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Abstracts of Award Winning and Honorable Mention Essays for 1977

Award Winning Essays

First Award - Gravitational Interaction and Spontaneous Breaking of Symmetries by Abhay Ashtekar, The Enrico Fermi Institute, University of Chicago, Chicago, Illinois, 60637.

Abstract - An explicit example of spontaneous symmetry breaking due to gravitational interaction is given. It is shown that, in the framework of quantum field theory in curved space-times, the "dragging of inertial frame" effects lead to a spontaneous symmetry breaking in the ultra-relativistic regime. This situation is compared with those which arise in other interactions. It is pointed out that spinning-up of relativistic configurations is analogous to cooling-down of systems in solid state physics - especially in magnetism - and in high-energy physics. This analogy may turn out to be significant in the investigation of thermodynamical properties of the gravitational field.

Second Award - Is The Universe Expanding? by G.F.R. Ellis, Department of Applied Mathematics, University of Cape Town, Cape Town, S.A.

Abstract - It is shown that spherically symmetric static exact solutions of Einstein's Field Equations can reproduce the same cosmological observations as the currently favored Friedmann-Robertson-Walker universes, if the usual assumptions are made about the local physical laws determining the behavior of matter, provided that the Universe is inhomogeneous and our galaxy is situated close to one of its centres. Only (i) unverifiable a priori assumptions, (ii) detailed physical and astrophysical arguments, or (iii) observation of the time variation of cosmological quantities, can lead us to conclude that the universe we live in is not such a static space-time.

Third Award - What is the Effective Stress-Energy of Particles Created from the Vacuum? by Robert M. Wald, The Enrico Fermi Institute, University of Chicago, Chicago, Illinois, 60637.

Abstract - When spontaneous particle creation occurs in a strong gravitational field, it seems clear on physical grounds that the particle creation must "back react" on the gravitational field. It is generally believed that in the semiclassical approximation this effect can be described by assigning an effective stress-energy to the created particles which acts as a source of the gravitational field via Einstein's equation. In this essay, the author discusses an axiomatic approach for determining the renormalized value of this effective stress-energy.

Fourth Award - The Irreversible Thermodynamics of Black Holes by P. Candelas, Center for Relativity University of Texas at Austin and Balliol College, Oxford, and D.W. Sciama, Department of Astrophysics, Oxford.

Abstract - The action of quantum fluctuations of the gravitational field may be regarded as the origin of the dissipative processes associated with Hawking radiation. In this picture the black hole possesses internal coherence by virtue of the localization of its mass. The cumulative effect of the quantum fluctuations in the geometry is that this coherence is corrupted and the mass is sapped away.

Fifth Award - The Black Flash Model of QSOs by G.A. Shields and J.C. Wheeler, Department of Astronomy, University of Texas at Austin.

Abstract - A model for QSOs and the nuclei of Seyfert Galaxies is proposed in which mass lost from stars in a galactic nucleus repeatedly builds to a critical density and then collapses to the center where it accretes onto a massive black hole ($\sim 10^8$ $M_\odot$), emitting great luminosity. This model describes a means of starting with an ordinary nucleus and developing conditions found in QSOs. By invoking intermittent flashes we overcome a difficulty previously encountered in similar models in which plausible sources of mass in reasonable galactic nuclei fail by a factor $\sim 10^{-2}$ of fueling a black hole at QSO luminosities.

Honorable Mention Essays (Alphabetical Order)

1. Bounce of Spheres in Einstein Cartan Theory by S. Banerji, Department of Physics, The University of Burdwan, Burdwan 713104, India.

Abstract - Boundary conditions on the surface of a sphere in the Einstein-Cartan theory are discussed. It is pointed out that an Einstein-Cartan sphere must bounce outside the Schwarzschild radius. Except in extreme cases the presence of tersion does not appreciably alter the conditions of the gravitational collapse of stars.

2. The Homogeneity and Isotropy of the Universe by John D. Barrow, Department of Astrophysics, Oxford, U.K., and Richard A. Matzner, Relativity Center, University of Texas, Austin, Texas .

Abstract - The authors analyse those models of the universe consistent with the observed isotropy, entropy, element abundances, and with the existence of galaxies. The finiteness of the entropy measured as the number of photons per baryon in the universe today, $S_b \sim 10^8$, limits the amount of dissipation that could have taken place in the past and hence the degree of irregularity allowed in the singularity structure. This observation essentially rules out the chaotic cosmology in its full generality and appears to constrain the singularity to be of simultaneous Robertson-Walker character with only small curvature fluctuations.

