Quantum Gravity, Higher Derivatives & Nonlocality

Online Workshop, 8th to 12th March 2021

Abstracts

Monday 8th

Session 1: Towards a (local) theory of quantum gravity

Gerardus 't Hooft (Utrecht)

Title: Negative energies in quantum gravity

Abstract: Several approaches have been considered towards a coherent theory that attempts to reconcile gravitation with quantum mechanics. One often encounters the need to allow for negative energy states. Alternatively, one may introduce not only a lower bound for energy, providing us with a flat background metric being the vacuum state, but also an upper bound, giving us an `anti-vacuum' state. Vacuum and anti-vacuum are dual to one another, as we see in the Penrose diagram for eternal (or long-living) black holes. Such a model for the quantum black hole would solve the information problem and produce a unitary evolution law. Negative energy states also emerge in an attempt to employ local conformal symmetry to turn gravity into a renormalizable quantum field theory. An attractive feature of such a theory is that it might render all physical interaction constants to become determined and computable following renormalisation group equations. This would include all mass parameters and the cosmological constant. Yet negative energies generate new problems.

John Donoghue (Massachusetts)

Title: The Quantum Field Theory of Quadratic Gravity

Abstract: Quadratic gravity is a renormalizable quantum field theory for gravity. Because of the higher derivatives in the theory, there are concerns about unitarity, causality and/or stability. I will describe how unitarity emerges intact, how causality has violations on small scales, and briefly discuss stability.

Roberto Percacci (SISSA)

Title: Recent progress in Metric-Affine and Higher Derivative Gravity

Abstract: Metric-Affine Gravity (MAG) is a promising extension of General Relativity, but in spite of having been studied for a long time, it is still little understood. I will give some results for its spectrum about flat space, and the possibility of finding ghost- and tachyon-free theories. We know much more about Higher Derivative Gravity (HDG), to which it is closely related. I will describe some new results for the beta functions of HDG and try to relate them to speculations about Planckian and trans-Planckian physics.

Session 2: EFT of gravity, unitarity problem, Wilsonian *vs* non-Wilsonian UV completion

Claudia de Rham (Imperial College London)

Title: Positivity in Gravitational Theories

Abstract: In standard effective field theories, the notion of causality is intrinsically linked with that of subluminality and with a set of positivity constraints to be imposed on the low-energy scattering amplitudes. I will highlight how the presence of gravity leads to a more subtle relation between causality, (sub)luminality and positivity bounds. I will clarify why a mild level of negativity or superluminality is not in contradiction with causality, analyticity or Lorentz invariance and show how consistent gravitational low energy effective theories can self-protect by ensuring that any time advance and superluminality calculated within the regime of validity of the effective theory is necessarily unresolvable for such theories. These considerations are particularly relevant for putting constraints on cosmological and gravitational effective field theories and I will provide explicit criteria to be satisfied so as to ensure causality and a standard high energy completion in gravitational effective field theories.

Alberto Salvio (Tor Vergata and INFN)

Title: Quadratic Gravity

Abstract: An extension of general relativity (GR) obtained by adding local quadratic terms to the action will be considered. Such theory can be a viable UV completion of GR. The additional terms soften gravity above a certain scale and render gravity renormalizable. The presence of 4 derivatives implies via the Ostrogradsky theorem that the *classical* Hamiltonian is unbounded from below. Nevertheless, I will argue that the relevant solutions are not unstable, but metastable: when the energies are much below a threshold (that is high enough to describe the whole cosmology) runaways are avoided. Remarkably, the chaotic inflation theory of initial conditions ensures that such bound is satisfied and testable implications for the early universe will be discussed. I will also argue that the basic unitarity condition is satisfied when the theory is correctly formulated at the quantum level. Moreover, thanks to the UV softening of gravity, sufficiently light objects must be

horizonless and I will discuss explicit analytic examples of horizonless ultracompact objects, which have interesting physical implications.

Gia Dvali (LMU, Munich)

Title: Saturons and QFT meaning of self-UV-completion via classicalization

Abstract: We discuss the phenomenon of saturation and its role in non-Wilsonian UV-completion by classicalization both in gravity and in non-gravitational theories and the role of black holes/saturons. We also discuss physical manifestations of saturation for systems such as black holes or de Sitter.

