The day the universe froze: New dark energy model includes cosmological phase transition

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This photo shows research associate Sourish Dutta, left, and physics professor Robert Scherrer. Credit: John Russell, Vanderbilt University

Imagine a time when the entire universe froze. According to a new model for dark energy, that is essentially what happened about 11.5 billion years ago, when the universe was a quarter of the size it is today.

The model, published online May 6 in the journal *Physical Review D,* was developed by Research Associate Sourish Dutta and Professor of Physics Robert Scherrer at Vanderbilt University, working with Professor of Physics Stephen Hsu and graduate student David Reeb at the University of Oregon.

A cosmological phase transition - similar to freezing - is one of the distinctive aspects of this latest effort to account for dark energy - the mysterious negative force that cosmologists now think makes up more than 70 percent of all the energy and matter in the universe and is pushing the universe apart at an ever-faster rate.

Another feature that distinguishes the new formulation is that it makes a testable prediction regarding the expansion rate of the universe. In addition, the micro-explosions created by the largest particle colliders should excite the dark energy field and these excitations could appear as exotic, never-seen-before sub-atomic particles.

"One of the things that is very unsatisfying about many of the existing explanations for dark energy is that they are difficult to test," says Scherrer, "We designed a model that can interact with normal matter and so has observable consequences."

The model associates dark energy with something called vacuum energy. Like a number of existing theories, it proposes that space itself is the source of the repulsive energy that is pushing the universe apart. For many years, scientists thought that the energy of empty space averaged zero. But the discovery of quantum mechanics changed this view. According to quantum theory, empty space is filled with pairs of "virtual" particles that spontaneously pop into and out of existence too quickly to be detected.

This sub-atomic activity is a logical source for dark energy because both are spread uniformly throughout space. This distribution is consistent with evidence that the average density of dark energy has remained constant as the universe has expanded. This characteristic is in direct contrast to ordinary matter and energy, which become increasingly dilute as the universe inflates.

The theory is one of those that attribute dark energy to an entirely new field dubbed quintessence. Quintessence is comparable to other basic fields like gravity and electromagnetism, but has some unique properties. For one thing, it is the same strength throughout the universe. Another important feature is that it acts like an antigravity agent, causing objects to move away from each other instead of pulling them together like gravity.

In its simplest form, the strength of the quintessence field remains constant through time. In this case it plays the role of the cosmological constant, a term that Albert Einstein added to the theory of general relativity to keep the universe from contracting under the force of gravity. When evidence that the universe is expanding came in, Einstein dropped the term since an expanding universe is a solution to the equations of general relativity. Then, in the late 90's, studies of supernovae (spectacular stellar explosions so powerful that they can briefly outshine entire galaxies consisting of millions of stars) indicated that the universe is not just expanding but also that the rate of expansion is speeding up instead of slowing down as scientists had expected.

That threw cosmologists for a loop since they thought gravity was the only long-range force acting between astronomical objects. So they had no idea what could possibly be pushing everything apart. The simplest way to account for this bizarre phenomenon was to bring back Einstein's cosmological constant with its antigravity properties. Unfortunately, this explanation suffers from some severe drawbacks so physicists have been actively searching for other antigravity agents.

These antigravity agents (dubbed "dark energy models" in the technical literature) usually invoke quintessence or even more exotic fields. Because none of these fields have been detected in nature; however, their proponents generally assume that they do not interact significantly with ordinary matter and radiation.

One of the consequences of allowing quintessence to interact with ordinary matter is the likelihood that the field went through a phase transition - froze out - when the universe cooled down to a temperature that it reached 2.2 billion years after the Big Bang. As a result, the energy density of the quintessence field would have remained at a relatively high level until the phase transition when it abruptly dropped to a significantly lower level where it has remained ever since.

This transition would have released a fraction of the dark energy held in the field in the form of dark radiation. According to the model, this dark radiation is much different than light, radio waves, microwaves and other types of ordinary radiation: It is completely undetectable by any instrument known to man. However, nature provides a detection method. According to Einstein's theory of general relativity, gravity is produced by the distribution of energy and momentum. So the changes in net energy and momentum caused by the sudden introduction of dark radiation should have affected the gravitational field of the universe in a way that has slowed its expansion in a characteristic fashion.

In the next 10 years or so, the large astronomical surveys that are just starting up to plot the expansion of the universe by measuring the brightness of the most distant supernovas should be able to detect the slowdown in the expansion rate that the model predicts. At the same time, new particle accelerators, like the Large Hadron Collider nearing operation in Switzerland, can produce energies theoretically large enough to excite the quintessence field and these excitations could appear as new exotic particles, the researchers say.

More information: link.aps.org/abstract/PRD/v79/e103504

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