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Abstracts of Award Winning and Honorable Mention Essays for 2010

Award Essays

First Award – Building Up Spacetime with Quantum Entanglement – by Mark Van Raamsdonk, Department of Physics and Astronomy, University of British Columbia, 6224 Agricultural Road, Vancouver, B.C., V6T 1W9, Canada; e-mail: mav@phas.ubc.ca.

Abstract – In this essay, we argue that the emergence of classically connected spacetimes is intimately related to the quantum entanglement of degrees of freedom in a non-perturbative description of quantum gravity. Disentangling the degrees of freedom associated with two regions of spacetime results in these regions pulling apart and pinching off from each other in a way that can be quantified by standard measures of entanglement.

Second Award – Membrane Paradigm Realized? – by Samir D. Mathur, Department of Physics, The Ohio State University, Columbus, OH 43210; e-mail: mathur@mps.ohio-state.edu.

Abstract – Are there any degrees of freedom on the black hole horizon? Using the 'membrane paradigm' we can reproduce coarse-grained physics outside the hole by assuming a fictitious membrane just outside the horizon. But to solve the information puzzle we need 'real' degrees of freedom at the horizon, which can modify Hawking's evolution of quantum modes. We argue that recent results on gravitational microstates imply a set of real degrees of freedom just outside the horizon; the state of the hole is a linear combination of rapidly oscillating gravitational solutions with support concentrated just outside the horizon radius. The collective behavior of these microstate solutions may give a realization of the membrane paradigm, with the fictitious membrane now replaced by real, explicit degrees of freedom.

Third Award – The Dangers of Extremes – by Donald Marolf, Physics Department, UCSB, Santa Barbara, CA 93106; e-mail: marolf@physics.ucsb.edu.

Abstract – While extreme black hole spacetimes with smooth horizons are known at the level of mathematics, we argue that the horizons of physical extreme black holes are effectively singular. Test particles encounter a singularity the moment they cross the horizon, and only objects with significant back-reaction can fall across a smooth (now non-extreme) horizon. As a result, classical interior solutions for extreme black holes are theoretical fictions that need not be reproduced by any quantum mechanical model. This observation suggests that significant quantum effects might be visible outside extreme or nearly extreme black holes. It also suggests that the microphysics of such black holes may be very different from that of their Schwarzschild cousins.

Fourth Award – The Necessity of Torsion in Gravity – by Richard T. Hammond, Department of Physics, University of North Carolina at Chapel Hill, Chapel Hill, NC 27599 and ARO Research Triangle Park; e-mail: rhammond@email.unc.edu.

Abstract – It is shown that torsion is required for a complete theory of gravitation, and that without it, the equations of gravitation violate fundamental laws. In the first case, we are reminded that, in the absence of external forces, the correct conservation law of total angular momentum arises only if torsion, whose origin is intrinsic spin, is included into gravitation. The second case considers the "mass reversal" transformation. It has been known that under a global chiral transformation and "mass to negative mass" transformation, the Dirac equation is invariant. But global transformations violate special relativity, so this transformation must be made local. It is shown that the torsion is the gauge field for this local invariance.

Fifth Award – Conditions for Spontaneous Homogenization of the Universe – by Krzysztof Bolejko[1] and William R. Stoeger[2], [1]Steward Observatory, University of Arizona, Tucson, AZ 85721, and Nicolaus Copernicus Astronomical Center, Bartycka 18, 00-716 Warszawa, Poland, [2]Vatican Observatory Research Group, University of Arizona, Tucson, AZ 85721; e-mail: bolejko@camk.edu.pl.

Abstract – The present-day Universe appears to be homogeneous on very large scales. Yet when the casual structure of the early Universe is considered, it becomes apparent that the early Universe must have been highly inhomogeneous. The current paradigm attempts to answer this problem by postulating the inflation mechanism. However, inflation in order to start requires a homogeneous patch of at least the horizon size. This paper examines if dynamical processes of the early Universe could lead to homogenization. In the past similar studies seem to imply that the set of initial conditions that leads to homogenization is of measure zero. This essay proves the contrary: a set of initial conditions for spontaneous homogenization of cosmological models can form a set of non-zero measure.

