What Happened Before the Big Bang?

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Spreading through a bounce: A state that initially has small fluctuations (left) bounces and develops larger fluctuations (right). Time proceeds along the horizontal axis, with the volume plotted vertically. Credit: Martin Bojowald, Penn State

New discoveries about another universe whose collapse appears to have given birth to the one we live in today will be announced in the early on-line edition of the journal *Nature Physics* on 1 July 2007 and will be published in the August 2007 issue of the journal's print edition.

"My paper introduces a new mathematical model that we can use to derive new details about the properties of a quantum state as it travels through the Big Bounce, which replaces the classical idea of a Big Bang as the beginning of our universe," said Martin Bojowald, assistant professor of physics at Penn State. Bojowald's research also suggests that, although it is possible to learn about many properties of the earlier universe, we always will be uncertain about some of these properties because his calculations reveal a "cosmic forgetfulness" that results from the extreme quantum forces during the Big Bounce.

The idea that the universe erupted with a Big Bang explosion has been a big barrier in scientific attempts to understand the origin of our expanding universe, although the Big Bang long has been considered by physicists to be the best model.

As described by Einstein's Theory of General Relativity, the origin of the Big Bang is a mathematically nonsensical state -- a "singularity" of zero volume that nevertheless contained infinite density and infinitely large energy. Now, however, Bojowald and other physicists at Penn State are exploring territory unknown even to Einstein -- the time before the Big Bang -- using a mathematical time machine called Loop Quantum Gravity.

This theory, which combines Einstein's Theory of General Relativity with equations of quantum physics that did not exist in Einstein's day, is the first mathematical description to systematically establish the existence of the Big Bounce and to deduce properties of the earlier universe from which our own may have sprung. For scientists, the Big Bounce opens a crack in the barrier that was the Big Bang.

"Einstein's Theory of General Relativity does not include the quantum physics that you must have in order to describe the extremely high energies that dominated our universe during its very early evolution," Bojowald explained, "but we now have Loop Quantum Gravity, a theory that does include the necessary quantum physics." Loop Quantum Gravity was pioneered and is being developed in the Penn State Institute for Gravitational Physics and Geometry, and is now a leading approach to the goal of unifying general relativity with quantum physics. Scientists using this theory to trace our universe backward in time have found that its beginning point had a minimum volume that is not zero and a maximum energy that is not infinite. As a result of these limits, the theory's equations continue to produce valid mathematical results past the point of the classical Big Bang, giving scientists a window into the time before the Big Bounce.

Quantum-gravity theory indicates that the fabric of space-time has an "atomic" geometry that is woven with one-dimensional quantum threads. This fabric tears violently under the extreme conditions dominated by quantum physics near the Big Bounce, causing gravity to become strongly repulsive so that, instead of vanishing into infinity as predicted by Einstein's Theory of General Relativity, the universe rebounded in the Big Bounce that gave birth to our expanding universe. The theory reveals a contracting universe before the Big Bounce, with space-time geometry that otherwise was similar to that of our universe today.

Bojowald found he had to create a new mathematical model to use with the theory of Loop Quantum Gravity in order to explore the universe before the Big Bounce with more precision. "A more precise model was needed within Loop Quantum Gravity than the existing numerical methods, which require successive approximations of the solutions and yield results that are not as general and complete as one would like," Bojowald explained. He developed a mathematical model that produces precise analytical solutions by solving of a set of mathematical equations.

In addition to being more precise, Bojowald's new model also is much shorter. He reformulated the quantum-gravity models using a different mathematical description, which he says made it possible to solve the equations explicitly and also turned out to be a strong simplification. "The earlier numerical model looked much more complicated, but its solutions looked very clean, which was a clue that such a mathematical simplification might exist," he said. Bojowald reformulated quantum gravity's differential equations -- which require many calculations of numerous consecutive small changes in time -- into an integrable system -- in which a cumulative length of time can be specified for adding up all the small incremental changes.

The model's equations require parameters that describe the state of our current universe accurately so that scientists then can use the model to travel backward in time, mathematically "un-evolving" the universe to reveal its state at earlier times. The model's equations also contain some "free" parameters that are not yet known precisely but are nevertheless necessary to describe certain properties. Bojowald discovered that two of these free parameters are complementary: one is relevant almost exclusively after the Big Bounce and the other is relevant almost exclusively before the Big Bounce. Because one of these free parameters has essentially no influence on calculations of our current universe, Bojowald colludes that it cannot be used as a tool for back-calculating its value in the earlier universe before the Big Bounce.

The two free parameters, which Bojowald found were complementary, represent the quantum uncertainty in the total volume of the universe before and after the Big Bang. "These uncertainties are additional parameters that apply when you put a system into a quantum context such as a theory of quantum gravity," Bojowald said. "It is similar to the uncertainty relations in quantum physics, where there is complimentarity between the position of an object and its velocity -- if you measure one you cannot simultaneously measure the other." Similarly, Bojowald's study indicates that there is complementarity between the uncertainty factors for the volume of the universe before the Big Bounce and the universe after the Big Bounce. "For all practical purposes, the precise uncertainty factor for the volume of the previous universe never will be determined by a procedure of calculating backwards from conditions in our present universe, even with most accurate measurements we ever will be able to make," Bojowald explained. This discovery implies further limitations for discovering whether the matter in the universe before the Big Bang was dominated more strongly by quantum or classical properties.

"A problem with the earlier numerical model is you don't see so clearly what the free parameters really are and what their influence is," Bojowald said. "This mathematical model gives you an improved expression that contains all the free parameters and you can immediately see the influence of each one," he explained. "After the equations were solved, it was rather immediate to reach conclusions from the results."

Bojowald reached an additional conclusion after finding that at least one of the parameters of the previous universe did not survive its trip through the Big Bounce -- that successive universes likely will not be perfect replicas of each other. He said, "the eternal recurrence of absolutely identical universes would seem to be prevented by the apparent existence of an intrinsic cosmic forgetfulness."

Source: Penn State

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