This is a transcript of Mysteries of Physics podcast episode 3 'MULTIVERSE', published on 22 March 2023.

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Funding Statement: Great Mysteries of Physics is a series supported by FQxI, the Foundational Questions Institute - a think tank and funding agency that explores the foundations and boundaries of science. Find out more at fqxi.org.

Miriam: Welcome back to Great Mysteries of Physics from The Conversation. I'm Miriam Frankel, and I'm your host for the series.

So far in this series, we've investigated time and fundamental constants, and in both of those episodes we touched on the multiverse theory, which is one answer to the question of why the universe seems so mysteriously fine tuned for life.

But is there actually any evidence whatsoever to back up the idea that there are multiple universes? What about the theory suggesting that the universe is cyclic, being born and dying over and over, and perhaps most excitingly, if there are other universes out there, could we ever create one in the lab?

But first, how did this wild idea that there is a multiverse consisting of a vast and perhaps infinite number of universes come about at all? I posed that question to Andrew Pontzen, a Professor of Cosmology at University College London in the UK.

Andrew Pontzen: The idea that there's multiple different universes, I think is actually kind of a deeply human idea, the idea that there are sort of multiple alternatives to the way that reality is playing out. And so the fact that that then turns up in theoretical physics I think is perhaps not such a huge surprise when you see it like that. It is just quite an instinctive idea that things could turn out in multiple different ways.

Miriam: Do you think maybe it's also part of this thing that, you know, we used to think that the earth was at the center of the universe and we've just kind of become less and less special. Oh, there are other galaxies. Oh, there are other solar systems? Uh, maybe there are other universes.

Andrew Pontzen: It's absolutely true that, you know, the more we learn about reality, the smaller we appear to be. And so the whole history of science, in a sense, is like a broadening of our minds to imagine. Actually reality is just bigger and bigger and bigger than what we originally thought.

Miriam: Well, this idea that we belong to something bigger than our universe is quite intuitive, there are actually many different models of the multiverse. And some are more popular than others among physicists.

Katie Mack, who is the Hawking Chair in Cosmology and Science Communication at the Perimeter Institute for Theoretical Physics in Canada, explains the basics.

Katie Mack: There are a lot of different ways to talk about a multiverse. There's a lot of different interpretations of that concept. In essence, multiverse is generally taken to mean a universe outside of our observable universe.

So, I say observable universe because I'm talking about the part of the space of the cosmos that we have some ability to observe, to interact with, and that's a very well defined region. It's a region of space around us about 46 billion light in radius. Now, you can define anything outside that region as being essentially a separate universe because it is in principle, completely unobservable to us because we can't interact with it in any way. And for a lot of purposes in astrophysics, we will define different universes based on that sort of causality notion that that idea of being something that can be reached or not. So one way to think of a multiverse is just to say, well, the universe might be really, really big and much bigger than our observable universe and so there could be other regions of the universe that are far beyond our horizon that have different things happening in them, have different laws of physics, have different processes, different histories, and that idea is I think, totally well accepted in cosmology that our universe doesn't end at the cosmic horizon, that there is something beyond that and we have good reason to believe that the universe goes on far, far beyond our observable universe. And there's been a lot of discussion in recent years about the possibility that there are vast other regions and they might have different properties. And it might be that the constants of nature, the laws of physics in our universe, are sort of environmentally dependent, that they could have been different if we were in a different part of the much larger space. And that's a kind of multiverse, because then you can have other sort of universes in a sense that have different physics in them just by virtue of being in a different part of this landscape.

Miriam: The multiverse is consistent with several physical theories out there, some better established than others. One is string theory, a yet to be proven attempt at a theory of everything, which suggests that the universe is ultimately made up of tiny vibrating strengths.

But string theory makes one vital assumption. That instead of the universe having three spatial dimensions, so width, depth and height, plus one for a time, there are multiple. These different dimensions are compacted so tightly together that we don't really notice them at all. And each compactification corresponds to a different universe, each with its own physical laws.

