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Abstracts of Award Winning and Honorable Mention Essays for 2015

Award Essays

First Award – **Local Conformal Symmetry: the Missing Symmetry Component for Space and Time** by Gerard 't Hooft; Institute for Theoretical Physics, Utrecht University and Spinoza Institute, Postbox 80.195, 3508 TD Utrecht, the Netherlands; e-mail: g.thooft@uu.nl

Abstract – Local conformal symmetry is usually considered to be an approximate symmetry of nature, which is explicitly and badly broken. Arguments are brought forward here why it has to be turned into an exact symmetry that is *spontaneously* broken. As in the B.E.H. mechanism in Yang-Mills theories, we then will have a formalism for disclosing the small-distance structure of the gravitational force. The symmetry could be as fundamental as Lorentz invariance, and guide us towards a complete understanding of physics at the Planck scale.

Second Award – **Gravity as the Breakdown of Conformal Invariance** by Giovanni Amelino-Camelia[1], Michele Arzano[1], Giulia Gubitosi[2], and João Magueijo[2]; [1]Dipartimento di Fisica, Università La Sapienza and Sez. Roma1 INFN, P.le A. Moro 2, 00185 Roma, Italia, [2]Theoretical Physics, Blackett Laboratory, Imperial College, London, SW7 2BZ, United Kingdom; e-mail: giovanni.amelino-camelia@roma1.infn.it, michele.arzano@roma1.infn.it, g.gubitosi@imperial.ac.uk, j.magueijo@imperial.ac.uk

Abstract – We propose that at the beginning of the universe gravity existed in a limbo either because it was switched off or because it was only conformally coupled to all particles. This picture can be reverse-engineered from the requirement that the cosmological perturbations be (nearly) scale-invariant without the need for inflation. It also finds support in recent results in quantum gravity suggesting that spacetime becomes two-dimensional at super-Planckian energies. We advocate a novel top-down approach to cosmology based on the idea that gravity and the Big Bang Universe are relics from the mechanism responsible for breaking the fundamental conformal invariance. Such a mechanism should leave clear signatures in departures from scale-invariance in the primordial power spectrum and the level of gravity waves generated.

Third Award – **Nature Abhors a Horizon** by Per Kraus[1] and Samir D. Mathur[2]; [1]Department of Physics and Astronomy, UCLA, Los Angeles, CA 90095-1547, [2]Department of Physics, The Ohio State University, Columbus, OH 43210; e-mail: pkraus@ucla.edu, mathur.16@osu.edu

Abstract – The information paradox can be resolved if we recognize that the wavefunctional in gravity $\Psi[g]$ should be considered on the *whole* of superspace, the space of possible g. The largeness of the Bekenstein entropy implies a vast space of gravitational solutions, which are conjectured to be fuzzball configurations. In the WKB approximation, the wavefunctional for a collapsing shell is oscillatory in a small region of superspace, and the classical approximation picks out this part. But the wavefunctional will be damped ('under the barrier') in the remainder of this vast superspace. We perform a simple computation to show that at the threshold of black hole formation, the barrier is lowered enough to make the latter part oscillatory; this alters the classical evolution and avoids horizon formation.

Fourth Award – **Fractionated Branes and Black Hole Interiors** by Emil J. Martinec; Enrico Fermi Inst. and Dept. of Physics, University of Chicago, 5640 S. Ellis Ave., Chicago, IL 60637-1433; e-mail: e-martinec@uchicago.edu

Abstract – Combining a variety of results in string theory and general relativity, a picture of the black hole interior is developed wherein spacetime caps off at an inner horizon, and the inter-horizon region is occupied by a Hagedorn gas of a very low tension state of fractionated branes. This picture leads to natural resolutions of a variety of puzzles concerning quantum black holes.

Fifth Award – **The Essence of Gravitational Waves and Energy** by F. I. Cooperstock; Department of Physics and Astronomy, University of Victoria, P.O. Box 3055, Victoria, B.C. V8W 3P6, Canada; e-mail: cooperst@uvic.ca

Abstract – We discuss the essential element of gravity as spacetime curvature and a gravitational wave as the propagation of spacetime curvature. Electromagnetic waves are necessarily localized carriers of spacetime curvature and hence are also gravitational waves. Thus electromagnetic waves have dual character and detection of gravitational waves is the routine of our everyday experience. Regarding the transferring energy from a gravitational wave to an apparatus, both Rosen and Bondi waves lack the essential characteristic of inducing a gradient of acceleration between detector elements. We discuss our simple invariant energy expression for general relativity and its extension. If the cosmological term is present in the field equations, its universal presence characteristic implies that gravitational waves would necessarily have an energy aspect in their propagation in every case.

