Episode 2, “Black Hole Detection”
Dramatis Personae:
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-Kelly Weinersmith
-David Tsang
-Jocelyn Read

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Ben: Over the course of my studies in theoretical physics, I’ve travelled across the continent and around the world, sampling new ideas and tasting different answers to the questions of “How?” and of “Why?”. And still I find there remains a deep hunger, which lives within me. A burning desire to share these great ideas with the people around me. And so, I have assembled a team of some of the greatest, most lucid, most creative minds I’ve 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*!

01:12

[Intro song; *Tell Balgeary, Balgury is Dead* by Ted Leo and the Pharmacists]

01:48

Ben: Okay. Gravitational collapse 101. Let’s consider what happens when we let a cloud of gas—say, hydrogen—out in space collapse under its own weight. First, the cloud’s gonna collapse to a ball whose radius, whose general size is maintained by the thermal pressure of the gas because, as the gas collapses, it’s gonna gain gravitational potential energy that’s gonna turn into thermal energy, drive a pressure that keeps the ball aloft. But, gradually the ball will cool and radiate photons out to space and the radius is gonna decrease and the pressure inside the ball will increase until maybe it can trigger nuclear fusion. If the ball isn’t heavy enough, it won’t be able to trigger this nuclear fusion and we’ll end up with something called a “brown dwarf.” But, if there’s enough mass in our ball of gas, nuclear fusion will start in the center and we’ll get a star. Now, in a star, the photons liberated by the fusion taking place inside the core will blow out like a steady wind from the center, puffing out the radius of the ball of gas, and that will hold the radius of the star aloft. But, eventually, the star’s gonna run out of fuel and it’ll start to collapse under its own weight again. Then what? Well, novas, supernovas, a fairly complicated thing, but what you end up with at the end of the day is that if your ball of mass is smallish, it won’t exceed something called the Chandrasekhar Limit, and it will collapse down into a white dwarf. Now, a white dwarf is a system where the electron degeneracy pressure, a quantum mechanical pressure, will keep it from collapsing down any farther and you’ll end up with this lump. But, if the ball is a little bit heavier than that, maybe around three solar masses or less, the pressure from the gravity is gonna be so strong that the electrons are gonna get squished inside of their protons in all the atoms and you’ll end up with, essentially, a nucleus—a big pile of neutrons. And only neutron degeneracy pressure, another type of quantum mechanical pressure, will keep it from collapsing down any further, and we call this object a neutron star. Now, it's not clear whether there are any more steps down the ladder of gravitational collapse, we do know that below the bottom rung lays the most exotic of the celestial objects: a black hole. A black hole is what you get if you let matter get so dense that it punches a hole in spacetime itself. In layman's terms, a black hole is an object made of nothing but gravity. And unlike any of the previously mentioned astronomical objects, which have a surface that you can punch and throw rocks at, black holes are defined by their event horizons: causal, out-of-bounds lines, which can be thought of as boundaries for the black hole. Now, the acceleration due to gravity is so strong in an event horizon that any outgoing photon which moves at the speed of light will be barely able to sit still on that boundary, hence the name "black hole." So, the question we're going to ask today is: can we actually *see* these objects? How can we see something that doesn't actually emit any light?

04:33

Ben: Today, my guest is Kelly Weinersmith. Say hi, Kelly.

Kelly: Helloooo!

Ben: She's a PhD student from the University of California, Davis, where she studies parasites and behavioral ecology, right?

Kelly: True!

Ben: And she's the host of "The Weekly Weinersmith," a new podcast starring her and her husband, Zach Weinersmith, who is famous for webcomics.

Kelly: *Saturday Morning Breakfast Cereal*!

Ben: That's right. And Kelly has also submitted a research proposal to the SciFun challenge. Do you wanna tell us anything about your proposal?

