a small component of hot dark matter (HDM) can also be present. A natural candidate for the HDM is neutrino. Neutrinos physics is one of the most fascinating research areas that has stemmed from the interplays between cosmology, astrophysics and particle physics. Cosmology provides an independent tool for the investigation of neutrino properties since it is sensitive to the absolute scale of neutrino masses. Measuring the masses of these particles would be of extreme value to unravel the departure from the Standard Model (SM) of Particle Physics. A robust detection of neutrino masses is among the key goals of upcoming Cosmic Microwave Background (CMB) and Large-Scale Structure (LSS) surveys. In this talk, I will review the main physical effects of massive neutrinos on cosmological observable and summarize recent progress on neutrino mass constraints obtained by combining different cosmological measurements. I will also show a new approach to produce fast non-standard cosmological simulations with massive neutrinos by applying deep learning algorithms.

Beyond II / 53

TBA

Beyond II / 54

TBA

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Poster session

1 minute 1 slide oral presentation;

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Einstein-Gauss-Bonnet gravity in four space-time dimensions

Lovelock's theorem asserts that the most general theory of gravity in D=4 space-time dimensions is given by the action containing the Einstein-Hilbert term and a cosmological constant. Already in D=5 an additional term is possible - the Gauss-Bonnet action - which in D=4 turns into a total derivative not contributing to dynamics. In general, the contribution of the Gauss-Bonnet action to Einstein equation is proportional to (D-4). Here I will present an idea of multiplying the Gauss-Bonnet action by 1/(D-4) and defining the four-dimensional case as a smooth D->4 limit of the Einstein equation. Thus defined the theory propagates only the graviton and it satisfies the criteria of Lovelock's theorem, but bypasses its results. This theory has several novel predictions, including the corrections to the dispersion relation of cosmological tensor and scalar modes and singularity resolution for spherically symmetric solutions.

Beyond II / 57

Massive Gravity on a Brane

dRGT theory is the unique ghost-free theory of massive gravity and it realizes a full nonlinear completion of the linear Fierz-Pauli theory for a massive spin-2 field. In addition to being an interesting field theoretic modification of General Relativity, it could potentially explain the late-time cosmic acceleration of our universe as an alternative to a small cosmological constant. However, dRGT is an effective field theory with a very low strong coupling scale $\Lambda_3 \sim (1000km)^{-1}$ and in order to have a consistent modification of gravity that is compatible with short distance tests of GR, the theory must be UV completed in some way. It seems that a UV completion analogous to the Higgs mechanism for massive non-Abelian gauge theory will not work in flat space but there does exist a known mechanism for dynamically generating mass for the graviton in AdS space. We utilize this mechanism in a Randall-Sundrum-like scenario where our world is a flat boundary of a cutoff AdS space. The dRGT action is on the boundary and the bulk has gravity coupled to scalar fields that dynamically gains a mass. This massive graviton then has a 'zero-mode' which plays the role of the graviton on the brane and it's effective 4d dynamics are such that they raise the cut-off of massive gravity from $(1000km)^{-1} \sim 10^{-19}MeV$ to as high as $10^{19}MeV$.

Beyond II / 58

Gravitational Effects of Disformal Couplings

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Constraining the inflationary field content

Author: Laura Iacconi[1]

Co-authors: David Wands [1]; Matteo Fasiello [1]

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Understanding the laws of inflation can shed light on the processes that govern physics at very high energy scales, beyond current experimental limits. In particular, the characterisation and detection of primordial gravitational waves produced during inflation can be an excellent test for the particle content of the very early universe. We consider an inflationary realisation whose tensor spectrum is sourced already at linear order. We show how this set-up supports a sufficient production of primordial gravitational waves to make the signal detectable at interferometer scales. We complement theoretical consistency checks on the model with stringent observational bounds on its parameter space stemming from CMB measurements, LIGO and Big Bang Nucleosynthesis bounds, as well as constraints from Primordial Black Holes production and UltraCompact MiniHalos.