Katie Mack: There are these many, many different possibilities for how string theory could be set up. They're called string vacua, so a vacuum. When we think about a vacuum, in the colloquial sense, we mean like a, you know, a sort of space where there's no stuff, right, like an empty space. In physics, we often use the term vacuum to mean the sort of state of nature. So there are certain parameters of the theory of particle physics in the universe we live in, and that's our vacuum. And there could be some other vacuum that's, you know, basically a theory with different parameters and that's a different vacuum state. And so anyway, there are lots of different possible vacuum states possible in string theory and so you have this string landscape they call it, where you can have all these different properties of how space works in these different places. And so that has been one way that people talk about a multiverse is these different string landscape vacuum states.

Miriam: Another theory that predicts a multiverse is inflation, which suggests that the universe suddenly blew up hugely a fraction of a second after the big bang.

Katie Mack: The idea is that expansion was caused by a kind of energy in space, uh, called a scalar field. And this scalar field made the universe expand very, very rapidly. And at some point the expansion slowed down because the scalar field decayed. And when that happened, the universe started expanding sort of more gently, um, and when the scalar field decayed it dumped a bunch of energy in the universe, it created hot plasma state that we think of now as the sort of hot big bang, the beginning of the universe, when the universe was very, very hot and dense. Um, so before that time, before that hot dense state, we think there might have been this very, very rapid expansion governed by this field, this sort of energy field that caused that rapid expansion.

So the thinking is what if that field is everywhere in space, you know, throughout a large space, but inflation only stops in some small subset of that larger space. So that field could be bouncing around. And it could cause the end of inflation in some places, but keep going in other places. And so what you would have is you'd have this really large space that's inflating, that's getting bigger and bigger and bigger, and a little region of it stops inflating and becomes a kind of self-contained little universe that's doing its normal sort of evolution. But, other parts of the universe are continuing to expand rapidly. And so you could have these little pocket universes that kind of fall out of this rapidly expanding space. And as that happens, it creates these little bubbles of space that are separated by vast, vast distances because the space in between them is, is expanding, uh, very, very rapidly. And this process where you can have part of the universe come out of inflation and then other parts continue and then another part comes out and another part continues. That's all connected to an idea of eternal inflation, where, you know, maybe there was no beginning to inflation, maybe it's always been happening, and just every once in a while little universe pops out and that would naturally create lots of universes with lots of different properties where every time a universe kind of falls out of this expanding state that sets its own laws of physics, its own properties.

Miriam: So if inflation led to our little cosmic bubble in space, why couldn't it lead to others? The idea is exciting because there's actually pretty good evidence for the theory of inflation. It's helped explain why the universe looks the way it does, and it's delivered testable predictions. But it does also pose some pretty weird questions.

Katie Mack: There's been some interesting discussion around that concept. I think that based on how we think inflation might have worked, it's a little bit difficult to get away from the possibility that this happened, that you did have these multiverses sort of created in the inflationary process just because of how, you know, the scalar field could be bouncing around in different parts of the universe. It's sort of natural that you would create little pocket universes in that process. And so this has been criticized as a failing of inflation because what we'd hoped for with inflation, the reason that inflation was hypothesized in the beginning was to explain why the universe looks the way it does. You know, why it's got the sort of kinds of fluctuations in matter that it has, uh, why it's got the shape it has in terms of how light moves through it. And so on, and the idea that, you know, inflation causes a very, very inhomogeneous universe, lots and lots of different bits of universe, and therefore doesn't really predict anything specific. It predicts a lot of different things, um, has been considered to be a failing of inflation because it doesn't give us a unique solution. Now, I think that the counter to that is it does seem to solve some of the problems it was invented to solve.

Miriam: Another theory that seems consistent with a multiverse is quantum mechanics, which rules the tiny world of atoms and particles, and it is a staggeringly accurate description of reality, endlessly tested in laboratories around the world unlike string theory. To Andrew, quantum mechanics is the best reason to believe in the multiverse.

Andrew Pontzen: I mean experiments show us that reality is much less certain than we think it is. So if you imagine somehow shrinking yourself down to the scale of individual atoms or, or even subatomic particles, then the idea of things being in a single fixed kind of pinpointable location - even that basic idea just fails to hold according to our experiments on those scales. And so there's a sense in which there's a mystery. You know, why does our reality around us on our scales look so solid and certain when we know from experiments that reality on tiny scales is not?

