Episode 20: Time Dilates When You're Having Fun
Physicists: Jocelyn Read, Ken Clark

Transcribed by Denny Henke

Ben: Over the course of my studies in theoretical physics I've traveled across the continent and around the world sampling new ideas and tasting different answers to the questions of how and why. And still I find there remains a deep hunger that 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 have 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!

[1:49]

There is a famous song which I'm sure you've heard because it's iconic. It's the iconic song that seems to synonymous with a certain iconic movie. The song, however, was not written for the movie, it was written in 1931 by Herman Humpfeld for a Broadway comedy called Everybody's Welcome and for that reason, even though the song is very, very famous, it's prelude is less so. So, I'm going to read the prelude to you because it's relevant. "This day and age we are living in gives cause for apprehension. With speed and new invention and things like 4th dimension. Yet we get a trifle weary with Mr. Einstein's Theory so we must get down to Earth at times, relax, relieve the tension. And no matter what the progress or what may yet be proved the simple fact of life is such that it cannot be removed." And you'll probably recognize the song from here, it goes "You must remember this, a kiss is just a kiss, a sigh is just a sigh, the fundamental things apply as time goes by." So, this was the funnest way I could think to start us about a conversation about, as they put it, Mr. Einstein's Theory. Today, we're going to be talking about the speed of light, we're going to talk about special relativity, and we're going to talk about what it tells us about the mysteries of the fourth dimension. To help talk to us today about time I'd like to introduce our guest, Michael Mookie Terracciano, author of the webcomic "Dominic Deegan: Oracle for Hire" about a guy who can use magic to look through time and his adventures with his girlfriend who has tusks. His comic has been going steadily for about ten years now. Welcome to the show Michael.

Michael: How's it going man, thanks for having me.

Ben: Do you have anything you want to tell the audience about? Maybe they could purchase from you?

Michael: Everything you need to know about me and my web comic is available on my website dominic-deegan.com and there's a store there. I sell collections of the stories in book form. I'm still catching up to what I have online as to what I have in print. There's close to 3,000 comics on the site and I've got seven stories collected in book form. I'm still about five years behind in print form what I have in book form. Yeah, if you want to come on by, check out the comic, dominic-deegan.com. I hope you like what you see.

Ben: Awesome. So, in light of your knowledge of magic and things to do with seeing through time I'm going to summon for you today two of my favorite Titanium Physicists. Arise Dr.

Jocelyn Read! Nice, Dr. Jocelyn did her undergraduate at UBC, her Ph.D. at the University of Wisconsin, Milwaukee. She's now a professor at Cal State University Fullerton and she's still working on neutron stars. Now, arise Dr. Ken Clark! It's a bird, it's a plane, no, wait it's Dr. Ken. Dr. Ken did his undergraduate at the University of Toronto and then his Masters and Ph.D. at Queens University and he's now at Penn State working on Ice Cube. How about if we start by talking about time

Michael: Time, alright.

Ben: Issac Newton was the first person to hammer down numerical laws describing motion. If you're going to describe motion you have to describe things changing with respect to something else. So, if two balls are rolling down the hill one ball might be rolling faster than the other ball, how do you quantify the difference in how they are moving. So, if you're going to talk about speeds, in essence the speed tells you how fast something's moving with respect to time.

Jocelyn: I mean, people were doing stuff similar to this before Newton.

Ben: Yeah.

Jocelyn: Galileo was trying to quantify the speed of light with lanterns on different hills.

Ben: It's part of the paradigm of the time was that you could just, kind of say, okay, we're not going to ask the question, what is time, we're just going to assume that all clocks that work really well give an accurate to representation of time.

Jocelyn: There's some platonic ideal clock in the sky that just measures, bong, bong, that time that applies to the entire universe.

Michael: Right, the god clock. Which, I kinda like that idea, just this big clock.

Jocelyn: Just, fair warning, don't get your whole world view too caught up in this because we're going to show later...

Laughter.

Michael: You're breaking my god clock philosophy? I didn't know you you guys

Jocelyn: Don't get into your fundamental beliefs...

Michael: Dammit, I am a god clock fundamentalist. I thought...

Ken: Any second now...

Ben: Einstein came around and smashed the god clock.

[6:45]

Jocelyn: Well one of the key things that special relativity gives you is that there is no universal time, that time is dependent entirely on who is measuring it.

Michael: I think it's the coolest concept about relativity. I think it's fantastic.

Ben: So, today we're going to get into that in a little more detail.

Michael: Sweet.

Ben: And first I think it's probably appropriate to talk about the speed of light.

Michael: It's kind of the whole basis of Einstein's theory isn't it.

Ben: Yeah, that's right. People knew that light traveled at a finite speed since the 1600's. Nobody knew exactly what they were, there were some theories that imagined that there were little particles of light that were being emitted by whatever was shining. And other theories that described it as a wave.

Michael: Have they ever decided on whether light is a wave or a particle?

Jocelyn: They've firmly decided that it's both.

Laughter

Ken: Firmly decided not to decide.

Jocelyn: Yeah but that get's into quantum theory which is the other crazy modern physics thing.

Michael: Oh, god, is that being discussed tonight too?

Ben: No.

Ken: Ok, good.

Jocelyn: We're going to stick to one sort of counter-intuitive understanding of the universe at a time.

Ken: Alright, good.

Ben: So, like I said, some people thought light was a wave. So the question is, what's it waving in? Nobody knew. And then this guy, Maxwell, James Clerk Maxwell, he lived in the 1800s and he was Scottish and what he did was...

Jocelyn: He came up with a theory that he considered to be great guns.

Ben: So, before Maxwell there were a lot of people who were doing work on electric forces like Benjamin Franklin. Electric charges, right? And then other people were working on magnetism. And the deal is that magnets affect electric charges as well as other magnets and you can make a magnetic field using moving charges. And so Maxwell combined all of these equations and said, oh, I'm going to add another little bit of an equation to this part and then he ended up with four equations bundled together called the Maxwell equations named after him.

Michael: Huh.

