STELLAR FIRMA

SEASON SEASON 3

BEN AND TIM DO SCIENCE

A THIRD TIME (PT 2)

Content Warnings

- **Innuendo & sexual references**
- **Discussions of: body horror & death**
- **Mentions of: alcohol, comedic violence**
- **SFX: occasional beeping**

BRYN: Hello, and welcome to the super secret special bonus episode of Tim and Ben Do Science.

BEN: Again, I don't think Bryn's understood this. It is in a public feed.

TIM: Calling it 'super secret' — it's not, it's just the next one. Do you think— When you watched the first episode of *Sherlock* and then there was an episode 2, you were like, **[gasps]** 'A secret bonus episode!'

BEN: Yeah, it gets even more secret by the finale of any season. Bryn thinks he's the only one—

BRYN: I've decided to call it that cos I'm having fun, and you guys can't stop me.

TIM: It's true, we can't. He's physically in a different place to us. We'd love to, but we simply can't stop him.

BRYN: Today we are talking about episode 62 of Stellar Firma. We've done three different Tim and Ben Do Science episodes now. We've discussed many topics within and around science, and how we have used, abused, or completely ignored them in Stellar Firma.

BEN: Oh, yes.

BRYN: And we've come back with this very special episode, because Tim and Ben decided to come into my house, come into my own home—

TIM: With our dirty shoes of knowledge.

BEN: Get him up on the terminal, and then salt him.

BRYN: Canonized within the podcast as an angry man with glasses, shaking my head at them, and I've decided that this hubris can only be rewarded with me actually shaking my head angrily at them in real life, and questioning them about everything they said in this episode.

BEN: And friends, he is wearing his glasses.

TIM: Reader, I saw them shake.

BRYN: So, as an incredibly rapid recap, hello, my name is Bryn, I am part of Rusty Quill Gaming along with Ben, and I have been asked to do Tim and Ben Do Science episodes for Stellar Firma at the end of each season because of my degrees in applied maths and theoretical physics. My master's dissertation was indeed on black holes, and I consider them in some senses my specialist subject. We've had three science specials. We have left the score as one special each. The points are pretty even between Tim and Ben here, but we haven't decided the final contest, cos it will all be based on just how much they annoy me during this, our final Super Secret Special Bonus Episode.

TIM: Congratulations, Ben, yep—

BEN: In which case, I think it's in the bag, yeah. I adore that we made the same joke at the same time.

TIM: You know what? I actually won a prize from the Stuttgart Institute of All Science for 'Most Enthusiastically Wrong,' so I am very confident here.

BEN: There we go.

BRYN: Now, in episode 62, Trexel claims that science cannot know everything.

TIM: True.

BRYN: And I, as the resident science man, here at Stellar Firma, the podcast, not, you know, the in-character company, would like to dispute that. Which is that science can eventually, we hope, provide the answers to everything.

BEN: Oh, that is a lot of caveats. Come on, like, that is not like— I'm gonna take away your biology point.

BRYN: So, the first claim. The first claim in episode 62 is that messing around with gravity causes issues with time. And in fact, the very brief itself, the very brief itself in this episode was that the black holes are causing time pockets of unstable time.

TIM: Sure, yes.

BRYN: We're going to here accept that premise. It's not completely accurate.

TIM: Can I show my working for me saying that? Cos I appreciate pockets. Bit of a tricky idea to observe time in pockets.

BEN: Well, to be fair Tim, I don't think this your working. I think this is the brief giver's.

TIM: Oh, is it?

BEN: We've been set up with a—

TIM: Well, it's something I would fully agree with for one fact I know. And if I've got a fact, I have to share. It is my curse upon this Earth. Which is: when they are doing sat-nav, which basically involves the difference of times between clocks in— Its core relies on knowing the time at various places, one of those places on a satellite, and when they first did it, it was all vastly wrong because they haven't accounted for the fact— I think it was something to do with the gravity at one point on a satellite, and the gravity on Earth when you were doing it, were different to the point that the speed of time was slightly different, and therefore the clocks were desynching, and you had to account for the difference in gravity because of its affect on time. I think something like that. Bryn, did any of that even sound like the truth?

BRYN: You are correct, yeah. Yeah, GPS works on exchanging signals with satellites. The signals are essentially time codes. The time codes have to be incredibly precise to accurately place where the receiver is, and the gravitational effect of where the receiver is has to be taken into account because the timing has to be so precise. Um, and the strength of gravity is not just different on the surface of the Earth and where the satellite is, but in fact varies depending where exactly you are on the surface of the Earth by a few percentage points.

TIM: So we're aging all at different speeds, but it's so little that it doesn't really matter in the day to day of our lives?

BRYN: Absolutely.

BEN: Is that because of our old friend density?

TIM: Well because we're stupid, is that what you're saying?

BRYN: Okay, so, in episode 62, Trexel claims that gravity is sort of time, and time is basically gravity.

BEN: Yeah, that sounds right.

TIM: 'That sounds right.' That sounds like the kind of thing somebody would say at a TED talk to a smattering of knowing laughs.

BRYN: And that is absolutely wrong.

TIM: Aww, what?

BRYN: So, gravity has a significant effect on time, and Tim is correct in that. Well, let's delve a little bit into the history of gravity. So, our understanding of gravity as a scientific construct, and the mathematics behind it, not the fact that we observe that gravity is a thing that exists, dates back to primarily Isaac Newton. Although there were plenty of other scientists before him who laid the foundation for his work, such as Galileo, and— He's not even the only one. So, Newton was the one who laid the mathematical understanding of the laws of gravity as they apply to us, and our understanding of the universe followed the laws that Newton laid down for a great many times. We discussed way back in Tim and Ben Do Science no. 1 how science is a method of understanding the universe, and essentially a form of model, and we apply the results of that model, and see how accurate they are. And the Newtonian model is pretty accurate in everyday situations, but as we approached the twentieth century, we started to discover more and more situations where the Newtonian model was a little bit inaccurate, and this has led to the explosion in twentieth century physics, primarily in the quantum area of study, which is the study of the very, the subatomic, and the cosmological area of study, which is the study of the very big.

BEN: Enter Andrew Einstein.

BRYN: So, the Newtonian physics breaks down when things are very heavy, very big, very small, or very fast. Those are the key things that can cause the Newtonian models of physics to stop working to an acceptable degree of accuracy.

TIM: So is Newtonian physics what we call today a "basic bitch"?

BRYN: I mean…

TIM: It loves pumpkin spice latte.

BRYN: And Ben has correctly identified one of the key figures in revolutionizing our understanding of gravity specifically — was indeed Mr. Albert Einstein.

TIM: Isaac Einstein.

BRYN: Dr. Albert Einstein. **Professor** Albert Einstein.

BEN: I think it's Antonio Einstein.

BRYN: Yeah. Yeah. I imagine he had many titles within his life.

BEN: Gonna run out of A names soon, but I'm gonna keep going. I believe in myself.

BRYN: And Einstein formulated both the special theory of relativity, and the general theory of relativity. So, my first question: do you know what topic essentially the special theory of relativity is on, and what topic the general theory of relativity is on? I've listed four ways Newtonian physics breaks down, and basically, the special theory applies to one of them, and the general theory applies to one of them.

TIM: I think special theory of relativity is when it's your birthday.

BEN: Yes, well, the general theory— If it's speed.

