Physics, poetry and the search for quantum gravity: Carlo Rovelli's *Reality Is Not What It Seems*

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Reality Is Not What It Seems: The Journey to Quantum Gravity By Carlo Rovelli
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General relativity and quantum mechanics are the two jewels of modern physics. They have provided an enormous insight into nature's inner workings, showing that space bends and curves under the weight of matter (general relativity) and that this same matter is quantized at the atomic and nuclear level (quantum mechanics). The theories have also revealed myriad new aspects of the world—gravitational waves, black holes, nuclear physics, and condensed matter, to name a few. And while they are esoteric when compared to our everyday experiences, the theories are the most accurate description of the fundamental motions of matter yet developed.

However, in the few circumstances that require one to apply both theories, it becomes immediately apparent that the truth of these theories is approximate, and that something more is required to combine them into a unified whole. The curved spacetime of general relativity is a smooth, infinitely divisible fabric upon which mass and energy evolves. This inherently contradicts quantum mechanics, which states that all things are made up of a finite number of constantly jittering quanta leaping from one point to the next.

While we do not currently know the resolution to this conflict, theoretical physicist Carlo Rovelli's recent book *Reality Is Not What It Seems: The Journey to Quantum Gravity* describes one possible solution to the search for a theory of quantum gravity, loop quantum gravity.

The basic principle of loop quantum gravity combines the quantized nature of mass and energy as shown in the mathematics of quantum mechanics and the curved spacetime of general relativity to assert that, similar to particles, space itself is quantized. Rather than being a continuum, space consists of discrete amounts of length, area and volume that are incredibly small but not arbitrarily so. There are "atoms of space," a billion billion times smaller than atomic nuclei, and these do not lie somewhere *in* space but rather themselves *are* space. They are all that humans observe and are a part of.

Rovelli has spent his entire three-decade career developing the conceptual foundations and advanced mathematics at the core of loop quantum gravity. He has also paid close attention to the advances in cosmology and particle physics to see if any experiments provide evidence for or against these hypotheses. To date, while none of the collected data clearly supports loop quantum gravity, none of it flatly refutes the hypothesis. Other theories are also being developed. "The situation," Rovelli writes, "is still fluid" (p. 219).

There is something unique in Rovelli's popular writings on physics, which include, in addition to *Reality Is Not What It Seems*, his best-selling *Seven Brief Lessons in Physics*, and the recently-published in English, *The Order of Time*. While he is an accomplished physicist with an immense theoretical knowledge (including published scientific texts on quantum gravity), he has the uncommon gift of being able to translate these conceptions into a language that is both comprehensible and exhilarating. His approach to science is materialistic and is also deeply informed by philosophy, literature and poetry.

Carlo Rovelli was born into an era of immense social upheaval in Italy and around the world. He was 12 years old when student protests broke out in Italy, France and other countries in the spring of 1968, and he grew up in an era when humanity was taking significant steps into outer space while at the same time war was being waged in Vietnam, Laos, Cambodia and elsewhere. Rovelli himself helped found Radio Alice, a left-wing radio station that was shut down by Italy's military in 1977 (it was re-opened for two years after that). He was also arrested in 1987 for refusing to participate in what at that time was compulsory military service.

Concurrently, Rovelli was developing a deep appreciation for the laws of nature. In his concise work on loop quantum gravity, *Seven Brief Lessons in Physics*, he relates to his readers the first time he began to understand general relativity:

> It was summer. I was on a beach at Condofuri in Calabria, immersed in the sunshine of the Hellenic Mediterranean, and in the last year of my university studies. Undistracted by schooling, one studies best during vacations. I was studying with the help of a book that had been gnawed at the edges by mice because at night I'd used it to block the holes of these poor creatures in the rather dilapidated hippie-ish house on an Umbrian hillside where I used to take refuge from the tedium of the university classes in Bologna. Every so often, I would raise my eyes from the book and look at the glittering sea: it seemed to me that I was actually seeing the curvature of space and time imagined by Einstein. As if by magic: as if a friend was whispering into my ear an extraordinarily hidden truth, suddenly raising the veil of reality to disclose a simpler, deeper order. (p. 5-6)

Reality Is Not What It Seems takes its readers on a similar adventure. Rovelli guides his readers through contradictions in modern physics that are just as important as those that arose at the end of the 19th century between the mechanics developed by Galileo, Kepler and Newton and the newly uncovered electromagnetism of Faraday, Ampere and Maxwell—contradictions that would produce the advances of relativity and quantum mechanics. Simultaneously, he imbues readers with a sense of wonder, joy, and most importantly, understanding of both the science presented and the process through which it develops.

