Silence is olden

Forget the big bang, the birth of the universe was a very quiet affair, whispers Michael Brooks

EVERYONE knows that, in space, no one can hear you scream. Very few people, however, realise just how deep the cosmic quiet can be. The moment our universe came into existence, the silence was truly extraordinary. It was a split second of utter isolation when nothing and nowhere was connected. If you did let out a scream, it wouldn't even make it past your lips. "Each point of space lived its own life," says Aurélien Barrau, a cosmologist at the Joseph Fourier University in Grenoble, France.

This is a radical departure from our usual picture of space-time as a smooth, continuous fabric. And it comes courtesy of researchers trying to work quantum theory into our current understanding of the universe, which is based on Einstein's general theory of relativity. This does a fine job of describing gravity on the scale of stars and galaxies, but when it comes to the entire history of the universe, the theory is left wanting.

In a sense, general relativity predicts its own demise. As we wind back the clock on the cosmos, things get closer together and gravity becomes ever stronger. According to general relativity, the cosmos arose out of a point of infinite density called the singularity, where space and time curved so radically that the physics breaks down. So this theory alone can't tell the full story of the universe's birth.

Once things get very small, quantum theory is king. To describe the start of everything, then, we need the two theories to combine into a single theory of quantum gravity.

Contrary to what you might have heard, we have ways of doing this. String theory is the most widely known example. It describes how the messy array of particles that make up matter and forces, including gravity, can be pared down to vibrations of one-dimensional strings. But it doesn't tell us much about the fundamental nature of space and time, so several alternatives have emerged in recent years.

Although it is early days and we don't know whether any of these theories will work in every detail, we are already seeing some fascinating results. Most tantalising of all is that at least three entirely independent quantum gravity theories have the cosmos kicking off with something we could call a moment of silence.

Winding back the clock, we seem to reach an instant when every point in space becomes disconnected from every other point. This means that nothing – no sound, no information, no light – can travel between them. Perhaps this moment of silence will give us a new telling of the oldest story?

Steven Carlip of the University of California, Davis, was one of the first to spot that the various paths to quantum gravity were converging. In 2012, he gathered up all the theories and found that many of them shed a spatial dimension or two as the universe winds back to its hot, dense start. In other words, geometry appears to have been radically different in the beginning.

The moment of silence goes further and ›

Tabletop cosmology

Did the universe begin not with a bang, but a silence? It's no easy thing to check. But there is one tantalising possibility, and it comes from a surprising source: artificial materials that are being developed as invisibility cloaks.

So-called metamaterials do strange things with radiation. Whereas most materials steer microwaves or visible light in one direction, metamaterials can bend it in the opposite. But they also slow it down or speed it up in the same way that changes in energy densities did in the early universe.

That means metamaterials could be used to create a tabletop simulation of the evolving conditions during the first moments of creation. Igor Smolyaninov is already working on such tabletop universes in his laboratory at the University of Maryland. He has made metamaterials from columns of magnetic particles suspended in a fluid, and shown that changing their temperature can simulate universes appearing and disappearing in the multiverse.

Jakub Mielczarek of the Jagiellonian University in Krakow, Poland, points to a parallel between Smolyaninov's experiment and quantum gravity (see main story). The equivalence, he says, relates to the fact that the atoms in these kinds of magnetic materials have a property called spin that can be oriented randomly or aligned. When the spins are random, which happens above a certain temperature, there is no net magnetic field. Drop the temperature, though, and the spins align to create one.

Similarly, it is possible that chunks of the hot, early universe were randomly aligned, giving a cosmos with four dimensions of space, but no time. As the universe cooled, perhaps a directionality emerged that we refer to as time. Exploring this transition in the lab, Mielczarek says, might give clues that the universe underwent such phase changes.

sees space and time break up completely. Exactly how and when this happened is hard to work out, but it seems to arise from primordial quantum fluctuations. Carlip and his colleagues have done calculations in an offshoot of string theory called dilaton gravity. They showed that space is split into discrete chunks in the first 10^{-43} seconds of the universe. Each chunk experiences nothing from outside its own existence (see diagram right).

The same thing happens in a theory known as causal dynamical triangulation (CDT), in which the universe is composed of units of space-time shaped like triangular-based pyramids. The ways the pyramids fit together give space and time the curvature that general relativity says is caused by the presence of mass and energy.

