GRAVITY RESEARCH FOUNDATION
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Abstracts of Award Winning and Honorable Mention Essays for 1986

Award Winning Essays

First Award - Does String Theory Solve the Puzzles of Black Hole Evaporation? by M. J. Bowick, L. Smolin and L. C. R. Wijewardhana, Yale University Physics Department, New Haven, CT. 06511.

Abstract - The authors point out that the massive modes of closed superstring theories may play a crucial role in the last stages of black hole evaporation. If the Bekenstein-Hawking entropy describes the true degeneracy of a black hole - implying loss of quantum coherence and the unitary evolution of quantum states - it becomes entropically favorable for an evaporating black hole to make a transition to a state of massive string modes. This in turn may decay into massless modes of the string (radiation) avoiding the naked singularity exposed by black hole evaporation in the semiclassical picture. Quantum coherence may be maintained if the entropy of an evaporating black hole is much larger than that given by the Bekenstein-Hawking formula. In that case the transition to massive string modes is unlikely. String theories might thus resolve the difficulty of the naked singularity, but it appears likely that they will still imply loss of quantum coherence.

Second Award - Feeble Forces and Gravity, Itzhak Bars and Matt Visser, Physics Department, University of Southern California, Los Angeles, CA 90089-0484.

Abstract - The authors develop a scenario in which feeble intermediate range forces emerge as an effect resulting from the compactification (a la Kaluza-Klein) of multidimensional theories. These feeble forces compete with gravity and in general permit different bodies to fall to Earth with different accelerations. The authors show that these feeble forces are mediated by vectors (V) and/or scalars (S), whose dimensionaless coupling constants are typically of order

$$g_V \approx g_S \approx 10^{-20} \quad .$$

Under certain plausible assumptions the ranges of these feeble forces are expected to be of order 1 metre to 1 kilometre. It is conjectured that the general strategy will prove applicable to realistic multidimensional theories such as the ten dimensional superstring theories. The authors speculate that deviations from the standard gravitational force - similar to the ones reported recently as a "fifth force" - may be interpreted as evidence for higher dimensions.

Third Award - A New Test of the Weak Equivalence Principle, Gordon D. Pusch, Department of Physics, Virginia Polytechnic Institute and State University.

Abstract - The Eotvos, Dicke, and Braginski experiments do not rule out the recent suggestion that the weak equivalence principle (WEP) might be violated at intermediate ranges (10^{-1} m $\leq r \leq 10^4$ m). The author briefly discusses the problems inherent to Eotvos-type apparatus in searches for WEP-violating forces ("hyperforces") between laboratory masses, and suggests an alternative detector free of such problems. The proposed detector is driven by a "hyperforce" torque at the rotational frequency. If the detector is tuned to this frequency, the signal, enhanced by resonance, may be detected synchronously. The author derives the response equations for the detector and discusses how spurious responses due to gravity torques may be suppressed.

Fourth Award - Does $\Omega < 1$ Imply that the Universe will Expand Forever? L. H. Ford, Department of Physics and Astronomy, Tufts University, Medford, Massachusetts 02155.

Abstract - The issue of whether the present observational evidence that the mean mass density of the universe is less than the critical density (i.e. $\Omega < 1$) implies an infinite future expansion of the universe is discussed. Although in conventional cosmological scenarios, $\Omega<1$ necessarily leads to a universe that will grow infinitely old, this conclusion can be avoided in ways which are reasonably natural. One of these is to assume the existence of a small negative cosmological constant. Another way is to postulate the existence of unstable fields with a long time scale for the onset of the instability. An example is a scalar field with a negative squared mass and $|m|<10^{-32}$ eV. Other examples include fields for which the instability is generated by quantum corrections in curved spacetime. All of these are capable of halting the expansion of an open universe and forcing it to recollapse into a "big crunch".

Fifth Award - Cosmological Textures, R. L. Davis, Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305.

Abstract - The notions of phase transitions and causality, combined with the standard cosmological model, lead to the appearance of topological defects in the early universe. The most familiar types of defects are solitons, strings and domain walls. Another type can exist when the spatial universe is compact. When these appear the whole universe takes on a winding number, and the consequences are quite amusing: For example, it is possible that a closed universe can mimic open or flat universes. Another possibility is that the vacuum has a non-abelian magnetic field strength at all points in the universe.

Honorable Mention Essays (Alphabetical Order)

1. Thermodynamics and General Relativity Could Determine the Geometry of the Universe, by Selcuk S. Bayin, Department of Physics, Canisius College, Buffalo, NY 14208.

