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Abstracts of Award Winning and Honorable Mention Essays for 2019

Award Essays

First Award – **Information Content of the Gravitational Field of a Quantum Superposition** by Alessio Belenchia[1], Robert M. Wald[2], Flaminia Giacomini[3], Esteban Castro-Ruiz[3], Časlav Brukner[3], and Markus Aspelmeyer[3]; [1]Centre for Theoretical Atomic, Molecular, and Optical Physics, School of Mathematics and Physics, Queen's University, Belfast BT7 1NN, United Kingdom, [2]Enrico Fermi Institute and Department of Physics, The University of Chicago, 5640 South Ellis Avenue, Chicago, Il 60637, [3]Institute for Quantum Optics and Quantum Information (IQOQI), Boltzmanngasse 3, 1090 Vienna, Austria; e-mail:
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Abstract – When a massive quantum body is put into a spatial superposition, it is of interest to consider the quantum aspects of the gravitational field sourced by the body. We argue that in order to understand how the body may become entangled with other massive bodies via gravitational interactions, it must be thought of as being entangled with its own Newtonian-like gravitational field. Thus, a Newtonian-like gravitational field must be capable of carrying quantum information. Our analysis supports the view that table-top experiments testing entanglement of systems interacting via gravity do probe the quantum nature of gravity, even if no "gravitons" are emitted during the experiment.

Second Award – **Non-Perturbative de Sitter Vacua via α′ Corrections** by Olaf Hohm[1] and Barton Zwiebach[2]; [1]Institute for Physics, Humboldt University Berlin, Zum Groβen Windkanal 6, D-12489 Berlin, Germany, [2]Center for Theoretical Physics, Massachusetts Institute of Technology, Cambridge, MA 02139; e-mail: ohohm@physik.hu-berlin.de, zwiebach@mit.edu

Abstract –The higher-derivative α′ corrections consistent with $O(d,d)$ duality invariance can be completely classified for cosmological, purely time-dependent backgrounds. This result is used to show that there are duality invariant theories featuring de Sitter vacua as solutions that are non-perturbative in α′, thus suggesting that classical string theory may realize de Sitter solutions in an unexpected fashion.

Third Award – **Can Fermionic Dark Matter Mimic Supermassive Black Holes?** by C. R. Argüelles[1], A. Krut[2], J. A. Rueda[2][3], and R. Ruffini[2][4]; [1]Instituto de Astrofisica de La Plata, (CCT La Plata, CONICET, UNLP), Paseo del Bosque, B1900FWA La Plata, Argentina, [2]ICRANet, Piazza della Repubblica 10, I-65122 Pescara, Italy, [3]INAF, Istituto de Astrofisica e Planetologia Spaziali, Via Fosso del Cavaliere 100, 00133 Rome, Italy, [4]INAF, Viale del Parco Mellini 84, 00136 Rome, Italy; e-mail: charly@carina.fcaglp.unlp.edu.ar, andreas.krut@icranet.org, jorge.rueda@icra.it, ruffini@icra.it

Abstract – We analyze the intriguing possibility to explain both dark mass components in a galaxy: the dark matter (DM) halo and the supermassive dark compact object lying at the center, by a unified approach in terms of a quasi-relaxed system of massive, neutral fermions in general relativity. The solutions to the mass distribution of such a model that fulfill realistic halo boundary conditions inferred from observations, develop a highly-density core supported by the fermion degeneracy pressure able to mimic massive black holes at the center of galaxies. Remarkably, these *dense core-diluted halo* configurations can explain the dynamics of the closest stars around Milky Way's center (SgrA*) all the way to the halo rotation curve, without spoiling the baryonic bulge-disk components, for a narrow particle mass range $mc^2 \sim 10\text{-}10^2$ keV.

Fourth Award – **How to Hide a Cosmological Constant** by Steven Carlip; Department of Physics, University of California, Davis, CA 95616; e-mail: carlip@physics.ucdavis.edu

Abstract – Naive calculations in quantum field theory suggest that vacuum fluctuations should induce an enormous cosmological constant. What if these estimates are right? I argue that even a huge cosmological constant might be hidden in Planck scale fluctuations of geometry and topology—what Wheeler called “spacetime foam”—while remaining virtually invisible macroscopically.

Fifth Award – **Einstein's Dream** by Richard T. Hammond, Department of Physics and Astronomy, University of North Carolina at Chapel Hill, Chapel Hill, NC 27599 and Army Research Office, Research Triangle Park, 800 Park Offices Dr, Durham, NC 27703; e-mail: rhammond@email.unc.edu

Abstract – It is shown the antisymmetric part of the metric tensor is the potential for the torsion field, which arises from intrinsic spin. To maintain gauge invariance, the nonsymmetric part of the metric tensor must be generalized to include the electromagnetic field. This result leads to a link between the cosmological constant and the electromagnetic field.

