Episode 1: Big Rips
Physicists: Jocelyn Read, David Tsang

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 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 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]

In 1998 Saul Pearlmutter and 31 associates from the Supernova Cosmology Project published a paper which changed the way physicists think about the universe. By looking at the color and the brightness of photons emitted by standard candles called type 1A supernova they could determine not just the distance these photons traveled to reach us but how the rate of the expansion of the universe has changed over its history. Their results were astounding. Firstly, our universe is not only expanding but the rate at which it is expanding is accelerating. Second, in terms of gravitational influence, the matter causing the acceleration should make up about 73% of the matter in the universe. So, prior to these findings, physicists had always expected the universe to either re-collapse under it's own wait or for the expansion to slow forever as the matter in the universe became more and more rarified. The discovery made by Pearlmutter and his collaborators indicate that our universe must be full of a type of matter that doesn't rarefy as it's stretched out, a matter that we call dark energy. This discovery led to the award of the 2011 Nobel prize in physics. And no one knows much about dark energy. Orthodox generally relativity assumes that it's a non-zero cosmological constant, you know, of Einstein's biggest blunder fame. But other sources have been proposed, including one we will be talking about today, a type of matter called phantom energy. Just as the only thing worse than being in a dark room is being in a dark room full of ghosts, phantom energy is the worst of all the types of dark energies. If phantom energy is indeed the source of the cosmological acceleration of the universe then Einstein's theory of general relativity predicts a grisly end to us all, a big rip where run away acceleration of the universe will tear us all to pieces. Alright, so today on the Titanium Physicists podcast I have a guest, Ryan North.

Ryan: Hi.

Ben: He's the author of Dinosaur Comics at quantz.com and he has a new book out, *Dinosaur Comics: Everybody Knows Failure is Just Success Rounded Down*. How's it going Ryan?

Ryan: Good, good. How are you?

Ben: Are you having a good night?

Ryan: I am. I just walked my dog.

Ben: Alright. So, Ryan, for today I have assembled two of my best Titanium Physicists. Arise Dr. David Tsang!

Dave: I rise from my graveeeeeeeee!!
Ben: Dr. Dave, he did his undergraduate at UBC with me, his PhD and masters at Cornell. He's currently in CalTech working as a postdoc astrophysicist. And now, arise Dr. Jocelyn Read!

Jocelyn: WWWWWhhhhhhaaaaaaaaaaaaa.

Laughter.

Ben: Dr. Jocelyn did her undergraduate at UBC and her PhD at Wisconsin Milwaukee.

Jocelyn: And I'm very scary.

Ben: Yah. She's currently at the University of Mississippi working on neutron stars. Alright guys, let's start talking about big rips.

Ryan: So, before we start, I just want to make it clear that I'm the only non-Doctor here, right?

Dave: You could be a doctor.

Laughter.

Jocelyn: There are many people that don't consider physicists real doctors either so.

Ryan: Well, I do.

Jocelyn: Yayyyyy!

Ben: Sweet.

Ryan: That's something.

Dave: I could write you a prescription for physics.

Ben: For pain!

Laughter.

Ben: So, Dave, tell Ryan about the expanding cosmology would you?

Ryan: Tell the non-Doctor...

Dave: Well, non-Doctor.

Ryan: But use little words.

Dave: So, you know that light travels with a constant speed right?

Ryan: Yes. (crosstalk) ...Einstein's observer speed

Dave: That's right. So, based on how long light takes to travel, we can, or how long light takes to get to us, we can figure out how far something away from us is. And Hubble, Edwin Hubble way back when, found out that galaxies that are further away from us tend to be moving faster than the galaxies that are closer to us. And uh...

Crosstalk

Dave: ...Faster away from us. In all directions the galaxies are moving away from us. And what physicists decided from this was that this implied that the universe was expanding. And you can backtrack to figure out that the universe must have come from a Big Bang. And ah...

Ryan: I don't want to interrupt you but I am absolutely going to interrupt you right there.

Dave: Absolutely.

Ryan: Everything is expanding away from us but that doesn't necessarily mean we are at the center of the universe, right? It's sort of like we are on the skin of a balloon and...

Dave: That's right.

Ryan: ...that's expanding and so everything is moving away.

Dave: A good way to think about it is we're inside a muffin or a cake and that the whole thing is expanding out so at any point inside that muffin, that delicious, delicious muffin, ah, other points are moving away from you as the whole thing sort of gets bigger.