Rovelli also takes a materialist and dialectical approach to physics and science as a whole. He stresses early on, “Scientific thinking explores and redraws the world, gradually offering us better and better images of it, teaching us to think in more effective ways. Science is a continual exploration of ways of thinking. Its strength is its visionary capacity to demolish preconceived ideas, to reveal new regions of reality, and to construct new and more effective images of the world. This adventure rests upon the entirety of past knowledge, but at its heart is change” (p. 8). Such an approach is present throughout the book and is a refreshing departure from other philosophers of science who treat the field as a mechanical and absolute mode of thinking.

This worldview is highlighted in an ardent defense of the scientific method as the correct way to understand nature.

> The sociology of science has shed light on the complexity of the process of scientific understanding; like any other human endeavor, this process is beset by irrationality, intersects with the game of power, and is affected by every sort of social custom and cultural influence. Nevertheless, despite all this, and in opposition to the exaggerations of a few postmodernists, cultural relativists, and the like, none of this diminishes the practical and theoretical efficacy of scientific thinking. Because in the end, in the majority of cases, it is possible to establish with clarity who is right and who is wrong. And even the great Einstein could go on to say (and he did so): ‘Ah I made a mistake!’ Science is the best strategy if we value reliability (p. 211).

The history of quantum gravity is presented as part of the broader development of science, culture and politics. Rovelli reviews the development of ideas of the physical structure of the world, from the pre-Socratic philosophers Thales, Anaximander and Democritus, to the Latin materialist poet Lucretius, to Newton, Einstein and the originators of quantum theory. One passage on the work of Lucretius gives a sense of Rovelli’s approach and his own thinking about the world:

> The medieval cosmos so marvelously sung by Dante was interpreted on the basis of a hierarchical organization of the universe that reflected the hierarchical organization of European society.
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> There is none of this in the world of Democritus as sung by Lucretius. There is no fear of the gods; no ends or purposes in the world; no cosmic hierarchy; no distinction between Earth and heavens. There is a deep love of nature, a serene immersion within it; a recognition that we are profoundly part of it; that men, women, animals, plants, and clouds are organic thread of a marvelous whole, without hierarchies. There is a feeling of deep universalism, in the wake of the splendid words of Democritus: ‘To a wise man, the whole earth is open, because the true country of a virtuous soul is the entire universe’ (p. 39).

Rovelli’s account of modern physics, from Newton to Maxwell’s theories of electromagnetism, to Einstein and quantum theory, provides tantalizing insights into the way this development involved an ever greater understanding of the interaction, integration and *movement*of all aspects of the material world. With Einstein’s theory of general relativity, he writes, “Space is no longer different from matter. It is one of the ‘material’ components of the electromagnetic field. It is a reality that undulates, fluctuates, bends and contorts” (p. 82).

Quantum theory brought with it a further development of a dialectical understanding of reality. “In the world described by quantum mechanics,” Rovelli writes, “there is not reality except in the *relations* between physical systems. It isn’t *things* that enter into *relations*, but rather *relations* that ground to the notion of thing. The world of quantum mechanics is not a world of objects: it is a world of events” (p. 135). One is reminded of Engels’ statement (in *Ludwig Feuerbach and the End of Classical German Philosophy*) that the world exists not as a “complex of ready-made things, but as a complex of processes.”

While the specific history of quantum gravity has many triumphs, Rovelli also walks his readers through what is arguably its greatest tragedy, which occurred during the first serious attempt to develop the theory. It was spearheaded by the young Soviet physicist Matvei Bronstejn (who was not, Rovelli notes, related to Trotsky). Bronstejn, who was a friend and colleague of the Soviet physicist Lev Landau, came of age when the Stalinist degeneration of the Soviet Union was beginning to tear away at the progressive impulse the October 1917 revolution provided to Russian and world society.

