

# A Deeper Understanding

For Roderich Tumulka, the old physicists' nostrum to 'shut up and calculate!' is not good enough. Instead, he wants to understand the reality behind quantum mechanics.

fq(x)  
News

by MARC KAUFMAN

FQXi Awardee: Roderich Tumulka, Rutgers University

October 19, 2007

We may not be able to see them, but we've still managed to learn a fair amount about black holes. They are created as a result of the gravitational collapse of a star. Matter cannot escape once it crosses the black hole's "horizon." And every black hole contains a singularity – an infinitely dense point that exerts an infinite gravitational pull and causes an infinite curvature of space-time – such that any particle that comes into contact with a singularity will be utterly destroyed; it is literally the end of space and time.



**RODERICH TUMULKA**  
Photo Credit: Vishnya Maudlin

We know still more things about black holes – complicated and mind-bending things about their place in our universe and their role in our understanding of space and time. But many scientists are motivated by what they don't know rather than what they do know, and when it comes to black holes, there is a very basic thing scientists don't know: What, exactly, happens to matter once it crosses the horizon?

One problem behind this question is that Schrödinger's Equation – the most fundamental physical law of all matter and an equation at the heart of quantum

mechanics, the spectacularly successful theory that describes the atomic and subatomic world – ceases to work in the presence of a singularity. Another, broader problem is that there is no consensus in the physics community about what Schrödinger's Equation actually means, or how quantum phenomena actually work.

Some scientists say that while quantum mechanics can accurately predict the results of experiments and calculate probabilities, it is vague and doesn't tell you what's really going on. Others advise their students not to delve too deeply into the meaning of it all; just "Shut up and calculate!" For these physicists, quantum mechanics was never meant to be clear, it was just meant to be useful.

But for Roderich Tumulka, a mathematical physicist at Rutgers University, who likes his math clear and his physics precise, that latter approach simply isn't good enough. Using the \$45,960 grant he received from The Foundational Questions Institute, Tumulka wants to solve both problems with Schrödinger's Equation at once: by finding a new equation applicable inside a black hole, and by developing an explanation of the reality behind quantum mechanics. Along the way, he hopes to show that while it's true that any matter touching the singularity gets destroyed, there are certain types of singularities that may be responsible for particle creation in very much the same way that an electron can create photons.

## Origins in Bohm

Growing up in Germany, Tumulka knew he had an aptitude for math and science at an early age. But while he was usually quick to assimilate new theories, quantum mechanics threw him for a loop.

"When I first heard about quantum mechanics, I didn't like it very much because I couldn't understand it," Tumulka says. "I thought the reason I couldn't understand it was because the topic was

way above the high school level or the teacher couldn't explain it well enough. At the university, I attended lectures on theoretical physics and was eager to hear the professors explain quantum mechanics, but still it didn't make sense to me. I blamed it on the professor, and I figured I had to learn from books. The books were better than the lectures, but even then I couldn't really understand it. Then I thought I didn't know enough about the mathematics, so I learned more mathematics and still couldn't understand it. Then I thought maybe I had to learn more about philosophy, so I tried to read the writings of Bohr and philosophers. But that didn't help either."

Finally Tumulka concluded that Nobel laureate Richard Feynman was probably right when he famously said, "I think it is safe to say that no one understands quantum mechanics."

Fortunately, the young Tumulka wasn't the only one who refused to 'shut up and calculate.' When he attended a lecture by Detlef Dürr on Bohmian mechanics in 1996, his entire perspective changed.

"I was impressed; it was the first time I heard a proposal that actually had something to say about how the quantum world works," Tumulka remembers. "I had already looked into several approaches that seemed to me to have some promise to resolve the puzzles of quantum mechanics. Some of these approaches have led to beautiful mathematics, but none of them has brought us closer to an explanation of quantum mechanics."

But in that packed lecture hall in Frankfurt, Tumulka listened to Dürr explain how Bohmian mechanics, by means of the idea that quantum particles have trajectories, could make quantum mechanics intelligible and help alleviate Tumulka's concerns. "In the lecture, Detlef was very frank in criticizing the conventional, orthodox quantum philosophy," Tumulka says. "I know that some in the audience perceived his criti-

cisms as arrogant, but I was delighted by the clarity of his presentation.”

So pleased was Tumulka that two years later he went to Munich to do his Ph.D. research with Dürr. The subject was clear: Bohmian mechanics.

### A Risky Choice

“It’s either a courageous choice or a foolish choice,” says Sheldon Goldstein with a chuckle, analyzing the career path of his fellow Rutgers mathematical physicist and close friend. “The foundations of quantum mechanics are a pretty dangerous thing to work in. It’s dangerous to your career, because it’s not regarded very favorably by the physics establishment.”

“Foundational questions are just not very fashionable,” Tumulka agrees. “Bohmian mechanics tends not to get a lot of funding from ordinary sources (like the National Science Foundation), partly because these sources don’t consider research into the foundations of quantum mechanics as the kind of research that will pay off.”

