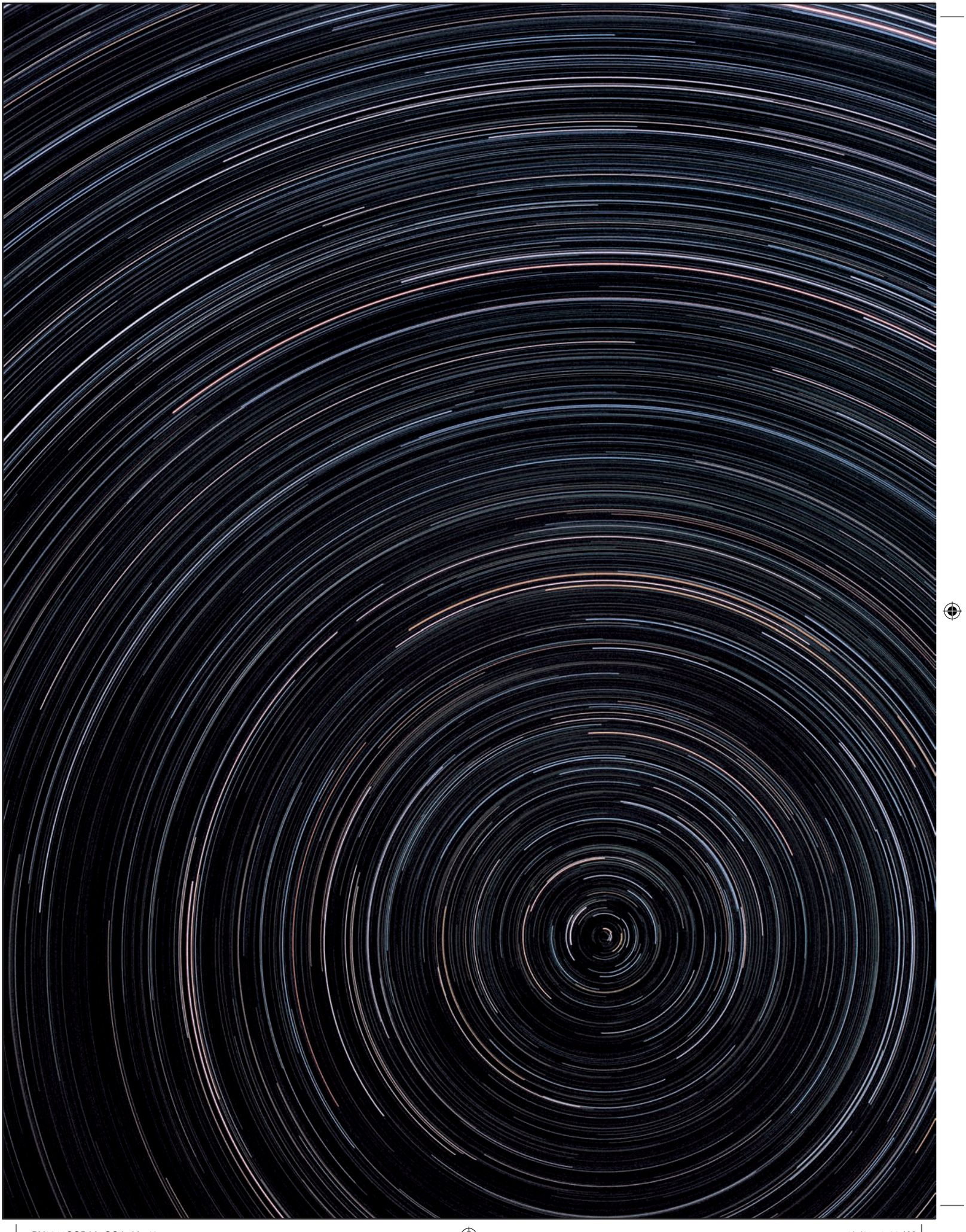

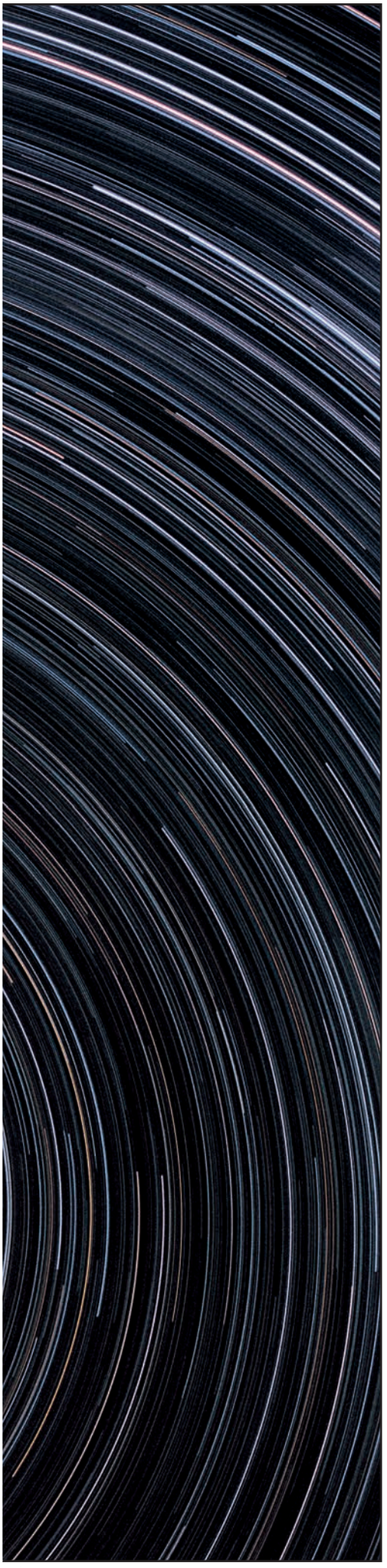

PHYSICS OF THE DIVINE

A group of scientists are embarking on a controversial search for God within the fractured logic of quantum physics.

By ZEEYA MERALI

WHEN HE DESCRIBES HIS LINE OF WORK, JOHN POLKINGHORNE JESTS, HE encounters "more suspicion than a vegetarian butcher." For the particle physicist turned Anglican priest, dissonance comes with the territory. Science parses the concrete: the structure of the atom and the workings of the brain. Religion confronts the intangible: questions about ethics and the purpose of life. Taken literally, the biblical story of Genesis contradicts modern cosmology and evolutionary biology in full.

Yet 21 years ago, in a move that made many eyes roll, Polkinghorne began working to unite the two sides by seeking a mechanism that would explain how God might act in the physical world. Now that work has met its day of reckoning. At a series of meetings at Oxford University last July and September, timed to celebrate Polkinghorne's 80th birthday, physicists and theologians presented their answers to the questions he has so relentlessly pursued. Do any physical theories allow room for God to influence human actions and events? And, more controversially, is there any concrete evidence of God's hand at work in the physical world?

Sitting with Polkinghorne on the grounds of St. Anne's College, Oxford, it is difficult to regard the jovial gentleman with suspicion. Oxford has been dubbed the "city of dreaming spires," and Polkinghorne is as

quintessentially English as the university's famed architecture, with college towers and church spires standing side by side. The bespectacled elder statesman of British science walks with a stick and wears hearing aids in both ears. But he retains a spring in his step and a quick wit. ("He will charm you in conversation, as long as you get him in his better ear," a colleague says.)

