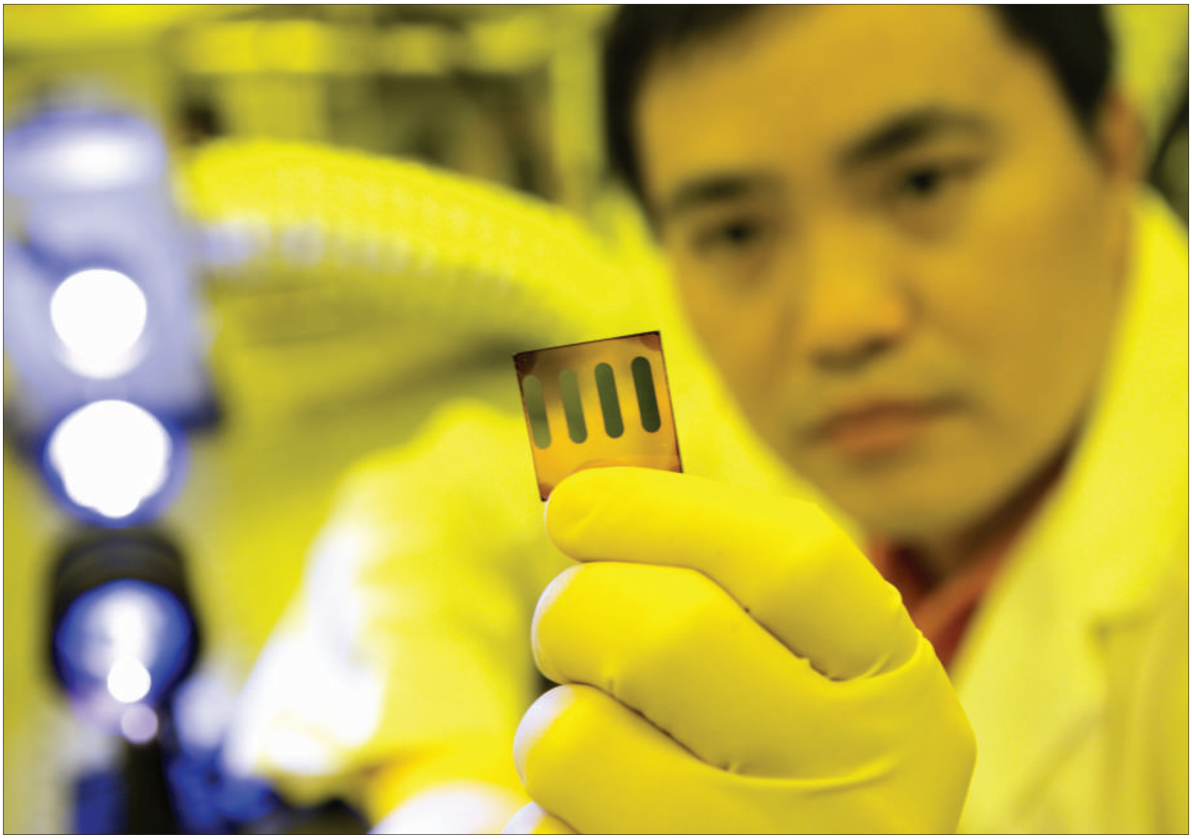

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The Birth of Time: Quantum Loops Describe the Evolution of the Universe

What was the Big Bang and what happened before it? Scientists from the Faculty of Physics, University of Warsaw have attempted to answer the question. Within the framework of loop quantum gravity they have put forward a new theoretical model, which might prove useful for validating hypotheses about events prior to the Big Bang. This achievement is one of the few models describing the full Einstein's theory and not merely its greatly simplified version.

Physicists from the Faculty of Physics, University of Warsaw have put forward -- on the pages of Physical Review D -- a new theoretical model of quantum gravity describing the emergence of space-time from the structures of quantum theory. It is not only one of the few models describing the full general theory of relativity advanced by Einstein, but it is also completely mathematically consistent. "The solutions applied allow to trace the evolution of the Universe in a more physically acceptable manner than in the case of previous cosmological models," explains Prof. Jerzy Lewandowski from the Faculty of Physics, University of Warsaw (FUW).

While the general theory of relativity is applied to describe the Universe on a cosmological scale, quantum mechanics is applied to describe reality on an atomic scale. Both theories were developed in the early 20th century. Their validity has since been confirmed by highly sophisticated experiments and observations. The problem lies in the fact that the theories are mutually exclusive.

