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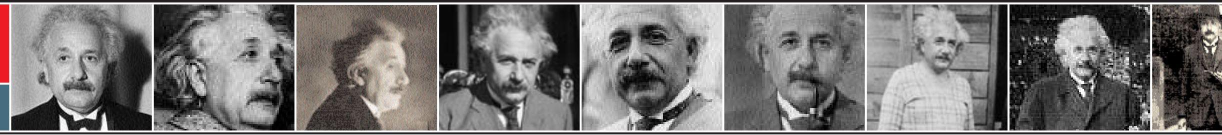

Einstein's Grand Quest for a Unified Theory

He failed, of course, but he didn't exactly waste his time

BURIED IN ALBERT EINSTEIN'S MAIL ONE SPRING day in 1953 lay a letter from an ordinary mortal, a 20-year-old high-school dropout named John Moffat. Two more disparate correspondents would be hard to imagine. Moffat was an impoverished artist and self-taught physicist. Einstein was a mythic figure—the world's most famous scientist. Moffat was living with his British father and Danish mother in Copenhagen. Einstein was at the Institute for Advanced Study in Princeton, New Jersey. Yet both men were outsiders of a sort. In his later years, Einstein had become increasingly isolated from the mainstream physics community, refusing to embrace the strange but powerful theory of quantum mechanics—with its particles that are also waves and that transform simply because they're observed. Nature, he argued, couldn't be so perverse. So for nearly 30 years he had pursued what most physicists considered a quixotic goal: the creation of a unified field theory to describe all the forces of nature.

That was the occasion for Moffat's letter. He thought he could offer Einstein some constructive criticism. "I wrote him to say that I wasn't happy about what he was doing," Moffat recalls. There was nothing unusual about this. Plenty of people sent letters to Einstein, not all of them rational. But in Moffat's case something unexpected happened: Einstein wrote back.

"Dear Mr. Moffat," the reply began. "Our situation is the following. We are standing in front of a closed box which we cannot open, and we try hard to discover about what is and is not in it." That closed box is the universe, of course, and no one had done more to pry off the lid than Einstein. Yet in the eyes of nearly all his colleagues he had contributed almost nothing of importance to physics for almost 20 years.

Were they right? Did he squander his genius by chasing vainly after an ultimate theory? That is the conventional view. But at least a few physicists now argue that Einstein was far ahead of his time, raising questions that will challenge researchers for decades. "It's often said that Einstein wasted his time later in life," Moffat, who went on to become a theoretical physicist, says. "This of course is erroneous. Einstein never wasted his time."

EINSTEIN'S SPLIT WITH MAINSTREAM PHYSICS came at the very height of his career. In 1927, when he was 48, the world's leading physicists gathered at a conference in Brussels to

Einstein and his colleagues, Valentine Bargman and Peter Bergman, discuss physics at Princeton in 1940. What most bothered Einstein about quantum mechanics wasn't that God plays dice, but that our own observations influence how the dice roll.

BY TIM FOLGER

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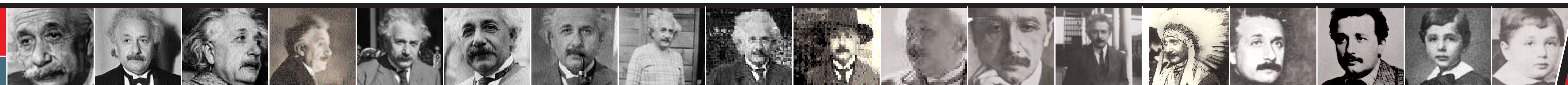

debate an issue that remains contentious to this day: What does quantum mechanics have to say about reality? Einstein had won the Nobel Prize in physics for research that showed that light consists of particles—research that helped lay the groundwork for quantum mechanics. Yet he dismissed the new theory out of hand. At the conference, he clashed with the great Danish physicist Niels Bohr, launching a feud that would last until Einstein's death in 1955.

Bohr championed the strange new insights emerging from quantum mechanics. He believed that any single particle—be it an electron, proton, or photon—never occupies a definite position unless someone measures it. Until you observe a particle, Bohr argued, it makes no sense to ask where it is: It has no concrete reality; it exists only as a probability.

