FEATURE 18 January 2017

Mapping the multiverse: How far away is your parallel self?

There seems to be an infinity of invisible worlds lurking out there. Now we're starting to get a handle on where they are, and what it might take to reach them

Sam Chivers

By **Shannon Hall**

SOME of your doppelgängers mimic your every thought and action, only with a snazzier haircut. Some live in a world where the Nazis won the second world war, or where the dinosaurs survived, or where things fall up instead of down. Not here. Not in this universe. But they are out there – in the multiverse, where every possible world exists, along with all the infinite versions of you.

Travel any distance in modern fundamental physics and you will soon find yourself in the multiverse. Some of our most successful theories, from quantum mechanics to cosmic inflation, lead to the conclusion that our universe is just one of many. "It's proven remarkably difficult to come up with a theory of physics that predicts everything we can see and nothing more," says Max Tegmark at the

Massachusetts Institute of Technology.

So where are these unseen universes in relation to ours? How many are there? What goes on inside them? And can we ever hope to visit one? Such questions might sound daft, particularly given the lack of observational evidence that the multiverse exists. And yet thanks to new ideas on where distant universes might be hiding or how to count them, physicists are beginning to get their bearings. Rather fittingly, though, there is not just one answer – depending on which version of the multiverse you're navigating, there are many.

The journey into this confusion of worlds starts in our own. The universe we call home was born from the big bang some 13.8 billion years ago, during which time light has travelled further than you might expect – 47 billion light years, thanks to the universe's ongoing expansion. This is the limit of what we can see, because light from more distant reaches would not have had time to reach us yet. But we're pretty sure space-time stretches further, perhaps to infinity.

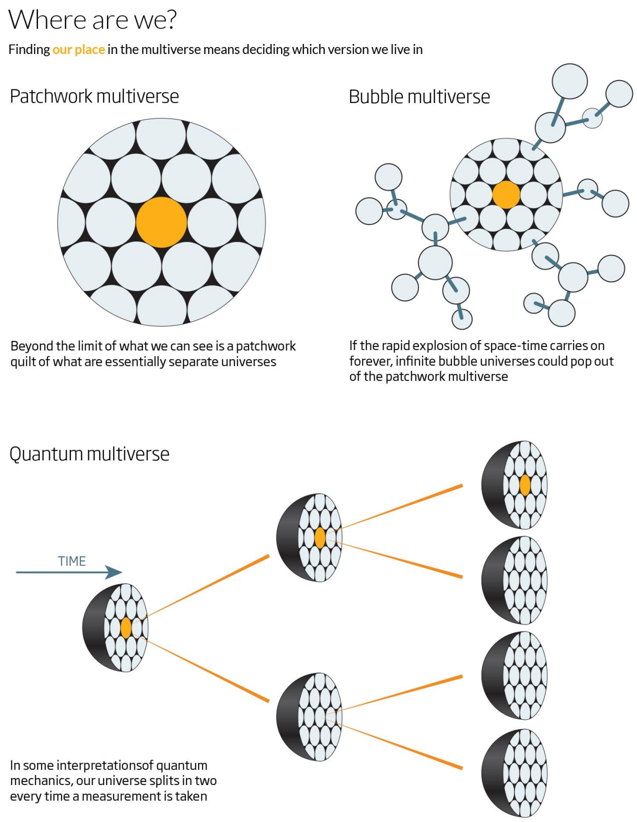
Past the cosmic horizon is a patchwork quilt of separate universes like ours, all bound by the same laws of physics. At least that's the assumption: those laws don't change over the distances we can see, so there is no reason to think they will suddenly transform beyond them. The only real differences are in the details: any intelligent life out there might live in a solar system that contains five planets instead of eight, say, or two suns.

What are the chances those details are exactly the same, to the point where there's another version of you? Tegmark thinks it's entirely plausible. Assuming space stretches on forever, then there are an infinite number of patchwork universes, and everything allowed by the laws of physics will happen – more than once. He has even calculated the distance you would have to travel to meet your doppelgänger. It's a 1 followed by a hundred thousand trillion trillion zeros.

