Geometric Foundations of Gravity 2025

Monday 30 June 2025 - Friday 4 July 2025

University of Tartu

Book of Abstracts

Contents

2

Weak equivalence principle and nonrelativistic limit of general dispersion relations

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We study the weak equivalence principle in the context of modified dispersion relations, a prevalent approach to quantum gravity phenomenology. We find that generic modified dispersion relations violate the weak equivalence principle. The acceleration in general depends on the mass of the test body, unless the Hamiltonian is either 2-homogeneous in the test particles'4-momenta or the corresponding Lagrangian differs from the homogeneous case by a total derivative only. The key ingredient of this calculation is a 3 þ 1 decomposition of the parametrization-invariant relativistic test particle action derived from the dispersion relation. Additionally, we apply a perturbative expansion in the test particle's spatial velocity and the inverse speed of light. To quantify our result, we provide a general formula for the Eötvós factor of modified dispersion relations.

3

Ghosts and strong coupling in Bimetric MOND

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Modified Newtonian dynamics (MOND) is a phenomenological theory which aims to explain dark matter. However, the theory is criticized for not being a good fit to observations at multiple scales and with lack of fundamental motivations. Bimetric MOND (BIMOND) is a theory with a fundamental relativistic action including two copies of Eintein-Hilbert terms (each equiped with a separate dynamical metric) and a function of a scalar constructed through contorsion (the difference of the two Levi-Civita connections). In this talk I will show that this theory is in fact not viable as a fundamental theory. This is shown through perturbation theory around Minkowski and Hamiltonian analysis around a very simple background.

5

Well-posed evolution and gravitational collapse of self-interacting vector fields

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Dynamical evolution of self-interacting vector fields often faces instabilities and apparent pathologies when performing numerical simulations. By displaying a detailed analysis of the initial-value problem of the theory in the language of scalar-tensor theories, I will show that the former are actually due to the breakdown of the hyperbolicity of the theory (Tricomi-type or Keldysh-type). I will also give numerical evidences that these issues can be avoided by means of the "fixing-the-equations" approach, enabling stable numerical evolutions in spherical symmetry. Finally, I will report on initial configurations for the massive vector field leading to gravitational collapse and the formation of black holes, for a particular class of self-interactions in which no "pathologies" take place.

6

Interacting Models of Dark Energy and Dark Matter in Einstein scalar Gauss Bonnet Gravity

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We study the dynamics of the interacting models between the Gauss-Bonnet (GB) coupled scalar field and the dark matter fluid in a homogeneous and isotropic background. A key feature of GB coupling models is the varying speed of gravitational waves (GWs). We utilize recent constraints on the GW speed and conduct our analysis in two primary scenarios: model-dependent and model-independent. In the model-dependent scenario, where determining the GW speed requires a specific GB coupling functional form, we choose an exponential GB coupling. We adopt a dynamical system analysis to obtain the necessary constraints on the model parameters that describe different phases of the universe and produce a stable late-time accelerating solution following the GW constraint, and find that to satisfy all these constraints, fine-tuning of the free parameters involved in the models is often needed. In the model-independent scenario, the GW speed is fixed to one, and we construct the autonomous system to identify the late-time stable accelerating critical points. Furthermore, we adopt a Bayesian inference method using late-time observational data sets, including 31 data points from cosmic chronometer data (Hubble data) and 1701 data points from Pantheon+ and find that all the observational constraints can be satisfied without finetuning. In addition, we also utilize simulated binned Roman and LSST data to study the evolution of the universe in the model-independent scenario. We find that the model shows significant deviation at higher redshifts from ΛCDM and fits the current data much better than ΛCDM within the error bars.