Philip Mannheim (Connecticut)

Title: Solution to the ghost problem in higher derivative gravity

Abstract: While one can construct c-number propagators as matrix elements of q-number operators between quantum states in a quantum Hilbert space, one cannot go the other way round and construct the Hilbert space starting from the c-number propagator. Starting from the quantum Hilbert space of fourth-order derivative theories Bender and Mannheim [PRL 100, 110402 (2008), PRD 78, 025022 (2008)]) constructed the c-number propagator and found that it was not given by the matrix element between the vacuum and its Hermitian conjugate (as had previously been presupposed) but by the matrix element between the vacuum and its CPT conjugate, with there then being no ghosts states of negative norm. While the overlap of a state with its Hermitian conjugate might be negative the correct inner product is the overlap of a state with its CPT conjugate, and none of these overlaps are negative. Thus, rather than get rid of the ghost states Bender and Mannheim showed that they actually were never there in the first place. Consequently, the fourth-order derivative conformal gravity theory is unitary. And since it is also renormalizable it provides a consistent quantum gravity theory in four spacetime dimensions.

Tuesday 9th

Session 1: Asymptotic safety approach to gravity

Frank Saueressig (IMAPP, Nijmegen)

Title: Introducing Form Factors in Asymptotically Safe Gravity

Abstract: The asymptotic safety program strives for a high-energy completion of gravity and gravity-matter systems by interacting renormalization group fixed points. The fixed points render the theory safe from unphysical divergences at high energies and equip the construction with predictive power.

In this talk I will give a pedagogical introduction to the program. In particular, I will argue that the inclusion of form factors – generalizing the running couplings encountered in quantum field theory to curved spacetime – is essential for investigating questions related to the causality and unitarity of the construction. Moreover, I will outline how form factors provide a concrete perspective for formulating various quantum gravity programs in a unifying language.

Alessia Platania (Perimeter Inst.)

Title: Non-perturbative unitarity and fictitious ghosts in quantum gravity

Abstract: According to the asymptotic-safety conjecture, a (non-perturbatively) renormalizable quantum field theory of gravity could be constructed based on the existence of a non-trivial fixed point of the gravitational renormalization group flow. The existence of this fixed point can be established, e.g., via the non-perturbative methods of the functional renormalization group (FRG). In practice, the use of the FRG methods requires to work within truncations of the gravitational action, and higher-derivative operators naturally lead to the presence of several poles in the propagator. The question is whether these poles represent a real problem for the unitarity of the theory. In this talk I will show with explicit examples that the inclusion of quantum effects at all scales is of crucial importance to assess unitarity of field theories. In particular, poles appearing in truncations of the action could correspond to fake degrees of freedom of the theory. Possible conditions to determine, within truncations, whether a pole represents a fake or a genuine degree of freedom of the theory will be discussed.

Astrid Eichhorn (Southern Denmark and CP3-origin)

Title: Interplay of matter and quantum gravity

Abstract: I will review the state-of-the art in matter-gravity theories which could be asymptotically safe and highlight both structural features of such theories as well as potential phenomenological consequences. In particular, in view of the general theme of the workshop, I will highlight the role of higher-derivative terms in matter-gravity theories and how a certain set of derivative interactions gives rise to the so-called weak-gravity bound.

Session 2: String (field) theory, higher Derivatives & nonlocality

Ashoke Sen (Harish-Chandra Res. Inst.)

Title: String field theory

Abstract: I shall describe how string field theory can be used to prove unitarity and analyticity of scattering amplitudes in string theory.

Irina Aref'eva (Steklov Math. Inst.)

Title: Notes on Cauchy problem for nonlocal equations

Abstract: Cauchy problem for nonlocal equations of motion is considered. Special attention is payed to nonlocal equations in string field and p-adic string theories. In these cases, it is possible to reduce the problem to modified diffusion equations. Their special features on semi bounded spaces will be discussed.

Branko Dragovich (Belgrade Inst. and Math. Inst. SANU)

Title: On nonlocality of p-adic and zeta strings

Abstract: I plan to give a brief review of p-adic and zeta strings pointing out their nonlocality. I will also discuss potential role that these strings may have in nonlocal cosmology.