3. On the Outside of Cold Black Holes by Jiri Bicak, Department of Mathematical Physics, The Charles University, Prague.

Abstract - Some general features of the behavior of fields and particles around extreme (or nearly extreme) black holes are outlined, with an emphasis on their simplicity. In particular, simple solutions representing interacting electromagnetic and gravitational perturbations of an extreme Reissner-Nordstrom black hole are presented. As an application, the motion of the hole in an asymptotically uniform weak electric field is examined and "Newton's second law" is so explicitly verified for a geometrodynamical object.

4. The Black Hole Dynamo by R.D. Blandford, California Institute of Techonology 130-33, Pasadena, California 91125, and R.L. Znajek, Institute of Astronomy, The Observatories, Madingley Road, Cambridge CB3 OHA, United Kingdom.

Abstract - Observations suggest that quasars, radio galaxies etc. are powered by plasma falling into massive black holes. Accreting plasma can in general be expected to carry angular momentum and magnetic flux. This makes a hole act like an electric dynamo: electromotive force is induced, current flows and the hole's rotational energy ends up being dissipated by resistance in the circuit. Resistance outside the hole produces the relativistic particles, rapidly varying radiation and directivity characteristic of active galaxies. Resistance inside the hole causes the hole's irreducible mass to increase at the rate I^2R, where I is the current through the hole and R ($\sim$30 ohms) is the electric resistance of the hole.

5. Possible Test of the Strong Principle of Equivalence by Kenneth Brecher, Department of Physics and Center for Space Research Massachusetts Institute of Technology, Cambridge, MA 02139

Abstract - The author suggests that redshift determinations of x-ray or gamma ray lines produced at the surface of neutron stars and arising from different physical processes would provide a significant test of the strong principle of equivalence for strong gravitational fields. As a complement to both the high precision weak field solar system experiments and the cosmological time variation searches, such observations could further test the hypothesis that physics is locally the same at all time and in all places.

6. The Energy-Momentum Tensor and the Definition of Particle States for Robertson-Walker Space-Times by M.R. Brown and C.R. Dutton, Department of Astrophysics, Oxford.

Abstract - The authors present a new regularisation scheme (an adaptation of dimensional regularisation) whereby the vacuum expectation value of the Energy-momentum tensor of a quantised matter field propagating on an arbitrary Robertson-Walker background is mathematically well-defined and may be computed unambiguously. Its eventual physical value is seen to be independent of the ordering of its component field operators. They also discuss the possibility of the definition of 'vacuum state' on an arbitrary spacelike hypersurface from the now well defined requirement that this state has minimum energy.

7. On the Way Towards a Nonsingular Gravitational Collapse - The Properties of the Yang-Mills Cosmos by M. Camenzind, Institut für Theoretische Physik, Universität Hamburg, Federal Republic of Germany.

Abstract - Adding gravitational self-interaction to general relativity in an intrinsic way changes drastically the behavior of a physical system under the gravitational collapse. In the analysis presented here of this question for homogeneous and isotropic matter distributions the author shows that (i) the SO(1,3) gauge theory of gravity of the Yang-Mills type has the correct Newtonian limit for the late universe, (ii) it defines intrisically a dynamical gravitational stress-energy-momentum tensor $\ddot{G}_{ab}$, and (iii) negative self-energy always prevents homogeneous and isotropic matter from forming a bigbang singularity; if the present universe disposes of a negative self-energy, pair creation on the eve of the lepton era generates sufficient gravity to stop the fatal collapse.

8. The Road to Singularities, and the Roses on the Way by C.B. Collins, Department of Applied Mathematics, University of Waterloo, Waterloo, Ontario, Canada.

Abstract - A survey of current investigations of space-time singularities is given. The different approaches adopted by various research schools is discussed, and an analogy is drawn between this study and the mounting of an expedition which sets out on a long trail of discovery. A heuristic discussion is given of the latest classification of singularities and some brief comments are made on how physically relevant each type of singularity is. Roughly speaking; it seems that the milder types (at which physical quantities remain well-behaved) are pathological cases, whereas the crude "big-bang" type of singularity is more generic.

9. On The Ergoregion Instability by Neil Comins and Bernard F. Schutz, Department of Applied Mathematics & Astronomy, University College, Cardiff, U.K.

Abstract - Ergoregions -- regions of negative energy -- occur in rotating stars and black holes. Friedman has shown that in stars (but not in black holes) they give rise to an instability. This instability has astrophysical interest, and it bears a close resemblance to other instabilities peculiar to general relativity, in which rotation and the emission of radiation both play essential roles. The authors show that this instability can be understood using effective-potential methods and WKBJ techniques. Its characteristic feature is that a counter-rotating mode of any radiation field (scalar, electromagnetic, gravitational) is rendered unstable when the dragging of inertial frames increases to the point where the mode is forced to rotate forwards with the star. Separating modes according to their angular dependence $e^{im\phi}$, it is found that in an ergoregion all $|m|$ greater than some minimum have unstable modes, but that the instability is weak: the e-folding time is proportional to m^2.

