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Abstracts of Award Winning and Honorable Mention Essays for 2012

Award Essays

First Award – **Can Effects of Quantum Gravity Be Observed in the Cosmic Microwave Background?** by Claus Kiefer and Manuel Krämer, Institute for Theoretical Physics, University of Cologne, Zülpicher Straße 77, 50937 Köln, Germany; e-mail: kiefer@thp.uni-koeln.de mk@thp.uni-koeln.de

Abstract – We investigate the question whether small quantum-gravitational effects can be observed in the anisotropy spectrum of the cosmic microwave background radiation. An observation of such an effect is needed in order to discriminate between different approaches to quantum gravity. Using canonical quantum gravity with the Wheeler-DeWitt equation, we find a suppression of power at large scales. Current observations only lead to an upper bound on the energy scale of inflation, but the framework is general enough to study other situations in which such effects might indeed be seen.

Second Award – **What Can the Information Paradox Tell Us about the Early Universe?** by Samir D. Mathur, Department of Physics, The Ohio State University, Columbus, OH 43210; e-mail: mathur@mps.ohio-state.edu

Abstract – In recent years we have come to understand how the information paradox is resolved in string theory. The huge entropy S_{bek}=A/4G of black holes is realized by an explicit set of horizon sized ‘fuzzball’ wavefunctions. The wavefunction of a collapsing shell spreads relatively quickly over this large phase space of states invalidating the classic black hole geometry the shell would have created. We argue that a related effect may occur in the early Universe. When matter is crushed to high densities we can access a similarly large phase space of gravitational ‘fuzzball’ solutions. While we cannot estimate specific quantities at this point, a qualitative analysis suggests that spreading over phase space creates an extra ‘push’ expanding the Universe to larger volumes.

Third Award – **The Unbearable Beingness of Light – Dressing and Undressing Photons in Black Hole Spacetimes** by Timothy J. Hollowood and Graham M. Shore, Department of Physics, Swansea University, Swansea, SA2 8PP, UK; e-mail: t.hollowood@swansea.ac.uk g.m.shore@swansea.ac.uk

Abstract – Gravitational tidal forces acting on the virtual e^+e^- cloud surrounding a photon endow spacetime with a non-trivial refractive index. This has remarkable properties unique to gravitational theories including superluminal low-frequency propagation, in apparent violation of causality, and amplification of the renormalized photon field, in apparent violation of unitarity. Using the geometry of null congruences and the Penrose limit, we illustrate these phenomena and their resolution by tracing the history of a photon as it falls into the near-singularity region of a black hole.

Fourth Award – **Holographic Space-Time** by Tom Banks[1,2], [1]NHETC and Department of Physics and Astronomy, Rutgers University, Piscataway, NJ 08854-8019, and [2]SCIPP and Department of Physics, University of California, Santa Cruz, CA 95064-1077; e-mail: banks@scipp.ucsc.edu

Abstract – The theory of holographic space-time (HST) generalizes both string theory and quantum field theory. It provides a geometric rationale for supersymmetry (SUSY) and a formalism in which super-Poincaré invariance follows from Poincaré invariance. HST unifies particles and black holes, realizing both as excitations of non-commutative geometrical variables on a holographic screen. Compact extra dimensions are interpreted as finite dimensional unitary representations of super-algebras and have no moduli. Full field theoretic Fock spaces and continuous moduli are both emergent phenomena of super-Poincaré invariant limits in which the number of holographic degrees of freedom goes to infinity. Finite radius de Sitter (dS) spaces have no moduli and break SUSY with a gravitino mass scaling like $\Lambda^{1/4}$. In regimes where the Covariant Entropy Bound is saturated, QFT is not a good description but HST is. Inflation is such a regime. Following ideas of Jacobson, the gravitational and inflaton fields are emergent classical variables, describing the geometry of an underlying HST model, rather than "fields associated with a microscopic string theory". The phrase in quotes is meaningless in the HST formalism, except in asymptotically flat and AdS space-times and in some relatives of these.

