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Abstracts of Award Winning and Honorable Mention Essays for 2024

Award Essays

First Award – **Holographic Inflation, Primordial Black Holes and Early Structure Formation** by Tom Banks, NHETC and Department of Physics, Rutgers University, Piscataway, NJ 08854-8019; email: tibanks@ucsc.edu and Willy Fischler, Department of Physics and Texas Cosmology Center, Weinberg Institute, Center for Theory, University of Texas, Austin, TX 78712; email: fischler@physics.utexas.edu

Abstract – Evidence has accumulated that there are supermassive black holes (SMBHs) in the centers of most galaxies, and that these were formed in the very early universe by some as yet unknown process. In particular, there is evidence [15] that at least some galaxies formed as early as $10^8 - 10^9$ years after the Big Bang host SMBHs. We suggest that the holographic model of inflation, whose dark matter candidates are primordial black holes carrying a discrete gauge charge, which originated as a small subset of the inflationary horizon volumes in the very early universe, can provide the seeds for this early structure formation. Aspects of the model pointed out long ago suggested an early era of structure formation, with structures dominated by dark matter. The additional assumption that the dark matter consists of discretely charged black holes implies black hole dominance of early structures, which seems to be implied by JWST data.

Second Award – **The Secret Structure of the Gravitational Vacuum** by Samir D. Mathur, Department of Physics, The Ohio State University, Columbus, OH 43210, USA; email: mathur.16@osu.edu

Abstract – We argue that the vacuum of quantum gravity must contain a hierarchical structure of correlations spanning all length scales. These correlated domains (called 'vecros') correspond to virtual fluctuations of black hole microstates. Larger fluctuations are suppressed by their larger action, but this suppression is offset by a correspondingly larger phase space of possible configurations. We give an explicit lattice model of these vecro fluctuations, noting how their distribution changes as the gravitational pull of a star becomes stronger. At the threshold of formation of a closed trapped surface, these virtual fluctuations transition into on-shell black hole microstates (fuzzballs). Fuzzballs radiate from their surface like normal bodies, re-solving the information paradox. We also argue that any model without vecro-type extended vacuum correlations cannot resolve the paradox.

Third Award – **Universal Acceleration and Fuzzy Dark Matter** by Douglas Edmonds, Department of Physics, Penn State Hazleton, Hazleton, PA 18202; email: edmonds@psu.edu, Joshua Erlich, Department of Physics, William and Mary, Williamsburg, VA 23185; email: jxerli@wm.edu, Djordje Minic and Tatsu Takeuchi, Department of Physics, Virginia Tech, Blacksburg, VA 24061; emails: dminic@vt.edu, takeuchi@vt.edu

Abstract – Observations of velocity dispersions of galactic structures over a wide range of scales point to the existence of a universal acceleration scale $a_0 \sim 10^{-10}$ m/s^2. Focusing on the fuzzy dark matter paradigm, which proposes ultralight dark matter with mass around 10^{-22} eV and de Broglie wavelength $\lambda \sim$ few $\times$ 10^2 parsecs, we highlight the emergence of the observed acceleration scale from quantum effects in a fluid-like description of the dark matter dynamics. We then suggest the possibility of a natural connection between the acceleration scale and dark energy within the same paradigm.

Fourth Award – **In Search of the Biggest Bangs since the Big Bang** by John Ellis[1,2], Malcolm Fairbairn[1], Juan Urrutia[3,4] and Ville Vaskonen[4,5,6], [1]TPPC Group, Physics Department, King's College London, Strand WC2R 2LS, UK; [2]Theoretical Physics Department, CERN, CH-1211 Geneva 23, Switzerland; [3]Keemilise ja Bioloogilise Füüsika Instituut, Rävala pst. 10, 10143 Tallinn, Estonia; [4]Department of Cybernetics, Tallinn University of Technology, Akadeemia tee 21, 12618 Tallinn, Estonia; [5]Dipartimento di Fisica e Astronomia, Università degli Studi di Padova, Via Marzolo 8, 35131 Padova, Italy; [6]Istituto Nazionale di Fisica Nucleare, Sezione di Padova, Via Marzolo 8, 35131 Padova, Italy; emails: john.ellis@cern.ch, malcolm.fairbairn@kcl.ac.uk, juan.urrutia@kbfi.ee, ville.vaskonen@kbfi.ee

Abstract – Many galaxies contain supermassive black holes (SMBHs), whose formation and history raise many puzzles. Pulsar timing arrays have recently discovered a low-frequency cosmological "hum" of gravitational waves that may be emitted by SMBH binary systems, and the JWST and other telescopes have discovered an unexpectedly large population of high-redshift SMBHs. We argue that these two discoveries may be linked, and that they may enhance the prospects for measuring gravitational waves emitted during the mergers of massive black holes, thereby opening the way towards resolving many puzzles about SMBHs as well as providing new opportunities to probe general relativity.