Polkinghorne's dual identity emerged early. He grew up in a devout Christian family but was always drawn to science, and in graduate school he became a particle physicist because, he explains modestly, he was also "quite good at mathematics." His scientific pedigree is none too shabby. He worked with Nobel laureate Abdus Salam while earning a doctorate in theoretical physics from Cambridge University, where he later held a professorial chair. One of his students, Brian Josephson, went on to win a share of the Nobel Prize in Physics in 1973. Polkinghorne himself joined Nobel laureate Murray Gell-Mann in research that led to the discovery of the quark, the building block of atoms. But in 1979, after 25 years in the trenches, Polkinghorne decided that his best days in physics were behind him. "I felt I had done my bit for the subject, and I'd go do something else," he says. That is when he left his academic position to be ordained.

Even as Polkinghorne changed careers, science seemed be making God's role in the world increasingly irrelevant. In 1988 his Cambridge colleague Stephen Hawking addressed the issue head-on in his wildly successful book, *A Brief History of Time,* concluding that the universe could have been created without any need to invoke a Creator. A year later Polkinghorne countered with *Science and Providence: God's Interaction With the World,* in which he framed the concept of divine action in a way that could be tackled by physicists. "I started with the statement that I believe that God acts in the world, but he is not a show-off conjurer who violates the same laws of nature that he made," he says. "My question was, Is there a way of describing God's actions that is consistent with science?"

