Gravity Research Foundation

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Abstracts of Award Winning and
Honorable Mention Essays for 1984

Award Winning Essays

First Award - Dark Matter and Inflation by Lawrence M. Krauss, Lyman Laboratory of Physics, Harvard University, Cambridge, MA 02138.

Abstract - The author demonstrates that dark matter consisting of any type or types of stable weakly interacting elementary particle is incompatible with the minimal predictions of inflation, based on present observation of galaxy clustering, and assuming galaxies are good tracers of mass in the universe. If we wish to resolve this problem by particle physics alone, we seem to be driven to the possibility that the initial dark matter was unstable.

Second Award - Gravity and Grand Unified Theories by Leonard Parker and David J. Toms, Department of Physics, University of Wisconsin-Milwaukee, Milwaukee, WI 53201.

Abstract - The authors have carried out a renormalization group analysis of the gravitationally significant coupling constants in SU(5) grand unified theories in curved spacetime. They find that the effective values of many of these coupling constants at high curvature are determined by quantum effects depending on the numbers and types of elementary particle fields present. The resulting high curvature behavior of the theory evidently has interesting properties under conformal transformations of the spacetime metric.

Third Award - A New Class of Ideal Clocks by Clifford M. Will, McDonnell Center for the Space Sciences, Department of Physics, Washington University, St. Louis, MO 63130.

Abstract - The author has found a new class of ideal clocks within general relativity. They are self-gravitating systems such as rotating stars, rotating black holes and binary star systems. The gravitational redshift of the observed period of rotation of such clocks in a given, weak external gravitational field is shown to be the same as that of an ideal atomic clock. Because the clocks have structure and dynamics determined by gravitational interactions, the full non-linear machinery of general relativity must be used. This result is important for the binary pulsar PSR 1913+16, where the gravitational redshift of the pulsar's frequency caused by the companion's gravitational field is an observable effect.

Fourth Award - The Principle of Equivalence at Finite Temperature by John F. Donoghue, Barry R. Holstein and R. W. Robinett, Department of Physics and Astronomy, University of Massachusetts, Amherst, MA 01003.

Abstract - The authors demonstrate that the equivalence principle is violated by radiative corrections to the gravitational and inertial masses at finite temperature. They argue that this result can be attributed to the Lorentz noninvariance of the finite temperature vacuum.

Fifth Award - Planck Length is the Lower Bound to All Physical Length Scales by T. Padmanabhan, Astrophysics Group, Tata Institute of Fundamental Research, Homi Bhabha Road, Bombay 400 005, India.

Abstract - The effect of quantum fluctuations of gravity on the measurement of proper distances is considered. It is shown that, when the length scales are of the order of Planck length, the concept of a unique distance between points ceases to exist. It is also shown that the quantum expectation value of the proper length is bounded from below by Planck length in any spacetime.

Honorable Mention Essays (Alphabetical Order)

1. Superconducting Gravimeters by Jeeva Anandan, Max-Planck-Institute für Physik und Astrophysik, -Werner-Heisenberg-Institute für Physik-, D-8000 Munich 40, Fed. Rep. of Germany.

Abstract - The general principles needed to compute the effect of a stationary gravitational field on a superconducting system, which exhibits macroscopic quantum phenomena, are formulated from a general relativistic point of view. These principles are then applied to four specific superconducting devices which can, in principle, measure the gravitational field. Each effect obtained results from the interaction of a quantum mechanical wave-function, spread out over the entire superconductor, with the gravitational field that is treated relativistically.

2. Is the S - Matrix Scheme Adequate For Interacting Quantum Field Theory In Curved Spacetime? by Jürgen Audretsch and Peter Spangehl, Fakultät für Physik, Universitat Konstanz, Postfach 5560, D-7750 Konstanz, W.-Germany.

Abstract - First the authors show that there is a well defined and feasible S-matrix scheme for interacting quantum field theory in Robertson-Walker universes, if one restricts to added up transition probabilities. Based on this they treat rigorously for the interaction $\lambda\phi^2\Psi^2$ the first order process of pair annihilation and show, that for arbitrarily large curvature the total cross section agrees exactly with the one in Minkowski space. Finally they give reasons for the conclusion that this result must be taken as an indication of the fact, that the physical situation (i.e. an expanding universe influences cross sections, decay rates, etc.) cannot be adequately described by an S-matrix scheme.

3. The General Solution of Einstein's Equations Far From A Singularity by John D. Barrow and David H. Sonoda, Astronomy Centre, University of Sussex, Brighton BN1 9QH U.K.

Abstract - The authors investigate the general behaviour of spatially homogeneous cosmological models at large times. Using existing techniques from stability theory they discover that some known exact solutions are asymptotically stable despite possessing special properties. Some consequences of these results are then discussed.

