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The multiverse could be much, much bigger than we ever imagined

A new way of interpreting the elusive mathematics of quantum mechanics could fundamentally change our understanding of reality

By Karmela Padavic-Callaghan

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The many-more-worlds interpretation enlarges the multiverse
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The multiverse could be infinitely bigger than we ever imagined, according to a new interpretation of quantum mechanics that describes realms upon realms of parallel universes created with every decision we make.

At the heart of quantum mechanics is the wave function, an infamously abstract and fuzzy mathematical tool that is extremely good at describing the behaviour of photons, electrons and other denizens of the quantum realm. But what exactly is the wave function? After almost a century of arguments, physicists still disagree on how...
to make the leap from mathematics to the tangible, physical world.

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In the most conventional view, known as the Copenhagen interpretation, the wave function mathematically describes all possible states of an object before it is "observed", an act that leaves it in an unambiguous state by "collapsing" the wave function.

For example, in the Schrödinger's cat thought experiment, a cat is placed in a box that will be flooded with poison gas when an atom decays. Because the behaviour of the atom is quantum mechanical, when the box is closed, the cat's wave function simultaneously contains both its alive and its dead states. When an observer opens the box, the wave function collapses and the cat is either dead or alive, with the other possibility vanishing. Its behaviour from then on is fully non-quantum, or classical. Once observed as dead, the cat doesn't come back to life.

Many worlds

A cat that is both living and dead may be hard to swallow, but another view of quantum mechanics created by physicist Hugh Everett in the 1950s has even more startling implications. In the many-worlds interpretation, the wave function doesn't collapse into only one certain, classical state, because each quantum state that it contains is already perfectly real – in one of many parallel worlds. When you open the box and observe a living cat, a replica of you in another world has just found it dead, with the act of observation effectively giving rise to two separate worlds.

Whichever view you favour, a big open question remains: how does this emergence of what we perceive to be classical behaviour apply to the whole universe?

"All the stars, galaxies, planets, life, they all start off as quantum fluctuations in the very, very early universe. As the universe expanded, eventually these things became classical," says Arsalan Adil at the University of California, Davis. "And quantum theory is really well tested, so we agree that it is, to some approximation, the correct theory, but we'd like to understand how a classical world emerges from that."

One issue with both the Copenhagen and many-worlds interpretations is exactly what counts as an "observer", which is particularly a problem in the early universe when there was nothing and no one to make observations. To sidestep this, Adil and his colleagues began with the less anthropocentric idea of looking at collections of particles, with the behaviour of each particle determined by the way energy is structured across all particles in the system.

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"We are big, warmish objects that are used to interacting with other big, warmish objects that are well localised in position, and we construct some scientific story based around these things. But you can kind of turn it the other way around and say that what the universe actually gives us in its most raw form, getting rid of our human perspective, is just some energy structure," says team member Zoe Holmes at the Swiss Federal Institute of Technology in Lausanne.

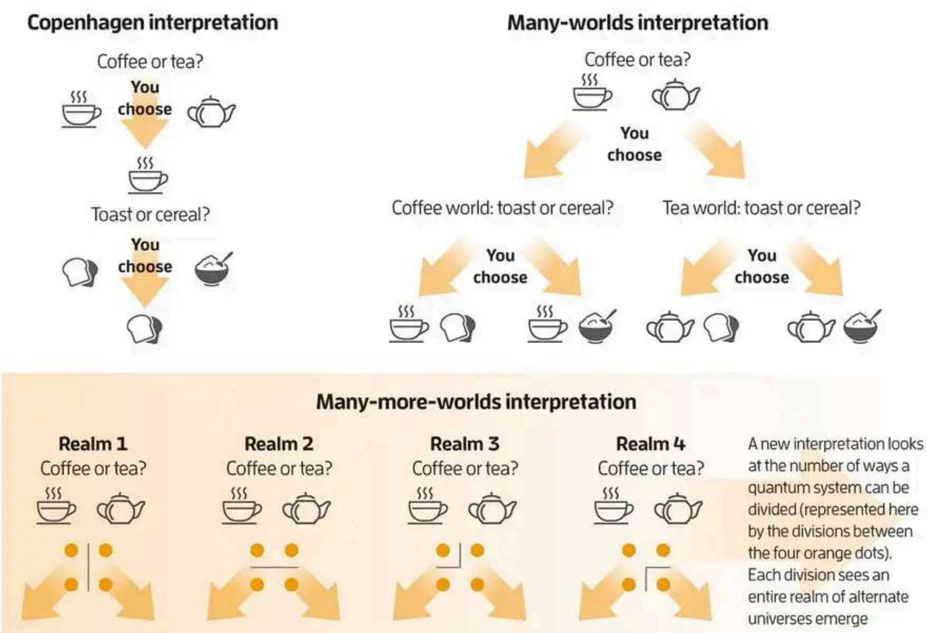
Freed of the need to consider distinct "observers", the team developed an algorithm that identifies ways to divide these systems of particles into subsystems. Any subsystem is considered a valid view of the world, as long as the interactions between subsystems lead to one of them becoming classical – essentially a much more general version of opening the box in Schrödinger's thought experiment. "You can have part of the Earth and the Andromeda galaxy in one subsystem, that's a perfectly legitimate subsystem," says Arsalan.

