NICHOLAS DIBELLA: So last time, at the end of last class, I began to talk to you about quantum tunneling, which allows for a lots of crazy events to occur. It allows me to walk through chalkboards. It allows me to fly. It allows for various types of magic to be true. And it's just so wonderful that quantum mechanics allows for these really strange things to occur. It kind of gives us hope-- it gives possibility-- that pretty much whatever you can imagine can occur.

And today, I'd like to expand on this theme of possibility, and talk to you all about parallel universes. So you're all here today in this room at MIT, watching me talk about some stuff. But would you believe that in a far, far away galaxy there is an exact copy of this classroom with ab exact copy of each one of you-- each person-- with each person having every single characteristic of you, having the exact DNA, the exact memories, the exact preference of ice cream, the exact everything, and an exact copy of me talking to you about stuff?

Well, according to some parallel universe theories, this actually is the case. Whereas, in this universe, I simply mention that fact and continue to talk about some other things, in another universe I could mention that fact and just leave the room.

[DOOR CREAKING]

[MURMURS]

Hi. We're not in that universe, however. OK.

Now, what do I mean by parallel universes? Well, first I need to be a little bit more precise on what I mean by universe, because it's used in a few different ways. Now, usually when we think about the universe, we think about "the universe"-- the everything that's out there. We think of that as being the universe.

Well, in this phrase, parallel universes, the type of universe that I'm referring to is a little bit different. And there's one type of parallel universe that I'd like to talk about first, and that has a very specific meaning of universe. And that's the observable universe, which I'll write down here.

So as you all know, the universe is pretty big-- pretty big. But there's only a certain fraction of it that we can see. And that's because of the big bang. And let me tell you briefly about the big bang. You'll get a lot more about this in a couple of weeks, but let me just briefly go over the big bang.

So a long time ago, all the galaxies, and all the stars, and all the matter were a lot closer than they were today-- extremely close. Infinitely close, in fact. And it's speculated that about 14 billion years ago, all of the matter and all of the energy in the universe was concentrated at a single point. And for some reason, these bits of matter just started to expand away from each other.

And the reason for the expansion was that space itself expanded. And as a result, everything sitting on space would get farther apart from each other. And that might sound kind of weird, so let me give you an analogy. Suppose you're an ant and you're living on top of a volleyball. So this is you.

And according to you, your universe consists only of two dimensions. You can either walk one way or you can walk another way, similar to how we move around on the surface of the Earth. Relative to the ground there's only, essentially, two directions we can move. Well, that's what the universe is like for this ant living on a volleyball.

Of course, we, the omniscient observers, see the whole volleyball, and so we recognize that the ant's actually living on the surface of a three dimensional object. But the ant doesn't know that. Well, what would happen if we expanded this ant's universe? What would happen if we expanded this volleyball?

We still want to see it of course. Let's say this is before, and this is after. Of course, the ant is still the same size, it's just that the volleyball has gotten much bigger. So the ant's still lower here, but something has changed for the ant. On this universe there could be, for instance, lots of other ants just specked all around, just sitting around various points.

We didn't completely raise erase perfectly, so let me make this a little bit better. So there are these points on the volleyball that the ant observes, and they're all separated at certain distances from each other. And once you expand this volleyball, these points, as a result of the expansion of the volleyball, get farther apart from each other.

So I drew five dots there. Now there are still five dots, but they are farther apart from each other. And then that's something that the ant would observe.

Well, suppose right at the expansion, one of these other ants-- suppose these dots are ants-- sent a signal-- send some light beam to our friendly ant, the ant that we started off with. So right before the expansion, some ant sent a signal. So the signal travels from this ant to that ant.

Well, suppose the ant sends right when the expansion starts. Well, it's going to take some time for that signal to reach the original ant, because light travels at a certain speed, and it takes a certain time to get there. Similarly, in our universe, and our universe's very early history, light from other stars and other galaxies has taken time to reach us since the big bang. And there are some stars that have since moved very far away from us-- extremely far away from us-- and the light from those stars simply hasn't had enough time to reach us yet.

And so, there's a certain distance away from us that is the maximum distance that we can observe. And this distance defines a whole sphere called the Hubble sphere, which we refer to as the observable universe. So there's only a small section of the whole universe that we can observe, and we call that the observable universe.

AUDIENCE: What's the radius of--

NICHOLAS DIBELLA: What's the radius of the Hubble sphere? The radius of the observable universe? I think it's 40 billion light years. And that's and that's different from the age of the universe, because actually the space between us has actually expanded. And there are some effects that give rise to that increased distance.

And in terms of meters, I have that for you. In terms of meters, it's about 10 to the 27th meters, which is pretty big. It would take it would take lights about 40 billion years to reach from here until the end of the Hubble volume-- to the end of the observable universe.

Now, as each year passes by, light has an extra year to travel. And so, for each year that passes by, the observable universe increases by one light year. So the observable universe is getting bigger and bigger.

Now, strictly speaking, we don't really know if there's anything outside of the observable universe, because we just can't observe it. And so, you might say that anything that's outside of the observable universe is just subject to mystical speculations or metaphysical speculations, and science can't do anything about those places. Well, actually, surprisingly, we can say some things about what's outside of the observable universe, although the things that we say are more indirect.

Now, there's the question that space might be finite or it might be infinite. And we now have a kind of good answer to that question. But first, what does it mean for space to be finite or space to be infinite? Well, if space were finite, you might imagine that you take off from a rocket ship on earth, and then you travel and you keep traveling farther and farther away. And then, you eventually reach a sign that says, this is the end of the universe. Dead end. You might reach a sign that says that.

