strong evidence.” Each group has seen hints of an expected signature of gravitational waves, but without the statistical certainty of a firm discovery, Ransom and others say. Researchers will now pool their data to see whether they can reach that threshold together.

“If this is confirmed, we’ll have 20 years of work studying this new background,” says Monica Colpi, who studies the theory of gravitational waves and black holes at the University of Milan–Bicocca in Italy. “It will put an army of astrophysicists to work.”

Catching a wave

Three collaborations have amassed decades’ worth of pulsar data and are reporting similar results: the North American group NANOGrav; the European Pulsar Timing Array, with the contribution of astronomers in India; and the Parkes Pulsar Timing Array in Australia. A fourth collaboration, the Chinese Pulsar Timing Array, says it has found a signal with merely three years of data, owing to the exceptional sensitivity of the Five-hundred-meter Aperture Spherical Telescope (FAST), which opened in 2016 in the Guizhou region.

Keija Lee, a radio astronomer at Peking University in Beijing who led the FAST study, says he was not surprised by the result[4]. “My calculation for the gravitational-wave sensitivity of FAST observation was done back in 2009, when I was a PhD student.”

All the groups use massive radio telescopes to monitor ‘millisecond’ pulsars. These are incredibly dense neutron stars that spew radio waves from their magnetic poles. Each time a pulsar rotates on its axis, its radio beam travels in and out of the line of sight to Earth, resulting in a pulse with regular intervals. Millisecond pulsars rotate the fastest, up to several hundred times per second.

“We can use them basically as clocks,” says Andrew Zic, a radio astronomer at the Australia Telescope National Facility in Sydney and a lead author of the Parkes paper[3]. Slight changes in the arrival time of a pulsar’s signals can mean that the space between the star and Earth has been altered by the passage of a gravitational wave.

The timing of a single pulsar would not be reliable enough to detect gravitational waves. Instead, each collaboration monitors an array of dozens. As a result, they have found a signature called the Hellings–Downs curve, which predicts how, in the presence of gravitational waves coming from all possible directions, the correlation between pairs of pulsars varies as a function of their separation in the sky. NANOGrav was first to spot the signal[1], and reported it to colleagues in 2020. But the team decided to wait for the other collaborations to see hints of the curve before publishing.

“Seeing the Hellings–Downs curve actually appear for the first time in a real way – that was a beautiful moment,” says Chiara Mingarelli, a gravitational-wave astrophysicist at Yale University in New Haven, Connecticut, and a member of NANOGrav. “I’m never tiring of seeing it.”

> **“This finding will put an army of astrophysicists to work.”**

Alberto Vecchio, an astrophysicist at the University of Birmingham, UK, and a member of the European team, says his first reaction when he saw his group’s results[2] was, “Bloody hell, there could be something interesting here.”

The long game

Einstein first predicted gravitational waves in 1916. On 14 September 2015, the twin detectors of the Laser Interferometer Gravitational-Wave Observatory (LIGO) in Louisiana and Washington State confirmed his prediction by detecting a burst of waves from the merger of two black holes. Physicists have since captured gravitational waves from dozens of such events.

If the latest signal is from the combined gravitational waves of thousands of pairs of supermassive black holes across the Universe, it would be the first direct evidence that such binaries exist and that some have orbits tight enough to produce measurable gravitational waves. Colpi says a major implication is that each of the pairs will ultimately merge – creating bursts similar to the ones seen by LIGO, but on a much larger scale. The signals of some of these collisions will be detected in space by the Laser Interferometer Space Antenna (LISA), a European Space Agency mission due to launch in the 2030s.

Researchers hope that they will eventually go beyond the Hellings–Downs curve and see signals of individual supermassive-black-hole binaries close enough to the Milky Way – and therefore loud enough, in gravitational-wave terms – to stand out against the background signal. “To see an isolated source, it has to be really strong,” says Vecchio.

But for now, other origins of these waves cannot be ruled out, including possible residual gravitational noise from the Big Bang.

“It’s been a long and patient game,” says Zic. “Now we’re really starting to open the window into this ultra-low-frequency gravitational-wave spectrum.”

