Episode 25: The No Bear Theorem
Physicists: Jocelyn Read, David Tsang
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Transcribed by Denny Henke

Ben: Fascination, it is an unquenchable hunger that compels our hearts. As long as there are elegant explanations too complicated phenomena science will never lose its romance. Over the years I've traveled the world indulging in my fascination with physics and now I find that a new hunger has woken within me a fiery need to share these great ideas with the people around me 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]

Ben: I remember when I first learned what happens to you when you fall into a black hole. It was the summer of 2001 when I first learning general relativity. Bill Unrue had lent me a preprint of Sean Carrol's new textbook and it had been a hot day but it was evening and I was alone it was lonely and I was house sitting for my parents. I remember feeling very sad when I learn about how everybody you know will die. No, wait that wasn't the first time. The first time was around 1995 I think. I went to see Stephen Hawking's movie A Brief History of Time. The physicists in the movie made all sorts of claims that no one ever explained and one of them was that if you fall into a black hole you get stretched into spaghetti and that's how you die. No, no that wasn't the first time either. The first time was when I was eight years old. That's about right, I watched the movie, The Black Hole, it was a Disney movie, it was about a spaceship, near a black hole, I really liked space and robots when I was a kid and that movie had a lot of robots and a lot of space things. So yeah, everybody in the movie ends up falling into the black hole and I really loved that movie. I had a picture book and a cassette tape, anyway, today's topic is, falling into a black hole. Alright, so it's been awhile since we had a journalist on, but who better to sort out what's hidden from the rest of the universe, today our guest is Anne Casselman. So Anne is a science journalist and she has written for Scientific American, Readers Digest, National Geographic and a ton of other places. Welcome to the show Anne!

Anne: Thank you!

Ben: Awesome! Okay, so Anne, for you today I have assembled two of my greatest Titanium Physicists, it's the A-Team, arise Dr. Jocelyn Read! Dr. Jocelyn did her undergraduate at UBC, her PhD at the University of Wisconsin, Milwaukee and she is currently faculty in the physics department at Cal State Fullerton, congratulations on your job Jocelyn!

Jocelyn: Thank you.

Ben: She's a specialist in neutron stars. And now arrives Dr. David Tsang! Dr. Dave was an undergraduate with me at UBC and he did his PhD at Cornell. He is currently a postdoc at McGill and Caltech and he researches black holes and neutron stars and planets. Alright everybody, let's start talking about black holes.

Jocelyn: One place to start might be just that the force of gravity pulls every mass in the universe towards each other so stuff generally likes to collapse. You know that's how the Sun formed, that's how pretty much everything in the universe formed with stuff being pulled together by gravity.

David: Yeah, stars form by collapsing gas clouds, the only thing that stops them from collapsing even further is pressure and heat from the fusion that occurs. But if gravity is left unchecked it will sort of suck everything down until…

Jocelyn: You form a black hole.

David: You form a black hole. Until basically you need more and more energy to be able to escape that gravitational well until you can't ever escape.

Anne: And why is a black and why is it a hole?

David: So John Wheeler first coined the term black hole to describe it. It’s just a very evocative term. Really, what we're talking about is a singularity in space time. So, gravity is best described by Einstein's theory of general relativity as curvatures of space time and here space time has become so curved that the gravitational attraction becomes extremely strong. So, the black holes appear black because no light can escape. You can't have anything leave the event horizon because light cannot travel fast enough to hit the escape velocity.

Anne: And so the event horizon is like the border of the black hole?

Jocelyn: Exactly

Anne: And is it a hole?

Jocelyn: It’s a hole mostly in the sense that stuff which falls into it from any direction through the horizon will never come out again. So it's a hole just in the way that there is some boundary in space that if anything crosses that boundary it is lost forever.

David: So it's not like a two dimensional hole, it is a 3-D object that if you throw something in it can't ever, ever come out.

Anne: So if you approached a black hole from, like, a helicopter like, up down, side to side, other side to side, if you approached it from any of those angles you still just disappear forever?

David: Yes.

Anne: That is so weird.

Ben: Let me tell you on evocative story. I am not sure how technically true this is but it's a good enough picture of how these things come together, right? So you have a big cloud of gas in the cloud of gas has a little center of mass and over time the cloud of gas slowly collapses down into a star like the Sun. And the star has a center of mass and all of the particles and the star are being drawn towards the center mass. Actually, the earth has the center of mass as well, and we are drawn towards it, that's the force of gravity, right. So what keeps us from falling into the core of the earth? It is the electromagnetic force. So the deal is the electromagnetic force is usually much stronger than the gravitational force and so rigid objects like the mantle of the earth and the crust of the earth and the bottom of my chair are rigid enough to keep my butt from falling down into the center of the earth. So in a star, the picture is a little bit more dynamic. So the thing that keeps the star, like the Sun, puffed out is that in the core of the Sun there's a whole bunch of nuclear fusion going on and that's generating photons and the photons are kind of moving out and as they try to migrate out from the center of the star out into space they bounce off a lot of things and that creates a pressure. And the pressure is what keeps the star puffed up. But essentially what happens is this process can only last as long as the star can't keep fusing things and generating these photons to puff it up. So, eventually this star runs out of fuel, it stops being able to generate these photons and it starts to kind of shrivel up. There's a bunch of very complicated things that happen but in essence once the star can't fuse stuff anymore it loses its ability to resist the gravitational pressure.

