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One universe, from many

Cosmologist **Laura Mersini-Houghton** says our cosmos is part of a multiverse and there is evidence to prove it. She tells Rowan Hooper about her radical ideas

HOW did our universe begin? This is among the most profound questions of all, and you would be forgiven for thinking it is impossible to answer. But Laura Mersini-Houghton says she has cracked it. A cosmologist at the University of North Carolina at Chapel Hill, she was born and raised under communist dictatorship in Albania, where her father was considered ideologically opposed to the regime and exiled. She later won a Fulbright scholarship to study in the US, forging a career in cosmology in which she has tackled the origins of the universe – and made an extraordinary proposal.

Mersini-Houghton's big idea is that the universe in its earliest moments can be understood as a quantum wave function – a mathematical description of a haze of possibilities – that gave rise to many diverse universes as well as our own. She has also made predictions about how other universes would leave an imprint upon our own. Those ideas have been controversial, with some physicists arguing that her predictions are invalid. But Mersini-Houghton argues that they have been confirmed by observations of the radiation left over from the big bang, known as the cosmic microwave background.

Here, she tells *New Scientist* about her ideas and her life, which she has described in her new book *Before the Big Bang: The origins of our universe in the multiverse*.

Rowan Hooper: Let's start with your own story of growing up in Albania. To what extent has that shaped your thinking?

Laura Mersini-Houghton: It's contributed a lot. I was lucky because I had the kind of parents who spotted early on that I was interested in natural sciences and math and then nurtured my interest. Another factor that helped a lot was that my mom worked at a non-profit organisation in Albania called the League of Writers and Artists. I got to spend a lot of time with composers, writers and artists, and that opened my horizons to spot early on that there is so much joy in creativity.

You talk in your book about how you think of your life in quantum terms; if you hadn't made a particular decision then you would be living a different life. Can you elaborate?
In a quantum universe, everything is based on probability: until you make a measurement on a subatomic particle, all you have are probabilities regarding all possible outcomes. All certainty about the world is gone. Sometimes, during late-night contemplation, I can see parallels between my life in our "classical" world and the quantum world. I can see how my life resembles a quantum world interwoven with uncertainties and unlikely events. If you think of communist Albania, there was a kind of quantum ambiguity where many bad things could happen at any time for no reason at all, certainly not because of your own doing. There is an analogy with the quantum universe, where any outrageous possibility has a non-zero chance to occur.

> "I don't think of having copies of myself in other worlds – and I hope there aren't any"

NASA, ESA, CSA, AND STSCI

Getting back to physics, can you explain why our universe is so unlikely and how that led you to think about the multiverse?
It starts with the second law of thermodynamics, which states that the entropy of any system – which roughly means its level of disorder – always increases with time. Therefore, the entropy of our universe at its first moment of existence must have been incredibly small. But the probability of finding a universe that arises spontaneously is directly proportional to its entropy. Since our universe started with a very small entropy, that gives it an exponentially small chance of existing.

We know from observations and theory that the universe started as a very small, smooth patch full of energy, and the Oxford mathematician Roger Penrose found that the chance of starting with the universe like that is 1 chance in 10 to the power 10 to the power 123. So there's almost no chance to spontaneously start with a universe like ours. And that number intrigued me because, well, here we are – we can observe the universe around us. This is our home. We know it exists for sure.

Yet I can't ask the question "why do we have this universe?" if all I am allowed to start with is this universe: I need a pool of possible universes from which I can choose from. So that led me to think that we really need an initial quantum multiverse. That would allow me to meaningfully ask the question of why we got this universe rather than something else.

What do you mean by "an initial quantum multiverse"?
I mean that in the very first moment, before the universe emerged in space-time, you can think of the universe as a wave function in an abstract space of energies.

I began thinking about all this in the early 2000s, around the time that string theory was the leading candidate for a "theory of everything" that unifies gravity with the other three quantum forces to explain our universe. String theory is the idea that nature at a fundamental level is 11 dimensional and particles are actually just the bit we can see of tiny loops of vibrating strings. With string theory, after curling up the extra spatial dimensions to make them sufficiently small to be invisible, you end up with a whole landscape of possible initial energy states, or potential big bang energies, that could start a whole family of different universes.

At the time, string theorists thought this was really bad because they were looking to end up with only one universe – one that looked like ours – described by one theory, and they were ending up with a nearly infinite number of universes. But to me it was great news because I needed a fundamental theory to provide that pool of energies that would allow me to ask the question, "why did I start with this one rather than something else?".

