GRAVITY RESEARCH FOUNDATION

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Abstracts of Award Winning and Honorable Mention Essays for 1980

Award Winning Essays

First Award - A Neutrino Dominated Universe By D.N. Schramm, Enrico Fermi Institute, University of Chicago, Chicago, Illinois; and Gary Steigman, Bartol Research Foundation, University of Delaware, Newark, Delaware, 19711.

Abstract - Relic neutrinos produced during the early evolution of the Universe will be abundant today ($n_\nu \sim n_\gamma$) and, if they have a small mass ($3 \lesssim m_\nu \lesssim 10$ eV), may supply the dominant contribution to the total mass density. We review the data on the mass on various scales (galaxies, binaries, small groups, large clusters) and conclude that ordinary matter (nucleons) is capable of accounting for the inferred mass on all scales except that of clusters of galaxies. Were the mass in clusters mainly in nucleons, too much helium and too little deuterium would have been produced during primordial nucleosynthesis. Relic neutrinos with $m_\nu \gtrsim 3$ eV are heavy enough to collapse into clusters of galaxies; for $m_\nu \lesssim 10$ eV they are too light to collapse along with binaries and small groups. Such neutrinos would supply the dominant contribution to the mass in the Universe.

Second Award - Soliton Concept in General Relativity by G. Neugebauer and D. Kramer, Sektion Physik der Friedrich-Schiller-Universität Jena, DDR-69 Jena, Max-Wien-Platz 1.

Abstract - Soliton physics has made considerable progress in solving non-linear problems. This paper is meant to relate the soliton concept to the stationary axisymmetric vacuum fields in General Relativity. The authors present a functional transformation which, working as a non-linear creation operator, generates gravitational fields of isolated sources. When applied to flat space-time ('gravitational vacuum') this operation leads to a non-linear superposition of an arbitrary number of Kerr particles. This superposition also includes the Tomimatsu-Sato fields. The functional transformations form an infinite-parameter group which contains the Kinnersley-Geroch group as a subgroup.

Third Award - Towards a Non-Friedmannian Universe by Roberto Fabbri, Istituto di Fisica Superiore, University of Florence, 50127 Florence, Italy; and Francesco Melchiorri, Istituto di Ricerca sulle Onde Elettromagnetiche, CNR, 50127 Florence, Italy.

Abstract - The authors present the result of an experiment of the Florence group which has detected a quadrupole anisotropy in the cosmic background radiation. They show that this result implies that the Universe either has large metric perturbations outside the particle horizon, or will become largely irregular in the future.

Fourth Award - Quantum Cosmology and Geometric Quantization by James A. Isenberg, Department of Applied Mathematics, University of Waterloo, Ontario, Canada N2L 3G1; and Mark J. Gotay, Department of Mathematics and Statistics, University of Calgary, Alberta, Canada T2N 1N4.

Abstract - The Kostant-Souriau method of geometric quantization is applied to homogeneous and isotropic cosmological models with positive intrinsic curvature and a massless Klein-Gordon scalar field. These models are studied because classically they collapse to a singularity. It is rigorously shown that the quantized models collapse as well (so that there is no "quantum bounce"). This work demonstrates the practical usefulness of geometric quantization for the study of physical systems.

Fifth Award - The Atom As a Probe of Curved Spacetime by Leonard Parker, Physics Department, University of Wisconsin-Milwaukee, Wisconsin 53201.

Abstract - A one electron atom is considered in a general curved spacetime. The Hamiltonian of the Dirac equation is written in Fermi normal coordinaates, including all interaction terms of first order in the Riemann tensor of the spacetime. Expressions are obtained for the shifts in various atomic energy levels caused by the curvature. There is a possibility that these shifts would be observable in the spectrum of Hydrogen falling into small black holes (radius about 10^{-3}cm) left over from the early universe.

Honorable Mention Essays (Alphabetical Order)

1. A Gravitational Entropy? by John D. Barrow, Department of Astrophysics, Oxford University, South Parks Road, Oxford, U.K.

Abstract - Hawking has shown that certain pure gravitational fields possess a thermal entropy and an intrinsically thermodynamic structure. The author examines the idea that there also exists a geometrically defined gravitational entropy for cosmological space-times. This hypothesis is shown to possess many appealing interconnections with existing results in relativistic cosmology together with a number of consequences which are testable by observation.

