GRAVITY RESEARCH FOUNDATION

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Abstracts of Award Winning and Honorable Mention Essays for 2014

Award Essays

First Award – **From B-Modes to Quantum Gravity and Unification of Forces –** by: Lawrence M. Krauss[1] and Frank Wilczek[2]; [1]Department of Physics and School of Earth and Space Exploration, Arizona State University, PO BOX 871404 Tempe, AZ 85287-1404 and Mount Stromlo Observatory, Research School of Astronomy and Astrophysics, Australian National University, Weston, ACT, Australia 2611, [2]Department of Physics, MIT, Cambridge MA 02139; e-mail: krauss@asu.edu, wilczek@mit.edu

Abstract – It is commonly anticipated that gravity is subject to the standard principles of quantum mechanics. Yet some – including Einstein – have questioned that presumption, whose empirical basis is weak. Indeed, recently Freeman Dyson has emphasized that no conventional experiment is capable of detecting individual gravitons. However, as we describe, if inflation occurred, the Universe, by acting as an ideal graviton amplifier, affords such access. It produces a classical signal, in the form of macroscopic gravitational waves, in response to spontaneous (not induced) emission of gravitons. Thus recent BICEP2 observations of polarization in the cosmic microwave background will, if confirmed, provide firm empirical evidence for the quantization of gravity. Their details also support quantitative ideas concerning the unification of strong, electromagnetic, and weak forces, and of all these with gravity.

Second Award – **Black Holes as Gravitational Atoms** – by: Cenalo Vaz; University of Cincinnati, Cincinnati, Ohio 45221-0011; email: Cenalo.Vaz@UC.Edu

Abstract – Recently, Almheiri, Marolf, Polchinski, Stanford, and Sully argued, via a delicate thought experiment, that it is not consistent to simultaneously require that (a) Hawking radiation is pure, (b) effective field theory is valid outside a stretched horizon and (c) infalling observers encounter nothing unusual as they cross the horizon. These are the three fundamental assumptions underlying Black Hole Complementarity and the authors proposed that the most conservative resolution of the paradox is that (c) is false and the infalling observer burns up at the horizon (the horizon acts as a "firewall"). However, the firewall violates the equivalence principle and breaks the CPT invariance of quantum gravity, leading Hawking to propose that gravitational collapse may not end up producing event horizons, although he did not give a mechanism for how this may happen. In this essay, we support Hawking's conclusion in a quantum gravitational model of dust collapse. We will show that continued collapse to a singularity can only be achieved by combining two independent and entire solutions of the Wheeler-DeWitt equation. We interpret the paradox as simply forbidding such a combination, which leads naturally to matter condensing on the apparent horizon during quantum collapse.

Third Award – **What Drives the Time Evolution of the Spacetime Geometry?** – by: T. Padmanabhan; IUCAA, Post Bag 4, Ganeshkhind, Pune - 411 007, India; e-mail: paddy@iucaa.ernet.in

Abstract – I show that in a general, dynamic spacetime, the rate of change of gravitational momentum is related to the difference between the number of bulk and boundary degrees of freedom. All static spacetimes maintain holographic equipartition; i.e., in these spacetimes, the number of degrees of freedom in the boundary is equal to the number of degrees of freedom in the bulk. It is the departure from holographic equipartition that drives the time evolution of the spacetime. This result, which is equivalent to Einstein's equations, provides an elegant, holographic, description of spacetime dynamics.

Fourth Award – **Schrödinger's Cat and the Firewall** – by: Timothy J. Hollowood; Department of Physics, Swansea University, Swansea, SA2 8PP, UK; e-mail: t.hollowood@swansea.ac.uk

Abstract – It has been argued that when black holes are treated as quantum systems there are implications at the horizon and not just the singularity. Infalling observers will meet a firewall of high energy quanta. We argue that the question of whether an observer falling into a black hole experiences a smooth horizon or a firewall is identical to the question of whether Schrödinger's cat is either in a definite state, alive or dead, or in a superposition of the two. Since experience with real macro-systems indicates the former, the black hole state vector is seen to describe a set of decoherent alternatives each with a smooth horizon and the entanglement puzzle is thereby side stepped.

Fifth Award – **Gravitational Waves and the (Quantum) Nature of the Primordial Seed** – by: Rafael A. Porto; School of Natural Sciences, Institute for Advanced Study, Olden Lane, Princeton, NJ 08540 and Deutsches Elektronen-Synchrotron DESY, Theory Group, D-22603 Hamburg, Germany; e-mail: rporto@ias.edu

Abstract – At first glance, the (indirect) measurement of primordial tensor modes by the BICEP2 collaboration supports an inflationary paradigm for early universe cosmology together with *quantum vacuum* fluctuations (*aka* gravitons) as the origin of the spectrum. In this essay we argue that the observed signal may instead be a signature of *semi-classical* sources of perturbations during inflation. In this scenario, despite a large tensor-to-scalar ratio $r \simeq 0.2$, it may be possible to write an effective field theory of a rolling scalar field without super-Planckian excursions. If the results from BICEP2 withstand further scrutiny, measurements of primordial non-Gaussianity with large scale structure surveys, and direct detection of gravitational waves with the new generation of observatories, will be of paramount importance to elucidate the (quantum) origin of structure in the universe.

