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Abstracts of Award Winning and Honorable Mention Essays for 2013

Award Essays

First Award – **Information Conservation Is Fundamental: Recovering the Lost Information in Hawking Radiation –** by: Baocheng Zhang[1], Qing-yu Cai[1], Ming-sheng Zhan[1], and Li You[2]; [1]Wuhan Institute of Physics and Mathematics, Chinese Academy of Sciences, Wuhan 430071, People's Republic of China, [2]Department of Physics, Tsinghua University, Beijing 100084, China; e-mail: zhangbc@wipm.ac.cn, qycai@wipm.ac.cn, mszhan@wipm.ac.cn, lyou@mail.tsinghua.edu.cn

Abstract – In both classical and quantum world, information cannot appear or disappear. This fundamental principle, however, is questioned for a black hole by the acclaimed "information loss paradox". Based on the conservation laws of energy, charge, and angular momentum, we recently show the total information encoded in the correlations among Hawking radiations equals exactly the same amount previously considered lost, assuming the non-thermal spectrum of Parikh and Wilczek. Thus the information loss paradox can be falsified through experiments by counting the covariances of Hawking radiations from black holes, such as the manmade ones speculated to appear in LHC experiments. The affirmation of information conservation in Hawking radiation will shine new light on the unification of gravity with quantum mechanics.

Second Award – **What Is the Shape of the Initial State? –** by: Nishant Agarwal[1], R. Holman[2], and Andrew J. Tolley[3]; [1]McWilliams Center for Cosmology, Department of Physics, Carnegie Mellon University, Pittsburgh, PA 15213, [2]Department of Physics, Carnegie Mellon University, Pittsburgh, PA 15213, [3]Department of Physics, Case Western Reserve University, Cleveland, OH 44106; e-mail: nishanta@andrew.cmu.edu, rh4a@andrew.cmu.edu, andrew.j.tolley@case.edu

Abstract – We argue that a plausible operational definition for an initial state of the Universe is the initial quantum state of the curvature perturbations generated during inflation. We provide a parameterization of this state and generalize the standard in-in formalism to incorporate the structures in this state into the computation of correlators of the perturbations. Measurements of these correlators using both the CMB as well as large scale structure probe different structures in the initial state, as they give rise to bi- and tri-spectra peaked on different shapes of triangles and quadrilaterals in momentum space. In essence, the shapes implied by the correlators feed directly into information about the shape of the initial state and what physics could have preceded inflation to set this state up.

Third Award – **What Happens at the Horizon? –** by: Samir D. Mathur, Department of Physics, The Ohio State University, Columbus, OH 43210; e-mail: mathur.16@osu.edu

Abstract – The Schwarzschild metric has an apparent singularity at the horizon $r = 2M$. What really happens there? If physics at the horizon is 'normal' laboratory physics, then we run into Hawking's information paradox. If we want nontrivial structure at the horizon, then we need a mechanism to generate this structure that evades the 'no hair' conjectures of the past. Further, if we have such structure, then what would the role of the traditional black hole metric which continues smoothly past the horizon? Recent work has provided an answer to these questions and, in the process, revealed a beautiful tie-up between gravity, string theory and thermodynamics.

Fourth Award – **On Negative Mass –** by: Jonathan Belletête and M.B.Paranjape; Département de physique, Université de Montréal, Québec, Canada, H3C 3J7; e-mail: jonathan.belletete@umontreal.ca, paranj@lps.umontreal.ca

Abstract – The Schwarzschild solution to the matter free, spherically symmetric Einstein equations has one free parameter, the mass. But the mass can be of any sign. What is the meaning of the negative mass solutions? The answer to this question for the case of a pure Schwarzschild negative mass black solution is still elusive; however, in this essay, we will consider negative mass solutions within a Schwarzschild-de Sitter geometry. We show that there exist reasonable configurations of matter, bubbles of distributions of matter, that satisfy the dominant energy condition everywhere, that are non-singular and well behaved everywhere, but correspond to the negative mass Schwarzschild-de Sitter geometry outside the matter distribution. These negative mass bubbles could occur as the end of a quantum tunneling transition.

Fifth Award – **Dark Energy with Rigid Voids versus Relativistic Voids Alone –** by: Boudewijn F. Roukema; Nicolaus Copernicus University, ul. Gagarina 11, 87-100 Toruń, Poland; e-mail: boud@astro.uni.torun.pl

Abstract – The standard model of cosmology is dominated - at the present epoch - by dark energy. Its voids are rigid and Newtonian within a relativistic background. The model prevents them from becoming hyperbolic. Observations of rapid velocity flows out of voids are normally interpreted within the standard model that is rigid in comoving coordinates, instead of allowing the voids' density parameter to drop below critical and their curvature to become negative. Isn't it time to advance beyond nineteenth century physics and relegate dark energy back to the "no significant evidence" box?