Ben: Maxwell had these equations and some of them said that if you had a changing electric field you get a magnetic field and others of them said if you have a changing magnetic filed you get a changing electric field so if you take an electric charge and move it around a lot, this will cause waves that expand outwards and he said hey that's light. And so he proved that these waving electromagnetic waves were in fact what everybody recognizes as light and that was history. But here's the thing, nobody at the time knew what was waving. I mean, if you have a slinky and you make a wave go down the slinky the wave is traveling through the the slinky right, it needs a medium.

Michael: Right.

Ben: As we're speaking here waves are traveling through the air, so the air is the medium. The question was, what was the medium of these electromagnetic waves and at the time everybody thought that these waves would travel through something called luminiferous aether. The idea is that you know, we, on the planet earth are traveling like some flotsam floating in a river...

Michael: ...through the luminiferous aether.

Ben: And this river is the luminiferous aether, it's flowing around us and electromagnetic waves are propagating through it. So, some people wanted to test it.

Jocelyn: The Earth is whipping around the sun and the sun is perhaps moving relative to distant stars. So you know, what's the absolute motion of the sun, that's what people were trying to measure with the aether is some reference frame for the universe and the sun is moving through it and by the way that light propagates you can tell how we're moving through this stuff that it's propagating through.

Ben: It's kinda like how a boat measures it's speed in the ocean, right. Because they used to drag these things behind them to tell how fast they were moving relative to the water around them. So, in essence, that's all we're saying, we're saying that the sun was traveling through this aether, we want to be able to use a little bit of physics to figure out how fast we are moving relative to this fluid.

Michael: Gotchya.

Jocelyn: Sort, of the key thing is if you sort of send something out and it's with the current it's going to get a little boost and if it's against the current it's going to get a little delay.

Michael: Alright, I'm with you so far.

Ben: What they were going to do is they were going to send pulses of light, so, waves through this aether, through the aether in different directions to see how we're moving through it.

Michael: Oh, ok.

Ben: So, I want you to hold your arms out at 90°. So, hold one arm straight in front of your body and then your left arm out to the side.

Michael: Alright.

Ben: So they build an apparatus that took a beam of light and then it splits this beam of light and sends half of it to your right arm and half of it to your left arm. And, at the end of your hands there are two mirrors so then the light hits those mirrors and bounces back and hits your head. Can you imagine it now.

Michael: I think so.

Ben: So, this was the set-up. It's called an interferometer and the idea here is that you take this thing and you put it in a fluid so that waves moving down the arm and back, because they're at 90° to one another the fluid probably won't be moving in the same direction for both arms. So, maybe one arm will be across the direction the fluid is moving and the other arm will be straight into the fluid flow.

[11:55]

Michael: Oh, ok.

Ben: So, the idea here is that the two arms are going to feel the motion of the fluid in different ways:

Michael: Gotchya.

Ben: It's called an interferometer, specifically a Michelson interferometer.

Michael: An interferometer, Gotchya. Okay.

Ben: So here's how it works. I want you to imagine like a snake.

Michael: I like snakes. Alright, I'm with you on this.

Ben: Okay, so imagine a snake and that it has stripes. It goes red, yellow, red, yellow, every other...

Michael: Gotchya.

Ben: One inch, really reliable.

Michael: A nice, reliable snake. Gotchya.

Ben: So, we're going to take these two, we're going to take two snakes, identical snakes and then what we're going to do is, we're going to take them together at the middle point where the light beam gets split in two and we're going to stretch them, one along the right arm and then one along the left arm.

Michael: Okay.

Ben: You bring them out and you bounce them off the mirrors and then you stretch them back.

Michael: Alright.

Ben: So, what we're going to compare is how the little red yellow stripes on the snakes line up when they return to the center.

Michael: Now that they're all bent and bounced off of mirrors and stuff.

Ben: That's right, yeah.. So, the deal is that if one of the two arms is slightly longer than the other then their stripes will be slightly out of alignment.

Michael: Alright, I think so.

Ben: The deal is that light has a wavelength. When you split these light beams into two and bounce them down off the arms the distance it has to travel is slightly longer or shorter than the other then when they recombine at the center one will kind of be advanced or um, recessed behind the others, they won't match up exactly anymore.

Michael: My brain's catching up but I think I'm still with you.

Ben: So the deal with light is that it kind of you interferes. Actually, you like music, right?

Michael: I LOVE music, absolutely love music.

Ben: You ever set-up like stereo speakers.

Michael: Oh yeah. I used to play music quite often.

Ben: Right-on! So, you setup two stereo speakers, they're essentially emitting the same sound at the same time, right. As you walk around the room the amplitude of the sound changes because these waves are, in essence, interfering with each other. The waves can overlap, they can pass through each other, right, okay?

Michael: Oh, I see. Okay.

Ben: And that makes it louder or softer but in the end, in the room there will be kind of a pattern. Right, so there will be some dead spots and some really loud spots.

Michael: Mmmhmmm.

Ben: So, in essence, the same thing happens to light when you make light interfere with itself. If you shine two dots of light at the same place on the wall you'll see these weird fringes emerge from it which is essentially.... Okay, back to this interferometer...

Michael: Okay, yes, right.

Ben: You take one beam of light and you split it in two. So at the very start its in phase with itself and you split it in two and part of it goes down the left arm, part of it goes down your right arm. Because, you're in the aether, so the amount of time it takes for this wave to travel through the aether, bounce off the mirror and come back depends on how the aether is flowing around it.

Michael: Gotchya.

Jocelyn: So, if the flow of the water is along your arm it gets a little time gained from going down along with the flow but then it looses more time when it's trying to go against the flow on the way back.

Michael: Like, when you're in an airplane and like when you're with the air currents you arrive a little faster or if you're flying into the air current you're going to arrive a little later. Is that the same general principles that work with light as well.

Jocelyn: Yes, exactly. The plane is light and the air is aether.

Michael: This is past tense. This is what they found.