Well, that's not what I mean by space being finite. What I mean by space being finite, is something like this volleyball universe of the ant. It's finite for-- I mean, we, the omniscient observer, look at this volleyball and we see that it has a finite size. Of course, this is an analogy. It's an analogy to the real world, where our universe might possibly be some four dimensional hypersphere that we're living on top of. So it's a four dimensional extension to this volleyball.

In that sense, the universe might be finite. And one consequence of this is actually that if you started at some point in the universe-- supposed you started here. If you started at this point in the universe and you traveled, say, this direction, and just kept traveling straight forward, eventually you would return to where you started off. And that seems kind of weird, right? If I keep traveling this way, then ordinarily I wouldn't think that eventually I'd return here, but actually we know that the earth is earth is round, so eventually we're going to reach back at our original point.

And that's similar to what would happen in a finite universe. Well, it looks like this actually isn't the case. There are some very interesting measurements that people have done about some radiation that we observe in the sky called the cosmic microwave background radiation. People have done measurements of the stuff. I'm not going to get into exactly what that stuff is, but in a couple of weeks you'll know more about it.

But there is this radiation that we just see when we look out-- when we point our telescopes and look at the sky. There's this radiation. And the way that this radiation looks actually gives us an indication to the geometry of the universe. There are these spots, for instance, in the radiation that would indicate whether the universe is spherical, or it might be hyperbolic, or it might be flat. It might just be one big line-- one hyperplane we would have to say.

And it looks like the universe actually is infinite. And it looks like the universe is flat, which is probably the least interesting case that's conceivable. But that's what it looks like. So it looks like the whole universe is infinite and flat.

So let's assume that's the case. It's supported by observations. And I think it's actually seems-- it's kind of hard to reason from intuition that the universe should be infinite, so I would try to reason from intuition that the universe should be infinite. But maybe it seems natural to some of you that the universe should be infinite rather than finite. In that case, you'd probably like this. You'd probably like this fact. Question?

AUDIENCE: What do you mean the universe is flat?

NICHOLAS DIBELLA: Oh, what do I mean the universe is flat? Well, this is what I mean by the universe being curved. For these ants, their universe is curved.

AUDIENCE: Oh, so it's not like it's a flat plane, just it doesn't curve?

NICHOLAS DIBELLA: Yeah, it doesn't curve. If it went one direction, you wouldn't return to where you started off. That's what I mean by the universe being flat. And it looks like the universe is flat and infinite.

AUDIENCE: In all geometries, would you be turned toward where you started though?

NICHOLAS DIBELLA: In all geometries, would what?

AUDIENCE: Like, if you're on a hypersphere, then unless you come back to where you started, it's not like that some different geometry it would be possible for it to be curved, but [INAUDIBLE]

NICHOLAS DIBELLA: Oh, yeah. It could be possible, that the geometry is curved but we don't return where we started. You can imagine something like-- I don't know. Something like this. So I go from 1D to 2D, and then you have to use your minds to make a 3D. And then you have to use your minds to make it 4D. Yeah, you can imagine something like this. You travel this way, keep going, keep going, keep going, and then you never return to where you started.

Yeah, that's possible. You could have fun thinking about possible geometries the universe could be. But that's not going to correspond to reality unfortunately. We can fun thinking about it. And for a long time, this is all that people were able to do, just think about it. We didn't have data long time ago. We don't have measurements that indicated that the universe is infinite. Question?

AUDIENCE: How is 4D supposed to look?

NICHOLAS DIBELLA: OK, how is 4D supposed to look. I can't tell you how 4D is supposed to look. Nobody can tell you what 4D looks like. You just have to have to try to visualize an analogy of what some properties of it would be like. You can't actually see it, and that's something that we have to live with unfortunately. I mean, sorry. Yeah, question?

AUDIENCE: There are actually diagrams of what they think it might possibly look like, except not. They kind of explain--

NICHOLAS DIBELLA: Well, I know there are some diagrams I've heard of that, once you look at them, you kind of get an illusion that you're seeing the fourth dimension. Is that kind of what you're describing?

AUDIENCE: No, like, diagrams that show hypercubes.

NICHOLAS DIBELLA: Oh, oh, oh. Well, those diagrams that you're talking about are-- they're four dimensional objects that are embedded onto a two dimensional surface. So you're not really seeing it.

AUDIENCE: And how would they think that it's flat and infinite?

NICHOLAS DIBELLA: How, do they actually do this? How do they actually infer from the data that it's flat and infinite? Well, that's--

AUDIENCE: If you can only see as far as the observable universe, then that means that no matter what you see, you can't tell what's beyond that, and it could be.

NICHOLAS DIBELLA: OK. Well, we can't directly observe what's outside of the observable universe, but we can make indirect inferences.

AUDIENCE: But nothing comes from there. Like, you can't see radiation. You can't--

NICHOLAS DIBELLA: Nothing comes from there, but the universe-- the total universe-- has a certain geometrical shape. And there are clever ways of making these inferences. I don't have time to get into them now, but we'll talk later. So for the purpose of the rest of today's class, assume that the universe is infinite. This is the assumption we're going to make.

This has so many wonderful consequences, the assumption that the universe is infinite. I should say "the universe" is infinite. there are some theories about the early-- well, pretty much all the theories about the early universe speculate that a long time ago after this massive expansion following the big bang-- well, during this expansion-- all the material that was present dispersed randomly and formed certain arrangements of matter. And not only did it form some types of arrangements of matter, but actually this expansion created all different possible arrangements of matter to spread out.