Honorable Mention Awards **(Alphabetical Order)**

1. **General Relativity as a Two-Dimensional CFT** by Tim Adamo; Department of Applied Mathematics & Theoretical Physics, University of Cambridge, Wilberforce Road, Cambridge, CB3 0WA, UK; e-mail: t.adamo@damtp.cam.ac.uk

Abstract – The tree-level scattering amplitudes of general relativity encode the full non-linearity of the Einstein field equations. Yet remarkably compact expressions for these amplitudes have been found which seem unrelated to a perturbative expansion of the Einstein-Hilbert action. This suggests an entirely different description of GR which makes this on-shell simplicity manifest. Taking our cue from the tree-level amplitudes, we discuss how such a description can be found. The result is a formulation of GR in terms of a solvable two-dimensional CFT, with the Einstein equations emerging as quantum consistency conditions.

2. **A Holographic Big Bang?** by N. Afshordi[1], R. B. Mann[1], and R. Pourhasan[2]; [1]Perimeter Institute for Theoretical Physics, Department of Physics and Astronomy, University of Waterloo & Perimeter Institute for Theoretical Physics, [2]University of Iceland, Science Institute, Dunhaga 3, 107 Reykjavik, Iceland; e-mail: nafshordi@pitp.ca, rbmann@uwaterloo.ca

Abstract – We present a cosmological model in which the universe emerges out of the collapse of a 5-dimensional star as a spherical 3-brane. The initial singularity of the big bang becomes hidden behind a causal horizon. Near scale-invariant primordial curvature perturbations can be induced on the brane via a thermal atmosphere that is in equilibrium with the brane, circumventing the need for a separate inflationary process and providing an important test of the model.

3. **The Unruh Effect and Oscillating Neutrinos** by Dharam Vir Ahluwalia[1], Lance Labun[2], and Giorgio Torrieri[3]; [1]Department of Physics, Indian Institute of Technology, Kalyanpur, Kanpur, Uttar Pradesh 208016, India and Department of Physics and Astronomy, University of Canterbury, Christchurch 8140, New Zealand, [2]Department of Physics, University of Texas, Austin, TX 78712, [3]IFGW, Universidade Estadual de Campinas, Campinas, São Paulo, Brazil; e-mail: dharam.vir.ahluwalia.1952@gmail.com, lance@phys.ntu.edu.tw, lunogled@gmail.com

Abstract – We point out that neutrino oscillations imply an ambiguity in the definition of the vacuum and the coupling to gravity, with experimentally observable consequences due to the Unruh effect. In an accelerating frame, the detector should see a bath of mass Eigenstates neutrinos. In inertial processes, neutrinos are produced and absorbed as charge Eigenstates. The two cannot be reconciled by a spacetime coordinate transformation. This makes manifestations of the Unruh effect in neutrino physics a promising probe of both neutrinos and fundamental quantum field theory. In this respect, we suggest $p \rightarrow n + \ell^+ + \nu_\ell$ ($\ell^+ = e^+, \mu^+, \tau^+$) transitions in strong electromagnetic fields as a promising avenue of investigation. In this essay we discuss this process both in the inertial and comoving frame, we briefly describe the experimental realization and its challenges, and close by speculating on possible results of such an experiment in different scenarios of fundamental neutrino physics.

4. **Cosmological Constant, Quantum Measurement, and the Problem of Time** by Shreya Banerjee, Sayantani Bera, and Tejinder P. Singh; Tata Institute of Fundamental Research, Homi Bhabha Road, Mumbai 400005, India; e-mail: shreya.banerjee@tifr.res.in, sayantani.bera@tifr.res.in, tpsingh@tifr.res.in

Abstract – Three of the big puzzles of theoretical physics are the following: (i) There is apparently no time evolution in the dynamics of quantum general relativity, because the allowed quantum states must obey the Hamiltonian constraint. (ii) During a quantum measurement, the state of the quantum system randomly collapses from being in a linear superposition of the eigenstates of the measured observable, to just one of the eigenstates, in apparent violation of the predictions of the deterministic, linear Schrödinger equation. (iii) The observed value of the cosmological constant is exceedingly small, compared to its natural value, creating a serious fine-tuning problem. In this essay we propose a novel idea to show how the three problems help solve each other.

