Countdown to oblivion: Why time itself could end

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Editorial: *The value of asking 'What if?'*

"We could run into the end of time," Ben Freivogel tells a seminar at the Massachusetts Institute of Technology in Cambridge. Several colleagues seem nonplussed, and one Nobel laureate looks downright exasperated. "I'm aware that this sounds like a crazy conclusion," Freivogel admits, generating a round of what sounds like relieved laughter. But perhaps their relief is short-lived.

The nature of time, our perception of it and even whether it exists at all are hot topics for both physicists and philosophers. But Freivogel isn't pushing a strange new concept of time.

His idea is arguably even more baffling. He thinks that time, as described by Einstein's theory of general relativity, could simply end in our universe, taking us with it. He gives us another 5 billion years or so before the axe falls (see "Five billion years to go", below).

This unsettling idea arises from a popular theory called eternal inflation. In this theory, different parts of space can undergo dramatic growth spurts, essentially ballooning into separate universes with their own physical properties. The process happens an infinite number of times, creating an infinite number of universes, called the multiverse.

Measure problem

The infinities involved mean that anything that can happen does happen – an infinite number of times. That makes it difficult to figure out how common a universe like ours is. "It sort of pulls the rug out from underneath your intuition of how to define probabilities," says Freivogel's colleague Raphael Bousso of the University of California, Berkeley.

To get around this problem, physicists take a "cut-off" of the multiverse, cutting out a finite patch of space-time and counting the universes within it to get a representative sample.

However, doing this inevitably slices through individual universes on the edge of the sample. This leads to incorrect probabilities of experimental outcomes in the multiverse – unless, Freivogel and his team argue, the mathematical cut-offs somehow have real and dire consequences for the places they intersect. Time would end there, they say, causing everything present to disappear. "The world, including you, would just cease to exist," says Bousso.

Predictive power

The idea is more than strange, not least because it is not clear how these mathematical constructs could impinge on the real world.

But the team say the cut-offs have to be considered real if they are to be used to calculate probabilities in the multiverse. These are key to making cosmological predictions about properties in our own universe such as the strength of dark energy.

The alternative, they say, is that applying cut-offs is simply not the right way to calculate probabilities in eternal inflation. "We're stuck between a rock and a hard place," says Bousso. "If you don't like the cut-off, then you have no way of making predictions and deciding what's probable in eternal inflation."

Ken Olum of Tufts University in Medford, Massachusetts, who was not involved in the work, agrees that there is a problem. "The whole issue is one that needs resolution," he says. "If we don't take the cut-off seriously, then we better figure out how to do calculations that are consistent with each other."

The trouble began last year, with a thought experiment raised over breakfast at a conference by Alan Guth of MIT and Vitaly Vanchurin of Stanford University in California. They imagined a scenario in which someone flips a coin and sets an alarm depending on the outcome. Heads and the alarm is set to wake you up after 1 minute, tails and you get 1 billion years' sleep. Before going to sleep, the chance of waking up in 1 minute or 1 billion years is 50:50.

Changing odds

Now imagine that the experiment happens in an infinite number of universes. If a cut-off is taken to study a subset of these universes, far more people in that subset – wherever the cut-off is made – will have woken up after a short nap than a long one. So the odds are no longer 50:50.

How can the probability change once you get up? The team argue that the only way to make sense of the changing odds is if the cut-off is physical. If the cut-off is real, then many of the people who got tails – and went to sleep for 1 billion years – would hit the end of time before their alarm could go off (arxiv.org/abs/1009.4698).

"If we do have the end of time, then that's a strange situation, but at least it solves this paradox," says Olum.

The radical idea "certainly is one way to resolve the paradox", says Guth. But he adds that it is hard to lend much credence to the suggestion, since it is far from clear what physical mechanism could cause time to vanish.

No physical meaning

Instead, Guth suggests the paradox could just be an artefact of the measurement technique, since the exponential nature of eternal inflation means that newer universes will always be more common than older ones.

He suspects cut-offs have no physical meaning: people who don't wake up before the cut-off will still wake up, just after it. The cut-off "is the end of the data set. It doesn't necessarily mean it's the end of the world."

However, Bousso says we have to take the cut-off seriously, since it's the only good way physicists have of calculating probabilities. "In current approaches to understanding eternal inflation, the cut-off and only the cut-off defines what is possible, likely, unlikely and impossible," he says.

For the moment, Guth says he is comfortable with not fully understanding how probabilities work in eternal inflation. "We are dealing with something that's exponentially expanding and expanding forever," he says. "It is conceivable that will introduce new problems that ordinary actuaries have never encountered."

Five billion years to go

To calculate probabilities in the infinite multiverse, physicists have devised "geometric cut-offs", ways of slicing off finite samples of space-time. This lets them count finite numbers of events and extrapolate out to the whole multiverse by taking larger and larger samples.

But doing this inevitably slices through some universes that lie on the edge of whatever cut-off is used, a process that Ben Freivogel at MIT and colleagues say could end time there (see main story).

So could this happen to our universe? Sadly, yes. They say several methods of taking cut-offs suggest a universe the same age as ours, 13.7 billion years old, is likely to reach the end of time in 5 billion years or so.

"The point is that the way people treat eternal inflation, time can end, no matter whether we understand precisely how time would actually do that," says team member Raphael Bousso of the University of California, Berkeley.

"Is there a way of thinking about the end of time that makes it seem less weird?" he asks.

One of the cut-off methods offers a way to visualise the process. It slices the multiverse by taking a single "causal patch" – a region of space beyond which light has not had time to reach since that region's big bang. From this viewpoint, you can think of our 5-billion-year expiration date as the average time needed for a galaxy located anywhere inside our 13.7-billion-light-year causal patch to reach the edge of the region.

What would it mean for time to end in this way? The team speculate that reaching the edge of a causal patch might be like encountering the event horizon of a black hole, the boundary beyond which nothing that falls in can escape.

So just as someone watching an object fall into a black hole will see the object burn up, someone inside a given universe might see an object hitting the edge of the cut-off – where time ends – incinerate on contact.