Fifth Award – **Fully Extremal Black Holes: A Black Hole Graveyard?** by Francesco DiFilippo, Institute of Theoretical Physics, Faculty of Mathematics and Physics, Charles University, V Holešovičkách 2, 180 00 Prague 8, Czech Republic, email: francesco.difilippo@matfyz.cuni.cz , Stefano Liberati, SISSA – International School for Advanced Studies, Via Bonomea 265, 34136 Trieste, Italy; IFPU – Institute for Fundamental Physics of the Universe, Via Beirut 2, 34104 Trieste, Italy; INFN Sezione di Trieste, Via Valerio 2, 34127 Trieste, Italy; email: liberati@sissa.it and Matt Visser, School of Mathematics and Statistics, Victoria University of Wellington, PO Box 600, Wellington 6140, New Zealand; email: matt.visser@sms.vuw.ac.nz

Abstract – While the standard point of view is that the ultimate endpoint of black hole evolution is determined by Hawking evaporation, there is a growing evidence that classical and semi-classical instabilities affect both black

holes with inner horizons as well as their ultra-compact counterparts. In this essay we start from this evidence pointing towards extremal black holes as stable endpoints of the gravitational collapse and develop a general class of spherical and axisymmetric solutions with multiple extremal horizons. Excluding more exotic possibilities, entailing regular cores supporting wormhole throats, we argue that these configurations could be the asymptotic graveyard, the endpoint, of dynamical black hole evolution — albeit the timescale of such evolution are still unclear and possibly long and compatible with current astrophysical observations.

Honorable Mention Awards **(Alphabetical Order)**

1. **Infrared gravity and a celestial obstruction to monogamy constraints** by Francesco Alessio, NORDITA, KTH Royal Institute of Technology and Stockholm University, Hannes Alfv´ens väg 12, SE-11419 Stockholm, Sweden and Department of Physics and Astronomy, Uppsala University, Box 516, SE-75120 Uppsala, Sweden, email: Francesco.alessio@su.se and Michele Arzano, Dipartimento di Fisica "E. Pancini", Università di Napoli Federico II, I-80125 Napoli, Italy and INFN, Sezione di Napoli, Complesso Universitario di Monte S. Angelo, Via Cintia Edificio 6, 80126 Napoli, Italy; email: michele.arzano@na.infn.it

Abstract – We argue that gravitational interactions between particles require a departure from the familiar picture of their quantum states in terms of tensor products of one-particle states. This modification is essential in order to accommodate the existence of a new boost-like relativistic angular momentum charge which pairs of particles must carry asymptotically due to long-range effects of gravity. These findings challenge conventional assumptions, prompting a reevaluation of the constraints on quantum entanglement between particle subsystems in a black hole geometry.

2. **Observable Signatures of No-Scale Supergravity in NANOGrav** by Spyros Basilakos[a,b,c,2], Dimitri V. Nanopoulos [d,e,f,3], Theodoros Papanikolaou[g,h,b,4], Emmanuel N. Saridakis[b,i,j,5], Charalampos Tzerefos[k,b,6], [a]Academy of Athens, Research Center for Astronomy and Applied Mathematics, Soranou Efesiou 4, 11527, Athens, Greece, [b]National Observatory of Athens, Lofos Nymfon, 11852 Athens, Greece, [c]School of Sciences, European University Cyprus, Diogenes Street, Engomi, 1516 Nicosia, Cyprus, [d]George P. and Cynthia W. Mitchell Institute for Fundamental Physics and Astronomy, Texas A&M University, College Station, Texas 77843, [e]Astroparticle Physics Group, Houston Advanced Research Center (HARC), Mitchell Campus, Woodlands, Texas 77381, [f]Academy of Athens, Division of Natural Sciences, Athens 10679, Greece, [g]Scuola Superiore Meridionale,Largo San Marcellino 10, 80138 Napoli, Italy, [h]Instituto Nazionale di Fisica Nucleare (INFN), Sezione di Napoli, Via Cinthia 21, 80126 Napoli, Italy, [i]CAS Key Laboratory for Researches in Galaxies and Cosmology, Department of Astronomy, University of Science and Technology of China, Hefei, Anhui 230026, P. R. China, [j]Departamento de Matemáticas, Universidad Católica del Norte, Avda. Angamos 0610, Casilla 1280 Antofagasta, Chile, [k]Physics Department, University of Athens, Panepistemiopolis, Athens 15783, Greece; emails: [2]svasil@academyofathens.gr, [3]dimitri@physics.tamu.edu, [4]papaniko@noa.gr,[5]msaridak@noa.gr, [6]chtzeref@phys.uoa.gr

Abstract – In light of NANOGrav data we provide for the first time possible observational signatures of Superstring theory. Firstly, we work with inflection-point inflationary potentials naturally realized within Wess-Zumino type no-scale Supergravity, which give rise to the formation of microscopic primordial black holes (PBHs) triggering an early matter-dominated era (eMD) and evaporating before Big Bang Nucleosythesis (BBN). Remarkably, we obtain an abundant production of primordial gravitational waves (PGW) at the frequency ranges of nHz, Hz and kHz and in strong agreement with Pulsar Time Array (PTA) GW data. This PGW background could serve as a compelling observational signature for the presence of quantum gravity via no-scale Supergravity.

