Abstracts of Award Winning and Honorable Mention Essays for 1996

Award Essays

First Award - Gravitationally Induced Neutrino-Oscillation Phases - by D.V. Ahluwalia[*] and C. Burgard[+], [*]Mail Stop H-846, Los Alamos National Laboratory, Los Alamos, NM 87545; [+]Universität Hamburg/DESY, II. Institut für Experimentalphysik Notkestr.85, D-22607 Hamburg, Germany.

Abstract - In this essay, the authors introduce a new effect of gravitationally induced quantum mechanical phases in neutrino oscillations. In the neighborhood of a neutron star, gravitationally induced quantum mechanical phases are roughly 15% of their kinematical counterparts. When this information is coupled with the mass square differences implied by the existing neutrino-oscillation data the authors find that the new effect may have profound consequences for the type-II supernova evolution.

Second Award - Physics with Nonperturbative Quantum Gravity: Radiation from Quantum Black Holes - by Marcelo Barreira[*], Mauro Carfora[+], Carlo Rovelli [*], [*]Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, PA 15260; [+]Dipartimento di Fisica, Università di Pavia, Pavia, Italy.

Abstract - The authors study quantum gravitational effects on black hole radiation, using loop quantum gravity. Bekenstein and Mukhanov have considered the modifications caused by quantum gravity on Hawking=s thermal black-hole radiation. Using a simple ansatz for the eigenstates the area, they have obtained the intriguing result that quantum gravity affects the radiation considerably, yielding a non-thermal spectrum. The authors replace the simple ansatz with the eigenstates of the area computed using loop quantum gravity. They derive the emission spectra using a classical result in number theory by Hardy and Ramanujan. They do not recover the Bekenstein-Mukhanov spectrum, but do recover a Hawking thermal spectrum. The Bekenstein-Mukhanov result is therefore likely to be an artifact of the naive ansatz. The result is an example of concrete application of nonperturbative quantum gravity.

Third Award - Birth of the Universe as Quantum Scattering in String Cosmology - by M. Gasperini and G. Veneziano, Theory Division, CERN, CH-1211 Geneva 23, Switzerland.

Abstract - In a Wheeler-De Witt approach to quantum string cosmology, the present state of the Universe arises from the scattering and reflection of the wave function representing the initial string vacuum in superspace. This scenario is described and compared with the more conventional quantum cosmology picture, in which the birth of the Universe is represented as a process of tunneling "from nothing" in superspace.

Fourth Award - Relativity at Action or Gamma-Ray Bursts - by Tsvi Piran, The Racah Institute for Physics, The Hebrew University, Jerusalem, Israel.

Abstract - Gamma ray bursts - short bursts of few hundred keV γ-rays - have fascinated astronomers since their accidental discovery in the sixties. Gamma ray bursts were ignored by most relativists who did not expect that they are associated with any relativistic phenomenon. The recent observations of the BATSE detector on the Compton Gamma Ray Observatory have revolutionized our ideas on these bursts and the picture that emerges shows that gamma ray bursts are the most relativistic objects discovered so far.

Fifth Award - Gravitational Critical Phenomena in the Realm of the Galaxies and Ising Magnets - by D. Hochberg and J. Pérez-Mercader, Laboratorio de Astrofísica Espacial y Física Fundamental, Apartado 50727, 28080 Madrid, Spain.

Abstract - In the non-relativistic and quasi-static limit, it is possible to map exactly the system of galaxies in the observable universe onto an Ising magnet. Techniques from the theory of critical phenomena as applied to magnets can then be employed to calculate rigorously the galaxy-to-galaxy correlation function, whose critical exponent is predicted to be between 1.530 to 1.862. This is compared to the empirical/observational value of 1.6 to 1.8

1. Testing the Equivalence Principle in the Quantum Regime - by Catalina Alvarez and Robert Mann, Department of Physics, University of Waterloo, Waterloo, Ontario N2L 3G1 Canada.

Abstract - The authors consider possible tests of the Einstein Equivalence Principle for physical systems in which quantum-mechanical vacuum energies cannot be neglected. Specific tests include a search for the manifestation of non-metric effects in Lamb-shift transitions of Hydrogenic atoms and in anomalous magnetic moments of massive leptons. They discuss how current experiments already set bounds on the violation of the equivalence principle in this sector and how new (high-precision) measurements of these quantities could provide further information to this end.