4. Is Gravitation a Yang-Mills-Like Gauge Phenomenon? Experimental Tests of Poincare Gauge Theory With Propagating Torsion Using Vorticity in Superfluid ^{4}He by R. Y. Chiao, Department of Physics, University of California, Berkeley, CA 94720.

Abstract - Currently, there are two views of gravitation given by (A) standard general relativity and (B) Yang-Mills-like gauge theory. Superfluid helium should be an ideal place to test these views experimentally, because vorticity in this superfluid should be linked with (A) the Lense-Thirring field or (B) the rotation field strength associated with propagating torsion of a Yang-Mills-like Poincare gauge theory, respectively, in these two views. Three experimental tests of the Poincare gauge theory are proposed to see (1) a Meissner effect (2) flux trapping between two tori of curculating superfluid, and (3) the force between these tori. A preliminary result of experiment (2) is presented, which improves a previous upper limit of Hayashi and Shirafuji by five orders of magnitude.

5. General Relativistic Effects of Rotation on the Structure and Surface Emission of Fast Pulsars by B. Datta, R. C. Kapoor and A. Ray, Tata Institute of Fundamental Research, Bombay 400005, India.

Abstract - The general relativistic effects of rotation on the structure and surface emission of the fast pulsar PSR 1937+214 are illustrated using a rotationally perturbed interior spherical metric. The results are found to differ markedly from those derived on the basis of simple spherical models and are expected to be generally valid for the class of fast pulsars.

6. Isotropy Groups as Universal Symmetry Groups in General Relativity by Arthur E. Fischer, Department of Mathematics, University of California, Santa Cruz, California 95064.

Abstract - A unified approach to symmetry groups in physical theories is discussed. The unifying concept is that of the isotropy subgroups of a group acting on a set. The set itself is a species of structures $\Sigma(S)$ of various types on a carrier set S. There is a natural action of the group of bijections of S, Aut(S) on $\Sigma(S)$. When the species of structures is taken to be the space of physical systems on a state space, there is a natural notion both for the symmetry group of a physical system, and for the solutions of that system. The main idea is that symmetry groups in all of their manifestations can be described as the isotropy subgroups of a group acting on a species of structures. This one concept seems to be the proper abstraction needed to describe the essential features of the various roles played by symmetries in physical theories. This concept is also universal in the sense that the axioms for the system are left unspecified, and so the ideal presented here apply to arbitrary physical systems. Several examples are given.

7. Universes With Unpredictable Death: Probabilistic Programming of the Gravitational Collapse by J. Koiller, Instituto de Matematica, Universidade Federal do Rio de Janeiro, Caixa Postal 68530 - CEP 21944, Rio de Janeiro; J.R.T. de Mello Neto and I. Damião Soares, Centro Brasileiro de Pesquisas Fisicas/CNPq, Rua Dr. Xavier Sigaud, 150 - Urca CEP 22290 - Rio de Janeiro.

Abstract - The authors consider exact perturbations (governed by Einstein equations) of a class of Bianchi IX cosmological models and prove that they can program such perturbations so that for any given positive integer N (N = ∞ included) the universe undergoes N nonperiodic oscillations before collapsing. For N = ∞ the universe undergoes periodic oscillations.

8. Equivalent Lagrangians and the Quantization of Gravity by D. A. Konkowski, Department of Physics and Astronomy, University of Maryland, College Park, Maryland 20742.

Abstract - Archival theories (e.g. Newtonian mechanics and Maxwellian electrodynamics) and model theories (e.g. two-dimensional field theories and harmonic maps) which admit more than one variational formulation are described. The non-uniqueness in their variational description leads to ambiguities in their quantization and predictions of different quantum behavior. A non-linear σ-model and an N-dimensional free particle are considered in detail. The difficulty encountered in choosing the correct variational description a priori appears to be a precursor to certain ambiguities in the path integral approach to gravitation.

9. Strong Cosmic Censorship and the Strong Curvature Singularities by A. Królak, Institute of Physics, Polish Academy of Sciences, Aleja Lotników 32/46, 02-668 Warsaw, Poland.

Abstract - It is shown that a general weakly asymptotically simple and empty spacetime which has a partial Cauchy surface with an asymptotically simple past must be globally hyperbolic. This result implies that the Cauchy horizon in the Reissner-Nordstrom and Kerr spacetimes is unstable.

10. On Using the Solar System to Detect Gravitational Radiation by Bahram Mashhoon, Institut für Theoretische Physik, Universität zu Köln, D-5000 Cologne 41, Federal Republic of Germany.