And there's a brilliant way of understanding this, which is to imagine that actually, the reality we experience is just one kind of facet of a much more complicated multiverse where pretty much anything that can happen does happen, and we just experience one version of events. And so for me, that is actually, although it sounds crazy, it's sort of the least crazy option for understanding how quantum mechanics can be right and yet our reality can seem so concrete.

Miriam: I love how whenever you're discussing quantum mechanics, you're always talking about the least crazy option... Could time flow backwards? You know, what's the worst?

Andrew Pontzen: No, that's exactly right. I mean, quantum mechanics is just super counterintuitive and you do just have to look for what explanations are least horrible.

Miriam: So quantum mechanics suggests that a particle can be in several different states at the same time such as different locations. This is called a superposition. It is in fact, only when we measure it that it picks a state at random. But what happens to all the other states? It's just utterly bizarre and one interpretation is that every possible outcome of the measurement actually happens, but in a different universe.

So while we see a certain measurement outcome at random in our universe, that's not ultimately how nature works. But the sort of multiverse that this theory gives rise to is different to the one based on inflation.

Andrew Pontzen: So in the early universe you have inflation, and inflation at its end generates lots of different universes. And so that then kind of makes it seem like, well, once a universe has been created, that's it. You know, the universe that we live in is our universe, and that's the end of it. And there are other universes out there, but they're not all that relevant to us today. But if you look instead at the quantum multiverse, then actually new universes are being created all the time, that every time that some kind of quantum measurement gets made. So the famous one would be, you know, Schroedinger's cat in a box where there's some quantum process going on and like radioactivity for instance, so something that's unpredictable at the quantum level and as a result, either a cat gets killed or it doesn't get killed. And so inside that box, according to quantum mechanics, until you actually look at it, there is a dead cat and a live cat kind of in superposition. So the quantum multiverse explanation for what's going on there is that you've actually created two universes by this process. In one universe, the cat is alive and in one universe the cat is dead.

And essentially when you open the box, you learn which of those universes you've ended up in. But of course, there's a copy of you in the other universe as well that's seeing that you know, the cat is alive when you perhaps saw that the cat is dead. So in that picture, it's a continual process. It's just going on all the time that universes are kind of branching and there's just more and more and more of these universes all the time.

Miriam: As Katie points out, this many worlds interpretation of quantum mechanics is also the most popular with science fiction writers. It's the idea behind the movie, Everything Everywhere All at Once, which recently won big at the Oscars.

Katie Mack: You know, stories, science fiction, this idea that there are sort of parallel universes where you know, you might have everything the same as our universe, except one thing is different. And then that, you know, changes, it sort of branches off into a different future. And you know, that's where you get these sort of mirror universes, these parallel universes uh, where in science fiction stories you might have, like, you know, one person is evil in this other universe and then they can meet their evil universe twin and you know, various things happen.

Miriam: Importantly, though the universes in the quantum multiverse are not able to talk to each other.

Katie Mack: Although the many worlds interpretation does suggest that you have many, many universes that are just a little bit different based on slightly different quantum mechanics outcomes. It also includes no possibility at all to communicate between those universes. You can't move from one universe to another. There's no communication between the universes. Once those universes are split off, they're entirely separate with no possible connection between them.

Miriam: So they couldn't like crash into each other?

Katie Mack: Nope.

Miriam: No. But in the bubble universe, potentially they could.

Katie Mack: Yeah. So the bubble universe idea, the inflationary multiverse idea where you have these little bubbles of universe, you could have a situation where two universes kind of pop out of the inflationary landscape, very, very close together, and then as they expand in their own kinds of expansion, as a normal universe evolves, they might bump into each other in that process.

Miriam: So Katie's talking about a universe crash. Let's just take that in. Some physicists believe that this may mean that we could find evidence of other universes existing, though far from everyone agrees. Here's Andrew.

Andrew Pontzen: In principle, this idea could be tested. I mean, so finding some evidence for this in the real universe would of course be absolutely the most exciting thing we'd ever learned. I mean, imagine if we actually knew, we have evidence that there are other universes out there. Um, this is not something I've been directly involved in, but it’s something I’ve been following because my colleague Hiranya Peiris has been, um, leading a lot of this work. And it's about combing through the data that we already have from things like, um, the European Space Agency's Planck satellite, and that data shows us light leftover from the very early universe. And so if one of these collisions between two young universes had taken place, it would almost leave like a circular scar in that light. It could be very subtle, so it could be sort of hiding away so that you don't sort of just see it very obviously, if you look at the image that you can get from the Planck satellite.