Fifth Award – **Secret Life of the Spacetime** by T. Padmanabhan, IUCAA, Post Bag 4, Ganeshkhind, Pune – 411 007, India; e-mail: paddy@iucaa.ernet.in

Abstract – Just as the thermal properties of normal matter *demand* the existence of microscopic degrees of freedom, the thermal properties of null surfaces – perceived as local Rindler horizons by accelerated observers – demands the existence of microscopic degrees of freedom to spacetime. The distortion of the null surfaces, just like the deformation of elastic solid, costs entropy. I show how, just like in the case of an elastic solid, one can describe the dynamics of *spacetime solid* by introducing an entropy density to the distortion of null surfaces in the spacetime.

Honorable Mention Awards **(Alphabetical Order)**

1. Gravity's Weight on Worldline Fuzziness by Giovanni Amelino-Camelia, Valerio Astuti, and Giacomo Rosati, Dipartimento di Fisica Università "La Sapienza" and Sez. Roma 1 INFN, P.le A. Moro 2, 00185 Roma, Italy; e-mail: amelino@roma1.infn.it valerio.astuti@roma1.infn.it giacomo.rasati@roma1.infn.it

Abstract – We investigate a connection between recent results in 3D quantum gravity, providing an effective noncommutative-spacetime description, and some earlier heuristic descriptions of a quantum-gravity contribution to the fuzziness of the worldlines of particles. We show that 3D gravity-inspired spacetime noncommutativity reflects some of the features suggested by previous heuristic arguments. Most notably, gravity-induced worldline fuzziness, while irrelevantly small on terrestrial scales, could be observably large for propagation of particles over cosmological distances. However, the relevant phenomenology will have to take into account our findings for the particle-momentum dependence of the effects, which differ from what had been so far assumed heuristically.

2. Can a Tabletop Experiment Probe the Planck Scale? by Jacob D. Bekenstein, Racah Institute of Physics, Hebrew University of Jerusalem, Jerusalem 91904, Israel; e-mail: bekenste@vms.huji.ac.il

Abstract – I describe a tabletop experiment that may be sensitive to Planck scale signals. In particular, its combination of a single photon's and a macroscopic probe's degrees of freedom affords a way to test Wheeler's assertion that space-time is no longer a smooth manifold at scales below Planck's. The scheme makes few assumptions beyond conservation of energy and momentum and incurs no theoretical prejudices about quantum gravity.

3. Understanding 'Nothing' by Adam R. Brown[1,2] and Alex Dahlen[1,3], [1]Physics Department, Princeton University, Princeton, NJ 08544, [2]Princeton Center for Theoretical Science, Princeton University, Princeton, NJ 08544, [3]Berkeley Center for Theoretical Physics, Berkeley, CA 94720; e-mail: Adambro@princeton.edu adahlen@berkeley.edu

Abstract – Spacetime is dynamic; it can warp, contort, contract, and expand and, most dramatically, it can appear and disappear. This essay is about 'nothing' – the state of zero metric – from which spacetime appears, and to which spacetime disappears. By studying generalizations of Witten's 'bubble of nothing' in the context of perturbatively-stabilized compact extra dimensions, we show that 'nothing' should be understood as an infinitely negatively curved spacetime. Armed with this understanding, we show that a proposed mechanism for the appearance of spacetime from nothing – the 'quantum creation of a universe' of Hawking and Turok – does not work.

4. Quantum States of the Spacetime and Formation of Black Holes in AdS by Marcelo Botta Cantcheff, IFLP-CONICET CC 67, 1900, La Plata, Buenos Aires, Argentina and CERN, Theory Division, 1211 Geneva 23, Switzerland; e-mail: bottac@cern.ch

Abstract – We argue that a non-perturbative description of quantum gravity should involve two (non-interacting) copies of a dual field theory on the boundary and we describe the states of the spacetimes accordingly. So, for instance, a complete description of the asymptotically Anti-de-Sitter spacetimes is given by two copies of the conformal field theory associated to the global AdS spacetime. We also argue that, in this context, gravitational collapse and formation of a black hole may be described by unitary evolution of the dual non-perturbative degrees of freedom.

5. How to Measure an Anti-Spacetime by Marios Christodoulou, Aldo Riello, Carlo Rovelli, Centre de Physique Théorique, Case 907, Luminy, F-13288 Marseille, EU; e-mail: rovelli@cpt.univ-mrs.fr

Abstract – Can a spacetime region with a negative lapse function be detected, in principle? Fermions do not couple to the metric field and require a tetrad field: we show that this implies that a fermion interference effect could detect a negative lapse region, distinguishing “forward evolving” from “backward evolving” spacetimes having a gravitational field described by the same metric.