Olaf Hohm (Humboldt, Berlin)

Title: Duality and Higher Derivatives

Abstract: I review work on the interplay of higher derivative corrections in string theory and their duality properties under the T-duality group O(d,d). In particular, for cosmological (purely time-dependent) backgrounds invariance under O(d,d) allows one to classify all independent higher-derivative invariants (to arbitrary order in the inverse string tension \alpha').

Wednesday 10th

Session 1: Higher Derivatives, Lorentz (non)-invariance & (non)locality

Andrei Barvinsky (Lebedev Inst.)

Title: Lorentz non-invariance as the palladium of locality, unitarity and renormalizability in quantum gravity

Abstract: We consider Lorentz symmetry violating models of Horava-Lifshitz gravity type. Projectable version of these models is guaranteed to maintain UV renormalizability, locality, unitarity and even asymptotic freedom in lower dimensions, based on the BRST structure of renormalization in a special class of regular background covariant gauges. Generalized unimodular gravity descending from this class of theories admits inflation and dark energy scenarios along with the Stueckelberg fields covariantization and features equivalence to the k-essence theory whose gradient expansion starts with the approximation of the cuscuton model. Renormalization of this model hints its further generalization and the use of a generalized renormalization group of a special functional form.

Richard Woodard (Florida)

Title: The Case for Nonlocal Modifications of Gravity

Abstract: The huge amounts of undetected and exotic dark matter and dark energy needed to make general relativity work on large scales argue that we should investigate modifications of gravity. The only stable, metric-based, and invariant alternative to general relativity is f(R) models. These models can explain primordial inflation, but they cannot dispense with either dark matter or dark energy. I advocate nonlocal modifications of gravity, not as new fundamental theories but rather as the gravitational vacuum polarization engendered by infrared quanta produced during primordial inflation.

Ilya Shapiro (Juiz de Fora)

Title: Exact Renormalization Group Equations from the Perturbative Quantum Gravity

Abstract: Deriving the exact, well-defined, and gauge-fixing independent renormalization group beta functions in quantum gravity is not just a dream. There are two situations when this dream may become a real thing. The first example is the superrenormalizable quantum gravity models. These models can be polynomial or nonlocal. In the last case, it is difficult to make practical calculations with the available techniques. However, in the polynomial gravity, this calculation can be, and in fact, was done. The first purpose of the talk is to explain why the corresponding result satisfies the aforementioned requirements and, at the same time, has a very restricted area of applicability. The second part shows how the exact and well-defined beta functions can be obtained in the effective approach to quantum gravity combined with the Vilkovisky-DeWitt unique effective action. Within this framework, these beta functions provide a reliable description of the running of Newton and cosmological constants between the Planck scale in the far UV and the Hubble scale in the far IR limits.

Remark: The talk is based on collaborations with M. Asorey, J.-L. Lopez, L. Modesto, L. Rachwal, B. Giacchini and T.P. Netto.

Leslaw Rachwal (Juiz de Fora)

Title: Higher derivative gauge theory as a toy-model for Quantum Gravity

Abstract: Higher derivative gauge theories serve as a well-studied and well understood toy example for the more ambitious task of HD Quantum Gravity. In this talk we draw the parallel and shed some light on lessons that could be learned from analysis of the gauge theory models. The high energy behavior of non-abelian gauge theories with higher derivatives is rather different from that of ordinary gauge theories. The requirement of asymptotic freedom imposes very stringent constraints

that are only satisfied by a small family of higher derivative theories. For a low number of extra derivatives, the theory remains asymptotically free, but for a larger number of derivatives the theory is strongly interacting both at extreme infrared and ultraviolet regimes. The critical total number of extra derivatives where such a transition between the two regimes occurs is eight. The introduction of an extra parameter in the theory improves its ultraviolet behavior leading in some cases to ultraviolet finite theories with vanishing beta-function.