Jocelyn: Other chocolate chips in the muffin.

Dave: Yeah, right.

Ryan: I feel like my balloon analogy was just as good but didn't have chocolate chips in it.

Dave: Well, we're...

Jocelyn: That was it's main failing.

Dave: Yeah, exactly. Balloons aren't as delicious. Trust me.

Ryan: Oh I'll take your word for it.

[6:48]

Jocelyn: It's sort of easier to imagine yourself in the middle of an expanding cookie, an expanding muffin than on the surface of a balloon since we usually do think in three dimensions.

Ryan: Okay, so...

Dave: Also, muffins are delicious.

Ryan: Yes, so, sorry to interrupt you David.

Dave: Oh, no problem.

Jocelyn: Interrupt more.

Ryan: So, we're in an expanding universe and shit's about to go foul.

Dave: So, the universe is expanding, ah, we knew this from Hubble. What Saul Pearlmutter and Adam Riess and the other people that won the Nobel Prize recently found out is that by looking at supernovae exploding they found that the universe is actually, not only expanding, but also that expansion is accelerating. And, I mean, before they figured this out we thought that the universe was either closed or flat, so the universe was going collapse back in on itself or that it would just keep coasting forever.

Ryan: There's no middle ground where it sort of slows down and stops and we're good?

Dave: Right. Well, it doesn't really stop.

Jocelyn: That's kind of the coasting forever one.

Ryan: Right.

Dave: So, you can imagine, you can imagine throwing baseballs. Like, if you threw a baseball straight up it would either come all the way back down but if you threw it with exactly the escape energy it would just sort of trail off to infinity forever.

Ben: The escape energy of the gravity of the Earth you mean.

Dave: Right.

Ryan: Yeah, yeah. Well, I mean, this is me throwing a baseball, it's going to go pretty far.

Dave: Yeah, yeah.

Jocelyn: And so, instead, you have the Big Bang launching you against the gravity of everything in the universe.

Ryan: Okay, I'm with you.

Jocelyn: Which wants to, which, you know, if you're thinking about regular mass that wants to fall back down or, contract back in on itself.

Ryan: Right, so instead of having a contraction and then maybe another Big Bang, another contraction, we've got an endlessly expanding universe.

Dave: And that expansion is accelerating faster and faster.

Jocelyn: Yeah, so see this is like...

Ryan: That seems crazy.

Jocelyn: We threw a baseball and it didn't just sort of arc but it actually went for awhile and then started going up faster into the sky.

Ryan: So, it sounds like something's wrong with that baseball.

Ben: Something's wrong with the muffin that we're in, that it's getting bigger and bigger.

Dave: So, this muffin just keeps growing and growing and growing.

Ryan: Right.

Dave: We're the little sprinkles in that muffin. We're the delicious baryonic sprinkles.

Ryan: Right.

Dave: And we just keep moving further and further apart from everything. So, that's the regular picture of dark energy.

Ben: We mentioned phantom energy before. Dark energy has the quality that as you stretch it out it keeps making this muffin larger and larger at an accelerating pace. But phantom energy kind of has a, has a unique characteristic. So, regular energy, the more you stretch it out, you imagine a thing full of toffee held between two or three people, and as they stretch it it gets thinner and thinner.

Ryan: Right.

Ben: Phantom energy has negative pressure and what that means is, the more you push on it, or in this case, the more you pull on it, the more of it there is. So, somehow it's becoming thicker and denser and gravitationally more powerful the more you stretch it out.

Dave: So, regular matter would just get thinner as you stretch it whereas something like the cosmological constant stays the same as you stretch it.

Jocelyn: It's constant.

Dave: Right. So it stays at a constant density no matter how much you stretch it. Whereas the main difference with phantom energy, it gets even more powerful as you pull it apart.

Ryan: Right, so we've got normal matter that we're used to where if you stretch it it gets thinner. We've got magic, constant matter, where you stretch it and you still have the same thickness and then you've got double magic, ghost matter where you stretch it and you end up with more mass than when you started, or the same thickness...

Jocelyn: Yes. But we also have to keep in mind that the difference with the dark energy and the phantom energy is that they are doing the opposite of what normal matter does. Which normal matter will pull things to it and then the cosmological constant or the phantom energy pushes stuff apart.

Dave: It's kind of like love and a valediction forbidding mourning. That's right, I got John Donne up in your face.