2. The Wigner Inequalities for a Black Hole - by John D. Barrow, Astronomy Centre, University of Sussex, Brighton BN1 9QH U.K.

Abstract – Wigner's inequalities for the minimum size and maximum running-time of a clock are applied to a black hole. They give the Hawking lifetime of a black hole as the maximum time that a black hole could be used to measure and identify the information content of a black hole.

3. Primordial Gravitational Waves: A Probe of the Very Early Universe - by R.A. Battye[*] and E.P.S. Shellard[+], [*]Theoretical Physics Group, Blackett Laboratory Imperial College of Science, Technology & Medicine, University of London, Prince Consort Road, London SW7 2BZ, U.K.; [+]Relativity and Gravitation Group, Department of Applied Mathematics and Theoretical Physics, University of Cambridge, Silver Street, Cambridge CB3 9EW, U.K.

Abstract - The authors discuss the potential cosmological role of gravitational wave astronomy as a probe of the very early universe. The next generation of detectors - now in production - may be able to observe a stochastic background of gravitational waves produced by violent processes during the earliest moments after the creation of the universe. Viable theoretical scenarios within detector sensitivity include strongly first-order phase transitions, possibly at the end of inflation, and networks of cosmic strings. At this stage, other primordial backgrounds from slow-roll inflation, global topological defects and the standard electroweak phase transition appear to be out of range. The discovery of any of these possible cosmological sources will have enormous implications for our understanding of the very early universe and for fundamental physics at the highest energies.

4. On the Importance of Testing Gravity at Distances Less than 1 Cm - by Silas R. Beane, Department of Physics, Duke University, Durham, NC 27708-0305.

Abstract - If the mechanism responsible for the smallness of the vacuum energy is consistent with local quantum field theory, general arguments suggest the existence of at least one unobserved scalar particle with Compton wavelength bounded from below by one tenth of a millimeter. The author shows that this bound is saturated if vacuum energy is a substantial component of the energy density of the universe. Therefore, the success of cosmological models with a significant vacuum energy component suggests the existence of new macroscopic forces with range in the sub-millimeter region. There are virtually no experimental constraints on the existence of quanta with this range of interaction.

5. How Impossible is Topology Change? - by Arvind Borde, Institute of Cosmology, Department of Physics and Astronomy, Tufts University, Medford, MA 02155 and Department of Mathematics, Southampton College, Long Island University, Southampton, NY 11968.

Abstract - It is often stated that topology change is impossible in classical general relativity. In particular, it appears to be widely believed that the pleasure of topology change comes at a fixed price: topology-changing spacetimes must be singular. This perception is wrong. The author discusses here both the kinematics and the dynamics of topology change in order to clarify what precisely the obstacles are and (with luck) to dispel a few of the more widespread misconceptions about this process. Some of the work presented here extends the work of Geroch and Tipler to a wider class of spacetimes and some of it offers novelties - such as an explicit example of non-singular 2-dimensional topology change - that have been claimed in the literature to be impossible.

6. Cosmic Connections - by Neil J. Cornish*, David N. Spergel+, and Glenn D. Starkman*, *Department of Physics, Case Western Reserve University, Cleveland, OH 44106-7079; +Princeton University Observatory, Princeton, NJ 08544 and Department of Astronomy, University of Maryland, College Park, MD 20742.

Abstract - The universe may be multiply-connected on observable scales. This multiple-connectedness could explain the homogeneity of the universe on the very largest scales. Experiments in the next few years would detect this cosmic topology if it exists.

7. Extensible Black Hole Embeddings for Apparently Forbidden Periodicities - by Aharon Davidson and Uzi Paz, Physics Department, Ben-Gurion University of the Negev, Beer-Sheva 84105, Israel.

Abstract - Imposing extendibility on Kasner-Fronsdal black hole local isometric embedding is equivalent to removing conic singularities in Kruskal representation. Allowing for globally non-trivial (living in $M_5 \times S_1$) embeddings, parameterized by k, extendibility can be achieved for apparently forbidden frequencies $\omega_1(k) \leq \omega(k) \lneq \omega_2(k)$. The Hawking-Gibbons limit, $\omega_{1,2}(0) = 1/(4M)$ for Schwarzschild geometry, is respected. The corresponding Kruskal sheets are slices in some Kaluza-Klein background. Euclidean k discreteness, dictated by imaginary time periodicity, is correlated with (torsion) flux quantization.