Honorable Mention Awards **(Alphabetical Order)**

1. **Solving the Riddle of the Incompatibility between Renormalizability and Unitarity in N-Dimensional Einstein Gravity Enlarged by Curvature-Squared Terms** – by: Antonio Accioly, José Helayël-Neto, Eslley Scatena, Rodrigo Turcati; Laboratório de Física Experimental (LAFEX), Centro Brasileiro de Pesquisas Físicas (CBPF), Rua Dr. Xavier Sigaud 150, Urca, 22290-180, Rio de Janeiro, RJ, Brazil; e-mail: accioly@cbpf.br, helayel@cbpf.br, scatena@cbpf.br, rturcati@gmail.com

Abstract – One of the puzzling aspects of N-dimensional Einstein Gravity augmented by (curvature)^2-terms (NDEG) is why renormalizability and unitarity, one of the most important properties of any physical theory, cannot be reconciled in its framework. Actually, the reason why these properties are mutually incompatible within the context of generic higher-derivative models, not necessarily related to gravity, is one of the unsolved mysteries of physics. Here a simple solution to the NDEG riddle, based on the analysis of the interparticle gravitational potential, is presented. The main argument used to support our discussion is that tree-level unitarity and the existence of a singularity in the potential are intertwined.

2. **Shadow Dark Matter as a Manifestation of *i* ↔ - *i* Symmetry in Pre-Quantum Trace Dynamics** – by: Stephen L. Adler; Institute for Advanced Study, Einstein Drive, Princeton, NJ 08540; e-mail: adler@ias.edu

Abstract – We propose an alternate version of the “shadow world” hypothesis for the origin of dark matter. Instead of postulating that the shadow world is a “mirror” world under parity or charge-parity reflection, we suggest that the existence of a shadow world arises from the fact that i or $-i$ can be the imaginary unit in complex quantum mechanics. This mechanism is a natural consequence of “trace dynamics” pre-quantum theory, from which quantum mechanics over the complex number field emerges as a statistical mechanical approximation. Because the pre-quantum dynamics does not pick out a preferred imaginary unit, the emergent quantum dynamics contains two sectors, one based on i and the other on $-i$, with both sectors coupled to gravity.

3. **Easy Holography** – by: Heikki Arponen; Espoontie 12 A 2, 02770 Espoo, Finland; e-mail: heikki.a.arponen@gmail.com

Abstract – It is argued that the role of infinite dimensional asymptotic symmetry groups in gravity theories are essential for a holographic description of gravity and therefore to a resolution of the black hole information paradox. I present a simple toy model in two dimensional hyperbolic/ anti-de Sitter (AdS) space and describe, by very elementary considerations, how the asymptotic symmetry group is responsible for the entropy area law. Similar results apply also in three dimensional AdS space. The failure of the approach in higher dimensional AdS spaces is explained and resolved by considering other asymptotically noncompact homogeneous spaces.

4. **From Bricks to Quasinormal Modes: A New Perspective on Black Hole Entropy.** – by: Michele Arzano, Stefano Bianco, and Olaf Dreyer; Dipartimento di Fisica and INFN, "Sapienza" University of Rome, P.le A. Moro 2, 00185 Roma, EU; e-mail: michele.arzano@roma1.infn.it, stefanobianco3@gmail.com, olaf.dreyer@gmail.com

Abstract – Calculations of black hole entropy based on the counting of modes of a quantum field propagating in a Schwarzschild background need to be regularized in the vicinity of the horizon. To obtain the Bekenstein-Hawking result the short distance cut-off needs to be fixed by hand. In this note we give an argument for obtaining this cut-off in a natural fashion. We do this by modeling the black hole by its set of quasinormal modes. The horizon then becomes an extended region: *the quantum ergosphere*. The interaction of the quantum ergosphere and the quantum field provides a natural regularization mechanism. The width of the quantum ergosphere provides the right cut-off for the entropy calculation. We arrive at a dual picture of black hole entropy. The entropy of the black hole is given both by the entropy of the quantum field in the bulk and the dynamical degrees of freedom on the horizon.

5. **Holograms of Flat Space** – by: Arjun Bagchi[1][2] and Daniel Grumiller[3]; [1]Center for Theoretical Physics, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge. MA 02139, [2]School of Mathematics and the Maxwell Institute of Mathematical Sciences, University of Edinburgh, Edinburgh EH9 3JZ, United Kingdom, [3]Institute for Theoretical Physics, Vienna University of Technology, Wiedner Hauptstrasse 8-10/136, A-1040 Vienna, Austria; e-mail: arjun.bagchi@ed.ac.uk, grumil@hep.itp.tuwien.ac.at

Abstract – The holographic principle has a concrete realization in the Anti-de Sitter/Conformal Field Theory (AdS/CFT) correspondence. If this principle is a true fact about quantum gravity then it must hold also beyond AdS/CFT. In this essay we address specifically holographic field theory duals of gravitational theories in asymptotically flat spacetimes. We present some evidence of our recent conjecture that 3-dimensional conformal Chern-Simons gravity with flat space boundary conditions is dual to an extremal CFT.