Ryan: So, just so I'm not lost, this, these two types, the cosmological constant that you're referring to, I always thought of that as a number but it sounds like it's a type of matter in this situation.

Dave: It's the energy of empty space.

Ryan: Okay. And, this, ah, phantom energy, I take it no one has ever observed this energy and we're just assuming it exists because it makes the numbers fall out properly?

Jocelyn: Okay, the point of this whole thing that Ben set us off to investigate is this paper saying, you know, we always look at something between no dark energy and cosmological constant dark energy and all the measurements are kind of converging toward this cosmological constant dark energy. But you can actually go further in the, you know, past the cosmological constant into this phantom energy and there's a region of that
that's also allowed by the current measurements.

[11:44]

Ryan: Okay, so, this might not exist but if it does this is what it would behave like.

Dave: Yeah.

Ben: So, in essence, it's like when the field theorists saw these, this behavior, this accelerating expansion of the universe they said well, there's two possibilities for it. One possibility, is it's a type of matter like an antigravity matter, but the more you stretch it the thinner it gets. And the second said the more, that it's a type of anti-gravity force that the more you stretch it the, it stays the same width. And then these dark, these ghost energy guys, these phantom energy guys came in and said, well, there's a third type of matter that we haven't considered. Which is a type of matter that as you stretch it out it gets, you know, heavier.

Ryan: Right. You're being very particular in distinguishing between phantom energy and ghost energy.

Ben: Well, no one calls it ghost energy.

Laughter.

Ryan: You're reserving the right to invent or discover a ghost energy down the...

Ben: Yeah, I'll patent my special energy generating machine that will burn ghosts.

Dave: Perhaps trap them in a proton beam.

Ben: That's right, put them in a big furnace afterwards and you know, the oil crisis will be over.

Jocelyn: Yay!

Ryan: So, I'm with you so far. We've got phantom energy that you stretch it and it gets thicker. Phantom matter...

Ben: Yeah.

Ryan: You're calling it energy but it's matter right?

Ben: Nobody knows what it is. They call it energy because everything with mass is a type of energy according to Einstein. Mass can be converted to energy, back and forth.

Ryan: Okay...

Ben: So they call it energy because it comes from the word dark energy which refers to the fact that we don't know what type of energy is causing this accelerating expansion of the universe. And they call that dark energy to contrast with dark matter which I don't want to get into now but it's this other matter that we see gravitationally but we can't observe optically so we call it dark matter. So, anyway, that's the hierarchy of names. That's why we call this stuff phantom energy specifically. Okay, so the deal with this is that phantom energy does more than just sit there as you stretch it out. It does more than just sit on your desk. It has a gravitational affect and the gravitational affect, as we said before, is to cause expansion in the universe. So, the more of it there is the faster the expansion take place. And so we end up with this kind of runaway expansion effect. So, at first the universe is expanding and then suddenly the amount of phantom energy doubles and then so the expansion goes twice as fast and then the phantom energy quadruples as a result and then the expansion quadruples its speed and so on and so you get runaway cosmological expansion.

Ryan: Right.

Ben: And so...

Ryan: What kind of time frame are we talking I here?

Dave: 35 billion years.

Ben: So, our universe is currently 14 billion years old and the effect of phantom energy can cause this thing called the big rip which is the net result of this runaway expansion about 35 billion years after the Big Bang, right?

Ryan: Gigayears.

Ben: Gigayears. So, that's a billion years. So, in other words, in 14 billion years we're going to stop seeing galaxies.

Ryan: Noooooooooo.

Jocelyn: Wait, wait, wait, wait, wait... but that, that's going to happen without phantom energy. We should back up and talk about stopping seeing stuff in the regular situations before we go all crazy with the ghosts. Well, okay, so we have the constant speed of light and the universe started a finite time ago so that already says there's only so far we can see out before we reach the edge of how far light could have traveled since the universe began. So, that's the limitation on what we see right now is how, you know, how far away could light have started from us and then still reach us. Now, as the universe is expanding, if we go further and further in time at some point we have, the universe is expanding out of the cone back in time of stuff we can see. So, when I say cone, I've cut a slice through space and ah, I'm just considering one sort of slice through space and I can see out to a circle.

Ryan: Right.

Jocelyn: And going back in time that circle get's bigger and bigger so it makes a little cone coming up to the point where I am now.