6. Quantum Gravity and Inflation by Joseph P. Conlon, Rudolf Peierls Center for theoretical Physics, 1 Keble Road, Oxford, OX1 3NP, United Kingdom; e-mail: j.conlon1@physics.ox.ac.uk

Abstract – We study quantum gravity constraints on inflationary models arising from requiring that the entropy that can be associated to the inflationary fields is smaller than that of the de Sitter entropy. Violation of the de Sitter entropy bound occurs at parametrically the same point that transPlanckian flat directions become realisable. This is of significance given the importance of the latter for observable CMB tensor modes.

7. Effective Temperature, Hawking Radiation, and Quasi-Normal Modes by Christian Corda, Institute for Theoretical Physics and Advanced Mathematics Einstein-Galilei, Via Santa Gonda 14, 59100 Prato, Italy and Inter-University Centre Engineering of Life and Environment, LIUM University, Via Lugano 2, 6500 Bellinzona, Switzerland; e-mail: cordac.galilei@gmail.com

Abstract – Parikh and Wilczek have shown that Hawking radiation’s spectrum cannot be strictly thermal. Such a non-strictly thermal character implies that the spectrum is also not strictly continuous and thus generates a natural correspondence between Hawking radiation and black hole’s quasi-normal modes. This issue endorses the idea that, in an underlying unitary quantum gravity theory, black holes result in highly excited states. We use this key point to re-analyze the spectrum of black hole’s quasi-normal modes by introducing a black hole’s *effective temperature*. Our analysis changes the physical understanding of such a spectrum and enables a re-examination of various results in the literature which realizes important modifications on quantum physics of black holes. In particular, the formula of the horizon’s area quantization and the number of quanta of area are modified becoming functions of the quantum “overtone” number n. Consequently, Bekenstein-Hawking entropy, its sub-leading corrections and the number of microstates, i.e. quantities which are fundamental to realize unitary quantum gravity theory, are also modified. They become functions of the quantum overtone number too. Previous results in the literature are re-obtained in the very large n limit.

8. Tricritical Quantum Point and Inflationary Cosmology by Lawrence B. Crowell, Alpha Institute of Advanced Study 10600 Cibola Lp 311 NW Albuquerque, NM 87114 and 11 Rutafa Street, H-1165 Budapest, Hungary; e-mail: lcrowell@swcp.com

Abstract – The holographic protection due to inflationary cosmology is a consequence of a quantum tricritical point. In this scenario, a closed spacetime solution transitions into an inflationary de Sitter spacetime. The saturation of the holographic entropy bound is prevented by the phase structure of the system which changes the topology of the early universe.

9. Violation of Chandrasekhar Mass Limit: The Exciting Potential of Strongly Magnetized White Dwarfs 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 consider a relativistic, degenerate, electron gas under the influence of a strong magnetic field, which describes magnetized white dwarfs. Landau quantization changes the density of states available to the electrons, thus modifying the underlying equation of state. In the presence of very strong magnetic fields a maximum of either one, two, or three Landau level(s) is/are occupied. We obtain the mass-radius relations for such white dwarfs and their detailed investigation leads us to propose the existence of white dwarfs having a mass ~ 2.3 $M_{\odot}$, which overwhelmingly exceeds the Chandrasekhar mass limit.

10. Signs and Cosmology by Arundhati Dasgupta and Adamantia Zampeli, Department of Physics and Astronomy, University of Lethbridge, Lethbridge, Canada T1K 3M4; e-mail: arundhati.dasgupta@uleth.ca a.zampeli@uleth.ca

Abstract – Using a new effective action predicted from quantum gravity where the sign of the Euclidean Einstein action is reversed, we discuss WKB solutions in quantum cosmology and predict that this sign change might explain the origin of phantom scalars.

