Dr. Perry Phillips, Herman Lectures, Part 3 Podcast

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Okay, let's unpack this. You think you know what the universe is made of, but it turns out the stuff we can see is barely the tip of the cosmic iceberg. Oh, absolutely.

I mean, imagine you're standing in a field, right? You throw a baseball straight up into the air as hard as you can. Right. You expect gravity to grab hold of it, slow it down, and eventually pull it right back down into your glove.

Yeah, basic physics. But instead, the baseball keeps going. Yeah.

And it doesn't just keep going; it actually starts speeding up. Like it has a rocket attached to it. Exactly.

Rocketing into the stratosphere faster and faster. Just seemingly defying every law of physics you thought you understood. Which sounds completely absurd.

Right. But that impossible reality-breaking scenario is exactly what our universe is doing right now. It really is.

So today, we are doing a deep dive into this fascinating lecture by Perry Phillips. It's called Big Bang, The Beginning of the Universe, Part 3, Dark Matter, Multiverses, and Other Difficulties. It is quite a title.

It is. And our mission for this deep dive is to help you, listening right now, understand the invisible forces that are actively shaping our reality. We're going to look at how scientists use some truly mind-bending cosmic clues to solve impossible paradoxes.

Yeah. And how a tiny split-second event, billions of years ago, might mean we are just one single universe floating in an infinite sea of them. What's fascinating here is that we aren't just exploring what we currently know about the universe.

We are looking at the incredibly ingenious and honestly sometimes maddening ways we actually figured it all out. Because it wasn't easy. No, not at all.

Cosmology is essentially this giant detective story. But the crime scene is 14 billion years old, and almost all of the evidence is completely invisible. Which is wild to think about.

And let's start with the biggest piece of invisible evidence out there, going back to that baseball analogy. The expansion. Yeah.

If there's a giant explosion like the Big Bang, and all the matter in the universe is flying outward, logic kind of dictates that the collective gravity of all that matter should be pulling everything back inward. Right. You'd think the expansion should be slowing down.

Exactly. And for decades, the big debate in astronomy was simply a matter of density. Like, was there enough mass in the universe to eventually pull everything back together into this massive collapse? Like a big crunch-type thing? Exactly.

A big crunch. Or would it just, you know, expand forever, constantly decelerating but never quite stopping? Right. But then astronomers started looking at data from about 5 billion years ago, and they realized something impossible was happening.

The baseball kept going. Yes. The expansion of the universe wasn't slowing down at all.

It was actively accelerating. Which is completely wild. And that acceleration is driven by what we now call dark energy.

Right. But to even understand the energy side of things, we have to look at dark matter, which has its own bizarre origin story. Oh, it really does.

Back in the 1930s, there was this astronomer named Fritz Wicke, and he was looking at galactic clusters. Specifically, the Coma Cluster. Which is just a massive, massive group of galaxies.

Right. So he was measuring how fast these galaxies were zipping around within the cluster. And he noticed this huge mathematical problem.

Yeah, it was a huge discrepancy. Wicke calculated the mass of all the visible stars and gas in that cluster. And from that mass, he knew exactly how much gravitational pull the cluster should have.

Okay. But the galaxies are moving incredibly fast. Like, so fast that the visible gravity shouldn't have been nearly strong enough to hold them together.

Oh, wow. Yeah. By all the laws of physics, those galaxies should have completely dispersed and flown apart into deep space after just, you know, a billion years.

But they were still there. Exactly. They were still there.

And that mystery basically just sat on a shelf until Vera Rubin came along in the 1970s. Right. Vera Rubin.

She did this groundbreaking work on spiral galaxies like our neighbor Andromeda. And to understand what she found, you just have to think about our own solar system. Right.

So Mercury is very close to the Sun. It feels a massive amount of gravity, so it has to orbit very fast to stay in place. Makes sense.

