Episode 29: Dark Equivalence
Physicists: Jocelyn Read, David Tsang

Transcribed by Denny Henke

Ben: Oh. Hello old friend, it's good to see you. Let's talk about this word fascination. It describes an unquenchable urge which compels our hearts to quest and be captivated. As long as there are elegant explanations to 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]

Let's talk about the history of general relativity. The theory of general relativity was Albert Einstein's magnum opus. Now, most people know Einstein's name because of the work he did as a patent clerk. In 1905, a year now referred to as his miracle year, Einstein published four papers, one on the photo electric effect, one on Brownian motion, one on special relativity and one on mass and energy equivalence. A little patent clerk, in one year, proves that atoms exist, he invents quantum mechanics, and he establishes special relativity, revolutionizing all of physics. So, that's why Einstein is famous but that's not why he's great. The reason Einstein is great is because he spent the next ten years or so inventing a theory which explains gravity. In 1916 published his theory, his theory of general relativity, and nothing has ever been the same since. Now, Einstein's theory of gravity explains the pull of gravity in terms of curvature on a surface called spacetime. Now, just the way the path of a skateboarder will weave and turn as they surf around a skate park, Earth's trajectory around the Sun can be explained in terms of bending along with the curvature of spacetime. So, it's a geometric theory of gravity. Just think, you know, skate park. Now, Einstein's theory is kinda like the laws of architecture, it doesn't tell you what is possible it just tells you what's impossible. Since, physicists have had to rely on their imaginations to sketch out models of geometry which can then be used to explain the gravity we see in our universe. So, Einstein's theory is wonderful, it's like legos, it gives you the building blocks but what you build with them is up to you. Now, when was the first useful model of spacetime geometry ever made? There was a man born in 1873 in Frankfurt, his name was Karl Schwarzschild. Schwarzschild was a physicist and and astronomical and mathematical genius. In 1914 World War I broke out and he joined the German army and in 1915 he was sent to the Russian front where he contracted a horrible autoimmune disease called pemphigus. Then, in the hospital waiting to die, he solved Einstein's equations, he came with the spacetime geometry which now bears his name, the Schwarzschild geometry. Now, you might not be familiar with the name but you've heard of this Schwarzschild geometry before. It describes the gravity of a system where all the mass in the space has been concentrated down to a central point. In his hospital bed Schwarzschild discovered the most powerful monster in the universe, the black hole. So, today, we're going to talk about black holes and time. Now, clearly, if human kind ever builds itself a fleet of mighty rockets and we march out into the darkness where we're going to come across monsters. Listen, there are always monsters in the darkness. Today, my guest is the host of the pseudo pod podcast a show where short horror fiction is read aloud, it's Alasdair Stuart. Hello Alasdair, welcome to our show!

Alasdair: Hello, how are you doing?

Ben: I'm doing great! So on the pseudo-pod podcast Alasdair introduces each short story but he also ends each short story with a few comments. His comments are always really insightful and often personal reflections on the themes from the stories. In my mind they are the highlight of each show and Alasdair has recently compiled a book of short story essays based on his show post-scripts called The Pseudopod Tapes and it's probably wonderful and you can purchase it and you probably should off of Amazon. In addition Alasdair puts a lot of fun content out on his blog at www.alasdairstuart.com. It's fun to read and a link will be put up on our website. So, Alasdair, shall we go?

Alasdair: Let's go!

[5:32]

Ben: Wooooo! Ok, so, for you today I have assembled two of my finest Titanium Physicists. It's the A-Team, arise Dr. Jocelyn Read. Dr. Jocelyn did her undergrad at UBC, her PhD at the University of Wisconsin, Milwaukee and she's currently faculty in the physics department at Cal State Fullerton! She's a specialist in neutron stars. Now arise Dr. David Tsang! Dr. Dave was an undergraduate at UBC. He did his PhD at Cornell and he's currently a post doc at McGill and Caltech researching black holes and neutron stars and planets. Alright, so, recently Dave has been involved with the Astro McGill podcast where he hosts and recently he's talked to a guy who one a Nobel Prize, so you should try listening to that too cause Dave is great! Alright, let's start talking about time.

So, the topic you wanted to know about was time and black holes and it's really interesting because, let me just give the punchline away for you. Let's say you have a rocket, okay, we're space travelers and you say I'm going to go fly down to near the edge of that black hole and take some readings and you do and it takes you a couple of minutes to get down there and then you spend two hours tooling around down near the black hole and then you use your rocket to fly back out and you find that ten years has passed on my spaceship while you were down there tooling around. The deal is that when you're near a heavy gravitational object time moves slower, so, we can explain to you why this happens. It's entirely reasonable but we need to take quite a long running start I'm afraid. But, in the end everything will make sense.

Alasdair: Ok, i'm strapped in.

Ben: Awesome! Ok, so, time dilation. We start with time dilation. You ever heard of time dilation before?

Alasdair: I have

Ben: And the twin paradox, have you ever heard of the twin paradox before?

Alasdair: I have!

Ben: Wonderful.

Jocelyn: So, this comes in, just in with special relativity, so just, just the way you have to explain how space and time play together to make electromagnetism work and all sorts of other, day to day… If you have two people moving past each other close to a significant fraction of the speed of light person a looks over to person b and it looks like they're moving slow compared to person a. And then person b looks back and says, actually, no, person a is the one that's moving slow.

Alasdair: Got it

Jocelyn: So, you have this relativistic time dilation which means that things that are moving fast compared to you appear to have slower clocks and we measure this on earth when some cosmic particles come in from distant parts of the galaxy or whatever and they are produced in the atmosphere and come down and they live for much longer than if we tried to create them in a laboratory.

Alasdair: Wow.

