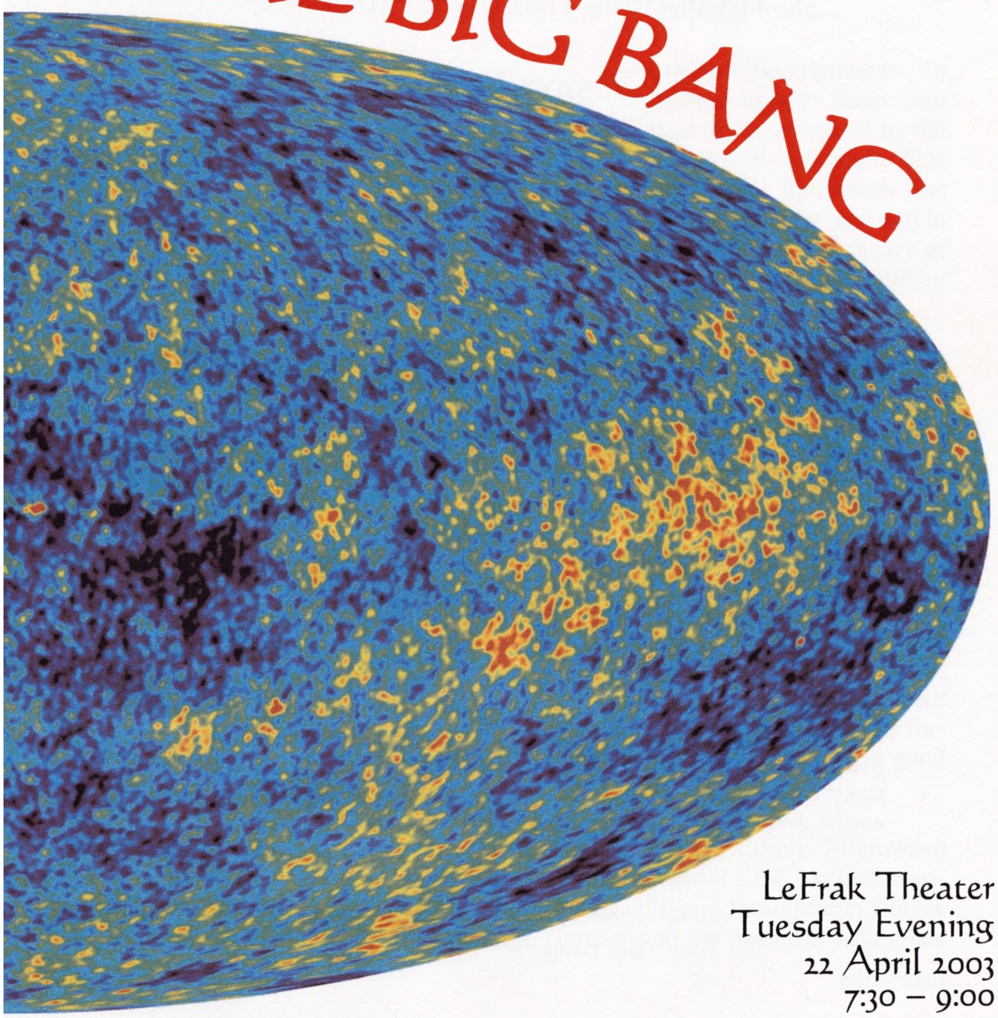
AMERICAN MUSEUM OF NATURAL HISTORY
HAYDEN PLANETARIUM

Isaac Asimov Memorial Panel Debate 2003

THE BIG BANG



LeFrak Theater
Tuesday Evening
22 April 2003
7:30 – 9:00

The Evening's Program

Welcome & Introduction of Panelists
host

Opening Questions to Panelists
panelists

Directed Free Debate Among Panelists
panelists & moderator

Questions from the Audience

Closing Remarks
host

Adjourn

Book Sale / Book & Program Signing
Hall of Northwest Coast Indians
panelists & host

The late Dr. Isaac Asimov, one of the most prolific and influential authors of our time, was a dear friend and supporter of the American Museum of Natural History. In his memory, the Hayden Planetarium is honored to host the annual Isaac Asimov Memorial Panel Debate — a panel series, generously endowed by relatives, friends and admirers of Isaac Asimov and his work. The Isaac Asimov Memorial Panel series brings the finest minds in the world to the Museum each year to debate pressing questions on the frontier of scientific discovery. Proceeds from ticket sales of the Isaac Asimov Memorial Panels will benefit the scientific and educational programs of the Hayden Planetarium.

