GRAVITY RESEARCH FOUNDATION
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Abstracts of Award Winning and Honorable Mention Essays for 1971

Award Winning Essays

<u>First Award</u> - Black Holes by Stephen W. Hawking, Institute of Theoretical Astronomy, University of Cambridge, Cambridge, England.

<u>Abstract</u> - It is assumed that the singularities which occur in gravitational collapse are not visible from outside but are hidden behind an event horizon. A black hole on a spacelike surface is defined to be a connected region on the surface bounded by the event horizon. As time increases, black holes may merge together but may never bifurcate. The areas of the boundaries of the black holes can never decrease. These areas are related by the Carter-Israel conjecture to the masses and angular momenta of the black holes. Together with the previous results this gives upper bounds on the amount of energy that can be extracted from the black holes. In particular, if the bursts of gravitational radiation that Weber reports are produced by collisions of black holes, then the black holes must have masses at least a hundred times that of the sun.

<u>Second Award</u> - The Role of Rotation in the Conversion of Gravitational Energy by P.A. Sturrock, Institute for Plasma Research, Stanford University, Stanford, California.

<u>Abstract</u> - It is believed that gravitation provides the enormous energies released explosively in quasars (and radio galaxies), and the high nonthermal luminosities of quasars (and Seyfert Galaxies). A model of quasars is proposed in which both types of energy conversion take place. The model comprises a rapidly rotating nucleus in a slowly rotating nebula, the two components being coupled by a magnetic field. Differential rotation leads to the formation of an open field configuration with current sheets. The open-field pattern leads to an explanation of explosions as "galactic flares", and the current sheets produce the nonthermal luminosity by synchrotron radiation.

<u>Third Award</u> - Black Holes: The Strongest Energy Storehouse in the Universe by Demetrios Christodoulou and Remo Ruffini Joseph Henry Laboratories, Princeton University, Princeton, New Jersey.

Abstract - Recent theoretical advances have clearly put in evidence that black holes in addition to being the only astrophysical objects that are fully describable by general relativity alone are the strongest storage of energy in the universe. In this paper, the authors give a new formula establishing for the first time the energetics limit of a black hole (50% of the total mass energy can be extracted from a black hole!). They also give two new mechanisms of extraction of energy of unprecedented efficiency. They briefly discuss the singularity problem in a realistic black hole.

Fourth Award - A New Test for Gravitational Binding of Galaxy Clusters by Donald Goldsmith and Joseph Silk, Department of Astronomy, University of California, Berkeley, California.

Abstract - The discrepancy between the gravitational binding mass and the observed mass of clusters of galaxies poses a formidable problem for attempts to apply gravitation theory over cosmological distances. The authors describe a new test to determine whether the Coma cluster of galaxies forms a gravitationally bound system. Recent analyses have shown that the "missing mass" required to bind the cluster should be present in the form of diffuse, hot gas. The authors have calculated the emission from this gas, and show that new ultraviolet observations of Lyman alpha radiation can finally determine the parameters of the elusive intergalactic gas. Such observations are now within technological capability.

Fifth Award - Essay on Physical Processes in a Symmetric Universe by Roland Omnes, Faculté des Sciences, University of Paris, Batiment 211, 91 Orsay, France.

Abstract - This essay describes the results which have been obtained up to now in a discussion of the physical processes which should occur in a symmetric universe (containing as much matter as antimatter). They include the discovery of a separation mechanism between nucleons and antinucleons in thermal radiation at high temperature. Another new effect, which is related to the Leidenfrost mechanism concerns the hydrodynamical coalescent behavior of matter and antimatter. Quantitative applications to the problem of the origin of matter and galaxies are given. Other astrophysical applications still under investigation are sketched with a view to unequivocal experimental tests.

Honorable Mention Essays (Alphabetical Order)

1. Do Black Holes Have a Baryon Number? by Jacob D. Bekenstein, Joseph Henry Laboratories, Princeton University, Princeton, New Jersey.