Ben: Yeah, yeah, that's right. So, the amount of time that you'd gain or loose in terms of distances on earth is really small because light travels really fast. But this interferometer takes advantage of the fact that even though the amount of time difference the light beam will feel as it travels down these two arms is really, really small, as the light bounces off the mirrors and get's recombined and it will form an interference pattern, a sheet, off to the side.

Michael: Gotchya.

Ben: So, the moral of the story is you have this interference pattern that you can look at, whenever you setup the machine you get this interference pattern. And the idea is that if we move the orientation of these two arms with respect to the aether, so we change it so that we reorient it, this interference pattern is going to change because they amount of time difference between the photon traveling down the left arm and it traveling down the right arm will change depending on how we orient it with respect to the aether.

Michael: Now, this interferometer was meant to try to prove the who luminiferous aether thing.

Ben: Yeah, that's right.

Michael: Gotchya.

Ben: So, the idea here is that we move this interferometer, we rotate it a little bit and check to see how this pattern changes. And even thought it's a really subtle effect, because the wavelength of light is so small, you should be able to see this pattern changing as you reorient your arms.

Jocelyn: Actually they left the machine in place and let the earth's motion around the sun change it around.

Michael: Oh really!?

Ben: They even put it up on top of a mountain. They did all sorts of things.

Michael: Oh really!?

Jocelyn: They didn't want any like local eddies of aether to affect it.

Laughter.

Ben: So, the moral of the story is, no matter how they oriented it, no matter what time of year it is, no matter how the earth was speeding around the sun, no matter where the sun was, no matter whether it was day or night, this pattern didn't change.

Michael: So, then there was no interference to be had.

Jocelyn: It was constant.

Michael: I'm sorry, there was no special luminiferous aether river like interference that could be changed, it was all just the same interference...

Jocelyn: Yeah, this was one of the first indications that no matter how you are moving you measure the same velocities of light.

[16:55]

Michael: Because the speed of light is constant.

Ken: You got it.

Ben: Right

Michael: Yes.

Ben: So, Michelson and Morley did this experiment...

Michael: And they discovered that there is no luminiferous aether affecting light.

Ben: No luminiferous aether and nobody knew what to make of that until Albert Einstein came along. And Albert Einstein supposed, he said, what if this is all working because there's no aether and the speed of light is constant so there was an idea. Einstein didn't invent relativity, it was invented by a guy named Galileo.

Laughter

Michael: Who's that? I have never heard of, I'm kidding.

Ben: So Galileo invented this thing called Galilean relativity as we refer to it now and the idea was that if you were in a room and you closed all the windows that you couldn't feel any vibrations, you couldn't tell whether or not your room was moving or not. There wouldn't be any experiments you could do to say I'm traveling down a train track at 3 km an hour. You would just, you know, if it's moving at a constant velocity you can't tell if you have no outside information how fast you are moving and therefore all motion is relative. So Einstein took this a little bit further and said what if everything is relative again but in addition to that everybody, regardless of how they're traveling, sees light traveling at exactly the same speed.

Michael: I can't even imagine the thought process to even conceive that.

Jocelyn: Well it's just generalizing the same idea. The same way that I can't make any other measurements telling me that I'm moving, I can't you know bounce some light off two mirrors on opposite sides and measure some interference pattern compared to a different orientation. You know, I can't do the Michelson Morley experiment in my smoothly moving closed box and figure out where I am moving relative to some absolute rest train. We just tried to do that.

Ben: Actually it's kind of a crazy thing because the way we are intuitively used to the world, in Galilean relativity if something's moving, when two people see it moving, they can disagree on how fast it's moving. So imagine that you are driving in the car and you look out the window and there's a seagull sitting in the air just outside, you know flying, but kind of outside your window abreast with your car. You look out and you see that seagull and you say hey that seagull is sitting still. Whereas somebody standing on the side of the road would see your car go past and then a seagull flying 60 miles an hour next to your window and he'll say that's seagull is flying 60 miles an hour.

Michael: Right, right.

Ben: It's crazy windy today.

Laughter.

Ben: The crazy thing about what Einstein said, was he said, well what if this doesn't happen for light. What if, regardless of whether you're in a car, whether you're in a rocket ship, whether you're sitting still, you're always going to see light traveling at the same speed. It's a little bit crazy but as Jocelyn said it's entirely equivalent to what Michelson Morley findings were.

Michael: I get it, it's fantastic. I guess I just don't think about, I don't contemplate light on a regular basis like these guys, with their job to do. I imagine.

Jocelyn: Well actually it wasn't Einstein's job to do he was a patent clerk.

Michael: All, that's right, he was a patent clerk. Right!! Well, then I'm just a moron then.

Laughter.

Jocelyn: Well, you know, if we're all going to compare ourselves to Einstein then...

Laughter.

Ben: So, the deal is that Einstein said well okay, what if everybody will measure how fast light is moving and they'll all agree on the same number regardless of how fast they're moving relative to one another. Which is crazy in terms of birds flying outside windows but what's even crazier is that he came up with a series of thought experiments that let him build all of this thing that we now call special relativity. So, the nice thing about special relativity is that you can understand it by looking through these experiments one by one.

Michael: Are you going to read me the thought experiments... Or...

Laughter

Ben: Jocelyn, you're up.

Michael: Alright, we're doing these, oh shoot, alright.

Jocelyn: Yeah, yeah. So, the thing is you just take this idea and you start playing with it and you start understanding some of these bizarre consequences of special relativity. So, one of the things you can do is, okay, we can imagine we have one of these photons of light, and we have...

Michael: A light snake.

Jocelyn: ...2 mirrors that are just so great that we can just bounce the photon back and forth between the mirrors.

Ben: I like to imagine that we have a grandfather clock. So, it's a clock. It's got a face then it's got a tall body, a tower, right? And then I replace the pendulum mechanism with a decent clock mechanism so the clock works on its own. And then I have taken out the pendulum so I have this long tube under the clock face and I put a mirror at the very top and a mirror at the very bottom and then I've got this tennis ball of photons and then I bounce it off the bottom and the tennis ball of photons go down, up down up, down up over and over.