5. **The Temperature/Entropy Connection for Horizons, Massless Particle Scattering, and the Origin of Locality** by Tom Banks; Department of Physics and SCIPP, University of California, Santa Cruz, CA 95064 and Department of Physics and NHETC, Rutgers University, Piscataway, NJ 08854; e-mail: banks@scipp.ucsc.edu

Abstract – I explain, in non-technical terms, the basic ideas of Holographic Space-time (HST) models of quantum gravity (QG). The key feature is that the degrees of freedom (DOF) of QG, localized in a finite causal diamond are restrictions of an algebra of asymptotic currents, describing flows of quantum numbers out to null infinity in Minkowski space, with zero energy density on the sphere at infinity. Finite energy density states are constrained states of these DOF and the resulting relation between asymptotic energy and the number of constraints, explains the relation between black hole entropy and energy, as well as the critical energy/impact parameter regime in which particle scattering leads to black hole formation. The results of a general class of models, implementing these principles, are described, and applied to understand the firewall paradox, and to construct a finite model of the early universe, which implements inflation with only the minimal fine tuning needed to obtain a universe containing localized excitations more complex than large black holes.

6. **Uncovering the Effective Spacetime - Lessons from the Effective Field Theory Rationale** by Carlos Barceló[1], Raúl Carballo-Rubio[1], and Luis J. Garay[2,3]; [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, [3]Instituto de Estructura de la Materia, CSIC, Serrano 121, 28006 Madrid, Spain; e-mail: carlos@iaa.es, raulc@iaa.es, luisj.garay@ucm.es

Abstract – The cosmological constant problem can be understood as the failure of the decoupling principle behind effective field theory, so that some quantities in the low-energy theory are extremely sensitive to the high-energy properties. While this reflects the genuine character of the cosmological constant, finding an adequate effective field theory framework which avoids this naturalness problem may represent a step forward to understand nature. Following this intuition, we consider a minimal modification of the structure of general relativity which as an effective theory permits to work consistently at low energies, i.e., below the quantum gravity scale. This effective description preserves the classical phenomenology of general relativity and the particle spectrum of the standard model, at the price of changing our conceptual and mathematical picture of spacetime.

7. **New Singularities in Unexpected Places** by John D. Barrow and Alexander A. H. Graham; Department of Applied Mathematics and Theoretical Physics, University of Cambridge, Wilberforce Road, Cambridge, CB3 0WA, UK; e-mail: J.D.Barrow@damtp.cam.ac.uk, A.A.H.Graham@damtp.cam.ac.uk

Abstract – Spacetime singularities have been discovered which are physically much weaker than those predicted by the classical singularity theorems. Geodesics evolve through them and they only display infinities in the derivatives of their curvature invariants. So far, these singularities have appeared to require rather exotic and unphysical matter for their occurrence. Here we show that a large class of singularities of this form can be found in a simple Friedmann cosmology containing only a scalar-field with a power-law self-interaction potential. Their existence challenges several preconceived ideas about the nature of spacetime singularities and impacts upon the end of inflation in the early universe.

8. **The Third Way to 3D Gravity** by Eric Bergshoeff[1], Wout Merbis[2], Alasdair J. Routh[3], and Paul K. Townsend[3]; [1]Centre for Theoretical Physics, University of Groningen, Nijenborgh 4, 9747 AG Groningen, The Netherlands, [2]Institute for Theoretical Physics, Vienna University of Technology, Wiedner Hauptstrasse 8-10/136, A-1040 Vienna, Austria, [3]Department of Applied Mathematics and Theoretical Physics, Centre for Mathematical Sciences, University of Cambridge, Wilberforce Road, Cambridge, CB3 0WA, UK; e-mail: e.a.bergshoeff@rug.nl, merbis@hep.itp.tuwien.ac.at, A.J.Routh@damtp.cam.ac.uk, p.k.townsend@damtp.cam.ac.uk

Abstract – Consistency of Einstein's gravitational field equation $G_{\mu\nu} \propto T_{\mu\nu}$ imposes a “conservation condition” on the *T*-tensor that is satisfied by (i) matter stress tensors, as a consequence of the matter equations of motion, and (ii) identically by certain other tensors, such as the metric tensor. However, there is a third way, overlooked until now because it implies a “non- geometrical” action: one *not* constructed from the metric and its derivatives alone. The new possibility is exemplified by the 3D “minimal massive gravity” model, which resolves the “bulk vs boundary” unitarity problem of topologically massive gravity with anti-de Sitter asymptotics. Although all known examples of the third way are in three spacetime dimensions, the idea is general and could, in principle, apply to higher-dimensional theories.