8. Origin of the Primordial Magnetic Field - by John Bruce Davies, Department of Physics, University of Colorado, Boulder, CO.

Abstract - The author shows that the primordial magnetic field is generated in the plasma of the early Universe by motions of a primordial electric field which itself is produced by the prevailing temperature and pressure gradients in the density perturbations present at the time of decoupling. Using reasonable values for the relevant physical parameters at this time gives a primordial magnetic field whose magnetic flux values are similar to those observed in the Sun, stars, white dwarfs and pulsars. Radio galaxies and their relics in clusters have much higher magnetic indicating a history of dynamo amplification.

9. Gravity as a Source of Phase Transitions - by E. Elizalde*+ and S.D. Odintsov+, *Center for Advanced Studies, CEAB, CSIC, Camí de Santa Bàrbara, E-17300 Blanes; +Department of ECM and IFAE, Faculty of Physics, University of Barcelona, Diagonal 647, E-08028 Barcelona, Spain.

Abstract - After going through several distinguished examples, the authors argue that gravity is definitely a source of phase transitions of quite different nature: usual scalar effective potential ones, chiral symmetry transitions and even transitions involving the chromomagnetic vacuum. In such context, the authors emphasize the fact that curvature-induced phase transitions of those kinds - where an interplay between general relativity and elementary particle physics occurs - ought to be relevant in the construction of models of the inflationary universe.

10. The Redshift Periodicity of Galaxies as a Probe of the Correctness of General Relativity - by Valerio Faraoni,

Department of Physics and Astronomy, University of Victoria, P.O. Box 3055, Victoria, B.C. Canada V8W 3P6.

Abstract - Recent theoretical work determines the correct coupling constant of a scalar field to the Ricci curvature of spacetime in general relativity. The periodicity in the redshift distribution of galaxies observed by Broadhurst *et al.*, if genuine, determines the coupling constant in the proposed scalar field models. As a result, these observations contain important information on the problem whether general relativity is the correct theory of gravity in the region of the universe at redshifts $z < 0.5$.

11. Lightcone Fluctuations - by L.H. Ford, Institute of Cosmology, Department of Physics and Astronomy, Tufts University, Medford, MA 02155.

Abstract - It is argued that quantum fluctuations of the lightcone of spacetime should play a crucial role in any quantum theory of gravity. Even in the absence of a complete theory, one can gain some insight as to the physical phenomena which are associated with lightcone fluctuations. A model is discussed in which a bath of gravitons in a squeezed vacuum state serves as the source of metric and lightcone fluctuations. It is shown that the classical lightcone is indeed smeared out in this model. The two point functions of quantum field theory become finite for distinct points, and photons can propagate faster than the classical speed of light. Some potential observable consequences of lightcone fluctuations are discussed.

12. The General Solution of the Quantum Einstein Equations? - by Rodolfo Gambini[*] and Jorge Pullin[+], [*]Instituto de Física, Facultad de Ciencias, Tristan Narvaja 1674, Montevideo, Uruguay; [+]Center for Gravitational Physics and Geometry, Department of Physics, 104 Davey Lab, The Pennsylvania State University, University Park, PA 16802.

Abstract - The authors suggest how to interpret the action of the quantum Hamiltonian constraint of general relativity in the loop representation as a skein relation on the space of knots. Therefore, by considering knot polynomials that are compatible with that skein relation, one guarantees that all the quantum Einstein equations are solved. The authors give a particular example of such invariant and discuss the consistency of the constraint algebra in this approach.

13. Torsion Power - by Richard T. Hammond, North Dakota State University, Physics Department, Fargo, ND 58105.

Abstract - The demand for gravitation with torsion spans the realm from classical general relativity where conservation of total angular momentum plus intrinsic spin requires the need for torsion, to string theory, which calls for the necessity of torsion as an antisymmetric field. Despite both the intense theoretical activity and the experimental efforts to measure torsion, research into the mechanisms of the production and radiation of torsion has been severely neglected. It is shown that torsion waves can be generated by particles with spin, and the radiated power is computed. With these results, new generations of experiments may be developed that could measure torsion waves, the effects on rotating collapsed objects, and the role of torsion waves in the development of the early universe.

