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Physics

Quantum 'arrow of time' suggests early universe had no entanglement

One way to explain why time only moves forward is the quantum arrow of time, and it has major implications for both the universe's early period and its eventual demise

By Leah Crane

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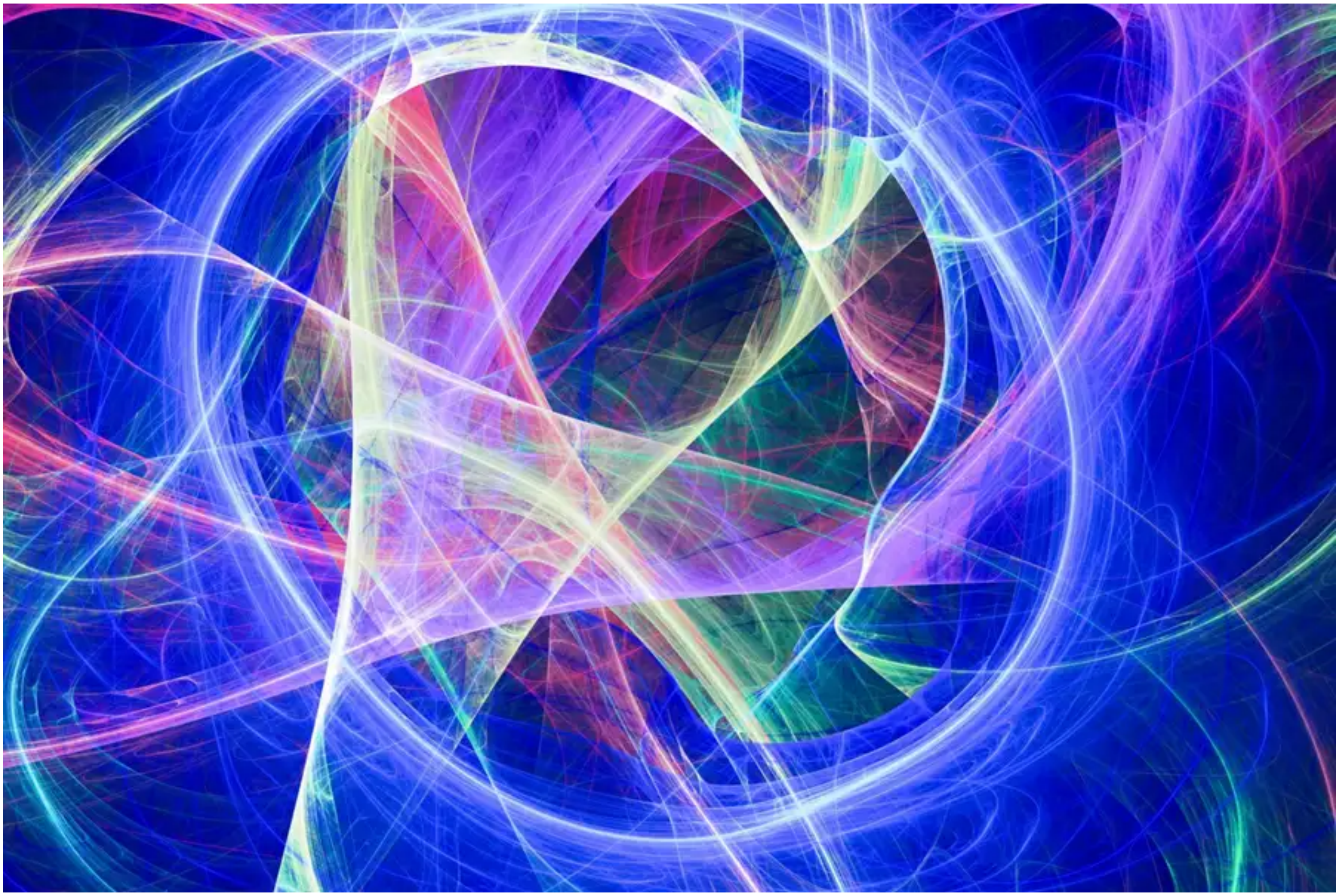

Was there entanglement at the dawn of time?
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In the beginning, there was no quantum entanglement. That is the conclusion of a study exploring the so-called entanglement past hypothesis. The finding is part of a quantum reinvention of our notions about why time only flows in one direction.

When two particles become entangled 🔗 /article/mg26234921-800-how-quantum-entanglement-really-works-and-why-we-accept-its-weirdness/, each can no longer be thought of as an independent object – their properties are tied together, even if they are physically far apart. However, unless these particles are perfectly isolated from the environment, outside interference will eventually cause their entanglement to break down in a process called decoherence.