Honorable Mention Awards **(Alphabetical Order)**

1. **The Large-Scale Structure of Vacuum** – by: F. D. Albareti[1], J. A. R. Cembranos[2], and A. L. Maroto[2]; [1]Departamento de Física Teórica, Universidad Autónoma de Madrid, Campus de Cantoblanco, 28049 Madrid, Spain, [2]Departamento de Física Teórica, Universidad Complutense de Madrid, Ciudad Universitaria, 28040 Madrid, Spain; e-mail: fdalbareti@ucm.es, cembra@ucm.es, maroto@ucm.es

Abstract – The vacuum state in quantum field theory is known to exhibit an important number of fundamental physical features. In this work we explore the possibility that this state could also present a non-trivial space-time structure on large scales. In particular, we will show that by imposing the renormalized vacuum energy-momentum tensor to be conserved and compatible with cosmological observations, the vacuum energy of sufficiently heavy fields behaves at late times as non-relativistic matter rather than as a cosmological constant. In this limit, the vacuum state supports perturbations whose speed of sound is negligible and accordingly allows the growth of structures in the vacuum energy itself. This large-scale structure of vacuum could seed the formation of galaxies and clusters very much in the same way as cold dark matter does.

2. **Are the Most Super-Massive Dark Compact Objects Harbored at the Center of Dark Matter Halos?** – by: C. R. Argüelles and R. Ruffini; Dipartimento di Fisica and ICRA, Sapienza Università di Roma, P.le Aldo Moro 5, I-00185 Rome, Italy and ICRANet, P.zza della Repubblica 10, I-65122 Pescara, Italy; e-mail: carlos.arguelles@icranet.org, ruffini@icra.it

Abstract – We study an isothermal system of semi-degenerate self-gravitating fermions in General Relativity. The most general solutions present mass density profiles with a central degenerate compact core governed by quantum statistics followed by an extended plateau, and ending in a power law behavior r^{-2}. By fixing the fermion mass m in the keV regime, the different solutions depending on the free parameters of the model: the degeneracy and temperature parameters at the center, are systematically constructed along the one-parameter sequences of equilibrium configurations up to the critical point, which is represented by the maximum in a central density (ρ_0) vs. core mass (M_c) diagram. We show that for fully degenerate cores, the Oppenheimer-Volkoff mass limit $M_c^{cr} \propto M_{pl}^3 / m^2$ is obtained, while instead for low degenerate cores, the critical core mass increases showing the temperature effects in a nonlinear way. The main result of this work is that when applying this theory to model the distribution of dark matter in big elliptical galaxies from miliparsec distance-scales up to 10^2 Kpc, we do not find any critical core-halo configuration of self-gravitating fermions, able to explain both the most super-massive dark object at their center together with the Dark Matter halo simultaneously.

3. **In What Sense a Neutron Star–Black Hole Binary Is the Holy Grail for Testing Gravity** – by: Manjari Bagchi[1] and Diego F. Torres[2]; [1]International Centre for Theoretical Sciences, Tata Institute of Fundamental Research, Bangalore 560012, India, [2]ICREA & Institute of Space Sciences, Barcelona 2a Planta E-08193, Spain; e-mail: manjari.bagchi@icts.res.in, dtorres@ieec.uab.es

Abstract – Pulsars in binary systems have been very successful to test the validity of general relativity in the strong field regime. So far, such binaries include neutron star–white dwarf and neutron star−neutron star systems. It is commonly believed that a neutron star−black hole binary will be much superior for this purpose. But in what sense is this true? Does it apply to all possible deviations?

4. **Unraveling the Nature of Gravity through Our Clumpy Universe** – by: Shant Baghram[1][2], Saeed Tavasoli[1], Farhang Habibi[1], Roya Mohayaee[3], and Joseph Silk[3]; [1]School of Astronomy, Institute for Research in Fundamental Sciences (IPM), P.O. Box 19395-5531, Tehran, Iran, [2]Department of Physics, Sharif University of Technology, P.O. Box 11155-9161, Tehran, Iran, [3]IAP, CNRS, Sorbonne University, 98bis Bld Arago, Paris, France; e-mail: baghram@ipm.ir, tavasoli@ipm.ir, farhang@ipm.ir, mohayaee@iap.fr, silk@iap.fr

Abstract – In this work, we introduce a novel probe to test the nature of gravity with cosmological observations. We show that how by using a void-galaxy catalogue of large scale structure surveys we can estimate amount of magnitude change of Supernova type Ia flux as a standard candle by the gravitational lensing/delensing of structures along the line of sight. We also show the effect of peculiar velocity of the sources on the distance modulus. We use the void-finder catalogue on Sloan Digital Sky Survey Data, Data Release 10 to find the distribution of matter along the line of sight of Supernova type Ia's which we chose from the Union sample. We study the relation of magnitude change of these Supernova type Ia's with the amount of convergence introduced by the structures in line of sight. We conclude that current data is not capable to find any deviation from general relativity. However the method proposed in this essay will be a very promising tool to probe the nature of gravity with future surveys in different scales and in different red shifts.

