GRAVITY RESEARCH FOUNDATION
FIFTY-EIGHT MIDDLE STREET
GLOUCESTER, MASSACHUSETTS
01930

Abstracts of Award Winning and Honorable Mention Essays for 1979

Award Winning Essays

First Award - The Homogeneity of the Universe by F.G.R. Ellis, Department of Physics, University of Alberta, Edmonton, Alberta, Canada.

Abstract - The observational and philosophical grounds for our belief in the spatial homogeneity of the Universe are reconsidered. On the one hand, spatial homogeneity cannot be directly verified observationally, and on the other hand, it raises a series of philosophical problems which counter its attractiveness to a considerable degree. It is pointed out that there are several possible alternative approaches to the question of the homogeneity of the universe which may provide at least as attractive a philosophical basis as the current approach, and which merit detailed investigation as possible alternative bases for our cosmological world-view.

Second Award - Gravitational Instantons by Tohru Eguchi, University of Chicago, Chicago, Illinois and Andrew J. Hanson, Palo Alto, California.

Abstract - The path-integral approach to quantum field theory assigns special importance to finite action Euclidean solutions of classical field equations. In Yang-Mills gauge theories, the instanton solutions of classical field equations with self-dual field strength have given rise to a new, non-perturbative treatment of the quantum field theory and its vacuum state. Since gravitation is also a species of gauge theory, one might think that similar phenomena would occur in gravity. The authors recently sought and found a new self-dual solution to Euclidean gravity which plays a role parallel to that of the Yang-Mills instanton. Gravitational instantons now promise to yield new insights into the nature of quantum gravity.

Third Award - A New Method for Solving Perturbation Equations by Robert M. Wald, Enrico Fermi Institute, University of Chicago, Chicago, Illinois.

Abstract - A new, generally applicable, technique is described for constructing solutions of a coupled linear system of partial differential equations when a decoupled equation has been derived. This method has already yielded an extremely simple derivation of perturbation formulas given by Cohen and Kegeles and by Chrzanowski as well as new formulas for the complete solutions of the coupled Einstein-Maxwell equations describing Reissner-Nordström perturbations. It is hoped that it will prove valuable for many other applications.

Fourth Award - Testing General Relativity at the Quantum Level by Ephraim Fischbach and Belvin S. Freeman, Institute for Theoretical Physics, State University of New York at Stony Brook, Stony Brook, New York.

Abstract - It is shown that the effect of a gravitational field on a hydrogen atom is to admix states of opposite parity such as $2S_{\frac{1}{2}}$ and $2P_{\frac{1}{2}}$. The phase of this admixture is such as to produce circular polarization of the radiation emitted in transitions such as $2S_{\frac{1}{2}} \rightarrow 1S_{\frac{1}{2}} + \gamma$ which arises from the interference between the gravity-induced amplitude and that due to the weak neutral current. The predicted magnitude of the circular polarization, which could be sufficiently large to be detected in white dwarfs or in certain binary systems, varies from theory to theory. It is thus possible that a study of this effect could provide a feasible means of testing general relativity at the quantum level.

Fifth Award - Shear Hell Holes and Anisotropic Universes by B.J. Carr, Kellogg Radiation Laboratory, Caltech, Pasadena, California and J.D. Barrow, Department of Astrophysics, South Parks Road, Oxford, England.

Abstract - If the early Universe were highly anisotropic, primordial black holes may have formed prolifically (despite previous claims to the contrary) even if the initial density fluctuations were small. However, the holes would initially be endowed with an immense amount of shear, so it is not obvious that they would evolve into the conventional type of stationary black hole envisaged by the "No Hair" theorem. If they do settle down to a stationary state, it may only be on a considerable timescale; and in principle there might exist soliton-type solutions which represent holes with shear which persists indefinitely. Such "shear hell holes", as we term them, could have even more dramatic properties than the usual stationary holes: in particular, they might be prolific generators of gravitational radiation and they could be associated with interesting quantum effects.

Honorable Mention Essays (Alphabetical Order)

1. Interference and the Gravitational Field by J. Anandan, Dept. of Physics and Astronomy, Center for Theoretical Physics, University of Maryland, College Park, Maryland 20742.

Abstract - By using the operational procedures for determining the geometry of space-time and the experimentally known equivalence between inertial mass and the active gravitational mass, it is argued that there must exist a deep connection between general relativity and quantum theory. This argument, together with the phase shift in the quantum interference of two coherent beams, which is obtained for a particle with arbitrary spin, leads to a modification of Einstein's field equations. The modified equations satisfy all the experimental tests satisfied at present by Einstein's field equations, but may be renormalizable.