For many, though, this is just the first step. The expansion of the multiverse beyond the patchwork version started with a theory devised by Alan Guth, a cosmologist at MIT, in 1980. He proposed that in the first split second following the big bang, the early universe underwent a stupendous growth spurt, expanding by a factor of 10^{25}. This exponential ballooning, known as inflation, is beloved by cosmologists because it fixes several major problems with the big bang story.

In one guise, known as eternal inflation, the theory has space-time expanding exponentially forever, but with quantum effects that stop the ballooning in small regions. Our universe grew up in one of the resulting bubbles, and the same happened elsewhere. What's more, these quantum effects continue today, fuelling an endless froth of bubbles, each containing a universe.

Exactly where each bubble emerges is random. Picture a table of haphazardly placed billiards balls: one of those balls is our universe, and the others are additional universes separated by space-time. Then forget that picture. The analogy falls apart when you remember that each ball is growing as each universe expands, the table is stretching as the fabric between universes continuously inflates, and more balls are popping up at random as quantum effects spawn more universes. That's a spooky game of snooker.



Wherever they pop up, it's possible that these bubble universes – unlike those of the patchwork multiverse – contain physics gone wild. In 2000, Joseph Polchinski of the University of California at Santa Barbara and his colleagues threw string theory into the mix. The result gives rise to universes drastically different from our own, where unfamiliar laws of physics act on unimaginable particles. "It's the multiverse on steroids," says Alexander Vilenkin of Tufts University in Medford, Massachusetts.

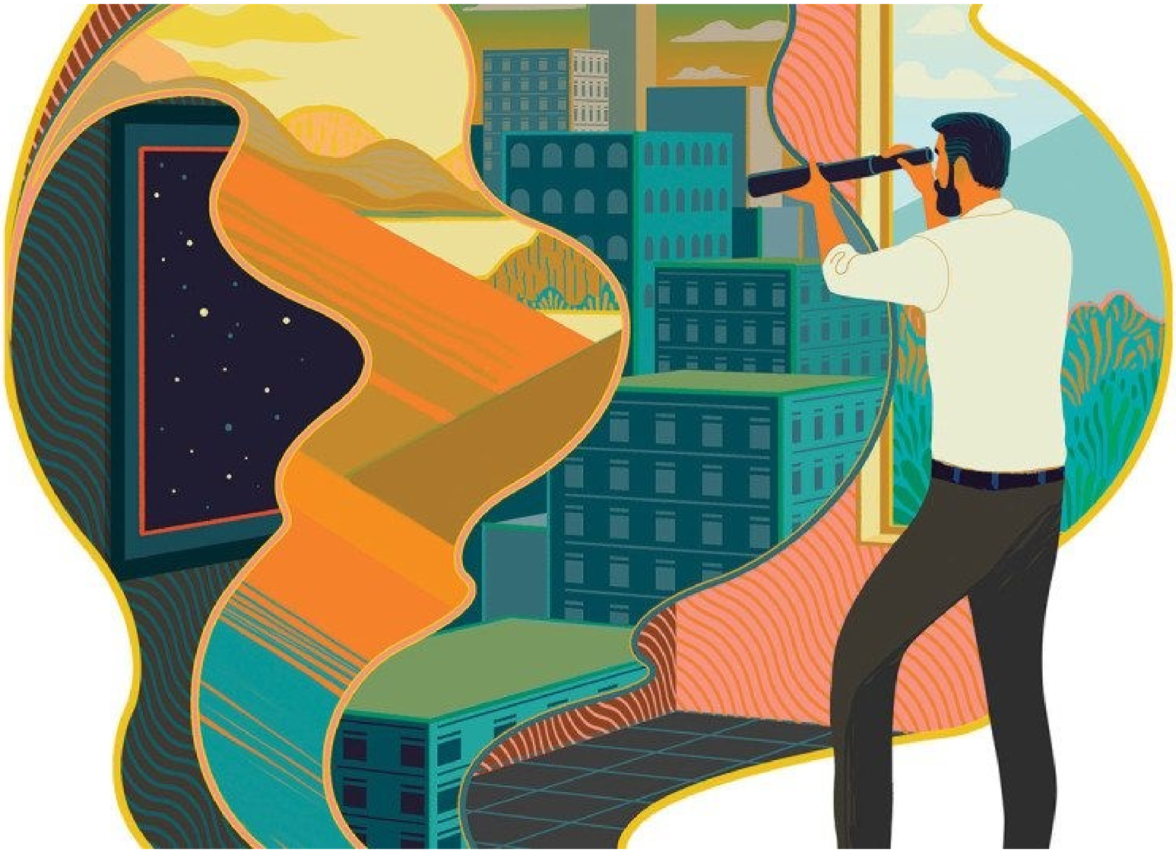
The reason is that string theory, a comprehensive but untested theory of nature, operates in 10 dimensions – six more than the ones we know so well. These extra dimensions are scrunched up into unimaginably small spaces. In our universe, they form a particular configuration, which determines the properties of our particles and laws of physics. But they can form at least 10^{500} different configurations, which means an infinite number of universes can fall into that many categories, each with different particles and laws of physics. Basically, anything goes.