As a priest with a past, Polkinghorne discussed the question with old friends. "Gell-Mann thought I was crazy," he says with a chuckle. But Salam, a practicing Muslim and one of the physicists to mathematically unify two of the fundamental forces of nature—electromagnetism and the weak force, which governs radioactivity—identified with Polkinghorne's quest. Even the most strident atheists from the old crowd enjoyed the debate. Steven Weinberg, who shared the Nobel with Salam in 1979, is a regular sparring partner. "Whenever we meet," Polkinghorne says, "he's always the one to put religious matters on the agenda, and though we don't agree, we always discuss things."

This spirit of respect persuaded another physicist and theologian, Bob Russell, to support Polkinghorne in his search for a physics of the divine. Russell, who founded the Center for Theology and Natural Sciences to foster interaction between science and religion in California in 1981 (before Polkinghorne was ordained), eventually teamed with the Vatican Observatory to launch a Divine Action Program. That group has been meeting with Polkinghorne and others to discuss religion and science ever since. "It's often assumed that scientists are intrinsically atheist," Russell says, "but science can be a spiritual experience. For some, it is about reading the mind of God."

IF DIVINE ACTION IS HIDDEN BY DESIGN, CAN

Reviewing the evidence at Polkinghorne's birthday conference at Oxford last July, Russell concluded that the best place to seek scientific support for God is in quantum mechanics, the physical laws describing the subatomic realm. Soon after quantum theory was developed in the early part of the 20th century, physicists realized it had some peculiar properties. For people seeking a place for God in the physical world, the most important of those properties is the uncertainty principle, which states that you can never predict the outcome of a quantum experiment with certainty; you can only calculate the probability of getting a particular result.

As a result of the uncertainty principle, quantum events are starkly different from those in the familiar, large-scale world. When you toss a coin, you could in theory make a foolproof prediction (heads or tails) if you knew every piece of information about the flip—the speed and height of the toss, the movement of all the air currents in the room, and so on. At the quantum scale, in contrast, equivalent events are intrinsically indeterministic: The universe simply does not contain enough information for you to predict a result. This fundamental indeterminism has been repeatedly confirmed in the lab. For instance, physicists have shown that two identical radioactive atoms will decay at different times. There is no way to explain why they behave differently or to predict the precise time of decay.

Russell notes that the known laws of physics do not force a quantum experiment to yield a certain result but allow a choice of outcomes. Perhaps God makes that choice, he argues, swooping in to manipulate the outcome and influence an event in the physical world. That interpretation not only allows a place for God but addresses a philosophical mystery that long bothered Einstein and many of his followers: Is there some deeper determinism that controls the outcome of seemingly random quantum events?

A major criticism of Russell's view of uncertainty as God's tool for shaping the world is that quantum events usually play out only on the subatomic level. There is no clear evidence that messing with the decay of atoms or the bouncing of electrons can affect human behavior or change the course of history. For instance, a midsize asteroid contains about 10^{40} atoms. An unthinkably large number of quantum events would need to be fixed to steer all of those atoms toward Earth in a way that would have led, say, to the extinction of the dinosaurs.

Polkinghorne pondered this problem for decades before finding a work-around in the byways of chaos theory, a branch of mathematics that describes the underlying order in large, seemingly unpredictable systems, from weather to economics. Through the machinery of chaos, a tiny change in

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starting conditions can lead to vastly different outcomes over time. One common metaphor for how this might work is the so-called butterfly effect, the idea that a butterfly flapping its wings in Los Angeles could trigger a series of events that ends with a hurricane in China. Polkinghorne sees room for God in the deep mysteries of chaos theory and the limits of prediction. A divine intelligence in command of chaos could manipulate a vast number of quantum events with just a few well-chosen controls. The results could then grow large enough to have a meaningful impact on human lives.

Among other researchers, though, adding chaos to the argument did not help. Paul Ewart, an atomic and optical physicist at Oxford, describes himself as "pessimistic" about finding God hidden within the uncertainty principle, with or without chaos to lend a helping hand. From a scientist's perspective, the difficulty is that this model of divine action is by definition hidden from view, making an experiment to detect it almost impossible to devise. It would be like proving the reality of an invisible, tasteless, odorless, silent, intangible tiger lurking in your garden. Short of God's materializing in the lab and shouting, "Look at me!" Ewart notes, it is difficult to think of any incontrovertible proof. "I think we are an infinite distance from understanding God's workings," he says.

A CUNNING EXPERIMENT BRING IT INTO VIEW?