Jocelyn: So we know this happens because you know, we create this particle trying to set in a laboratory and it decays in an instant but then if it's produced in our atmosphere and it comes through and it lives for seconds. So this is like a real thing we measure.

Alasdair: That's amazing.

Ben: For a more comprehensive explanation of time dilation check out Titanium Physicists Episode 20, we go into it for about half an hour. All right, so lets give him some names. So there's two people, Danny DeVito and Arnold Schwarzenegger, right. And Danny DeVito is in a rocket and Arnold Schwarzenegger is home on Earth…

David: And we don't understand why this movie is so good but it is, that's the twin paradox.

Ben: Yeah, that's the twin paradox.

Laughter.

Ben: And so the twin paradox says that, you know, Danny DeVito, he'll take off from Earth and he'll fly past Arnold Schwarzenegger on Earth and he'll look at Arnold Schwarzenegger's watch using his telescope and he'll say, oh, time's moving really slow on Earth. And then, Arnold Schwarzenegger will look at Danny DeVito's watch through his telescope and say, oh, times' moving really slowly in Danny DeVito's…

David: No, I think he'll say, (in Arnold Schwarzenegger voice) time's moving really slowly in Danny DeVito's spaceship…

Ben: Ya. So, the spaceship, Danny DeVito's spaceship goes off to Alpha Centauri, he goes almost to the speed of light, travels all the way out there, turns his spaceship around comes back, stops his spaceship. Twin paradox says that because of this time dilation, what happens is, Danny DeVito is going to come back and he will only be two years older but Arnold Schwarzenegger will be 20 years older. That's called the twin paradox.

Jocelyn: And it's like, oh my gosh, this is supposed to be symmetrical. They both saw each other moving slowly, how the heck did that just happen?

[10:05]

Ben: Yeah. The very essence of the twin paradox is, everybody's like, how come one is older than the other but at its heart in special relativity there's kind of an asymmetry between what they see right, so Arnold Schwarzenegger saw Danny DeVito's clock moving slowly so from Arnold Schwarzenegger's perspective it makes sense that Danny DeVito comes back and less time has passed for him But Danny DeVito, when he did his flyby of Earth, he looked through his telescope and he saw Arnold Schwarzenegger's clock moving slowly, just as slowly as you know, vice versa, and so how come Arnold Schwarzenegger's time hasn't also been really slow, why isn't Arnold Schwarzenegger the one who's really young and Danny DeVito's the one who's really old? So, that's the heart of the question, What's the difference between these two people, what's the difference between Danny DeVito and Arnold Schwarzenegger.

Alasdair: I had never before realized that one of the central questions in physics is exactly the same as one of the central questions in movie criticism.

Laughter

Jocelyn: It's all connected man.

Alasdair: It is, it's like a beautiful mind but without Russel Crowe

Ben: So here, I'll cut the answer short. The deal is that Danny DeVito doesn't experience the same thing on his trip to Alpha Centauri as Arnold Schwarzenegger, right? Let's suppose Danny DeVito put his ship on auto pilot, you know he went into a dark room and he sat quietly in his dark room and Arnold Schwarzenegger

David: Drinking limoncello

Ben: Drinking limoncello… and Arnold Schwarzenegger did the same so he shut out all the lights and he sat in a dark room waiting for his twin brother to come home. They wouldn't have experienced the same thing even though they each saw the other persons time dilating Danny DeVito would have experienced much deferent set of experiences over the course of his trip. he would feel tremendous acceleration as his rocket accelerated him up to near the speed of and then he would feel a deceleration as it decelerated down and he turned around and then he'd accelerate back up again, right.

Joselyn: Even sitting, drinking alone, he would suddenly be pushed from one wall to another wall by this acceleration.

Ben: And also by the drink. And Arnold Schwarzenegger sits at home and he doesn't feel any of this.

David: He just goes on and films Expendables Three.

Ben: Right. So, the moral of the story is even though it looks symmetric in terms of the people looking at each others watches, their experiences weren't symmetric, one of them had a clearly different experience from the other and at its heart that's why Danny DeVito experiences less time and Arnold Schwarzenegger experiences more time.

David: It's because of the acceleration that Danny DeVito experienced less time passage than Arnold Schwarzenegger

Ben: Right. Yes. In the end it's not the time dilation itself that's responsible for Danny DeVito being young, it's this weird acceleration.

Joselyn: It was that turn around at the end to come back that ruined everything.

Ben: Yeah. So. Here's the really crazy thing. So, Einstein muddled this question over, he came up with a similar answer but then he started thinking about people who were alone in rooms with no windows, drinking alone. And he asked himself, what's the difference between being somebody in a spaceship in deep space with their blinds down just drinking alone, if their rocket ship is pushing forward and accelerating them at 9.81 per second $meters^2$, Earth's gravity, what's the difference between what that person experiences and what somebody experiences at home if they pull down the blinds and sit still at the table drinking?

Joselyn: Your push toward the ground now.

Ben: Yeah, right? I mean, I feel an acceleration towards the ground, or rather, the ground pushes me up 9.81 per second $meters^2$ acceleration force all the time. So, Einstein said hey, what if there's no difference, what if there's no difference from somebody who's in a rocket ship accelerating if they can't look out the ship and somebody who's sitting at home with the blinds pulled down.

Joselyn: Then the internet has turned us all into space explorers!

Ben: That's right!

Laughter

Ben: So, Einstein called this the equivalence principle. He said, it's equivalent, somebody in a rocket ship accelerating, their experience is indistinguishably equivalent, from somebody who's in say an elevator, you know, there are no windows in an elevator, no clocks, they just feel the push of the floor up on them with some acceleration. Now, this is absolutely bonkers because there's no difference between somebody in a, so if you're in an elevator and somebody cuts the cord so you're elevator free falls down the elevator shaft, there's no difference from your experience up there than there is for somebody who's weightless in space. So, here's the crazy thing, the difference in Danny DeVito's time was because he was accelerating and there's no difference between accelerating and and sitting in a gravitational field then gravitational fields must cause time to go slower.

