Black Holes Collide

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Jorge: [00:00:00] Hey, Daniel. I have a question about smashing things together.

Oh,

Daniel: well you came to the right place. I know

Jorge: you're a professional smasher, I guess I'm actually wondering if it's the right way to study

Daniel: things. Mm. I don't know. I mean, what could

Jorge: go wrong? I mean, does it work for everything? Like, let's say you're trying out a new restaurant.

It's mashing. Plates together really the best

Daniel: way to test it. I mean, I would read that restaurant review. Wouldn't you,

Jorge: or what about movies? Like you would smash Blueray disc together.

Daniel: maybe that's how they came up with awesome crossover event. Maybe

Jorge: that's the origin of the Marvel multiverse.

Daniel: Somebody had a stack of DVDs on their coffee table and

Jorge: Eureka, somebody smashed two comic books together, or a comic book with a Blueray.

There you go.

Daniel: That's what happened. Smashed two Hollywood actors together.[00:01:00]

Jorge: Hi, I'm Jor hammer cartoons, and the co-author of frequently asked questions about the

Daniel: universe. Hi, I'm Daniel. I'm a particle physicist and a professor at UC Irvine. And I'm the other co-author of frequently asked questions about the.

Jorge: Whoa, what a coincidence, what are the chances that we would collide on a podcast

Daniel: like this?

What happens when you smash two co-authors together? Do you get one big author?

Jorge: you get, you get a Voltron author. Maybe. Can I be like left foot jokes

Daniel: aside? You get a really fun book that neither of us could have written on our own filled with amazing physics insights, deep revelations about the nature of the universe and hilarious

Jorge: cartoons.

Yeah. Tackles really. Amazing and frequent questions about the universe, like why we can't get to other stars or is there an afterlife possible in this universe or

Daniel: why Daniel doesn't believe in time travel? Wait, you don't believe in time [00:02:00] interval didn't you read the book, man.

Jorge: I'm gonna have to go back in time and read it.

Daniel: it's too late. You're

Jorge: outta time. I ran outta time. That's why . But anyways, welcome to our podcast. Daniel and Jorge explained the universe, a production of iHeartRadio

Daniel: in which we smash up the two most amazing things in the universe. Your brain. And the entire universe, we try to take everything that's out there, all the craziness, the insanity, the frothing quantum mess.

That is our reality and squeeze all of it into your brain because we believe in you. We believe that your beautiful brain, even though it's a tiny part of the universe, Can contain within it, a whole idea of the universe that we can look out into the depths of space and actually understand what's going on out there on the podcast.

We talk about everything that's happening out there and explain all of it to you. That's

Jorge: right. We smash together scientific ideas and discoveries and collide them with, uh, bad puns and a lot of. Conversation [00:03:00] here in order to pick up the pieces and hopefully make sense of this amazing and wonderful cosmos that we live in.

And

Daniel: you give me a hard time for it sometimes, but I really do think that smashing stuff together is really the best way to understand it. I mean, like who hasn't tried a sample of their neighbor's plate at the table. Right. And mixed it with their own dinner to create something new. .

Jorge: Wow. Do you ask for their permission for

Daniel: us though?

At least. I mean, usually it's somebody in my family, so yes. Reaching over to my wife's plate to try a French fry and dip it in whatever sauce is on my plate. And you never know that could have been a culinary invention that rocked the world. It

Jorge: just seems a little, you know, sort of a little destructive way of studying the universe.

You know, I'm more of an engineering type. I like to take things apart. Not smash

Daniel: em together. That's because you care about putting them back together. I just wanna know what's going on inside

Jorge: well, I mean, doesn't, it seem a little destructive in a way, like, you know, it's sort of like a little kid who smashes things out of, uh, anger.

Daniel: It is destructive. Absolutely. But you know, sometimes that's all you can [00:04:00] do. Joking aside, if you have a toaster. Yes. You can take it apart, carefully piece by piece and catalog what's inside it. And that probably. A better way to understand how a toaster works than taking two toasters and making a toaster Collider.

But sometimes the forces that hold these things together are so strong. And that the only way to break it up to understand what's going on inside is to smash it up. And that's the case, for example, with

Jorge: protons. But have you actually look, maybe there's a screwdriver for protons you just need to get the right one with the right, you know, shape.

Yeah.

Daniel: The screwdriver for protons is another pro. I guess it's more like a hammer than a

Jorge: screwdriver, but then what is that screwdriver made out of Daniel?

