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**NICHOLAS**

Over the past couple of weeks, I talked about this thing called the universe, which is pretty big.

**DIBELLA:**

I talked about the possible beginnings of the universe, whether there was a big beginning of time, whether there will be an end, whether the universe is finite, what its shape is. Hello. And I described this basic picture that's-- we've begun to form over the past 100 years or so. And the basic picture is that yes, there was a beginning of time. We call it the big bang. There won't be an end. The universe will live forever. And the universe is also infinite and flat, in the sense that I described last time. Flat means that if you form a triangle and you added up the angles in the triangle, then you can get 180 degrees.

How I also talked about how we didn't fully understand the beginning what this big bang really was, and actually, when you think a little bit harder about it, we don't really understand the big bang. Our current physics theories basically, break down. And so it's entirely possible that there wasn't a beginning and most of our modern theories to explain this beginning-- I'll say, that it wasn't the beginning, there was time beforehand. So you don't really know if there is a beginning, but we're pretty sure that there won't be an end. And it's certainly also very plausible that the universe is infinite. We don't know for sure, but it's definitely-- all the observational data that we have is totally consistent with the universe being infinite and flat, in that sense I described.

That was the last two weeks. Does anybody have any questions? OK. Now, today, I'd like to describe some very interesting things that happen as result of the universe being very big. I'll assume for the rest of the class the universe is in fact, infinite. It might not be infinite, it might just be very large, but all the data seems to indicate that the universe is infinite. In an infinite universe, the craziest things happen. Anything that's possible happens. I mean, right now, there's a possibility that I'll just get bored with this class. You know, I'm teaching, but maybe I'm bored. There's a possibility that I'll get bored and just want to leave. So in another universe-- we say, in a parallel universe, I just leave the class. Bye.

**AUDIENCE:**

Bye.

**AUDIENCE:**

[INAUDIBLE]

**NICHOLAS**

Hi. Fortunately, we're not in that universe, we're in this universe. And I don't--

**DIBELLA:**

**AUDIENCE:** [INAUDIBLE]

**NICHOLAS** How do I know this universe, what?

**DIBELLA:**

**AUDIENCE:** Isn't parallel universe [INAUDIBLE]?

**NICHOLAS** Well, it is. I'll describe what I mean by parallel universes in more detail, more precisely, in a

**DIBELLA:** little bit. Yeah. I mean, certainly, our universe could be parallel to another universe. What's that?

**AUDIENCE:** Nothing.

**NICHOLAS** OK. So let me be a little more precise now. So we have to make a distinction between the

**DIBELLA:** whole universe and the observed universe. Whole versus observed. Now, the whole universe is exactly what it sounds like, it's the whole universe, but unfortunately, we can't observe the whole universe because the light was emitted only a finite amount of time ago from all the points in universe. In particular, about 13.7 billion years ago. So light hasn't had time to reach us for the most distant of galaxies, but it has had time to reach us from less distant galaxies, in particular the galaxies whose light has had time to reach us in the past 13.7 years.

And we call the points-- called the regions of space-- the region of space that we can see the observed universe. And the observed universe has been increasing in size ever since the beginning. So a long time ago, on the point where we are right now, had observed universe that was not very big. I'll just draw it like this. Let's say this is us. It's spherical. The observing universe is spherical. Any direction is as good as any other. If light has had time to reach us from there, then it has had time of year is just from there, and it's had time to reach us from there, and so all directions. So the observed universe is spherical. And is increasing in time.

So maybe-- let's say maybe, a billion years after the Big Bang, the observed universe was this size. Maybe after a little bit more time-- let's say this is 10 billion years after the Big Bang. So this is us. And it should continue to grow in size for a long time. So us. And the universe-- the observed universe just keeps growing and growing in size. It's obviously, very big. It's about 40 billion light years across. Well actually, 40 billion times two. A light year is just how long-- a light year just how long light-- how far light travels in a year. And the radius of the observed universe is about 40 billion light years. That's a little bit greater than 13.7 billion light years.

13.7 billion years being the age of the universe. That's a detail that comes in from general relativity. Distances get stretched to detail.

OK. So the observed universe is smaller than the whole universe, and you might wonder well, if you can't observe anything outside this observed universe then how do we know-- how do we know for sure if anything exists outside of it? I mean, we can't see it. So it's entirely possible that the universe just stops right there. I mean, it could just conceivably stop. There could be some kind of a boundary, some kind of a-- maybe some kind of a stop sign.

But as I talked about last time, none of the predictions of general relativity about the overall size and shape of the universe predicts a universe like this. This kind of finites. General relativity does predict a kind of finite, but it's the kind of finite that's my vitamin water bottle is. The kind of finite that's closed. So you're still standing on one part of the universe and you keep walking, and eventually, you make a circle. Or it could mean more like the universe at the surface of a sphere. You keep walking on the surface of this hypersphere, and then you eventually reach-- you return to your original point.

But as I talked about last time, it doesn't look like the universe is like that. Our data is not consistent with that kind of finites. It's certainly not consistent with that kind of finite. And it's actually consistent with an infinite universe that's flat. So all of our data seems to indicate that the universe is infinite. And that's exactly what I'll assume for this class. So we have indirect evidence that the universe is infinite. Direct evidence would be that we somehow measure that it's infinite. But how would you measure that it's infinite? The best we can ever do is really have indirect evidence. Any questions about that?

Now, according to our best modern theories about the very early universe, there is matter and energy present. The energies were very high. The temperatures were very high. And all the matter and energy were spread around pretty randomly in the very beginning, right after the Big Bang. And this process of spreading everything around, actually led to pretty much all possible initial arrangements of matter and energy. I'll just a matter, just to keep things simple.