Honorable Mention Awards **(Alphabetical Order)**

1. **IR Quantum Gravity Solves Naturally Cosmic Acceleration and its Coincidence Problem** by Fotios K. Anagnostopoulos[1], Georgios Kofinas[2], and Vasilios Zarikas[3][4]; [1]National and Kapodistrian University of Athens, Physics Department, Panepistimioupoli Zografou, 15772 Athens, Greece, [2]Research Group of Geometry, Dynamical Systems and Cosmology, Department of Information and Communication Systems Engineering, University of the Aegean, Karlovassi 83200 Samos, Greece, [3]Theory Division, General Department, University of Thessaly, Greece, [4]Nazarbayev University, School of Engineering, Astana, Republic of Kazakhstan, 010000; e-mail: fotis-anagnostopoulos@hotmail.com, gkofinas@aegean.gr, vzarikas@teiste.gr

Abstract – The novel idea is that the undergoing accelerated expansion of the universe happens due to infrared quantum gravity modifications at intermediate astrophysical scales of galaxies or galaxy clusters, within the framework of Asymptotically Safe gravity. The reason is that structures of matter are associated with a scale-dependent positive cosmological constant of quantum origin. In this context no extra unproven energy scales or fine-tuning are used. Furthermore, this model was confronted with the most recent observational data from a variety of probes, and with aid of Bayesian analysis, the most probable values of the free parameters were extracted. Finally, the model proved to be statistically equivalent with ΛCDM, and thus being able to resolve naturally the concept of dark energy and its associated cosmic coincidence problem.

2. **Cosmic Inflation without Inflaton** by Gustavo Arciniega[1], Pablo Bueno[2] , Pablo A. Cano[3], José D. Edelstein[4], Robie A. Hennigar[5], and Luisa G. Jaime[6]; [1]Centro Tecnológico, Facultad de Estudios Superiores Aragón, Universidad Nacional Autónoma de México, Av. Rancho Seco S/N, Col. Impulsora Popular Avícola, Nezahualcóyotl, Estado de México, 57130, México, [2]Instituto Balseiro, Centro Atómico Bariloche, S. C. de Bariloche, Río Negro, R8402AGP, Argentina, [3]Instituto de Física Teórica UAM/CSIC, C/ Nicolás Cabrera, 13-15, C.U. Cantoblanco, 28049 Madrid, Spain, [4]Departamento de Física de Partículas, Instituto Galego de Física de Altas Enerxías (IGFAE), Universidade de Santiago de Compostela, E-15782 Santiago de Compostela, Spain, [5]Department of Mathematics and Statistics, Memorial University of Newfoundland, St. Johns, Newfoundland and Labrador, A1C 5S7, Canada, [6]Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México, A.P. 70-543 CDMX 04510, Mexico; e-mail: gustavo.arciniega@gmail.com, pablo@itf.fys.kuleuven.be, pablo.cano@uam.es jose.edelstein@usc.es, rhennigar@mun.ca, luisa.jaime1@gmail.com

Abstract – We propose a novel explanation for universe's inflationary period. We argue that when the Einstein-Hilbert action is supplemented by an infinite tower of higher-curvature terms—selected order by order by the criterion that they give rise to a well-posed cosmological evolution—the usual Big Bang characteristic of Einstein gravity is replaced by a singularity-free period of exponential growth of the scale factor, which is gracefully connected with standard late-time ΛCDM cosmology. No inflaton or any additional fields besides the metric are required.

3. **Is Gravity Actually the Curvature of Spacetime?** by Sebastian Bahamonde[1][2] and Mir Faizal[3][4]; [1]Laboratory of Theoretical Physics, Institute of Physics, University of Tartu, W. Ostwaldi 1, 50411 Tartu, Estonia, [2]Department of Mathematics, University College London, Gower Street, London, WC1E 6BT, United Kingdom, [3]Department of Physics and Astronomy, University of Lethbridge, 4401 University Drive, Lethbridge, Alberta T1K 3M4, Canada, [4]Irving K. Barber School of Arts and Sciences, University of British Columbia - Okanagan, 3333 University Way, Kelowna, British Columbia V1V 1V7, Canada; e-mail: sbahamonde@ut.ee, sebastian.beltran.14@ucl.ac.uk, mirfaizalmir@googlemail.com

Abstract – The Einstein equations, apart from being the classical field equations of General Relativity, are also the classical field equations of two other theories of gravity. As the experimental tests of General Relativity are done using the Einstein equations, we do not really know, if gravity is the curvature of a torsionless spacetime, or torsion of a curvatureless spacetime, or if it occurs due to the non-metricity of a curvatureless and torsionless spacetime. However, as the classical actions of all these theories differ from each other by boundary terms, and the Casimir effect is a boundary effect, we propose that a novel gravitational Casimir effect between superconductors can be used to test which of these theories actually describe gravity.