1. Agazie, G. *et al. Astrophys. J.* **951**, L8 (2023).
2. Antoniadis, J. *et al.* Preprint at https://arxiv.org/abs/2306.16214 (2023).
3. Reardon, D. J. *et al. Astrophys. J.* **951**, L6 (2023).
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PHILOSOPHER WINS CONSCIOUSNESS BET WITH NEUROSCIENTIST

The pair wagered decades ago over when they would learn how the brain achieves consciousness.

By Mariana Lenharo

A 25-year science wager has come to an end. In 1998, neuroscientist Christof Koch bet philosopher David Chalmers that the mechanism by which the brain’s neurons produce consciousness would be discovered by 2023. Both scientists agreed publicly on 23 June, at the annual meeting of the Association for the Scientific Study of Consciousness (ASSC) in New York City, that it is an ongoing quest – and declared Chalmers the winner.

What ultimately helped to settle the bet was a study testing two leading hypotheses about the neural basis of consciousness, whose findings were unveiled at the conference.

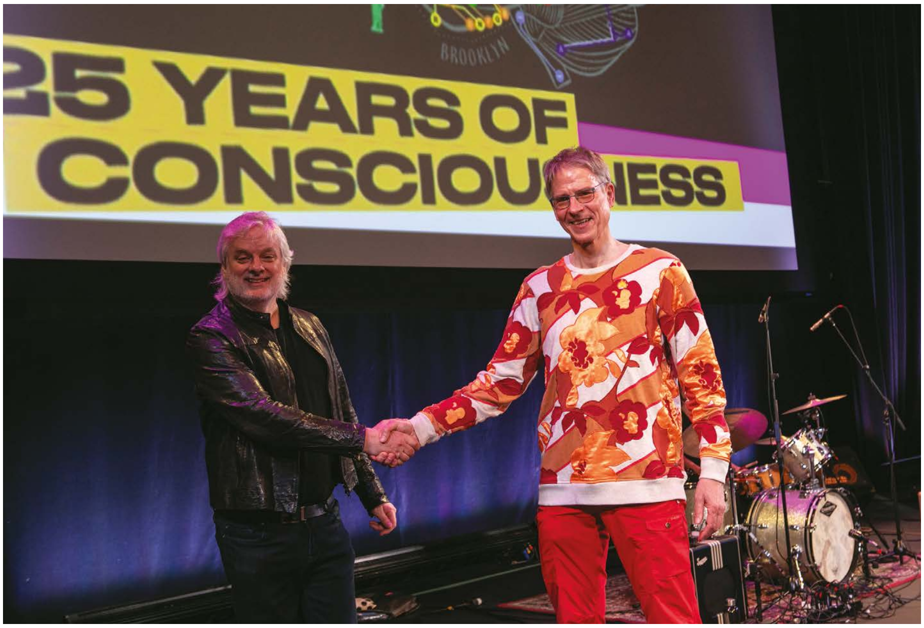
“It was always a relatively good bet for me and a bold bet for Christof,” says Chalmers, who is now co-director of the Center for Mind, Brain and Consciousness at New York University. But he also says this isn’t the end of the story, and that an answer will come eventually: “There’s been a lot of progress in the field.”

The great gamble

Consciousness is everything that a person experiences – what they taste, hear, feel and more. It is what gives meaning and value to our lives, Chalmers says.

However, despite a vast effort, researchers still don’t understand how our brains produce it. “It started off as a very big philosophical mystery,” Chalmers adds. “But over the years, it’s gradually been transmuting into, if not a ‘scientific’ mystery, at least one that we can get a partial grip on scientifically.”

Koch, who holds the title of meritorious



JESSE WINTER FOR *NATURE*

David Chalmers (left) and Christof Koch met on 23 June in New York City to settle up their bet.

investigator at the Allen Institute for Brain Science in Seattle, Washington, began his search for the neural footprints of consciousness in the 1980s. Since then, he has been invested in identifying "the bits and pieces of the brain that are really essential – really necessary to ultimately generate a feeling of seeing or hearing or wanting", as he puts it.

At the time that Koch proposed the bet, certain technological advances made him optimistic that the mystery would be solved sooner rather than later. Functional magnetic resonance imaging (fMRI), which measures small changes in blood flow that occur with brain activity, was taking laboratories by storm. And optogenetics – which allows scientists to stimulate specific sets of neurons in the brains of animals such as non-human primates – had come on the scene. Koch was a young assistant professor at the California Institute of Technology in Pasadena at the time. "I was very taken by all these techniques," he says. "I thought: 25 years from now? No problem."

