Program of Dialogue on Science, Ethics, & Religion

Summary
Before the Beginning....The Return of the Cyclic Universe

January 16, 2003

In the last fifty years a great deal of evidence has accumulated in support of a "consensus" theory of the evolution of the universe. This theory holds that a "big bang" precipitated a huge split-second inflation of the universe, followed by a gradual expansion that continues to this day and is now accelerating.

"But just maybe that turns out to be wrong," says Paul Steinhardt, Ph.D. Dr. Steinhardt is Albert Einstein Professor of Science and Professor of Physics at Princeton University. Dr. Steinhardt and his colleague Neil Turok of Cambridge University have put forward a competing idea: that the universe exists in an infinite cycle of expansion and contraction.

Dr. Steinhardt compared the consensus model with the new cyclic theory at a January 16 lecture sponsored by the Dialogue on Science, Ethics, and Religion (DoSER), a program of the American Association for the Advancement of Science (AAAS).

Dr. Steinhardt explained that cosmology has been a subject of human inquiry as far back as recorded history, but it really only began as a science about 80 years ago. That was when telescopes became large and precise enough to get a detailed look at the universe beyond this solar system.

The last ten years have been "especially remarkable," he said. "There's a whole host of new technologies that — just by historical coincidence — have suddenly become available and opened up new windows on the universe, providing a wealth of data and tight new constraints on cosmological models."

This data eliminated many of the ideas for the origin and evolution of the universe that had been on the table up to that point. The only theory to survive was the consensus model, which combines the idea of the big bang with inflationary theory and recent ideas about dark energy.

The assumption about a big bang — a beginning to space and time – stems from the discovery that when data from today's universe is plugged into Einstein's equations of general relativity and extrapolated backward about 15 billion years, temperature and density become infinite and space completely curls up.

The consensus model makes two other assumptions. One, it assumes that very little matter and radiation existed at the beginning of the universe because these forms of energy self-gravitate and resist expansion. "If you have too much matter and radiation, it will cause the universe, after a few instants, to simply collapse again," Dr. Steinhardt explained.

Second, it assumes that some as-yet unknown cosmic field existed at the formation of the universe to drive the initial inflation. The inflationary theory holds that the universe doubled in size about once every 10^{-35} seconds for less than half a minute. That adds up to about 100,000 doublings, which means that the size of the universe at the beginning of the big bang was infinitesimally small.

Inflation caused the universe to stretch, uncurling space-time and smoothing out its wrinkles. This would explain how matter and radiation came to be so evenly distributed throughout the universe. A big bang by itself would have been turbulent and thus would have distributed energy more randomly.

The unknown cosmic field that launched inflation is assumed to have operated under quantum principles, that is, it would have been random and unstable. Its decay ended the initial period of inflation and also created variations in energy that led to imperfections in the otherwise smooth texture of the universe. These imperfections seeded the stars, planets, and galaxies.

The consensus model acknowledges but does not explain the presence in the universe of dark energy. The exact properties of dark energy are unknown but it is believed to be vacuum energy — space that is empty of all particles. The model says that some billions of years ago this form of energy dominated the universe.

The consensus model also does not have a solid explanation for the relatively recent observation that the expansion of the universe is undergoing acceleration. The uncertainties presented by dark energy and acceleration are what motivated Dr. Steinhardt and his colleagues to begin exploring alternative models.

Steinhardt and Turok's cyclic theory borrows from a 20th century theory of a cyclic universe but is fundamentally different. Like the older theory, the new cyclic model suggests a universe that expands and cools over and over again, "perhaps forever or perhaps so far back we essentially have lost all memory," according to Dr. Steinhardt. But unlike the older theory, the new model is dynamic: key events that occur in one cycle play a role in setting up the next cycle and determining the features of the universe in that cycle.

The 20th century cyclic model assumed that the universe expands for a period until the self-gravitational pull of matter and radiation resists further expansion and leads to collapse. Matter and radiation again become very concentrated and this pressure leads to an expansion. The cycle repeats itself symmetrically and indefinitely.

In the 1930s cosmologist Richard Tolman pointed out that, by the Second Law of Thermodynamics (which states that the entropy of the universe increases over time), each cycle should have more entropy than the previous one and each "bounce" would be larger and longer than the one before.

This was a problem for cosmologists uncomfortable with the idea of a beginning to the universe. "Going forward in time that's not a problem," said Dr. Steinhardt. "But going backward in time it very rapidly gets converted to being zero. If your idea was to get away from a beginning to the universe, you couldn't: it was just a few bounces ago." The earlier cyclic model also conflicted with evidence obtained through improved space observation techniques and "so this model is now dead on several counts," stated Dr. Steinhardt.