Beyond II / 60

Gravity and cosmology beyond Einstein

I will give an introductory review talk on extensions of general relativity, covering the following contents.
1. Introduction
2. General relativity and Lovelock gravity
3. PPN formalism
4. EFT approach
5. Massive gravity
6. Summary

Beyond II / 61

Resolving the strong coupling problem in massive gravity

Theories of massive gravity and their generalizations have been used for the description of the late time and early universe cosmologies. These theories however are strongly coupled at a certain low energy scale. We show how this problem can be avoided by embedding massive gravity and its generalizations into higher dimensional theories.

Beyond II / 62

TBA

Beyond III / 63

Flavor, CP, and Baryons

Author: Mu-Chun Chen[1]

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I will review flavor models based on non-Abelian discrete symmetries, motivated by neutrino oscillation data. I will discuss how CP violation, a necessary condition for baryogenesis, can be entirely group theoretical in origin in certain class of the non-Abelian discrete groups. I will then describe a proposal where successful baryogenesis can be achieved through flavon decays.

Beyond III / 64

Quantum scale invariance, hierarchy generation and inflation

Global and local Weyl invariant theories can solve the hierarchy problem and generate all mass scales spontaneously, initiated by a dynamical process of "inertial spontaneous symmetry breaking" that does not involve a potential. I will discuss how inflation readily occurs in a scale invariant version of Starobinsky (R2) inflation and how an hierarchy of mass scales may be generated, stable against both Standard Model and gravitational quantum corrections.

Beyond IV / 65

Monodromy inflation and an emergent mechanism for stabilising the cosmological constant

We show how a pair of field theory monodromies in which the shift symmetry is broken by small, well motivated deformations, naturally incorporates a mechanism for cancelling off radiative corrections to the cosmological constant. The lighter monodromy sector plays the role of inflation as well as providing a rigid degree of freedom that acts as a dynamical counterterm for the cosmological constant. The heavier monodromy sector includes a rigid dilaton that forces a global constraint on the system and the cancellation of vacuum energy loops occurs at low energies via the sequestering mechanism. This suggests that monodromy constructions in string theory could be adapted to incorporate mechanisms to stabilise the cosmological constant in their low energy descriptions.

Beyond I / 66

Understanding the dynamical nature of late-time cosmic acceleration from dark energy and f(T) modified gravity

In this talk I will briefly introduce the present understanding about the cosmic acceleration at present from the perspective of phenomenological study. I will review the latest observational status of the late-time cosmic acceleration and then depict how to do the model building of dynamical dark energy. Afterwards, I will also give an introduction to a type of torsional based modified gravity, which can also realize the cosmic acceleration at present. This so-called f(T) gravity and beyond theories can be depicted in a language of effective field theory and thus we can examine certain operators that are most connected with various cosmological observations.

Beyond III / 67

TBA

Beyond III / 68

Self-stopping relaxion

I will review the mechanism of cosmological relaxation of the electroweak scale and will discuss relaxion particle production during the evolution of the relaxion field, an effect which had been so far ignored in the relaxion literature. I will present its implications on the relaxion mechanism in general.

Beyond IV / 69

Reverse Engineering the Universe

I will give a brief review of inflationary cosmology, including its motivation, observational status, the problem of initial conditions, and the string landscape scenario. I will also describe the problems with hilltop inflation and then I will show that the theory of alpha-attractors and D-brane inflation together can completely cover the range or values of n_s and r favored by Planck 2018.