Daniel: Exactly. That's the only tool you have. If everything in the universe is a proton, then basically you're just smashing protons together.

Jorge: Wait, does doesn't everything eventually fall apart or break apart?

Can you just wait for things to, you know, break open?

Daniel: I mean, I have grant deadlines and you know, I gotta get stuff done. I can't just wait till the heat death of the universe when everything collapse. I see

Jorge: it's a lack of patience, not a lack of, uh, [00:05:00] better methods.

Daniel: You're encouraging procrastination to the heat death of the universe, right.

That's really on brand for you. Yeah,

Jorge: there you go. And in the meantime, the grant could support you right? While you wait.

Daniel: That's right. I'm gonna write a grant for waiting for 10 to the 14 years until the universe does its experiments for me. We'll see how that goes. I'll cut you in if it gets funded. Yeah.

Yeah. As long

Jorge: as it's for 10 to the $14, , I'm totally in now, but smashing things together does seem to be the preferred way. Physicists, like to explore things at the smallest levels, because there is no screwdriver for opening things like protons or even quirks.

Daniel: There is no screwdriver. There are no tweezers.

And it's something that we can actually do. We can manipulate protons. We can tune their energy. We can smash them together to see what's going on inside. And the same thing is true for even bigger stuff. We can't take stars apart. We don't have the machinery to understand what's inside a planet. So the best way to learn about it is to watch collisions of enormous astronomical objects to see what's going on

Jorge: inside.

Yeah. I guess sometimes it's hard to fake [00:06:00] things apart, like you said, right? Like it's hard to take a star apart. That would be pretty difficult.

Daniel: It's pretty hard to take a star apart. It's even hard to look inside a star. We had the Parker solar probe recently, which came super close to the sun and almost fried itself, but not quite.

And it gives us a picture of what's going on on the surface and helps map a little bit of the insides. But, you know, we have questions about what's going on deep, deep in the heart of our son that we could only really answer by Sping it into another

Jorge: star. Yeah, I guess sometimes it's hard to look inside of things.

So you kinda have to break them apart because they don't open up so easily. To be honest in engineering, we do sometimes match things together or squish 'til they break, just press test them. Now don't

Daniel: worry. I don't know how to build a star Collider, so I'm not going to shoot Proxima. Centara at our star.

Anytime soon, that's a grand proposal that will never be funded, but we don't have to build these colliders ourselves. We don't have to construct. Cosmic colliders to smash plans together because the universe is doing it for us. We just have to look out there [00:07:00] into the skies and find the experiment already underway.

Jorge: Yeah. Because it is a pretty big universe. And even though it's huge and empty, it's pretty big and pretty full of stuff. And so there's always something going on in the universe. And sometimes that going on is

Daniel: a big collision. We have seen comets slam into planets. We have seen binary stars collapse into each other.

We have seen all sorts of crazy stuff. Smash into itself and learned an incredible amount in the process.

Jorge: Yeah. We've seen galaxy smash together, right? That's sort of how dark matter was

Daniel: confirmed. Yeah. We can see galaxies merging in the middle of this process of swirling around each other and their stars forming one new elliptical galaxy and you're right.

We've even seen galaxy clusters collide. The bullet cluster is two big groups of galaxies. Enormous. Piles of galaxy smashing into each other dark matter, coming out on either side, which tells us, as you said, that dark matter is its own thing. And not just some weird twist on

Jorge: gravity. Yeah. I guess smashing things together is a good way to explore things, especially if [00:08:00] they're sort of mysterious and kind hard to know that.

They're there or what's going on inside of them. Right? Like smashing things with dark matter in them. So it of helps you see the dark matter. Yeah. It helps

Daniel: you separate the dark matter from the rest of the stuff, because different things smash differently. Right. The gas and the dust in those galaxies smashed into each other, making huge explosions and bright flashes of light, but the dark matter passed right through.

So that tells you that dark matter really is different from normal kind of matter. So yeah, absolutely smashing stuff together. Great way to figure out what's going.

Jorge: Great way to support physicists. We like to smash things as little kids. Yeah.

Daniel: But you know, don't like smash your kids together if you're not sure what they're up to, there is a limit to this idea.

Jorge: I see. Well, I think they usually smash themselves pretty good without your help or

Daniel: direction. All right. But in no way, am I endorsing kids smashing on the podcast?

Jorge: I don't even know why you would bring it up. I guess, you know, I guess kids are mysterious also. They're hard to understand. Yes, absolutely.