5. **Disjoint Regions of Space-Time cannot Be Independently Observed** – by: Vijay Balasubramanian[1], Bartlomiej Czech[2], and Jan de Boer[3]; [1]David Rittenhouse Laboratories, University of Pennsylvania, 209 S 33rd Street, Philadelphia, PA 19104 and CUNY Graduate Center, Initiative for the Theoretical Sciences, 365 Fifth Avenue, New York, NY 10016, [2]Stanford Institute for Theoretical Physics, Stanford University, 382 Via Pueblo Mall, Stanford, CA 94305-4060, [3]Institute for Theoretical Physics, University of Amsterdam, Science Park 904, Postbus 94485, 1090 GL Amsterdam, The Netherlands; e-mail: vijay@physics.upenn.edu, czech@stanford.edu, J.deBoer@uva.nl

Abstract – It is commonly assumed that the locality of physics implies that disjoint regions of space are described by distinct Hilbert spaces that can be independently measured. We use the relation between entanglement and geometry in the AdS/CFT correspondence to show that this assumption cannot be generally true. The disagreement with naïve intuition typically increases with the size of spatial regions.

6. **Holographic Space-Time and the Resolution of Black Hole Singularities** – by: Tom Banks[1] and W. Fischler[2]; [1]Department of Physics and SCIPP, University of California, Santa Cruz, CA 95064 and Department of Physics and NHETC, Rutgers University, Piscataway, NJ 08854, [2]Department of Physics and Texas Cosmology Center, University of Texas, Austin, TX 78712; E-mail: banks@scipp.ucsc.edu, fischler@physics.utexas.edu

Abstract – The theory of Holographic Space-time is a general approach to quantum gravity. In this article we want to outline recent progress we have made in understanding the production, evaporation and properties of black holes in Minkowski space, as seen through the lens of Holographic Space-time. In particular, we will demonstrate the nature of the black hole singularity, and the relation of trajectories in the black hole interior and "mirages" seen on the horizon by external observers. The singularity itself will be seen to be non-singular in the quantum theory, a result of space-time geometry's "attempt" to mock up the causal connections in the quantum theory with variations in space-like separation.

7. **Mutiny at the White-Hole District** – by: Carlos Barceló[1], Raúl Carballo-Rubio[1], and Luis J. Garay[2]; [1]Instituto de Astrofísica de Andalucía, CSIC, Camino Bajo de Huétor 50, 18008 Granada, Spain, [2]Departamento de Física Teórica II, Universidad Complutense de Madrid, 28040 Madrid, Spain and Instituto de Estructura de la Materia, CSIC, Serrano 121, 28006 Madrid, Spain; e-mail: carlos@iaa.es, raucarrub@gmail.com, luisj.garay@ucm.es

Abstract – The white-hole sector of Kruskal solution is almost never used in physical applications. However, it might contain the solution to many of the problems associated with gravitational collapse and evaporation. This essay tries to draw attention to some bouncing geometries that make a democratic use of the black- and white-hole sectors. We will argue that these types of behaviour could be perfectly natural in some approaches to the next physical level beyond classical general relativity.

8. **A Viable Starobinsky-like Inflationary Scenario in the Light of Planck and BICEP2 Results** – by: Spyros Basilakos[1], José Ademir Sales Lima[2], and 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, Department ECM, and Institut de Ciències del Cosmos (ICC), Universitat de Barcelona, Av. Diagonal 647 E-08028 Barcelona, Catalonia, Spain; e-mail: svasil@Academyofathens.gr, jas.lima@iag.usp.br, sola@ecm.ub.edu

Abstract – The recent CMB data from Planck and BICEP2 observations have opened a new window for inflationary cosmology. In this Essay we compare three Starobinsky-like inflationary scenarios: (i) the original Starobinsky proposal; (ii) a family of dynamically broken SUGRA models; and (iii) a class of "decaying" vacuum $\Lambda(H)$ cosmologies. We then focus on the $\Lambda(H)$ variant, which spans the complete cosmic history of the universe from an early inflationary stage, followed by the "graceful exit" into the standard radiation regime, the matter epoch and, finally, the late-time accelerated expansion. Most conspicuously, the "running" $\Lambda(H)$ models also provide a robust prediction for the tensor-to-scalar ratio of the CMB spectrum, $r \simeq 0.16$, which is nicely compatible to within 1σ with the value $r = 0.20^{+0.07}_{-0.05}$ recently measured by the BICEP2 collaboration.