Quantum physicist Antoine Suarez of the Center for Quantum Philosophy in Zurich argues that the God seekers are better off pursuing another quantum effect, entanglement. In entanglement, two particles become twinned in such a way that the measurement of one always determines the properties of the other, no matter how far apart they may be. Imagine setting up a pair of entangled quantum "coins" (such as photons with a specific orientation), then giving one to Alice in Oxford and another to Bob in Zurich. When you ask Alice and Bob to flip their coins, they would both get heads or both get tails, even though the results of the tosses should be random and independent. Most physicists accept entanglement as just one more counterintuitive reality of quantum physics. But Suarez claims entanglement tests conducted with real photons in the lab suggest that quantum effects must be caused by "influences that originate from outside of space-time."

In an oft-repeated version of the photon experiment, a pair of entangled photons, A and B, are created by a laser beam. Each photon follows a different path around a table until it hits a "beam splitter," a half-silvered mirror that acts as a crossroads. From this point each photon continues its journey down one of two paths, either short or long—another type of quantum coin toss. In every case A and B will follow the same route, both traveling the long path or both traveling the short one. But why?

Seeking an explanation, Suarez and his colleague Valerio Scarani (now at the National University of Singapore) proposed a way to modify the basic experiment, which had been carried out by physicists in Geneva. Their intent was not to address theological questions but to challenge quantum theory by testing one of its fundamental predictions: that the timing of quantum events has nothing to do with their outcomes. They proposed instead that the outcome might be influenced by the course of events as the experiment takes place. For instance, if particle A hits the beam splitter even a tiny fraction of a second before particle B, its trajectory and outcome might influence what happens to B in its wake, somehow communicating across time. To test the idea, Suarez and Scarani needed to design an experiment that disrupted the cause-and-effect relationship between the photons by making sure that neither one arrived before the other.

THEIR CUNNING SCHEME was based on another famous theory of physics that gives quantum mechanics a run for its money in terms of odd predictions: Einstein's theory of relativity. Early in the 20th century, Einstein realized that time is not absolute; it runs at a slower or faster rate depending on how quickly you are moving. (Your watch falls about 177 nanoseconds behind on a cross-country flight.) Because relativity monkeys around with the rate at which time flows, there is no universal clock ticking away at a set rate that everyone will agree on. Two people moving relative to each other can even disagree on the order in which two events take place. If Alice and Bob are seated on two space shuttles moving in different directions, it is possible to set up a scenario in which they both flip quantum coins, but Alice says she flipped her coin before Bob, while Bob swears he tossed his coin first. According to Einstein, they would both be right, depending on whether you looked at the situation from Alice's or Bob's point of view.

In an analogous "before-before" experiment, Suarez's colleagues in Geneva deployed entangled photons A and B through beam splitters, after which each particle would follow either a short or a long path. The physicists used acoustic waves that had the effect of altering time for the photons—the equivalent of putting Alice and Bob in those opposite-moving space shuttles. In this setup, a miniature observer running alongside photon A would swear it had been set on its course first, while an observer next to photon B would say with equal certainty that events had happened in the reverse order.

Suarez was sure that by messing up the time-ordering in this way, it would be impossible for the photons to coordinate their paths. He was proved wrong. On every run, the photons still met the same fate. Whatever causes the twin photons to behave in the same way, it must work independently of time. "There is no story that can be told within the framework of space-time that can explain how these quantum correlations keep occurring," Suarez says.

These results have intriguing philosophical implications, he notes, especially for the spiritually inclined. "You could say the experiment shows that space-time does not contain all the intelligent entities acting in the world because something outside of time is coordinating the photons' results," Suarez says. "Physics experiments cannot

demonstrate the existence of God, but this test shows that today's physics is compatible with all major religious traditions. There is strong experimental evidence for accepting that nonmaterial beings act in the world."

Polkinghorne concurs. Although quantum physics itself is a purely material and mathematical description of the world, he says, "the mysteries of quantum objects leave room for God in an explanation of the physical world."

Other attendees at the Oxford events say that attributing quantum matchups to the hand of God is a leap of faith too far. Jean Staune, a mathematical physicist and philosopher at the Interdisciplinary University in Paris, who attended the September meeting, puts it like this: The before-before experiment shows that "if an intelligence is directing quantum events, then that intelligence exists outside the material universe. But it doesn't prove that such a mind exists."