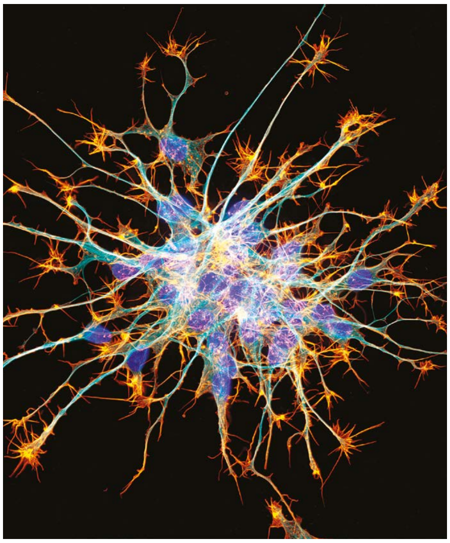
Adversarial collaboration

For many years, the bet was mostly forgotten. Then, a few years ago, it resurfaced, thanks to Per Snaprud, a science journalist based in Stockholm who had interviewed Chalmers back in 1998. His recording of the chat reminded Chalmers and Koch of the terms they had set in the wager – and of the case of wine that was at stake.

At around that time, both researchers had become involved in a large project supported by the Templeton World Charity Foundation, based in Nassau, the Bahamas, that aimed to accelerate research on consciousness.

The goal was to set up a series of 'adversarial' experiments to test various hypotheses of consciousness by getting rival researchers to collaborate on the studies' design. "If their predictions didn't come true, this would be a serious challenge for their theories," Chalmers says.

The findings from one of the experiments – which involved several researchers, including Koch and Chalmers – were revealed at the ASSC meeting. It tested two of the leading hypotheses: integrated information theory (IIT) and global network workspace theory (GNWT). IIT proposes that consciousness is a 'structure' in the brain formed by a specific type of neuronal connectivity that is active for as long as a certain experience, such as looking at an image, is occurring. This structure is thought to be found in the posterior cortex, at the back of the brain. GNWT, by contrast, suggests that consciousness arises when information is broadcast to areas of the brain through an interconnected network. The transmission, according to the theory, happens at the beginning and end of an experience and involves the prefrontal cortex, at the front of the brain.



TORSTEN WITTMANN/SPL

Neurons' role in consciousness is still unclear.

Six independent laboratories conducted the adversarial experiment, following a pre-registered protocol and using various complementary methods to measure brain activity. The results – which haven't yet been peer reviewed – didn't perfectly match either of the theories.

"This tells us that both theories need to be revised," says Lucia Melloni, a neuroscientist at the Max Planck Institute for Empirical Aesthetics in Frankfurt, Germany, and one of the researchers involved. But "the extent of that revision is slightly different for each theory".

Unfulfilled predictions

"With respect to IIT, what we observed is that, indeed, areas in the posterior cortex do contain information in a sustained manner," Melloni says, adding that the finding seems to suggest that the 'structure' postulated by the theory is being observed. But the researchers didn't find evidence of sustained synchronization between areas of the brain, as had been predicted.

In terms of GNWT, the researchers found that some aspects of consciousness, but not all of them, could be identified in the prefrontal cortex. Furthermore, the experiments found evidence of the broadcasting postulated by advocates of the theory, but only at the beginning of an experience – not also at the end, as had been predicted.

So GNWT fared a bit worse than IIT during the experiment. "But that doesn't mean that IIT is true and GNWT isn't," Melloni says. What it means is that proponents need to rethink the mechanisms they proposed in light of the new evidence.

Other experiments are under way. As part of the Templeton foundation's initiative, Koch is involved in a study testing IIT and GNWT in the brains of animal models. And Chalmers is working on a project evaluating two other hypotheses of consciousness.

It's rare for proponents of competing theories to come together at the table and be open to having their predictions tested by independent researchers, Melloni says. "That took a lot of courage and trust from them." She thinks that projects such as these are essential for the advancement of science.

As for the bet, Koch was reluctant to admit defeat, but the day before the ASSC session, he bought a case of fine Portuguese wine to honour his commitment. Would he consider another wager? "I'd double down," he says. "Twenty-five years from now is realistic, because the techniques are getting better and, you know, I can't wait much longer than 25 years, given my age."