2001 Theory of Everything
2002 Search for Life in the Universe
2003 Big Bang

Big Bang Basics

What could possibly induce a rational astrophysicist to believe that all the matter, energy, and space of the Universe began fourteen billion years ago in a primeval fireball smaller than an atom and that it has been expanding ever since? The short answer is that the Big Bang is supported by a preponderance of evidence and is the most persuasive theory ever put forth on the origin and evolution of the Universe.

Skeptics among the general public may say that the Big Bang is "just a theory" and that it should therefore be discounted. But successful theories are not just airy notions — they are scientific propositions whose predictions are consistently confirmed by experiment. Note that, since the beginning of the twentieth century, physicists no longer label successful theories as "laws." This change of vocabulary reflects our humble recognition that data from newer and better experiments will continue to deepen and revise our concept of the physical world.

Confidence in Big Bang cosmology comes from several strong arguments. In 1929, Edwin Hubble observed that distant galaxies recede from us faster than those nearby, in direct proportion to their distance from us, as measured by the increase in wavelength of features in their spectra — the so-called redshift. This implies that we live in an expanding universe. A theoretical foundation that would account for Hubble's conclusion already existed (though unrecognized) in Albert Einstein's 1916 theory of gravity, better known as the general theory of relativity. And since Einstein's theory preceded Hubble's observation, Big Bang proponents can't be accused of inventing a theory just to fit the evidence.

We can also turn back the clock to a time when the Universe was much smaller, denser, and hotter, and apply modern physics to extrapolate the behavior of the cosmos. We think our current theories work only after the first 0.0000000000000000000000000000000000000000001 second of the birth of the Universe. At that time, its ambient temperature was upwards of a trillion degrees, and atoms had not yet assembled from nuclear particles — indeed, nuclear particles themselves had not yet formed. Combining all we know of quantum mechanics and particle physics, as well as what we have learned from smashing atoms to smithereens in particle accelerators, we conclude that, as the cosmic soup expanded and cooled, protons and neutrons formed and combined to make specific and predictable assortments of atoms. We deduce that the Universe was born with 75 percent of its mass as hydrogen and about 25 percent as helium. Current surveys of galaxies that have undergone very little star formation find that they contain between 22 and 27 percent helium — in good agreement with Big Bang predictions.

By far the most powerful support for the Big Bang is the Cosmic Microwave Background (CMB). About twenty years after the notion of a hot, explosive origin for the Universe was proposed by Belgian physicist and Jesuit priest Georges Lemâitre, American cosmologist George Gamow and his physicist colleagues

continued...

ABOUT THE PARTICIPANTS

PANELISTS

ALAN GUTH is Victor F. Weisskopf Professor of Physics and a Margaret MacVicar Faculty Fellow at MIT. Guth is best known for inventing the inflationary theory, originally proposed to avoid the overproduction of magnetic monopoles in the early universe. He has continued to work on the consequences of the inflationary theory, and he has also explored the creation of a new universe in a hypothetical laboratory and the possibility of time travel. Guth grew up across the Hudson River in New Jersey, attending high school in Highland Park. He has been elected a member of the National Academy of Sciences and has received the Franklin Medal for Physics of the Franklin Institute and the Dirac Prize of the International Center for Theoretical Physics. He has written a popular-level book called *The Inflationary Universe: The Quest for a New Theory of Cosmic Origins* (1997).