This gets to a pitfall Polkinghorne has worked hard to avoid: If you explain away every scientific unknown by invoking God, you end up with a "God of the gaps," one that can be eroded anew every time a new part of the science puzzle is solved. "The trouble is that if science later advances, God will be left high and dry," says Christopher Isham, a practicing Christian and a theoretical physicist at Imperial College London. He questions the merit of trying to validate religious experience by appealing to science. "For me, religious belief is more about mystical feelings about the world, and God is something one encounters in one's self," says Isham, who converted to Christianity at the age of 40. He was asked to act as an adviser on the Divine Action Program when it was conceived 20 years ago but has lost interest over time.

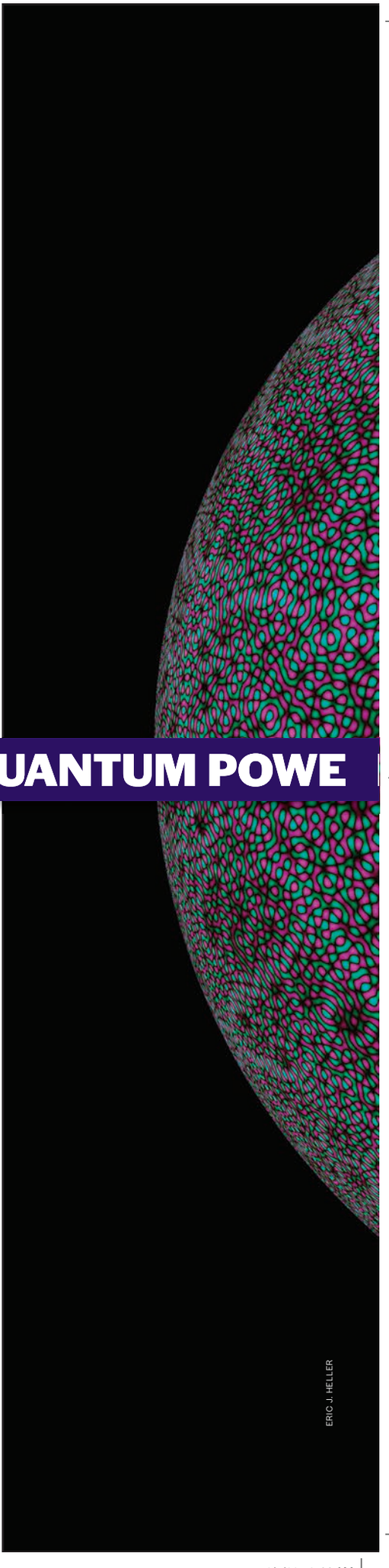
"Most physicists are amateur metaphysicists," adds Nicholas Saunders, a theologian who reviewed Polkinghorne's arguments for scientific evidence of divine action at the July meeting. Also a lawyer with some training in physics, Saunders admits he is "not a fan" of such theories—not so much because they yield bad science as because they lead to bad theology. For example, suppose you accept that God steps in every so often to fix the outcome of a quantum event in the brain—manipulating the motion of electrons to cause a neuron to fire, perhaps, influencing your decision on whether to become a priest or a scientist. In what sense would your career choice then really be your own? And if scientists ever did manage to uncover mechanisms used by God to influence the physical world, it would become even harder to defend why God does not use this power to alleviate suffering. "It does rather raise the question of why the universe is, frankly, a bit crummy," Saunders says. Discovering God's quantum powers would also seem potentially to give us godlike control ourselves, although Saunders is not too concerned: "It's one thing to understand a mechanism and another to manipulate it."

When I put these dissents to Polkinghorne, his jolly demeanor fades. "We need to find a middle ground where God is not a cosmic tyrant, with us as puppets," he concedes. "The answer has to lie along the lines that God has given humans real freedom, even if they grievously misuse it. But after seeing some of the horrific events that took place in the 20th century, it is hard to say that without a quiver in your voice."

Despite the many critiques that his work has inspired, Polkinghorne insists, in the wake of his birthday meetings, that the challenge to prove God compatible with physics has largely been met. "Physics asks how the world works, and when it answers that question it finds a very deep, marvelously patterned order. But it doesn't explain where that order comes from. I believe that the order is a reflection of the mind of God."

What about Isham's God-of-the-gaps concern, in which science explains it all, making God irrelevant for good? Polkinghorne counters that, by its very nature, science can never provide a complete picture of the world. "Without the concept of God," he says, "we'll always be forced to treat some things like strange, brute facts."

WOULD DISCOVERING GOD'S QUANTUM POWE


ERIC J. HELLER

Opposite: Waves on a sphere follow the unpredictable rules of quantum mechanics. Pages 48-49: The predictable trails of stars as Earth rotates.