NONLINEARITY, NONLOCALITY AND ULTRAMETRICITY
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Abstracts

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Some cosmological viability constraints of modified gravity

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In this talk, I will discuss some cosmological viability constrains on some extensions of General Relativity, focusing on $f(R)$ and its nonlocal extensions.

The p-adic view on causality and "true randomness"

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Random numbers are needed in a number of applications, from computer simulations to data protection; basically, there are two types of generators of random numbers. The first type are pseudo-random number generators (PRNG), the software/hardware implementations of algorithms which produce random-looking sequences of numbers which by their algorithmic nature are not random but are rigorously proven to pass a number of statistical tests; or it is shown mathematically that to distinguish the produced

sequences from truly random ones is an infeasible task since the task is polynomially equivalent to some hard mathematical problem for which no algorithms solving the problem in polynomial time are known. The second type of generators constitute the ones which derive random numbers from some physical processes which are believed to be chaotic and unpredictable by physical reasons. The latter generators are usually called true random number generators (TRNG). The only reason why the sequences of numbers produced by the latter generators are judged as random is that they pass standard batteries of statistical tests and (if a generator exploits some quantum system) by a reference to immanent randomness of quantum processes. However, in order to use a generator in sensitive applications, a mathematical evidence is needed. In the talk we discuss what kind of such an evidence can be obtained for quantum TRNG. The talk is mostly based on the paper Vladimir Anashin. Free Choice in Quantum Theory: A p-adic View. Entropy 2023, 25(5), 830; https://doi.org/10.3390/e25050830

Landscape, Swampland and Extra Dimensions

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I argue on the possibility that compact extra dimensions obtain large size by higher dimensional inflation, relating the weakness of the actual gravitational force to the size of the observable universe. Although this can be realised for any number of extra dimensions, the requirement of (approximate) flat power spectrum of primordial density fluctuations consistent with present observations makes this simple proposal possible only for one extra dimension at around the micron scale. I will also discuss mechanisms for stabilising the radion modulus after the end of five-dimensional inflation. This scenario can then be nicely combined with the Dark Dimension proposal for the cosmological constant.

On relations between the real Kähler and the complex Hilbert Spaces quantum mechanics

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We analyze the relations between the standard formulation of quantum mechanics in complex Hilbert space and its counterpart in real Kähler space. Specifically, we demonstrate that the conventional quantum framework in complex Hilbert space can be faithfully reformulated within a real Kähler space without loss of structure or predictive power. A key result is the explicit isomorphism between Hermitian operators in the complex Hilbert space and Kähler-Hermitian operators in the real formulation. A remarkable property of the double degeneracy of observable spectra in Kähler quantum mechanics will be discussed. Furthermore, we also address the implications of this reformulation for composite quantum systems, emphasizing how entanglement and tensor-product structures manifest in the Kähler-space framework.

The talk is based on

I. Aref'eva and I. Volovich, Notes on Real Quantum Mechanics in a Kähler Space, in preparation.

Self-accelerating Scorer beams

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The self-similar solution of the (1+1)-dimensional optical paraxial diffractive system is found by employing the self-similarity method, leading to the discovery of a beam solution composed of Scorer functions, for which reason we refer to it as the Scorer beam. Through theoretical analysis and numerical simulation, we explore several characteristics of both infinite- and finite-energy Scorer beams, particularly focusing on their non-diffractive and self-accelerating properties. Additionally, we compare the Scorer beam with â€" and distinguish from â€" the related Airy beam. This investigation provides both theoretical and numerical insights that may guide the experimental realization of Scorer beams.

Scalar-tensor cosmology: unifying metric, Palatini and hybrid approaches

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First, how the standard (metric) scalar-tensor gravity can accommodate its Palatini and hybrid extensions will be shown. Then some applications for constructing viable cosmological models by using minisuperspace reformulation will be presented.

Towards p-adic boundary value problems

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In this talk, I plan to report on first progress on p-adic boundary value problems, in particular for elliptic divergence operators and their relationship with diffusion.

Effective action in six-dimensional supersymmetric gauge theories

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The talk is a brief review of structure of quantum effective action in six-dimensional gauge theories. The $N = (1, 0)$ supersymmetric theories are constructed in harmonic superspace. Aspects of maximally extended global 6D super Yang-Mills theory are discussed. Manifestly $N = (1, 0)$ supersymmetric and gauge invariant quantum effective action is constructed and results of one-and two-loop calculations of its divergences are presented.

Rewriting life's alphabet: Genetic code expansion and the rise of Xenobiology

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All life on Earth shares a remarkable commonality: it is written in the same chemical language. This language - the genetic code - enables cells to build proteins, the essential molecular machines of life, using the same 20 canonical amino acids as basic building blocks. Alongside DNA and a handful of other key polymers, these amino acids form the foundation of all known biology. Today, this once-fixed code is being deliberately expanded. Scientists are now reprogramming the genetic code to include noncanonical amino acids - new chemical entities not found in nature - offering a powerful way to endow proteins and cells with entirely novel properties. This is made possible through synthetic biology, genome engineering, and clever manipulation of molecular machines that govern protein synthesis. At the heart of this approach are custom-built enzyme-tRNA pairs known as orthogonal translation systems. These act as parallel decoding machines, introducing new amino acids into proteins in both living cells and synthetic setups. Such reprogramming enables site-specific labeling, structural probing, and even the creation of therapeutic proteins - using bioorthogonal chemistries such as click reactions to attach functional groups without interfering with native biology. This talk will introduce the principles behind genetic code expansion, from its biochemical underpinnings to its physical implications. I will highlight real-world applications, including how these exotic amino acids serve as powerful probes in spectroscopy and microscopy, and how synthetic organisms can be designed to operate with "genetic firewalls" - built-in safety systems that isolate engineered life from the natural biosphere. Expanding the genetic code marks a shift from understanding life to engineering it. By extending nature's toolkit, we gain control over

biological function and form. This frontier invites a new generation to build systems, materials, and cells that nature never had - but now can. References: [1] Kubyshkin, V., Budisa, N. (2019) Anticipating alien cells with alternative genetic codes: away from the alanine world! Curr. Opin. Biotechnol. 60, 242-249; doi: 10.1016/j.copbio.2019.05.006 [2] Kubyshkin, V., Budisa, N. (2019) The Alanine World Model for the Development of the Amino Acid Repertoire in Protein Biosynthesis Int. J. Mol. Sci. 20(21), e5507; doi: 10.3390/ijms20215507. [3] Budisa, N., Kubyshkin, V., Schmidt, M. (2020) Xenobiology: A Journey towards Parallel Life Forms. ChemBioChem, 21(16), 2228-2231; doi: 10.1002/cbic.202000141

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.

The Chern-Simons current in systems of DNA-RNA transcriptions

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A Chern-Simons current, coming from ghost and anti-ghost fields of supersymmetry theory, can be used to define a spectrum of gene expression in new time series data where a spinor field, as alternative representation of a gene, is adopted instead of using the standard alphabet sequence of bases A,T,C,G,U. After a general discussion on the use of supersymmetry in biological systems, we give examples of the use of supersymmetry for living organism, discuss the codon and anti-codon ghost fields and develop an algebraic construction for the trash DNA, the DNA area which does not seem active in biological systems. As a general result, all hidden states of codon can be computed by Chern-Simons 3 forms. Finally, we plot a time series of genetic variations of viral glycoprotein gene and host T-cell receptor gene by using a gene tensor correlation network related to the Chern-

Simons current. An empirical analysis of genetic shift, in host cell receptor genes with separated cluster of gene and genetic drift in viral gene, is obtained by using a tensor correlation plot over time series data derived as the empirical mode decomposition of Chern-Simons current.