[7:49]

Jocelyn: There’s a bunch of things that stars can collapse to and basically black holes are the most extreme one. They are the case where every possible way for matter to resist being crushed down is overwhelmed by just the amount of mass that's just trying to all compress down and be pulled together and when there is no type of matter forces at all that can resist this then you end up with a black hole and that is sort of the point of no return. So you can have different intermediate things we call white dwarfs or neutron stars where quantum mechanics makes its last stand against gravity. But if you have too much matter all clumped together that's still not enough. There is a limit and everything just keeps collapsing to beyond what we can detect anything besides just a black hole.

David: So if you have a star about the size of our Sun and it reaches the end of its fusion and it starts collapsing it will form what's known as a white dwarf that's held up because electrons don't like to be too to each other. It’s held up by a quantum mechanical affect called degeneracy pressure. If you have a star that's somewhere between eight and 20 times the size of our Sun that star will collapse to form a neutron star where the star is held up by neutron degeneracy pressure which is even stronger than electron degeneracy pressure. And if a star is greater then around 20 solar masses, it will most likely form a black hole when it collapses where nothing, no forces are strong enough to keep this thing from collapsing all the way to a black hole. But these collapsed stars are not the only black holes that we know of. There are also large black holes at the centers of each galaxy. For instance, at the center of our galaxy, there is an object we call Sagittarius A star, and it seems to be a 2 million solar mass black hole. So it's a black hole 2 million times the mass of our Sun.

Anne: So does that mean that the black hole is actually that size but how do you measure the size of the black hole?

Jocelyn: Well one of the ways as you look at the stars that are near the black hole, you can see movements of stars around this point where we think there is this black hole and they orbit this kind of the same way the planet orbits the Sun and the speed at which it whips around the black hole tells us about the mass of that black hole.

David: So there is this group of astronomers at UCLA that have been tracking these stars that are called S stars. They're tracking the stars in the infrared and they need the infrared because there's a whole bunch of dust in our way and we can't really see with normal light but we can see it in the infrared. Oh yeah these stars whip around really, really fast. They’re ones that just zip around like crazy because of sort of the kinematics of how they're moving we can figure out how strong the force of gravity is that must be pulling on them. And So if you calculate how big a mass must be affecting the stars it comes out to about 2 million solar masses and that is pretty big.

Anne: And so does that mean that the black hole is that big?

David: We, have, sort of limits on how big that object is and it's actually really, really small. Like the only thing that has that much mass and that little volume must be a black hole.

Anne: So, the event horizon is kind of a threshold of which if you cross over then is that it you get sucked in? Like at what point can you or a black hole and what point are you like a part of it?

Ben: Okay, the event horizon is the point of no return and there is a really fun thought experiment description for it that you can describe using classical mechanics. So, let's say I throw a ball up in the air. The thing that determines how high it goes before it collapses down isn't how much energy I give the ball it is how fast I throw the ball, the speed, right. So, if I take a cannonball if I take a softball and I throw them with the same initial speed they will both rise up to the same height before collapsing down.

Jocelyn: That’s why Earth has one escape velocity. Anything on Earth gets fired up with the escape velocity that means it's fast enough that it won't come back down again but it will hurtle off into space.

Anne: Right, okay.

[11:58]

Ben: The kicker is that the only thing that matters is velocity. So light has a velocity, it's the speed of light. Even though it doesn't have mass in terms of classical mechanics, light shouldn't feel gravity at all because it is massless. There should be a planet out there, they called it a dark star back in the day, that's so heavy that on the surface of it the speed of light is the escape velocity. So the idea here is that even light wouldn't be able to escape this thing and essentially that's kind of what's happening to a black hole. In a black hole the thing that determines how far away from a gravitational object you can travel is it speed and so there is a radius around a black hole called the event horizon where photons, things traveling at the speed of light, can't escape. So they're traveling really, really fast, it’s kind of like a fish trying to swim upstream even if it's a really, really fast fish the stream is rushing down so fast that at most it can stay in one spot. So, in the geometry, these photons are trying to swim out of the black hole geometry, but even though they're traveling at the speed of light they can only sit in one spot, and the radius that they're sitting act is called the event horizon. It is the boundary between the region that you can escape from the black hole. So if you're just outside the event horizon, if you have a really, really strong rocket you could still kind of get away from it, you won't necessarily have to fall inside of it. But once you're on the other side of that, not even light can make it back outside.

Anne: So we talk about the event horizon and it's like, is it like, a door threshold you just walk over and then you'd be sucked in. Or, would you be like would you start to get sucked in towards the event horizon already, and then it would just be a question of like, once you hit the event horizon, which you would in inevitably do because it would draw you in.

Jocelyn: So you are always pulled towards something massive like a black hole the same way you're pulled towards the Earth. So you feel a pull, the event horizon is the point, where no matter what to do you cannot escape it.

David: Game over man!

Jocelyn: Yeah, so if you're a little bit outside of the event horizon you still have some chance to like put on your super rockets and escape with some extra power.

Anne: Ok, I will remember that.

Jocelyn: You're still falling in it but you have hope until you cross the event horizon and then there's nothing left.

Anne: Got it. Ok. Thank you.

David: So, it literally is … abandon all hope.

Ben: Yeah.

Anne: Would you know that the event horizon was there.

David: That's a good question.

Ben: That's a great question.

Jocelyn: You might not.

Anne: Would you feel it, feel your spaceship being like wwwwwhhhhheeerrrrrrrr, just getting like pulled in?

Ben: Yeah, you kind of can't. Let's say you were in the spaceship and it was really big black hole we're going to get in to this in a second, but if you were in a spaceship, and you closed all the windows to your spaceship so you couldn't see outside…

David: And you fell into the galactic center, say…

Ben: And it was a very big black hole you could pass the event horizon and not even know it. It's not like there's a speed bump there or a doorway or any particular lights, you don't hear, the angel Gabriel doesn't come out and tap you on the shoulder, it's just, you'll feel nothing, you'll feel exactly the same way that you would falling normally.