Dave: So, if a star moves farther away past this point where light will take the lifetime of the universe to reach us then we can't see it anymore.
Ryan: Right.

Ben: Okay, here's another way to think about it. The universe has this thing called the Hubble Constant. Hubble, as Dave said, discovered that all of the galaxies in the universe were receding from us. The rate at which they are getting farther away from us is determined by the distance, alright? So, at some point, at some distance from us, right now, there's an object where the distance between us and that far, far away galaxy is increasing at the speed of light. So, it's increasing every second, ah, $3x10^8$ meters are bubbling up between us and that distance, right?

Ryan: Right.

Jocelyn: So, so, we can never ever see that galaxy...

[16:44]

Ben: That's right.

Jocelyn: Because, because no matter how long we go along our light cone is never going to be able to go back and see where that galaxy was because that galaxy is going away at the speed of light.

Ben: Right.

Dave: So the light is like a guy on a treadmill.

Ben: Exactly, yes. So, a photon trying to walk the distance between there and here will never arrive the distance because it's, the treadmill is pushing it back faster than it can move in this direction.

Jocelyn: It's like a black hole.

Ben: It is, it's like a black hole...

Jocelyn: Everywhere.

Ben: Turned inside out.

Jocelyn: Inside space.

Ben: Yeah. We call this, what, cosmological horizon. Right?

Jocelyn: Right.

Ben: So, the deal is that ah, if an object, a galaxy falls to that distance or behind it, it will get redshifted, it will turn dark, dark, dark red and it's spectrum will shift and get, you know, the photons will end up loosing an infinite amount of energy trying to make the trip. So once an object's past that distant galaxy we won't be able to see it anymore. And as it crosses that it will fade from regular you know, yellowish light, to reddish light, to infrared, to radio to, you know, microwave radio and then it will fade away completely.

Ryan: How long would this fade take? I guess it depends on how long it takes to cross this threshold?

Ben: Yeah, exactly, it depends...

Jocelyn: And how fast the expansion is happening.

Ben: But it happens in a finite amount of time.

Ryan: Right.

Ben: So, in a finite amount of time it will go from red to black and not being there any more according to, you know, the person with the telescope trying to watch it.

Ryan: Right.

Ben: And Jocelyn said our universe isn't old enough yet for us to see this happening but if we let, if we wait a few more billion years we'll be able to see this horizon.

Jocelyn: Yeah. So, hold your breath.

Laughter.

Ben: Hold your breath and you'll see this curtain past which...

Dave: I think it's something like...

Jocelyn: Yeah.

Dave: 9 or 10 billion years.

Jocelyn: And then, and then galaxies far away will slowly wink out.

Dave: So, eventually it will look like our galaxy is just sitting by itself and we won't be able to see...

Ryan: That's ah, that's a really spooky image.

Dave: And people born then, like civilizations that arise then won't have any clue that there's any other galaxies besides our own.

Ryan: So, you mean, your saying is to take thirty, or nine, I think it was nine Gigayears for it to start happening from our present to notice it. In that time is this like the sort of thing where within a generation you'd notice stars are missing where they used to be there when gramma was alive or is it, you know, within the next several billion years the stars start going out one by one until...

Jocelyn: It would start with the furthest ones away.

Ryan: No one but Astronomers would notice them with super telescopes in space.

Dave: Right, right.

Ben: So...

Jocelyn: And then, if we're just doing like regular, boring old cosmological constant acceleration this is, you know, most of the stars we see are in our galaxy. Pretty much everything we see. There are a few smudgy nearby galaxies you can see in the sky with binoculars but most of what we see are within our galaxy.

Dave: Still within our galaxy cluster.

Jocelyn: That would, in the cosmological constant scenario, our galaxy stays bound to itself and just sort of floats along.

Dave: And our galaxy stays bound within our galaxy cluster called the local group.

Jocelyn: Right, that's true.

Ryan: But, we're not considering that we're considering the phantom energy...
Jocelyn: The crazy...

Ben: That's right, in this one specific scenario with this crazy phantom energy, this acceleration would ramp up so quickly that it would start, first it would pull apart the very distant galaxies from us so we wouldn't be able to see them. And then it would...

Dave: So the force, the force increases. This sort of dark energy force pulling everything apart, increases as time goes on until it is comparable to the force of gravity holding, like a distant galaxy cluster together and that galaxy can get pulled apart. And the same thing can happen for a galaxy...