TIM: So, fast. When things are very, very fast.

BEN: Yes, I think. Cos that's the one where it's like, the faster the speed of light you go, the more time slows down.

TIM: I think special is when you're very, very small. Or, indeed, when you're very, very big, or indeed when you're very, very dense.

BEN: Alright, now. Fair enough.

BRYN: So, the special theory of relativity is about high speeds.

BEN: Aah, no! That was the special.

TIM: We eliminated the best one!

BRYN: That was the special, I'm afraid. And I am gonna give a point to Ben here, because he has correctly identified that the theory of traveling at high speed when you're close to the speed of light, time slows down, and indeed, space contracts. So traveling at high speed causes effects on space-time.

BEN: So, actually, and this is more me like— So, is the general theory e=mc^2, right? Or is that special?

BRYN: e=mc^2 is a subset of part of the equation that applies to cases in the special theory of relativity.

BEN: Yeah, so that is the one that is about the light—

TIM: Not even all of it. “Cases.” So when people say the theory of relativity is e=mc^2, what they’re essentially saying is beeeeeep, because they’ve actually conveyed no information of use.

BEN: Well, it’s definitely one of those things where I didn’t think that Einstein like said, “I’ve got my theory,” and it’s just that on a piece of paper, it’s just e=mc^2. And he’s like, “What do you make of that?”

TIM: He had e=mc, and he’s sitting there with a piece of chalk going, “Hmmm, what will complete this? I’ve got it! Squared!”

BEN: “Whoooa, how do I finish this theory?” Yeah.

BRYN: So, one of the outcomes of the special theory of relativity is that mass is another form of energy. So up to that point, our understanding of energy was it came in various forms, stuff like kinetic, electrical, blah blah blah.

TIM: Sexual.

BRYN: The consequences of Einstein's special theory of relativity is that mass itself is a form of energy. And that the key thing is, is the reason an object that has mass, that when you're talking about the theory of special relativity, you refer to it as a "massive object," which is misleading, cos massive in this case means, "has mass," as opposed to having zero mass, can never reach the speed of light because as you increase the energy towards that object, more and more energy goes into increasing the mass of the object, and less and less goes into increasing the kinetic energy, i.e. the velocity of the object. So, e=mc^2 is an object at rest, how much mass energy it contains. Where c is the speed of light, m is the mass of the object, and e is that energy, so, an object at rest has a mass energy of e=mc^2, but the real useful equation is how you then apply that as an object starts to move, and so it's really about how the energy divides between the speed of the object and the mass of the object as its speed continues to increase.

TIM: So it's energy equals mass times the universal constant, which is the speed of light squared?

BRYN: Yes.

TIM: I said that as if that as if I understood what that therefore means, but I just feel better about myself.

BEN: What you've successfully identified what the letters are.

TIM: What 'c' is. Yeah, yeah. To be honest, in day to day, that's more than I need.

BEN: I mean, that's all you need. That's the kind of knowledge you pick up by playing Elite Dangerous, right? Cos they will measure distance in 'c' won't they, cos it's like, light second, I think?

BRYN: Effectively, yeah. 'C' is the distance light travels in a single second.

TIM: When I'm playing Elite Dangerous, it feels like a light year, cos that game is very slowly paced, oof.

BEN: Oh, it is. Oh, it is.

TIM: Not getting up from that one, are they?

BEN: Take that, Frontier Developments.

BRYN: Okay, so, that's the theory of special relativity.

TIM: Bryn Monroe 'moving on' noise.

BRYN: Absolutely. But, we're not really concerned with that in episode 62, cos episode 62 is mostly about black holes and gravity, and that brings us on to the general theory of relativity. So, special relativity is the effect on space-time of an object traveling very fast. General relativity is the effect on space-time of an object being very massive, and we're moving back here to the conventional understanding of the word massive, being big and chonky and heavy.

TIM: Yeah.

BRYN: So one of the things early on in the episode is 'we have to fix the time dilation of—'

TIM: Ooh, I've definitely heard that phrase used, um, but…

BRYN: Caused by the… well. This is my question.

BEN: He can't even say it, Tim. It's so unscientific he can't even say.

BRYN: What do we understand by the phrase 'time dilation,' and what can cause time dilation?

BEN: Uh, it's the experience of time from our perspective becoming longer. I mean, that's it, like, fundamentally a second from our perspective— From our perspective a second is always a second, but from the perspective of an observer, it is more than a second.

TIM: It's where the relativity comes in.

BRYN: Absolutely. Point to Ben. Time dilation, time slowing down. It's when your experience of a second actually takes longer to an outside observer. What two things can cause time dilation?

TIM: Uhhh… Speed.

BRYN: That is the first one, yeah. If you are traveling very fast, time will dilate.

TIM: And I’m gonna say… weirdly… size?

BEN: Gravity.

BRYN: Gravity. Yes.

TIM: Size… of gravity?

BEN: You actually explained this in a real case study, Tim.

TIM: Oh, did I?

BEN: The whole sat-nav thing, cos it was gravity affecting the time.

BRYN: Absolutely, yeah.

TIM: Oh, bums. I shouldn’t have had these two beers. I’ve forgotten facts even I knew ten seconds ago.

BRYN: So, if you are close to an object that exerts a strong force of gravity, time is dilated. So in fact, from the perspective of an outside observer in interstellar space, the entirety of human existence happens in a dilated timeframe. Because the perspective of a second to someone floating out in interstellar space far away from any sources of gravity would in fact be that the time is progressing slower for all of those of us here on the surface on the Earth.

TIM: So is time, and the speed of light, intrinsically linked because we observe things sort of related to the speed of light? And time is basically the difference between those pers— Like, time isn't a thing, like time is like the result of some things, and we perceive it as time passing, say.

BEN: Oooooh. You're getting into the like, perspective of linear time—

TIM: But then time can't go backwards, so time sort of has to be a thing, because we know backwards time travel is impossible, so it sort of is a thing, but it's like, if like time travel is— You know, if you're perceiving time differently because all the light's falling into a black hole so you can't, so like that's what's messing with the constant— Is— Beeeeeeeeeeep.

BEN: You missed the real like, the toke inhale at the start of what you just started saying.

TIM: Yeah, but do you know the sort of reasonable point at the middle of my lack of words for it?

BRYN: I mean, you're asking a very good question, which is the fundamental question is, "What is time?"

TIM: What is time?

BRYN: And there's gonna be two different answers to this question, based on—

TIM: Are they yes and no? Cos if they're yes and no, Bryn, I'm gonna be very cross.

BRYN: —what you mean by the question. And one is gonna be about "what is the human perception of time," and one is, "what is our active, physical understanding of time." And human perception is philosophy, potentially psychology, maybe even biology. I'm not gonna get into that one.

TIM: To do with the framerate of your eyes.

BRYN: From a physical perspective, time is a coordinate. It's a measure of the distance between two things. Similar to space, and therefore—

TIM: Is the phrase 'space-time' moving into view very quickly?

BRYN: Absolutely. When we start discussing general relativity, we have to start discussing space-time, because time and space are intrinsically linked, and they are our way, and the universe's way to separate different things. So things are not just separated in space, they're separate in time, and they are separate in space-time. And the experience of space-time and how space-time is affected by gravity is really the key to general relativity. Now the key thing is that there is a common misunderstanding which is that space and time are very similar, and that is not true. So even within the construct of general relativity, where you have measurements in space-time, space and time are still treated slightly differently, and I could go very deep into the mathematics here, and essentially, mathematically speaking, the key differences when you're doing four dimensional mathematics, space dimensions—

TIM: I'm sorry, what did you just **[bleep]**ing say? Four dimensional mathematics?