Honorable Mention Awards (Alphabetical Order)

1. Combining Together Gravity, Massive QED and the Very Long Baseline Interferometry to Gravitationally Constrain the Photon Mass – by Antonio Accioly[1,2], José Helayël-Neto[1], Eslley Scatena[2], [1]Laboratório de Física Experimental (LAFEX), Centro Brasileiro de Pesquisas Físicas (CBPF), Rua Dr. Xavier Sigaud 150, Urca, 22290-180, Rio de Janeiro, RJ, Brazil, [2]Instituto de Física Teórica (IFT), São Paulo State University (UNESP), Rua Dr. Bento Teobaldo Ferraz 271, Bl. II-Barra Funda, 01140-070 São Paulo, SP, Brazil; e-mail: accioly@cbpf.br, Helayel@cbpf.br, scatena@ift.unesp.br.

Abstract – A constraint between the photon mass and the parameters γ (the post-Newtonian parameter measured by experimentalists) and ν (the photon frequency) is found by judiciously combining together General Relativity and Massive QED. By adopting this scenario and by considering the most recent measurements of the solar gravitational deflection of radio waves obtained by means of the Very Long Baseline Interferometry, gravitational upper bounds on the photon mass are estimated.

2. Gravity in Quantum Spacetime – by Giovanni Amelino-Camelia, Niccolò Loret, Gianluca Mandanici, and Flavio Mercati, Dipartimento di Fisica, Università di Roma "La Sapienza" and Sez. Roma 1 INFN Piazzale Moro 2, Roma, Italy; e-mail: Giovanni.Amelino-Camelia@roma1.infn.it.

Abstract – The literature on quantum-gravity-inspired scenarios for the quantization of spacetime has so far focused on particle-physics-like studies. This is partly justified by the present limitations of our understanding of quantum-gravity theories, but we here argue that valuable insight can be gained through semi-heuristic analyses of the implications for gravitational phenomena of some results obtained in the quantum-spacetime literature. In particular, we show that the types of description of particle propagation that emerged in certain quantum-spacetime frameworks have striking implications for gravitational collapse and for the behaviour of gravity at large distances.

3. Gravity and Yang-Mills Theory – by Sudarshan Ananth, Indian Institute of Science Education and Research, Pune 411021, India; e-mail: ananth@iiserpune.ac.in.

Abstract – Three of the four forces of Nature are described by quantum Yang-Mills theories with remarkable precision. The fourth force, gravity, is described classically by the Einstein-Hilbert theory. There appears to be an inherent incompatibility between quantum mechanics and the Einstein-Hilbert theory which prevents us from developing a consistent quantum theory of gravity. The Einstein-Hilbert theory is therefore believed to differ greatly from Yang-Mills theory (which does have a sensible quantum mechanical description). It is therefore very surprising that these two theories actually share close perturbative ties. This essay focuses on these ties between Yang-Mills theory and the Einstein-Hilbert theory. We discuss the origin of these ties and their implications for a quantum theory of gravity.

4. Testing Hawking Particle Creation by Black Holes through Correlation Measurements – by R. Balbinot[1], I. Carusotto[2], A. Fabbri[3], and A. Recati[2], [1]Dipartimento di Fisica dell'Università di Bologna and INFN sezione di Bologna, Via Irnerio 46, 40126 Bologna, Italy, [2]CNR-INFM BEC Center and Dipartimento di Fisica, Università di Trento, via Sommarive 14, I-38050 Provo, Trento, Italy, [3]Departmento de Fisica Teorica and IFIC, Universidad de Valencia-CSIC, C. Dr. Moliner 50, 46100 Burjassot, Spain; e-mail: balbinot@bo.infn.it, carusott@science.unitn.it, afabbri@ific.uv.es, recati@science.unitn.it.

Abstract – Hawking's prediction of thermal radiation by black holes has been shown by Unruh to be expected also in condensed matter systems. We show here that in a black hole-like configuration realized in a BEC this particle creation does indeed take place and can be unambiguously identified via a characteristic pattern in the density-density correlations. This opens the concrete possibility of the experimental verification of this effect.