Generalized second order NPDEs with similar classes of solutions

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Starting from specific forms of reaction-diffusion equations with functional coefficients that accept certain classes of solutions, we will investigate possible generalizations of those equations that preserve the same classes of solutions. Generalizations will consist of higher-order nonlinearities for the reaction-diffusion coefficients. The study allows, for example, to identify second-order nonlinear equations that can be solved using Ricatti or Bernoulli as auxiliary equations.

Dynamical black holes in collapsing FLRW universes

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Models of dynamical black holes in collapsing spatially flat FLRW universes are constructed according to the method proposed recently [I. I. Cotaescu, Eur. Phys. J. C **82** (2022) 86]. The dynamics of these black holes is studied pointing out the horizons evolution and their physical interpretation.

Ensemble averaging in LLM geometries

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We consider dynamics of ensembles of geodesics in Lin-Lunin-Maldacena (LLM) geometries, first black and white and then grayscale (coarse-grained). We find that ensemble averaging over geodesics converges to an "average" geodesic which on long timescales coincides with the geodesic in grayscale geometries. The same conclusion holds accordingly also for the two-point functions of the dual CFT in the eikonal regime. We then construct a black hole geometry by encircling the singularity of the grayscale LLM solution with a thermal horizon and find that the geodesics and two-point functions

in this background are obtained in the first approximation simply by compactifying the ensemble-aberaged results on the thermal circle. All of this suggests that we might understand black holes as averages over microstate solutions

Non-Archimedean Test Function Spaces: A Discussion

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I'll give a discussion of commonly used test function spaces in the non-Archimedean setting, and point out some of their shortcomings. I'll also show the impossibility of defining a p-adic test function space which has all the desired properties.

Nonlocal de Sitter $\sqrt{dS}$ gravity model and its localdescription

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A simple nonlocal de Sitter gravity model ($\sqrt{dS}$) is defined by the action

$$S = \frac{1}{16\pi G}\int \Big(R - 2\Lambda + \sqrt{R-2\Lambda}\mathcal{F}(\Box)\sqrt{R-2\Lambda}\Big)\sqrt{-g}\,\mathrm{d}^4x.$$

Ist shows good properties on cosmological and galactic scales. In this talk we will show that each cosmolgical solution can be described locally by a

scalar field. The rotation curves of spiral galaxies (Milky Way and M33) are also well described by the $\sqrt{dS}$ model.

This talk is based on joint work with Branko Dragovich, Zoran Rakic and Jelena Stankovic.

Braided noncommutative quantum field theory

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We discuss braided (quantum) field theories and their BV (algebraic) quantization. We use the homological (L-infinity algebra) description and the homological perturbation theory. Examples of scalar field theories with two different noncommutative deformations are presented and their renormalizability properties are analyzed. The obtained results are compared with the results already present in the literature.

Adelic dynamics and DBI Lagrangians

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A family of Dirac-Born-Infeld (DBI) Lagrangians has been known and widely considered in many different fields of physics. In the last several

decades they find a significant room of application in cosmology and inflation theory. Dynamics governed by DBI Lagrangians are closely related to dynamics of the tachyon fields. We are focussed on quantum dynamics of tachyon-like systems with a special attention on nonarchimedean spaces, their p-adic and adelic aspects and connection with dynamics on "real-Archimedean" space.

Nonlinear Dynamics of Toxin-Antitoxin Systems in Regulating Gene Transfer and Persistence

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Bacterial defense systems protect bacterial cells against foreign DNA invasion. They include toxin-antitoxin (TA), and restriction-modification (R-M) systems, with the latter two forming a generalized TA group. These systems regulate horizontal gene transfer (HGT) and play a critical role in controlling the spread of antibiotic resistance (ABR) and virulence genes, through mechanisms that currently remain unclear. TA systems also contribute to bacterial persistence by enabling phenotypic switching into a dormant state, a key survival strategy under antibiotic stress. Given the nonlinear and inherently quantitative nature of these processes, mathematical modeling provides a critical tool for understanding their regulatory dynamics. This talk will present mathematical models describing the dynamics of both R-M and TA systems. First, we will introduce a mechanistic model of Type-II R-M systems, which incorporates the dynamic regulation of restriction (R) and methylation (M) enzymes by a regulatory protein

(C). Through analytically derived stability diagrams and stochastic simulations, we reveal the conditions under which C-regulated R-M systems exhibit monostability or bistability [1]. The results indicate that M-to-R ratio shifts are influenced by factors such as plasmid replication rates and cell division timing, ultimately affecting bacterial permissiveness to foreign DNA. Importantly, our findings suggest that bacterial populations can tune R-M activity to create heterogeneous HGT barriers, which may impact the acquisition of ABR and other pathogenic genes over evolutionary timescales. Second, we will present a mathematical framework for Type-I TA systems [2], which are implicated in bacterial persistence through toxin-antitoxin regulation. In these systems, an antisense RNA inhibits toxin expression, thereby controlling the transition between active and dormant states. Our mathematical model captures the bistability and hysteresis inherent in TA-mediated persister formation, demonstrating how distinct inhibitory mechanisms govern toxin dynamics. Stability analysis confirms the existence of physiological parameter ranges that allow for the stable co-existence of persister and non-persister states. Additionally, stochastic simulations provide insight into the emergence of phenotypic heterogeneity, highlighting the role of noise in state-switching dynamics. By integrating these models, this work provides a quantitative framework for understanding bacterial defense and persistence strategies, offering useful insights into the regulatory principles governing these systems.

[1] Djordjevic, M., Zivkovic, L., Ou, H. Y., & Djordjevic, M. (2025). Nonlinear regulatory dynamics of bacterial restriction-modification systems modulates horizontal gene transfer susceptibility. Nucleic Acids Research, 53(2), gkae1322. [2] Markovic, S., Djordjevic, M., OU, H., & Djordjevic, M. (2025). Bistability in type I toxin-antitoxin systems may lead to stress-induced persister formation, submitted.

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Langlands Duality and Invariant Differential Operators

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Langlands duality is one of the most influential topics in mathematical research. It has many different appearances and influential subtopics. Yet there is a topic that until now seems unrelated to the Langlands program. That is the topic of invariant differential operators. That is strange since both items are deeply rooted in Harish-Chandra's representation theory of semisimple Lie groups. Here we start building the bridge between the two programs.

Isoperiodic deformations of meromorphic differentials on Riemann surfaces and applications to Mathematical Physics

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We study deformations of elliptic and hyperelliptic Riemann surfaces and of a Abelian differential of the second or third kind on the surface which preserve the periods of the differential with respect to a chosen canonical homology basis of the surface. We derive differential equations with

rational coefficients governing the deformations. We apply these results to the algebra-geometric solutions to the Boussinesq equation, KdV equation, sine-Gordon equation, KP equation, the Neumann system, the Toda lattice, and $SU(N)$ Witten-Seiberg theory. The talk is based on new joint results with Vasilisa Shramchenko and: [1] V. Dragović, V. Shramchenko, Isoharmonic deformations and constrained Schlesinger systems, arXiv: 2112.04110. [2] V. Dragović, V. Shramchenko, Deformation of the Zolotarev polynomials and Painleve VI equations, Letters Mathematical Physics, 111, 75, 28 p. 2021. [3] V. Dragović, V. Shramchenko, Algebro-geometric approach to an Okamoto transformation, the Painleve VI and Schlesinger equations, Annales Henri Poincare, Vol. 20, No. 4, 1121–1148, 2019.