9. **From Continuum Mechanics to General Relativity** – by: Christian G .Böhmer[1] and Robert J. Downes[2]; [1]Department of Mathematics, University College London, Gower Street, London, WC1E 6BT, UK, [2]Centre for Advanced Spatial Analysis, University College London, Gower Street, London, WC1E 6BT, UK; e-mail: c.boehmer@ucl.ac.uk, r.downes@ucl.ac.uk

Abstract – Using ideas from continuum mechanics we construct a theory of gravity. We show that this theory is equivalent to Einstein's theory of general relativity; it is also a much faster way of reaching general relativity than the conventional route. Our approach is simple and natural: we form a very general model and then apply two physical assumptions supported by experimental evidence. This easily reduces our construction to a model equivalent to general relativity. Finally, we suggest a simple way of modifying our theory to investigate non-standard space-time symmetries.

10. **Einstein's Signature in Large-Scale Structure** – by: Marco Bruni[1], Juan Carlos Hidalgo[2][1], and David Wands[1]; [1]Institute of Cosmology and Gravitation, University of Portsmouth, Dennis Sciama Building, Portsmouth PO1 3FX, United Kingdom, [2]Instituto de Ciencias Físicas, Universidad Nacional Autónoma de México, Cuernavaca, Morelos, 62210, Mexico; e-mail: marco.bruni@port.ac.uk, hidalgo@fis.unam.mx, david.wands@port.ac.uk

Abstract – Newtonian gravity and general relativity provide complementary theoretical frameworks for modelling large-scale structure in ΛCDM cosmology. While Newtonian simulations are used to study the non-linear evolution of the matter density, a relativistic approach is essential to determine initial conditions that are set during a period of inflation in the very early universe. Most inflationary models predict an almost Gaussian distribution for the primordial metric perturbation, ζ. However, it is the Ricci curvature of comoving-orthogonal spatial hypersurfaces, R, that drives structure formation at large scales. Here we show how the non-linear relation between the spatial curvature, R, and the metric perturbation, ζ, translates into a specific non-Gaussian distribution for the matter density. Our analysis shows the non-linear signature of Einstein's gravity in large-scale structure.

11. **Cosmic Coincidence or Graviton Mass?** – by: Saurya Das; Department of Physics and Astronomy, University of Lethbridge, 4401 University Drive, Lethbridge, Alberta, Canada T1K 3M4; e-mail: saurya.das@uleth.ca

Abstract – As a result of some remarkable recent advances in astrophysical observations of high red-shift supernovae and the cosmic microwave background radiation we now have a better than ever understanding of the large scale structure of our universe, and its evolution. It is now more or less accepted that it was created at the big-bang singularity, about 14 billion years ago, that it underwent a short but rapid inflationary phase, then an expanding phase in which it transited from radiation to a matter dominated era, and is currently homogeneous and isotropic, and in an accelerating phase, and made up of about 70% *Dark Matter*, characterized by a pressure to density ratio $w \equiv p/\rho = -1$, and the remaining non-relativistic matter (mostly dark),with $w = 0$. One also assumes that the universe obeys the laws of general relativity, and quantum mechanics, the latter being important at very early times. Beneath this apparent simplicity, problems remain however, among them perhaps the most notorious being the extremely small value of the cosmological constant Λ, for it to be a candidate for dark energy, about 10^{-124} in Planck units, known as the *smallness problem* (e.g. vacuum energy of quantum fields predict 50 orders of magnitude or more, greater than the observed value), and also its almost equality with H_0^2/c^2, where H_0 = the current value of the Hubble parameter, also known as the *coincidence problem*. In this article, we show that both these problems can be resolved in one stroke, provided one assumes that the origin of Λ lies in the quantum wave function of gravitons (and of photons) which pervade our universe, albeit having a small mass, but consistent with all observations.

12. **CMBR, Dark Matter, Dark Energy: Relics of the Dark Ages? Correlating the Continuum and Quantum Universes** – by: John Bruce Davies; Dept. of Physics (retd), University of Colorado, Boulder, CO; e-mail: DaviesResearch@yahoo.com

Abstract – General relativity governs the large-scale gravitational properties of continuum space-time, while the particle and field history of the universe is governed at the microscopic level by quantum mechanics and component phase transitions. We show that these models correlate in their timing and descriptions of important Universe properties and events. The time of decoupling of radiation from matter, resulting in the relic CMBR, coincides with the continuum Universe expanding through its own Event Horizon. Next, the effect of increasing energy density as we go back in time forms a singularity in the continuum and coincides with the cosmic phase change of breaking of electroweak symmetry and we examine whether Dark Matter could be a relic of this age. At the earlier time when the Higgs Field is postulated to give mass to the quantum system, we investigate the effect of the Uncertainty Principle and whether Dark Energy is the relic from this phase transition. Using our extension of FLRW to the earliest Universe, we show that an exponentially accelerating solution approaches a flat Universe for any initial condition, resulting in an equation of state similar to that of Dark Energy.