4. **Bright Primordial Extremal Black Holes** by Yang Bai and Nicholas Orlofsky; Department of Physics, University of Wisconsin-Madison, 1150 University Avenue, Madison, WI 53706-1390; e-mail: yang.bai@wisc.edu, norlofsky@wisc.edu

Abstract – We show that primordial (nearly) extremal black holes could exist in our current Universe and provide a viable explanation for dark matter, given a dark electromagnetism and a heavy dark electron. When primordial black holes are formed, the spatial fluctuation of dark charge distributions naturally provide a dark charge hair for black holes, which prevents black holes from total evaporation via Hawking radiation. The discharge process via the Schwinger effect is also dramatically suppressed because of the heaviness of the dark electron. In the current era of the universe, the temperatures of these near-extremal black holes have a simple relation to their masses: $T \sim 10^4\,^{\circ}\mathrm{C} \times \sqrt{M/g}$. Observing the black-body radiation signals from isolated black holes, black hole-dark electron atomic states, and black-hole binary merging events could provide a direct test of Hawking radiation.

5. **Do We Come from a Quantum Anomaly?** By Spyros Basilakos[1][2], Nick E. Mavromatos[3], and Joan Solà Peracaula[4]; [1]Academy of Athens, Research Center for Astronomy and Applied Mathematics, Soranou Efessiou 4, 115 27 Athens, Greece, [2]National Observatory of Athens, Lofos Nymfon, 11852, Athens, Greece, [3]Theoretical Particle Physics and Cosmology Group, Physics Department, King's College London, Strand, London WC2R 2LS, UK, [4]Departament de Física Quàntica i Astrofísica, and Institute of Cosmos Sciences (ICCUB), Univ. de Barcelona, Av. Diagonal 647 E-08028 Barcelona, Catalonia, Spain; e-mail: svasil@academyofathens.gr, nikolaos.mavromatos@kcl.ac.uk, sola@fqa.ub.edu

Abstract – We present a string-based picture of the cosmological evolution in which (CP-violating) *gravitational anomalies* acting during the inflationary phase of the universe cause the vacuum energy density to "run" with the effective Hubble parameter squared, H^2, thanks to the axion field of the bosonic string multiplet. This leads to baryogenesis through leptogenesis with massive right-handed neutrinos. The generation of chiral matter after inflation helps in cancelling the anomalies in the observable radiation- and matter- dominated eras. The present era inherits the same "*running vacuum*" structure triggered during the inflationary time by the axion field. The current dark energy is thus predicted to be mildly dynamical, and dark matter should be made of axions. Paraphrasing Carl Sagan: *we are all anomalously made from starstuff*.

6. **On Dark Energy and Quantum Gravity** by Per Berglund[1], Tristan Hübsch[2], and Djordje Minić[3]; [1]Department of Physics and Astronomy, University of New Hampshire, Durham, NH 03824, [2]Department of Physics and Astronomy, Howard University, Washington, D.C. 20059, [3]Department of Physics, Virginia Tech, Blacksburg, VA 24061; e-mail: per.berglund@unh.edu, thubsch@howard.edu, dminic@vt.edu

Abstract – Realizing dark energy and the observed de Sitter spacetime in quantum gravity has proven to be obstructed in most every usual approach. We argue that additional degrees of freedom of the left- and right-movers in string theory and a resulting doubled, non-commutatively generalized geometric formulation thereof can lead to an effective model of dark energy consistent with de Sitter spacetime. In this approach, the curvature of the canonically conjugate dual space provides for the dark energy inducing a positive cosmological constant in the observed spacetime, whereas the size of the above dual space is the gravitational constant in the same observed de Sitter spacetime. As a hallmark relation owing to a unique feature of string theory which relates short distances to long distances, the cosmological constant scale, the Planck scale, and the effective TeV-sized particle physics scale must satisfy a see-saw-like formula—precisely the generic prediction of certain stringy cosmic brane type models.

7. **Magic of the Kerr Spinning Gravity: New Scale for Unification of Gravity with Particle Physics** by Alexander Burinskii; Theor. Phys. Laboratory, NSI, Russian Academy of Sciences, B. Tulskaya 52 Moscow 115191 Russia; e-mail: bur@ibrae.ac.ru

Abstract – In particle physics Gravity is considered as the most weak interaction. Meanwhile, it is resists to quantization and to conceptual unification with particle physics. In the same time, the famous Kerr-Newman (KN) solution, being completely compatible with gravity by nature, generates several important properties of the spinning particle, in particular, the obtained by Carter gyromagnetic ratio of the Dirac electron. We investigate this phenomenon and obtain that principal role in compatibility of the KN spinning particle with gravity is played by spin, which due to extreme high spin/mass ratio deforms space topologically, increasing effective scale of gravitational interaction.