Session 2: Nonlocal theories of gravity

Nikolai Krasnikov (INR, Moscow)

Title: Several aspects of nonlocal field theories and gravity

Abstract: I give a review of nonlocal field theory including gravity. Besides, I discuss the case of gamma_5 anomalous models and give an example how nonlocal field theory can make sense to gamma_5 anomalous models. Also, I consider nonlocal extension of Georgi Glashow SU (5) GUT and show that the introduction of additional nonlocal terms can cure bad predictions of standard Georgi Glashow SU (5) GUT.

Alexey Koshelev (Beira Interior)

Title: Ghosts in ghost-free analytic infinite derivative gravity theories

Abstract: In this talk I will discuss the problem of definition of a non-local gravity action around an arbitrary background. The issue is manifest in a quadratic in curvature action where it can be shown to be impossible to satisfy the ghost-free condition around several backgrounds simultaneously. Two suggested resolutions will be put forward for further discussion: higher order in curvature actions or maybe benign ghosts.

Terry Tomboulis (UCLA)

Title: Nonlocal vertices, UV "opaqueness" and causality

Abstract: There are several physical motivations for considering nonlocality of interactions. A basic one is the well-known argument, discussed over several decades, that, in the presence of gravitational interactions, there must be a fundamental limitation on the resolution achievable by any conceivable experiment probing scales of the order of some fundamental (Planck order) length. We will present some recent work on how one may implement this picture in field theory within a multi-scale analysis framework, which allows sequestering of the extreme UV, so that interactions become `soft' and coarse over such scales, thus preventing finer resolution. This naturally results in nonlocal vertices of particular types, with Feynman rules resembling those of string field theory. A central question that will be discussed is how local gauge symmetries can be accommodated within such a multi-scale framework. For these interactions, a rigorous asymptotic analysis of potential acausal effects in scattering amplitudes can be given bounding them by exponential suppression, thus essentially confining them to Planck scale effects.

Leonardo Modesto (SUSTech)

Title: Nonlocal Quantum Gravity

Abstract: In the quantum field theory framework the only theory compatible with classical stability, perturbative unitarity, causality, and finiteness at quantum level is: ``Nonlocal Quantum gravity''. 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. After a review of the main properties of the theory, we present new results about the coupling to matter. In particular we propose a finite theory of all fundamental interactions compatible with stability, causality, and unitarity. As an important implication of the theory, the anomaly-free Weyl conformal symmetry elegantly solves the problem of spacetime singularities, otherwise unavoidable in a generally covariant local or non-local gravitational theory. According to the last statement, we provide explicit examples of singularity-free black hole solutions, having finite curvature invariants and, most importantly, geodesically complete. Indeed, no massive or massless particle can reach the singularity in a finite amount of proper time or of affine parameter. Finally, we will propose a new scenario for the early universe in nonlocal finite quantum gravity based on conformal invariance as an alternative to inflation.

Thursday 11th

Session 1: Black Holes, spacetime singularities & higher derivatives

Anupam Mazumdar (VSI, Groningen)

Title: Nonlocality in Quantum Gravity

Abstract: I will discuss the role of classical and quantum nonlocality in gravity and how such non-local interactions help us resolving some of the problems in ultraviolet. I will shift my focus on how to test such a hypothesis in cosmological observations and in particular in a laboratory.

Breno Giacchini (SUSTech)

Title: Regularization of Newtonian-limit singularities in higher-derivative gravity models

Abstract: In this talk we review some recent results concerning the occurrence of regular solutions in local and nonlocal higher-derivative gravity models. We show that, even though fourth-order gravity still has curvature singularities, any local model with at least six derivatives in the spin-2 and spin-0 sectors has a regular Newtonian limit, without curvature singularities, when coupled to a pointlike source. Also, we discuss the general conditions for the regularity of the higher-order curvature invariants, in both local and nonlocal models, in the linearized limit.

Jens Boos (William & Mary)

Title: Regular solutions in weak-field infinite-derivative theories: Green function approach

Abstract: In the weak-field regime it is sometimes possible to introduce notions of retarded non-local Green functions. A particular class of theories where this is possible has recently been dubbed "infinite-derivative theories." They typically feature non-local operators containing formal power series of Lorentz invariant differential operators. In this talk I will (i) introduce the notion of non-local causal Green functions and demonstrate that they satisfy DeWitt's "asymptotic causality" criterion, (ii) give an overview over regular weak-field solutions in infinite-derivative gravity, and (iii) comment on spacetime aspects involving the regularity of a uniformly accelerated source in a non-local theory. If time permits, I will highlight the problematic role of contour integration and Wick rotation in such non-local theories and comment on possible workarounds.

