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"Why [should] not every one of these stars or suns have as great a retinue as our sun, of planets, with their moons, to wait upon them?" **Christiaan Huygens, 1698**

Purpose

The possibility of life on Mars and Europa and the detection of extra-solar planets have rekindled interest in how the discovery of life beyond the boundaries of Earth might impact on the perception humans have of themselves and their place in the universe. On a Caribbean island far from city lights, where starry intimations of many possible worlds are clearly visible in the night sky, fourteen scientists, philosophers, and theologians gather to explore the broader issues raised by the Martian meteorite ALH84001, the images of Jupiter's moon sent back by the space probe Galileo, and the spectroscopic evidence of other biospheres. Questions about the origin of life, whether it is "written into the laws of nature" or the result of a freakish accident unique to our planet, about evolution, whether there is compelling evidence for or against assertions of directed ingenuity and creative adaptation, and about the theological implications of extraterrestrial intelligence, of finding, if we should, after thousands of years of speculation, that we are not alone, have long engaged the leading thinkers assembled in Lyford Cay in their separate studies. To consider them as interconnected matters, bridging diverse efforts to break the cosmic code, is the purpose of the conversation taking place in Nassau under the aegis of the John Templeton Foundation. Discussion of the significance of the search humankind has begun for life elsewhere focuses, finally, on what the search means for us here.



Chair

Paul Davies is a British theoretical physicist based in South Australia and the author of over twenty books. He obtained a doctorate from University College, London in 1970 and was a research fellow at the Institute of Theoretical Astronomy in Cambridge until 1972, when he was appointed lecturer in mathematics at King's College, London. In 1980, he was offered the chair of theoretical physics at the University of Newcastle upon Tyne, a post that he held until moving to Australia in

$$N = R_* \times f_p \times n_e \times f_i \times f_c \times L$$

An equation, proposed by Frank Drake, an American astronomer, in 1961 for estimating the number (N) of technological civilizations in our Galaxy

1990, first as professor of mathematical physics at the University of Adelaide and then as professor of natural philosophy, until 1996. He is currently visiting professor of physics at Imperial College, London. Dr. Davies's research has been mainly in the field of quantum gravity and cosmology, topics on which he has published more than one hundred papers. His books, *The Physics of Time Asymmetry* (1974) and *Quantum Fields in Curved Space* (1981), written with former student Nicholas Birrell, remain standard texts for researchers. He has made several important contributions to the theory of black holes and cosmological models. His interests, however, spread much wider, ranging from particle physics to astrobiology. He is currently working on the problem of biogenesis and the role of cosmic impacts on the early development of life. For many years, he has pursued the broader philosophical and theoretical implications of science through books and lectures, work for which he was awarded the 1995 Templeton Prize for Progress in Religion. His best known text on the subject is *The Mind of God* (1992). Dr. Davies has a strong commitment to bringing science, and its deeper implications, to the wider public. In addition to a string of best-selling books, he makes almost daily media appearances and writes regularly for newspapers and journals around the world. He was for several years a columnist for *The Economist* and *The Australian*. He devised and presented a highly successful series of science documentaries on BBC Radio 3, two of which were published in book form as *The Ghost in the Atom* and *Superstrings: A Theory of Everything?* Recently his two television series, "The Big Questions" and "More Big Questions," won critical acclaim when screened on Australia's SBS channel. In the UK, Dr. Davies's Templeton Prize was the subject of an Equinox documentary on Channel 4, and last year an entire episode of Border Television's series "The Beatitudes" was devoted to an interview with him on science and the meaning of life. Dr. Davies is a Fellow of the Institute of Physics, the Australian Institute of Physics, The World Economic Forum, and the World Academy of Arts and Science. He is a consultant to several publishers, as well as a number of scientific and cultural organizations in the UK and Australia. His most recent book is *Fifth Miracle: The Search for the Origin of Life* (Allen Lane The Penguin Press, 1998).



