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Abstracts of Award Winning and Honorable Mention Essays for 2020

Award Essays

First Award – **The Noise of Gravitons** by Maulik Parikh[1][2], Frank Wilczek[1][3][4][5], and George Zahariade[2]; [1]Department of Physics, Arizona State University, Tempe, AZ 85287, [2]Beyond: Center for Fundamental Concepts in Science, Arizona State University, Tempe, AZ 85287, [3]Department of Physics, Stockholm University, Stockholm SE-106 91, Sweden, [4]Center for Theoretical Physics, Massachusetts Institute of Technology, Cambridge, MA 02139, [5]Wilczek Quantum Center, Department of Physics and Astronomy, Shanghai Jiao Tong University, Shanghai 200240, China; e-mail: maulik.parikh@asu.edu, frank.wilczek@asu.edu, george.zahariade@asu.edu

Abstract – We show that when the gravitational field is treated quantum-mechanically, it induces fluctuations – noise – in the lengths of the arms of gravitational wave detectors. The characteristics of the noise depend on the quantum state of the gravitational field, and can be calculated exactly in several interesting cases. For coherent states the noise is very small, but it can be greatly enhanced in thermal and (especially) squeezed states. Detection of this fundamental noise would constitute direct evidence for the quantization of gravity and the existence of gravitons.

Second Award – **Lorentzian Quintessential Inflation** by David Benisty[1][2] and Eduardo I. Guendelman[1][2][3]; [1]Physics Department, Ben-Gurion University of the Negev, Beer-Sheva 84105, Israel, [2]Frankfurt Institute for Advanced Studies (FIAS), Ruth-Moufang-Strasse 1, 60438 Frankfurt am Main, Germany, [3]Bahamas Advanced Study Institute and Conferences, 4A Ocean Heights, Hill View Circle, Stella Maris, Long Island, The Bahamas; e-mail: benidav@post.bgu.ac.il, guendel@bgu.ac.il

Abstract – From the assumption that the slow roll parameter $\in$ has a Lorentzian form as a function of the e-folds number *N*, a successful model of a quintessential inflation is obtained. The form corresponds to the vacuum energy both in the inflationary and in the dark energy epochs. The form satisfies the condition to climb from small values of $\in$ to 1 at the end of the inflationary epoch. At the late universe $\in$ becomes small again and this leads to the Dark Energy epoch. The observables that the models predicts fits with the latest Planck data: $r \sim 10^{-3}$, $n_s \approx 0.965$. Naturally a large dimensionless factor that exponentially amplifies the inflationary scale and exponentially suppresses the dark energy scale appears, producing a sort of *cosmological see saw mechanism*. We find the corresponding scalar Quintessential Inflationary potential with two flat regions – one inflationary and one as a dark energy with slow roll behavior.

Third Award – **A Proof of the Strong Cosmic Censorship Conjecture** by Shahar Hod; The Ruppin Academic Center, Emeq Hefer 40250, Israel and The Hadassah Institute, Jerusalem 91010, Israel; e-mail: shaharhod@gmail.com

Abstract – The Penrose strong cosmic censorship conjecture asserts that Cauchy horizons inside dynamically formed black holes are unstable to remnant matter fields that fall into the black holes. The physical importance of this conjecture stems from the fact that it provides a necessary condition for general relativity to be a truly deterministic theory of gravity. Determining the fate of the Penrose conjecture in non-asymptotically flat black-hole spacetimes has been the focus of intense research efforts in recent years. In the present essay we provide a remarkably compact proof, which is based on Bekenstein's generalized second law of thermodynamics, for the validity of the intriguing Penrose conjecture in physically realistic (dynamically formed) curved black-hole spacetimes.

Fourth Award – **Cosmological Constant in Coherent Quantum Gravity** by Craig Hogan; University of Chicago, 5640 S. Ellis Ave., Chicago, IL 60637 and Fermilab; e-mail: craighogan@uchicago.edu

Abstract – It is argued that quantum states of geometry, like those of particles, should be coherent on light cones of any size. An exact classical solution, the gravitational shock wave of a relativistic point particle, is used to estimate gravitational drag from coherent energy flows, and the expected gravitational effect of virtual transverse vacuum energy fluctuations on surfaces of causal diamonds. It is proposed that the appropriately spacetime-averaged gravitational effect of the Standard Model vacuum state leads to the observed small nonzero value of the cosmological constant, dominated by gravitational drag of virtual gluonic strings at the strong interaction scale.

Fifth Award – **Principle of Equivalence at Planck Scales and the Zero-Point-Length of Spacetime – A Synergistic Description of Quantum Matter and Geometry** by T. Padmanabhan; IUCAA, Pune University Campus, Ganeshkhind, Pune – 411 007, India; e-mail: paddy@iucaa.in

Abstract – At mesoscopic scales close to, but somewhat larger than, Planck length one could describe quantum spacetime and matter in terms of a quantum-corrected geometry. The key feature of such a description is the introduction of a zero-point-length into the spacetime. When we proceed from quantum geometry to quantum matter, the zero-point-length will introduce corrections in the propagator of matter field in a specific manner. On the other hand, one cannot ignore the self gravity of matter fields at the mesoscopic scales and this will also modify the form of the propagator. Consistency demands that, these two modifications coming from two different directions, are the same. I show that this non-trivial demand is actually satisfied. Surprisingly, the principle of equivalence, operating at Planck scales, ensures this consistency in a subtle manner.

