Episode 3, "Time Travel"
Dramatis Personae:
-Ben Tippett
-Christopher Hastings
-David Tsang
-Jocelyn Read

The Titanium Physicists Podcast
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Ben: Over the course of my studies in theoretical physics, I've travelled across the continent and around the world, sampling new ideas and tasting different answers to the questions of "How?" and of "Why?". And still I find there remains a deep hunger, which lives within me. A burning desire to share these great ideas with the people around me. And so, I have assembled a team of some of the greatest, most lucid, most creative minds I've encountered in my travels. And I call them…my Titanium Physicists! You're listening to the Titanium Physicists Podcast and I'm Ben Tippett. And now…*allez physique*!

01:12

[Intro song; *Tell Balgeary, Balgury is Dead* by Ted Leo and the Pharmacists]

01:48

Ben: Hi, everyone. I'm not sure if you've heard the name Kurt Gödel before, but he's probably the logician who future historians would say outlined the undoing of all of mankind's great works. Just to put him in historical place, he was born in Austria in 1906 and then died as an American in 1978. His most famous works were his incompleteness theorems for logical systems. So, the story I'm about to tell you is passed around in the physics community for 50 years or so, so I can't attest to its veracity. Gödel and Einstein were best friends and they worked together at the Institute of Advanced Study at Princeton. The story goes that they used to walk to work together. Over the course of their walks, Einstein would explain his theory of general relativity to the great logician, and Gödel was so smart that, based on their conversations alone, he understood it to the point of disagreeing with Einstein. To Einstein's dismay, Gödel claimed that if the universe was rotating, Einstein's own equations predicted that time travel would be possible. Einstein asked for proof and Gödel asked for more time. So, at Einstein's 70th birthday party, Gödel presented him with an exact solution: a spacetime which was curved in such a way that it would be possible to go backwards in time to a time before you were born and punch your great grandfather in the face. Such spacetime trajectories are called "closed timelike curves," and Gödel's paper was the first to demonstrate that Einstein's theory of gravity permitted them. It is both a science fiction aficionado's dream and a conservative physicist's nightmare that the most successful theory for gravity of all time allows for time travel. The possibility is both unbelievable and undeniable. And over the course of years, a great deal of work has been done by normal relativists, who have in turns generated their own models of time machine geometry and have argued strongly in favor of their unphysicality. Today, we're going to be talking about how the laws of physics may or may not allow you to travel back in time.

03:37

Ben: To do this, I've invited special guest Christopher Hastings. Hi, Christopher!

Christopher: Hi! Thank you so much for having me.

Ben: Cool! Christopher Hastings is the genius writer behind the webcomic Dr. Mcninja at drmcninja.com. It's a comic about a physician who's also a ninja and has been published regularly since 2005. In 2007 it won the web cartoonists' choice award for outstanding action comic, and in 2011 Chris was hired by Marvel comics to write the miniseries *Deadpool: Fear Itself*. So, welcome on the show, buddy!

Christopher: Thank you very much! I'm so eager to learn about how time travel is *definitely* real.

Ben: Oh, yes. You'll, uh, have learned many things by the end of today.

David: Or maybe beforehand.

Jocelyn: *laughs*

Christopher: Oh, no. We've already begun.

Ben: So, Chris, for you today I have assembled two of my finest titanium physicists. Arise, Dr. David Tsang!

David: Muahahaha!

Ben: So, Dr. Dave and I were undergraduates at UBC together and he did his PhD and Master's at Cornell. He's currently at Caltech working as a postdoc astrophysicist. And now arise, Dr. Jocelyn Read!

Jocelyn: RAAHHHR!

Ben: Dr. Jocelyn did her undergraduate at UBC and her PhD at the university of Wisconsin, Milwaukee. She's currently at the university of Mississippi working on neutron stars.

04:50

Ben: Alright, so let's start talking about going back in time! So, Chris…

Christopher: Yes!

Ben: So, I don't know if you believe it, but you aren't actually a three-dimensional person walking over the surface of the Earth.

Christopher: Really?

Ben: In general relativity you're actually some kind of four-dimensional snake.

Christopher: Okay.

Ben: This object, uh, it's the collection of points at which you exist from the initial origins of the cell until you die. And we call that line your "world line."

Christopher: Mm.

Ben: A world line is, well, it's a four-dimensional blob kind of shaped like a long snake going from the past into the future.

Christopher: Okay.