So you can imagine, for example, having some kind of a box. Some kind of a finite box. Let's say, it's a very small box and only has room for say, four atoms. So one atom could go here, another atom can go here, another one can go here, another one can go here. So you have four slots for atoms. So how many different possible arrangements are there in this box? You can only fit four. Does anybody have an answer?

**AUDIENCE:** 16.

**NICHOLAS**

**DIBELLA:**

Yes, 16. There are 16 possible arrangements because you can fit two-- you have two possibilities here. The atoms there are not. Two possibilities here. Two there. Two there. So two, times two, times two, times two, 16 possibilities. And so it's a finite number of possibilities of different arrangements you can have in this box. So 16 possible arrangements. You can also think of a bigger box that maybe has 100 slots for atoms, then that would lead to two, times two, times two, times two. A hundred two's, which is a very large number, but it's still a finite number.

Now, in an infinite universe-- in infinite universe, these arrangements will start to repeat each other. They'll start to repeat. I mean, there are only 16 possible arrangements in this box, for example. Now, if you have many of these boxes in the universe, each arrangement having some possibility of arising, then eventually, you're going to start getting repeats. Some of them are going to recur. And in infinite universe, every possible arrangements recurs and in fact, it occurs infinitely many times.

So there are infinitely many possible different occurrences of every single possible arrangement of matter and energy at the beginning of the universe. And that also should mean that today, there should be also, every single possible arrangement of matter and energy in the universe as well, for every single kind of a finite box. Because if you start off with one arrangement, you start with one configuration, then there's a chance that it will become another one. There's a chance it will become another one and every single-- pretty much every single possible arrangement has some chance of arising. So in infinite universe, you get them all.

In this room, for example, there are air molecules in the room, and it's theoretically possible that all the air in the room will somehow randomly spontaneously rush towards me, and they'll all rush towards right here, suffocating you all. That's totally possible. It's not going to happen in a billion, billion, billion years, actually, many more years than that, but it's totally possible. And in fact, let's say the chances of that happening are one in a billion, billion, billion. Let's say that's a chance. They're much, much lower than that, but let's say that's the chances of the air rushing towards me. It's theoretically possible. Let's say that's the chances of the air rushing towards me.

Now, if I had a billion, billion, billion copies of this room that are exactly the same, the same

distribution of matter and energy and same motions and everything then eventually, if that's really the chance is one in a billion, billion, billion, eventually that would happen. You would eventually get a repeat. And if you look-- I mean, you would probably get a repeat if you have a billion, billion, billion different copies.

Now, if you look at even more copies, if you look at a billion, billion, billion, billion, copies then the chances of a repeat happening are even higher. And then you look at even more samples, more copies, the chances are even higher. And if you have an infinite number of copies, an infinite number of boxes like this, then boxes that form the volume of a room, an infinite number of copies then the chances of getting a repeat are complete certainty. It must happen in infinite universe. You will get these repeats.

Now, we can look at the distribution of matter and energy in this room, for example and its universe is infinite. We'll eventually find a copy of it. We eventually find a copy of every single aspect of this room. Everything is made up of atoms and electrons and everything, and if the universe is infinite then this whole arrangement will repeat.

So if you travel far enough, you'll eventually find a copy of room 4270 on a campus like MIT on a pile like earth, and eventually, you'll get a complete repeat of the entire observed universe.

**AUDIENCE:** [INAUDIBLE]

**NICHOLAS** What's that?

**DIBELLA:**

**AUDIENCE:** So are we alive again?

**AUDIENCE:** So yeah, if you travel far enough. I mean, our current understanding of modern biology is that humans are made up of molecules and atoms, which are in turn made up of electrons and protons and quarks and photons and whole lot of other small things. I mean, these different particles interact in a very complex way to give rise to the very vast experience that we know as being the human experience. But in principle, we're completely reconstructed both from these fundamental pieces. And so yeah, if you travel far enough, you'll eventually find a complete repeat of all the matter and energy that make us up, that make up humans. And you'll find-- yeah, if you travel far enough, you'll find exact copy of you. You, the student in the green shirt. You, yeah. The one that asked the question.

And I mean, he's not really you. You're you. He's really a clone of you, a copy of you, a counterpart of you. Yes?

**AUDIENCE:** Isn't there a chance when he finds himself, he might not be wearing a green shirt because he might have chosen a blue shirt or something? [INAUDIBLE]

**NICHOLAS** Yeah, there's a chance that instead of wearing a green shirt today, he wore blue shirt today.

**DIBELLA:** So not only will he find the exact-- in a second. Not only will he find the exact distribution of matter and energy-- I mean, if I don't find the green shirt that's a little bit different, but let's say I still find the same human. But not only will I find the same distribution of matter, I'll also find every single possible history and every single possible future.

Now, if I look at a air molecule right here, sitting over here, and I follow its path, it might do something. It might do some kind of weird-- some kind of a weird path and then eventually land up on his glasses. All right. There might do some kind of weird path like that or it could instead of doing that, it could walk in this direction and then just go into the vent. There are a lot of possible paths that a given atom could take. There all possible histories that an atom can take. And really, pretty much every conceivable path that something can take is possible, theoretically. And so for any-- if something is possible, then it will happen in an infinite universe.