Honorable Mention Awards **(Alphabetical Order)**

1. **How Black Holes Store Information in High-Order Correlations** by Charis Anastopoulos and Konstantina Savvidou; Department of Physics, University of Patras, 26500 Greece; e-mail: anastop@upatras.gr, ksavvidou@upatras.gr

Abstract – We explain how Hawking radiation stores significant amount of information in high-order correlations of quantum fields. This information can be retrieved by multi-time measurements on the quantum fields close to the black hole horizon. This result requires no assumptions about quantum gravity, it takes into account the differences between Gibbs's and Boltzmann's accounts of thermodynamics, and it clarifies misconceptions about key aspects of Hawking radiation and about informational notions in QFT.

2. **Quantum Weak Equivalence Principle and the Gravitational Casimir Effect in Superconductors** by Sebastian Bahamonde[1], Mir Faizal[2][3][4], James Q. Quach[5], and Richard A. Norte[6][7]; [1]Laboratory of Theoretical Physics, Institute of Physics, University of Tartu, W. Ostwaldi 1, 50411 Tartu, Estonia, [2]Department of Physics and Astronomy, University of Lethbridge, 4401 University Drive, Lethbridge, Alberta T1K 3M4, Canada, [3]Irving K. Barber School of Arts and Sciences, University of British Columbia - Okanagan, 3333 University Way, Kelowna, British Columbia V1V 1V7, Canada, [4]Canadian Quantum Research Center, 204-3002, 32 Ave, Vernon, BC, V1T 2L7, Canada, [5]Institute for Photonics and Advanced Sensing and School of Chemistry and Physics, The University of Adelaide, South Australia 5005, Australia, [6]Department of Precision and Microsystems Engineering, Delft University of Technology, Mekelweg 2, 2628CD Delft, The Netherlands, [7]Kavli Institute of Nanoscience, Delft University of Technology, Lorentzweg 1, 2628CJ Delft, The Netherlands; e-mail: sbahamonde@ut.ee, mirfaizalmir@googlemail.com, quach.james@gmail.com, r.a.norte@tudelft.nl

Abstract – We will use Fisher information to properly analyze the quantum weak equivalence principle. We argue that gravitational waves will be partially reflected by superconductors. This will occur as the violation of the weak equivalence principle in Cooper pairs is larger than the surrounding ionic lattice. Such reflections of virtual gravitational waves by superconductors can produce a gravitational Casimir effect, which may be detected using currently available technology.

3 **Demystification of Non-Relativistic Theories in Curved Background** by Rabin Banerjee; S. N. Bose National Centre for Basic Sciences, JD Block, Sector III, Salt Lake City, Kolkata -700 106, India; e-mail: rabin@bose.res.in

Abstract - We discuss a new formalism for constructing a non-relativistic (NR) theory in curved background. Named as Galilean gauge theory, it is based on gauging the global Galilean symmetry. It provides a systematic algorithm for obtaining the covariant curved space time generalization of any NR theory defined in flat space time. The resulting background is just the Newton-Cartan manifold. The example of NR free particle is explicitly demonstrated.

4. **Maximum Force and Naked Singularities in Higher Dimensions** by John D. Barrow; DAMTP, University of Cambridge, Wilberforce Rd., Cambridge CB3 0WA, United Kingdom; e-mail: J.D.Barrow@damtp.cam.ac.uk

Abstract – We discuss the existence of maximum forces in 3 + 1 dimensional spacetimes and show that the existence of a mass-independent maximum force does not occur in general relativity in spaces of more than three dimensions. Instead, the maximum force increases with the masses of merging objects as $M^{\left(\frac{N-3}{N-2}\right)}$ and allows unbounded gravitational forces to occur. This suggests that naked singularities can arise in more than three dimensions because they are unprotected by a maximum force at the horizon surface. This creates a new perspective on the expectation of naked singularities in higher dimensions.

5. **Angle Deficit and Non-Local Gravitoelectromagnetism around a Slowly Spinning Cosmic String** by Jens Boos; Theoretical Physics Institute, University of Alberta, Edmonton, AB T6G 2E1, Canada; e-mail: boos@ualberta.ca

Abstract – Cosmic strings, as remnants of the symmetry breaking phase in the Early Universe, may be susceptible to non-local physics. Here we show that the presence of a Poincaré-invariant non-locality–parametrized by a factor $\exp(-\Box \ell^2)$ –regularizes the gravitational field and thereby changes the properties of spacetime: it is now simply connected and the angle deficit around the cosmic string becomes a function of the radial distance. Similar changes occur for the non-local gravitomagnetic field of a rotating cosmic string, and we translate these mathematical facts into the language of non-local gravitoelectromagnetism and thereby provide a physical interpretation. We hope that these insights might prove helpful in the search for traces of non-local physics in our Universe.