5. From Black Holes to Emergent Gravity – by Rabin Banerjee, S. N. Bose National Centre for Basic Sciences, Block JD, Sector III, Salt Lake, Kolkata – 700098, India; e-mail: rabin@bose.res.in.

Abstract – Many inequivalent approaches to study black holes yield identical results. Any meaningful theory of gravity should explain the origin of this property. Here we show that the basic holomorphic modes characterizing the underlying two dimensional conformal symmetry near the horizon bring about this universality. Moreover these modes lead to a law of equipartition of energy for black holes which suggests a statistical origin of gravity. This emergent nature of gravity is further bolstered by showing the equivalence of entropy with the action $(S = -\frac{i}{\hbar} I)$ and expressing the generalised Smarr formula for mass as a thermodynamic relation, $S = \frac{E}{2T}$ where S, E and T are the entropy, energy and temperature, respectively, of a black hole.

6. Of Inflation and the Inflaton – by R. Brout, Department of Applied Mathematics, University of Waterloo, Waterloo, Ontario N2T 3G1, Canada, and Service de Physique Théorique, Université Libre de Bruxelles, The International Solvay Institutes, B1050 Bruxelles, Belgium; e-mail: robert.brout@ulb.ac.be.

Abstract – Due to intra-field gravitational interactions, field configurations have a strong negative component to their energy density at the planckian and transplanckian scales, conceivably resulting in a sequestration of the transplanckian field degrees of freedom. Quantum fluctuations then allow these to tunnel into cisplanckian configurations to seed inflation and conventional observed physics: propagating modes of QFT in a geometry which responds to the existence of these new modes through the energy constraint of general relativity, $H^2 = \rho/3$. That this tunneling results in geometries and field configurations that are homogeneous allows for an estimate of the mass of the inflation, $m = O(10^{-6})$, and the amplitude of the inflation condensate, $<\varphi> = O(10)$, both consistent with phenomenology.

7. Scalar Averaging in Cosmology – by A. A. Coley, Department of Mathematics and Statistics, Dalhousie University, Halifax, NS B3H 3J5, Canada; e-mail: aac@mathstat.dal.ca.

Abstract – The averaging problem in cosmology is of considerable importance for the correct interpretation of cosmological data. In this essay an approach to averaging based on scalar curvature invariants is presented, which gives to significant effects on cosmological evolution.

8. Spacetime Energy-Momentum, the Observer and Uncertainty in General Relativity – by F. I. Cooperstock[1] and M. J. Dupre[2], [1]Department of Physics and Astronomy, University of Victoria, P.O. Box 3055, Victoria, B.C. V8W 3P6, Canada, [2]Department of Mathematics, Tulane University, New Orleans, LA 70118; e-mail: cooperst@uvic.ca, mdupre@tulane.edu.

Abstract – In this essay, we introduce a new approach to energy-momentum in general relativity. Spacetime, as opposed to space, is recognized as the necessary arena for its examination, leading us to define new extended spacetime energy and momentum constructs. From local and global considerations, we conclude that the Ricci tensor is the required element for a localized expression of energy-momentum to include the gravitational field. We present and rationalize a fully invariant extended expression for spacetime energy, guided by Tolman's well-known energy integral for an arbitrary bounded stationary system. This raises fundamental issues which we discuss. The role of the observer emerges naturally and we are led to an extension of the Uncertainty Principle to general relativity, of particular relevance to ultra-strong gravity.

9. Hollowgraphy Driven Holography – by Aharon Davidson and Ilya Gurwich, Physics Department, Ben-Gurion University, Beer-Sheva 84105, Israel; e-mail: davidson@bgu.ac.il, gurwichphys@gmail.com.

Abstract – Hawking-Bekenstein entropy formula tells us that no quantum degrees of freedom can reside in the interior of a black hole. We suggest that this is a consequence of the fact that the volume of any interior sphere of finite surface area simply vanishes. Obviously, this is not the case in general relativity; however, we show that such a phenomenon does occur in gravitational theories which admit a spontaneously induced general relativity. Due to a phase transition (one parameter family degenerates) which takes place at the would have been horizon, the recovered exterior Schwarzschild solution connects, by means of a self-similar transition profile, with a novel 'hollow' interior exhibiting a vanishing spatial volume (and a locally varying Newton constant). This constitutes the so-called 'hollowgraphy' driven holography.