Beyond IV / 70

The Search for Inflationary B-modes with the BICEP/Keck Telescopes

The LCDM cosmological model fits a wealth of observational data extremely well but assumes a very specific type of initial conditions (near-scale-invariant, Gaussian, adiabatic perturbations). Inflationary theories can naturally produce these initial conditions, while also generically predicting a background of gravitational waves—which have so far not been detected. There are a wide range of inflationary models which make different predictions for the strength of the gravitational wave background, which is customarily characterized by the scalar-to-tensor ratio r. Primordial gravitational waves will have left an imprint in the polarization pattern of the cosmic Microwave Background (CMB) which we can potentially detect as a curl component, or B-mode, in the pattern at degree angular scales. The BICEP/Keck series of experiments are small aperture refracting telescopes specifically designed to search for this signal. The latest BK15 results use measurements at 95, 150 and 220GHz, in conjunction with additional bands from WMAP and Planck, to constrain the foreground signal and set the limit $r < 0.07$ (95% confidence). I will describe the current instruments, data and analysis, and also the major BICEP Array upgrade which is projected to reach sensitivity of $\sigma(r) \sim 0.003$ within the next five years.

Beyond IV / 71

Testing primordial Non-Gaussianty: perspectives beyond Planck

Tests of primordial non-Gaussianity (PNG) are a powerful tool to shed light on the physics of the Early Universe. Currently, the best limits on PNG come from Planck measurements of Cosmic Microwave Background (CMB) temperature and polarization anisotropies, which nearly saturated the CMB constraining power. After briefly reviewing current Planck PNG bounds for a variety of models, I will discuss how these could be further improved in the future using different probes, such as galaxy clustering, or CMB B-mode polarization and spectral distortions.

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TBA

Beyond IV / 73

TBA

Beyond IV / 74

TBA

Beyond IV / 75

TBA

Beyond IV / 76

TBA

Beyond IV / 77

Updates on the Cosmological Collider Physics

We review quasi-single field inflation and the cosmological collider physics, emphasizing on recent progress. The cosmological collider is a model-independent way of extracting the mass and spin information of heavy particles at the energy scale of inflation. The same mechanism can also be used as a direct probe of the expansion history of the universe. After the introduction, we survey the recent progress including neutrino physics, particle scanner, superheavy dark matter, tests of particle symmetries and the tension of today's Hubble parameter measurements.

Beyond IV / 78

Primordial Standard Clocks as Direct Probes of the Scenario of the Primordial Universe

How to model-independently distinguish the inflation scenario from alternatives to inflation is an important challenge in modern cosmology. In this talk, we show that massive fields in the primordial universe function as standard clocks and imprint clock signals in the density perturbations, which directly record the scale factor of the universe as a function of time, a(t). This function is the defining property of any primordial universe scenario, so can be used to identify the inflation scenario, or one of its alternatives, in a model-independent fashion. The signals also encode the mass and spin spectra of the particle physics at the energy scale of the primordial universe.

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TBA

Beyond III / 80

Scale invariance, Stueckelberg breaking of Weyl gravity and inflation

Weyl conformal geometry may play a role in early cosmology where effective theory at short distances becomes conformal. We consider the original Weyl gravity action, quadratic in the scalar curvature and in the Weyl tensor of Weyl conformal geometry; this action is invariant under Weyl scaling gauge transformations. In the absence of matter fields, we show that Weyl action has spontaneous breaking of this symmetry: the Weyl gauge field (of local scale transformations) becomes massive (mass ˜ Planck scale) after absorbing a compensator (dilaton), in a gravitational Stueckelberg mechanism. As a result, one obtains the Einstein-Hilbert action, a positive cosmological constant and the Proca action for the massive Weyl gauge field ("photon"). The Einstein-Hilbert action is then just a "low energy" limit of Weyl quadratic gravity which thus avoids its long-held previous criticisms, while Planck scale is an emergent scale of this symmetry breaking (where Weyl geometry becomes Riemannian). The results remain valid in the presence of matter with non-minimal coupling. Successful inflation in Weyl gravity is possible, with results close to the Starobinsky model. Based on arXiv:1812.08613, 1904.06596.