3. **Equivalence Principle and Machian Origin of Extended Gravity** by [1]Elmo Benedetto, [2]Christian Corda and [3]Ignazio Licata, [1]Department of Computer Science, University of Salerno, Via Giovanni Paolo II, 132, 84084 Fisciano (Sa), Italy, email: ebenedetto@unisa.it; [2]SUNY Polytechnic Institute, 13502 Utica, New York, email: cordac.galilei@gmail.com, [3]Institute for Scientific Methodology (ISEM) Palermo, Italy, email: ignazio.licata3@gmail.com

Abstract – Chae's analyses on GAIA observations of wide binary stars have fortified the paradigm of extended gravity with particular attention to MOND-like theories. We recall that, starting from the origin of Einstein's general relativity, the request of Mach on the structure of the theory has been the core of the foundational debate. This issue is strictly connected with the nature of the mass-energy equivalence. This was exactly the key point that Einstein used to derive the same general relativity. On the other hand, the current requirements of particle physics and the open questions within extended gravity theories, which have recently been further strengthened by analyses of GAIA observations, request a better understanding of the Equivalence Principle. By considering a direct coupling between the Ricci curvature scalar and the matter Lagrangian a non-geodesic ratio between the inertial and the gravitational mass can be fixed, and MOND-like theories are retrieved at low energies.

4. **Interaction of Gravitational Waves with Matter**, Nigel T. Bishop[1a], Vishnu Kakkat[2b], Amos S. Kubeka[2c], Monos Naidoo[1d], and Petrus J. van der Walt[1e], [1]Department of Mathematics, Rhodes University, Grahamstown 6140, South Africa, [2]Department of Mathematical Sciences, University of South Africa, P.O. Box 392, Pretoria, South Africa; emails: [a]n.bishop@ru.ac.za, [b]kakkav@unisa.ac.za, [c]kubekas@unisa.ac.za, [d]monos.naidoo@gmail.com, [e]peetvdw@worldonline.co.za

Abstract – It is well-known that gravitational waves (GWs) undergo no absorption or dissipation when traversing through a perfect fluid. However, in the presence of a viscous fluid, GWs transfer energy to the fluid medium. In this essay, we present a review of our recent series of results regarding the interaction between gravitational waves and surrounding matter. Additionally, we examine the impact of a viscous fluid shell on gravitational wave propagation, focusing particularly on GW damping and GW heating. Furthermore, we explore the significance of these effects in various astrophysical scenarios such as core-collapse Supernovae and primordial gravitational waves.

5. **R^2 Effectively from Inflation to Dark Energy** by Philippe Brax and Pierre Vanhove, CEA, DSM, Institut de Physique Théorique, IPhT, CNRS, MPPU, URA2306, Saclay, F-91191 Gif-sur-Yvette, France; emails: philippe.brax@ipht.fr , pierre.vanhove@ipht.fr

Abstract – We consider the single-parameter $R+cR^2$ gravitational action and use constraints from astrophysics and the laboratory to derive a natural relation between the coefficient c and the value of the cosmological constant. We find that the renormalization of c from the energy of the inflationary phase to the infrared, where the acceleration of the expansion of the Universe takes place, is correlated with the evolution of the vacuum energy. Our results suggest that the coefficient of the R^2 term may provide an unexpected bridge between high-energy physics and cosmological phenomena such as inflation and dark energy.

6. **Emergent Universe from an Unstable de Sitter Phase** by Molly Burkmar[a,1] and Marco Bruni[a,b,2] ,[a]Institute of Cosmology & Gravitation, University of Portsmouth, Dennis Sciama Building, Burnaby Road, Portsmouth,

PO1 3FX, United Kingdom, [b]INFN Sezione di Trieste, Via Valerio 2, 34127 Trieste, Italy; emails: [1]molly.burkmar@port.ac.uk, [2]marco.bruni@port.ac.uk

Abstract – In the Emergent scenario, the universe should evolve from a non-singular state replacing the typical singularity of General Relativity, for any initial condition. For the scalar field model in [1] we show that only a subset of initial conditions leads to emergence, either from a static state (an Einstein model), or from a de Sitter state.
Assuming a scenario based on CDM interacting with a Dark Energy fluid, we show that in general flat and open models expand from an unstable de Sitter state at high energies; for closed models this state is instead a transition phase with a bounce. All models are non-singular, with a subset accelerating at high energies, going through a matter-dominated decelerated era, then accelerating toward a de Sitter phase.

7. **Emergent universality of free fall from quantum mechanics** by Juan A. Cañas*[1], A. Martín-Ruiz†[1], and J. Bernal[2] ,[1]Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México, 04510 Ciudad de México, México, [2]División Académica de Ciencias Básicas, Universidad Juárez Autónoma de Tabasco, 86690, Cunduacán, Tabasco, México; emails: *juan.canas@correo.nucleares.unam.mx, †alberto.martin@nucleares.unam.mx

Abstract – Classical and quantum mechanical descriptions of motion are fundamentally different. The universality of free fall (UFF) is a distinguishing feature of the classical motion (which has been verified with astonishing precision), while quantum theory tell us only about probabilities and uncertainties thus breaking the UFF. There are strong reasons to believe that the classical description must emerge, under plausible hypothesis, from quantum mechanics. In this Essay we show that the UFF is an emergent phenomenon: the coarse-grained quantum distribution for high energy levels leads to the classical distribution as the lowest order plus quantum corrections. We estimate the size of these corrections on the Eötvös parameter and discuss the physical implications.