6. **On the Emergence of Quantum Effective Field Theory** - by: Tom Banks[1][2]; [1]NHETC and Department of Physics and Astronomy, Rutgers University, Piscataway, NJ 08854-8019, [2]SCIPP and Department of Physics, University of California, Santa Cruz, CA 95064-1077; e-mail: banks@scipp.ucsc.edu

Abstract – It has long been clear that Quantum Effective Field Theory's (QUEFT) failure to describe Quantum Gravity cannot be encoded in a series of higher dimension operators in field theory. Holographic Space Time (HST) provides a model for how field theory emerges from a real theory of QG. Most of the degrees of freedom in a finite causal diamond are associated with its null boundary and are not high energy. Energy, as measured by a geodesic observer is associated with particles passing in and out of the holographic screen. Coupling between particles and the horizon vanishes as the area of the screen goes to infinity. Particle interactions are the residuum of this adiabatically switched off coupling. This picture accounts for the Unruh effect, and the gross properties of de Sitter space, and obviates the necessity for a firewall at the horizon of old black holes. A prescient argument due to Jacobson [5] shows that General Relativity will describe the hydrodynamics of HST, even in regimes where QUEFT is a bad approximation, as a consequence of near saturation of the Covariant Entropy Bound. I argue that the inflationary era is an example of such a regime.

7. **From Inflation to Dark Energy through a Dynamical Λ: An Attempt at Alleviating Fundamental Cosmic Puzzles** – by: Spyros Basilakos[1], José Ademir Sales Lima[2], Joan Solà[3]; [1]Academy of Athens, Research Center for Astronomy and Applied Mathematics, Soranou Efesiou 4, 11527, Athens, Greece, [2]Departamento de Astronomia, Universidade de São Paulo, Rua do Matão 1226, 05508-900, São Paulo, SP, Brazil, [3]High Energy Physics Group, Departament ECM, and Institut de Ciències del Cosmos (ICC), Universitat de Barcelona, Av. Diagonal 647 E-08028 Barcelona, Catalonia, Spain; e-mail: svasil@academyofathens.gr, limajas@astro.iag.usp.br, sola@ecm.ub.edu

Abstract – After decades of successful hot big-bang paradigm, Cosmology still lacks a framework in which the early inflationary phase of the universe smoothly matches the radiation epoch and evolves to the present 'quasi' de Sitter spacetime. No less intriguing is that the current value of the effective vacuum energy density is vastly smaller than the value that triggered inflation. In this Essay we propose a new class of cosmologies capable of overcoming, or highly alleviating, some of these acute cosmic puzzles. Powered by a decaying vacuum energy density, the spacetime emerges from a pure nonsingular de Sitter vacuum stage, "gracefully" exits from inflation to a radiation phase followed by dark matter and vacuum regimes, and, finally, evolves to a late time de Sitter phase.

8. **Entanglement Entropy from Surface Terms in General Relativity** – by: Arpan Bhattacharyya, Aninda Sinha; Centre for High Energy Physics, Indian Institute of Science, Bangalore 560 012, India; e-mail: arpan@cts.iisc.ernet.in, asinha@cts.iisc.ernet.in

Abstract – Entanglement entropy in local quantum field theories is typically ultraviolet divergent due to short distance effects in the neighborhood of the entangling region. In the context of gauge/gravity duality, we show that surface terms in general relativity are able to capture this entanglement entropy. In particular, we demonstrate that for 1+1 dimensional CFTs at finite temperature whose gravity dual is the BTZ black hole, the Gibbons-Hawking-York term precisely reproduces the entanglement entropy which can be computed independently in the field theory.

9. **Before the Bang** – by: Tirthabir Biswas; 6300 St. Charles Avenue, Department of Physics, Box 92, Loyola University, New Orleans, LA 70118; e-mail: tbiswas@loyno.edu

Abstract – While inflation has been an extremely successful cosmological paradigm, almost certainly something must have happened before it began. Can the pre-inflationary phase be of any theoretical or phenomenological significance? Could Quantum Gravity have played any interesting role in this story? These are some of the questions we want to explore in this article.

10. **Effective Theory for Quantum Gravity** – by: Xavier Calmet; Physics & Astronomy, University of Sussex, Falmer, Brighton, BN1 9QH, UK; e-mail: x.calmet@sussex.ac.uk

Abstract – In this paper, we discuss an effective theory for quantum gravity and discuss the bounds on the parameters of this effective action. In particular we show that measurement in pulsars binary systems are unlikely to improve the bounds on the coefficients of the R^2 and $R_{\mu\nu}R^{\mu\nu}$ terms obtained from probes of Newton's potential performed on Earth. Furthermore, we argue that if the coefficients of these terms are induced by quantum gravity, they should be at most of order unity since R^2 and $R_{\mu\nu}R^{\mu\nu}$ are dimension four operators. The same applies to the non-minimal coupling of the Higgs boson to the Ricci scalar.