6. **Four Metrics** by Michael Creutz; Senior Physicist Emeritus, Physics Department, Brookhaven National Laboratory, Upton, NY 11973; e-mail: mike@latticeguy.net

Abstract – A central idea in general relativity is that physics should not depend on the space-time coordinates in use. But the qualitative description of various phenomena can appear superficially quite different. Here we consider falling into a classical black hole using four distinct but equivalent metrics. First is the Schwarzchild case, with extreme time dilation at the horizon. Second, rescaling the dilation allows falling into the hole in finite proper time. Third, time and space are rescaled into a Penrose motivated picture where light trajectories all have unit slope. Fourth, a white hole variation of the second metric allows passage out through the horizon, with reentry forbidden.

7. **Gravitational Fields of the Magnetic-Type** by A. Danehkar; Department of Astronomy, University of Michigan, 1085 S. University Avenue, 311 WH, Ann Arbor, MI 48109; e-mail: danehkar@umich.edu

Abstract – Local conformal symmetry introduces the conformal curvature (Weyl tensor) that gets split into its (gravito-) electric and magnetic (tensor) parts. Newtonian tidal forces are expected from the gravitoelectric field, whereas general-relativistic frame-dragging effects emerge from the gravitomagnetic field. The symmetric, traceless gravitoelectric and gravitomagnetic tensor fields can be visualized by their eigenvectors and eigenvalues. In this essay, we depict the gravitoelectric and gravitomagnetic fields around a slowly rotating black hole. This suggests that the phenomenon of ultra-fast outflows observed at the centers of active galaxies may give evidence for the gravitomagnetic fields of spinning supermassive black holes. We also question whether the current issues in our contemporary observations might be resolved by the inclusion of gravitomagnetism on large scales in a perturbed FLRW model.

8. **Will Gravitational Waves Discover the First Extra-Galactic Planetary System?** by Camilla Danielski[1] and Nicola Tamanini[2]; [1]UCL CSED, Atlas Building, Office G23 - 25, Fermi Avenue, Harwell Campus, Didcot, OX11 0QR, United Kingdom, [2]Max-Planck-Institut für Gravitationsphysik, Albert-Einstein-Institut, Am Mühlenberg 1, 14476 Potsdam-Golm, Germany; e-mail: camilla.danielski@cea.fr, nicola.tamanini@aei.mpg.de

Abstract – Gravitational waves have opened a new observational window through which some of the most exotic objects in the Universe, as well as some of the secrets of gravitation itself, can now be revealed. Among all these new discoveries, we recently demonstrated that space-based gravitational wave observations will have the potential to detect a new population of massive circumbinary exoplanets everywhere inside our Galaxy. In this essay we argue that these circumbinary planetary systems can also be detected outside the Milky Way, in particular within its satellite galaxies. Space-based gravitational wave observations might thus constitute the means to detect the first extra-galactic planetary system, a target beyond the reach of standard electromagnetic searches.

9. **There Is no Coincidence after All!** by Saurya Das; Theoretical Physics Group, Department of Physics and Astronomy, University of Lethbridge, 4401 University Drive, Lethbridge, Alberta T1K 3M4, Canada; e-mail: saurya.das@uleth.ca

Abstract – We show that if Dark Matter is made up of light bosons, they form a Bose-Einstein condensate in the early Universe, This in turn naturally induces a Dark Energy of approximately equal density and exerting negative pressure. This explains the so-called coincidence problem.

10. **Ricci Linear Weyl/Maxwell Mutual Sourcing: Electric Current from Spacetime Curvature** by Aharon Davidson and Tomer Ygael; Physics Department, Ben-Gurion University of the Negev, Beer-Sheva 84105, Israel; e-mail: davidson@bgu.ac.il, tomeryg@post.bgu.ac.il

Abstract – We elevate the field theoretical similarities between Maxwell and Weyl vector fields into a full local scale/gauge invariant Weyl/Maxwell mutual sourcing theory. In its simplest form, and exclusively in 4-dimensions, the associated Lagrangian is scalar field free, hosts no fermion matter fields, and Holdom kinetic mixing can be switched off. The theory is then characterized by the following distinctive features: (i) The Weyl/Maxwell mutual sourcing term is necessarily spacetime curvature (not just metric) dependent, implying that (ii) A non-vanishing spacetime curvature can induce an electric current. (iii) In line with Weyl-Dirac (and Einstein-Hilbert) action, the mutual sourcing term is inevitably Ricci linear, and comes thus with the bonus that (iv) The co-divergence of the Maxwell vector field plays the role of a dilaton.