10. Co-Moving Coordinate Systems and the Breather Universe – by John Bruce Davies, Dept. Of Physics (Retd.), University of Colorado, Boulder, CO 80309; e-mail: DaviesResearch@yahoo.com.

Abstract – Recent observation of acceleration of the expansion of the Universe has caused a crisis in the accepted model with the postulation of Dark Energy as a cause. We propose that returning to Einstein's original equation governing the spatial and time dependence of the gravitational potential can remove this crisis without invoking phantom energies. Using the Newtonian limit approximation and only radial dependence, we derive a Klein-Gordon semi-linear equation governing the gravitational potential valid in the time after decoupling of matter from radiation. This original equation has solutions that co-move with the expansion of the Universe. Certain of these localized-in-space traveling waves have time dependencies that are periodic, which are termed Breathers. To an observer located at our local co-moving coordinate system, the observable Universe will then appear to be oscillating, with deceleration changing to acceleration and so on.

11. A Gyrolasers System to Detect Gravito-Magnetic Effects on Earth – by A. Di Virgilio[1], U. Schreiber[2], N.Beverini[3], A. Tartaglia[4], [1]INFN Sez. di Pisa, Pisa, Italy, [2]Forschungseinrichtung Satellitengeodaesie and Technische Universitaet Muenchen, Germany, [3]Univ. of Pisa and CNISM, Pisa, Italy, [4]Polit. of Torino and INFN, Torino Italy; e-mail: angela.divirgilio@pi.infn.it, schreiber@fs.wettzell.de, beverini@df.unipi.it, angelo.tartaglia@polito.it.

Abstract – A system of several gyrolasers rigidly attached to one another can be used to measure the frame dragging of the Earth. The system has to be composed of several gyros for two reasons: to reconstruct the speed and orientation of the Earth axis, and to improve the signal to noise ratio. If the apparatus astride the zero Sagnac point is composed of 4 equal gyrolasers in pairs (twins), two above and two below the zero Sagnac configuration, it will be possible to simultaneously have null measurements and four times the maximum gravitomagnetic signal: a unique signature and enhanced signal. Accuracy of 1% seems feasible with about 2.5 months of good data.

12. Dark Energy, with Signatures – by Sourish Dutta[1], Robert J. Scherrer[1], and Stephen D. H. Hsu[2], [1]Department of Physics and Astronomy, Vanderbilt University, Nashville, TN, 37235, [2]Institute of Theoretical Science, University of Oregon, Eugene, OR 97403-5203; e-mail: sourish.d@gmail.com, robert.scherrer@vanderbilt.edu, hsu@uoregon.edu .

Abstract – We propose a class of simple dark energy models which predict a late-time dark radiation component and a distinctive time-dependent equation of state $w(z)$ for redshift $z < 3$. The dark energy field can be coupled strongly enough to Standard Model particles to be detected in colliders and the model requires only modest additional particle content and little or no fine-tuning other than a new energy scale of order milli-electron volts.

13. Extremal Black Holes, Gravitational Entropy and Nonstationary Metric Fields – by Ariel Edery[1,2] and Benjamin Constantineau[1], [1]Physics Department, Bishop's University, 2600 College Street, Sherbrooke, Québec, Canada J1M 0C8, [2]Kavli Institute for Theoretical Physics, University of California, Kohn Hall, Santa Barbara, CA 93106; e-mail: aedrey@ubishops.ca, bconstantine07@ubishops.ca.

Abstract – There has been a long-standing debate as to whether extremal black holes have zero or non-zero entropy. A semi-classical approach yields zero entropy and an approach based on string microstate counting yields a non-zero entropy. We show conclusively that extremal black holes have zero entropy by pointing out a simple fact: they are static or stationary throughout the spacetime and therefore have one metric field configuration. In contrast, non-extremal black holes, including the Schwarzschild black hole, are nonstationary in some region and this implies they have a non-zero entropy. Numerical simulations of gravitational collapse as viewed by an asymptotic observer reveal that the gravitational entropy of a black hole is due to nonstationary metric fields residing near the surface of the event horizon.