But as you move further out to planets like Jupiter or Saturn, the gravitational pull from the sun gets much weaker, so they orbit much more slowly. Yeah, that is just standard Newtonian physics. And it is exactly how you would expect a spinning galaxy to behave, too.

Right. The dense, brightly packed center of the galaxy has the most mass, so the stars near the center should orbit incredibly fast. And the stars way out on the wispy outer edges should orbit much slower.

Exactly. But when Rubin actually measured the rotation, she found that the outer edges of these spiral galaxies are rotating just as fast as the inner parts. Which just completely breaks the math.

It makes no sense. I mean, it's like watching kids on a playground merry-go-round. Right.

If that thing spins too fast, the kids holding onto the very outer edge are going to go flying off into the sandbox. Yes. But in these galaxies, the stars don't fly off.

They just stay in formation, spinning at absolutely impossible speeds. It implies they are strapped in by invisible seatbelts. I love that.

Yeah. And that seatbelt is dark matter. That is a brilliant way to picture it.

And it is so vital to understand why this matters to you as the listener. It means we are essentially living in a ghost universe. Ghost universe.

Yeah, because the vast majority of the structure that allows our galaxy to hold itself together, which is literally the only reason our solar system and our planet can even exist in the first place, is made of a completely unknown substance. We can't see it. No, it doesn't absorb or emit light.

It doesn't interact with electromagnetism at all. Wow. The only reason we know this ghost matter is there is because we can see its gravitational pull keeping that cosmic merry-go-round intact.

Just sitting there in this massive invisible halo around our galaxy, keeping us safe. Exactly. So we have this ghost universe filled with dark matter acting as the glue pulling things together and dark energy acting as the accelerator pushing space apart.

Right. But to figure out how our universe actually works, cosmologists had to calculate the exact recipe of all this invisible stuff. So how do you measure the ingredients of something you can't even see? Well, to find that recipe, scientists had to look at the oldest light in the sky.

Okay. It is called the Cosmic Microwave Background Radiation, or the CMBR. You can kind of think of it as the fading afterglow of the Big Bang itself.

Right. The afterglow. Yeah.

For the first 380,000 years after the universe began, it was basically this superheated glowing fog of plasma. Just totally opaque. Exactly.

But once it cooled enough for light to finally travel freely, that initial burst of radiation was locked in. Oh, I see. Today we have these highly sensitive instruments like the Atacama

Cosmology Telescope that look at this ancient radiation and map out tiny temperature differences.

Like hot and cold spots. Yes. They look for these microscopic hot and cold spots in the sky, which they call anisotropies.

Anisotropy. Okay. It just sounds like a very expensive scientific word for splotches.

I mean, yes, basically splotches. But these splotches are incredibly important. The scientists literally map them out and count how wide they are.

Right. They tally up how many of these hot and cold splotches are one degree wide in the sky, how many are half a degree, a quarter degree, and so on. Yep.

And they create a graph of these sizes. What they found is that the vast majority of these splotches peak right at one degree in diameter. And this is where the really rigorous detective work comes in.

Scientists take all the potential ingredients of the universe to see what makes the math work. Okay. They look at the amount of dark matter, the amount of dark energy, the overall geometrical shape of space, the rate of cosmic expansion, which is known as the Hubble constant, and the amount of what they call baryonic matter.

And baryonic matter is just the technical term for ordinary stuff, right? Exactly. Protons, neutrons, everything that makes up stars, planets, you, and me. Okay.

So they plug all of these variables into their equations, constantly tweaking the amounts of each ingredient. They know they've found the true cosmic recipe only when the mathematical output perfectly matches that graph of the one-degree splotches we actually observe in the sky. That's like reverse engineering a recipe.

Yeah. But getting that recipe right created a massive crisis because the Hubble constant, that critical rate of expansion they needed to make the math work for the CMBR, was completely different from the Hubble constant astronomers have been measuring for decades. Yeah, using data from the WMAP satellite, the numbers just didn't align.