Participants

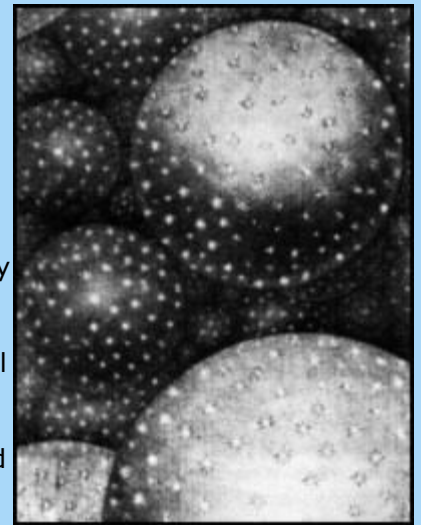
George V. Coyne, S. J. is the director of the Vatican Observatory. Long before the National Aeronautics and Space Administration (NASA) introduced its Ranger and Apollo programs, he studied the lunar surface, and his broadly-based research interests also include the birth of stars. He invented a special technique, known as polarimetry, as a powerful tool for astronomical investigation. He is currently studying cataclysmic variable stars, that is, binary stars where one super-dense star is capturing matter from its companion, and searching for protoplanetary disks in the vicinity of young stars. An abiding and parallel fascination with the interrelationship of science and religion led him to found a series of studies concerning controversies about Galileo, entitled *Studi Galileiani*, and to organize several conferences around the theme "Scientific Perspectives On Divine Action." A graduate of Fordham University, where he majored in mathematics and earned his licentiate in philosophy, he received his Ph.D. in astronomy from Georgetown University in 1962 and a licentiate in theology from Woodstock College in 1966. Dr. Coyne joined the Vatican Observatory as an astronomer in 1969 and the next year began teaching in the Lunar and Planetary Laboratory of the University of Arizona. He was named a senior research fellow at Arizona in 1976 and, in 1977, the director of its Catalina Observatory and associate director of the Lunar and Planetary Laboratory. He became associate director of the Arizona Observatories in 1978, the same year he was appointed to his Vatican Observatory post, and, in 1979, served as acting director. Dr. Coyne holds honorary degrees from St. Peter's University and Loyola University (Chicago) in the United States, the University of Padua, and the Pontifical Theological Academy of Jagellonian University in Cracow. He has published more than one hundred scientific papers and edited a number of books.



The distinguished zoologist **Richard Dawkins** has been contributing importantly to our understanding of evolutionary biology for three decades. In addition to dozens of widely-cited articles in leading science journals, he has written seven highly-acclaimed books that make the science of evolution accessible to the general public. Born in Kenya, he went from Oundle School to Oxford University, where he studied at Balliol College and took a D.Phil. in 1966. After two years as an assistant professor of zoology at the University of California, Berkeley, he returned to Oxford as senior research officer in the department of zoology. Appointed university lecturer in zoology and a fellow of New College in 1970, he became ad *hominem* reader in zoology in 1990 and was named Charles Simonyi Reader in the Public Understanding of Science and a professional fellow of New College in 1995. The next year he also was appointed to a new university chair as Professor of Public Understanding of Science. In recognition of his contributions to his field, Oxford awarded him the senior degree of D.Sc. in 1989, and he also has received honorary degrees from St. Andrews University, the Australian National University, and Westminster University. Dr. Dawkins's first book, *The Selfish Gene* (1976), an exploration of the analogies between genetic evolution of biological species and cultural evolution of human societies, has been translated into thirteen foreign languages. He received the Royal Society of Literature Award and the *Los Angeles Times* Literary Prize for *The Blind Watchmaker* (1986), a defense of evolution by cumulative natural selection in which he argues that "the origin of life on a planet can be a very improbable event indeed by everyday standards...and still be sufficiently probable to have occurred, not just once but many times, all over the universe." A BBC program based on the book won the *Sci.Tech* Prize for Best Television Documentary Science Program of the Year. Among Dr. Dawkins's many other awards are the Zoological Society of London Silver Medal, the Royal Society of London Michael Faraday Award, the Nakayama Prize for Achievement in Human Science, and Japan's International Cosmos Prize. He is a Fellow of the Royal Society of Literature and an honorary fellow of Regent's College, London. The former European editor of *Animal Behaviour Monographs* and *Animal Behaviour*, he has served as executive editor of *Oxford Surveys in Evolutionary Biology* and as a member of the Science Consultative Committee of the British Broadcasting Corporation. In 1997 he was the president of the Biology Section of the British Association for the Advancement of Science. Dr. Dawkins has delivered more than forty invited lectures and keynote addresses. His 1996 book, *Climbing Mount Improbable*, more intriguing tales of the evolution of living complexity out of primeval simplicity, was number one on the *Observer* Best Seller List. Allen Lane The Penguin Press and Houghton Mifflin have just published his latest study, *Unweaving the Rainbow*.