11. **Dark Matter, Dark Energy, and Fundamental Acceleration** by Douglas Edmonds[1], Djordje Minic[2], and Tatsu Takeuchi[2]; [1]Department of Physics, Penn State Hazleton, Hazleton, PA 18202, [2]Department of Physics, Virginia Tech, Blacksburg, VA 24061; e-mail: bde12@psu.edu, dminic@vt.edu, takeuchi@vt.edu

Abstract – We discuss the existence of an acceleration scale in galaxies and galaxy clusters and its relevance for the nature of dark matter. The presence of the same acceleration scale found at very different length scales, and in very different astrophysical objects, strongly supports the existence of a *fundamental* acceleration scale governing the observed gravitational physics. We comment on the implications of such a fundamental acceleration scale for constraining cold dark matter models as well as its relevance for structure formation to be explored in future numerical simulations.

12. **Predictivity Lost, Predictivity Regained: a Miltonian Cosmic Censorship Conjecture** by Roberto Emparan; Institució Catalana de Recerca i Estudis Avançats (ICREA) Passeig Lluís Companys 23, E-08010 Barcelona, Spain and Departament de Física Quàntica i Astrofísica, Institut de Ciències del Cosmos, Universitat de Barcelona, Martí i Franquès 1, E-08028 Barcelona, Spain; e-mail: emparan@ub.edu

Abstract – Cosmic censorship is known to fail in some well-controlled phenomena, calling into question the predictive power of General Relativity and opening up the possibility of observing Planck-scale physics. We propose that the cosmic censorship conjecture can be amended so that its spirit prevails. Naked singularities that, classically, have zero mass are allowed. Physically, these are Planck-sized 'black holes', which evaporate in a few Planck times. General Relativity fails only for a tiny interval in time, to then quickly regain control in a Miltonian evolution that returns us to the predictive paradise of Einstein's equations. If this refinement of the conjecture is correct, then, even though Nature does allow to expose breakdowns in the smooth fabric of spacetime, it limits them to a mostly harmless minimum.

13. **How Close Is Our ΛCDM Physical Universe to de Sitter dS_4 Spacetime?** by Arthur E. Fischer; Department of Mathematics, University of California, Santa Cruz, California 95064; e-mail: aef@ucsc.edu

Abstract – We introduce a methodology for *quantitatively* measuring *at all times* how close our physical ΛCDM universe is to de Sitter spacetime dS_4 by studying and comparing the scale factors $a_{\Lambda\mathrm{CDM}}(t)$ and $a_\Lambda(t)$ of these two spacetimes. The main idea in this study is to align these two scale factors by calibrating an adjustable parameter A_0 that arises naturally in the de Sitter scale factor by requiring that these scale factors be *future-asymptotically convergent*. Once this parameter is adjusted and the *scale factors* are aligned, we can define a normalized **Convergence Index**

$$\mathrm{Cdex}(t) \equiv \frac{a_\Lambda^2(t) - a_{\Lambda CDM}^2(t)}{a_\Lambda^2(t)}$$

that computes how close the *line elements* of these two spacetimes are to one another. Thus, for example, at the present time t_0 = 13.796 Gy, to an accuracy of 12.99%, and at $2t_0$ = 27.592 Gy, to an accuracy of 1.18%, our ΛCDM cosmology can be replaced by de Sitter spacetime. As a by-product of our results, we *prove that the* ΛCDM *universe with cosmological constant* Λ *converges as the universe expands to the de Sitter spacetime with de Sitter radius* $\ell = \sqrt{3/\Lambda}$ *and constant sectional curvature* ${}^{(4)}K = 1/\ell^2 = \Lambda/3$.

14. **Information Loss Paradox Revisited: Farewell Firewall?** by Wen-Cong Gan[1] and Fu-Wen Shu[2][3][1]; [1]GCAP-CASPER, Physics Department, Baylor University, Waco, TX, 76798-7316, [2]Department of Physics, Nanchang University, No. 999 Xue Fu Avenue, Nanchang, 330031, China, [3]Center for Relativistic Astrophysics and High Energy Physics, Nanchang University, No. 999 Xue Fu Avenue, Nanchang 330031, China; e-mail: Wen-cong_Gan1@baylor.edu, shufuwen@ncu.edu.cn

Abstract – Unitary evolution makes pure state on one Cauchy surface evolve to pure state on another Cauchy surface. Outgoing Hawking radiation is only subsystem on the late Cauchy surface. The requirement that Hawking radiation to be pure amounts to require purity of subsystem when total system is pure. We will see this requirement will lead to firewall even in *flat* spacetime, and thus is invalid. Information is either stored in the entanglement between field modes inside black hole and the outgoing modes or stored in correlation between geometry and Hawking radiation when singularity is resolved by quantum gravity effects. We will give a simple argument that even in semi-classical regime, information is (at least partly) stored in correlation between geometry and Hawking radiation.

