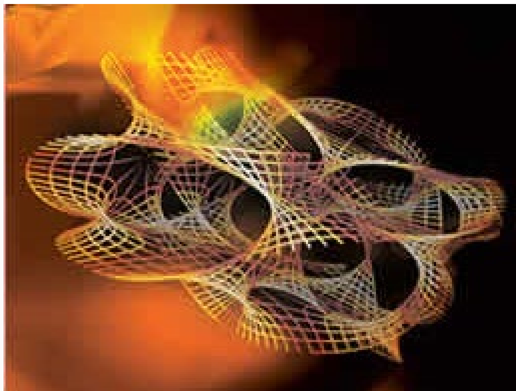
John Templeton Foundation

THE HUMBLE APPROACH INITIATIVE



MULTIVERSE AND STRING THEORY:
Toward Ultimate Explanations in Cosmology

A symposium sponsored by the John Templeton Foundation

19, 20, and 21 March 2005 — Stanford University

"What is it that breathes fire into equations and makes a universe for them to describe?"
— Stephen Hawking

AT TOP: According to string theory, our universe is ten dimensional. It can be often represented as a product of our 4D spacetime and a 6D compact Calabi-Yau space, which may have very nontrivial topological properties. The cover figure is a 3D representation of a specific Calabi-Yau manifold called quintic. It allows us to appreciate the complexity of the Calabi-Yau space, which is one of the reasons for muti-vauum structure of string theory.

Credit: Jean-Francois COLONNA (CMAP/Ecole Polytechnique, FT R&D, http://www.lactamme.polytechnique.fr)

Purpose

Contact: Mary Ann Meyers, Ph.D., Senior Fellow

The concept of a multiplicity of possible or actual universes is a very ancient one. In recent years, however, advances in physics and cosmology have given the "multiverse" idea a plausible scientific basis. Its new lease on life can be traced to the theory of inflation, which in its original form, suggested by Alan Guth, held that a split second after the Big Bang the universe abruptly jumped in size by a huge factor. Most theorists agreed that inflation could explain many puzzles about the structure and evolution of the universe. In the variant introduced by Andrei Linde, inflation spawns a network of branching "bubble" universes with different laws of physics operating inside of them. It has become fashionable to invoke some species of the multiverse theory to account for the well-known examples of parameter fine-tuning associated with the emergence of life in the observable universe where Earth has its home. A small group of physicists and philosophers met at Stanford University in the spring of 2003 to examine various conjectures spawned by multiverse theories. In the two years since the original gathering, scientific work on the subject, particularly in the context of string theory (the best candidate for the "theory of everything"), has proceeded apace. Stanford's Leonard Susskind coined the term "stringy landscape"—the landscape of all possible vacuum states in string theory—for the set of ideas embedded in a paper by Shamit Kachru, Renata Kallosh, Linde, and Sandip Trivedi that gave strong arguments for string theory possessing a vast landscape of metastable vacua, each giving rise to a possible low-energy world with different physical laws and different values of the cosmological constant. Significant progress in investigation of the stringy landscape and counting the number of possible vacua was achieved by

Michael Douglas of Rutgers University and by several other investigators. It seems undeniable that the possibility of a multiplicity of different universes raises deep scientific, philosophical, and theological questions. What can we say about the properties of different parts of the multiverse (different vacua) in string theory? How does the concept of the multiverse modify our understanding of the origin and the fate of the physical universe? Does the cosmos reproduce eternally? Will it, or some of its parts, eventually collapse and disappear? Can the multiverse theory be made consistent with Occam's razor? Is the theory falsifiable, and if so, how? Can science ever provide an "ultimate explanation" for the "laws of nature"? What context of cultural and intellectual currents affect the way scientists today think about our world? Under the aegis of the John Templeton Foundation, sixteen researchers from several disciplines have again come together at Stanford to explore the difficult and interlocking questions that are currently enlarging our cosmic perspective so dramatically.

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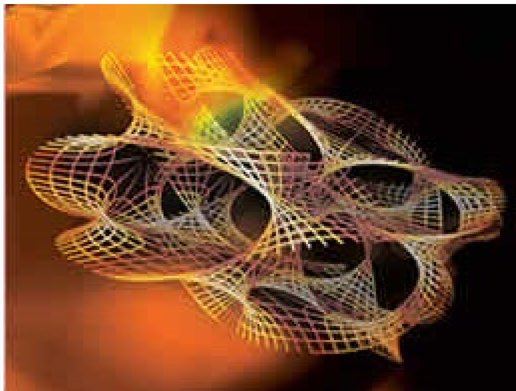

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Approach

The symposium is part of the Templeton Foundation's *Humble Approach Initiative.* The goal of the initiative is to bring about the discovery of new spiritual information by furthering high-quality scientific research. The "humble approach" is inherently interdisciplinary, sensitive to nuance, and biased in favor of building linkages and connections. It assumes an openness to new ideas and a willingness to experiment. Placing high value upon patience and perseverance, it retains a sense of wondering expectation because it recognizes, in Loren Eisley's haunting phrase, "a constant emergent novelty in nature that does not lie totally behind us, or we would not be where we are." A fundamental principle of the Foundation, in the words of its founder, is that "humility is a gateway to greater understanding and open[s] the doors to progress" in all endeavors. Sir John Templeton believes that in their quest to comprehend foundational realities, scientists, philosophers, and theologians have much to learn about and from one another. The humble approach is intended as a corrective to parochialism. It encourages discovery and seeks to accelerate its pace.