Christian de Duve, who shared the 1974 Nobel Prize in Medicine and Physiology for pioneering work on cell structure and function, has devoted his career to studying the biochemistry of life. The contributions to science made by the eminent cell biologist over more than half a century have been recognized by a dozen major awards and nearly as many decorations. He was the first to identify and describe two key intracellular components: membrane-bounded vesicles he called lysosomes (after the Greek word for "digestive bodies"), which expose the extracellular materials engulfed by cells to acid and digestive enzymes, and peroxisomes, particulate entities that carry out a variety of oxidative reactions centered around hydrogen peroxide (hence its name). A native of Belgium, he studied at the University of Louvain where he earned an M.D., Ph.D., and advanced master's degree in chemical sciences. After postdoctoral fellowships at the Medical Nobel Institute in Stockholm and Washington University in St. Louis, he was appointed a lecturer in physiological chemistry on the Faculty of Medicine of the Catholic University of Louvain in 1947. Four years later, he was named professor and head of the department, a position he held until becoming emeritus professor in 1985. Dr. de Duve also has been associated with The Rockefeller University in New York since 1962 when he was appointed professor of biochemical cytology. He was made Andrew W. Mellon Professor in 1974 and Andrew W. Mellon Professor Emeritus in 1988. The founder of the International Institute of Cellular and Molecular Pathology in Brussels, he served as president director from 1974 to 1991. He now serves as a member of the Institute's board of directors. Dr. de Duve has been a member of the UNESCO International Committee on Bioethics, the World Health Organization Advisory Committee for Medical Research, the Advisory Board of the Ciba Foundation, the Advisory Committee of the Max Planck Institute for Immunobiology, and the International Advisory Board of the Basel Institute for Immunology, as well as serving on numerous government committees and commissions concerned with scientific research in Belgium and as a special adviser to the Commission of European Communities. A past member of the editorial boards of eight major journals in biology and



Thomas Wright's 1750 book, *An Original Theory of the Universe*, contained this illustration of the autor's "endless immensity" of galaxies.

biochemistry, he is a member or honorary member of numerous academic, medical, and scientific societies throughout the world, including the U.S. National Academy of Sciences, the American Philosophical Society, and the Royal Society. Dr. de Duve has been awarded sixteen honorary degrees by universities in Europe, South America, Canada, and the United States. He is the author of some 375 scientific papers and three books. The most recent, *Vital Dust: Life as a Cosmic Imperative* (Basic Books, 1995), is a narrative history of the entire sweep of what is known about the origin and development of living matter from simple ocean chemistry to humans with their unique capacity for speech and consciousness. In it he considers how the biologically-determined mind can lead to culture, ethical values, and social behavior and concludes that the beginning and unfolding of life was not an utterly contingent event but the expected consequence of the prebiotic conditions on Earth and, presumably, elsewhere in a carbon-rich universe teeming, he believes, with the possibility of conscious intelligence.



The historian of science at the United States Naval Observatory (USNO), **Steven J. Dick** is the author of three books on the debate over extraterrestrial life from the Greek atomist Democritus to the late twentieth century. He studied astrophysics at Indiana University and took a Ph.D. in the history and philosophy of science there in 1977. After a year as assistant editor of *Adventures in Experimental Physics*, a twentieth-century history of science series, he served as an associate editor for science, technology, and the history of science and technology of the *American Academic Encyclopedia*. In 1979, he joined the scientific staff of the Naval Observatory as an astronomer, a position he held until being named historian of science in 1989. For three years in the mid-1980s, Dr. Dick was an astronomer at the USNO Southern Hemisphere Station in South Island, New Zealand. In the early 1990s, he acted as historian of the National Aeronautics and Space Administration's High Resolution Microwave Survey-Search for Extraterrestrial Intelligence program. Currently president of International Astronomical Union's Commission 41 (History of Astronomy), he was chairman of the Historical Astronomy Division of the American Astronomical Society in 1993-94. He served on a panel of scientists convened by Vice President Albert Gore in 1996 to advise him on the implications of the Martian meteorite ALH84001. The author of some seventy scientific and historical articles and a member of the editorial boards of the *Journal for the History of Astronomy*, the *Journal of Scientific Exploration*, and the new *Journal for Astronomical History and Heritage*, Dr. Dick won the Ernest M. Eller Prize in Naval History for the best article on U.S. naval history published in a scholarly journal in 1992. The first book in his pioneering history of the origins of extraterrestrial life debate, *Plurality of Worlds*, was published in 1982. *The Biological Universe*, his second, came out in 1996, and Cambridge University Press has just published his third, *Life on Other Worlds*.