14. Gravitation, Thermodynamics, and the Fine-Structure Constant – by Shahar Hod, The Hadassah Institute, HaNeviim 37, Jerusalem 91010, Israel; e-mail: shaharhod@gmail.com.

Abstract – The dimensionless fine-structure constant $\alpha \equiv e^2/\hbar c \approx 1/137.036$ has fascinated many scientists since its introduction by Sommerfeld almost a century ago. Dirac and Feynman have conjectured that this important physical constant may be composed of fundamental mathematical quantities like π. In this essay we argue that the interplay between gravity, quantum theory, and thermodynamics may shed much light on the origins of this mysterious constant. In particular, we show that a unified quantum theory of gravity may set a lower bound on the value of the fine-structure constant, $\alpha > \ln 3/48\pi \approx 1/137.3$.

15. Holographic Time – by Craig J. Hogan, Fermilab and The University of Chicago, 5640 S. Ellis Ave., Chicago, IL 60637; e-mail: craighogan@uchicago.edu.

Abstract – Nature may impose an absolute limit on bandwidth at the Planck frequency, $\approx 2 \times 10^{43}$ Hz. If macroscopic classical spacetime emerges holographically from a lower-dimensional quantum theory, this information bound may lead to a new kind of uncertainty in spacetime. In such a holographic world, measurement of time can be directional. Clocks oriented in different directions drift apart from each other with a random error of about a Planck time per Planck time. That error shows up as a new source of Planckian noise in phase differences of light travelling in two different directions. Unlike fluctuations from Planck scale vacuum fluctuations, which average away when measuring the positions of macroscopic bodies, the holographic difference between the two directional phases is almost the same in nearby regions of space, even at macroscopic separation. These fluctuations might be detectable with a pair of correlated, nearly-colocated Michelson interferometers.

16. Quantum Gravity and Turbulence – by Vishnu Jejjala[1], Djordje Minic[2], Y. Jack Ng[3], Chia-Hsiung Tze[2], [1]Centre for Research in String Theory, Department of Physics, Queen Mary, University of London, Mile End Road, London E1 4NS, UK, [2] Institute for Particle, Nuclear and Astronomical Sciences, Department of Physics, Virginia Tech, Blacksburg, VA 24061, [3]Institute of Field Physics, Department of Physics and Astronomy, University of North Carolina, Chapel Hill, NC 27599; e-mail: v.jejjala@qmul.ac.uk, dminic@vt.edu, yjng@physics.unc.edu, kahong@vt.edu.

Abstract – We apply recent advances in quantum gravity to the problem of turbulence. Adopting the AdS/CFT approach we propose a string theory of turbulence that explains the Kolmogorov scaling in 3+1 dimensions and the Kraichnan and Kolmogorov scaling in 2+1 dimensions. In the gravitational context, turbulence is intimately related to the properties of spacetime, or quantum, foam.

17. Arithmetic Quantum Gravity – by Axel Kleinschmidt[1] and Hermann Nicolai[2], [1]Physique Théorique et Mathématique & International Solvay Institutes, Université Libre de Bruxelles, Boulevard du Triomphe, ULB-CP231, 1050 Bruxelles, Belgium, [2]Max-Planck-Institut für Gravitationsphysik, Albert-Einstein-Institut, Am Mühlenberg 1, 14476 Golm, Germany; e-mail: axel.kleinschmidt@ulb.ac.be, nicolai@aei.mpg.de.

Abstract – The arithmetic chaos of classical (super)gravity near a space-like singularity is elevated to the quantum level via the construction of a *cosmological quantum billiard system*. Its precise formulation, together with its underlying algebraic structure, allows for a general analysis of the wavefunction of the universe near the singularity. We argue that the extension of these results beyond the billiard approximation may provide a concrete mechanism for emergent space as well as new perspectives on several long-standing issues in canonical quantum gravity. The exponentially growing complexity of the underlying symmetry structure could introduce an element of *non-computability* that effectively 'screens' the cosmological singularity from a complete resolution.