Abstract - Cosmological gravitational waves may permeate the universe with an energy density comparable to the critical density for spatial closure. The existence of these waves may have important consequences for the dynamics and evolution of the solar system, and the advent of space exploration has opened the possibility of detection of this radiation by using the solar system. The influence of the background radiation on the solar system is studied. The osculating elements of the planetary orbits undergo random walks as a result of interaction with the stochastic background. The external waves also excite the pulsation, toroidal and precession modes of rotation fluid masses such as the Sun and the Earth's outer core. The rotation axis of the Earth is expected to execute a complex precessional motion with respect to surface features due to resonant interaction with the incident radiation. The results of recent Earth-Mars range measurements and polar motion data are used to set upper limits on the energy density of continuous gravitational radiation incident on the solar system. These results are of fundamental importance for the theory of gravitation and for cosmology.

11. The Unit Gravitational Charge $(hc/4)^{\frac{1}{2}}$ (The Uniton) Solves the Cosmological Problem Without Inflation by Lloyd Motz, Rutherfurd Observatory, Columbia University, New York, N.Y.

Abstract - The most serious and difficult problem that has confronted cosmologists since Einstein's pioneering work and Friedmann's time-dependent formulation of the cosmological equations has been the circumvention of the initial cosmological singularity. But there is no way of doing this if the universe was radiation dominated throughout its early history as demanded by the standard model, for, then, the pressure in Einstein's equations was always positive and a singularity at t = 0 was inevitable because $\ddot{R}$ (dot ≡ time derivative) was then always negative. One cannot avoid this conclusion as long as one assumes that there was no large change in the rest mass M of the universe in the past. Dropping this unwarranted assumption the author shows in this paper that if $\dot{M}$ was large at some time in the past, then a solution of Einstein's equations exists with $\dot{R} = 0$ and $R \neq 0$ at $t = 0$. This eliminates the initial singularity and also solves the "horizon" and "flatness" problems. But $\dot{M}$ large means a phase change in the past from massive particles (unitons) to non-massive ones (baryons). To eliminate the initial singularity we must therefore accept the existence of unitons.

12. A Constraint on Physical Quantum States In Cosmological Spacetimes by A. H. Najmi, University of Utah, Department of Physics, Salt Lake City Utah 84112 and A.C. Ottewill, University of Chicago, Enrico Fermi Institute, 5640 S. Ellis Avenue, Chicago, Illinois 60637.

Abstract - The problem of constructing the Hilbert space of physical states for a free scalar quantum field propagating on a cosmological background is considered. The concept of energy-momentum for such a field is discussed and it is noted that, according to current renormalization theory, for a state $|M\rangle$ to have finite energy density its associated anticommutator function $\langle M|\hat{\phi}(x)\hat{\phi}(x')+\hat{\phi}(x')\hat{\phi}(x)|M\rangle$ must be of a particular form first discussed by Hadamard. This restriction is shown to lead to a constraint on the construction of the Hilbert space of physical states. This constraint is used to reject a recently proposed scheme for the construction of this space which was based on a principle of energy minimization.

13. Post-Newtonian Approximation for a Rotating Frame of Reference by Robert A. Nelson, Department of Physics and Astronomy, University of Maryland, College Park, Maryland 20742.

Abstract - The field equations of general relativity are solved to Post-Newtonian order for a rotating frame of reference. A new method of approximation is used based on a 3 + 1 decomposition of the equations. The results are expressed explicitly in terms of the gravitational potentials. The spacetime is asymptotically flat but not locally flat. The spacetime metric contains gravitational terms, inertial terms, and coupled gravitational-inertial terms. The inertial terms in the equation of motion are in agreement with terms obtained by other authors using kinematic methods. The metric and equation of motion reduce to those for an inertial frame of reference under a simple coordinate transformation. The total energy of a particle is given. For the restricted three-body problem this represents the relativistic extension of Jacobi's integral to Post-Newtonian order.

14. Positive Energy Via A Teleparallel Hamiltonian by James M. Nester, Theoretical Physics Institute, University of Alberta, Edmonton, Alberta, Canada T6G 2J1.

Abstract - The author describes the Hamiltonian formulation for teleparallel theories. For these theories the energy-momentum flux integrand at spatial infinity is quite naturally fully 4-covariant, while the Hamiltonian is mostly quadratic. These features permit a new, strictly tensorial, proof of the positivity of energy for Einstein gravity from its teleparallel formulation. The Schwarzschild solution is used to provide insight into the proof and its various allowed positive "localizations" of gravitational energy.

15. On the Way to A Large Unification Theory by M. Novello and L.M.C.S. Rodrigues, Centro Brasileiro de Pesquisas Fisicas, Rua Dr. Xavier Siguad, 150 - Urca, 22290, Rio de Janeiro - RJ - BRASIL.