Right. Traditionally, we measured expansion just by looking at the movement of relatively nearby stars in supernovae. But the difference between the two measurements was what statisticians call a three-sigma difference.

Which is massive in statistics. Yeah. It basically means there is a 99.7% chance that this discrepancy is not just a mathematical fluke.

It was a real fundamental contradiction. It was a huge deal in cosmology. It meant our two most trusted, highly refined ways of measuring reality were fundamentally disagreeing with each other.

Right. But a breakthrough came fairly recently when an astronomer at the University of Chicago named Wendy Friedman started using a completely different method to measure distance. She looked at what is called the red giant branch.

Okay, I want to make sure we don't gloss over this. How does looking at a red giant star solve a mathematical crisis about the expansion of the universe? It's incredibly clever, actually. So a red giant star is in the later stages of its life.

Okay. Right before its core gets hot enough to explosively ignite its helium, it reaches a very specific, highly predictable, peak brightness. It's called a helium flash.

Oh, I've heard of that. Yeah. And because astrophysicists know exactly how intrinsically bright that flash actually is, they can compare it to how dim it appears to us here on Earth.

By measuring the difference between its true brightness and its apparent brightness, they can calculate exactly how far away that star is with stunning accuracy. It acts as this perfect standard cosmic yardstick. Ah, I see.

So by using this highly accurate red giant yardstick, she was able to bridge the gap between the two conflicting measurements. And Bradford Benson, another cosmologist in the source material, pointed out that having these completely unrelated astrophysical phenomena- one, looking at the ancient afterglow of the Big Bang, and the other, looking at the very specific helium flashes of dying stars agreeing at a 5% level shouldn't be seen as a crisis at all, but as a triumph. Right.

Now, I have to push back on that. A 5% error margin is a triumph. Oh, you have to think of that.

I'm baking a cake, and I am off by 5%. That cake is going to the trash. It's completely ruined.

Fair point. Yeah. So why is a 5% difference considered an astonishingly close triumph when we're talking about the literal recipe for the universe? Well, if we connect this to the bigger picture, you really have to appreciate the sheer, mind-boggling scale of what they are attempting to measure here.

Okay. We are talking about calculating the expansion rate of reality itself, stretching across billions of light-years. They measure this expansion in a unit called kilometers per second per megaparsec.

Which, Phillips correctly points out, sounds a bit like measuring in furlongs for Fortnite. It really does. It's incredibly abstract.

So to get two totally distinct mechanisms to agree within 5% across that kind of incomprehensible cosmic distance, it's just a monumental testament to human ingenuity. Okay, fair enough. I won't hold the cosmos to my baking standards.

Sorry, I believe for the best. But speaking of the Big Bang, mapping out this cosmic microwave background radiation might have finally given us the recipe to the universe. But it also created two massive pounding headaches for the Big Bang theory itself.

Oh yes. The horizon problem and the flatness problem. Let's tackle the horizon problem first.

So this one is a profound paradox. Imagine you look 14 billion light-years deep into space in one direction. Okay, looking left.

Right. Then you turn around and look 14 billion light-years deep in the exact opposite direction. Let's be right.

You are now looking at two regions of space that are separated by a vast gulf of 28 billion light years. Right, yeah. And yet, when we look at the microwave background radiation, those two completely opposite regions look identical.

Perfectly identical. The physical makeup, the exact temperature, the distribution of those hot and cold splotches, they match perfectly. But here is the problem.

Nothing can travel faster than the speed of light, right? Right. Since the universe is only about 14 billion years old, light hasn't had anywhere near enough time to travel between those two horizons. So they couldn't have interacted.

Exactly. So how did opposite ends of the universe communicate to normalize their temperatures? Think about leaving a cup of hot coffee in a cold room. It takes time for the heat to transfer and for everything to reach the same temperature.

These two edges of the universe were never close enough to exchange heat or information. So how are they perfectly balanced? It is deeply weird. And then you have the flatness problem, which might be even weirder.