11. Restoring Time Dependence into Quantum Cosmology 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@bgu.ac.il

Abstract – Mini superspace cosmology treats the scale factor $a(t)$, the lapse function $n(t)$, and an optional dilation field $\varphi(t)$ as canonical variables. While pre-fixing $n(t)$ means losing the Hamiltonian constraint, pre-fixing $a(t)$ is serendipitously harmless. This suggests an alternative to the Hartle-Hawking approach, where the pre-fixed $a(t)$ and its derivatives are treated as explicit functions of time, leaving $n(t)$ and a mandatory $\varphi(t)$ to serve as canonical variables. The naïve gauge pre-fix $a(t) = const$ is forbidden, however, causing evolution to freeze altogether, so pre-fixing the scale factor necessarily introduces explicit time dependence into the Lagrangian. Invoking Dirac's prescription for dealing with primary constraints, we construct the corresponding mini superspace total Hamiltonian, noticeably time dependent and furthermore linear in momenta, and calculate the Dirac brackets to be promoted to commutation relations in the quantum theory.

12. Turbulence and Chaos in Anti-de-Sitter Gravity by Henrique P. Oliveira[1], Leopoldo A. Pando Zayas[2], and César A. Terrero-Escalante[3], [1]Universidade do Estado do Rio de Janeiro, Instituto de Física, Departamento de Física Teórica, CEP 20550-013 Rio de Janeiro, RJ, Brazil, [2]Michigan Center for Theoretical Physics, Randall Laboratory of Physics, The University of Michigan, Ann Arbor, MI 48109-1120, [3]Facultad de Ciencias, Universidad de Colima, Bernal Díaz del Castillo 340, Col. Villas San Sebastián, Colima 28045, México; e-mail: hp.deoliveira@pq.cnpq.br lpandoz@umich.edu cterrero@ucol.mx

Abstract – Due to the AdS/CFT correspondence the questions of instability of Anti-de-Sitter spacetimes sits in the intersection of mathematical and numerical relativity, string theory, field theory and condensed matter physics, In this essay we revisit that important question emphasizing the power of spectral methods and highlighting the effectiveness of standard techniques for studying non-linear dynamical systems. In particular, we display explicitly how the problem can be modeled as a system of nonlinearly coupled harmonic oscillators. We highlight some of the many open questions that stem from this result and point out that a full understanding will necessarily require the interdisciplinary cooperation of various communities.

13. Triple-Horizon Spherically Symmetric Spacetime and Holographic Principle by Irina Dymnikova, Department of Mathematics and Computer Science, University of Warmia and Mazury, Sloneczna 54, 10-710 Olsztyn, Poland and A.F. Ioffe Physico-Technical Institute, Politekhnicheskaja 26, St. Petersburg, 194021 Russia; e-mail: irina@matman.uwm.edu.pl

Abstract – We present a family of spherically symmetric spacetimes, specified by the density profile of a vacuum dark energy, which have the same global structure as the de Sitter spacetime but the reduced symmetry which leads to a time-evolving and spatially inhomogeneous cosmological term. It connects smoothly two de Sitter vacua with different values of cosmological constant and corresponds to anisotropic vacuum dark fluid defined by symmetry of its stress-energy tensor which is invariant under the radial boosts. This family contains a special class distinguished by dynamics of evaporation of a cosmological horizon which evolves to the triple horizon with the finite entropy, zero temperature, zero curvature, infinite positive specific heat, and infinite scrambling time. Non-zero value of the cosmological constant in the triple-horizon spacetime is tightly fixed by quantum dynamics of evaporation of the cosmological horizon.

14. Directly Observing Entropy Accumulate on the Horizon and Holography by Ariel Edery and Hugues Beauchesne, Physics Department, Bishop's University, 2600 College Street, Sherbrooke, Québec, Canada J1M 0C8; e-mail: aedery@ubishops.ca hbeauchesne10@ubishops.ca

Abstract – Recent numerical simulations of gravitational collapse show that there exists a special foliation of the spacetime where matter and entropy accumulate directly on the inside of the horizon surface. In this foliation, the time coincides with the proper time of the asymptotic static observer (ASO) and for spherical symmetry, this corresponds to isotropic coordinates. In this gauge, the three-volume in the interior shrinks to zero and only the horizon area remains at the end of the collapse. In a different foliation, matter and entropy accumulate in the volume. The entropy is however independent of the foliation. Black hole holography is therefore a mapping from an arbitrary foliation, where information resides in the volume, to the special ASO frame, where it resides directly on the horizon surface.