Ben: And here's the kicker: um, your world line is kind of wrapped around the geometry of space. It follows certain physical laws that cause it to, uh, take a certain shape, depending on where you are and how high the gravity is. Now, the laws of general relativity, which talk about the curvature of spacetime on which your worm is laid, can let your worm kind of twist around and bite its own tail. So, we call that a closed timelike curve. It's called a "timelike curve" because, uh—

Jocelyn: Well, it's timelike because he's measuring time along it as an observer. So, since you can measure time by carrying a little clock with you over your entire life, as everyone does, that makes it a timelike curve.

Ben: Right. And it's closed because you're biting your own tail. So, the criterion in general relativity for past time travel are these things called closed timelike curves. If a closed timelike curve exists, it means you can travel into your own past. Dig it?

Christopher: I am digging it so far.

Ben: So, there's lots of different geometries that will allow you to do this. The first was started by this Kurt Gödel guy, and it's very old, and what it describes is a universe where everything's uniform and it's made out of dust and a cosmological constant, but everything's spinning slightly, and the result of this angular momentum at every point causes these closed timelike curves to exist. But nobody believes that this was realizable because it requires, essentially, a whole universe full of spinning matters to get, uh.

Jocelyn: It takes a lot of energy to spin a universe.

Christopher: I see. And...are you saying our universe is *not* spinning?

Ben: Our universe is not spinning.

Jocelyn: We've checked.

Christopher: Okay.

David: Gödel's solution also doesn't have the universe expanding, which we know it does, so. There are different solutions, apparently, that include expanding universes, but…

Jocelyn: We haven't found them.

07:06

Christopher: I have a question related to the, the earlier, uh, points you made while explaining this to me: how is gravity related to time?

Jocelyn: Well, maybe we should start out with special relativity, because that's when you start stitching space and time together. Before—before gravity, Einstein was just trying to explain stuff about how light worked, and the speed of light was being measured in the same in every direction, and the theory of special relativity that comes out of that says that if you're moving relative to someone else, what you measure as time and space get kind of mixed compared to what they're measuring as time and space.

Ben: Okay, so, to put it another way, Einstein noticed that, no matter how fast you were going relative to anyone else, the speed of light would always look the same. So, a truck, as it's moving down the highway, will look like it's moving at different speeds depending on whether you're also on the highway moving towards it or also on the highway driving the same speed, at which point in time it would look like it's not moving at all because it would sit still with respect to you.

Christopher: Right.

Ben: So, Einstein decided that light didn't do that. What light did instead was, it didn't matter how fast you were moving, or where you were, you would always measure light to be travelling at the same speed. And there was a terrible consequence to that, which was that depending on how fast you were moving, time would move at a different pace and distances would also shrink and expand, depending on how fast you were.

Christopher: Oh, my.

Ben: So, one consequence of this—have, have you ever heard of the twin paradox?

Christopher: I have not.

Ben: Okay, so the twin paradox was written to describe one of the strange features of special relativity, and the idea here is that if you take two twins—so, they're both born on the same day—and if you take one and put him in a rocketship and have him accelerate out towards the stars and then come back on a many-year journey where he's travelling almost at the speed of light…

Christopher: Mmhm.

Ben: The amount of time which has passed for one twin, say the guy who stands on Earth—we'll call him Ben—it might take 70 years for his twin to get back. But then, the twin in the rocketship, let's call him—

Christopher: Evil Ben.

Ben: Evil Ben.

Christopher: *laughs*

Ben: It might only take him 30 years to make the round trip, because time's travelling at a different rate for him, because he's accelerating and travelling at different speeds compared to the, the Ben, Nice Ben at home.

Christopher: Yeah, so I, I actually, I have heard of this. I've heard that, uh, if we wanted to try to send an astronaut into the future, it would be as simple as sending him in a ship towards a black hole and then slingshotting around it to go fast enough to make it work.

09:30

Jocelyn: I don't, I—I'm not sure what that means, actually.

Christopher: Oh, well I had, I had—I had *heard* several points that a, a way to get someone fast enough to make it seem as though they were travelling to the future, that is to say, through this relativity thing, um,

Jocelyn: So, th—So, that they, they wind up being young when they come back and meet old people on Earth?

Christopher: Right.

Jocelyn: That kind of future?

Christopher: That a way to do that would be to get them to spin around a black hole and then eject back out of it, and that would be a way.

Jocelyn: I mean,

David: Well, it's...any, any massive object will allow you to accelerate by slingshotting around it.

Jocelyn: Yeah, we launched, where we—

David: You're basically stealing some of its energy.

Jocelyn: We sent satellites out to the outer reaches of the solar system by slingshotting them around planets.

Christopher: But not fast enough for them to be future satellites.

David: So, you have to—you have to go a very significant portion of the speed of light in order for it to be noticeable.

Christopher: Right.