So you can think of not just-- I mean, it's certainly true that an atom-- a given atom will do infinitely many different things in infinite universe, but you can look at more complex things like, look at a system of five atoms or of 10 atoms or 10 to the 23 atoms or even more. And so you can look at all the atoms to make up a person. So while in our universe you decided to wear the green shirt today and another universe, you decided to wear a blue shirt today. At least your clone decided to wear a blue shirt today.

**AUDIENCE:** [INAUDIBLE] everything is supposed to repeat itself [INAUDIBLE]. But then wouldn't the clone [INAUDIBLE]?

**NICHOLAS** OK. So yes. Some of your clones will pick out the green shirts. Some of your clones will pick out the blue shirt. It really depends on how you define you. If you define you as being you must necessarily wear a green shirt on July 13, 2008, then obviously, those guys that don't wear a green shirt aren't you or at least they're not clones of you, how you define them. But you might define a clone if you as having some kind of essential characteristics that you share. For example, maybe-- I'm not going to speculate about your personality, but let's say, you're a

happy guy. You're a smart guy. You have certain idiosyncrasies. But there are certain non-essential characteristics of you, like the shirt you decide to wear in a day, but you'd still consider it as being you.

So yeah, clones of you-- yeah, some of them will wear green shirts. Some of them will wear blue shirts. Some of them won't wear any shirts at all, and then I'd have to direct you to the office to find a shirt. Yes, certainly. Question? Or actually, you had a question first.

**AUDIENCE:** It was along those lines. It's just if in an alternate-- on an alternate planet, such as ours, and you have the exact same situation, wouldn't his mind think in the exact same way? So we may see the exact same decisions to wear a green shirt?

**NICHOLAS**  
**DIBELLA:** Yeah. So the question is if he's really a clone of him then wouldn't he think the same way and make the same decisions he made? Well, maybe not. I mean, very often, I'm uncertain about what I should do. And like, should I wear this shirt, should I wear the shirt, and sometimes I just kind of randomly choose it. And so-- I mean, there's a chance he would wear the blue shirt, then in another universe he wears the blue shirt. Yes, question?

**AUDIENCE:** [INAUDIBLE] repeat itself, if you made certain mistakes, would you be able to change them?

**NICHOLAS**  
**DIBELLA:** If he made certain mistakes-- if everything repeats itself and you made certain mistakes, would you be able to change them?

**AUDIENCE:** Yeah. Then everything wouldn't repeat itself because the situation [INAUDIBLE].

**NICHOLAS**  
**DIBELLA:** Then everything wouldn't what?

**AUDIENCE:** Everything wouldn't repeat itself because the situation would be different, like after you change [INAUDIBLE].

**NICHOLAS**  
**DIBELLA:** Well, what you can do is you can travel-- I mean, these parallel universes are so far away from us that we probably wouldn't be able to reach them in a billion, billion, billion-- many lifetimes. But let's say you did reach one of these parallel universes where there's a clone of you, and you have the experience in knowing oh, he's going-- she's going to make this mistake, let me prevent it. And then you decide to prevent this mistake that your clone makes. Well, you're not really changing your past, you're changing the future of the clone.

I mean, in that particular universe your past doesn't repeat itself. But if you travel to another universe, you'll find someone who does repeat that mistake that you made. But you might not really care about these counterparts, these clones of yours. They're not you. I mean, I care about my past. I care about my future. I don't care about his or hers.

**AUDIENCE:** [INAUDIBLE]

**NICHOLAS** Yeah. I mean, they're not really you. You're you. Those are just clones of you that think  
**DIBELLA:** similarly, but fundamentally differently. Yes?

**AUDIENCE:** How do we know these parallel universes exists?

**NICHOLAS** How do we know they exist? Well, these parallel universes are really just a prediction of  
**DIBELLA:** assuming that the universe is infinite, and assuming that all possible initial conditions, all possible initial arrangements of matter were present in the very early universe. And those are two pretty reasonably uncontroversial assumptions.

Yeah, we don't know for sure that the universe is infinite. We certainly know it's very large, but it's totally conceivable that the universe is infinite. And all the lines of evidence seem to be pointing that it is infinite. So the infinity assumption-- some people don't believe it. Some people think that our evidence points towards it. But it's reasonably uncontroversial.

You might be you might be wondering about this other assumption the assumption of all possible initial conditions. That's really a prediction of a theory about the variable universe that hasn't totally been tested yet. It makes predictions. It's called-- it's a version of inflation, which I was describing last time. It makes predictions about things that we can observe like the cosmic microwave background. It makes predictions that are totally confirmed by the cosmic microwave background.

If you look at this radiation, these microwaves that permeates all of space, you'll see that the temperature is very uniform, pretty much the same, but it changed a little bit. And the precise way that it changes is exactly what inflation predicts. And so the fact that inflation makes predictions that are confirmed in one case should make us at least suspect that other predictions that it makes are also true. I mean, we don't have to totally believe them, but it's totally plausible that-- well, this prediction of all possible initial conditions in fact, true. And later, I'll talk about even more predictions that inflation makes, that are even stranger than what I'm describing right now. Is that clear? Does that answer your question?



**AUDIENCE:** Yeah.

**NICHOLAS** Question?

**DIBELLA:**

**AUDIENCE:** If everything is possible because there's chances of [INAUDIBLE], wouldn't there be a universe that-- parallel universes don't exist?

**NICHOLAS** Wouldn't there be-- if everything's possible, then wouldn't there be a parallel universe, such

**DIBELLA:** that other parallel universes don't exist? No. I mean, so I have to be a little more precise by what I mean by everything is possible. So I define occurrences as being what matter and energy do. How they move, where they are located. All the different possible ways that matter and energy can move and be distributed, that's what I define as a possibility.