P. JAMES E. PEEBLES is Albert Einstein Professor of Science Emeritus at Princeton University. Peebles received both the Eddington Medal and Gold Medal from the Royal Astronomical Society, and he wrote the ubiquitous graduate texts, *Principles of Physical Cosmology* and *The Large Scale Structure of the Universe*. Born in Winnipeg, Manitoba, Canada, Peebles became a naturalized U.S. citizen in 1991. He is married to Alison Peebles with three children, Lesley, Ellen, and Marion, as well as six grandchildren.

LEE SMOLIN is a founding member and researcher at Perimeter Institute for Theoretical Physics in Waterloo, Canada, which is a new, privately-endowed research institute. Smolin is also Adjunct Professor of Physics at the University of Waterloo. He has made major contributions to the quantum theory of gravity, being a co-inventor of loop quantum gravity, which is the most successful approach so far studied. Smolin has also worked in cosmology and is the inventor of a theory called cosmological natural selection, which applies a Darwinian methodology to the question of how the laws of physics are chosen. Born in New York City, and raised a few blocks from the Museum, Smolin was educated at Hampshire College and received his PhD from Harvard University. Before moving to Canada to be part of founding Perimeter Institute, Prof. Smolin held professorships at Yale, Syracuse, and Penn State Universities. Smolin has also written two books for the general public, *The Life of the Cosmos* (1977) and *Three Roads to Quantum Gravity* (2001), both of which explore the philosophical ramifications of developments in contemporary physics and cosmology.

DAVID SPERGEL is a Professor in the Department of Astrophysical Sciences at Princeton University. Spergel received his undergraduate degree from Princeton in 1982 and his PhD from Harvard in 1985, where he worked on the search for dark matter detection. After a Long-Term Membership at the Institute for Advanced Studies, Spergel joined the Princeton faculty in 1988. Currently a MacArthur Fellow, Spergel's research interests include the physics of the early Universe, galaxy formation and evolution, and the structure of our Galaxy. Recently, he has been developing new techniques for detecting planets around other stars. Spergel leads the Wilkinson Microwave Anisotropy Probe (WMAP) Science Team in interpreting the results [see image on cover]. Launched in June 2001, WMAP has made a map of the fluctuations in the residual radiation from the Big Bang, a snapshot of physical conditions 380,000 years after the Universe began. Spergel is married to Laura Kahn, M.D., and has three children, Julian, eight, Sarah, five, and Joshua, two.

PAUL STEINHARDT is Albert Einstein Professor of Science in the Department of Physics, Princeton University. One of the architects of the "inflationary model" of the Universe, Steinhardt has also developed the "quintessence" model of dark energy and introduced the concept of quasicrystals, a new state of solid matter with what were once considered to be "forbidden symmetries." His current efforts are focused on developing the cyclic theory of the Universe "bouncing" from one cycle to the next, as well as exploring models of quintessence and candidates for dark matter. The son of two lawyers, Steinhardt vividly recalls an influential visit to the Museum and the Hayden Planetarium at the age of four. Today, he spends most of his time outside physics with his four children and their activities. Working with Neil Turok, Steinhardt has begun writing a popular book called *The Endless Universe*, describing developments in cosmology from an inflationary universe to a cyclic universe.

HOST & MODERATOR

NEIL DEGRASSE TYSON is the Frederick P. Rose Director of the Hayden Planetarium and a Visiting Research Scientist in astrophysics at Princeton University, where he also teaches. Tyson's professional research interests include star formation, exploding stars, dwarf galaxies, and the structure of our Milky Way. In addition to his professional publications, Tyson writes a monthly essay for *Natural History* magazine entitled "Universe." Tyson's recent books include a memoir *The Sky is Not the Limit: Adventures of an Urban Astrophysicist*; a playful Q&A book on the Universe for all ages titled *Just Visiting This Planet*; and the companion book to the Rose Center for Earth & Space, *One Universe: At Home in the Cosmos* (coauthored with Charles Liu and Robert Irion).