A quiet birth

In CDT, the chunks of space-time can all be different, and computer simulations combine them in billions of different ways. The idea is that comparing the different outputs lets us identify the scenarios that appear most often. These are the most likely histories of the universe. "We hope that our simulations will give us an indication of how the universe wants to behave near the initial singularity without arranging things by hand," says Renate Loll of Radboud University Nijmegen in the Netherlands, one of the creators of the theory. Interestingly, though, certain combinations of choices result in starkly different universes – as different as ice is from steam.

The CDT universe can exist in one of three distinct "phases". One is familiar to us, where different regions are connected and act on each other through the transmission of signals or forces. Another is a universe that is just one homogeneous lump, with everything effectively part of everything else. The third option has the space-time units completely disconnected – each chunk is alone. A moment of silence, in other words.

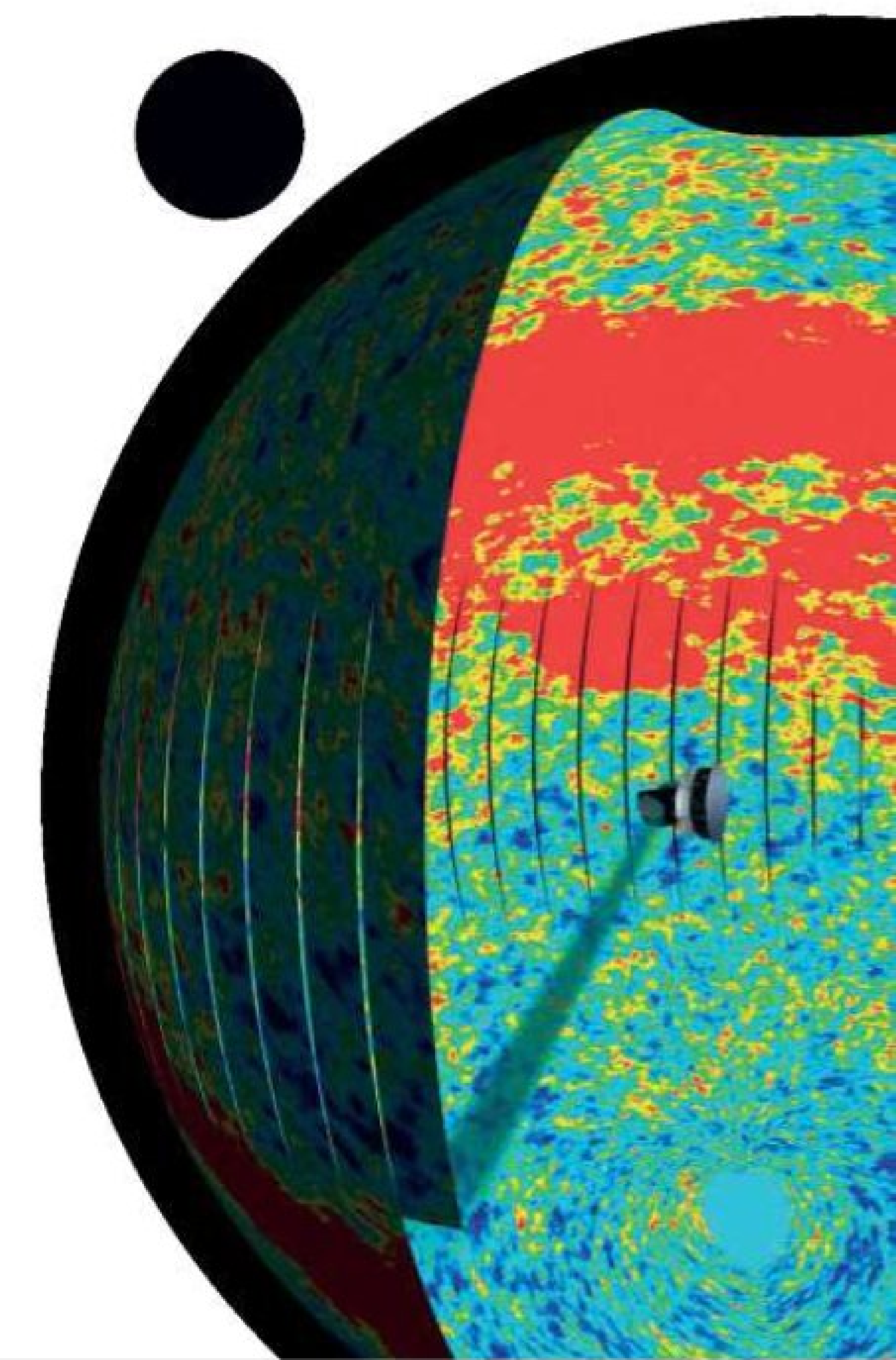
Although it is too soon to say for sure, the idea that the universe could have moved between these phases may herald a fresh understanding of quantum gravity. "The early universe is our most reliable entry door to quantum gravity," says Sabine Hossenfelder of the Nordic Institute for Theoretical Physics in Stockholm, Sweden. "Investigation of such a phase transition in the early universe will allow us to increase our understanding about what space and time fundamentally are."