2. Does Matter Break the Link Between Symmetry and Linearization Instability? by Judith M. Arms, Departments of Mathematics and Physics, University of Utah, Salt Lake City, Utah 84112.

Abstract - Previous research has found that perfect fluids coupled with gravity, unlike gravitational field alone or coupled to gauge fields, are linearization stable on symmetric spatially compact spacetimes. It is shown that first class constraints which generate gauge transformations form the link between symmetry and linearization instability. With fluids coupled to gravity, comoving coordinates lead to second class constraints and linearization stability. For fluids represented by potentials, however, (some of) the constraints generate the gauge transformations, re-establishing symmetry as a criterion for instability.

3. Observables of the Gravitational Field by Anne Magnon-Ashtekar, Départment de Mathématiques, Université de Clermont-Fd, 63170 Aubiére, France.

Abstract - There are available in the literature several distinct definitions of energy-momentum and angular momentum of the gravitational field. The relation between these notions is analysed. It is shown that, in spite of their different origins, these definitions are so intertwined that for a large class of gravitational fields, there exists an unambiguous notion of total energy-momentum and angular momentum. These quantities represent the basic classical observables of the gravitational field. One expects them to play an important role also in quantum gravity. Some possibilities are indicated in this regard.

4. Is the Cosmological Particle Creation Adequately Described by an Asymptotic In-Out Calculation? by Jürgen Audretsch, Fachbereich Physik, Universität Konstanz Postfach 7733, D-775 Konstanz (W. Germany)

Abstract - The aim of this essay is to demonstrate that asymptotic in-out calculations, although correct from a formal mathematical point of view, have in return little or nothing to do with the physical situation and the expected outcome of a cosmological gravitational particle creation, if this creation is supposed to be appropriately localized in time and attributed to the occurrence of strong gravitational fields (curvature). To demonstrate this, the author treats rigorously the example of a universe with an expansion-contraction behaviour showing temporarily arbitrarily strong gravitational fields (high tidal forces, large curvature), which nevertheless produces in an in-out calculation exactly no particles. In other words, according to an in-out calculation this universe "works and works and produces nothing".

5. A New Representation of the Feynman Propagator in Curved Spacetime by T.S. Bunch, Dept. of Physics, University of Wisconsin-Milwaukee, Milwaukee, Wisconsin 53201.

Abstract - A new representation of the Feynman propagator, G(x,y) in curved spacetime is described. The representation is obtained for x in a normal neighborhood of y by Fourier transformation in the Riemann normal co-ordinates of x, the resulting expression being a generalization to curved spacetime of the familiar momentum space expression of Minkowski spacetime. The well-known DeWitt-Schwinger representation can be derived from the new representation which is also used to generalize normal ordering of field operators to curved spacetime and to evaluate the divergence in a two-loop correction to the propagator in $\lambda\phi^4$ field theory.

6. Gravitational Screens and the Apparent Superluminal Separation in Quasars by S.M. Chitre and J.V. Narlikar, Tata Institute of Fundamental Research, Bombay 400 005, India.

Abstract - Very long baseline interferometry of radio sources has revealed in the last few years the existence of components in the nuclear regions which appear to be separating from each other at speeds greatly in excess of the speed of light. The authors discuss the possibility that the observed speeds are not real. If a gravitational screen in the form of a galaxy or any other suitable clump of matter intervenes between the source and the observer, the differential bending of radio waves produced by the screen can, under certain circumstances, generate large magnification of the real velocity of separation. The geometrical and astrophysical considerations of this idea are briefly outlined.

7. Why Quantize Gravity? by P.C.W. Davies, Department of Mathematics, King's College, Strand, London WC2R 2LS.

Abstract - Some reasons commonly advanced for the quantum nature of gravity are examined. It is concluded that no compelling reason exists that gravity should not be a truly classical field, provided certain weak cosmological assumptions are made. It is argued that not only does classical gravity circumvent the notorious mathematical problems of quantum gravity, it provides a natural explanation for the so-called collapse of the wave-function during quantum measurement.

8. Magnetohydrodynamic Solution to the Problem of the Origin of Galaxies in an Expanding Universe by A.J. Fennelly, Dept. of Physics and Astronomy, Western Kentucky University, Bowling Green, Kentucky 42101.