BRYN: Yes. You have to calculate four dimensional mathematics because when you're dealing with gravity, you are calculating how affects space and how it affects time, and that change is consistent across space and time. So you deal with four dimensional quantities — you are calculating the difference in both space and time, between events, and how those are affected by the gravitational field.

BEN: Fundamentally, it's about, you know, when people say it's about the journey, not the destination, they're idiots, because the journey is the destination.

TIM: Bam. Kaboom.

BRYN: Is that true?

TIM: Are you Jack Kerouac?

BEN: No.

BRYN: I don't know about that.

TIM: That's the kind of thing you'd write in a book, and teens would love it, but it would be wrong.

BEN: Oh, yeah yeah yeah yeah. Very much like a college understanding going, "Wow, that's deep man."

TIM: Yeah, dude.

BRYN: So the key difference, and the mathematics are incredibly complicated, but the key difference between space and time is actually simply one of sign. So if you treat space dimensions as when they combine, when you're calculating by multiplying them together as interacting in the sense that both numbers are positive, and therefore you times them together, then you have to do, when you do it the same with time, you have to give a negative sign.

TIM: For the listener at home, you'll have noticed that Bryn has entered his area of expertise, and the density of facts to the frequency of stupid interjections, has very much changed. Bryn, back over to you.

BRYN: Aaand everything gets very complicated, yes, but. So, there have been— People do conduct physics in more complex space-time to sort of understand how different universes might work if they had different sets of physical and time-like dimensions, and you have to— If you're constructing a universe you want to play in, you have to state how many spatial dimensions it has, and how many time-like dimensions it has, because at any point they are separable. So space and time are related, but not identical.

BEN: So these people are playing physics jazz.

BRYN: Basically, yes.

TIM: And also, it must be a great place, because at no point can anybody really say, “No, you’re wrong.” Because, how would you prove it?

BRYN: Maths.

BEN: I guess in that field, it’s all about the working, right? They keep going.

BRYN: Absolutely, yep, yep.

TIM: And is there definitely a point where like, our fundamental— Cos I know maths isn’t just numbers, because algebra is not— Maths is relationships, because algebra is maths, and there are no numbers involved—

BEN: I mean at this point, maths is also time, Tim, so like, we’re way—

TIM: But also, Ben, in a very fundamental way, space, and you did forget that.

BEN: Yep.

TIM: So, is there a point when it's like, 'well, guess what, the way that we've developed our fundamental understanding of the relationships that make up maths is wrong in a way that means it's impossible for you to ever understand it, cos you've started from the wrong point'?

BRYN: Yeah, maybe.

TIM: So, really they're wasting their time.

BEN: I think that is the problem with like—

TIM: And their space!

BEN: We've got to the point where we're shackled by our own ability to perceive and process information, right?

TIM: It's standpoint theory the whole way down. It's really tricky after a while.

BRYN: So, most of physics is, you know, studying the relationship between forces and how forces affect objects—

TIM: Most of physics is trying to obtain tenure, Bryn, you know that.

BRYN: Good point.

BEN: Kapow. Take that, the university system.

BRYN: In the Newtonian formulation, gravity is a force. But in the relativistic formulation, gravity is no longer a force, and you have both correctly identified the well-known understanding is that gravity is in fact a distortion of space-time. The major metaphor for that being the heavy, weighty balls on the rubber sheet, and our mental picture of how that works— There's a reason it's become very well known, because it is a useful one.

BEN: Thank you the book *Black Holes and Uncle Albert.*

BRYN: Absolutely.

TIM: I feel like there must be a question coming at some point, but I've forgotten where we started, so I'm gonna be very confused when it arrived.

BEN: Episode 62, Trexel says something stupid.

BRYN: So.

TIM: So.

BRYN: I've copied out a whole speech from Trexel here.

BEN: Oh, you didn't wanna do that, that's not…

TIM: Would you like to share it with me so I can deliver it live?

BRYN: "It's density, David. Gravity is sort of time, for some reason that was explained to me, but I've never looked into it. But as far as I can understand it, if you suddenly go 'kaboom,' there's a big thing here, time's all like, 'whoa buddy, need to fill that mass with some time,' and it sucks time out of all the other places, or if you like, there's loads of mass here, like a mountain, but it needs to go away now, kablam. Time's all like, 'there was loads of time in that, I was storing all my time in that mountain, and now it's spilling out all over the place.'"

BEN: Well, this podcast is quite funny! I like it.

TIM: So basically, I confused time with gas. Uhh… and pressure.

BEN: Oh, god.

TIM: Is there a certain like, mass to time to pressure relationship that I can claim is what I was talking about, or…

BRYN: Well, so, I think— Would we like to offer any commentary from, uh, our current understanding of the phrase, 'Whoa buddy, need to fill that mass with some time, and it sucks time out from all the other places.'

TIM: So I suppose we could say, like, something with a lot of mass has a lot of gravity… and therefore has an effect on time. So if you introduce a sudden point of mass, that would impact the time.

BRYN: It would, indeed.

TIM: Would the time say 'Whoa buddy, need to fill that with some time,' maybe not.

BEN: Yeah, hang on a minute as well. You're treating time like a fluid? Like apparently there is a finite amount of time that pours out of other bits of time?

TIM: Yeah, I don't know if time…

BEN: Into the puddle of time? Like you're creating a time lake.

TIM: Does— Bryn, does time flow?

BEN: I mean, well—

TIM: What a question. We're not talking about the passage, Ben. I'm talking about actual, physical time, moving—

BEN: Can you get a bucket of time and pour it—

TIM: And just pour it over someone's head so they get really old really quickly.

BEN: Pour it onto God's head, like Gatorade at the end of…

TIM: Like a science prank. You chuck a cup of time in someone's face and their face gets thirty years older than the rest of them.

BRYN: So I'm not sure about the part 'fill that mass with some time,' but it certainly doesn't suck time out of all the other places.

BEN: Very, very quickly: Tim has successfully identified the metaphysics of the end of The Last Crusade, where Belloq drank time out of the fake cup, and that's what happened.

TIM: That's what aged him.

BRYN: Absolutely. So in fact, the key thing is is that the presence of a lot of mass slows time down, and in fact, the places far away will continue to have the same amount of time they always did before. It's not being sucked away, it's— The mass itself is what distorting space-time, and effectively slowing down time.

BEN: I'm just gonna very quickly say 'event horizon,' and then step, and just see if I've…

TIM: Yeah, just nod.

BRYN: The second half of that sentence, then, is, "There was loads of time in that. I was storing all my time in that mountain, and now it's spilling out all over the place." That's a bit closer, if in fact a—

BEN: I'm sorry, no, hold the hell up, Bryn.

TIM: Trexel Geistman, Ph.D. It is confirmed.

BRYN: If you suddenly removed a source of mass, suddenly time dilation would lessen, so you would have suddenly… more, in some sense, time.

BEN: Okay, but it… Again, it didn't spill.

BRYN: It didn't, indeed, spill.