15. **Horizons 2020** by D. Grumiller[1], M.M. Sheikh-Jabbari[2][3], and C. Zwikel[1];
[1]Institute for Theoretical Physics, TU Wien, Wiedner Hauptstr. 8, A-1040 Vienna, Austria, [2]School of Physics, Institute for Research in Fundamental Sciences (IPM), P.O.Box 19395-5531, Tehran, Iran, [3]The Abdus Salam ICTP, Strada Costiera 11, Trieste, Italy; e-mail: grumil@hep.itp.tuwien.ac.at, jabbari@theory.ipm.ac.ir, zwikel@hep.itp.tuwien.ac.at

Abstract – Horizons of black holes or cosmologies are peculiar loci of spacetime where interesting physical effects take place, some of which are probed by recent (EHT and LIGO) and future experiments (ET and LISA). We discuss that there are boundary degrees of freedom residing at the horizon. We describe their symmetries and their interactions with gravitational waves. This fits into a larger picture of boundary plus bulk degrees of freedom and their interactions in gauge theories. Existence and dynamics of the near horizon degrees of freedom could be crucial to address fundamental questions and apparent paradoxes in black holes physics.

16. **The Hidden Scalar Lagrangians within Horndeski Theory** by Gregory W. Horndeski;
2814 Calle Dulcinea, Santa Fe, NM 87505-6425; e-mail: horndeskimath@gmail.com

Abstract – In this essay I show that there exists a new way to obtain scalar-tensor field theories by combining a special scalar field on the cotangent bundle with a scalar field on spacetime. These two scalar fields act as a generating function for the metric tensor. When using these two scalar fields in the Horndeski Lagrangians, we discover, while seeking Friedmann-Lemaître-Robertson-Walker type cosmological solutions, that hidden in the Horndeski Lagrangians are non-degenerate second-order scalar Lagrangians. In accordance with Ostrogradsky's work, these hidden scalar Lagrangians lead to multiple vacuum solutions, and thereby predict the existence of the multiverse. The multiverse is comprised of numerous different types of individual universes. *E.g.*, some begin explosively, and then coast along exponentially forever at an accelerated rate, while others begin in that manner, and then stop expanding and contract.

17. **Scrambling and the Black Hole Atmosphere** by Ted Jacobson[1] and Phuc Nguyen[2];
[1]Maryland Center for Fundamental Physics, University of Maryland, College Park, MD 20742, [2]Department of Physics and Astronomy, Lehman College, City University of New York, Bronx, NY 10468; e-mail: jacobson@umd.edu, n.hong.phuc@gmail.com

Abstract – We argue that the black hole scrambling time is the same as the time for the thermal atmosphere to fall across the horizon or escape, to be replaced by new atmosphere. We propose that these times agree because the physical scrambling process is part and parcel of the atmosphere refreshment process. This goes some way toward explaining why the scrambling is nonlocal, and therefore how it can be so fast.

18. **A Possible Thermodynamic Origin of the Space-Time Minimum Length** by Qing-Quan Jiang, Yan Han, and Jin Pu; School of Physics, University of Electronic Science and Technology of China, Chengdu, Sichuan 610054, China and College of Physics and space science, China West Normal University, Nanchong 637002, China; e-mail: qqjiangphys@yeah.net, wsygnqr@126.com, pujin@cwnu.edu.cn

Abstract – In this paper, by applying the generalized uncertainty principle (GUP) at the final stage of black hole evaporation, we have proposed a thermodynamic explanation for the minimal scale of quantum gravity, i.e. it may stem from the basic requirements of the third law of thermodynamics for quantum gravitation system. At the same time, we have interestingly found that the third law of black hole thermodynamics acts as a supervisor in quantum gravity spacetime to ensure the causality of the spacetime as that does in classical gravity.

19. **Screening Away the H_0 Tension** by Jose Beltrán Jiménez [1], Dario Bettoni[1], and Philippe Brax[2]; [1]Departamento de Física Fundamental and IUFFyM, Universidad de Salamanca, E-37008, Salamanca, Spain, [2]Université Paris-Saclay, CNRS, CEA, Institute de physique théorique, 91191, Gif-sur-Yvette, France; e-mail: jose.beltran@usal.es, bettoni@usal.es, philippe.brax@cea.fr

Abstract – This Essay explores consequences of a dark non-linear electromagnetic sector in a Universe with a net dark charge for matter. The cosmological dynamics can be described by a Lemaître model and understood thanks to a screening mechanism driven by the electromagnetic non-linearities that suppress the dark force on small scales. Only at low redshift, when the screening scale enters the Hubble horizon, do cosmological structures commence to feel the dark repulsion. This repulsive force enhances the local value of the Hubble constant, thus providing a promising scenario for solving the Hubble tension. Remarkably, the dark electromagnetic interaction can have a crucial impact on peculiar velocities, i.e. introducing a bias in their reconstruction methods, and having the potential to explain the presence of a dark flow.

20. **On Three-Body Decay Rates** by Barak Kol; Racah Institute of Physics, Hebrew University, Jerusalem 91904, Israel; e-mail: barak.kol@mail.huji.ac.il

Abstract – The gravitational three-body problem is generically chaotic and negative energy motions generically decay to a binary + free body. We define and determine the system's differential decay rate within the ergodic approximation.

