4th International FLAG Workshop : The Quantum and Gravity

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Book of Abstracts

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”Phase Space Diagram for the Cauchy Horizon (In)Stability of Regular Black Holes”

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Regular black hole solutions typically come with an outer event horizon and an inner Cauchy horizon. In the case of the Reissner-Nordstrom geometry, the analysis based on the Ori model shows that the Cauchy horizon in unstable against perturbations, because of the mass-inflation effect. However, when such analysis is applied to regular black hole solutions, a richer picture emerges. We present the first global study on the fate of the perturbed spacetime at the Cauchy horizon, depicting the phase space related to the dynamical system which describes the perturbation itself. In particular, we analyze the stability of a new regular black hole solution obtained from a model of asymptotically safe gravitational collapse [Phys.Rev.Lett. 132 (2024) 3, 031401], which has the peculiarity of having a logarithmic mass function.

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1- and 2-loop diagrams in de Sitter and anti de Sitter

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I present a general approach to de Sitter and anti de Sitter Quantum Field Theory based on the analyticity properties of the correlation functions which are closely similar to the ones which are equivalent to the positivity of the spectrum of the hamiltonian in every Lorentz frame Minkowski QFT (that is, the spectral condition). In this context I present an important family of plane waves well adapted to the de Sitter geometry and discuss the harmonic analysis of propagators in terms of them. Applications include the Kallen-Lehmann representations and 1-loop and two-loop calculations in the dimensional regularization in both the de Sitter and the anti de Sitter cases.

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An overview of cosmological tensions - Addressing systematics and fundamental physics solutions

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The standard concordance model has successfully explained all cosmological survey data for over two decades with unprecedented precision. However, our understanding of cosmology appears to be at a turning point in that predictions from the standard cosmological model from different surveys seem to give best-fit cosmological parameters that are in tension with each other. This may be due to systematics in our understanding of the underlying astrophysics for particular sectors. However, it may also be an indication of new physics in one or more cosmological sectors. In this talk, the

specific areas where cosmic tensions have featured will be reviewed together with possible future areas of interest where new cosmic tensions may arise. The talk will also discuss some of the most promising areas of new physics that may address some of the cosmic tensions problem. There will also be a brief review of the CosmoVerse consortium and its upcoming activities and plans.

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Aspects of Spherically Symmetric Geometrodynamic in the Jordan and Einstein Frames

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In this talk we will introduce and perform ADM analysis for spherically symmetric solution of General Relativity. We will discuss with particular care the problem of the boundary terms to be introduced in the general case of spherical symmetry. We will derive the Hamiltonian equations of motion for Brans-Dicke theory, with spherical symmetry, stressing the importance of the boundary terms. We will pass from the Jordan to the Einstein frames, and we will show that the BMBM Black Hole is solution of the Hamiltonian equations of motion in the Jordan frame. This solution maps into naked-singularity Janis's solution in the Einstein frame. We will discuss this result.

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Birefringence from cosmological pseudoscalar fields

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Cosmic birefringence is a rotation of the polarization plane of photons coming from sources of astrophysical and cosmological origin. We discuss the imprints of a cosmological pseudoscalar field on Cosmic Microwave Background (CMB) propagation. Phenomenological or theoretically motivated redshift dependence of the pseudoscalar fields - such as axionlike dark matter, quintessence, or early dark energy - lead to CMB polarization power spectra which exhibit different multipole dependencies.

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Conceptual Insights into Black Hole Paradoxes

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This talk provides a conceptual analysis of the AMPS (firewall) and AMPSS paradoxes in black hole physics. We begin by cataloguing the various possible resolutions of the AMPS paradox through "causal structures", explaining that solutions like ER=EPR introduce non-local connections in semi-classical physics. Next, we address the AMPSS paradox, showing how resolutions tied to the program of holographic interior reconstruction offer insights into the status of the perturbative series in Quantum Gravity. Additionally, we demonstrate that the implicit assumptions behind the holographic interior reconstruction resolution of the AMPSS paradox are the same as those underpinning an unrelated ER=EPR resolution of the AMPS paradox.

