GRAVITY RESEARCH FOUNDATION
PO BOX 81389
WELLESLEY HILLS MA 02181-0004
USA

Abstracts of Award Winning and Honorable Mention Essays for 1991

Award Essays

First Award - The Tilted Universe - by Michael S. Turner, NASA/Fermilab Astrophysics Center, Fermi National Accelerator Laboratory, Batavia, IL 60510-0500 and Departments of Physics and Astronomy & Astrophysics, Enrico Fermi Institute, The University of Chicago, Chicago, IL 60637-1433

Abstract - The simplest interpretation of the Cosmic Microwave Background Radiation (CMBR) dipole anisotropy is that it arises due to our motion with respect to the cosmic rest frame. However, the existence of a superhorizon-sized isocurvature perturbation can give rise to a dipole anisotropy intrinsic to the CMBR. In this case the cosmic rest frame and the CMBR rest frame do not coincide, and when viewed from the CMBR rest frame the Universe appears "tilted": matter streams uniformly from one side of the Universe to the other. The intrinsic dipole model provides an explanation for the puzzling observation that most of the matter within a $100h^{-1}$ Mpc cube centered on our galaxy has a large velocity (of order 600 kms^{-1}) with respect to the CMBR.

Second Award - Quantum Hair and Quantum Gravity - by Sidney Coleman*, Lawrence M. Krauss#, John Preskill^ and Frank Wilczek+, *Lyman Laboratory of Physics, Harvard University, Cambridge, MA 02138, #Center for Theoretical Physics and Department of Astronomy, Yale University, New Haven, CT 06511, ^Lauritsen Laboratory of High Energy Physics, California Institute of Technology, Pasadena, CA 91125, +School of Natural Sciences, Institute for Advanced Study, Olden Lane, Princeton, NJ 08540

Abstract - The recent discovery that black holes may harbor a type of quantum hair, invisible classically, but measurable via quantum interference experiments, can have important dynamical effects which alter the process of black hole evaporation. A consideration of the effects of quantum hair on such processes as black hole evaporation and black hole scattering may lead to important new insights into such issues as: the origin of black hole entropy, the loss of quantum coherence, and the existence of topology changing processes---all of which must be addressed any theory of quantum gravity.

Third Award - Rotation in Cosmology - by Yu. N. Obukhov, Department of Theoretical Physics, Moscow State University, 117234 Moscow, USSR

Abstract - Cosmological models for a universe with expansion and rotation are considered. In particular, the author analyses some effects of the universal rotation on observational cosmology. He shows that pure cosmic rotation does not produce causality violations, parallax effects, or anisotropy of the microwave background radiation. The cosmic rotation may be detected by studying the angular dependence of standard cosmological tests and is directly measurable via polarization observations. The latter are used to obtain experimental estimates for the direction and value of the rotation of the universe.

Fourth Award - Strong Curvature Naked Singularities in Non-Self-Similar Gravitational Collapse - by P. S. Joshi and I. H. Dwivedi, Tata Institute of Fundamental Research, Homi Bhabha Road, Bombay 400 005, India

Abstract - It is shown that strong curvature naked singularities form in a non-self-similar gravitational collapse of radiation. The imploding radiation space-times with a general form of mass function are analyzed and the authors show that a strong curvature property holds along all families of non-spacelike geodesics terminating at the singularity in past. In view of the strength of the singularity and the non-self-similar nature of space-time, the authors believe this is a very serious counter-example which must be taken into account for any possible formulation of the cosmic censorship hypothesis.

Fifth Award - Vacuum Nonsingular Black Hole - by Irina Dymnikova, Polish Academy of Sciences, Nicolaus Copernicus Astronomical Center, Bartycka 18, 00-716 Warsaw, Poland

Abstract - The spherically symmetric vacuum stress-energy tensor with one assumption concerning its specific form generates the exact analytic solution of the Einstein equations which for large r coincides with the Schwarzschild solution and for small r behaves like the de Sitter solution. It describes a spherically symmetric black hole which is singularity free everywhere.

Honorable Mention Awards (Alphabetical Order)

1. Interference of Geometries in Quantum Gravity - by J. Anandan, Department of Physics and Astronomy, University of South Carolina, Columbia, SC 29208

Abstract - The intensity of the wave function of a quantum particle is shown to undergo a spatial oscillation due to the influence of the quantum superposition of space-time geometries in a simply connected region, even though each geometry is flat in this region. This new gravitational effect suggests the existence of a preferred quantum gauge in quantum gravity.