Kelly: Sure! So, the proposal is to fund my research looking at brain-infecting parasites and their effects on behavior. Which is a totally cool topic to begin with, but actually the awesome thing about the proposal is that it is the only proposal to already be funded, and so you should *really* check out scifun.rockethub.com and look at the other projects that aren't funded yet, and there are 48 of them and they're all equally awesome.

Ben: That's magnificent. Alright, Kelly. So, you and I are friends from "Science, Sort Of" and today I've assembled two of my very best titanium physicists. Arise, Dr. David Tsang!

David: Muahahahaa!

Kelly: *laughs*

Ben: Dr. Dave was an undergraduate at UBC with me, but he did his PhD and Master's at Cornell. He's currently at Caltech working as a postdoc astrophysicist. Now, my other Titanium Physicist: arise, Dr. Jocelyn Read!

Jocelyn: Raaahhwr!

Ben: Good! Dr. Jocelyn did her undergraduate at UBC, her PhD at the University of Wisconsin, Milwaukee, and she's currently at the University of Mississippi working on neutron stars. Alright, guys. Let's start telling Kelly about these black holes and whether or not we can detect them.

06:10

Jocelyn: Okay! Well, so, so one of the, one of the defining things about a black hole is that there's no surface. If you were falling into a black hole, you would just fall in without ever hitting anything and you would sail right through the horizon, down into the center, be cut off from the rest of the universe and, well, who knows what happens then, but there's no running into the surface of a black hole. You just—

Kelly: Do you fall forever?

Jocelyn: Well, I mean…

Ben: No. You don't. You'd hit—

Jocelyn: No, you would, you would hit the singularity in the middle and get—

Ben: Crushed.

David: Right.

Kelly: Okay.

Jocelyn: Well, plus other bad stuff's probably happening.

David: You get sort of stretched out into spaghetti.

Jocelyn: Well, not if it's a very—

Kelly: So instead of getting *crushed* you get *stretched*?

David: You get stretched by tidal forces. But it, it depends. If the black hole's very, very large you won't.

Ben: For a while. Eventually you get stretched.

David: Yeah.

Ben: Right.

Kelly: So, I kind of thought that black holes, you get sucked in, and then...it was something about black holes are an area with lots of gravity, so I always imagined you would get squished instead of stretched. Can you explain why you get stretched?

David: So, Newton's Law of Gravitation tells us that the, the force of gravity falls off with distance as, um, the distance squared. So, something that's closer to another object feels the force of gravity stronger, right?

Kelly: Yes.

David: So, in, uh, what are called "tidal forces," the difference between your feet and your head as you're falling into the black hole—uh, there's extra force on your feet compared to what's on your head, so you'll feel this sort of pulling you apart.

Kelly: Ahhhhh. Okay, I got it.

David: So, it's a stretching.

Ben: Yeah, I, I've got a crazier one. Alright, so, first off—tidal forces from the moon are what cause the tides, and so the gravitational field from the moon is like a pair of fingers squishing the Earth. So the—the—y'know, there's a bubble of ocean above, uh, behind the earth and a bubble of the ocean facing the moon. But it's kind of like this—imagine that you had a colander. So, it's a nice, round surface, and then you have, like, an orange, which is another round surface. Now, the curvature of these two don't match. And so if you push the orange into the side of the colander, the face of the orange will get all deformed and smushed-out, as it has to try and conform to the face of the broader surface. And that's essentially what happens in these tidal forces is that the curvature of gravity becomes so different in different directions over an elongated body that it ends up, effectively, pulling you, lengthwise, and squishing you, widthwise.

08:29

Kelly: I see. I think I followed David's thing—

Ben: Damn it!

Kelly: —better…

David: *laughs*

Kelly: *laughing* I'm sorry.

All: *laugh*

Kelly: I guess this isn't a contest, huh?

David: The appetizer course goes to—Dr. Dave!

Ben: Ohhh!

Kelly: Ohhh!

Ben: Um, so, the, the thing about black holes is that, it turns out that you can observe black holes astronomically.