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Cosmological constant and Dark Dimension scenario

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When the Higgs potential or the vacuum energy are derived in the framework of higher dimensional effective field theories on a multiply connected spacetime with compact dimensions and non-trivial boundary conditions (as in the case of the Scherk-Schwarz SUSY breaking), the usual calculations lead to the conclusion that these quantities are naturally UV-insensitive. By means of a thorough analysis of the assumptions on which these calculations are based, I will show that this paradigm actually misses a crucial source of UV-sensitivity, ultimately connected to the non-trivial topology of the spacetime in these theories. As a consequence, the conclusions on the UV-insensitivity of the Higgs mass, of the Higgs potential, and on the existence of a Dark Dimension, that requires a specific relation between the physical vacuum energy and a Kaluza-Klein scale of order meV, need to be carefully reconsidered.

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Effective Quantum Spacetimes From Functionl Renormalization Group

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We construct effective spacetime geometries by self consistently deforming the classical Schwarzschild-de Sitter solution. This has been done in the context of the Functional Renormalization Group Asymptotic Safe program by exploring how quantum modifications induced by the running of the Newton and Cosmological constants impact the infrared and ultraviolet regimes of the modified solution.
The quantum corrections, stemming from the flow of the coupling constants, give rise to two new regimes. Firstly, a phase transition AdS/dS occurs in the UV regime, when the mass of the object exceeds a critical threshold. Secondly, we predict the formation of horizons whenever the mass of the object is of the order of the Planck mass.

1

Emergence of inflaton potential from asymptotically safe gravity

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Asymptotic safety is a powerful mechanism for obtaining a consistent and predictive quantum field theory beyond the realm of perturbation theory. It hinges on an interacting fixed point of the Wilsonian renormalization group flow, which controls the microscopic dynamics. Connecting the fixed point to observations requires constructing the set of effective actions compatible with this microscopic dynamics. In this talk, I will describe how to make this connection at the level of a four-dimensional scalar-tensor theory. As a result, I will show how single-field inflationary models, compatible with observations, naturally emerge from a gravitational UV fixed point. The talk is based on arXiv:2403.08541.

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Euler-Mellin-Feynman Integrals and Intersection Theory

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I elaborate on the vector space structures of Euler-Mellin-Feynman Integrals,
emerging from the application of Intersection Theory of (twisted) De Rahm Co-homology,
and discuss the crucial role of the intersection numbers as fundamental mathematical quantities,
ruling linear relations (integration-by-parts identities or contiguity relations, differential and difference equations),
as well as quadratic relations (Riemann bilinear relations), and higher order relations obeyed by those integrals.
I comment on the correspondence between the vector space of integrals and the D-module structure of the differential operators acting on them.
I report on the methods we introduced for evaluating intersection numbers of differential n-forms, and their application to the
direct decomposition of integrals in terms of master integrals, to be considered as the generators of the vector space.
I conclude on the applicability of these novel techniques and ideas in various areas of modern Physics and Mathematics.

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Functional renormalisation of UV-safe gauge theories coupled to matter

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Certain types of large-N gauge theories coupled to matter offer interacting UV fixed points that are under strict perturbative control, beyond the paradigm of asymptotic freedom. In this work, we derive and investigate functional RG equations for the quantum effective potential of the theory to leading order in a derivative expansion. We thereby find the RG flows, fixed points, and scaling dimensions of infinitely many canonically irrelevant interaction monomials to leading order in the small Veneziano parameter. We also find that results can be resummed into closed expressions. Implications for vacuum stability and the size of the conformal window, links with RG studies in the MS bar scheme, and extensions towards larger Veneziano parameters are indicated.

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Gauge invariant quantum backreaction in U (1) axion inflation

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We evaluate the quantum backreaction due to a gauge field coupled to a pseudo scalar field driving a slow-roll inflationary stage, the so-called axion inflation. The backreaction is evaluated for the first time using a gauge invariant approach, going to second order in perturbation theory and considering inflaton fluctuations as well as scalar perturbations of the metric. Within our gauge invariant, but observer-dependent approach, we naturally consider as physical observer the one comoving with the inflaton field. Looking at the effective expansion rate and slow-roll parameter we show how the backreaction of the gauge field quickly becomes non-negligible and brings the system out of the perturbative regime, towards what is often called the strong backreaction regime.