15. Einstein's Real "Biggest Blunder" by Homer G. Ellis, Department of Mathematics, University of Colorado at Boulder, Boulder, Colorado 80309-0395; e-mail: ellis@euclid.colorado.edu

Abstract – Albert Einstein's real "biggest blunder" was not the 1917 introduction into his gravitational field equations of a cosmological constant term Λ, rather was his failure in 1916 to distinguish between the entirely different concepts of *active* gravitational mass and *passive* gravitational mass. Had he made the distinction and followed David Hilbert's lead in deriving field equations from a variational principle, he might have discovered a true (not a cut and paste) Einstein-Rosen bridge and a cosmological model that would have allowed him to predict, long before such phenomena were imagined by others, inflation, a big bounce (not a big bang), an accelerating expansion of the universe, dark matter, and the existence of cosmic voids, walls, filaments, and nodes.

16. Generalized Dark Gravity by Tiberiu Harko[1] and Francisco S. N. Lobo[2], [1]Department of Physics and Center for Theoretical and Computational Physics, The University of Hong Kong, Pok Fu Lam Road, Hong Kong, P. R. China, [2]Centro de Astronomia e Astrofísica da Universidade de Lisboa, Campo Grande, Ed. C8 1749-016 Lisboa, Portugal; e-mail: harko@hkucc.hku.hk flobo@cii.fc.ul.pt

Abstract – The late-time cosmic acceleration may be due to infra-red modifications of General Relativity. In particular, we consider a maximal extension of the Hilbert-Einstein action and analyze several interesting features of the theory. Generally, the motion is non-geodesic and takes place in the presence of an extra force which is orthogonal to the four-velocity. These models could lead to some major differences, as compared to the predictions of General Relativity or other modified theories of gravity, in several problems of current interest, such as cosmology, gravitational collapse or the generation of gravitational waves. The study of these phenomena may also provide some specific signatures and effects which could distinguish and discriminate between the various gravitational models.

17. Black Holes Have Long Hair by Shahar Hod, The Ruppin Academic Center, Emeq Hefer 40250, Israel and The Hadassah Institute, HaNeviim 37, Jerusalem 91010, Israel; e-mail: shaharhod@gmail.com

Abstract – The influential 'no-hair' conjecture suggests that black holes may be characterized by only three conserved parameters: mass, charge and angular momentum. However, counterexamples in which the conjecture fails are well-known in the literature. In this essay we study such Einstein-matter theories in which hairy black-hole configurations have been discovered. In particular, we analyze the spatial behavior of the matter fields which reside outside the black-hole horizon. We prove a theorem which reveals the central role played by the null circular geodesic (the "photonsphere") of such hairy black holes. According to this theorem, the asymptotic decline of the hair outside the horizon cannot start before the black-hole photonsphere is crossed. We therefore conclude that hairy blackholes must have *long* hair which extends beyond the photonsphere.

18. Holography, Quantum Gravity and Confinement by Viqar Husain[1,2] and Dawood Kothawala[2], [1]Perimeter Institute for Theoretical Physics, 31 Caroline St. N. Waterloo ON, Canada N2L 2Y5, [2]Department of Mathematics and Statistics, University of New Brunswick, Fredericton, NB, Canada E3B 5A3; e-mail: vhusain@unb.ca dkathawa@unb.ca

Abstract – In the holographic dictionary between gauge theory in four dimensions and gravity in five dimensions, there is an encoding in the bulk geometry of the phases of the gauge theory. If the correspondence holds at all scales, it is natural to expect that gauge theory contains information about quantum gravity in one higher dimension. We argue that the confining phase of gauge theory has a correspondence with singularity avoidance in quantum gravity. This comes from the observation that confinement appears to be generically associated with repulsion deep in the bulk on the gravity side, which in turn is a consequence of the violation of energy conditions in quantum gravity that lead to singularity avoidance.