2. Is Quantum Gravity Finite? by M.R. Brown, Department of Astrophysics, South Parks Road, Oxford, OX1 3RQ.

Abstract - The author presents a formulation of quantum gravity that is finite when calculated to any given order in the Planck length. He further argues that when this picture of the local structure of space-time is incorporated in other quantum field theories, Q.E.D. for example, there is no longer any ultra-violet divergence problem and these theories are rendered finite.

3. The Double Quasar 0957 + 561 as a Gravitational Test Probe by B.F. Burke, P.E. Greenfield, and D.H. Roberts, Massachusetts Institute of Technology.

Abstract - The radio source 0957+561 is associated with a pair of quasars only 6" apart. The quasars have apparently identical redshifts, and have been proposed as an example of the gravitational "lens" effect of an intervening massive object.

A synthesis of radio and optical data supports this model, and all serious objections presently seem to be resolved. The optical data show the distribution of mass in the form of stars, and form the basis for a priori predictions. The radio maps may not agree with the predictions in detail, and the anomalies should provide evidence for "hidden mass" in galaxies and clusters of galaxies and clusters of galaxies. Measurements of time variations of the fluxes of the two quasars should provide a new class of cosmological measurement.

4. Angular Momentum Distribution In Relativistic Accretion Discs by M. Camenzind, Institut für Theoretische Physik, Universität Zürich.

Abstract - The standard accretion discs around black holes and non-magnetized neutron stars are based on a given angular momentum distribution, $j = j_{Kep} = (MR)^{1/2}$ in the Newtonian limit. The author discusses here the alternative fluid approach for accretion models of the inner disc. The specific energy E and the specific angular momentum distribution J determine the structure of the disc, in analogy to rotating Newtonian stellar models. The relativistic transport equations for the quantities E and J are derived for general viscous and conductive matter. The author discusses the effectivity of viscous and conductive dissipation of angular momentum and the possible occurrence of convection.

5. The Variation of G: A Modern Look by V.M. Canuto, NASA Goddard Institute for Space Studies, Goddard Space Flight Center, New York, NY 10025.

Abstract - In this paper the author takes up the question of the possible variation of the gravitational constant, G, with cosmological time. He first shows that the old criticism by Teller and Gamow is unfounded. Then he presents a new motivation for this old idea as well as a new formalism, specifically constructed to account for it. Applications of the new theory to cosmology, astronomy and geophysics then follows. The global result is that nowhere is the variation of G ever found to contradict any of the data analyzed so far.

6. Unique Determination of the Classical Equation of State by Self-Gravitation by John Bruce Davis, CIRES, University of Colorado/NOAA, Boulder, CO 80309.

Abstract - By considering an isothermal self-gravitating body in equilibrium and thus at a minimum of internal energy, a new field equation is obtained governing pressure, density, and the self-gravitational field. An asymptotic method of solution of this new equation coupled with the hydrostatic equation and the Poisson equation of self-gravitation is described. The solution yields the unique determination of the classical equation of state, the only information input being the density and bulk modulus of the material at one particular pressure.

7. Bouncing Quantum Cosmologies by Jacques Demaret, Institut d'Astrophysique, Université de Liège, B 4200 Cointe-Ougree, Belgium.

Abstract - Spatially homogeneous cosmological models of Bianchi types I, V and IX (as well as their isotropic counterparts: the Einstein-de Sitter, open and closed Friedmann-Robertson-Walter (FRW) models, respectively), filled with a perfect fluid with an equation of state of the type $p = (\gamma-1)\rho$ (γ = constant comprised between 1 and 2) are quantized in the framework of an ADM-type canonical

quantization scheme introduced by Demaret and Moncrief.

This method which generalizes a method due to Lund and originally restricted to space-times filled with a pressureless fluid ($p = 0$) is based on Schutz's Hamiltonian theory of a relativistic perfect fluid, extending to general relativity Seliger and Whitham's velocity-potential version of classical hydrodynamics. It leads to a Schrodinger-like equation for the wave function of the universe, which admits a true physical interpretation in terms of probability as in orthodox mechanics.

Contrary to Misner's early results based on a different quantization scheme, the method used here leads to the conclusion that, apart from a set of measure zero of models comprising FRW models as well as Bianchi models filled with a fluid with a stiff equation of state ($p = \rho$), all Bianchi models are non-singular, in the sense that the quantum wave function becomes zero at the classical singularity. Such a non-singular model can be interpreted as a contracting universe bouncing into an expanding universe, due to quantum gravitational fluctuations. A similar conclusion of non-singularity of a quantum Bianchi I universe has recently been obtained by Narlikar by using a different method of quantization, i.e the method of path integration.

