New Scientist

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By Gina Rippon

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Quantum physics

On the edge of the quantum realm

What lies beyond quantum mechanics? We now have mathematical tools to help us look

Karmela Padavic-Callaghan

QUANTUM entanglement can link two objects even when they are separated by extremely large distances. But a new study has found a limit at which such quantum correlations stop – and, surprisingly, something even stronger may begin. "Honestly, we are at the edge of science here," says Jean-Daniel Bancal at Paris-Saclay University in France.

To verify that two quantum objects are entangled, physicists use what are called Bell tests: they repeatedly measure the system to determine all of its possible states, then create a "probability distribution" to show how likely the system is to be in any one state.

Bancal and Victor Barizien, also at Paris-Saclay University, have now calculated exactly which probability distributions are allowed by quantum theory, and suggest that any quantum objects that don't match actually belong to some more exotic, post-quantum theory.

Normally, physicists would calculate a probability distribution based on the physical details of an object, but the pair devised a way to invert this method. Instead, they started with the many possible probability distributions and determined which could be matched to their physical quantum system (*Nature Physics*, doi.org/g89w7s). "This is a great technical achievement," says Valerio Scarani at the National University of Singapore.

Ivan Šupić at University Grenoble-Alpes in France says that fully characterising the set of all possible quantum correlations becomes exceedingly difficult as objects become more complex – because there are more potential states for the system. That means that while it is fairly easy to see where classical correlations end and quantum ones begin, it is more problematic to work out when something quantum crosses into something that is possibly post-quantum.

Martin Plesch at the Slovak Academy of Sciences says the work may also offer mathematical tools for making quantum communication and computing protocols more secure, allowing researchers to measure the properties of a quantum device and determine how they are correlated, instead of having to know the details of its hardware – something that is impossible for traditional computing devices.

"It is hard to work out when something quantum crosses into something possibly post-quantum"

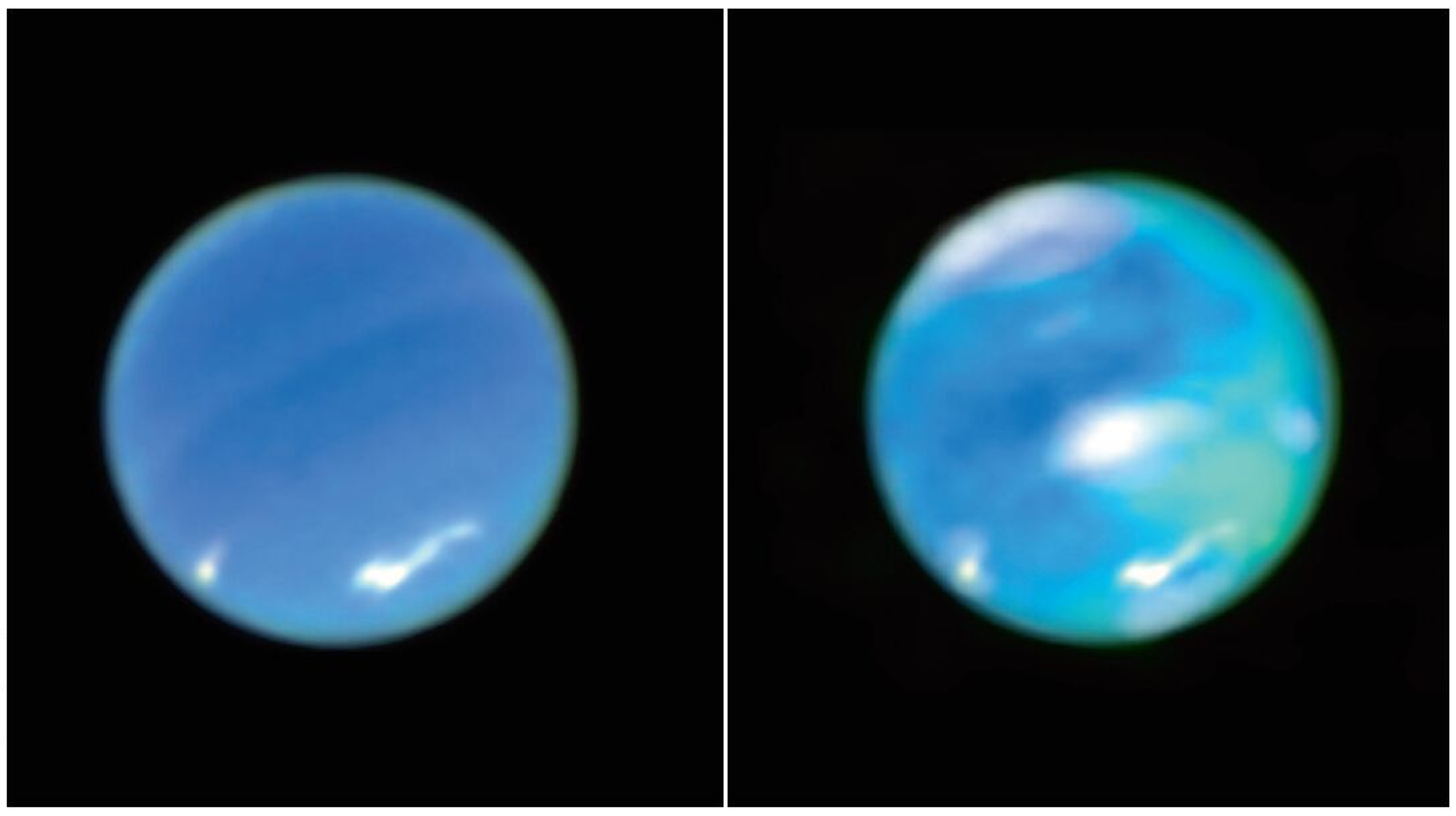
"We don't have to trust the manufacturer of the device. We can just test the device on 'What is it doing?' And results like this make the tests more rigorous," says Plesch.