Zeta functions in Physics: a comprehensive review

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A very short but somehow comprehensive review of the zeta-function regularization procedure in Physics, designed for pseudodifferential operators corresponding to observable quantities, will be given. The most influential bibliography on the subject and its different aplications will be recalled.

Quantum-like Modelling of the Genetic Code

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The Kronecker tensor product of matrices is one of the most important operations in quantum mechanics and quantum informatics. The article is devoted to various applications of this mathematical operation for revealing hidden interrelations among molecular-genetic structures and for developing quantum biology and algebraic biology. Special attention is paid to matrix representations of the set of DNA nucleobases and their hydrogen bonds. These representations reveal, in particular, hidden symmetries in alphabets of DNA n-plets and also possibilities of applications of hyperbolic numbers and their extensions for modeling some hidden regularities in long DNA sequences.

Stuart-Landau Oscillator: Variations on a theme

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The two-dimensional Stuart-Landau system is a paradigmatic model of nonlinear oscillator that exhibits Hopf bifurcation. We propose a generalisation to arbitrary dimensions, retaining its essential features, including

exact solvability. We shall discuss the asymptotic behaviour of possible trajectories, limit cycles and basins of attraction. Modulation of its parameters, the dynamics of coupled oscillators and an ultrametric analogue will be commented upon.

Beyond Algebraic Solutions to Stringy Spacetime

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Active feedback between geometry and physics is woven throughout the study of Nature at its fundamental level, and is of key importance in string theory. Methods of complex algebraic geometry in particular have brought about an unrivaled abundance of solutions, counted well into hundreds of orders of magnitude, reciprocated by the discovery of the wholly unexpected mirror symmetry. However, recent developments demonstrate that there are rich additional possibilities, made possible by certain generalizations that, at first glance, appear to be non-algebraic. Nevertheless, they are remarkably well-aligned within an overall mirror-symmetric framework, are amenable to almost as comprehensive quantitative analysis, and hint at a deeper relationship with symplectic geometry.

Feynman diagrams, operator formalism and conformal field theory.

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We develop an operator approach to the evaluation of multiple integrals for multiloop Feynman massless diagrams. A commutative family of graph building operators for ladder diagrams is constructed and investigated. The complete set of eigenfunctions and the corresponding eigenvalues for these operators are found. This enables us to explicitly express a wide class of four-point ladder diagrams and a general two-loop propagator-type master diagram (with arbitrary indices on the lines) as Mellin-Barnes-type integrals. Special cases of these integrals are explicitly evaluated. A certain class of zig-zag four-point and two-point planar Feynman diagrams (relevant to the bi-scalar D-dimensional "fishnet" field theory and to the calculation of the $\hat{I}^2$-function in $\ddot{I}\bullet 4$-theory) is considered. The graph building operators and convenient integral representations for these Feynman diagrams are obtained. The explicit form of the eigenfunctions for the graph building operators of the zig-zag diagrams is fixed by conformal symmetry and these eigenfunctions coincide with the 3-point correlation functions in D-dimensional conformal field theories. By means of this approach, we exactly evaluate the diagrams of the zig-zag series in special cases. In particular, we find a fairly simple derivation of the values for the zig-zag multi-loop two-point diagrams for D=4. The role of conformal symmetry in this approach, especially a connection of the considered graph building operators with conformal invariant solutions of the Yang-Baxter equation is investigated.

Amazing Efficiency of the Harmonic Superspace Methods

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Harmonic $N = 2$ superspace was discovered in Dubna in 1984 [1,2] as the powerful unique tool of the geometric superfield off-shell description of $N = 2$, 4D supersymmetric field theories with the maximal spins 1, 2, and 1/2 ($N = 2$ Yang-Mills theories, supergravity and matter hypermultiplets). In my talk I give a brief account of the basic achievements of the harmonic methods (not only in supersymmetry), including the newest applications in $N = 2$ theories of higher spins with $s > 2$. The harmonic superspace approach makes it possible to set up the previously unknown off-shell formulations of the gauge $N = 2$ higher-spin theories in terms of the unconstrained analytic $N = 2$ superfields, in both conformal and non-conformal cases [3-5]. It is expounded how to deduce N = 2 higher-spin theories on the curved AdS4 background, proceeding from the harmonic description of the superconformal theories [6]. The basic idea consists in introducing a constant isotriplet cik that breaks $N = 2$ superconformal symmetry $SU(2, 2|2)$ down to the AdS4 supersymmetry $OSp(2|4; R)$.

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Magnetic flows on spheres

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We consider motion of a material point placed in a constant homogeneous magnetic field in $\mathbb{R}^n$ and restricted to the sphere S^{n-1}. While there is an obvious integrability of the magnetic system in $\mathbb{R}^n$, the integrability of the system restricted to the sphere S^{n-1} is highly non-trivial. We prove complete integrability of the obtained restricted magnetic systems for $n \leq 6$.

The talk is based on the paper arXiv:2504.20515 [math.DG].

Possible influence of a fifth force on stellar orbits around the Galactic Center

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So called fifth force is a concept which naturally emerges in the context of modern attempts to unify gravity with the other forces in nature. It represents an effective repulsive (anti-gravity) force which could balance out the normal attractive gravity force on galactic scales, and consequently, which could produce nearly flat rotation curves of spiral galaxies without need for dark matter. Fifth force also arises in the weak field limit of massive gravity theories and some Extended Theories of Gravity (ETG), in the form of a Yukawa-like correction to the Newtonian gravitational potential. Here we present a short overview of our investigations of possible influence of fifth force on the observed stellar orbits around the central supermassive black hole (SMBH) of our Galaxy. We fitted the simulated stellar orbits in Yukawa gravity into the observed orbits of several S-stars around Sgr A* at the Galactic Center (GC), and obtained the constrains on the parameters of Yukawa interaction which describe the intensity and the range of a fifth force. Assuming that the range of Yukawa interaction corresponds to the Compton wavelength of graviton, we also obtained an upper bound for graviton mass which was compatible with the value obtained by LIGO from gravitational-wave data. Taking into account that the GRAVITY Collaboration has recently measured the Schwarzschild precession in the orbit of S2 star and found that it was close to the prediction of General Relativity (GR), but with possible small deviations from it, we also studied whether these deviations could be caused by a fifth force. In such a case, we found that it is possible to use these discrepancies to further improve the constraints on the intensity and the range of a fifth force, as well as on upper bound for graviton mass.

Quantum corrections to cosmological potentials and the origin of the cosmological constant.

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We demonstrate how one can calculate the leading quantum corrections to arbitrary scalar potentials even in non-renormalizable theories. We derive the generalised RG equation for the effective potential which takes into account all the leading terms in all orders of perturbation theory, just like it takes place in renormalizable case. Application of this formalism to the co-called alpha-attractors in inflationary cosmology leads to increase of the potential at the minimum which can be interpreted as appearance of the cosmological constant due to quantum corrections. Choosing the set of parameters dictated by inflation scenario one can get the value of the cosmological constant satisfying the modern data.

Ultrametrics, dendrograms, quantum potential and medical diagnostics of neurological diseases

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We apply p-adic analysis in combination with quantum information to medical diagnostics of neuronal diseases. EEG signals are transferred into dendrograms - finite 2-adic trees. They are represented as subsets of $\mathbf{Z}_2$. From distribution of tress, we construct the quantum potential (as in Bohmian mechanics). It is used as a signature of neurological diseases.