Michael: Oh I see. Alright. So, the light snake is going up, is our swinging pendulum. It's our...

Jocelyn: We have a light snake pendulum clock.

Michael: It's our metronome so to speak.

Jocelyn: Yes.

[21:57]

Michael: Cool, alright. I'm with you.

Jocelyn: So, we want the bouncing to be same up and down, our little ball is going up and down in the clock and now the crazy thing we're going to do is we're going to put the clock on one of these uniformly moving trains. So, first off, you're sitting on the train with the clock and you look at the thing moving up and down and you say okay, I know the distance, I know the speed of light, that gives me the time. Now, think about someone who's sitting outside the train and you've got a really great window and the person can watch your light clock from outside as it's moving along and now just in your minds eye, kind of trace out the path of the light ball moving up and down that that person sees and it's making kind of an angular, sawtooth pattern, right?

Michael: Okay.

Jocelyn: Now, the thing is though, on the train you know the speed of light and you know the distance and so that's giving you the time interval. Now this person outside, measures a longer distance cause it's that...

Michael: I see, right.

Jocelyn: ...diagonal length between lips at the top and the bottom. But the speed of the light has to be the same so that means that they're measuring time differently from you. So you know you see you kinda cut out so many light pulses take one second.

Michael: Okay.

Jocelyn: But the person sitting by the roadside says well that many light pulses, the light went a way longer distance so it takes more than one second.

Michael: For it to go up, to reach the top and the bottom of the clock.

Jocelyn: Yeah, this is this idea of time dilation.

Michael: Right.

Jocelyn: So that if things are moving, an external person watching them will say that time is moving differently for that moving thing.

Michael: That's a cool thought experiment. It's very accessible. That's a very accessible way to explain time dilation.

Ben: Yeah, Einstein was a genius.

Michael: Yeah, seriously.

Jocelyn: We should talk about the muons now.

Ken: So, muons are these particles that we know, they take a certain time to decay. Ok, I think they take 2.2 microseconds, something like that. They decay really fast. If you had one in front of you after 2.2 microseconds it's probably gone, it's decayed into something else.

Michael: Is that their only property, they just decay? It's the one important property that we're worried about, for this, for this discussion.

Michael: Okay, alright.

Ken: But another good thing about them is that we have a really good source of them, so, there's all sorts of cosmic rays and stuff that hit the earth and they produce muons in our atmosphere so we're constantly bombarded with these things.

Michael: And these things are just around all the time?

Ken: They're just around all the time, they're just decaying, it's what they do, basically.

Michael: Alright, cool.

Ken: This is there role in life.

Michael: Seems like they got the shit end of the stick but alright, if that's what they gotta do, then cool.

Ken: It does but they are really important for this very reason, that they do this cool thing. This I their role. Is that we know if one is sitting in front of us, it takes you know, 2 microseconds to decay. But, when they are created they are created going really fast, like very close to the speed of light when they come down. And what we can do is we can actually measure them as they get close to the earth and we can see that they last for a lot longer than 2.2 microseconds and the reason for that is exactly what Jocelyn was saying as that their internal clocks that tell them when they should decay, they're being stretched out, so the time is going slower for them.

Michael: Really?!

Ken: And you can do these really cool experiments, where you like count the number up on the top of a mountain and count the number at the ground and you can actually determine how fast they are going relative to the speed of light by looking at how many last for that long. Yeah, it's really cool.

Ben: Alright. So, rule number one for relativity is that the faster you see somebody going the slower their clock will be moving relative to yours.

Jocelyn: The slower you see their clock moving. They don't notice anything. The muons just like, I'm a muon, ahhh, I'm dead. The muon doesn't know that it's, it's just like, oh my gosh there's this huge earth coming up towards me but I'm going to decay before I hit it anyway so I don't really care. And of course the muons sees all these humans moving in slow motion around it because those humans are going past them super fast.

Michael: Wait, they're going slow because... We appear to be going slow because they're going so fast.

Jocelyn: Well, they see us going fast. They see us going fast.

Michael: I'm with ya, okay, I'm back. I'm back on board.

Ben: Okay, so, there are a few rules to relativity. I should have mentioned this earlier. These effects only really kick in when you get really close to the speed of light. The first one is that all these things are relative. So, everybody in their own room is going to think that they're right.

Second thing is that the speed of light is constant. The third thing is the rule called time dilation. So, if you look out your window and you see a rocket ship moving past you and supposing you can see the clock inside that rocket ship you'll see the hands of that clock ticking by extra slowly. But, conversely, a person in the rocket ship, if they're moving at a constant velocity, will think that their system, their reference frame it's called, is correct. They'll look out their window, see the world rush past them at a constant velocity and so if they look out and see a clock rush past them, say they go past Big Ben, they will see the time on the clock ticking by extra slowly.

[27:19]

Michael: Gotchya. Yes.

Ben: So, there are more rules in special relativity. So, there's time dilation. There's one called length contraction.

Michael: Length contraction?

Ben: That's right. In length contraction. The idea here is that, let's say I have a rocket ship and it's a hundred meters long.

Michael: Gotchya.

Ben: If it gets really close to the speed of light and then it uses it's engine to go really fast, it's going almost the speed of light, but suppose I have a camera, the rocket ship flies past me and I take a photograph of the rocket as it's passing me and then I want to figure out how long the rocket is so I look at the photograph with a ruler, the rocket ship will seem to shrink. So, the faster it goes, the closer to the speed of light it goes the more that hundred meter rocket ship will get squished down and the reason for this is actually kind of the converse of this time dilation. Yeah, I've got a quick explanation for it. So, you've got this rocket ship, suppose that this rocket ship it's going out to Alpha Centauri, it's going really far away. Time dilation will be occurring on the rocket ship. So, what feels like, you know a year and a half to go this distance, the people on board the rocket ship, it will feel like two months have passed, much less than a year because their time is being dilated.

Michael: Mmmmhmmm.

Ben: Here's the thing, for me it looks like this rocket ship has traveled a light year and a third in the amount of time that it's been going, traveling, the people on the rocket though only feel like a couple months have passed.