13. **Quantum Gravity, Dynamical Phase Space and String Theory** – by: Laurent Freidel[1], Robert G. Leigh[2], and Djordje Minic[3]; [1]Perimeter Institute for Theoretical Physics, 31 Caroline St. N., Waterloo ON, N2L 2Y5, Canada, [2]Department of Physics, University of Illinois, 1110 W. Green St., Urbana IL 61801, [3]Department of Physics, Virginia Tech, Blacksburg VA 24061; e-mail: lfreidel@perimeterinstitute.ca, rgleigh@illinois.edu, dminic@vt.edu

Abstract – In a natural extension of the relativity principle we argue that a quantum theory of gravity involves two fundamental scales associated with both dynamical space-time as well as dynamical momentum space. This view of quantum gravity is explicitly realized in a new formulation of string theory which involves dynamical phase space and in which space-time is a derived concept. This formulation naturally unifies symplectic geometry of Hamiltonian dynamics, complex geometry of quantum theory and real geometry of general relativity. The space-time and momentum space dynamics, and thus dynamical phase space, is governed by a new version of the Renormalization Group.

14. **Emergence of String-like Physics from Lorentz Invariance in Loop Quantum Gravity** – by: Rodolfo Gambini[1] and Jorge Pullin[2]; [1]Instituto de Física, Facultad de Ciencias, Iguá 4225, esq. Mataojo, 11400 Montevideo, Uruguay, [2]Department of Physics and Astronomy, Louisiana State University, Baton Rouge, LA 70803-4001; e-mail: rgambini@fisica.edu.uy, pullin@lsu.edu

Abstract – We consider a quantum field theory on a spherically symmetric quantum space time described by loop quantum gravity. The spin network description of space time in such a theory leads to equations for the quantum field that are discrete. We show that to avoid significant violations of Lorentz invariance one needs to consider specific non-local interactions in the quantum field theory similar to those that appear in string theory. This is the first sign that loop quantum gravity places restrictions on the type of matter considered and points to a connection with string theory physics.

15. **Matter May Matter** – by: Zahra Haghani[1], Tiberiu Harko[2], Hamid Reza Sepangi[3], and Shahab Shahidi[1]; [1]School of Physics, Damghan University, Damghan, Iran, [2]Department of Mathematics, University College London, Gower Street, London, WC1E 6BT, UK, [3]Department of Physics, Shahid Beheshti University, G. C., Evin, Tehran 19839, Iran; e-mail: z.haghani@du.ac.ir, t.harko@ucl.ac.uk, hr-sepangi@sbu.ac.ir, s.shahidi@du.ac.ir

Abstract – We propose a gravitational theory in which the effective Lagrangian of the gravitational field is given by an arbitrary function of the Ricci scalar, the trace of the matter energy-momentum tensor, and the contraction of the Ricci tensor with the matter energy-momentum tensor. The matter energy-momentum tensor is generally not conserved, thus leading to the appearance of an extra force, acting on massive particles in a gravitational field. The stability conditions of the theory with respect to local perturbations are also obtained. The cosmological implications of the theory are investigated, representing an exponential solution. Hence a Ricci tensor - energy-momentum tensor coupling may explain the recent acceleration of the Universe, without resorting to the mysterious dark energy.

16. **Equation of Motion with Gravitational Radiation** – by: Richard T. Hammond; Department of Physics, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina and Army Research Office, Research Triangle Park, North Carolina 27709-2211; e-mail: rhammond@email.unc.edu

Abstract – A new approach to gravitational radiation reaction is developed which is generalized from a successful solution to the electrodynamic problem in Minkowski space-time.

17. **A New Spin on Black Hole Hair** – by: Carlos A. R. Herdeiro and Eugen Radu; Departamento de Física da Universidade de Aveiro and I3N, Campus de Santiago, 3810-183 Aveiro, Portugal; e-mail: herdeiro@ua.pt, eugen.radu@ua.pt

Abstract – We show that scalar hair can be added to rotating, vacuum black holes of general relativity. These hairy black holes clarify a lingering question concerning gravitational solitons: if a black hole can be added at the centre of a boson star, as it typically can for other solitons. We argue that it can, but only if it is spinning. The existence of such hairy black holes is related to the Kerr superradiant instability triggered by a massive scalar field. This connection leads to the following conjecture: *a* (*hairless*) *black hole which is afflicted by the superradiant instability of a given field must allow hairy generalizations with that field.*

18. **Quantum-Gravity Fluctuations and the Black-Hole Temperature** – by: Shahar Hod; The Ruppin Academic Center, Emeq Hefer 40250, Israel and The Hadassah Institute, Jerusalem 91010, Israel; e-mail: shaharhod@gmail.com

Abstract – Bekenstein has put forward the idea that, in a quantum theory of gravity, a black hole should have a discrete energy spectrum with concomitant discrete line emission. The quantized black-hole radiation spectrum is expected to be very different from Hawking's semi-classical prediction of a thermal black-hole radiation spectrum. One naturally wonders: Is it possible to reconcile the *discrete* quantum spectrum suggested by Bekenstein with the *continuous* semi-classical spectrum suggested by Hawking? In order to address this fundamental question, we shall here consider the zero-point quantum-gravity fluctuations of the black-hole spacetime. In a quantum theory of gravity, these spacetime fluctuations are closely related to the characteristic gravitational resonances of the corresponding black-hole spacetime. Assuming that the energy of the black-hole radiation stems from these zero-point quantum-gravity fluctuations of the black-hole spacetime, we derive the effective temperature of the quantized black-hole radiation spectrum. Remarkably, it is shown here that this characteristic temperature of the *discrete* (quantized) black-hole radiation agrees with the well-known Hawking temperature of the *continuous* (semi-classical) black-hole spectrum.