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Ghost-driven instabilities in black hole evaporation

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A quantum ghost that destabilizes the Schwarzschild solution, transforming it into a naked singularity, may seem like a physicist's worst nightmare. However, in this talk, we will argue that this scenario not only represents the natural evolution of a black hole under a conservative high-energy gravity framework, but is also a desirable outcome. There is much evidence that the Einstein-Hilbert action needs to be corrected by the addition of quadratic curvature terms at higher energies; although these terms introduce ghost particles at the quantum level, we will show that during the evaporation of a Schwarzschild black hole the onset of a ghost-driven instability is essential to avoid a pathological evolution. Furthermore, we propose that the endpoint of this instability is a new type of naked singularity, which can exist only within modified theories of gravity. This solution avoids the observable physical inconsistencies associated with standard naked singularities and could potentially exist in our universe. While a complete theory of quantum gravity might ultimately resolve the ghost and singularity issues, our approach provides new insights into how black hole evaporation might occur at higher energies.

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Gravitational Collapse in Scale-Dependent Gravity

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In this talk we consider the Oppenheimer-Snyder (OS) gravitational collapse in the general framework of scale-dependent gravity. Recent investigations show that a spherically symmetric solution of asymptotically safe gravity, when considered for a negative ω-parameter (so, properly speaking, in scale-dependent gravity), develops a singularity at a finite non-zero radial coordinate. The inner geometry of the collapsing star is described, as usual, by the spatially flat Friedmann-Robertson-Walker (FRW) metric. We study in detail the proper time evolution of the event and apparent horizons. Matter is uniformly distributed without any assumptions about its equation of state. The outer asymptotically-safe/scale-dependent black hole metric is smoothly matched to the inner geometry, and this yields the energy density, pressure, and equation of state of the collapsing matter. Finally, the properties of the equation of state and the energy conditions are considered and discussed.

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How to modify dust collapse to produce a regular black hole (the cases of Asymptotic Safety and Non Linear Electrodynamics)

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Implementing strong curvature modifications to General Relativity (GR) may lead to the resolution of the spacetime singularity that arises at the end of gravitational collapse.
In the following, we consider the toy model of homogeneous dust collapse and explore the conditions under which such modified scenarios may produce a regular black hole.
Finally we showcase two illustrative examples: one from Asymptotically Safe gravity and one from GR coupled to a theory of non-linear electrodynamics.

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IR finite correlation functions in de Sitter space, a smooth massless limit, and an autonomous equation

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We consider a theory of a massive scalar field in de Sitter spacetime. Through the Yang-Feldman-type equation, the one-, two-, and three-loop quantum corrections for the long-wavelength modes' two-point and four-point correlation functions have been calculated. The corresponding massive perturbative series being summed rids of secular effects. In contrast to the standard theory of a massive scalar field based on the de Sitter-invariant vacuum, we developed vacuum-independent

reasoning that may not possess de Sitter invariance but results in a smooth massless limit of the correlation function's infrared part (with the expected secular growth in that case). The main "building block" of the elaborated approach is the free massive field's correlation function, which coincides with the Ornstein-Uhlenbeck process's one and has a clear physical interpretation. Our outcomes correspond to the Schwinger-Keldysh technique's results at the late-time limit and were also compared with those obtained in the framework of the stochastic approach and with the Hartree-Fock approximation. At last, we have constructed an autonomous equation for the two-point function. Integrating its approximate version, one can obtain a non-analytic expression with respect to the self-interaction coupling constant λ. Our result almost coincides with the stochastic one in the whole interval of a new dimensionless parameter.

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Local invariances in metric-affine theories and the heat kernel for non-minimal second-order operators

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We study non-linear transformations of the torsion tensor, and we find two such variations that close and give rise to Lie algebras. We focus on one of these, obtaining an invariant Lagrangian that significantly restricts the parameter space of couplings, providing its flat-space particle content. We argue that the invariance may yield a radiatively stable theory in the 1-loop approximation. Eventually, we sketch the derivation of the second Seeley-DeWitt coefficient for second-order non-minimal operators that is needed to perform the covariant 1-loop functional integration of quantum fluctuations for torsion excitations.

