THE DARK SIDE

Hayden Planetarium

Isaac Asimov Memorial Debate 2004

The Dark Side

LeFrak Theater ✦ American Museum of Natural History

Wednesday ✦ April 21, 2004 ✦ 7:30 pm

THE EVENING'S PROGRAM

Welcome & Introduction of Panelists

Opening Questions to Panelists

Directed Free Debate Among Panelists

Questions from the Audience

Closing Remarks

Adjourn

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

All Things Dark & Mysterious

One of the most powerful and far-reaching theoretical models ever devised is Einstein's theory of general relativity (GR). It's been proven time and time again, as scientists devise ever more precise experiments to test the theory, only to extend the envelope of the theory's accuracy.

Published in 1916, GR outlines the relevant mathematical details of how everything in the universe moves under the influence of gravity — the most familiar of nature's forces — the best and the least understood phenomena in nature.

The 1920s brought the discovery of other "island universes" — galaxies outside our own Milky Way. In fact, the Universe is littered with them forming grand web-like structures as far as the eye & telescope can see. Bound together by mutual gravity, the thousands of individual galaxies within a cluster orbit the cluster's center, moving like bees circling a beehive. Research into this motion of galaxies revealed that their average velocity had a shockingly high value. The clusters should swiftly fly apart, leaving barely a trace of their buzzing bee-like existence after just a few hundred million years. But clusters are more than ten billion years old, nearly as old as the universe itself. There must be a significantly larger gravitational force than we could see, and therefore more matter somewhere, holding them together.

Scientists looking at individual galaxies found similar phenomena in the velocities of stars swarming around their galactic centers. Even straggling stars, gas and dust far beyond a galaxy's luminous disk remained bound to the system. There must be more mass hidden in a "halo" around each galaxy.

From galaxy to galaxy and from cluster to cluster, the discrepancy between the mass in visible objects and the object's total mass ranges from a factor of just two or three up to (in some cases) factors of many hundreds. Across the universe, the factor averages about six: cosmic "dark matter" has about six time the total mass of all the visible matter. Where & what is this dark matter?

Meanwhile, another line of inquiry arises out of the theory of general relativity — a mysterious, repulsive pressure associated with the vacuum of space-time itself.

Einstein's equations of gravity included a term — using for its symbol, the Greek letter Lambda (Λ), which allowed him preserve the status quo of a static universe — one that neither expands nor contracts. To invoke an unstable condition as the natural state of a physical system violates scientific credo: you cannot assert that the entire universe is a special case that happens to be precariously balanced forever and ever. So, in spite of being uneasy with Lambda, Einstein admitted its existence. Moreover, to give something a name does not make it real, and Einstein could see that Lambda had no known counterpart in the physical universe.

GR radically departed from all previous thinking about the attraction of gravity. It regards gravity as the response of a mass to the local curvature of space and time as caused by some other mass. In other words, concentrations of matter cause distortions — dimples, really — in the fabric of space-time.

Again back in the late 1920s, Edwin P. Hubble discovered that the universe is not static. He had found and assembled convincing evidence (using the seeming shift in observed light) that the more distant a galaxy, the faster that galaxy is receding from Earth. In other words, the universe is growing. Embarrassed by Lambda, and consequently the lost opportunity to have predicted the expanding universe himself, Einstein discarded the cosmological constant, calling its introduction his life's "greatest blunder."

About the Participants

Panelists

Katie Freese, Professor of Physics at the University of Michigan, works on a wide range of topics in theoretical cosmology and astroparticle physics. She has demonstrated that dark matter cannot be made of ordinary material such as neutrons and protons but instead must be something exotic, and she has explored ideas for detecting supersymmetric dark matter candidates. Her work has also focused on constructing a successful model for inflation: an early expansionary phase of the Universe that helps explain its current, smooth appearance. Recently, she has addressed cosmologies in which our three-dimensional observable universe is embedded in higher dimensions.

Brian Greene, Professor of Physics & Mathematics at Columbia University, concentrates his work on superstring theory — a developing theory of quantum gravity as well as a unified theory of all forces and all matter. Much of his research has examined the physical implications and mathematical properties of the extra dimensions required by superstring theory — studies that collectively go under the heading "quantum geometry." Greene is also the best-selling author of *The Elegant Universe: Superstrings, Hidden Dimensions, and the Quest for the Ultimate Theory* and *The Fabric of the Cosmos: Space, Time, and the Texture of Reality*.

Robert Kirshner, Clowes Professor of Science at Harvard University, co-discovered dark energy — the accelerated expansion of the Universe named "Science Breakthrough of the Year for 1998" from *Science* magazine. He has authored more than 200 research papers dealing with supernovae, the large-scale distribution of galaxies, and the size and shape of the Universe. He became a member of the National Academy of Sciences in 1998, and he was elected President of the American Astronomical Society in 2003. Kirchner is the author of *The Extravagant Universe: Exploding Stars, Dark Energy, and the Accelerating Cosmos*.

MICHAEL S. TURNER, currently serving as Assistant Director for Mathematical and Physical Sciences at the National Science Foundation (NSF), focuses his research on the application of modern ideas in elementary-particle theory to cosmology and astrophysics: detecting dark matter, describing how dark matter helped form structure in the Universe, and determining the nature of dark energy, among other topics. In addition to heading the $1–billion NSF directorate, Turner also holds the position of Bruce V. and Diana M. Rauner Distinguished Service Professor in the Department of Astronomy & Astrophysics at the University of Chicago and also holds an appointment [as a senior scientist] in the Department of Physics and Enrico Fermi Institute at Chicago. He is a member of the National Academy of Sciences and a fellow of the American Physical Society and the American Academy of Arts and Sciences.