18. Vacuum Structure and Dark Energy – by Lance Labun and Johann Rafelski, Department of Physics, University of Arizona, 1118 E. Fourth St., Tucson, AZ 85721; e-mail: labun@physics.arizona.edu, rafelski@physics.arizona.edu.

Abstract – We consider that the universe is trapped in an excited vacuum state and the resulting excitation energy provides the observed dark energy. We explore the conditions under which this situation can arise from physics already known. Considering the example of how macroscopic QED fields alter the vacuum structure, we find that the energy scale 1 meV – 1 eV is particularly interesting. We discuss how dark energy of this form is accessible to laboratory experiments.

19. Gravitational Waves from Coalescing Binary Sources – by M. D. Maia, Universidade de Brasília, 70910-900 Brasília D. F., Brazil; e-mail: maia@unb.br.

Abstract – Coalescing binary systems (e.g. pulsars, neutron stars and black holes) are the most likely sources of gravitational radiation, yet to be detected on or near Earth, where the local gravitational field is negligible and the Poincaré symmetry rules. On the other hand, the general theory of gravitational waves emitted by axially symmetric rotating sources predicts the existence of a non-vanishing news function. The existence of such a function implies that, for a distant observer, the asymptotic group of isometrics, the BMS group, has a translational symmetry that depends on the orbit periodicity of the source, thus breaking the isotropy of the Poincaré translations. These results suggest the application of the asymptotic BMS-covariant wave equation to obtain a proper theoretical basis for the gravitational waves observations.

20. Let's Talk About Varying G – by Adam Moss, Ali Narimani, and Douglas Scott, Department of Physics & Astronomy, University of British Columbia, Vancouver, BC, V6T 1Z1 Canada; e-mail: adammoss@phas.ubc.ca, anariman@phas.ubc.ca, dscott@phas.ubc.ca.

Abstract – It is possible that fundamental constants may not be constant at all. There is a generally accepted view that one can only talk about variations of *dimensionless* quantities, such as the fine structure constant $\alpha_e \equiv e^2/4\pi\varepsilon_0\hbar c$. However, constraints on the strength of gravity tend to focus on G itself, which is problematic. We stress that G needs to be multiplied by the square of a mass, and hence, for example, one should be constraining $\alpha_g \equiv Gm_p^2/\hbar c$, where m_p is the proton mass. Failure to focus on such dimensionless quantities makes it difficult to interpret the physical dependence of constraints on the variation of G in many published studies. A thought experiment involving talking to observers in another universe about the values of physical constants may be useful for distinguishing what is genuinely measurable from what is merely part of our particular system of units.

21. The Warping of Extra Spaces Accelerates the Expansion of the Universe – by Ishwaree P. Neupane, Department of Physics and Astronomy, University of Canterbury, Private Bag 4800, 8041 Christchurch, New Zealand; e-mail: ishwaree.neupane@canterbury.ac.nz.

Abstract – Generic cosmological models derived from higher dimensional theories with warped extra dimensions have a nonzero cosmological constant-like term induced on the 3+1 space-time, or a physical 3-brane. In the scenario where this 3+1 space-time is an inflating de Sitter "brane" embedded in a higher-dimensional space-time, described by warped geometry, the 4D cosmological term is determined in terms of two length scales: one is a scale associated with the size of extra dimension(s) and the other is a scale associated with the warping of extra space(s). The existence of this term in four dimensions provides a tantalizing possibility of explaining the observed accelerating expansion of the universe from fundamental theories of gravity, e.g. string theory.

22. Equipartition of Microscopic Degrees of Freedom, Spacetime Entropy and Holography – by T. Padmanabhan, IUCAA, Post Bag 4, Ganeshkhind, Pune - 411 007, India; e-mail: paddy@iucaa.ernet.in.