Anne: So does that mean that, were you to cross the event horizon, you would all of a sudden see all of the light that couldn't escape the event horizon. Like would it be really bright inside of a black hole.

David: That's a very good question.

Ben: Yeah, that's a great question. The short answer is that on the inside of a black hole it's like a stream moving in towards the center that is so fast the fish traveling at the speed of light can always that one spot at the event horizon. Inside that the river is traveling even faster so even photons that try to move out at the speed of light end up getting sucked into the middle.

David: But if you were a bear and you were falling into a black hole then you could just open your mouth and you could be sort of be going past all these fish did you know you'd get a lot of Fish.

Ben: Yeah. You can, if you're a bear, traveling into the black hole…

David: That's a terrible metaphor, I'm sorry.

Anne: I know, I was going to say the same thing, and the fish of the photons.

Ben: The fish are the photons. The fish trying to swim out, they're slowly getting sucked into the middle, but you know, a grizzly bear can still eat them on the way past.

Anne: So you might not be able to see your food…

Ben: No, no, you'd see it.

Anne: So you would see it.

Jocelyn: You'd see it when you hit it.

Ben: Yeah.

Anne: Ha ha, I love it. So it would be like you'd be in the dark and all of a sudden you'd just like, hit dinner… and then you'd hit more dinner.

David: This would be a very efficient way for a bear to eat but not a very efficient way for a bear to survive.

Ben: That's right, but the kicker is that like, if a fish is swimming there maybe 10 minutes later it will get sucked into the middle.

Jocelyn: If it falls behind even a little tiny bit it is like, game over.

Ben: No, you will see every fish that ever got stuck in the black hole but you will see some fish to answer your question.

Anne: Weird.

Ben: So it's not like a big mirror box. All of the photons eventually gets sucked down into the middle but there are some that are kicking around trying their best to swim out, that your grizzly bear would be able to eat on the way in so you will see some photons.

Jocelyn: The grizzly bear is now being swept down over the the waterfall to the singularity.

Ben: Yeah that's right. The grizzly bear is also doomed.

[17:06]

David: So a good question is what happens to this grizzly bear?

Anne: I was just thinking that, what happens to the grizzly bear? I mean, we've talked about the fish, but, more importantly…

David: See how that worked into a segue. That was an awesome segue.

Ben: Yeah, that was good, let's talk about what happens to the grizzly bear.

Anne: Wait, wait, because the grizzly bear would be us were we to fall into a black hole just to spell everything out, is that right?

Ben: No, here's the thing, grizzly bears are much tougher than us, like, a grizzly bear could probably take getting hit buy a small car but we couldn’t. So if it's going to kill the grizzly bear it will totally kill us. So it's even better to talk about the grizzly bear falling into a black hole.

David: That’s an excellent and salient point Ben.

Ben: Everybody’s so good at this.

Anne: Wait, can't we just pick an even larger, stronger animal, if like…

David: Like, like

Anne: Well I was going to say a dinosaur.

Jocelyn: Wait, one of those armored ones like from the early dinosaur era with all of the plates.

David: He’d be even more screwed because they're larger right?

Jocelyn: So we run into an issue here that what you feel as you fall into the black hole depends on how much bigger the black hole is than you are.

Ben: We mentioned earlier that if you fall into a black hole you get stretched like spaghetti.

Anne: Yes, and that was like a teaser because we talked about everything but we have not talked about spaghetti.

Ben: Right, so the force that is causes that is called a tidal force. So on Earth what causes the tides.

Anne: The moon.

Ben: The moon causes the tides right.

David: And the Sun.

Ben: And the Sun. The Sun causes a much smaller tide. In conjunction both of them do. So essentially the deal is that the Earth itself is very rocky but the water on the surface of the Earth is very squishy and the gravitational field of the Moon is what's causing the tides. So here's the question, how come when it's a full moon at midnight, you can't jump really high?

Laughter

Anne: Those questions never occurred to me.

Ben: I know, so if the gravitational field from the moon it is attractive enough to squish all the water on the Earth and to displace it and cause these crazy tides why can't when the moon is right directly above me why can't I jump really high? And the answer is that it's not quite the gravitational attraction of the Moon that's causing the water on the earth to kind of distend, and form tides, it's actually the difference between the force of gravity on the moon from different points on the Earth, right? So when the moon is directly above me I'm going to feel some gravitational attraction towards the moon, right?

Anne: You are, when you jump.

Ben: I am, naturally, right. But it's not very strong, it's actually fairly weak, but somebody standing on the other side of the Earth from me will also feel an attraction towards the moon, right, through his feet down towards the bottom. But the force he feels towards the moon will be weaker then the force that I feel towards it because I am slightly closer to the moon then he is right?

Anne: Right.

Ben: I'm an Earth's distance closer to the moon than him. So the deal is that around the surface of the Earth different people will feel an attraction towards the moon that's slightly and the overall effect of this is that…

David: Maybe the best thing about this is imagine you have a pearl necklace that you dropped from space it starts off as a circle and it's falling towards the Earth, okay. Now the pearl closest to the Earth feels a stronger force then the pearl that's farthest from the Earth right. So the one that's closest to the earth falls faster than the one that is further from the earth. So it stretches out downwards. Now the two on either side, let's say the pearl on the right-hand side and the pearl of the left hand side, now they have a slight…

Jocelyn: They have a slight angle on the force to go to the center of the earth instead of straight down.

David: Right exactly. So, they feel a slight relative force pushing them together, so they get squished inwards so you get the stretching up and down and the squishing horizontally. That's what would happen to a bear.