BEN: It's not like somebody was standing like, a little bit away, and suddenly they got older cos they got washed in a little tidal wave of time.

TIM: Is time at all springy? And what I mean by that, is if you had a large mass, and that was slowing down time, if you in an instant, got rid of that mass— Would it go like faster and faster and faster until it sort of like evened out? Because you know what?

BEN: You're obsessed!

TIM: Knowing science, knowing science… that could be a thing.

BEN: No, you're obsessed with treating time like a state of matter.

TIM: I love it.

BRYN: I don't think it would, but given that there's no known physical process to suddenly and completely remove mass in that way…

TIM: Yeah.

BEN: Surely they've used mass— They're simulating other dimensions, Bryn, come on.

TIM: I think I could conceivably get at least a bit of funding to look into it. I think it's at that level.

BRYN: Possibly. Possibly.

BEN: Bouncy time question mark?

TIM: Bouncy time question mark? And I'll just buy a bouncy castle and a watch, and see where I get.

BEN: Oh, 'I've actually just funded my children's birthday party.'

TIM: 'I've just broken into a party and called in funding.'

BRYN: I've got in my notes here about this episode, just the sentence in all caps, 'NO BLACK HOLES FOR TREXEL.' And I can't remember if that's my comment, or if that was a sentence in the episode.

BEN: Ah, no, he has been— I think he has been banned from black holes.

TIM: I'm on the list, unfortunately. I keep on saying 'I'm.' I am not Trexel. I must remember that.

BEN: Yeah, this is concerning, Tim. I'm glad the show is over so we can stop this journey.

TIM: No, because luckily all of my other characters will be completely unlike Trexel. It's not the only character I can play, honest.

BRYN: So, we make the claim in episode 62 that Stellar Firma is in fact powered by black holes.

BEN: Yes.

BRYN: And the whole problem of the episode comes down to dealing with the effects of these black holes.

TIM: Yes. Are you about to bring me up on the idea that of in the business of taking in or putting out energy to quote unquote power things, which one I think black holes are in the business of doing?

BRYN: [baffled] No?

TIM: No? **[sus]** Mmmkay.

BRYN: … My notes on this hypothetical supposition, Stellar Firma is powered by black holes, is "This can actually work 😊"

TIM: Is there some sort of like black hole paddle, and it's spinning as all the time goes past, moving the paddle like a turbine? Is that what happens?

BRYN: No.

BEN: The other question— Has this got something to do with Hawking radiation?

BRYN: No, although that is an interesting feature of black holes, and I'm excited that you know about it.

BEN: Isn't it like, theoretically that's the only thing that like escapes, or is output by a black hole?

BRYN: Absolutely, yeah. It's not gonna be powerful enough to provide any energy, but it does indeed exist.

TIM: You could read a book by it, but you're not gonna light a house.

BEN: You could read *A Brief History of Time,* ironically.

TIM: You could. But nobody ever has. Everyone's bought it, no one's read it. Not even Steve.

BRYN: So. The key thing now— As I've said, the effect of a black hole at the centre Stellar Firma as a space station, I think—

BEN: [stammers] Look. We never really, y'know— It might be an omnicron. Who knows.

BRYN: Who knows. Who can say. The effect on time of a black hole being somewhere, y'know, in the centre, or maybe at the bottom of Stellar Firma as a space station, it would be consistent around it. It's not gonna have massively uneven effects. It's not gonna cause time pockets. But. But. If we had this black hole, there is gonna be an effect. I think the question really should be, 'What is a black hole?'

TIM: I remember, I believe, from last time, that a black hole is a super dense point that has— It's, it's, um, a matter that has got so dense that light can no longer escape it, which is the black hole within the black hole. And when it gets to that point, it becomes a black hole.

BEN: And I'm gonna say, it is a prolapse in space-time.

BRYN: Oh, Ben.

TIM: And a red dwarf is a— Oh, god, what is it, when—

BEN: Hive? Is it a hive?

TIM: No, no. What is it when the bit of muscle in your thing comes out?

BEN: Oh, hernia.

TIM: A hernia. A red dwarf is a hernia in space.

BRYN: Jesus. Earlier you uttered the phrase 'event horizon.' I'm gonna give a point to Tim there for a decent explanation of what a black hole is. I'm gonna allow Ben to expand on what an event horizon is to earn an equal point.

BEN: Yes. It's alright, Tim, I know what an event horizon is.

TIM: I know.

BEN: It is the area around a black hole at which light cannot escape.

BRYN: Correct. Okay.

BEN: It's the point of no return, fundamentally.

TIM: In episode 2 of Tim and Ben Do Science, you called it the point at which the hole becomes black. I believe it's how—

BEN: Did I?

TIM: I think you described it as such.

BEN: That sounds like something that you would say.

TIM: I know, which is why it surprised me when I listened back.

BEN: Ah, well fair, fair enough.

TIM: Somebody's gonna listen to it back and it turns out it's me, and I just think I said everything. And there was that bit where I talked about my Ph.D. You know. The one I have.

BRYN: Okay, so. Now. One of the key things about a black hole is that when matter passes over the event horizon, it is no longer possible to observe it, and we say that no information can come back out. So we cannot know anything about the matter that is still inside that black hole in any real sense. But a black hole can have three properties. So a black hole— All other information about what makes up the black hole, what's inside it, has been erased. It is impossible to tell. But there are three properties about the black hole that is possible to observe from outside the black hole. Can we guess what those properties are?

BEN: One will be its size.

BRYN: What do you mean by its size?

BEN: Well, the diameter of the event horizon.

TIM: Well, I would say there more accurately, its mass. So you don't know what's going on with it, but you know how much stuff has gone in, because the more stuff that goes in, the more dense it, the larger it becomes. So you can work it out from that, surely.

BRYN: I’m gonna give the point to Tim there. So.

BEN: This is unacceptable.

BRYN: its effect on other things around it. One of the key things is its mass. And there is a sense in which you’re right, Ben, in that the size, the shape of the event horizon, its actually very difficult to observe that. It’s difficult to tell from outside exactly where the event horizon is. What you have to do is work out what its effect on everything around it is—

BEN: Cos space is quite dark, isn’t it.

BRYN: From that, work out its mass—

TIM: Space. Even with a big torch.

BRYN: And there is the Schwarzschild equation will calculate from its mass what the radius of the event horizon is. So its mass is the first, and it’s the easiest, and it’s the key one. And most black ones, as far as we know, only have this single property, they have a mass. Because the other two are rarer, but there are two other properties a black hole can have which can have an effect on the things around it.

BEN: Well, I guess one would be its, I just don’t know the word for this, but its like, radiance, right? Cos I said that like, Hawking radiation is a thing that can be observed out of a black hole, so its an observable property of a black hole?

BRYN: It is, yes. Once again, however, it is entirely dependent on the mass of the black hole.

BEN: Ahhh, okay.

BRYN: Black holes vary gradually as the Hawking radiation leaks out of them. Is it worth stopping here to explain what Hawking radiation is? No, if you wanna know what Hawking radiation is, go and read my master's dissertation which is available on the Rusty Quill discord. I don't know if that will explain it either. It won't, it's completely incomprehensible even to me.

TIM: Is it one of those ones where to understand the paper, you already need to have written the paper?

BRYN: Yeah.

BEN: Go to Wikipedia.

BRYN: I wrote it fifteen years ago, when I was much smarter. Hawking radiation is a thing which is emitted by black holes.