I mean, the theory says that these parallel universes necessarily exist. I mean, it would be a contradiction if one parallel universe, people don't-- there aren't other parallel universes parallel to that. Well, it's certainly true that there will exist parallel universes where there exist scientists like us that-- I mean, none of them believe in parallel universes, that's totally possible, but just because somebody doesn't believe in something doesn't make it false. So it's possible that there are reasonably intelligent beings, just like us, but they haven't-- they've been around for a long, long time, maybe longer than us, and they haven't even figured anything out. I mean, that's totally possible. Yeah?

**AUDIENCE:** Wouldn't there also be a possibility that humans wouldn't exist right now in that universe?

**NICHOLAS** Yeah. There's also a possibility humans don't exist in that universe. Yeah, I mean, you can't

**DIBELLA:** you can use your imagination to think of a lot of very interesting things that could happen. I mean, seemingly magical worlds that we see in the movies like the magical worlds-- the magical world of Harry Potter. If everything-- if all those magical events that happen in the books can be described-- if you can think of a physical mechanism by which they can work, if you don't postulate some kind of a nonphysical thing, but if you try to describe them physically and if you can think of a mechanism by which they can work then it would totally happen somewhere else. At least if you really believe in quantum mechanics, which I haven't really talked about. If you really believe in quantum mechanics then the magical world of Harry Potter should exist. Star Wars, Star Trek, all these magical worlds should exist somewhere. Yes?

**AUDIENCE:** So basically, what you mean by parallel universes is since space is infinite, but matter arrangement is finite, there's an infinite number of arrangements that we are on?

**NICHOLAS**  
**DIBELLA:** Yes. So by parallel universe-- so what I mean-- I mean, we can define our observed universe as being our universe, and then another-- a parallel universe is a region of space equal in size to our observed universe, but where things are different, where the matter and energy is difference. Where there are no humans. Where there are maybe, more humans, smarter humans, better humans, faster humans, et cetera. Yeah, that's what I mean by parallel universe. Questions?

**AUDIENCE:** [INAUDIBLE]

**NICHOLAS**  
**DIBELLA:** Oh, OK. OK. So as I said, these very strange parallel worlds are really the result of two reasonably uncontroversial assumptions. And so it's quite amazing that these predictions would happen, but they do. And actually, we call this whole ensemble of parallel universes, as I've described them, we call them level one multiverse. We come up with a better name, multiverse. So this whole thing is a level and multiverse. Any final questions before I move onto the level two multiverse? OK. The level 2 multiverse--

**AUDIENCE:** Can I go to the bathroom?

**NICHOLAS**  
**DIBELLA:** Oh, let's see. I mean, yeah, you can certainly go to the bathroom. I was going to have a break in about 15 minutes.

**AUDIENCE:** OK. I'll wait.

**NICHOLAS**  
**DIBELLA:** OK. We can have a break now, but there won't-- well, we have a five minute break now, but there won't be another break for the rest of the class.

**AUDIENCE:** No, I'd rather have a 15-minute break.

**NICHOLAS**  
**DIBELLA:** No, there won't be a 15-minute break. There will be a five minute break. I was planning on having a five minute break in 15 minutes.

**AUDIENCE:** Oh. [INAUDIBLE].

**NICHOLAS**  
**DIBELLA:** You sure?

**AUDIENCE:** Yeah.

**NICHOLAS**  
**DIBELLA:** OK. Onto the level to multi-verse The level one multi-verse certainly sounds strange with all these parallel people, these parallel magical worlds and places where really good things happens to me, really bad things happens to me, really good things happen to you, and so forth. Certainly sounds strange that these things could exist, but the level two multi-verse, you actually have universes just like our own, but the very constants of nature are different. Things like the speed of light. Things like the mass of the electron. The mass of a proton. The number of space dimensions. The number of time dimensions. And parallel level two universes, they are universes that have different [INAUDIBLE], different constants, different speeds of light. So I'll write some examples. It's a different--

In our universe, the speed of light is 299,790,458 meters per second. It's good to know that for parties. But in other universes, you can conceive of the speed of light being something like 25 miles per hour. That's certainly possible. You can also have different mass of the electron. The abbreviation for electron. I mean, in this universe, it's about 9.1 times 10 to the minus 31 kilograms, but in another universe, it might be something like 30 pounds. Who knows? You could also have, as I said, different number of dimensions of space and time, different dimensionalities.

I know we're all familiar with the three space dimensions. I mean, we can move forward and backwards, left and right, and down and up. We're all familiar with three space dimensions, and the one time dimension that just moves forward. I mean, I just look at my watch or my cell phone, time marches on. So one time dimension. But other universes you can actually have different space time dimensionalities. Different from three plus one. You had a question?

**AUDIENCE:** I was wondering if in parallel universes if possible, that the universe was made at different [INAUDIBLE].

**NICHOLAS**  
**DIBELLA:** Was made, what?

**AUDIENCE:** You know, we think that the universe was made by [INAUDIBLE]. Is it possible that in another universe that, that universe was made in a different way?

**NICHOLAS**  
**DIBELLA:** So that's really a matter-- so the question is, is it possible that in other universes, the universe was made in a different way. So it's really a matter of how you're defining universe. I'll describe

how these universe come about in a little bit. Actually, let me just describe how these universes come about, then I'll come back to your question. OK.

So these things sound crazy, right? So why should we even believe them? Because there are predictions of this model. A particular version of inflationary theory, that I mentioned before, called chaotic eternal inflation. I'll just write it down. [INAUDIBLE] Prediction of-- And this is probably the best-- there's so many versions of inflation, but this certainly looks the most promising.