Bronstejn was part of a generation of physicists who grew up just after Einstein finalized his general theory of relativity, and while the basis of quantum mechanics was being fleshed out. He paid close attention to the argument by Landau that quantum fluctuations, the inherent vibration of all subatomic particles, meant that one could not measure an arbitrarily small part of an electric field. While Landau’s argument was shown to be incorrect, it laid the basis for further theoretical work by Bronstejn.

Rather than apply Landau’s reasoning to an electric field, Bronstejn applied it to the gravitational fields worked out by Einstein a decade before. Here, Landau was correct—an arbitrarily small section of a gravitational field could not be described by quantum mechanics. If one places a particle at an increasingly small region of space, quantum mechanics dictates that it will at some point escape with a velocity that increases as the region of space the particle is contained in becomes smaller. However, a high velocity means a high energy, and Einstein showed that a high energy makes space curve. Finally, if you curve space enough, it collapses into a black hole and one can no longer measure that region of space. Using this argument, Bronstejn demonstrated one of the ways that, on a fundamental level, quantum mechanics and general relativity are incompatible.

This work was, however, cut short. In an account of one of the consequences of Stalinist counterrevolution that deserves further investigation, Rovelli notes:

> Matvei and Lev are sincere communists. They believe in revolution as the liberation of mankind, the construction of a genuinely better society, without injustice, without the immense inequalities that we still see growing systematically throughout the world. They are enthusiastic followers of Lenin. When Stalin assumes power, they are both perplexed, then critical, then hostile. They write articles that are slightly but openly critical. This was not the communism they wanted.
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> But these are harsh times. Landau gets through them, not easily, but survives. Matvei, the year after having been the first to understand our ideas on space and time had to change in a radical way, is arrested by Stalin’s police and condemned to death. His execution takes place on the same day as his trial, February 18, 1938. He is thirty years old (p. 154).

It will never be known if Bronstejn would have been able to more fully work out his early insights if his life was not tragically cut short as part of the Stalinist purges.

Since then, nearly every theoretical physicist of the 20th century, in some way or another, contributed to the search for quantum gravity. One of the more interesting failures was when Richard Feynman attempted to use the techniques he developed for describing photons and electrons on gravitational fields. However, photons and electrons are fundamental units of matter—quanta—*in* spacetime. Feynman's efforts, while valiant, made it very clear that a theory of quantum gravity must describe quanta *of* spacetime, a different and more difficult problem.

One of the many reasons that the theory has so far proved elusive is that the experimental tests for quantum gravity require regimes far more extreme than those encountered on Earth. No one has ever been able to focus enough energy into a small enough point to create a black hole at the quantum scale—no such events have been detected at the world's most powerful particle accelerator, the Large Hadron Collider, nor have they been detected in cosmic ray collisions that occur regularly in the upper atmosphere, which can be at even higher energies than those generated at the LHC. Such direct experimental tests are still currently beyond humanity's technological capacity.

Other experiments, however, provide some limits on the validity of various theories of quantum gravity, including string theory and loop quantum gravity. As Rovelli explains, there have been three major results in theoretical physics in the recent period: the discovery of the Higgs Boson at the Large Hadron Collider, the analysis of cosmic microwave background radiation by the Planck satellite and the direct detection of gravitational wavesby LIGO. The most interesting result from all three experiments is that there was nothing particularly surprising about any of their results.

This is not to say that they are not monumental achievements of human technique. They absolutely are—each required billions of dollars and engaged thousands of some of the most intelligent people across the planet for decades. From the standpoint of theoretical physics, however, each result was predicted by the existing theories. There is no evidence for some of the more esoteric theories such as supersymmetry or alternatives to general relativity. According to Rovelli, "General relativity, quantum mechanics, and, within quantum mechanics, the Standard Model [of Particle Physics]," are the correct theories to describe nature (p. 215).

