# Abstracts of Award Winning and Honorable Mention Essays for 2002

## Award Essays

First Award – Black Holes in the Lab? – by Steven B. Giddings, Department of Physics and SLAC, Stanford University, Stanford, CA 94305/94309.

Abstract – If TeV-scale gravity describes nature, black holes will be produced in particle accelerators, perhaps even with impressive rates, at the Large Hadron Collider. Their decays, largely via the Hawking process, will be spectacular. Black holes also would be produced in cosmic ray collisions with our atmosphere, and their showers may be observable. Such a scenario means the end of our quest to understand the world at shorter distances, but may represent the beginning of the exploration of extra dimensions.

Second Award – The Holography of Gravity Encoded in a Relation between Entropy, Horizon Area and Action for Gravity – by T. Padmanabhan, Inter-University Centre for Astronomy and Astrophysics, Post Bag 4, Ganeshkhind, Pune - 411 007, India.

Abstract – The author provides a general proof of the conjecture that one can attribute an entropy to the area of *any* horizon. This is done by constructing a canonical ensemble of a subclass of spacetimes with a fixed value for the temperature $T = \beta^{-1}$ and evaluating the *exact* partition function $Z(\beta)$. For spherically symmetric spacetimes with a horizon at r = a, the partition function has the generic form $Z \propto \exp[S - \beta E]$, where $S = (¼)4\pi a^2$ and $|E| = (a/2)$. Both $S$ and $E$ are determined entirely by the properties of the metric near the horizon. This analysis reproduces the conventional result for the black-hole spacetimes and provides a simple and consistent interpretation of entropy and energy for De Sitter spacetime. For the Rindler spacetime the entropy per unit transverse area turns out to be (¼) while the energy is zero. Further, the author shows that the relationship between entropy and area allows one to construct the action for the gravitational field on the bulk and thus the full theory. In this sense, gravity is intrinsically holographic.

Third Award – A New Era in High-Energy Physics - by Eun-Joo Ahn* and Marco Cavagilà[+], *Department of Astronomy and Astrophysics, University of Chicago, 5640 S. Ellis Ave., Chicago, IL 60637; [+]Center for Theoretical Physics, Massachusetts Institute of Technology, 77 Massachusetts Ave., Cambridge, MA 02139-4307.

Abstract – In TeV-scale gravity, scattering of particles with center-of-mass energy of the order of a few TeV can lead to the creation of nonperturbative, extended, higher-dimensional gravitational objects: *Branes.* Neutral or charged, spinning or spinless, Einsteinian or supersymmetric, low-energy branes could dramatically change our picture of high-energy physics. Will we create branes in future particle colliders, observe them from ultra high-energy cosmic rays, and discover them to be dark matter?

Fourth Award – An Alternative to Inflation - by Stefan Hollands and Robert M. Wald, Enrico Fermi Institute and Department of Physics, University of Chicago, 5640 S. Ellis Ave., Chicago, IL 60637.

Abstract – Inflationary models are generally credited with explaining the large-scale homogeneity, isotropy, and flatness of our universe as well as accounting for the origin of structure (i.e., the deviations from exact homogeneity) in our universe. The authors argue that the explanations provided by inflation for the homogeneity, isotropy, and flatness of our universe are not satisfactory, and that a proper explanation of these features will require a much deeper understanding of the initial state of our universe. On the other hand, inflationary models are spectacularly successful in providing an explanation of the deviations from homogeneity. The authors point out here that the fundamental mechanism responsible for providing deviations from homogeneity – namely, the evolutionary behavior of quantum modes with wavelength larger than the Hubble radius – will operate whether or not inflation itself occurs. However, if inflation did not occur, one must directly confront the issue of the initial state of modes whose wavelength was larger than the Hubble radius at the time at which they were "born." Under some simple hypotheses concerning the "birth time" and initial state of these modes, it is shown that non-inflationary fluid models in the extremely early universe would result in the same density perturbation spectrum and amplitude as inflationary models, without any "fine tuning."

Fifth Award – The End of Black Hole Uniqueness - by Roberto Emparan* and Harvey S. Reall[+], *Theory Division, CERN, CH-1211 Geneva 23, Switzerland; [+]Physics Department, Queen Mary College, Mill End Road, London E1 4NS, United Kingdom.