David: That's right. As stuff falls into a black hole, it'll heat up, just because it's gaining kinetic energy 'cos it's dropping true gravitational potential. So, as this stuff heats up, it starts emitting an, uh, emitting light just because it gets hotter and hotter, just like, uh, if you heat something up on the sto—on the sur—on, on a fire to really hot it starts glowing. So, we can learn a lot about, uh, black holes, even though we don't get light from them directly, by looking at stuff that falls in.

Ben: Well, hold on, Dave. So, when we say "stuff falling in,"—black holes are usually surrounded—well, the black holes that we can see usually have some kind of gas around them that's in the process of falling into it. So it's usually kind of swirling around the middle trying to enter the black hole around the equator. And then—

David: That's right. It's called an accretion disk.

Ben: Right, an accretion disk. And when stuff tries to fall into the black hole it ends up running into that accretion disk. And it's like, uh, if you dropped a bowling ball off, off a bridge and it slams into the water and then the water absorbs all of the gravitational energy, right? So, what—what we see is the accretion disk heating up.

David: That's right. So, the accretion disk, as—as it's swirling around it rubs up against itself, and that friction causes it to heat up. And that's what—that's the energy that we're seeing and this can get really hot, up to x-ray temperatures. So, we can actually observe these, uh, accretion disks in the x-rays as they're falling into black holes.

Kelly: Cool!

Ben: So, we take an x-ray telescope out and we see all these bright spots, and those bright spots are black holes.

David: That's right.

Ben: Yeah.

David: Or they could also be neutron stars.

Jocelyn: Yeah.

David: Um, neutron stars also have something similar, where—so, these, these accretion discs usually come from the binary companions of these objects, so you can have a black hole or a neutron star with a large main sequence star or a giant star that it's in a binary orbit with. And as this binary gets closer and closer, the black hole or neutron star starts stripping away material from its companion, and that material sort of slooshes down and forms this accretion disk around the, um, compact object.

10:36

Ben: Right. And so, we see these binaries and one of them is a star, so we can look at it in visible light, and we can say, "there's a star." And then we look at it closer and we see that it's orbiting something, right? So, we see the star getting towards us and going farther away from us back and forth periodically. And then we see that the object it's orbiting isn't bright.

David: That's right, and based on how that star is moving, uh, we can look at the doppler motion of its spectral lines, for instance. We can sometimes infer what size the companion object must be. So, we can see from the way a certain star is moving that it must have a very massive object that's moving it around.

Ben: Right.

David: And that's often how we can infer the size of black holes.

Kelly: So, I know what "doppler motion of its spectral lines" means, but that sounds like something most people wouldn't know.

David: Ah, so, um, if you have a—uh, a spectral line is just a transition line from, uh, a particular atom that's been excited, and, um.

Jocelyn: So, it's, it's just light of a particular frequency—

David: That's right.

Jocelyn: —that, that's always at the same frequency because the same process happens.

David: That's right. And so, as the star sort of moves around in an orbit, that gets doppler shifted bluer and redder as it's going around, so just like as a, uh, siren moves past you it gets higher pitched and then lower pitched. It gets higher pitched as it's coming towards you and lower pitched as it's going away—you get something appearing bluer when it's, uh, moving towards you, and redder as it's going away. And that's the doppler shifting of a spectral line.

Ben: Yeah. I want you to imagine a, uh, like a merry-go-round where you've taken kids and put them on the horses of the merry-go-round. And then you've turned up the speed of the merry-go-round really fast so they're all screaming.

Kelly: *laughing*

Ben: And if you do it fast enough, all the kids'll scream at the same pitch on the merry-go-round as they go around in a circle. On the side that's moving towards you, their screams will be doppler shifted higher frequency, and the ones moving away from you on that—the other side, their screams will be doppler shifted to a lower frequency, so the one side will sound like *high pitched scream* and the other side will sound like *low pitched scream*, even though they're really going *medium pitched scream*. You get it?