While these results have left string theorists and others in a quandary, they provide a clue toward loop quantum gravity. Rovelli states that the reason for this is that the latter theory uses what we already know about physics, rather than trying to start from an arbitrary hypothesis, and as such is not mostly disproven by modern research.

> Our fantasy is too limited to 'imagine' how the world may be made, unless we search for inspiration in the traces we have at our disposal. The traces that we have, our clues, are either theories that have been successful, or new experimental data, nothing else. It is in this data and in these theories that we must try to uncover what we have been unable yet to imagine. … The radical conceptual consequences, the quanta of space … are not bold hypotheses: they are the rational consequences that follow from taking the basic insights of our best theories seriously (pp. 216-217).

Of course, this being theoretical physics, even the "rational consequences" can boggle the mind. The most alien of the proposals of loop quantum gravity is the disappearance of time as a constant, uniform background to the world of things—which already received a significant blow from Einstein's special theory of relativity, which demonstrated that concepts such as simultaneity are not absolute.

Rovelli does not argue against cause and effect. Rather, he argues that time by itself is a placeholder for, as Lucretius puts it, "the movement of things." A legend about Galileo demonstrates this point. As a pendulum swings, the experimentalist noticed that the oscillations all seemed to have the same duration, independent of amplitude. In order to confirm this, Galileo needed to measure these oscillations repeatedly. As there were no clocks in his time, he used his pulse instead, and found that, indeed, the oscillation duration is the same.

But, as Rovelli asks, "How could Galileo know that *his own individual pulse-beats* all lasted for the same amount of time?" Are the pulse-beats a measure of the pendulum swings, or are the pendulum swings a measure of the pulse-beats? And so while it is useful to use the concept of time, as Newton did, as a placeholder for motion, actual events happen in relation to each other, not in relation to time. "In other words, the existence of the variable time is a useful assumption, not the result of an observation" (p. 180).

And while this may seem at odds with anyone who has taken introductory physics and has seen all the equations which use time as the flow along which events unfurl, one of the early results in research into loop quantum gravity is that time does in fact disappear from the equations. This does not mean that matter becomes immobile. On the contrary, it is the constant interplay of different physical processes that are the world, and they are the relations that order the world. Rather than asking how many times the pendulum swings per second, one asks how many times the pendulum swings per pulse-beat.

Another consequence of loop quantum gravity, and one that is in theory testable, is that black holes are ultimately unstable and, after several billion years, explode. The reason is that they cannot infinitely squeeze matter into a singularity. Loop quantum gravity says that there is a minimum volume, and so matter cannot be squeezed into a unit smaller than that. As a result, an immense pressure builds up as matter is squeezed as much as it can be squeezed. It is hypothesized that this pressure, over time, is enough to overcome even the colossal gravity of a black hole.

"Seeing these black hole explosions would be a fantastic confirmation of the theory," writes Rovelli. And we are at a stage of cosmic evolution where we might even see such a phenomenon. As observations of distant and old stars are made more precise, we have a better understanding of how old black holes might be. At the same time, astronomers have already detected what are called 'fast radio bursts' that could be the signal of exploding primordial black holes. More data is required before something concrete can be said. "Let's wait and see" (p. 228-229).

A great deal more could be said about *Reality Is Not What It Seems.* The journey of quantum gravity in the 20th century is an exciting and promising one. And yet, as Rovelli stresses time and again, physics is not a finished product. It must incorporate all the latest discoveries and through them discover even more fundamental laws that govern the motion of matter. What has been discovered, Rovelli writes, is "not wrong physics, as is frequently said. It's an approximation" (p. 42).

Rovelli's book is not only a fascinating account of the evolution of physics, but it is clearly informed and motivated by the author's sense of the immense possibilities of science and of the extreme dangers that confront mankind. He writes:

> Today … we have the instruments to bring light to the homes of the ten billion human beings who will soon inhabit the planet. To travel in space toward other stars. Or to destroy one another and devastate the planet. It depends on our choice, on which leaders we call upon to decide for us (p. 75).

The extraordinary beauty and promise of modern science only increases one's motivation to fight for a society in which this promise can be realized.