Einstein scoffed at this. He believed, emphatically, in a universe that exists completely independent of human observation. All the strange properties of quantum theory are proof that the theory is flawed, he said. A better, more fundamental theory will eliminate such absurdities. "Do you really believe that the moon is not there unless we are looking at it?" he asked.

"He saw in a way more clearly than anyone else what quantum mechanics was really like," the British physicist Julian Barbour explains. "And he said, 'I don't like it.'" In the years following the conference in Brussels, Einstein leveled one attack after another at Bohr and his followers. But for each attack Bohr had a ready riposte. Then in 1935 Einstein devised what he thought would be the fatal blow. Together with two colleagues at Princeton, Nathan Rosen and Boris Podolsky, he found what appeared to be a serious inconsistency in one of the cornerstones of quantum theory: the uncertainty principle.

Formulated in 1927 by the German physicist Werner Heisenberg, the uncertainty principle puts strict limits on how accurately one can measure the position, velocity, energy, and other properties of a particle. The very act of observing a particle also disturbs it, Heisenberg argued. If a physicist measures a particle's position, for example, he will also lose information about its velocity in the process.

Einstein, Podolsky, and Rosen disagreed, and they suggested a simple thought experiment to explain why: Imagine that a particle decays into two smaller particles of equal mass and that these two daughter particles fly apart in opposite directions. In order to conserve momentum, both particles have to have identical speeds. If you measure the velocity or position of one particle, you will know the velocity or position of the other—and you will know it without disturbing the second particle in any way. The second particle, in other words, can be precisely measured at all times.

Einstein and his collaborators published their thought experiment in 1935, with the title, "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?" The paper was in many ways Einstein's swan song: Nothing he wrote for the rest of his life would match its impact. If he was right, then quantum mechanics was inherently flawed.

Quantum physics, of course, eventually carried the day. Bohr argued that Einstein's thought experiment was meaningless: If the second particle was never directly measured, it was pointless to talk about its properties before or after the first particle was measured. But it wasn't until 1982, when the French physicist Alain Aspect constructed a working experiment based on Einstein's ideas, that Bohr's argument was vindicated. In 1935 Einstein was still convinced that he had refuted quantum mechanics. And from then until his death 20 years later, he devoted nearly all his efforts to the search for a unified field theory.

Einstein's office at Princeton [ck]. "He was always interested in deep questions," physicist Carlo Rovelli says, "and a lot of physicists didn't care about deep questions. They left the deep questions to Einstein."

His work was not without promise at first. He was attempting to unite the force of gravity—which he had successfully described in his general theory of relativity—with the force of electromagnetism, and the two forces are similar in many ways. The strength of both, for instance, is inversely proportional to the square of the distance between two bodies, and both have an infinite range. Einstein wasn't alone in his conviction that he could solve the problem. In 1919 the German mathematician Theodor Kaluza and, later, the Swedish physicist Oskar Klein had suggested a unique way to join the two forces. Just as Einstein had introduced a fourth dimension into his equations of general relativity to describe gravity, Kaluza and Klein suggested that a fifth dimension was needed to incorporate electromagnetism.

Einstein spent the last two decades of his life refining this idea. At the same time, he tried to iron out what he saw as problems in his general theory of relativity. In cases where gravity was extremely strong, his theories broke down. Moreover, they seemed to permit the formation of what we now call black holes: objects of such enormous density that their gravity traps even light. "Einstein didn't like black holes," Moffat says. "The real motivation for generalizing his gravity theory was to see if he could find, as he called them, 'everywhere regular solutions' that fit the equations." Such solutions, Einstein hoped, would eliminate black holes entirely.

In 1939 the physicist J. Robert Oppenheimer used the theory of general relativity to show in detail how black holes could form. Yet Einstein was undeterred. Throughout the 1940s, he continued his fruitless search for a revolutionary new theory, even as quantum mechanics advanced at a blinding pace. "He was in denial," Moffat says. "Even Einstein went into denial, because he had invested so much time in this—years!" Near the end of his life, Einstein realized that he wouldn't live to complete his work. "I have locked myself into quite hopeless scientific problems," he wrote, "the more so since, as an elderly man, I have remained estranged from the society here."

