Physicist Abhay Ashtekar contends that before the Big Bang there was an earlier universe which collapsed and then rebounded back to form the universe we know today

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Physicists do not have the tools to unravel the origins of the universe. They have shown that around 13,700 million years ago all matter and energy were concentrated within a tiny volume which subsequently expanded in the process known as the Big Bang. But they still have no explanations about this "day zero" or about whether something might have happened before the expansion phase began. The theory of loop quantum gravity, formulated 25 years ago by Abhay Ashtekar, could hold some of the answers.

Ashtekar, Director of the Institute for Gravitational Physics and Geometry at Pennsylvania State University (United States), and his colleague and collaborator Carlo Rovelli, of the Université de la Mediterranée (France), discussed the latest advances in the theory of loop quantum gravity in the Foundation's Madrid headquarters. Both men were in Spain for the LOOPs 11 International Conference, organized with the support of the BBVA Foundation.

Loop quantum gravity is currently a firm candidate to overcome one of the great challenges for modern physics: how to unify the laws of general relativity with those of quantum mechanics. Quantum mechanics and relativity together form the set of physical principles that describe our known reality. And both theories operate perfectly - only not in the same domain. Quantum physics explains the world of elementary particles, at microscopic scales, while general relativity, which sees gravity as the distortion of space-time in the presence of matter, describes events unfolding at enormous distances. But, what happens when gravity is extremely strong and the relevant distances extremely small? There is no proven theory that holds for these conditions, which were precisely those prevailing at the start of the universe, according to the Big Bang model.

Microscopic foam

Loop quantum gravity predicts that at very small scales - specifically the "Planck distance" of considerably less than a billionth of the diameter of an atom - space-time is formed by a web of interwoven loops that make up a kind of foam. Hence the name of the theory.

It argues that the Big Bang was preceded by one or several collapse and expansion phases, forming a pattern theorists have dubbed the Big Bounce.

According to the classic Big Bang model, going back in time we arrive at what physicists call a singularity; a point where the density of matter and the space-time curvature become infinite and general relativity equations cease to apply. This does not happen with loop quantum gravity. Instead, the singularity, and therefore the Big Bang itself, "is replaced by the Big Bounce," says Ashtekar.

"The region of the Big Bang is inaccessible for conventional physics," Rovelli continues. "With loop quantum gravity we can do the sums and compute what might have occurred. The results of these calculations are strong proof that before the Big Bang there was an earlier universe which collapsed then rebounded back to form our own."

Testing loop quantum gravity

One of the challenges now facing loop quantum gravity is to test its predictions through observation. The space missions currently scrutinizing cosmic microwave radiation - a light emitted just after the Big Bang which still fills the whole of the universe - may just come up with the evidence needed. One such mission is the Planck satellite of the European Space Agency (ESA), which is gathering data as we write.

"There is a chance that Planck may provide some clues, but it is still too early to say," says a cautious Rovelli. "For the moment, our theory cannot be experimentally verified - also the case with string theory - but we are working hard to achieve this."