BEN: Sure.

BRYN: It gradually— Black holes very gradually lose mass as the Hawking radiation essentially evaporates off them. So the amount of Hawking radiation and the rate at which they evaporate is controlled by their mass. So, unfortunately, it doesn’t count as a separate property, because it’s derived from their mass as well.

TIM: Can you therefore tell its age?

BRYN: Good question, but no. Because—

TIM: I thought it was real smart.

BRYN: It can have started at any size. The mass of the black hole determines its size…

TIM: So you need to know how it started, and they’re quite old, I’ve heard.

BRYN: And the bigger it is the slower it evaporates as well, so most of the observable black holes we know of are very big, and therefore evaporate incredibly slowly. And the hypothesized micro-black holes that could exist evaporate relatively fast, and therefore it’s very difficult to observe them.

TIM: So are we still stuck on one answer, which is ‘mass,’ and we’ve not got any of the other two.

BEN: Yeah, it’s really interesting, cos—

BRYN: The other ones are quite difficult, potentially.

BEN: Yeah I'm racking my brains about things that we could know about a black hole, and a lot of them are functions of its mass, so…

BRYN: Because that is the key one.

TIM: Its… velocity in space. Its movement within space. Cos it's not gonna be stationary, everything's moving about.

BRYN: Yes. Its velocity through space is mostly gonna be determined what else is around it, and again, by its own mass, but there's one aspect of its movement which is independent of what is near it.

TIM: Its rate of expansion.

BEN: Wait, independent— Movement that's independent— But like, movement is only, is relatively, cos otherwise I'd say like, acceleration, but that's all relative to the things around it…

BRYN: What do planets do?

BEN: Orbit?

BRYN: They orbit other things, but how—

BEN: But that's obv…

TIM: Spin! It's spin! It's spin!

BEN: Spin! Yeah yeah yeah.

BRYN: We got there, we got there. Okay, I'm gonna give—

TIM: I meant to say the velocity of its spin.

BRYN: I think I'm gonna have to give the point to Tim there. You both contributed to that answer, but Tim came up with the idea of velocity, and I think that's the key one.

BEN: He got us in the ballpark.

TIM: I got us in the spin door.

BEN: Yeah, yep.

BRYN: So as far as we can tell, most black holes don't spin, but some black holes do. And the spin of a black hole which, essentially, much like a planet or a star, it is roughly spherical in terms of that being the event horizon itself spherical.

TIM: It'll be an oblique spheroid of some kind, Bryn.

BRYN: Yeah. If it can be spinning, and we can tell that by the effect of its gravity on the things around it potentially, if it is spinning. The third property a black hole can have— Now, I want you to think about the forces— If the only thing that a black hole can do, cos we can't pass information in and out of it, the only thing we can do is observe its effect on the things around it, what— Well, mass and the spin are the gravitational forces it exerts. What other force could a black hole potentially exert on things outside the area of a black hole?

BEN: Its draw, or its pull?

BRYN: How do you mean?

BEN: Well, how quickly things begin to fall into it before they get to the— Yeah, that is a function of the mass again.

BRYN: That's gonna be a mass. What other forces exist in the universe? What else can pull on things apart from gravity?

TIM: Pull on things apart from gravity in space…

BRYN: In a physics context.

TIM: It's wind.

BEN: Charisma.

TIM: What's the black hole's wind? What can— Cos if you said to me, you know, 'what moves things about,' it's, well, your propulsion?

BEN: Mag… magnetism.

TIM: Magma.

BEN: No, magnetism.

BRYN: Magnetism.

TIM: Is Ben correct?

BRYN: We're almost there. I'm gonna give—

BEN: Cos it's the weak magnetic force, right?

BRYN: I'm gonna give the point to Ben for this one.

TIM: That seems fair. I said 'magma.'

BEN: Magmatism!

BRYN: Our current understanding is there are four fundamental forces in the universe. Four ways for objects to interact with each other. The first one we've been talking about loads is gravity. The second one is the electro-magnetic force, so that is— Magnets are part of it, but the much more common expression is charge. So if we remember back to physical chemistry, uh, atoms, protons, electrons, protons are positive, electrons are negative, they have an effect on each other. So, electrically charged objects — static electricity is a good example of that, where it charges up objects and they can attract each other or repel each other. Now, we more commonly see that as magnetism. In magnetism, cos magnets pull on each other, but really that is an outgrowth of magnetic charge as outgrowth of electrical charge, essentially.

TIM: Which is why motors are magnets spinning at each other.

BRYN: Yeah.

TIM: So generators are magnets spinning at each other.

BRYN: Yeah, yeah. Basically. So the three properties a black hole can have are its mass, its spin, and its charge. Because it can pull on stuff gravitationally, but it can potentially also pull on stuff electrically.

TIM: Is this how we're getting back round to the idea that a black hole could power something, because it has a charge?

BRYN: Oooh.

TIM: Cos if it has a charge… then… you… I mean, it would be pretty tricky to stick the wires in, but you could…

BRYN: Well… I mean, you're not gonna stick wires in. So…

TIM: Oh no, the wires have been sucked beyond the event horizon.

BRYN: I believe it is extremely rare for a black hole to have a charge. Because most matter is not charged, and therefore if it pulls in matter from the rest of the universe, it's never gonna acquire one. So I think the charge of a black hole is more or less theoretical. But if a spinning black hole had a charge, that could potentially create electric current if you— You could just put electric wires near it, and it would essentially act like its own generator. I hadn't thought of that, but I guess that's possible.

TIM: Wow. How the worm has turned, Bryn.

BRYN: Well done, Tim. That is definitely a point for Tim.

TIM: Thank you. Thank you so much. I've never been proud of myself.

BEN: I'm not even mad, that was, you know.

BRYN: So, the commonly accepted method, and given that spinning black holes seem to exist relatively frequently if not quite as frequently as non-spinning black holes. The commonly accepted method to extract energy from a black hole is if you, say, fly your space ship near the black hole, and as you're passing the black hole, you toss a huge, huge block of garbage into the black hole. As you leave the area close to the black hole, you will, without doing anything else, just by tossing away your garbage, have gained speed.

TIM: Yes. In the same way that if you are holding a ball in space, and you chucked it away from you, you would gain speed.

BRYN: No. More than that.

TIM: More than that.

BEN: Well, cos otherwise you'd toss your garbage away anywhere in space and it would be fine.

TIM: That's a very good point. And then it would just be like, 'Yeah, Bryn, obviously,' and then we would just like punch you in the face and break your glasses for being a nerd.

BRYN: And you are, you are essentially stealing momentum from the black hole. And if you do this, the black hole will gradually slow down the rate at which it spins. But this a well understood property of spinning black holes, because the distortion of space-time around a spinning black hole is slightly different from the distortion of space-time around a stationary black hole. And, it creates an area of very weird space-time in a small kind of—

TIM: Pocket?

BRYN: It's an oblate spheroid, so if the event horizon of the black hole is going to be more or less completely spherical, the weird space-time— the faster the black hole is spinning, will get squashed at the axis, and elongate around the equator of spin. So you have to do it in this weird area of space-time, which I think is— I want to call it the ergosphere, and I can't remember. God it's been too long since I read up about spinning black holes, but hey.