The most recent manifestation of the moment of silence has come via a theory known as loop quantum gravity. In this theory, space-time is made up of a woven fabric of braids and knots. The way the strands intertwine creates a zoo of particles and forces.

One way researchers can try to validate the theory is through loop quantum cosmology (LQC), which looks for ways that loop quantum gravity could have uniquely shaped cosmic history. It attempts to see how the braids and knots would have fared under the high-energy, high-density conditions at the beginning of the universe.

When Barrau and his colleagues wound back the LQC universe's expansion, they saw conditions that slow the passage of light. When they kept squeezing everything into ever hotter, denser states, the LQC cosmos eventually reached a point where light couldn't travel at all. If light can't travel, communication can't happen, no forces can be transmitted and every region of space-time is disconnected from every other one. It's another moment of silence.

The researchers aren't taking their model too seriously. "We have to make tons of assumptions," Barrau concedes. But they are excited that LQC has now joined the group of theories that point to a quiet cosmic birth. "The silence might help us to understand relations between these formulations," says Barrau's colleague Jakub Mielczarek of the



Probing the silence might be possible in cosmic microwave maps

Jagiellonian University in Krakow, Poland.

One attribute of LQC gives particular cause for optimism: inflation appears in an intriguingly natural way. Inflation is a period of ultra-rapid growth that cosmologists have long believed must have happened in the moments following the creation of the universe. Their faith was bolstered by the recent discovery of a signature in the cosmic microwave background radiation that formed 370,000 years after the big bang.

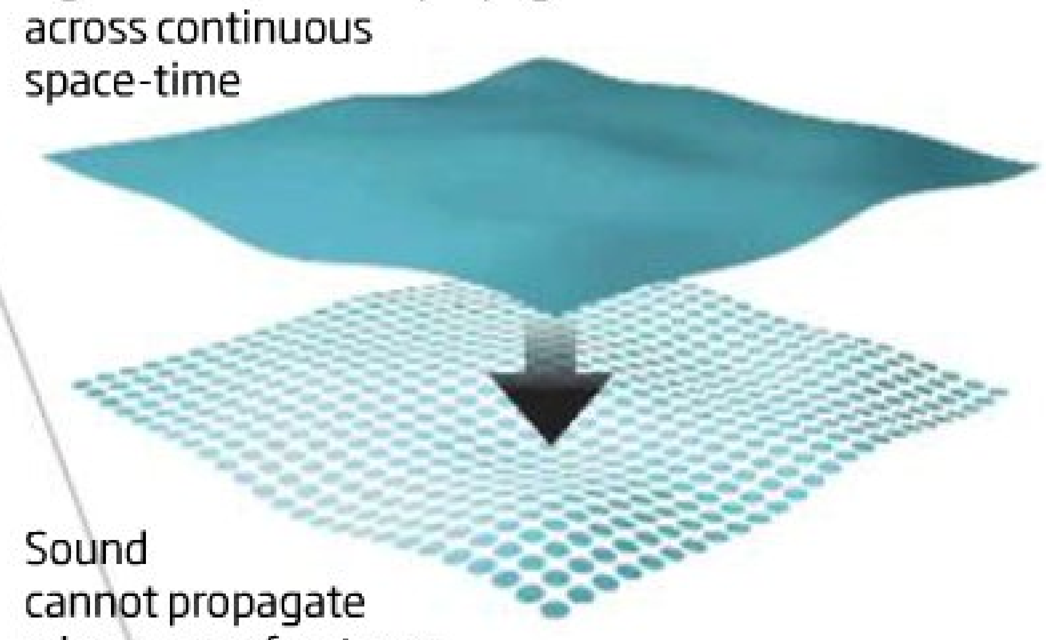
The standard big bang story has a period of inflation put in by hand. In the LQC model, it happens as a natural consequence of what is termed "the bounce". This is the moment before our universe came into being; LQC doesn't see the birth of our universe as the beginning of everything. In 2006, Parampreet Singh, who is based at Louisiana State University, and his colleagues showed that if you wind back the clock on a loop quantum universe, you eventually hit a moment where the braids and knots are overloaded with energy and create a repulsive force that causes space to turn inside out and begin expanding again.