J. ANTHONY TYSON, a Distinguished Member of the Technical Staff at Bell Labs, Lucent Technologies, and Distinguished Professor in the Department of Physics, University of California, Davis, centers his current astrophysics research on observational probes of dark matter and dark energy. He has led the development of cameras and analysis techniques for ground-based imaging of the distant, younger Universe. Tyson discovered a backdrop of distant star-forming galaxies that can be used to image foreground dark matter concentrations — allowing the development of dark matter structures to be charted over cosmic time. This will directly constrain the equation of state of dark energy, and thus its physical nature. Tyson is a Fellow of the American Physical Society and the American Academy of Arts and Sciences, and a member of the National Academy of Sciences and the American Philosophical Society. He was also featured in the PBS series *The Astronomers*.

HOST & MODERATOR

NEIL DEGRASSE TYSON is the Frederick P. Rose Director of the Hayden Planetarium. 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). He is currently working on a PBS NOVA mini-series called *Origins: Fourteen Billion Years of Cosmic Evolution.*

Then it was discovered that dozens of the most distant supernovae ever observed appeared noticeably dimmer than expected, given the well-documented behavior of this species of exploding star. Comparison of the distance determined by the "standard candle" nature of these particular supernovae to the distance calculated by the redshift method resulted in a conclusion that these supernovae are farther away than the prevailing cosmological models had placed them and .we have a universe that expanded faster than we thought, placing galaxies farther away than their recession speed would have otherwise indicated. And there was no easy way to explain the extra expansion without invoking Lambda, the cosmological constant.

So Einstein's cosmological constant was real and now cosmologists could estimate its value, because they could calculate the effect it was having: the difference between what they had expected the expansion to be and what it actually was. That value of Lambda suddenly acquired a physical reality that needed a name: "dark energy."

The shape of our four-dimensional universe comes from the relationship between the amount of matter and energy that exists in the cosmos and the rate at which the cosmos is expanding. A convenient mathematical measure of this is Omega (Ω) yet another Greek letter with a firm grip on the cosmos. If you take the matter-energy density of the universe, and divide it by the matter-energy density required to just barely halt the expansion (known as the "critical" density), you get Omega.

With dark energy added to ordinary matter, ordinary energy and "ordinary" dark matter, the mass-energy density of the universe raised to the critical level. In fact, the Wilkinson Microwave Anisotropy Probe (WMAP) measured and mapped the cosmic microwave background to the highest precision yet. Astrophysicists can now say with confidence that omega is indeed one — the matter-energy density of the universe we know and love equals the critical density. 73 percent dark energy, 23 percent dark matter, and a measly 4 percent ordinary matter — the stuff you and I are made of.

So what is the stuff? Perhaps dark energy is a quantum effect — where the vacuum of space, instead of being empty, actually seethes with particles and their antimatter counterparts. These "virtual particles" pop in and out of existence in pairs, and don't last long enough to be measured. Each pair of virtual particles exerts a little bit of outward pressure as it ever-so-briefly elbows its way into space. Unfortunately, when you calculate the amount of repulsive "vacuum pressure" that arises from the abbreviated lives of virtual particles, the result is more than 10^{120} times bigger than the value of the cosmological constant derived from the supernova measurements and WMAP. That may be the most embarrassing calculation ever made, the biggest mismatch between theory and observation in the history of science.

Yet dark energy is not adrift, with nary a theory to call home. It inhabits one of the safest homes we can imagine: Einstein's equations of general relativity. It's Lambda. Whatever dark energy turns out to be, we already know how to measure it and how to calculate its effects on the past, present, and future of the cosmos.

Without a doubt, Einstein's greatest blunder was having declared that Lambda was his greatest blunder.

Adapted by Stephanie L. Parello from the essay "Dark Energy,"
Natural History magazine, December 2003/January 2004, by Neil deGrasse Tyson;
and the chapter "Let There Be Dark," from the book
Origins: Fourteen Billion Years of Cosmic Evolution, 2004,
by Neil deGrasse Tyson & Donald Goldsmith

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 Background Radiation (CBR) — left-over electromagnetic radiation produced in the hot Big Bang — about 14 billion years ago

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

Gravity — the weakest of the four fundamental forces; the mutual attraction of all matter

Lambda Λ — the cosmological constant in Einstein's equations which allowed him to create a static universe, one that neither expands nor contracts; the mysterious repulsive "negative gravity" we now call dark energy

Omega Ω — the matter-energy density of the universe divided by the critical density; tells us the shape of the cosmos since both mass and energy cause space-time to warp, or curve. If Omega is less than one, the actual mass-energy falls below the critical value, and the universe expands forever in every direction for all of time, taking on the shape of a saddle, in which initially parallel lines diverge. If Omega equals one, the universe expands forever, but only barely so; in that case, the shape is flat — preserving all the geometric rules we learned in high school about parallel lines. If Omega exceeds one, parallel lines converge, and the universe curves back on itself, ultimately recollapsing into the fireball whence it came.

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

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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 benefit the scientific and educational programs of the Hayden Planetarium.

2001 Theory of Everything
2002 Search for Life in the Universe
2003 Big Bang
2004 Dark Side