19. Gravitation and Vacuum Entanglement Entropy 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 – The vacuum of quantum fields contains correlated fluctuations. When restricted to one side of a surface these have huge entropy of entanglement that scales with the surface area. If UV physics renders this entropy finite, then a thermodynamic argument implies the existence of gravity. That is, the causal structure of spacetime must be dynamical and governed by the Einstein equation with Newton's constant inversely proportional to the entropy density. Conversely, the existence of gravity makes the entanglement entropy finite. This thermodynamic reasoning is powerful despite the lack of a detailed description of the dynamics at the cutoff scale, but it has its limitations. In particular, we should not expect to understand corrections to Einstein gravity in this way.

20. Modified Gravity As a Common Cause for Cosmic Acceleration and Flat Galaxy Rotation Curves by Priti Mishra and Tejinder P. Singh, Tata Institute of Fundamental Research, Homi Bhabha Road, Mumbai 400 005, India; e-mail: priti@tifr.res.in tpsingh@tifr.res.in

Abstract – Flat galaxy rotation curves and the accelerating universe both imply the existence of a critical acceleration, which is of the same order of magnitude in both the cases in spite of the galactic and cosmic length scales being vastly different. Yet, it is customary to explain galactic acceleration by invoking gravitationally bound dark matter and cosmic acceleration by invoking a 'repulsive' dark energy. Instead, might it not be the case that the flatness of rotation curves and the acceleration of the universe have a common cause? In this essay, we propose a modified theory of gravity. By applying the theory on galactic scales, we demonstrate flat rotation curves without dark matter and, by applying it on cosmological scales, we demonstrate cosmic acceleration without dark energy.

21. Hawking Radiation As a Mechanism for Inflation by Sujoy Kumar Modak[1] and Douglas Singleton[2], [1]S.N. Bose National Centre for Basic Sciences, JD Block, Sector III, Salt Lake, Kolkata-700098, India, [2]Physics Department, CSU Fresno, Fresno, CA 93740-8031; e-mail: sujoy@bose.res.in dougs@csufresno.edu

Abstract – The Friedman-Robertson-Walker (FRW) space-time exhibits particle creation similar to Hawking radiation of a black hole. In this essay we show that this FRW Hawking radiation leads to an effective negative pressure fluid which can drive an inflationary period of exponential expansion in the early universe. Since the Hawking temperature of the FRW space-time decreases as the universe expands this mechanism naturally turns off and the inflationary stage transitions to a power law expansion associated with an ordinary radiation dominated universe.

22. Gauge-Invariant Variables in General-Relativistic Perturbations – Globalization and Zero-Mode Problem by Kouji Nakamura, TAMA Project, Optical and Infrared Astronomy Division, National Astronomical Observatory of Japan, Osawa 2-21-1, Mitaka 181-8588, Japan; e-mail: kouji.nakamura@nao.ac.jp

Abstract – An outline of a proof of the local decomposition of linear metric perturbations into gauge-invariant and gauge-variant parts on an arbitrary background spacetime. We explicitly construct the gauge-invariant and gauge-variant parts of the linear metric perturbations based on some assumptions. We also point out the zero mode problem is an essential problem to globalize this decomposition of linear metric perturbations. The resolution of this zero-mode problem implies that the possibility exists for the development of the higher-order gauge-invariant perturbation theory on an arbitrary background spacetime in a global sense.

23. How to Measure the Speed of Gravity by M. B. Paranjape, Groupe de Physique des Particules, Département de Physique, Université de Montréal, C.P. 6128, succursale centre-ville, Montréal, Québec, Canada, H3C 3J7; e-mail: paranj@lps.umontreal.ca

Abstract – We propose a simple laboratory experiment to measure the speed of propagation of gravitational phenomena. A measurement of this speed would be a direct confirmation of one dynamical aspect of Einstein's theory of general relativity, that gravitational effects are not instantaneous and propagate at a finite velocity.