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Naturalness, renormalization and the cosmological constant problem

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It has been known for a long time, since the seminal works of Fradkin and Tseytlin as well as Taylor and Veneziano, that the calculation of the (euclidean) effective action in quantum gravity gives rise to quartic and quadratic UV-sensitive contributions (Planck scale) to the vacuum energy. The comparison of this result to the measured value of the vacuum energy, that is inferred from the observed accelerated expansion of the universe, reveals an extremely severe naturalness problem. Nowadays, this issue is well known as the strongest facet of the "cosmological constant problem". In this talk, I will show that the appearance of these UV-sensitive terms is due to a not entirely correct treatment of the measure in the path integral. We will see that, when the measure is fully taken into account, these terms completely disappear and the vacuum energy only presents a mild logarithmic sensitivity to the UV scale. I will then explain why usual calculations give rise to quartic and quadratic UV-terms.

Nonsingular black holes: effective models and observational signatures

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Quantum gravity effects are generally expected to resolve the classical singularity of the Schwarzschild black hole. In this talk we present a general approach to construct effective models for nonsingular black holes and discuss their possible observational signatures.

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Numerical Relativity in effective field theories of gravity

Author: Aaron Held[None]

The age of gravitational-wave astronomy is now in full swing. For the first time, we gain observational access to the highly dynamical strong-field regime of the gravitational interaction. Constraining potential deviations from General Relativity (GR) requires reliable waveform predictions, not just in GR, but also when higher curvature corrections contribute to the dynamics. I will present an overview of recent progress on
(i) mathematical well-posedness,
(ii) numerical nonlinear waveforms, and
(iii) statistical comparison to observational data.
In combination, the above constitutes a feasible pathway to use current and future gravitational-wave observations to constrain effective field theories of gravity.

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On the impact of perturbative counterterms on black holes

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Motivated by considerations in Quantum Gravity, I will discuss black hole-like spacetimes obtained from higher derivative theories of gravity, focusing particularly on the Goroff-Sagnotti counterterm. We find that static, asymptotically flat, and spherically symmetric geometries are completely characterized by their asymptotic mass and the coupling associated with the counterterm. This coupling induces distinct corrections at the sixth order of the parametrized post-Newtonian expansion. The resulting spacetime geometries still exhibit an event horizon. I will discuss various thermodynamic aspects using the Wald formalism to derive the entropy and compute the first law of thermodynamics for the static black holes in this theory. From a phenomenological perspective, I will show how corrections to the shadow size can be determined analytically and used to provide an initial bound on the new coupling. Finally, I will present some recent developments regarding the geometry inside the event horizon.

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Path integral measure and the RG equations of pure gravity

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It is largely known that the calculation of the (euclidean) effective action in quantum gravity is plagued by the appearance of quartic and quadratic UV-sensitive contributions to the vacuum energy. However, it has been recently shown in the Einstein-Hilbert truncation of pure gravity that a careful treatment of the measure in the path integral reveals the disappearance of these problematic terms. The resulting vacuum energy only presents a mild logarithmic sensitivity to the UV scale. Along the same lines, in this talk I will present the derivation and solution of the renormalization group equations of Einstein-Hilbert truncated pure gravity. Differently from what happens in previous implementations, we will see that the RG flow of the cosmological constant is not governed by the fourth power of the running scale. This gives rise to a significantly different renormalization pattern.

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Physical and unphysical running of couplings

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In particle physics the running couplings are used to solve the
problem posed by large logarithms, and they faithfully reproduce
the overall dependence of scattering amplitudes on the energy.
I will show that in certain circumstances the standard definition of
running couplings fails to satisfy these properties, and will give
the physically relevant definition.
This applies in particular to higher derivative gravity.
The physical running differs from the one that is known in the
literature and allows the theory to be asymptotically free without
tachyons.

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Probing the nature of gravity on black hole horizons

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We describe a recently developed tool which enables a description
of spacetime as a manifold with a Lorentz-invariant limit length
built-in. This is accomplished in terms of quantities depending

on two spacetime events (bitensors) and looking at two-point function,
all this being well suited to embody nonlocality in the small scale.
What one obtains is a metric bitensor (called minimum-length metric
or quantum metric, or qmetric for brief), with components singular
in the coincidence limit of the two events capable to provide
a finite distance in the same limit.
We discuss here how this metric structure can be seen to include
also the case of null separated events,
and describe some results one gets with the null qmetric
which do have immediate thermodynamic/statistical
interpretation for horizons.
One of them is that the area transverse to null geodesics
converging to a base point goes to a finite value in the
coincidence limit (instead of shrinking to 0).
We comment on the discreteness this seems to imply
for the area of black hole horizons as well as on possible ensuing
effects in gravitational waves from coalescence of binary compact bodies.