Ben: That's right. But, I mean, it's still noticeable for speeds travelling slower than the speed of light. In the...70s, was it? They took two atomic clocks and they set one up in the laboratory and put the other on a supersonic jet. And then they flew the supersonic jet around the world really fast and brought it home. It turns out that the clock that had gone on the jet was accurate enough that it could measure that a smaller amount of time had elapsed for the one that was on the jet than the one that stayed at home.

Jocelyn: And GPS satellites are doing this right now. They have a bit of a correction on their clocks to take in to the fact that they're orbiting around the Earth at pretty high speeds, and that's enough when you're trying to do very precise GPS measurements that you need to correct for it.

Ben: So, the moral of the story is that if you're dealing with accurate enough time measurement things, you can measure this in almost everyday speeds. Very fast speeds, but not speed of light speeds. But to get it so that your twin brother comes home 30 years younger than you are, you need to go close to the speed of light because this effect is amplified the closer to the speed of light you get.

Jocelyn: And by "close to the speed of light" that means "in the frame of the twin that stays home." The guy travelling doesn't see himself get any closer to the speed of light at all.

Christopher: Oh, right! Okay. And, and uh, we have no practical way of doing this, correct?

Ben: Yeah, rockets aren't powerful enough to take us close to the speed of light. Right, so you were asking the question, what does time travel have to do with gravity?

11:39

Christopher: Yes! Or, what does time in general have to do with gravity, I guess.

Ben: Right. So, just—we introduced the idea that, depending on your speed relative to one another, two people will have time pass at different rates.

Christopher: Mmhm.

Ben: So, in the twin paradox, you had, one person was moving at a fast velocity and accelerating into it and accelerating back and he will end up younger, because less time has passed for him than his brother at home.

Christopher: To clarify, that is to say he will age slower, relative to his twin. He, he won't be becoming younger, right?

Ben: No. Yeah, he will age slower. So, if Nice Ben at home has a telescope and he's watching Evil Ben on the rocketship, and suppose the telescope is fine enough that he could watch the hands on the clock tick past, he would see that the hands on Evil Ben's rocketship's clock was moving slower than the hands of his own watch. So, this introduced the idea that different people will have time pass at different rates depending on their situation. And one of Einstein's big revelations in defining general relativity was that, depending on where you were in a gravitational field, time would pass at different rates. So, uh, one rule of thumb is, the heavier the gravity is where you're standing, the slower time is passing.

David: So, there's a difference in the passage of time between what we experience on Earth and what you see in a jet plane or, or in space.

Jocelyn: Or in a GPS satellite.

David: Or in a GPS satellite.

Jocelyn: For the GPS you need to add a little bit for the GPS satellite speed, and you need to add a little bit for it being farther away from the center of the Earth and the people using it.

Christopher: So how, how was it determined that, um, gravity affects time?

Ben: Well, in general relativity Einstein basically says that curvature of spacetime *is* gravity.

Christopher: Oh! Well, how'd he figure that out?

13:21

David: Um.

Ben: Yeah, there was a lot of supposition in it, but there was one big observation that, that lots of this intuition is based on. That's the, the idea of curved surfaces.

Christopher: Mmhm.

Ben: So, let's say you want to put an object in orbit at some fixed distance from the Earth. What really matters is what the object's velocity is. And so, two objects with the same velocity will follow the same paths through space, right?

Christopher: Mmhm.

Ben: So, if I threw a ball up at 1 m/s, it will follow the same trajectory, whether it's a cannonball or whether it's a baseball. Okay?

Christopher: Okay.

Ben: So, prior to Einstein, everybody was talking about "forces," but the idea that the force from having to do with the gravitational weight of an object and the force of its inertia cancelling out was a little bit too suspicious. So, what Einstein said was, instead of this, let's suppose that we have this surface called spacetime all things are travelling over in special relativity, what if gravity is just the curvature of that? So, you, you imagine this, this surface kind of bumped up, it has little bumps in it, and little troughs in it.

Christopher: Mmhm.

Ben: And as a consequence, it doesn't matter how heavy your ball is, it'll still roll over the same path across this bumpy sheet.

Christopher: Ah, that's very interesting!

Ben: Uh, the consequence of this is that, depending on how strong your gravity is,

Jocelyn: Or how curved spacetime is.

Ben: Yeah, right. One consequence of this is that matter will cause spacetime to curve.

Christopher: Mmhm.

Ben: And then the trajectory that matter follows, uh, will be determined by how the spacetime is curved.

David: A lot of these methods of time travel have to do with curving spacetime in strange ways such that you can get a timelike curve, a curve, uh, a world line that you would be able to follow to come back and attach to itself.