This phenomenon inspired an idea called the decoherent, or quantum, arrow of time. This posits that because decoherence is irreversible, it could be the fundamental reason why time flows forward 🔗 /article/mg25433910-600-could-we-ever-go-back-in-time-relativity-does-not-rule-it-out/ and never backward. It's related to the more traditional thermodynamic arrow of time where the direction of time's flow is governed by the idea that entropy, or disorder, must always increase – a concept at the core of the second law of thermodynamics.

If you follow the thermodynamic arrow of time back to the beginning of time to reconstruct the starting state of the universe – a state known as the "thermodynamic past hypothesis" – you will conclude it must have been one of extremely low entropy. Jim Al-Khalili 🔗 https://jimal-khalili.com/ at the University of Surrey in the UK and Eddy Keming Chen 🔗 https://www.eddykemingchen.net/ at the University of California, San Diego, have now performed a similar analysis to discover the entanglement past hypothesis.

Their research suggests that there was no quantum entanglement in the earliest moments of the universe. As the cosmos evolved, there was more and more entanglement and, correspondingly, more and more decoherence.

"People have been vaguely aware that you need some kind of past hypothesis to get the decoherent arrow of time, but it hasn't really been worked out in detail before," says Emily Adlam 🔗 https://www.researchgate.net/profile/Emily-Adlam at Chapman University in California. "This clarifies what exactly that beginning state of the universe is."

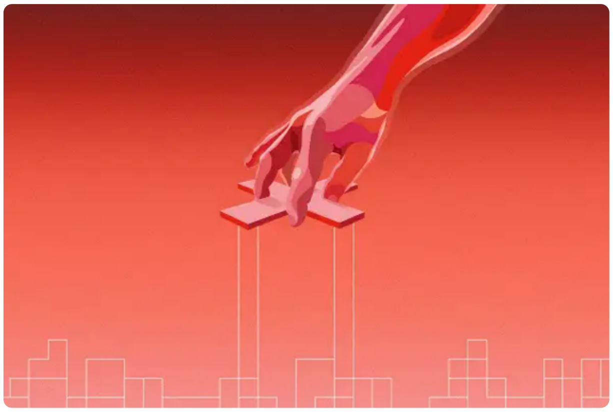
While we cannot directly observe the beginning state of the universe and it may not seem relevant to the current state of things, it is crucial to our understanding of how things have evolved since then – and even what "since then" really means.

"Once you get beyond that very early universe, you have thermodynamic entropy, you have gravity clumping everything up, so you move away from concerns about quantum entanglement," says Al-Khalili. "Once you have an arrow, once you have a direction to time, everything else happens on its own – we just needed the starting point."

Al-Khalili and Chen also found that a low-entanglement initial state would have low thermodynamic entropy 🔗 /definition/second-law-thermodynamics/, which hints that the thermodynamic and quantum arrows of time may be connected to one another.

Moreover, the decoherent arrow might be more useful for understanding the behaviour of the universe. "For the thermodynamic arrow of time, you're sort of zooming out," says Al-Khalili, meaning there is a degree of subjectivity in measuring its precise properties. "The decoherent arrow of time is a bit more objective," says Al-Khalili. This suggests that it is more of a fundamental law of the universe.

"The hope is that you derive the thermodynamic past hypothesis from the entanglement past hypothesis and then they become different aspects of one another," says Adlam. That would give us a more complete understanding of the nature of time.



Is everything predetermined? Why physicists are reviving a taboo idea

🔗 /article/mg25033340-700-is-everything-predetermined-why-physicists-are-reviving-a-taboo-idea/

Superdeterminism makes sense of the quantum world by suggesting it is not as random as it seems, but critics say it undermines the whole premise of science. Does the idea deserve its terrible reputation?

All this could mean that the end of the universe 🔗 /article/mg25433911-400-will-time-ever-end-the-answer-lies-in-the-death-throes-of-the-cosmos/ isn't as simple as we thought. The general consensus is that the universe is most likely to end in a state called heat death, in which all energy is evenly distributed throughout space and nothing ever changes. But the decoherent arrow of time suggests the cosmos will continue to evolve even after this point.

"There's going to be the thermodynamic heat death, everything becomes a soup with no structure, but it will take many, many billions of years later to reach maximum entanglement," says Chen. "This means that there are actually interesting things that happen after the heat death of the universe."

If the entanglement past hypothesis is true, it could set in stone the very existence of time 🔗 /article/mg25433910-500-what-is-time-the-mysterious-essence-of-the-fourth-dimension/, says Al-Khalili. "The flow of time, one can quite easily argue that that is subjective, but the direction of time, I would argue, is fundamental, and therefore time is real," he says.