The English-born American physicist **Freeman J. Dyson** is widely recognized for his contributions to quantum electrodynamics and the theory of interacting electrons and photons -- and perhaps even better known for his creative speculations on subjects ranging from space travel to extraterrestrial civilizations. An engaging author, widely sought-after lecturer, and an unusually conscientious citizen of the world, he has been for half a century a persistent scientific and political gadfly in the most positive sense of the word. He went to Cambridge University from Winchester College, and after civilian service doing operations research at the headquarters of the RAF Bomber Command during World War II, he took his B.A. in mathematics at Cambridge in 1945. A fellow at Trinity College, Cambridge, in 1946-47, he was a Commonwealth Fellow at Cornell University and the Institute for Advanced Study in Princeton for the next two years. After another two years as a research fellow at the University of Birmingham, he became a professor of physics at Cornell in 1951. Two years later, he returned to the Institute for Advanced Study where he was a professor of physics until 1994 when he became professor emeritus. He has been a visiting professor at Yeshiva University and the Max Planck Institute for Physics and Astrophysics. During the late 1950s, Dr. Dyson helped design the nuclear reactor, Triga, and the Orion space ship at General Atomic Laboratories in San Diego, California. He originated the idea for what is known as the "Dyson sphere," a hypothetical shell of artificial material that an advanced civilization of intelligent beings with an expanding population might build around a parent star. The "colonists," he suggested, would be able to capture almost all of the energy released by the

Adaptation of a detail from a William R. Leigh illustration in H. G. Wells's 1908 non-fiction *Cosmopolitan* article, "The Things That Live on Mars"

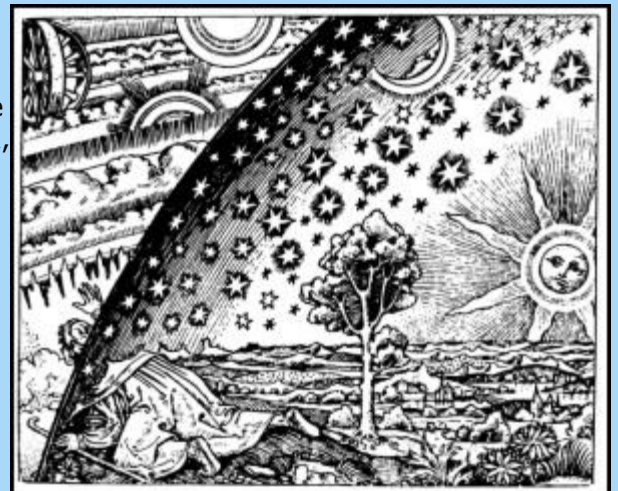
star in the form of electromagnetic radiation, which would then be re-radiated as infrared radiation making the star visible to infra-red telescopes. Dr. Dyson served as chair of the Federation of American Scientists in 1962-63 and was a member of the National Research Commission on Life Science from 1989 to 1991. The recipient of honorary degrees from seventeen American and European colleges and universities, including Princeton, Oxford, and the Federal Institute of Technology (ETH) in Zurich, he is a Fellow of the Royal Society and a member of the U.S. National Academy of Sciences, as well as a foreign associate of the French Academy of Sciences and an honorary fellow of Trinity College, Cambridge. Among his other honors are a dozen major science prizes, including the Enrico Fermi Award of the U. S. Department of Energy. The author of nearly 300 scientific papers, he also has been a frequent contributor to *The New Yorker*, *The Atlantic Monthly*, and *The New York Review of Books*. His capacity for luminous exploration of the intellectual challenges and moral dilemmas of modern science first came to the attention of the general public in 1979 when the Alfred P. Sloan Foundation commissioned him to write a memoir of his life in science, *Disturbing the Universe*. He won the National Book Critics Circle Award for Non-Fiction in 1984 for his powerful plea for international control of the world's nuclear arsenal, *Weapons and Hope*. In his probing *Origins of Life* (1986), he suggested careful scrutiny of the notion that life began twice. *Infinite in All Directions* (1988), an explanation of what past and recent scientific theories tell us about the beginning of the universe, its present state, and its likely destiny, won the Phi Beta Kappa Award in Science. His latest book is *Imagined Worlds* (Harvard University Press, 1997).



Bernd-Olaf Küppers has long focused his attention on basic questions of natural science and the philosophy of science at the borders of physics, chemistry, and biology. His scientific interests cover a wide range of problems including the theory of molecular self- organization, the experimental study of precellular evolution, and the metatheoretical questions of theory formation at the borders of physics and biology. A graduate of Göttingen University where he studied physics, astrophysics, and mathematics, he went on to study with Nobel laureate Manfred Eigen and received a Ph.D. in biophysics from Braunschweig Technical University in 1975. Dr. Küppers earned another Ph.D. in philosophy at Heidelberg University sixteen years later. After a brief period of research at Columbia University, he worked at the Max Planck Institute for Biophysical Chemistry in Göttingen from 1971 to 1993. The following year he held a distinguished professorship awarded by the Japanese government. Since 1994, he has been a professor of natural philosophy and director of the world-renowned Institute of Philosophy at Friedrich Schiller University in Jena. The author of some 100 scholarly papers and the winner of the Woitschach Research Prize awarded by the German Association of Science Foundations, Dr. Küppers is the editor of the international journal, *Philosophia Naturalis*. He has edited or written nine books, including the monograph, *Molecular Theory of Evolution* (2nd Edition 1985), in which he presented a physico-chemical theory of the origin of life. In his latest book, *Information and the Origin of Life* (The MIT Press, 1990), he approaches the evolution of living systems from the perspective of modern information theory. His most recent study, *The Power of Knowledge*, will be published next year.