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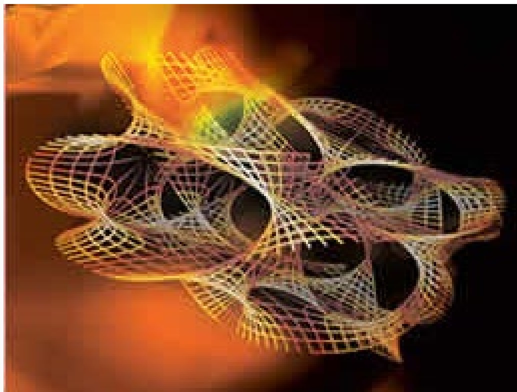

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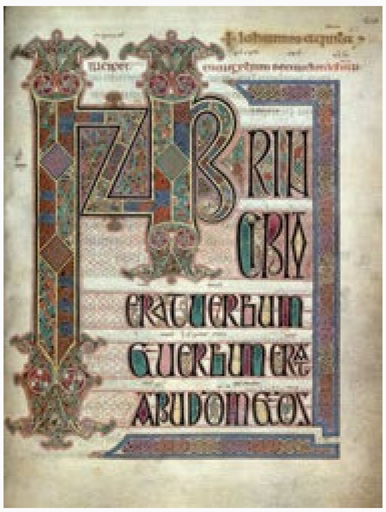
Chairs

Paul Davies is the professor of natural philosophy in the Australian Centre for Astrobiology at Macquarie University. After earning a Ph.D. in physics at University College, London, in 1970, he held academic appointments in astronomy, physics, and mathematics at the universities of Cambridge, London, Newcastle upon Tyne, and Adelaide. His research has spanned the fields of cosmology, gravitation, and quantum field theory, with particular emphasis on black holes and the origin of the universe. Dr. Davies is also widely known as an author. He has written more than twenty-five books, both popular and specialist works, including The Physics of Time Asymmetry, Quantum Fields in Curved Space (co-authored with Nicholas Birrell), The Mind of God, About Time, How to Build a Time Machine, and, most recently, The Origin of Life, which was published by Penguin in 2003. He also has extensive experience in television and radio, including the presentation of two Australian television series entitled “The Big Questions.” His work in astrobiology was the subject of a BBC television documentary, “The Cradle of Life.” He has won numerous awards for his scientific and media work, including the 1995 Templeton Prize. He received the 2001 Kelvin Medal presented by the UK Institute of Physics and the 2002 Michael Faraday Prize of the Royal Society for his contributions to promoting science to the public. The asteroid 1992 OG was officially named (6870) “Pauldavies” in his honor.

Theoretical cosmologist **Andrei Linde** is the author of theories of the origin of the universe that have revolutionized cosmology. He helped lay the foundation for the concept of inflation—the idea that the universe began not with a hot big bang but with an extraordinarily rapid expansion of space in a vacuum-like



Using a reed pen, an unknown Northumbrian monk produced a stunning piece of religious art in the early eighth century known as the Lindisfarne Gospels. The image here is the opening of the Gospel of John: In principio erat verbum ("In the beginning was the Word"). The Lindifarne Gospel is in the British Library.

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state—while working at the Lebedev Physical Institute in his native Russia. A graduate of Moscow State University, Dr. Linde took his Ph.D. in physics at Lebedev in 1975 and became a professor there in 1985. He was the Morris Loeb Lecturer at Harvard in 1987, joined the staff of CERN in 1989, and came to Stanford in 1990. After his initial contribution to inflationary cosmology, Dr. Linde went on to propose other promising versions of this theory, such as "chaotic inflation." Published in 1986, his theory of a chaotic self-reproducing inflationary universe suggests that our universe is one of many inflationary universes that sprout from an eternal cosmic tree. His current research involves the theory of dark energy and cosmological models based on string theory. He proposed the first model of dark energy based on string theory in the paper published in 2003 with Shamit Kachru, Renata Kallosh, and Sandip Trivedi, which became the first in a series of papers implementing the anthropic principle in string theory. The winner of the Lomonosov Award of the Academy of Sciences of the USSR, Dr. Linde received the Oskar Klein Medal in physics in 2001 and shared the Dirac Medal awarded by the Abdus Salam International Centre for Theoretical Physics in Trieste, Italy on the centenary of Nobel laureate Paul Dirac's birth in 2002. Last year, he shared with Alan Guth the Peter Gruber Foundation Cosmology Prize, and earlier this year, he was awarded the Robinson Prize by the University of Newcastle upon Tyne. He is the author of two books on inflationary theory and more than 200 scientific papers.