9

Gravitational wave propagation in hybrid metric-Palatini gravity

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In this work we analyze the propagation properties of gravitational waves in the hybrid metric-Palatini gravity theory. We introduce the scalar-tensor representation of the theory to make explicit the scalar degrees of freedom of the theory and obtain their equations of motion in a form decoupled from the metric tensor. Then, we introduce linear perturbations for the metric tensor and for the two scalar fields and obtain the propagation equations for these three quantities. We analyzed the theory both at non-linear and at linear level through the Newman-Penrose formalism so to find the polarization states. We show that the tensor modes propagate at the speed of light and feature the usual $+-$ and $\times-$polarization modes also present in General Relativity (GR), plus two additional polarization modes: a longitudinal mode and a breathing mode, described by the same additional degree of freedom. On the other hand, the theory features two additional scalar modes not present in GR. These modes are massive and, thus, propagate with a speed smaller than the speed of light. The masses of the scalar modes depend solely on the interaction potential between the two scalar fields in the theory, which suggests that one can always fine-tune the potential to make the scalar modes massless and reduce their propagation speed to the speed of light. This feature potentially renders the theory unfalsifiable in the context of gravitational wave propagation.

10

A Directive for deriving (Algebraically) General Solutions of Einstein's Equations based on the Canonical Killing Tensor Forms

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This work serves as a sequel to our previous study, where, by assuming the existence of the canonical Killing tensor forms and applying a general null tetrad transformation, we obtained a variety of solutions (Petrov types D, III, N) in vacuum with cosmological constant Λ. Among those, there is a unique Petrov type D solution with a shear-free, diverging and non-geodesic null congruence which will be presented in full detail in the following sections. Additionally, in this work we will introduce a Petrov type I solution with a shear-free, diverging and non-geodesic null congruence, obtained by employing Lorentz transformations, within the concept of symmetric null tetrads, instead of the general null tetrad transformation. Building upon this and in line with the concept of symmetric null tetrads, which played a crucial role in deriving the most general Petrov type D solution (Debever-Plebanski-Demianski solution), we propose a new directive. This directive suggests that, by assuming the canonical forms of Killing tensor and implying Lorentz transformations correlating the spin coefficients between themselves ($\pi = -\bar{\tau}, \kappa = -\bar{\nu}$, etc.) can yield a broader class of (algebraically) general solutions to Einstein's equations, rather than relying on boosts and spatial rotations.

11

Finsler geometry as a window to Planck scale physics

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We discuss the problem of describing the effective quantum spacetime probed by a high energetic particle by Finsler Geometry. We highlight the main theoretical gains and challenges of this approach in quantum gravity.
We also discuss the use of present and future experiments and observations to constrain Finslerian departures of Riemannian Geomety at the Planck scale and the prospects for future tests.

12

No vacuum? No problem!

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In spite of their unequivocal potential and the increasing number of counterexamples, ghost-ridden theories remain eminently disregarded as necessarily unphysical. In this talk, we will being by providing a lightning review of the problematic, and troubleshooting proposals in the literature.

Then, we will present our own recent constructive method to avoid catastrophe in the face of a ghost*. This not only encompasses all prior results, but also extends them in a consequential and counter-intuitive manner.

*Terms and conditions apply.

14

Quadratic gravity with propagating torsion and asymptotic freedom

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Perturbative nonrenormalizability of gravity based on Hilbert-Einstein or Palatini actions prompted vast research in higher-derivative theories. The actions that are at least quadratic in curvature lead to a renormalizable theory, but they bring along the issue of possible unitarity violation from ghost and tachyonic degrees of freedom. Whether ghosts can or cannot be quantized consistently, is still a matter of debate. Tachyons, on the other hand, are generally considered unhealthy, and they can be avoided by an appropriate choice of couplings. Within the Wilsonian definition of the renormalization group flow, such choice leads to uncontrolled growth of the couplings in the UV.

I will consider a class of actions quadratic in curvature and torsion, which is a natural generalization of metric quadratic gravity. Using the heat kernel technique, I compute the torsion contributions to the one-loop counterterms. Vectorial and axial components of torsion preserve the qualitative picture of the renormalization group flow of the metric sector. However, there exists a specific nonminimal kinetic term for the pure tensorial (hook-antisymmetric traceless) component of torsion that switches the sign of the beta function of the R^2 term while preserving the negative sign in front of the Weyl^2 term. This behavior renders the gravitational couplings asymptotically free in the absence of tachyons.