9. **How Emergent Is Gravity?** by Swastik Bhattacharya and S. Shankaranarayanan; School of Physics, Indian Institute of Science Education and Research, Thiruvananthapuram (IISER-TVM), Trivandrum 695016, India; e-mail: swastik@iisertvm.ac.in, shanki@iisertvm.ac.in

Abstract – General theory of relativity (or Lovelock extensions) is a dynamical theory; given an initial configuration on a space-like hypersurface, it makes a definite prediction of the final configuration. Recent developments suggest that gravity may be described in terms of macroscopic parameters. It finds a concrete manifestation in the fluid-gravity correspondence. Most of the efforts till date have been to relate equilibrium configurations in gravity with fluid variables. In order for the emergent paradigm to be truly successful, it has to provide a statistical mechanical derivation of how a given initial static configuration evolves into another. In this essay, we show that the energy transport equation governed by the fluctuations of the horizon-fluid is similar to Raychaudhuri equation and, hence gravity is truly emergent.

10. **Entanglement Time in the Primordial Universe** by Eugenio Bianchi, Lucas Hackl, and Nelson Yokomizo; Institute for Gravitation and the Cosmos, Physics Department, Penn State, University Park, PA 16802; e-mail: ebianchi@gravity.psu.edu, lucas.hackl@psu.edu, yokomizo@gravity.psu.edu

Abstract – We investigate the behavior of the entanglement entropy of space in the primordial phase of the universe before the beginning of cosmic inflation. We argue that in this phase the entanglement entropy of a region of space grows from a zero-law to an area-law. This behavior provides a quantum version of the classical BKL conjecture that spatially separated points decouple in the approach to a cosmological singularity. We show that the relational growth of the entanglement entropy with the scale factor provides a new statistical notion of arrow of time in quantum gravity. The growth of entanglement in the pre-inflationary phase provides a mechanism for the production of the quantum correlations present at the beginning of inflation and imprinted in the CMB sky.

11. **The Equivalence Principle in a Quantum World** by N. E. J Bjerrum-Bohr[1], John F. Donoghue[2], Basem Kamal El-Menoufi[2], Barry R. Holstein[2], Ludovic Planté[3], and Pierre Vanhove[3,4]; [1]Niels Bohr International Academy and Discovery Center, The Niels Bohr Institute, Blegdamsvej 17, DK-2100 Copenhagen *θ*, Denmark, [2]Department of Physics-LGRT, University of Massachusetts, Amherst, MA 01003, [3]Institut de physique théorique, Université Paris Saclay, CEA, CNRS, F-91191 Gif-sur-Yvette, [4]Institut des Hautes Études Scientifiques Bures-sur-Yvette, F-91440, France; e-mail: bjbohr@nbi.dk, donoghue@physics.umass.edu, bmahmoud@physics.umass.edu, holstein@physics.umass.edu, ludovic.plante@cea.fr, pierre.vanhove@cea.fr

Abstract – We show how modern methods can be applied to quantum gravity at low energy. We test how quantum corrections challenge the classical framework behind the Equivalence Principle, for instance through introduction of non-locality from quantum physics, embodied in the Uncertainty Principle. When the energy is small we now have the tools to address this conflict explicitly. Despite the violation of some classical concepts, the EP continues to provide the core of the quantum gravity framework through the symmetry - general coordinate invariance - that is used to organize the effective field theory.

12. **Weakly Coupled Gravity beyond General Relativity** by Xián O. Camanho[1], José D. Edelstein[2], and Alexander Zhiboedov[3]; [1]Max-Planck-Institut für Gravitationsphysik, Albert-Einstein-Institut, 14476 Golm, Germany, [2]Department of Particle Physics and IGFAE, University of Santiago de Compostela, E-15782 Santiago de Compostela, Spain, [3]Center for the Fundamental Laws of Nature, Harvard University, Cambridge, MA 02138; e-mail: xian.camanho@aei.mpg.de, jose.edelstein@usc.es, azhiboed@physics.harvard.edu

Abstract – We explore four dimensional weakly coupled gravity beyond General Relativity in an on-shell language, focusing on the graviton 3-point vertex. This admits a novel structure which can be attributed to a term cubic in the Riemann tensor. We consider a generalization of the Shapiro time delay experiment that involves polarized gravitons and show that the new vertex leads to causality violation. Fixing the problem demands the inclusion of an infinite tower of massive higher spin states. Perturbative string theory provides an example of this phenomenon, the only known so far. Interestingly enough, the same argument being applied to inflation suggests that stringy signatures may be hidden in the non-Gaussianities of the primordial gravity wave spectrum.