TIM: So is this in any way related, cos obviously we're dealing in like a hyper-specific 'this only happens in a weird special place around black holes,' but given that we're talking about going past and like using its— Is it in any way related to the idea of like when you slingshot yourself around mass to gain speed?

BRYN: A little bit. A little bit. That, I mean, that process is just, you let gravity pull you in, and then you've gained speed from that, and then because you exit at a slightly different angle, you don't lose as much speed as you gained. But I guess it's similar in a sense, but here—

TIM: But I suppose it's only similar in the sense that you're exchanging forces with each other, which is how everything works.

BRYN: This relies on very specific, weird effects on space-time of the spinning black hole, and this idea that if you chucked something into the black hole, you'd go faster than you otherwise would, and the black hole slows down slightly.

TIM: Would you have to be so close that you couldn't escape?

BRYN: No. It's very crucial that this ergosphere extends past outside the radius of the event horizon.

TIM: There you go. It's the first question you have to ask yourself when you're going out for a night out, "Is the ergosphere beyond the event horizon," and if you don't ask yourself that, you're just asking for trouble.

BRYN: You are very much asking for trouble.

BEN: You've been elongated to an infinite length, and compressed into an infinite point.

TIM: But you do get to meet God, who is in the middle of a black hole. Bryn, confirm. That's that god particle that Bryn loves talking about so much. I looked that up. I looked that up—

BRYN: Can I take points away from Tim?

TIM: I'm actually going to support you here. I looked up a while ago, and the guy who was talking about that, to be fair, that's a shortening of the phrase "that goddamn particle," not…

BRYN: Because they couldn't find it, yep.

TIM: So to be fair, the guy who named it wasn't being a ding-dong, and was like, but then he did do another book that used the same title.

BRYN: Yup.

TIM: Thus compounding his mistake, and taking away all the points he got for actually not calling it the god particle, really.

BRYN: Okay.

TIM: I've angered Bryn.

BRYN: Well. In our episode 62, which is what we're still talking about.

TIM: Nominally.

BRYN: We've got these time pockets of messed up time, because we're apparently, when we're stealing energy from the black hole, which I assume is due to this ergosphere transference, almost certainly, perhaps the garbage is being flung out of the black hole with a little pocket of weird space-time around it, who can say. Trexel's proposed solution to this problem as part of the consultancy, is to simply put another black hole on one side of the Stellar Firma probably space station.

TIM: Yes. Balance it out.

BRYN: Which he claims will, “Suck the time bubbles out.”

TIM: Is, is there— Now, this is a completely separate question, but one I’d love to ask. What is this podcast, if not a completely separate question that uses some of the same words? So if you have a black hole, and then you have another black hole far enough away that they don’t, I was about to use the phrase ‘suck each other off,’ but that’s not the phrase I mean to say.

BRYN: Oh dear!

TIM: It’s lad science! Laaaa.

BEN: Also, ah, Tim, are you gonna try and invite a black hole railgun?

TIM: Well, sort of. Is there a theoretical point at which the black holes are far enough away from each other that they don’t fall into each other?

BRYN: Yes.

TIM: Maybe they’re orbiting each other.

BRYN: Absolutely.

TIM: So you have like two black holes— You have a point in the middle of those two terrifying forces at which it is all fine and normal, because the power of one and the power of the other have cancelled itself out at that point.

BEN: Tim, I think you're talking about a really difficult Lagrange Point.

BRYN: Ooh, ooh, Ben.

TIM: Ooh, ooh, Ben.

BRYN: Lagrange Points.

TIM: Hey Ben. Follow that up with an explanation, why don't you?

BEN: Uh, yes, so, a lagrange point is a point where, like obviously, it's mainly a sci-fi thing, but it's associated with ideas of FTL. It's like a point where things will float, like in a fixed point within a system, I think? Because like the gravitational forces are acting in balance, so that you kind of like— It's a place where you can literally like float in space.

TIM: It's where the pivot would be. If the forces were all bars, it's where the pivot would be.

BRYN: Definitely giving a point to Ben there. Very sexy use of the phrase "lagrange point," and correctly.

TIM: It's good stuff.

BRYN: So Tim, the answer to your question is yes, and Ben, yeah, you would probably call that a lagrange point.

BEN: And I stole Tim's point!

TIM: I can't believe this. I should have never have brought it up.

BRYN: So. So. This is a common misunderstanding of black holes. Black holes are not magic. From outside the event horizon of a black hole, it acts the same way any other concentration of mass would. And the more common concentrations of masses that we're familiar with in this context are suns and planets. If you are—

TIM: And also pencils and horses.

BRYN: Well indeed. But we're talking about, you know, kind of…

TIM: Big, really big horses. Massive horses.

BEN: Yes. Massive horses.

BRYN: A black hole is not going to suck anything in. If it is where something was before. If our sun was spontaneously replaced with a black hole, it would be very bad for other reasons, but the planets would all continue to orbit, assuming the new black hole had the same mass as the current sun does. The planets would all continue to orbit exactly as they have. There would be no change.

TIM: Assuming they were beyond the event horizon, because if they were within the event horizon, things would go very badly very quickly.

BRYN: Yes, absolutely.

TIM: Is that the thing? There's always a thing that's like, "Oh, when the sun turns into a black hole, which it might—"

BRYN: No, it's not big enough.

BEN: I don't think our sun can.

TIM: Oh, if a sun did turn into a black hole, it would exp— Does it also expand, or is that when it turns into a red dwarf it expands?

BRYN: The life cycle of a star is that, yeah, as it transitions through the different stages of its life, it does both expand and contract, and yeah, the giant stage is when it expands. A black hole is normally a contraction, so a black hole is, in physical size, a lot smaller in general.

TIM: It gets smaller. Cos that's how density works. No, I was just vaguely remembering an idea of like, when our sun reaches the end of its life, the orbit of our planet at the very least, and probably most of them, is within the area to which it will expand, really messing stuff up as it goes.

BRYN: I think the latest calculations of the Earth will remain outside of the radius of the sun, because as the sun's expanding, it's also becoming— It's actually bleeding off mass slightly? And so it will actually have a slightly lesser gravitational effect—

TIM: Like a slow-punctured balloon.

BRYN: So the current radius of the orbit the Earth is on will be inside the sun when it's in its giant phase. But as it gets there, the Earth will actually move slightly further away from the sun at the same time.

BEN: Oh, it scoots away.

BRYN: Because of all the various effects that are happening. But yes, if you put this black hole on one side of Stellar Firma— Now obviously if you spontaneously create it, you're massively changing the gravitational conditions in which this… space station? Exists, and it will probably fall in. But, in any normal— If you bring a black hole there, if you just give the space station a little push, the space station will probably orbit the black hole. It also also is suggested that the black hole will suck out these time bubbles, somehow differently to the rest of the things on the space station.

TIM: Yes. I totally appreciate that's bollocks.

BEN: No, it's because the space-time.

TIM: To be fair, Ben does make a very valid point, that it is the space-time… so.

BRYN: Well, I believe that even at the time in the episode, David 7 objects to this plan.

TIM: On moral grounds.

BRYN: Well, whether his objection's justified or not— He claims that putting a black hole on one side of the station will probably cause Stellar Firma to fall into the black hole.

BEN: Yeah, they've got a point, right?

BRYN: Trexel's solution to this is that, "We put a second black hole on the other side of the space station in order to stabilize it."

TIM: The lagrange point is back.