8. **How Low Can Vacuum Energy Go when Your Fields Are Finite-Dimensional?** by ChunJun Cao[1], Aidan Chatwin-Davies[2], and Ashmeet Singh[3]; [1]Joint Center for Quantum Information and Computer Science, University of Maryland, College Park, MD 20742, [2]KU Leuven, Institute for Theoretical Physics, Celestijnenlaan 200D B-3001 Leuven, Belgium, [3]Walter Burke Institute for Theoretical Physics, California Institute of Technology, 1200 E. California Blvd., Pasadena, CA 91125; e-mail: ccj991@gmail.com, aidan.chatwindavies@kuleuven.be, ashmeet@caltech.edu

Abstract – According to the holographic bound, there is only a finite density of degrees of freedom in space when gravity is taken into account. Conventional quantum field theory does not conform to this bound, since in this framework, infinitely many degrees of freedom may be localized to any given region of space. In this essay, we explore the viewpoint that quantum field theory may emerge from an underlying theory that is locally finite-dimensional, and we construct a locally finite-dimensional version of a Klein-Gordon scalar field using generalized Clifford algebras. Demanding that the finite dimensional field operators obey a suitable version of the canonical commutation relations makes this construction essentially unique. We then find that enforcing local finite dimensionality in a holographically consistent way leads to a huge suppression of the quantum contribution to vacuum energy, to the point that the theoretical prediction becomes plausibly consistent with observations.

9. **Can the Emergent Gravity Challenge the Standard Particle Dark Matter Paradigm?** by Man Ho Chan; Department of Science and Environmental Studies, The Education University of Hong Kong, Tai Po, New Territories, Hong Kong, China; e-mail: chanmh@eduhk.hk

Abstract – Observations reveal the existence of missing mass (or unseen mass) in our universe. Most astrophysicists believe that the existence of some unknown particles can account for the missing mass. However, some propose that the current gravitational theory may not be correct for large scales so that the existence of missing mass in our universe may be just a delusion. In this article, we discuss and test one of the most popular versions of modified gravity, the Emergent Gravity. We show that the Emergent Gravity theory can simultaneously explain the tight correlations in galaxies and galaxy clusters, which suggests that it is a good theory to challenge the standard particle dark matter paradigm in astrophysics.

10. **Infinite Towers of Supertranslation and Superrotation Memories** by Geoffrey Compère; Université Libre de Bruxelles, Gravitational Wave Centre and International Solvay Institutes, CP 231, B-1050 Brussels, Belgium; e-mail: gcompere@ulb.ac.be

Abstract – A framework that structures the gravitational memory effects and which is consistent with gravitational electric-magnetic duality is presented. A correspondence is described between memory observables, particular subleading residual gauge transformations, associated overleading gauge transformations and their canonical surface charges. The existence of an infinite tower of subleading soft graviton theorems is argued to imply an infinite number of conservation laws at spatial infinity and, in turn, an infinite number of memory effects at null infinity. It is shown that the leading order mutually commuting supertranslations and (novel) superrotations are both associated with a leading displacement memory effect, which suggests the existence of new boundary conditions.

11. **Membrane Gravity Correspondence** by Yogesh Dandekar; International Centre for Theoretical Sciences (ICTS-TIFR), Shivakote, Hesaraghatta Hobli, Bengaluru 560089, India; e-mail: yogesh.dandekar@icts.res.in

Abstract – We discuss a novel description of the dynamics of black holes in terms of the dynamics of 'Membranes'. The membrane description emerges naturally if we consider black holes in the limit of a large number of spacetime dimensions *D*. This 'Large *D* membrane paradigm' can be systematically constructed in a perturbation theory in $1/D$. A similar membrane description can be constructed for the case of finite-dimensional black holes - and it reproduces black hole dynamics correctly in some nontrivial cases - which is quite striking.

12. **Quantum Gravity as an Emergent Phenomenon** by Shounak De, Tejinder P. Singh, and Abhinav Varma; Tata Institute of Fundamental Research, Homi Bhabha Road, Mumbai 400005, India; e-mail: shounakde@alumni.iitg.ac.in, tpsingh@tifr.res.in, abhinav.varma.17@ucl.ac.uk

Abstract – There ought to exist a reformulation of quantum theory which does not depend on classical time. To achieve such a reformulation, we introduce the concept of an atom of spacetime-matter (STM). An STM atom is a classical non-commutative geometry, based on an asymmetric metric, and sourced by a closed string. Different such atoms interact via entanglement. The statistical thermodynamics of a large number of such atoms gives rise, at equilibrium, to a theory of quantum gravity. Far from equilibrium, where statistical fluctuations are large, the emergent theory reduces to classical general relativity. In this theory, classical black holes are far-from-equilibrium low entropy states, and their Hawking evaporation represents an attempt to return to the (maximum entropy) equilibrium quantum gravitational state.