So imagine a very long time ago, you've got all every possible arrangement of matter. So in this room, for instance, there are air molecules, there are molecules making up you, there are atoms and subatomic particles, and there's a finite number of particles in this room. And there is a finite number of ways that you can arrange those particles.

I could, for instance-- I'll make an analogy. Suppose I've got a rectangular universe. Before I had a volleyball universe, now suppose I have a rectangular universe. Suppose I have a rectangular universe that has four different types of particles. No-- let's say there are two different types of particles. So there's particle 1 and particle 2. These are all the different types of particles in our fake universe-- our play universe. We have 1 and 2.

And suppose there's only space in our universe for four different particles. Or yeah, say there's only space for four of them. Then what can we do? We can put 1 here. We can put 2 here. We can put another 2 here. And we can put another particle 1 there.

I know it looks like there's more there's more space for more particles, but let's say that this is the most that our universe our fake universe can accommodate. So this is one possible arrangement of those particles. Another possible arrangement of those particles would be to have 1, 2, 1, 1. Another one would be 1, 2, 1, 2. In fact, how many different arrangements are there in this universe?

AUDIENCE: 16.

NICHOLAS DIBELLA: 16. Yeah, it's 16. There's two for this one, there's two for this one, two for this one, and two for this one. Two, times two, times two, times two, is 16. So there are 16 different possible arrangements of these particles. In this universe. And so, there are really 16 different types of realities in this universe.

Reality is defined essentially by how various particles are arranged. And somehow the way these particles are arranged gives rise to how we perceive them and so forth. So the arrangement of particles gives rise to the reality that those particles impart to us.

Now, our universe, of course, is not rectangular like this. Well, that's actually not so important. But our universe is much bigger than this universe that we have here. I'll go here to this board. Our observable universe is a sphere. Remember, the whole universe we suspect is flat and infinite, but our observable universe is some finite sphere.

And our observable universe has a certain radius. And this radius happens to be-- I have it written down-- 8 times 10 to 26th meters. Now, suppose a particle has a radius of about-- OK, what we want to do now is fit particles into this universe. And we're going to ask how many particles can we fit inside of it. It's going to be a lot of particles, because the observable universe is really big and the particles are really small. But we can get a rough estimate for how many particles we can put inside of it.

So a particle-- say this is a little particle-- looks like a TIE fighter. What am I doing? OK, say this is a particle, and it's got a length of about 10 to the minus 13 meters, which is significantly smaller than the length of the observable universe. Well, now you can ask, how many of these particles can you fit inside of this universe?

And to do that, you can simply calculate the volume of this universe and divide by the volume of a subatomic particle, which might be a proton, or a neutron, or something like that. Simply take those two volumes and divide them. Take the radius, cube it. Use the formula for the volume of a sphere and then just divide by that formula applied with this radius. And you get about 10 to the 118th particles.

AUDIENCE: That's more than a google.

NICHOLAS DIBELLA: That's more than a google, yeah. But it's not more than a googleplex. Particles--

AUDIENCE: What's a googleple?

NICHOLAS DIBELLA: A googleplex is 10 to the 10 to 100. So it's 10 to the google. So a google is 1 followed by 100 zero's, but imagine a number of followed by a Google of zeros. Yeah. There's not even there's not even space for that many particles in the observable universe. That's how big a googleplex is.

Did you guys hear that the term googleplex was actually proposed by a nine-year-old or something like?

AUDIENCE: Somebody's nephew.

NICHOLAS DIBELLA: Yeah, some mathematician's nephew or something like that.

AUDIENCE: What's a googleplex again?

NICHOLAS DIBELLA: What's a googleplex again? It's 10 to the google. And a google is 10 to the 100. That's just cool stuff-- cool math terms to know. Like zenzizenzic and other stuff. Disregard that. Disregard that.

10 to the 118th particles can fit in our universe. That's how many particles can fit. But now we can ask, how many different arrangements of particles can there be in this universe? And that's an extremely large number.

Over here in this simple universe, we had space for four particles, and we found that the number of different arrangements was just 2 to the power of 4. And that was 16.

AUDIENCE: [INAUDIBLE]

NICHOLAS DIBELLA: Oh yeah, you can also have no-- so it would be three. Yeah, it would be three. Yeah, you could have no particles there, so it would be three. But once we apply that idea to this-- 2, 3, raised to a huge number. It's not going to make a whole lot of difference. And oh, yeah, and here I'm just thinking about one particle. So I should have said 3 to the fourth, because you could have zero particle at a slot.

So 10 to the 118th particles can fit in our universe. And that means that there are 2 to the 10, to 118th different arrangements. And that number is actually greater than a googleplex.

AUDIENCE: Whoa.

NICHOLAS DIBELLA: And that's actually-- I mean, I said 2 versus 10. That didn't really make a whole lot of difference. Now, that number's actually about 10 to the 10 to the 118th. It's approximately that.

That's how huge it is.

Now, I can ask, if the universe started out with every different possible arrangements of particles-- If we started out with this vastly huge number of different ranges of particles, then by now you'd still expect to find every possible arrangement of particles. You'd still expect to find that. The laws of physics will allow that to happen.

So now I can ask-- well, if you do have an infinite universe, then how far do I have to travel before I reach an exact copy of our observable universe? How far do I have to travel to get to that? Well, there are 10 to the 10 to the-- is that right? Is that approximation good? I think it is, right? Maybe I made a mistake.