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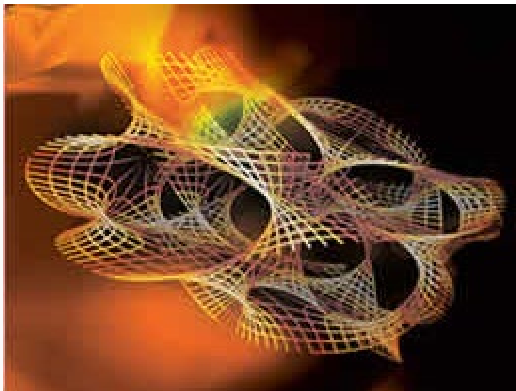

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Nick Bostrom is a philosopher of science. A native of Sweden, he received his undergraduate degree from the University of Gothenburg and went on to earn a master's degree in philosophy and physics at the University of Stockholm and another master's degree in computational neuroscience at King's College, London. He was awarded a Ph.D. in philosophy from the London School of Economics in 2000. The late Robert Nozick, the Harvard philosopher, selected his dissertation as one of the best dissertations in philosophy in the year of its presentation. Dr. Bostrom began his teaching career as a lecturer at Yale University. In 2003, he won a prestigious postdoctoral fellowship from the British Academy to work at Oxford University, where he also holds a junior research fellowship at Harris Manchester College. He is the recipient of a John Templeton Foundation research award. The former editor of the *Journal of Evolution and Technology*, Dr. Bostrom is the author of some sixty articles published in scholarly journals and chapters in volumes of collected works. Routledge published his first book, *Anthropic Bias: Observation Selection Effects in Science and Philosophy*, in 2000. Two other books, *How Can Human Nature be Ethically Improved?*, which he edited with Julian Savulescu, and *Global Catastrophic Risks*, which he edited with Milan Cirkovis, will be published later this year by Oxford University Press.

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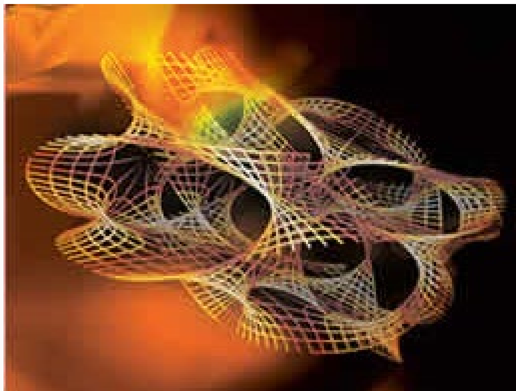

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An expert on black holes, **Brandon Carter** is a director of research at the Laboratoire de l'Univers ses Théories, a center for theoretical astrophysics, on the Meudon campus of the Paris Observatory, now affiliated with France's National Center for Scientific Research (C.N.R.S.). He is widely known for introducing the term "anthropic principle," the "strong" version of which has commonly been misrepresented in an oversimplified form as the concept that the presence of life, in particular the presence of intelligent observers, constrains the nature of the universe. As actually formulated by Dr. Carter (first at the 1973 Krakow symposium celebrating the 500th anniversary of the birth of Copernicus and, in more developed form, at a 1983 Royal Society meeting in London), the original "weak" anthropic principle was actually a (Bayesian) prescription for taking account of the inevitable bias in the interpretation of what we see in the universe, due to our biological nature as intelligent observers, by attribution of equal a priori probability to all comparable (terrestrial or extraterrestrial) observers, wherever they may exist in the past, present, or future. The more controversial "strong" version of the anthropic principle involved a further hypothesis to the effect that beyond the part of the universe we perceive directly, there may be other parts, with possibly different values of the fine structure constant or other such fundamental parameters, whose (biologically favorable) observed values may then be explicable as the consequence of a selection effect. Recently Dr. Carter's work has focused on neutrino stars, cosmic strings, and brane dynamics. An Australian by birth, he was educated at George Watson's College in Edinburgh, began his undergraduate work in physics and mathematics at St.

Andrew’s University, and completed it at Cambridge University where he studied at Pembroke College. He went on to take his Ph.D. in mathematics and theoretical physics at Cambridge in 1968. For the next four years, he was a research fellow at Pembroke and did post-doctoral research as a member of the university’s Institute of Astronomy. In 1973, he joined the Cambridge faculty as a lecturer in applied mathematics and theoretical physics, a post he held for two years until joining the staff of the C.N.R.S. as a researcher in astrophysics. He assumed his present position in 2002. Dr. Carter has been a visiting scientist at Princeton University, the University of California, Santa Barbara, the Enrico Fermi Institute at the University of Chicago, and Cambridge’s Isaac Newton Institute. A Fellow of the Royal Society, he is the author of more than one hundred scientific papers.