13. **Reflections on the Energy of Black Holes** by Tevian Dray[1] and Carlo Rovelli[2]; [1]Department of Mathematics, Oregon State University, Corvallis, OR 97331, [2]CPT, Aix-Marseille Université, Université de Toulon, CNRS, F-13288 Marseille, France; e-mail: tevian@math.oregonstate.edu, rovelli@cpt.univ-mrs.fr

Abstract – Inside a black hole, there is no *local* way to say which side of a sphere is the inside, and which is the outside. One can easily be gulled by this fact into mixing up the sign of the energy. We lead the reader astray with a naïve treatment of the energy of a null shell in black hole spacetimes. We then resolve the confusion, showing that global, rather than local, considerations offer good guidance.

14. **A Classical Non-Quantum All-Time Time-Symmetric Zero-Energy Single-Bounce Model for the Creation, Big Bang, and Death of the Universe** by Arthur E. Fischer; Department of Mathematics, University of California, Santa Cruz, Santa Cruz, California 95064; e-mail: aef@ucsc.edu

Abstract – In this essay we show how the ΛCDM (Lambda Cold Dark Matter) standard model for cosmology can be extrapolated backwards through the big bang into the infinite past to yield an all-time model of the universe with scale factor given by

$$a_{global}(t) = \left(\frac{\Omega_{m,0}}{\Omega_{\Lambda,0}}\right)^{1/3}\left(\sinh\frac{3}{2}t/t_{\Lambda}\right)^{2/3}$$

defined and continuous for all $t \in (-\infty, \infty)$, and smooth and satisfying Friedmann's equation for all $t \neq 0$. At the big bang $t = 0$, there is a cusp singularity and our model shows the details of the behavior of the universe at this singularity. Our model is a zero-energy single-bounce model and an examination of the $(a, \dot{a})$-plot of the $E = 0$ level curve gives critical information about the big bang and the initial and final states of the universe, and argues in particular that the final state of the universe is *stable* and thus our destiny is sealed. Our results also show that much can be said *classically* about the birth, big bang, and death of the universe before one needs to reach for *quantum* gravitational effects.

15. **Black Holes Have Moment of Inertia** by Yuan K. Ha; Department of Physics, Temple University, Philadelphia, PA 19122; e-mail: yuanha@temple.edu

Abstract – A new property of black holes is found. Every black hole in the universe now has a moment of inertia. The moment of inertia of a Schwarzschild black hole is the rotational equivalent of the rest mass of a moving body. It is exactly equal to *mass* × (*Schwarzschild radius*)^2. Spherical symmetry requires all mass of the black hole to be located at the Schwarzschild radius. The black hole is a hollow massive shell. This surprising result can shed new light on why the entropy of a black hole is proportional to area and not to volume, the singularity issue, the information loss problem, and the perplexing firewall paradox.

16. **Gravity between Newton and Einstein** by Dennis Hansen[1], Jelle Hartong[2], and Niels A. Obers[3][4]; [1]Institut für Theoretische Physik, Eidgenössische Technische Hochschule Zürich, Wolfgang-Pauli-Strasse 27, 8093 Zürich, Switzerland, [2]School of Mathematics and Maxwell Institute for Mathematical Sciences, University of Edinburgh, Peter Guthrie Tait road, Edinburgh EH9 3FD, UK, [3]Nordita, KTH Royal Institute of Technology and Stockholm University, Roslagstullsbacken 23, SE-106 91 Stockholm, Sweden, [4]The Niels Bohr Institute, Copenhagen University, Blegdamsvej 17, DK-2100 Copenhagen Ø, Denmark; e-mail: dehansen@phys.ethz.ch, j.hartong@ed.ac.uk, obers@nbi.ku.dk

Abstract – Statements about relativistic effects are often subtle. In this essay we will demonstrate that the three classical tests of general relativity, namely perihelion precession, deflection of light and gravitational redshift, are passed perfectly by an extension of Newtonian gravity that includes gravitational time dilation effects while retaining a non-relativistic causal structure. This non-relativistic gravity theory arises from a covariant large speed of light expansion of Einstein's theory of gravity that does not assume weak fields and which admits an action principle.

17. **Hawking Radiation May Violate the Penrose 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 – We analyze the Hawking evaporation process of Reissner-Nordström black holes. It is shown that the characteristic radiation quanta emitted by the charged black holes may turn near-extremal black-hole spacetimes into horizonless naked singularities. The present analysis therefore reveals the intriguing possibility that the semi-classical Hawking evaporation process of black holes may violate the fundamental Penrose cosmic censorship conjecture.

18. **Spacetime Equilibrium at Negative Temperature and the Attraction of Gravity** by Ted Jacobson[1] and Manus Visser[2]; [1]Maryland Center for Fundamental Physics, University of Maryland, College Park, MD 20742, [2]Institute for Theoretical Physics, University of Amsterdam, 1090 GL Amsterdam, The Netherlands; e-mail: jacobson@umd.edu, m.r.visser@uva.nl

Abstract – We derive the Einstein equation from the condition that the free conformal energy of all small causal diamonds is equal to that of a flat empty diamond, as would be expected for near-equilibrium states. The attractiveness of gravity hinges on the negativity of the absolute temperature of these diamonds, a property we infer from the generalized entropy.