And so I was talking about the microwave background, the way it has these fluctuations. It has these slight deviations in uniformity. And this kind of inflation can exactly explain that deviation from uniformity. With inflation, you can also explain why the universe is flat. I mean, I mentioned last time that the observation seems to indicate that the universe is flat, but you might still be scratching your head and wondering well, why is it flat? I mean, why did that have to be the case? Inflation provides an answer.

It also provides an answer as to why the universe is so uniform. It explains this cosmological principle that I talked about last time, where the universe is really boring. You just travel and you see a galaxy here, see a galaxy there. Things don't really change very much. The density doesn't really change a whole lot. So inflation can also explain the uniformity of the universe. It can also explain some other things like, why there are no magnetic monopoles, if you've heard of that. Yes, question?

**AUDIENCE:** When you said, [INAUDIBLE] why is the universe [INAUDIBLE] earth is so flat. You said [INAUDIBLE]. It's also because of the gravity.

**NICHOLAS** Why is the earth so flat?

**DIBELLA:**

**AUDIENCE:** You said, why the earth is so flat?

**NICHOLAS** No, no. Why is the universe so flat?

**DIBELLA:**

**AUDIENCE:** Oh, sorry.

**NICHOLAS** Oh, yeah. I mean, but it's all related to gravity. I mean, these all come from theories. All these

**DIBELLA:** predictions are theories of gravity, essentially. Yeah. Right. So inflation can explain a lot of

features about our world and things that we observe, but also makes interesting predictions. Hello. They also makes interesting predictions. Like, it predicts the existence of these parallel universes. So it's-- I'll just describe, very briefly, how these universes come about.

So in this chaotic eternal inflation, the universe is infinite and it's expanding, and it's going to continue expanding forever, but there are some-- so let's say, this is the whole universe. But there is some patches, some pockets that eventually form. Some pocket universes that you actually form, and that stop expanding, and when these pockets-- the forming of these pockets are really big bangs in themselves.

You get these really weird particles that I was describing before that have repulsive gravity, and they form these pockets and when this happens, when these pockets form-- well, we call them universes. We call these pocket universes. And so this is really how we define a universe in the level two multiverse. So I mean, if you're talking about a pocket that formed, then that's a universe. And these pockets form-- the way they form is by a big bang kind of thing. And so it's really kind of by definition that universes have formed by big bang.

I mean, you can ask questions about the space in between these universes. Obviously, no big bangs happened there, but they could happen there. You can call those universes if you want, but they would be completely devoid of observers and intelligent life. And so no one would be there to call it the universe. So these pockets form and it's really like a random process that they form.

I mean, I'll talk more about quantum mechanics in a little bit, and even more in another lecture, but it's really fluctuations, quantum fluctuations that give rise to the existence of these pockets, these bubbles. And so occasionally, you'll get a bubble that forms and that's really our universe. Our universe formed by the creation of one of these bubbles. And when these bubbles form, a process occurs called-- oh, let's see. Oh, I'll just tell you. It's called symmetry breaking. A process occurs called, symmetry breaking. But you can't really go into a lot of detail about, but when this process occurs, each one of these bubbles is endowed with its own set of physical constants. It's own mass of electrons. It's own speed of light. It's own space time dimensionality.

And so you have an infinite number of universes forming. These are really-- each one of these is really-- it's really level one multiverse. So the level two multiverse consists of an infinite ensemble of level one multiverses, and each one has its own set of constants. So some will

form with three space dimensions and one time dimension. The electron mass will be the same mass that we have here. Speed of light will be the speed of light that we have here. And the universe would be just as we observe it.

But in others, you'll get maybe five space dimensions in, four time dimensions and others, you'll get maybe a 25 mile per hour speed of light. They'll happen. There's some kind of distribution of all these different constants, some kind of distribution of all these physical parameters. Yes?

**AUDIENCE:** [INAUDIBLE] like a different dimensional space dimensions. How would time dimensions work?

**NICHOLAS**  
**DIBELLA:** How would different time dimensions work? Well, it's hard to imagine what it would be like. We observe change in one direction. So it's kind of hard to imagine intuitively how it would work, but you can certainly work out the consequences by looking at your equations and adding in another extra dimension, adding in another time dimension and seeing what happens. You can certainly do that. It's easy to change the equations and try to understand mathematically what a universe with extra space dimension or extra time dimension is. But it turns out that if you make these changes, if you change-- if you tweak the number of space dimensions, and you tweak the number of time dimensions, it turns out that the combination that we live in today, three space dimensions and one time dimension is the only combination that's suitable for intelligent life.

It turns out-- let's see, I had something written. Oh, yeah. So yeah, if you live in a world with five space dimension and four time dimensions for example, atoms couldn't exist. You can just work through the equations. Atoms couldn't exist. They would be completely unstable. They would decay in a split second.

If you had one extra time dimension, events would be completely unpredictable. And when we do experiments, we always have some kind of an arrow bar, some kind of uncertainty attached to them. Well, if you had more time dimensions, then the arrow bar would become infinite. So you couldn't make any predictions. The world would be completely unpredictable. And you can also think about what would happen if the electromagnetic force was stronger than-- was stronger than nuclear force, for example. And it could work what happened, carbon would be unstable, for example.

And so our universe seems to be really-- seems to be magically fine tuned-- magically fit for life to form.