But there may also be consequences for how we think about quantum theory, says Scarani. Some probability distributions that lie beyond the post-quantum border break laws of physics that would make them impossible to find in nature. But others don't. This leads to a big question: is our world entirely inside the quantum border – or not?

The question remains tantalisingly open, especially since there aren't any rigorous and agreed-upon post-quantum theories, but this new work could help point the way, says Barizien. ▮

Solar system

Auroras seen on Neptune for the first time



NASA, ESA, CSA, STSCI

Green blotches in the right hand image show the auroras lighting up Neptune's sky

INFRARED auroras have been spotted swirling in Neptune's atmosphere, verifying decades of scientific speculation.

When NASA's Voyager 2 mission flew by Neptune in 1989, it found intriguing hints of aurora activity in the ice giant's clouds. However, scientists were unable to verify the phenomenon at the time, as existing instruments were too weak. Now, the James Webb Space Telescope (JWST) has finally provided the power to detect them.

"This was really a fulfilment of years' worth of anticipation," says Heidi Hammel at the Association of Universities for Research in Astronomy in Washington DC.

Hammel and her colleagues used JWST's NIRSpec, a powerful infrared imaging tool, to analyse the different wavelengths of light emitted by the planet. In 2023, JWST detected infrared auroras on Uranus. This time, it found them on Neptune as well (*Nature Astronomy*, doi.org/pd4q).

The images also allowed Hammel and her team to begin constructing a map of Neptune's magnetic field. This is particularly exciting, as the planet is known to have some of the most unusual magnetic poles in the solar system.

Unlike Earth, Jupiter or Saturn, Neptune's magnetic poles aren't centred at its rotational poles. Instead, "they're offset by almost half the planet's radius", says Hammel. As a result, its auroras appear as irregular blobs much closer to its equator.

In addition to detecting auroras, the JWST observations indicate that Neptune's ionosphere – the layer of charged particles blanketing some planets – is cooling down. It is now, on average, about 10 per cent colder than when Voyager 2 passed by nearly 36 years ago. While the authors of the new study aren't sure why this cooling occurred, they hope their next JWST observation period, scheduled for 2026, will offer more clues. ▮

Joanna Thompson