Beyond V / 81

Constraining primordial gravitational waves from inflation

I discuss the prospects for constraining gravitational waves from non-minimal inflationary models using: (i) the large scale structure, through the so-called "fossil" signatures; (ii) cross-correlations of tracers of the large scale structure with secondary CMB anisotropies from kinetic and polarized Sunyaev–Zel'dovich effects. I show how these different routes for testing primordial gravitational waves will help us learn more about the early universe.

Beyond II / 82

Searching for Dark Matter across different Scales

In this talk, I will discuss the methods to search for dark matter or dark sector particles having the masses from GeV to the Solar Mass. We can probe their properties by colliders, neutrino or gamma ray experiments.

Beyond V / 83

Weyl Symmetry for Dark Matter and Dark Energy

I will start by reviewing the mimetic formulation for irrotational fluid-like Dark Matter. It turned out that the latter can be described by a Weyl-invariant higher-derivative scalar-tensor theory beyond the Horndeski class of theories. Then I will proceed by discussing a novel vector extension of the mimetic construction. This novel vector-tensor theory provides a Weyl-invariant higher-derivative and generally covariant description for the unimodular gravity.

Beyond V / 84

TBA

Beyond V / 85

TBA

Beyond V / 86

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Beyond V / 87

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Beyond V / 88

TBA

Beyond V / 89

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Beyond V / 90

TBA

Beyond V / 91

TBA

Beyond I / 92

Gravitational wave energy budget in strongly supercooled phase transitions

Author: Marek Lewicki[1]

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I will discuss efficiency factors for the production of gravitational waves through bubble collisions and plasma-related sources in strong phase transitions, and the conditions under which the bubble collisions can contribute significantly to the signal. I will also show that generically the sound-wave period is much shorter than a Hubble time leading to a reduction of GW signal produced by sound waves and possibly suggesting a significant amplification of the turbulence-sourced signal. I will illustrate our findings in two examples, the Standard Model with an extra $|H|^6$ interaction and a classically scale-invariant $U(1)_{B-L}$ extension of the Standard Model. The contribution to the GW spectrum from bubble collisions is found to be negligible in the $|H|^6$ model, whereas it can play an important role in parts of the parameter space in the scale-invariant $U(1)_{B-L}$ model.

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Time-crystal ground state in Cosmology and production of gravitational waves from QCD phase transition

Author: Andrea Addazi [1]

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We propose a novel mechanism for the production of gravitational waves in the early Universe that originates from the relaxation processes induced by the QCD phase transition. While the energy density of the quark-gluon mean-field is monotonously decaying in real time, its pressure undergoes

a series of violent oscillations at the characteristic QCD time scales that generates a primordial multi-peaked gravitational waves signal in the radio frequencies' domain. The signal as an echo of the QCD phase transition, and is accessible by the FAST and SKA telescopes.

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The sound of DHOST

Authors: Antoine Lehébel[1]; Eugeny Babichev[2]

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In generic higher-order scalar-tensor theories which avoid the Ostrogradsky instability, the presence of a scalar field significantly modifies the propagation of matter perturbations, even in weakly curved backgrounds. This affects notably the speed of sound in the atmosphere of the Earth. It can also generate instabilities in homogeneous media. I will use this to constrain the viable higher-order scalar-tensor models.

95

New mechanism of producing superheavy fields during inflation

Author: Sabir Ramazanov[1]

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I will discuss a new mechanism of producing superheavy fields (with the masses much larger than the inflationary Hubble rate) during inflation. The key ingredient of the mechanism is a linear coupling of the superheavy field to a function of the inflaton. During inflation this induces almost constant force dragging the corresponding field to the non-zero value. I will discuss implications of the mechanism proposed for Dark Matter and baryon asymmetry generation as well as its phenomenological consequences. The talk is based on [arxiv:1805.05904], [arxiv:1809.08108] and [arxiv:1812.03516].

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Oscillons and Dark Matter

Authors: Oriol Pujolas Boix[1]; Fabrizio Rompineve[2]; Jan Olle[None]

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Oscillons are localized, massive, long-lived and oscillating classical field configurations that arise in scalar field theories with attractive self-interactions. Focusing on axion models arising from string

theory, we find that oscillons can be formed generically with extremely large lifetimes. I will discuss the phenomenological impact of these oscillons in dark matter.