But if you comb through that data, then there's every chance you could find something. Right now nothing has been found that would actually, you know, really tell us oh yeah, there's definitely other universes out there.

Miriam: And what is something exactly what, what are you looking for? A void?

Andrew Pontzen: It's not as simple as a void. I mean, imagine that you were just blowing normal bubbles with soap solution, you know. Where two bubbles collide, what you end up with is a sort of double bubble. And where they're joined together, you'll see, you know, there's a sort of circle that's very prominent. And you'd imagine even if you were living inside one of those bubbles, you could very clearly see there's like a circle feature on your sky.

And so it's that, I mean, it's literally that, that there would be some extra energy where these two universes have collided and that would turn up as a circular feature in our cosmic microwave background light.

Miriam: Oh my God, that's so exciting. Um, but if we did see a circle like that. I mean, how certain would you be that that was due to another multiverse? There must be other possible explanations.

Andrew Pontzen: I think it's quite difficult to imagine other explanations if you had a really, really clear circle, you know, if it was absolutely jumping out of the data at you, then there's quite a limited range of things that could possibly explain that.

Miriam: Although no such thing has been found, Andrew and many others believe that every set of improved observational data offers hope.

Andrew Pontzen: It's quite a slow process. You know, we've got to increase the sensitivity, and in particular, people are looking for what are known as gravitational waves from that very early time and finding or not finding those could be very important in terms of our understanding of what was going on in the early universe, and therefore, its implications for the multiverse.

Miriam: And are there any other ways that experimentally might give support for the multiverse theory?

Andrew Pontzen: Right now we're actually building experiments in a laboratory made with condensed matter physics, which tests a sort of analogue for these processes. So it's not that we are kind of trying to recreate the processes themselves, but we are trying to recreate this process of making bubbles within a broader, what would be the multiverse, and seeing what happens and how they relate to each other and what happens if they collide.

Miriam: Okay. Can you give us a bit more details on that? What material have you got and how is it inflating?

Andrew Pontzen: First of all, I should say, this is quite cutting edge stuff. So what we have is what's called a Bose-Einstein condensate. So that's basically where you cool material down. It behaves in a very, very different way. When you get it down, it's very dilute gas that's very, very cool, and it behaves in a very different way from familiar materials. It behaves in a way where quantum effects start to become important throughout the material, whereas we normally think of quantum effects as being important, just sort of in very, very tiny scales.

When you have one of these Bose-Einstein condensates, the quantum effects kind of suffuse the whole experiment, and that's the key thing that we want to capture. We want to be in that regime. We're trying to recreate the idea that quantum effects somehow could cross the whole universe and see how that applies when you recreate a system like that in the laboratory. What the system isn't doing is expanding. So we are not literally recreating the sort of expanding multiverse in that sense, but it turns out that you can do a sort of mapping from the things that you measure in the experiment onto a description of the early universe, there's a kind of mathematical mapping that takes you from one to the other, right?

Miriam: So you figure out what happens quantum mechanically that might give rise to another bubble or whatever, and then you take that science and sort of superimpose it on something expanding?

Andrew Pontzen: That's right. Yeah. So, it turns out that the expansion in a way is not the most important feature of what we're talking about, and so you can get at most of what we want to understand without having the expansion in there. Then you can sort of mathematically imagine what happens if you also have the expansion by adding that on at a later stage.

Miriam: You are listening to Great Mysteries of Physics from The Conversation, but now we want to tell you about another podcast. Are you curious about how the universe began, what it's made of and how it all works?

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Now back to the multiverse. So, as Andrew explained, at ultra cold temperatures, quantum effects start to spread over an entire gas instead of being confined to single atoms from molecules. And the team think that they can create a system in which bubbles of low energy will spontaneously form inside a background of higher energy, much like our own universe may have arisen as a bubble within a higher energy multiverse. So if successful, the experiment may help shed some light on how entire universes can be born. Something we don't really have a clue about. Are there any other ways that experimentally might give support for the multiverse theory?