Abstract - The author introduces a suggestive model where certain quantities in Friedmann models are treated like their thermodynamic counterparts; temperature, entropy, Gibbs energy and so on. Within this model, changes in the symmetry of the universe are interpreted as first-or second-order phase transitions. The thermodynamics introduced gives a new way of determining the geometry of the universe. By choosing a specific local equation of state ($p = \alpha \rho$) the author shows that with respect to the thermodynamics that has been introduced it is always more advantageous

for the universe to be in a Bianchi V (open) symmetric state.

2. <u>On a Complete Theory for Unconventional Vacua</u>, Mario Castagnino and Rafael Ferraro, Instituto de Astronomia y Fisica del Espacio Casilla de Correos 67, Sucursal 28, 1428 Buenos Aires, Argentina.

<u>Abstract</u> - Physical concepts can only be really understood in the frame of complete theories but a complete theory of unconventional vacua (i.e. vacua in bounded or curved space-time or using accelerated observers system) is missing. In this essay the authors sketch such a theory. An observer dependent Hamiltonian is introduced. It can be shown that a great number of vacua studied in the literature are, in fact, the quantum states that minimize the VEV of this Hamiltonian. Interesting phenomena-like Hawking radiation-are clarified, using the formalism, and the energy that excites the particles detector is singled out.

3. <u>Positive Energy Test for Gravitational Theories</u>, De-Ching Chern and James M. Nester, Department of Physics, National Central University, Chung-li, Taiwan 32054, Republic of China.

<u>Abstract</u> - Some alternate theories of gravity fit the experimental evidence just as well as Einstein's theory. Such is the case for certain Poincare gauge theories. Hence, there is a need for a strong theoretical test. The requirement of positive total energy, recently established for Einstein's theory, promises to fulfill this need. The results obtained by the authors to date lead to the expectation that this test will eliminate almost all of the otherwise viable Poincare gauge theories.

4. <u>Nonlinear Wave Interactions in General Relativity</u>, Corneliu D. Ciubotariu, Department of Physics, Polytechnic Institute of Jassy Splai Bahlui 71, C. P. 483, Jassy 6600, Romania.

<u>Abstract</u> - Nonlinear wave interaction has a wide application in various fields of physics. In this work the author extends the nonlinear wave-wave interaction to the effects involving gravitation. Within the context of a weakly nonlinear analysis of the Einstein equations, the unperturbed geometry plays the role of a nonuniform medium for the propagation and interaction of gravitational and non-gravitational waves. The author shows that the interaction between gravitational waves can be described by a system of nonlinear equations which are similar to those used for the study of the interaction of waves in fluids and plasmas.

5. <u>How unique are the Friedmann-Robertson-Walker models of the universe?</u>, C. B. Collins, Department of applied Mathematics, University of Waterloo, Waterloo, Ontario, Canada, N2L 3G1.

<u>Abstract</u> - By accepting the validity of certain conjectures in classical general relativity and kinetic theory, it is argued that, in a sense, the spatially homogeneous and isotropic Friedmann-Robertson-Walker (FRW) cosmological models are unique. This is accomplished in two steps. First, there is reason to believe that kinetic theory requires perfect fluids to be shear-free. Secondly, it seems that general relativity constrains expanding shear-free fluids to be irrotational. The uniqueness of the FRW models then follows, since it has already been established that they are the only space-times which represent an expanding shear-free irrotational perfect fluid that are physically reasonable on a global scale.

6. Lower Bounds on Axion Rest Mass in a General Cosmological Scenario, B. Datta, Indian Institute of Astrophysics, Bangalore 560034, India and P. S. Joshi, Tata Institute of Fundamental Research, Bombay 400005, India.

Abstract - On the basis of general properties and the large scale structure of spacetime, the authors derive general lower limits on the rest mass of the axion, assuming that axions make up the dark matter in the universe. These limits on mass are derived in terms of the possible age of the universe.

7. Gravitational Bags, Aharon Davidson and E. I. Guendelman, Physics Department, Ben-Gurion University of the Negev, Beer-Sheva 84105, Israel.

Abstract - In an attempt to account for the constitution of matter, Einstein was actually ready to modify his original field equations. The type of gravitational bags he suggested are shown to arise in Kaluza-Ikein theories, where the compactification of the extra dimensions is induced spontaneously, and may accompany superstring theories as well. The key factor is an effective four-dimensional local cosmological constant. Cosmologywise it implies solitary evolution, while the static case corresponds to a gravitational bag. Such a bag consists of a core of asymptotically-free fields confined by means of a stable spherically symmetric domain wall. It is asymptotically flat, does not have an event horizon, and its surface area is at most 9/4 the area of an equal mass black hole.