24. Gravitational Anderson Localization by Ira Z. Rothstein, Department of Physics, Carnegie Mellon University, Pittsburgh, PA 15213; e-mail: izr@andrew.cmu.edu

Abstract – We present a higher dimensional model where gravity is bound to a brane due to Anderson localization. The extra dimensions are taken to be a disordered crystal of branes with randomly distributed tensions of order of the fundamental scale. Such geometries bind the graviton and thus allow for arbitrarily large extra dimensions. The hierarchy problem can be solved by having the standard model brane live a distance away from the brane on which the graviton is localized. The scenario is quite robust and only relies upon the assumption of time reversal invariance. The statistical properties of the system are worked out and it is shown that the scenario leads to a continuum of four dimensional theories with different strengths of gravitational interactions. We live on one particular brane whose gravitational constant is $G_{N.}$

25. Black Hole Probes of Automorphic Space by Rolf Schimmrigk, Theory Group, Department of Physics, CERN, CH-1211, Geneva 23, Switzerland; e-mail: rschimmr@iusb.edu

Abstract – Over the past few years the arithmetic Langlands program has proven useful in addressing physical problems. In this paper it is shown how Langlands' reciprocity conjecture for automorphic forms, in combination with a representation theoretic notion of motives, suggests a framework in which the entropy of automorphic black holes can be viewed as a probe of spacetime that is sensitive to the geometry of the extra dimensions predicted by string. If it were possible to produce black holes with automorphic entropy in the laboratory, their evaporation would provide us with information about the precise shape of the compact geometry.

26. Extended Equivalence Principle: Implications for Gravity, Geometry and Thermodynamics by C. Sivaram[1] and Kenath Arun[2], [1]Indian Institute of Astrophysics, Bangalore, 560 034, India, [2]Christ Junior College, Bangalore, 560 029, India; e-mail: sivaram@iiap.res.in kenath.arun@cjc.christcollege.edu

Abstract – The equivalence principle was formulated by Einstein in an attempt to extend the concept of inertial frames to accelerated frames, thereby bringing in gravity. In recent decades, it has been realized that gravity is linked not only with geometry of space-time but also with thermodynamics especially in connection with black hole horizons, vacuum fluctuations, dark energy, etc. In this work we look at how the equivalence principle manifests itself in these different situations where we have strong gravitational fields. In recent years the generalised uncertainty principle has been invoked to connect gravity and curvature with quantum physics and now we may also need an extended equivalence principle to connect quantum theory with gravity.

27. Measuring Space-time Geometry over the Ages by Albert Stebbins, Theoretical Astrophysics Group, MS209, Fermi National Accelerator Laboratory, Box 500, Batavia, IL 60510; e-mail: stebbins@fnal.gov

Abstract – Theorists are often told to express things in the “observational plane”. One can do this for space-time geometry, considering “visual” observations of matter in our universe by a single observer over time, with no assumptions about isometries, initial conditions, nor any particular relation between matter and geometry, such as Einstein’s equations. Using observables as coordinates naturally leads to a parameterization of space-time geometry in terms of other observables, which in turn prescribes an observational program to measure the geometry. Under the assumption of vorticity-free matter flow we describe this observational program, which includes measurements of gravitational lensing, proper motion, and redshift drift. Only 15% of the curvature information can be extracted without long time baseline observations; this increases to 35% with observations that will take decades. The rest would likely require centuries of observations. The formalism developed is exact, non perturbative, and more general than the usual cosmological analysis.

28. Explaining the Supernova Data without Accelerating Expansion– by W.M.Stuckey[1], T.J.McDevitt,[2] and M.Silberstein[3], [1]Department of Physics, Elizabethtown College, Elizabethtown, PA 17022, [2]Department of Mathematical Sciences, Elizabethtown College, Elizabethtown, PA 17022, [3]Department of Philosophy and Foundations of Physics, Committee for Philosophy and the Sciences, University of Maryland, College Park, MD 20742; e-mail: stuckeym@etown.edu mcdevitt@etown.edu msilbers@umd.edu

Abstract – The 2011 Nobel Prize in Physics was awarded “for the discovery of the accelerating expansion of the Universe through observations of distant supernovae”. However, it is not the case that the type 1a supernova data necessitates accelerating expansion. Since we do not have a successful theory of quantum gravity, we should not assume general relativity (GR) will survive unification intact, especially on cosmological scales where tests are scarce. We provide a simple example of how GR cosmology may be modified to produce a decelerating Einstein-de Sitter cosmology model (EdS) that accounts for the Union2 Compilation data as well as the accelerating ΛCDM (EdS plus a cosmological constant).