Daniel: Kids are hard to understand, but there are better [00:09:00] ways to understand what's going on inside your children than smashing them together. Right.

Jorge: Right. I guess you could talk to them. I

Daniel: guess you could just make references to them on the podcast and hope they listen.

Jorge: Yeah. Maybe like 20 years from now when they're in therapy, they'll be like, what did my father think of me?

Oh, it's right here on this podcast. What . But anyways, there is something mysterious out there in the universe that we would like to know more about. We would like to know what's going on inside of him. But so far they are one of the hardest. To look at and figure out.

Daniel: And a lot of people write to me and ask what happens when these two mysterious objects in the universe come together.

Is it just like other collisions or are some of the fundamental rules of the universe broken? So today

Jorge: on the podcast, we'll be tackling the question. What happens when

black holes collide? This is a very sensational question. I feel what happens when black holes

Daniel: go collide. It's sort of like shark versus shark, [00:10:00] like which shark eats the other one, you know, , it's one black hole sucking in the other one. They sucking each other. What does that even mean, man? Yeah,

Jorge: I know.

It's like, can I hole fall into another hole? Like, you know,

Daniel: holy moly, that's a complicated.

Jorge: That is a whole lot of holes there in that theory,

Daniel: we need a holistic understanding of how this works

Jorge: but this is sort of part of our, I guess, a recent theme we've had going on in the podcast. We can almost call it like smash month or smash week.

Daniel: exactly. We got smashing on the brain over here with podcast headquarters.

Jorge: Hopefully it'll be a smashing success, but we have been smashing things together. We smashed photons together last time and we smashed, what else did we

Daniel: smash? We did a whole list on our episodes question about smashing stuff together.

That was the theme annihilation questions.

Jorge: And then we smashed light together, which it turns out you can't smash together. And now we're smashing black holes. What's next. Daniel smashing universes.

Daniel: oh, wow. Universe collisions. Actually, there is a theory about different [00:11:00] bubbles in the multiverse, bumping into each other and leaving an imprint on the cosmic microwave background.

Radiation. I just read about this

Jorge: theory.

Daniel: Yeah. Oh yeah. The big bounces. Yeah. There was a theory by Roger Penrose and. He claimed to see evidence for it in the cosmic microwave background radiation, but nobody could confirm it. So it's definitely not something we've seen, but a pretty awesome

Jorge: idea. Yeah.

Also it's called the big balance, not the big smash. So we can't talk about it.

Daniel: this episode sponsored by smash burger

Jorge: by smash mouth .

Daniel: But I remember the first time I heard about black holes being collided and I thought, wow, that's incredible. Like two things that we definitely do not understand. And I thought to myself, I wanna see what happens, what comes out, what's revealed in the shards of that collision.

Like show me the answer universe. Yeah.

Jorge: What are the shards of the two sharks? When they collide

Daniel: and it's sort of amazing, you know, that it happens out there in the universe and that we can see it. So to me, it feels like we are peeking [00:12:00] under the rug of nature, really understanding something deep about the nature of space and time by looking for these extreme collisions.

When nature has to tell us how things

Jorge: work. Yeah, because black holes are pretty extreme in the universe, right? There are some of the most extreme conditions imaginable. Maybe they're breaking the laws of physics inside, or at least the laws that we know. And so you can imagine amazing things are gonna happen when you smash two of them together.

Yeah.

Daniel: They're probably gonna smash the laws of physics.

Jorge: And I guess maybe a more philosophical question is, is Daniel can two holes actually collide. Like what what's actually hitting each other. Nothing's gonna hit each other. Is there just two holes?

Daniel: I guess you could think of them as like merging, right?

If you and a friend are both digging holes in the ground, you just keep digging, then eventually you just get one big hole. Right? So those two holes can sort of merge.

Jorge: Mm. So it's more of a black hole merger.

Daniel: It is, but it actually, the map doesn't quite work that way because the black hole that comes out is a little bit smaller than the sum of the two black holes that went in, which is pretty weird.

Wait, what? [00:13:00]

Jorge: Well, you just spoiled it. you said another hole comes out. I guess the two holes don't cancel each other.

Daniel: Yeah. They do an amazing dance of relativity to form something new that comes out. Well, then,

Jorge: as you said, this kind of thing happens all the time in a yours and we get to observe it. Right.

Daniel: We certainly do. And we learn a lot about the nature of space and time in the process.