David: Dun, dun, duuuuuunnnnn.

Alasdair: So that means time flows differently on every single body that exerts a gravitational field in the universe because they're not of a uniform size.

Ben: Correct.

Joselyn: Not only that but it also depends on how far away you are from the center. So, on the top of a skyscraper you're a bit farther away from the center of the Earth you actually feel a little bit less gravity than someone who's like standing down on the street below you. And that person down on the street below you is experiencing a slightly slower flow of time

Alasdair: Oh my god, this explains why so many of the Star Fleet officers responsible for watching star dates ultimately kill themselves, there's no way to be so accurate. That's amazing, so time is actually subjective it changes not only dependent on the individual but on the individual's location.

Joselyn: We actually have to include this affect in your GPS.

Ben: Yeah

Joselyn: Your GPS is based on careful timing of pulses from different satellites so you actually need to take into account how far up the satellites are compared to how far you are and take into account all these little differences in how time is flowing both because of the gravitational potential and because of the relative speed of satellites whipping around while your staying on the surface.

[16:12]

Alasdair: Is this one of the reasons why GPS satellites tend to be locked in geostationary orbit, to try and mitigate this kind of effect?

Ben: No. So it's, in essence, how does GPS work? They're just clocks, above the Earth in an orbit and they're just broadcasting the time. They're just saying, beep the time is now 5:08:01pm beep. Right?

Joselyn: Plus 32…

Ben: Plus 32015… So, the deal is your GPS receiver it knows where all the satellites are, they're in geostationary orbit so it knows the location of all these satellites so if it hears the time from two or three different satellites it can calculate the amount of time for that radio signal to get broadcast down to Earth and from that triangulation it can figure out where your location on the Earth is.

David: But in order to do that the satellites have to know very well what the time is.

Ben: Yeah. So, the deal is way up high, you know, up in space, far away from the Earth, the pull of the Earth's gravity decreases so time is moving slightly faster up there. So, they had to include a calculation to compensate for the fact that gravity is less up in space because otherwise the clocks would be moving too fast and all the GPS locations would go wonky because we wouldn't be able to accurately use the time to triangulate our location because time's moving slower up there, to so many decibel places.

Alasdair: That's so unspeakably brilliant, I'm almost at a loss for words. That's amazing!

Joselyn: Science!

Alasdair: Science! Exactly. So, the thing which we're taught is a universal constant is only a universal constant because of lots of forensic maths.

Ben: Yes. yes.

Alasdair: Oh, I owe you guys a drink and by you guys I mean not just you but possibly every scientist ever.

Ben: Yeeaah.

Joselyn: That could get expensive. Some of these people can drink a lot!

Laughter

Ben: He said one drink per scientist not that he would buy everyone drinks till he got us drunk.

David: So, now we can actually talk about how time changes near a black hole. So, very close to a black hole you have a lot of gravitational acceleration. For instance, in Doctor Who, there's an episode, I believe called "The Satan Pit" where ah, the 10th Doctor, David Tenant, goes and meets the devil and the devil is being kept in a prison that is suspended beyond… pretty close to a black hole.

Alasdair: Yea, if I remember correctly it's actually orbiting one.

David: So, the Doctor and Satan should both experience time much more slowly for them than how other people would experience it far away from that black hole. In this case, ah, that close to a black hole time would run 20% slower for them then say Rose sitting in the Tardis, up far away from the black hole. So, luckily, the Doctor has a time machine so he can always correct for these kinds of factors but I don't think they took that into consideration in that episode. So, let's say that the doctor is talking to Satan for about 4 minutes, ah, Rose will see the Doctor talking in a much huskier voice for 5 minutes.

Joselyn: I think you need to demonstrate the husky voice Dave.

Ben: Instead of allez-y, he'll say allez-y.

David: Oooh

David: Oh, smooth.

Alasdair: I like that.

Ben: That's why Satan has such a deep voice, cause he's hanging out next to a black hole. He actually talks like this most of the time (In a silly, raised voice).

Laughter

Alasdair: Satan is making, making awful, awful sense there…

Laughter and indistinguishable funny Satan voice with lots more laughter

Joselyn: Right, so this is actually how we can actually measure this whole thing about time traveling closer to the surface of things not only for GPS satellites which requires incredible precision but we first measured this, almost a century ago when we were trying to understand how big certain crazy ass compact stars were. So, you know Sirius, the brightest star in the sky.

Alasdair: Yes

Joselyn: It has a white dwarf that it orbits so that's Sirius B and this was the first time that people kind of figured out what white dwarfs were and so they, then they tried to measure the shift of wavelengths of certain features in the white dwarf, in the companion of Sirius. So, they look at Sirius, elements have kind of a fingerprint of wavelengths that they like to absorb or emit, okay, so they have a precise frequency that they're going to either absorb light or emit light at. And you look at these elements in both the main star and in this little tiny companion star and you find that the companion star, the wavelengths have been shifted so that they are at much lower frequency. So, just like the devil is talking in this super low voice the wavelengths from these elements have been shifted to a much lower frequency when they measure it.

[21:09]

Alasdair: So time dilation.

Joselyn: Exactly.

David: So, even if, even after you correct for all of the relative motion between the two stars, ah, you see this time dilation effect.