Andrew Pontzen: The most striking other way to get support for the multiverse theory is to go back to the quantum multiverse. So not so much thinking about inflation itself, but thinking about overall laws of quantum mechanics and the fact that they do kind of point towards a multiverse. If you start building quantum computers, then David Deutsch has made the argument that if you can build quantum computers and you can make them bigger and bigger and bigger so that you know, you go far beyond the kind of systems that people are building today and make really highly functional quantum computers that handle huge amounts of information, then it's really hard to come up with any explanation for how those quantum computers are working, except by imagining that they are harnessing the power of sort of multiple universes together. And so in a way, building a fully functioning quantum computer would in itself be pointing you towards evidence for the multiverse.

Miriam: I was also wondering, you know, there are some ideas that, you know, sort of advanced alien species or whatever could be creating new universes or potentially we could one day in the lab. Is that completely mad or is there any sort of way that you think that that would be possible? And if so, how?

Andrew Pontzen: Well, the easiest way to create a new universe is to simulate it. And that is to, you know, use a computer, program in some laws of physics and uh, hey presto, inside your computer, you've just created a universe. And we actually do this all the time. We create our own mini universes inside computers and then we can experiment on them because as cosmologists you know, we would love nothing more than to just prod the universe and get it to do different things.

Miriam: But you don't have any conscious beings in there?

Andrew Pontzen: We don't have conscious beings. No, absolutely not.

Miriam: Yet.

Andrew Pontzen: Uh, so people have made arguments that if you imagine sort of extrapolating what we are doing right now into the far future, why not? Why couldn't there be conscious beings that evolve within these simulated universes? Now I'm really skeptical of this argument. As somebody who does simulations myself, I don't think we are actually pushing in that direction. I don't think what we are trying to build is facsimiles of the universe that will then evolve conscious beings in them. I think when you start picking at that argument in detail, it doesn't quite stack up to me. But there are other people who would take the opposite view and take it really seriously, the idea that we may create fully functioning universes in the future, and then the sort of corollary of that is oh, well then why do we believe we are in a sort of natural universe? Maybe we are actually inside one of those simulated universes. As I say, it's not something I personally lose any sleep over or think is particularly likely.

Miriam: Mm-hmm, no

Andrew Pontzen: But it is something that some people do take seriously.

Miriam: Yeah, I'm a bit skeptical too. We don't really know how consciousness even works, so how do you simulate it?

Andrew Pontzen: That's right. Yeah. I mean, you have to get over the idea of just being able to simulate consciousness, that's true. But even, I think even if you get over that, even if you believe it's possible to have consciousness in an electronic system, I still think it's too much of a leap to say that we are likely to be inside a simulation or likely ever to produce these simulations that conscious beings evolve within.

Miriam: Some physicists have suggested that it should be possible to trigger inflation in a particle accelerator, even coming up with blueprints for creating a baby universe in a lab, hidden in a miniature black hole. Or we might search the cosmic microwave background, not just for signs of universe collisions, but also for signs that our universe was created in the lab of a superior alien species.

These ideas are, however, speculative and controversial. We don't even have evidence that there is a multiverse in the first place. And there are alternatives. One such model suggests that the universe may be cyclical, so appearing and dying over and over.

Andrew Pontzen: Well, the cyclical universe is the idea that the end of our universe doesn't have to be an ending to everything. That somehow the end of the universe may result in the rebirth of a new universe. And there are many, many different versions of this idea. But right now we think that the universe will end in what we call a heat death. So that's essentially that the sources of energy become harder and harder to find in our universe, it keeps expanding at an ever accelerating rate. The stars in our own galaxy eventually die. Things eventually all collapse into black holes. And actually those black holes eventually even radiate away through Hawking radiation. And in the end, in this heat death end to the universe, it completely loses track of any sense of time in fact. And people have speculated, I mean, notably people like Roger Penrose for example, that once it's lost any track of time at all, it may be that that can kind of match onto a new beginning to the universe.

Miriam: And why do we not hear so much about the cyclical universe as the multiverse? Do you think it's not as popular, is it as a theory? Why do you think that is?