When cosmologists say space is Euclidean, they mean it is geometrically flat. Like if you somehow drew a giant triangle across the universe, the angles would add up to exactly 180 degrees. Right.

Today, our universe is flat to a 0.4% margin, which is about one part in 250. Right. But you have to work backward mathematically here.

Because as the universe expands, any slight geometric curvature gets massively magnified over time. So to be flat to one part in 250 today, that means that just one second after the Big Bang, the universe had to be flat to one part in 10 to the 15th. That is a one with 15 zeros.

Phillips uses a great analogy for this in the lecture. Imagine aiming a rifle at a two and a half foot goose sitting across a bay. OK.

If you are standing just five feet away from the goose, you have plenty of room for error. But the further back you walk, the less variability you can have in your aim if you still want to hit the target. At one second after the Big Bang, your aim had to be accurate to one part in 10 to the 15th.

And if you rewind the clock all the way back to 10 to the minus 37 seconds after the Big Bang. Oh boy. Your aim had to be accurate to one part in 10 to the 60th.

That level of fine tuning is almost impossible for the human brain to comprehend. Here's where it gets really interesting because I want to expand on that goose analogy. Hitting an accuracy of one part in 10 to the 60th.

It's not just shooting a regular goose across a bay anymore. No, not at all. That's like trying to shoot a microscopic goose that is sitting on another planet while you are heavily blindfolded and you still somehow hit it dead center.

It is an absurdly improbable scenario. The math became so terrifyingly precise that physicists literally started sounding like theologians. The lecture notes that some people started quoting John Calvin's phrase, that's the way the mop flops.

Meaning that's just the way it is. The universe was just created that finely tuned from the very beginning. And we should clarify: we are just neutrally reporting this quote from the source material.

We're not taking a stance on intelligent design here. Absolutely. We're just illustrating how extreme the math got.

When hardcore cosmologists start throwing their hands up and saying, well, it's just made that way, you know, the problem is deep. Exactly. But science hates relying on That's just the way the mop flops.

Yes, they do. They needed a deterministic answer, an actual physical mechanism to explain these impossible odds without relying on pure chance. And that quest leads us to the ultimate cosmic hack, inflation.

Yes, inflation was proposed in the 1980s by a physicist named Alan Guth at MIT. Right. And what's funny is he wasn't even trying to solve the flatness or horizon problems.

He was looking for magnetic monopoles. Let's explain what that means. Why was he looking for them? Well, the leading grand unified theories of physics at the time heavily predicted that the extreme heat of the early universe should have produced a massive amount of incredibly heavy particles that possessed only a single magnetic pole.

Like an isolated north or an isolated south without their opposite half. Yes, exactly. They mathematically had to exist.

But when scientists looked out into the universe, they couldn't find a single one. So Guth was trying to figure out where they all went. Right.

And his proposal to solve the missing magnet problem was radical. He suggested that incredibly early in the universe's history, between 10 to the minus 37 and 10 to the minus 33 seconds, a microscopic seed of the universe experienced a repulsive form of gravity. And in that tiny fraction of a second, this seed, which was smaller than a single proton, doubled in size a hundred times over, expanding to about the size of a marble.

That is the ultimate cosmic weight loss, squeezing the entire mass and energy of the universe down smaller than a proton. It's insane. But this single elegant idea of inflation magically solves all our problems at once.

Okay. First, it solves the missing monopoles. They do exist, but inflation stretched space out so vast and so fast that it diluted them.

Yeah, they are spread out so thinly across the cosmos that we just can't find them. Second, it solves the horizon problem. Because they were originally cut off.

Exactly. Before inflation happened, everything was packed tightly together inside that proton-sized seed. It had plenty of time for the heat to transfer and reach a uniform temperature.

Right. Then, whoosh! Inflation blew it up, locking in that perfectly balanced temperature across the entire sky. This raises an important question, though.