19. **The Canonical Frame of Purified Gravity** by Jose Beltrán Jiménez[1], Lavinia Heisenberg[2], and Tomi S. Koivisto[3]; [1]Departamento de Física Fundamental, Universidad de Salamanca, E-37008 Salamanca, Spain, [2]Institute for Theoretical Studies, ETH Zurich, Clausiusstrasse 47, 8092 Zurich, Switzerland, [3]Nordita, KTH Royal Institute of Technology and Stockholm University, Roslagstullsbacken 23, 10691 Stockholm, Sweden and Laboratory of Theoretical Physics, Institute of Physics, University of Tartu, W. Ostwaldi 1, 50411 Tartu, Estonia; e-mail: jose.beltran@usal.es, lavinia.heisenberg@gmail.com, tomik@astro.uio.no

Abstract – In the recently introduced gauge theory of translations, dubbed Coincident General Relativity, gravity is described with neither torsion nor curvature in the spacetime affine geometry. The action of the theory enjoys an enhanced symmetry and avoids the second derivatives that appear in the conventional Einstein-Hilbert action. While it implies the equivalent classical dynamics, the improved action principle can make a difference in considerations of energetics, thermodynamics, and quantum theory. This essay reports on possible progress in those three aspects of gravity theory. In the so-called purified gravity, 1) energy-momentum is described locally by a conserved, symmetric tensor, 2) the Euclidean path integral is convergent without the addition of boundary or regulating terms and 3) it is possible to identify a canonical frame for quantization.

20. **Weak Gravity Conjecture in the Sky** by Nemanja Kaloper; Department of Physics, University of California, Davis, CA 95616; e-mail: kaloper@physics.ucdavis.edu

Abstract – We point out that the physics at the extreme IR—cosmology—might provide tests of the physics of the extreme UV—the Weak Gravity Conjecture. The current discrepancies in the determination of H_0 hint at a modification of ΛCDM. On the other hand the discourse on WGC to date suggests that fields which support cosmic acceleration may produce relativistic matter after they traverse a ~ Planckian distance in field space. We explain how this offers a simple realization of the requisite cosmic phenomenology which improves the fits of H_0. Hence a resolution of H_0 discrepancies may be a rare opportunity to link the two extreme limits of quantum field theory.

21. **Is Dark Matter Fact or Fantasy? — Clues from the Data** by Philip D. Mannheim; Department of Physics, University of Connecticut, Storrs, CT 06269; e-mail: philip.mannheim@uconn.edu

Abstract – We discuss arguments both in favor of and against dark matter. With the repeated failure of experiment to date to detect dark matter we discuss what could be done instead, and to this end look for clues in the data themselves. We identify various regularities in galactic rotation curve data that correlate the total gravitational potential with luminous matter rather than dark matter. We identify a contribution to galactic rotation curves coming from the rest of the visible Universe, and suggest that dark matter is just an attempt to describe this global effect in terms of standard local Newtonian gravity within galaxies.

22. **The Nature of the Gravitational Vacuum** by Samir D. Mathur; Department of Physics, The Ohio State University, Columbus, OH 43210; e-mail: mathur.16@osu.edu

Abstract – The vacuum must contain virtual fluctuations of black hole microstates for each mass M. We observe that the expected suppression for $M \gg m_p$ is counteracted by the large number $Exp[S_{bek}]$ of such states. From string theory we learn that these microstates are extended objects that are resistant to compression. We argue that recognizing this 'virtual extended compression-resistant' component of the gravitational vacuum is crucial for understanding gravitational physics. Remarkably, such virtual excitations have no significant effect for observable systems like stars, but they resolve two important problems: (a) gravitational collapse is halted outside the horizon radius, removing the information paradox; (b) spacetime acquires a 'stiffness' against the curving effects of vacuum energy; this ameliorates the cosmological constant problem posed by the existence of a Planck scale Λ.

23. **A Cosmological Basis for $E = mc^2$** by F. Melia; Department of Physics, The Applied Math Program, and Department of Astronomy, The University of Arizona, Tucson AZ 85721; e-mail: fmelia@email.arizona.edu

Abstract – The Universe has a gravitational horizon with a radius $R_h = c/H$ coincident with that of the Hubble sphere. This surface separates null geodesics approaching us from those receding. We see it retreating at proper speed c, giving rise to the eponymously named cosmological model $R_h = ct$. The gravitational radius therefore appears to be highly relevant to cosmological theory, and we here explore its possible impact on fundamental physics by calculating the binding energy of a mass m within R_h, showing that it is equal to mc^2. This energy is stored when the particle is at rest near the observer, transitioning to a purely kinetic form equal to the particle's escape energy when it approaches R_h. In other words, a particle's gravitational coupling to that portion of the Universe with which it is causally connected appears to be the origin of rest-mass energy.