Resolution of singularities in infinite-derivative gravity theories.

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In my talk I will overview an infinite derivative gravity construction and will demonstrate that it is capable to resolve singularities present in GR in a unitary way. I will also show that causality is preserved in such models.

Learning theory as physics

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Application of physical ideas in learning theory will be discussed, in particular: The second law of thermodynamics and Eyring's formula of kinetics in learning; Grokking (delayed generalization) as a physical (dynamical) phenomenon.

Time-Varying Energy Landscapes and Temperature paths: Dynamic Transition Rates in locally Ultrametric Complex Systems.

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In this work, we study the dynamics of complex systems with time-dependent transition rates, focusing on p-adic analysis in modeling such systems. Starting from the master equation that governs the stochastic dynamics of a system with a large number of interacting components, we generalize it by p-adically parametrizing the metabasins to account for states

that are organized in a fractal and hierarchical manner within the energy landscape. This leads to a not necessarily time homogeneous Markov process described by a time-dependent operator acting on an ultrametric space.

We prove well-posedness of the initial value problem and analyze the stochastic nature of the master equation with time-dependent transition-operator. We demonstrate how ultrametricity simplifies the description of intra-metabasin dynamics without increasing computational complexity.

We apply our theoretical framework to two scenarios: glass relaxation under rapid cooling and protein folding dynamics influenced by temperature variations.

In the glass relaxation model, we observe anomalous relaxation behavior where the dynamics slow down during cooling, with lasting effects depending on how drastic the temperature drop is. In the protein folding model, we incorporate temperature-dependent transition rates to simulate folding and unfolding processes across the melting temperature.

A review: basic fractional nonlinear-wave models and solitons

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This report provides a concise summary of one- and two-dimensional (1D and 2D) models for the propagation of linear and nonlinear waves in fractional media, with physical realizations in optics and semi-classical matter waves. The calculus based on the concept of fractional derivatives is a branch of formal mathematics that has been known in the course of 200+ years. Ca. 20 years ago, this concept had appeared in physics in

terms of the Laskin's fractional quantum mechanics, which is based on the one- and multidimensional linear Schrödinger equations with the fractional operator of kinetic energy [1]. These equations are written for the wave function of particles which, in their classical form, move by random Lévy flights. The latter implies that the mean distance $|x|$ of the particle, which moves (in the 1D space) by "flights" from the initial position, $x = 0$, grows with time as $|x| \ t^{1/\alpha}$, where α is the Lévy index (LI), which takes values $0 < \alpha \leq 2$. The kinetic-energy operator in the fractional Schrödinger equation is represented by the fractional Riesz derivative, $(-\frac{\partial^2}{\partial x^2})^{\alpha/2}$, the usual (nonfractional) quantum mechanics corresponding to $\alpha = 2$. While fractional quantum mechanics remains far from experimental implementation, much interest has been drawn to the proposal to emulate the fractional diffraction, governed by the same equations, by means of the classical wave propagation in specially devised optical cavities [2]. This possibility suggests, in turn, to include the self-focusing cubic nonlinearity, as the generic feature of the optical media. In terms of the respective nonlinear fractional Schrödinger equation, many theoretical results have been reported for solitons, vortices and other modes supported by the cubic (or quadratic, alias second-harmonic-generating) optical nonlinearities, see an illustration in the figure, and a brief review of previous results on this topic in [4]. For the solitons, a crucially important issue is their stability. In the 1D model with the cubic or quadratic nonlinearity, the solitons are stable against the onset of the collapse for LI values $1 < \alpha \leq 2$ and $0.5 < \alpha \leq 2$, respectively. In 2D, the cubic self-focusing makes all solitons unstable against the collapse, while the quadratic nonlinearity admits stable solitons for $1 < \alpha \leq 2$. Recently, the first experimental implementation of the effective fractional group-velocity dispersion has been reported for the light propagation in a fiber-laser cavity [5]. This was quickly followed by the first demonstration of fractional solitons in the same setting [6]. An intriguing possibility is to derive a fractional Gross-Pitaevskii (GP) equation for a Bose-Einstein condensate of particles which move by Lévy flights at the classical level, while the usual cubic nonlinearity in this equation represents, in the mean-field (semi-classical) approximation, effects of inter-particle collisions. While the rigorous derivation of the fractional GP equation has not been reported yet,

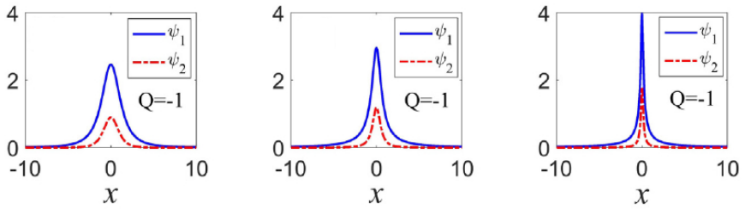


Figure 1: Examples of stable two-component solitons produced in Ref. [3] by the fractional second-harmonic-generating system with mismatch parameter $Q = -1$ and LI values $\alpha = 1.5$ (left), 1.0 (central), and 0.7 (right).

preliminary results have been recently presented, such as stable 1D and 2D solitons produced by the fractional GP equation including the spin-orbit coupling [7].

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Wavefunction of the Universe and the effective action

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We explain how to construct the effective action which corresponds to the given initial state of the Universe in a path-integral formulation of quantum gravity. We also show how this construction can be realized within the piecewise-flat quantum gravity theory.

Quantum Gravity, Gravitized Quantum Theory and all that

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I will discuss the problem of quantum gravity from the point of view of gravitized quantum theory. The crucial insight is that the fixed Born rule of quantum theory becomes dynamical in the context of quantum gravity, implying triple and higher order quantum interference that can be experimentally tested. Such effects are impossible in quantum theory and quantum field theory and they are central empirical features of quantum gravity.

Scale-Free Computing Inspired by the Genetic Code

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The origin and evolution of biological systems are deeply and inseparably linked to the storage, transmission, and processing of information. The final and most complex step in the flow of genetic information is protein synthesis during the translation process. Microbial phylogenetic studies have revealed that translation was highly developed at the root of the universal phylogenetic tree, suggesting its key role in the abiotic-biotic transition. The simplest abstract description of translation, the genetic code, is characterized by hierarchical organization and various symmetries. These symmetries are not mere mathematical peculiarities but are deeply intertwined with the molecular mechanisms governing gene expression and the faithful decoding of genetic information, indicating that certain symmetries can be evolutionarily very distant. Remarkably, the hierarchical organization of the genetic code and its symmetries are describable through arithmetic regularities in nucleon numbers of its constituents. Here we will show that the invariance within these arithmetic regularities provides a mathematical foundation for scale-free computation. Its emergence from symmetries across evolutionary epochs of the genetic code at the progenotic stage, coupled with its grounding in nucleon (mass) regularities, suggests its persistent relevance and a nontrivial origin for living organisms at the mesoscopic scale. Furthermore, this connection between scale-free computing and nucleon organization in living matter may support theories of emergent gravity.