[INTERPOSING VOICES]

NICHOLAS DIBELLA: I have things written down.

[INTERPOSING VOICES]

NICHOLAS DIBELLA: Well, actually, I think it's OK. I think it's OK Yeah, doesn't matter a whole lot. But now I can ask-- eventually, as I travel from our observable universe to another universe to another universe to another universe, eventually, you'd expect these arrangements to repeat. Because they have to eventually. If you come across 2 to 10 to 118th arrangements and then you get to another one, well, you have to repeat it, because there's only that many different arrangements.

And so, if you travel far enough, then applying that reason to our own universe, you'd expect to find an exact copy of our own universe. And you'd have to travel about-- well, you could take the size of our observable universe and just multiply it by the number of different arrangements. And so, you'd expect to find an exact copy of our universe at about 10 to 10th to the 118th meters away. I mean this is a really huge number, so we don't have to be a whole lot precise about how we manipulate them.

So you'd expect to not only find a copy of yourself, but you also expect to find a copy of New York. You expect to find a copy of the planet Mars. You expect to find a copy of the Andromeda galaxy. You'd expect to find an exact copy of every single piece of matter in the huge observable universe.

In another you are having this exact same conversation. OK, OK. In another-- now, here years where quantum comes in. Here's where quantum mechanics comes in. According to quantum mechanics, there's a-- what I'll do next, my next action, isn't predicted with 100% certainty. My next action could be that I throw a chalk at you, or it could be that you use some sort of mental powers to pull the chalk from me somehow, through some very complicated contrived quantum tunneling mechanism.

But the fact is that my future isn't known with complete certainty. And so, there are a number of possibilities of what my future would be. And there's a number of possibilities of what your future would be-- and your future, and your future, and the entire future of the observable universe actually. And actually, there's an infinite number of possible futures of every particle for the observable universe.

And there's a non-zero probability associated with each one of these possible outcomes. And that means, that if you travel far enough, you'd eventually not only reach an exact duplicate of her of our universe at this instant, but you'd also find an exact duplicate of our universe that has the same exact future of 10 minutes from now, and the same exact history, and same exact everything. And you'd expect to find infinitely many of those. It's crazy, but it's true.

And actually, this is the least controversial type of parallel universe. This is the least controversial type. This is only what's called a level I multiverse. So the multiverse is the whole collection of all these universes, which we say are parallel-- we call them parallel universes. The multiverse is the collection of all of these. And this is the simplest type of multiverse.

AUDIENCE: So are all the different really possible though? Because, don't they have to obey laws of physics and stuff like that?

NICHOLAS DIBELLA: Yeah, yeah. OK. Every arrangement that obeys the laws of physics is possible. But the laws of physics are pretty flexible.

[LAUGHTER]

No. I mean, flexible in the sense that if you conceive of something happening, then if you're smart enough, then you can figure out a way for it to happen. And actually, precisely proving that it's possible for me to, I don't know, as a result of lifting up my foot I cause one of the students in the back to think about Harry Potter, to prove that that's possible is really hard. And it might actually not be possible.

But I suspect that it's possible, because you have all these different things that could happen. I could somehow affect the air molecules here and cause them to do something that will propagate, reaching the students in the back, and then affecting his neurons in some way. It would be it would be very complicated, but it's really hard to prove that. But I hope it's true. And I hope I'm not crazy for hoping that it's true, because I think it would be so cool if it's true.

Some people object to these ideas because they find them weird. But I actually hope they're true because they're weird. And I think it's really cool. Yeah, question?

AUDIENCE: Yes. So all this depends on that that the universe is infinite?

NICHOLAS DIBELLA: Yeah. This all that depends on the assumption that the universe is infinite. OK. If the universe is big enough however, but not infinite-- if it's really large, but still finite-- then it's still possible to find an exact copy of our universe. But it wouldn't be guaranteed. It wouldn't be guaranteed. Question?

AUDIENCE: Do you mean the universe or the amount of matter in the universe?

NICHOLAS DIBELLA: Well, necessarily both.

AUDIENCE: Space could be infinite, but there might not be--

NICHOLAS DIBELLA: Oh, that's true, that's true. Space could be infinite, but there might not be an infinite amount of matter. So you can imagine, for instance, what's been called an island universe. You have an infinite universe, but there's only matter and energy at a very small island in the universe. And if that's true, then you can make predictions about what you'd observe with various astronomical measurements.

You can make definite predictions with that type of model. And people have made some predictions with that type of model. And it turns out that those models are ruled out by observation. The island universe is ruled out by observation.

AUDIENCE: So there has to be enough matter to fill the entire universe?

NICHOLAS DIBELLA: Yeah. There has to be-- matter has to persist throughout the whole universe. And there's good evidence that it does.

AUDIENCE: But how could there ever have been an infinite amount of matter in one point?

NICHOLAS DIBELLA: How could there ever have been an infinite amount of matter at one point?

AUDIENCE: [INAUDIBLE] had to create it. So it must have been all--

NICHOLAS DIBELLA: Well, that's a hard question. And actually, a process called inflation might explain that. And I'm going to talk about inflation in a minute. Where am I on time? Let me see.

Yeah, we could take a break here. We'll take a break here. I'll return talking about inflation and the level II multi-verse.

I mentioned that the level one multi-verse is the least controversial, and it's the least weird. So if you thought that was crazy, well, listen to this. Now, I'm going to discuss the level II multi-verse.