Beyond II / 97

Cosmology of models with spontaneous scalarization: instability and a cure.

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I will discuss scalar-tensor models of gravity, which predict the spontaneous scalarization of neutron stars or/and black holes. In the cosmological setup, the scalar field responsible for scalarization is subject to a tachyonic instability during inflation as well as at other cosmological stages, depending on the model. The instability poses a problem for viability of such models. I will show that for the case of scalarization with the Gauss-Bonnet term, a catastrophic instability develops during inflation within a period of time much shorter than the minimum required duration of inflation. As a result, the standard cosmological dynamics is not recovered. On the other hand, in the case of standard scalarization by Damour-Esposito-Farese, it is possible to make a simple modification of the original model by coupling the scalar to the inflaton field. For generic couplings the scalar (including its perturbations) relaxes to zero with an exponential accuracy by the beginning of the hot stage.

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Dark matter and baryon-number generation in quintessential inflation via hierarchical right-handed neutrinos

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Incorporating three generations of right-handed Majorana neutrinos to quintessential inflation, we construct a model which simultaneously explains inflation, dark energy, dark matter and baryogenesis. These right-handed neutrinos have hierarchical masses $M_3 \sim 10^{13}$GeV, $M_2 \sim 10^{11}$GeV, $M_1 \sim 10$keV and are produced by gravitational particle production in the kination regime after inflation. The heaviest, the intermediate, and the lightest account for reheating, CP violation of leptogenesis, and dark matter, respectively. We consider various constraints from particle experiments and cosmological observations. If we adopt the Randall-Sundrum brane-world scenario, these constraints on parameters are satisfied without fine-tuning.

This talk is based on 1905.12423.

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Emergent inflation from a Nambu–Jona-Lasinio mechanism in gravity with non-dynamical torsion

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We discuss how inflation can emerge from a four-fermion interaction induced by torsion. Inflation can arise from coupling torsion to Standard Model fermions, without any need of introducing new scalar particles beyond the Standard Model. Within this picture, the inflaton field can be a composite field of the SM-particles and arises from a Nambu-Jona-Lasinio mechanism in curved space-time, non-minimally coupled with the Ricci scalar. The model we specify predicts small value of the r-parameter, namely r ˜ 10−4 ÷ 10−2, which nonetheless would be detectable by the next generation of experiments, including BICEP 3 and the AliCPT projects.

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Possible resolution of a spacetime singularity with field transformations

Co-author: Atsushi Naruko

In this talk, we show that there is a class of spacetime curvature singularities which can be resolved with metric and matter field transformations. As an example, we consider an anisotropic power-law inflation model with gauge and scalar fields in which a space-like curvature singularity exists at the beginning of time. First, we provide a transformation of the metric to the flat geometry. The transformation is regular in the whole region of spacetime except for the singularity. In general, matter fields are still singular after such a metric transformation. However, we explicitly show that there is a case in which the singular behavior of the matter fields can be completely removed by a field re-definition. Since the action is invariant under any metric and matter field transformations, the regularity of the action at the original singularity is a necessary condition for the complete removal of a singularity.

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Hunting Axion Dark Matter with New Techniques

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Identification of dark matter has been an outstanding problem in physics for decades, and axion (or axion like partciles) is its candidate with great motivations. A number of observations and experiments have tried to detect axion by using the axion-photon conversion by assuming the axion is coupled to photon, while no signal yet to be found. In this talk, I will discuss new techniques to search for axion dark matter (ADM) by focusing on another phenomena, birefringence, which is caused by the same coupling. The polarimetry observation of protoplanetary disks puts the best constraint on ADM for fuzzy dark matter mass ($m = 10^{-22}$eV). I also propose to use gravitational wave interferometer like LIGO for ADM search by installing a new detector which does not affect the detection of gravitational waves.