Fixed points of the renormalization group transformation in a generalized fermionic hierarchical model

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A two-dimensional hierarchical lattice is considered, in which an elementary cell is represented by the vertices of a square. In the generalized hierarchical model, the distance between opposite vertices of a square differs from the distance between neighboring vertices and is a parameter of the new model. At each vertex of the lattice, the field is defined by a set of 4 generators of the Grassmann algebra. The Hamiltonian of the field is described by the interaction of the 4-th degree. The transformation of the renormalization group in the space of coupling coefficients defining this interaction is defined as a nonlinear mapping. All branches of fixed points of this mapping are described.

p-adic countable state SOS model

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Previous studies mainly focused on the p-adic Potts model with countable spin values, demonstrating that this model has only one p-adic Gibbs

measure. Furthermore, it was shown that the model exhibits a phase transition in the set of generalized Gibbs measures. A challenge remained to find a countable spin p-adic model where the set of all p-adic Gibbs measures would include at least two elements. In this talk we discuss the one-dimensional p-adic SOS model and demonstrated that the set of all p-adic Gibbs measures has continuum cardinality.

Modern Cosmology: Facts, Misconceptions and Myths

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Cosmic evolution and black holes in modified gravity

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Review of unified inflation dark energy epoch in $F(R)$ gravity is done. Some discussions of BH and their shadows in $F(R)$ gravity is proposed. Comparison with acceleration epoch in Einstein-Gauss-Bonnet gravity is done too.

Ultrametricity in physics of complex systems: from proteins to quantum chaos.

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Ultrametricity is a fundamental mathematical concept that describes spaces with the metric satisfying the strong triangle inequality and the induced topology of hierarchical architectures. Due to the violation of the Archimedes' axiom of measurement in such a metric, such spaces are also called non-Archimedean. Examples can be found in taxonomy, where phylogenetic trees are ultrametric, geography for measuring landscape complexity, and physics, where complex systems have intrinsically an ultrametric structure. The Noble Prize Giorgio Parisi demonstrated this within the theory of spin glasses, where the overlap between spins exhibits ultrametricity, with the mathematical solution given by the full replica symmetry breaking. In the talk, we discuss the last two decades progress in application of ultrametric models in physics of complex systems. Particular attention will be paid to the model of ultrametric diffusion with a sink, which allowed us to describe the process of CO- rebinding kinetics in Myoglobin; and the ultrametric properties of periodic orbits in a Hamiltonian system with fully chaotic dynamics.

Holography on Bruhat-Tits Buildings

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I will describe non-archimedean holography on various Bruhat-Tits buildings and the connections with p-adic AdS/CFT on the Bruhat-Tits tree.

Towards a theory of entanglement in p-adic quantum information

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We outline a program aimed to set the foundations of a p-adic theory of quantum information. The approach we propose starts by first providing a suitable notion of a p-adic Hilbert space over a quadratic extension of the filed of p-adic numbers $\mathbb{Q}_p$. A state for a p-adic quantum system is defined as a functional acting on the (ultrametric) Banach $*$-algebra of p-adic bounded observables. The statistical interpretation of the theory is then completed by introducing the notion of a SOVM as a suitable p-adic counterpart to a POVM of the complex quantum theory. To extend the formalism to compound systems, and to introduce a proper notion of entanglement in p-adic quantum mechanics, we next address the construction

of the tensor product of p-adic Hilbert spaces. To this end, we first consider two p-adic Hilbert spaces as simple vector spaces and define their algebraic tensor product. Then, we introduce a norm by adapting the projective norm used in the tensor product of complex Banach spaces to our case study. By metrically completing the resulting p-adic normed space, and after providing a suitable inner product together with an orthonormal basis, we obtain the tensor product of p-adic Hilbert spaces. Next, we show that this space is isomorphic to the space of trace-class operators. Finally, we study the tensor product of subspaces of p-adic Hilbert spaces, highlighting both the analogies and the non-trivial differences with respect to the standard complex case.

Primordial Black Holes in Induced Gravity

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A model of the induced gravity is proposed that, under a conformal transformation, becomes a chiral cosmological model with two fields. To form primordial black holes, a second inflationary phase is necessary, which occurs near the quasi-de Sitter solution. The length of the plateau in the Hubble parameter of the Einstein system determines the mass of the primordial black holes. In models with two fields, there is initially a slow roll along the classical inflaton field, followed by a second field that grows. The Hubble parameter during the second phase has a sufficient number of e-folds to form primordial black holes during the radiation-dominated era, with masses similar to dark matter candidates. To analyze single-field models of induced gravity that correspond to the second inflation phase near the quasi-de Sitter point, the superpotential method was developed.

Detecting High Frequency Nonlinear Quantum Phenomena Using Weak Measurements

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Due to the equivalence of averaging over time and over ensemble, and the inherent time averaging during the act of measurement as a consequence of finite time resolution of the time measuring device, high frequency phenomena are indistinguishable from mixed states in standard quantum mechanics. In this talk we will analyze whether mixed states can be distinguished from quickly oscillating pure states under nonlinear evolution using weak measurements. We will show that if weak measurements in postselected systems are used, mixed states and quickly oscillating states produce different results. An experimental procedure is proposed which could in principle determine whether mixed states stemming from black body radiation, decoherence, thermalization in solid state materials, Unruh radiation and Hawking radiation, among others, are secretly quickly oscillating pure states under nonlinear evolution or fundamentally mixed. The analysis presented in this talk applies to all fast oscillations, including those at Planck scale. As such, tabletop weak measurements can be used to probe (very specific) potential high energy behavior, where strong nonpostselected measurements cannot be applied. This talk will also demonstrate that weak measurements are not equivalent to a set of strong measurements without postselection since measurements which are impossible for all practical purposes need to be excluded.

New AI Methods for Simplifying Multi-Omics Data Analyses in Precision Medicine

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Abstract Large quantities of multi-omic data are increasingly becoming available. They provide complementary information about cells, tissues and diseases. We need to utilize them to better stratify patients into risk groups, discover new biomarkers and targets, re-purpose known and discover new drugs to personalize medical treatment. This is nontrivial, because of computational intractability of many underlying problems on large interconnected data (networks, or graphs), necessitating the development of new algorithms for finding approximate solutions (heuristics) [1]. We develop versatile data fusion artificial intelligence (AI) frameworks, that utilize the state-of-the-art network science methods, to address key challenges in precision medicine from time-series, multi-omics data: better stratification of patients, prediction of biomarkers and targets, and re-purposing of drugs, applied to different types of cancer [2,3], Covid-19 [4,5], Parkinson's [6,7] and other diseases. Our new methods stem from graph-regularized non-negative matrix tri-factorization (NMTF), a machine learning (ML) technique for dimensionality reduction, inference, fusion and co-clustering of heterogeneous datasets, coupled with novel graphlet-based network science algorithms. We utilize our new frameworks to for improving the understanding the molecular organization and diseases from the omics data embedding spaces [8,9,10]. Also, we utilize local topology to correct for the topological information missed by random walks, which are used in many ML methods [11], and to enable embedding of networks into more linearly

separable spaces, allowing for their better mining [12]. The aim is to develop an overreaching framework encompassing all multi-omics data that would simplify currently complex and energy inefficient AI methodologies for multi-omics data analyses [13].

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BV quantization of braided field theories

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In this talk, we will analyze braided noncommutative field theories: spinor and scalar quantum electrodynamics, and ϕ^3 theory. The classical dynamics of these theories is formulated in the framework of L-infinity algebra, while quantization of these theories is performed using the algebraic BV formalism. We derive algebraic version of correlation functions, Schwinger-Dyson equations and Ward identities based on the homological perturbation lemma.

Jordanian $sl(2)$ chain

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We study the homogeneous periodic XXX Heisenberg spin-1/2 chain further deformed by the Jordanian $sl(2)$ twist element. Namely, we show how the Jordanian twist element deforms the projector operators of the spectral decomposition of the $SL(2)$-invariant Yang R-matrix. We explicitly express the monodromy matrix entries in terms of the local spin operators and obtain the creation operators of the Bethe vectors as the complicated polynomials of the entries of the monodromy matrix. Moreover, we show that the off-shell action of the transfer matrix on the Bethe vectors has the expected triangular form.