16

Removing spurious degrees of freedom from EFT of gravity

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Effects of ultraviolet completions of gravity can be captured in low-energy regimes by local higher curvature corrections. Such description, however, is limited to yield strictly perturbative corrections, due to unphysical Ostrogradsky instabilities induced by higher derivatives in the correction terms. I will present a procedure for expunging spurious degrees of freedom from effective theories of gravity, and casting them as lower-derivative theories that capture all the information about the corrections, but propagates only the massless spin-2 graviton degree of freedom. Resulting reduced theories fall under the category of Minimally modified gravity theories, that preserve spatial diffeomorphisms, but modify temporal diffeomorphisms in a way that preserves the constraint structure. Such theories are free from Ostrogradsky instabilities, and can be used to study the ultraviolet effects self-consistently.

17

$\tilde{\xi}$-attractors in metric-affine gravity

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We propose a new class of inflationary attractors in metric-affine gravity. Such class features a non-minimal coupling $\tilde{\xi}\,\Omega(\phi)$ with the Holst invariant $\tilde{calR}$ and an inflaton potential proportional to $\Omega(\phi)^2$. The attractor behaviour of the class takes place with two combined strong coupling limits. The first limit is realized at large $\tilde{\xi}$, which makes the theory equivalent to a $\tilde{calR}^2$ model. Then, the second limit considers a very small Barbero-Immirzi parameter which leads the inflationary predictions of the $\tilde{calR}^2$ model towards the ones of Starobinsky inflation. Because of the analogy with the renown ξ-attractors, we label this new class as $\tilde{\xi}$-attractors.

18

Quintessence models in the late Universe

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Scalar-tensor theories have shown great potential in inducing tailored modifications compared to cosmic evolution in the ΛCDM model. We reconsider quintessence models in this work in the context of three driving potentials. We center the action of these models in the late Universe which leaves early ΛCDM cosmology unchanged. The effects show the potential of producing a faster expanding cosmology with a high Hubble constant. The models are constrained using the cosmic chronometer data, Pantheon plus, and transversal baryonic acoustic oscillation data.

19

Quintessential inflation in Palatini F(R,X) gravity

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Palatini $F(R,X)$ gravity, with X the inflaton kinetic term, proved to be a powerful framework for generating asymptotically flat inflaton potentials. Here we show that a quadratic Palatini $F(R,X)$ restores compatibility with data of the Peebles-Vilenkin quintessential model. Moreover, the same can be achieved with an exponential version of the Peebles-Vilenkin potential if embedded in a Palatini $F(R,X)$ of order higher than two.

20

Geometry of Disformal Transformations

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Disformal transformations are specific deformations of the metric, involving other fields and their derivatives. They have been used to relate different modified gravity models. For instance, mimetic and teleparallel gravities.

We will put forward a geometric formulation of disformal transformations, thereby elucidating the role of the non-metric fields therein. We will also identify key properties for disformal transformations that guarantee physical equivalence between the connected theories.

21

Black Hole Solutions in Extended Metric-Palatini Gravity

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Extended metric-Palatini gravity, quadratic in the antisymmetric part of the affine curvature, is known to lead to the general relativity plus a geometric Proca field. The geometric Proca, equivalent of the non-metricity vector in the torsion-free affine connection, qualifies to be a distinctive signature of the affine curvature. In this talk, we explore how shadow and photon motion near black holes can be used to probe the geometric Proca field. To this end, we derive static spherically symmetric field equations of this Einstein-geometric Proca theory, and show that it admits black hole solutions in asymptotically AdS background. We perform a detailed study of the optical properties and shadow of this black hole and contrast them with the observational data by considering black hole environments with and without plasma. As a useful astrophysical application, we discuss constraints on the Proca field parameters using the observed angular size of the shadow of supermassive black holes M87* and Sgr A* in both vacuum and plasma cases. Overall, we find that the geometric Proca can be probed via the black hole observations.

22

Local Symmetries of Finsler Gravity and Its Dynamics

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Finsler spacetimes are constructed such that they deliver a causal structure on the set of events, give a definition of observers as well as their measurements and encode the gravitational dynamics. In my master thesis "Local Symmetries of Finsler Gravity and its Dynamics"I focus on the notion of observers with the overall goal of determining the possible observer transformations. In a short talk I would like to summarise first results of my research: At the beginning I define the notion of local symmetry transformations of Finsler spacetimes and introduce one possible generator for such symmetries. I then analyse the algebraic structure of this candidate and have a look at its specific form in the case of (α,β)-metrics. Furthermore, I examine the Lie derivatives of the fundamental building blocks of the geometry defined by the n-th partial derivatives of the Finsler-Lagrange function.