Joselyn: So normally we talk about doppler shift from relative motion, right, so if like ah car goes by with its motor you get that wwwwhhhhiiiirlllllll sound, right? And so, it's high pitched when it's coming at you then when it's going away it has a low pitch. That's the same kind of frequency shift. With Sirius it's thought that kind of frequency pitch that makes it seem like its moving away from you at 80 km/second accept it's sitting right beside its companion Sirius.

Alasdair: Got it. Okay, I see that. That's, again, sort of amazing because what I'm seeing from that is lots of, echoes of larger process at different levels of the universe like you mention doppler shift, red shift/blue shift, I would imagine being the visual equivalency for that. Um, so, you have this, you can actually measure the impact of time dilation by the frequency of the star. That's really interesting to me because one of the things I studied for a very small amount of massively amateurish amount of time was the history of planet hunting and how, I think, at least two occasions, the next planet in the solar system was found by not be looking for it but by gravitational distortion in the furthest planet out's orbit. So, the idea of being able to measure time dilation by looking at something which it causes rather than by looking at it is something which I kind of clasp onto that way. That's fascinating.

David: So, something even cooler happens as you approach a black hole. The time dilation acts actually becomes infinite as you get to the, what's called the event horizon.

Ben: Have you ever heard of an event horizon before, Alasdair?

Alasdair: Yes

Ben: Okay

Ben: So, we said before that every massive object kind of has a Schwarzschild geometry, okay, and that, the deal is, not every object, like the Earth isn't a black hole, it doesn't have the black hole geometry, and one way to imagine it is the Earth will be of a certain mass and so if you were to draw the curvature of the earth you just draw this big curvature in a sink and then you just fill up the sink with water up to a certain height. So, the deal is that we only see the part of it that's outside the water metaphorically and so what happens in gravitational collapse is it's kind of like you drain all the water from the sink. The surface of the star or the, you know, big object collapses down and exposes more and more and more of the geometry and so you can talk about locations in the geometry in terms of how much acceleration you need to stand at that point, right? So, right now I'm standing on the surface of the Earth, there's 9.81 per second meters^2, of acceleration on the surface of the earth. Now, if I took the Earth and I shrunk it down to half of it's radius, so I took my big hulk hands and I wrap them around the earth and I crush it down to half it's radius then the force of gravity to stand on the surface of the earth would be, what, four times higher than it is right now. Okay. And so the deal is, it's just kind of like you imagine the surface receding so if you have a cataclysmic gravitational collapse like the kind that makes a black hole the surface will recede down as all the matter collapses down to a point and all that will be left is this big curved sink and so there's going to be a radius in this curved sink with the acceleration due to gravity is so violent, so fast that not even light will be able escape away from it. If you move just a little bit inside that radius what will happen is, since not even light can't escape, you can't go the speed of light so you have no hope of escaping so you'll probably get sucked down into the middle. And so that boundary between the inside of the black hole where you're going to get crushed to death and the outside where you still have a chance to see your loved ones again, that's the event horizon.

Laughter

Ben: So, the event horizon is lots of fun and the deal is it takes an infinite amount of acceleration, so you'd need a rocket that was turned on full blast and it exerted an infinite amount of acceleration to stay at the radius of the event horizon.

Joselyn: There's a point where you're still not at the center but it takes an infinite amount of acceleration to balance gravity.

Ben: And then, so if you and I and Alasdair had rocket ships, if I was in some orbit at some really, really high radius so I hardly feel the force of gravity on myself but you wanted to do some measurements you took your rocket really close to the event horizon, to keep from falling in, you would have to exert an intense amount of acceleration like a 100 billion g's of acceleration to keep from crossing the event horizon and getting crushed to death. And so, in the course of you going down and then coming back you undergo so much acceleration that you personally will feel much much less time passing than I will waiting for you to come back.

[26:10]

Alasdair: Go back to Danny DeVito and Arnold Schwarzenegger…

Joselyn: Or Satan.

Alasdair: Or Satan and the Doctor.

Ben: The Doctor and Rose.

Alasdair: Yeah

David: Let's say that Satan's prison is actually extremely close to the event horizon and I think the Doctor actually went down by a rope which didn't make any sense, let's say that Satan's prison is really really close to the event horizon of the black hole, the Doctor spars with Satan and escape back to the Tardis only to find that Rose has basically lived her entire life, died and is now a pile of dust.

Alasdair: Because the dilation is so accelerated because it's a black hole.

David: Because the gravity is so intense near the event horizon that the Doctor's experienced time pass much, much more slowly.

Joselyn: Just sort of similar to the way acceleration becomes infinite, the amount of time dilation is also going to become infinite as you pass the horizon.

Alasdair: So, we're well into the frog hopping towards the pond and each hop is half the distance of the last one so it never actually gets there.

Joselyn: So, that's what someone looking at you from outside.

David: So, let's say that Arnold Schwarzenegger has just had about enough of Danny DeVito and has basically thrown him into a black hole: "You're going into a black hole!" and he falls into the black hole. Now, Arnold, sitting there, watching Danny DeVito fall will see Danny DeVito get closer and closer and closer to that event horizon but because of time dilation is occurring, one second for Danny DeVito will be longer and longer and longer for Arnold Schwarzenegger.

Joselyn: So, Danny DeVito is going wwwwwwhhhhhhaaaaahahahahahahahaaaaaaaaaaaaaaaa (from high pitch to lower pitch)

David: And Arnold Schwarzenegger will actually just see Danny DeVito get stuck at the event horizon and very quickly red shift away.

Ben: He'll never really see Danny DeVito crossing the event horizon. He'll just kind of see him freeze in place and then slowly get redder and redder.

David: Like at the end of an 80's movie.
Laughter

Alasdair: 80's and pre-end credits sequence freeze frame is being used to describe time dilation in black holes. Yeah, I'm hugely impressed. Yeah, I can see that, so…

David: Thanks. Then, where are they now and at the end, you know, it says, Danny DeVito, is in a black hole

Alasdair: And Arnold Schwarzenegger was found not guilty for murdering Danny DeVito because technically he isn't dead and never will be.