These bubble universes would be largely unrecognisable. Photons might outpace our speed of light, for instance, and apples might fall upwards from a tree's branch. They would also be inhospitable to us, because the stability of atoms depends on a certain balance of the constants in our theories, says Sabine Hossenfelder of the Frankfurt Institute for Advanced Studies in Germany. "So if you go to another universe, it might also have areas of stability for atom-like things, but they would be very different from ours… Probably what would happen is that you would decay immediately."

And even if there is another universe conducive to our sort of life, it would be well beyond reach – more distant than in the patchwork multiverse. "You could never get there even if you travelled at the speed of light forever because you would have to travel through a piece of space that is still inflating and doubling in size like crazy," Tegmark says.

Cosmic hidey-holes

Or maybe there is a shortcut. At least, there was. Last year, Vilenkin and his colleagues suggested that other universes might be nestled within the black holes that formed during the first second of our



Sam Chivers

universe's existence. The idea is that small patches of space-time shifted into a different quantum state, forming tiny bubbles. Then, when inflation ended, those bubbles collapsed to form primordial black holes. But in the largest of these black holes, inflation continued, creating baby universes.

Vilenkin's theory predicts a distinctive distribution of black holes. Should this match the distribution of black holes in our universe, which we have only begun to chart, we'll have proof that this multiverse exists. We would even discover the mass a primordial black hole must have to contain another universe, potentially pointing us towards other universes dotted around the night sky.

We could never visit them, or could we? Nikodem Poplawski of the University of New Haven, Connecticut, and his colleagues also think that black holes harbour hidden universes, but these ones might still be attached to our own. They came up with the idea in an attempt to revise Einstein's theory of general relativity, which indicates that there are "singularities" at the heart of black holes that take up no space but are infinitely dense and infinitely hot. This aspect of the theory has always been hard to swallow. Even Einstein himself thought that singularities could not exist in physical reality.

If Poplawski is correct, they don't. According to his theory, the matter within a black hole doesn't collapse to a single point, but instead hits a barrier before bouncing back. "But it cannot go back outside the black hole, which means the matter has to create a new space," Poplawski says. "So the black hole becomes a doorway to a new universe."

The natural conclusion is that our universe was also formed within a black hole in another universe – an idea that sheds a rather different light on our beginning. "The big bang is replaced by a big bounce," says Poplawski. This origin explains our universe's expansion and does away with the need for inflation. In a study out last month, Poplawski even calculated that our parent black hole is probably a billion times the mass of the sun, on a par with the supermassive black holes that lurk in the centres of most massive galaxies.