Abstract – Are higher-dimensional black holes uniquely determined by their mass and spin? Do non-spherical black holes exist in higher dimensions? This essay explains how the answers to these questions have been supplied by the discovery of a new five-dimensional black hole solution. The existence of this solution implies that five-dimensional black holes exhibit much richer dynamics than their four-dimensional counterparts.

Honorable Mention Awards (Alphabetical Order)

1. Conformal Coupling's Outrageous Legacy – by L. Raul Abramo*, Leon Brenig[+], and Edgard Gunzig[#], *Instituto de Física, Universidade de São Paulo, CP 66318, 05315-970 São Paulo, Brazil and Theoretische Physik der Universität München, Theresienstr. 37, D-80333 München, Germany; [+]RggR, Université Libre de Bruxelles, CP 231, 1050 Bruxelles, Belgium and Service de Physique Statistique, Université Libre de Bruxelles, CP 231, 1050 Bruxelles, Belgium; [#]RggR, Université Libre de Bruxelles, CP 231, 1050 Bruxelles, Belgium and Instituts Internationaux de Chimie et de Physique Solvay, CP 231, 1050 Bruxelles, Belgium.

Abstract – In Einstein's gravity, non-minimal coupling of a scalar field to the scalar curvature leads to a paradoxical situation. On the one hand, it opens the way to qualitatively new cosmological dynamics. On the other hand, that path is not devoid of its dangers: there are sectors of non-minimally coupled scalar-gravity theories for which the Einstein-Hilbert action reverses its sign, which seems to indicate that the whole system is unstable. The authors show how conformal coupling bypasses this problem. Due to a subtle interplay between gravity and the scalar field, classical and quantum stability are guaranteed globally. This liberates conformal coupling from a serious obstacle. Inflationary solutions in the new sector are also presented, which are validated by current observations.

2. Gravitational Rainbow of Massive Particles – by Antonio Accioly, Instituto de Física Teórica, Universidade Estadual Paulista, Rua Pamplona 145, 01405-900, São Paulo, SP, Brazil.

Abstract – Dispersive photon propagation cannot take place within the context of general relativity. What about the remaining massless particles? It can be shown that at the tree level the scattering of massless particles of spin 0, ½, 1 or whatever by a static gravitational field generated by a localized source such as the sun, treated as an external field, is non-dispersive. It is amazing, however, that massive particles, regardless of whether they have integral or half-integral spin, experience an energy-dependant gravitational deflection. Therefore, general relativity and gravitational rainbows of massive particles can coexist without conflict. The author addresses this issue in the essay.

3. On the Spin of Gravitational Bosons – by D.V. Ahluwalia*, N. Dadhich[+], M. Kirchbach*, *Theoretical Physics Group, Fac. de Fisica de la UAZ, Zacatecas, Ap. Postal C-600, ZAC 98062, Mexico; [+]Inter-University Center for Astronomy and Astrophysics (IUCAA), Post Bag 4, Ganeshkhind Pune 411 007, India.

Abstract – The authors unearth spacetime structure of massive vector bosons, gravitinos, and gravitons. While the curvatures associated with these particles carry a definite spin, the underlying potentials cannot be, and should not be, interpreted as single spin objects. For instance, the authors predict that a spin measurement in the rest frame of a massive gravitino will yield the result 3/2 with probability one half, and ½ with probability one half. The simplest scenario leaves the Riemannian curvature unaltered; thus avoiding conflicts with classical tests of the theory of general relativity. However, the quantum structure acquires additional contributions to the propagators and it gives rise to additional phases.

4. A Mission to Test the Pioneer Anomaly – by John D. Anderson*, Michael Martin Nieto[+], and Slava G. Turyshev*, *Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109; [+]Theoretical Division (MS-B285), Los Alamos National Laboratory, University of California, Los Alamos, NM 87545.

Abstract – Analysis of the radio tracking data from the Pioneer 10/11 spacecraft has consistently indicated the presence of an anomalous small Doppler frequency drift. The drift can be interpreted as being due to a constant acceleration, $a_P = (8.74 \pm 1.33) \times 10^{-8}$ cm/s$^2$, directed *towards* the Sun. Although it is suspected that there is a systematic origin to the effect, none has been found. The nature of this anomaly has become of growing interest in the fields of relativistic cosmology, astro- and gravitational physics as well as in the areas of spacecraft design and high-precision navigation. The authors present a concept for a designated deep-space mission to test the discovered anomaly. A number of critical requirements and design considerations for such a mission are outlined and addressed.