19. **Wormholes and Entanglement in Holography** – by: Kristan Jensen[1] and Julian Sonner[2]; [1]C. N. Yang Institute for Theoretical Physics, SUNY, Stony Brook, NY 11794-3840, [2]Center for Theoretical Physics, Massachusetts Institute of Technology, Cambridge, MA 02139 and L. N. S., Massachusetts Institute of Technology, Cambridge, MA 02139; e-mail: kristanj@insti.physics.sunysb.edu, sonner@mit.edu

Abstract – In this essay, we consider highly entangled states in theories with a gravity dual, where the entangled degrees of freedom are causally disconnected from each other. Using the basic rules of holography, we argue that there is a non-traversable wormhole in the gravity dual whose geometry encodes the pattern of the entanglement.

20. **Emergent Lorentz Covariance: How General Relativity and Lorentz Covariance Arise from the Spatially Covariant Effective Field Theory of the Transverse, Traceless Graviton** – by: Justin Khoury[1], Godfrey E. J. Miller[2], and Andrew J. Tolley[3]; [1]Center for Particle Cosmology, Department of Physics & Astronomy, University of Pennsylvania, 209 South 33rd Street, Philadelphia, PA 19104, [2]Princeton Consultants, Inc., 2 Research Way, Princeton, NJ 08540, [3]Department of Physics, Case Western Reserve University, 10900 Euclid Ave, Cleveland, OH 44106; e-mail: jkhoury@sas.upenn.edu, godfrey.miller@gmail.com, andrew.j.tolley@case.edu

Abstract – Traditional derivations of general relativity from the graviton degrees of freedom assume space-time Lorentz covariance as an axiom. In this essay, we survey recent evidence that general relativity is the unique spatially-covariant effective field theory of the transverse, traceless graviton degrees of freedom. The Lorentz covariance of general relativity, having not been assumed in our analysis, is thus plausibly interpreted as an accidental or emergent symmetry of the gravitational sector. From this point of view, Lorentz covariance is a necessary feature of low-energy graviton dynamics, not a property of space-time. This result has revolutionary implications for fundamental physics.

21. **Can Matter Really Get inside a Black Hole?** – by: Huiquan Li; Yunnan Observatories, Chinese Academy of Sciences, 650011 Kunming, China and Key Laboratory for the Structure and Evolution of Celestial Objects, Chinese Academy of Sciences, 650011 Kunming, China; e-mail: lhq@ynao.ac.cn

Abstract – It has been taken as a truth that collapsing matter can eventually cross the horizon and enter into the interior of a black hole in a finite proper time. However, the Rindler/tachyon dual description we suggested recently implies that this should not be the case. A test particle falling towards the event horizon of a non-extreme black hole can actually be viewed as an unstable particle, whose dynamics is described by the tachyon field theory. This means that the collapsing process of a free particle in Rindler space is essentially a tachyon condensation process. In terms of the results in tachyon condensation, we learn that the infalling particle should strongly couple to bulk modes and should decay completely into something like gravitons before reaching the horizon. Hence, there should be no matter that can cross a horizon and get inside the black hole as still matter. It will be “dissolved” into spacetime when approaching the horizon.

22. **Remnants, Fuzzballs or Wormholes?** – by: Samir D. Mathur; Department of Physics, The Ohio State University, Columbus, OH 43210; e-mail: mathur.16@osu.edu

Abstract – The black hole information paradox has caused enormous confusion over four decades. But in recent years, the theorem of quantum strong-subaddditivity has sorted out the possible resolutions into three sharp categories: (A) No new physics at $r >> l_p$; this necessarily implies remnants/information loss. A realization of remnants is given by a baby Universe attached near r ~ 0. (B) Violation of the ‘no-hair’ theorem by nontrivial effects at the horizon r ~ M. This possibility is realized by fuzzballs in string theory and gives unitary evaporation. (C) Having the vacuum at the horizon, but requiring that Hawking quanta at $r \sim M^3$ be somehow identified with degrees of freedom inside the black hole. A model for this ‘extreme nonlocality’ is realized by conjecturing that wormholes connect the radiation quanta to the hole.