BEN: I think you'll find it's called the Lageistman point.

BRYN: What effect do we think having two black holes equidistant from the… space station? would be.

TIM: I think… we would get very long and thin.

BEN: I think you're overthinking this. I think the answer is, 'nothing.'

TIM: Is it nothing?

BRYN: I'm gonna give a point to Ben here. It's not quite nothing, but it's pretty close to nothing. So, firstly, yeah, if you've got two identical black holes equidistant from where you are, almost all the effect of the two of them is going to be completely cancelled out. And that is indeed the point of putting them there— Stabilization, you're cancelling the effect.

TIM: Trexel Geistman had a point. Did you just say Trexel Geistman had a point there, Bryn? Cos I think you just said that Trexel Geistman had a point. Because the whole point was that I put a second one there— I, not— Sorry, Trexel—

BRYN: Yes.

TIM: Puts a second one there to cancel out the first one.

BRYN: Well, I mean… yes. So, in that sense it worked. In the second sense is what it means you've accomplished nothing, because these pockets of distorted space-time will also have the effect—

BEN: Well, not nothing, Bryn. Because assumedly we've expended an astronomical amount of energy to create two black holes, so something happened.

BRYN: Well, although the forces have all been balanced out, and in that sense the total effect is zero, you have massively increased the strength of the gravitational field in which you are living.

TIM: In what direction?

BRYN: The force effect has been cancelled out, so you're not being pulled in any specific direction. What has increasing the strength of the background gravitational field done?

TIM: Has it messed with time?

BRYN: It has indeed messed with time. What has it done?

TIM: It slowed it down.

BRYN: Indeed. Point for Tim!

TIM: Which gives us… Which gives us! More time to work on projects. That's increasing our lead times, that's improving efficiency.

BRYN: The exact opposite.

TIM: … because they're— It's going so— Yeah, they're— They've got—

BRYN: You have effectively slowed down time.

TIM: Very importantly, Bryn, very importantly: the clocks that we're running that by are on our side of the time dilation. So they're like, "It's late," and I'm like, "I'm sorry, look at this calendar, it's still seventy years ago for you." I don't know how I'm calling them, because time doesn't work like that, Bryn as you well know.

BRYN: That… I have to confess, Tim, it's very disappointing to award you a point and for you to instantly say something for me to have to go "the complete opposite."

TIM: Yes. I got— In classic fashion, I often get the idea, but get it the wrong way around, much like when I learn someone's name isn't one name, it's another name, and then I automatically call them the wrong name. It's a very similar principle.

BRYN: So yes. Unfortunately, Trexel's solution will not solve the problem because the two equidistant black holes will have no effect on anything, except causing greater problems down the road by slowing down time within Stellar Firma, meaning that everyone having to deal with you from outside is more impatient at you, effectively.

TIM: But it does mean we can time travel until they're all dead, so what are they gonna do, sue us? I've used the word time travel and Bryn has gone quiet. But we are traveling through time in terms of the perspective— from their perspective, we're traveling forward in time really fast.

BEN: Yeah, relatively. Relatively time traveling.

BRYN: I guess so, I guess so. You're just gonna outlive everyone by living longer than they are because you're experiencing at a slower rate.

TIM: True victory is attending your enemy's funeral as we know.

BEN: But the trouble is— I guess you could get out— Of course you could get out, because we're not beyond the event horizon, so, you know. It's just very inefficient. You'd just have to spend a lot of fuel.

BRYN: Absolutely. I've got some notes here that David is correct about the messed up time with two black holes, so apparently David 7 said something at least partially correct about how this would have a detrimental effect.

TIM: There you go.

BEN: Bryn, it was ages ago, but I'm glad I was right in the past.

BRYN: Absolutely. I'm gonna give a point to Ben for saying something correct in character, even though I don't remember what it was.

TIM: Ehh. Ehh.

BEN: I will take it, but that does feel unfair given that Tim is playing Trexel.

TIM: I am literally paid to be wrong.

BRYN: Uh, David also brings up the very strange worry— The question of 'will everyone be spaghettified,' and again, I love that we've clearly heard the term 'spaghettification—'

TIM: From you!

BRYN: What is spaghettification? What do we think spaghettification is, and how is it related to a black hole?

BEN: It's when you go beyond the event horizon, and you are pulled— You, like, theoretically become like an infinite length, because you're being pulled into like an infinitely small point. Because time stops functioning at the event horizon, you're both at the event horizon and in the middle of the black hole at the same time? So…

TIM: I always thought it was because, like, if you're sticking your hand into it, like, when you go through that point, the bits of you that have passed beyond are being pulled in at a great speed, faster than the bits behind it. So, it lengthens until it snaps because the bit closer to the centre of the black hole is going faster than the bits behind it, so it has to get thinner and longer until of course it just breaks down.

BRYN: I'm gonna give a point to Tim there.

BEN: Fair.

BRYN: I think that's pretty close, yeah. That's essentially what happens. It's essentially that as you get closer to the centre of the black hole, and this can be on the event horizon, but it's not necessarily—

BEN: Fair.

BRYN: Depending on the size of the black hole, it doesn't necessarily happen on the event horizon—

BEN: Also, I guess you couldn't—

BRYN: It can actually be outside it if you get the right sort of black hole.

TIM: In theory, if the gravity on a planet is stronger, you get a bit shorter, so you have been squished. So, like, it's just pulling and pushing.

BRYN: Well, spaghettification is a description of a very specific phenomenon that does only occur really in black holes.

TIM: Cos of the extremeness of the force.

BRYN: Because of the extremeness. Because it is to do as well with, and you said something very important here, Tim, about the fact that if— Say you're falling in feet first, the idea that your feet, because they're going to be closer to the centre, will end up being pulled faster than the rest of you.

TIM: Cos they're accelerating.

BRYN: So you need what's called a gravitational gradient. So you need effectively— You are spaghettified if the gravitational forces on your feet and on your head are different enough for there to be a substantial effect.

TIM: Cos they are different right now? I am experiencing more gravity on my feet than my head.

BRYN: Yes, but the difference is so small that it's completely irrelevant.

TIM: It doesn't matter. It's why you get taller when you're lying down.

BRYN: Ye— Uh— Maybe? Yeah?

TIM: Yeah, because your head is not being pulled toward your feet, your body is being pulled—

BEN: But that's compression, not spaghettification, that's just to do with things squishing due to—

TIM: No, but then—

BEN: No, no, spaghettification is due to acceleration—

TIM: Yeah, and you're decelerating against the floor.

BRYN: So the compression would happen even if the force on your head and your toes were identical, as long as it was downwards. Whereas spaghettification is very specifically a different force on your head your toes.

TIM: I withdraw my point, your honour, although I did enjoy the fact that I got to say "standing on the floor is decelerating against the floor," because that is true, I believe.

BRYN: That is accurately.

TIM: You are constantly decelerating against the floor, and I just like to be right in some form.

BRYN: Yeah. And— Spaghettification, yeah, you get stretched out, you get long and thin, and you are fundamentally ripped apart by gravitational tidal forces because the pull on your feet is so much stronger than the pull on your head. And so one thing to remember is if you're ever falling into a black hole, try and fall in sideways.

TIM: Yeah. Well… I mean, what? So you can enjoy the right side of your brain being torn apart the left side of your brain?

BEN: Definitely fall in head-first cos you'll get killed more quickly.