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Macroscopic effects on neutralino dark matter depletion through large R-charge

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The presence of a large, non-vanishing background charge in the universe can interestingly have implications on symmetry restoration at high temperature. In theories with continuous global symmetries, like the R-symmetry of the MSSM, these can lead to important cosmological effects seemingly independent of the short-distance scale physics. Here we explore the effect of temporary R-symmetry violation on the density of neutralino dark matter in the presence of a large initial R-charge in the early universe. In particular, this behaviour may be important for models in which the dark matter experiences feeble annihilation rates with the primordial plasma, common in supersymmetric models.

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How does torsion affect light propagation?

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Einstein's theory of gravity (general relativity, GR) is based on Riemannian geometry. Modified theories of gravity such as f(R) theories are also based on Riemann spaces and so are intrinsically limited. In order to better understand the nature of gravity it is worth going further, beyond Riemannian geometry. The simplest extensions of Riemannian geometry are based on non-null non-metricity tensors and non-symmetric connections. I will briefly discuss these extensions and focus on models with a totally antisymmetric torsion tensor, i.e. with a null non-metricity tensor. I will show how the presence of torsion affects light propagation and I will discuss how to use cosmological observations to test some of these non-Riemannian extensions of the geometry of our Universe.

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Complementary probes of cosmic inflation

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A rigorous constraint analysis on inflationary cosmology entails several probes which collectively survey an extensive range of energy scales. We complement the current cosmic microwave background data with an updated compilation of the cosmic abundance limits of primordial black holes, with which we infer stringent constraints on the runnings of the scalar spectral index. The constraints on the higher-order inflationary power spectrum parameters are notably improved by further including imminent measurements of the cosmic microwave background spectral distortions, clearly illustrating the effectiveness of joint large-scale and small-scale cosmological surveys.

Based on arXiv:1904.09590.

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Role of matter in modified gravity: a search for new interactions

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Modified gravity theories are typically constructed in the Jordan frame, where the matter follows the geodesics of the metric. This is nothing more than a choice of field variable that leaves the observables intact. However recent developments in classical field theory revealed that fixing variables may affect how the fundamental assumptions in the theory building process are represented. For instance, the construction of "beyond-Horndeski" theories in the Jordan frame representation requires an intricate constraint analysis to exploit degeneracies, while using different variables one can obtain arguably simpler formulations within the framework of standard (i.e. Horndeski) scalar-tensor theory.

In this talk, I will adopt Bekenstein's perspective of multiple geometries and consider two applications where a generic matter coupling unveils new interactions: i. a massive spin–2 theory; ii. a vector-tensor theory with an Abelian gauge field.

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Could the H0 Tension be Pointing Toward the Neutrino Mass Mechanism?

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Within the framework of ΛCDM, the local determination of the Hubble constant disagrees – at the 4.4σ level – with that inferred from the very accurate CMB observations by the Planck satellite. This clearly motivates the study of extensions of the standard cosmological model that could reduce such tension. Proposed extensions of ΛCDM that reduce this so-called Hubble tension require an additional component of the energy density in the Universe to contribute to radiation at a time close to recombination.

In this talk, I will show that pseudo-Goldstone bosons – associated with the spontaneous breaking of global lepton number in type-I seesaw models – lead to a non-standard early Universe evolution that can help to reduce the Hubble tension. I will show that current CMB observations can set a lower bound on the scale at which lepton number is broken as high as 1 TeV. Finally, I will argue that future CMB observations will test wide and relevant regions of parameter space of scenarios in which the spontaneous breaking of global lepton number is the mechanism behind the observed neutrino masses.