Abstract - In the universe prior to recombination the plasma conductivity λ can be in range $\sim 10^{12} - 10^{3}$ mho/m. Then plasma instabilities of a frozen-in magnetic field couple to the fluid motion to augment perturbations in density. The fluid flow depends exponentially on the conductivity. Ultimately this leads to exponential growth of the density perturbations in an anisotropic, spatially homogeneous, magnetohydrodynamic (MHD) background model. This growth is at the rate $te^{2\lambda t^{1/4}}$ for isothermal and $te^{8\lambda t}$ for adiabatic perturbations. Thus galaxies can grow in certain MHD expanding universes in Einstein's gravitation theory.

9. Towards a Unified Gauge Theory of Gravitational and Strong Interactions? by Friedrich W. Hehl and Djordje Sijacki, Institute for Theoretical Physics, University of Cologne, D-5000 Cologne 41, W. Germany.

Abstract - The authors study the spacetime properties of leptons and hadrons and find it necessary to extend general relativity to the gauge theory based on the 4-dimensional affine group. This group translates and deforms the tetrads of the locally Minkowskian spacetime. Its conserved currents, momentum and hypermomentum, act as sources in the two field equations of gravity.

A Langrangian quadratic in torsion and curvature allows for the propagation of two independent gauge fields: translational e-gravity mediated by the tetrad coefficients, and deformational Γ-gravity mediated by the connection coefficients. For macroscopic matter e-gravity coincides with general relativity up to the post-Newtonian approximation of 4th order. For microscopic matter Γ-gravity represents a strong Yang-Mills type interaction. In linear approximation, for a static source, a confinement potential is found.

10. Origin of the Cosmic Matter Distribution - by Craig Hogan and Niccolό Caderni, Institute of Astronomy, Madingley Road, Cambridge CB3 OHA, England.

Abstract - An initially cold, perfectly homogeneous and isotropic universe spontaneously produces density fluctuations due to simple quantum discreteness at the elementary particle level. These microscopic inhomogeneities can grow via gravitational instability into the macroscopic clustering hierarchy observed today.

11. Gravitational and Doppler Redshifts of Quasars Interpreted as Massive Black Holes Ejected from Galaxies by Z. Horák, Technical University of Prague, 160 00 Praha 6, Czechoslovakia.

Abstract - This is a first attempt to find a realistic explanation of the observed redshifts of quasars associated with galaxies, by considering, in addition to the inertial, also the gravitational time dilation in the strong field of quasars interpreted as huge black holes accreting matter from surroundings. This interpretation allows us an understanding of the observed predominance of excess redshifts of quasars and permits the construction of semiquantitative models for the pair NGC 4319/Markarian 205. The proposed models do not contradict the present astrophysical knowledge, but a selection of the most satisfactory model is still difficult because of the existing uncertainty in estimates of the sizes of radiating regions in matter accreted by a flying black hole.

12. Definitions of a Black Hole Without Use of the Boundary at Infinity by Andrzej Królak, Instytut Fizyki Teoretycznej, Hoza 69, 00-681 Warszawa, Poland.

Abstract - Black holes are defined without any reference to the boundary at infinity of space-time. One definition does not require any global causality condition, the other is applicable to closed Friedman-like space-times. The are theorem is found to hold in both cases.

13. Machian Effects in a Rotationally Perturbed Closed Universe - by Steve M. Lewis, University of Maryland.

Abstract - Mach's principle is discussed in the context of a rotating closed universe. In particular, a rotating shell of perfect fluid matched onto a closed Freidman-Robertson-Walker universe is considered, the solution being exact to first order in the rotation. The rotation terms vary as hypergeometric functions, leading to bizarre effects which appear to be anti-Machian. A discussion of the role of an observer in such a universe is given.

14. A Class of Non-Trivial Solutions to the Good Cut Equation by Robert W. Lind Department of Physics, University of Wisconsin-Platteville, Platteville, Wisconsin.

Abstract - The good cut equation ($\eth^2 Z = \sigma$) is the link between a physical asymptotically flat space-time (characterized by σ) and its associated H-space (characterized by Z and interpreted by Penrose as a non-linear graviton). In this essay a class of regular, non-trivial ($\sigma \neq 0$) solutions to the good cut equation is obtained by writing σ in terms of a potential function ϕ.

15. On the Nature of a Spacetime Singularity by Bahram Mashhoon, W.K. Kellogg Radiation Laboratory, California Institute of Technology, Pasadena, California.

Abstract - The nature of a spacetime singularity is investigated within the framework of Einstein's theory of gravitation. A definition of a singular point is proposed based on the breakdown of the fundamental assumption of the theory, namely, Einstein's principle of equivalence. It is assumed that tidal gravitational forces do not tend to definite values as a "physical" singularity is approached. The first few tidal terms are discussed in some detail and spacetime singularities are then classified according to the tidal acceleration term that fails to reach a proper value.