If that universe contains any form of "scalar field", a mist-like quality that exerts a certain kind of force at every point in space, the result is a natural period of inflation. This isn't as artificial as it might sound – all cosmology theories put a scalar field into their universe as the seed for the various forces. In a bouncing universe with a scalar field, inflation is nearly unavoidable. "You have to fine-tune the conditions if you want to prevent inflation," Barrau says.

"Squeeze the universe beyond the moment of silence and time disappears"

A big silence

Several approaches to quantum gravity predict that space-time breaks up into disconnected chunks as you rewind to the birth of the cosmos



The model can even tell us how long that inflation lasts. LQC predicts a period of inflation twice as long as cosmological observations tell us it really lasted. That's not bad, Mielczarek thinks – it could have been 10, 10 thousand or 10 trillion times too big. And at least there is a value. "I don't know any other model where the duration of inflation is computable," he says.

The LQC model does have a peculiarity – one that has caused celebration and consternation in equal measure. If you squeeze the universe a little harder, so that it goes beyond the moment of silence, light begins to move again, albeit in a pretty weird way. On this side of the silence, its speed turns out to be an imaginary number, the square root of a negative number. In the equations, that means time has actually turned into space. We get four dimensions of space and absolutely no time.

All roads converge

Although that is a conceptual problem for most of us, for Barrau and his colleagues it provided a eureka moment. It chimes, they say, with the way Stephen Hawking and James Hartle envisaged bypassing the singularity. They managed to do this using a universe with four space dimensions and no time.

Others, like Martin Bojowald at the Pennsylvania State University, see this transition to 4D space as a problem. Bojowald finds the consequences of this model fascinating, but thinks the way Barrau and his colleagues have modelled quantum fluctuations is misguided and is likely to have pushed them away from reality.

Not that he knows how to do it better, he admits. "The result shows us a lot of new issues that people hadn't expected," he says. "This might actually be very stimulating." Singh is not quite so benevolent. He sees the moment of silence as a consequence of assumptions that are "very preliminary and speculative", as he puts it. "The conclusions are quite premature and unlikely to be true."