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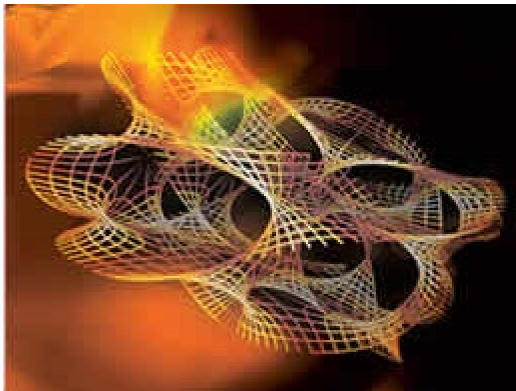

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Savas Dimopoulos is a theoretical physicist widely known for proposing (with Howard Georgi) the supersymmetric extension of the standard model of particle physics, the self-contained picture of fundamental particles and their interactions. His theories about the supersymmetric unification of the strong and electroweak forces, first published in 1981, were subsequently confirmed by experiments at the Stanford Linear Accelerator Center and CERN. Dr. Dimopoulos's and Dr. Georgi's prediction of the presence of "superpartners" of each of the fundamental particles will be tested at CERN's Large Hadron Collider beginning in 2007. More recently Dr. Dimopoulos (with Nima Arkani-Hamed and Gia Dvali) made the startling suggestion that the extreme weakness of gravity can be attributed to the existence of large extra dimensions of space, perhaps as big as a millimeter, where the scale at which gravity becomes comparable to other forces is lowered to the electroweak scale. Among the implications of his thinking is the notion that our universe is a three-dimensional island floating inside a fourth dimension—a membrane called a D-brane—and but one of innumerable parallel universes. Motivated by his consideration of the anthropic principle, he has recently proposed (together with Nima Arkani-Hamed) the theory of split supersymmetry, which also will be tested at the Large Hadron Collider in two years. A native of Athens, Dr. Dimopoulos was graduated from the University of Houston and received his Ph.D. in physics from the University of Chicago in 1978. He did post-doctoral work at Columbia University and joined the Stanford faculty in 1979. He also has taught at Harvard and served as a visiting professor at the University of California, Santa Barbara, and Boston University. From 1994 to 1997, he was a staff member at CERN. The recipient of an Alfred P. Sloan Foundation Fellowship and a Distinguished Alumnus Award of the University of Houston, Dr. Dimopoulos is a fellow of the Japanese Society for the Promotion of Science. He is the author of 147 scientific papers.

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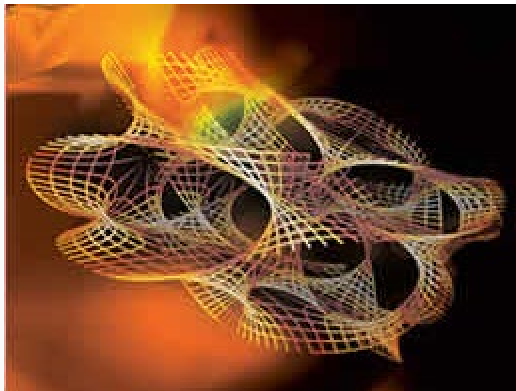

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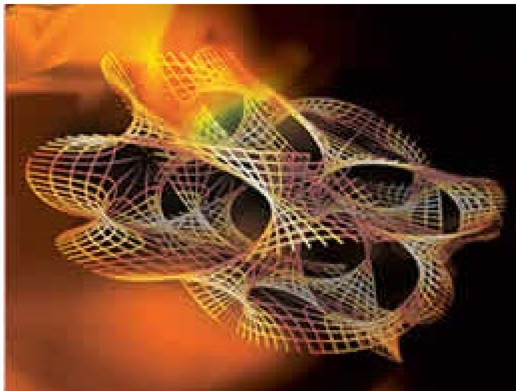
A professor of physics at Rutgers University, **Michael R. Douglas** is director of the university’s New High Energy Theory Center. His research focus is on string theory, as a theory of fundamental interactions and quantum gravity, on non-perturbative methods in field theory, and on the relations of these fields with mathematics. His best-known works include the first non-perturbative formulations of string theory and pioneering studies of the stringy geometry of “branes,” which led to the discovery of noncommutative field theory arising within string theory. A graduate of Harvard University, he earned his Ph.D. in physics at Caltech in 1988. He was an Enrico Fermi Fellow at the University of Chicago before coming to Rutgers as a research associate in 1990 and joining the physics faculty as an assistant professor the next year. Dr. Douglas was named to his present position in 2000. He has been a visiting researcher at ENS in Paris, the Artificial Intelligence Laboratory at the Massachusetts Institute of Technology, and the Kavli Institute for Theoretical Physics at the University of California, Santa Barbara. The Gordon Moore Visiting Scholar at Caltech last year, he has held the Louis Michel Visiting Professorship at the Institut des Hautes Études Scientifique in Bures-sur-Yvette, France, since 1999. He is a life member of Clare Hall, Cambridge University. The recipient of an Alfred J. Sloan Foundation Fellowship, a National Science Foundation Young Investigator Award, and the Sackler Prize in the Physical Sciences, he also has been a Clay Mathematical Institute Mathematical Emissary. Dr. Douglas, who presently serves as editor of *Communications in Mathematical Physics*, is a former editor of the *Journal of High Energy Physics* and continues to serve on its advisory board. The author of more than ninety articles in scientific journals, he is the co-editor (with Costas Bachas, Adel Bilal, N. A. Nekrasov, and Francois David) of *Unity from Duality: Gravity, Gauge Theory and Strings*, which was published by Springer in 2002.