Abstract - A current conjecture of gravitation theorists is that black holes are fully described by their mass, charge, and angular momentum. Black holes are thought to arise from stars whose bulk is made up of baryons. Thus one might think that black holes should also have a baryon number. A field theoretical argument is sketched which shows this is not so. It also shows that the strong interactions are turned off in the realm of black holes. This implies that one might profit by studying elementary particles from the viewpoint of black hole physics.

2. A Macroscopic Vortex Model of the Electron Where Equilibrium, Which Produces Virtual Spin 1/2, Is Provided by Gravity by Winston H. Bostick, Stevens Institute of Technology, Hoboken, New Jersey.

Abstract - A macroscopic vortex model of the electron based on the inertial waves of fluid mechanics is held in equilibrium by the earth's gravitational field. The model exhibits de Broglie waves, satisfies the relativistic generalization of the Schroedinger wave equation, has virtual spin of 1/2, and has the $1+\frac{\alpha_v}{2\pi}$ correction to the virtual gyromagnetic ratio, and can show a virtual lack of conservation of parity.

3. Gravitation, Rotation, and High Energy Astrophysics by Kenneth Brecher, Department of Physics, University of California, San Diego, California.

Abstract - The release of the gravitational binding energy of dense, magnetized, rotating astronomical objects by the transfer of their rotational kinetic energy to the surrounding medium is considered. The high effective temperature of such objects naturally leads to the efficient production of energetic particles and magnetic fields. Non-thermal radiation and mass ejection also follow, suggesting a single gravitational-rotational approach to the fundamental physics of pulsars, quasars, and galactic nuclei.

4. Rotational Energy in General Relativity by Jeffrey M. Cohen, Institute for Advanced Study, Princeton, New Jersey 08540.

Abstract - A simple positive definite expression is given for the rotational energy of a slowly rotating star in general relativity. To second order in the angular velocity ω of the body, it is shown that in general relativity, the usual Newtonian relation between angular momentum J of a uniformly rotating body and rotational energy E_{rot} holds i.e. $J/\omega = 2E_{rot}/\omega^2$. It is also pointed out that the mass of the Crab pulsar is larger than 0.4 solar masses.

5. The Geometry of the Einstein Evolution Equations by Arthur E. Fischer and Jerrold E. Marsden, Department of Mathematics, University of California, Berkeley, California 94720.

Abstract - In this essay the geometrical meaning of the Einstein equations of evolution is explored from a modern point of view. Using methods of global analysis and infinite-dimensional geometry, several difficulties of the more traditional formulations are remedied. The essence of our method is to extend the usual configuration space M to TxDxM. The lapse function N_t and shift vector field X_t then enter naturally as velocities canonically conjugate to the configuration fields $(\xi,\eta)\varepsilon TxD$. Using these methods, the authors give a satisfactory geometric interpretation of various terms which appear in the Einstein system. The maintenance in time of the constraint equations appears in a natural way as conservation laws associated with dynamical symmetries, and explicit relationships are given for evolutions with differing prescribed lapse functions and shift vector fields.

6. The Origin of Cosmic Nonuniformity by Ray Hively, Department of Physics, Harvard University, Cambridge, Massachusetts and David Layzer, Harvard College Observatory, Cambridge, Massachusetts.