A philosopher with a deep interest in science and religion, **John Leslie** taught at the University of Guelph in Ontario, Canada for nearly thirty years. A thorough understanding of concepts emanating from the latest fundamental research in physics and cosmology informs his work, which deals with many of the great issues of existence, including the origin of the universe and the destiny of its human inhabitants. Born in India, he won a scholarship to Oxford University, where he majored in psychology and philosophy at Wadham College. He then worked in advertising for several years before returning to Oxford to take his M.Litt. in philosophy in 1968. He joined the Guelph faculty as a lecturer, becoming a full professor in 1982 and professor emeritus in 1996. He has served as chairman of the Guelph-McMaster Joint Doctoral Program, one of the largest philosophy Ph.D. programs in Canada, and as secretary of the Canadian Philosophical Association. A Fellow of the Royal Society of Canada, he has won two University of Guelph Research Excellence Awards and held a Canada Council research grant, Social Sciences and Humanities Research Council (SSHRC) Fellowship, a Forster Fellowship, and a SSHRC grant.



Medieval view of the universe as depicted in a nineteenth-century woodcut

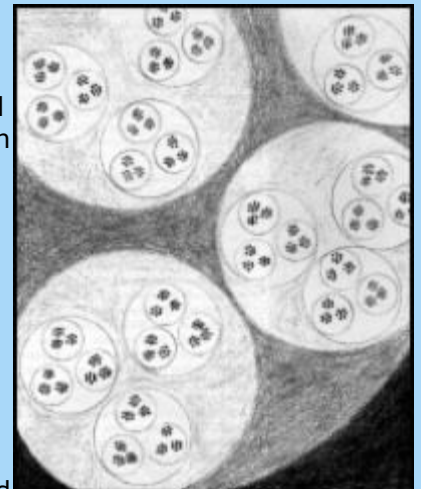
Professor Leslie has been a visiting professor of religious studies at the University of Calgary and of astrophysics at the University of Liège and a visiting fellow in the research department of philosophy at the Australian National University. In the autumn of 1998, he was the British Academy-Royal Society of Canada Exchange Lecturer. In addition to articles in academic journals and chapters for numerous collections, he is the author of four books, including *Universes* (1989) in which he examines evidence that our universe is fine-tuned for producing life and the possibility of multiple worlds. His latest study is *The End of the World: The Science and Ethics of Human Extinction* (Routledge, 1996).



Christopher P. McKay has been a planetary scientist in the Space Science Division of the National Aeronautics and Space Administration's Ames Research Center since 1982. His interest in searching for extraterrestrial life dates from the fall of 1976 when two Viking spacecraft landed on the surface of Mars and he read, with growing excitement, the published interim reports of the experiments underway to detect metabolic activities on Earth's cold, dust-covered solar neighbor. A graduate of Florida Atlantic University, where he majored in physics, he had just begun graduate work in astro-geophysics at the University of Colorado, where he completed a Ph.D. in 1982. Dr. McKay's first field work was in the dry valleys of Antarctica as a scientist with Florida State University's Cryptoendolithic Microbial Ecology Research Project. He was subsequently a research diver in the 1986 Antarctic Lakes Project, a member of the expeditions to the Siberian arctic permafrost regions in 1990-91 and 1994 and a member of the National Geographic Expedition to the Gobi Desert of Mongolia in 1991-92, the NASA/United States Geographical Survey Expedition into the Lechuguilla Cave in New Mexico in 1994-95, the McGill University Expedition to Axel Heiberg Island in the Canadian Arctic in 1995-96, and the NASA Expedition to the Atacama Desert in Chile in 1994-95 and 1997. He also has made several expeditions to Negev Desert in Israel. Associate editor of *Planetary Space Science*, he is a member of the United States Committee for the International Permafrost Association. His various honors include the U.S. Antarctic Service Medal, the Urey Prize of the Division of Planetary Sciences of the American Astronomical Society, the Arthur S. Flemming Award, the NASA Ames Associate Fellow Award, and the Thomas O. Paine Memorial Award. The author of some 175 scientific papers and the editor of four books, Dr. McKay has helped identify promising locations and approaches for finding evidence of past Martian life. His latest volume (with P. J. Thomas and C. F. Chyba) is *Comets and the Origin and Evolution of Life* (Springer, 1997).



