

Hunting for Theories of (Not) Everything

Giovanni Amelino-Camelia is probing the quantum nature of spacetime—one step at a time.

by Marc Kaufman

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FQXi Awardee: Giovanni Amelino-Camelia

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In his youth, there were two things that regularly competed for Giovanni Amelino-Camelia's attention: his favorite soccer team, Napoli, and "anything that came close to being scientific." And since Napoli was struggling in the Italian soccer league in the summer of 1978, Amelino-Camelia found himself watching a series of programs on special relativity instead of soccer. "That was really the point of no return for me," he remembers.

"Although I was 13-years old, nothing could have happened after that to keep me away from fundamental physics," he says. "It was lucky for me that those television shows were broadcast in a year when Napoli did very poorly!"

Lucky for him, and, in many ways, lucky for us, because almost 30 years later Amelino-Camelia, at La Sapienza Universi-

ty in Rome, Italy, is dedicated to pursuing answers to foundational questions. Armed with a \$65,000 grant from FQXi, he is currently making a run at redefining the way physicists attack perhaps the most vexing and elusive puzzle of all, the problem of quantum gravity, by searching for what he dubs as a set of "theories of *not* everything."

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- Giovanni Amelino-Camelia

For decades, physicists have struggled to bring together general relativity and quantum mechanics. But like pieces taken from different jigsaw puzzles, they cannot be merged without modification. And, for better or for worse, more and more physicists seem to believe that this modification can be packaged into a single grand theory that unifies the classical and quantum worlds and addresses all open problems in fundamental physics—a theory of everything (TOE).

So far, the best candidate for a TOE is *string theory*, which posits that elementary particles are actually composed of tiny vibrating strings and that the universe contains extra dimensions. However, critics argue that there is no experimental evidence for the theory, and no way to falsify it experimentally. Another candidate is the relative newcomer *loop quantum gravity* (LQG), which describes particles as tangles that emerge from the quantum foam of spacetime. Although LQG is not intended strictly as a TOE, it still has extremely ambitious goals, attempting to provide a full solution to the quantum-gravity problem using principles from Einstein's general relativity as a guide, says Amelino-Camelia.

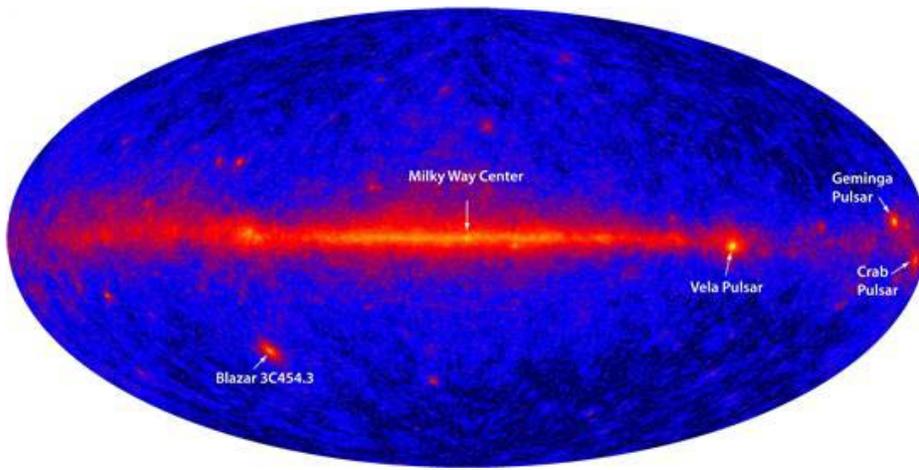
Cart Before the Horse?

While Amelino-Camelia acknowledges the promise and the excitement generated by string theory, LQG, and other darlings of today's physicists, he believes these ultra-ambitious research programs might be putting the cart way before the horse.

"The logical path usually takes you first to a partial solution then to a full solution," says Amelino-Camelia. "Some of my colleagues appear to believe that we will be smart enough to solve everything in one shot. Take my word for it, we are not smart enough. Surely I am not smart enough."