23. **A Quantum Rosetta Stone for the Information Paradox** – by: Leopoldo A. Pando Zayas; Michigan Center for Theoretical Physics, Randall Laboratory of Physics, The University of Michigan, Ann Arbor, MI 48109-1120; e-mail: lpandoz@umich.edu

Abstract – The black hole information loss paradox epitomizes the contradictions between general relativity and quantum field theory. The AdS/CFT correspondence provides an implicit answer for the information loss paradox in black hole physics by equating a gravity theory with an explicitly unitary field theory. Gravitational collapse in asymptotically AdS spacetimes is generically turbulent. Given that the mechanism to read out the information about correlation functions in the field theory side is plagued by deterministic classical chaos, we argue that quantum chaos might provide the true Rosetta Stone for answering the information paradox in the context of the AdS/CFT correspondence.

24. **Nanomechanical Sensing of Gravitational Wave-Induced Casimir Force Perturbations** – by: Fabrizio Pinto; Department of Physics, Faculty of Science, Jazan University, P.O. Box 114, Gizan 45142, Kingdom of Saudi Arabia; email: fpinto@jazanu.edu.sa

Abstract – It is shown by means of the optical medium analogy that the static Casimir force between two conducting plates is modulated by gravitational waves. The magnitude of the resulting force changes is within the range of already existing small force metrology. It is suggested to enhance the effects on a Casimir force oscillator by mechanical parametric amplification driven by periodic illumination of interacting semiconducting boundaries. This represents a novel opportunity for the ground-based laboratory detection of gravitational waves on the nanoscale.

25. **Prospects of Detecting Spacetime Torsion** – by: Dirk Puetzfeld[1] and Yuri N. Obukhov[2]; [1]ZARM, University of Bremen, Am Fallturm, 28359 Bremen, Germany, [2]Theoretical Physics Laboratory, Nuclear Safety Institute, Russian Academy of Sciences, B. Tulskaya 52, 115191 Moscow, Russia; e-mail: dirk.puetzfeld@zarm.uni-bremen.de, yo@thp.uni-koeln.de

Abstract – How to detect spacetime torsion? In this essay we provide the theoretical basis for an answer to this question. Multipolar equations of motion for a very general class of gravitational theories with nonminimal coupling in spacetimes admitting torsion are given. Our findings provide a framework for the systematic testing of whole classes of theories with the help of extended test bodies. One surprising feature of nonminimal theories turns out to be their potential sensitivity to torsion of spacetime even in experiments with ordinary (not microstructured) test matter.

26. **Quantum Channels in Quantum Gravity** – by: Mukund Rangamani[1][2] and Massimilliano Rota[1]; [1]Centre for Particle Theory & Department of Mathematical Sciences, Science Laboratories, South Road, Durham DH1 3LE, UK, [2]School of Natural Sciences, Institute for Advanced Study, Einstein Drive, Princeton, NJ 08450; e-mail: mukund.rangamani@durham.ac.uk massimilliano.rota@durham.ac.uk,

Abstract – The black hole final state proposal implements manifest unitarity in the process of black hole formation and evaporation in quantum gravity by postulating a unique final state boundary condition at the singularity. We argue that this proposal can be embedded in the gauge/gravity context by invoking a path integral formalism inspired by the Schwinger-Keldysh like thermo-field double construction in the dual field theory. This allows us to realize the gravitational quantum channels for information retrieval to specific deformations of the field theory path integrals and opens up new connections between geometry and information theory.

27. **Planck Stars** – by: Carlo Rovelli[1] and Francesca Vidotto[2]; [1]Aix-Marseille Université, CNRS-CPT, 13288 Marseille, France, [2]Radboud University Nijmegen, Institute for Mathematics, Astrophysics and Particle Physics, Mailbox 79, P.O. Box 9010, 6500 GL Nijmegen, The Netherlands; e-mail: rovelli@cpt.univ-mrs.fr, F.Vidotto@hef.ru.nl

Abstract – We show that a collapsing star might reach a stage of its life where quantum-gravitational pressure counteracts weight. This stage is long for an external observer, but short (a bounce) in the star's proper time, because of the huge gravitational time dilation. A black hole is a bouncing star that appears frozen because it is seen in slow motion. At the end of the Hawking evaporation such "Planck star" can be much larger than planckian. The existence of Planck stars can be observable: it may produce a signal around 10^{-14} *cm*. Therefore cosmic rays might contain a trace of a quantum gravitational phenomenon.

28. **Can a Variable Gravitational Constant Resolve the *Faint Young Sun Paradox*?** – by: Varun Sahni[1] and Yuri Shtanov[2]; [1]Inter-University Centre for Astronomy and Astrophysics, Post Bag 4, Ganeshkhind, Pune 411 007, India, [2]Bogolyubov Institute for Theoretical Physics, 14-b Metrologicheskaya St., Kiev 03680, Ukraine and Department of Physics, Taras Shevchenko National University of Kiev, 64/13 Vladimirskaya St., Kiev 01601, Ukraine; e-mail: varun@iucaa.ernet.in, shtanov@bitp.kiev.ua

Abstract – Solar models suggest that four billion years ago the young Sun was ~75% fainter than it is today, rendering Earth's oceans frozen and lifeless. However, there is ample geophysical evidence that Earth had a liquid ocean teeming with life 4 Gyr ago. Since $L_\odot \propto G^7(M_\odot)^5$, the Sun's luminosity $L_\odot$ is exceedingly sensitive to small changes in the gravitational constant G. We show that a percent-level increase in G in the past would have prevented Earth's oceans from freezing, resolving the *faint young Sun* paradox. Such small changes in G are consistent with observational bounds on $\Delta G/G$. Since $L_{\rm SNIa} \propto G^{-3/2}$, an increase in G leads to fainter supernovae, creating tension between standard candle and standard ruler probes of dark energy. Precisely such a tension has recently been reported by the Planck team.