24. **de Sitter Entropy as Entanglement** by K. Narayan; Chennai Mathematical Institute, H1 SIPCOT IT Park, Siruseri 603103, India; e-mail: narayan@cmi.ac.in

Abstract – We describe connected timelike codim-2 extremal surfaces stretching between the future and the past boundaries in the static patch coordinatization of de Sitter space. These are analogous to rotated versions of certain surfaces in the *AdS* black hole. The existence of these surfaces via the *dS/CFT* framework suggests the speculation that dS_4 is dual to two copies of ghost-like CFTs in a thermofield-double-type entangled state. In studies of entanglement in ghost systems and "ghost-spin" chains, we show that similar entangled states in two copies of ghost-spin ensembles always have positive norm and positive entanglement.

25. **The Magical Emergence of Einstein-Hilbert Action from the Quantum Measure for Closed Loops in Spacetime** by T. Padmanabhan; IUCAA, Pune University Campus, Ganeshkhind, Pune-411 007, India; e-mail: paddy@iucaa.in

Abstract – Let $C(\sigma; x)$ be the number of closed loops, of length σ and passing through an event x^i in a spacetime. The total path length contributed by these closed loops, in a spacetime region V, is given by the integral of $L(\sigma; x) \equiv \sigma C(\sigma; x)$ over V. While both $C(\sigma; x)$ and $L(\sigma; x)$ are ill-defined classically, there is a natural definition of a quantum measure for $C(\sigma; x)$ which renders it finite. This measure allows us to use $L(0; x)$ to probe the quantum microstructure of spacetime. Remarkably enough $L(0; x) \propto R(x)$, the Ricci scalar. *Thus the total length contributed by infinitesimal closed loops in a region of spacetime gives us the Einstein-Hilbert action!* This deep relation shows how the quantum nature of spacetime paths can lead to emergent geometrical quantities.

26. **From Topological to Topologically Massive Gravity through the Gauge Principle** by Giandomenico Palumbo; Center for Nonlinear Phenomena and Complex Systems, Universite Libre de Bruxelles, CP 231, Campus Plaine, B-1050 Brussels, Belgium; e-mail: giandomenico.palumbo@ulb.ac.be

Abstract – It is well known that three-dimensional Einstein's gravity without matter is topological, i.e. it does not have local propagating degrees of freedom. The main result of this work is to show that dynamics in the gravitational sector can be induced by employing the gauge principle on the matter sector, which is described by a fermionic term that supports a global gauge symmetry. By gauging this symmetry, a vector-spinor field is added to the original action to preserve the local gauge invariance. Finally, by integrating out this spin-3/2 fermion field, we obtain a gravitational Chern-Simons term, which gives rise to local propagating degrees of freedom in the gravitational sector that is described by topologically massive gravity.

27. **Love in Extrema Ratio** by Paolo Pani and Andrea Maselli; Dipartimento di Fisica, "Sapienza" Università di Roma & Sezione INFN Roma1, Piazzale Aldo Moro 5, 00185, Roma, Italy; e-mail: paolo.pani@uniroma1.it, andrea.maselli@roma1.infn.it

Abstract – The tidal deformability of a self-gravitating object leaves an imprint on the gravitational-wave signal of an inspiral which is paramount to measure the internal structure of the binary components. We unveil here a surprisingly unnoticed effect: in the extreme-mass ratio limit the tidal Love number of the central object (i.e. the quadrupole moment induced by the tidal field of its companion) affects the gravitational waveform at the leading order in the mass ratio. This effect acts as a magnifying glass for the tidal deformability of supermassive objects but was so far neglected, probably because the tidal Love numbers of a black hole (the most natural candidate for a compact supermassive object) are identically zero. We argue that extreme-mass ratio inspirals detectable by the future LISA mission might place constraints on the tidal Love numbers of the central object which are roughly 8 orders of magnitude more stringent than current ones on neutron stars, potentially probing all models of black hole mimickers proposed so far.

28. **Gravitational Waves and Human Evolution: Do We Owe Everything to Binary Neutron Star Mergers?** by Tsvi Piran[1] and Bernard F. Schutz[2]; [1]Racah Institute of Physics, The Hebrew University of Jerusalem, Jerusalem 91904, Israel, [2]School of Physics and Astronomy, Cardiff University, Cardiff CF24 3AA, UK, and Max Planck Institute for Gravitational Physics, Potsdam 14476, Germany; e-mail: tsvi.piran@mail.huji.ac.il, SchutzBF@cardiff.ac.uk

Abstract – The LIGO/Virgo observation of the binary neutron-star merger GW170817 confirmed the role of gravitational-wave (GW) emission in creating such mergers. Follow-up astronomical observations also confirmed that most of the heaviest elements (r-process elements) in the Universe have been made in the resulting explosions. We point out here that the radioactive r-process isotopes ^{238}U and ^{232}Th have assisted biological evolution on Earth, and even particularly the evolution of advanced intelligence, through three different effects: helping keep Earth's iron core molten, powering volcanism and plate tectonics, and supplying a background radiation field that creates mutations. Therefore, even though the GW signals that impinge on Earth are extremely weak, their indirect effect seems to be critical for life as we know it.