13. **Casimir Effects Are not an Experimental Demonstration that Free Vacuum Gravitates**: C**onnections to the Cosmological Constant Problem** by Massimo Cerdonio[1] and Carlo Rovelli[2]; [1]INFN Section and University, via Marzolo 8, I-35131 Padova, Italy, [2]Aix Marseille Université, CNRS, CPT, UMR 7332, 13288 Marseille, France and Université de Toulon, CNRS, CPT, UMR 7332, 83957 La Garde, France; e-mail: cerdonio@pd.infn.it, rovelli@cpt.univ-mrs.fr

Abstract – We discuss a concrete model of a Casimir cavity, with plane parallel metallic plates kept in mechanical equilibrium by a spring and placed in a weak gravitational field. We show that simple basic physics implies that the plates cannot be idealized as massless and therefore the effect of the vacuum is inextricably connected with the interaction with the matter of the plates. In Casimir cavities it is a vacuum bound by matter which is at work. Therefore the existence of the Casimir force does not imply that free vacuum gravitates and contributes to the Cosmological Constant.

14. **Bose-Einstein Condensation as an Alternative to Inflation** 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 – It was recently shown that gravitons with a very small mass should have formed a Bose-Einstein condensate in the very early Universe, whose density and quantum potential can account for the dark matter and dark energy in the Universe respectively. Here we show that the condensation can also naturally explain the observed large scale homogeneity and isotropy of the Universe. Furthermore gravitons continue to fall into their ground state within the condensate at every epoch, accounting for the observed flatness of space at cosmological distances scales. Finally, we argue that the density perturbations due to quantum fluctuations within the condensate give rise to a scale invariant spectrum. This therefore provides a viable alternative to inflation, which is not associated with the well-known problems associated with the latter.

15. **Imprint of Modified Einstein's Gravity on White Dwarfs: Unifying Type Ia Supernovae** by Upasana Das and 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 – We establish the importance of modified Einstein's gravity (MG) in white dwarfs (WDs) for the first time in the literature. We show that MG leads to significantly sub- and super-Chandrasekhar limiting mass WDs, depending on a single model parameter. However, conventional WDs on approaching Chandrasekhar's limit are expected to trigger type Ia supernovae (SNeIa), a key to unravel the evolutionary history of the universe. Nevertheless, observations of several peculiar, under- and over-luminous SNeIa argue for the limiting mass widely different from Chandrasekhar's limit. Explosions of MG induced sub- and super-Chandrasekhar limiting mass WDs explain under- and over-luminous SNeIa respectively, thus unifying these two apparently disjoint sub-classes. Our discovery questions both the global validity of Einstein's gravity and the uniqueness of Chandrasekhar's limit.

16. **Is Spacetime Lorentzian or Just Most Probably Lorentzian?** by Aharon Davidson and Ben Yellin; Physics Department, Ben-Gurion University of the Negev, Beer-Sheva 84105, Israel; e-mail: davidson@bgu.ac.il, yellinb@post.bgu.ac.il

Abstract – An algebraic FLRW equation, the result of a legitimate pre-gauging of the cosmological scale factor $a(t)$, signals a non-dynamical Hartle-Hawking mini-superspace. The missing ingredient, a generalized momentum whose Dirac bracket with the lapse function $n(t)$ does not vanish, can be provided by scaling the general relativistic measure. Consequently, the time independent Hartle-Hawking wave function $\psi(a)$ is traded for a time dependent $\psi(n,t)$. The emerging time dependent quantum cosmology comes with a distinct theoretical fingerprint: For any given time t, unlike in the Hartle-Hawking prescription, there is now a probability, which we calculate, that spacetime is Lorentzian and a complementary probability that it is Euclidean. Invoking the 'most classical' $\psi(n,t)$ wave packet, the no-boundary proposal (with or without an embryonic era) is re-examined. An analogy to the 5-dim Schwarzschild-deSitter quantum black hole is established.

17. **Initial Intrinsic Inflation Defines the Finite Mass Universe** by John Bruce Davies; Dept. of Physics (retd), University of Colorado, Boulder, CO; e-mail: DaviesResearch@yahoo.com

Abstract – Extending the FLRW model and applying to the earliest continuum Universe, we show that an exponentially accelerating solution for the Scale Factor approaches a flat Universe for any initial condition, resulting in an equation of state similar to that of Dark Energy. The largest total energy density of the expanding observable Universe is due to the inflation solution of a constant energy density starting with the Planck energy density at the initial Planck time. Assuming that this initial inflation ends in the phase change that results in the constituents attaining the finite mass of the observable Universe, the time of this phase change is determined at about 10^{-22} sec. At this time the observable Universe is about the size of a nucleon. This time is also the mean lifetime of the Higgs boson, which particle is considered to mediate the Higgs Field that gives mass to the constituent particles of the Universe.

18. **Modular Space-Time** 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 West Green St., Urbana IL 61801, [3]Department of Physics, Virginia Tech, Blacksburg VA 24061; e-mail: lfreidel@perimeterinstitute.ca, rgleigh@uiuc.edu. dminic@vt.edu

Abstract – We have recently introduced metastring theory as a reformulation of string theory which does not rely on an *a priori* space-time interpretation or a presumption of locality found in local effective field theory. In this essay, we focus on the concept of *modular space-time* as the natural quantum gravitational notion of space-time that emerges from metastring theory.