So in the level I multi-verse, the only kind of weird thing that happened was that there were universes outside of our own that had different arrangements of matter. And there's only a finite number of arrangers of matter and a finite amount of space that are possible. So if you travel far enough, then eventually you reach a copy of our arrangement of matter, and you'd find a copy of our history and our future. And that's pretty much all there is to a level I multiverse. Question?

AUDIENCE: There's no way anything could get more complicated than what we just did.

NICHOLAS DIBELLA: There's no way that anything could get more complicated?

AUDIENCE: It's not possible

NICHOLAS DIBELLA: It's not possible. OK. Well, in a level II multiverse, not only are there different arrangements of matter in finite Hubble volumes, but we also have different dimensionalities of space and time. We also have different properties of particles. For instance, the mass of the electron is different in a parallel level II universe than it is here. Different properties of particles, and different physical constants.

I'm going to talk more about this in the second, what each one of these means. But first, let me tell you how this could happen. So there's a-- hi.

There's a popular theory that's proven enormously successful to explain the early universe, and this theory goes by the name of inflation. And inflation refers to an extremely, extremely rapid expansion of space in the early universe. So you can imagine, a very long time ago, you had the universe, for instance.

Say this is the whole universe, and it expands very rapidly. It's hard to visualize that, but just try to think in your heads that the distance between points expands, and expands really rapidly. That's what I mean by space expanding. So space expands everywhere. Space everywhere expands.

However, there are some regions in the universe where space stops expanding. And it stops expanding just because of what are called quantum fluctuations. There is a quantum probability that space here will stop expanding, and there there's a possibility here that space will stop expanding. And so, there are lots of regions that pop up around the universe where space has stopped expanding. And we call these regions bubbles. So the universe has expanded, and there are some bubbles where space has stopped expanding. And there are some other regions where space continues to expand really fast.

Well, it turns out that when this happens a very mysterious process called symmetry breaking-- spontaneous symmetry breaking-- occurs. And it occurs in each one of these bubble universes. So this is a bubble. It occurs in each one of these bubbles. And as a result, the symmetry breaking, what happens is that these values become fixed-- the dimension of space becomes fixed, the dimension of time becomes fixed. I mean, the number of dimensions of space and the number of dimensions of time become fixed.

So in our universe, for instance, there are probably three dimensions of space and just one dimension of time. And that's exactly what we observe. I can walk forward, backwards, upwards, downwards, sidewards, rightwards, whatever. So there are three different directions we can travel, and those are the three dimensions of space. And there also appears just to be one dimension of time that we travel, and we travel into the future.

So there's one dimension of time. And that's what's symmetry breaking did for our bubble. It fixed the dimensionality of space and time to be 3 and 1. Symmetry breaking also fixed-- by fixed, I mean it determined-- determined the different properties of particles. For example, it fixed the value of the electron mass, which is, as you know, about 9.1 times 10 to the minus 31 kilograms. It fixed the mass of the proton, which is about 1.67 times 10 to the minus 27 kilograms. It's fixed the mass of-- those only the two ones that are the mass I know.

It fixed the mass of lots of other different particles, and it also fixed things like charges-- like, electric charge. Why? Well, I'll get to why in a minute. But it's also fixed electric charge. It also fixed some property called spin, which is a type of intrinsic angular momentum. Don't worry about it if you haven't heard of it.

It also fixed-- well, it fixed a whole bunch of properties of particles. There are certain properties that particles have, and they have these properties because a type of symmetry breaking occurred in the early universe as a result of inflation. Let me write this down-- inflation. And so, different properties of particles were determined, and different dimensionalities space and time would determined. And also, different physical constants are determined. I mean, the speed of light is about 2.99792458 times 10 to the 8 meters per second, for example. And that value was determined by symmetry breaking.

It's also conceivable that our bubble universe could have been-- what's the word I'm looking for-- given, or could have been imparted with a different set of these numbers. Our universe could have had a dimensionality of space being four. There could be four dimensions of space and one dimension of time. And if that were the case, then our world would be quite different. And actually, we probably wouldn't exist in this world.

First, it's easy to visualize what four dimensions of space would mean in terms of how we can move. We would have four different independent directions that we can move. That's what it would mean for there to be four dimensions of space. But actually, you can make some predictions about how atoms would behave if the laws of physics are the same but the dimensionalities of space and time are different. And you can make these predictions by simply fixing up the equations of the laws of physics in an appropriate manner, and then get at some results.

By the way, all of these bubble universes have the same laws of physics. They have the same laws of physics. The only things that are different are the dimensionalities of space and time, the properties of matter, and the physical constants, like the speed of light. Also what could differ-- Well, within each one of these universes there could be a whole slew of type I universes. So type I is kind of contained in type II. So you have infinite number of type I, an infinite number of type I there, and so forth. But they all have the same laws of physics.

Now, you can make certain predictions about what the world would be like in a universe with different dimensionalities from that of our own. For example, if the dimension of space-- let's say there are four space dimensions and five time dimensions. Which is conceivable. Its hard to imagine, but it's conceivable. And you can fix the equations of physics to include for this number of dimensions.

Let's say there are five time dimensions. Well, such a world would be very different from our own. Because it turns out that if our universe were like this, then it would be absolutely impossible to make a prediction about any event with a non infinite uncertainty. So we couldn't make any prediction.

We're able to make pretty good predictions in our own universe, right? I mean, I predict that this chalk, once I drop it, will fall on this paper with an uncertainty of say 1 mile. I don't know. So there's an uncertainty of one mile of where this chalk will fall.