8. Gravity, Antigravity and Broken Lorentz Symmetry, M. Gasperini, Dipartimento di Fisica Teorica dell'Universita, Corso M.D'Azeglio 46, 10125 Torino, Italy and I.N.F.N., Sezione di Torino, Italy.

Abstract - The appearance of repulsive interactions, as a consequence of a breaking of the SO(3,1) gauge symmetry of gravity, is discussed using an SO(3) invariant quasi-riemannian theory as an effective geometric model of Lorentz noninvariant gravitational dynamics. Two examples are considered in particular: one shows that an SO(3,1) breaking in the early universe, if sufficiently strong, may prevent the singularity of the standard cosmological model; the other that a breaking, even infinitesimal, in the field of a central source, may render the interior of the Schwarzschild sphere a classically impenetrable region.

9. Repulsive Gravitation, Ø. Grøn, Oslo College of Engineering, Cort Adelers gt. 30, Oslo, Norway Institute of Physics, University of Oslo, P. O. Box 1048 Blindern, Oslo, Norway.

Abstract - The possibility of repulsive gravitation is shown to be a consequence of general relativity, although in the Newtonian limit gravitation is always attractive. In a general relativistic class of electron models emerging as solutions of the Einstein-Maxwell equations, the Poincare stress, which was earlier introduced ad hoc to stabilize the models, is explained as due to quantum mechanical vacuum properties. The models are in equilibrium under the action of repulsive electric and gravitational forces and an attractive pressure gradient due to vacuum polarization. Cosmological consequences of repulsive vacuum gravitation are pointed out. In particular it gave rise to an inflationary era, which made the universe become isotropic and nonrotating. It is suggested that the expansion of the universe is due to repulsive gravitation.

10. Zero-Point Fields in Noninertial Frames, by Shahen Hacyan, Universidad Nacional Autonoma De Mexico, Instituto De Astronomia, Observatorio Astronomico Nacional, Apartado Postal 70-264, Ciudad Universitaria, Mexico 20, Mexico.

Abstract - The energy spectrum of the zero-point field is Lorentz invariant and thus cannot be detected in an inertial frame. The spectrum is distorted, however, by the Doppler effect or the gravitational redshift in a noninertial frame. It is suggested that this idea can be applied to fields of any spin, emphasizing the formal equivalence between quantized fields and random classical fields. Thus, the radiation produced by black holes or by acceleration is not due to the creation of particles but is a direct manifestation of the zero-point field and is of the same nature, whether real or virtual.

11. Cosmic Strings within the Horizon, T. M. Helliwell, Department of Physics, Harvey Mudd College, Claremont, California, 91711, U.S.A. and D. A. Konkowski, School of Mathematical Sciences, Queen Mary College, University of London, Mile End Road, London, E1 4NS, U.K.

Abstract - Cosmological scenarios predict at least one straight cosmic string within the horizon today. In this paper the authors discuss the properties and effects of such a string. They review the exact solutions to Einstein's equations which model the string and the universe outside it. They then describe how a straight string's flat but conical exterior spacetime produces gravitational effects. They discuss the bending of geodesics, Doppler shifts, and wakes, and their possible observable effects: lines of quasars or galaxies, sharp edges to galaxies, and anisotropy in the cosmic microwave background. Finally, they predict a quantum effect due to the conical topology; that is, they predict the production of Casimir-like vacuum fluctuations.

12. Geometry-Induced Inflation, B. L. Hu, Department of Physics and Astronomy, University of Maryland, College Park, Maryland 20742, D. J. O'Connor, Center for Relativity, Department of Physics, University of Texas, Austin, Texas 78712.

Abstract - The authors show how quantum geometric effects near the Planck time can provide natural inflation in a general class of cosmological spacetimes.

13. Discrete gravity Without Coordinates, Alexander N. Jourjine, Physics Department, University of Wisconsin, Madison, Wisconsin 53706.

Abstract - Using the language of the cell complex cohomology the author formulates discrete Einstein gravity in a geometrically natural and invariant way.

14. Central Engine or Locomotive? R. C. Kapoor, Indian Institute of Astrophysics, Bangalore 560034.

Abstract - The astrophysical aspects of proposals of escape of supermassive black holes from galactic nuclei and their implications in relation to quasars are discussed. It is concluded that high velocity recoil of the central engine can at best be considered an exception rather than a rule since it requires a violent release of mass energy in an asymmetrical manner, spectacular in nature. However, scope for the concept of low velocity motion in the inner regions of the host galaxy exists in view of some recent observations.