2. The Dual Higgs Mechanism and the Origin of Mass in the Universe - by A. Aurilia*, and E. Spallucci†, *Department of Physics, California State Polytechnic University, Pomona, CA 91768, †Dipartimento di Fisica Teorica, Università di Trieste, Italy and Istituto Nazionale di Fisica Nucleare, Sezione di Trieste, Italy

Abstract - The idea that a background of invisible material pervades the whole universe is as old as the history of natural philosophy. Modern particle physics and cosmology support that idea and identify in the cosmic vacuum the ultimate source of matter-energy, both seen and unseen, in the universe. In the framework of the inflation-axion scenario, the authors suggest an unusual realization of the Higgs mechanism which converts the latent energy of the vacuum into observable mass. The existence of a new spontaneously broken symmetry is pointed out which has the same effect of the Peccei-Quinn symmetry in creating axions as pseudo-Goldstone bosons. However, such particles are eliminated from the physical spectrum in favor of massive pseudoscalar particles.

3. Is the Universe Improbable? - by John D. Barrow, Astronomy Centre, University of Sussex, Brighton BN1 9QH, UK

Abstract - The author discusses arguments which compare the Bekenstein-Hawking entropy of the mass of the visible universe today with the observed entropy of the microwave background in order to evaluate the likelihood of the observed universe having arisen from arbitrary initial conditions. He discovers that they lead to paradoxical conclusions which undermine the credibility of any evaluation of the likelihood of the observed universe from such simple considerations.

4. Is Absolute Zero Really Zero? - by Selçuk Ş. Bayin, Department of Physics, Middle East Technical University, Ankara, Turkey

Abstract - It is expected that the next generation of theories in physics will come from a synthesis of quantum mechanics, relativity, and thermodynamics. Such a theory still doesn't appear in sight. However, using the approximate methods of quantum field theory on curved background spacetime and some suggestive models suggests some important changes that may be induced on the third law of thermodynamics and cosmology.

5. The Tale of Time, Wormholes and Prickly Spacetime - by Stephen P. Braham, Institute for Theoretical Physics, Sidlerstrasse 5, CH-3012 Bern, Switzerland

Abstract - The author describes recent calculations in a complicated quantum cosmological model. The model has reached a state of development in which it has a very rich structure. The model supports complicated topology and shows an arrow of time, a greatly improved interpretational structure and a convergent, parameterized, Euclidean, path integral. It also strongly suggests generalizing the Hartle-Hawking prescription to include spacetimes which are not completely smooth.

6. Topology, Cosmology, and Principles of Equivalence - Sean M. Carroll and George B. Field, Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, MA 02138

Abstract - Schiff has conjectured that any consistent theory which obeys the Weak Equivalence Principle will necessarily obey the Einstein Equivalence Principle. Although there is a known counterexample to Schiff's conjecture, it has been demonstrated to hold for a wide class of theories. The authors examine the theoretical and experimental implications of the counterexample discovered by Ni. It is of great theoretical interest, in that it involves a topological interaction between electromagnetism and gravity similar to those being studied in particle physics. Observationally, Ni's counterexample is tightly constrained by observations of polarized radiation from distant galaxies. The authors also comment on the implications of Schiff's conjecture and articulate the connection between non-metric theories of gravity and the exotic particles which cosmologists believe dominate the Universe.

7. Nonlinear Clumping in the Early Universe - by John Bruce Davies, CIRES, University of Colorado, Boulder, CO 80309

Abstract - Mounting evidence indicates that, at large scales, much of the luminous matter in the Universe is clumped closely together in galactic superclusters with large low-density voids between the clusters. Such matter distributions are fossil relics from the early Universe. By examining a fluid dynamic Universe just after the separation of matter from radiation, it is shown that the governing non-linear equations have solutions that produce clumped distributions of matter. In the limit of zero flow velocities, the system of equations reduces to a single non-linear Klein-Gordon wave equation for the gravitational potential. Known analytical solutions of these equations yield clumped distributions of matter. The full set of nonlinear equations are numerically solved for an arbitrary region of the Universe with initial conditions being those at the time of separation. Clumping of matter separated by low-density voids is obtained through self-organization of the initial flow perturbations. Predicted void size is of the correct order as expected from scaling arguments on large scale galactic structures. Computed flow velocities correlate with the galactic streaming motions observed in clusters.