Xavier Calmet (Sussex)

Title: Quantum Gravitational Corrections to the Entropy of a Schwarzschild Black Hole

Abstract: We calculate quantum gravitational corrections to the entropy of black holes using the Wald entropy formula within an effective field theory approach to quantum gravity. The corrections to the entropy are calculated to third order in curvature. We show that, at this order in curvature, interesting issues appear that had not been considered previously in the literature. The fact that the Schwarzschild metric receives corrections at this order in the curvature expansion has important implications for the entropy calculation. Indeed, the horizon radius and the temperature receive corrections. These corrections need to be carefully considered when calculating the Wald entropy. The non-local terms in the effective action lead to a pressure for the Schwarzschild Black Hole.

Session 2: Black Holes, spacetime singularities & higher derivatives

Roger Penrose (Oxford)

Title: Why Quantizing Gravity Cannot, on its Own, Solve the Gravitational Singularity Problem

Abstract: Ever since the inevitability of space-time singularities in gravitational collapse—and in a cosmological big bang—was established in the mid to late 1960s as being a generic feature of classical general relativity, the viewpoint has been common that, with an appropriate quantization of the theory, actual physical singularities would be avoided. However, it has long been evident to me that standard quantization procedures cannot by themselves provide a full answer, since in our actual universe these two phenomena are enormously far from being time-reverses of one another.

In this talk, I argue how the big bang singularity can be essentially resolved in terms of conformal physics and geometry, a picture that now gains much physical support from observations, whereas the treatment of future-type singularities must await a better understanding of quantum mechanics itself, the resolution of whose measurement problem is argued to be a result of the interplay between general relativity's equivalence principle and the superposition principle of quantum mechanics.

Kellog Stelle (Imperial College London)

Title: Black Holes in Higher Derivative Gravity

Abstract: Spherically symmetric solutions in curvature-squared gravity display a wide variety of new possibilities above those of Einstein's theory. Indicial analysis reveals different classes of structure at the center. The Schwarzschild solution is still there, but its mass-parametric family reaches a bifurcation point where a non-Schwarzschild branch forks off, with a trade-off of stability favoring the new branch at low masses. Other solutions have no horizons, and a vanishing metric at the center, but asymptote to Schwarzschild-like behavior at large distances. Insight into the overall solution phase picture of such solutions has begun to be obtained from numerical studies.

Valeri Frolov (Alberta)

Title: Remarks on Nonsingular black holes

Abstract: Classical solutions describing black holes in the General Relativity possess curvature singularity in their interior. It is believed that this theory should be modified in the domain where the spacetime curvature becomes very high. We discuss models in which the curvature invariants are restricted by some fundamental scale. We demonstrate that in such models instead of the singularity inside a black hole there exists a deSitter-like regular core. We also briefly discuss quantum radiation from evaporating non-singular black holes and the existence of the mass gap for nonsingular mini-black hole production in the collision of two ultrarelativistic particles.

Bob Holdom (Toronto)

Title: Ultraviolet completion and not quite black holes

Abstract: When it comes to black holes, the Einstein action gives us little choice. But the Einstein action should eventually be subsumed into a UV complete theory of gravity, and such a theory may provide an alternative description for what we know as black holes. We consider the horizonless solutions called 2-2-holes that emerge from quadratic gravity. Within a Planck length of the would-be horizon, strong gravity and high curvatures quickly turn on. These solutions are analogous to the hadrons and/or the quark matter states of QCD. They are very close to being completely black, but not quite. An ideal probe to test for not quite black holes are the low frequency gravitational waves that are excited in and around them when they are newly formed, as in the merger events observed by LIGO. The resulting gravitational wave echoes have some striking features, and this has led us to conduct our own search of LIGO data. On the more theoretical side I hope to comment on quadratic gravity as a local quantum field theory for gravity.