8. **Black hole horizons must be veiled by photon spheres** by Raúl Carballo-Rubio and Astrid Eichhorn CP3-Origins, University of Southern Denmark, Campusvej 55, DK-5230 Odense M, Denmark; emails: raul@sdu.dk , eichhorn@cp3,sdu.dk

Abstract – Horizons and bound photon orbits are defining features of black holes that translate into key features of black hole images. We present a purely geometric proof that spherically symmetric, isolated objects with horizons in gravity theories with null-geodesic propagation of light must display bound photon orbits forming a photon sphere. Identifying the key elements of the proof, we articulate a simpler argument that carries over to more general situations with modified light propagation and implies the existence of equatorial spherical photon orbits in axisymmetric spacetimes with reflection symmetry. We conclude that the *non*-observation of photon rings with very-large-baseline interferometry would be a very strong indication against a horizon, irrespective of whether or not the image shows a central brightness depression.

9. **On the measurements in Quantum Gravity** by Juanca Carrasco-Martinez, Department of Physics, University of California, Berkeley, California 94720; Theoretical Physics Group, Lawrence Berkeley National Laboratory, Berkeley, California 94720; email: jc.carrasco@berkeley.edu

Abstract – In this essay, we argue that certain aspects of the measurement require revision in Quantum Gravity. Using entropic arguments, we propose that the number of measurement outcomes, and the accuracy (or the range) of the measurement are limited by the entropy of the black hole associated with the observer's scale. This also implies the necessity of modifying

the algebra of commutation relationships to ensure a finite representation, changing the Heisenberg Uncertainty Principle in this manner.

10. **An analytic framework modeling the gravitational environment of stars orbiting a galactic supermassive black hole** by Man Ho Chan, Department of Science and Environmental Studies, The Education University of Hong Kong, Tai Po, New Territories, Hong Kong, China; email: chanmh@eduhk.hk

Abstract – The gravitational interplay between a supermassive black hole and dark matter has set up an exotic environment at the center of a galaxy. In this article, I present an analytic framework modeling the gravitational influence on the stars orbiting a galactic supermassive black hole. In particular, we discuss two intriguing features, stellar orbital precession and orbital shrinking, which demonstrate an extraordinary gravitational environment near a galactic supermassive black hole. Moreover, I show that these features can be analytically determined by the supermassive black hole mass.

11. **Distinguishing Bounce and Inflation via Quantum Signatures from Cosmic Microwave Background** by S. Mahesh Chandran and S. Shankaranarayanan, Department of Physics, Indian Institute of Technology Bombay, Mumbai 400076, India; emails: maheshchandran@iitb.ac.in, shanki@iitb.ac.in

Abstract – Cosmological inflation is a popular paradigm for understanding Cosmic Microwave Background Radiation (CMBR); however, it faces many conceptual challenges. An alternative mechanism to inflation for generating an almost scale-invariant spectrum of perturbations is a *bouncing cosmology* with an initial matter-dominated contraction phase, during which the modes corresponding to currently observed scales exited the Hubble radius. Bouncing cosmology avoids the initial singularity but has fine-tuning problems. Taking an *agnostic view* of the two early-universe paradigms, we propose a quantum measure — Dynamical Fidelity Susceptibility (DFS) of CMBR — that distinguishes the two scenarios. Taking two simple models with the same power-spectrum, we explicitly show that DFS behaves differently for the two scenarios. We discuss the possibility of using DFS as a distinguisher in the upcoming space missions.

12. **Consequences of disentanglement** by Hong Zhe (Vincent) Chen, Department of Physics, Broida Hall, University of California, Santa Barbara, CA 93106-9530; email: hzchen@ucsb.edu

Abstract – If entanglement builds spacetime, then conversely, disentanglement ought to destroy spacetime. From the quantum null energy condition and quantum focusing conjecture, we obtain sufficient disentanglement criteria which necessitate infinite energies and strong spacetime singularities. We apply our results to the strong cosmic censorship proposal, where strong singularities at the Cauchy horizons in black holes are desirable. Using our disentanglement criteria and without resorting to any detailed calculations, we provide an exceedingly general and physically transparent explanation of strong cosmic censorship in semiclassical gravity.

13. **Temporal Pound-Rebka experiment as gravitational Aharonov-Bohm effect** by R.Y. Chiao, University of California, Merced, School of Natural Sciences, Merced, CA 95344; email: raymond_chiao@yahoo.com; N. A. Inan, Clovis Community College, 10309 N. Willow, Fresno, CA 93730; University of California, Merced, School of Natural Sciences, Merced, CA 95344 and Department of Physics, California State University Fresno, Fresno, CA 93740-8031; email: ninan@ucmerced.edu; D. A. Singleton, Department of Physics, California State University Fresno, Fresno, CA 93740-8031; email: dougs@mail.fresnostate.edu; M. E. Tobar, Quantum Technologies and Dark Matter Labs,

Department of Physics, University of Western Australia, Crawley, WA 6009, Australia; email: michael.tobar@uwa.edu.au

Abstract – One of the classical tests of general relativity is the precision measurements by Pound and Rebka of red-shift/blue-shift of photons in a gravitational field. In this essay, we lay out a temporal version of the Pound-Rebka experiment. The emission and absorption of photons occurs at different times, rather than at different spatial locations as in the original Pound-Rebka experiment. This temporal Pound-Rebka experiment is equivalent to a gravitational Aharonov-Bohm Effect and is testable via current or near future satellite experiment.