14. Interpolating Black Holes - by Viqar Husain, Center for Gravitational Physics and Geometry, Department of Physics, Pennsylvania State University, University Park, PA 16802-6300.

Abstract - The author describes an unusual three parameter family of static spherically symmetric black hole solutions of general relativity. The solutions arise from gravitational coupling to a one parameter generalization of the electromagnetic stress-energy tensor. This parameter determines the range of the matter field. One class of the black hole metrics 'lies between' the Schwarzschild and Reissner-Nordstrom solutions, while the other class 'lies beyond' the latter, in the sense of radial falloff of the metric. The author also points out that a recent 'no short hair' conjecture does not apply to these solutions.

15. Do We Know the Geometry of the Universe? - by Marc Kamionkowski and Nicolaos Toumbas, Department of Physics, Columbia University, New York, NY 10027.

Abstract - It is quite remarkable that seventy years after Hubble discovered the expansion of the Universe, we still have no idea in which of the three Friedmann-Roberston-Walker geometries we live. Most of the current literature has focussed on flat or open models. Here, the authors construct a viable model of the Universe which has closed geometry even though the nonrelativistic-matter density is less than critical. Furthermore, in this model, the cosmic microwave background could come from a causally-connected region at the antipode of the closed Universe. This model illustrates that the geometry of the Universe is unconstrained by current data. The authors discuss observations which may reliably determine the geometry of the Universe in the near future.

16. Violating the Weak Energy Condition, Quantum Hair, and Black Hole Thermodynamics - by Lawrence M. Krauss and Hong Liu, Department of Physics, Case Western Reserve University, Cleveland, OH 44106-7079.

Abstract - It is known that the process of black hole evaporation can be interpreted in terms of violations of the weak energy condition due to quantum fluctuations near the event horizon of a black hole. The authors argue here that the effects of recently proposed quantum hair on black holes can be recast in this light. This suggests further potentially interesting implications for semiclassical effects in black hole physics.

17. The Equivalence of Precession Phenomena in Metric Theories of Gravity - by Timothy P. Krisher, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109.

Abstract - The property of general covariance in theories of gravity can lead to an equivalence of apparently different physical effects. An important example is provided by the phenomenon of geodetic precession of a gyroscope as it falls freely in the gravitational field of a massive body. A simple argument is presented that demonstrates clearly, without the need for detailed coordinate transformation calculations, how geodetic precession of a gyroscope and the effect of frame-dragging are fundamentally equivalent. The argument applies to a general class of metric theories of gravity. There exist potentially important implications of this equivalence for interpreting experiments proposed to test frame-dragging.

18. Scale Factor Duality and Supersymmetric Cosmology - by James E. Lidsey, Astronomy Unit, School of Mathematical Sciences, Queen Mary & Westfield, Mile End Road, London, E1 4NS, U.K.

Abstract - It is shown that spatially flat, isotropic cosmologies derived from the Brans-Dicke gravity action exhibit a scale factor duality invariance. This classical duality is then employed to uncover a hidden $N = 2$ supersymmetry at the quantum level.

19. Cosmologies with Photon Creation and the 3K Relic Radiation Spectrum - by J.A.S. Lima, Physics Department, Brown University, Providence, RI 02912 and Departamento de Física Teórica e Experimental, Universidade Federal do Rio Grande do Norte, 59072-970, Natal, RN, Brazil.

Abstract - A new Planckian distribution for cosmologies with photon creation is derived using thermodynamics and semiclassical considerations. This spectrum is preserved during the universe evolution and compatible with the present spectral shape of the cosmic microwave background radiation (CMBR). Accordingly, the widespread feeling that cosmologies with continuous photon creation are definitely ruled out by the COBE limits on deviation of the CMBR spectrum from blackbody shape should be reconsidered. It is argued that a crucial test for this kind of cosmology is provided by measurements of the CMBR temperatures at high redshifts. For a given redshift z greater than zero, the temperature is smaller than the one predicted by the standard FRW model.

20. Thermodynamics of Negative Mass Holes? - by C.O. Lousto, Department of Physics, University of Utah, 201 JFB, Salt Lake City, UT 84112.