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WHEN MOFFAT FIRST READ EINSTEIN'S papers in 1953, he didn't dismiss them as professional physicists did. But then Moffat was no physicist at the time. As an out-of-work 20-year-old in Copenhagen, he had become interested in cosmology while browsing through the library in his spare time. To his surprise, he found that he could easily absorb the advanced mathematics and physics in popular science books and magazines. He plowed through four years' worth of college-level material in about a year, then he moved on to professional physics journals. "I got hold of some of Einstein's papers and decided that there was some weakness in what he was doing," he says. "So I wrote two papers and sent them to him at Princeton. I never thought I'd hear anything from him."

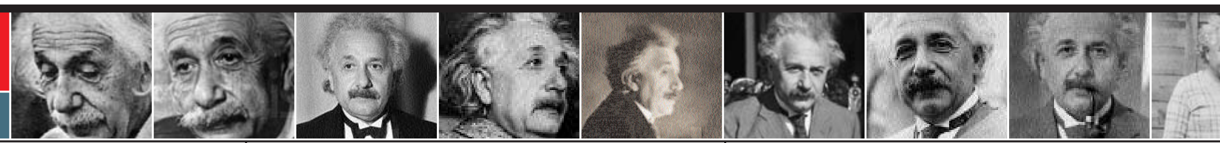
Moffat had identified a mistaken assumption in the mathematics Einstein was using to describe the electromagnetic force. Einstein conceded that Moffat had a point. They went on to exchange several letters over the next six months, inspiring Moffat to pursue a career in physics. Although he lacked all formal training in the field, Moffat knew that Einstein's letters might earn him an audience with other physicists. So he contacted Niels Bohr's secretary at the University of Copenhagen and mentioned the letters. Bohr readily agreed to meet him. "Einstein was confiding his problems in physics with me," Moffat says, "and Bohr wanted to know what he was saying."

During the two-hour interview that followed, Bohr mumbled so inaudibly that Moffat had to strain to hear him. Bohr had hoped to hear of a change of heart on his rival's part, but Moffat's letters disappointed him: Einstein was still openly skeptical of quantum mechanics. "Finally, Bohr said that as far as he was concerned, Albert had become an alchemist," Moffat remembers. In his search for a transcendent theory, Einstein had lost touch with the gritty, roll-up-your-sleeves world of experimentation. He was practicing metaphysics, not physics. "He thought Einstein was wasting his time," Moffat says. "And he told me I was wasting my time with my interest in Einstein's ideas."

It didn't end there. A local newspaper went on to publish a story about Moffat's encounters with Einstein and Bohr, and that story prompted the British consulate in Copenhagen to contact the Department of Scientific and Industrial Research in London. The department brought Moffat to London and paid his way to the Institute of Advanced Study in Dublin, for an interview with Erwin Schrödinger. A polymath who spoke six languages, Schrödinger was most famous for the wave equation that now bears his name—an elegant mathematical description of one of the central mysteries of quantum theory: that all particles can also behave like waves.

Schrödinger was sick in bed with severe bronchitis when Moffat arrived for a two-day visit. During their interview, the great physicist would peer at his young visitor through round, rimless spectacles. Moffat knew that he wouldn't hesitate to dismiss him as an impostor and send him back to a life of obscurity in Denmark. Once again, however, things went smoothly until Moffat mentioned his interest in Einstein's work. "He got very angry," Moffat remembers. "He started shouting at me from his bed. He said Einstein was a fool. I was quite overwhelmed." What most enraged Schrödinger was that he, too, a decade earlier, had tried to develop a unified theory with an approach very similar to Einstein's. But he had abandoned the effort when it became apparent to him that he was getting nowhere. He couldn't tolerate Einstein's refusal to do the same.

MOFFAT WENT ON TO BE ACCEPTED INTO THE graduate program in physics at Cambridge University, thanks in part to Schrödinger's strong recommendation. In 1958, he became the first student in the 800-year history of the school to earn his Ph.D. without



first completing an undergraduate degree. Moffat now works at the Perimeter Institute near Toronto, Ontario—an iconoclastic veteran among some of the world's best and brashest young physicists. If he was first drawn to Einstein by his mistakes, he now believes the old man may have been on the right path after all. He just started down it a few decades too soon.

In the 1930s, when Einstein began his work on the unified field theory, physicists believed that there were only two universal forces that the theory would have to unite: gravity and electromagnetism. They have since learned that there are two other fundamental forces as well: a strong force that binds atomic nuclei and a weak force that governs radioactive decay. "Einstein defined what later became a fundamental problem in physics," says Carlo Rovelli, a theoretical physicist at the University of the Mediterranean in Marseille, France. "But he was missing an ingredient."