29. **Detecting Modified Gravity in the Stars** – by: Jeremy Sakstein[1], Bhuvnesh Jain[2], and Vinu Vikram[2]; [1]DAMTP, Centre for Mathematical Sciences, University of Cambridge, Wilberforce Road, Cambridge CB3 0WA, UK and Perimeter Institute for Theoretical Physics, 31 Caroline St. N, Waterloo, ON, N2L 6B9, Canada, [2]Department of Physics & Astronomy, University of Pennsylvania, Philadelphia, PA 19104; e-mail: J.A.Sakstein@damtp.cam.ac.uk, bjain@physics.upenn.edu, vinu@physics.upenn.edu

Abstract – Modified theories of gravity have received a renewed interest due to their ability to account for the cosmic acceleration. In order to satisfy the solar system tests of gravity, these theories need to include a screening mechanism that hides the modifications on small scales. One popular and well-studied theory is chameleon gravity. Our own galaxy is necessarily screened, but less dense dwarf galaxies may be unscreened and their constituent stars can exhibit novel features. In particular, unscreened stars are brighter, hotter and more ephemeral than screened stars in our own galaxy. They also pulsate with a shorter period. In this essay, we exploit these new features to constrain chameleon gravity to levels three orders of magnitude lower than the previous measurements. These constraints are currently the strongest in the literature.

30. ***R^n* Gravity Is Kicking and Alive: the Cases of Orion and NGC 3198** – by: P. Salucci[1], C. Frigerio Martins[2], and E. Karukes[1]; [1]SISSA/ISAS, via Bonomea 265, 34136 Trieste, Italy, [2]AG/USP, Instituto de Astronomia e Geofísica/Universidade de São Paulo, Rua do Matão 1226, 05508-090 São Paulo, Brazil; e-mail: salucci@sissa.it, uelchris@hotmail.com, ekarukes@sissa.it

Abstract – We analyzed the Rotation Curves of two crucial objects, the Dwarf galaxy Orion and the low luminosity Spiral NGC 3198, in the framework of R^n gravity. We surprisingly found that the no Dark Matter power-law F(R) case fits them well, performing much better than LCDM Dark Matter halo models. The level of this unexpected success can be a boost for R^n gravity.

31. **How the Quantum Emerges from Gravity** – by: Anushrut Sharma[1] and Tejinder P. Singh[2]; [1]Indian Institute of Technology Bombay, Powai, Mumbai 400076, India, [2]Tata Institute of Fundamental Research, Homi Bhabha Road, Mumbai 400005, India; e-mail; anushrut@iitb.ac.in, tpsingh@tifr.res.in

Abstract – The dynamics of a massive, relativistic spinning particle could be described either by the Dirac equation or by the Kerr solution of Einstein equations. However, one does not know a priori as to which of the two systems of equations should be used in a given situation, and the choice is dictated by experiments. It is expected that the Dirac equation holds for microscopic masses, and the Kerr solution for macroscopic masses. This suggests that Einstein gravity and the Dirac theory are limiting cases of a common underlying theoretical framework. Here we propose that such a framework is provided by a geometric theory of gravity on a Riemann-Cartan spacetime, which includes torsion. The Dirac equation emerges as the torsion dominated, gravity-free limit of this framework.

32. **A New Solution to an Old Problem of Radiation and Gravity** – by: C. S. Unnikrishnan[1] and George T. Gillies[2]; [1]Gravitation Group, Tata Institute of Fundamental Research, Homi Bhabha Road, Mumbai 400 005, India, [2]School of Engineering and Applied Science, University of Virginia, Charlottesville, VA 22904-4746; e-mail: unni@tifr.res.in, gtg@virginia.edu

Abstract – The assumed universality of the equivalence principle suggests that a particle in a gravitational field has identical physics to one in an accelerated frame. Yet, energy considerations prohibit radiation from a static particle in a gravitational field while the accelerating counterpart emits. Solutions to the fundamental problems of radiation from charges in a gravitational field and consequences to the equivalence principle usually contrast the far-field and global nature of radiation with the local validity of the equivalence principle. Here, we suggest reliable physical solutions that recognize the essential need for motional currents and the magnetic component for radiation to occur. Our discussion reiterates the need for a fresh careful look at universality of free fall for charged particles in a gravitational field.