Abstract - The author discusses the stability properties of black holes as a thermodynamic system in equilibrium with a radiation bath (canonical ensemble) by using the Helmholtz free energy potential. He analytically extends the analysis to any value of the variable in the Helmholtz potential and shows that this leads us to deal with negative mass holes. The author then studies their curious thermodynamical stability behavior.

21. Collapsing Void in an Expanding Universe - by D.R. Mandal[*] and S. Banerji[+], [*]Department of Physics, Basirhat College, Basirhat, North 24-Parganas, W. Bengal, India; [+]Department of Physics, the University of Burdwan, Burdwan - 713 104, India.

Abstract - The authors consider here the model of a spherical void in an expanding Robertson-Walker (RW) universe with flat space sections. The void is taken as a sphere of low density conducting perfect fluid (Region I) surrounded by a spherical shell of pure radiation (Region II). The metric in Region I is assumed to be a special form of the solution of Maiti (1982) and that in Region II is that of Vaidya. The RW universe (Region III) surrounding the above combination is assumed to be filled with a perfect fluid having a linear equation of state so that the scale factor is given by t^n. The matching conditions are written down and solved. The arrow of time shows that the void appears to contract when seen by a comoving observer in the RW universe. If, however, the RW universe is filled with dust ($p = 0$), then the void remains static and the Vaidya metric reduces to that of Schwarzschild. The coordinates of Region II are extended to Regions I and III.

22. Gravitational Wave 'Pulsar': A New Source of Gravitational Waves Caused by Neutrino Asymmetry in a Strong Magnetic Field - by S. N. Nazin and K. A. Postnov, Sternberg Astronomical Institute, 13, Universitetskii pr., 119899 Moscow, Russia.

Abstract - A new type of astrophysical source of gravitational radiation - a 'gravitational wave pulsar' caused by neutrino emission asymmetry in a strong magnetic field of the rotating neutron star - may appear:

1. During Thorne-Żytkow object formation in a close binary system. The amplitude is $rh_{TZ} \sim 10^{-5}$ cm for assumed accretion rates of order M solar masses per year;
2. During Neutron Star (NS) formation in supernova explosions. The amplitude of the signal may attain $h_{SN} \sim 10$ cm and be detectable for galactic supernovae;
3. At late stages of binary NS or NS-BH (Black Hole) merging. The amplitude $rh_{NS} \sim 5 \times 10^2$ cm may be reached. The waveforms from merging NS binaries may additionally be modulated with the spin period of the magnetized component. Such modulation may be detectable up to distances ~ 1 Mpc.

23. Topology Change in (2 + 1) - Dimensional Gravity with Non-Abelian Higgs Field - by Alexander I. Nesterov, Departamento de Física, CUCEI, Universidad de Guadalajara, Guadalajara 44460, Jalisco, México.

Abstract - The author studies the topology change in (2+1)D gravity coupling with non-abelian $SO(2,1)$ Higgs field from the point of view of Morse theory. He shows that the Higgs potential can be identified with the Morse function. The critical points of the latter (i.e. loci of change of the spacetime topology) coincide with zeros of the Higgs field. In these critical points the two-dimensional metric becomes degenerate but the curvature remains bounded.

24. Measuring the Gravitational Acceleration of Antimatter with an Antihydrogen Interferometer - by Thomas J. Phillips, Physics Department, Duke University, Durham, NC 27708-0305.

Abstract - The gravitational force on antimatter ($\bar{g}$) has never been directly measured. A method is suggested for making this measurement by directing a low-energy beam of neutral antihydrogen atoms through a transmission-grating interferometer and measuring the gravitationally-induced phase shift in the interference pattern. A 1% measurement of $\bar{g}$ should be possible from a beam of about 10^5 or 10^6 $\bar{H}$ atoms. If more antihydrogen can be made, a much more precise measurement of $\bar{g}$ would be possible. A method is suggested for producing an antihydrogen beam appropriate for this experiment.

25. Entropy of the Gravitational Field - by Tony Rothman* and Peter Anions+ , *Princeton Plasma Physics Lab, Princeton University, Princeton, NJ 08543, +National Center for Supercomputing Applications, University of Illinois, 405 N. Mathews Ave., Urbana, IL 61801.