23

Propagation of gravitational waves in general quadratic teleparallel gravity theories

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General theory of relativity, which is currently the widely accepted theory of gravity, directly predicts the existence of gravitational waves. This phenomenon was directly measured only in 2015 and in 2017 observational data confirmed the prediction that gravitational waves propagate at the speed of light. However, there are phenomena that general relativity cannot satisfactorily explain without introducing problematic concepts such as dark matter and dark energy. This has led us towards the investigation of alternative theories of gravity. One such group of theories is the general quadratic teleparallel theories of gravity, where gravity results from the torsion and non-metricity of space. Studying the propagation of gravitational waves in such theories helps assess the viability of these theories. In this talk I will present my Master's thesis, where formulas describing the speed and polarisations of gravitational waves in general quadratic teleparallel theories of gravity were derived. Furthermore, different cases of this group of theories were separately examined and analysed to see what happens with different sets of constants.

26

Schwarzschild black holes embedded in a Dehnen-type dark matter halo with quintessence

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We consider a Schwarzschild-like BH immersed in both a Dehnen-type DM halo and a surrounding quintessence field. We derive the composite spacetime metric and analyze its geometric features, including horizon structure, curvature invariants, and the classical energy conditions. We then investigate geodesic dynamics, focusing on effective potentials, circular orbits, and ISCOs. Additionally, we examine the BH shadow. These analyses provide insight into the imprints of dark sector fields on BH observables and offer predictions that may be testable with current and upcoming astrophysical instruments

27

Black holes and naked singularities in four dimensional dS and AdS Chamseddine gravity

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We analyze solutions of Chamseddine's topological gravity in four space-time dimensions and discover various black hole solutions with(out) torsion as well as those that describe naked singularities. Because all of the solutions belong to the sector with vanishing scalar fields, they share peculiar trait that all conserved charges are vanishing.

28

The Maldacena-Shenker-Stanford Conjecture in General Relativity and beyond

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The Maldacena-Shenker-Stanford (MSS) conjecture establishes the existence of an upper bound to the Lyapunov exponent of a thermal quantum system with a large number of degrees of freedom. Holographic calculations of out-of-time order correlation functions (OTOCs), which are conveniently employed as indicators of the magnitude of quantum chaos, motivate such a statement, leading to the identification of black holes as the fastest scramblers in nature.
This talk aims to give an insight into the universality of the MSS conjecture. We claim that it can be violated in various metric $f(R)$ gravity models as a consequence of the propagation of metric instabilities in a degenerate Schwarzschild-de Sitter background. Then, following a detailed investigation of the Extended Geometric Trinity of Gravity, a set of three dynamically equivalent theories arising from an ad-hoc extension of the corresponding constituting theories of the Trinity of Gravity (namely General Relativity, the Teleparallel Equivalent to General Relativity, and the Symmetric Teleparallel Equivalent to General Relativity), we conclude that the violation occurs independently of the conferred representation of gravity in such a framework.

29

On the quantum equivalence between Teleparallel Gravity and GR

Author: Davide Zarrilli[None]

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In this talk I will show our recent work on the quantization of Teleparallel Gravity (or TEGR), which is classically equivalent to GR. I compute the quadratically divergent counterterms that arise in the action, showing that they break the equivalence with GR at the quantum level. I then compute the logarithmically divergent counterterms and discuss their implications.

30

Imaging black holes and horizonless compact objects

Author: Diego Rubiera-Garcia[1]

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We present the theoretical and phenomenological basis of the imaging of astrophysical objects compact enough to hold a photon sphere, namely, an unstable bound light orbit. We discuss the features of the two most salient features of such an imaging (the photon rings and the shadow) for black holes and horizonless compact objects alike and comment on the possibilities and difficulties within this field as supplied by very-long baseline interferometry technologies.