Jocelyn: So as the necklace falls it doesn't stay at a perfect circle it's going to elongate a little bit, and the sides are going to get pulled in a little bit by the tidal forces. And this is the same shape that the oceans of the earth make relative to the earth.

David: I just realized, we should have thrown a pig into the black hole because then we could have talked about pearls before swine.

Laughter

Ben: Yeah so the deal is that this tidal force kind of depends on how large the object is with respect to its distance away from the gravitational object right. So, the earth is really large and it feels the tidal force from the moon because its size scale is sufficiently large that it can, whereas I am relatively small compared to the force of gravity on the moon so my body doesn't feel the tidal force because the force of gravity attracting me to the moon isn't that different across my body, okay.

Anne: That, makes sense

Jocelyn: But if your body spanned of the world it would.

Ben: Yeah, that's right.

Jocelyn: If you were on earth sized person you would be feeling kind of funny because this orbiting moon around you is pulling you in different directions as it goes.

Anne: Yes, okay.

Jocelyn: So the same thing happens with black holes. If you were a really tiny thing falling into a huge black hole you don't care you could just fall in. You're like what, was that an event horizon, I don't know. But if you're falling into small black hole, that's actually more dangerous because tidal forces from the black hole could be enough to tear you apart or spaghettify you by stretching you a whole lot along the lines of your fall and squeezing you around the middle.

[22:33]

David: And that's what we call spaghettification. So if you threw, say a bear, into a

Jocelyn: A black hole with the mass of the Sun which is only like 3 km across…

David: So well before you actually fall into the event horizon the bear would have been spaghettified, so you would get bear spaghetti.

Anne: Wow. Okay.

David: Yeah, but if you threw the bear into a galactic center, say, like 2 million solar masses, like the one at the center of our galaxy, the bear would be fine through the event horizon.

Jocelyn: Only later…

Anne: I was just going to say…

David: You'd have to give him oxygen.

Jocelyn: Eventually as the bear, so the bear falls through the event horizon and continues to fall the tidal forces will continue to increase so eventually the bear will be spaghettified.

David: Right but we don't have to see it.

Anne: So he goes from like spaghetti to spaghettini to like angel hair pasta.

David: But the key thing here is that we won't have to see it.

Jocelyn: Yeah, we'll never see the bear being torn apart horribly.

Anne: Right, but if we were following the bear, like what would that feel like?

Jocelyn: That's the kind of the case where we might not notice that we were falling into a black hole until you know sometime before the death by spaghettification it would start to feel a little woozy probably and, maybe you're like, oh I'm getting a kind of nice chiropractory back cracking sensation.

Anne: Eww. Okay, hoping you're going head or feet first.

Jocelyn: Yeah, yeah I am assuming that. So you might feel like you're kind of hanging from a bar and it's kind of a nice stretch but then it just keeps increasing

Anne: Well, so the take-home that I am getting is like just never find yourself in a space from which photons cannot escape.

Ben: Well, as Dave said, if it was a solar mass black hole, so 3 km wideish, you would get spaghettified even before you entered the event horizon.

Anne: Right.

Ben: So, don't ever go near any black hole ever because.

Jocelyn: Death by spaghetti.

Ben: So, let's start talking about what happens if two people, okay so there's, a bear…

David: Figure skater!

Ben: You throw the bear into the black hole and then you have Toller Cranston, who's a figure skater, and he is watching the bear falling into the black hole, okay? We will explain it in a second but here is the short answer, this is the crazy part okay. So the bear, it will see itself fall into the black hole, right, so it says okay I'm moving towards the black hole, there, I have to look around, there I have crossed the event horizon two minutes into my freefall and then four minutes in I am spaghetti inside the black hole. Toller Cranston on the outside of the black hole will see something entirely different. He'll see the bear go towards the black hole and then he'll never see across the event horizon.

Anne: It will just stay there.

Ben: It will stay there for the duration of the universe.

Jocelyn: It will continue getting darker and redder because the photons from the bear are trying to escape. So one of the things that happens is light tries to get out of a potential gravity well is that it gets stretched out and that makes it look redder, red shift, right?

Anne: Mmmhmmm.

Jocelyn: So, as something falls towards a black hole, if it's sending light before you the light is getting stretched as it tries to escape the gravity and you'll see it look kind of red. And as it falls towards the black hole the light will get redder and redder and redder and then eventually it will turn into like infrared or radio or microwave or something and then get longer and longer wavelengths as it approaches the black hole.

Anne: So how near to the event horizon does the figure skater need to be in order to see the bear's red ghost of photons past.

Ben: As long as the figure skater stays outside of the event horizon he'll never see the bear cross it. So technically it's like Jocelyn said, as the photon climbs out of the gravitational well, it takes energy and as it loses energy it becomes red right. So Blue photons have more energy then red photons, gamma rays are more energetic than radio waves, so as these photons climbed out they get more and more red in color, they get dimmer and dimmer and the deal is that the photons coming off the bear…

David: Yeah let's say the bear is taillights

Ben: Yeah, ok, so we've put some blue tail lights on the bear as the bear gets closer and closer to the event horizon, these photons that are coming out of the blue taillights will get redder and redder as they approach us because they have to use energy to get out to where the figure skater is standing.

David: Not just that, but if the bear was flashing his hazards as he was falling in, we would see a longer and longer time between the hazard flashing.

Anne: That's so cool.

Ben: So the bear would fade out, it gets dark really fast actually. But, theoretically those photons are still climbing there way out and they'll be climbing their way out of the black hole for the rest of time. So, if we have a really really exceptionally sensitive microwave detector we could still point it at the black hole and look at the bear as it fell through.

Anne: So, I was just going to say, in the real world, aren't there these like red ghosts by black holes?