Exploring Noisy Hamiltonian Dynamics

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We analyze some noise effects on Hamiltonian Dynamics. In particular, we focus in the paradigmatic Henon-Heiles Hamiltonian system where we study the effect of noise in the escapes from the potential. Furthermore, we develop some techniques such as probability basins aiming to quantify the unpredictability of the noisy Hamiltonians. This is a joint work with A. R. Nieto and J.M. Seoane from URJC, Spain.

Landscape of QCD Vacuum

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Intermittent oscillations are one of the most intriguing non-linear phenomena in reaction systems. They occur when two attractors coexist in the phase space of the dynamical system and cause apparently unpredictable behavior with sudden jumps between bursts of large amplitude oscillations and potentially long quiescent periods. Our model of oscillatory reaction explains the role of the slow manifold governing intermittent oscillations.

From Casimir invariants to equations for all spins and helicities

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Principle equations which contain field equations for particles of all spins and helicities are proposed. In particular, from Poincare Casimir invariants field equations for massive Klein-Gordon, Dirac, vector and Rarita-Schwinger fields were obtained. The same approach was applied to massless particles. In that case the Weinberg idea that Lorentz invariance induces local gauge transformations is confirmed. As is well known Wigner define a

particles as irreducible representation of Poincare group. But, as Weinberg showed irreducible representations for vector field with helicity ± 1 do not exist. Namely, Lorentz transformation of some physically relevant fields like vector field, have additional term in the form of gauge transformations. So, for these fields we can obtain actions as gauge invariant expressions of eigenvectors. In particular we can obtain Maxwell equations and Einstein equation in weak field approximation. As a consequences, Wigner's definition of particles as irreducible representations of Poincare group, which valid in massive case, in massless case must have an improvement. We can define physical massless fields as a class of equivalence, where two fields are equivalent if they relate by gauge transformation. The action is expression which depend on class of equivalence. This approach can be widely used to construct field theory for systems in various fields of physics. The only input parameter is symmetry group of the system, so that all theories with same symmetry group will look the same at sufficiently low energy.

Lebesgue-like measure and integration theory on the Levi-Civita field

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The Levi-Civita field $\mathcal{R}$ is the smallest non-Archimedean ordered field extension of the real numbers that is real closed and Cauchy complete in the topology induced by the order. In this talk, I will define a new measure on $\mathcal{R}$ that leads to a family of measurable sets in $\mathcal{R}$ for which most of the classic results for Lebesgue measurable sets in $\mathbb{R}$ hold. Then I will generalize that measure to higher dimensions using simplexes as the basic building blocks for measurable sets. Then I will introduce a family of measurable functions defined on measurable subsets of $\mathcal{R}$ (resp. $\mathcal{R}^2$ or $\mathcal{R}^3$). I will study

the properties of measurable functions, show how to integrate them over measurable subsets of $\mathcal{R}$ (resp. $\mathcal{R}^2$ or $\mathcal{R}^3$), and show that the resulting integral satisfies similar properties to those of the Lebesgue integral of Real Analysis.

Generalization of Boltzmann nonlinear equation using subdynamics approach

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Macroscopic and microscopic approaches concerning irreversible processes are paradoxically different. As the experiments show, macroscopic systems irreversibly evolve towards the thermodynamical equilibrium, maximizing the entropy, independently of their initial conditions. In contradistinction, fundamental equations of classical and quantum mechanics are reversible. In order to solve this contradiction, Boltzmann introduced a semi-phenomenological integro-differencial irreversible equation for the one-particle velocity distribution function [1]. His famous H-theorem, statistical mechanics analog of entropy, unfortunately holds only for dilute gases.

A decisive step in the understanding of irreversibility was made by Ilya Prigogine and Brussels group, by introducing SUBDYNAMICS approach [2]. Using such a SUBDYNAMICS of correlations, I obtained ab initio a general Boltzmann-like equation without dilute gases restrictions [3]. The perturbative formal solution of Liouville equation is decomposed into two SUBDYNAMICS. The C-SUBDYNAMICS contains all collisions making that the system forgets all initial condition, hence, it cannot go back. The remaining T-SUBDYNAMICS vanishes in the thermodynamic limit when the number of particles and the volume of the system tend to infinity so that

their ratio, i.e., density remains constant. I demonstrated the factorization of the two-particles distribution function into a nonlinear product of two one-particle distribution functions, necessary to establish the Lyapounov functional, which is the general statistical mechanics analog of entropy [4]. The dynamics of correlations is conveniently represented in terms of diagrams composed of elementary vertices, i.e., crossings of two lines representing interaction of two particles correlations. I established a topological theorem proving this factorization in the thermodynamical limit [5]. Diagrams are a compact representation of heavy formulas, which are however, necessary for the final demonstration of the factorization [4].

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Fifty years of Group Theory in Particle Physics and Beyond

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The development of Group Theory in Mathematics as well as its impact in Physics has been spectacular during the twentieth century, and more

particularly these last fifty years. If its contribution to Particle Physics deserves a special consideration, its usefulness cannot be neglected in other domains like Statistical Physics for example, and might also be of interest in Theoretical Biology. Some of these aspects will be examined.

Cosmological solutions of a nonlocal de Sitter $\sqrt{dS}$ gravity

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General relativity (GR) is a physical theory considered as one of the most beautiful mathematically and the most successful phenomenologically. Although very successful, GR is not a complete theory of gravity and there are many attempts to modify it. One of very promising directions of research is nonlocal modified gravity. We consider here the nonlocal de Sitter model $\sqrt{dS}$ which is given by the following action: $S = \frac{1}{16\pi G}\int \sqrt{-g}\big(R - 2\Lambda + \sqrt{R-2\Lambda}\,\mathcal{F}(\Box)\,\sqrt{R-2\Lambda}\big)d^4x$, where R is scalar curvature and Λ is cosmological constant. $\mathcal{F}(\Box) = \sum_{n=1}^{+\infty}\left(f_n\Box^n + f_{-n}\Box^{-n}\right)$ is an analytic function of the d'Alembert-Beltrami operator $\Box = \nabla_\mu\nabla^\mu = \frac{1}{\sqrt{-g}}\partial_\mu(\sqrt{-g}g^{\mu\nu}\partial_\nu)$ and its inverse $\Box^{-1}$. Derivation of equations of motion (EoM) for gravitational field $g_{\mu\nu}$ is presented in detail in [2]. To solve the corresponding equations of motion, we first solve eigenvalue problem $\Box\sqrt{R-2\Lambda} = q\sqrt{R-2\Lambda}$, where $q = \zeta\Lambda \quad (\zeta \in \mathbb{R})$ is an eigenvalue and $\sqrt{R-2\Lambda}$ is an eigenfunction of operator $\Box$. We presented and discussed several exact cosmological solutions for homogeneous and isotropic universe. One of these solutions mimics effects that are usually assigned to dark matter and dark energy, see [1]. Some

other solutions are examples of the nonsingular bounce ones in flat, open and closed universe. There are also singular and cyclic solutions.

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Signals of the doomsday

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The measured standard model parameters indicate that we might live in a false Higgs vacuum, possibly with a very long lifetime. However, small black holes can serve as catalysers and significantly speed up the phase transition. In fact, bubbles of true vacuum might already exist in our universe. We calculate the spectrum of Higgs particles produced by such a bubble, and use event generators to study their decay and subsequent evolution of the decay products to obtain the spectrum of emitted photons and neutrinos as a long-range signature. If the propagation of the bubble walls slows down due to interaction with the surrounding matter and plasma, these signals can reach us before the bubble wall hits us, thus representing the signals of the doomsday.