15. Black Holes Without Singularities, Richard P. A. C. Newman, Department of Mathematics, University of York, Heslington, York YO1 5DD, England.

Abstract - The conventional interpretation of the Hawking-Penrose singularity theorems is that the gravitational collapse of an isolated system leads, in general circumstances, to the formation of a singularity. Consideration is given to an alternative interpretation according to which collapse scenarios may give rise, not to singularities, but to closed timelike curves. Certain exact solutions give support to this view. The principal properties of non-spacelike geodesically complete space-times are established. it is shown that the formation of closed trapped surfaces, whether achronal or not, implies the presence of closed timelike curves. All closed trapped surfaces and closed timelike curves are shown to lie entirely within the black holes. Indeed, weak cosmic censorship holds in the sense that the region visible from infinity is globally hyperbolic.

16. The Spin Axes of the Sun and Fast Pulsars: Implications for the Lorentz Invariance of Gravity, Ken Nordtvedt, Montana State University, Bozeman, MT 59715.

Abstract - Gravitational equations of motion which violate Lorentz invariance predict that spinning celestial bodies moving in a preferred inertial frame will precess about their velocity vector relative to the preferred frame. By noting that the Sun's spin axis is today, after 5 billion years, still close to the Solar System's polar axis, and that the pulses from several fast pulsars have been seen without interruption over a period of several years, it can be concluded that the gravitational interaction is Lorentz invariant to high accuracy. A parameter α_2 which quantifies the degree of Lorentz invariance violation in post-newtonian gravity, can be empirically constrained to be less than 10^{-6} -- a three order of magnitude improvement over the previous observational constraints on the gravitational interaction.

17. A Scheme to Unify Gravity With Electro-Weak Interactions, M. Novello, Centro Basileiro de Pesquisas Fisicas, Rio de Janeiro - Brasil and H. Heintzmann, Koln University, Koln - FRG.

Abstract - Starting from Jordan's formulation of Einstein's equations the authors show how a generalization of the Lanczos potential leads to a unification of gravity and electroweak interactions. In the case of a SU(2) X U(1) symmetry a la Salam-Weinberg they find three extra massive tensor bosons of masses 365 and 520, 3 GeV.

18. Uncertainty Principle and the Horizon Size of our Universe, T. Padmanabhan and T. R.Seshadri, Tata Institute of Fundamental Research, Homi Bhabha Road, Bombay 400 005,India.

Abstract - Quantum uncertainties prevent simultaneous measurement of the expansion factor S(t) and its time derivative $\dot{S}(t)$. Consequently the 'Hubble size' $(\dot{S}/S)^{-1}$ has an inherent uncertainty in the quantum state that describes the semiclassical evolution of the universe. The authors show that the quantum uncertainty in the Hubble size of the universe is amplified to unacceptably large values in any inflationary process.

19. Can Gravitational Attraction be Compensated by Gravimagnetic Effects? H. Pfister and Ch. Schedel, Institut fur Theoretische Physik der Universitat, D-7400 Tubingen, Federal Republic of Germany.

Abstract - Two spherical mass shells (radius R, distance d), relativistically corotating with angular velocity ω, are held in stationary state by a Weyl strut. In first order of the rest mass density ρ, the global solution of Einstein's equations is given. In order ρ^2, the conservation laws $T^{\mu}{}_{\eta;\mu} = 0$ produce singularities of the surface stresses at the 'poles' of the shells, where the Weyl strut impinges. Their strength is a measure for the force F between the shells. For $d \geq 2R$, the attraction between rotating shells is even stronger than for static shells. For $d < 2R$ (overlapping shells), gravimagnetic repulsion can partly compensate the attraction: For $d \to 0$, and $v = \omega R \to 1$, $F(v)/F(0)$ reaches the value 1/3 for constant mass density ρ, and the value 1/10 for quadrupolar density distribution.

20. Trigonometric Parallaxes in Cosmology, Kjell Rosquist, Institute of Theoretical Physics, University of Stockholm, Vanadisvagen 9, S-113 46 Stockholm, Sweden.

Abstract - The role of trigonometric parallaxes in cosmology is discussed. Two differential relations relating the trigonometric parallax distance to other astronomical distances are given. It is shown that measurements of trigonometric parallaxes give important information about the space-time geometry which makes it possible to determine the energy density of the universe even if no dynamical model for the universe is assumed. Such measurements could also in principle serve as a check on the validity of the Einstein equations over cosmological distances. On this basis it is argued that measurements of trigonometric parallaxes of objects at cosmological distances offer an opportunity to put cosmology on a more solid observational foundation.