31

Generalized Hidden Conformal Symmetry in Quadratic f(T) Gravity

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We find the non-extremal charged rotating black holes in quadratic $f(T)$ gravity are holographically dual to two different hidden conformal field theories. The two conformal field theories can be merged to find a very general hidden conformal field theory, which is generated by the $SL(2, Z)$ modular group. We also carry out the the calculation to the extremal limit of the black holes, and find the corresponding dual quantities. Contrary to the existence of two different dual conformal field theories for the extremal charged rotating black holes in Einstein gravity, we find only one dual theory exists for the extremal charged rotating black holes in quadratic $f(T)$ gravity.

32

Cartan geometry and gravitation

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It was discovered by the French mathematician Elie Cartan that the geometry of a surface could be revealed by rolling a ball on it. Remarkably, the mathematical description of this rolling process involve ingredients familiar from modern gauge theories. Cartan-geometrical descriptions of General Relativity and teleparallel gravity are presented and it is argued that typically Cartan-geometric descriptions of gravity will introduce new - and potentially phenomenologically relevant - degrees of freedom in the gravitational sector.

33

Causality and Stability from the Acoustic Metric

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Scalar-tensor theories with derivative interactions form backgrounds which spontaneously break Lorentz invariance (cosmology during inflation or the dark energy era is the archetype). I will discuss how to think about the dynamics of free scalar perturbations, phonons, on general anisotropic backgrounds, showing that phonons move on null geodesics of an acoustic spacetime described by its own metric and own connection. This acoustic metric and its inverse give the dispersion relation, rays and phase velocities and construct two sound cones. The acoustic connection features non-metricity with respect to the usual spacetime.

I will discuss how to read off true instabilities, ghosts and gradient instabilities, from the invariant properties of the acoustic metric, but also discuss false instabilities that may appear for some observers, relating this to Cherenkov radiation and the ill-posedness of the Cauchy problem.

35

Algebraic classification of the gravitational field in general metric-affine geometries

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We present the full algebraic classification of the gravitational field in four-dimensional general metric-affine geometries. As an immediate application, we determine the algebraic types of the broadest family of static and spherically symmetric black hole solutions with spin, dilation and shear charges in Metric-Affine Gravity.

36

On the geometric origin of the energy-momentum improvement terms

Authors: Anastasios Petkou[1]; Damianos Iosifidis[2]; Konstantinos Siampos[3]; Manthos Karydas[4]

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I will show how the Belinfante-Rosenfeld improvement terms, that render the energy-momentum tensor symmetric, emerge by coupling the matter to the affine-connection. In this sense the improvement terms correspond to the hypermomentum of matter. I will show how this is realized in two standard examples, the Maxwell field and the Dirac field. I will also show how the connection-matter couplings can also result in a traceless energy tensor when the theory is invariant under frame rescalings, by revisiting the known example of a comformally invariant scalar field. Generalizations to higher derivative theories will also be discussed

37

Chiral gauge theory of gravity and dark matter

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Lorentz gauge theory of gravity with a symmetry breaking "Cartan khronon" field demonstrates its successful explanation for the ΛCDM model, with an emergent integration 3-form behaving as ideal dust. Within the chiral scheme of this theory, only the right-handed regime recovers the general relativity. A natural question that arises is what happens with the left-handed gravity? When both right- and left- handed gravity are included, we find the integration 3-form is essential to formulate non-trivial cosmology. This talk discusses cosmology based on both-handed gauge theory of gravity and why the integration 3-form is a compelling dark matter candidate.

38

Strong hyperbolicity in teleparallel gravity

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We review the current state of the numerical relativity formalism for teleparallel theories of gravity and assess the hyperbolicity of the 3+1 decomposition of the equations of motion in the Hamiltonian formulation. For this, we analyse a simplified version of the analog to the ADM equations in the teleparallel equivalent of general relativity. We consider linear perturbations around a flat spacetime and impose these conditions in the tetrad and its conjugate momenta. We present the form of the 3+1 equations of motion and outline the procedure in order to consistently study their hyperbolicity properties.