19. **Cosmology and Short-Distance Gravity** by M. Gasperini; Dipartimento di Fisica, Università di Bari, Via G. Amendola 173, 70126 Bari, Italy and Istituto Nazionale di Fisica Nucleare, Sezione di Bari, Bari, Italy; e-mail: gasperini@ba.infn.it

Abstract – If the observed dark-energy density ρ_Λ is interpreted as the net contribution of the energy density of the vacuum, $\rho_\Lambda \equiv \rho_V \sim M_V^4$, and the corresponding vacuum length scale $\lambda_V = M_V^{-1}$ as the cutoff scale controlling the low-energy, effective field-theory limit of gravity, it follows that the conventional cosmological scenario based on the effective gravitational equations may be valid only up to the Tev energy scale. Such a possibility would be strongly disfavored by the existence of a relic background of primordial gravitational radiation of intensity compatible with present (or near future) experimental sensitivities.

20. **Observational Hints of a Pre-Inflationary Scale?** by A. Gruppuso[1,2] and A. Sagnotti[3,4]; [1]INAF-IASF Bologna, Istituto di Astrofisica Spaziale e Fisica Cosmica di Bologna, Istituto Nazionale di Astrofisica, via Gobetti 101, I-40129 Bologna, Italy, [2]INFN, Sezione di Bologna, Via Irnerio 46, I-40126 Bologna, Italy, [3]Department of Physics, CERN Theory Division, CH - 1211 Geneva 23, Switzerland, [4]Scuola Normale Superiore and INFN Piazza dei Cavalieri 7, I-56126 Pisa Italy; e-mail: gruppuso@iasbo.inaf.it, sagnotti@sns.it

Abstract – We argue that the lack of power exhibited by cosmic microwave background (CMB) anisotropies at large angular scales might be linked to the onset of inflation. We highlight observational features and theoretical hints that support this view, and present a preliminary estimate of the physical scale that would underlie the phenomenon.

21. **How Fast Can a Black Hole Rotate?** by Carlos A. R. Herdeiro and Eugen Radu; Departamento de Física da Universidade de Aveiro and CIDMA, Campus de Santiago, 3810-183 Aveiro, Portugal; e-mail: herdeiro@ua.pt, eugen.radu@ua.pt

Abstract – Kerr black holes have their angular momentum, J, bounded by their mass, M: $J_c \leq GM^2$. There are, however, known black hole solutions violating this *Kerr bound*. We propose a very simple universal bound on the rotation, rather than on the angular momentum, of four-dimensional, stationary and axisymmetric, asymptotically flat black holes, given in terms of an appropriately defined *horizon linear velocity*, v_H. The v_H bound is simply that v_H cannot exceed the velocity of light. We verify the v_H bound for known black hole solutions, including some that violate the Kerr bound, and conjecture that only extremal Kerr black holes saturate the v_H bound.

22. **Ten Shades of Black** by Shahar Hod; The Ruppin Academic Center, Emeq Hefer 40250, Israel and The Hadassah Institute, Jerusalem 91010, Israel; e-mail: shaharhod@gmail.com

Abstract – The holographic principle has taught us that, as far as their entropy content is concerned, black holes in (3+1)-dimensional curved spacetimes behave as ordinary thermodynamic systems in flat (2+1)-dimensional spacetimes. In this essay we point out that the *opposite* behavior can also be observed in black-hole physics. To show this we study the quantum Hawking evaporation of near-extremal Reissner-Nordström black holes. We first point out that the black-hole radiation spectrum departs from the familiar radiation spectrum of genuine (3+1)-dimensional perfect black-body emitters. In particular, the would-be black-body thermal spectrum is distorted by the curvature potential which surrounds the black hole and effectively blocks the emission of low-energy quanta. Taking into account the energy-dependent gray-body factors which quantify the imprint of passage of the emitted radiation quanta through the black-hole curvature potential, we reveal that the (3+1)-dimensional black holes effectively behave as perfect black-body emitters in a flat (9+1)-dimensional spacetime. This intriguing property of near-extremal black holes may be related to the Large-Extra-Dimensions scenario inspired by modern superstring theories.