Christopher: I get it.

David: So, Gödel's, uh, rotating universe was one such way of generating one of these closed timelike curves.

15:01

Christopher: Ah.

David: Um, there are a bunch of other ways as well.

Ben: His way was fairly elaborate. Turns out that you can think of much simpler examples that aren't *quite* so exotic that have these, these special time travel possibilities. One was invented by a guy named Tipler, called the Tipler cylinder. So, if you can imagine a massive cylinder, so, a cylinder that is infinitely long. So, it stretches up infinity and down infinity, but at any point it has a finite radius. And then you imagine the cylinder spinning a bit.

Christopher: Mmhm.

Ben: If the object's spinning, uh, fast enough, what happens is that if you get really close in, the gravity of the spinning object kinda pulls you along with it, and travelling in a circle around the cylinder is a closed timelike curve. In other words, you could go up to the cylinder, if you went close enough, and travel on a specific trajectory that would take you back in time.

Christopher: Right.

David: So people think right now that if you have, if you could find a—what's called a "cosmic string," which is a topological defect in spacetime, if you find a rotating one of these, then it can act like a Tipler cylinder and you can just sort of go around it until you travel back in time.

Christopher: So, is it more likely that they don't exist or that they are rare and hard to find?

David: We haven't found any evidence of them yet.

Christopher: Ah.

Jocelyn: There—there are conjectures that it is impossible to create them if they don't begin—if they don't exist to begin with, so if you start out with a, a universe that doesn't have any of these kind of things, you cannot create one.

David: But there could be one from when the universe started.

Christopher: Right.

Ben: So, oh! Interestingly enough, so, black holes aren't that exotic. So, we know that black holes exist.

Christopher: Right.

Ben: If a black hole is spinning, then the black hole solution at it's very center has a region that has these closed timelike curves. So if somehow you could climb down into the middle of a black hole, you could kinda go back in time.

Christopher: Oh!

Ben: Climbing into a black hole is easy, climbing out's really tough.

Christopher: Yeah.

Ben: Unfortunately, these—this place where these closed timelike curves are allowed are behind the event horizon, so you'd nev—you wouldn't be able to escape and we wouldn't be able to see you travelling back in time.

Jocelyn: So, so there's, there's—yeah, so there's—this, this theorem basically says that these closed timelike curves are always hidden behind an event horizon that you cannot escape from. So we, we can never tell they're there.

Ben: So, there's kind of 2 ways you can go about using spacetime to get back in time. One of them involves the curvature of spacetime and the other involves travelling faster than the speed of light.

Christopher: Right.

Ben: Einstein's equations tell you that if you're accelerating by throwing objects behind you, you'll never quite reach the speed of light. You'll approach it asymptotically, but you'll never quite get there.

Jocelyn: Well, I mean, because consider your perspective. You, you know, shine your flashlight ahead like, okay, it's going that fast. Turn the flashlight off, start accelerating like crazy, shine the flashlight again, oh! Same speed of light going ahead of you. You never catch up *at all* to the speed of light.

17:48

Christopher: And, and that is just generally impossible through physical means, is that what you're saying?

Jocelyn: That's—the theory of special relativity predicts that you will always measure the same speed of light.

Christopher: Oh, I see.

Jocelyn: And, and it's been very well-tested. All of particle physics uses special relativity. There's certainly some possibility that there's some extreme region of physics that doesn't behave like this, but with the theories we have, you—you just—you can't do it. So, so, from the perspective of someone watching someone try and accelerate, what they would see is—okay I see the little par—I see my little, uh, guy riding with his flashlight, and each time he tries to get closer to the speed of light, that I—you know, I see him travelling. But it takes more energy for each incrementally smaller fractional change in velocity to make him travel faster than light compared to me. So that's, that's what I see watching someone trying to go faster than light.

Ben: So, unless you're willing to use some kind of really bonkers, out-there mechanism, you're not going to make yourself go faster than the speed of light. BUT! Some bonkers mechanisms have been proposed, right? There's warp drive spacetimes. You could somehow teleport yourself, then you'd be able to do this. Um, and the trick involves the idea of simultaneity. So, uh, let's suppose you could teleport yourself to a certain distance away from you instantaneously.

Christopher: Yes!

Ben: Okay. So, the idea of "instantaneous" is a really old fashioned, pre-relativistic description of events.

Christopher: Mmhm.