OK, It worked. My uncertainty was non-infinite. It was pretty big, but it was non infinite. And it turned out to correspond to what we observed. Well, if these were the dimensionalities of space and time, you wouldn't be able to get any better than infinite uncertainty.

You can also can imagine there being just one space dimension, and there being like four time dimensions. So let say one space and four time. Well, in this universe with these dimensionalities, it turns out that all atoms are unstable. They're immediately unstable.

If I had an atom it would just exist for a split second and then that would be the end it. It would be impossible for molecules to form. It would be impossible for atoms just to sit there, much less than stick together to other atoms. And it would be impossible for macromolecules to form. It would be impossible for simple cells to form-- What's that?

AUDIENCE: No sentient life there.

NICHOLAS DIBELLA: Yeah, no. No life there. This type of universe would be completely devoid of intelligent people like us.

[LAUGHTER]

Yeah?

AUDIENCE: What would it be like outside of these bubbles?

NICHOLAS DIBELLA: Outside of these bubbles?

AUDIENCE: Would the amount of dimensions and all properties of physical constant be changing all the time? They would never be the same?

NICHOLAS DIBELLA: You mean--

AUDIENCE: If you left the bubble, and you were just in the rest of space, I guess continuing to expand.

NICHOLAS DIBELLA: I'm not exactly sure. I think-- Yeah, I'm not sure what it's like outside the bubbles. I don't completely understand this. I'm telling you the stuff that I do know.

AUDIENCE: Do you know if it would be like just one moment they're inside the bubble and everything is normal, and the next minute they're outside the bubble and it's completely different?

NICHOLAS DIBELLA: Oh, oh, oh, oh. OK. Well, I can kind of answer that. I can kind of answer that. These bubbles are infinite in size. So once you're in one of these bubbles you can't get out. You're not going to be able to get out. And you can't interact with the other bubbles unfortunately.

AUDIENCE: How are they infinite in size if there's more than one of them?

NICHOLAS DIBELLA: That's kind hard to imagine how they can be infinite in size and with more than one of them. But that's simply-- I know it's hard to visualize. But infinity is a really weird concept, and it does weird things to you when you think about it.

AUDIENCE: But the entire universe in its entirety is infinitely larger than infinitely large things.

NICHOLAS DIBELLA: Yeah. You have to be pretty careful when you use the word infinity. You might have heard about different types of infinity, like countable infinity, uncountable infinity. For instance, there are more irrational numbers than there are rational numbers. And I'll let you all wonder about that. The point is, the way you deal with infinity is kind of weird, and it's kind of confusing, and it does weird things to you.

AUDIENCE: [INAUDIBLE] any amount of any number-- any combination of sounds has to be a number.

NICHOLAS DIBELLA: Any combination of what?

AUDIENCE: Any combination of sounds ever has to be [INAUDIBLE] of a number. But there are infinite numbers. And there are less-- you have to have--

NICHOLAS DIBELLA: I don't know what you're talking about. What? Talk to me after class. I don't know.

OK. Well, getting back to this. In this universe with these dimensionalities, atoms would cease to exist. They'd just be completely unstable.

Now, this level of multiverse actually provides a nice explanation for the question, why is there one dimension of time and why are there three dimensions of space? Why is the mass of an electron this number? Why is the speed of light this number? Why is Newton's gravitational constant this number?

It provides a nice explanation for that. Because there are infinitely many bubbles. And there are infinitely many different types of symmetry breakings that can occur. So you'd expect to find some probability distribution of various dimensionalities of space and time. You'd expect to find a probability distribution of various properties of particles and various values of physical constants. And so, it just kind of occurred by chance that our universe has these certain values.

If it were the case that these other bubbles didn't exist. If it were the case that they were just one universe with one set of numbers for physical constants, one set of numbers for properties of particles, one set of dimensionalities for space and time. If there were just one universe with those very specific sets of numbers, then it's very hard to explain why those numbers and why not other numbers.

Well, the level II multiverse provides a very elegant explanation-- it just occurred by probability. It's just a result of symmetry breaking occurring in the early universe. That's a wonderful explanation. Another explanation that's been traditionally proposed is that something fine-tuned those values. Well, that's a kind of controversial view that I think is less elegant than this multiverse theory.

Question?

AUDIENCE: Well, you were saying that all this is happening from our universe. So from our big bang all this happened?

NICHOLAS DIBELLA: Yeah. From our big bang, this all happened. OK. So there's one huge universe, which is "the universe." Which you could say is "the multiverse." And inside the multiverse there are various infinite bubbles that arised as a result of this process called inflation occurring. And a result of this symmetry breaking occurring, fixed these various numbers.

AUDIENCE: But does that mean that all this happening now, is that-- if space is infinite, could there be another big bang?

NICHOLAS DIBELLA: Oh, could there be another big bang? Yeah, there there could be. There could be another big bang. This whole subject of talking about the universe as a whole, this is the subject of cosmology. And there are a lot of really cool ideas in cosmology. You can talk about multiple big bangs. You could talk about the universe expanding and then contracting, and then being a cyclic universe. There are lots of cool ideas.

It's possible that there could be multiple big bangs. And I think it might be possible within this theory. And that might even-- there are various versions of inflation, and there are probably lots of versions where multiple big bangs do occur. But I'm not an expert on it, and so I'm just feeding you what I know.

Was there another question? Yeah.

AUDIENCE: How many meters is on kilometer?

NICHOLAS DIBELLA: How many meters is one kilometer? 1,000.