16. On the New 600 Km/Sec "Aether Drift" by Richard A. Matzner, Relativity Center, University of Texas, Austin, Texas 78712.

Abstract - The author discusses the dipole anisotropy of the 3K cosmological microwave background which indicates a 600 km/sec drift of the center of mass of the Galaxy toward $\ell \sim 260^o$, $b \sim 33^o$. The most natural explanation is that the Galaxy is at rest in the homogeneous frame of the universe, while the radiation streams past. Such a picture is consistent with the dynamics of pressureless matter (i.e. galaxies) and of incoherent radiation in an expanding universe. A mechanism is pointed out which would enhance a dipole term over other possible anisotropies, and the suggestion is made that a much stronger dipole anisotropy exists in the cosmological neutrino background.

17. Structure of Spacelike Infinity by Niall Ó Murchadha, Physics Department, University College, Cork, Ireland.

Abstract - Since it takes an infinite amount of time for a signal to reach spacelike infinity, there exists a whole sequence of stable asymptotic structures there. These structures are classified by the way that the gravitational radiation falls off near infinity. Associated with each structure is an asymptotic symmetry group, which contains the Poincaré group. An analysis of the irreducible representations of these symmetry groups reveals when the total mass and total angular momentum are well-defined and immediately gives the necessary asymptotic conditions: for the mass to be well-defined the metric must approach the Minkowski metric faster than $r^{-\frac{1}{2}}$; for angular momentum to be well-defined the 1/r part of the metric must be Schwarzschild-like.

18. Stokesian Fluids and Cosmology by M. Novello, Centro Brasileiro de Pesquisas Fisicas, Av. Wenceslan Braz. 71, CEP 20000, Rio De Janeiro, RJ, Brazil.

Abstract - The author discusses models of fluid behavior which are apparently beyond any experimental evidence on terrestrial materials. He considers fluids which have anisotropic stress and which respond to external stimuli in a non-linear way. Such behavior can be either of a stokesian type (the response depends only on the deformation) or of a non-stokesian form (it can depend, for instance, on the local rotation of the fluid). Instead of looking for special materials which could have such properties he shows how it is possible to detect similar behavior in usual ordinary forms of matter under certain specific situations. In this vein, Einstein's equations are used in this essay as a tool to construct explicit examples of such circumstances. It is indeed very stimulating that one can easily find models of Universes which can be interpreted as having such unusual materials as the main source of its curvature. Astonishing enough in these examples the "strange materials" are nothing but classical long range fields coupled to ordinary matter in a curved space. From the cosmological point of view the analysis of matter which are not limited to the perfect fluid behavior should be of importance in order to describe strong deviations from the usual models in such drastic periods which certainly occured in early epochs.

19. A Source-Independent Experiment To Test the Metric Theories of Gravitation in Newtonian Limit by Ho Jung Paik, Dept. of Physics and Astronomy, University of Maryland, College Park, Maryland 20742.

Abstract - A "source-independent" null experiment for the Newtonian law of gravity is proposed. The new scheme involves detection of the Laplacian of the gravitational potential, $\nabla^2\phi(\underset{\sim}{r})$, in free space, i.e. where $\rho(r) = 0$. This quantity should vanish identically regardless of the mass distribution in the rest of the universe, if the inverse square law is exact. A departure from null in $\nabla^2\phi(r)$ could be measured by monitoring the breathing mode of a sphere or by summing three gravity gradients at a single point along any three orthogonal directions. The "source-independent" behavior of the proposed technique will allow a test of the inverse square law in the intermediate range between 1 m and 10 km in which large geological objects might be used as sources. This experiment constitutes a new test of metric theories of gravitation in the Newtonian limit.

20. Gravitational Energy-Momentum: The Einstein Pseudo-Tensor Re-Examined by T.N. Palmer, Dept. of Astrophysics, Oxford University, South Parks Road, Oxford, U.K.

Abstract - By using a suitable 2-point scalar field, a covariant formulation of the Einstein pseudo-tensor is given. A unique choice of scalar field is made possible by examining the role of linear and angular momentum in their correct geometric context. It is shown that, contrary to many text-book statements, linear momentum is not generated by infinitesimal coordinate transformations on space-time. Use is made of the nonintersecting lifted geodesics on the tangent bundle, $T\mu$, to space-time, to define a globally regular 3-dimensional Lagrangian submanifold of $T\mu$, relative to an observer at some point z in space-time. By intergrating over this submanifold rather than a necessarily singular spacelike hypersurface, gravitational linear and angular momentum, relative to z, are defined, and shown to have sensible physical properties.