8. Particle Production From Signature Change - by Tevian Dray*, Corinne A. Manogue^ and Robin W. Tucker+, *^Mathematical Sciences Research Institute, 1000 Centennial Drive, Berkeley, CA 94720, *Department of Mathematics; Oregon State University, Corvallis, OR 97331, ^Department of Physics, Oregon State University, Corvallis, OR 97331, +Department of Physics, University of Lancaster, Bailrigg, Lancs. LA1 4YB, UK

Abstract - Surfaces with nontrivial topology play an increasing role in quantum gravity. While most work has focused on Euclidean surfaces, the ultimate theory must describe a Lorentzian spacetime. However, "Lorentzian" surfaces with nontrivial topology may have regions where the metric is degenerate. The propagation of fields on such surfaces needs to be examined. This essay considers the (massless) scalar field on manifolds whose metric changes signature. Choosing the wave equation so that there will be a conserved Klein-Gordon product determines the junction conditions one needs to obtain global solutions. The resulting mix of positive and negative frequencies depends only on the total width of the Euclidean regions and not on the detailed form of the metric.

9. Foiling the Cosmic Censor With Negative Energy Fluxes? - by L. H. Ford*, and Thomas A. Roman+, *Department of Physics and Astronomy, Tufts University, Medford, MA 01255, +Department of Physics and Earth Sciences, Central Connecticut State University, New Britain, CT 06050

Abstract - Quantum field theory allows violations of classical energy conditions, such as the weak energy condition, in the form of locally negative energy densities and fluxes. Conceivably, a negative energy flux directed at an extreme charged black hole could be manipulated to produce a naked singularity. However, it appears that quantum field theory places constraints on the magnitude and duration of such effects. These restrictions prevent an unambiguous observation of a naked singularity.

10. Dark Matter and the Equivalence Principle - by Joshua A. Frieman and Ben-Ami Gradwohl, NASA/Fermilab Astrophysics Center, Fermi National Accelerator Laboratory, P.O. Box 500, Batavia, IL 60510

Abstract - It is generally assumed that the dark matter in galaxies and clusters is subject only to gravitational forces. Yet, if the dark matter is non-baryonic, it can interact with additional long-range fields that are invisible to experimental tests of the equivalence principle. The authors discuss the astrophysical and cosmological implications of an additional long-range force of gravitational strength coupled only to the dark matter. If the interaction is repulsive, the masses of galaxy groups and clusters may have been systematically underestimated; it is possible that the universe is closed or flat ($\Omega \geq 1$) but has simply been misinterpreted as open. Such an interaction also gives rise to a new pseudo-tidal force between the baryonic core and the dark halo of a galaxy in a rich cluster. Implications for the growth of large-scale density perturbations are also studied.

11. Causal Horizons, Accelerations and Strings - by M. Gasperini, Dipartimento di Fisica Teorica dell'Università, Via P. Giuria 1, 10125 Torino, Italy, and Istituto Nazionale di Fisica Nucleare, Sezione di Torino

Abstract - All the points of a string are always causally connected provided their relative acceleration is smaller than the critical value $a_c = (m\alpha')^{-1}$, where m is the mass and $1/\alpha'$ the string tension. It is pointed out that this limiting acceleration characterizes the transition to an unstable regime in which an approximate description of the string motion around the classical path of a point particle is no longer consistent.

12. Is the Horizon Formation Under the Spherically Symmetric Gravitational Collapse Unavoidable? - by B. Gliner, Stanford Linear Accelerator Center, Stanford University, P.O. Box 4349, Stanford, CA 94305

Abstract - The influence of quantum evaporation on the course of gravitational collapse is considered in the semiclassical approximation. It is shown by direct evaluation that if the stress-energy tensor of Hawking's emission has the classical structure with positive energy density, then in the process of collapse of a homogeneous dust sphere the formation of an event horizon does not take place, and the collapsing sphere disintegrates completely before a singularity formation. This result can be probably expanded to the case of a non-classical structure of the stress-energy tensor with negative energy-density.

13. Entropy, Inflation and the Arrow of Time - by Dalia S. Goldwirth and Tsvi Piran, Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138

Abstract - There is a well known "large entropy" problem - the observed entropy of the universe is very large. Recently Penrose has pointed out that there is also a "small entropy" problem - the observed entropy of the universe is very small compared to its maximum theoretical limit. These problems are related to what is called the arrow of time: something that provides a direction to time and distinguishes the future from the past. The authors consider two different arrows or time: (1) the thermodynamic arrow of time, the direction in which entropy increases. (2) the cosmological arrow of time, the direction in which the Universe is expanding. The authors consider a model of the universe which has an inflationary period followed by the present expansion. They show that the entropy problems have a natural solution within the model and that the arrows of time also emerge.