These days Einstein's once-lonely quest engages thousands of physicists around the world, most of them string theorists. While their work is grounded in quantum mechanics, it relies heavily on some of the same components that Einstein used. According to string theory, the fundamental constituents of the physical world are not pointlike particles, but infinitesimal, one-dimensional loops, or strings. All the particles and forces in the universe arise from these strings vibrating at different frequencies. But here's the catch, and no doubt it would have made Einstein smile: The strings need 11 dimensions in which to vibrate. And these extra dimensions are described by essentially the same mathematics that Einstein used in his own five-dimensional unified field theory.

Moffat is not so sure that string theory is an improvement on Einstein's ideas. But for much of the past decade he has returned to the theory that Einstein was working on when he died—the same one that prompted Moffat's fateful letter. Moffat argues that the mathematics Einstein hoped would describe electromagnetism in his unified field theory gives rise, instead, to a slight repulsive force that reduces the strength of gravity. And that force might help solve certain long-standing puzzles in astronomy.

Two thousand light-years from Earth, for instance, two young blue stars in a system called DI Herculis whirl about each other every 10 1/2 days. Their paths shift slightly from one orbit to the next—a phenomenon known as precession—but when astronomers use general relativity to predict this shift, their answers are off by a factor of four. Most astronomers believe that a third star, unobserved as yet, is disturbing the orbit. But Moffat doesn't think so. In his modified version of Einstein's later theory, the gravitational pull between the two stars is weakened just enough to slow the stars' orbits down a bit. By his new calculations, the precession agrees exactly with observations.

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There's no small historical irony to all this. One of the first rigorous tests of general relativity was an observation of the precession of Mercury's orbit around the sun. Before Einstein, most astronomers assumed, as with DI Herculis, that a third body would make the orbit conform to Newton's equations. Some even claimed to have observed the mystery planet and have named it Vulcan. Einstein's general theory of relativity made the third planet unnecessary.

Could the third star in DI Herculis turn out to be as illusory as Vulcan? If so, it would be very big news indeed. Moffat claims that his theory would eliminate the need for dark matter and dark energy—two phenomena, as yet undetected, that physicists have invoked to account for the motions of galaxies and expansion of the universe. It's a long shot, Moffat says, but Einstein's last theory may have some life in it yet.

One day, over lunch at a bistro near Moffat's office, I asked him if we will ever see the likes of Einstein again. He shook his head. "If you go and visit Chartres cathedral in France, you'll realize that it took 150 years to build, and we don't know the names of the artisans who built it. They're anonymous. Maybe physics is going to become like this. We may one day have a great edifice for Western civilization—not a theory of everything, but still a great edifice." To claim there is an ultimate theory is "pure hubris," Moffat said. "There's always something new on the horizon, and then everything starts all over again."

Einstein was the first victim of his own success, Giovanni Amelino-Camelia, a physicist at the University of Rome, likes to tell his students. He gave rise to the romantic notion that a genius who follows his intuition can create a perfect theory that explains all the data. And then he fell prey to that notion himself. "It's a success which has really been a mixed blessing for theoretical physics," Amelino-Camelia says. "If we didn't have that one example we would have no examples. And that would teach people how science is really done."

And yet, once upon a time, Einstein *did* revolutionize physics. And he did so in large part thanks to his stubborn, independent, audacious spirit. The general theory of relativity was developed in defiance of centuries of physics. It consumed Einstein for 11 years—from 1905 to 1916—and in the end was proved triumphantly correct. It's no wonder the memory of that achievement sustained him in later years. In 1953, when the letter from John Moffat found its way to Princeton, Einstein was still doing what he had always done—asking big questions and looking for the answers.

At lunch that day in Ontario, Moffat said that he had one more letter from Einstein to show me. He rummaged through a folder, pulled out a copy, and pointed to the date: May 25, 1953. Then he read the words that have guided him for more than half a century: "Every individual . . . has to retain his way of thinking if he does not want to get lost in the maze of possibilities. However, nobody is sure of having taken the right road, me the least."

Einstein and Niels Bohr fought for nearly half a century over quantum mechanics. "An inner voice," Einstein wrote, "tells me that it is not yet the real thing."