Ralph Alpher and Robert Herman predicted the existence of a signal left over from the time when the Universe had cooled to about 3000 kelvins. They reasoned that this signal, having cooled appreciably during the subsequent expansion of the Universe, should still be detectable as an omnidirectional bath of microwave energy with a characteristic temperature of only a few kelvins. Their proposition was confirmed in 1965, when a part of the CMB was serendipitously discovered by two Bell Labs physicists, Robert Wilson and Arno Penzias. For this work, Wilson and Penzias were awarded the Nobel Prize in physics in 1978.

In spite of Big Bang successes, several nagging questions remained. Among the unexplained features of the cosmos is that its matter and energy are distributed much more smoothly than any simple expansion after the original Big Bang explosion would allow. Why, for instance, isn't any particular region of the sky much hotter or colder than regions on the other side of the sky? After all, they are too far away from one another to have a clue as to what the other is doing. Beginning around 1980, the concept of "inflation" was advanced by Alan Guth, Paul Steinhardt, and others, which helped to explain this Big-Bang anomaly. Inflation holds that the exotic energetics of the extremely early Universe triggered a cosmic "change of state," manifested by a period of hyper-expansion that moved previously interacting parts of the Universe out of reach of one another. The theory does require, however, that the Universe be born with critical density — just enough mass and energy for the cosmos to exist at the boundary between ultimate recollapse and eternal expansion.

So what do we know, and what do we not know? We know galaxy velocities and distances, and that the expanding Universe was hotter in the past than today. This coherent cosmic picture (based on a minimum of assumptions) represents an unprecedented marriage of astrophysics and particle physics.

In a recent development, the most precise measurements yet gathered on the CMB have revealed the Universe to have just the critical density needed by inflation. Encouraging. But those same data establish the contents of the cosmos to be 4 percent ordinary matter, 23 percent mysterious dark matter, and 73 percent a peculiar "dark energy." So we must confess to having little or no understanding of what comprises 96 percent of the Universe. Is the tail wagging the dog? The new data now help distinguish among new and competing ideas of cosmic origins.

Tonight's panelists will debate several alternative models for the Big Bang that address particularly the earliest moments of the Universe. Are their proposals just details that modify Big Bang theory, or do they signal a fundamental shift in our notions of cosmic origins? ★

Adapted by Kyrie Bogin-Tinch from the essay "In Defense of the Big Bang," *Natural History* magazine, December 1996 / January 1997, by Neil deGrasse Tyson.

Abbreviated Glossary

Big Bang — theory holding that all of space, time, matter and energy originated about 14 billion years ago as a tiny, super-dense, superheated fireball that has been expanding ever since

Black Hole — a region of space whose gravitational field is so powerful that the fabric of space-time has curved back on itself, allowing nothing, not even light, to escape

Cosmic Microwave Background (CMB) — left-over electromagnetic radiation produced in the hot Big Bang; its temperature today — after the Universe has expanded and cooled for 14 billion years — is 2.73 kelvins

Cosmology — the study of the formation, evolution, and large-scale structure of the Universe

Critical Density — an average density of matter and energy that would poise the expanding Universe exactly between eternal expansion and ultimate collapse

Dark Energy — a newly proposed form of energy whose pressure in the vacuum of space may be working against gravity to increase the rate at which the Universe expands

Dark Matter — invisible matter that does not interact with light and whose presence has been inferred only from it gravitational influence on ordinary matter; it is believed to make up most of the mass of the Universe

ElectroMagnetic Spectrum (EMS) — all known forms of light, ranging (from longest to shortest wavelengths) from radio, to microwave, infrared, optical (visible), ultraviolet, X-rays, and gamma rays

Inflation — theory positing that heat and the interactions of elementary particles led to extremely rapid expansion of the Universe in the first few moments of its history

Kelvin Scale — a temperature scale running upward from absolute zero (about –462° on the Fahrenheit scale) and measured in units known as kelvins