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Regular primordial black hole constraint from isotropic gamma-ray background

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The literature is flourishing in exotic and theoretical
black hole solutions realized in the framework of general relativity
or modified gravity theories to cure the singularity affecting the
vacuum solutions of general relativity. On the other hand, the
Schwarzschild solution is the standard lore when computing constraints
on primordial black hole abundance arising from the isotropic diffuse
gamma-ray background. In this study, we present an extension of such
constraint by considering a sample of the most common regular black
hole solution. We show that the constraint changes and the so-called
asteroid mass width, where primordial black holes may contribute to
the totality of the dark matter, can be enlarged or closed by those
non-Schwarzshild solutions.

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Remarks on Perturbative Quantum Gravity

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Is the lack of perturbative renormalizability in Einstein's general relativity a failure of the perturbative QFT framework to describe quantum aspects of gravity at the fundamental level? My answer is NO. In fact, the addition of quadratic curvature invariants to the Einstein-Hilbert action makes it possible to achieve "strict" renormalizability in four dimensions. In this talk I show that strict renormalizability is still a very powerful criterion for selecting unique and predictive theories in sub-Planckian regimes, even when gravity is taken into account. After describing some aspects of Quadratic Gravity, I will compare it with other approaches and argue that it is the most predictive

as it can explain new physics in the sub-Planckian regime, for example, it offers a natural explanation for the inflationary phase in the early Universe. Finally, I will make some comments on the (super-)Planckian regime.

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Rotational holographic transport in AdS/CMT

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When the AdS/CFT duality is used to describe strongly interacting condensed matter system it is referred to as AdS/CMT. In this talk I will consider rotational holographic transport in strongly coupled 2+1 dimensional systems, from the point of view of 3+1 dimensional gravity in anti de-Sitter background. We consider the moment of inertia
as a kind of transport coefficient, identified with the moment of inertia of a charged rotating black hole in AdS_4 background. In the low-temperature region, we find the behaviour of the density with temperature and angular velocity Ω, and find the behaviour of $\frac{1}{T}\frac{\partial}{\partial\Omega}\frac{I}{A}$ in the presence of charge.

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Searching for dark matter signals with the stellar kinematics

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With increasing precision of the observations of the stellar kinematics around the SMBH, tiny effects from dark matter, including its gravitational perturbation and the direct coupling with the ordinary matter may be detectable. In this two work, we search for possible evidence of the dark matter using accurate orbital measurements of the S-star around Sgr A*.

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Searching for quantum gravity footprint around stellar-mass black holes

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According to the asymptotically safe gravity, black holes can have characteristics different from those described according to general relativity. Particularly, they are more compact, with a smaller event horizon, which in turn affects the other quantities dependent on it, like the photon ring and the size of the innermost stable circular orbit. We decided to test the latter by searching in the literature for observational measurements of the emission from accretion disk around stellar-mass black holes.

All published values of the radius of the inner accretion disk were made homogeneous by taking into account the most recent and more reliable values of mass, spin, viewing angle, and distance from the Earth. We do not find any significant deviation from the expectations of general relativity. Some doubtful cases can be easily understood as due to specific states of the object during the observation or instrumental biases.

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String Theory and Loop Quantum Gravity: True Theory vs ad hoc Hypothesis?

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As physicists know, string theory suggests to replace the 0-dimensional (point) particles of the standard model with 1-dimensional vibrating strings. So each particle world line (1-dimensional)) is replaced with string world sheet (2-dimensional): this avoids formation of singularities when particles are strongly compressed together, giving for the first time an acceptable description of the state of primordial universe. One of the best results of the theory is the natural appearance just in the spectrum of the simplest string of a massless spin-2 state, which well represents the state of a graviton, suggesting string theory as a first example of quantum gravity. This at the expense of increasing the spacetime dimensions at least to 11. So the mathematics of the theory becomes very difficult.
On more recent years a second proposal has been made for quantum gravity: the so called loop quantum gravity (LQG). In this case the machinery of the standard model is left unaltered, with the advantage of a much simpler mathematics in the 4-dimensional spacetime, gaining also here a good explanation of the initial singularity of the universe only through the quantization of the gravity. At the end the two theories show many similarities also due to the appearance in LQG of spin foams, which resemble the world sheets of string theory.
I think that the hypothesis of loop quantum gravity when incorporated inside the standard model can well become a complete theory of matter, as string theory wants also. So the word moves on to the experiments. Only their results can make it possible to choose between these two descriptions of the world. And being an experimentalist I believe that the best way to discriminate between string theory and LQG is to demonstrate the existence of the extradimensions foreseen by the string theory.