Kelly: I do. You shouldn't be a parent.

Jocelyn: *laughs*

David: Now, now imagine you have one of these children, and they're being spun around by a very fat man. Based on the speed of that spinning we can tell how big that fat man is.

Jocelyn: *laughing*

Kelly: Ahh. Alright.

Jocelyn: But actually, based on the spinning you can just tell how big the combination of the kid and the fat man is.

David: That's true.

Ben: Right.

David: That's true.

12:49

Kelly: So, how do you tell the difference between the fat man being a black hole and the fat man being a—what did you say? A neutron star?

David: What an excellent leading question!

Ben: Holy crap.

Kelly: Oh, I'm good. Yes.

David: So, the difference between, if you remember, the difference between a neutron star and a black hole—or, one of the differences—is that a neutron star has a surface. A neutron star or a white dwarf, they, they have surfaces. So, as this material's falling in, if it falls into a black hole it just gets—it passes through the event horizon and it's lost to our universe, it can't get back out again. But, as it's, uh—when it goes onto the surface of a neutron star, it can sort of build up there. And this, um, material can just sort of build up and up and up until there's enough material that gets hot enough to start fusing, and you get what's called an x-ray flash. And, um, that's one of the ways we can actually tell the difference between neutron stars and black holes is, um, systems where there's a surface for this, uh, material to build up on are thought to be neutron stars, whereas systems where we never see these flashes are thought to be black holes.

Kelly: So, if the kid throws up—

Ben, David: *laugh*

Kelly: —you'll see it on the fat man. If it doesn't—

David: Right, if the fat man's a neutron star. But if the fat man—

Kelly: —otherwise it disappears.

David: —soaks up all the, all the puke, then he's gonna be a black hole.

Kelly: I got it.

Jocelyn: And we can actually, we have some idea before the bursts which ones are neutron stars and which ones are black holes. Because neutron stars can only be so fat, right? 'Cos they're be—they're like matter's last stand against gravity, right? So, this—the nuclei, or, the neutrons are going as fast as they can, trying to keep the star from collapsing. And at some point if you add enough mass to this it'll collapse to a black hole—there's a limit as to how big this can be before it just can't support any more weight. So, if, if you know from the binary thing that this—whatever the compact object is—is more than about three times the mass of the Sun, then you think it's gonna be a black hole. And if it's less than that, then you think it's gonna be a neutron star. So you can look at these things, and you can say "Oh, look, hey, all the ones that are bigger than the neutron stars aren't showing these flashes."

Kelly: Okay.

Jocelyn: So, the black hole picture totally makes sense.

Ben: Um, so how do we know that there isn't something denser than a neutron star that isn't a black hole?

14:53

Jocelyn: Well, we don't. There—there—there actually *could* be things that are denser than, sort of, a typical neutron star but still not a black hole. So, so the neutron stars, the idea is that the degenerate neutrons—so, okay, when we say "degeneracy pressure," this is like a quantum uncertainty thing. The faster something is moving, or, the more precisely you know the speed something's moving, the less precisely you know where it is, and vice versa. So, this is like an uncertainty principle. And so, if you're trying to squish a lot of things into a small area, you're localizing them, therefore they have to be moving with uncertain speeds, so they're, they're moving fast, and this is a pressure that keeps it from collapsing. So, it could be these neutrons in a neutron star providing this pressure, but you could also, actually, imagine a *further* collapse where, instead of a bunch of neutrons going around, you actually have quarks. So each, each neutron and proton is made up of three quarks, and you could actually have this fluid of quarks that's supporting a quark star. So, you can have these, these various things. And so this, this is one of the, the questions, actually, is "is there some possibility that you could have these strange stars that would be...well, it's actually—it's very hard to make them denser, or, it's har—you can't easily make them support more than three solar masses, but you can have these other, kind of—

Kelly: What is that?