The O'Hara Professor of Philosophy Emeritus at the University of Notre Dame, Ernan McMullin is an internationally-respected philosopher of science who has written and lectured extensively on subjects ranging from the relationship between cosmology and theology, to the role of values in understanding science, to the impact of Darwinism on Western religious thought. He is an expert on the life of Galileo, and for more than a quarter of a century, he has contemplated the probability and implications of extraterrestrial life. A graduate of Maynooth College in Ireland, where he received an undergraduate degree in physics and a bachelor of divinity degree in theology, he went on to study theoretical physics on a fellowship at the Dublin Institute for Advanced Studies and earned a Ph.D. in philosophy at the University of Louvain in 1954. Joining the Notre Dame faculty as an assistant professor of philosophy that same year, he became a full professor in 1967 and was named to the John Cardinal O'Hara Chair in 1984. Dr. McMullin chaired the Notre Dame department of philosophy from 1965 to 1972. He has been a visiting professor at the University of Minnesota, the University of Cape Town, the University of California at Los Angeles, Princeton, and Yale, a Phi Beta Kappa National Lecturer, and a Cardinal Mercier Lecturer at the (Flemish) University of Leuven. In addition, he has served as president of the American Catholic Philosophical Association, the Metaphysical Society of America, the Philosophy of Science Association, and the Western Division of the American Philosophical Association, as chair of the History and Philosophy of Science Section of the American Association for the Advancement of Science (AAAS), as a member of the executive committees of the History of Science Society, the Council for Philosophical Studies, and the Society of Christian Philosophers, and as a member of numerous scholarly and scientific committees, congresses, and panels. A fellow of the American Academy of Arts and Sciences, the International Academy of the History of Science, and the AAAS, he holds honorary degrees from Maynooth, the National University of Ireland, and Loyola University (Chicago). Among other honors, he has won the Aquinas Medal of the American Catholic Philosophical Association, the Centennial Medal of John Carroll University, the Founder's

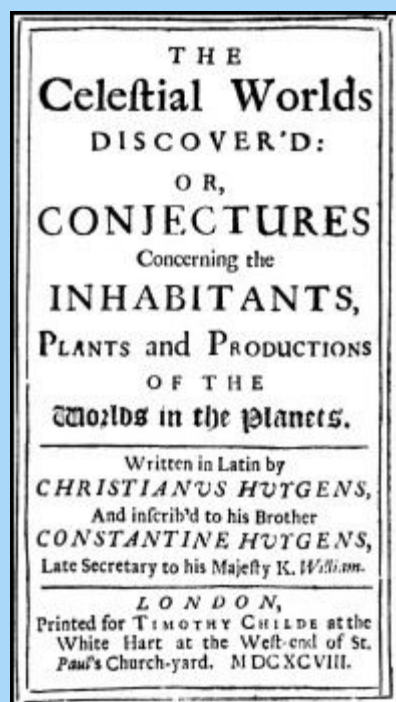


An eighteenth-century concept of a hierarchal universe of star and galaxy clusters conceived by Immanuel Kant and Johann Lambert

Medal of the Metaphysical Society of America, and two Notre Dame faculty awards. Dr. McMullin currently serves on the editorial boards of *The Oxford Companion to the History of Science and Its Uses*, *the Encyclopedia of the Scientific Revolution*, *Perspectives on Science*, *International Studies in the Philosophy of Science*, and *the British Journal for the Philosophy of Science*. The author of numerous scholarly articles and the editor of a series of monographs on logic published in the mid-1960s by Prentice Hall and of nine major books, his latest volume is *The Inference That Makes Science* (Marquette University Press, 1992). He is working on a study of rationality, realism, and the growth of knowledge.



Arthur Peacocke devoted the first twenty-five years of his career to teaching and research in the field of physical chemistry, specializing in biological macromolecules and making significant contributions to our understanding of the structure of DNA. His principal interest during the past twenty-five years has been in exploring the relation of science to theology. After going up to Oxford, where he was a scholarship student at Exeter College, he worked in the Physical Chemistry Laboratory, with Nobel laureate Sir Cyril Hinshelwood, and earned a D.Phil. in physical biochemistry in 1948. For the next eleven years, he taught at the University of Birmingham and then returned to Oxford as a fellow and tutor at St. Peter's College from 1959 to 1973. In addition to publishing more than 125 papers and three books in his field, he served as editor of *Biopolymers*, the *Biochemical Journal*, and a series of monographs on physical biochemistry published by Oxford University Press. While lecturing at Birmingham, Dr. Peacocke also had studied theology, and he was ordained a priest in the Church of England in 1971. He went on to serve as dean, and as a fellow, of Clare College, Cambridge, for eleven years. He became founding director of the Ian Ramsey Centre at St. Cross College, Oxford, in 1985, a position he held until 1988. In 1995, he resumed the directorship of the Centre, which studies issues in the relation of theology to science, to oversee the administration of a grant from the John Templeton Foundation. A founder of the Science and Religion Forum in the United Kingdom, of the corresponding European society (ESSSAT), and of the Society of Ordained Scientists, a new dispersed religious order, he was honorary chaplain of Christ Church Cathedral, Oxford, from 1989 to 1996 and is now an honorary canon. Dr. Peacocke has been awarded the senior degree of D.Sc. as well as a D.D. by Oxford and honorary degrees from Georgetown University and De Pauw University in the United States. He was made a member of the Order of the British Empire by Queen Elizabeth II in 1993. The author of nine books exploring the relationship between science and religion, his most recent studies are *From DNA to Dean: Reflections and Explorations of a Priest-Scientist* (Canterbury Press, 1996) and *God and Science: A Quest for Christian Credibility* (SCM Press, 1996).