Andrei Zelnikov (Alberta)

Title: Ghost-free modification of the Polyakov action and 2D black holes

Abstract: In this paper we discuss possible effects of nonlocality in black hole spacetimes. We consider a two-dimensional theory in which the action describing matter is a ghost-free modification of the Polyakov action. For this purpose, we write the Polyakov action in a local form by using an auxiliary scalar field and modify its kinetic term by including into it a nonlocal ghost-free form factor. We demonstrate that the effective stress-energy tensor is modified, and we study its properties in a background of a two-dimensional black hole. We obtain the expression for the contribution of the ghost-free auxiliary field to the entropy of the black hole. We also demonstrate that if the back-reaction effects are not taken into account, such a ghost-free modification of the theory does not change the energy flux of the Hawking radiation measured at infinity. We illustrate the discussed properties for black hole solution of a 2D dilaton gravity model which admits a rather complete analytical study.

Friday 12th

Session 1: Cosmology, higher derivatives & nonlocality

Alexei Starobinsky (Landau Inst.)

Title: Geometric inflationary models based on higher-derivative gravity

Abstract: Contrary to widespread opinion, local higher-derivative gravity models need not always have difficulties due to the presence of ghosts. I consider f(R) higher-derivative and purely geometric gravity in which ghosts are absent at the classical level and which is renormalizable in the scalar sector. At the quantum level, when the squared Weyl tensor have to added to it for renormalizability in the tensor sector, the tensor ghost appears, as is well known. However, if there exists a hierarchy in this theory due to the dimensionless coefficient in front of the R^2 term being much more than both unity and the similar coefficient in front of the C^2 term, then such theory can be used at high curvatures when the R^2 term in the action density exceeds the Einstein one (though not up to arbitrarily large curvatures, of course). Indeed, the most remarkable application of this gravity theory to actual cosmology - the R+R^2 inflationary model (1980) – leads to the result that the coefficient of the R^2 term should be about 5\times 10^8. Moreover, it can be shown that another inflationary model having formally the same observational predictions for the primordial scalar and tensor perturbation spectra - the Higgs one - can be approximately described by the R+R^2 model during inflation in the same Jordan frame, i.e., without a conformal transformation. Due to renormalizabity of this model in the scalar sector, one-loop quantum gravitational corrections to this model can (and should) be taken into account. It follows from observational data on the primordial scalar (matter density) perturbation spectrum that running of the coefficient in front of the R^2 term with curvature due to one-loop quantum-gravitational corrections is small and does not exceed a few percent. The same refers to the R\Box R correction considered perturbatively, without increasing the number of degrees of freedom, and to the correction from the Gauss-Bonnet-like non-local term in the conformal anomaly which becomes local in a conformally flat space-time. On the other hand, one-loop quantum-gravitational corrections become crucial after the end of inflation when they provide the decay of scalarons (quanta of the scalar degree of freedom in f(R) gravity) into particle-antiparticle pairs of all quantum fields of matter, but not to gravitons.

Masahide Yamaguchi (Tokyo Inst. Tech.)

Title: Cosmological perturbations in Palatini formalism

Abstract: We investigate cosmological perturbations of scalar-tensor theories in Palatini formalism. First, we introduce an action where the Ricci scalar is conformally coupled to a function of a scalar field and its kinetic term and there is also a k-essence term consisting of the scalar and its kinetic term. This action has three frames that are equivalent to one another: the original Jordan frame, the Einstein frame where the metric is redefined, and the Riemann frame where the connection is redefined. For the first time in the literature, we calculate the quadratic action and the sound speed of scalar and tensor perturbations in three different frames and show explicitly that they coincide. Furthermore, we show that for such action the sound speed of gravitational waves is unity. Thus, this model serves as dark energy as well as an inflaton even though the presence of the dependence of the kinetic term of a scalar field in the non-minimal coupling, different from the case in metric formalism. We then proceed to construct the L3 action called Galileon terms in Palatini formalism and compute its perturbations. We found that there are essentially 10 different (inequivalent) definitions in Palatini formalism for a given Galileon term in metric formalism. We also see that, in general, the L3 terms have a ghost due to Ostrogradsky instability and the sound speed of gravitational waves could potentially deviate from unity, in sharp contrast with the case of metric formalism. Interestingly, once we eliminate such a ghost, the sound speed of gravitational waves

also becomes unity. Thus, the ghost-free L3 terms in Palatini formalism can still serve as dark energy as well as an inflaton, like the case in metric formalism.