21. Gravity and the Baryon Number and Entropy of the Universe by Leonard Parker, Physics Deparmtent, Univ. of Wisconsin-Milwaukee, Milwaukee, Wisconsin 53201.

Abstract - A problem under current investigation is how a universe consisting almost entirely of matter can arise from an initial state which is symmetric with respect to matter and antimatter. A successful explanation must yield a ratio of baryon number density to entropy density which is in the observed range. A model is discussed in which both the entropy and baryon number of the universe result from the creation of elementary particles by the strong gravitational field in the early stages of the expansion. The matter-antimatter asymmetry arises through an interaction which violates baryon number conservation and CP invariance.

22. Radiation Reaction and the Initial-Value Problem by B.F. Schutz, Dept. of Applied Mathematics and Astronomy, University College, P.O. Box 78, Cardiff, CF1 1XL, Wales, U.K.

Abstract - A new derivation of the formulas for gravitational radiation reaction is given. The approach is entirely local, involving only the near zone, so the approximations involved should be well-behaved. In place of a condition that there be no incoming radiation, the present method uses a statistical approach, deriving the source's most likely evolution from imperfectly-known initial data. It is argued that this is closer to the real situation than one which places the system in an idealized asymptotically flat spacetime with no incoming radiation. The method also links the so-called electromagnetic and thermodynamic arrows of time. The present derivation is confined to ultra-weak self-gravity ($V^6 >> M/R$) but can in principle be extended to more realistic regimes. It gives the usual quadrupole formula for energy loss but not Thorne's expression for the reaction potential.

23. Boundary-Layer Behavior at the Inner Edge of Black Hole Accretion Disks by William R. Stoeger, S.J., Department of Physics and Astronomy, University of Maryland, College Park, Maryland 20742.

Abstract - The author studies further the flow of accreting material into black holes from the Keplerian disks surrounding them. Solving the system of relevant equations in Schwarzschild geometry for the case where the kinematic viscosity ν = constant, he discovers a boundary layer at the disk's inner edge, where the flow becomes non-Keplerian. He also shows that, despite the operation of viscous stresses across this inner edge and the presence of the boundary layer there, very little extra energy or angular momentum is radiated or transported outward from inside that radius -- a result many have often assumed but no one has carefully demonstrated. Finally, he indicates how the qualitative features of these results pertain to other accretion-disk situations.

24. High Energy Gravity and the Very Early Universe by Hidezumi Terazawa, Institute for Nuclear Study, University of Tokyo, Midori-cho, Tanashi, Tokyo 188, Japan.

Abstract - It is suggested that gravity may not be asymptotically free at short distances due to the interactions of the graviton with matter. If gravity becomes strong indeed at high energies, a revolutionally change of our present theory on the early universe seems to be necessary. During the first extremely small fraction of a second in the big-bang universe, gravity was so strong that it might not be described by Einstein's theory of general relativity. Such possibility of abnormally strong gravity at high energies or short distances is discussed in some detail. A possible explanation is proposed for the non-vanishing mean baryon-number-density of the universe. It is also pointed out that the universe may well escape from the catastrophic singularity of Penrose and Hawking.

25. General Relativity and the Eternal Return by Frank J. Tipler, Dept. of Mathematics, University of California at Berkeley, Berkeley, California 94720.

Abstract - An arbitrarily close return to a previous initial state of the Universe, such as is predicted by the Poincaré recurrence theorem cannot occur in a closed universe governed by general relativity. The significance of this result for cosmology and thermodynamics is pointed out.

26. The Interaction of Weak Gravitational Waves with a Binary System by Michael S. Turner, Astronomy and Astrophysics Center, Enrico Fermi Institute, The University of Chicago, Chicago, Illinois 60637.

Abstract - The interaction of a gravitational wave with free test particles or even test particles coupled by non-gravity forces is well understood. The situation discussed in this essay is the interaction of a gravitational wave with a system of two masses bound by their own self-gravity. The wave has secular effects on the orbital and center-of-mass motions of the binary system if the frequency of the wave is an integer multiple of the orbital frequency. The center-of-mass effect is a new phenomenon--"resonant gravitational radiation pressure". The orbital effects may prove to be useful in the detection of single sources or stochastic sources of gravitational waves in the 10^{-4} Hz to 10^{-10} Hz range.