AUDIENCE: OK, that's it.

NICHOLAS DIBELLA: Very deep, philosophical question. OK. Does anybody have the time? I'm not going to look at my--

AUDIENCE: 2:39

NICHOLAS DIBELLA: 2:39 OK. Let's see.

So this is the level II multiverse. I think I'm going to skip level III and going to just go to IV. I don't think we have time to do all of them. But level III would actually take a long time to explain, because, well, level III has to do with the many worlds interpretation of quantum mechanics, and I would have to explain that first and then talk about crazy consequences.

But actually, the level III multiverse doesn't add any qualitatively new features. Like, you we still have these different sets of numbers. You still have different arrangements of matter. So I'm just going to push forward to level IV, which is the highest level multiverse. You guys ready?

AUDIENCE: No.

AUDIENCE: Always.

AUDIENCE: Never.

AUDIENCE: It's scary.

NICHOLAS DIBELLA: It's scary?

AUDIENCE: Yeah. It's [INAUDIBLE]. How did they even come to this?

NICHOLAS DIBELLA: How did they come to this? Well, inflation was discovered by--

AUDIENCE: We're still discovering things on Earth that we don't know. How do we figure out--

NICHOLAS DIBELLA: There are a lot of really smart people that have thought of these things, and inflation was actually discovered by physicists here at MIT, Alan Guth. He discovered this inflation mechanism. And it actually it explains a whole lot of phenomena that are really hard to explain, and impossible to explain with other mechanisms.

It explains why, for example, the universe is roughly uniform. Why the universe roughly looks the same no matter where you go. It looks roughly the same. It explains lots of things like that.

Question?

AUDIENCE: Is he still here?

NICHOLAS DIBELLA: Yeah, yeah. I have his book [INAUDIBLE]. Oh, good. Cool, cool.

AUDIENCE: So you must ask him--

NICHOLAS DIBELLA: Yeah.

AUDIENCE: Is he a teacher.

NICHOLAS DIBELLA: Yeah, actually next semester I'm taking a class that he's teaching, called The Early Universe. And that's really cool that we students get to take classes taught by the absolute experts on these fields. So yeah, come to MIT.

[LAUGHTER]

OK. So now level IV multi-verse. I looking doing that too.

Now, level II multi-verse, we had different dimensionalities of space and time, different properties of particles, different physical constants, but the same laws of physics. Well guess what's going to be different in the level IV universe? Different laws of physics, yeah.

AUDIENCE: That's weird.

NICHOLAS DIBELLA: It's been noticed for a long time that-- well, the universe is explained very well by mathematical models. A lot of you probably haven't taken any mathematical classes on physics, but there are lots of equations in physics that give rise to these various predictions that I'm talking about. And I gave you some equations in the second class. Maybe I shouldn't have-- but somebody influenced me.

But there are various equations in physics. And there are various equations that are very specific to a particular set of laws of physics. And we say that these laws of physics have a particular mathematical structure. And it's been a view for a long time that these mathematical structures merely approximate the universe. Maybe the universe is impossible to describe with math.

Our models predict very well what we should observe in the universe, but they're not perfect. In fact, we know for a fact that we don't have the precise-- we don't have the absolute correct model for our universe. Well, because, actually, quantum mechanics and general relativity don't work with each other. They contradict each other. And this is a problem in modern physics that people are working on solving.

String theory is one hope for-- what's that?

AUDIENCE: So only one is right?

NICHOLAS DIBELLA: Well--

AUDIENCE: Or is it mixable? [INAUDIBLE]

NICHOLAS DIBELLA: The question is, is there only one mathematical structure that can model the universe? Well, you could probably think of different sets of equations to give the same results. But if that's the case, then it might have to be that they're all really manifestations of the same thing.

AUDIENCE: OK.

NICHOLAS DIBELLA: They might all be isomorphic, is the technical term-- the term the mathematicians use.

AUDIENCE: So how would they decide which model is the right or wrong one?

NICHOLAS DIBELLA: How would they decide which model is right for our universe? Well, first of all, you to have a consistent model. You have to have a consistent theory. It has to be consistent. General relativity plus quantum mechanics is not consistent.

When you try to talk about the quantum mechanics inside of black holes for instance, you get at results like infinite probabilities. And what does an infinite probability mean? It's meaningless. It doesn't really mean anything.

And so, the theory we have right now is inconsistent. And people are searching for a consistent theory. And so far, string theory looks like it's our best hope. But that's not worked out yet. But it's doing better than other theories, and so, it receives a lot more attention. But it's still the fundamental problem.

AUDIENCE: How do they determine consistency then?

NICHOLAS DIBELLA: How do you determine consistency? Well, you check to see, here are two things, do they agree with each other? If this is true and this is true, it implies that this is true.

AUDIENCE: Is it consistency with experiments of what we already know?

NICHOLAS DIBELLA: OK. Various types of consistency-- OK. First and foremost, it has to be consistent in itself. If it's not consistent in itself--

AUDIENCE: That's bad.

NICHOLAS DIBELLA: Then it gets bad. And secondly, we hope that it models the actual universe. I can think of a theory right now that's consistent, but it doesn't model the universe. I could propose a theory that the whole universe is determined by how I move this pen. I can think of various rules of how it works. But it doesn't agree with experiment. So we need something that agrees with experiment.

But it's been asked, why-- well, actually, it's been remarked by Einstein, that perhaps the most incomprehensible thing about the universe is that it is comprehensible. And it's comprehensible with the aid of mathematics. And many people have wondered, why does math work so well? Why does it work so well?