**AUDIENCE:** Maybe we were created as a backup.

**NICHOLAS** Maybe we were created so that we could exist.

**DIBELLA:**

**AUDIENCE:** Like, maybe we were created because-- like, this universe was the only one that could support life.

**NICHOLAS** Oh, yeah. Yeah. So people were puzzled by this for a long time. So why do we three space

**DIBELLA:** dimensions or one tiny dimension? Why is this-- why does this be like this? Why is the mass of electron this, and so forth? People are puzzled by this for a long time. Well, the chaotic eternal inflation provides any answer for it.

Universes with other constants and dimensionalities do exist, they do form, but in those universes you just don't have intelligent life. Or you don't have stable system. You don't have complexity. They're barren, their dead, basically. And so we shouldn't be surprised to find ourselves in a universe where we exist. I mean, obviously, we shouldn't be surprised to find ourselves in a universe where we exist because we exist. Yeah, we just look at ourselves. But we also shouldn't be surprised to find ourselves in a universe with three space dimension and one time dimension.

As for the other constants-- and the other constant like speed of light, mass the electron, it's a little unclear what different combinations would be able to support intelligent life and complexity, and so forth. But we certainly might be able to answer these questions by just looking at a distribution of different constants and whatever, and say, well, the ones that can support life, the ones that can support observers, would be ones that we shouldn't be surprised to find ourselves in.

So the hope is that-- I mean, so this is actually a testable theory. The hope is that if we actually form this distribution of constants and dimensionalities and everything, the hope is that we would find ourselves in a universe that is consistent with our existence and that is typical among members that have constants and dimensionalities that can support life. So if we find ourselves in a universe that isn't typical among these universes that can support life, then that would be a defect of the theory.

So it actually has predictive power. Well, it's actually, it's falsifiable. I mean, it predicts the

existence of these other universes, and also predicts that the universe should be flat, and so on and so forth, but these other universes are so far away that we really have no hope of ever observing them. But it's certainly falsifiable. The theory is certainly falsifiable.

And one way that people often define science, a scientific theory, is that it has to be falsifiable, that you can do an experiment or you can do an observation that, if it contradicted the theory, would automatically say, the theory is false. And that's true of this theory. It's possible that it's false. And we can test it by working through these distributions and seeing if our universe is a typical member. And people working on it,

Don't know the answer. People are working on it. So it's unknown.

And there are actually a lot of people that really don't like the solution. I mean, we explain-- I mean, chaotic eternal inflation explains away previously puzzling facts about our universe by saying that these features of our universe like, speed of light, and so forth, they were just randomly created without any real cause. They're just randomly created. But a lot of people are unsatisfied by this. They think it's kind of a cop out.

Many people feel that we should be able to derive these things like, three space dimensions and one time dimension, and so forth, from fundamental principles. A lot of people think we should be able to derive it. But we're having a hard time deriving them. And currently, it looks like the multiverse-- these multiverse theories offer the best hope of explaining it. But it's certainly possible that it could be derivable in principle from fundamental principles, but we don't know. But inflation certainly offers an answer. OK. Are there any questions about the level two multiverse? OK.

So just described the level two multiverse, and now we're going to march forward onto the level three multiverse. And this is a prediction of the so-called many worlds interpretation of quantum mechanics. So a prediction of many worlds.

Quantum mechanics, is a theory that was developed in the 1920s and it's been enormously successful in the describing the very small. In fact, it's one of the two most successful physical theories ever proposed. The other I talked about last time was general relativity.

Now, we've only tested quantum mechanics on small things like molecules and atoms and electrons, but it's certainly believable, reasonable to think that quantum mechanics applies to bigger objects. After all, bigger objects are made of smaller objects, right? I mean, I'm made



up of a lot of atoms. This table is made up of a lot of atoms. And each of these atoms can be described using quantum mechanics.

And so it's reasonable to think that pretty much every system is described by quantum mechanics, including the universe itself. So many worlds interpretation of quantum mechanics. OK. In quantum mechanics, there is a fundamental randomness to nature. According to quantum mechanics, you don't know for sure what you'll get as a result of experiments. For example, if you measured the position of an electron, you don't know if you'll find it to be here, or here, or here, or here, or so forth.

Well, there are some things that we know, some things that we can predict with a reasonable degree of certainty like, if I drop this chalk it will probably fall. It did. That proves quantum mechanics. But in general, you don't know for sure what you'll get in an experiment. You don't know for sure what you'll get when you measure something.

Now, we have a tool in quantum mechanics to help us calculate the probabilities, and it's called, the wave function. And this wave function tells us the probability of observing certain things. Probability of observing a certain speed of an electron or [INAUDIBLE] principal of a person, and so forth. But it's hard to do experiments, quantum mechanical experiments with people and larger objects. But this wave function tells us everything we want to know about probabilities of a given system. What speed you'll measure, what positions you'll measure, what energy you'll measure, and so forth.

Now, this wave function, there's nothing peculiar about the way that this wave function changes. So every object has its own wave function. I have a wave function. You have a wave function. An electron has a wave function. An atom has a wave function. In principle, the universe has a wave function. There's nothing-- and there's nothing peculiar about the way that it changes under most circumstances.

The wave function just obeys-- it generally just obeys a simple equation and tells the wave function how to change. It completely tells the wave function how to change. You can totally predict how the wave function changes under most circumstances. The circumstances where you don't know how it changes is when you make a measurement on something.

So there are two fundamental processes. There is measurement and there's non-measurement. When you're not measuring something, when you're not looking at it, you're for sure how its wave function changes. But when you measure something the wave function is

set to collapse, and you don't know for certainty what it will collapse to. You don't know if you'll measure one speed or another, if you'll measure one energy or another. You have some kind of a probability for each speed and for each possible outcome, but you don't know what it will be. You don't know what the result of your experiments will be.