Jocelyn: Yeah, so, so let's see... so, so, okay, so, but I wanted to say something first.

Laughter.

Jocelyn: Sorry. Okay, so where was I - one other way to think about this is if you can't see the light from something, if it's causally disconnected, there's no connection that's holding you together. So, you're severed from any kind of communication with that other galaxy.

Ryan: And nothing anyone can do in that galaxy can ever affect me.

Jocelyn: Exactly. Now, the crazy thing with the big rip or this phantom energy is that it keeps accelerating and more accelerating and accelerating more, so that it actually unbinds and disconnects the Milky Way from itself.

Ben: So, eventually we wouldn't be able to see, you know, the outer spiral arms or the middle belt of the Milky Way. All we'd be able to see is our little...

Jocelyn: Solar system.

Ben: Solar system, yeah.

Jocelyn: And then, it keeps going. It unbinds the solar system, it explodes the earth, it disassociates every atom in your body.

Dave: Yeah, at about 10^{-19} seconds before the end of the universe the atoms in your body would rip apart.

Ben: That's right. So, let's draw a picture here. So, from, so...

Laughter.

Ben: Big rip...

Dave: It will rip your face right off.

[21:44]

Ben: Big rip -60 million years, suddenly the astronomers on earth see all of the other stars in the solar system start to go out, right.

Dave: In the Milky Way.

Ben: We stop seeing the outer spiral arms and we stop seeing the middle of the solar system and this happens...

Jocelyn: The galaxy.

Dave: Galaxy Ben.

Ben: Yeah, in the galaxy, so and then about three months before the big rip takes place, Pluto disappears.

Ryan: Wait, wait. The first scenario was how long before everybody dies?

Jocelyn: 60 million years.

Ryan: And then we jump to three months?

Jocelyn: Yeah, Milky Way is really big compared to the solar system.

Ben: That's right.

Ryan: So, it takes...

Unintelligible Crosstalk

Dave: Did you have something better to do in those...

Ryan: No, my, I mean, I guess, I guess I am approaching from the point of view of someone who likes the image. But this is a really spooky and terrifying picture of the stars going out one by one further away and getting closer and closer and closer and closer. And it will be great if this could happen in like two hour movie time frame. Where maybe a ragtag group of heroes...

Jocelyn: The last... So, you know, you start with the Milky Way getting pulled apart and you see that happening and you're like oh shoot, I only have 60 million years but you don't really care. But it's as soon as Pluto disappears you have three months.

Ben: That's not even enough time to write a NASA grant to get a Shuttle to go blow something up on an asteroid.

Dave: To be fair, to be fair, the sun has already exploded by this point.

Ryan: Well, we fixed it.

Jocelyn: Yeah, we fixed it.

Dave: We fixed it, right. We sent Bruce Willis.

Ben: Right.

Ryan: To blow it up.

Dave: Yeah.

Jocelyn: Think about it though, that's a pretty good like, you know, last three months in the universe scenario. That's a lot of debauchery that...

Ryan: This is the same no matter where you are in the universe, right? If you're on a planet somewhere you've got about three months from the point of, emanating, at the same distance that Pluto is from where you are...

Jocelyn: Exactly.

Dave: It's more about the gravitational binding energy.

Ryan: So, if we're writing this story, every sentient species in the universe has three months to figure this out and they are all now alone.

Ben: That's right.

Jocelyn: Yes, they've been alone for millions of years.

Dave: They're sad.

Ben: They're terrified and alone and they've got three months to figure something out.

Ryan: Okay.

Jocelyn: Come on, party!

Ben: So, half an hour before the big rip.

Ryan: Whoa, whoa, whoa. What about three months?

Ben: Okay, yeah, so three months happens...

Ryan: We just sat around.

Ben: Yeah.

Jocelyn: Oh no, that's the debauchery remember?

Ben: Right.

Ryan: I can't go for three months.

Dave: You don't have to worry about any babies.

Ryan: I get hungry.

Ben: Listen, eating sandwiches and taking naps is it's own type of debauchery.

Jocelyn: Food is an important part of enjoying yourself at the end of the world.

Ryan: So, so over the course of three months, um, if you're on earth and it's like it is now for some reason, ah, you're watching the planets blink out.

Dave: They're suddenly shooting away from you and you can't, you can't see them anymore.

Ben: Right.

Dave: They redshift away from you.