8. <u>A Scalar Geodesic Deviation Equation and a Phase Theorem</u> by P. Dolan and P. Choudhury, Imperial College, Department of Mathematics, United Kingdom.

<u>Abstract</u> - A scalar equation is derived for η, the distance between two structureless test particles falling freely in a gravitational field: $\ddot{\eta} + (k - \Omega^2)n=o$ An amplitude, frequency, and a phase are defined for the relative motion. The phases are classed as elliptic, hyperbolic and parabolic according as $K-\Omega^2 > 0, < 0, = 0$. In elliptic phases the authors deduce a positive definite relative energy E and a phase-shift theorem. The relevance of the phase-shift theorem to gravitational plane waves is discussed.

9. <u>Galaxies as Gravitational Lenses: Realistic Models</u> by C.C. Dyer and R.C. Roeder, Scarborough College and Dept. of Astronomy, University of Toronto, West Hill, Ontario, Canada, M1C 1A4.

<u>Abstract</u> - The gravitational lens effects associated with a transparent mass distribution are quite different from those of the well-known opague sphere. The authors have shown that any spherical galaxy whose distribution of mass, when projected onto the plane of the sky, decreases outward from the centre of the galaxy and diverges less rapidly than $1/h$ as $h \longrightarrow 0$, must always produce an odd number of images, usually one or three, of a source located behind the galaxy. Using optical scalar techniques, the amplification of each image can readily be obtained. For a given source and galaxy, the authors define a dimensionless focal length, a function of impact parameter, and a dimensionless distance factor, depending on lens parameters and source distance. The central value of the ratio of these quantities determines the multiplicity of the images. The mass distribution of the galaxy is a crucial function, and in the case of the observation of the lens effect in the double quasar, 0957+561A,B the authors show that the mass distribution must be that given by the so-called "King model". Thus the observation and theory of the lens effect in transparent distributions have combined to allow the determination of the large-scale structure of a galaxy too distant to be studied in great detail.

10. Galactic Nuclei Without Supermassive Black Holes by Martin J. Duncan, Center for Radiophysics and Space Research, Cornell University and J. Craig Wheeler, Department of Astronomy, University of Texas at Austin.

Abstract - Observations of elliptical galaxies which show a rise in stellar density and velocity dispersion toward the center may not require the presence of supermassive black holes. In collisionless stellar systems a radial bias in the velocity distribution can be maintained which reproduces the luminosity and velocity dispersion profiles. Detailed spherically symmetric numerical models incorporating cosmological infall which pay particular attention to the details of the innermost core give a good fit to the velocity distribution without requiring a supermassive black hole. The rise in the luminosity is somewhat too shallow in the inner regions, but this problem may be solved by removing the restriction of spherical symmetry.

11. Quantum Mechanics as a Classical System--An Approach to Gravitizing Quantum Mechanics, by Edwin Ihrig, Department of Mathematics, Arizona State University, Tempe, Arizona 85281.

Abstract - The relationship between using a coordinate free method of finding the free particle Hamiltonian and introducing gravity into a classical theory is discussed. Quantum Mechanics is formulated as a classical theory to provide a possible framework for introducing a gravity into microscopic physics.

12. Microwave Radiation and The Age of the Universe by P.S. Joshi, Tata Institute of Fundamental Research, Bombay 400 005, India.

Abstract - It is shown that the presence of microwave background radiation in a general relativistic spacetime universe implies a finite upperbound to the extension of any timelike curve in the past; each timelike curve is past b-incomplete. These considerations provide upperbound to the age of the universe which is obtained using the local observations concerning the microwave radiation energy density.

13. The Global Existence Problem and Cosmic Censorship in General Relativity by Vicent E. Moncrief, Department of Physics, Yale University, New Haven Connecticut, and Douglas M. Eardley, Institute for Theoretical Physics, University of California, Santa Barbara, California.

Abstract - The Cosmic Censorship Conjecture is the biggest open question in classical general relativity. It states that naked singularities do not evolve from regular initial conditions and may be formulated for either isolated systems or cosmological spacetimes. In this essay the authors reformulate the conjecture as a global existence problem for Einstein's equations. In this form the conjecture is amenable to a definite analytical attack using techniques of modern global analysis. As an example of the facility of their ideas the authors prove one of their conjectures for a special (though infinite dimensional) class of spacetimes.

14. Quantum Gravitational Effects in the Laboratory by C. Mukku, Department of Mathematics, Imperial College, London SW7 2BZ, U.K., and W.A. Sayed, Blackett Laboratory, Imperial College, London SW7 2BZ, U.K.