14. Vacuum Stability and Finiteness in Euclidean Quantum Gravity - by J. Greensite, Physics and Astronomy Department, San Francisco State University, 1600 Holloway Avenue, San Francisco, CA 94132

Abstract - A stabilized, reflection positive, and diffeomorphism invariant action is introduced for Euclidean quantum gravity. The stabilized action, unlike the Euclidean Einstein-Hilbert action, is bounded from below, but still leads to the usual Einstein field equations in the classical limit. In lattice formulations of the stabilized theory, it is argued that the expectation value of any local scalar operator is finite and independent of the lattice spacing.

15. Wormholes and the Construction of Compactified Phases - by E. I. Guendelman, Department of Physics, Weizmann Institute of Science, Rehovot 76100, Israel

Abstract - In the context of Classical General Relativity, assuming the positive energy condition, the author studies the possibility of connecting a region where some dimensions are compact to another region where compactification does not exist. In some simple models, where compactification is achieved through the condensation of gauge fields, he finds that the matching of these two regions implies the existence of a wormhole. He also discusses the possibility of spontaneous quantum nucleation of a compactified phase in the midst of an uncompactified space.

16. The General Second Law of Thermodynamics and the Principle of Least Action - by Geoff Hayward, Department of Physics, University of British Columbia, Vancouver, B.C. V6T 2A6, Canada

Abstract - When the semi-classical approximation to the microcanonical partition function holds, it is possible to identify the entropy of an isolated system with the negative of its classical Euclidean action. This paper demonstrates that in this semi-classical approximation, the generalized second law of thermodynamics follows directly from the principle of least action.

17. A Deflationary Universe - by J. C. Jackson, Department of Applied Mathematics and Theoretical Physics, University of Cambridge, Silver Street, Cambridge, CB3 9EW, UK

Abstract - Recent attempts to reconcile the low density of the Universe with primordial inflation have led to a revival of interest in the de Sitter model, i.e. an almost empty spatially flat universe with a positive cosmological constant. This has additional attractive features, in connection particularly with the age and volume of the Universe. Here the author shows that these features are shared by a large class of open non-flat vacuum-dominated models, many of which have a negative cosmological constant and are decelerating, and do not need any dramatic evolutionary effects to make them compatible with the classical tests of observational cosmology. This vacuum-energy may have observable effects on low-density clusters of galaxies and is not necessarily incompatible with inflation in the past.

18. Stability of Neutron and Boson Stars: A New Approach Based on Catastrophe Theory - by Fjodor V. Kusmartsev, Eckehard W. Mielke, and Franz E. Schunck, Institute for Theoretical Physics, University of Cologne, D-5000 Köln 41, Federal Republic of Germany

Abstract - In the framework of general relativity, the authors investigate the stability of stars by classifying the singularities of smooth mappings. These maps arise from the functional dependence of the mass *M* and the particle number *N* of the star on its dynamical variables. The new approach of the authors avoids the mathematical limitations of perturbation theory. In fact, it is capable of providing more information than perturbation theory and predicts novel oscillation and collapse regimes for a certain range of *N*. Moreover, the stability criteria described by the authors are rather universal and apply to neutron stars as well as to the boson stars.

19. Astrophysical Jets and Theories of Gravitation - by Mario Livio and Nathan Rosen, Department of Physics, Technion, Haifa 32000, Israel

Abstract - The authors point out that a recently discovered hydrodynamical jet formation mechanism described by Fryxell, Taam, and McMillan and by Matsuda, Sekino, Shima, and Sawada provides a tool that is capable of distinguishing between general relativity and bimetric general relativity. It is the first time that such a large scale phenomenon as the mere presence or absence of relativistic jets can distinguish between theories of gravitation. The present observational situation seems to favor general relativity over bimetric general relativity.

20. The Unbounded Action in Nonperturbative Quantum Gravity - by Eric Myers, Center for Relativity, Department of Physics, University of Texas, Austin, TX 78712

Abstract - This paper considers one of the problems that must be overcome before a nonperturbative theory of quantum gravity can be formulated - the unboundedness of the Euclidean action. The author presents a brief outline of the "density of states reconstruction" method of analyzing data from Monte Carlo simulations and then proposes a way to use this method to overcome the unboundedness problem.

21. Quantum Einstein Gravity Without C-Number Background Metric - by Noboru Nakanishi, Research Institute for Mathematical Sciences, Kyoto University, Kyoto 606, Japan

Abstract - In quantum gravity, it is unreasonable to assume the existence of a spacetime manifold at the precision beyond the Planck scale. Hence, quantum gravity should be formulated and solved without introducing any c-number background metric from the outset. This essay discusses how this idea can be realized.