5. Twilight for the Energy Conditions? – by Carlos Barceló* and Matt Visser[+], *Institute of Cosmology and Gravitation, University of Portsmouth, Portsmouth PO1 2EG, Britain; [+]Physics Department, Washington University, Saint Louis, MO 63130-4899.

Abstract – The tension, if not outright inconsistency, between quantum physics and general relativity is one of the great problems facing physics at the turn of the millennium. Most often, the problems arising in merging Einstein gravity and quantum physics are viewed as Planck scale issues ($10^{19}$ GeV, $10^{-34}$ m, $10^{-45}$ s), and so safely beyond the reach of experiment. However, over the last few years it has become increasingly obvious that the difficulties are more widespread. There are already serious problems of deep and fundamental principle at the semi-classical level, and worse, certain classical systems (inspired by quantum physics, but in no sense quantum themselves) exhibit seriously pathological behavior. One manifestation of these pathologies is in the so-called "energy conditions" of general relativity. Patching things up in the gravity sector opens gaping holes elsewhere; and some "fixes" are more radical than the problems they are supposed to cure.

6. Changing Alpha: Some Matters of Gravity – by John D. Barrow*, João Magueijo[+], and Håvard Bunes Sandvik[+], *DAMTP, Centre for Mathematical Sciences, Cambridge University, Wilberforce Rd., Cambridge CB3 0WA, UK; [+]Blackett Laboratory, Imperial College, Prince Consort Rd., London SW7 2BZ, UK.

Abstract – The authors show how recent evidence for a small cosmological variation of the fine structure 'constant' can be tested by local experiments that probe the behavior of gravity. In particular, in the simplest theory, 'fifth force' experiments should see a positive effect with just an order of magnitude increase in current sensitivity. Space experiments should easily see the predicted effects.

7. Missing Mass and the Acceleration of the Universe. Is Quintessence the Only Explanation? – by Selçuk Ş. Bayin, Middle East Technical University, Department of Physics, Ankara Turkey.

Abstract – Detailed observations of the temperature fluctuations in the microwave background radiation indicate that we live in an open universe. From the size of these fluctuations, it is concluded that the geometry of the universe is quite close to Euclidean. In terms of Friedmann models, this implies a mass density within 10% of the critical density required for a flat universe. Observations can only account for 30% of this mass density. Recently, an outstanding observation revealed that the cosmos is accelerating. This motivated some astronomers to explain the missing 70% as some exotic dark energy called quintessence. In this essay, the author presents an alternative explanation to these cosmological issues in terms of the Friedmann Thermodynamics. This model has the capability of making definite predictions about the geometry of the universe, the missing mass problem, and the accelerations of the universe in line with current observations. For future observations, he also predicts where this model will start differing from the quintessence models.

8. Brane-Antibrane Inflation – by C.P. Burgess, Physics Department, McGill University, 3600 University St., Montréal, Québec, Canada, H3A 2T8.

Abstract – Inflationary cosmology has become central to our understanding of the initial conditions on whose foundations the current successes of the Hot Big Bang model rest. This is despite the well-known difficulties in finding systems whose dynamics naturally provide all the features which successful inflation demands. Although string theory provides our best description of the physics of the relevant energy scales, it has only recently begun to shed insight into what the inflationary dynamics might be: the physics of brane-antibrane collisions. This essay is meant to summarize the difficulties that have blocked this realization until now, as well as the new insights about inflation that are now beginning to emerge.

9. Can a Black Hole be Used as a Portal to Other Universes? – by Lior M. Burko, Department of Physics, University of Utah, Salt Lake City, UT 84112.

Abstract – The author studies numerically the evolution of space-time inside a black hole under perturbations of non-compact support. Using a very simplified toy model of a spherical charged black hole that is perturbed nonlinearly by a self-gravitating, spherical scalar field, he finds that a portion of the Cauchy horizon survives as a non-central, null singularity

10. Brane-World Cosmology – by A. A. Coley, Department of Mathematics and Statistics, Dalhousie University, Halifax, Nova Scotia, Canada B3H 3J5.

Abstract – The author shows that generically the initial singularity is isotropic in spatially homogeneous cosmological models in a brane-world scenario. He then argues that it is plausible that the initial singularity is isotropic in typical brane world cosmological models. Therefore, brane cosmology naturally gives rise to a set of initial data that provide the conditions for inflation subsequently to take place, thereby solving the initial conditions problem and leading to a self-consistent and viable cosmology.