Ben: Black. Jupiter will go black and then Mars will go black and then...

Jocelyn: And then we'll get pulled away from...

Ryan: We still got the sun.

Jocelyn: The sun.

Ben: Yeah, the sun will go black.

Ryan: But then we're dead, right? Like we're frozen.

Jocelyn: Well, we already fixed it once, we can probably make some mini Suns on the Earth.

Ryan: Right, sweet. We plug in the space heaters.

Ben: Well, you need a space heater because that's all that's left. You and space.

Dave: We probably have enough, we've probably got enough, collected enough energy by this point that we can at least survive for the thirty, the three months that...

Ryan: On batteries.

Dave: Yeah.

Ryan: Okay, so, we're at half an hour.

Ben: Half an hour and you get pulled off the earth.

Dave: The Earth just ripped

Jocelyn: The Earth explodes.

Ben: That's right. You get sucked off the surface of the Earth and you find yourself floating in a void.

Ryan: Now, is this painful?

Dave: As opposed to the three months before when you were just sucked off.

Ryan: Is this, is this painful? Like, am I being sucked off as in I'm being torn to pieces or just like the...

Ben: It's not the pleasurable kind of...

Ryan: Planet has been neutralized and I'm just sort of floating around in space which is kind of cool.

Jocelyn: You just sort of watched everything get, you know, there must be some tidal forces, actually, at this point. The length scales of the expansion...

Ben: No, there are no tidal forces.

Jocelyn: Really?

Ben: Yeah, because it's ah, because it's a...

Jocelyn: It's just unbound.

Ben: No, because spacetime in these models is really uniform so there's no tidal forces.

Jocelyn: Okay.

Dave: So, basically gravity stops being able to hold the Earth together so it just sort of...

Ryan: So, over these three months my perceived weight is going down.

Dave: Yes.

Ben: Correct.

Ryan: Sweet. So, we're doing...

Jocelyn: Wait.

Ryan: We're being able to jump further and further and further because the Earth's having less and less affect of gravity because there's something outside pulling us away from it with more and more.

Jocelyn: But it's not a tide pulling us away. It's everywhere at once expanding.

Dave: It's inside you.

Jocelyn: That's what I'm saying, if we're at the point where the Earth's exploding...

Ben: Yes.

Jocelyn: There's probably some noticeable effects even on a human scale.

Ryan: Like, I would be uncomfortable? I'd be sort of...

Jocelyn: Yeah, you'd feel kind of like...

Dave: Stretched out with a force of a G...

Jocelyn: ...really good chiropractor.

Dave: You'd be, you'd be sort of puffing out with the force of a G but you're body could still hold itself together in that case.

Ben: Oh, yeah.

Ryan: So there's this half hour point where I'm...

Dave: Floating in space with a helmet on, maybe.

Ryan: ... the force of a G pulling me in every direction and hopefully my eyeballs haven't popped.

[26:46]

Dave: You've got a helmet on, okay?

Ryan: Yeah, obviously.

Jocelyn: But the helmet is getting pulled in every direction.

Dave: Right, and suddenly...

Jocelyn: The helmet doesn't protect you.

Dave: And suddenly you notice all these electrons flying around and your atoms start unbinding.

Ryan: Go on. Sounds survivable.

Ben: Well, first you'd get pulled to pieces, right?

Dave: Right, your face will get ripped off.

Ben: Right. Far before your electrons, well, I don't know, how, you're held together with like, covalence bonds, right?

Jocelyn and Dave: Yeah.

Ben: Covalence bond is stronger than like the...

Dave: Right. Your face will come apart before the atoms do.

Ben: Yes, but only briefly before the atoms.

Dave: Very briefly, very briefly.

Ben: And then...

Jocelyn: We're in, we're in the last sort of...

Dave: We're in the last ten minutes

Jocelyn: Somewhere between, what is it, so where between 30 minutes and 10^{-19} seconds.

Ben: Your atoms start pulling themselves apart.

Ryan: But I'm, I'm dead before that point.

Ben: If you're lucky.

Laughter.

Ryan: If you're...

Jocelyn: Well, I don't know, you're a future person on this rebuilt Milky Way, ah, rebuilt, ah, solar system, who knows what you can do.

Ben: Also, French ghosts are pulling you apart so.

Jocelyn: When are they French?

Dave: Are they French?

Ben: You guys have been out of Canada too long.