Natural Selection — mechanism proposed by naturalist Charles Darwin to explain species' apparent adaptation to their various environments; it requires that genetic traits be inheritable and that there be variation in the traits from one generation to the next, allowing features unfavorable to survival to be culled by the environment

Redshift — a stretching of electromagnetic waves as the emitting object recedes from the viewer; in cosmology, the redshift of galaxies is the primary measure of the expanding Universe

Relativity, general theory of — theory that describes the bending of space-time in the presence of mass, creating the phenomenon we perceive as gravity

Thermodynamics — the branch of physics that accounts for the nature and behavior of heat energy

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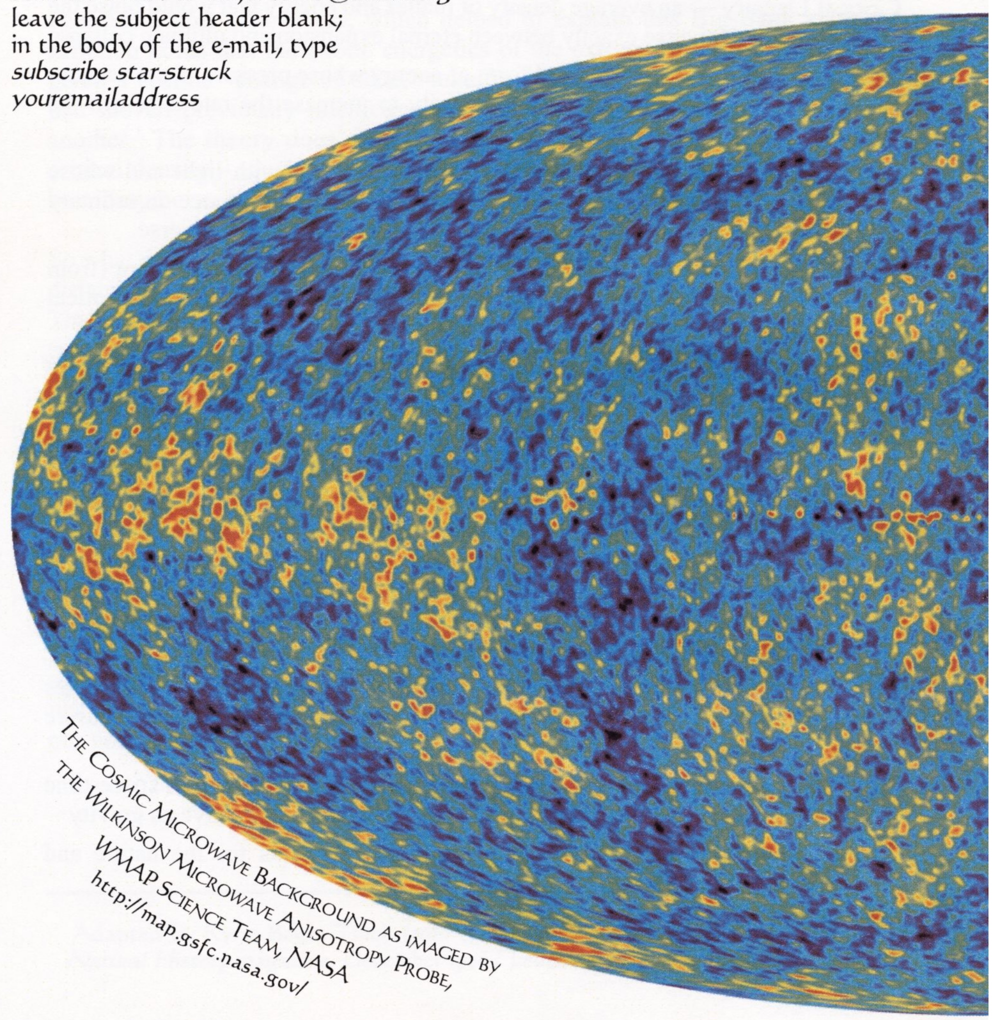

The Cosmic Microwave Background as imaged by
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