14. **Large Fluctuations in the Sky** by Sayantan Choudhury, Centre For Cosmology and Science Popularization (CCSP), SGT University, Gurugram, Delhi- NCR, Haryana- 122505, India; emails: sayanphysicsisi@gmail.com, sayantan ccsp@sgtuniversity.org

Abstract – Renormalization of quantum loop effects generated from large fluctuations is a hugely debatable topic of research these days which rules out the Primordial Black Hole (PBH) formation within the framework of single-field inflation. In this article, we briefly discuss that the correct implementation of regularization, renormalization, and resummation techniques in a setup described by an ultra-slow-roll phase sandwiched between two slow-roll phases in the presence of smooth or sharp transitions can lead to a stringent constraint on the PBH mass (i.e. $O(10^2\text{gm})$), which we advertise as a new *No-go theorem*. Finally, we will give some of the possible way-outs using which one can evade this proposed *No-go theorem* and produce solar/sub-solar mass PBHs.

15. **The JWST and standard cosmology** by A. A. Coley, Department of Mathematics & Statistics, Dalhousie University, Halifax, Nova Scotia, Canada B3H 3J5; Email: alan.coley@dal.ca

Abstract – Recent observations from the James Webb Space Telescope have identified a population of massive galaxy sources at $z > 7 - 10$, formed less than 700 Myr after the Big Bang. Such massive galaxies do not have enough time to form within the standard cosmological model, and hence these observations pose a significant challenge. A number of possible solutions to this problem have been put forward. In this essay we discuss two more theoretical and speculative possibilities.

16. **Is the Page-time paradox paradoxical?** by Bruno Arderucio Costa, Instituto de Ciencias Nucleares, Universidad Nacional Autonoma de Mexico Apartado Postal 70-543, Cd. Mx., 04510, Mexico; Center for Relativity and Cosmology at Troy University, AL; email: arderucio@alumni.ubc.ca

Abstract – I discuss how five reasonably sounding assumptions lead to a dilemma—the Page-time paradox—, which appears to challenge a conventional statistical mechanical underpinning of black hole thermodynamics. By inspecting the conceptual subtleties behind each hypothesis, I list questions that require clarification before the puzzle can be deemed paradoxical. I devote particular attention to using thermodynamic arguments for a system that never reaches equilibrium. As a proof of concept, I show that the paradox is absent in a modified setting that admits an equilibrium thermodynamics formulation.

17. **Rethinking the Effective Field Theory formulation of Gravity** by Jesse Daas*, Cristobal Laporte, Frank Saueressig and Tim van Dijk, Institute for Mathematics, Astrophysics, and Particle Physics, Radboud University, Nijmegen, The Netherlands; Emails: J.Daas@science.ru.nl, cristobal.laportemunoz@ru.nl, f.saueressig@science.ru.nl, tim.vandijk@ru.nl

Abstract – General relativity is highly successful in explaining a wide range of gravitational phenomena including the gravitational waves emitted by binary systems and the shadows cast by supermassive black holes. From a modern perspective the theory is not fundamental though, but constitutes the lowest order term in an effective field theory description of the gravitational force. Consequently, the gravitational dynamics should receive corrections by higher-derivative terms. This essay discusses structural aspects associated with these corrections and summarizes their imprint on static, spherically symmetric geometries. Along these lines, we critically reassess the common practice of using local field redefinitions in order to simplify the dynamics at the danger of shifting physics effects into sectors which are beyond the approximation under consideration.

18. **Intrinsic Anti-Symmetry of Spacetime Encompasses the Universe** by John Bruce Davies, Dept. of Physics (Retd.), University of Colorado, Boulder, CO 80309, 117 Corbett Ave, Toronto, ON, Canada M6N 1V3; Email: DaviesResearch@yahoo.com

Abstract – By linearizing the Bianch Indentities we obtain conservation laws that include anti-symmetric curvature and metrics, i.e. gravitational fields, with torsion gradients affecting both the curvature and metrics and that antisymmetric curvature is conserved and related to angular momentum. We apply these simplified Einstein-Cartan relations to observed phenomena in the Universe and show the necessity to incorporate anti-symmetric components in order to understand and measure them. At the local non-relativistic level, we show that torsion gradients produced in a kitchen blender result in symmetric and anti-symmetric curvature as predicted. At the extreme densities around the event horizon of a Black-Hole, recent photographs prove the existence of anti-symmetric phenomena. Integrating the governing equations of fluid dynamics and gravitational fields forward in time we have shown that non-linear growth of initial perturbations produces galaxy-sized clumping in the early matter-dominated Universe. Because of anti-symmetry demanding angular momentum conservation, these future galaxies must eventually in totality cancel out their spin directional vectors and amplitudes with numerous recent observations having confirmed these phenomena. Encompassing the wide range of these scales, we have proven the necessity and sufficiency of these conservation laws, that include anti-symmetry of Spacetime, in order to understand existing phenomena and history of the Universe.