39

Global Portraits of Inflation in Nonsingular Variables

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

40

Chiral signatures from the Barbero–Immirzi parameter in inflationary tensor modes

Authors: João Luís Rosa[None]; Mehraveh Nikjoo[None]; Tom Zlosnik[None]

The Ashtekar connection-based approach of general relativity offers a compelling avenue for reexamining gravitational dynamics, particularly through its Hamiltonian formulation. This framework introduces the Barbero–Immirzi parameter, a factor whose role varies between classical and quantum treatments.

Classically, the Barbero–Immirzi parameter does not appear in the equations describing the propagation of gravitational waves. However, depending on the chosen quantization scheme, this parameter can crucially influence vacuum fluctuations of tensor modes during inflation, most notably by inducing chiral asymmetries.

In this talk, I will examine both classical and quantum scenarios within the context of non-minimal inflationary models, which are increasingly supported by observations. The focus will be on the behavior of propagating tensor modes and their potential imprints on the observational data.

41

Primordial Black Holes, Extremality, and Dark Matter: Rethinking Evaporation Limits

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Earlier studies investigating the allowed fraction of dark matter as primordial black holes (PBHs) tend to completely rule out PBHs with masses smaller than ˜10^{-15} solar masses. This is due to the lack of evidence for Hawking radiation coming from the final evaporation stages of such small PBHs. These limits, however, make the key assumption that these PBHs can be modelled as uncharged, non-rotating Schwarzschild black holes. Extending either the modell of particle physics or of gravity can easily allow for a range of extremal black holes, that behave fundamentally differently in this regard. In this talk, we will present changes to these lower mass bounds when charge is included, i.e., by going to Reissner–Nordström black holes as models for PBHs. Concretely, we will add a "dark" U(1) charge, present in the early universe when the PBHs was formed; while not present in today's universe, it might still appear as a black hole charge. We use the Hiscock and Weems model of charged black hole evaporation, to correctly include the Schwinger effect. We then investigate and present the updated mass bounds for PBHs as dark matter candidates and their dependence on mass and charge of the corresponding "dark" electrons.

42

Gauge theory, gravity, and nontrivial constitutive laws

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In BF-theory terms, apart from the structure group itself, gravity and Yang-Mills theory or electromagnetism are distinguished in the constitutive law, or the simplicity constraints. This is suggestive of a unified topological phase, which is broken into separate internal and external gauge theory, with clear, almost canonical preferences for the excitation B-field for either part. But what if one component has a modified constitutive law? As the interactions are independent, there should be no effect. We will consider how to formalize this in terms of a constitutive diagram, alongside a discussion of spontaneous simplicity constraints, a heuristic description of internal and external gauge theory, and a geometric issue for the unified phase of spacetime.

43

Internal gauge structure and ghost instabilities in general torsion theories

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We analyze which internal affine gauge transformations can be attributed to the torsion, focussing on those that tensor give rise to Lie algebras. We find two such non-trivial structures, in which the gauge parameters are a two form and a scalar. In the first case gauge invariant variables are singled out, and a higher derivative power-counting renormalizable invariant action is derived. The Lagrangian depends on four free parameters, and a stability analysis shows that it is free from ghost instabilities in Euclidean signature, though we find a tachyonic scalar mode.

44

Regularisation of the action and its non-uniqueness in the Euclidean teleparallel gravity

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We investigate the regularization of the Euclidean gravitational action in the teleparallel equivalent of general relativity (TEGR), where the action is dynamically equivalent to that of GR but depends on both the tetrad and an undetermined spin connection. We evaluate the action using both bulk and quasi-local surface integrals across three frames: proper, canonical, and a newly introduced Euclidean free-falling frame. While all yield finite action, the results differ, revealing a fundamental non-uniqueness. In particular, the Euclidean free-falling frame admits an infinite family of inequivalent finite action solutions, raising important questions about the interpretation and regularization of gravitational actions in teleparallel geometry.

45

Self-excited instantons and the non-trivial structure of the teleparallel vacuum

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In this talk, I will review our new approach to constructing gravitational instantons in teleparallel gravity, based on the observation that the teleparallel action can be written as a product of torsion and excitation forms. This naturally leads to the idea of considering solutions in which these two forms are equal—solutions we call self-excited, in analogy with self-dual solutions in Yang-Mills theory. These self-excited solutions turn out to be instantons, with their action fully determined by the topological Nieh–Yan term, which leads to some insights about the topological aspects of teleparallel theories. We will present some of these results and provide possible evidence for the existence of a non-trivial vacuum structure, and discuss implications for our understanding of teleparallel gravity.