11. **Hybrid Modified Gravity Unifying Local Tests, Galactic Dynamics and Late-Time Cosmic Acceleration** – by: Salvatore Capozziello[1], Tiberiu Harko[2], Francisco S.N. Lobo[3], Gonzalo J. Olmo[4]; [1]Dipartimento di Fisica, Università di Napoli "Federico II" and INFN Sez. di Napoli, Compl. Univ. di Monte S. Angelo, Edificio G, Via Cinthia, I-80126, Napoli, Italy, [2]Department of Mathematics, University College London, Gower Street, London, WC1E 6BT, United Kingdom, [3]Centro de Astronomia e Astrofísica da Universidade de Lisboa, Campo Grande, Ed. C8 1749-016 Lisboa, Portugal, [4]Departamento de Física Teórica and IFIC, Centro Mixto Universidad de Valencia - CSIC. Universidad de Valencia, Burjassot-46100, Valencia, Spain; e-mail: capozzie@na.infn.it, t.harko@ucl.uc.uk, flobo@cii.fc.ul.pt, gonzalo.olmo@csic.es

Abstract – The non-equivalence between the metric and Palatini formalisms of $f(R)$ gravity is an intriguing feature of these theories. However, in the recently proposed hybrid metric-Palatini gravity, consisting of the superposition of the metric Einstein-Hilbert Lagrangian with an $f(R)$ term constructed à la Palatini, the "true" gravitational field is described by the interpolation of these two non-equivalent approaches. The theory predicts the existence of a light long-range scalar field, which passes the local constraints and affects the galactic and cosmological dynamics. Thus, the theory opens new possibilities for a unified approach, in the same theoretical framework, to the problems of dark energy and dark matter, without distinguishing a priori matter and geometric sources, but taking their dynamics into account under the same standard.

12. **Is Quantum Gravity a Super-Quantum Theory?** – by: Lay Nam Chang[1], Zachary Lewis[1], Djordje Minic[1] and Tatsu Takeuchi[1][2]; [1]Department of Physics MC 0435, Virginia Tech, Blacksburg, VA 24061, [2]Kavli Institute for the Physics and Mathematics of the Universe (WPI), The University of Tokyo, Kashiwa-shi, Chiba-ken 277-8583, Japan; e-mail: laynam@vt.edu, zlewis@vt.edu, dminic@vt.edu, takeuchi@vt.edu

Abstract – We argue that quantum gravity should be a super-quantum theory, that is, a theory whose non-local correlations are stronger than those of canonical quantum theory. As a super-quantum theory, quantum gravity should display distinct experimentally observable super-correlations of entangled stringy states.

13. **Thermodynamics in Black-Hole/CFT Correspondence** – by: Bin Chen[1][2][3], Jia-ju Zhang[1][2]; [1]Department of Physics, Peking University, Beijing 100871, P.R. China, [2]State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing 100871, P.R. China, [3]Center for High Energy Physics, Peking University, Beijing 100871, P.R. China; e-mail: bchen01@pku.edu.cn, jjzhang@pku.edu.cn

Abstract – The area law of Bekenstein-Hawking entropy of the black hole suggests that the black hole should have a lower-dimensional holographic description. It has been found recently that a large class of rotating and charged black holes could be holographically described by a two dimensional (2D) conformal field theory (CFT). We show that the universal information of the dual CFT, including the central charges and the temperatures, is fully encoded in the thermodynamics laws of both outer and inner horizons. These laws, characterizing how the black hole responds under the perturbation, allow us to read different dual pictures with respect to different kinds of perturbations. The remarkable effectiveness of this thermodynamics method suggests that the inner horizon could play a key role in the study of holographic description of the black hole.

14. **Black Holes vs. Firewalls and Thermo-Field Dynamics** – by: Borun D. Chowdhury; Institute for Theoretical Physics, University of Amsterdam, Science Park 904, Postbus 94485, 1090 GL Amsterdam, The Netherlands; e-mail: b.d.chowdhury@uva.nl

Abstract – In this essay, we examine the implications of the ongoing *black holes vs. firewalls* debate for the thermo-field dynamics of black holes by analyzing a CFT in a thermal state in the context of AdS/CFT. We argue that the thermo-field doubled copy of the thermal CFT should be thought of not as a fictitious system, but as the image of the CFT in the heat-bath. In case of strong coupling between the CFT and the heat-bath this image allows for free infall through the horizon and the system is described by a black hole. Conversely, firewalls are the appropriate dual description in case of weak interaction of the CFT with its heat bath.

15. **New Mass Limit of White Dwarfs** – by: Upasana Das, Banibrata Mukhopadhyay; Department of Physics, Indian Institute of Science, Bangalore 560012, India; e-mail: upasana@physics.iisc.ernet.in, bm@physics.iisc.ernet.in

Abstract – Is the Chandrasekhar mass limit for white dwarfs (WDs) set in stone? Not anymore — recent observations of over-luminous, peculiar type Ia supernovae can be explained if significantly super-Chandrasekhar WDs exist as their progenitors, thus barring them to be used as cosmic distance indicators. However, there is no estimate of a mass limit for these super-Chandrasekhar WD candidates yet. Can they be arbitrarily large? In fact, the answer is no! We arrive at this revelation by exploiting the flux freezing theorem in observed, accreting, magnetized WDs, which brings in Landau quantization of the underlying electron degenerate gas. This essay presents the calculations which pave the way for the ultimate (significantly super-Chandrasekhar) mass limit of WDs, heralding a paradigm shift 80 years after Chandrasekhar's discovery.