11. Atomic Probes of Quantum Gravity Fluctuations – by Lawrence B. Crowell, Alpha Institute of Advanced Study, 11 Rutafa Street, H Budapest, H-1165, Hungary.

Abstract – The phenomenology behind a proposed quantum optical experiment is discussed that should in principle detect quantum gravity fluctuations on the scale of an atom.

12. Mass Tunneling in Brane World and Formation of Charged Black Holes – by Herman J. Mosquera Cuesta*[+#], André Penna-Firme*[%], Abdel Pérez-Lorenzana*[&], *The Abdus Salam International Centre for Theoretical Physics, I-34100, Trieste, Italy; [+]Centro Brasileiro de Pesquisas Físicas, Laboratório de Cosmologia e Física Experimental de Altas Energias, Rua Dr. Xavier Sigaud 150, 22290-180 RJ, Brazil; [#]Centro Latinoamericano de Física (CLAF), Avenida Wenceslau Braz 173, Rio de Janeiro, RJ, Brazil; [%]Universidade Federal do Rio de Janeiro (UFRJ), Faculdade de Educação, Av. Pasteur, 250, 22290-180, RJ, Brazil; [&]Departmento de Física, Centro de Investigación y de Estudios Avanzados del I.P.N. Apdo. Post. 14-740, 07000, México, D.F., México.

Abstract – Solutions of Einstein-Maxwell field equations suggest that charged black holes should exist. However, no physical process has been identified that effectively violates the charge neutrality in a collapsing star. In this essay, the authors demonstrate that such a process is possible in theories with an infinite extra dimension, where free massive particles localized on the brane can leak into the extra space. Because of color confinement only electrons, rather than protons, can escape. This leakage generates an electric charge asymmetry on initially neutral brane matter. Although the effect is quite small, it could be enhanced on large densities as in astrophysical objects. At the supernova collapse of a massive star, the residual charge in the imploding matter must be inherited by its remnant giving origin to a Reissner-Nordström black hole.

13. String Theory as a Calculational Tool for Loop Quantum Gravity – by Rodolfo Gambini* and Jorge Pullin[+], *Instituto de Física, Facultad de Ciencias, Universidad de la República, Iguá 4225, CP 11400 Montevideo, Uruguay; [+]Department of Physics and Astronomy, Louisiana State University, 202 Nicholson Hall, Baton Rouge, LA 70803-4001.

Abstract – The authors propose a "large N" limit of loop quantum gravity. They show that the resulting theory has as a solution a Chern-Simons state in the connection representation. Transformed to the loop representation this will connect with the recent results of Ooguri and Vafa concerning topological strings and knot theory, opening a new relation between the two main approaches to quantum gravity available at present. In this perspective, string theory can be used as a calculational tool to find wavefunctions in the loop (or spin-network) representation of quantum gravity, suitably augmented to incorporate the other interactions.

14. Fermion Families and Long-Range Force Problems: Interrelation and Resolution – by E.I. Guendelman and A.B. Kaganovich, Physics Department, Ben Gurion University of the Negev, Beer Sheva 84105, Israel.

Abstract – The authors study a generally covariant model with SSB of scale invariance where two measures of integration in the action enter: the standard $\sqrt{-g}d^4x$ and a new $\Phi d^4x$, where $\Phi$ is a density built out of degrees of freedom independent of the metric. Under normal laboratory conditions where the fermionic matter dominates, it is found that starting from a single fermionic field we obtain exactly three different types of spin ½ particles that can be identified with known fermion families. It is automatically achieved that for two of them, fermion masses are constants, the energy-momentum tensor is canonical and the "fifth force" is absent. For the third family, a self-interaction appears as a result of SSB of scale invariance.

15. Retro-MACHOs: π in the sky? – by Daniel E. Holz* and John A. Wheeler[+], *Institute for Theoretical Physics, University of California, Santa Barbara, CA 93106; [+]Princeton University, Princeton, NJ 08544.

Abstract – Distant black holes can be revealed through their reflection of light from the Sun. Such retro-MACHO events involve photons leaving the Sun, making a π rotation about the black hole, and then returning to be detected at the Earth. Our calculations show that, although the light return is quite small, it may nonetheless be detectable for stellar-mass black holes at the edge of our solar system. For example, all (unobscured) black holes of mass $m$ or greater will be observable to a limiting magnitude $M$ at a distance given by $0.027 \text{ pc} \times \sqrt[3]{10^{(M-30)/2.5}\left(m/10M_{sun}\right)^2}$. Retro-MACHOS offer a way to image black holes *directly* and would be a stunning confirmation of strong-field general relativity. Utilizing this effect, it is possible to construct a black hole early warning system, using the Sun as a beacon to scan the horizon for nearby black holes.