David: Yes.

[27:45]

Anne: And what do they look like?

Jocelyn: Well we haven't been able to resolve hey black hole well enough to see anything like the details of even how big its horizon is much less anything nearby.

David: We're getting very close to being able to image the black hole horizon at the galactic center.

Anne: Wow.
David: I think we are within two black hole radius' away. I think.

Jocelyn: Yeah, so within your lifetime you may be able to see a picture of the black hole at the center of the galaxy.

Anne: Wow. That's kind of cool, that's very cool.

David: It is very cool.

Jocelyn: It's so super cool.

Anne: Ha ha, are we going to have a party when that happens?

Ben: Yes

David: Well, we will.

Anne: Yeah, well I hope I…

Jocelyn: Yeah, you're invited!

Anne: Thank you. I did you just invite myself.

Ben: Right.

Anne: Wow.

Ben: So, I guess there's, there's this kind of a fundamental contradiction that's one of the most wonderful things about relativity here which is that, the bear and the figure skater are…

Laughter

Jocelyn: I'm sorry, (laughter) just, you know, the fundamental properties of general relativity and talking about the bear (Laughter)

Anne: The bear with taillights.

Ben: The bear with tail lights and Toller Cranston…

Anne: The tail lit bear…

Ben: Are going to describe fundamentally different histories of the universe alright. So the bear will say it took me two minutes, I fell through the event horizon, I got turned to spaghetti, that's the history of the universe, whatever it took 10 minutes. Toller Cranston, the figure skater outside, will have a completely different picture. He'll say the bear started falling towards the event horizon, never quite crossed it, it's still there.

Jocelyn: And it's frozen.

Ben: And his grandkids will be like oh yeah, we got a really good telescope and we look at this bear as it was falling through the event horizon.

David: We see it's taillights in the radio.

Ben: Yeah, that's right and then his great, great,great grand kids is like, in this future 10,000 years civilization, will also be like, well its in the oh well it's in the super deep radio but we can still see the bear falling through the horizon.

Anne: Ha ha, super deep radio. This poor bear.

Jocelyn: There's not very many photons coming out at this point, it's a very dark bear.

Ben: It's like Dave was saying the amount of time between light flashes, it gets longer and longer as it gets closer to the event horizon.

David: The bear has his blinker on, he doesn't know, he's a bear.

Ben: That's right.

Laughter

David: He doesn't know how to drive.

Anne: What if he is turning right, let's give him some credit.

David: He's trying to reverse out of the black hole.

Ben: That's right. So…

Laughter

Meep, meep, meep, meeeep, meeeeeeeep, meeeeeeeeeep, meeeeeeeeeeeeeeeep

Laughter

Anne: Oh, that's amazing. Several take homes, but one of them is if I am navigating a space shuttle, if I come anywhere near somewhere where there are like a whole bunch of things just staring straight and not moving into something and they're turning gradually red, although I wouldn't even notice, would I? But to not be like, oh, I wonder what they're looking at, let me go take a look like you don't want to do that.

Jocelyn: You, you would actually probably know that something was weird because if you try to look at the stars behind it, they would be all distorted around, like the light from stars behind the black hole is getting curved around the black hole. So when you look at it you see this weird distorted star field.

Anne: Okay, so I'm keeping and eye out for distorted star fields.

Jocelyn: You see sort of like suddenly stars look all funny shaped and are like making this weird sort of circular stretched pattern and then there is some sort of very faint very red stuff coming from the center of the pattern. That's sort of a region of space to avoid.

David: If you see a bear pass you in a Ford Fiesta looking at a map, then…

Laughter

Anne: Don't follow the bear.

Laughter

Anne: Got it, no matter how much salmon awaits him…

Ben: Right. Well that was good. So thanks Dave and Jocelyn. You have pleased me, your efforts I have born fruit and that fruit is sweet! Here is some fruit! Dave, blueberries. Nice. And Jocelyn, here is some wild Pacific salmon.

Laughter

Jocelyn: Interesting fruit, Ben.

Ben: Fantastic, well it's called the fruit of the Sea.

David: That's tuna

Ben: That's chicken of the sea.

Laughter

Jocelyn: I had all sorts of fruit eating noises prepared and you left me at a loss.

Laughter

Ben: Okay, so I would like to thank my guest, thanks Anne. I hope you had fun on our ridiculous show.

Anne: You’re very welcome, I've had fun.

Ben: Okay, cool. Alright everybody, my Ti-Phi-ters, suppose you interact with the titanium physicist, a little bit more if you would like to keep track of us why not follow us on Twitter at @titaniumphysics or on our Facebook group. If you would like to hang out with us and socialize why not join our online forum or if you would like to send me an email directly or to ask a question or propose a topic you can email me at barn@titaniumphysics.com. Let's suppose you want to listen to us more conveniently if you've got and iPod or an iPad you can try subscribing to our show using the iTunes store or the iPod podcast app. While you're there write us a review. Your reviews determine our ranking within the podcast app in the iTunes Store which in turn determines how many new listeners discover our show. If you have a Zune or a BlackBerry you can subscribe to our show on those doodads as well using their respective podcast apps or you can download the sStitcher radio app which will let you subscribe to listen to all of your favorite podcasts. You can download the Stitcher app for free onto your iPhone and android phone Kindle fire or other devices. Stitcher is convenient because it lets you subscribe to your favorite podcast and listen to them. For all of this information and more visit hour website at www.titaniumphysics.com. The titanium physicist podcasts is a member of the BrachioMedia Network if you enjoyed our show you might also enjoy Science Sort Of where we talk about Weekly events in science or the Weekly Weinersmith where Kelly and Zack Weinersmith interview scientists about their work, you learn a whole bunch so check them out. The intro music is by Ted Leo and the Pharmacists and the end music is by John Vanderslice. Good day my friends and remember to keep science in your hearts.