16. **Cosmological Zitterbewegung**– by: Parth Girdhar[2], Archil Kobakhidze[1][2]; [1]ARC Centre of Excellence for Particle Physics at the Terascale, [2]School of Physics, The University of Sydney, NSW 2006, Australia; e-mail: pgir1104@uni.sydney.edu.au, archilk@physics.usyd.edu.au

Abstract – We describe a new phenomenon of zitterbewegung of a free Dirac particle in cosmological spacetimes. Unlike the similar effect theorized by Schrödinger in 1930, the cosmological zitterbewegung is a real, physically attainable effect, which originates from the mixing of positive and negative frequency modes of a field operator in cosmological spacetimes. We briefly discuss the potential for observing this effect in laboratory experiments with trapped ions.

17. **Death and Resurrection of the Zeroth Principle of Thermodynamics** – by: Hal M. Haggard, Carlo Rovelli; Centre de Physique Théorique de Luminy, Aix-Marseille Université, F-13288 Marseille, EU; e-mail: haggard@cpt.univ-mrs.fr, rovelli@cpt.univ-mrs.fr

Abstract – The zeroth principle of thermodynamics in the form "temperature is uniform at equilibrium" is notoriously violated in relativistic gravity. Temperature uniformity is often derived from the maximization of the total number of microstates of two interacting systems under energy exchanges. Here we discuss a generalized version of this derivation, based on informational notions, which remains valid in the general context. The result is based on the observation that the time taken by any system to move to a distinguishable (nearly orthogonal) quantum state is a universal quantity that depends solely on the temperature. At equilibrium the net information flow between two systems must vanish, and this happens when two systems transit the same number of distinguishable states in the course of their interaction.

18. **Spin from the Nonsymmetric Metric Tensor** – by: Richard T. Hammond; Department of Physics, University of North Carolina at Chapel Hill, Chapel Hill, NC, Army Research Office Research Triangle Park, NC; e-mail: rhammond@email.unc.edu

Abstract – A solution to the gravitational field equations based on a non-symmetric metric tensor is examined. Unlike Einstein's interpretation of electromagnetism, or Moffat's generalized gravity, it is shown that the non-symmetric part of the metric tensor is the potential of the spin field, and its intimate connection to string theory is established. This formulation solves the longstanding problem of electromagnetism and torsion, naturally showing how electromagnetism, through its intrinsic spin, can create torsion.

19. **The Two-Body Problem in General Relativity** – by: Shahar Hod; The Ruppin Academic Center, Emeq Hefer 40250, Israel, The Hadassah Institute, HaNeviim 37, Jerusalem 91010, Israel; e-mail: shaharhod@gmail.com

Abstract – General relativity, Einstein's theory of gravity, predicts a universe full of black holes and gravitational waves. The prospects of detecting gravitational waves from inspirals of compact astrophysical objects into supermassive black holes have made it highly important to analyze in detail the gravitational two-body problem. While the two-body problem in Newtonian gravity (the weak-field limit) has a well-defined compact analytic solution, the corresponding problem in general relativity (the strong-field regime) is very complex and cannot be solved analytically. In this essay we propose to model the two-body problem in general relativity using the analytically solvable model of a ring of particles in orbit around a central black hole. We use our model to calculate the ISCO (innermost stable circular orbit) frequency which characterizes the two-body dynamics. Remarkably, our *analytically* derived expression for the characteristic ISCO frequency predicts with astonishing accuracy the actual (*numerically* computed) value of this fundamental parameter.

20. **Boundary Unitarity and the Black Hole Information Paradox** – by: Ted Jacobson; Maryland Center for Fundamental Physics, Department of Physics, University of Maryland, College Park, MD 20742-4111; e-mail: jacobson@umd.edu

Abstract – Both AdS/CFT duality and more general reasoning from quantum gravity point to a rich collection of boundary observables that always evolve unitarily. The physical quantum gravity states described by these observables must be solutions of the spatial diffeomorphism and Wheeler-deWitt constraints, which implies that the state space does not factorize into a tensor product of localized degrees of freedom. The “firewall” argument that unitarity of black hole S-matrix implies the presence of a highly excited quantum state near the horizon is based on such a factorization, hence is not applicable in quantum gravity. In fact, there appears to be no conflict between boundary unitarity and regularity of the event horizon.

21. **In-In Formalism, Pseudo-Instantons and Rethinking Quantum Cosmology** – by: Ali Kaya; Department of Physics, McGill University, Montreal, QC, H3A 2T8, Canada, Boğaziçi University, Department of Physics, 34342, Bebek, İstanbul, Turkey; e-mail: ali.kaya@boun.edu.tr

Abstract – Unlike flat space quantum field theories that focus on scattering amplitudes, the main observables in quantum cosmology are correlation functions. The systematic way of calculating correlations is called *in-in* formalism, which requires only a single asymptotic region, i.e. past infinity. The rules in perturbation theory and the path integral measure are very different for in-in and in-out formalisms, and thus the results which are standard in one approach may not necessarily hold in the other one. We show that stationary phase approximation works completely different for a scalar in-in path integral. Hence, in a cosmological background there are solutions, pseudo-instantons, that allow tunneling between locally stable vacua even in infinite volume, which is counterintuitive from an in-out perspective. We argue that various familiar notions of in-out formalism must be reexamined in the in-in formalism, which might have important consequences for quantum cosmology.