16. Inflation and Branes: Degeneracies and Consistencies – by James E. Lidsey and Greg Huey, Astronomy Unit, School of Mathematical Sciences, Queen Mary, University of London, Mile End Road, London, E1 4NS, U.K.

Abstract – The consistency equation relating the primordial power spectra of scalar and tensor perturbations represents a key prediction of single field inflationary models based on conventional Einstein gravity. An identical relationship arises in a class of braneworld cosmologies, resulting in a degeneracy between the predictions of the different scenarios. Possible ways of lifting such a degeneracy are discussed. The dS/CFT correspondence may provide further insight into the origin of the degeneracy.

17. A Proposal to Resolve the Black Hole Information Paradox – by Samir D. Mathur, Department of Physics, The Ohio State University, Columbus, OH 43210.

Abstract – The entropy and information puzzles arising from black holes cannot be resolved if quantum gravity effects remain confined to a microscopic scale. The author uses concrete computations in nonperturbative string theory to argue for three kinds of nonlocal effects that operate over macroscopic distances. These effects arise when a bound state is made of a large number of branes and occur at the correct scale to resolve the paradoxes associated with black holes.

18. The Fulling-Davies-Unruh Effect is Mandatory: The Proton's Testimony – by George E. A. Matsas* and Daniel A. T. Vanzella[+], *Instituto de Física Teórica, Universidade Estadual Paulista, Rua Pamplona 145, 01405-900, São Paulo, SP Brazil; [+]Physics Department, University of Wisconsin-Milwaukee, 1900 E. Kenwood Blvd., Milwaukee, WI 53211.

Abstract – The authors discuss the *decay of accelerated protons* and illustrate how the Fulling-Davies-Unruh effect is indeed *mandatory* to maintain the consistency of *standard* Quantum Field Theory. The confidence level of the Fulling-Davies-Unruh effect must be the same as that of Quantum Field Theory itself.

19. Spacetime Foam – by Y. Jack Ng, Institute of Field Physics, Department of Physics and Astronomy, University of North Carolina, Chapel Hill, NC 27599-3255.

Abstract – Spacetime is composed of a fluctuating arrangement of bubbles or loops called spacetime foam, or quantum foam. The author uses the holographic principle to deduce its structure and shows that the result is consistent with gedanken experiments involving spacetime measurements. He proposes to use laser-based atom interferometry techniques to look for spacetime fluctuations. The analysis makes it clear that the physics of quantum foam is inextricably linked to that of black holes. A negative experimental result, therefore, might have important ramifications for semiclassical gravity and black hole physics.

20. Wave Equations for the Perturbations of a Charged Black Hole – by Zoltán Perjés, KFKI Research Institute for Particle and Nuclear Physics, H-1525, Budapest 114, P.O.B. 49, Hungary.

Abstract – A pair of simple wave equations is presented for the symmetric gravitational and electromagnetic perturbations of a charged black hole. One of the equations is uncoupled and the other has a source term given by the solution of the first equation. The derivation is presented in full detail for either axially symmetric or stationary perturbations and is quite straightforward. This result is expected to have important applications in astrophysical models.

21. Casimir Force between a Gravitational Field and a Finite Object – by Fabrizio Pinto, InterStellar Technologies Corporation, 115 North Fifth Avenue, Monrovia, CA 91016.

Abstract – In a typical Casimir effect, the boundaries of two semi-infinite media exert a force upon one another across a vacuum gap separating them. In this paper, the author argues that a static gravitational field can be regarded as a "soft" boundary which interacts with a test object of finite size through the electromagnetic zero-point-energy field. Therefore, a pressure exists upon a single slab placed in a gravitational field and surrounded by a vacuum. Interestingly, this extremely small Casimir pressure of the gravitational field may cause relative displacements in ground-based sensing microstructures larger than those from astrophysical gravitational waves in macroscopic antennas.

22. GPS Observables in General Relativity – by Carlo Rovelli, Centre de Physique Théorique de Luminy, F-13288 Marseille, EU and Department of Physics, University of Pittsburgh, Pittsburgh PA 15250.