21. **Analytic Infinite Derivative Gravity, R^2-like Inflation, Quantum Gravity and CMB** by Alexey S. Koshelev[1], K. Sravan Kumar[2], and Alexei A. Starobinsky[3]; [1]Departamento de Física, Centro de Matemática e Aplicações (CMA-UBI), Universidade da Beira Interior, 6200 Covilhã, Portugal, [2]Van Swinderen Institute, University of Groningen, 9747 AG, Groningen, The Netherlands, [3]L. D. Landau Institute for Theoretical Physics RAS, Moscow 119334, Russian Federation; e-mail: alex.koshelev@ubi.pt, sravan.korumilli@rug.nl, sravan.mph@icloud.com, alstar@landau.ac.ru

Abstract – Emergence of R^2 inflation which is the best fit framework for CMB observations till date comes from the attempts to attack the problem of quantization of gravity which in turn have resulted in the trace anomaly discovery. Further developments in trace anomaly and different frameworks aiming to construct quantum gravity indicate an inevitability of non-locality in fundamental physics at small time and length scales. A natural question would be to employ the R^2 inflation as a probe for signatures of non-locality in the early Universe physics. Recent advances of embedding R^2 inflation in a string theory inspired non-local gravity modification provides very promising theoretical predictions connecting the non-local physics in the early Universe and the forthcoming CMB observations.

22. **Geometry Creates Inertia** by Amitabha Lahiri; S. N. Bose National Centre for Basic Sciences, JD Block, Sector III, Salt Lake, Kolkata – 700106; e-mail: amitabha@bose.res.in

Abstract – The dynamics of fermions in curved spacetime is governed by a spin connection, a part of which is contorsion, an auxiliary field independent of the metric, without dynamics but fully expressible in terms of the axial current density of fermions. Its effect is the appearance of a quartic interaction involving all fermions. Contorsion can couple to left and right-handed fermions with different strengths, leading to an effective mass for fermions propagating on a background containing fermionic matter.

23. **Testing Gravity with Neutrinos: from Classical to Quantum Regime** by Giuseppe Gaetano Luciano and Luciano Petruzziello; Università degli Studi di Salerno and INFN, Sezione di Napoli; e-mail: gluciano@sa.infn.it, lupetruzziello@unisa.it

Abstract – In this manuscript, we survey the main characteristics that provide neutrinos with the capability of being the perfect candidate to test gravity. A number of potentially resourceful scenarios is analyzed, with particular emphasis on how the versatility of neutrinos lends itself to understand the multifaceted nature of the gravitational interaction, both at classical and quantum scales. As a common thread running through the two different regimes, we consider the fundamental principles underpinning General Relativity and its possible quantum extensions. The Essay is completed with a discussion on some open problems and future perspectives.

24. **Nonsingular Black Holes from Charged Dust Collapse: A Concrete Mechanism to Evade Interior Singularities in General Relativity** by Rodrigo Maier; Departamento de Física Teórica, Instituto de Física, Universidade do Estado do Rio de Janeiro, Rua São Francisco Xavier 524, Maracanã, CEP20550-900, Rio de Janeiro, Brazil; e-mail: rodrigo.maier@uerj.br

Abstract – In this essay we examine the gravitational collapse of a nonrelativistic charged perfect fluid interacting with a dark energy component. Given a simple factor for the energy transfer, we obtain a nonsingular interior solution which naturally matches the Reissner-Nordström-de Sitter exterior geometry. We also show that the interacting parameter is proportional to the overall charge of the final black hole thus formed. For the case of quasi-extremal configurations, we propose a statistical model for the entropy of the collapsed matter. This entropy extends Bekenstein's geometrical entropy by an additive constant proportional to the area of the extremal black hole.

25. **Ghost Problems from Pauli-Villars to Fourth-Order Quantum Gravity and their Resolution** by Philip D. Mannheim; Department of Physics, University of Connecticut, Storrs, CT 06269; e-mail: philip.mannheim@uconn.edu

Abstract – We review the history of the ghost problem in quantum field theory from the Pauli-Villars regulator theory to currently popular fourth-order derivative quantum gravity theories. While these theories all appear to have unitarity-violating ghost states with negative norm, we show that in fact these ghost states only appear because the theories are being formulated in the wrong Hilbert space. In these theories the Hamiltonians are not Hermitian but instead possess an antilinear symmetry. Consequently, one cannot use inner products that are built out of states and their Hermitian conjugates. Rather, one must use inner products built out of states and their conjugates with respect to the antilinear symmetry, and these latter inner products are positive. In this way one can build quantum theories of gravity in four spacetime dimensions that are unitary.