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Georgi Dvali is a professor of physics at New York University whose research is focused on foundational theories of gravity and elementary particles. Among other questions, he is seeking to explain why gravity is the weakest of the four known fundamental forces of nature. With Stanford's Savas Dimopoulos and other colleagues, he is exploring the hypothesis, posited by string theorists, that the universe has more than three dimensions as he looks for confirmation of his idea that gravity, unlike other forces, may be spread through these hidden dimensions, as well as those we experience in everyday life—and its relative strength reduced by "stretching" on a giant scale. Although yet to be confirmed, his theory about the so-called leakage of gravity could give greater weight to the prediction that the expansion of the universe is accelerating, which is strongly supported by observational data. He is also currently exploring implications of the string theory

landscape. A native of Georgia, Dr. Dvali was graduated from Tbilisi State University, where he took first-class honors in theoretical physics and went on to earn a Ph.D. in high energy physics and cosmology in 1992. After post-doctoral research at the Abdus Salam International Centre for Theoretical Physics (ICTP) in Trieste, Italy, and INFN in Pisa, Italy, he worked as a scientific associate at CERN in Geneva, Switzerland, and in 1997 returned to ICTP as a member of the High Energy Physics Group. He joined the NYU faculty as an assistant professor in 1998 and was appointed to his present professorship in 2003. Dr. Dvali has held a David and Lucille Packard Fellowship and an Alfred P. Sloan Fellowship. In 2001 he was the recipient of New York City Mayor's Award for Excellence in Science and Technology. His work has been supported by a grant from the National Science Foundation. In addition to giving invited lectures in the United States, Britain, Europe, Japan, and Turkey, he has published some 110 papers in scientific journals.

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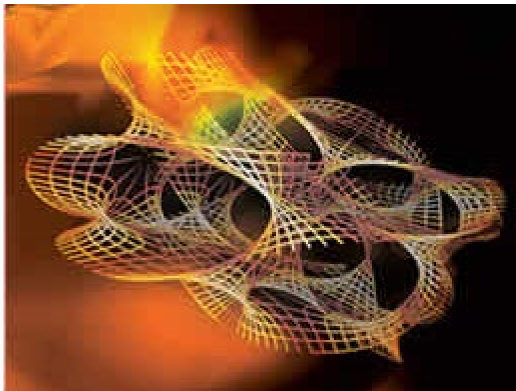

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Shamit Kachru, an associate professor of physics at Stanford University, works primarily on string theory and M theory. He was previously engaged in investigations of “stringy” modifications of geometry, duality and exact results in supersymmetric compactifications, and supersymmetry breaking. Of Kashmiri decent, he is a graduate of Harvard University, where he was elected to Phi Beta Kappa. He took his Ph.D. in physics at Princeton University in 1994. Dr. Kachru began his academic career as a Junior Fellow in the Harvard Society of Fellows and soon joined the physics faculty of the University of California, Berkeley, where he was an assistant professor. He was named to his current post at Stanford in 1999. The recipient of an Alfred P. Sloan Foundation Fellowship, Dr. Kachru also has held a William F. Milton Fund Research Grant given by Harvard, a Department of Energy Outstanding Junior Investigator Award, a Bergmann Memorial Research Grant given by the U.S.-Israel Bi-national Science Foundation, and a David and Lucille Packard Foundation Fellowship. A member of the editorial board of the *Journal of High Energy Physics*, he is the author of more than sixty papers published in scientific journals.

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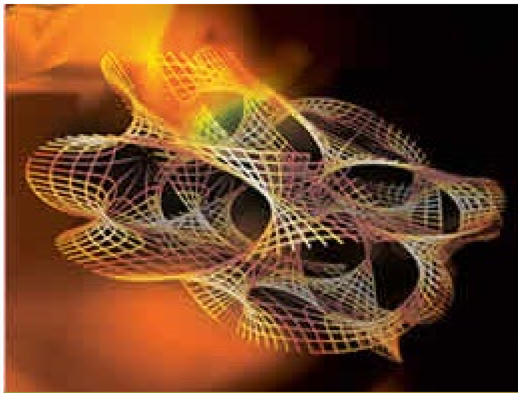