If the universe expanded from smaller than a proton to the size of a marble in a fraction of a millisecond, that means it expanded significantly faster than the speed of light. Didn't we just establish earlier that absolutely nothing can go faster than light? Oh, that's a great point. How does that not break the laws of physics? The critical mechanism here is that physical objects traveling through space cannot exceed the speed of light.

But inflation wasn't the movement of objects. It was the expansion of space itself. The actual fabric of space can stretch faster than light, carrying the matter and energy along for the ride without violating Einstein's speed limit.

That is such a trippy concept. The fabric of reality itself stretching. It is.

And it completely solves the flatness problem, too. I mean, imagine you are an ant walking on a small five-inch balloon. If you draw a triangle on that balloon, you can clearly measure the sharp curve of the surface.

The angles add up to more than 180 degrees. But if that balloon suddenly undergoes inflation and blows up to the size of the planet Earth, no matter where you walk, the surface beneath you is going to look perfectly flat. Inflation stretched any chaotic curvature of the incredibly early universe into the beautifully flat Euclidean space we observe today.

And perhaps most beautifully, inflation also explains those microscopic temperature splotches, the anisotropies in the cosmic microwave background. The ones we talked about earlier. Yes.

In quantum mechanics, thanks to Heisenberg's uncertainty principle, empty space is never actually empty. It's not. No, it is constantly boiling with virtual particles popping in and out of existence, creating these tiny microscopic fluctuations in energy.

When inflation happened so violently, it actually froze those microscopic quantum wrinkles and blew them up to macroscopic cosmic proportions. Those frozen quantum jitters became the dense pockets of gravity that eventually pulled in matter to form our galaxies, our stars, and ultimately our planets. It's incredible.

The largest structures in the universe are literally just magnified shadows of quantum jitters. So inflation is this brilliant, elegant solution, but it opens the door to something that is equally thrilling and honestly completely terrifying. Oh, definitely.

Because if one tiny quantum seed inflated to become our entire universe, why wouldn't other seeds have inflated too? You've just hit on the multiverse. The multiverse. Yeah.

Mathematically and philosophically, if the mechanism for inflation exists- this repulsive gravity acting on a microscopic seed- there is no scientific reason to assume it only happened once and then magically stopped forever. The problem, of course, is that a multiverse is largely untestable. Unless another expanding universe somehow physically collides with ours and leaves a detectable bruising mark on our cosmic microwave background radiation, we can never see them.

But the lecture argues we actually need the multiverse to explain the biggest mystery of all, which is dark energy. Right. Remember how we said empty space is boiling with virtual photons popping in and out of existence? Well, theoretical physicists tried to calculate exactly how much energy all those popping photons should be generating in the vacuum of space.

And they based this calculation on the shortest possible wavelength in physics, the Planck length, which is 10 to the minus 33 meters, tied to the Planck time of 10 to the minus 43 seconds. OK. When they mathematically calculated the energy of these virtual photons popping into existence, the number they got for predicted dark energy was 10 to the 120th times greater than the dark energy we actually observe gently accelerating our universe.

10 to the 120th times. That is a catastrophic error. It's massive.

Phillips calls this the most embarrassing theoretical prediction that has ever been made in physics. Which is saying something. Because if dark energy was even slightly higher than what we observe, the universe would have blown apart so violently that galaxies and stars could never form.

Right. And if it was slightly lower, gravity would have won immediately, and the universe would have collapsed back in on itself in a fraction of a second. We are balancing on a razor's edge.

We really are. And this is where string theory provides a potential framework. OK.

String theory is the idea that the fundamental ingredients of reality aren't tiny dots, but microscopic vibrating strings of energy operating across extra dimensions. The math of string theory allows for a vast landscape of possible vacuum states or varying conditions for universe seeds. It suggests there is something like 10 to the 500th power possible seeds.

That's a huge number. It is. And even if you subtract the 10 to the 120 range of dark energy that would instantly destroy a universe, the math shows you are still left with 10 to the 380th power possible viable universes.