BRYN: Well, depending on the size of the black hole, the spaghettification effect may or may not be enough to kill you.

TIM: That's lasagnafication.

BRYN: I mean, if you're falling into a black hole, obviously you've got bigger concerns, probably.

BEN: I mean, hey, you might travel to another dimension. We don't know.

BRYN: Absolutely. But—

TIM: You will be dead when you get there.

BRYN: If you wanna give yourself the best chance to survive, it's important to fall in sideways. If you think you're already gone, and you want to die as quickly as possible, then—

TIM: How would you turn in— How would you reorientate yourself sideways? If you're falling in, how are you sort of like—

BEN: I mean, to be honest, at the point where you know you're falling in—

TIM: You just chuck your shoe or something to try and make it spin.

BEN: Also, how quickly does this process… Like, is it even, you know.

BRYN: I've also got here in my notes, "Time is relative, well done Trexel." So I'm gonna award a point for Tim for saying something correct in character.

BEN: Sorry, what?

TIM: Cos time! Is! Relative! Ben, it's what we've learned!

BEN: It's so basic.

BRYN: I mean, as you said, Ben, I've gotta be fair. Like, you know, I can't penalize Tim for the fact that he's playing Trexel.

BEN: I mean, you can, cos it benefits me.

TIM: Time is relative, the sun is hot, the is doomed to repeat mistakes the father— These are all fundamental things that we know, Ben.

BEN: Ahh, good stuff.

TIM: Good, yes.

BRYN: And I'm gonna award another point to Ben for correctly pointing out when Trexel is describing the shape of something that it's a cuboid, not a cube.

BEN: I love we're getting retroactive points.

BRYN: Hells, why not. Well, we're close— I think we're close to finishing here, because the eventual solution actually is once we've realize the dual black holes won't work, is we create a time annex to store the messed up time pockets, and we build time robots out of…

BEN: Oh, yes! This is the thing! This is the thing specifically that we invented to annoy him!

BRYN: Countdownium.

TIM: Countdownium.

[Ben and Tim sing]

BRYN: Countdownium is apparently a time-resistant metal, and its internal time cannot be altered.

BEN: Yes.

TIM: Yes. Now, can you conclusively prove that Countdownium can't do that, Bryn?

BEN: And bear in mind that you are a scientist.

TIM: Sounds like somebody's about to say, "No," and try and quickly follow up with the word 'but,' but it'll be far too late.

BRYN: The laws of physics as we currently understand them do not allow for a metal with that property to exist.

BEN: Ooh, a lawyer's just walked in.

TIM: Okay, okay, okay. But much like wormholes, do they allow for if it could exist, that it could not continue to exist?

BRYN: I don't know. So, as we've discovered— Well, time is not a fluid. Time cannot penetrate things, it cannot flow from one place to another, it is a property, it is part of space-time which is a fundamental property of the universe. So anything that exists within the universe has to experience space-time, but now, interestingly—

TIM: Yeah.

BRYN: There are some things that effectively do not experience time.

TIM: Is it… things… from other dimensions?

BRYN: No.

TIM: Okay.

BRYN: We talked earlier about how when things travel fast, they can never reach the speed of light, because they are massive. So what is it that—

TIM: Something without mass.

BEN: Well, it's light.

BRYN: Light itself. Ben is correct. A point for Ben.

TIM: Oh, because light is moving at the speed of light, so light can't experience any time, because it's going as fast as time. Light is going speed of time, because time is the speed of light.

BRYN: Yes.

TIM: Which I want printed on something.

BEN: The speed of tiiime!! Bowowowow.

TIM: Cos you know what? You know what? You know what everybody? I might not have much knowledge, but when I hear something, by god I can put it in a phrase.

BEN: I mean, you just named a prog rock album.

TIM: Yeah yeah yeah.

BRYN: So the speed of light is indeed the speed of time. And photons, which are the particle that makes up light and other forms of electro-magnet radiation, travel at the speed of light. And they effectively, because they travel at the speed of light, they— Within special and general relativity, the mathematical formulation of how they act and interact and move means that they experience their entire timeline in a single point. They essentially travel in space without moving through time, because time has no meaning for them, because they are traveling at the speed of light. And to do that they have to be massless, that's very important. Massive particles cannot achieve speed of light travel, only massless particles can, and photons are the key example of that. So, photons are the particle that represents light, and light is electromagnetic radiation, and electromagnetism is a force, and so photons are a force carrying particle, and massless, and so, yes, the other force carrying particles— so gravitons are the particle that carries gravity, they also are massless and travel at the speed of light.

TIM: Whoa, whoa, whoa, gravity is a particle?

BRYN: No.

TIM: Well then what the piss did you just say?

BRYN: It's a distortion of space-time.

TIM: No, okay, that's great, that's great, but you just said there's a particle that carries gravity. I heard you with my ears.

BRYN: So we mentioned earlier how Newtonian physics breaks down under certain circumstances. There are two branches of non-Newtonium physics—

TIM: I feel like I'm in a pub, and about to fight somebody.

BRYN: General and special relativity. The other is quantum mechanics.

TIM: The one that Einstein doesn't like.

BRYN: The two theories are not compatible.

TIM: Oh.

BRYN: So that is the key thing is that—

TIM: So when it sounds like that doesn't make sense because you just said that, the answer is yes.

BRYN: There are two competing theories of our understanding of the universe. One deals with black holes, planets, galaxies, the evolution of the universe, the life scale of the universe, how it started, how it's gonna end. One deals with tiny particles, the interaction of nucleuses, electrons, and subatomic particles. And in one formulation, gravity is a force similar to the other forces, and it's carried by a force-carrying particle, and in the other formulation, gravity is a distortion of space-time. Currently the two theories do not work together. There are bits of theories which combine aspects of the two, so you can study relativistic quantum mechanics, but…

TIM: If you really want to.

BRYN: There are boundaries to it, and a lot of things that go wrong, and problems as well. But fundamentally, these two branches of non-Newtonian physics do not fit together, and we don't yet have an understanding of what the model that brings them all back together will look like.

TIM: In which case I forgive you.

BRYN: Thank you. So, Countdownium, if it's a metal, and has mass, cannot exist in a sense that is unaltered by time. And I'm very glad that we're wrapping up these, these Tim and Ben do Science Specials pointing out the fact that the two major branches of physics theory are fundamentally incompatible, and in fact, there's a huge amount that we just don't know. And it's still being actively researched, and, you know… there's plenty of fun, cool, interesting things to learn about physics, and plenty of fun, cool, interesting things to still be discovered, in my optimistic opinion.

TIM: We just need to pitch the sitcom in we get those two branches of science living in a house together, and they just don't get along. One of them's messy, one of them's really uptight. **[a near bryntermission]** It'll be Quantum that's uptight.

BEN: Relatively Quantum.

TIM: Relatively Quantum will be the name of it, and it will run for season after season, far beyond the point that everyone's lost interest, but there's too much money and inertia to stop.

BRYN: Thank you so much. We hope you've enjoyed this. We hope you have understood at least some of it. If you have further questions, then do feel free to ask them— I can't promise that I will see the questions and answer them, but I will try. Thank you for joining us for the journey through the Science of Stellar Firma.

TIM: Thank you.

BEN: Thank you.

TIM/BRYN: Bye!

BEN: Goodbye.

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