Dave: Why?

Jocelyn: I still don't get it.

Ben: Phantom. It's the French word for ghosts.

Dave: But it's also the English word for phantom.

Ben: What other types of phantoms are there but ghosts?

Jocelyn: And it's...

Ben: There's opera phantoms and...

Dave: It could be energy of the phantom of the opera. The music of the night if you will.

Laughter.

Ryan: So, my atoms are being pulled apart.

Ben: That's right.

Ryan: Which would release a tremendous amount of energy would it not?

Ben: Ah, the energy...

Jocelyn: Well, there's that much energy...

Dave: It's small compared to the amount of energy that's pulling you apart.

Ryan: Right, but it's still, I mean, it's still something to be pretty proud of.

Dave: Yeah, you did let loose a pretty good rip.

Jocelyn: ... atoms.

Ryan: It's something.

Dave: Then 35 billion years from now that would basically, every single subatomic particle would be separated from every single other subatomic particle.

Ben: And nothing else could exist.

Jocelyn: It's only 20 billion years from now.

Ben: It's 20 billion years.

Dave: Oh, sorry 20 billion years, I'm sorry. 20 giga years. Or Jiga years if you're Doc Brown.

Ben: Yeah.

Ryan: And then it just disperses until we have a bunch of undifferentiated low level energy floating in an empty void?

Jocelyn: Well, there must be some sort of weird like string theory, quantum gravity kind of thing happening in the ultimate moment.

Ben: Well, if memory serves you end up with each point in the universe right now becomes infinitely large a few months later. But not really a Big Bang, it's just the phantom energy universe keeps on going on past that. There's no singularity that ends it. It's just that past the big rip, nothing with any width can exist.

Ryan: Being wide is pretty much all that I do.

Ben: I know.

Laughter.

Ben: I've been practicing a lot lately. I don't know what the deal is.

Ryan: So, this is a pretty depressing ending.

Jocelyn: Or awesome.

Dave: It's only for this one specific case though.

Ryan: Yeah, yeah.

Dave: And even the times we're giving are only for one particular realization of this phantom energy.

Ryan: But it's still a...

Jocelyn: It could take like 40 Gigayears. It is accelerating.

Ben: Yeah.

Jocelyn: We do expect the galaxies to start winking out at some point.

Dave: But they won't blow up, it's unlikely that they will blow apart based on current measurements of...

Ryan: You start with they won't then you correct with well it's unlikely.

Dave: Well, we have some error in the.

Jocelyn: It's science.

Dave: Science cannot guarantee your survival.

Ben: That's right. I think you should take consolation Ryan in the fact that your enemies will also be ripped to shreds.

Ryan: I've got 30 Gigayears to ensure that.

Ryan: Um, we never, Our ragtag group of heroes didn't stop this.

Ben: No, there's no way to stop it. Phantoms always win.

Ryan: It's a great image, the, I think the image of watching the stars blink out is nice. Since we have this time frame where it accelerates and you can have a generation where you know, in that three month period before it gets really bad, you've got maybe a generation of 40 years where it's noticeably getting worse.

Ben: Yes.

Ryan: And I think that's really cool.

Dave: Well, still close-by stars start winking...

Ryan: Yeah.

Dave: Or start accelerating red shifting away from us.

Ryan: Yeah, and you have a lonelier night sky every evening. That's creepy. That's like really creepy.

Ben: You can wish upon a star and then it would go away. And then your wish won't come true, right.

Ryan: Oh nuts, it's impossible to affect that star nor can it affect me.

Ben: That's right. Good. Any other questions Ryan?

Ryan: Ah, no, I think this was covered in an awesome yet depressing way.

Ben: That's about our...

Jocelyn: Yay!!!

Dave: We're you scared? Did you pee yourself?

Ryan: It's not scary because, I mean, I have to face reality that I will probably not be around to see it but...

Dave: Quitter.

Laughter.

Ryan: It is, but it's a really great image and I think there's something you could do with that, sort of have fun with it if you were going to tell a story or something with it.
[31:43]

Ben: Awesome. Alright. Well. That's about our half an hour. Well, thanks Dave and Jocelyn. Your efforts have pleased me. They've born fruit, your efforts have, and that fruit is sweet. Ah, I'd like to thank my guest, Ryan North. Everybody go to his website and buy some t-shirts and buy his book, *Everybody Knows Failure is Just Success Rounded Down.*

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