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Working on the leading edge of high-energy theoretical particle physics for more than thirty years, **Renata Kallosh** has been a professor of physics at Stanford University since 1990. She has done much of the important research in the still-evolving field of supersymmetry and black holes. In particular, she was the first to perform quantization of supergravity. Using string theory in her investigations of puzzling questions about quantum gravity, Dr. Kallosh has provided a formula for the macroscopic entropy of a sub-class of extreme black holes and shown it to be universal. Her current studies also involve looking at the possible role of M-theory in cosmology. With her husband, Andrei Linde, she examined some of the assumptions in recent cosmic models, which were built on the discovery that the expansion of the universe appears to be speeding up, and found that dark energy, the mysterious component of space thought to drive acceleration, may eventually become negative, which may lead to a collapse of the universe. More recently she was working on general issues of string cosmology where a significant progress has been achieved due to a new mechanism of stabilization of the runaway moduli, which she discovered in collaboration with Shamit Kachru, Andrei Linde, and Sandip Trivedi. Dr. Kallosh is a native of Russia and earned her baccalaureate degree at Moscow State University. After taking her Ph.D. in physics at Moscow's Lebedev Physical Institute in 1968, she remained there as a junior fellow and was named a professor in 1981. Nine years later, she became a scientific associate at CERN for a year before immigrating to the United States and joining the Stanford faculty. Dr. Kallosh was one of the organizers of the Nobel Symposium on “String Theory and Cosmology” that was held last year in

Stockholm. A member of the editorial board of the *Journal of High Energy Physics*, she has published some 175 papers on particle physics, supergravity, string theory and cosmology.

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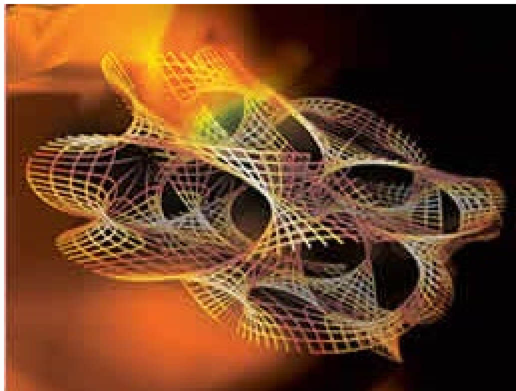

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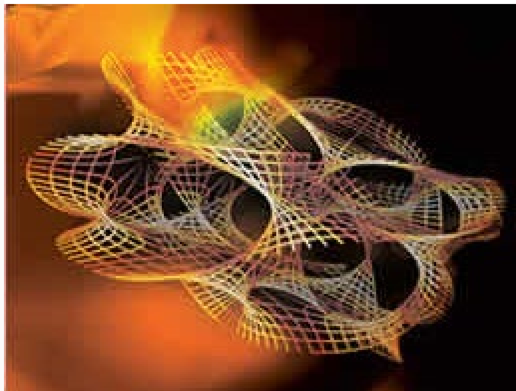
Eva Silverstein is an associate professor of physics at Stanford University and the Stanford Linear Accelerator Center (SLAC) whose research on string theory has focused on vacuum stability, connections among string backgrounds, supersymmetry breaking, and cosmology. She was one of the first to suggest a semi-realistic theory of vacuum stabilization, and with several collaborators she recently initiated an investigation that found a physical mechanism that may explain why the most beautiful and symmetric states and laws are realized in physics. She has determined where certain basic instabilities drive string theory backgrounds, culminating recently in work with collaborators on a new mechanism for topology changing transitions, including processes changing the number of components of space. A graduate of Harvard University, Dr. Silverstein received her Ph.D. in physics from Princeton University in 1996. After a year as a postdoctoral associate at Rutgers University, she joined the faculty of SLAC as an assistant professor in 1997. She was appointed to her present position in 2001. The recipient of a John D. and Catherine T. MacArthur Fellowship in 1999, she also has held an Alfred P. Sloan Foundation Fellowship and Outstanding Junior Investigator Award given by the United States Department of Energy and the U.S.-Israel Bi-national Science Foundation's Bergmann Memorial Research Award. Dr. Silverstein has given numerous invited lectures and is the author of more than fifty scientific papers.



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A staff scientist with the Vatican Observatory Research Group at Castel Gandolfo, Italy, and the University of Arizona, **William R. Stoeger, S. J.** is also an adjunct associate professor of astronomy at Arizona. He specializes in theoretical cosmology and high-energy astrophysics. Through his teaching and writing, he has contributed to epistemological aspects of the interrelationships of science, philosophy, and theology. A member of the Society of Jesus since 1961, Dr. Stoeger was graduated *summa cum laude* from Spring Hill College in Mobile, Alabama, and earned a master's degree in physics at the University of California, Los Angeles, in 1969. He received a second master's degree in sacred theology at the Jesuit School of Theology in Berkeley, California, and was ordained a Roman Catholic priest in 1972. He received a Ph.D. in astrophysics from Cambridge University in 1979, the year he joined the staff of the Vatican Observatory as an astronomer. In the past, Dr. Stoeger's research dealt with various problems connected with the physics of accretion onto black holes and mathematical and physical issues connected with torsion and bi-metric theories of gravity, as well as the harmonic map structures contained in gravitational theories. More recently, with colleagues in South Africa, England, and the United States, he has been concentrating on observationally-oriented projects in theoretical cosmology in an attempt to build more adequate bridges between theory and
cosmologically-relevant astronomical observations. He spent a sabbatical year in the applied mathematics department at the University of Cape Town and has been the Visiting Davies Professor at the University of San Francisco. Secretary of the Vatican Observatory Foundation, Dr. Stoeger serves on the