Towards p-adic quantum computing via representations of the p-adic rotation group

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We discuss p-adic quantum mechanics, where physics takes place in a three-dimensional p-adic (rather than Euclidean) space. In particular, we study the p-adic rotation group $SO(3)$, and we outline a program aimed at classifying its irreducible projective unitary representations, by exploiting its profinite structure and its Haar measure. These representations can be interpreted as a theory of p-adic angular momentum and spin, where the p-adic qubit arises as a two-dimensional representation. We describe the foundations of this program, starting from the main features of $SO(3)$ (in parallel to its real counterpart), such as a p-adic analogue of the Cardano (aka nautical) angles decomposition. We show that all finite-dimensional projective unitary representations of $SO(3)$ factorise on some $SO(3)$ modulo p, through which we find explicit p-adic qubit representations for every prime p. We further address the Clebsch-Gordan problem and identify entangled states for composite systems of two p-adic qubits. In the realm of quantum computing, we finally propose to construct p-adically controlled quantum logic gates on the single-, two- and n-qubit levels, using elements from the same 2-dimensional unitary representations of $SO(3)$. As in the standard approach, our emphasis lies primarily on p-adic quantum logic gates operating on two qubits (from the known four-dimensional unitary representations of $SO(3)$), with the ultimate aim to provide a universal set of gates.
Based on arXiv:2104.06228, arXiv:2306.07110, arXiv:2401.14298, and arXiv:2112.03362.

The origin of multiscale synchronization in human connectome networks

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In neuroscience, synchronization processes are increasingly recognized as key mechanisms in different aspects of global brain functions and brain disorders. Research into these large-scale processes has been fueled by brain imaging data and the availability of the structure of the human connectome. We investigate the synchronization of phase oscillators located at the network nodes (brain regions) and interacting along the weighted edges (neuronal bundles connecting them) in the human connectome core network. It comprises the central part of the connectome associated with the eight hubs—key nodes that transmit information between different brain parts. We consider both the network with its natural (empirical) edge weights, which affect interactions among oscillators, and its binary version dominated by topology features. We show the results of the topology and spectral analysis of these networks and simulations of the synchronization of Kuramoto oscillators when the strength of the global pairwise coupling varies from significant negative to large positive values. The emergence of partial synchronization as a relevant pattern in human connectomes has been observed at negative pairwise couplings, causing the phase frustration effects, and at positive couplings below the master-stability threshold, where the cluster synchronization mechanisms become active. Identifying nodes in these clusters by the Laplacian eigenvector localization methods reveals the role of brain hubs in these processes. Both partial synchrony patterns induce multiscale oscillations in the global phase order parameter, which we study using multifractal analysis. We show how the related singularity spectra depend on the coupling strength and sign and the weights of the edges.

A model of universe as harmonic oscillator with periodic and avoided singularities of the mass and energy density

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Kostadin Trencevski, Emilija Celakoska, Ilija Jovceski It is presented a model of the universe which is intersection of two 4D spheres whose radii change by $cos(w\tau)$ and $\sin(w\tau)$. The time flow is admitted when the universe belongs to both spheres as harmonic oscillators. However, the critical mass density of the universe is limited and it helps the universe to avoid these periodic singularities. When this critical mass density is achieved, then the universe belongs only to one 4D sphere, and then there is no flow of time. This epoch can be called "frozen epoch". Dual to the space part of the universe there is also 3D temporal part, which enables motion in each direction. Symmetrically, there exist also two "Big Bang" singularities in this temporal part. The critical energy density is also limited and it helps the universe to avoid the "temporal Big Bang" singularities and then analogous "frozen epochs" also appear. As a consequence the universe periodically moves from spatial to temporal frozen epoch and back. At the present time the universe moves toward the temporal frozen epoch. The scalar curvature is calculated and the Cosmic Microwave Background radiation is explained. This model can be supported by the recent observations with the JWS Telescope, as it provided observation of many large galaxies close to the last singularity.

New slow-roll approximations for inflationary models with the Gauss-Bonnet term and nonminimal coupling.

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We propose new versions of the slow-roll approximation for inflationary models with the Gauss-Bonnet term and nonminimally coupled scalar fields. We derive more precise expressions for the standard slow-roll parameters as functions of the scalar field. Using numerical analysis, we investigate the inflationary dynamics and find that the proposed slow-roll approximations are more accurate and provide more precise estimations for inflationary parameters compared to the previously known ones.

Sasaki-Ricci flow and deformations of contact action-angle coordinates on spaces $T^{1,1}$ and $Y^{p,q}$

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We are concerned with completely integrable Hamiltonian systems and generalized action-angle coordinates in the setting of contact geometry. We investigate the deformations of the Sasaki-Einstein structures, keeping the Reeb vector field fixed, but changing the contact form. We examine

the modifications of the action-angle coordinates by the Sasaki-Ricci flow. We then pass to the particular cases of the contact structures of the five-dimensional Sasaki-Einstein manifolds $T^{1,1}$ and $Y^{p,q}$.

Operational verification of the existence of a spacetime manifold

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We argue that there exists an operational way to establish the observability of the notions of space and time. Specifically, we propose a theory-independent protocol for a gedanken-experiment, whose outcome is a signal establishing the observability of the spacetime manifold, without a priori assuming its existence. The experimental signal contains the information about the dimension and the topology of spacetime (with the currently achievable precision), and establishes its manifold structure, while respecting its underlying diffeomorphism symmetry. We also introduce and discuss appropriate criteria for the concept of emergence of spacetime, which any tentative theoretical model of physics must satisfy in order to claim that spacetime does emerge from some more fundamental concepts.

Real Quantum Mechanics in a Kähler Space

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Complex numbers are central to the traditional formulation of quantum mechanics in complex Hilbert spaces. However, whether their use represents a fundamental necessity — as opposed to mere convenience — remains an open question. While several real-number reformulations of quantum mechanics have been proposed, we focus here on a framework proposed in [1] that recasts quantum mechanics within real Kähler spaces.

This Kähler-space formulation retains all defining features of quantum mechanics while introducing a critical advantage: it naturally embeds a Hamiltonian symplectic structure akin to classical mechanics. This alignment unifies classical and quantum dynamics under a shared geometric perspective. Furthermore, we demonstrate that finite-dimensional quantum systems exhibit manifest ergodicity within this framework, resolving long-standing interpretive ambiguities inherent to conventional complex formulations. Relations with p-dic and adelic quantum mechanics will be also discussed.

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Scatering of UHECR at small pitch angle by plasma wave turbulence

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Modification of hillas limit due to geometry of turbulence and resonant interaction with damped plasma waves.

Brownian Motion in the p-Adic Integers is a Limit of Discrete Time Random Walks

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Vladimirov defined an operator on balls in $\mathbb{Q}_p$, the p-adic numbers, analogous to the Laplace operator in the real setting. Kochubei later gave a probabilistic interpretation of this operator. The Vladimirov–Kochubei operator generates a real-time diffusion process in the ring of p-adic integers, a Brownian motion in $\mathbb{Z}_p$. The current work proves that this process is a limit of discrete-time random walks. It motivates the construction of the Vladimirov–Kochubei operator, provides further intuition about ultrametric diffusion, and gives an example of the weak convergence of stochastic processes in a profinite group.