29. **On The Behavior of Gravitational Force at Small Scales** by Marco Piva; INFN, Sezione di Pisa, Largo B. Pontecorvo 3, 56127 Pisa, Italy; e-mail: piva0505@gmail.com

We point out the idea that, at small scales, gravity can be described by the standard degrees of freedom of general relativity, plus a scalar particle and a degree of freedom of a new type: the fakeon. This possibility leads to fundamental implications in understanding gravitational force at quantum level as well as phenomenological consequences in the corresponding classical theory.

30. **Is Holography Implicit in Canonical Gravity?** by Suvrat Raju; International Centre for Theoretical Sciences, Tata Institute of Fundamental Research, Shivakote, Bengaluru 560089, India; e-mail: suvrat@icts.res.in

Abstract – We conjecture that, in asymptotically anti-de Sitter space, two solutions of the Wheeler-DeWitt equation that coincide asymptotically must also coincide in the bulk. This suggests that the essential elements of holography are already present in canonical gravity. Our argument sheds light on why holography works only in gravitational theories, and also on the significance of anti-de Sitter boundary conditions.

31. **Strong Gravity Signatures in the Polarization of Gravitational Waves** by S. Shankaranarayanan; Department of Physics, Indian Institute of Technology Bombay, Mumbai 400076, India; e-mail: shanki@phy.iitb.ac.in

General Relativity is a hugely successful description of gravitation. However, both theory and observations suggest that General Relativity might have significant classical and quantum corrections in the *Strong Gravity regime*. Testing the strong field limit of gravity is one of the main objectives of the future gravitational wave detectors. One way to detect strong gravity is through the *polarization of gravitational waves*. For quasi-normal modes of black-holes in General Relativity, the two polarisation states of gravitational waves have the same amplitude and frequency spectrum. Using the principle of energy conservation, we show that, the polarisations differ for modified gravity theories. We obtain a diagnostic parameter for polarization mismatch that provides a unique way to distinguish General Relativity and modified gravity theories in gravitational wave detectors.

32. **Discovering Intermediate Massive Black Holes through Tidally Disrupted Stars** by Martina Toscani[1], Giuseppe Lodato[1], Elena Maria Rossi[2]; [1]Department of Physics, University of Milan, Celoria 16, Milan, 20133, Italy, [2]Leiden Observatory, J.H. Oort Building, Niels Bohrweg 2, NL-2333 CA Leiden, The Netherlands; e-mail: martina.toscani@unimi.it, giuseppe.lodato@unimi.it, emr@strw.leidenuniv.nl

Abstract – Stars are spheres of gas held together by self-gravity. When flying by a black hole, however, the star self-binding force can be overwhelmed by the black hole tides and the star can be torn apart. This is a physically rich and fascinating event which will be described by first introducing the concept of black hole from a mathematical point of view. We will then dive into the physics of the tidal disruption and proceed describing the accompanying electromagnetic flare and gravitational wave burst in the frequency range of the Laser Interferometer Space Antenna. This empowers such events to discover the elusive black holes with mass intermediate between the solar and the million/billion solar masses.

33. **Is Dark Matter Due to Retardation?** by Asher Yahalom; Ariel University, Ariel 40700, Israel; e-mail: asya@ariel.ac.il

Abstract – Galaxies are huge physical systems having dimensions of many tens of thousands of light years. Thus any change at the galactic center will be noticed at the rim only tens of thousands of years later. Those retardation effects seems to be neglected in present day galactic modelling used to calculate rotational velocities of matter in the rims of the galaxy and surrounding gas. The significant differences between the predictions of Newtonian instantaneous action at a distance and observed velocities are usually explained by either assuming dark matter or by modifying the laws of gravity (MOND). In this essay we will show that taking general relativity seriously without neglecting retardation effects one can explain the radial velocities of galactic matter without postulating dark matter.

34. **An Oscillatory Core to Hawking's Information Missing Puzzle** by Ding-fang Zeng; Institute of Theoretical Physics, Beijing University of Technology, China, Bejing 100124; e-mail: dfzeng@bjut.edu.cn

Abstract – We describe in this work a picture for blackholes' inner structure and microscopic state in which matters falling into the horizon or consisting of them are oscillating around instead of accumulating statically on their central point, thus resolving the Schwarzschild singularity naturally. After quantizing, this picture not only blurs the horizon remarkably, but also provides an interpretation for the Bekenstein-Hawking entropy as measures of the number of consisting matters' oscillation modes. Since each microscopic blackhole has its own dynamic mass distribution and special r_h-t curve when evaporating and distinguishable from each other, thermal features of the Hawking radiation are only averaged description of many such objects with equal mass and symmetry, information missing puzzle is solved naturally in our picture.