Laughter

Joselyn: Yeah, nice! So, the other crazy thing is Danny DeVito just like falls through without noticing anything particularly different about the horizon.

Ben: In essence that's still an application of the equivalence principle. Which is that if Danny DeVito's not accelerating, if he's in free fall the whole time he might as well just be floating out in space and so he doesn't ever notice that he's crossed the event horizon even though from somebody standing outside of the black hole it takes an infinite amount of time to cross, the universe ends before Danny DeVito can cross that event horizon.

David: And this is assuming that the black hole is large enough such that Danny DeVito doesn't get turned into spaghetti which was the topic of another show.

Ben: Yeah, yeah, we talked all about spaghettification.

Joselyn: So, you see Danny DeVito going rrrrraaaaaawwwwwaaaaaaaaaa (high to low pitch) but Danny DeVito is going rrrrrrrraaaaaaaaaaaaaaaaaaa (high pitch) the whole time.

David: Yeah, just like he does now.

Alasdair: It's a different speed for him…

Ben: Well, that was fun. I thought that was really neat. So, thank you Dave, thank you Joselyn. You have pleased me, your efforts have born fruit and that fruit is sweet. Here is some fruit! Dave, you get a persimmon, the longest aging fruit in the world and Joselyn, you get an eggplant because they're black.

Joselyn: What??!! (gobble, burp)

Ben: Enjoy it!

Joselyn: I assume it's roasted?

Ben: Yes! Sure.

Joselyn: Okay. (gobble gobble)

Ben: Good, wonderful. Alright, I'd like to thank my guest Alasdair Stuart. Thanks Alasdair!

Alasdair: Thanks for having me on, it's been great.

Ben: Awwwww I had so much fun with you. We'll have you on again in the future.

Alasdair: Fantastic!

Ben: So, hey Ti-Phi-ters, that's you, listeners of the show are called Ti-Phi-ters. Everybody gets that wrong, Dave, it's your fault. Listen, Ti-Phi-ters, I love the show and I hope you do to but for every listener to the show I know there's got to be a hundred other people who would love to listen but they don't know how. So I want you to spread the word about our show. There are three ways you can do this. The first is iTunes its still the biggest place in the world where people go to find new podcasts and iTunes puts shows with the most ratings at the front where everyone can see them so if you've got a minute give us an iTunes review. It will increase our rank in the stack and more people will end up seeing us. The second is to teach people how to listen to podcasts. I know this sounds weird but everybody now and days has a smart phone or a tablet and a very low percentage of these people actually listen to podcasts on them so if you know of somebody who might like the show ask them if they know how to listen to podcasts and if they don't point them to the Stitcher App, it's free and easy to use and also it works on every handheld device. So tell them to take the Stitcher App, download it for free and then look up our show. Surely your grandmother will thank you for it. Now, the third way to spread the word is to tell people online about us. If you see somebody on the internet talking about a topic one of our episodes cover post a comment telling them about the show. It would be nice if people started treating podcasts like their reference material. Anyway, that's it. I hope you'll help us out and point new listeners in our direction. So, that's it for the main part of the show. Remember, that if you like listening to scientists talk about science in their own words you might enjoy listening to other shows on the BrachioMedia Network like the Weekly Weinersmith or Science Sort of. Editing support for the Titanium Physicists podcast is provided by a gentleman named John Heath - thanks John. The intro song to our show is by Ted Leo and the Pharmacists and the end song is by John Vanderslice. Until next time remember to keep science in your hearts.

[33:02]

Ben: Yeah, do you have any questions to start the show? We thought we would start talking.

Alasdair: Yes!

Ben: Yeah, okay.

Alasdair: The Schwarzschild geometry.

Ben: Yes.

Alasdair: This is an interesting one because on the prologue on the science shows I've seen have represented spacetime's geometrical shape as a flat sheet and how gravity will distort that depending on the size of the object which the gravity is being exerted by. At the risk of completely destroying any possibility of describing this in audio rather than visually, how does the Schwarzschild geometry differ from this slightly … sheet.

Joselyn: A lot of the time the way you make a picture of the Schwarzschild geometry is you try and take a cross section through the black hole. Okay, so you try and take a slice and far away, you're just making a flat piece of paper say that would slice through it but then as you get towards the black hole what you end up with is something that kind of looks like a funnel just in extends down forever in the middle. This is what we see no matter which direction in space you made the slice and it also kind of ignores what time is doing but this is similar to the kind of picture you make if you take this rubber sheet analogy and you put, you know, you just punch as hard as you can down the middle of it until it just goes down for infinity and it tears and you don't really know what's going on, that's that funnel shape is the kind of geometrical model you can think of as a black hole analogy.

David: So, if you just looked at a black hole it would appear round, look at a Schwarzschild black hole, it would appear just as a round sphere and um it's really just the slicing. The analogy with the bent rubber sheet towards this funnel is really just a slicing of that black hole so we take a cross section and it allows us to see sort of the structure of a four dimensional object in 3D space. Just like um, you know, you can see a 2D structure of an orange when you slice it ah, even though the orange is a 3D object.

Joselyn: Or if you see those cool, like, slices of humans…

Alasdair: Yes!

Joselyn: Where you can see inside them.

David: When you slice them.

Joselyn: There's various, there's medical imaging things where they've done this with people that have donated their bodies to science after they've died and they go through and slice it into thin sheets.

Alasdair: Oh, after they've died.

Laughter

Joselyn: A key point there.