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Light Dark Matter from Inelastic Cosmic Ray Collisions

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Direct detection experiments relying on nuclear recoil signatures lose sensitivity to sub-GeV dark matter for typical galactic velocities. This sensitivity is recovered if there exists another source of flux with higher momenta. Such an energetic flux of light dark matter could originate from the decay of mesons produced in inelastic cosmic ray collisions. I present in this talk the dark matter flux expected from such cosmic beam dump experiment and the resulting limits on the model parameters using direct detection experiments such as XENON1T and the projected LZ. A particular model involving a hadrophilic scalar mediator is also considered and I show how the limits compare with dedicated beam dump experiments such as MiniBooNE.

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Preheating on curved field-space manifolds.

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I will discuss preheating in multi-field models of inflation with a curved field-space manifold. In the case of two-field generalizations of α-attractor models with is a highly curved hyperbolic field-space manifold, analytical progress can be made for preheating using the WKB approximation and Floquet analysis. I will show the emergence of a simple scaling behavior of the Floquet exponents for large values of the field-space curvature, that enables a quick estimation of the reheating efficiency for any large value of the field-space curvature. In this regime one can observe and explain universal preheating features that arise for different values of the potential steepness. In general preheating is faster for larger negative values of the field-space curvature and steeper potentials. For very highly curved field-space manifolds preheating is essentially instantaneous. (arXiv:1810.02804 [astro-ph.CO])

In case of multi-field models with non-minimal couplings, where the field-space in the Einstein frame is highly curved near the origin, I will describe recent lattice simulations that have been used to capture significant nonlinear effects like backreaction and rescattering. I will show how we can we extract the effective equation of state and typical time-scales for the onset of thermalization, quantities that could affect the usual mapping between predictions for primordial perturbation spectra and measurements of anisotropies in the cosmic microwave background radiation. For large values of

the nonminimal coupling constants, efficient particle production gives rise to nearly instantaneous preheating. Moreover, the strong single-field attractor behavior that was identified for these models in linearized analyses remains robust in the full theory, and in all cases considered the attractor persists until the end of preheating. (arXiv:1905.12562 [hep-ph])

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Holographic Views of the Emergent Dark Universe

Author: Yun-Long Zhang[1]

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We study a model of the emergent dark universe, which lives on the time-like hypersurface in a five-dimensional bulk spacetime. The holographic fluid is assumed to play the role of the dark sector, mainly including the dark energy and apparent dark matter. Based on the modified Friedmann equations, we present a Markov-Chain-Monte-Carlo analysis with the observational data, including type Ia Supernova and the direct measurement of the Hubble constant. We obtain a good fitting result and the matter component turns out to be small enough, which matches well with our theoretical assumption. The effective potential of the model with a dynamical scalar field is reconstructed and the parameters in the swampland criteria are also extracted. [Refs. 1712.09326 & 1812.11105]

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TBA

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TBA

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Primordial-Black-Holes-as-CDM Scenario and Gravitational Waves

Author: Misao Sasaki[None]

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TBA

Author: Alexander Vikman[None]

TBA

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EGB gravity in 4-dimensional space-time

Author: Drazen Glavan[None]

a counter example to Lovelock theorem.

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TBA

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TBA

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CMB Spectral Distortions from Coherent Oscillations of Axions

Author: Bryce Cyr[1]

[1] *McGill*

We investigate the impact of a Chern-Simons coupling, an interaction that is naturally present due to symmetry considerations, between axions and electromagnetism in the early universe. The inclusion of this coupling induces a parametric resonance in the U(1) gauge field once the axion starts oscillating, generating an explosive amount of photon production. These resonantly produced photons are highly non-thermal, and so their production between redshifts of 10^6 and 10^3 can disturb the blackbody nature of the CMB resulting in a spectral distortion. We compute the induced spectral distortion via this process and comment on general constraints and limitations of this model.

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TBA

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Minimalism in modified gravity

It is generally believed that modification of GR inevitably introduce extra physical degree(s) of freedom. In this talk I argue that this is not the case by constructing modified gravity theories with two local physical degrees of freedom. After classifying such theories into two types, I show explicit examples and discuss their cosmology and phenomenology.

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TBA