Michael: Right.

Ben: So, somehow, they know how fast they're moving, they can see everything moving past their ship, somehow the distance that they have traveled in their reference frame, to them, the distance they have traveled for that period of time must be shorter.

Michael: It feels shorter for them, the travelers, than it looks to us the observers.

Ben: That's right.

Jocelyn: They would actually measure it to be shorter.

Ben: That's right. So, it's actually the converse. So, I was telling you about how this rocket ship, as it goes really fast it shrinks.

Michael: Okay.

Ben: Similarly, they're in the rocket ship, they look out the window and they've seen the whole universe get accordioned in, so all of this distance in the direction that they are traveling, has been squished in by a certain amount, okay.

Michael: Huh.

Ben: So what would, before they got on the rocket ship, look like a light year and a half, once they get up to full speed, that distance between us and the next star only looks like it's a couple of light months.

Michael: A couple of light months. Jeeze.

Ben: So, in essence, the deal is, time time is slower for them, but in the direction that they are traveling, they look out the window, they see everything moving past them at this really high, close to the speed of light speed, so they look out the window and they see a rock, that rock will be squished down, right? Instead of being round it will be like a...

Jocelyn: A pancake.

Ben: It will be shaped like a mint, a scotch mint.

Jocelyn: A pancake.

Michael: A scotch mint pancake, sure.

Ben: They'll look out and they'll see, you know, a long train that they pass by, and the train, instead of being a kilometer long, will only seem like a half kilometer long.

Michael: That's crazy.

Ben: And so this distance that they're traveling between us and the next star will also seem like it's shrunk down by a certain amount.

Jocelyn: Oh, oh. Ben, do you know what time it is?

Ben: Adventure time!

Jocelyn: Rocket barn time!

Ben: Oh, rocket barn time! Okay!

Michael: What's happening?

Ken: Okay, it's time to get excited.

Ben: It's time to get excited.

Michael: Oh no, what's happening? Am I going to be questioned on what I've learned so far?

Ben: No, no.

Jocelyn: We're just, you know how your mind is going, oh my god, that's so weird, oh my god that's so weird? We're just going to, like, double the weirdness factor with the next one.

Michael: Sonofa...

Ben: Right.

Laughter.

Ben: Okay.

Michael: Actually, what I think is the, what I think is the best part is that you guys are really excited about this and that the thing is your enthusiasm is rubbing off on me a little bit.

Ben: Aw yeah.

Michael: Is that we're going to blow his freaking mind!!

Weird sounds.

Ben: It's pretty cool stuff.

Michael: No, no I love it. It's your enthusiasm for the subject is infectious. So, hit me. Blow my mind. Whatya got?

Ben: Simultaneity goes out the window.

Michael: Oh god.

Ben: So, simultaneity is the idea that...

Jocelyn: We're used to thinking that we can say like, if I have two events that happen far apart, like a flash of lightning and the crash of a meteor, that we can say that, oh, those happened at the same time.

Michael: Right.

Jocelyn: That's this idea that we have that there is this universal time advancing through the universe the same way.

Ben: There's a classic example of this. Imagine that you're standing on a platform of a railway and there's a guy in a Japanese bullet train going past at that moment. And the moment the Japanese bullet train passes you, on either end of the bullet train they get hit by lightening. Pttchooowww. Okay?

Michael: Okay.

Ben: So, they get hit by lightning and a quarter second later or whatever, you see a flash on the left, a flash on the right, arriving to you at the same time.

Michael: Okay.

Ben: Okay, so you would describe that as say, okay, those two flashes of light happened at the same time, lightning hit at the same time.

[32:20]

Michael: Gotchya.

Ben: The guy in the bullet train, in the time it took the light to go from those ends of the train to you, the guy in the bullet train, has moved forward just a little bit down the track, he's going to see the light from the front end lightning flash before he sees the the light from the backend lightning flash.

Michael: Right.

Ben: Okay, so the guy on the bullet train is going to say, no no, those lightning strikes didn't happen at the same time. First the front of the train got hit by lightning then the back of the train got hit by lightning.

Michael: Okay.

Ben: Okay, so simultaneity, this idea that people can agree on the order that things happen in is kind of out the window. Unless one thing causes another thing, it turns out that it's kind of up to debate.

Jocelyn: It just depends on which uniformly moving observer chooses to measure things.

Ben: Right. So there is an extreme version of this.

Michael: Oh boy, is this where my mind is going to get blown, you guys are getting excited.

Ben: It's called the rocket barn.

Michael: You guys are going to bake me aren't you. Oh boy. If there's nothing but silence on my end after you guys are done its probably because my brain has literally blown up and I'm on the floor somewhere. But, I'm ready for this. Rocket barn. Alright.

Ben: Okay, suppose you have this barn and you've built it so that it has a front door and a back door. And it has a remote control so you can press a button and the front door and the back door will both close at the same time and then they'll open back up. An infinitesimal amount of time, they'll just clap. Closed, open.

Michael: Sounds good.

Ben: Let's say the barn is 50 meters long, it's not that long. And then we take a rocket and the rocket is twice the length of the barn, a 100 meters long. Okay.

Michael: Okay.

Ben: And let's say I want to fly the rocket straight down the middle of the barn, so I'm going to, I'm in the rocket ship and I'm going to speed up the rocket ship and you're outside looking at the rocket. To you, I'm going so fast, so close to the speed of light that my rocket looks like it's only 25 meters long, that it's a tiny little Mario Rocket.

Michael: Gotycha.

Jocelyn: Pancake rocket.

Michael: Pancake rocket.

Ben: Pancake rocket. And now I'm going to fly that pancake rocket right down through the middle of the barn. And, when I'm in the middle of the barn, Buddy's going to press the remote control and then the front door and the back door are going to close for a second. So, I have managed to close the front door and the back door of the barn. And I've managed to enclose this 100 meter rocket inside this little barn.

Michael: Because it's moving so quickly, it's gotten smaller.