Jorge: Well, as usual, we were curious how many people out there had heard of black holes colliding and what maybe they think happens when they do so.

Daniel: Thank you to everybody who participates in these segments for our podcast.

We hope you have a good time answering random questions without any chance to prepare. If you'd like to participate and hear your speculation on the podcast for everybody else to enjoy, please, don't be shy. Write to us two questions@danielandjorge.com.

Jorge: So think about it for a second. What do you think happens when two black holes collide?

Here's what people had to say. Yeah. I think we know this,

Daniel: right. So if two black holes collide a, they make a bigger black hole, but B I think some people have discovered that they make gravitational [00:14:00] waves, but that seems like too simple, an answer. So I read black hole blues by Jan 11. And my best guess is when black holes collide, they circle around each other faster and faster.

And as they get, um, Closer to each other. They're circling almost at the speed of light at the very last split second. And when they collide, the force has enough energy, uh, to overpower the energy that an entire galaxy might put out. And that's why we can sense the gravitational waves. It'll galaxies away.

Um, here on earth with the, uh, the new instruments we have in general, I don't think there is a direct collision of a black hole, but rather they orbit each other closer and closer and

Jorge: closer with

Daniel: probably the stronger one feeding off of the weaker one. Ultimately after all the fireworks are done, I would assume [00:15:00] that the smaller one

Jorge: would be eventually absorbed into the larger one.

And you

Daniel: have one substantially larger black hole when two black fold collide. I think they just merged into a larger one. We can observe gravitational waves, uh, happening while. Occurs. But other than that, I think they just merge from black holes, collide gravity waves make their way to our clever listening devices here on earth.

And, um, I think probably there's a lot of energy released and they become one black hole when black holes collide. I mean, you're very, very heavy, heavily dense. And it's very strong gravity coming from these things. So when they collide, it's gotta kind of one wins out, which everyone is [00:16:00] a more dense and B strongly have stronger gravitational forces.

And then it kind of

Jorge: absorbs. They make a

Daniel: lot of gravity waves and then they make one big.

Jorge: Black hole. All right. Lot of fun answers here. I like the one that said, uh, when they collide, they eat each. Kind of like sharks, but

Daniel: who is eating? Who, man, that doesn't really

Jorge: answer the question. What if, what if one shark starts eating the tail of the other shark and then the other shark starts eating the tail of the other shark.

What's gonna happen? It's like a yin yang

Daniel: shark somehow. Yeah. A ying shark. Yep. Maybe the shark ends up eating itself. Maybe

Jorge: you get a shark NATO. cause they're spinning around

Daniel: so fast. That's probably how that crossover event happened. Right? A shark DVD and a tornado DVD.

Jorge: Boom. That's right. Yeah. One bad idea.

Smashed another bad idea.

Daniel: Why not right. Who knows what happens when you collide the craziest things in the universe? So I love the creativity there. Thank you. Yeah. Why not?

Jorge: Maybe that should be the [00:17:00] style of the podcast. Why not?

Daniel: let's

Jorge: get smashing. Well, let's break it down for people here. Daniel, maybe let's start with the basics.

What is a black

Daniel: hole? Black hole, as you said, is a hole in space and time, but it's a really strange. You know, really what it is, is a location where there's so much mass and energy in one spot that it's dense enough, that particles that are near it are doomed to fall in, you know, mass and energy tells space how to bend and then space tells particles and mass and other things.

How to move. So the more mass and energy you have somewhere, the more space curve, which is why, for example, satellites, orbit the earth, instead of just flying away, you could think of all of gravity. In fact, as the invisible curvature of space, rather than like a Newtonian tugging. And so black holes are where space is curved so much.

There are particles that can never escape.

Jorge: So there are sort of holes in space and there are sort of holes caused by gravity, right? Like that's another way to do sort of think [00:18:00] about it, right? It's it's like, there's, there's so much stuff and energy in them that it just sucks everything in and, and it sucks them so much.

You, they can never get out. Mostly,

Daniel: you can think about gravity in two different ways. You can think about like a force. Something is pulling on you. Like the earth is tugging on you. That's sort of Newton's idea of gravity, but black holes come out of general relativity, which encourage you to think about gravity in a very different way, says that gravity isn't a force is just that space is curved, but you can't see that curvature.

The only thing you can see is the effect of that curvature on the motion of objects. So you shine a flashlight, for example, through curved space, then it seems to you to. That bending is just because it's moving in a straight line through curved space. You can't see. So when you apply that to black holes, you don't get like a really strong force of gravity.