Maybe it's the case that the universe actually is mathematical. Math isn't merely an approximation, but the universe is mathematical. And that's the main idea behind this level IV multiverse.

So in our universe there is-- well, if it's true that the universe is mathematical, then in our universe there's a mathematical structure that is the universe. So the main assumption here is that the universe is mathematical.

Well, what kind of mathematical models? Well general relativity is, for instance, some sub branch of differential geometry and spacetime is a pseudo-Riemannian manifold. It's very complicated math. They're very complicated mathematical structures. But the fact is that they are mathematical structures. And the assumption behind the level IV multiverse is that the universe is mathematical.

Now, we can ask, why this mathematical structure and not other mathematical structures? And a nice answer to that question, similar to the answer to the question, why these dimensionalities, why these concepts and not others, is that there are many other universes with different laws of physics, which correspond to different mathematical structures. So I just proposed one before with the had to do with this pen. If I could formulate that into a mathematical theory that's consistent, then according to level for multiple IV multiverse theories there exist universes that obey the laws of physics as dictated by this pen.

In our universe--

AUDIENCE: And when you say there exists, would that mean that if you travelled far enough or something, or if you search the whole physical universe, you say, "there exists"--

NICHOLAS DIBELLA: "There exists," yeah, yeah.

AUDIENCE: You're going to find it somewhere?

NICHOLAS DIBELLA: You're going to find it somewhere. Yeah. But you probably won't be able to get to it because it's so far away.

AUDIENCE: Yeah.

NICHOLAS DIBELLA: And because it's moving away from a--

AUDIENCE: A different bubble or something.

NICHOLAS DIBELLA: Yeah, a different bubble. You probably won't be able to reach these.

AUDIENCE: Kind of like, existence is a iffy sort of a thing.

NICHOLAS DIBELLA: Existence is an iffy sort of thing. This is the most controversial level of multiverse. The first one that I described you seemed crazy at the time, but now we have different laws of physics, different constants. And level I we're at home with. question?

AUDIENCE: In the multiverse, is it possible for universes to overlap?

NICHOLAS DIBELLA: Is it possible for universes to overlap? Well, it depends on how you define universe. Is it possible-- are you asking for there to be two different level IV universes overlapping? Because if that's the case, then that would require the overlapped universe to obey-- well, it might require it to obey two different mathematical laws at the same time, or might just be an amalgam of the two.

AUDIENCE: Well if you have the two different mathematical structures though, right, sometimes mathematical structures do overlap.

NICHOLAS DIBELLA: Yeah. Yeah-- so, it's-- yeah. Yeah. Question?

AUDIENCE: Two things-- one, how fast or far can a modern rocket go?

NICHOLAS DIBELLA: How far what?

AUDIENCE: How far or fast can a modern rocket go?

NICHOLAS DIBELLA: I don't know how fast a modern rocket can go.

AUDIENCE: How far can it go?

NICHOLAS DIBELLA: How far can it-- well, if you just leave it, if you wait long enough, it'll go arbitrarily far-- a rocket.

AUDIENCE: OK.

AUDIENCE: It can go fast enough to cause the Doppler-- I know that things [INAUDIBLE] that had the Doppler effect [INAUDIBLE].

NICHOLAS DIBELLA: OK, yeah, yeah. Yeah. Yeah, rockets can go pretty fast. Let me get back to multiverses though. OK. What time is it?

AUDIENCE: 2:52

NICHOLAS DIBELLA: 2:52. OK. I have few more minutes. OK.

So in this level IV multi-verse you have different laws of physics. Our universe has one specific type that what we hope to one day find. We might not find it, but we hope we will find it. If we do find it, then that would be evidence for this level IV multiverse. It would be evidence for the assumption that the universe is mathematical. It we have evidence because we then would have a mathematical structure for our universe.

And if other universes exist with different laws of physics, then than that would be a rather nice explanation for why these laws not others. Well, it's because, every conceivable set of physical laws would exist. Every conceivable set of laws would exist would, and there's some probability distribution that your universe is equipped with these laws and not some others.

AUDIENCE: How would you ever determine--

NICHOLAS DIBELLA: How did you ever determine those probabilities? I don't know. I don't know. And I don't know how you would actually figure out if the level IV multiverse theories are true. Other than that they answered some questions rather nicely, like why these laws and not others.

It might actually be completely impossible the answer. It might be forever in the realm of metaphysics. But it provides a nice sense of closure to all of these universes. We can explain everything so nicely with the aid of parallel universes. Things it seems the things that seem once to be so mysterious, now they just fall under the rug or something.

Is that a-- I don't know. Am I using the phrase right? Fall under the rug? Swept under the rug? Is swept under the rug a bad phrase? Like, a mean phrase?

OK. Well, these questions are answered so nicely is what I'm trying to say with parallel universes. And they seem crazy, and they are crazy. But there is lots of evidence for them, particularly the lower level type multiverses. And so, we should take them seriously. And even if you don't take them seriously, you should at least appreciate them, that they give us nice things to talk about, nice things to think about. And they give us lots of more opportunities to make jokes. That's always one of my favorites.

AUDIENCE: Do you have any joke?

NICHOLAS DIBELLA: Do I have any jokes? Well, sure. I have lots of jokes. I had one joke-- I was planning on saying, one other type of conceivable universe that's level IV. In our universe, gravitation is not responsible for people falling in love, but it's conceivable that in another universe gravitation is responsible for people falling in love.

[LAUGHTER]