Abstract – The principle of equipartition, applied to area elements of a surface ∂V which are at the local Unruh temperature, allows one to identify the number density of the microscopic degrees of freedom in any diffeomorphism invariant theory of gravity. The entropy associated with these degrees of freedom matches with the Wald entropy for the theory. The holographic relation, between the equipartition energy of the surface degrees of freedom and the bulk gravitating energy, also allows one to attribute an entropy density to the spacetime. The field equations can be obtained by extremising this entropy. Moreover, when the microscopic degrees of freedom are in local thermal equilibrium, the spacetime entropy of a bulk region resides on its boundary.

23. Huge Quantum Gravity Effects in the Solar System – by Don N. Page, Theoretical Physics Institute, Department of Physics, University of Alberta, Room 238 CEB, 11322 - 89 Avenue, Edmonton, Alberta, Canada T6G 2G7; e-mail: don@phys.ualberta.ca.

Abstract – Normally one thinks of the motion of the planets around the Sun as a highly classical phenomenon, so that one can neglect quantum gravity in the Solar System. However, classical chaos in the planetary motion amplifies quantum uncertainties so that they become very large, giving huge quantum gravity effects. For example, evidence suggests that Uranus may eventually be ejected from the Solar System, but quantum uncertainties would make the direction at which it leaves almost entirely uncertain, and the time of its exit uncertain by about a billion billion years. For a time a billion billion years from now, there are huge quantum uncertainties whether Uranus will be within the Solar System, within the Galaxy, or even within casual contact of the Galaxy.

24. The Entropy of a Quantum State of Gravity – by Carlo Rovelli[1] and Francesca Vidotto[1,2], [1]Centre de Physique Théorique de Luminy, Case 907, F-13288 Marseille, EU, [2]Dipartimento di Fisica Nucleare e Teorica, Università degli Studi di Pavia and Instituto Nazionale di Fisica Nucleare, Sezione di Pavia, via A. Bassi 6, 27100 Pavia, EU; e-mail: rovelli@cpt.univ-mrs.fr, vidotto@cpt.univ-mrs.fr.

Abstract – Passerini and Severini have recently shown that the Braunstein-Ghosh-Severini (BGS) entropy $S_\Gamma = -Tr[\rho_\Gamma \log \rho_\Gamma]$ of a certain density matrix ρ_Γ naturally associated to a graph Γ, is maximized, among all graphs with a fixed number of links and nodes, by regular graphs. We ask if this result can play a role in quantum gravity and be related to the apparent regularity of the physical geometry of space. We show that in Loop Quantum Gravity the matrix ρ_Γ is precisely the Hamiltonian operator (suitably normalized) of a non-relativistic quantum particle interacting with the quantum gravitational field, if we restrict elementary area and volume eigenvalues to a fixed value. This operator provides a spectral characterization of the physical geometry and can be interpreted as a state describing the spectral information about the geometry available when geometry is measured by its physical interaction with matter. It is then tempting to interpret its BGS entropy S_Γ as a genuine physical entropy: we discuss the appeal and the difficulties of this interpretation.

25. The Connection between 'Emergence of Time from Quantum Gravity' and 'Dynamical Collapse of the Wave-Function in Quantum Mechanics' – by Tejinder P. Singh, Tata Institute of Fundamental Research, Homi Bhabha Road, Mumbai 400 005, India; e-mail: tpsingh@tifr.res.in.

Abstract – There are various reasons to believe that quantum theory could be an emergent phenomenon. Trace Dynamics is an underlying classical dynamics of non-commuting matrices, from which quantum theory and classical mechanics have been shown to emerge, in the thermodynamic approximation. However, the time that is used to describe evolution in quantum theory is an external classical time and is, in turn, expected to be an emergent feature – a relic of an underlying theory of quantum gravity. In this essay we borrow ideas from Trace Dynamics to show that classical time is a thermodynamic approximation to an operator time in quantum gravitational physics. This prediction will be put to test by ongoing laboratory experiments attempting to construct superposed states of macroscopic objects.

26. Gravity of ITS from BITS VIA Information, Holography and Vacuum Energy – by C. Sivaram, Indian Institute of Astrophysics, Bangalore 560034, India; e-mail: sivaram@iiap.res.in.