Jocelyn: Hmm?

Kelly: What's a solar mass?

Jocelyn: The mass of our Sun.

Kelly: Oh, okay, thanks.

Jocelyn: So, yeah, whenever you're talking about gravity, most of the time you can, you can measure things in terms of solar masses better than in terms of kilograms.

David: A solar mass is about, uh, 2x10^30 kilograms.

Kelly: Woah. Alright, got it. And we use our Sun as the standard.

Jocelyn: Yeah.

Kelly: Okay.

16:26

Ben: So, I think that one way we can talk about this is in terms of surfaces, right? Dave was talking about it earlier, any ball of matter is going to have some surface—some kind of outer edge. And so even if it's one of these weird, uh. What's it called, a strange star?

Jocelyn: Quark star.

Ben: Oh, okay. So, if it’s made of strange quarks, then it’s called a strange quark star?

Jocelyn: Yes.

Ben: Unlike the, y’know, uppity quark stars. So, I think one interesting way to look at, at, at, at gravity—black holes specifically—is in terms of this analog system where you imagine the black hole—the gravity in the black hole—as a waterfall. Okay. So, there are fish in a stream—say it’s Niagara Falls. Up the Niagara River there are fish in the stream, and they can talk to each other, let’s suppose. And they talk to each other with sound waves. Okay?

Kelly: Mmhm.

Ben: Now, uh, there’s a point at which the water moving through the air moves faster than the speed of sound in water, if the waterfall is high enough. Alright? So, this is an acoustic horizon, and what it means is, any fish farther down the waterfall than that level? They won’t be able to talk with the surface, because when they try to squeak it at each other, uh, the sound waves can’t move up the waterfall ‘cos the water is moving down, vertically, faster than the sound waves can move up, okay?

Kelly: Mmhm.

Ben: So, this acoustic horizon is the analog to our event horizon in gravity. The role the boundary of a star plays in the system is it’s like a grate. So it’s like, you know, uh, Niagara River council people say “we can’t have people going over this waterfall, so we’re going to put a grate across the river and that’s gonna keep anything from falling past a certain level.”

Kelly: Mmhm.

Ben: So, they put an iron grate across it, and then stuff can build up on the grate. And so, any object in our gravitational system, any compact object that’s bigger than a black hole will act like one of these grates. And so, matter that falls in on the object will just pile up on the surface of it. And Dave was telling you earlier about how fusion can happen in gas once it hits the surface, so the idea is that I—what, what would you say, hydrogen gas is kind of like an egg, and that if you hit it hard enough, fast enough, it splatters and you can make something new with it?

Jocelyn: That’s...that’s not what I would say.

All: *laugh*

Ben: Maybe that’s what you *should* say, Jocelyn. Okay, so, anyway. Flashes of fusion start to take place as streams of matter go down and hit this, this surface, this grate. And so this is a characteristic feature that we'd see in any system where you have a compact body that is larger than a black hole, right?

Jocelyn: That—that's actually the, the thing about strange quark matter, is that—so, pretty much any matter, yes. But, there's this idea that strange quark matter would be more stable than regular matter. Like, sort of an *Ice-Nine* scenario, if you've ever read the Vonnegut book? Where there's this form of water that's solid that, as soon as one crystal touches it, the water can collapse down to this more stable state and the Earth freezes. So, so there could be this strange matter that does the same thing. And so if, *if* there was this particular kind of, sort of crazy model—which is hard to be compatible with some other things—but if stuff accreted onto that, it could just immediately get converted to strange quark matter without giving the thermonuclear bursts.

David: True.

Ben: So it's like the Blob.

Jocelyn: Yeah.

19:33

Kelly: I've lost track of the question we're answering.

Ben: *laughs*

Jocelyn: We're—well, we're trying to see whether something's a black hole or not. And, and the thing is that you can think of some sort of crazy scenarios that are technically not a black hole because there's a, there's matter there, there's a surface that's not in the horizon, but still hard to see with other light. So, we started out looking at these x-ray things bursting and saying "hey, look. The neutron stars burst. The things we think are black holes don't burst. That's totally compatible with this horizon idea."