22. **Matters on a Moving Brane** – by: Tomi Sebastian Koivisto[1], Danielle Elizabeth Wills[2]; [1]Institute of Theoretical Astrophysics, University of Oslo, P.O. Box 1029 Blindern, N-0315 Oslo, Norway, [2]Centre for Particle Theory, Department of Mathematical Sciences, Durham University, South Road, Durham, DH1 3LE, UK; tomi.koivisto@fys.uio.no, d.e.wills@durham.ac.uk

Abstract – A novel generalisation of the Dirac-Born-Infeld string scenario is described. It is shown that matter residing on the moving brane is dark and has the so-called disformal coupling to gravity. This gives rise to cosmologies where dark matter stems from the oscillations of the open strings along the brane and the transverse oscillations result in dark energy. Furthermore, due to a new screening mechanism that conceals the fifth force from local experiments, one may even entertain the possibility that the visible sector is also moving along the extra dimensions.

23. **Singularity Free Rainbow Universe** – by: Barun Majumder; Indian Institute of Technology Gandhinagar, Ahmedabad, Gujarat 382424, India; e-mail: barunbasanta@iitgn.ac.in

Abstract – Isotropic quantum cosmological perfect fluid model is studied in the formalism of Rainbow gravity. It is found that the only surviving matter degree of freedom played the role of cosmic time. It is possible to find the wave packet naturally with a suitable choice of the Rainbow functions which resulted from the superposition of the wave functions of the Schrödinger-Wheeler-deWitt equation. The many-worlds interpretation of quantum mechanics is applied to investigate the behavior of the scale factor and the behaviour is found to depend on the operator ordering. It is shown that the model in the Rainbow framework naturally avoids singularity and a bouncing non-singular universe is found.

24. **Loop-Deformed Poincaré Algebra** – by: Jakub Mielczarek; Institute of Physics, Jagiellonian University, Reymonta 4, 30-059 Cracow, Poland, Department of Fundamental Research, National Centre for Nuclear Research, Hoża 69, 00-681 Warsaw, Poland; e-mail: jakub.mielczarek@uj.edu.pl

Abstract – In this essay we present evidence suggesting that loop quantum gravity leads to deformation of the local Poincaré algebra within the limit of high energies. This deformation is a consequence of quantum modification of effective off-shell hypersurface deformation algebra. Surprisingly, the form of deformation suggests that the signature of space-time changes from Lorentzian to Euclidean at large curvatures. We construct particular realization of the loop-deformed Poincaré algebra and find that it can be related to curved momentum-space, which indicates the relationship with recently introduced notion of relative locality. The presented findings open a new way of testing loop quantum gravity effects.

25. **The Fate of Lorentz Frame in the Vicinity of Black Hole Singularity** – by: Douglas G Moore, V. H. Satheeshkumar; Department of Physics, Baylor University, Waco, TX, 76798-7316; e-mail: Douglas_Moore1@baylor.edu, V_HSatheeshkumar@baylor.edu

Abstract – General Relativity is known to break down at singularities. However, from an order-of-magnitude argument, it is expected that quantum corrections become important when the curvature is of the order of Planck scale avoiding the singularity. By calculating the effect of tidal forces on a freely falling inertial frame, and assuming the least possible size of the frame to be of the Planck length, we show that the Lorentz frames cease to exist at a finite distance from the singularity. Within that characteristic radius, one cannot apply General Relativity nor Quantum Field Theory as we know them today. Additionally we consider other quantum length scales and impose limits on the distances from the singularity at which those theories can conceivably be applied within a Lorentz frame.

26. **Emergence of the Lorentzian Structure in Classical Field Theory** – by: Shinji Mukoyama[1], Jean-Philippe Uzan[2]; [1]Kavli Institute for the Physics and Mathematics of the Universe, Todai Institutes for Advanced Study, University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba 277-8583, Japan, [2]Institut d'Astrophysique de Paris, UMR-7095 du CNRS, Université Pierre et Marie Curie, 98 bis bd Arago, 75014 Paris (France), Sorbonne Universités, Institut Lagrange de Paris, 98 bis bd Arago, 75014 Paris (France); e-mail: shinji.mukohyama@ipmu.jp, uzan@iap.fr

Abstract – The Lorentzian metric structure allows one to implement the relativistic notion of causality in any field theory and to define a notion of time dimension. We propose that at the microscopic level the metric is Riemannian and that the Lorentzian structure, usually thought as fundamental, is in fact an effective property, that emerges in some regions of a 4-dimensional space with a positive definite metric. We argue that a decent classical field theory for scalars, vectors and spinors in flat spacetime can be constructed, and that gravity can be included under the form of a covariant Galilean theory instead of general relativity.