10. Repulsive Gravity by P.C.W. Davies, Department of Mathematics, King's College London.

Abstract - The existence of negative energy states in quantum field theory can lead to significant new gravitational phenomena including repulsive gravity. The recent discovery of quantum conformal anomalies suggests that quantum vacuum effects dominate the cosmological dynamics at sufficiently early epochs. Repulsive gravity may cause the universe to 'bounce', thereby avoiding cosmological singularities in a wide class of cosmological models.

11. Supergravity by Daniel Z. Freedman and Peter van Nieuwenhuizen, Institute for Theoretical Physics, State University of New York at Stony Brook.

Abstract - Supergravity field theories are extensions of Einstein gravitation with a new gauge principle, local sypersymmetry, which relates bosons and fermions. Spacetime geometry and the concept of spin are intimately linked. Certain quantum corrections, which are infinite in ordinary gravity-matter systems are finite in a class of supergravity theories. Matter and gravity are unified in these theories, and there is the prospect that the weak, electromagnetic and strong interactions can be described naturally in this framework. In this essay general features of supergravity and some open problems are discussed.

12. Quantum Mechanical Instability of Black Hole Interiors by William A. Hiscock, Center for Theoretical Physics, Department of Physics and Astronomy, University of Maryland, College Park, MD 20742

Abstract - Building upon previous numerical and two dimensional studies, general arguments are given to show that the existance of the blackbody radiation discovered by Hawking creates stress-energy tensor divergences on the Cauchy horizon in the Kerr-Newman interior. Thus, given quantum mechanics, the Kerr-Newman metric cannot describe the interior of a black hole. This not only removes any a priori reason for believing a black hole interior might possess such exotic features as closed timelike lines, access to other asymptotically flat spacetime regions, etc., but also suggests that quantum mechanics may preclude the existance of such features.

13. Gravity and Matter of Common Origin by Kurt Just, Department of Physics, University of Arizona, Tucson, AZ 85721

Abstract - A quantum theory of gravity is initiated by deriving Einstein's gravitational field explicitly from a fundamental Dirac spinor of lepton and quark fields.

14. The Motion of a Charged Particle as Viewed from Heaven by Malcolm Ludvigsen, Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, PA 15260.

Abstract - A new approach to the problem of the motion of a self-interacting massive charged particle in general relativity is presented. A charged Robinson-Trautman solution is used as a G.R. model for such a particle. Such a solution is shown to generate a unique world line in its own H-space. This is argued to be the asymptotically observed world line of the particle. Using the R-T dynamical relations, the equation of motion is derived and, in the limiting case of zero curvature, is shown to be the same as the classical Lorentz-Dirac equation of motion.

15. The Symmetry Aspects of Quantum Field Theory in General Relativity by Marcos Duarte Maia, Universidade de Brasilia, Departamento de Matematica, 70.000 Brasilia D.F. Brazil.

Abstract - Some proposed models for a quantum field theory in General Relativity are briefly analysed. Their main difficulties are consequences of the initial choice of the group of symmetries of the (quantum) field equations. The necessity to select spacetime isometries in a general covariant theory and the unphysical character of the Poincare translations in a tangent plane theory are discussed.

Starting from some basic requirements a model is proposed in which the groups of symmetries are derived from the proper homogeneous groups of isometries of the minimal isometric local enbedding spaces of spacetimes.

16. Gravitons From a Spinning Rod by George L. Murphy, Department of Physics, The University of Western Australia, Nedlands, Western Australia 6009.

Abstract - As an indication of the need to consider quantum effects in general relativity, it is shown that the familiar problem of gravitational radiation from a spinning rod cannot be treated classically unless the mass of the rod exceeds several tons. If laboratory sources of gravitational waves ever become feasible, they will have to be described quantum-mechanically, and should make possible the detection of individual gravitons.

17. Anomalous Redshifts and Conformal Gravity by Jayant V. Narlikar, Center for Theoretical Physics, University of Texas at Austin, Austin, Texas 78712.

Abstract - One of the many difficulties of interpreting the redshifts of the quasi stellar objects arises from the increasing data on the anomalous redshifts. In a typical case two objects in close proximity exhibit widely different redshifts. The excess redshift of one object in this case may be of non-cosmological origin. As the available data does not seem to support the gravitational or the Doppler redshift hypotheses, a new hypothesis is proposed. This is based on the conformally invariant gravitation theory of Hoyle and Narlikar and it predicts that the object with the excess redshift should turn out to be younger than its companion.