The 21st century cyclic theory is inspired by super-string theory, which seeks to resolve the mathematical incompatibility between quantum mechanics and the General Theory of Relativity. Dr. Steinhardt said there are several ways to explain this theory and one makes use of super-string theory. In this model, the universe is a three-dimensional "hypersurface" embedded in a space of extra dimensions and existing within a thin membrane ("brane").

"Our quarks, our electrons, our photons — everything that we know — is stuck like flies on flypaper on this membrane," Dr. Steinhardt said.

A parallel brane exists a microscopic 10^{-30} meters distant. This other brane cannot be seen or touched — it is thus a form of dark energy. Though the two branes do not touch, they interact gravitationally and through the virtual quantum exchange of particles, strings, and membranes.

Over the course of trillions of years, the branes stretch out and smooth out the distribution of matter and energy. The stretching occurs through the influence of dark energy, which is self-repulsive. "It is the engine that drives the whole cycling of the universe," Dr. Steinhardt said. Stretching decreases the density of matter and radiation in the universe until it is essentially empty, at which point the branes are unable to resist the force between them. They collapse against each other. As they collide, the rules of quantum physics cause the flattened branes to wrinkle. Different regions of the branes collide at different instants, and this leaves an impression on the universe afterward in fluctuations in temperature and density. This is a very different but equally plausible theory of how the structures of the universe were seeded, Dr. Steinhardt explained.

The "crunch" creates new matter and radiation and so replenishes the universe. The branes stretch once again in a renewed cycle of expansion and contraction. Importantly, only an insignificant amount of entropy is created at the crunch. This means that the cycles don't build in size but rather continue evenly and infinitely both forward and backward in time.

The cosmologist emphasized a key distinction between the old and new cyclic models. "In the old cyclic model it was our three dimensions that were contracting," he said. "In this model, our three dimensions — our branes — don't contract. What's contracting is the extra dimension as those two branes come together."

Dr. Steinhardt noted that the new cyclic model fits all available evidence and does so using "fewer ingredients." The consensus model requires "an ingredient to drive inflation and a second ingredient to make dark energy, and we don't really know what either of them are." In the cyclic model, "you only need this single ingredient, which is the energy associated with these branes."

Furthermore, the cyclic model gives a purpose to dark energy and does not have the problem of explaining a beginning to the universe. Inflation is no longer needed, and neither is an explanation for dark energy's appearance billions of years after the universe is formed.

"This model is in some sense a more complete theory of cosmic history. Anything that happens today, in a statistical sense, happened in the past and happens in the future."

Dr. Steinhardt said that the two models are "empirically distinguishable" so cosmologists "will have a lot of fun, developing both theories, trying to imagine how we can distinguish them and debating which of them provides a better model." He noted that evidence for that debate will eventually come from more precise measurements of the background microwave radiation emitted in the universe. The hyper-swift inflation of the consensus model would be a violent occurrence, producing gravitational waves (fluctuations in space-time) that should still be coursing through the universe. The universe's expansion under the cyclic model would be much slower and therefore produce exponentially weaker waves.

Following Dr. Steinhardt's remarks, Francisa Cho, Ph.D., described the cyclic universe of Indian cosmology. According to Dr. Cho, who is Associate Professor of Buddhism and East Asian religions at Georgetown University, the Indian and scientific cosmologies are similar despite the "overt differences in rhetoric."

In the Hindu religion, the universe cycles endlessly through creation and destruction. "The actual impetus for the creation of the world is the lila, the play of the gods," Dr. Cho said. "Out of this energy the universe is born."

At the moment of creation the universe is non-differentiated and non-material – like pure energy. But immediately de-evolution begins. Four ages, or yugas, make up one complete cycle and each successive age experiences more degeneration. "Perhaps you can call it a kind of entropy," said Dr. Cho. "Things move to a state of chaos both from a physical and moral point of view."

This chaos entails “condensation of matter and differentiation.” In terms of human existence, genders emerge, class distinctions are created, and property is divided up and owned. Degeneration continues until a final cataclysmic destruction takes place through fire, water, and wind.

Unlike Steinhardt and Turok’s model, in Indian cosmology each cycle is unique. “Different cycles are created by different gods, primarily Brahma, Vishnu, and Shiva,” said Dr. Cho. Therefore the lengths of the yugas vary and nature itself varies within a single yuga. For example, near the beginning of a cycle, humans simply eat earth. As nature degenerates, humans must cultivate or hunt and gather from the earth to eat.

Against the endless repetition of cycles, human action becomes insignificant and pointless, noted Dr. Cho, adding however that the Buddhist religion offers a slightly different perspective. Because the Buddha reappears once every cycle, history has more significance and people through their actions can transcend their circumstances.

This distinction between Hinduism and Buddhism highlights the diversity in the Indian perspective on creation, said Dr. Cho, who concluded by posing the question of whether science might take some inspiration from Indian cosmology, both in its overall picture of the universe and also in its ability to hold at one time multiple explanations of existence.

Summary composed by Catherine Baker, Science Writer