Abstract – The author presents a complete set of gauge invariant observables in the context of general relativity coupled with a minimal amount of realistic matter (four particles). These observables have a straightforward and realistic physical interpretation. In fact, the technology to measure them is realized by the Global Positioning System: they are defined by the physical reference system determined by GPS readings. The components of the metric tensor in this physical reference system are gauge invariant. Surprisingly, their evolution equations are local.

23. New Vistas in Braneworld Cosmology – by Varun Sahni* and Yuri Shtanov[+], *Inter-University Centre for Astronomy and Astrophysics, Post Bag 4, Ganeshkhind, Pune 411 007, India; [+]Bogolyubov Institute for Theoretical Physics, Kiev 03143, Ukraine.

Abstract – Traditionally, higher-dimensional cosmological models have sought to provide a description of the fundamental forces in terms of a unifying geometrical construction. In this essay the authors discuss how, in their present incarnation, higher-dimensional 'braneworld' models might provide answers to a number of cosmological puzzles including the issue of dark energy and the nature of the big bang singularity.

24. Testing Gravity in Large Extra Dimensions using Bose-Einstein Condensates – by Steinn Sigurdsson, 525 Davey Laboratory, Department of Astronomy and Astrophysics, Pennsylvania State University, University Park, PA 16802.

Abstract – Recent conjectures that there are mesoscopically "large" extra dimensions, through which gravity propagates have interesting implications for much of physics. The scenario also implies gross departures from Newton's law of gravity at small length scales. Testing departures from Coulomb's law on sub-millimetre scales is hard. It is now possible routinely to create Bose-Einstein condensates with de Broglie wavelengths of order a $\mu m$ and a total size of order $10\mu m$. BEC condensates move coherently under gravitational acceleration and the author proposes that the transverse fringe shift due to the acceleration of a pair of interfering BECs passing a dense linear mass may be measurable and may provide direct evidence for anomalous gravitational acceleration. Ideally such experiments are best carried out in free fall to maximize the time spent by a BEC in the non-Newtonian regime.

25. Gravity on Large and Small Scales: Submillimetre Constraints – by C. Sivaram, Indian Institute of Astrophysics, Bangalore 560034, India.

Abstract – Over the past two years there have been exciting indications and suggestions that gravity could behave differently on large as well as small length scales. Recent astronomical observations show that on large scales the universe is expanding at an accelerating rate. This suggests the presence of a dominant repulsive gravity component over cosmological scales. Again deviation from Newtonian gravity over submillimetre scales is motivated by recent ideas to unify gravity with other interactions. The author suggests that there is a submillimetre connection underlying both phenomena and ongoing experiments to detect gravity deviations on small length scales used together with Casimir force measurements would soon tightly constrain the presence of any extra large dimensions. Any modified dynamics would also be possibly constrained.

26. A Machian Model of Dark Energy – by R.G. Vishwakarma, Inter-University Centre for Astronomy and Astrophysics, Post Bag 4, Ganeshkhind, Pune 411 007, India.

Abstract – Einstein believed that Mach's principle should play a major role in finding a meaningful spacetime geometry, though it was discovered later that his field equations gave some solutions which were not Machian. It is shown in this essay that the kinematical $\Lambda$ models, which are invoked to solve the cosmological constant problem, are in fact consistent with Mach's ideas. One particular model in this category is described which results from the microstructure of spacetime and seems to explain the current observations successfully and also has some benefits over the conventional models. This forces one to think whether Mach's ideas and the cosmological constant are interrelated in some way.

27. Vacuum Selection by Inflation as the Origin of the Dark Energy – by Jun'ichi Yokoyama, Department of Earth and Space Science, Graduate School of Science, Osaka University, Toyonaka 560-0043, Japan.

Abstract – The author proposes a new mechanism to account for the observed tiny but finite dark energy in terms of a non-Abelian Higgs model, which has infinitely many perturbative vacua characterized by a winding number, together with inflationary cosmology. Inflation homogenizes field configuration and practically realizes a perturbative vacuum with vanishing winding number, which is expressed by a superposition of eigenstates of the Hamiltonian with different vacuum energy density. As a result, there may naturally be nonvanishing vacuum energy density with fairly large probability, under the assumption that the cosmological constant vanishes in some vacuum state. Since the predicted magnitude of dark energy is exponentially suppressed by the instanton action, observations may be fit without introducing any tiny parameters.