Abstract - Some interesting consequences of the effects of gravitation and finite temperature on quantum field theory are presented which have important implications for experimental high energy physics and the status of the "No-Hair" Conjecture for black holes. The authors point out two consequences for laboratory situations in high energy physics which disprove the usual assertion that quantum gravi-

tational effects are only important at planckian energies. The first of these is that beams of particles in circular accelerators cannot be cooled to below a certain temperature determined simply by the accelerator's radius, while the second shows that spontaneously broken gauge symmetries may be restored by quantum gravitational effects. The authors end by describing briefly circumstances under which these effects might have a bearing on the "No-Hair" conjecture.

15. Performance of Accelerated Detectors by T. Padmanabhan, C-337, Theoretical Astrophysics Group, Tata Institute of Fundamental Research, Homi Bhabha Road, Bombay 400 005, India.

Abstract - The question of detection of particles by an accelerated detector is analysed. It is shown that when the acceleration vanishes at least asymptotically, there are no spurious effects. A discussion of limitations imposed on the detector's acceleration because of the uncertainty principle is presented. This is used to analyse the previous investigations in this field.

16. Thin Charged Shells, Cosmic Censorship and the Laws of Black Hole Mechanics by M. Prószyński, Institute of Theoretical Physics, Warsaw University, Hoza 69, 00-681 Warsaw, Poland.

Abstract - The collapse of a thin spherical shell of charged matter which surrounds a spherically symmetric black hole or has a flat interior is analysed in connection with the cosmic censorship and the laws of black hole mechanics. A notion of an effective potential is introduced to describe the development of the shell. Neither the second law nor the cosmic censorship can be violated when the shell implodes from infinity. The violation of the third law is discussed.

17. The Closure of the Universe and Upper Limits on Micro-Mini Black Holes by Tony Rothman and Richard A. Matzner, Relativity Center, University of Texas at Austin, Austin, TX 78712.

Abstract - In the past several years, a variety of techniques has been used to put upper limits on the possible number of black holes in the Universe . The masses considered ranged from $10^{18} M_o$ down to the canonical mini black hole of 10^{15} grams. Black holes emitting particles have a lifetime $\tau(\text{sec}) \sim 10^{-26} M^3(\text{gm})$. Thus 10^{15} gm holes are evaporating now and smaller holes would have disappeared before the present era. Any upper limits placed on such holes would necessarily be very indirect. Further any statement about particle emission from smaller holes is suspect, as no particle theory exists at such high energies. Nevertheless, Novikov et al suggested that limits might be placed on holes in the mass range 10^{9}-10^{10} grams (truly micro-mini black holes: μmBH,) which would have evaporated approximately 100 seconds after the Big Bang, during the era of nucleosynthesis of the light elements. Particles injected by such holes into the background effect the final nucleo-synthesis abundances of ^{4}He and deuterium. By predicting the final abundances of ^{4}He and deuterium, as a function of black hole density, one places upper limits on μmBH's by comparison with the observed abundances of these isotopes. The essay is based upon that suggestion.

Computer calculations of nucleosynthesis show that the black holes that explode before the age of the universe reaches 1000 seconds can change deuterium abundances. In particular, if such black holes were present, the limits of Gott et al indicating an open universe no longer hold, and the observed deuterium is compatible with a closed universe.

18. The Sign and Magnitude of the Constant of Gravity in General Relativity by Ian W. Roxburgh, Queen Mary College, University of London.

Abstract - The magnitude and sign of the constant of gravity in the general theory of relativity are usually considered to be undetermined by the theory and are chosen so that in the weak field limit the theory reduces to Newtonian theory and is therefore in agreement with empirical results about the world. It is here emphasized that the weak field limit is really the Universe plus a localized source, and an analysis of this problem demonstrates that in general relativity the constant of gravity is necessarily positive and is determined by the large scale distribution of matter in motion. The significance of this result is highlighted by comparison with a scalar theory where gravity is shown to be necessarily repulsive. The relationship between these results and the usual interpretation of general relativity is discussed and the differences are resolved by an analysis of the interpretation of the equations governing possible cosmological models.

19. Path Integral and Gravitational Radiation Damping by G. Schäfer and H. Dehnen, Fakultät für Physik der Universität Konstanz D-7750 Konstanz, Postfach 5560, West Germany.

Abstract - The energy loss of a bound quantum mechanical matter system due to gravitational damping is calculated in Feynman's path integral formalism. The classical limit is discussed confirming the classical quadrupole radiation formula exactly.