27. **Black Hole Space-Times without General Relativity** – by: Duff Neill[1], Ira Z. Rothstein[2]; [1]Department of Physics, M.I.T, Cambridge MA, 02139-4307, [2]Department of Physics, Carnegie Mellon University, Pittsburgh PA 15213; e-mail: dneill@MIT.EDU, izr@cmu.edu

Abstract – In this essay we show that black hole space-times can be derived without any recourse to Einstein's equation. We assume only the existence of a Hilbert space representation of the Poincare group and an unitary S-matrix determining the transitions between these states. This approach treats gravity on the same footing as the other forces, which are usually considered to be distinct in that they are not geometric. Our results show that the information contained in Einstein's theory of general relativity, at least for asymptotically flat static space-times, is contained in the on-shell dynamics of massless particles with spin two *or* one, and thus sheds new light of the unification of gravity with the other forces.

28. **Towards a Holographic Theory of Cosmology – Threads in a Tapestry** – by: Y. Jack Ng; Institute of Field Physics, Department of Physics and Astronomy, University of North Carolina, Chapel Hill, NC 27599; e-mail: yjng@physics.unc.edu

Abstract – In this Essay we address several fundamental issues in cosmology: What is the nature of dark energy and dark matter? Why is the dark sector so different from ordinary matter? Why is the effective cosmological constant non-zero but so incredibly small? What is the reason behind the emergence of a critical acceleration parameter of magnitude 10^{-8} cm/sec^2 in galactic dynamics? We suggest that the holographic principle is the linchpin in a unified scheme to understand these various issues.

29. **CosMIn: The Solution to the Cosmological Constant Problem** – by: Hamsa Padmanabhan, T. Padmanabhan; IUCAA, Post Bag 4, Ganeshkhind, Pune - 411 007, India; e-mail: hamsa@iucaa.ernet.in, paddy@iucaa.ernet.in

Abstract – The current acceleration of the universe can be modeled in terms of a cosmological constant Λ. We show that the extremely small value of $\Lambda L^2_P \approx 3.4 \times 10^{-122}$, the holy grail of theoretical physics, can be understood in terms of a new, dimensionless, conserved number CosMIn, which counts the number of modes crossing the Hubble radius during the three phases of evolution of the universe. Theoretical considerations suggest that $N \approx 4\pi$. *This single postulate leads us to the correct, observed numerical value of the cosmological constant!* This approach also provides a unified picture of cosmic evolution relating the early inflationary phase to the late accelerating phase.

30. **The Unreasonable Effectiveness of Exponentially Suppressed Corrections in Preserving Information** – by: Kyriakos Papadodimas[1], Suvrat Raju[2]; [1]Centre for Theoretical Physics, University of Groningen, Nijenborgh 4, The Netherlands, [2]International Centre for Theoretical Sciences, Tata Institute of Fundamental Research, IISc Campus, Bengaluru 560012, India.; e-mail: k.papadodimas@rug.nl, suvrat@icts.res.in

Abstract – We point out that non-perturbative effects in quantum gravity are sufficient to reconcile the process of black hole evaporation with quantum mechanics. In ordinary processes, these corrections are unimportant because they are suppressed by e^{-S}. However, they gain relevance in information-theoretic considerations because their small size is offset by the corresponding largeness of the Hilbert space. In particular, we show how such corrections can cause the von Neumann entropy of the emitted Hawking quanta to decrease after the Page time, without modifying the thermal nature of each emitted quantum. Second, we show that exponentially suppressed commutators between operators inside and outside the black hole are sufficient to resolve paradoxes associated with the strong subadditivity of entropy without any dramatic modifications of the geometry near the horizon.

31. **How to Determine the Area Quantum with the Help of a Black Hole** – by: K. Ropotenko; State Service for Special Communication and Information Protection of Ukraine, 13 Solomianska str., Kyiv, 03680, Ukraine; e-mail: ropotenko@ukr.net

Abstract – According to the holographic principle the concept of two dimensional area is distinctive in our four dimensional world. In this essay, I address the question of whether there is a smallest physical element of area. I propose two different methods for determining the area quantum with the help of a black hole. At first, I find it from the quantization condition for an internal angular momentum of a black hole. Secondly, I infer it from a diffusion equation for a black hole. In both cases I obtain the same value. These methods and results may have important implications for a statistical interpretation of black hole entropy.

32. **Inflationary Dark Energy from a Condensate of Spinors in a 5D Vacuum** – by: Pablo Alejandro Sánchez[1], Mauricio Bellini[2]; [1]Departamento de Física, Facultad de Ciencias Exactas y Naturales, Universidad Nacional de Mar del Plata, Funes 3350, (7600) Mar del Plata, Argentina, [2]Instituto de Investigaciones Físicas de Mar del Plata (IFIMAR), Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Argentina; e-mail: pabsan@mdp.edu.ar, mbellini@mdp.edu.ar

Abstract – What is the physical origin of dark energy? Could this energy be originated by other fields than the inflaton? In this work we explore the possibility that the expansion of the universe can be driven by a condensate of spinors. These spinors are free of interactions on 5D relativistic vacuum in an extended de Sitter spacetime. The extra coordinate is considered as noncompact. After making a static foliation on the extra coordinate, we obtain an effective 4D (inflationary) de Sitter expansion which describes an inflationary universe. In view of our results we conclude that the condensate of spinors here studied could be an interesting candidate to explain the presence of dark energy in the early universe.