19. **A topological and geometrical model for the big bang and inflation** by Arthur E. Fischer, Department of Mathematics University of California Santa Cruz, California 95064; email: aef@ucsc.edu

Abstract – We construct a mathematical model for the big bang and inflation. Our starting point is the **Microverse**($\boldsymbol{S}^3_{\boldsymbol{R}}$), defined as the static Friedmann all-radiation metastable micro-cosmological closed universe based on the geometry of the round 3-sphere $\boldsymbol{S}^3_{\boldsymbol{R}}$ of radius $\boldsymbol{R}$. The big bang is then modeled as the catastrophic change in topology from $\boldsymbol{S}^3_{\boldsymbol{R}}$ to the punctured 3-sphere $\boldsymbol{S}^3_{\boldsymbol{R}} - \{P\}$. After the puncture, inflation begins and is modeled as a continuous sequence of height-decreasing $h_\phi = \boldsymbol{R}_\phi(1+\cos\phi)$, radius-increasing $\boldsymbol{R}_\phi = \frac{\pi \boldsymbol{R}}{\pi-\phi}$, curvature-decreasing $\boldsymbol{K}_\phi = \frac{1}{\boldsymbol{R}_\phi^2}$, spherical caps $\{\boldsymbol{S}^{3,\phi}_{\boldsymbol{R}_\phi} \mid \phi \in (0,\pi)\}$, whose geometric limit

$$\lim_{\phi\to\pi} \boldsymbol{S}^{3,\phi}_{\boldsymbol{R}_\phi} = \boldsymbol{B}^3_{\pi\boldsymbol{R}}$$

is the flat open 3-ball $\boldsymbol{B}^3_{\pi\boldsymbol{R}}$ of radius $\pi\boldsymbol{R}$, at which time inflation stops. Our model answers the multiple related cosmological questions “Why did inflation start?”, “Why did inflation end?”, “Why is the universe flat?” (the flatness problem), and “How can causally disconnected points have homogeneous properties?” (the horizon

problem).

20. **Supermassive blackhole-Ultralight dark matter connection** by T. R. Govindarajan, The Institute of Mathematical Sciences, Chennai, India; Krea University, Sricity, India; email: trg@imsc.res.in

Abstract – A novel proposal linking the origin of supermassive blackhole formation and ultra- light dark matter. Ultralight bosons of mass $10^{-22} - 10^{-24}$ eV which is one of the front running proposals for dark matter could also be linked with the formation and evolution of supermassive blackholes at the center of all the galaxies.

21. **Holomorphic gravity and its regularization of Locally Signed Coordinate Invariance** by Eduardo Guendelman Department of Physics, Ben-Gurion University of the Negev, Beer-Sheva, Israel; Frankfurt Institute for Advanced Studies (FIAS), Ruth-Moufang-Strasse 1, 60438 Frankfurt am Main, Germany; Bahamas Advanced Study Institute and Conferences, 4A Ocean Heights, Hill View Circle, Stella Maris, Long Island, The Bahamas; email: guendel@bgu.ac.il

Abstract – We expect the final theory of gravity to have more symmetries than we suspect and our research points in this direction, to start with, standard general coordinate invariance can be extended to complex holomorphic general coordinate transformations. This is possible by introducing a non-Riemannian Measure in integration (NRMI) and where we avoid the non-holomorphic standard $\sqrt{-g}$ measure of integration. Second, although globally signed transformations produce a change of boundary conditions and like global parity and global time reversal are not symmetries of nature, locally signed coordinate transformations where the Jacobian changes sign locally but the Jacobian approaches one asymptotically should be symmetries of nature, The holomorphic extension can regularize the regions of space time where the Jacobian changes sign. Consequences for Quantum Gravity are discussed.

22. **Singularity or Structure?** By Yuan K. Ha, Department of Physics, Temple University, Philadelphia, Pennsylvania 19122; email: yuanha@temple.edu

Abstract – It is commonly believed that black holes do not have any structure and that they are purely geometrical objects. The Singularity Theorem affirms that black holes always have singularities. A remarkable paper by Roy Kerr recently shows that singularities never existed in Kerr spacetime. The Penrose argument that light rays of finite affine lengths inevitably end up in singularities is severely challenged. We reveal a new structure of black holes based on energy and angular momentum consideration. The Kerr black hole is found to have an intrinsic moment of inertia which persists even when the rotation stops. Quantum particles are forbidden to enter the black hole by the very presence of an extended structure. Singularities are dramatically excluded in this dynamic approach.

23. **A glimpse into the magical world of quantum gravity** by Shahar Hod, The Ruppin Academic Center, Emeq Hefer 40250, Israel and The Hadassah Institute, Jerusalem 91010, Israel; email: shaharhod@gmail.com

Abstract – In this essay it is proved that, in a self-consistent quantum theory of gravity,
the asymptotically measured orbital periods of test particles around central compact objects are fundamentally

bounded from below by the compact universal relation $T_\infty \geq \frac{2\pi e\hbar}{\sqrt{G}c^2 m_e^2}$ [here {m_e, e} are respectively the proper mass and the electric charge of the electron, the lightest charged particle]. The explicit dependence of the lower bound on the fundamental constants {G, c, $\hbar$} of gravity, special relativity, and quantum theory suggests that it provides a rare glimpse into the yet unknown quantum theory of gravity.

24. **Entanglement production through a cosmological bounce** by Viqar Husain, Irfan Javed, Sanjeev Seahra and Nomaan X, Department of Mathematics and Statistics, University of New Brunswick, Fredericton, NB Canada E3B 5A3; emails: vhusain@unb.ca, i.javed@unb.ca, sseahra@unb.ca, nomaan.math@unb.ca

Abstract – In quantum gravity, it is expected that the Big Bang singularity is resolved, and the universe undergoes a bounce. We show that matter-gravity entanglement entropy rises rapidly during the bounce, declines, and then approaches a steady-state value higher than before the bounce. These observations suggest that matter-gravity entanglement is a feature of the macroscopic universe and that there is no Second Law of entanglement entropy.