That is an unfathomable amount of universes. It is. And it leads to a concept called the anthropic principle or the principle of mediocrity.

What's that? It basically argues that the only reason we are observing a universe with these perfect, highly improbable razor-edge conditions is that if it were any different, we simply wouldn't exist to observe it. Oh, I see. Out of 10 to the 380 viable universes bubbling out of the cosmic foam, we just happen to live in one of the lucky seeds where the math allows for stars, carbon, and human life.

So what does this all mean? I have to ask about the limits of science here. OK. If we are forced to rely on the concept of a multiverse to make our math work, but we know we can never actually build a telescope powerful enough to test or see these other universes, is this still astronomy? Or has this just become pure philosophy? It's a fantastic question, and it's one cosmologists debate constantly.

The reality is that theoretical physics often has to follow the math where it logically leads, even if our physical instruments are centuries away from following. Right. We are attempting to map the architecture of reality using the only tool that can reach that far into the dark, which is mathematics.

It really blows the line. And there's actually a running joke among cosmologists about just how deeply they believe in inflation, since we can't fully prove the multiverse part of it yet. Oh, I love this joke.

The joke goes that Martin Rees, a famous astrophysicist, would happily bet his dog that inflation is real. Right. Andre Linde, who pioneered a lot of the crucial math for this, says he would confidently bet his own life on it.

OK. And Steven Weinberg, a giant in particle physics, famously joked he'd be willing to bet Martin Rees' dog and Andre Linde's life on it. It perfectly captures their confidence in the underlying math, despite the incredibly abstract nature of it all.

And it echoes an insightful point made by cosmologists Alex Vilenkin and Dilya Purov in their book Cosmology for the Curious. What do they say? They discuss the concept of quantum tunneling, which is this well-documented phenomenon where subatomic particles spontaneously pass through a barrier they technically shouldn't have the energy to cross, driven purely by probability waves. But applying that to the whole universe.

Exactly. They point out that the idea of an entire universe bursting into existence from a state of absolute nothingness via quantum tunneling implies something profound. OK.

It means that the fundamental laws of physics must have existed prior to the universe itself in order to guide its birth. Wow. A state of true nothingness somehow transmuting into something under the spell of abstract laws of nature is, in their exact words, deeply mystifying.

It is deeply mystifying. And reaching that boundary of knowledge evokes that famous image from the astronomer Robert Jastrow. Yes.

Again, just reporting this neutrally from the source. He pictured a scientist who has spent his entire life scaling the rugged mountain of ignorance, fighting for every inch of data. Right.

And as he finally pulls himself over the final rock to conquer the highest peak of physics, he is greeted by a band of theologians who have been sitting there comfortably for centuries. It's a striking image. It just captures the sheer philosophical awe of realizing how close our advanced math brings us to the ultimate unknown.

It perfectly illustrates how science brings us to the very edge of human comprehension, where the mechanics of reality get so strange they almost feel like poetry. Exactly. And why should you, the listener, care about any of this? Good question.

Because every single atom vibrating in your body right now, the device you're listening to this on, every thought you are actively having, only exists because it is balancing precariously on a 1 in 10 to the 60th mathematical knife-edge. It's humbling. We are the wildly improbable survivors of a cosmic lottery that has been playing out since a fraction of a second after time began.

Which brings us right back to that deeply mystifying concept that Lincoln mentioned. Yeah. If the abstract laws of physics and quantum mechanics had to exist prior to the universe in order to govern its explosive birth, we are faced with a profound puzzle.

Right. Think about it. If there was absolutely no space, no time, and no matter before the Big Bang, where did those physical laws exist? Exactly.

Where did the math live? Are the mathematical rules of reality an actual fundamental substance that just sits completely outside of time, waiting in the dark for a universe to govern? It's a huge question. It's like we spent a century mapping out the invisible ghost universe, pulling our galaxy together, only to realize the ultimate invisible force is the math itself. Something for you to ponder the next time you look up at the night sky.