So there are two fundamental processes. There is non-measurement and measurement. Now, for a long time, physicists have scratched their heads to figure out what this measurement really is. I mean, what this collapse of the wave function really is. It collapses randomly. You don't know what it's going to collapse to. What does it mean? And people for a long time have tried to come up with theories to explain what measurement is.

And in the 1950s, an alternative interpretation of quantum mechanics came out. What I've described so far is by the traditional interpretation of quantum mechanics or really, the traditional formulation of quantum mechanics. They're really different formulations. This is the traditional way the quantum mechanics is formulated.

But in the 1950s, a new formulation was hypothesized, and that today, goes by the name of the many world interpretations. In 1950s, many world interpretation came out. It's actually probably not the best name for the interpretation. It's a very misleading name that's confused a lot of people. All it says-- all the many world interpretation says, is that the wave function just changes by this predictable equation that I described. There's no more of this collapse. There's no more of this mysterious collapse that occurs in measurement.

Measurement is now this process that occurs according to this equation, which I won't write down, and there's nothing very mysterious about it. I mean, there are certain types of interactions that a system can undergo, and some of these are just favorable to this measurement appearance, this collapse appearance that we see. And so that's what the many worlds interpretation is. It's just-- you just have one fundamental process. You just have the type of process that was supposed to happen with this non-measurement. So one fundamental process. OK.

Now, in both of these interpretations, both the traditional and the many worlds interpretation, you have something called a superposition. Now, I know I'm introducing a lot of terms today. I'm introducing a lot of terms-- I mean, to describe this kind of level three multiverse, but it'll be worth it. You have something called superposition. And this is really a mixture of state, mixture between states. I'll describe a little more in one second. OK.

One possible state is that you've got a cat, if a cat that's alive-- that's totally a possible physical state.

**AUDIENCE:** [INAUDIBLE]

**NICHOLAS**  
**DIBELLA:** We can-- I'll get to that in a second. You can have a state that's alive. So you have a state where a cat is alive. That's one possibility state. And you can also conceive of a cat being dead. That's another possible state. Now, according to quantum mechanics, you can also have a cat that's both alive and dead. The technical term, it's a superposition. You can have a cat that's a superposition of being alive and dead. And you can also have superpositions of other crazy states. You can have a superposition of a cat and a dog. A superposition of an airplane and a planet. For any two physical states that you can think of, if you just combine the two, if you just form a superposition of the two, then that's also a physically valid state according to quantum mechanics. Anybody have a question about that? Yes?

**AUDIENCE:** It's just weird having a cat alive and dead at the same time.

**NICHOLAS** Yeah.

**DIBELLA:**

**AUDIENCE:** [INAUDIBLE] be possible?

**NICHOLAS**  
**DIBELLA:** OK. So quantum mechanics predicts that these are totally valid physical states. But yeah, we don't observe things-- we don't observe dead alive cats. We don't observe dog cats, and so forth. And so you might be wondering why is that the case.

Well, let's suppose you did have a superposition of a cat being alive and dead. Suppose you had a cat that was both alive and dead at the same time. The way to do this-- the way to actually get a superposition-- well, I'll describe this famous thought experiment. It's called, the shredding your cat thought experiment. And what you do is you take a cat, you put the cat inside of a box, put some radioactive poison in the box, and then you close it. OK. And let's say that there is a 50% chance that after an hour the poison will have decayed. It might decay, it might not decay, we don't know. There's some probability that it will decay.

Well, after an hour, the cat-- you don't know if the thing-- you don't know if the poison has decayed. So according to quantum mechanics, after an hour, the cat is both alive and dead. It's in a superposition of being alive and dead, and only when you open it will you find the cat

to be alive or dead. So in the traditional interpretation of quantum mechanics, once you open up the box, you give the cat aliveness or deadness. So once you open the box, you'll either see a dead cat or an alive cat. And I guess if you found a dead cat then someone can accuse you of killing the cat. But that's one of the reasons that this is a thought experiment, we don't actually do it.

So in this traditional interpretation, you give the cat aliveness or deadness by opening up the box and measuring it. It's as simple as that. The cat is either alive or dead. In the many worlds interpretation, once you open the box, you'll find the cat to be either alive or dead, but in reality, in true quantum reality, the cat is both alive and dead. We only perceive a small fraction of this true quantum reality. And we perceive one of them. We perceive one or the other. The alive cat or the dead cat.

And according to this many worlds interpretation, other parts of this true quantum reality, you can call them parallel universes, parallel worlds. In other parts of the true reality, you will measure the cat to be dead or you'll measure it to be the opposite where you measure it to be in this universe. We can't perceive this true quantum reality, we can only perceive a small fraction of it. I mean, these experiences that we're having really represent the small piece of the true quantum reality. And we can't-- we have a hard time-- well, it's quite possible that we'll never be able to interact with these other universes, other universes where there's a counterpart of me and I measure has to be alive or I measure the cat to be dead.

But if you believe in the many worlds interpretation of quantum mechanics then in fact, these universes do exist in a very real way in a kind of-- I mean, it's called, Hilbert space. That's the name of this true quantum reality. I mean, these other universes, they don't exist in the sense that if you travel very far you'd get to them. They exist in more of an abstract mathematical sense. It's called the Hilbert space. It's the quantum space. The quantum-- the true quantum reality is more of an abstract mathematical thing.