Ben: I think the kicker here, though, is that now that we've got a theoretical explanation for why the only compact body that won't have these fusion bursts will be black holes, is that you can then go out and look into the universe and try to see black holes. When we do observations—astronomical observations—you can look for these binary, rotating systems where one object is a big star and the other is, uh, a very heavy, compact body that isn't emitting light. And then, so, some of them have these fusion flares and others of them don't. So, the idea is that now we have a way to look at these and there's a criterion that you can use to tell whether or not you're looking at a black hole.

David: So, so there's more than *just*, uh, black holes that are around this size. There are also some theories which predict smaller black holes from, um, primordial formation that sort of zip around and, you know, they don't—they don't really get into binaries with stars, so they can't accrete matter, so we don't see them.

Kelly: They're moving?

David: Ah, they could be moving around. There's also, um, what are called supermassive black holes. These are, sort of, the most massive objects in the universe and they're sort of—they're thought to be at the center of galaxies. For instance, we have a f—a black hole that's four million times the mass of the Sun, uh, located at the center of our galaxy, the Milky Way.

Kelly: Wow.

21:13

Ben: It's in the Sagittarius constellation, right? So—

David: Yeah.

Ben: —the spot is called Sagittarius A* (pronounced A-star)

Jocelyn: So the question is why we know that that's a black hole and not just some really big star, or clump of other stuff.

David: So, there's, there's a bunch of different ways we can actually, uh, probe this. One way is just looking at how stars behave close to this, this object. So, some people have basically been tracking for decades the, uh, motion—

Jocelyn: Since '95.

David: Is that two decad—no, not quite, not quite decades.

Jocelyn: It's 15 years.

David: 1.5 decades, the, uh, the motion of certain stars that are very close to this, uh, galactic center. And, um, ac—you can, um, you can watch these stars in a sped-up animation. And, um, as they sort of approach this one point they suddenly whip around as if there was an *extremely* fat man there, uh, grabbing their arms and throwing them around.

Kelly, Jocelyn: *laugh*

David: And these stars just suddenly turn around on the spot and start moving the other way.

Jocelyn: There's gotta be something really big there—

David: Right, so—

Jocelyn: —and that's how we know how, how massive it is.

David: That's right, that's how we—

Kelly: So, why do they whip around? And not get sucked in?

David: Um, they don't get close enough to get sucked in.

Kelly: Okay.

David: So, they're, they're still quite a ways away from the black hole—quite a ways away from the event horizon. But also quite a ways away from what's called the tidal disruption radius, where they sort of get broken apart by the—where they get stretched apart. Just like you would get stretched.

Kelly: Okay.

Jocelyn: So there's sort of, like, comets that are orbiting the Sun and just, sort of, come in on this crazy orbit, come close to the Sun, and then whip around, and then we don't see them again for decades.

Kelly: Got it.

David: So, these are on the similar kind of orbits.

Ben: I'm not sure if there are any other real examples that you can give where people are literally taking videos of stars flipping around each other, but this is a, it's, I'll, I'll link to it on the website, but it's, it's a very dramatic scene because it honest-to-god looks like a video of stars. Usually stars don't move fast enough relative to one another that you can see them passing each other, but these stars are honestly flippin' around, around this central object and you can't see the central object, so it's—there's like a little x on it. And everything else is flying around the way, like, paper would if you had a, like, a whirlpool and a drain, and you threw some paper in your sink and you'd see these papers just like whippin' around this whirlpool and you'd say "well, what's that," and the answer is, "well, it's a black hole that we can't see." A very very very very very very very very very heavy black hole.