Abstract - The observation that gravitational clustering extends over a mass range of 20 decades suggests that the expanding cosmic medium is strongly unstable against the growth of local density fluctuations. Yet a purely gravitational theory cannot account for such an instability. This essay reports a new development in the cosmogonical theory based on the assumption that the cosmic expansion began from an initial state of global thermodynamic equilibrium at zero temperature. Detailed calculations of the subsequent evolution indicate that by the time its density has dropped to 100 gm/cm^3, the medium has changed from a fluid to a metallic solid. When its density has dropped to somewhat less than half the density of water, the medium shatters into fragments with masses of up to 10^{27} gm. Smaller fragments rapidly coalesce into fragments of this size. The cosmic medium then becomes unstable against the growth of local density fluctuations which, calculations show, develop into self-gravitating systems with properties similar to those of actual astronomical systems. The authors conjecture that a large fraction of the mass in the universe may still be in the form of subplanetary solid masses consisting mainly of hydrogen and helium. This might account for the well-known discrepancies between "dynamical" and "observed" masses estimated for our own galaxy, for certain galaxy clusters, and for the universe as a whole.

7. New Approaches to Statistical Dynamics of the Developing Solar System by Herbert Jehle, Physics Department, George Washington University, Washington, D.C. 20006.

Abstract - The distribution of orbital elements of the planets in the solar system, and also of the elements of the satellites of the major planets show distinct regularities. One of them, the commensurability of the periods of revolution, has been repeatedly discussed. Another, the small eccentricities and inclinations, has found a simple explanation in the Kant-du Ligondés Hypothesis of the development of the solar system. Still another one, concerning the distribution of the semi-major axes (or periods) has found a numerological formulation in the Titius-Bode Law, and its explanation has been attempted in terms of distribution of vortex rings in the early stage of the Kant-du Ligondés model. The author here proposes a simpler analysis of the regularities in this distribution of the semi-major axes. Instead of discussing the issue in terms of perturbation expansions, of individual orbits, it may be more advantageous to pursue the analysis in terms of the statistical distribution of integrals of the equations of motion, in particular the Jacobi integral. As regards the formulation of the development of such a statistical distribution, the cardinal point of the present paper is made in the "alternative discussion": It is the recognition that equations of motion (i.e., the continuity equation and the Bernouilli equation for the motion of a system of mass points in gravitational interaction) are best and most advantageously formulated in terms of a Schroedinger-type equation in which the h^3 characterizing the uncertainty principle is replaced by a macroscopic phase-space volume which characterizes the coarse-grainedness of the mass distribution in phase-space.

8. The Quantization of Mass (or Gravitational Charge) by L. Motz, Rutherfurd Observatory, Columbia University, New York, New York.

Abstract - In a previous paper (referred to as I in the text) it was shown that the Weyl Principle of Gauge invariance leads to the relationship $Gm^2 = \hbar c$ for a particle of inertial mass m obeying the Dirac equation, where G is the Newtonian gravitational constant. Instead of interpreting this equation to mean that G takes on the extremely large value $\hbar c/m^2$ inside a particle like an electron (as was done in I), the author rewrites it in the form $Gm^2/c = \hbar$ and treats it as a quantization condition on the square of the gravitational charge $\sqrt{G}m$. He shows that this same quantization condition can be obtained from the Machian definition of inertial mass in a rotating universe by using the Dirac-Schwinger procedure for quantizing charge. From this quantization condition he now deduces that the fundamental particle in nature (the uniton) has an inertial mass equal to about 10^{-5} gms. The consequences of the existence of unitons for the structure of elementary particles and cosmology are discussed.

9. The Effect of Cosmological Expansion on Self-Gravitating Ensembles of Particles by Peter D. Noerdlinger, NASA Ames Research Center, Moffett Field, California and Vahé Petrosian, Department of Applied Physics and Institute for Plasma Research Stanford University.

Abstract - The authors study the possible expansion of clusters or superclusters of galaxies, of mean rest mass density ρ_c, immersed in a universe containing a gas of particles having zero rest mass and having energy density ρc^2. The universe may also contain dust. It is shown that when $\rho > \rho_c$, the clusters or superclusters, respectively, expand with the universe; but if $\rho_c >> \rho$, the expansion is reduced in the ratio ρ/ρ_c. It therefore seems unlikely that clusters of galaxies could have formed prior to the epoch corresponding to the redshift $z \approx 2$ if the present value of ρ exceeds 10^{-29} gm/cm^3, unless most of this radiation was generated outside the clusters and subsequent to their formation. Superclusters, if they exist, will follow the expansion of a universe of even lower energy density.