While Goldstein is only half kidding about the dangers of research into the foundations of quantum mechanics, he, fellow Rutgers colleague Tim Maudlin, and Università di Genova professor Nino Zanghi collaborate on Tumulka’s project. The four, along with Dürr and Valia Allori, form a close-knit group of thinkers who share a demand for clarity in physics, the belief that to ‘shut up and calculate’ is unacceptable, and the knowledge that they are very much in the physics minority.

“One sort of mainstream physicist would say, ‘Well, there really aren’t any problems [with quantum mechanics] so these people are working on something totally pointless’ and the other sort of physicist would say, ‘Yeah, there are real problems but there won’t be any progress made,’” Goldstein explains. “And [Tumulka] happens to be working on a particular approach to the foundations that elicits the most hostility. He’s working on the most strongly realist version of quantum mechanics – the least romantic version – a version that removes all the paradox and more or less all of the mystery. It’s a version that conflicts most strongly and most explicitly with what most students are told are the most profound lessons of quantum mechanics.”

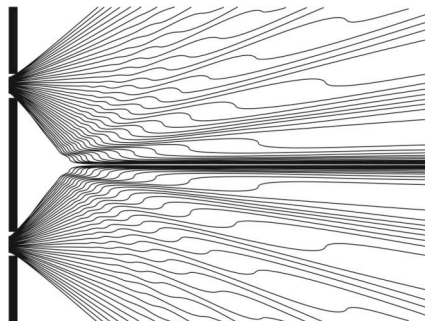
### We Need Another Equation

Tumulka believes that some of the problems with quantum mechanics can be solved by complementing Schrödinger’s Equation, which governs the wave function, with an equation of motion for the

particles themselves, like the one provided by Bohmian mechanics.

“It turns out that all of textbook quantum theory arises from that,” Goldstein agrees. “All of the predictions of that theory, even the appearance of randomness, emerges. Everything emerges from this straightforward motion of particles. And this just does the job for nonrelativistic quantum mechanics – it explains everything.”

But Tumulka is taking the research to another level. While Bohmian mechanics provides some physicists with satisfying explanations for nonrelativistic quantum mechanics -- which encompasses relatively ordinary or everyday situations -- Tumulka wants to adjust the theory so that it can help explain what is happening in more extreme cases such as those found in quantum field theory, string theory, and quantum gravity.



**ACCORDING TO BOHMIAN MECHANICS, in a double slit experiment, the particle moves along one of these trajectories, selected at random.**

“There’s a real challenge – mathematical, physical, conceptual – to formulate a theory with the same kind of clarity you have in Bohmian mechanics in the framework of much more challenging physical theories where things are much less clear and the mathematics are extremely difficult to start with,” Goldstein says. “So [Tumulka’s] work applies in much more challenging situations – situations where the clarity of the Bohmian kind of formulation could be immensely valuable.”

### The End of Space and Time

For Tumulka, it’s difficult to conceive of a more extreme situation than at the singularity within a black hole. If at a singularity, a particle reaches the end of space-time and is annihilated, then the natural question becomes, “Well, what happens next?”

According to Tumulka, there are two different types of singularity. Particles may be able to emerge from a timelike singularity but not from a spacelike singularity.

“A spacelike singularity is like doomsday; a timelike singularity is more like a wall or a door you can touch,” Tumulka explains. “A timelike singularity exists at every time or at least at some interval of time, but it’s like a surface in space. A spacelike singularity is more like one moment in time.”

Tumulka is currently focused on the idea that while anything that touches a timelike singularity would be annihilated and disappear from space-time, things can nonetheless emerge from them. And if there were no horizon around the singularity, a situation known as a “naked singularity,” Tumulka speculates that particles created there would be able to move throughout all space.

“Mathematically there’s a possibility of a singularity without a horizon – although it would not be called a black hole,” he says. “It’s a mathematical fact, but there is a question as to whether this occurs astronomically.”

Roger Penrose proposed that naked singularities do not occur in our universe, in what has become known as the cosmic censorship hypothesis. “If cosmic censorship is true, my work would be less relevant,” Tumulka says. “On the other hand, there is also the possibility that every particle itself, every electron, contains a singularity. It depends on the gravitational field created by the electron itself. We don’t know whether it does or not, but if it does, that would make my work more important.”

Either way, Tumulka’s work leads to equations describing the creation of particles at the singularity, which, in turn, leads to an interesting connection to quantum field theory.

“There’s a certain parallel between the creation/annihilation processes described in field theory and the particle creation/annihilation at a timelike singularity,” Tumulka says. “This analogy actually carries over to the equations, particularly in the Bohmian version for particle creation and annihilation. They are very similar. They have the same mathematical structure. I think that encourages the hypothesis that maybe every electron contains a singularity.”

Tumulka says his project aims to “obtain an equation for what comes out of the singularity. So it’s an equation for what the singularity looks like. Such a law has never been considered before – either in conventional quantum mechanics or in Bohmian mechanics. It forms an extension of quantum mechanics that was inspired by the Bohmian picture.”