You had your breakthrough in a coffee shop, and you wrote "QM on the landscape" on a napkin – quantum mechanics on the landscape of string theory. Tell us what you meant.
I had realised something that seems obvious in hindsight. We know for sure that our universe was very small in its first moments of existence. Therefore, it obeys the laws of quantum physics. What dawned on me specifically was that, based on the wave-particle duality of quantum mechanics, I could think of the universe as a wave function instead of as an object. The wave function is the mathematical entity that encodes quantum probabilities. But you can imagine it as a tree made up of many branches, each of which can produce a universe, and it spreads through the energy valleys of the string theory landscape, from where it takes its big bang energy.

Is this where quantum entanglement comes in, the idea that there can be this subtle quantum connection, between the branches?
You get these branches, these many worlds, but you need to decouple them from each other – you need to break that quantum entanglement. Think about when we separate gold from ore. We put the ore mixture into a

To some cosmologists, the existence of our universe is unlikely

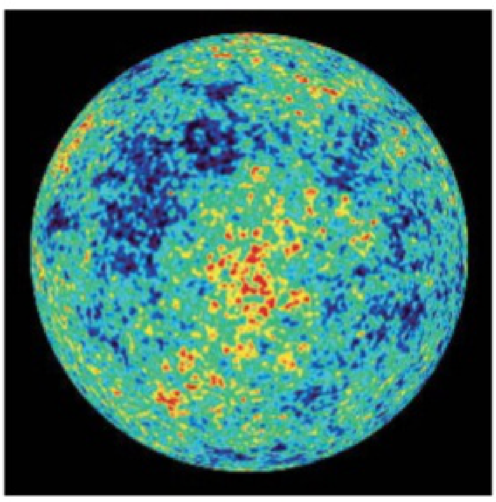
bath of a compound called borax, and since borax interacts differently with different minerals, they start separating from each other. In my hypothesis, the string theory landscape was our borax – it broke the entanglement and separated out the many worlds.

Somehow, early on, our universe went through a quantum-to-classical transition. It became a classical object where each event is determined with certainty. This could not have been the case unless the branches of the wave function of the universe completely decoupled. All the branches decouple as they are going through cosmic inflation. This is the phase, shortly after the big bang, when the universe went through a period of exponential expansion in size. My proposal was that, if this decoupling did happen, we would be able to see the remnants of it in the cosmic microwave background [or CMB], the radiation left over from those first moments of our infant universe. The idea was that, as the branches decoupled, traces of the entanglement would have been left behind.

So you made a testable prediction: that we should be able to see signs of our universe's primordial entanglement with other universes.
I made a series of predictions with Richard Holman and Tomo Takahashi in 2005 and 2006. We said we would be able to see signatures of this early entanglement. Our present universe is just a rescaled version of its infant self, with all its "birthmarks" still there. If you think of all these quantum universes as tiny quantum particles, they were all interacting with each other – gravitationally they were pulling on each other, and that left scars in our sky.

One prediction was the existence of a giant void or cold spot in the CMB. And such a void [about 900 million light years wide] was found in the observations of the Wilkinson Microwave Anisotropy Probe, a space-based observatory. It was confirmed by the Planck satellite, which also observed the CMB. We were the first to show how you can actually test the multiverse and that you don't need to go beyond the universe's observable horizon – you can just see it in our sky.

Is there evidence of other universes in the cosmic microwave background?



NASA WMAP SCIENCE TEAM/STEVE ALBERS

As you probably expected, your ideas proved controversial. For example, there was an analysis of the CMB data in 2016 that didn't support your conclusions. How have you reacted to the criticism?
I did a new analysis to check the status of my theory using the most recent data from the Planck satellite experiment with cosmologist Eleonora Di Valentino. The series of predictions we made in 2005 for anomalies in the CMB supports the origin of the universe from a quantum landscape multiverse.

There has been a long prejudice against the multiverse. It is an idea that goes back to ancient Hindu and Greek beliefs. But it took a long time to push the idea into mainstream physics. One thing that helped is my proposal to use quantum entanglement as a tool for testing the existence of the multiverse right here, thereby circumventing the speed of light limit constraints. That provided hope that even if we can't see the multiverse directly, we can still indirectly derive evidence and make predictions on where those signatures can be found in our sky.

Max Tegmark at the Massachusetts Institute of Technology has talked of having doppelgangers in other universes when articulating his vision of the multiverse. Would your version of the idea have those?
I don't think there is another Laura out there in some other universe that is my twin or my sister. Once the branches of the wave function have decoupled, they have their own independent existence from each other. So I don't think of having copies of myself in other worlds – and I hope there aren't. If you asked my family, they'd say one eccentric scientist is enough. ▮

Rowan Hooper is podcast editor at *New Scientist*. His latest book is *How to Spend a Trillion Dollars*