20. Electromagnetic-Gravitational Energy Systems by Kenneth H. Schatten, Laboratory for Planetary Atmospheres, NASA/Goddard Space Flight Center, Greenbelt, MD 20771.

Abstract - Two methods are considered to "tap" the earth's rotational energy formed from ancient "collapsed gravitational energy". One involves an orbiting "electromagnetic-gravitational" coupling system whereby the earth's rotation,

with its non-uniform mass distribution, first uses gravity to add orbital energy to a satellite, similar to a planetary "flyby". The second stage involves enhanced satellite "drag" as current carrying coils withdraw the added orbital energy as they pass through the earth's non-uniform magnetic field. A second more direct method couples the earth's rotational motion using conducting wires moving through the non-corotating part (ionospheric current systems) of the geomagnetic field. These methods, although not immediately feasible, are considerably more efficient than using pure gravitational coupling to earth-moon tides.

21. The Decay of the Gravitational Field by B.G. Schmidt, Max-Planck-Institute for Physics and Astrophysics, Garching (FRG).

Abstract - A new interpretation of the Einstein-Rosen waves is given, in which the two-parameter group acts globally as boosts in the t-z-plane and as rotations in the x-y-plane of Minkowski-space. This way exact solutions of Einstein's vacuum equations are presented, which have the asymptotic behaviour of the interior of a null cone in Minkowski-space, i.e. they admit a part of $\mathcal{I}^+$ and a regular I^+ as conformal boundary at infinity. Hence, it is demonstrated that gravitational wave solutions exist which decay in the way formulated by the $\mathcal{I}$-picture. The regularity of I^+ implies that the Bondi mass tends to 0, i.e. the field decays completely through $\mathcal{I}^+$.

22. Black Holes and Quantum Gravity by Robert M. Wald, Enrico Fermi Institute, University of Chicago, Chicago, IL 60637.

Abstract - The investigation of particle creation by black holes initiated by Hawking has provided an important theoretical testing ground for ideas on quantum effects occurring in strong gravitational fields. In a rather remarkable way, it recently has led to developments which lie at the foundations of thermodynamics and quantum theory. Further investigations may well point the way to fundamentally new elements occurring in the quantum theory of gravitation.

23. Gravitational Radiation From an Orbiting Pulsar by Joel M. Weisberg and Joseph H. Taylor, Five College Radio Astronomy Observatory and Department of Physics and Astronomy, University of Massachusetts, Amherst.

Abstract - The authors describe an experiment which establishes, with a high degree of confidence, the existence of gravitational radiation as predicted by general relativity. The experiment involves observations of binary pulsar PSR 1913 + 16, measurements of which now reveal a rate of change of orbital period within about fifteen per cent of that predicted by the general relativistic "quadrupole formula." The authors show that the gravitation theories of Rosen, Ni, and Lightman-Lee predict an orbital period increase, regardless of the relative masses of the pulsar and its (assumed compact) companion. The Brans-Dicke theory predicts a much more rapid period decrease than does general relativity, unless the masses and internal structures of the two bodies are very similar. Thus, in the absence of additional *ad hoc* assumptions, general relativity is the only well studied theory of gravity consistent with the data.

24. Quantum Mechanical Interference Induced by Gravity and Inertia by Samuel A. Werner, Department of Physics, University of Missouri, Columbia, MO ; Roberto Colella, Department of Physics, Purdue University, Lafayette, IN; Jean-Louis Staudenmann, Ames Laboratory, Iowa State University (working at Oak Ridge National Laboratory); and Albert W. Overhauser, Department of Physics, Purdue University, Lafayette, IN.

Abstract - The experiments described in this paper probe the simultaneous effects of gravity, inertia and quantum mechanics on the motion of the neutron. Using a neutron interferometer of the type developed by Bonse and Hart for x-rays we have observed quantum mechanical interference phenomena induced by the gravitational field of the Earth and by the Earth's rotation relative to the fixed stars. The importance of these experiments with regard to the role of the principle of equivalence in quantum mechanics is discussed.

25. Two Kinds of Rotation: An Argument for Torsion by Philip B. Yasskin, Department of Physics, Harvard University, Cambridge, MA 02138.

Abstract - There are now many theories of gravity with a torsion field as well as the usual metric field. One of the arguments for allowing torsion is based upon a gauge theory analogy. The purpose of this essay is to clarify exactly which symmetries are being gauged in this process. The principle observation is that special relativity is invariant under two different kinds of Lorentz transformations. The first type rotate the fields and move them from one point to another in space-time. The second type merely rotate the fields at each point without changing their location. To gauge both types of rotations requires a torsion field as well as a metric field.