David: Actually, also very recently, uh, just this year astronomers have been using, uh, what are—what's called very long baseline interferometry, where they interfere a millimeter away, sort of, near infared radiation and their, uh, measurements from the galactic center. And they're almost able to resolve down to the event horizon. Uh, they're able to actually see, um, hot spots, uh, from the matter falling into the black hole. And, uh, it's a very, very difficult measurement and it, uh, will only get better, uh, as time goes on. But right now they can start constraining things about the, um, about the black hole. Like how, how fast is this black hole spinning, how much stuff is falling into it, and things like that. So it's actually a very, very exciting time to be studying these things.

24:14

Kelly: Awesome.

Ben: Um, one—one thing that you can see specifically around black holes, uh...actually, the first test from general relativity is—this isn't a phenomena specific to black holes—the very first test in, I think 1919, when Arthur Eddington goes out into the wilderness because there's a full eclipse of the Sun, and he wants to measure the distance to the stars, and what he shows is that starlight that should be travelling past us ends up having its trajectory warped by the gravitational field of the Sun and then ends up hitting Earth. So, what you see is that these, these massive bodies end up bending light. And if it's a really, really, really, uh, compact object, like a black hole, you see it, it almost looks like a lens, the way it warps the light around it. And so—so Dave was mentioning some people who have done large scale interferometry of the supermassive black hole at the center of the galaxy—in their images, you can actually see the light warping around this sphere. It's, it's quite amazing.

Kelly: Yeah, it sounds awesome.

Ben: Oh yeah, it's awesome.

David: That's right, they—their resolution isn't *quite* good enough to be able to resolve the, the event horizon itself, but it's actually getting close. It's only on the order of a few times the event horizon now.

Kelly: So, what would knowing exactly where the event horizon is tell us? Why is that useful information?

David: It, it would be the first time we're able to directly image a black hole.

Kelly: Oh yeah. That would be pretty cool!

Jocelyn: I mean, well—you see, if you kind of look at a black hole against the stuff behind it, is this empty disk, and then around, around a ring, sort of around that horizon, you see all the stuff that would be behind the disk. The light from it has gotten bent around, so you see it in, in tiny, compressed, squished things around the ring. And then, in the center it's just black.

David: Sort of like looking through the, uh, the base of a wine glass.

Jocelyn: Actually, if you have a Mac, I think one of the effects you can do in the Photobooth will, will make a, like, black hole

Kelly: Cool.

David: Actually, using, um, using this gravitational lensing effect, but, uh, instead of just using one object, people use an entire galaxy. Recently astronomers have been able to, um, use this gravitational lensing to, uh, zoom in on a, what's called a quasar, which is a, um, a distant object thought to be very bright, hot gas falling in a supermassive black hole at the center of another galaxy. And they can actually get an image of this disk of gas that's being—being sucked down into a supermassive black hole. You can't see the black hole itself, but you can actually make out the disk at this galaxy that's billions and billions of, uh, kilometers away.

Kelly: Awesome!

Jocelyn: 'Cos it's, it's been magnified by the mass. We actually—we used the, the distortion of masses of all the light coming from behind them to weigh how much matter is in different structures. This is one of, one of the things that tells us that there's something called—well, I guess this is kind of getting ahead of the top—or, off-topic, but stuff like dark matter, if you have heard of that at some point?

Kelly: I have! We interviewed Sean Carrol about it very recently.

Jocelyn: Okay! So you probably heard a bit about the bullet cluster, but it's, it's basically, you, you look at this, you look at something that passes behind, um, or—or, or you, you look at stars that are behind something and how much the light from those stars gets distorted tells you how much mass is in the stuff moving in front of them.

Kelly: Got it! Awesome.

Jocelyn: These are all these really super, uh, relativistic behaviors of curved space that we actually now see in very common astrophysical things.

Kelly: Cool.

27:36

Ben: So, Kelly, do you now believe that black holes exist?

Kelly: Yes.

Ben: Do you believe that they're out there and waiting to eat us?