[35:19]

Ben: That what's an okay intro. It was a half an hour usually my mouth is pretty dry.

Jocelyn: I had to mute myself to stop giggling at your black hole stories.

Anne: I know, I was actually giggling a little bit being like, oh, oh I don't know if I should be laughing at this.

Ben: Why? They're funny.

Anne: They are funny.

Jocelyn: Yeah but we don't want to giggle over your whole intro and then you have to record it again.

Ben: No, it’s, I record two different tracks of us. I have my own vocal track and I can mute everybody out when I'm talking which is why I sound like I know what I'm talking about and nobody ever interrupts me on the show.

David: Ahhh, that's why it always sounds like we pay attention to what you say.

Ben: That’s right.

Laughter

Anne: That’s a good trick I need that in my life.

Jocelyn: Sorry I'm just going to mute you all now, okay, so where was I?

Anne: Exactly.

Laughter

Jocelyn: It also made me think it's not surprising you wound up a Titanium Physicist.

Ben: Well, um, it never occurred to me that the roots ran so deep before I wrote the introduction to the show to tell you the truth, but the issue…

Anne: I’m trying to think about when I first heard about falling into a black hole, I don't know when it would have been. I didn't watch that Disney movie.

Ben: Oh, it's great. They fall into the black hole and you know what's on the other side, inside the black hole?

Anne: What?

Ben: Hell.

Laughter

Anne: Is it hell inside of a black hole?

Ben: Well, also heaven because it's an American movie. And then the good guys leave the black hole through the other side whatever that means so it wasn't quite hell but the bad guy goes to hell when he's inside the black hole. It's very tricky.

Anne: Have you going back and like myth busted your, I don't know, memory forming physicist making moment from when you were eight?

Ben: Well, I remember, well, I mean, I didn't get much from the movie. Mostly it was just watching for the robots in the space stuff. But I remember there was a big issue of what happens if you fall into a black hole and then really I think going to university when I was actually learning general relativity was scratching a lifelong itch figure out exactly what happened on the inside of the black hole.

Anne: Interesting.

Ben: Yeah.

[37:34]

Anne: But not all black holes are made equal are they?

David: Um, black holes are surprisingly similar actually.

Anne: Really? Because they all collapse into like the same thing eventually?

Jocelyn: The only thing that they have that's different is mass and spin. Basically all you see is how fast it's spinning and how massive it is. Other than that they all look identical, everything else gets kind of…

David: When a black hole collapses the only thing it remembers is how massive it is and how much angular momentum it has. All other information is gone.

Anne: Right. And is the mass necessarily related to size though, or no?

David: Yes, it's directly related.

Anne: It is, okay.

Ben: We've been painting this picture of the black hole evolving in terms of matter collapsing down. So you imagine this sphere, it's collapsing down. Let's talk about what you would see if you were standing on the surface of this sphere, like the surface of the planet. We know that gravity gets weaker the farther away you get from an object right and the converse is, the closer you get to the center of mass of a really dense object the higher the gravity will be. So one of these balls of collapsing matter, if you're standing on the surface, as it collapses down in the radius gets smaller and smaller the force of gravity is going to increase dramatically.

David: As you're standing on the surface.

Ben: As you're standing on the surface. So will go from you know big dust it will overwhelm the electromagnetic force and then it will overwhelm these quantum mechanical forces and then there is no part of this matter that is strong enough to resist the force of gravity. And from that point on it will collapse down into, essentially a point, and all that's left behind outside of this point is essentially the gravitational field the curvature of spacetime. And so when we talk about black holes, we're not talking about the singularity specifically, we're not talking about the matter anymore, we're talking about the attributes of this geometry that's left behind when all of the matter has collapsed down into a point.

Anne: And, so when you were talking about mass… Is the mass the point? No…

David: By mass we mean the mass that we can Measure by its gravitational effects.

Anne: Right.

Jocelyn: The mass is sort of like when you're far away from it you can see how you're pulled towards it and that characterizes the mass.

Anne: Ok.

David: Because the properties of black holes are essentially just the geometry of space-time. Black holes that have the same mass will also have the same size. For instance if the Sun somehow collapsed into a black hole it would be about about 3 km across.

Anne: Ok.

David: Rather the event horizon is about 3 km across and so any black hole that is that mass will be that size.

Ben: Yeah, it doesn't matter what's the original matter was made from because all that's left is the gravitational footprint left behind before the matter collapsed down out of sight. If you had a horrible ball of bees where are the bees couldn't escape because they were gravitationally attracted to one another, a monstrous buzzing help planet collapsing under its own weight, eventually the black hole that's left behind would have the same size as the black hole left behind by the Sun.

Jocelyn: If it was a Sun's mass worth of bees.

Ben: Right, a Sun's mass worth of bees.

Anne: Right, okay.

Ben: So, it doesn't matter what the matter was that collapsed into the black hole, all that matters is how much mass was there originally that collapsed.

[40:49)

David: An interesting question would be what orientation should you fall into maximize you're chance of surviving?

Ben: You're not going to survive.

David: No, no, no. To maximize your time of survival.

Ben: Oh, to maximize your time of survival.

Jocelyn: I'm guessing I would want to, probably, go in feet down.

David: Lying down.

Ben: We're not

Jocelyn: Curled up into a little ball.

Jocelyn: Curled up into a little ball and then, you want, what orientation of your body do you think can best survive being stretched?

David: Probably ass first.

Jocelyn: Yeah, I'd guess. I'd guess that.