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Substructures of the Weyl group

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I will present examples of substructures of the Weyl group of transformations of the metric and discuss the physical properties of theories invariant under such symmetries.

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Testing scale-invariant inflation against cosmological data

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Fundamental scale invariance was proposed long ago as a new theoretical principle beyond renormalizability. Besides its highly predictive power, a scale-invariant formulation of gravity could provide a natural explanation for the long-standing hierarchy problem and interesting applications in cosmology.
We present a globally scale-invariant model of gravity and study its cosmological solutions. The system admits a dynamical flow from an unstable to a stable fixed point, during which scale symmetry gets spontaneously broken, and a mass scale —the Planck mass —is classically generated. This trajectory is compatible with an arbitrarily long stage of inflation.
We discuss the main results of the analysis performed in arXiv:2403.04316, where a numerical solution to the two-field dynamics of the system allowed us to corroborate previous analytical findings and set robust constraints on the model's parameters using the latest Cosmic Microwave Background data from Planck and BICEP/Keck.

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Using SgrA* to test Theories of Gravity

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The Galactic Center of the Milky Way can serve as a test bench to investigate physical phenomena at the edge of astrophysics and fundamental physics. As such, it offers a unique laboratory to probe General Relativity, modified theories of gravity, different paradigms of dark matter, and black hole mimickers. I will provide a general overview of the results achieved in recent years, emphasizing their importance in opening a new avenue to improve our understanding of the underlying theory of gravity in the surroundings of a supermassive compact object.

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Weak cosmic censorship and the rotating quantum BTZ black hole

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Tests of the weak cosmic censorship conjecture examine the possibility of a breakdown of predictivity of the gravitational theory considered, by checking if curvature singularities are cloaked behind an event horizon at all times, during the time-evolution of an initial regular configuration. The conjecture has been a subject of intense scrutiny, but no convincing counter-example has been found yet for classical theories of gravity.

A natural question to ask, therefore, is what is the impact (if any) of quantum gravity effects on the conjecture. In this talk, we will address this problem by focusing on an extremal, rotating, quantum version of the BTZ black hole. This has been holographically constructed some years ago starting from a solution for a black hole localized on a brane in anti de Sitter space in four dimensions, and it has recently been reconsidered and re-analyzed in details. The holographically-dual three-dimensional metric encodes the exact backreaction from strongly coupled quantum conformal fields. Our analysis reveals that, despite the inclusion of quantum effects and akin to the classical scenario, these attempts to destroy the black hole are doomed to be unsuccessful. Particles carrying the maximum angular momentum and still falling into an extremal quantum BTZ black hole can, at most, leave it extremal. We found numerical evidence that large backreaction of the quantum fields tends to disfavor violations of cosmic censorship.

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Weyl cohomology and the conformal anomaly in the presence of torsion

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Using cohomological methods, we identify both trivial and nontrivial contributions to the conformal anomaly in the presence of vectorial torsion in d = 2, 4 dimensions. In both cases, our analysis considers two scenarios: one in which the torsion vector transforms in an affine way, i.e., it is a gauge potential for Weyl transformations, and the other in which it is invariant under the Weyl group. An important outcome for the former case in both d = 2, 4 is the presence of anomalies of a "mixed"nature in relation to the classification of Deser and Schwimmer. For invariant torsion in d = 4, we also find a new type of anomaly which we dub Ψ-anomaly. Taking these results into account, we integrate the different anomalies to obtain renormalized anomalous effective actions. Thereafter, we recast such actions in the covariant nonlocal and local forms, the latter being easier to work with. Along the way, we pause to comment on the physical usefulness of these effective actions, in particular to obtain renormalized energy-momentum tensors and thermodynamics of 2d black holes.

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