Andrew Pontzen: I think the cyclical universe involves even more layers of speculation than some of these other multiverse ideas, so I don't think it's that it's intrinsically less interesting. I think that it's just that it involves even more extrapolation from what we would say that we actually know about physics.

Miriam: Interestingly though, in a cyclical world, the loss of physics and the fundamental constants may be different each time around. Meaning that a cyclical universe could help explain why the universe seems so fine tuned for life. In particular, some physicists believe it can explain why the cosmological constant, which is related to the expansive force of dark energy and is unnaturally low in our universe, takes such an unusual value.

Katie Mack: There's sort of an independent way of thinking about the sort of life cycle of the cosmos and some of those you can have the properties of the universe change with every cycle. And there've been suggestions that that's the reason for this value of the cosmological constant, that we've been through many, many cycles of the universe and it causes the cosmological constant to come to the level it's at over cycles.

Miriam: That said, the multiverse is the more popular theory, but not everyone agrees it is worth thinking about. Sabine Hossenfelder, a Research Fellow at the Frankfurt Institute of Advanced Studies in Germany has the following to say about the multiverse theory.

Sabine Hossenfelder: I think it's fine for entertainment, you know, I think it's very inspirational. People just love talking about it. Uh, you know, they live out their fantasies. What could happen if I could live my life in some other way, in some other universe when something went a little bit different in my life than it actually did? I'm not a big fan of this being used in science as a mode of investigation of the natural laws of nature.

Miriam: Okay, so can we talk a little bit about the reasons it is used in science? So, one very common idea is that in quantum mechanics, you can interpret the fact that every time you make a measurement, a number of things could happen in theory, until you measure something. So when you've measured something, there are all these other things that didn't happen. And so according to one interpretation of quantum mechanics, and quantum mechanics being a very successful theory, is that all these other things happen in parallel worlds, essentially, in a multiverse. So that seems to sit very nicely together with quantum mechanics, which is a weird theory, but it has been, you know, verified so many times. So, you know, what do you make of that argument, don't you think we should take that seriously?

Sabine Hossenfelder: Well, as you correctly said, that's an interpretation of the mathematics and it's not the only one. And I think it's fine so far as the interpretation is concerned, you know, you can write down your mathematics, calculate something with it, that's one thing. What do you think it means? That's another question entirely. And now some people go and say, well, what this mathematics actually means is that all the possible outcomes of the experiment are somehow real. It's just that most of them we never observe. And if you want to believe that, that's fine, but those other outcomes which we don't observe actually exist, isn't supported by the science. That's just something that you can interpret into it. It's fine as a belief system. I like to call such ideas ascientific, but it's not scientific.

Miriam: But it kind of says that this could be the possible way in which the universe, the multiverse works. But you think it's unscientific because we can't test that. Is that correct?

Sabine Hossenfelder: Yes, exactly. So it could be in the sense that we can't rule it out. That's exactly why it's not scientific.

Miriam: All right, so let's move on then, because there are other reasons to believe in the multiverse. So one of them being inflation. And so you know, if that could happen in one patch of space, why not another? Is that not a better argument then?

Sabine Hossenfelder: So for one thing, I'd slightly disagree that there is very good evidence for inflation. It's actually highly controversial, and there's a reason why there hasn't been a Nobel prize for it, which is that the evidence is not quite as good as some people might want you to believe. So that's the one problem. The other problem is that I think there's kind of a conflation of terminology. So when people talk about inflation, that has maybe some empirical support, they're talking about inflation in our universe because that's what we can observe. And then they say, well, if I take this mathematics very, very seriously and I actually believe that everything that I can mathematically write down actually exists in the same way that we exist, then other universes also exist.

But again, this isn't something that we can test. It's just an interpretation of the mathematics, and I'd say it's fine if you want to believe in it, because we can't rule it out - that those other universes exist - but we don't have any evidence that speaks for their existence either. So I actually think the physicists are a little bit confused with what they even mean when they talk about evidence. I sometimes hear people talk about some kind of mathematical evidence, so that's just not a thing. You know, evidence is something that you actually observe.

Miriam: Okay, so if we take something like, you know, inflation happening here and there, I mean, I know that it is speculative, but there are physicists who believe we might be able to see signs of collisions with other universes in the sky.