You get a place where space is bent so much that now it's just one directional like things inside the event of horizon of a black hole always end up at the singularity, according to general relativity, because that's the only [00:19:00] direction left in.

Jorge: Right. Yeah. But, uh, general relativity might be, uh, wrong too, right?

Like there's this possibility that maybe gravity is a force and there are force gravity particles and everything. Right. General

Daniel: relativity, almost certainly wrong at some level, not in the sense that it's making mistakes about GPS or that we're getting the numbers wrong, but it can't really be the true description of nature, as you said, because for example, it predicts singularities at the hearts of black hole and you know, that's not as much a physical prediction, like general relativity and.

There is a point of infinite density, as much as it's a breakdown of the theory. It says, well, here's what I predict. And that seems sort of nonsense. So at this point, replace me with a better theory. So we don't know what's going on at the heart of black holes. It could be that the right picture of gravity is as a sort of quantum field, the way we have all the other forces.

You could think about gravity as the exchange of gravitons so, yeah, you're right. General relativity, almost certainly wrong. On the other hand, it predicts black holes and we see them. So it's right about a lot of

Jorge: stuff. Well, black holes [00:20:00] are really strange and there are a couple of really strange things about them.

Like, first of all, like can't escape. So they just look like a giant, uh, hole space, but it also does interesting things like slow down. There are two

Daniel: different kinds of time dilation in our universe from relativity. One is much more commonly talked about, which is velocity based time dilation. If you see somebody moving fast through the universe relative to you, you see their clocks slowing down and that kind of time dilation is relative because if they look back at you, they see your clocks slowing down.

So you two disagree about whose clock is slowing down, which is really weird and confusing makes you doubt, like, you know, truth and the existence of reality. But the kind of time violation that happens near a black hole is different. The more space is curved, where you are, the more your clock will slow down and that's not a relative effect is absolute.

So if your friend gets near a black hole, where space is curved more, you'll see their clock slow down because they're in more curved space. They will see your clock going faster. [00:21:00] Right. It's the opposite of the relative time dilation that happens due to velocity here is absolute because everybody agrees.

So if you are falling near a black hole, your friend will see you slow down and you will see them

Jorge: sped up. Yeah. It's a pretty cool effect. And like, you will literally see them moving slow motion. Right. And they will literally see the entire rest of the universe moving in.

Daniel: Forward. Yeah. And so if you see somebody falling towards a black hole, the closer they get, the more their time slows down.

And so it actually takes an infinite amount of time for the last thing to fall into a black hole, like toss a banana into a black hole. You don't actually see it enter the black hole past the event horizon until time equals infinity. Right.

Jorge: We've had, I think, whole podcast about this, cuz it is, it's sort of a little bit mind bending because you do sort of see black holes growing over time.

Right. And at some point they're gonna overtake the banana, right? Yeah.

Daniel: That seems confusing because it suggests that black holes could never grow, cuz nothing could actually fall into them. That's why I said it's only true for the last thing to fall into a [00:22:00] black hole. Cuz as the banana falls towards the black hole, the event horizon actually grows before the banana crosses over a black hole.

Isn't like a pet. You need to put something in it for it to get bigger. It doesn't have to like eat the banana. The size of the event, horizon reflects the total gravitational energy of the system. So as the banana falls into the black hole, the event horizon actually grows out to meet it. And then if you throw something else like an apple after the banana, that also pulls out the event horizon.

So it'll come and encompass the banana. So that's how we see black holes actually grow out there in the universe is a continuous stream of stuff falling into it and pulling out the event

Jorge: horizon. Right, right. You don't have to feed them, but it it's nice to feed them. Right. you don't wanna black hole to star.

Daniel: I don't know. It depends where the black hole lives. If it lives in your basement. I don't think it's a good idea to feed

Jorge: it. I think if it lives in your basement, it's game over for you, for your

Daniel: house, you know, there is some size of a black hole where it's radiating away energy and you could feed it at the same rate.

So you could have a stable, black hole that you keep [00:23:00] as

Jorge: pet. You can have a pet then. You just contradict it yourself, just don't pet it. I guess , don't touch it.

Daniel: I wouldn't recommend it, but theoretically, it's possible to keep a black hole stable. I see.

Jorge: And so something else that's interesting about a black hole is that there are only a few things we can know about them, right?

