HEART OF THE MATTER Researchers wonder if there was actually a point of singularity when the density of the universe was very high.
(PHOTO: GETTY IMAGES)

Moment of truth

BIG BANG Theoretical physicist Abhay Ashtekar and his colleagues have come up with a new paradigm to study the earliest eras in the history of the universe. Their work shows that the conditions at the very beginning of the universe naturally gave way to the large-scale structure of the universe that we observe today, reports **Kalyan Ray**

Cosmic microwave background radiation (CMBR), an omnidirectional microwave signal, is the best evidence in support of the Big Bang theory so far. It was first detected by two young researchers, Arno Penzias and Robert Wilson, in 1964 who went on to receive a Nobel Prize in 1978. Two space probes—Cosmic Background Explorer (COBE) and Wilkinson Microwave Anisotropic Probe (WMAP)—further corroborated the presence of an all-pervasive microwave relic of the universe. Contrary to popular ideas, Big Bang actually is not a well-established fact because CMBR observations do not say anything directly about the Big Bang and the baby universe. CMBR describes a universe which was 3,80,000 years old. Was there anything before that? Was there a point of singularity when the universe's density was extremely high. There is barely any physics to describe those first few moments of the universe because that explanation is possible when scientists are able to find the Holy Grail of physics, marrying quantum mechanics (physics of the atomic world) with that of gravity, which rules the physics of the ultra-large, like the stars and galaxies.

Understanding the universe

Over the last few decades, two theories have emerged to describe the universe in its infancy. Both successfully combine quantum mechanics with gravity. But while the String Theory operates in 10 or 11 dimensions, Abhay Ashtekar's loop quantum gravity (LQG) works in three space and one time dimension and is the only serious contender to String Theory. Both had similar successes in describing quantum gravity and both can explain Black Hole radiation, proposed by Stephen Hawking, to show how and when quantum mechanics and gravity can be integrated.Neither String Theory nor LQG had any experimental support so far. But Ashtekar, director of Penn State University's Institute for Gravitation and the Cosmos and his colleagues, have now come up with ideas that can be tested using present or future experimental facilities like terrestrial and space borne telescopes. In the 1980s, Ashtekar provided a new formulation of general relativity that looked promising in integrating quantum mechanics with gravity. It was called loop quantum gravity. A more recent offshoot of that theory is its application to cosmology—Loop Quantum Cosmology (LQC). It is believed that cosmology provides the ultimate testing ground for all approaches to quantum gravity since the earliest moments of the universe operate at energy scales at which effects of quantum gravity manifest themselves. "In the past five years, work on LQC indicated possible interesting characteristic measurable signatures for cosmological observations. However, it has been a challenge to reliably study cosmological perturbations that can give signatures to be realistically searched in the exquisitely measured Cosmic Microwave Background (CMB) anisotropy and polarisation," Tarun Souradeep, an astrophysicist at Pune-based Inter-University Centre for Astronomy and Astrophysics, who is not associated with Ashtekar's work, told ***Deccan Herald.***

New studies

Ashtekar and his colleagues have now come up with a new paradigm to study the earliest eras in the history of the universe, using techniques from loop quantum cosmology. The new analysis, published in today's issue of *Physical Review Letters*, pushes physics farther back in time, all the way to the beginning. It shows for the first time that large-scale structures like galaxies seen in the universe evolved from fundamental fluctuations in the essential quantum nature of 'space-time,' which existed even at the very beginning of the universe around 14 billion years ago. The achievement provides new opportunities for testing these theories from observations expected from next-generation telescopes.

Ashtekar's earlier work had updated the concept of the Big Bang with the concept of a Big Bounce, which allows a new possibility that our universe emerged not from nothing but from a super-compressed mass of matter that previously may have had a history of its own. Even though the quantum-mechanical conditions at the beginning of the universe were vastly different from the classical-physics conditions after inflation, an era of extremely rapid expansion after the Big Bang, Penn State physicists reveals a surprising connection between the two different paradigms that describe these eras.

"We now have narrowed down the initial conditions that could exist at the Big Bounce, plus we find that the evolution of those initial conditions agrees with observations of the cosmic background radiation," said William Nelson, a coauthor of the paper from the Penn State. When scientists use the inflation paradigm together with Einstein's equations to model the evolution of the seed-like areas sprinkled throughout the cosmic background radiation, they find that the irregularities serve as seeds that evolve over time into the galaxy clusters and other large-scale structures that we see in the universe today. When the Penn State scientists used their new loop-quantum-origins paradigm with its quantum-cosmology equations, they found that fundamental fluctuations in the very nature of space at the moment of the Big Bounce evolve to become the seed-like structures seen in the cosmic microwave background.

Expansion mode

"Our new work shows that the initial conditions at the very beginning of the universe naturally lead to the large-scale structure of the universe that we observe today," Ashtekar said. "In human terms, it is like taking a snapshot of a baby right at birth and then being able to project from it an accurate profile of how that person will be at age 100."

"Not just space telescopes; even terrestrial missions such as the Sloan Digital Sky Survey IV will clarify the situation. By observing properties of galaxy clusters with space missions and earth-based telescopes, one would be able to pin down what happened at the true beginning, which in loop quantum cosmology is the bounce," he told ***Deccan Herald.***

Big Bang is a prediction of general relativity and it says that physics just stops there. But this can not be trusted because of very high density of matter. Albert Einstein himself recognised that the Big Bang prediction of general relativity cannot be trusted when he stated, "One may not assume the validity of field equations at very high density of field and matter and one may not conclude that the beginning of the expansion should be a singularity in the mathematical sense."

"Physics encountered similar situations in the past and each time such predictions turned out to be wrong. They arose because the theory just ignored some crucial effects. In the case of the Big Bang, one ignores quantum effects of gravity," said Ashtekar. "Of course, general relativity is a well-tested theory in regimes where quantum effects can be ignored and gravity is not too strong. These regimes do not occur on earth. Therefore observational tests of quantum gravity are difficult," admitted Ashtekar.

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