18. Excitations of the Gravitational Field by M. Novello, Department of Theoretical Astrophysics, California Institute of Technology, Pasadena.

Abstract - The author treats the geometry of spacetime as a stochastic variable. Fluctuations induce a deviation from Einstein's system of equations for the average geometry. A model is presented by means of which the extra terms, due to fluctuations, can be expanded in a series in the average geometry. Some new features induced by this expansion are analyzed.

A weak gravitational field propagates in the form of a wave with a velocity that depends on the properties of the fluctuation. The analogy with electrodynamics permits an index of refraction for the perturbed medium to be defined. It is then shown that an inhomogeneous perturbation of the matter density in a Friedman background grows faster than in Einstein's theory. This behavior is a very new feature which could prove to be of importance in our understanding of galaxy formation. In section VI the author studies the effects of an inhomogeneous rotation-dependent current on cosmological models. As a consequency of the presence of rotation, the perturbed system admits a shear-free rotating and expanding Universe without matter. The above properties seem appealing enough to suggest further investigation of the model.

19. A Convariant Flat Space Structure in Curved Space-Time by T.N. Palmer, Department of Astrophysics, University of Oxford.

Abstract - It is found that for any curved space-time there is a naturally, and covariantly defined Minkowski space structure, together with an associated ten parameter group whose generators are covariant vectorfields on the space-time. This structure is inherently nonlocal, and is discusses in relation to the associated problems of the non-uniqueness of the vacuum state in quantum field theory, and the nonuniqueness and non-covariance of classical gravitational energy-momentum.

20. A New Class of Stationary, Axially Symmetric, Vacuum Metrics by P.C. Peters, Department of Physics, University of Washington, Seattle, Washington 98195

Abstract - A new class of stationary, axially symmetric, vacuum metrics is exhibited, which serve as exterior metrics for rings of matter spinning on their own axes, as in vortex rings. Unlike the Kerr and other metrics associated with rotation about the axis of symmetry, these metrics are all locally static. However, when the global geometry is considered, including the identification of points involving cyclical coordinates, the stationary nature of the metrics is seen. In general, metrics of this kind can be generated through the Weyl formalism for static metrics.

21. Shear-Free Congruences, Null Surfaces, and What Next? by Ivor Robinson and Joanna Robinson, The University of Texas at Dallas, 12661 Coventry Road, Dallas, Texas.

Abstract - The authors discuss attempts to obtain analytic solutions to Einstein's equations for empty-space. They show how several distinct approaches have recently been combined and speculate on the possibilities for future development.

22. Algebraic Implications of New Gravitational Effects from General Relativity by Mendel Sachs, Department of Physics and Astronomy, State University of New York at Buffalo.

Abstract - Tracing the development of theories of gravitation, the author sees that the ideas about space, time and interactions, that underlie general relativity's superseding the Newtonian theory, have not yet been fully exploited. To the geometrical logic of space-time of general relativity theory must be added its algebraic logic. The symmetry group implies a factorization of Einstein's equations into a more general formalism (that entails 16, rather than 10 relations in space-time) and expression for equations of motion. The generalization implies the necessary use of a quaternion number (rather than a real number) algebra in the expressions of the laws of nature.

23. Gravitational Time by R. Skinner and C.C. Carbno, Department of Physics, University of Saskatchewan, Saskatoon, Canada S7N OWO.

Abstract - A method is given for determining gravitational time along a path in a space-time with projective and conformal structures. The method is a generalization of those of Marzke and Wheeler and Ehlers. It is shown that gravitational time can be defined only if the projective connection and a metric representative of the conformal equivalence class are related through sixteen conditions.

24. Generally Covariant Definition of Positive Frequency Solutions of the Wave Equation for Massless Particles by Andrzej Staruszkiewicz, Institute of Physics, Jagellonian University, Cracow, Poland.

Abstract - If s solution of the wave equation has a branching point at a null surface, then there are two and only two ways to extend the solution analytically across the null surface: the phase of a null coordinate, assumed zero for positive values of the coordinate, may be chosen $+\pi$ or $-\pi$ for negative values of the coordinate. It is shown that in the Minkowski space-time there exists a sufficiently general set of solutions for which the first choice gives negative frequency solutions while the second one gives positive frequency solutions. Moreover, the set of solutions having this property can be defined by a construction prescription which remains meaningful in an arbitrary space-time which does not have closed time-like lines and/or other global peculiarities. This allows to give a generally covariant definition of positive frequency solutions of the wave equation.

