Scientists mount ambitious experiments, propose dramatic new theories about dark energy

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A panel of physicists and astronomers will preview emerging theories and experiments aimed at solving the mystery of dark energy, an invisible force that dominates the universe, from 1:45 to 4:45 p.m. Friday, Feb. 18, at the annual meeting of the American Association for the Advancement of Science in Washington, D.C. The discussion will take place in the Omni Shoreham Hotel Diplomat Room on the lobby level.

"The theoretical talks are about theories that are not well-established, that are very speculative, imaginative and bold," said symposium organizer Sean Carroll, Assistant Professor in Physics at the University of Chicago. "These are not small ideas. They're probably long shots. We have to be bold to explain these things that the observers are finding."

Dark energy could have any one of several different explanations, which the symposium speakers will explore. Whatever it is, Carroll said, "the real hope is that this cosmological discovery will teach us something fundamental about how the universe works."

The discovery of dark energy first made news in 1998, when two groups of scientists who study exploding stars announced that their measurements indicated that the expansion of the universe was accelerating. Leading one of the groups was Adam Riess, now an astronomer at the Space Telescope Science Institute in Baltimore. The finding surprised Riess and his associates, because they had expected to find that the universe's expansion was actually slowing instead. The question astronomers now face is whether dark energy is unchanging, or slowly evolving as the universe expands.

"Using some of the most distant stellar explosions, detectable only with the Hubble Space Telescope, we are making sensitive measurements of past changes in the expansion rate of the universe-changes caused by the onset of dominance of dark energy," said Riess, the second speaker on the dark energy panel. "Specifically, we are trying to measure two properties of the dark energy: its current strength and its longevity."

The symposium's third speaker will be Leonard Susskind, the Felix Bloch professor of physics at Stanford University, who will bring string theory and the controversial Anthropic Principle into the dark energy discussion.

According to string theory, the universe contains as many as 11 dimensions, but most are so small as to be rendered invisible to human perception. Until a few years ago, string theorists had attempted to compactify all of the extra dimensions in such as way as to yield a cosmological constant of zero (where there is no energy in empty space). "That was very hard to do," Carroll said.

But the existence of dark energy has raised the possibility that the value of the cosmological constant may be very small. And now string theorists have found that there are probably billions of ways to configure multiple dimensions in a universe that has a positive or negative cosmological constant.

"Any one of those is a candidate for our real world, and all of them would have a different value for the cosmological constant," Carroll said. "But in regions where the cosmological constant is huge, people can't live because galaxies don't form; the universe recollapses or something like that."

This plays into the Anthropic Principle, the idea that the universe is fine-tuned to allow for the existence of life. There could be other parts of the universe where the cosmological constant takes on different values, but life exists only in regions where the value of the constant is small. "That's an extremely controversial idea, both technically and philosophically," Carroll said.

The fourth speaker, Licia Verde, assistant professor of physics at the University of Pennsylvania, will describe how scientists can compare the cosmic microwave background radiation with the distribution of galaxies in the sky to gain new insights about dark energy. When astronomers view the CMB-the afterglow of the big bang-through telescopes, they see the universe as it looked 380,000 years after the big bang. Verde refers to this as "cosmic archaeology."

The CMB is largely uniform, but it contains tiny ripples of varying density and temperature. These ripples became the seeds that gravity organized into the galaxies and galaxy clusters visible to astronomers in the sky today. If dark energy changed the way the universe expanded, it would have left its "fingerprints" in the way that it forced galaxies apart over the long history of time.

As of today, the data indicate that dark energy could well be Einstein's cosmological constant: a steady force of nature operating at all times and in all places, Verde said. But astronomical measurements are thus far too imprecise to know for sure. More exotic alternatives for dark energy, such as a breakdown of gravity on cosmological scales, remain possible.

Today scientists are developing multiple strategies for measuring dark energy in new and different ways. For example, Verde and her collaborators at Penn and the California Institute of Technology have proposed using a certain type of galaxy as "cosmic chronometers" to trace the expansion history of the universe.

These galaxies formed early in the history of the universe and at approximately the same time. Early-type galaxies are distributed across the universe as far as telescopes can see. Astronomers can determine the ages of these galaxies by the color of their stars, which changes as they grow older. By determining the age of those galaxies, "we could say things like: the universe was 6 billion years old when it was half of its present size, then it took another 4 billion years to get to 77 percent of its present size," Verde said.

The fifth speaker, New York University physics professor Gia Dvali, will address the possibility that there is no dark energy. In the scenario proposed by Dvali and his collaborators, "the universe's acceleration is due to modification of standard laws of gravity at very large distances," he said. This modification would be caused by the existence of an extra dimension of space.

Most of the known forces of nature, such as electromagnetism, would be confined to the three dimensions perceived by humans. "Only gravity can travel in the bulk of the extra space, but even gravity does so only after traveling an enormously large distance," Dvali said.

Dvali uses the analogy of a metallic sheet submerged in water to illustrate the principle. If one hits the sheet with a hammer, shock waves will carry away the energy in all directions. "Most of the energy will travel along the two-dimensional surface. Only at a substantial distance away from the source will the energy loss to water be appreciable," he said. "According to our picture, we are in a very similar situation. We think gravity is 'normal' because we only measure it directly at relatively short distances, but cosmic acceleration indicates leakage."

If gravity is modified at large distances, it's modified everywhere. That would make it possible to verify modified gravity by measuring the orbit of the moon to within one millimeter (four hundredths of an inch), and compare that to the lunar orbital prediction as dictated by Einstein's theory of gravity. Laser-ranging experiments left on the lunar surface by the Apollo astronauts have already measured the lunar orbit with an accuracy of approximately a centimeter (four tenths of an inch). A new, more precise experiment is in the planning stages.

"In the near future we may know if modified gravity is responsible for cosmic acceleration, and all this just by looking at the moon!" Dvali said.

The symposium's final speaker will be John Carlstrom, the S. Chandrasekhar Distinguished Service Professor in Astronomy & Astrophysics at the University of Chicago. Carlstrom and other scientists have undertaken a series of galactic mapping projects using a phenomenon called the Sunyaev-Zeldovich effect to watch the formation of galaxy clusters throughout the history of the universe.

The SZ effect can be used to determine when dark energy began interfering with galaxy-cluster formation and thus became an important force in the evolution of the universe. The effect describes the apparent cooling of radiation as it passes through the hot gas contained in intervening galaxy clusters. It is scientifically useful because it depends on the mass of a cluster rather than its distance from Earth.

"Looking at the SZ effect is looking at large-scale structure as traced by galaxy clusters," Carlstrom said. "That's very sensitive to this tug-of-war between gravity and the dark energy."

Carlstrom oversees two SZ mapping projects, the South Pole Telescope and the SZ Array in California. The SPT is under construction and on schedule to begin making observations as early as March 2007.

Carlstrom expects the SPT to survey thousands of square degrees of sky in a year, detecting approximately 10,000 galaxy clusters.

With the SZ Array, which just began operating, Carlstrom plans to survey 12 square degrees of sky. No research group has yet detected a galaxy cluster using the SZ effect. The SZ array is perhaps just days away from becoming the first.

Another project that will operate in tandem with the South Pole Telescope is the Dark Energy Survey, which is now under development by the University of Chicago, Fermi National Accelerator Laboratory and other institutions.

Said Verde, "It is a very exciting time to be working in physics and cosmology. A lot of spectacular new data is coming soon, and we should expect spectacular results."

Source: University of Chicago

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