29. Poor Man's Holography: How Far Can It Go? by Yu Tian[1] , Xiao-Ning Wu[2], and Hongbao Zhang[3], [1]College of Physical Sciences, Graduate University of Chinese Academy of Sciences, Beijing 100049, China, [2]Institute of Mathematics, Academy of Mathematics and System Science, CAS, Beijing 100190, China, [3]Crete Center for Theoretical Physics, Department of Physics, University of Crete, Heraklion 71003, Greece; e-mail: ytian@gucas.ac.cn wuxn@amss.ac.cn hzhang@physics.uoc.gr

Abstract – Almost a century ago Einstein, after Newton, shed a new light on gravity by claiming that gravity is geometry. There has been no deeper insight beyond that later on except the recent suspicion that gravity may also be holographic, dual to some sort of quantum field theory living on the boundary with one less dimension. Such a suspicion has been supported mainly by a variety of specific examples from string theory. This essay is intended to purport the holographic gravity from a different perspective. Namely we shall show such a holography can actually be observed by working merely within the context of Einstein's gravity, where neither string nor brane comes in. In particular, a perfect matching is explicitly derived between the bulk gravity and dual boundary system for both the equilibrium thermodynamics and non-equilibrium entropy production.

30. Accelerated Dark Flows and the Cosmological Axis by Christos G. Tsagas, Section of Astrophysics, Astronomy and Mechanics, Department of Physics, Aristotle University of Thessaloniki, Thessaloniki 54124, Greece and NORDITA, AlbaNova University Center, Roslagtullsbacken 23, SE-10691 Stockholm, Sweden; e-mail: tsagas@astro.auth.gr

Abstract – Recent independent surveys indicate the presence of large-scale peculiar motions much larger and much faster than anticipated by the current cosmological paradigm. These are the so-called "dark flows". We argue that observers living inside such fast dark flows can experience locally accelerated expansion within a globally decelerating universe. Moreover, to these observers, the universe should appear to accelerate slightly faster in one direction and equally slower in the opposite. Interestingly, an increasing number of reports claim that such a weak dipolar anisotropy, which is sometimes referred to as the "cosmological axis", may actually reside within the supernovae data.

31. Falling Right While Moving Slow: True Tests of the Weak Equivalence Principle for Anti-Particles by C.S.Unnikrishnan[1] and G.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@tfir.res.in gtg@virginia.edu

Abstract – A significant question in experimental gravity is the nature of free fall of antiparticles under gravity and elaborate preparations are underway to directly test this with cold anti-hydrogen. Earlier, the Shapiro delay of supernova 1987A neutrinos was interpreted as testing the weak equivalence principle (WEP). We establish the surprising result that the Shapiro delay of relativistic particles does not test WEP for intrinsic properties or quantum numbers of particles or antiparticles. The crucial message here is that a true test of the WEP involving intrinsic properties of matter or antimatter – the foundation of the relativistic gravity – necessarily requires non-relativistic 'cold' matter and anti-matter.

32. Gravity of $R^{\mu\nu} = 0$: A New Paradigm in GR by Ram Gopal Vishwakarma, Unidad Académica de Matemáticas, Universidad Autónoma de Zacatecas, C.P. 98068, Zacatecas, ZAC, Mexico; e-mail: rvishwa@mate.reduaz.mx

Abstract – The theory of General Relativity (GR) has been scrutinized by the experts for almost a century and describes accurately all gravitational phenomena ranging from the solar system to the universe. However, this success is achieved providing one admits three completely independent new components in the energy-stress tensor $T^{\mu\nu}$ – inflaton, dark matter, and dark energy, which though do not have any non-gravitational or laboratory evidence and have remained generally speculative. Moreover, the dark energy poses a serious confrontation between fundamental physics and cosmology. The present situation reminds us of Einstein's "biggest blunder" when he forced his theory to predict a static universe, perhaps guided by his religious conviction that that universe must be eternal and unchanging. It seems that we are making a similar blunder by forcing $T^{\mu\nu}$ into the field equations while the observations indicate that it is not needed. We seem to have a deep conviction that the spacetime will remain empty unless we fill it by the energy-stress tensor. However, we have been ignoring numerous evidences earnestly indicating otherwise. From a critical analysis of the present situation we develop an entirely new insight about the source of curvature in equations $R^{\mu\nu} = 0$, which, though may appear orthogonal to the usual understanding, is in striking agreement with all the known phenomena in GR.