GIOVANNI AMELINO-CAMELIA
La Sapienza University



THE FERMI GAMMA-RAY TELESCOPE reveals bright emissions across the sky. Will it also uncover the features of a quantum spacetime?
(Image: NASA / DOE / Intl. LAT Team)

That doesn't mean that Amelino-Camelia thinks TOE research should be abandoned. In fact, the majority of the simple models exploring portions of the quantum gravity problem that he works on were inspired by results obtained in the development of LQG.

"Even assuming my concerns are correct—and only time will tell—research looking for a full solution of the quantum gravity problem would be very valuable because it provides guidance for the development of meaningful theories of *not* everything," says Amelino-Camelia. "But if all we did was research on the more ambitious TOE level, then inevitably we would be wasting some opportunities for valuable insight within the reach of the *not* everything approach."

Doubly Special Relativity

Okay, we now have a decent understanding of what Amelino-Camelia is *not* looking for. But what exactly *is* he looking for? The simplest example of a theory of *not* everything is one that can describe a "quantum spacetime." Both general relativity and quantum mechanics are formulated using the intuitive concept of a classical spacetime, he explains. But many arguments—including some based on TOE studies—suggest the correct microscopic description of spacetime should be based on a nonclassical geometry, that is, on a quantum spacetime.

The concept gels well with a theory that Amelino-Camelia introduced in 2000, which he dubs "doubly special relativity." While Einstein's special relativity tells us that there is a maximum speed limit for

light, Amelino-Camelia's doubly special relativity posits that there is also a *minimum* length—the Planck length—below which space cannot contract. Spacetime, in this picture, is not continuous but can be thought of as being made up of pieces, or Planck-scale grains, that are just one hundred billion billionth the size of an atomic nucleus. This grainy spacetime is said to be *quantized*.

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*- Giovanni
Amelino-Camelia*

Instead of trying to fit this notion of a quantum spacetime straight into a larger quantum-gravity model, Amelino-Camelia argues that it will be fruitful to first fully examine its implications. Taking smaller bites out of the quantum gravity puzzle, in this way, gives physicists manageable chunks that they can chew on more easily.

Crucially, this opens up the possibility of examining each portion thoroughly and subjecting each portion to experimental scrutiny, explains Amelino-Camelia. Some aspects of the puzzle can be tested using today's technology, while others will hopefully be testable in the coming years, as new technologies are developed.

For example, different types of quan-

tum spacetime could affect particles in slightly different ways. In most scenarios, these tiny effects would be tough to detect. But one place where the effects might show up is in the behavior of some high-energy particles, called cosmic rays, and bursts of high-energy radiation, known as gamma rays. Cosmic rays and gamma rays travel huge distances across the universe, and over the course of their long journey the tiny effects of spacetime quantization would have had a chance to accumulate to an observable level, Amelino-Camelia explains.

Probing Spacetime

Cosmic rays have already helped to rule out some of the simplest quantum pictures of spacetime. Those models predicted that the maximum possible energy of cosmic rays, known as the GZK cutoff, would be significantly higher than currently thought. However, data recently gathered by the Pierre Auger cosmic-ray observatory does not support this. "In order to get to the level of probing more promising pictures, we still have some way to go," says Amelino-Camelia. "Although it is something we will realistically start doing within a few years."

In addition, some quantum-spacetime models predict a particular relationship between the speed of photons in gamma rays and their energy. NASA's Fermi Telescope, launched in June 2008, will provide new gamma-ray data, which will help physicists discriminate between these models (see image above left).

In this way, theories of *not* everything are falsifiable—giving them the edge over more ambitious TOE candidates.

John Stachel, a physicist at Boston University, Massachusetts, admires this drive to produce a falsifiable theory. "Amelino-Camelia grew impatient with the exclusively theoretical nature of most work on quantum gravity," he says. "The smallness of most predicted effects threatened to make the field more an area of speculative scholasticism than a part of science."

But it's not just about being able to scrutinize the theory using experiments and observations. Ultimately for Amelino-Camelia, theories of *not* everything offer a greater sense of wonder than an all-encompassing TOE ever could. "I do not see so much beauty in the picture of having a TOE," he says. "It seems to me it is much more appealing to find partial answers, answers that close the door on a few open issues but actually open the door on many more puzzling issues."