25. Axisymmetric Accretion Flows Very Near Black Holes and Rosen Collapsed Objects by William R. Stoeger, S.J., Department of Physics and Astronomy, University of Maryland College Park, Maryland 10742

Abstract - Motivated by the need for stronger observational leverage on the black hole hypothesis and for a more detailed characterization of axisymmetric accretion flows across the marginally stable circular orbit at r_{ms}, the author develops a general approach for describing the non-Keplerian accretion in the region $r_H \leq r \leq r_0$, where $r_H \equiv$ radius of the event horizon and $r_0 \geq r_{ms}$. The procedure used possesses many advantages, including easily imposed consistency with the Keplerian model for $r > r_0$, the avoidance of ad hoc boundary conditions ar r_{ms} and/or at r_H, and its application also to accretion in Rosen's bi-metric theory, whose spherically symmetric solution has the same qualitative orbital topography as that of general relativity. It becomes apparent, furthermore, that the particular viscosity law chosen in our procedure will have a crucial bearing on the flow in the region $r_{ms} < r < r_0$.

26. The Steady State Universe Revisited with Stochastic Electrodynamics as a Guide by M. Surdin, Universite de Bordeaux I 33405 Talence France.

Abstract - The steady state universe is considered in the light of Stochastic Electrodynamics. It is shown that the cosmic background radiation and the continuous creation of matter are rather well accounted for. Several other topics such as the anomalous redshifts and the diffuse gamma ray background are considered with interesting results.

27. Stability of Gravitational Systems by Victor Szebehely, University of Texas, Austin, Texas.

Abstract - A method is proposed to establish a quantitative measure of stability of gravitational systems. It consists of finding the critical (or bifurcation or catastrophe) value and comparing this with the actual state of the system. Classical triple stellar systems accordingly display strong gravitational stability. Computations show that our Solar system is less stable. Applying the method to the Sun-Earth-Moon system, we find it slightly unstable, supporting the capture origin of the Moon.

28. Unifying Gravity and "All" Other Fundamental Forces by Hidezumi Terazawa, Institute for Nuclear Study, University of Tokyo, Tanashi, Tokyo 188, Japan.

Abstract - A way to unify gravity and "all" other fundamental forces including strong, weak, and electromagnetic ones is discussed, based on a nonlinear fermion Lagrangian model of the Nambu-Jona-Lasinio type. It is emphasized that, given a set of fundamental fermions, the leptons and quarks, a single parameter, the Newtonian gravitational constant, is enough to determine not only all the other coupling strengths including the fine-structure constant and the strong, semi-weak, and Fermi coupling constants, but also the Weinberg angle and the weak-boson masses.

29. Causally Symmetric Spacetimes by Frank J. Tipler, Department of Physics and Astronomy, University of Maryland, College Park, Maryland 20742.

Abstract - Causally symmetric spacetimes are spacetimes with $J^+(S)$ isometric to $J^-(S)$ for some set S. The author discusses certain properties of these spacetimes, showing for example that if S is a maximal Cauchy surface with matter everywhere on S, then the spacetime has singularities in both $J^+(S)$ and $J^-(S)$. He also considers totally vicious spacetimes, a class of causally symmetric spacetimes for which $I^+(p) = I^-(p) = M$ for any point p in M. Two different notions of stability in General Relativity are discussed, using various types of causally symmetric spacetimes as starting points for perturbations.

30. The Third Integral of the Galaxy by Ferdinand Verhulst, Department of Mathematics, Imperial College, London, SW7 2BZ, U.K.

Abstract - Galaxies with an axisymmetric gravitational field which is symmetric with respect to the galactic plane are studied by considering the differential equations for the characteristics of the Liouville equation. From Birkhoff normal forms of the equations, obtained by averaging procedures, it is shown that in general no third integral exists although the system is non-ergodic. The bifurcations which are found correspond with axially-symmetric wave forms of the distribution function. Moreover it is argued that a slight deviation from symmetry with respect to the galactic plane triggers off the existence of a third integral in the solar neighbourhood.

31. The Ultimate Test of General Relativity? by Clifford M. Will, Institute of Theoretical Physics, Department of Physics, Stanford University, Stanford, California 94305.

Abstract - The binary system containing the pulsar PSR 1913+16 may provide the ultimate test of general relativity. Observations of secular changes in the orbital period of the system can test the existence of dipole gravitational radiation. The author presents and discusses a conjecture that among all possible viable theories of gravitation, only general relativity predicts no such dipole gravitational radiation. Evidence against this effect would thus yield a conclusive verification of general relativity.