Title page of Christiaan Huygens's *Celestial Worlds* (1698)

One of the world's leading theoretical astrophysicists, **Martin J. Rees**, England's Astronomer Royal, was for many years the director of Cambridge University's famed Institute of Astronomy. Since 1992 he has been the Royal Society Research Professor at Cambridge and an official fellow at King's College, Cambridge. His contributions to our understanding of the origin and nature of the universe have been exceptionally broad-based. Nearly two decades ago, he showed how the anthropic principle could be used to determine most of the fundamental constants of physics. He has added to our knowledge about the birth of stars and galaxies, demonstrated how deep-space quasars, the highly energetic cores of active galaxies seen through the Hubble Space Telescope, might be powered by massive black holes, and expounded theories that explain the mysterious explosions known as gamma-ray "bursters." A graduate of Cambridge, where he studied at Trinity College, he took an undergraduate degree in mathematics and earned a Ph.D. in theoretical astronomy in 1967. He was a fellow of Jesus College, Cambridge, a research fellow at California Institute of Technology, and a staff member of Cambridge University's Institute of Theoretical Astronomy before becoming a professor of astronomy at the University of Sussex in 1972. He returned to Cambridge the next year as Plumian Professor of Astronomy and Experimental Philosophy, a position from which he resigned in 1991 to devote more time to research and writing. Dr. Rees has lectured around the world and been a visiting professor at Caltech, Harvard, and the Institute for Advanced Study in Princeton, as well as a Regents Visiting Fellow at the Smithsonian Institution. He has served as president of the International Astronomical Union's Commission on High Energy Physics, the Royal Astronomical Society, and the British Association for the Advancement of Science and is currently a trustee of the British Museum. A Fellow of the Royal Society, a Fellow of the

Institute of Physics, and a Fellow of the Institute of Mathematics and Its Applications, he is a foreign honorary member of the American Academy of Arts and Sciences, a foreign associate of the U.S. National Academy of Sciences, an officer in the French Ordre des Arts et des Lettres, a foreign member of the American Philosophical Society, the Royal Swedish Academy of Sciences, and the Italian Accademia Nazionale dei Lincei, an honorary fellow of the Indian Academy of Sciences and of Jesus College and Trinity College, Cambridge, an honorary member of the Russian Academy of Sciences and the Norwegian Academy of Science and Letters, and a member of the Accademia Europaea and the Pontifical Academy of Sciences. Dr. Rees was knighted by Queen Elizabeth II in 1992. He has won a dozen major scientific prizes, including, most recently, the Bowser Prize of Philadelphia's Franklin Institute, and holds honorary degrees from seven universities. A member of the editorial boards of a number of leading scientific journals, he has published some 350 research papers and three technical books. His latest volume, *Before the Beginning* (Addison-Wesley/Helix, 1997), is both an overview of and meditation on what is known and what is merely conjectured about our universe. In it he suggests that the universe we observe may be part of a "multiverse" - "just one element in an infinite ensemble: a cosmic archipelago," a theory that makes it not altogether uncanny luck that the constants in the laws of physics have been finely tuned to allow for our existence.