Cosmology: 100 years after A. A. Friedmann

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A. A. Friedmann (04.06.1888 – 16.09.1925) proposed the first physical cosmological models in 1920s. Despite the fact that Friedmann's works were very famous soon after their publication, the study of dynamic models of the Universe in the USSR was actually banned in the 30s - 50s of the last century, and Soviet philosophers and propagandists wrote that models of the evolving Universe were invented by Lemaitre on the demand of the Roman Pope, because according to Soviet philosophers such the birth of the universe is very similar to the divine creation of the world described in the Bible. Thus, in the USSR, Friedman's works were in oblivion. Only in 1962, the Soviet Academy of Sciences held a special session dedicated to the 75th anniversary of A. A. Friedmann, P. L. Kapitsa in his speech noted that Friedman's mathematical works allowed us to understand the world in which we live. P. L. Kapitsa said that "... the name of Friedman has been in undeserved oblivion until now. This is unfair and it needs to be corrected. We must perpetuate this name. After all, Friedman is one of the pioneers of Soviet physics, a scientist who made a great contribution to domestic and world science." In 1963 , an article by Ya . B . Zeldovich was published, where he spoke about the significance of Friedman's work for cosmology, and in addition, in 1963 Zeldovich began to mention Gamov's work on the hot Universe model for the first time in Soviet scientific literature. Undoubtedly, the courage and boldness of Zeldovich for such actions were necessary for this, since Gamov was persona non grata for the official Soviet science of that time. We recall development of cosmology in Russia and in particular, achievements of Soviet radio astronomers in CMB studies. We discuss our recent results in gravitation and cosmology.

Planck length and metric geometry

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There is reason to believe (I.V.Volovich's hypothesis) that on Planck scales the geometry of space-time is non-Archimedean. However, the mechanism of geometry substitution during the transition to Planck scales has not been studied. The report will address this problem in the language of metric geometry. In particular, an explicit construction will be proposed for the geodesic between Archimedean and non-Archimedean spaces in the Gromov-Hausdorff space.

Unification of Conformal and Fuzzy Gravities with Internal Interactions based on the $SO(10)$ GUT

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Based on the observation that the dimension of the tangent space is not necessarily equal to the dimension of the corresponding curved manifold and on the known fact that gravitational theories can be formulated in a gauge theoretic way, we discuss how to describe all known interactions in

a unified manner. This is achieved by enlarging the tan- gent group of the four-dimensional manifold to $SO(2,16)$, which permits the inclusion of both gauge groups, the one that describes gravity as a gauge theory as well as the $SO(10)$ GUT. The gravity theories to be discussed are the Conformal and Fuzzy gravities.

p-Adic Quantum Mechanics, Quantum Walks, and the Discreteness of Space

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The talk aims to discuss our recent results on p-adic quantum mechanics. In the Dirac-von Neumann formulation of quantum mechanics (QM), the states of a (closed) quantum system are vectors of an abstract complex Hilbert space $\mathcal{H}$. A particular choice of space $\mathcal{H}$ goes beyond the mathematical formulation and belongs to the domain of physical practice and intuition. In practice, selecting a particular Hilbert space also implies choosing a topology for the space. The standard choice $\mathcal{H} = L(\mathbb{R}^3)$ implies that we are assuming that space $(\mathbb{R}^3)$ is continuous, i.e., it is an arcwise topological space, meaning a continuous path joins any two points in the space. Let us denote by $\mathbb{Q}_p$ the field of p-adic numbers; here, p is a fixed prime number. The space $\mathbb{Q}_p^3$ is 'discrete', i.e., the points and the empty set are the only connected subsets. The Hilbert spaces $L^2(\mathbb{R}^3)$, $L^2(\mathbb{Q}_p^3)$ are isometric, but the geometries of the underlying spaces $(\mathbb{R}^3,\ \mathbb{Q}_p^3)$ are radically different. By p-adic QM, we mean QM on $L^2(\mathbb{Q}_p^3)$; in this case, the time is a real number, but the position is a p-adic vector.

We first discuss the physical content of the p-adic Schrodinger equation. Recently, we found a connection between the mentioned equation and continuous-time quantum walks (CTQWs). In [1], we established that the 2-adic Schrodinger equation describes the scaling limit of a continuous-time

quantum walk in $\mathbb{Q}_p$. Using our results, we can recover the CTQWs introduced by Farhi and Gutmann,[2]. In quantum information theory, quantum walks are used extensively as algorithmic tools for quantum computation. In [3], we constructed a family of CTQWs using the solutions of the p-adic Schrodinger equation for some infinite potential wells. In practical terms, the QM on $\mathbb{C}^{2^l}$ (which is used in quantum computing) is a type of 2-adic QM.

The p-adic Schrodinger operators are nonlocal, which allows long-distance interactions. Thus, by definition, the p-adic QMis a nonlocal theory. Now, by the paradigm that the universe is not locally real, we have to choose between locality and realism. Since p-adic QM is nonlocal, we have that it is 'real.' Performing a Wick rotation, the p -adic Schrodinger equation becomes a p-adic heat equation, which describes a particle performing a random motion in a fractal space.

In p-adic QM, by definition, the Lorentz symmetry is broken. In [4], in the framework of the Dirac-von Neumann formalism, we introduce a new p-adic Dirac equation that predicts the existence of particles and antiparticles and charge conjugation like the standard one. We show that an isolated quantum system whose evolution is controlled by the p -adic Dirac equation does not satisfy the Einstein causality, which means that the speed of light is not the upper limit for the speed at which conventional matter or energy can travel through space.

In [5], in the p-adic framework, we develop the mathematical model for the two-slit experiment. In this model, each particle goes through one slit only. A similar description of the two-slit experiment was given in [6]: "Instead of a quantum wave passing through both slits, we have a localized particle with nonlocal interactions with the other slit." We obtain the same conclusion, but in our framework, the nonlocal interactions result from the discreteness of the space $\mathbb{Q}_p^3$.

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Ekaterina Pozdeeva (Moscow, Russia)
Igor Prlina (Belgrade, Serbia)
Natasa Przulj (Abu Dhabi, UAE)
Voja Radovanovic (Belgrade, Serbia)
Zoran Rakić (Belgrade, Serbia)
Miloje Rakocevic (Belgrade, Serbia)
Igor Salom (Belgrade, Serbia)
Miguel A.F. Sanjuan (Madrid, Spain)
Emmanuel Saridakis (Athens, Greece)
George Savvidy (Athens, Greece)
Branislav Sazdovic (Belgrade, Serbia)
Khodr Shamseddine (Manitoba, Canada)
Vladimir Skarka (Belgrade, Serbia)
Paul Sorba (Annecy, France)
Jelena Stanković (Belgrade, Serbia)
Dejan Stojkovic (Buffalo, USA)
Ilaria Svampa (Camerino, Italy)
Bosiljka Tadic (Ljubljana, Slovenia)
Francesco Toppan (Rio de Janeiro, Brazil)
Kostadin Trencevski (Skopje,

North Macedonia)
Branko Urosevic (Belgrade, Serbia)
Sergey Vernov (Moscow, Russia)
Mihai Visinescu (Bucharest, Romania)
Marko Vojinovic (Belgrade, Serbia)
Igor Volovich (Moscow, Russia)
David Weisbart (Riverside, USA)
Evgeny Zelenov (Moscow, Russia)
Rade Zivaljevic (Belgrade, Serbia)
George Zoupanos (Athens, Greece)
Wilson Zuniga-Galindo (Brownsville, USA)