33. **Quantum Phase Space, Holography and Black Hole Entropy** – by: C. Sivaram; Indian Institute of Astrophysics, Bangalore 560034; e-mail: sbfnooyi@gmail.com

Abstract – Intriguing and important connections are highlighted between quantum phase space and black hole entropy which hold at all stages of black hole evaporation providing a subtle physical basis for Hawking radiation with holography being an inbuilt feature. While the interior of any black hole of any mass or dimension has just one quantum unit of phase space as seen by an observer outside the horizon it is now shown that the entropy and phase space associated with a comoving observer collapsing into the horizon remains invariant. This introduces a new paradigm for understanding black hole entropy for observers both within and outside the horizon. The result that there are no singularities in phase space suggests that quantized curved phase space is the arena for quantum gravity and suitable actions and solutions are given.

34. **The Two Faces of Hawking Radiation** – by: Matteo Smerlak; Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut), Am Mühlenberg 1, D-14476 Golm, Germany; e-mail: smerlak@aei.mpg.de

Abstract – What happens when freely-falling Alice crosses a black hole horizon? In spite of recent challenges by Almheiri *et al.* –the so-called *firewall hypothesis*–, the consensual answer to this question tends to remain “nothing special”. Here I show that something rather special happens on the horizon, already at the semiclassical level: Alice records Hawking radiation at a temperature inversely proportional to her velocity relative to the horizon. This effect is not due to outgoing vacuum fluctuations, as in the conventional Hawking effect, but to incoming fluctuations. I suggest that this effect is best thought of in terms a *horizon-infinity duality*, which relates the perception of near-horizon and asymptotic geodesic observers–the two faces of Hawking radiation.

35. **Implications of the Higgs Discovery for Gravity and Cosmology** – by: Dejan Stojkovic; HEPCOS, Department of Physics, SUNY at Buffalo, Buffalo, NY 14260-1500; e-mail: ds77@buffalo.edu

Abstract – The discovery of the Higgs boson is one of the greatest discoveries in this century. The standard model is finally complete. Apart from its significance in particle physics, this discovery has profound implications for gravity and cosmology in particular. Many perturbative quantum gravity interactions involving scalars are not suppressed by powers of Planck mass. Since gravity couples anything with mass to anything with mass, then Higgs must be strongly coupled to any other fundamental scalar in nature, even if the gauge couplings are absent in the original Lagrangian. Since the LHC data indicate that the Higgs is very much standard model-like, there is very little room for non-standard model processes, e.g. invisible decays. This severely complicates any model that involves light enough scalar that the Higgs can kinematically decay to. Most notably, these are the quintessence models, models including light axions, and light scalar dark matter models.

36. **A Relational Approach to the Mach-Einstein Question** – by: Herman Telkamp; Jan van Beverwijckstraat 104, 5017 JA, The Netherlands, e- mail: herman_telkamp@hotmail.com

Abstract – Mach's principle is incompatible with general relativity (GR), it has not condensed into an established theory and suffers from inconsistencies. Yet, the problem is that Mach's principle is a consequence of Berkeley's notions, which are as good as irrefutable for their ontological nature. Moreover, the observed coincidence of the "preferred inertial frame" and the frame attached to the "fixed stars" is essentially Machian, while this coincidence is anomalous to both GR and Newtonian physics. Another issue is that GR needs dark energy to explain the accelerating expansion of the universe, while acceleration of receding masses is inherent to the Machian principle. So GR and Mach's principle question each other, while neither one can be falsified easily. This suggests that both are valid in their particular domain. A relational theory may reconcile the two, since it can cover both.

37. **Singularities and the Finale of Black Hole Evaporation** – by: Li Xiang[1], Yi Ling[2], You Gen Shen[3]; [1]Department of Physics, Jimei University, 361021, Xiamen, Fujian province, P. R. China, [2]Institute of High Energy Physics, Chinese Academy of Sciences, 100049, Beijing, P. R. China, [3]Shanghai Astronomical Observatory, Chinese Academy of Sciences, 200030, Shanghai, P. R. China; e-mail: xiang.lee@163.com, lingy@ihep.ac.cn, ygshen@shao.ac.cn

Abstract – In this essay we argue that once quantum gravitational effects change the classical geometry of a black hole and remove the curvature singularity, the black hole would not evaporate entirely but approach a remnant. In a modified Schwarzschild spacetime characterized by a finite Kretschmann scalar, a minimal mass of the black hole is naturally bounded by the existence of the horizon rather than introduced by hand. A thermodynamical analysis discloses that the temperature, heat capacity and the luminosity are vanishing naturally when the black hole mass approaches the minimal value. This phenomenon may be attributed to the existence of the minimal length in quantum gravity. It can also be understood heuristically by connecting the generalized uncertainty principle with the running of Newton's gravitational constant.