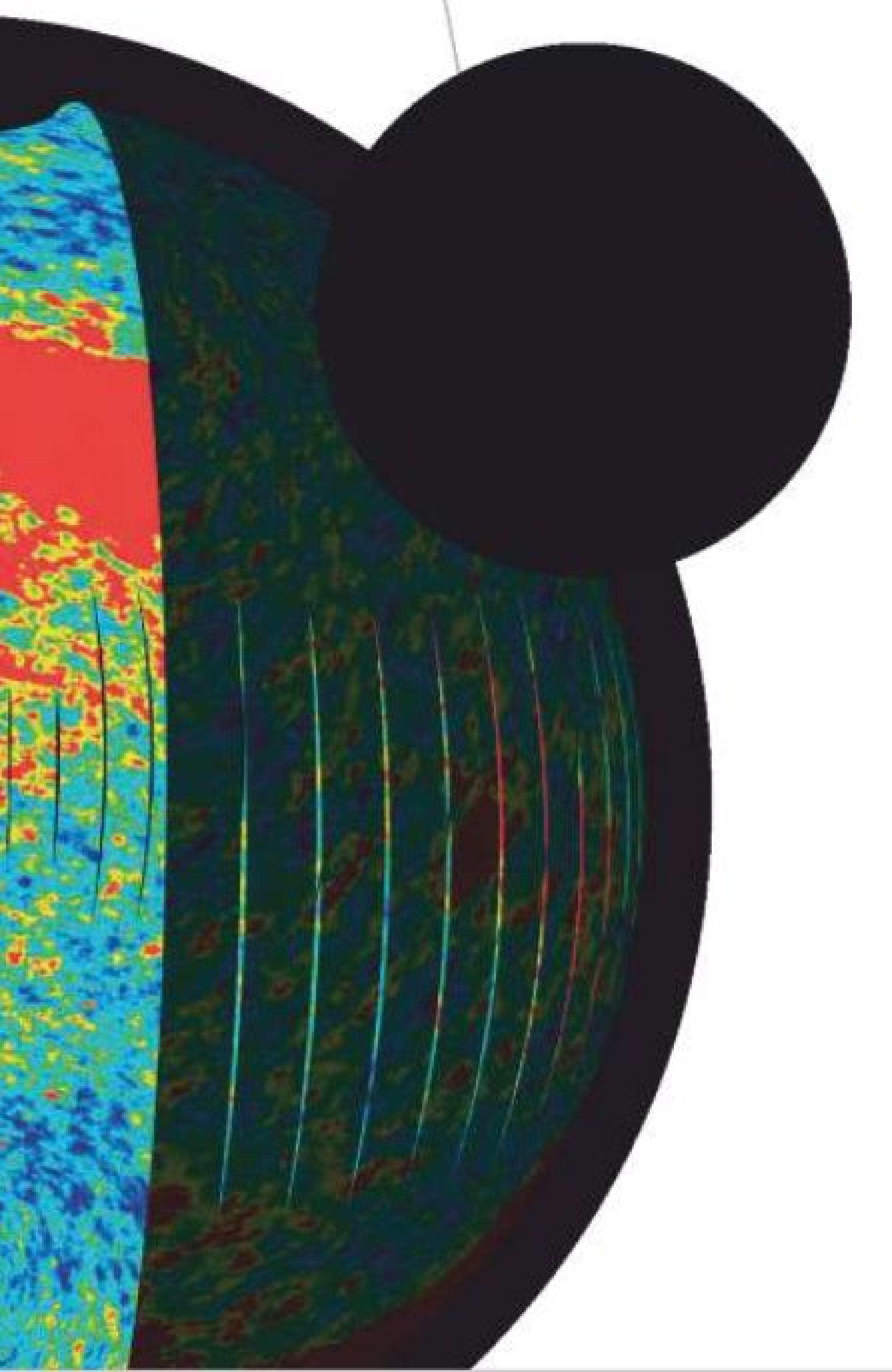
It will be a long time before we can properly test any of these models against the real universe. The best chance lies in subtle features of the cosmic microwave background radiation. Data from the European Space Agency's Planck satellite, for instance, is creating our most detailed map of this radiation across the entire sky. Even so, the craft didn't have the sensitivity to check the LQC model of creation. "We'll have to wait for post-Planck measurements," Barrau says.

If Carlip is arm-twisted into speculation, he thinks there is a chance that recent maps of the cosmic microwave background made by the BICEP2 telescope could be probing regions relevant to the big silence or disappearing dimensions. "It's conceivable that some observational signature exists," he says. He has no clue what it might look like, though.

The LQC researchers agree that nothing is visible yet, but other clues could come from experiments firmly rooted in the laboratory (see "Tabletop cosmology", left).

It is highly speculative stuff, of course – too speculative for some. But the synergy between various quantum gravity models provides good reason to keep exploring this territory. Singh points to the resonance between LQC and CDT when looking at the moment space-time turned from quantum to classical. Even though they arise from very different starting points, both approaches give a fully classical space-time before the universe has had a chance to expand significantly. "This probably tells us that the results are a reflection of a deeper truth about the quantum nature of space-time," Singh says.

Hossenfelder is also excited about the commonalities. "Each approach has its pros and cons," she says. But if different paths lead us to similar conclusions, Hossenfelder thinks we should certainly pay attention. "It looks like this convergence is trying to tell us something." Shhh... ■



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