I mean, there are black hole and stuff falls in and we never see it again, but there are a few things that you can

Daniel: tell about them. Everything that falls into the event, horizon is lost to us. And what happens to it? We cannot know information about what's inside the event, horizon can't escape, but that doesn't mean we can't measure things about the global black hole, like a black hole has mass it tugs on you, even though you're outside the event horizon.

And so you can use that to measure how much stuff is inside the event. Horizon, how much mass does this black hole have? So there are a few things you can measure. From outside the event horizon and that's the mass of the black hole. Also the electric charge of the black hole. Charge is conserved in the universe.

You drop an electron into a black hole that changes its charge and its electric [00:24:00] field. The same thing for its spin. Black holes can spin. So there's this theorum called the no hair Ethereum that says those are the only three things you can know about a stable black hole, mass spin and charge.

Jorge: Wait, why is it called the no hair theorem?

How does hair fall? get fit into this. I think it's

Daniel: a joke that says that you can't know whether black holes are hairy. Like you can't know what's going on inside the black hole. Does it have blonde hair? Does it have a Mohawk? It's like, you know, just an example of something you can't know about a black hole.

Mm, it could have been called the no tattoos theorem also.

Jorge: Yeah, that makes no sense to me. but, uh, that's the official name. All right. Well, that's a black hole. And so now the big question is what happens if I take two black holes and I smushed them or smash them or merge them together, apparently a lot of things happen.

So let's get into that. But first let's take a quick break.[00:25:00]

All right. We're talking about smashing black holes together and Daniel, this happens all the time, right? Like we've. Recently been able to listen to black holes colliding, and a lot of, they ha they happen more often than we

Daniel: thought. Yeah. Black hole collisions were first observed in 2015, but it was a very, very long search for black holes.

People started decades and decades before that, trying to invent systems that were sensitive enough. To the radiation emitted from black hole collisions so that we could see it here on earth. This is something predicted by Albert Einstein though. He thought we could never actually observe it. He thought this is a cool effect, too bad.

It's too tiny for

Jorge: us to ever see. Oh, I see. So before we could listen to them with gravitational ways, people were trying to see them, but they never found any. People

Daniel: were trying to listen to them with gravitational waves for a long time. That was Einstein's prediction that they would create from gravitational waves.

But that would be impossible for us to see these gravitational waves to observe them. [00:26:00] And, you know, I'm in the company who agreed with Einstein for a long time. When I was thinking about grad school, I had a few different choices and one was going to university that was deep into LIGO that was developing the technology and trying to observe gravitational waves.

And I remember thinking that's cool, but they're never gonna make that happen. And so I'm gonna go do particle physics. I. Yeah.

Jorge: Yeah. I'm in the company of Einstein as well. I, I have crazy hair as well.

Daniel: but Einstein was wrong. And so was I, because they did see gravitational waves, they did see this crazy pattern of radiation emitted from the collisions of black

Jorge: holes.

Yeah. I, I think what I was asking is like, could you see two black holes merging together? I mean, we can sort of see black holes out there in the. And we can definitely see their effect on the stars or, or the galaxy around them. Could you ever hope to, you know, detect a black hole collision without the gravitational waves detection?

Like, could you ever see two black holes actually colliding? You

Daniel: can actually see them, but you're right. You don't see the black holes themselves colliding [00:27:00] black holes are surrounded by accretion discs, all sorts of matter. On deck for falling into the black holes. And so sometimes when two black holes collide, there are creation, discs also collide and create light.

They've seen this a couple of times where they've seen flashes of bright light at the same time and in the same direction as they've observed gravitational waves. So they have seen in a couple of occasions, bright flashes of light emitted from black hole collisions. Right. But

Jorge: before 2015, like maybe you would see.

Bright flash of light, but you wouldn't be able to know if it was a black hole

Daniel: collision. Yeah, exactly. It just seemed like a flash of light and there's lots of weird flashes of light in the universe. Uh, and you can't necessarily tell that one is from a black hole or from something else or just from two stars colliding or two blobs of gas colliding.

So really the unique signature and the thing that told us that black holes were colliding were these patterns of gravitational waves, which are like ripples in space and time.

Jorge: So far since 2015, we've seen a whole bunch, or [00:28:00] have heard a whole bunch of these black hole collisions, like maybe like 10 a year or something.

Right. It's

Daniel: incredible. We have like 50 examples now and to appreciate how amazing that is, realize that we didn't know how often black holes collided. When Lego turned on, it was like a new kind of instrument and we're listening to something new in the universe or a new kind of eyeball we're looking for things in the universe.