23. **Gravitons to Photons – Attenuation of Gravitational Waves** by Preston Jones[1] and Douglas Singleton[2]; [1]Physics Department, California State University Fresno, Fresno, CA 93740 and Embry Riddle Aeronautical University, Prescott, AZ 86301, [2]Physics Department, California State University Fresno, Fresno, CA 93740; e-mail: pjones@csufresno.edu, dougs@csufresno.edu

Abstract – In this essay we examine the response of an Unruh-DeWitt detector (a quantum two-level system) to a gravitational wave background. The spectrum of the Unruh-Dewitt detector is of the same form as some scattering processes or three body decays such as muon-electron scattering *i.e.* $\mu^- + e^- \rightarrow \nu_\mu + \nu_e$ or muon decay i.e. $\mu \rightarrow e^- + \nu_\mu + \bar{\nu}_e$. Based on this similarity we propose that the Unruh-DeWitt detector response implies a "decay" or attenuation of gravitons, G, into photons, γ, via $G + G \rightarrow \gamma + \gamma$ or $G \rightarrow \gamma + \gamma + G$. Over large distances such a decay/attenuation may have consequences in regard to the detection of gravitational waves.

24. **Accelerating Universe as a Result of an Adjustment Mechanism** by Prado Martín-Moruno and Nelson J. Nunes; Instituto de Astrofísica e Ciências do Espaço, Universidade de Lisboa, Faculdade de Ciências, Campo Grande, PT1749-016 Lisboa, Portugal; e-mail: pmmoruno@fc.ul.pt, njnunes@fc.ul.pt

Abstract – In this essay we propose that the theory of gravity's vacuum is described by a de Sitter geometry. Under this assumption we consider an adjustment mechanism able to screen any value of the vacuum energy of the matter fields. We discuss the most general scalar-tensor cosmological models with second order equations of motion that have a fixed de Sitter critical point for any kind of material content. These models give rise to interesting cosmological evolutions that we shall discuss.

25. **State of Matter at High Density and Entropy Bounds** by Ali Masoumi; Tufts Institute of Cosmology, 255 Robinson Hall, 212 College Ave, Medford, MA, 02155; e-mail: ali@cosmos.phy.tufts.edu

Abstract – Entropy of all systems that we understand well is proportional to their volumes except for black holes given by their horizon area. This makes the microstates of any quantum theory of gravity drastically different from the ordinary matter. Because of the assumption that black holes are the maximum entropy states there have been many conjectures that put the area, defined one way or another, as a bound on the entropy in a given region of spacetime. Here we construct a simple model with entropy proportional to volume which exceeds the entropy of a single black hole. We show that a homogeneous cosmology filled with this gas exceeds one of the tightest entropy bounds, the covariant entropy bound and discuss the implications.

26. **Fundamental Scalar Fields and the Dark Side of the Universe** by Eduard G. Mychelkin and Maxim A. Makukov; Fesenkov Astrophysical Institute, 050020 Almaty, Republic of Kazakhstan; e-mail: edmych@gmail.com

Abstract – Geometrical and physical aspects of the origin of fundamental cosmic scalar fields are considered in interrelated fashion. It is shown that spacetime metrics are induced by two scalar fields in accord with the Papapetrou algorithm. One of these fields has Hubble mass-scale and the other has neutrino mass-scale. These two fields are identified, correspondingly, with dark energy and primordial dark matter backgrounds.

27. **Gravity in Six Elegant Steps** by T. Padmanabhan; IUCAA, Post Bag 4, Ganeshkhind, Pune - 411 007, India; email: paddy@iucaa.ernet.in

Abstract – The kinematical description of gravity, based on the principle of equivalence, is extraordinarily beautiful. In striking contrast, the field equation $G_{ab} = (1/2)T_{ab}$ is conceptually ugly, lacking in simple physical interpretation or even common ground to describe the left and right hand sides. I show how one can develop all of gravity in an elegant manner by recognizing that the gravitational dynamics describes the heating and cooling of spacetime.

28. **Two Roads to the Null Energy Condition** by Maulik Parikh; Department of Physics & Beyond Center for Fundamental Concepts in Science, Arizona State University, Tempe, Arizona 85287; e-mail: maulik.parikh@asu.edu

Abstract – The null energy condition has sweeping consequences in general relativity. I argue here that it has been misunderstood as a property of matter, when in fact it is better viewed as a constraint on spacetime geometry. I then derive precisely the geometric formulation of the null energy condition from worldsheet string theory, where it arises beautifully as simply Einstein's equations in two dimensions. But further, I show that there is an entirely different thermodynamic origin of the null energy condition, if one accepts that gravity is emergent. Thus, far from being an incidental property of matter, the validity of the null energy condition hints at the deepest origins of gravity.