And if you believe in the many worlds interpretation, then you should also believe in these parallel universes where instead of measuring the cat to be alive, you measure the cat to be dead. Instead of coming to this class and teaching, I walked out and left you all here for an hour and a half to waste time. Or you wore a blue shirt today instead of green, and other things happened. In other universes, in other universes in this true quantum reality, those things do happen if you believe in the many worlds interpretation.

So should you believe in the many worlds interpretation? Well, the traditional interpretation of quantum mechanics, to me, it doesn't really make any sense because it doesn't really describe what measurement is. So we-- I mean, that's my own opinion. So we need to understand what measurement is. We have to have some kind of idea what it is. And this many worlds interpretation does describe what measurement is. It's the dynamical process. It's not some kind of a weird-- it's kind of a weird, mysterious, collapse type of thing.

And this many worlds interpretation really describes things-- really describes the way things are in a very abstract sense. And actually, we can do experiments now where we follow how the wave functions of things change in time, the smallest things. And we can actually see the wave functions start to have this appearance of collapse. I mean, usually happens very fast, but we can actually, kind of see how this wave function starts to collapse. It's called de-coherence, and it's a very active topic in quantum research today.

There's also support for the many worlds interpretation quantum computing where you have interference effects in a variety of superpositions. So if you believe in this interpretation-- on the face of it is a very sensible thing. You just have one kind of process. You just have an equation to govern everything, but it has very weird prediction. But if you believe the fundamental principle, then you should believe the very weird predictions.

I'm not going to tell you what to believe. I could of course, said the same thing for the other. I could of course, said the same thing for the other parallel universes as well. I'm not going to tell you what to believe. You can choose for yourself. But these theories that we have, they look very sensible on the face of it. You just have these simple equations, but they predict very weird things, very wild and crazy things. But if you really believe the theories, if you look at them, you say, well, they agree with experiments. They saw the experiments that we've done, but they predict some weird things.

It might take a lot of emotional effort or psychological dissonance to get rid of, but if you believe in the foundations, then you should also believe in the predictions. That's my view of it. Whether you believe in the foundations is up to you. So in this many worlds interpretation, of our world that we experience, is just a small fraction of the true quantum reality. And there are a number of parallel-- infinitely many parallel universes in addition to ours that we can't interact with, but they're really there in a very kind of abstract sort of way, but they do exist. Think about that tonight. Does anybody have any questions about the level three multiverse?

OK. Do I have any more time? I have five minutes. There's one more. There's one more level. I suppose I can-- yeah, I can describe it pretty briefly. And I'll come back to it actually, in a later lecture when I discuss the nature of gality. But in this final level, this level four multiverse, this is the most controversial and the most weird.

OK. So in all these previous levels you get a variety of an infinitude of different universes, parallel universes. But in each one of them, you have the same physical laws. You have the same laws of nature. It might be that the constants are different, the masses are different, the speed of lights are different, the dimensionalities are different, but the underlying laws, they are all the same. So the obvious step is say, well, let's change the laws. Right?

So in the level four multiverse, you have universes with different laws of physics. OK. And this level four multiverse really stems from a very simple question that you can ask. We have certain laws that describe the universe, and you can look at those laws and say, well, that's very interesting, these are the laws. But you might be wondering, why are these the laws? Why these laws of physics and why not others? I mean, you could ask the same questions about-- you can ask the same questions about the constants and the dimensionalities, and chaotic internal inflation provide an answer for that. But didn't provide answer for why these laws and not others.

And so you might-- yeah so it's a puzzle. It's a puzzle about-- it's a puzzle. It's a puzzle. Why these laws and not others? What you can do to answer this question is you can say, well, maybe there's a vast ensemble of parallel universes that are actually described by a different set of physical laws, and we just happened to find ourselves in one where the laws allow life to form, allow stability of matter, and allow complexity to form, and there are actually universes that have other laws of physics.

So I mean, in our universe, we have, for example, a law of gravity whereby, every mass is attracted to every other mass. Although, I mention inflation, you can actually have your [INAUDIBLE] gravity, but forget that. Every mass is attracted to every mass, every other mass. So things pull each other. That's one law of nature.

The correct theory to describe is general relativity, but it's easy to understand basic things about it. You know, an object falls down, an apple falls down to the center of the earth because it's gravitationally attracted to it. Now, without law of gravity, it's certainly true that-- well, gravity is responsible for things being attracted to each other, but certainly not

responsible for people falling in love. It could be that in another universe, you have some laws of physics where gravity is responsible for people falling in love. I thought it was funny.

But you can also have-- you can also have set of laws of physics where instead of gravity becoming weaker and weaker and weaker as you go far away, it could become stronger and stronger and stronger. That's another possible theory. And you could think of many, many others. And so in this level four multiverse, you have universes where there are actually different laws of physics. And there's a lot more to be said about this multiverse. I don't have time-- maybe if I had a little more time, I could describe it, but I'll describe it later.

And the nature of these universes is very different from the nature of the universes that I've been describing. In these universes, their nature is completely mathematical. So the level four multiverse, every universe, every universe with its own law of physics is completely mathematical, and they're actually called mathematical structures. And so our universe has a certain mathematical structure. Well, our universe is a certain mathematical structure, and there are other universes that are different mathematical structures, and only in the mathematical structures that are complex enough to contain self-aware observers, will there be an appearance of a thing that we call, physical reality.

Yeah, there's a lot more to be said about this. And I will do that in the following-- I don't know. I don't know when I'll talk about it, but I'll talk more about this in the future OK. So that's it for today.