It's all just an analogy. Cuz gravitational radiation is not something you can see or hear. We're just trying to translate it into sort of human experience. But we didn't know if this kind of thing happened. Once in a century, once in a millennium or like 10 times a second. So when they turned this thing on, it could have been that they were waiting for years to hear the first one or that they came fast and hard and amazingly, we were lucky.

They're pretty common. And they saw gravitational wave. In the first test run, like they turned this thing on and they were just like doing calibration runs just to make sure everything was working and boom, they saw a signal in the first calibration run. So they were like off to the races, writing a paper on

Jorge: week two.

[00:29:00] Yeah. It's pretty amazing. Pretty cool. And they happen, uh, pretty often, maybe like once a month, once every month and a half. And do they happen here in our galaxy or are we listening to these collisions from like all over the universe? They

Daniel: happen all over the universe and we can see these things really far away, like billions of light years.

Now the further you are away from these things, of course, the fainter they are. And so if they're closer is easier for us to see them, if they're further away, then they need to be more dramatic, more powerful for us to observe them. But we've detected these collisions from black holes that are billions of light years away,

Jorge: but are they happening here in our milk away galaxy, we

Daniel: see black hole collisions, fairly commonly, but we can see them from really, really far away.

And they don't happen actually that often in any individual Galax. So we haven't actually seen one happen yet in the Milky way. Remember the black holes are not that common. We have really big ones in the center of the galaxy. Then you have black holes created from stellar collapse, but to get two black holes to collide, you really need like two black holes and a binary system.

Jorge: [00:30:00] Because I guess 50 seems like a lot of, uh, black holes colliding, but it's a big universe, right? There are trillions of galaxies out there. So the fact that we're only seeing, you know, maybe one a year, it means. Maybe they're not that common. Yeah.

Daniel: They're not that common sort of per galaxy, but they happen often enough for us to have a pretty nice data sample, which means that we can really study these things.

It's not just like we saw one. And then we're wondering if that was typical or not. We have like dozens of these things. So we can start to ask statistical questions about what's likely and what's common. We can see which ones are weird, which ones are normal. It's really an awesome moment. When you can start to do like population science on black hole C.

Mm.

Jorge: Yeah. Like statistical, you know, surveys. All right. Well maybe step us through here. What happens? What's like step by step. What's going on when two black holes collide, because you know, I think one thing that a lot of people might not know is that black holes can move, right? Like, it's weird to think of a hole moving like a hole in the ground.

Doesn't move, but black holes can move and they can sort of. Fly through space and, [00:31:00] and run into other black holes.

Daniel: Yeah. Black holes have baths, just like everything else. And so they have inertia and they can have momentum. Black hole can move in the same way. You can move past a black hole. Remember that velocity is just relative in our universe.

So, if you are flying past a black hole from its point of view, then from your point of view, the black hole is flying past you. Right? And so these things definitely can move. And a lot of people probably think about black hole collisions as like two black holes, just flying through space and bumping into each other, like two dogs in the park, smashing into each other or something, cuz they weren't looking where they were going.

Instead these two things have sort of been faded to collide. Since their birth. Remember that a lot of stars are born as binary systems. They were made near each other and gravitationally bound from the beginning, orbiting each other in a long dance. And that's how most black hole collisions happen. They start as a binary star system.

Then each one collapses into a black hole. Then you get black holes, orbiting each other. So they've always been neighbors. It's not like they're just two strangers that smash into each other [00:32:00] and they're overing each other. And they're slowly losing that energy radiating away their orbital energy until eventually they collide.

Jorge: Whoa. Yeah. Cuz I guess, um, most black holes come from stars. And so if you have a binary system and both stars turn into a black hole and you have a binary black hole system, right. But isn't that sort of rare. I mean, it's a little rare for a start to turn into a black hole, but now you ha you need to have both of them in the binary star system turn into black holes.

Exactly.

Daniel: And so those are the conditions you need. Uh, and we're still understanding, you know, black hole formation, but it depends on how much mass there was in each individual star. If it's a massive enough, then eventually it will collapse into a black hole. There's like no way to avoid it. Once it burns up its fuel.

The thing I think is interesting is understanding why these things are inevitable. Like why can't two black holes just orbit each other happily forever until the end of the universe. Why do they have to fall into each other?