22. Gravity-Spin Coupling and Neutrino Helicity Oscillations - by G. Papini and Y. Q. Cai, Department of Physics, University of Regina, Regina, Saskatchewan, S4S 0A2, Canada

Abstract - The covariant Dirac and Maxwell-Proca equations are solved exactly to first order in the metric deviation $\gamma_{\mu\nu}$. The solutions yield general gravity-total angular momentum coupling terms and provide independent support for the existence of the rotation-spin effects for neutrons and photons predicted by Mashhoon. The spin part of the general effect for fermions also applies to gravitational fields of arbitrary strength. Under specific conditions, the coupling is capable of flipping the helicity of the particles. This has, for neutrinos, interesting astrophysical implications.

23. Torsion, Minimum Time, String Tension and its Physical Implications - by Venzo de Sabbata and C. Sivaram, Dipartimento di Fisica, Università di Ferrara, Italy and Indian Institute of Astrophysics, Bangalore, India

Abstract - The authors consider torsion in general relativity. They consider physically the effect of the spin and link the torsion to defects in the space-time topology. They show that this introduces a minimal unit of time. This allows the possibility of identifying the defects in space time topology induced by torsion with the behavior of a string. The minimal length, derived by treating the spin as an extra dimension, is related to the string tension. Physical implications are considered for field theory (the energy-integral converges without the need for a cut-off), particle decay, evaporation of black holes, and information theory.

24. Loitering Cosmological Models - by Varun Sahni*, Hume Feldman# and Albert Stebbins+, *Inter-University Centre for Astronomy and Astrophysics, Poona University Campus, Ganeshkhind, Pune 411907 India, #Canadian Institute for Theoretical Astrophysics, 60 St. George, University of Toronto, Ontario M5S 1A1, Canada, +Fermilab Astrophysics Center, Fermi National Accelerator Laboratory, Batavia, IL 60510-0500.

Abstract - In this essay the authors present a new class of solutions to the Einstein equations in which the Universe expands as a Friedman Robertson Walker Universe with an intermediate stationary stage during which the scale factor or its first derivative remains a constant. Such a Universe is considerably older than a standard matter dominated FRW Universe and can successfully account for the existence of an old population of objects such as globular clusters. In addition cosmological models of the kind discussed in this essay permit the formation of gravitationally bound systems such as galaxies and their clusters out of very small initial conditions without violating the severe constraints imposed by the isotropy of the cosmic microwave background radiation.

25. How to Wick Rotate Generic Curved Spacetime - by Matt Visser, Physics Department, Washington University, St. Louis, MO 63130-4899

Abstract - It is an article of folklore that the collection of ideas identified as Euclidean quantum gravity may be derived from ordinary Lorentzian signature gravity by the procedure of Wick rotation. It is the purpose of this essay to shed some light on this ill-understood procedure. The author argues that it proves inappropriate and unhelpful to regard Wick rotation in terms of a complex deformation of time coordinate. Rather, Wick rotation can more usefully be viewed as a complex deformation of the spacetime metric. This simple reformulation of the Wick rotation procedure, while it leaves flat space physics unaffected, has profound implications for quantum gravity.

26. Non-existence of Apparent Horizons for Elongated Configurations of Matter Having Small Mass - by Jacek Wojtkiewicz, Institute for Theoretical Physics, Polish Academy of Sciences, Aleja Lotników 32/46, 02-668 Warsaw, Poland

Abstract - Let us have a time-symmetric, conformally flat and axisymmetric Cauchy hypersurface $\sum$. It is assumed that the distribution of matter present in $\sum$ is strongly elongated in the direction of symmetry axis and has compact support. Let the length of this configuration be L as measured in the flat background space. It is shown that if length L and ADM mass M associated with $\sum$ fulfill the relation: $M \leq \frac{1}{8} L$, then such a configuration of matter cannot be entirely surrounded by an apparent horizon. The proof makes use of the Penrose inequality and the second variation formula. This result can be regarded as a complement of the "hoop conjecture" (which, if true, gives a condition for existence of apparent horizons).

27. QCD Colored Black Holes - by Hongwei Yu* and Yongliu Wang[+], *Research Department, Changsha Railway Institute, Changsha, Hunan 410075, P.R.C., [+]Physics Department, Changsha Railway Institute, Changsha, Hunan, 410075, P.R.C.

Abstract - The authors consider gravity coupled to the SU(5) grand unified theory and obtain a family of exact solutions for the coupled SU(5) Einstein-Yang-Mills-Higgs system of fields. The solution is characterized by five physical parameters (mass M, angular momentum S, electric charge Q, magnetic charge 1/2e and QCD color charge C^Q) and represents a static spherically symmetric black hole with QCD color hair as well as electric hair and magnetic hair. The results show that black holes can carry not only abelian electromagnetic charges but also non-abelian QCD charges.