board of advisors of The Center for Theology and the Natural Sciences (CTNS) in Berkeley, California. He has published nearly one
hundred articles in scientific and other journals and was co-editor of the Philosophy in Science book series devoted to philosophical issues arising within the sciences. In addition, he has edited or co-edited four other books, including, most recently, (with Robert J. Russell and Francesco Ayala) *Evolutionary and Molecular Biology: Scientific Perspectives on Divine Action*, which was published in 1998 by the Vatican Observatory and CTNS.

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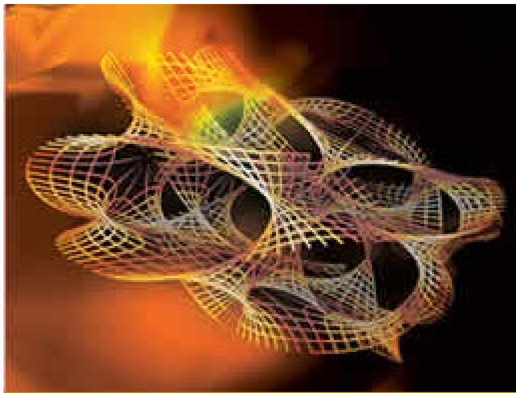

MULTIVERSE AND STRING THEORY:

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A symposium sponsored by the John Templeton Foundation

19, 20, and 21 March 2005 Stanford University

Nick Bostrom
Brandon Carter
Savas Dimopoulos
Michael R. Douglas
Georgi Dvali
Rodney D. Holder
Shamit Kachru
Renata Kallosh
Eva Silverstein
William R. Stoeger, S.J.
Leonard Susskind
Max Tegmark
Alexander Vilenkin

Participants

Leonard Susskind, the Felix Bloch Professor in Physics at Stanford University, has made pioneering contributions to some of the most important areas in contemporary theoretical physics. Thirty-five years ago, he developed the light cone frame as a tool for the study of relativistic quantum mechanics. In 1969, with Yoichira Nambu, he proposed a revolutionary, still mysterious idea called "string theory," which holds that the building blocks of the universe are not point-like particles, the familiar electrons and quarks, but unimaginably small, vibrating strings of some unknown component. Dr. Susskind has continued to refine his string hypothesis, now generally accepted as the only viable candidate to reconcile the differences between gravity and quantum mechanics despite its challenges to traditional understanding of space and time as well as energy and matter. Building on the idea that the universe can be compared to a hologram, in which information for a three-dimensional image can be stored on a flat surface, he discovered a matrix model as a more basic starting point for string theory. But he has also questioned string theory's applicability to cosmology if recent observations of an accelerating universe prove true. In 2002, he suggested that an ever more rapidly expanding universe is destined to repeat itself, but that the chances it would generate a world like ours are infinitesimal. The deep paradox he suggested is that either space is not accelerating for the reasons that scientist expect or we have yet to discover some other law of nature that is responsible for cosmic evolution. A graduate of City College of New York, Dr. Susskind earned his Ph.D. in physics at Cornell University in 1965. He held a National Science Foundation post-doctoral fellowship there the next year and in 1966 joined the faculty of Belfer

Graduate School of Science at Yeshiva University. Named a professor in 1970, he spent a year as a visiting professor at the University of Tel Aviv and went to Stanford in 1979. Dr. Susskind has been a Morris Loeb Lecturer at Harvard University and a Welch Lecturer at the University of Toronto. The recipient of the Pregel Award of the New York Academy of Sciences and the J. J. Sakurai Prize in Theoretical Physics, he also won a Science Writing Award given by the American Institute of Physics. He is a member of the National Academy of Sciences and the American Academy of Arts and Sciences. Dr. Susskind has published some two hundred papers in scientific journals.

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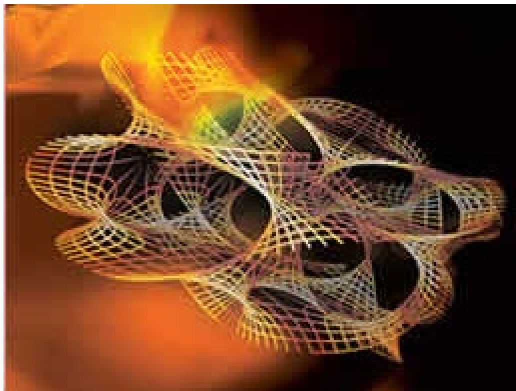
THE HUMBLE APPROACH INITIATIVE