Abstract - The authors develop a formulation of the entropy of the gravitational field by adopting the statistical mechanics expression for entropy $S = \ln \Omega$, where Ω is the phase space of the field bounded by a Hamiltonian. Phase space is calculated for gravitational waves and radiation and density perturbations in expanding FLRW spacetimes, attributing entropy to a lack of knowledge in the exact field configuration. In all cases, S behaves monotonically as required for a definition of gravitational entropy and is a good measure of inhomogeneity. It also reduces to black-hole entropy under appropriate circumstances.

26. Tilt of COBE Can Constrain Aspects of Superstring Geometry - by C. Sivaram, Indian Institute of Astrophysics, Bangalore 5600034 India.

Abstract - Superstring theories for which experimental evidence is meagre are considered a most promising approach to understand the quantum nature of gravity and its unification with other fundamental interactions. The geometric structure of these theories goes beyond the usual Riemannian one of general relativity. In the low energy limit they are well known not to simply reduce to Einstein's theory but also inevitably to contain an antisymmetric field associated with space time torsion and a dilation scalar field. Although equivalence principle tests and evidence from the binary pulsar would make their effects very small these fields could have dominated in the inflationary epoch and left their imprints in the COBE spectrum. This approach enables us to quantify quite precisely the relative strength of the antisymmetric field and consequent deviation from general relativity at that epoch.

27. Gravitational Aharanov-Bohm Phase and Atom Interferometry: New Grounds in Experimental Gravitation - by C.S. Unnikrishnan, Gravitation Experiments Group, Tata Institute of Fundamental Research, Homi Bhabha Road, Bombay - 400 005, India.

Abstract - Modern experimental gravitation in the laboratory mainly consists of two kinds of experiments: 1) experiments to test the foundation of the theory 2) experiments to test the predictions of the theory. The most prominent among the first type are tests of the equivalence principle and among the second type the whole current theme is centered around detection of gravitational waves. We propose new experiments in a third regime, at the interface of gravitation and quantum mechanics. We point out that a direct measurement of quantum phase changes induced by gravitational potential in situations without a gravitational field - an analogue of the scalar Aharanov-Bohm effect - is feasible. We show that the sensitivity of neutral atom interferometry is now sufficient to perform such experiments. This is the first time such experiments have become possible and the results would be highly significant since it will reveal a second layer of geometry in the structure of gravity, coming from the way the gauge potential appears in the quantum phase factor.

28. Why Quantum Mechanics Is Complex - by James T. Wheeler, Department of Physics, Utah State University, Logan, UT 84322.

Abstract - The author shows how the zero-signature Killing metric of a new, real-valued, 8-dimensional gauging of the conformal group can account for the complex character of quantum mechanics. The new gauge theory gives manifolds which generalize curved, relativistic phase space. The difference in signature between the usual momentum space metric and the Killing metric of the new geometry gives rise to an imaginary proportionality constant connecting the momentum like variables of the two spaces. Path integral quantization becomes an average over dilation factors, with the integral of the Weyl vector taking the role of the action. Minimal $U(1)$ electromagnetic coupling is predicted.

29. Averaging Problem in General Relativity Macroscopic Gravity and Using Einstein's Equations in Cosmology - by Roustam M. Zalaletdinov, School of Mathematical Sciences, Queen Mary & Westfield College, University of London, Mile End Road, London E1 4NS, England, U.K., and Department of Theoretical Physics, Institute of Nuclear Physics, Uzbek Academy of Sciences, Tashkent 702132, Uzbekistan, C.I.S.

Abstract - The averaging problem in general relativity is briefly discussed. A new setting of the problem as that of macroscopic description of gravitation is proposed. A covariant space-time averaging procedure is described. The structure of the geometry of macroscopic space-time, which follows from averaging Cartan's structure equations is described and the correlation tensors present in the theory are discussed. The macroscopic field equations (averaged Einstein's equations) derived in the framework of the approach are presented and their structure is analyzed. The correspondence principle for macroscopic gravity is formulated and a definition of the stress-energy tensor for macroscopic gravitational field is proposed. It is shown that the physical meaning of using Einstein's equations with a hydrodynamic stress-energy tensor in looking for cosmological models means neglecting all gravitational field correlations. The system of macroscopic gravity equations to be solved when the correlations are taken into consideration is given and described.