21. Testable Experimental Consequence of an Intermediate-Range Deviation From Newton's Law of Gravity, M. P. Silverman, Department of Physics, Trinity College, Hartford, Ct. 06106 USA.

Abstract - A recent reanalysis of the original Eotvos experiment suggests the existence of a repulsive intermediate-range deviation from newtonian gravity with coupling strength on the order of $\sim 7.2 \times 10^{-3}$ and a range on the order of 200 m. If such a force exists, it would induce a test mass in the interior of a laboratory-scale spherical mass shell in Earth orbit to undergo linear harmonic oscillation about the shell center. If the non-newtonian force couples to baryon number, two such test masses of different composition would oscillate at different frequencies. The fractional change in oscillation frequency is more than one million times the fractional change in acceleration incurred by the same test masses in an Eotvos experiment at the Earth's surface.

22. Is There a Connection Between Nonmetricity and the Large Numbers Hypothesis, Larry L. Smalley, ES65/Space Sciences Laboratory, Marshall Space Flight Center, AL 35812 and Department of Physics, The University of Alabama in Huntsville, Huntsville, AL 35899.

Abstract - In a scalar-tensor-nonmetric theory of gravity, the Weyl vector is obtained from the gradient of a scalar potential. The autotransport of the angular momentum vector of a satellite along the four-velocity of the central body is simply related to the Weyl vector (in a flat background metric). Using an ansatz for the potential, the residual secular acceleration of the moon can be used to predict the linear decrease in the semi-major axis of the earth satellite LAGEOS. The same model applied to the inner planets predicts effects at least two orders of magnitude smaller than present experimental limits. The model also predicts an independent coupling constant which can be combined with Planck's constant, the gravitational constant and the speed of light to form the purely dimensionaless number, 10^{84}. Considering that this number and the scale of the derived natural units are close to the large numbers described by the justaposition of cosmological and quantum theoretical contemplations of Dirac, it is suggested that the new constant is a universal constant.

23. Space-Time Dimensions, H. Terazawa, Institute for Nuclear Study, University of Tokyo, Midoricho, Tanashi, Tokyo 188, Japan.

Abstract - A few possible paradigms which may determine the number of space-time dimensions are presented and discussed.

24. Unstable Neutrinos Can Do It!, M. M. Vasanthi, Tata Institute of Fundamental Research, Homi Bhabha Road, Bombay 400 005, India.

Abstract - The author presents a cosmological scenario with unstable neutrinos which decays into a light neutrino and a relativistic boson. Theoretical and observational constraints severely narrow down the values of mass and lifetime of neutrinos. However, within this range, he constructs a model with (i) $\Omega = 1$, (ii) age of the universe $\geq$ 13 billion years and (iii) $h_o \simeq 0.5$. The dynamical modelling shows that (a) the initial condensates of primordial ν_L are disrupted by the decay, lowering their masses to acceptable values ~ 10^{12} $M_\odot$, (b) the relativistic boson contributes nearly 0.25 to Ω and (c) there emerges two prominent scales in dark matter distribution: one with a mass ~ $10^{12} M_\odot$ distributed over ~200 kpc around galaxies and another component with density ~10^{-27} gm cm^{-3} distributed over ~ 1 Mpc. The model agrees with observations at all scales.

25. The Quadrupole Formula, Jeffrey Winicour, Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, PA 15260, USA and Max-Planck-Institut fur Physik und Astrophysik, Institut fur Astrophysik, 8046 Garching bei Munchen, FRG.

Abstract - A simple statement and derivation of the quadrupole radiation formula for self-gravitating systems is presented. The primary physical ingredient is the existence of a Newtonian limit for general relativity based upon a family of outgoing null cones, supplemented by a weak asymptotic flatness condition. This eliminates extraneous incoming gravitational waves which would otherwise obscure the physical meaning of the quadrupole formula.

26. Is the Big Bang Hot?, Wu Zhong Chao, Department of Physics, Syracuse University, Syracuse, new York 13210 and Center for Astrophysics, China University of Science and Technology, Hefei, Anhui, China (Permanent Address).

Abstract - The assumption that the Big Bang is hot, which has played a most important role in both the Big Bang model and the inflationary Universe becomes redundant in quantum cosmology. The quantum state of the Universe is described by the Hartle-Hawking ground state, which is defined by a path integral over all compact 4-metrics. This ground state proposal gives the lowest temperature for the Universe one could have. The hot origin of the Universe comes from the decay of the oscillation of the massive scalar field in the Hawking model. The temperature associated with the fluctuation in this model is computed as a toy calculation.