25. **Listening to Quantum Gravity?** by Lawrence M. Krauss,[1] Francesco Marino,[2] Samuel, L. Braunstein,[3] Mir Faizal,[4,5] and Naveed A. Shah[6] ,[1]The Origins Project Foundation, 4738 E. Rancho Dr, Phoenix AZ 85018; email: lawrence@originsproject.org, [2]CNR-Istituto Nazionale di Ottica, Via Sansone 1, I-50019 Sesto Fiorentino (FI), Italy; email: francesco.marino@ino.cnr.it; [3]Computer Science, University of York, York Y010 5GH, United Kingdom; email: sam.braunstein@york.ac.uk, [4]Irving K. Barber School of Arts and Sciences, University of British Columbia - Okanagan, Kelowna, British Columbia V1V 1V7, Canada; email: mirfaizalmir@googlemail.com; [5]Canadian Quantum Research Center 204-3002 32 Ave Vernon, BC V1T 2L7 Canada; [6]Department of Physics, Jamia Millia Islamia, New Delhi - 110025, India; email: naveed179755@st.jmi.ac.in

Abstract – Recent experimental progresses in controlling classical and quantum fluids have made it possible to realize acoustic analogues of gravitational black holes, where a flowing fluid provides an effective spacetime on which sound waves propagate, demonstrating Hawking-like radiation and Penrose super radiance. We propose the exciting possibility that new hydrodynamic systems might provide insights to help resolve mysteries associated with quantum gravity, including the black hole information-loss paradox and the removal of spacetime singularities.

26. **Pauli-Villars and the Ultraviolet Completion of Einstein Gravity by** Philip D. Mannheim**,** Department of Physics, University of Connecticut, Storrs, CT 06269**; email:** philip.mannheim@uconn.edu

Abstract – Through use of the Pauli-Villars regulator procedure we construct a second- plus fourth-order derivative theory of gravity that serves as an ultraviolet completion of standard second-order-derivative quantum Einstein gravity that is ghost-free, unitary, and power counting renormalizable.

27. **Spacetime Foam, Dark Energy and Cosmological Constant Issue** by Alexander I Nesterov, Departamento de Física, CUCEI, Universidad de Guadalajara, Av. Revolución 1500, Guadalajara, CP 44430, Jalisco, México; email: nesterov@academicos.udg.mx

Abstract – The cosmological constant problem, vacuum energy, and dark energy are three interconnected concepts that have profound implications for our understanding of the universe. A proposed spacetime model based on nonassociative geometry and statistical physics of complex networks offers a fresh perspective on the problem. Our research indicates that spacetime topology is crucial in solving the cosmological constant problem and the dark energy issue. We show that the density of topological geons determines the cosmological constant, and the non-trivial topology of spacetime is the source of dark energy.

28. **Gravitational wave-induced reaction surface forces between neutron star mergers** 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, Türkiye; email: fabrizio.pinto@ieu.edu.tr

Abstract – It is shown that two neutron stars in a binary star system interact strongly in the last phases of a merger event through a novel type of dispersion gravitational interaction caused by the appreciable gravitational wave reflectance of compact stellar interiors. This interaction, a gravitational analog of induced van der Waals forces, seems sufficiently intense to affect both the dynamics of mergers and the figures of merging neutron stars so as to produce signatures potentially detectable by gravitational wave observatories. This phenomenon would represent an opportunity to observe gravitational wave reflection by extremely dense matter thus opening a new avenue for the study both of gravitational waves and of neutron star interiors.

29. **A Symmetry-centric Perspective on the Geometry of the String Landscape and the Swampland** by Tom Rudelius, Department of Mathematical Sciences, Durham University, Upper Mountjoy Campus, Stockton Rd, Durham DH1 3LE UK; email: thomas.w.rudelius@durham.ac.uk

Abstract – As famously observed by Ooguri and Vafa nearly twenty years ago, scalar field moduli spaces in quantum gravity appear to exhibit various universal features. For instance, they seem to be infinite in diameter, have trivial fundamental groups, and feature towers of massive particles that become light in their asymptotic limits. In this essay, we explain how these features can be reformulated in more modern language using generalized notions of global symmetries. Such symmetries are ubiquitous in non-gravitational quantum field theories, but it is widely believed that they must be either gauged or broken in quantum gravity. In what follows, we will see that the observations of Ooguri and Vafa can be understood as consequences of such gauging or breaking.

30. **Probing Hidden Dimensions via Muon Lifetime Measurements** by Jorge G. Russo, Institució Catalana de Recerca i Estudis Avançats (ICREA), Pg. Lluis Companys, 23, 08010 Barcelona, Spain; Departament de Física Cuántica i Astrofísica and Institut de Ciències del Cosmos, Universitat de Barcelona, Martí Franquès, 1, 08028 Barcelona, Spain; email: jorge.russo@icrea.cat

Abstract – In the context of Kaluza-Klein theories, the time dilation of charged particles in an external field depends on the charge in a specific way. Experimental tests are proposed to search for extra dimensions using this distinctive feature.