According to the general theory of relativity, reality is always uniquely determined (as in classical mechanics). However, time and space play an active role in the events and are themselves subject to Einstein's equations. According to quantum physics, on the other hand, one may only gain a rough understanding of nature. A prediction can only be made with a probability; its precision being limited by inherent properties. But the laws of the prevailing quantum theories do not apply to time and space. Such contradictions are irrelevant under standard conditions -- galaxies are not subject to quantum phenomena and quantum gravity plays a minor role in the world of atoms and particles. Nonetheless, gravity and quantum effects need to merge under conditions close to the Big Bang.

Traditional cosmological models describe the evolution of the Universe within the framework of the general theory of relativity itself. The equations at the core of the theory suggest that the Universe is a dynamic, constantly expanding creation. When theorists attempt to discover what the Universe was like in times gone by, they reach the stage where density and temperature in the model become infinite -- in other words, they lose their physical sense. Thus, the infinities may only be indicative of the weaknesses of the former theory and the moment of the Big Bang does not have to signify the birth of the Universe.

In order to gain at least some knowledge of quantum gravity, scientists construct simplified quantum models, known as quantum cosmological models, in which space-time and matter are expressed in a single value or a few values alone. For example, the model developed by Ashtekar, Bojowald, Lewandowski, Pawtowski and Singh predicts that quantum gravity prevents the increase of matter energy density from exceeding a certain critical value (of the order of the Planck density). Consequently, there must have been a contracting universe prior to the Big Bang. When matter density had reached the critical value, there followed a rapid expansion -- the Big Bang, known as the Big Bounce. However, the model is a highly simplified toy model.

The real answer to the mystery of the Big Bang lies in a unified quantum theory of matter and gravity. One attempt at developing such a theory is loop quantum gravity (LQG). The theory holds that space is weaved from one-dimensional threads. "It is just like in the case of a fabric -- although it is seemingly smooth from a distance, it becomes evident at close quarters that it consists of a network of fibres," describes Wojciech Kamiñski, MSc from FUW. Such space would constitute a fine fabric -- an area of a square centimetre would consists of 1066 threads.

Physicists Marcin Domagata, Wojciech Kamiñski and Jerzy Lewandowski, together with Kristina Giesel from the University of Louisiana (guest), developed their model within the framework of loop quantum gravity. The starting points for the model are two fields, one of which is a gravitational field. "Thanks to the general theory of relativity we know that gravity is the very geometry of space-time. We may, therefore, say that our point of departure is three-dimensional space," explains Marcin Domagata, PhD (FUW).

The second starting point is a scalar field -- a mathematical object in which a particular value is attributed to every point in space. In the proposed model, scalar fields are interpreted as the simplest form of matter. Scalar fields have been known in physics for years, they are applied, among others, to describe temperature and pressure distribution in space. "We have opted for a scalar field as it is the typical feature of contemporary cosmological models and our aim is to develop a model that would constitute another step forward in quantum gravity research," observes Prof. Lewandowski.

In the model developed by physicists from Warsaw, time emerges as the relation between the gravitational field (space) and the scalar field -- a moment in time is given by the value of the scalar field. "We pose the question about the shape of space at a given value of the scalar field and Einstein's quantum equations provide the answer," explains Prof. Lewandowski. Thus, the phenomenon of the passage of time emerges as the property of the state of the gravitational and scalar fields and the appearance of such a state corresponds to the birth of the well-known space-time. "It is worthy of note that time is nonexistent at the beginning of the model. Nothing happens. Action and dynamics appear as the interrelation between the fields when we begin to pose questions about how one object relates to another," explains Prof. Lewandowski.

Physicist from FUW have made it possible to provide a more accurate description of the evolution of the Universe. Whereas models based on the general theory of relativity are simplified and assume the gravitational field at every point of the Universe to be identical or subject to minor changes, the gravitational field in the proposed model may differ at different points in space.

The proposed theoretical construction is the first such highly advanced model characterized by internal mathematical consistency. It comes as the natural continuation of research into quantization of gravity, where each new theory is derived from classical theories. To that end, physicists apply certain algorithms, known as quantizations. "Unfortunately for physicists, the algorithms are far from precise. For example, it may follow from an algorithm that a Hilbert space needs to be constructed, but no details are provided," explains Marcin Domagata, MSc. "We have succeeded in performing a full quantization and obtained one of the possible models."

There is still a long way to go, according to Prof. Lewandowski: "We have developed a certain theoretical machinery. We may begin to ply it with questions and it will provide the answers." Theorists from FUW intend, among others, to inquire whether the Big Bounce actually occurs in their model. "In the future, we will try to include in the model further fields of the Standard Model of elementary particles. We are curious ourselves to find out what will happen," says Prof. Lewandowski.

Marcin Domagata, Kristina Giesel, Wojciech Kamiñski, Jerzy Lewandowski. Gravity quantized: Loop quantum gravity with a scalar field. Phys. Rev. D, 82, 104038 (2010) DOI: arXiv:1009.2445