Ben: So, by "instantaneous" what we usually mean in relativity is, it's kind of like, all of the events that, in my description, are happening at the same time, okay? Let's suppose a baseball hits me, then three seconds ago, that baseball was, you know, three meters away. You have this sense of how things are arranged in the past at any specific time. But that idea is kind of conjecture because you're not actually where the baseball *is*, you're just kind of deducing it from where it exists. And one consequence is that if you're travelling with a specific velocity, this plane of instantane—this instantaneous plane gets tilted in the direction that you're travelling because the baseball might have to travel five seconds farther to hit you, because you're running away from it.

Jocelyn: It's, it's tilted in time.

Ben: Yeah, that's fight. So this, this plane of instantanicity will be tilted in time, and so one consequence is, if you had the ability to teleport, what you could do is teleport from here to 100 miles away instantaneously, and then what you could do is accelerate, take a new velocity and tilt your plane of instantanicity so that it's tilted in a way that, when you teleport back to your original location 10 seconds in the past compared to your orig—

Christopher: Oh, okay.

Jocelyn: So, in fact, anything that goes faster than light implies the possibility of time travel.

20:27

David: Right.

Christopher: Ahh.

David: That's why people say tachyons go back in time when they travel faster than the speed of light. But that's, that's how Cable's bodyslide could also be used for him to time travel.

Christopher: And does he use it for time travel?

David: Well, he doesn't! He, he has the timeslides and the bodyslides, right?

Christopher: Ah.

David: And, and then, sometimes his timeslide doesn't work...it's all very inconsistent, let me tell you.

Jocelyn: It's relativistically inconsistent! It's very frustrating.

Ben: Maybe it was just too hard to explain to Cable, and so…

Christopher: *laughs*

Ben: He put two labels on the same button.

Christopher: Cable has to focus *very* hard to keep the machine, uh, disease that he—

David: The technovirus. The tecnovirus.

Christopher: Yes, the technovirus. So, you can't really try to explain difficult-to-comprehend concepts to him, 'cos otherwise he'll die from the technovirus.

David: Well, you don't really have to explain. He can just read your mind.

Christopher: Oh, right. Well, then he has no excuse.

Jocelyn: But, but, you know, any time you see, in, in any science fiction thing, someone communicating instantaneously, they've implied the possibility that they could easily just go back in time and, and change their own history.

Christopher: Oh.

Ben: Yeah, Star Trek. They have warp drives to travel faster than the speed of light.

Christopher: Right.

Ben: But you should be able to go back in time without having to go around the sun.

Christopher: Haha. I was going to say, they, they time travel all the time, though, but not…

Jocelyn: Not consistently.

Christopher: Not consistently.

David: Don't get us started about them whooping around the sun and, ugh.

Christopher: *laughs*

21:39

Ben: So, um, let's talk about what people have to say about time travel, because independent of these solutions existing, people have been trying to judge whether or not these solutions are actually reasonable. So, there's this thing called the grandfather paradox. You ever heard of it, Chris?

Christopher: Yes, I have.

Ben: Alright, so the grandfather paradox is when you go back in time and kill your own grandfather before he conceived your father. It's a paradox where you prevent your own existence.

Jocelyn: Or, in the case of Futurama,

Ben: Pause your own existence, right.

Christopher: They just ignored the paradox, I believe.

Jocelyn: No, that's the—

David: That's not a paradox, then.

Jocelyn: His past nastification gave him special mind powers.

Ben: That's right.

Christopher: Oh, that's right, yes.

David: You'd be infinitely inbred.

Christopher: Right.

Ben: That's why he's so dumb. Soo...right! It's called the grandfather paradox and the idea is that it's been studied. People said the fact that you can have inconsistent descriptions of the universe where, at any point in time everybody follows the law in physics, but in the end you get these huge inconsistencies in the original timeline, I guess you'd call it, you existed, but then, in your altered timeline, you stopped existing. Somehow those are the same universe. People have taken these general inconsistencies as a broad argument against these time travel geometries.

Christopher: Mmhm.

Ben: But some people did some thinking about this. They, they set up a little thought experiment where they imagined a wormhole. You know what a wormhole is?

Christopher: Uh, let's say I don't.

Ben: Okay. Imagine you have two baseballs, but when you poked one, your finger would go in it and come out the surface of the other baseball.

Christopher: Okay.

Ben: Broadly put, it's a little hole in spacetime with a worm guest, descriptively, but yeah. It's just a hole.

David: It joins to another part of spacetime.

Jocelyn: You, you imagine if, if you've got this curved spacetime, there's some little tunnel connecting one part to another that goes through imaginary dimensions.

Christopher: Got it.

Ben: But all we need to think about right *now* is the idea that these two wormholes are just kinda baseballs. You can pick them up and take them wherever you want, and earlier in the show we were talking about the twin paradox. If you take these two balls and you put one of them on the rocketship that goes out with Evil Ben, he will come back and that wormhole will have only aged 30 years, whereas the, the wormhole that stayed at home will have aged 60 years.