Ben: So, for the people outside, the farm workers, they see this rocket, you know, when it's at rest, when it was standing on the launchpad it was a hundred meters long but once I get it going full speed, to them it looks like this rocket's only 25 meters long.

Michael: A quarter of the size. Oh my god.

Ben: A quarter of the size. It fits right inside the barn, they open and close the doors so there's a second there where the barn is enclosing the rocket. Then, they open the door, the rocket flies out the other side and everybody claps. So, here's the thing, I mean, that's interesting as it is...

Michael: That's cool by itself, that, and I'm, and I confess, I'm still not 100% clear on why something get's smaller the faster the speed it's going.

Jocelyn: It looks smaller, I guess, is the key thing. Because...

Michael: But you also just said that this 100 meter rocket actually does fit into a 50 meter barn

Jocelyn: Now we're going to blow your mind by considering what the person on the rocket sees.

Michael: Oh boy. Oh Jesus. Oh no.

Jocelyn: Because the person on the rocket sees this barn coming towards them at super fast speed and the barn is also squished.

Ben: Right. So, the, you're inside the rocket, you're me, I'm at the guy that controls the rocket, I have walked the length of my rocket, once it's going at full speed I know first hand, I've measured it with my meter stick, I know that my rocket is 100 meters long on the inside.

Michael: Gotchya. Alright.

Ben: And I going so fast that this 50 meter barn looks like it's only 25 meters wide now, now that I've got full speed, everything is squished on the outside of my ship. So, how am I going to enclose my rocket ship, which is 100 meters long, inside this super extra narrow barn. Because we know that somebody even took, you know, somebody even took a photograph of the barn enclosing the rocket ship.

Michael: Right.

Ben: And the answer is, what I will see on the inside of the rocket ship is, I will fly my rocket into the barn, and right before the nose of my rocket hits the back-end of the barn, the door of the barn will close and then open and let the front of my rocket out. And then as the back of my rocket flies through the backend of the barn, just as it passes through the backend closes and opens. So, to me the barn was never enclosing the rocket at all. It was just first I saw the front doors closed, and then, after the back of the rocket was through I saw the back doors close.

Michael: Hang on, my brain is catching up to that.

Laughter.

Ben: Take your time.

Michael: I get it. My heart is telling me no, but no, you get it, you got this. My brain is still working the paperwork. But I see what you mean.

Ben: I've yelled at professors over this example so I'm...

Michael: But what about, I mean...

Laughter.

Ben: I was like this can't be true, you're lying, the math is lying, somethings gotta give.

Jocelyn: But there's all sorts of crazy like homework problems and stuff that physicists work through where you have things moving at some significant bit of the speed of light and stuff is bouncing around insisted of it or moving through it and you have...

[37:51]

Michael: This is the part of physics and reality that is so mindwarpingly crazy that, but I believe it, I believe it.

Ben: Okay, I'm going to resolve with the whole rocket barn for you now. Okay, so, you've got the example I gave you before where lightning struck the front of the bullet train and the back of the bullet train, right.

Michael: Yeah, yeah.

Ben: That's essentially what's happening. Is that we have two different observers. If you're on the outside you'll see the front of the barn and the back of the barn door closing simultaneously. But simultaneity goes right out the window in relativity, it's no longer trustworthy because time and space get all smushed up.

Michael: All smushed up and stretched out and accordioned.

Jocelyn: Mixed together.

Ben: Just like the way in my example, the guy on the inside of the bullet train saw the front of the train get hit by lightening first and then he saw the back of the train get hit by lightning. The guy in the rocket ship sees the front of the door of the barn closing first and then he sees the back doors closing.

Laughter.

Michael: Okay, so I have a question for you guys and forgive me if I'm jumping ahead or if I'm cutting you guys off or anything, what is the difference between special relativity and general relativity? Or is there a difference?

Jocelyn: There is a difference. In one sense they're both called relativity, sort of accidentally. General relativity to special relativity is sort of the same as electromagnetism to special relativity. And so general relativity is a theory of gravity.

Michael: Oh, okay.

Jocelyn: So, one of the things about special relativity is that it sort of leads to why physicists talk about spacetime. Because each observer is kind of measuring their own time. So if there's not one time there's this sort of volume of spacetime that each observer picks out, this is my time and this is space. And then another observer moves through this four dimensional thing and says no, no this is time and this is space. And they don't quite agree so we just talk about spacetime.

Michael: Gotchya. Oh, is this the example with like, it looks like a big grid?

Jocelyn: Yeah, yeah.

Michael: You put like a planet into it and it bends it?

Jocelyn: That's general relativity.

Ben: Yeah. In essence.

Michael: General relativity deals more with gravity, special relativity deals more with light and time.

Ben: That's right.

Michael: Alright, cool!

Ken: And rockets and barns.

Ben: And rockets and barns.

Michael: And rockets and barns and light snakes and great guns. Fantastic!

Ben: You got it.

Michael: Alright!

Ben: That was great. So, thank you Ken, thank you Jocelyn, you have pleased me. Your efforts have born fruit and that fruit is sweet. Here is some fruit. So, Ken you get this strawberry.

Ken: MMMmmmm, delicious.

Michael: Hey, strawberries are good man.

Ken: They sure are.

Ben: And Jocelyn, you get a raspberry.

Funny sound. Laughter.

Ben: Thematically appropriate.

Michael: There is only one man who would dare give me the raspberry.

Laughter

Ben: Alright, I would like to thank my guest Michael Mookie Terracciano, thank you very much for coming on.

Michael: Thank you for having me man. It was a real pleasure, it was a lot of fun.