Laughter

Joselyn: Unless we want to go back to the horror story side of this. But, so, if you tried to do that with a black hole you wouldn't get a flat sheet anymore because the space itself gets all wobbly and deformed in the middle.

Ben: It's kind of hard to describe. Usually when they do it on, say television, and you see this bent sheet, they're doing it because one of the main intuitions that general relativity, this geometric theory brings, is it explains why things are in orbit okay, so in Newtonian gravity, Newton's picture he imagined that there were something like angels with invisible strings and, you know, there was a string that goes from the Earth to the Sun and there are angels inside the sun dragging the Earth to the Sun and they're applying amount of force which depends on distance which then causes the Earth to travel in kind of an elliptical orbit.

Joselyn: The same as if you had like a rock on the end of the string and you whirl it around your head and it keeps going in a circle.

Ben: Right.

Joselyn: Gravity is an invisible string in the Newtonian picture. But, in the general relativity picture there is no string so instead of being pulled in on a string what's happening is the sun causes a deformation in spacetime so it causes spacetime to be smushed in some particular way and then what happens is the definition of how a straight line lies in the spacetime, becomes all wobbly and curve. It's like taking a pencil and drawing a straight line inside of a sink. You can take a felt marker and draw a straight line in the sink, you know look really closely and make sure your line is really straight but then when you take your head out of the sink you look down at your straight line and its a cruve.

Joselyn: You need to start it with one of those curvy bathroom sinks if you did it in a flat like industrial sink it wouldn't work.

David: Or, maybe a bowl Ben.

Ben: Yeah or a…

Joselyn: Oh, a bowl, yeah, draw your line in a bowl.

Alasdair: Line in a bowl, got it. Okay.

David: You're really mixing your drug metaphors here, actually.

Laughter

Ben: If you got a bowl and you try to draw a straight line what'll happen is that straight line, even though in all really close, microscopic inspections, the line is straight. When you take your head out of the bowl the line ends up curved. And, so the reason the Earth is going in a circle, kind of, around the Sun, is because the very nature of straight lines around the Sun become curved in on themselves.

Alasdair: So, the thing that I'm kind of taking away from this is threefold. Firstly, Fringe may have lied… which I'm not super happy about. Secondly, it strikes me that what you guys do for a living is actually one more removed that I ever previously thought, it's not that you're looking at this stuff, how best to describe this, directly. It's that the models geometry is put into place almost like glove boxes for radioactive materials. They are the things which you use to deal with the forces which cause the stuff, but you never see cross sections of it so it must be like intimating a large picture from a small section of it. That has never occurred to me before, that breaks my noodle, I'm kind of blown away by it.

[38:42]

David: So, spacetime itself is a four dimensional construct and our pitiful human minds can't really picture 4D very well so we can use mathematics to describe that and then to get a picture that we can actually look at that's when we take the three dimensional slices of four dimensional space.

Alasdair: So it's actually a four stage process. It's maths, model, interpretation, am I right?

David: Yeah

Alasdair: I feel smarter already. That's amazing. The other question which I have directly relates to that. It's kind of a two fold one. Firstly, how does gravity wells as generated by planetary bodies, how do those relate to the curvature of spacetime. And is that relationship more complex than simply the bigger the body the bigger the gravity well the heavier the curve.

Ben: So, the deal is that every massive object, close in enough, the Earth, the moon, to some degree, Jupiter, the Sun, causes a spacetime curvature that looks like the Schwarzschild curvature so they look like this funnely sinky thing. You know, the difference between the Sun and the Earth is just a matter of scale. The mass of the sun causes a lot more curvature than the Earth but if you get really close to the Earth as we are now the curvature that's caused by the Earth, so, our attraction to the Earth, is much larger than our attraction to the Sun which is why we're stuck to the surface of the Earth instead of getting sucked into the Sun.

David: So Einstein's equations actually say that spacetime curvature is sourced by matter and energy and that if matter and energy is present it will bend spacetime around it. For the Schwarzschild solution he just found a special case of this where if you have a whole bunch of matter at a single point this is how spacetime will curve around it. So, for planets and the Sun and stars and everything, well most things, you can approximate this by the Schwarzschild solution to a certain degree.

Joselyn: As long as the thing, the mass is in a sphere, then outside of the mass it looks exactly like the Schwarzschild spacetime.

David: As long as it's not rotating.

Joselyn: As long as it's exactly in a sphere. Right, and I mean a rotating black hole, doesn't look like Schwarzschild either but as, you know, outside of a planet, outside of a star, outside of a black hole, you can't immediately tell by the shape of space what's in the middle.

David: Right.

Alasdair: That's interesting because that leads into two other questions for me. The first one is, obviously my inner science fiction writer when you say, provided the matter is in a sphere, immediately goes, what circumstances would lead to it not being a sphere.

Ben: So, the Earth isn’t a perfect sphere, it’s kind of squished.

Alasdair: It’s squished

Ben: Yeah, like an orange.

David: In fact, we have satellites that fly around the Earth that measure the gravitational variation to see how much the Earth does deviate from a perfect sphere and that can a, those sorts of density variations ah, can tell us about where minerals are deposited…

Joselyn: Sometimes they can tell us where matter is distributed but I mean Dave also mentioned things that are rotating and you know, if you rotate, the Earth is actually kind of pulled out a bit at the equator because it’s spinning around so if, you know, if you spin something you feel that centrifugal force, and so the equator of the earth actually get’s pulled out a little extra, so the Earth isn’t a perfect sphere because it’s spinning so whenever things spin they then tend to deform a bit from that kind of force.

Alasdair: Got it.

David: In fact, when you have objects spinning they actually tend to drag space and time around with them very slightly so a spinning black hole will actually drag spacetime around with it so if you were just sort of sitting still around there you’d get drug by that spin.