31. **Stimulated absorption of single gravitons: First light on quantum gravity** by Victoria Shenderov,[1] Mark Suppiah,[1] Thomas Beitel,[1] Sreenath K. Manikandan,[2] and Igor Pikovski[1,3], [1]Department of Physics, Stevens Institute of Technology, Castle Point on the Hudson, Hoboken, NJ 07030; [2]Nordita, KTH Royal Institute of Technology and Stockholm University, SE-106 91 Stockholm, Sweden; [3]Department of Physics, Stockholm University, AlbaNova University Center, SE-106 91 Stockholm, Sweden; emails: vicshe24@bergen.org, marsup24@bergen.org, tbeitel1@stevens.edu, sreenath.k.manikandan@su.se, pikovski@stevens.edu

Abstract – In a recent work we showed that the detection of the exchange of a *single* graviton between a massive quantum resonator and a gravitational wave can be achieved. Key to this ability are the experimental progress in preparing and measuring massive resonators in the quantum regime, and the correlation with independent LIGO detections of gravitational waves that induce stimulated absorption. But do stimulated single-graviton processes imply the quantization of gravity? Here we analyze this question and make a historic analogy to the early days of quantum theory. We discuss in what ways such experiments can indeed probe key features of the quantized interaction between gravity and matter, and outline five experimental tests. This capability would open the first window into experimental exploration of quantum gravity.

32. **Two dark clouds on the space-time horizon** by Tejinder P. Singh, Inter-University Centre for Astronomy and Astrophysics, Post Bag 4, Ganeshkhind, Pune 411007, India; Tata Institute of Fundamental Research, Homi Bhabha Road, Mumbai 400005, India email: tejinder.singh@iucaa.in, tpsingh@tifr.res.in

Abstract – (i) Investigations of stellar systems known as wide binaries suggest that Newton's law of gravitation breaks down at low accelerations. This can be explained by proposing a fifth force with U (1) gauge symmetry, whose corresponding gauge boson is the sought for dark matter candidate. (ii) Relativistic causality (i.e. no faster than light signaling) permits nonlocal correlations stronger than those permitted by quantum mechanics. This can be explained if our universe possesses a second 4D spacetime with a signature opposite to ours. (iii) Such a fifth force, and a second spacetime, arise naturally in a recently proposed theory of unification based on an $E_8 \times E_8$ symmetry. Our spacetime arises from breaking of an $SU(2)_R \times U(1)_{Y\ DEM}$ symmetry, and the second spacetime arises from broken electroweak symmetry.

33. **Search for Gravitationally Lensed Interstellar Transmissions** by Slava G. Turyshev, Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109-0899; email: turyshev@jpl.nasa.gov

Abstract – We consider interstellar light transmission aided by a gravitational lens. We find that optimal reception efficiency occurs in lensing geometries where the transmitter, lens, and receiver are nearly aligned. We explore various signal detection strategies, employing both existing and emerging technologies. With this study, our understanding of interstellar power transmission via gravitational lensing has significantly progressed. We observe that detection signals from nearby stars may leverage established photonics and optical engineering technologies, and networks of collaborative astronomical facilities. Our findings confirm the feasibility of interstellar power transmission via gravitational lensing, directly impacting ongoing optical SETI efforts.

34. **A Novel Wideband Neutron-Earth Quantum Detector for Gravitational Waves and a Decisive Test of Quantum Gravity** by C. S. Unnikrishnan, School of Quantum Technology, Defence Institute of Advanced Technology, Pune - 411025, India; email: unni@diat.ac.in

Abstract – The detectors of astrophysical gravitational waves are based on optical interferometers. There is not yet

an analogue of a quantum mechanical atomic detector of photons for the detection of gravitational waves. I point out the remarkable fact that the already observed pico-electron volt quantization of energy levels of ultra-cold neutrons that are gravitationally bound to the Earth fortuitously coincide with the range of energies of the quanta of astrophysical gravitational waves. Thus, it is feasible to use a cold-neutron bouncing reservoir as a novel quantum sensor for directly detecting astrophysical gravitational waves, in a wide frequency band. These considerations also lead us to the discovery that many detected signals in interferometric detectors like LIGO correspond to the energy of a single gravitational quantum. This finding can result in the first decisive experimental tests of the quantization of gravity's radiation sector.

35. **Observables of super-extremal black holes: challenging Cosmic Censorship to comprehend the Cosmological Constant** by Jenny Wagner, Bahamas Advanced Study Institute & Conferences, 4A Ocean Heights, Hill View Circle, Stella Maris, Long Island, The Bahamas; email: thegravitygrinch@gmail.com

Abstract – Einstein's Field Equations have proven applicable across many scales, from black holes to cosmology. Even the mysterious Cosmological Constant found a physical interpretation in the so-called "dark energy" causing the accelerated cosmic expansion as inferred from multiple observables. Yet, we still lack a material source for this dark fluid. Probing the local universe to find it yields complementary information to the one from the cosmic microwave background. Could dark energy be sourced by super-extremal charged black holes? Contrary to intuition, such objects could exist with only weak observational signatures. The latter are introduced here to outline how sky surveys can identify individual candidates which challenge Cosmic Censorship on the one hand but may explain the physical origin of the Cosmological Constant on the other.