David: No no, you survive compression best along your spine right.

Anne: Is that true?

David: Yeah, yeah.

Anne: I did not imagine that.

David: Because you can carry a lot of shit on your head.

Anne: But that's compression, like, what about pulling apart?

David: So compression you want to be… so the compression is horizontally. So you want to…

Ben: Can you carry so much stuff on your head that you can carry more on your head but if you put it on your chest and you laid down on the ground it would crush you to death. Can you carry that much on your head? That's the question.

David: You wouldn't be able to breathe.

Ben: Right. Ok.

Jocelyn: Yes, you want your lungs to keep working so the lungs need to be able to…

David: To breathe in our space oxygen yeah.

Ben: What if you were spinning so you could you know distribute you could even use it to you know help you breathe.

Jocelyn: Interesting.

David: Yeah, yeah.

Ann: But spinning I mean, I don't know like just having read about Felix Baumgartner, how do you even say his last name, but yet reading about the risks of his crazy space sky dive. Like if you spend the wrong way, yeah I like your head would just, your head, spine..

David: You'd have to be spinning, I don't know if spinning would be able to counter act all of the tidal forces. I don't think it could.

Jocelyn: Well, so if you're spinning, so if you're falling like okay you're standing up and you're falling in feet first is you're spinning around kind of the same way you spin around if you standing up and spinning in circles on the ground then your only making things worse.

David: Yeah.

Jocelyn: Because that kind of spin is going to, like the, no wait that's not right.

Ben: No, it won't, the centrifugal force will…

David: … spin the other way you're making it worse.

Jocelyn: Yeah, so, okay, yeah if you're spinning really fast then it's like the earths equator bulges out and the poles come in, so you can counteract a little bit of the tidal forces by spinning around really, really, really fast.

Anne: Whoa, that's kind of cool.

David: But you would still get stretched.

Ben: You still get stretched.

Anne: And eventually you would die.

Ben: Yeah.

Jocelyn: Eventually you can't spin fast enough.

Ben: I mean eventually you're, the tidal forces, are much stronger than the atomic bonds so it doesn't matter how strong you think you think your muscles are because essentially all the atoms in your body are going (sound of something snapping).

David: It doesn't matter if you are a bear or not.

Ben: Literally, yeah even hey bear couldn't take it

[43:57]

Anne: I imagine there is a whole field of black hole, what it would do to stuff that you could relate to different types of pasta, like macaroni…

Jocelyn: And bears.

Anne: and bears, and like shells and… tortellini… rotini.

Jocelyn: If you want extra pasta you need to study neutron stars because there's actually phases of matter as you make, so this is sort of before it collapses to a black hole but it's getting super compressed you have the pasta phases of neutron star matter where, first you have nucleuses of of atoms and then you have sort of spaghetti nuclei and then you have, what, the lasagna phases…

David: Lasagna, yeah.

Anne: Oh my god this is awesome.

David: But there is no tortellini, tortellini's would be very hard to make.

Ben: Raviolis.

Jocelyn: No it's mostly spaghetti and lasagna and then you have of course the anti-spaghetti which is like.

Anne: Whoa.

David: The holes are spaghetti’s.

Anne: It’s gluten-free.

Jocelyn: But that's not very much of a sidetrack to other pasta and astrophysics.

Anne: I like it. Those Italians, they were onto something deep. I mean they had Galileo right, so, or did they? They did. Galileo's Italian wasn't he?

David: Sounds Italian

Anne: Him and the pasta makers.

Ben: He through the balls off of the Tower of Pisa

David: Did he really?

Ben: Yes, well…

Anne: I thought it was a feather and the ball.

Ben: In the story yeah.

David: I thought he rolled it down a ramp

Ben: In the story he rolled two balls down a ramp. But then in the other story you drop a feather, and when the feather in the ball landed at the same time and then everybody declared him a wizard and he got burnt by the Vatican because he make a feather fall at the speed of rock.

Jocelyn: Sounds like… history there. Wasn't it like a wooden ball and a metal ball so that they were the same shape and the same air resistance and then…

David: Yes

Ben: Yes, no, it was like he rolled different balls down ramps I think was the…

Laughter

Anne: Where does the feather come in though because there was definitely a feather.

David: He tickled the balls with a feather.

Laughter.

Ben: Jesus Christ Dave, we want a family friendly rating on this podcast.

Jocelyn: We do?!

Ben: Ah, not anymore.

David: You should have told us that to begin with Ben.

Jocelyn: Ok so if you look at the world in a quantum, in a really quantum way, and you look on the tiniest length scales.

David: There’s always a background fluctuations, quantum fluctuations, can suddenly become large enough that it can create a particle and antiparticle.

Jocelyn: So all the time on the tiniest scales, you don't just have a vacuum, you have this continuous just random happenstance, that say a positron and electron, come into existence like from some bit of energy that just randomly fluctuated, they go a little ways and then they basically always in normal everyday vacuum fall back together and cancel each other out and the result is nothing, the result is exactly the nothing that we observe. But if you have a black hole this little, this quantum foam can produce these two particles and then one of them will fall into the black hole and if they're just right on the horizon then one of them can't fall in and the other can escape.

David: So then you get you get this outflow of these, say an outflow of electrons from a black hole where some positrons will fall in. Or vice versa and so this sort of means that the black hole is a source of energy and this energy that it radiates off is called Hawking radiation. So it means that black holes, since black holes radiate they have, you can sort of look at their spectrum, they would have a temperature.

Jocelyn: So if you have a black hole that is the same mass as the Sun then it has a temperature of 60 billionths of a Kelvin. It’s really a tiny, tiny amount of radiation. There's more background radiation in the universe from the past history of stuff happening. And the smaller the black hole gets, the more Hawking radiation in it.

