The long-distance thinker

Martin Bojowald is on a journey back in time to see what happened during the Big Bang. Quirin Schiermeier tags along for the ride.

The journey southwest from Berlin to Golm, a small village near Potsdam, is a 90-minute train trip to the end of the world. Or that is how it seemed on a misty December morning. Outside Potsdam the only view from the window is farmland stretching to the horizon, until an ultra-modern glass building looms out of the fog.

This think-tank in the middle of nowhere is the Max Planck Institute for Gravitational Physics, often called the Albert Einstein Institute. As might be expected, it is home to theorists who are struggling with physics' deepest questions. How did the Universe begin? What will be its fate? And what happens to time, space and matter at these extremes?

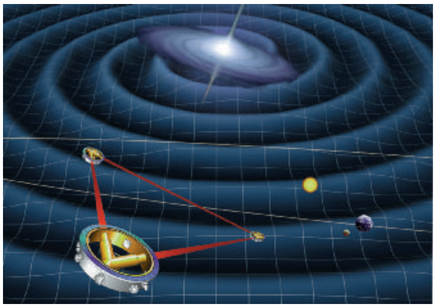
The forlorn landscape outside rather suits Martin Bojowald, a 31-year-old German theorist, who admits he spends most of his time staring into space. Except when writing papers or e-mails, he hardly uses a computer — and he does most of his deep thinking at home, where he feels less self-conscious about his apparent lack of activity.

Bojowald is a disciple of loop quantum gravity, a theory of gravity at the smallest of scales, which physicists can use to look inside black holes or back to the first few moments of the Universe.

Loop quantum gravity is a way to reconcile general relativity — Einstein's theory of how gravity shapes the cosmos — with our quantum picture of the atomic world. Gravity, alone among the four fundamental forces of nature, seems not to respect the rules of quantum physics. Loop quantum gravity tries to address this directly, by rewriting Einstein's equations within a quantum framework. A popular alternative route to 'quantum gravity' is provided by string theory, which has its roots in particle physics, and postulates that everything in the Universe is made of unobservable vibrating strings.

Any decent theory that claims to unite general relativity with quantum theory should be able to fix some of the cosmological puzzles unsolved by general relativity.

Martin Bojowald, whose idol is Einstein, hopes that his ideas on the Big Bang will gain some support from NASA's LISA mission (below).



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LISA/JPL/NASA

One enduring mystery is figuring out what happened during the Big Bang — the cosmic event that about 15 billion years ago gave birth to a hot, dense fireball and eventually, stars, galaxies and humans. Although Einstein's equations can describe much of the Universe's history, they break down the closer we get to this moment of creation.

Off with a bang

Conventional wisdom says that the Big Bang was the start of everything, including time, so questions about the Big Bang itself, or what came before, don't make sense. Or so we're told. But the breakdown in the laws of physics — the singularity problem — limits what we know about the starting conditions of the Universe. So it leads to arbitrary assumptions, such as an early period of rapid expansion (inflation), to get the Universe to where it is now.

It is in part thanks to Bojowald that a cosmology based on loop quantum gravity has become a respected, albeit controversial, notion. "Martin has opened the door to the possibility of calculating the predictions of loop theory for cosmology, and determining whether they can be tested against observations," says Roy Maartens, a cosmologist at the University of Portsmouth, UK.

In the loop quantum universe everything is quantized, or discrete, including time. Space can be chopped up into discrete 'cubes', just 10^{-99} cm^3. One cube would equal the smallest unit of space, but it is not 'empty' space; each cube incorporates space, time and matter in the form of intersecting 'loops'.

"This has few consequences for our understanding of the real world," says Bojowald. These loops operate on scales far outside our experience. "But the discreteness of loop theory makes it much easier mathematically and conceptually to come to terms with the early Universe," he says.

In the loop

Although the loop language is complex, the maths behind the theory is elegant. Bojowald has created a framework in which physical laws do not break down at the Big Bang singularity (M. Bojowald *Phys. Rev. Lett.* **86,** 5227–5230; 2001). His results suggest that at extremely small scales, quantum gravitation can be repulsive, which prevents the collapse of space-time into a singularity. This effect, which would contradict general relativity, might be a consequence of the quantization of Einstein's equations, Bojowald says.

Freed from the singularity, Bojowald can now look back to a time 'before' the Big Bang. He finds an inverted universe on the other side — a mirror-image of ours — expanding outwards as time runs backwards.

Bojowald's model also provides tantalizing insight into how inflation occurs (M. Bojowald *Phys. Rev. Lett.* **89,** 261301; 2002). A gravitational repulsion not only prevents the collapse of a contracting universe, he believes, but also pulls apart an expanding one. Maartens cautions that this idea has some way to go before it is fully convincing. But that long road doesn't intimidate Bojowald, who is a long-distance runner both in real life and in science.

"In the beginning, there was a lot of criticism," Bojowald says. "But things have changed, and meanwhile many cosmologists have got very interested in loop equations."

Bojowald hopes that data from the European Space Agency's 2007 Planck mission will provide indirect backing for his ideas. This satellite will test theories of the early Universe by looking at the radiation left over from the Big Bang. After 2011, data from NASA's Laser Interferometer Space Antenna could reveal a quantum gravity effect from the early Universe in its observations of ripples in space-time.

In the meantime, says Sean Carroll, a theoretical cosmologist at the University of Chicago, Illinois, string theory remains the more popular theory, given that it has solved many problems related to quantum gravity. "But," he adds, "any alternative concept is welcome and needs to be taken seriously." ■

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