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An associate professor of physics and astronomy at the Massachusetts Institute of Technology and the University of Pennsylvania, **Max Tegmark** focuses his research primarily on cosmological theory and connecting theory to observation. He uses data from analyses of galaxy clustering and the cosmic microwave background radiation to place sharp constraints on cosmological models, that is, to try to ground them in what can be measured in experiments. A native of Sweden with baccalaureate degree both from the Stockholm School of Economics and the Swedish Royal Institute of Technology, he studied theoretical cosmology with astronomer Joseph Silk at the University of California, Berkeley, and received his Ph.D. in physics in 1994. After two years as a research associate at the Max-Planck Institute for Physics in Munich, he spent more than three years doing post-doctoral research at the Institute for Advanced Study in Princeton before joining the Penn faculty in 1999 and the MIT faculty in 2004. Dr. Tegmark has held a Hubble Fellowship awarded by the Space Telescope Institute and currently holds a David and Lucille Packard Foundation Fellowship, a Cottrell Scholar Award given by the Research Corporation, and a National Science Foundation Career Grant. He shared the top honors awarded by *Science Magazine* for the "Number 1 Breakthrough of the Year" in 2003 for his work with the Sloan Digital Sky Survey (SDSS). Involving an analysis of a quarter-million galaxies, it resulted in the most accurate measurements to date of how the density of the universe fluctuates from place to place on scales of millions of light years. Dr. Tegmark's first work involved predicting the size of the earliest galaxies based on molecular physics. He has developed widely-used statistical techniques for analyzing cosmic microwave background and galaxy maps to measure cosmological parameters such as the amounts of ordinary matter and dark matter in the universe, the curvature of space, and the amplitudes of various types of density fluctuations that emerged in the first split second after the Big Bang. Many of his more than 150 scientific papers present ideas and data relevant to parallel universes, including evidence for infinite space and cosmological inflation, as well as for the possibility that the microwave background fluctuation level, the dimensionality of spacetime, and fundamental laws of physics can vary throughout a multiverse.

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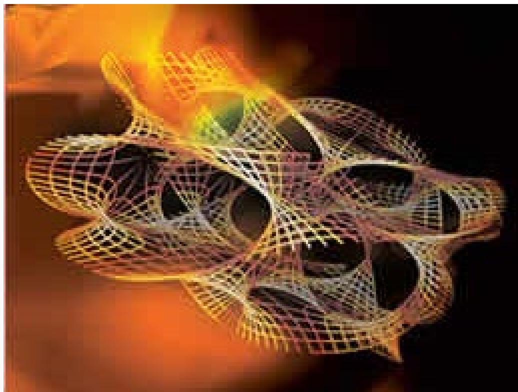

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Alexander Vilenkin has been engaged in research on the application of quantum theory to cosmology for more than twenty years. His pursuit of questions about the origin and the destiny of the universe became possible, however, only after he left his native Russia. Born in the Ukraine, he was graduated from Kharkov State University with a degree in physics, but could neither gain admission to a doctoral program nor find work in his field because he was Jewish. Emigrating in 1976, he was temporarily resident in Italy when he applied and was accepted at the State University of New York in Buffalo. Awarded a Ph.D. in physics the next year, he accepted a post-doctoral position at Case Western Reserve University in the physics of metals even as he conducted research in an area he found far more intriguing—black holes. In 1978, Dr. Vilenkin joined the faculty of Tufts University where he was named a professor of physics in 1987 and appointed director of the Tufts Institute of Cosmology two years later. His first major paper on inflation and quantum cosmology, published in 1982, explained how the universe could have been created *ex nihilo* through quantum energy spacetime fluctuations. In another paper, the following year, he made the then astonishing suggestion that almost all inflationary models are eternal—once the process starts it continues without end like a chain reaction, stopping in one region of space only to start in another, ultimately spawning an infinite number of "pocket universes." His variant account for the universe's birth "by quantum tunneling from nothing," involved a leap from no size at all—zero radius—to a radius large enough for inflation to take over. Continuing to explore the implications of this idea, he and Arvind Borde showed mathematically that a universe eternally inflating toward the future cannot be geodesically complete in the past, so that there must have existed in the indefinite past an initial “singularity,” an ultimate boundary, or beginning. Dr. Vilenkin is also a leading developer of the concept of cosmic strings—dense, linear “defects” in the fabric of space formed in the hot early universe, which he once thought might have a role in transforming matter and energy into galaxies. With Jaume Garriga, he has recently argued that there are an infinite number of regions of space the same size as our observable universe, but that their “histories”—or things that could possibly happen within these realms, including the evolution of intelligent life—are finite, so that every possible version of history will have occurred elsewhere. They call their work a “metaphysical exercise” and name their concept “many worlds in one.” A fellow of the American Physical Society, Dr. Vilenkin has been the recipient of a National Science Foundation Presidential Young Investigator Award and a research grant from the John Templeton Foundation. He is the author of more than 160 scientific papers and (with E. Paul Shellard) the book, *Cosmic Strings and Other Topological Defects* (Cambridge University Press, 1994 and 2000).