Sabine Hossenfelder: So those ideas, I would actually put them in a slightly different camp. You know, they come somewhere in the general overly speculative stuff that we have no particular reason to believe in, but at least is in some sense still scientific. Though again, I would actually disagree that there has been some debate about this entanglement with the other universe.

The way that I remembered it was actually ruled out pretty much immediately. But I mean, so let me put it this way. There's always the possibility that you modify a theory in such a way that it spits out a testable prediction, but it's kind of, I think what's in logic, it's called bait and switch. You know, first you talk about, oh, it's the strength landscape, internal inflation, and so on. And then you say, well actually I lump those other additional assumptions on top of it, and then I also assume this, and I assume this and, and blah, blah, blah, blah. And suddenly those universes can collide and they leave a trace in the C M B, and then they say, oh, now it's testable. But now we're talking about a completely different thing.

Miriam: Just to add, the CMB is the cosmic microwave background, so it's the radiation leftover from the big bang essentially.

Sabine Hossenfelder: Right. And there has been this idea that if two universes would've collided very early on, then the other universe might have left a trace in our cosmic microwave background without actually destroying the universe. So the difficulty with making this idea work is that it's hard to find a balance between the two. Most of the time when you get things to collide and you know, both of the universes get whoops. So you have to find a way to just barely leave the trace and I, I actually don't know if there are still people working on it. So yeah.

Miriam: Katie and Andrew, however, don't think the multiverse can be immediately dismissed as unscientific.

Andrew Pontzen: I'm always cautious about saying that anything is unscientific. I mean, I understand where people are coming from when they criticize theories for being unscientific, but you have to bear in mind that what we can measure today is not necessarily what we can measure tomorrow.

And if we just stopped whenever we were worried that we might not be able to measure something or test something, then I think that would cut off a lot of really good ideas in their prime. And things that in the past have seemed to be untestable, have later turned out to be testable. So I don't think it's a good idea to cut things off too harshly because they seem to be untestable today.

Katie Mack: I don't think that hypothesizing the existence of something unobservable is inherently unscientific. The wave function is unobservable. We have ways to infer the existence of the way function because the math all works perfectly well if the wave function exists. But to say that it's unscientific to have a mathematical framework that we never directly observe is a little beside the point because it's such a basic part of the science.

And so in terms of a multiverse, there are different kinds of possible multiverses and in general, they are unscientific in the sense of being unobservable, if that's the way you want to talk about it. But if they're a part of the theory, if they're a necessary feature of the mathematics that builds the theory, I don't think it's unreasonable to talk about them because it's just a basic part of the structure of reality as described by that mathematical theory, and if we find a different model that has a different mathematical structure and it works better then great, if not, then you know, we can say, well, this is a feature of our model. We can't prove that it's real or not, but it's how our model works.

Miriam: Whether it is possible to ever get direct evidence of other universes is hard to tell. Andrew Pontzen is hopeful that experiments and observations can shed light on the potential existence of other universes and the mechanisms that gave rise to them. But even if that leads us nowhere, the multiverse isn't likely to go away.

We simply need it to explain things like the apparent fine tuning of the cosmos. And as Katie Mack explains, the multiverse does appear at the heart of our theories of nature, from quantum mechanics to inflation. And these theories themselves aren't unscientific.

Quantum mechanics in particular has been experimentally verified over and over again in the lab. We use it in everyday technologies, but at its core, quantum mechanics is deeply unsettling, at least to some, it seems to suggest that nature's not objectively true and real for example, if we're not looking particles can be in many places at once. Or it seems that they may be spookily connected despite being light years apart, somehow sharing, information.

But why does the microcosmos of atoms and particles behave in such bizarre ways? Why don't we see it in the world of humans and cats? What is it that happens at the mysterious border between our macroscopic familiar world and the strange quantum realm? And what is it about observation that disrupts quantum systems? Could we use it as a type of fuel? Those are the questions we'll discuss in the next episode.

This podcast was created and presented by me, Miriam Frankel and produced by Hannah Fisher. The executive producers are Jo Adetunji and Gemma Ware, and the advisory editor is Zeeya Merali. The sound design is by Eloise Stevens, and music is by Neeta Sarl. Great Mysteries of Physics is a podcast from The Conversation UK with funding from FQxI.