David: That’s right the hotter it is, the smaller a black hole is, the hotter the radiation it emits is.

Anne: And the faster it cooks the pasta.

David: Well the hotter it is, this actually almost right.

Jocelyn: You’re also pastafying further outside the tiny black hole so it's got a very, you know, a very fine angel hair pasta by the time it reaches the heating point.

Anne: Overcooked and mushy.

David: Yeah, probably.

Jocelyn: It’s hard to cook pasta properly with black holes it turns out.

David: But, so a black hole, so black holes that people we're worried about CERN producing would have evaporated almost instantaneously because they would have radiated away their energy very, very quickly. They'd be very, very hot because they're so small, but that would carry away so much energy that they would disappear. You would run out of mass and they would evaporate.

Anne: Wow.

[49:21]

Ben: Yes, so the idea is that you know you get up close to the event horizon with your microscope and you look closely at it, you are in a rocket ship. And you'll see an electron and an anti-electron pair get made and usually they cancel each other out but in this case one of them falls in to the black hole and the other one moves away. And so the question is, where does that energy to make that new electron that is floating out in the universe unaccompanied by an anti-electron, where did that mass come from? And the consensus is that that mass got stolen from the black hole using this quantum mechanic affect. So because the really small black holes are really, really hot it means that, essentially all of the electrons it produces, or protons, all this weird radiation coming off it, carries away the energy and intrinsic to the black hole. So one of the CERN ones we just kind of shoot off a couple of electrons and then be gone and that's actually something you could look for. CERN was looking for them and didn't see any, so that's how we know it wasn't making black holes. You didn't see any of them, any of these telltale radiation trails.

Anne: Interesting.

David: So an interesting there was a paper that was, it was somewhat crazy, that popped up last year in physics circles. It was by a Russian scientist by the name of Dokuchaev and the title of the paper was “Is there life inside black holes?” and what he did was he, I'm presuming it was a him, I could be wrong. But what he did was he looked for stable orbits that are possible inside the event horizon of a black hole where the, where you could maybe have a planet orbiting around inside without collapsing into the singularity. And his idea was that, well if you happen to have a planet there, maybe you could have a civilization inside too and that would be an exceptionally weird civilization to live in.

Jocelyn: So what was…

Anne: Yeah it would be really weird.

David: It would be, you could do it with a charged black hole.

Ben: Ooooohhhhkay.

David: And I think you could do it with a rotating black hole.

Ben: Okay, yeah, so there’s, so the deal is the story we told where if you fall into a black hole and you crossed the event horizon you're doomed to get crushed in the middle like after spaghettification, everything gets sucked into the central Point. That doesn’t it work if the black hole is rotating because if you get…

Jocelyn: If it's rotating really fast.

Ben: Well if it's rotating, any black hole has rotation, this affect would kick into some degree. Because what happens if you get really close in and space-time gets kind of, centrifugal force kind of kicks in from the rotating space-time…

David: It sort of pulls you around.

Ben: And so if you get really close into the center of one of these rotating black holes or black hole with an electric charge you stop, you know you kind of stop feeling like you're getting sucked in to the center. So you can exist on the inner inside of one of these, essentially you cross another boundary, another one-way boundary, and then you can live on the inside of one of these crazy black holes. And that’s bonkers. But it's fun.

David: It is bonkers but it's fun.

Ben:Yeah, super fun. The inside of a rotating black hole has a ring shaped singularity instead of a normal one and not everything gets crushed by it. You can wander, you could live inside of one and…

Anne: But would like the stuff necessary for life handle, like doesn’t it need light or water and and other stuff.

Ben: Yeah, probably.

Jocelyn: It’s a very minimal condition for life.

Laughter

Ben: Yeah it's tongue-in-cheek, not being crushed to death is a very…

Anne: So, bacteria we're talking like bacteria or..

David: Let's say you have a giant, like a billion solar mass black hole, at the center of some galaxy and you had a bear and you threw the bear in, and the bear was smart and he knew one of these orbits…

Jocelyn: And the bear had a rocket.

David: And the bear had a rocket to push himself into one of these orbits, then maybe the bear can survive until he ran out of food and oxygen.

Anne: I think we should name this bear at this point, because he's just such a strong character.

David: How about Teddy Blackholespin?

Anne: Teddy Blackholespin, like Rumpelstiltskin.

Ben: That’s Teddy Ruxpin.

Jocelyn: That’s Teddy Ruxpin.

David: That’s Teddy Ruxpin.

Anne: Yeah, there ya go.

Ben: There’s got to be a better…

Jocelyn: It doesn't exactly run off the tongue.

Anne: No, it doesn’t. I don't know sorry, like I asked a question to which I have no answer and I'm not prepared to answer. It's hard naming the black hole navigating, orbiting bear.

David: Well given his probably eventual spaghettification, we could name him Meat Balls.

Laughter.

Anne: We should definitely name him Meat Balls.

Ben: Meat Balls the bear.

Jocelyn: So, as Meat Balls falls into the black hole and is spaghettified with the photon fish…

Ben: Yes, that's right.

Jocelyn: All, of course, equipped with tail lights, falling into a black hole made of bees.

Ben: Why does he have to be driving a Ford Fiesta instead of something classy like an with fins.

David: I just like the idea of a bear inside of a Ford Fiesta.

Ben: You wouldn't like it if you were in the Ford Fiesta with the bear.

David: Hunched over, like, you know fiddling with the clutch and …

Anne: Being like where the hazards, how do I turn them off.

Ben: Fiddling with the radio, having to constantly change the radio station because, because the radio waves are getting blue shifted at him as they're falling in.