Robert Brandenberger (McGill)

Title: String Cosmology and the Breakdown of Local Effective Field Theory

Abstract: I will argue that if string theory provides the correct quantum theory of gravity, then local effective field theory will inevitably break down in the early universe. I will discuss approaches to string cosmology which go beyond a local effective field theory description.

Session 2: Cosmology, higher derivatives & nonlocality

Thomas Hertog (KU Leuven)

Title: Observational Signatures of novel variations on Starobinsky inflation

Abstract: I discuss novel extensions of Starobinsky inflation that involve a particular class of higher-curvature corrections that cannot be reduced to a scalar. The embedding of these theories in anti-de Sitter space yields holographic 'unitarity' bounds on the dominant corrections. I discuss the leading corrections to the spectral properties of scalar and tensor perturbations and show that, remarkably, these are within reach of the next generation CMB experiments. I conclude with a discussion of the status of these models and their embedding in a proper quantum cosmology framework.

Gianluca Calcagni (CSIC, Madrid)

Title: Stochastic gravitational-wave background in quantum gravity

Abstract: Among all cosmological quantum-gravity or quantum-gravity-inspired scenarios, only very few predict a blue-tilted primordial tensor spectrum. We explore five of them and check whether they can generate a stochastic gravitational-wave background detectable by present and future interferometers: non-local quantum gravity, string-gas cosmology, new ekpyrotic scenario, Brandenberger-Ho non-commutative inflation and multi-fractional spacetimes. We show that non-local quantum gravity is unobservable, while all the other models can reach the strain sensitivity of DECIGO but not that of LIGO-Virgo-KAGRA, LISA or Einstein Telescope. Other quantum-gravity models are found to be non-detectable.

Based on arXiv:2012.00170 (JCAP 2021).

Anna Tokareva (Jyvaskyla)

Title: UV properties of non-local scalar theories

Abstract: We perform the one-loop computations of Feynman diagrams in UV-finite non-local scalar theories. We discuss issues connected with the transition from Euclidian amplitudes to the physical ones in Minkowski space and using an explicit example of fish diagram show that the unitarity is maintained. In the simplest case of exponential form-factor in the propagator, we obtain an analytical result for one-loop diagram and study its UV properties. We discuss the generic behaviour of the high energy loop amplitudes and possible applications of the results for non-local theories playing the role of UV completion for the non-renormalizable scalar field models, such as Higgs inflation model.

Anish Ghoshal (INFN, Tor Vergata)

Title: UV-completion in Particle Theory with Infinite Derivatives: Conformal Invariance, Laboratory and Cosmological Implications

Abstract: We will discuss the constructions of string-inspired higher-derivative non-local extension of particle theory which is explicitly ghost-free. Showing quantum loop calculations in the weak perturbation limit we explore the implications on the hierarchy problem and vacuum instability problem in Higgs theory. Then we will discuss the abelian and non-abelian model-building in infinite derivative 4-D QFT which naturally leads to the predictions of dynamical conformal invariance in the UV at the quantum level due to the vanishing of the beta-functions above the energy scale of non-locality M. The theory remains finite and perturbative up to infinite energy scales resolving the issue of Landau poles and in the limit, M going to infinity we can recover the local theory. We move on to the implications of infinite-derivatives in LHC, dark matter, astrophysical and inflationary observables, and comment on constraints on the scale M and dimensional transmutation of the scale M. Next, we will discuss the strong perturbation limit and show that mass gap that arises due to the interactions in the theory gets diluted in the UV due to the higher-derivatives again reaching a conformal limit in the asymptotic regions both for the scalar field case and Yang-Mills case. For the Yang-Mills, the gauge theory is confining without fermions and we explore the exact beta-function of the theory. We conclude by summarising non-locality as a framework for UV-completion in particle theory and gravity and the road ahead for its fate in model-building with respect to BSM physics, particularly, neutrinos, dark matter and axions.