This new perspective uncovered myriad realms of new worlds, beyond the simple dead-and-alive ones, leading the researchers to call it the many-more-worlds interpretation. To understand why, consider a quantum version of deciding whether to have coffee or tea at breakfast. In the Copenhagen interpretation, you make a decision and the wave function collapses. If you then decide between eating toast or cereal, a second wave function collapses. All of this takes place within the only universe that exists.

But in the many-worlds interpretation, the you who is craving coffee and the you who prefers tea both exist in parallel worlds, and each of those worlds will again branch into two depending on what you decide to eat (see "A quantum point of view", below).

A quantum point of view

Different interpretations of quantum physics have startling conclusions, from observers influencing reality to a proliferation of alternate universes



In the many-more-worlds interpretation, the interaction between you and your breakfast gives rise to one realm made up of many worlds, but more realms of worlds arise from less intuitive divisions of your world into subsystems like your cup and some faraway celestial object, or an even more odd designation of your left arm to one subsystem and your right to another. With many more perspectives, each giving rise to a realm of new worlds, the net effect is enlarging the already vast multiverse of Everett's interpretation.

Paolo Zanardi at the University of Southern California Dornsife says that the new interpretation achieves "a sort of operational democratisation" between the ways of segmenting reality, as it doesn't forbid any subsystem splits just because they are odd or counterintuitive, which he finds compelling and satisfying. But the algorithm the researchers use to find the various subsystems' divisions still contains some assumptions, like how long it takes for a subsystem to become classical, so there is room for more mathematical exploration and refining of the idea, he says.

"This is a good, serious, useful contribution to the growing literature on how to take a 'bare bones' quantum mechanical theory and extract from it something resembling the classical world of our experience," says Sean Carroll at Johns Hopkins University in Maryland.

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Carroll has also looked at dividing quantum systems into subsystems, but he has found that valid subsystems that lead to appropriately classical worlds are rarer than the multitude of realms suggested by Adil, Holmes and their colleagues. This may be because there are different ways to quantify when exactly a system is non-quantum enough to be considered classical, he says.

While those questions remain to be resolved, exactly what an enlarged multiverse might mean for our understanding of reality is still unclear, even for the team. Adil says he and his colleagues are currently "agnostic about the ontological conclusions" of what they have uncovered so far. Holmes says that when she is feeling sceptical, she worries that their work is akin to finding shapes in the clouds, rather than a reflection of reality.

Yet both researchers can't shake the feeling that they have come across something meaningful and want to pursue it further.

"I would say I think we know this is true, but we don't know whether it's important," says Holmes. "We have had so many arguments over this, we've tied ourselves in circles."

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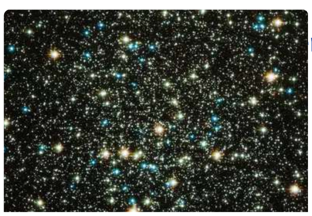

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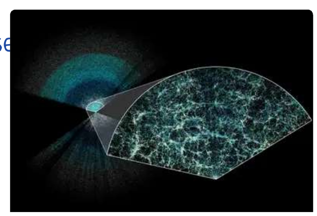

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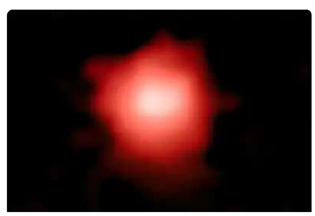

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