Lee Smolin is a theoretical physicist who has made significant contributions to the search for a quantum theory of gravity. A professor of physics at the Center for Gravitational Physics and Geometry at Pennsylvania State University, he is one of a small number of scientists actively seeking to reconcile - or "unify" - general relativity, Einstein's theory of gravity, and quantum mechanics, the prevailing theory of matter and motion developed in the 1920s. Among his most fruitful ideas is the loop formation of quantum gravity, which he developed with Carlo Rovelli and other physicists. It led to the prediction that space has a certain discrete or atomic structure at very small distances. He also has worked on cosmology and, in particular, proposed a hypothesis called "cosmological natural selection," in which Darwinian principles of evolution are applied to the universe, providing a possible explanation for some of the properties of the elementary particles and forces. His conjecture is that our universe forms part of an infinite chain of self-reproducing universes whose physical laws evolve through natural processes of self-organization. The black holes created by collapsing stars lead to the creation of new regions of space and time. These events resemble the big bang, and, indeed, the big bang in our past is assumed to be one such event. Dr. Smolin has hypothesized that the daughter worlds that emerge from "dark stars" may differ in small, random ways from their parents. But if, and to the extent, that changes of even the slightest degree affected the production of black holes, evolutionary pressure would favor universes with many of them. Dr. Smolin began his studies in physics at Hampshire College, where he majored in natural philosophy, and then went on to Harvard University, where he earned his Ph.D. in theoretical physics in 1979. After post-doctoral work at the Institute for Advanced Study in Princeton, the Institute for Theoretical Physics at the University of California, Santa Barbara, and the University of Chicago, he joined the Yale faculty as an assistant professor of physics in 1984, and in 1988, he became an associate and then a full professor of physics at Syracuse University before accepting his current position at Penn State five years ago. He has been a visiting scientist at more than a dozen universities and institutes and given some fifty invited lectures to scientific audiences. Much of Dr. Smolin's research has been supported by grants from the National Science Foundation, and he also has won awards from Syracuse and the Gravity Research Foundation in addition to a number of travel fellowships. The author of more than eighty scientific papers, he recently published *The Life of the Cosmos* (Oxford University Press, 1997) in which he uses arguments, drawn from both science and philosophy, to examine the consequences of his proposal that the laws of nature are, in part, the result of processes analogous to natural selection.



Apatient and dauntless explorer, seeking signs of intelligent life on other planets, astronomer **Jill Cornell Tarter** is the founding director of Project Phoenix, the SETI Institute's privately-funded continuation of a targeted search for extraterrestrial intelligence, which was originally supported through a Congressional appropriation to the National Aeronautics and Space Administration (NASA). Her work is listening for radio signals that would provide evidence of another distant technology. So far SETI scientists have looked at some 400 nearby stars. Over the next few years, their search will encompass about 1,000 of the 400 billion stars in the Milky Way, all within the relatively close distance of 200 light-years from Earth. With an undergraduate degree in engineering physics from Cornell University (named after her distant relative Ezra), where she was the only woman, and the first to hold the Procter & Gamble Scholarship, in the university's College of Engineering, Dr. Tarter began her study of astronomy at her alma mater and went on to concentrate in high-energy astrophysics at the University of California, Berkeley, where she completed a Ph.D. in 1975. Her dissertation on calculating the observable properties of brown-dwarf stars is still

considered a standard on the subject. As a post-doctoral research fellow at the NASA Ames Research Center, she became involved in a small search for signals from extraterrestrial civilizations using an 85-foot telescope at the Hat Creek Radio Observatory. In 1977, Dr. Tarter was appointed an assistant research astronomer at Berkeley's Space Science Laboratory then involved in cooperative agreement with NASA to manage a SETI observational program. Named associate research astronomer in 1983, she was made project director of the NASA/SETI High Resolution Microwave Survey in 1989 and guided the construction of computers to sift through cosmic noise and earthly interference in an effort to find faint extraterrestrial radio signals. When Congress abruptly terminated the program five years ago and the search project went private, Dr. Tarter and her associates began roving from telescope to telescope to carry on their research. In 1997, she became the first holder of the Bernard M. Oliver Chair at SETI. She also became the role model for Ellie, the heroine of the 1997 movie "Contact," which was based on Carl Sagan's novel. A peer-reviewed observing proposal, approved by Cornell, which runs the world's largest radiotelescope at Arecibo, Puerto Rico in collaboration with the National Science Foundation, gives the peripatetic searchers 2,000 hours of observing time spread over five years. Dr. Tarter lectures widely and is the author of more than 100 scientific articles. She has received a Lifetime Achievement Award for her contribution to exobiology from Women in Aerospace and is the winner of two NASA Public Service Medals and a Group Achievement Award in addition to a Person of the Year Award given by the Chabot Observatory. A former president of the International Astronomical Union's Commission 51, she is chair of the International Academy of Astronautics SETI Committee.



*He, who thro' vast immensity can pierce,
See worlds on worlds compose one universe,
Observe how system into system runs,
What other planets circle other suns,
What vary'd Being peoples ev'ry star,
May tell why Heav'n has made us as we are.*

• • •

*So Man, who here seems principal alone,
Perhaps acts second to some sphere unknown,
Touches some wheel, or verges to some goal;
'Tis but a part we see, and not a whole.*

from Alexander Pope's Essay on Man (1734)



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