10. Equilibrium Configurations of Rotating Relativistic Stars by J. Pachner and M.J. Miketinac, Department of Physics, University of Saskatchewan Regina, Saskatchewan, Canada.

Abstract - A method for investigating the behavior of an ideal fluid in general relativity, developed in earlier papers, is briefly described and extended to the computation of the equilibrium configurations of a rotating relativistic star in the first approximation. It is found that the spatial distribution of the angular velocity determines the shape of the star. To demonstrate the accuracy of the applied method the equilibrium rest mass of a non-rotating star is calculated and compared with the values given in a previous paper.

11. Causality, Cosmology, and Black Holes by F.A.E. Pirani, Department of Mathematics, King's College, Strand, London, WC2, England.

Abstract - If, as Wheeler has suggested, advanced fields should be expected in a contracting phase of the universe, just as retarded fields are observed in an expanding phase, then perhaps the selection of advanced or retarded fields is mediated by boundary conditions at an initial or final singularity. The same process may operate at local - black hole - singularities as at cosmological ones, so that advanced radiation may be emitted from collapsing objects. The possibility that such radiation, electromagnetic or gravitational, might be observed, and implications for the understanding of causality, are briefly discussed.

12. Quantum Theory of Gravitation and the Mass of the Electron
by Gerald Rosen, Drexel University, Philadelphia, Pennsylvania 19104

Abstract - Gravity-modified quantum electrodynamics formulated by Salam and collaborators is applied to the electron self-energy problem in all orders of perturbation theory. It is shown that the dressed physical mass of the electron is likely to be given by the formula $m = M \exp(-x/\alpha)$ where $M \equiv (\hbar c/16\pi G)^{\frac{1}{2}}$ is the universal quantum-gravitational mass constant, $\alpha = (137.04)^{-1}$ is the fine-structure constant, and $x = (.362)$ is a number to be computed from the details of the theory.

13. Implosions and Emplosions in Supermassive Objects
by Giora Shaviv and Gerald E. Tauber, Department of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel.

Abstract - It is shown that for small velocities the time dependent evolution of massive stars may be described by a series of static models. Those are linked to each other by one continuous time dependent parameter - the relativity effect. The fate of the dynamic system is analyzed by the behaviour of the static models. The method is illustrated for general relativistic polytropes.

14. Non-Equilibrium Processes in a Self-Gravitating Gas
by John M. Stewart, University of Cambridge, Institute of Theoretical Astronomy, Madingley Road, Cambridge CB 3 O EZ, England.

Abstract - Although gravitation seems to be the energy source for many of the violent events in the universe, the usual descriptions of matter are too simple to describe these events. This essay reviews the most general theory presently available of the structure of a self-gravitating gas. The applications discussed include the impossibility of isentropic expansion of a relativistic gas, the infinite velocity paradox of relativistic thermodynamics, and dissipative processes in the early universe. If the universe started with an arbitrary spectrum of primordial inhomogeneities, it is predicted that only fluctuations of about galactic size could survive this epoch.

15. Gravitational Collapse to Kerr-Newman Black Holes
by Robert Wald, Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08540.

Abstract - Stars with mass greater than the critical mass cannot complete their thermonuclear evolution without undergoing gravitational collapse. This essay is concerned with the final spacetime geometry resulting from the complete gravitational collapse of a star (or other body), as determined from the general theory of relativity. A new result is discussed which shows that

if (1) general (non-spherical) gravitational collapse produces black holes and (2) smooth (i.e., analytic) variation of the initial conditions of gravitational collapse causes smooth variation in the properties of the black holes produced by the collapse, then the generic final state of gravitational collapse is a Kerr-Newman black hole, fully specified by its mass, angular momentum, and charge.