Abstract - Is there a short-range gravity? The validity of the Salam-Weinberg theory and the existence of a tensorial field $A_{\mu\nu\lambda}$ - hidden in the conformal structure of any Riemannian spacetime - whose interaction provides an alternative way of restoring broken symmetries, allow an affirmative answer to this question. Using the same Higgs mechanism which yields a mass for the Salam-Weinberg vector field, the authors are able to predict a mass of 1.33 TeV/C^2 for the boson which mediates gravity-like forces - a value which permits this model to be experimentally probed.

16. On the Perihelion Precession of Mercury by N.C. Rana, Department of Physics, University of Durham, South Road, Durham DH1 3LE, U.K.

Abstract - The rate of advance of the perihelion of the planet Mercury has been calculated by a numerical integration method applied to an N-body system interacting via Newtonian gravitation only. It is found that the rate fluctuates but has a steady linear trend of about 528.93±0.01 arc sec cy^{-1} over a long term period of about five centuries. Taking into account the observed rate of precession we, therefore, find that the general relativistic

correction explains all but about 2.20 ± 0.55 arc sec cy^{-1} of the discrepancy. It may be necessary to invoke another cause like solar oblateness and/or to reanalyse the data on the motion of Mercury in order to account for the present discrepancy.

17. Singularities and the Hausdorff Condition by W. Rudnicki, Institute of Physics, Pedagogical University, Rejtana 16A, 35-311 Rzeszow, Poland.

Abstract - It is shown that violation of Hausdorff condition in strong gravitational fields cannot prevent formation of spacetime singularities. This result supports the view that singularities are durable features of our Universe.

18. Thermal Gravitational Radiation From Stellar Objects and its Possible Detection, by C. Sivaram, Indian Institute of Astrophysics, Bangalore 560 034.

Abstract - There has been a lot of current interest in attempting to detect or indirectly infer the presence of gravitational radiation especially from compact objects like pulsars. However, applications of general relativity would also expect us to explore the possibility of compact stellar objects generating high frequency (10^{16} - 10^{21} Hz) thermal gravitational radiation which in the case of very young neutron stars could be rather high. Also main sequence stars can generate such radiation from plasma Coulomb collisions. Moreover models of the earliest planck phase of the universe would predict a thermal gravitational wave background whose detection (at frequencies $\sim 10^{11}$Hz) would enable us to make a choice between both various cosmological models and particle physics models that attempt to unify fundamental interactions.

19. Failure of the Superposition Principle in the Presence of Gravitational Fields by Lee Smolin, Enrico Fermi Institute, The University of Chicago, Chicago, Illinois 60615.

Abstract - Nelson's stochastic formulation of quantum mechanics is extended to the case of a free particle propagating in the presence of a gravitational field. We find that, even in the case of weak fields, when gradients of the gravitational potential cannot be neglected the equations for the evolution of the probability distribution are nonlinear and cannot be reduced to a single complex equation in a complex square-root of the probability density. However, conservation of probability is maintained. This is in contrast with the usual formulation of quantum theory in a background gravitational field in which the linearity of the evolution equations is guaranteed but there are difficulties implementing the probability interpretation in an invariant manner. Unfortunately, the predicted violations from linear evolution are too small to be detected by present day experiments.

20. The Physics of Detecting Torsion and Placing Limits on its Effects by William R. Stoeger, Vatican Observatory, I-00120 Citta del Vaticano, Europe.

Abstract - The author presents the essential principles of torsion-detection physics and evaluates several conceivable types of experiments and observations for actually detecting torsion fields, re-emphasizing also the evident impossibility of successfully searching for its manifestation among cosmological relics. In particular, a polarized body, with net intrinsic (fundamental-particle) spin, is essential for detecting a torsion field. One which possesses only orbital angular momentum -- rotation -- or an unpolarized intrinsic spin density will not feel torsion. The fundamental problem in searching for such fields is the extremely small basic unit of the coupling or interaction energy between the torsion field and spin, $\varepsilon \cong 8\pi G' h^2/4C^4$. The best way of maximizing the total interaction energy is to increase the spin density of the source σ_s and, at the same time, the "spin number" S_D of the detector.

21. On the Quantum and Statistical Mechanics of Black Holes by James W. York, Jr., Department of Physics and Astronomy, University of North Carolina, Chapel Hill, N.C. 27514.

Abstract - In the quantum theory of black holes, the intrinsic dynamical degrees of freedom of the background spacetime are treated using canonical variables on null surfaces and a semi-classical form of the uncertainty principle. Quantum gravitational metric zero-point fluctuations tidally disrupt the classical structure of the event horizon and cause a quantum ergoregion of vacuum polarization to form and, therefore, to allow spontaneous decay, showing why a hole cannot achieve equilibrium in empty space. This description is complementary to the usual one in which the event horizon is quantum-mechanically inert. A statistical formulation of black-hole entropy is obtained. Direct calculations show that physical metric fluctuations are of order unity when the hole has mass approximately equal to $M_{Planck}/8\pi$.