Christopher: Right.

Ben: So, if you stick your finger in the one wormhole now, so your finger will stick out of the other wormhole 30 years in the past.

Christopher: Ohh.

Ben: Alternatively, if the past guy sticks his finger in that other wormhole, it'll stick out in the future, 30 years in the future. So, what these physicists imagined was that you had these two other wormholes separated in time by, i don't know, a couple seconds—30 seconds, say. And then you imagined playing billiards, okay? So, you rolled a cue ball into one wormhole…

24:09

Christopher: Sounds *very* irresponsible.

Ben: Yeah, well, let's say you've put both of them on a table and have put up ropes around the table, so that—

Christopher: Oh, oh, there's ropes!

Ben: Yeah.

Christopher: Okay, alright.

Ben: Everything's safe.

Christopher: As long as spacetime is safe, there's ropes.

David: There's caution tape.

Christopher: Okay, good.

David: I love caution tape.

Jocelyn: Everyone's wearing goggles.

Christopher: Goggles, good. Okay. Alright, please continue. I feel—

Ben: So, in this system—

Christopher: Sorry.

Ben: —where everybody's wearing goggles, if you do it just right you can make it roll through, it will come out the other wormhole from the past, and then bump into itself before it went into the hole in the first place. This is a little billiards equivalent to the grandfather paradox.

Christopher: Right.

Ben: And so, what these physicists were interested in is whether or not they could come up with a self-consistent description for why this wouldn't happen. And they came up with an idea, uh, it’s named after one of the guys who worked on it, Novikov: It’s the Novikov self-consistency condition. And all the idea is is that somehow Nature conspires to prevent that ever from happening. So, maybe the ball goes in the wormhole and bounces up against itself, but it will always bounce up against itself in a way that will cause it to go back into the past and bounce off itself in exactly the same way and allow it to go back through the wormhole.

Christopher: Right.

Ben: So, you can’t change the past, in other words. You can interact with your past selves, but you can’t change anything.

Christopher: Because—because nature is, for some reason, conspiring against you for its own preservation, is that it?

Jocelyn: But that’s—that’s pretty—that’s pretty much it. I mean, there’s no physical laws of “billiard interactions” that apply outside of the situation that we could just use in this billiards wormhole.

Ben: That’s right. We’re used to talking about billiard balls as following local laws of physics, um, where, you know, if this one ball has such and such an initial velocity it will end up travelling on such and such a trajectory, et cetera. Um, but what this condition is itself is it’s a global law of physics. It says because spacetime is connected in some specific way, you can only ever have situations where self-interaction can happen, but it’s only self-consistent. So, that’s how they got past the grandfather paradox, they said “well, you can go and stab your grandfather, but maybe that explains why your father looks like the mailman.”

Christopher: *laughs* Right.

26:16

Jocelyn: There’s also, if you—if you try and construct these sort of wormhole solutions, you often end up with event horizons preventing billiard balls from travelling through them to begin with.

Ben: Right. This is an idea called “topological censorship.” What’ll happen is, as soon as any matter at all enters one of these wormhole systems, the wormholes will turn into little black holes.

Christopher: Oh!

Ben: And then you’ll have two black holes instead of a wormhole.

Jocelyn: And nothing comes out.

Ben: Right.

David: So, the—the throat of the wormhole closes.

Ben: So, people propose various ways of getting around this. Uh, you, you need some kind of exotic anti-gravity energy. So, um, one idea is that if you somehow coat the inside throat of the wormhole with this magic energy that causes gravitational repulsion.

Christopher: Right. Very simple.

Ben: Yes, very. It's—

Jocelyn: Well, that's not *such* a crazy idea now that we have dark energy.

Ben: Well, we don't know what dark energy is.

Jocelyn: But, I mean, at a—at a very, sort of, simple level it causes expansion rather than collapse.

David: That's true.

Christopher: Okay, so let's do that.

Ben: Right, and then build a rocketship so we can make one of these back-in-time wormholes. Incidentally, there's another law that prevents us from building a system where you have closed timelike curves, and this one is worth mentioning. It's called the chronology protection conjecture that Stephen Hawking made. Everybody loves Stephen Hawking, right?

Christopher: Well, I don't trust him because he's a cyborg, but go on.

Ben: Listen, Cable's a cyborg, right?

David: So's—yeah, so's Cable.

Ben: The Terminator is a cyborg. You trust them.