46

New quantum foundations for metric-affine gravity

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Like general relativity, we would expect metric-affine gravity to be a non-renormalisable and perturbative quantum theory. In such cases, effective field theories are crucial for deriving universal low-energy predictions, and have enjoyed huge success. They must, however, must be constructed according to certain rules, and in particular they demand symmetry. We perform an exhaustive and systematic search for the possible tree-level symmetries of the distortion field, which carries most of the unwanted particles in metric-affine gravity. We include also un-free symmetries with scalar, vector and tensor generators, going beyond the previous search which led to the discovery of extended projective symmetry (see GeomGrav2024). We identify multiple new ghost-tachyon-free models that serve as attractive quantum foundations for metric-affine gravity. We also uncover a new approach for the non-linear completion of the Fronsdal theory from within metric-affine gravity.

47

Friedmann cosmology with hyperfluids

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In metric-affine gravity, both the gravitational and matter actions depend not just on the metric, but also on the independent affine connection. Thus, matter can be modeled as a hyperfluid, characterized by both the energy-momentum and hypermomentum tensors. The latter is defined as the variation of the matter action with respect to the connection, and it encodes extra (micro)properties of particles. For a homogeneous and isotropic universe, it was recently shown that the generic cosmological hypermomentum possesses five degrees of freedom: one in dilation, two in shear, and two in spin part. In this presentation, we discuss the implications of this perfect hyperfluid on the universe with the Friedmann-Lemaître-Robertson-Walker metric. We adopt a simple model with non-Riemannian Einstein-Hilbert gravitational action plus arbitrary hyperfluid matter, and solve analytically the cosmological equations for single and multiple component hypermomentum contributions using different assumptions about the equation of state. It is remarkable, that in a number of cases the forms of the time evolution of the Hubble function and energy density still coincide with their general relativity counterparts, only the respective indexes $w_{\rm eff}$ and w_ρ start to differ due to the hypermomentum corrections. The results and insights we obtained are very general and can assist in constructing interesting models to resolve the issues in standard cosmology.

48

Teleparallel gravity from the principal bundle viewpoint

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Since General Relativity is a classical gauge gravitational theory of diffeomorphisms, a natural question arises: does the same hold for TEGR?
In this talk, we explore the gauge structure of TEGR from the perspective of principal bundles. We also focus on the popular claim that TEGR can be viewed as a gauge theory of translations. It is explained that the standard way of approaching this claim, using the principal T(4)-bundle endowed with a translational connection, leads to inconsistencies. We suggest an alternative approach based on the affine group and affine bundles with affine connections, resulting in a consistent formulation of TEGR.

51

Avoiding singularities in Lorentzian-Euclidean black holes: the role of atemporality

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We investigate a Schwarzschild metric exhibiting a signature change across the event horizon, which gives rise to what we term a Lorentzian-Euclidean black hole. The resulting geometry is regularized by employing the Hadamard partie finie technique, which allows us to prove that the metric represents a solution of vacuum Einstein equations. In this framework, we introduce the concept of atemporality as the dynamical mechanism responsible for the transition from a regime with a real-valued time variable to a new one featuring an imaginary time. We show that this mechanism prevents the occurrence of the singularity and, by means of the regularized Kretschmann invariant, we discuss in which terms atemporality can be considered as the characteristic feature of this black hole. The physical foundation of the approach can be related to the conservation laws. In fact, the black hole is singularity free if Noether symmetries, related to the size and the mass of the gravitational system, are not violated. In other words, the emergence of imaginary time is the signature of a symmetry breaking. In this perspective, it is not possible to enter the black hole, and the event horizon becomes the limit of our knowledge according to the standard laws of physics. Future challenges are related to the observational signatures of atemporality which actually means that the information comes only from the external black hole solution, and, in addition, it is conserved. Other open issues are related to the quantum counterpart of the model. In fact, we could conceive the event horizon as a sort of potential barrier and the investigation of quantum particles impacting against it could open an interesting phenomenology to be explored.