That's not to say we should picture our universe as being within a universe, like a cosmic Russian doll. "It's not the same physical space in some sense – it's more like a parallel universe," says Damien Easson of Arizona State University in Tempe, who has made a similar speculation. "It really would be a different universe altogether, occupying a different part of the multiverse."

You might, however, be able to reach it via a shortcut through space and time known as a wormhole. If this multiverse were represented by billiard balls, they would be connected with invisible tunnels, and they'd all be different sizes, growing at different rates. Some would form further black holes, which in turn create more universes, themselves connected by invisible tunnels to those that created them.

With both the patchwork multiverse and the various bubbly versions, you can imagine them as contiguous – next to each other, or at least connected, even if the laws of physics in our universe mean you can't get from one to another. Not so for another sort, the worlds of the quantum multiverse. These are superimposed into the same space we occupy and are at once more intimate and more distant.

Since the 1920s, physicists have been baffled by quantum mechanics, which suggests that a particle can exist simultaneously in two or more possible states of being. So an electron, for example, can be in two places at once – until someone measures it. At that point, the electron has to "choose" one particular state. But what about the other state?

In the 1950s, Hugh Everett, then a graduate student at Princeton University, came up with the idea that all of these potential states are equally real – they simply exist in parallel universes. Suppose, for instance, that you conduct an experiment in which you measure the path of an electron. In our universe, the electron travels in one direction, but the measurement creates another universe where the electron travels in the opposite direction.

In the quantum multiverse, then, every measurement creates another universe that is folded into our own yet is invisible and inaccessible.

That's too outlandish for some. The main problem, says Michael Hall of Griffith University in Brisbane, Australia, comes from confusion over what constitutes a measurement. Does it have to be a physicist doing a quantum experiment? Or could it be every decision we ever make? Everett's theory doesn't have the answers, so his many worlds remain fuzzy and the number of universes is impossible to count.

Fed up with the uncertainty, Hall and his colleagues have come up with a new scenario called "many interacting worlds". Unlike Everett's original idea, it begins with a finite number of universes, all similar to ours in size and scope, superimposed on our universe. Here, quantum events are produced as a result of particles from one of these universes interacting with those from another.

Take quantum tunnelling, where particles defy ordinary physics by tumbling through an energy barrier as though it isn't there. If an electron is heading towards a barrier in our world, it might interact with an electron heading towards that same barrier in a parallel world. The particles will start to repel one another, causing one to give the other an energy boost so that it can achieve the unimaginable: it will break through the energy barrier.

Merging the multiverses

In Hall's theory, the probability of the electron breaking through is slightly different to the probability predicted by standard quantum mechanics. That's good news – in theory, the deviation is measurable and could tell us how many parallel universes we're dealing with.

But even if quantum many worlds do work in this way, how do they fit with the various cosmological multiverses? Hall thinks that his quantum multiverse and the inflationary multiverse can exist simultaneously, but argues that one has the upper hand. "There is, in essence, only one super quantum multiverse," he says. That's because inflating space-time creates new universes from small quantum effects, and in order for those effects to exist there must already be a quantum multiverse.

Others think that if more than one theory pans out, the inflationary multiverse probably came first. Once the frothing sea of inflation started churning up new bubble-like universes, a few would have created black holes, which formed more universes. Or perhaps those universes might branch off into other universes with every quantum measurement. “If this interpretation is correct, then the eternally inflating multiverse will constantly split into a multitude of eternally inflating copies,” Vilenkin says.

Ultimately, there is nothing to say that all these different multiverses couldn’t co-exist. Some theorists even think that Everett’s many worlds and the inflationary multiverse might actually be one and the same. Although they look different, they both constantly branch into new universes, says Leonard Susskind of Stanford University in California. And such an odd characteristic should not be taken lightly.

“Maybe they are different sides of the same story,” says Susskind. If so, the pioneers surveying the multiverse might finally agree that we only need one map to find our way.

Where are we in the multiverse?

This article appeared in print under the headline “Infinite frontiers”

Shannon Hall is a science writer based in New Hampshire

Magazine issue 3109, published 21 January 2017