Christopher: No! No no no no. Definitely not. Cable is a very tricky character and, uh, they were really only able to make one Terminator out of thousands, uh, y'know, trustworthy, so…

27:44

Ben: Okay, so, you might have to take this with a grain of salt, but here's how Stephen Hawking reasoned it. He said, let's say you have your two wormhole throats. And we're—we've got the twin paradox thing going on where one is three minutes older than the other one.

Christopher: Mmhm.

Ben: And to make these closed timelike curves we just need to bring them close enough together, so if one's on a three minute delay, then we need to bring them to within three light-minutes of each other, uh, because that's, uh, things can't travel faster than the speed of light, so they need to be close enough together so that you can cross the gap in the amount of time before—between the delay.

Christopher: Oh, okay.

Jocelyn: So, that's almost—almost half the way to the Sun.

Ben: Yeah, right. So you don't have to bring them that close, but in the process—so, if there's a three minute delay between them, there's a point where they're exactly three light-minutes apart.

Christopher: Mmhm.

Ben: And at that point, light can travel between these, at the speed of light, go in one and come out the other. And the argument is that stuff is going to pile up on that curve. So, one photon will cross through it and come out the other side and trace the curve again over and over and over and each time it will have some contribution to the gravity of the external system. And so, it's going to build up and build up and build up until, effectively, there's an infinite amount of energy as you bring these two, the buildup between these two balls, as you bring them closer and closer…

David: Way more than 1.21 Gigawatts.

Ben: So, the, the net result is that in the process of bringing these two wormhole throats close enough together, an almost infinite amount of energy will build up between them over the course of just, just bringing them close enough. The net result is that the whole thing will turn into a big black hole. And, and the kicker is that this particular description, the chronology protection conjecture, where spacetime turns into a black hole if, if you bring, if you *almost* create these closed timelike curves, it will happen in any situation where there are no closed timelike curves, and suddenly there is. So, if you take a cylinder—an infinitely long cylinder, again—you take your hand and you roll it over the cylinder until it gets rotating fast enough to build in these closed timelike curves, there'll be a point at which your whole cylinder becomes a black hole. Just prior to when you'd be able to time travel.

29:50

Christopher: Ah.

Jocelyn: So Ben, does that happen when you have closed lightlike curves or closed null curves?

Ben: Yeah, it's the closed lightlike curves that the, uh, stuff builds up along. So, any time you have a, uh, a regular spacetime and you're about to have closed timelike curves, at that point, that transition between the two, energy's going to build up. So, let's say—

Christopher: Mmhm.

Ben: —let's say you have your two wormhole throats and they're about 3 minutes apart, and it takes you two and a half minutes to cross the gap between it. Suddenly, you'll come in, uh, one second prior to where you entered, and then you'll make the transition and come in another second behind, and you'll go through this over and over and over until you end up at this lightlike path. And so, this lightlike curve is the, um—this transition between, uh, *not* time travelling and time travelling geometry is the point where all of the matter ends up piling up into spacetime. And so you have—you have everything turn into a black hole.

Jocelyn: Oo, one other thing we should mention is that you can—when you create a time machine, aside from everything turning into a black hole, you also can't use it to go back in time before the time machine itself was created.

Ben: Unless you're doing that thing where you travel faster than the speed of light.

David: I believe this was the main plot point of, uh, *Planetary*, if you've ever read that comic book.

Christopher: I haven't.

Jocelyn: I need to get to that point.

David: Spoilers.

Jocelyn: Geez, thanks, *Dave*.

31:07

Ben: Alright, so, I think that's it for time travel. Is there anything else? Um, any other questions, Chris?

Christopher: No, I, I—you've educated me very nicely today, thank you.

Ben: Wonderful! First off, let me thank my titanium physicists. Thank you, Jocelyn and Dave, you've pleased me! The fruits of your effort have borne fruit and the fruit is sweet fruit. I'd like to thank my guest, Christopher Hastings. Go to his website, Dr. McNinja. It's spelled drmcninja.com. Uh, his webcomic is wonderful and has all sorts of things with time travel and also apes in it.

Christopher: Mmhm.

Ben: Uh, so thank you very much for being on today.

Christopher: Well, thank you so much for inviting me.

Ben: So, if you'd like to contact us, you can contact us, barn@titaniumphysics.com, or you can follow us on Twitter at @titaniumphysics. You can visit out website at www.titaniumphysics.com or look for us on Facebook. If you have a question you'd like my titanium physicists to address, email your questions to tiphyter@titanuimphysics.com, that's ti-phy-ter. If you would like to become one of my titanium physicists, email physics@titanuimphysics.com, we're always recruiting. The Titanium Physicists Podcast is a member of Brachiolope Media. If you've enjoyed our show, you might also enjoy "Science, Sort Of," or "The Weekly Weinersmith." Check them out! Intro music is by Ted Leo and the Pharmacists, and the end music is John Vanderslice. Good day, my friends, and remember to keep science...in your hearts.