29. **Testing the Vainshtein Mechanism Using Stars and Galaxies** by Jeremy Sakstein and Kazuya Koyama; Institute of Cosmology and Gravitation, University of Portsmouth, Portsmouth PO1 3FX, UK; e-mail: jeremy.sakstein@port.ac.uk, kazuya.koyama@port.ac.uk

Abstract – The Vainshtein mechanism is of paramount importance in many alternate theories of gravity. It hides deviations from general relativity in the solar system whilst allowing them to drive the acceleration of the cosmic expansion. Recently, a class of theories has emerged where the mechanism is broken inside astrophysical objects. In this essay we look for novel probes of these theories by deriving the modified properties of stars and galaxies. We show that main-sequence stars are colder, less luminous and more ephemeral than general relativity predicts. Furthermore, the circular velocities of objects orbiting inside galaxies are slower and the lensing of light is stronger. We discuss the prospects for testing these theories using the novel phenomena presented here in light of current astrophysical surveys.

30. **Riding Gravity Away from Doomsday** by Ashoke Sen; Harish-Chandra Research Institute Chhatnag Road, Jhusi, Allahabad 211019, India; e-mail: sen@mri.ernet.in

Abstract – The discovery that most of the energy density in the universe is stored in the form of dark energy has profound consequences for our future. In particular our current limited understanding of quantum theory of gravity indicates that some time in the future our universe will undergo a phase transition that will destroy us and everything else around us instantaneously. However the laws of gravity also suggest a way out – some of our descendants could survive this catastrophe by riding gravity away from the danger. In this essay I describe the tale of this escape from doomsday.

31. **Gravitational Waves: Some Less Discussed Intriguing Issues**, by C. Sivaram; Indian Institute of Astrophysics, Sarjapur Road, Koramangala, Bangalore, 560034, India; e-mail: sivaram@iiap.res.in

Abstract – Attempts to detect gravitational waves is actively in progress with sophisticated devices like LIGO set up across continents. Despite being predicted almost hundred years ago there has so far been no direct detection of these waves. In this work we draw attention to some of the less discussed but subtle aspects arising, for example, from high orbital eccentricities, where emission near periastron could be millions of times more than that in the distant parts of the orbit. The strong field non-linear effects close to the compact objects can substantially slow down and deflect the waves in the last (few) orbit(s) where much of the intensity is expected. Spin-orbit and other forces could be significant. There would also be plasma like resonant absorption (of kilohertz radiation) during the collapse. Recent observation of supermassive black holes at high red shift implies cluster collapse where the gravitational wave intensity depends on very high powers of the mass. Any unambiguous claim of detection should perhaps consider several of these effects.

32. **The Cosmological Constant and Entropy Problems: Mysteries of the Present with Profound Roots in the Past** by Joan Solà; High Energy Physics Group, Departament ECM, and Institut de Ciències del Cosmos, Universitat de Barcelona, Av. Diagonal 647 E-08028 Barcelona, Catalonia, Spain; e-mail: sola@ecm.ub.edu

Abstract – An accelerated universe should naturally have a vacuum energy density determined by its dynamical curvature. The cosmological constant is most likely a temporary description of a dynamical variable that has been drastically evolving from the early Universe to the present. In this essay we propose a unified picture of the cosmic history implementing such an idea, in which the cosmological constant problem is fixed at early times and all the main stages, spanning from inflation – with "graceful" exit into the standard radiation regime – until the matter-dominated and dark energy epochs, are accounted for. Finally, we show that for a generic Grand Unified Theory associated to the inflationary phase, the amount of entropy generated from primeval vacuum decay can explain the entropy value today.

33. **Is the Higgs Mechanism True to the Equivalence Principle?** 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 – We raise and discuss the fundamental issue whether the interaction-induced inertia in the Higgs mechanism is the same as the charge of gravity, or the gravitational mass. True physical mass has to fulfill the dual role of inertia and the gravitational charge and should respect the weak equivalence principle. This is not yet addressed in the standard model that does not incorporate gravity. Hence the Higgs scenario still requires a gravitational completion. Some relevant analogies where interaction-induced inertia is not the same as the gravitational charge are mentioned. Probing this line of thought will provide valuable clues and perhaps a remarkable answer to the place and role of gravity in the standard model of particle physics.

34. **A Second Law for Higher Curvature Gravity** by Aron C. Wall; School of Natural Sciences, Institute for Advanced Study, 1 Einstein Dr, Princeton, NJ, 08540; e-mail: aroncwall@gmail.com

Abstract – The Second Law of black hole thermodynamics is shown to hold for arbitrarily complicated theories of higher curvature gravity, so long as we allow only linearized perturbations to stationary black holes. Some ambiguities in Wald's Noether charge method are resolved. The increasing quantity turns out to be the same as the holographic entanglement entropy calculated by Dong. It is suggested that only the linearized Second Law is a relevant consistency condition, when consistently truncating a quantum gravity theory.