Alasdair: Wow. So, it’s similar to, in terms of motion, in therms of effect, similar to the spin of the galaxy that forms about it as it rotates or on a much smaller level if you have a water wheel and you know, the paddles drag water around with them as they go. Am I right?

David: Yeah

Joselyn: You can even think of a whirlpool, so, that has a lot of similarities…

Ben: It turns out that there’s an analog between, say, gravity. The forces gravity, this curvature of gravity, and how fluid flows and so if you have an object spinning it’s kind of like if you took a basket ball and you put it in a sink and started spinning it would drag the water around with it in kind of a little whirlpoolly draggy thing and that happens in spacetime too so a heavy object that’s spinning will also have these weird spacetime effects as it drags things along in the direction that it’s spinning.

[43:27]

Joselyn: You can also I was thinking more like if you picture a whirlpool, sort of scary deep sea funnel things you could get, kind of pulled around, get pulled towards it from far away and as you get closer you get kind of whipped around it too and that’s kind of the thing you feel if you were, say, falling towards a very quickly spinning black hole.

Alasdair: Yeah, that sounds really, yeah… I absolutely get that. That’s cool.

Ben: Yeah.

Alasdair: That’s very cool.I have another question.

Ben: Okay

Alasdair: Size. Specifically, is there anything which dictates a uniformity of size to black holes or can they be of any size. Now, I’m coming at this from a kind of very ignorant point of view I would have thought that the amount of matter needed to collapse into a black hole in order to create it would create a certain uniformity of size but I’m not sure if that’s the case.

David: That's a very good question. In order to collapse into a black hole you just need certain amount of matter within a certain volume so it's actually a density. However, many of the black holes that we know of in the universe have come from stars that collapsed and they're also the much larger black holes which are at the center of galaxies and these are about billions of times the size of our Sun. Black holes turn out to be, this may be getting a little far afield, but black holes radiate out energy called Hawking radiation and the smaller a black hole is the faster that radiation will cause it to evaporate. So very very tiny black holes can evaporate in the blink of an eye so you wouldn't expect to see too many of them long after they've been created.

Joselyn: In classical and general relativity it's actually a deep principle that black holes of different masses have a very simple relationship between their mass and their size. So how far away you are before you start feeling a certain percentage of the effect is simple scaling you simply zoom in, you zoom out, and you can model a black hole of any mass just by how big you make it.

Alasdair: Wow.

David: Everything basically depends only on its mass.

Joselyn: In the classical.

David: In the classical.

Joselyn: In the classical general relativity. Once you get quantum stuff and Hawking radiation then you start getting the signature of other things that tell you, that give you some real size measurement but alone general relativity has no scale, no set length scale that's different from any other.

Alasdair: Got it. Okay. Let’s bounce onto Hawking radiation for a moment.

Laughter.

Joselyn: Everybody loves Hawking radiation

Alasdair: I have two questions which kind of instantly presented themselves when you mention this. Firstly, what differs about Hawking radiation that allows it to be emitted from a black hole rather than drawn into it.

Ben: So there is something called Hawking radiation and what it is is really specific. The idea is imagine you have a particle detector like a Geiger counter okay. Now, the particle detector is sitting on your workbench and your workbench is in a rocket ship. So if you take your rocketship fairly close to the black hole you're going to have to turn on your engines too maximum to keep from falling further in to the black hole so you are going to have to accelerate so you know your rocketship engines are on full blast you are feeling 800 g's or whatever, 5 g's, I don't know how big this black hole is or how close you are to it but you were feeling some acceleration. But what will happen is your particle detector will start going off it will start going tick tick tick tick tick tick tick tick tick tick tick and measuring particles. There is some question as to whether or not the particles are real or not because this affect comes from interaction between quantum mechanics general relativity. So what Stephen Hawking did, he said oh, well we don't know how to combine quantum mechanics and relativity. We don't know if you have a quantum mechanical electron we don't know what kind of space-time geometry it is creating because you know we don't know exactly where it is or how fast it's moving or anything like that. There's all sorts of limitations on what we know because of quantum mechanics so we don't actually know what kind of gravity quantum mechanical objects have. But, we can say, oh, how does a quantum mechanical field behave in a curved spacetime. This is a question we can answer and so he did this he put a quantum field near a black hole and he found out that if you stand still near a black hole the particle detector will detect the particles in the field even if there are no actual particles in the field. Right, so there are no actual electrons by you but your electron detector will say hey I am measuring all sorts of particles. So, this is what Hawking radiation is at its heart. It's if you are accelerating near a black hole if you're standing at a constant radius near black hole you're going to detect particles so what people have said is well if there is radiation it's probably coming from the black hole because the closer you get to the black hole the more intense this radiation you detect will be and so if it's being emitted from the black hole the black hole must be losing mass as a result. And then there's a question of okay so how does the intensity of the radiation emitted depend on the black hole, It turns out that the smaller the black hole is the more intense the radiation it puts off. So from that we deduce that really small black holes will emit a ton of this crazy radiation and that will cause them to lose mass really quickly.

[48:49]

Joselyn: It might be worth pointing out that we see this outside of the black hole's horizon. We're never getting around the standard idea that as soon as something falls into the black hole's horizon we will never see anything of it ever again. There's actually sort of a physical interpretation of Hawking radiation which says that in quantum mechanics you can just have random pairs of a particle and anti-particle beam spontaneously emerging from the quantum foam and then merging back together and disappearing and then one of the two in that pair falls into the black hole and the other one escapes and this is how we get these sort of particles being produced out of nothing near the horizon of the black hole.