Abstract – Aspects of information theory, holography and entropy have been much discussed in connection with black holes. However principles underlying these areas can be invoked in general physical situations to understand many basic properties of the gravitational field. Gravity stands apart from other fundamental interactions in that it is locally equivalent to an accelerated reference frame and can be transformed away. It is also identified with space-time geometry. Attempts to unify it with other interactions or to give a quantized description of the field have not been quite successful. Here a holographic hypothesis connecting BITS and ITS results in the emergence of both Newtonian and relativistic gravity as a manifestation of quantum vacuum thermodynamics. There are interesting implications for the quantum structure of space time.

27. On the Effective Equation of State of Dark Energy – by Martin S. Sloth, CERN, Physics Department, Theory Unit, CH-1211 Geneva 23, Switzerland; e-mail: sloth@cern.ch.

Abstract – In an effective field theory model with an ultraviolet frequency cutoff, there is a relation between the effective equation of state of dark energy and the ultraviolet cutoff scale. It implies that a measure of the equation of state of dark energy different from minus one, $\omega \neq -1$, does not rule out vacuum energy as dark energy. It also indicates an interesting possibility that precise measurements of the infrared properties of dark energy can be used to probe the ultraviolet cutoff scale of effective quantum field theory coupled to gravity. In a toy model with a vacuum energy dominated universe with a Planck scale cutoff, the dark energy effective equation of state may be calculated and is given by $\omega_{eff} \approx -0.96$.

28. Go with the Flow, Average Holographic Universe – by George F. Smoot, Institute for the Early Universe, Ewha Womans University & Advanced Academy, Seoul, Korea; Institute for the Physics and Mathematics of the Universe, University of Tokyo, Kashiwa, Chiba 277-8568, Japan; Lawrence Berkeley National Lab, 1 Cyclotron Road, Berkeley CA 94720; Physics Department, University of California, Berkeley, CA 94720; and Chaire Blaise Pascale, Universite Paris Denis Diderot, Paris, France; e-mail: gfsmoot@lbl.gov.

Abstract – Gravity is a macroscopic manifestation of a microscopic quantum theory of space-time, just as the theories of elasticity and hydrodynamics are the macroscopic manifestation of the underlying quantum theory of atoms. The connection of gravitation and thermodynamics is long and deep. The observation that space-time has a temperature for accelerating observers and horizons is direct evidence that there are underlying microscopic degrees of freedom. The equipartition of energy, meaning of temperature, in these modes leads one to anticipate that there is also an entropy associated. When this entropy is maximized on a volume of space-time, then one retrieves the metric of space-time (i.e. the equations of gravity, e.g. GR). Since the metric satisfies the extremum in entropy on the volume, then the volume integral of the entropy can readily be converted to surface integral, via Gauss's Theorem. This surface integral is simply an integral of the macroscopic entropy flow producing the mean entropy holographic principle. This approach also has the added value that it naturally dispenses with the cosmological constant/vacuum energy problem in gravity except perhaps for the second order quantum effects on the mean surface entropy.

29. Spin-Surfing the Space-Time Foam – 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@tifr.res.in, gtg@virginia.edu.

Abstract – In this essay we present the quantum spin as a novel test tool for probing directly the Planck scale space-time foam of quantum gravity. Quantum fluctuations of spatial support for the electric vector associated with the spin-1 photon affect its polarization sufficiently to allow us to gain deep insights and unprecedented constraints on the most important and fundamental aspect of quantum gravity - the fluctuating structure of space-time with a Planck scale 3D web.

30. Gravity and the Complexity of Coordinates in Fisher Information – by Asher Yahalom, Ariel University Center of Samaria, Ariel 40700, Israel; e-mail: asya@ariel.ac.il.

Abstract – The principle of Extreme Physical Information is a tool for deriving various equations of physics. The Physical Information is defined to be the difference between the Fisher information and the bound information specific to every physical system. Using the Extreme Physical Information, equations are obtained for the probability of finding the location of a physical entity (a system of particles or a field) in space-time. Those equations turn out to be the relevant physical equations (Dirac, Maxwell's equations etc.). A peculiarity of the method is that this only works if some of the coordinates that specify the whereabouts of the physical entity in space-time are chosen to be imaginary. I will argue that this peculiarity is a direct effect of Gravity.