Kelly: S...sure. And I believe we can measure them now in some ways.

Jocelyn: Cool!

Ben: That's awesome. Okay, I consider that a victory. I can't think of any other reasons why we should tell you anything more about black holes, Kelly, except for what happens when you fall in one. Do you wanna know what happens when you fall in a black hole?

Kelly: Absolutely.

Ben: Alright,

Kelly: I know you get stretched out.

Jocelyn: So, the question is: what happens if I see Jocelyn fall in a black hole?

Jocelyn: Okay, I'll illustrate: *scream that becomes distorted, as if in slow motion*

Ben: If I threw Jocelyn over a, say, a waterfall, the sound that she made as she was screaming over the waterfall would be doppler shifted as she accelerated down towards the bottom.

Jocelyn: *screams from high to low pitch*

Ben: Um, just in exactly the same way, the thermal light emitted from her body as she fell into the black hole would also be red-shifted.

Jocelyn: Or if I have a flashlight.

Ben: Right, if she had a flashlight. It would also be red-shifted, as we mentioned before in the—with the doppler shifting example. As she fell in towards this event horizon, I would see her moving slower and slower and getting redder and darker as the photons that come off her clothing and travel towards my eyes got more and more energy sucked away from them as they had to climb up this gravitational well to arrive at me. And then, so, I'd see her fade away over the course of millennia. And, in fact, uh, it would take longer than the total amount of time in the universe for her to cross over the event horizon from our perspective, whereas in her perspective it would only take a second. And then she'd be stretched like spaghetti and crushed, but we'd all be dead by then.

Jocelyn: I'd be like, "why are you all going so fast? No, no need to panic! I'm good!"

Ben: From her perspective, the universe would start going faster and faster, and then she would be crushed fairly quickly. So, anyway, food for thought.

Jocelyn: Unless it's a really, really, really, really big black hole. So, the bigger it is compared to me, the less I feel stretching from different parts of my body.

Ben: Totally, Yes, that's—

Jocelyn: And so it's kind of a question of relative size between me and the black hole. So, if it's huge, I can just sail right through it. I can be through the event horizon, and it's not until I'm, y'know, further in that I start getting stretched like crazy.

Ben: That's right. If she's lucky she'll die of old age, but—

David: Yeah.

Ben: We, standing on the outside, watching her fall into it will *definitely* die of old age before we see her cross the event horizon.

David: The moral of the story is: Once you go black hole you never go back-hole.

Kelly: *groan*

Jocelyn: *laughing* That's a terrible moral.

29:58

Ben: Okay, so, thank you, Jocelyn, and thank you, Dave. You have pleased me and your efforts have borne sweet, sweet fruit. I'm sure Kelly will agree.

Jocelyn: Woo!

Kelly: Yeah!

Ben: And I'd like to thank my guest, Kelly Weinersmith! Thank you very much for coming on the show and interrupting us when we got carried away.

Kelly: Thank you for teaching me about black holes.

Ben: I hope that you can use this lesson that you've learned in black holes later in life. Uh, I'm sure it will come in handy as the days go on.

Kelly: It will help me understand some of the jokes Zach makes about black holes.

Ben: Fantastic!

30:31

Ben: Okay, so you can email the Titanium Physicists Podcast at barn@titaniumphysics.com, or you can follow us on twitter at @titaniumphysics. You can visit our website at www.titaniumphysics.com or you can look us up on Facebook. If you've got a question you'd like my titanium physicists to address, email your questions to ti-phy-ter, that's tiphyter@titaniumphysics.com, and if you're a physicist and would like to become one of my titanium physicists, please email me at physics@titaniumphysics.com—we're always recruiting. The Titanium Physics Podcast is a member of Brachiolope Media, and if you've enjoyed this show, you might enjoy "Science, Sort Of" or "The Weekly Weinersmith."

Kelly: Yes!

Ben: 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!

31:28

[Outro song: *Angela* by John Vanderslice]