Ben: I'm glad you had fun. Alright everybody suppose you want to interact with the Titanium Physicists a little bit more. There's a variety of ways you can do this. So, why don't you head on down to www.titaniumphisics.com and once you're there you can follow a link to our online store and buy a cute Ti-Phi-ter T-shirt designed by Chelsea Anderson or you can follow a link to our brand new forums where you can hang out with us and you can be our online friend. All of the

BrachioMedia people are there in fact. Or, if you'd like to send us an email, go to the website and click the contact link to find our addresses. Send me your ideas, send me your questions, even volunteer to be on our show as a Titanium Physicist. Now, suppose you want to listen to our show a little more conveniently. If you've got and iPod or an iPad you can try subscribing to our show using the iTunes store. While you're there write us a review. We read every review you write about us and it helps new people discover us. If you have a Zune or a BlackBerry you can subscribe to our show on those doodads as well or you can use the Stitcher radio app which will lets you subscribe to listen to all of your favorite podcasts. You can download the Stitcher app for free onto your iPhone, android phone, Kindle fire or other devices. Stitcher is convenient because it lets you subscribe to your favorite podcasts and listen to them for free. The Titanium Physicist podcasts is a member of the BrachioMedia if you enjoyed our show you might also enjoy Science Sort Of or the Weekly Weinersmith, please check them out! The intro music is by Ted Leo and the Pharmacists and the end music is by John Vanderslice. Good day my friends and remember to keep science in your hearts.

[43:43]

Michael: Great guns?! Seriously?

Jocelyn: Yeah, there's a letter he wrote. This is not exact wording, it was like I have come up with a theory which I consider to be great guns.

Michael: As in like light is shot from a pistol.

Jocelyn: No, no, like you know, that's awesome.

Ben: Totally Awesome.

Michael: OOOOhhhhh! Great guns is like his exclamation, like "great guns! I've found a theory, I've developed a theory!"

Jocelyn: Here's the quote: "I have also a paper afloat with an electromagnetic theory of light which, till I am convinced to the contrary, I hold to be great guns."

Laughter.

Ken: That's pretty great.

Ben: So, it's an adjective instead of just an exclamation.

Michael: Oh, it's an adjective.

Jocelyn: Well, it's like a slang of the time, you know, like... I can't actually think of any cool slang.

Michael: I'm gettin' it and now going to use it. My wife is sitting in the room and she's already looking at me cross eyed like don't start saying great guns to me, ever.

Jocelyn: Like, this meal that you've cooked is great guns!

Michael: Oh, I'm gonna, I, I...

Laughter.

Michael: I'm totally using this in my life now. Thank you for that.

[45:04]

Ben: So... Hmmmm. Oh, by the way, these shows are always riddled with terrible false starts so,...

Michael: No, that's fine.

Laughter

Ben: Don't worry, it takes us a little while to get rolling.

Michael: Don't worry about it, I'm not like, going to throw my headset down, and like "I was expecting something so much more professional!!! My time is valuable!" Rawwlf, Rawwlf, Rawwlf.

Laughter

Michael: No, don't worry about it. I'm fine.

Jocelyn: It would be kind of cool if you did.

Ben: Yeah.

Michael: I can... Um, well, I'm in a pretty mellow mood.

Jocelyn: You have to come back though afterward.

Michael: I would have to come back.

Laughter

Michael: I could...

Ben: Or at the very end.

Michael: I could fake a storm off but I really just had a good sandwich for dinner and I'm really in a good mood right now, you feed me, I'm a happy man so, like I, yeah, it's cool. Whatever. I have a full tummy. This is great.

[46:10]

Michael: Ah, the aether! Aw, I love...

Ken: The aether.

Michael: Sorry, the luminiferous aether. I'm sorry that phrase didn't become science.

Ben: Yeah, it's a nice phrase.

Michael: Yeah, it's really poetic, just by itself.

Jocelyn: Yeah, it's beautiful.

Michael: Like, the luminiferous aether, like, of our love.

Laughter.

Michael: Actually it's almost too, I think it's almost too poetic to be hard science, or maybe I just don't know enough poetic science which is why I'm here.

[46:45**]**

Ben: You can make two photons overlap, you can shine them at the same place at the same time and the light you see on the, so suppose you have two and you shine them the same...

Michael: Alright, back up one second, I have to confess, one, this is one of those dumb questions, I was afraid to ask.

Ben: Yeah.

Michael: What exactly is a photon.

Ben: Okay, a photon is a particle of light.

Michael: Oh.

Ken: Or a wave of light, they haven't decided yet.

Ben: Yeah, I want you to imagine that it's like a little snake of light.

Michael: Perfect, alright. I like snakes. I like it.

Ben: Ken and Jocelyn both died a little.

Jocelyn: It's more like.

Laughter

Michael: I like the light snake. I could, I can, I can grok along with the light snake, sure.

Ken: Yeah, I like it too.

Laughter.

Michael: Yeah, so the photon is essentially what makes up, it's the particles that make up light.

Ben: Yeah.

Jocelyn: Yeah, but it's, the...

Michael: So, when you say

Jocelyn: The snake is made up of little bits so it looks like a wave when you see a lot of them moving together and it has all these wave properties. But you, they, they're sort of discreet bits of it at the lowest levels.

Michael: I Gotchya.

Ben: It's all chopped up like a worm.

Michael: Right. So, when you say that you can overlay like, what did you say, like you could fire photons at each other. What you were just saying when I stopped you.

[48:15]

Michael: Alright, because I remember reading relatively recently there was some concern over at CERN that, like, oh shit, we found them going a little faster than light, what the hell's going on.

Jocelyn: Those infamous neutrinos.

Michael: Those little neutrino bastards.

Ben: Yeah. Do you know what caused that?

Ken: I feel like I should stand up for neutrino people here, given that's what I work on.

Ben: Come on!

Ken: But yeah, you're right.

Michael: Wait, what?!

Ben: Yeah, there was a machine that, that wasn't plugged in right.

Michael: Awwwww, really?!

Ben: Yeah.

Michael: Awwwww maaaannnnnn! I can appreciate a story like that, that's a story with a good punchline. It's like, that's a story that someone who doesn't know much about physics, like me could you know, like tell that story and say they just had it unplugged. OOOOhhhhh shit.

Jocelyn: Actually it was more subtle than that. I mean, they checked everything, it was slightly misaligned as it was plugged in causing a little extra delay in the electronics.