26. **From Microscopic Black Hole Entropy toward Hawking Radiation** by Jun Nian[1] and Leopoldo A. Pando Zayas[1][2]; [1]Leinweber Center for Theoretical Physics, University of Michigan, Ann Arbor, MI 48109, [2]The Abdus Salam International Centre for Theoretical Physics, 34014 Trieste, Italy; e-mail: nian@umich.edu, lpandoz@umich.edu

Abstract – The AdS/CFT correspondence has recently provided a novel approach for counting the microstates of black holes impressively matching the macroscopic Bekenstein-Hawking entropy formula of rotating electrically charged asymptotically AdS black holes in 4, 5, 6, and 7 dimensions. This approach is designed for supersymmetric extremal black holes, but can also be extended to non-supersymmetric, near-extremal black holes. Besides the dual higher dimensional boundary CFT, an effective 2d CFT emerges in a certain near-horizon limit accounting for both the extremal and the near-extremal black hole entropies. This effective 2d description is universal across dimensions and comes naturally equipped with an approach to quantitatively tackle aspects of Hawking radiation.

27. **Quasilocal Conservation Laws in Cosmology: a First Look** by Marius Oltean[1], Hossein Bazrafshan Moghaddam[2], and Richard J. Epp[3]; [1]Institute of Space Studies of Catalonia (IEEC), Carrer del Gran Capità, 2-4, Edifici Nexus, despatx 201, 08034 Barcelona, Spain, [2]Department of Physics, Faculty of Science, Ferdowsi University of Mashhad, Mashhad, Iran, [3]Department of Physics and Astronomy, University of Waterloo, 200 University Avenue West, Waterloo, Ontario N2L 3G1, Canada; e-mail: oltean@ice.cat, hbazrafshan@um.ac.ir, rjepp@uwaterloo.ca

Abstract – Quasilocal definitions of stress-energy-momentum—that is, in the form of boundary densities (in lieu of local volume densities)—have proven generally very useful in formulating and applying conservation laws in general relativity. In this essay, we take a first basic look into applying these to cosmology, specifically using the Brown-York quasilocal stress energy-momentum tensor for matter and gravity combined. We compute this tensor and present some simple results for a flat FLRW spacetime with a perfect fluid matter source.

28. **Can a Closed Universe Mimic a Flat Universe and be Inflationary and Free of Cosmological Problems?** by Murat Özer; Department of Physics, Faculty of Arts and Sciences, Yildiz Technical University, 34220 Esenler, Istanbul, Turkey; e-mail: mhozer@yildiz.edu.tr

Abstract – We attempt to treat the initial state of the Universe according to Quantum Mechanics. Assuming that the Universe came into existence as a free particle through a quantum tunneling, it had to have a nonzero initial size required by the uncertainty principle. This particle, the Universe, may then be associated with a spreading Gaussian wave packet. Invoking the correspondence principle, the spreading and the width of the wave packet are identified with the expansion and the scale factor of the Universe, and the expression for the scale factor is obtained. Assuming that the Universe contained a scalar field only when it started, its expansion according to the law obtained required the creation of radiation and the Universe had to have a closed 3-geometry. It so happens that the energy density of the scalar field cancels the curvature term in the Friedmann equation giving rise to an effective curvature constant which is zero. Thus the Universe mimics an open inflationary Universe and is free of the cosmological problems of the standard model. The details of the expansion of the Universe are considered and its accelerated expansion today are remarked.

29. **You Can See a Clock Running Backwards in Time** by M. B. Paranjape; Groupe de physique des particules, Département de physique and Centre de recherche mathématiques, Université de Montréal, C.P. 6128, succ. centre-ville, Montréal, Québec, Canada, H3C 3J7; e-mail: paranj@lps.umontreal.ca

Abstract – The epitome of acausal or anti-chronological behaviour would be to see a clock running backwards in time. In this essay we point out that this is indeed possible, but there is no problem with causality. What you see isn't what is really happening. Locally, causality is always respected. However our observation should be cause for pause to astronomers and cosmologists, who strictly observe events occurring at very large distances or very long ago and certainly not locally. It can be that what you see isn't what you necessarily get.

30. **Neutron Stars as Probes of Dark Matter** by M. A. Pérez-García[1] and Joseph Silk[2][3][4]; [1]Department of Fundamental Physics, University of Salamanca, Plaza de la Merced s/n 37008 Spain, [2]Institut d'Astrophysique, UMR 7095 CNRS, Sorbonne Université, 98bis Blvd Arago, 75014 Paris, France, [3]Department of Physics and Astronomy, The Johns Hopkins University, Homewood Campus, Baltimore MD 21218, [4]Beecroft Institute of Particle Astrophysics and Cosmology, Department of Physics, University of Oxford, Oxford OX1 3RH, UK; e-mail: mperezga@usal.es, silk@iap.fr

Abstract – Neutron Stars (NSs) are compact stellar objects that are stable solutions in General Relativity. Their internal structure is usually described using an equation of state that involves the presence of ordinary matter and its interactions. However there is now a large consensus that an elusive sector of matter in the Universe, described as dark matter, remains as yet undiscovered. NSs should contain both types of matter. We argue that depending on the nature of the dark matter and in certain circumstances, the two matter components would form a mixture inside NSs that could trigger further changes, some of them observable. The very existence of NSs constrains the nature and interactions of dark matter in the Universe.