32:40

[Outro song: *Angela* by John Vanderslice]

33:27

Ben: Chris Hastings, do you have any questions?

Christopher: Well, I'm just uh, you know, in, in my own, uh, comic, uh, Dr. McNinja, um, there is time travel, which is why I was interested in talking about that today, and I'm curious what thoughts you have on the method of time travel in Dr. McNinja, which I'll explain, uh, thusly is that, um, basically there are, sort of, glowy time balls, um, out in different parts of the universe that, it turned out, are ways of entering a "time stream"—I'm making quote-y things with my fingers right now—uh, and that allow you to go back in time, uh, but, the thing is that if you—as soon as you go back in time, and immediately start changing things by doing so, you create an alternate, uh, an alternate timeline. And I'm, I'm curious what grounding that has in reality at all.

Ben: Well, what you—

Jocelyn: That—

Ben: Go ahead, Jocelyn.

Jocelyn: Oh, well, I was, I was going to say, that, that kind of thing is one of the ways to get around all these, um, sort of—

David: Paradoxes.

Jocelyn: —infinite build up kind of things.

Christopher: Right, yeah, it—it made it easier for my brain to comprehend time travel as I was trying to organize a story.

David: It—it certainly—it certainly avoids all the, uh, sort of, paradox problems.

Christopher: Mm.

David: Yeah, like grandfather paradox type problems where, you know, oh, yeah, you killed your grandpa, but it's in a different timeline.

Jocelyn: Yeah, the tricky part is our—our theories aren't really set up for multiple universes, which is what you need for a parallel timeline—you have to have some—

Christopher: Right.

Jocelyn: some version of the universe that's, that's different.

David: So, you have to connect our spacetime to, uh, a spacetime in a different universe that is, pretty much, almost the same, but a different one.

Christopher: Mmhm.

David: It's, it's not entirely clear why we would be connected to one that's so similar to ours.

Christopher: Oh, okay.

Ben: Yeah, so you'd have to punch through and make a wormhole—instead of a wormhole that goes back in time, you would have two sets of wormholes: one that took you from our universe to a different universe that went slightly back in time, and another one that went from some other universe to our universe. So, you'd have to have three different universes that would all be connected by these holes. Uh, and it's not clear why they would come out where they would, but…

Christopher: *laughs* No.

Ben: That's certainly a self-consistent system that you could imagine.

Christopher: Uh huh.

Ben: And probably build theoretically if you felt like putting your name on it,

Christopher: *laughs*

Ben: Um, but there's no reason to imagine that these three almost identical universes would be threaded together in such a way.

36:03

Christopher: I, yeah, i'm just—just curious for the sake of maybe trying to sprinkle in a little, kind of, um, you know, realism later on, but it seems that's not likely.

Jocelyn: You could try and, try and tie it into a mini-worlds quantum theory interpretation and say something about how similar universes are nearby—

Christopher: Mmhm.

Jocelyn: in this sort of infinite split-off of universes, and just argue that you're somehow shunted to the nearby universe and then, then you need to think about some reason for there to be discrete spacings of universes, but if we're in quantum theory that, that's fine, we can do discrete spacings and stuff all the time. Uh, you know, if you wanted to kind of spin a, uh, a quasi-scientific story about it, that's, that's probably the way I'd go.

Christopher: Ah, alright.

David: I prefer the *Doctor Who* solution, where, um, the TARDIS has to have, uh—well, no. The TARDIS has to have uh, uh, paradox compensators.

Christopher: Paradox compensators.

David: Yeah.

Christopher: And is that a thing, or?

David: Where it allows paradoxes to exist for a while.

Christopher: Oh, I see. That—that's very helpful.

Jocelyn: Or, or perhaps these, these time spheres were built by some trans-universal entity.

Christopher: Ohh.

Jocelyn: That, that would route them into alternate universes.

Christopher: I see.

Ben: Or, could it just be a dream.

Christopher, Jocelyn, David: *laughs*

Christopher: Okay, I should just go with that one.

David: Or they're just leftover time glory holes.

Ben: *laughs*

Christopher: Ugh.

Jocelyn: Dave, we just need an automatic mute button on you in certain circumstances.

David: *laughs*

Ben: As soon as your little green name starts glowing we hit the mute.

PAUSE

Ben: Uh oh, Dave’s gonna say something nasty...