Michael: Man. That's such fragile, precise science. It's almost like magic to me. I mean, maybe that's why I write a comic about magic spells because like everything that's so super scientific like this is like me kind of looking in wonder like a peasant at you wizards going like, you guys can do that on purpose oh, whoa that's crazy. Make a magic missile next.

Laughter

Jocelyn: That's sufficiently advanced technology is indistinguishable from magic.

Michael: That's Arthur C. Clark.

Jocelyn: Yes

Michael: Yeah.

[49:57]

Jocelyn: It was more just coming from this really fundamental thing that no matter what, what if you're moving at a uniform speed you can't tell any of your measurements apart from someone who's at rest so there's no real at rest that's any different from moving at a constant speed. You can't tell the difference.

[50:25]

Jocelyn: Okay, so, okay, so let's...

Michael: I'm just imagining. I just want to take a minute for myself... To appreciate the light snake grandfather clock metronome that we've connected for this thought experiment and just appreciate, that's what I'm doing tonight.

Laughter

Michael: Just imagining such a cool thing... But please, go on.

[50:51]

Michael: Gotchya

Ben: Okay, so, you'll only see, it will only be noticeable, that a clock will be ticking by slowly if it's moving really, really fast relative to you.

Michael: Gotchya

Ben: Or, if your clock's really accurate.

Michael: Or, like, speed of light fast.

Ben: That's, well, it...

Michael: Close to it.

Ben: So, it's a matter of...

Jocelyn: Well, the... Like the GPS satellites need to correct for this sort of thing. As they move around in their orbit.

Ben: That's right.

Michael: Oh, cool.

Ben: Even thought they're not moving super, duper fast, no where near the speed of light, because they are so accurate, and we use that accuracy to find out where we are on the maps, if we don't correct for those, the fact that they are moving relative to us, all of their clocks will be off.

Jocelyn: We'd be off in our calculations of where we are on the, by GPS, if we weren't keeping track of the orbital motions.

Michael: I don't know where I'd be without my GPS now and days. I'm glad someone smart thought of that. Hey guys, by the way, the earth is moving, you idiots.

Laughter.

Michael: Account for that. Oh, yes sir, yes sir.

Ben: Oh, that's right...

[52:14]

Michael: How do you count them at 2.2 microseconds.

Ken: Alright, so, all you have to do is you have to count, you just have to count the number that hit the top and the number that hit the bottom one and you can actually, from that, you can tell. So, the easy way to think of it is that if it hits both then you know that it traveled at that least that distance.

Michael: Oh, okay.

Ken: So, if you get one of the top and you catch it again at the bottom you know that it went that far. And by, and therefore, you can count the number that hit the top and count the number that hit the bottom and you can determine how many decayed in the middle.

Michael: Oh, okay.

Ken: So, we can do that and we can actually figure out how fast they're going by looking at how dilated their time is.

Michael: I see. If you get one that hit the top but it doesn't hit the bottom it wasn't traveling as fast, clearly it wasn't traveling as fast as the ones that hit the bottom and the ones...

Ken: That's a really good way to think of it. Exactly. So, we know that some of them decayed so they had to be going, they were probably going slower basically because they decayed in that time and going slower that made it that far.

Michael: And their internal clocks were not stretched as far because they weren't going as fast. So, their, the tick tocks of their light snake were pretty accurate.

Laughter.

Ken: That's right.

Laughter.

Michael: Were faster, as opposed to the ones that were going fast, like the really really fast so the, travel time was not stretched out.

Ken: You got it.

Michael: Cool.

Ken: The little snakes, the ones that tell them when it... Snakes... Those light snakes are the ones going faster just told them slower.

Michael: Gotchya.

Laughter.

Michael: No, I get that completely. I'm totally on board, I'm, I totally comprehend that, absolutely.

[54:08]

Jocelyn: That's a good explanation Ben.

Michael: And that's because they're moving so fast.

Ben: That's because they're moving so fast. And it's because this relativity thing kicks in. So, their time is dilated. Time seems to be moving slower to them than us. But for them...

Jocelyn: No, no, no, no, no, no, no. We see, they... We see their time moving slower, they think time is moving the same.

Ben: Yeah

Jocelyn: They...

Ben: Well, I mean yeah, so in the space capsule they're not going like... Aaaaawwwwwwwwwww to each other.

Laughter

Ben: They think they are talking normally, they're not talking extra slow.

Jocelyn: It's just, if we had some sort of a series of microphones setup along their path trying to eavesdrop on them those microphones would be piecing together crazy, weird slow conversations.

Ben: Actually, yeah, so if there was a microphone on board the ship, that was broadcasting back to us, they're communicating with each other it would sound extra slow.

Ken: That's true.

Ben: Yeah.

Michael: That's so wonderfully backwards and counter intuitive that I love it.

[55:33]

Michael: That's cool, that's cool. I, that's, I got one pinky on, I got one pinky hooked around the example and the rest of me is being dragged along. I get it. I do get it. Again, I'm hookin' on. But that's cool, that's the most, that's one of the reasons I agreed to do this show with you guys, I knew you guys were going to give me some really out of this world but totally, this is what reality is at these speeds, to the point where you can't, like, I mean, this doesn't make sense but it does make sense if you just think about it with all these... It's amazing, man, it's, wow... If that rant made any sense to anybody but me...

Ken: It did and it was perfect.

Jocelyn: I think we've each individually kind of been there ourselves. Actually, I'm there now, just, going oh my god...

Michael: You just sort of, you sound like your doing all the drugs and you sound like, whoa, yeah, I get that bro. Oh, yeah, those speeds, that's what reality's like, dude! Awwwwww. Reality is great guns, man, whoa!!!

Laughter.

Ken: Well done!!

Michael: Thank you.

Laughter.

Jocelyn: That's honestly like one of the things that I love about this, about this sort of stuff, is that it's really a mind blowing experience, just trying to understand it. You know.

Michael: Man, it's great. My brain feels like, my brain feels like it's gone to the gym. You know, it's like come on, special relativity, here we go. 30 more reps, you got this. Well, okay, barn doors, lightning strikes, OOOOhhhhh, we got this...

Laughter.