31. **Signatures of Minimal Length from Casimir-Polder Forces with Neutrons** by Fabrizio Pinto; Izmir University of Economics, Ekospace Center and Department of Aerospace Engineering, Faculty of Engineering, Teleferik Mahallesi, Sakarya Cd. No:156, 35330 Balçova İzmir, Republic of Turkey; e-mail: fabrizio.pinto@ieu.edu.tr

Abstract – In this essay it is shown that low energy neutron scattering experiments can provide a gain in excess of 18 orders of magnitude in constraining corrections to the Casimir-Polder potential due to minimal length scenarios.

32. **A Symmetry Principle for Emergent Spacetime** by Edgar Shaghoulian; Department of Physics, Cornell University, Ithaca, NY 14850 and 600 Warren Road #4-3F, Ithaca, NY 14850; e-mail: eshaghoulian@cornell.edu

Abstract – There are many examples where geometry and gravity are concepts that emerge from a theory of quantum mechanics without gravity. This suggests thinking of gravity as an exotic phase of matter. Quantifying this phase requires some sort of symmetry principle or order parameter that captures its appearance. In this essay we propose higher-form symmetries as a symmetry principle underlying emergent spacetime. We explore higher-form symmetries in gauge-gravity duality and explain how their breaking describes features of a gravitational theory. Such symmetries imply the existence of nonlocal objects in the gravitational theory – in gauge-gravity duality these are the strings and branes of the bulk theory – giving an alternative way to understand the nonlocality necessary in any ultraviolet completion of gravity.

33. **Nature Does Not Play Dice at the Planck Scale** by Tejinder P. Singh; Tata Institute of Fundamental Research, Homi Bhabha Road, Mumbai 400005, India; e-mail: tpsingh@tifr.res.in

Abstract – We start from classical general relativity coupled to matter fields. Each configuration variable and its conjugate momentum, as also space-time points, are raised to the status of matrices [equivalently operators]. These matrices obey a deterministic Lagrangian dynamics at the Planck scale. By coarse-graining this matrix dynamics over time intervals much larger than Planck time, one derives quantum theory as a low energy emergent approximation. If a sufficiently large number of degrees of freedom get entangled, spontaneous localisation takes place, leading to the emergence of classical space-time geometry and a classical universe. In our theory, dark energy is shown to be a large-scale quantum gravitational phenomenon. Quantum indeterminism is not fundamental, but results from our not probing physics at the Planck scale.

34. **Non-Abelian Firewall** by Douglas Singleton; Physics Department, California State University Fresno, Fresno, CA 93740; e-mail: dougs@mail.fresnostate.edu

Abstract – A simple, closed-form solution to the Yang-Mills field equations is presented which has a non-Abelian firewall - a spherical "horizon" where the energy density diverges. By the gravity/gauge duality, this non-Abelian firewall implies the existence of a gravitational firewall. Gravitational firewalls have been proposed as a way of resolving the information loss paradox, but at the cost of violating the equivalence principle.

35. **Resolving Hubble Tension with the Milne Model** by Ram Gopal Vishwakarma; Unidad Académica de Matemáticas, Universidad Autónoma de Zacatecas, C.P. 98068, Zacatecas, ZAC, Mexico; e-mail: vishwa@uaz.edu.mx

Abstract – The recent measurements of the Hubble constant based on the standard ΛCDM cosmology reveal an underlying disagreement between the early-Universe estimates and the late-time measurements. Moreover, as these measurements improve, the discrepancy not only persists but becomes even more significant and harder to ignore. The present situation places the standard cosmology in jeopardy and provides a tantalizing hint that the problem results from some new physics beyond the ΛCDM model. It is shown that a non-conventional theory - the Milne model, which introduces a different evolution dynamics for the Universe, alleviates the Hubble tension significantly. Moreover, the model also averts some long-standing problems of the standard cosmology, for instance, the problems related with the cosmological constant, the horizon, the flatness, the Big Bang singularity, the age of the Universe and the non-conservation of energy.

36. **Self-Gravitating Dark Matter Gets in Shape** by Jenny Wagner; Universität Heidelberg, Zentrum für Astronomie, Mönchhofstr. 12–14, 69120 Heidelberg, Germany; email: j.wagner@uni-heidelberg.de

Abstract – In our current best cosmological model, the vast majority of matter in the Universe is dark, consisting of yet undetected, non-baryonic particles that do not interact electro-magnetically. So far, the only significant evidence for dark matter has been found in its gravitational interaction, as observed in galaxy rotation curves or gravitational lensing effects. The inferred dark matter agglomerations follow almost universal mass density profiles that can be reproduced well in simulations, but have eluded an explanation from a theoretical viewpoint. Forgoing standard (astro-)physical methods, I show that it is possible to derive these profiles from an intriguingly simple mathematical approach that directly determines the most likely spatial configuration of a self-gravitating ensemble of collisionless dark matter particles.