Alasdair: So this and again I'm kind of coming at this from the perspective of someone who just watched Doctor Who since he was 10. This would be essentially, the event horizon of the black hole, would be an area of, if not of chaos, then certainly colossal quantum activity for as you to say the foam to be sufficiently excited for want of a better word to generate these random pairing and to create this probably illusory sensation of Hawking radiation being pushed out from the black hole itself. Am I right?

Joselyn: This this is why science matters

Laughter.

Joselyn: It’s the little black holes that are active.

David: Do we really want the girl in the podcast saying that

Joselyn: Look, look who else on this podcast is going to say that with authority?

Laughter

Alasdair: Nicely done.

Joselyn: The point is though that if it's the small black hole that you need to sort of comparison of the scale of the quantum activity to the scale of the curvature in the black hole and if it's little that becomes more important if it's an enormous black hole like the one at the center of our galaxy, sort of at the horizon the scale is so big that this kind of quantum effect isn't as pronounced.

Alasdair: Got it. How do you detect Hawking radiation.

Ben: Any particle detector will be able to detect the Hawking radiation.

Alasdair: Really? So these particles are of such an almost universal nature that anything from say a Geiger counter to and old-fashioned analog radio will pick it up as static or something like that?

Ben: Yeah, so the deal is that Hawking radiation gets generated in any type of quantum field so if it's an electron detector it will detect electrons made in this weird electron quantum mechanical field so when they pop up due to Hawking radiation you'll detect them.

Joselyn: You’ll get electrons and positrons.

Ben: Yup! So alternatively yes, there’s any electromagnetic field that’s near the black hole so Hawking radiation will be generated in that, so those will be photons that we detect. So pretty much any particle detector that we have ends up detecting particles it's some kind of quantum mechanical field and then that quantum mechanical field will get excited by the black hole.

Joselyn: This isn't something we've actually done.

Ben: It’s still a little bit theoretical and you'll note that when I said we deduced, there is a small accounting trick there which is essentially, we don't know, I emphasized this before. We don't know how quantum mechanical particles interact with gravity. We know how their trajectories will behave interacting with gravity. So even though we know how the quantum mechanical field we'll be excited by the black hole we don't know how the black hole will respond to that excitation. Right, because we don't know how mass is generated then lost due to these quantum effects so it's kind of still a paradox that the scientific field is mulling over I guess.

Alasdair: You see that cuts off my second question and raises another one because my second question was going to be if we can detect them then surely that has interesting implications for galactic cartography in that if you can detect areas where Hawking radiation is particularly pronounced and work out almost the possibility of a photographic negative of a stellar nursery, places where black holes are concentrated but if we can't detect them, or at least if we can't definitively or theoretically detect them, my girlfriend is a lawyer I'm used to linguistic polish, then what is the state of research into how quantum particles could be theoretically detected, I think would be my next question.

[53:21]

David: So, Hawking radiation from large black holes like solar mass black holes like black holes the size of the Sun or black holes the size of 10 billion times the size of the Sun, the amount of energy coming off of that is very very low, it's actually lower than the temperature, like the temperature of that radiation, if you like it is much lower than the temperature of the universe. So you wouldn't be able to see this. A black hole the size of the Sun has radiation coming off that's only about 100 nano kelvins in temperature so compare that to the temperature of the cosmic microwave background radiation which is about 2.7 K. You can't even tell that it's there so this is something you'd only be able to detect in very very small black hole.

Ben: Yeah, so incidentally you know how CERN people are like, so crazy journalists go up to the physicists at CERN and say “is it possible that CERN will create a black hole?” and the people at CERN say maybe and that maybe is they mean probably not, but you know there are some really crazy physics theories that allow for the creation of a black hole. And so, CERN was looking for black holes because what would happen is if they did make a black hole it would be so small that it would evaporate all of its mass off in Hawking radiation. So they were looking for this Hawking radiation to see, if they found it they would no that it was proof of existence that they were making black holes which would then confirm these crazy theories.

Alasdair: So, in 50 words you have done a better job of explaining the basic science behind CERN than anyone in my profession did over a roughly 2 year period.

David: Well, that’s a, that was only a minor sideline to, to what they were looking for.

Ben: Alright, that's it!

David: Okay two things…

Ben: What?

David: We forgot to use our catchphrase “once you go black hole you never come back whole.”

Ben: Oh, that’s good. Almost…

Laughter.

Joselyn: Well at 20% faster unless was sitting there talking for a long time it's like you know you was talking for four hours but it only seemed like three.

David: Yes

Joselyn: Okay that's not 20% at all but you know (… laughter…) roughly, order magnitude.

David: Five. Five.

Ben: Why don't you say 8 and 10 or something and I'll edit it so that you got the math right.

Joselyn: So you know the Doctor was down there talking to Satan for 10 hours and Rose was only waiting up there for eight hours but that's not such a huge difference that it needs to be, needed to be plot relevant.

Ben: No, no. He talks to her for 10 years, no, 10 hours and she waits 12 hours.

Joselyn: No she feels, she feels… so time is passing slower…

David: No Time goes faster

Joselyn: for the Doctor.

Ben: Time goes slower for the Doctor. Yeah.

David: Right so when he's…

Joselyn: So, when Rose looks at the Doctor, the Doctor… oh yeah oh yeah yeah. I gotcha.

David: The Doctor has been talking for four hours Rose sees it as him talking like in a deeper voice for five hours.

Joselyn: Yes

David: In a huskier voice.

Ben: In a huskier voice.

David: Nevermind.

Joselyn: Right right so I mean we can talk about Doppler shift now right?

Ben: Yeah, yeah. Sure.

David: Why don't you say that so we can get the numbers right on that.

Joselyn: I, I can't remember it, Dave you say the analogy. I need more coffee

David: Does that mean cucumbers are a fruit.

Ben: Yes, cucumbers are fruit.

David: Sonofabitch!