Jorge: Right. Like, uh, in our solar system, you know, our, the planets are orbiting the sun pretty stably, [00:33:00] pretty stably.

That's true. We're not falling to a sun

Daniel: yet. not today and not tomorrow, but you know, these orbits are not technically stable because every time you're in orbit around something, you're accelerating. Anything that's accelerating in our universe. That's changing. Its velocity is generating gravitational waves.

You know, what is a gravitational wave? It's just when your gravitational field changes. If you have an object in space, it has a gravitational field it's changing the shape, the curvature of space. If that object accelerates, then that curvature of space changes, but it doesn't change instantaneously. Just like if the sun disappeared, we wouldn't notice for eight minutes or whatever, it would take time for that gravitational information to propagate.

And so when something acceler. It's changing the curvature of space and that's what's happening when the earth is going around the sun it's accelerating. And so that radiates away some energy in terms of the information about updating the

Jorge: curvature. Right? Right. So we're slowly losing a little bit of energy in our orbit.

And so [00:34:00] eventually, I guess in the very, very, very, very far future, the earth is gonna fall into

Daniel: the sun. That's right. Other things will happen before the earth falls into the sun due to radiating gravitational energy because the earth is not that massive. But if you have two black holes that are really, really massive, they're gonna radiate a lot more gravitational energy.

And so as they lose energy, they fall into each other. Right. They can't maintain their orbit if they don't have that energy. So they're very orbit the thing that's accelerating them around each other is shaking the curer of space around them, creating these gravitational waves and forcing them to get closer and closer and faster and faster.

So it's more like a swirl in than a collision,

Jorge: right. It's sort of like if you have a still lake or a still body of water and you take two fingers and you sort of rotate them or spin them around each other, they're gonna be generating waves on the water. That's sort of how people see, uh, two black holes kinda radiating out energy as waves.

Exactly.

Daniel: And it's a deep concept. [00:35:00] That's really applicable to lots of different physical phenomena, right? Like how do you generate radio transmissions? You take electrons which have an electric field and you accelerate them up and down. You shake them. And that wiggles the electric field that wiggle in the electric field is nothing more than a photon it's passing of information and energy through that field.

So you take a mass. Now it has a curvature and space. You wiggle that mass, you accelerate it. That wiggling of space time is gravitational radiation. It carries away energy.

Jorge: Mm. All right. So they're not sort of, you know, uh, aimed at each other. They're more like swirling together. Uh, but then at some point they lose energy and they swirl faster and faster and closer and closer.

And at some point they start to touch, I guess. Or collide. Yeah. They

Daniel: start to touch and to think about that, you have to think about what you mean by two black holes touching, right? Like what is the edge of a black hole? What's the surface of it? Often we talk about it in terms of the event horizon, we talk about the event horizon as [00:36:00] if it's like something physical, you know, like a surface or a boundary or something.

It's really just sort of like a location past, which you can never escape the black hole, but it's not like there's anything there at the event horizon. There's no physical surface. It's just like past this point, you will never escape. Like

Jorge: the edge of a hole is not really a barrier. It's just where you fall.

Yeah,

Daniel: it's just where you fall in the subtle point also is that you can't measure the event horizon technically to calculate where the event horizon is. You need to know like what happens to every particle that comes near it. Then you find sort of like the surface in which if a particle passed through it, nothing ever escaped.

So you sort of need to know the fate of every particle to figure out exactly where the event horizon.

Jorge: Wait, wait, what, what do you mean? We can't tell where it is. Like, can we didn't we just take a picture of a black hole recently? Doesn't that? Give us a pretty good idea. By the way that the light bends around it, where the event horizon is, we did take a picture

Daniel: of black hole.

And that does give us clues about the size of the event [00:37:00] horizon, because actually what we're seeing there is the shadow of the black hole, which is larger than the event horizon, because. You know, some light, for example, will pass near it and get bent around it. So the shadow actually looks a little bit bigger than the event horizon, but check out our whole episode about the black hole image for details about that.

But in principle, even that picture doesn't tell you exactly where the event horizon is. Like it could be that there's a particle that could pass a little bit closer to the black hole that we're seeing in that picture. And then escape. You don't know for sure. Uh, now we can calculate it, right? General relativity lets you calculate the size of the event horizon.

So we have this short styled radi. But it's not like something you can locally measure. You can't say I'm in or I'm out at any given moment in the universe. It's not like some device you could build that could tell you I'm inside of black hole or I'm outside of black. You can either calculate it from general relativity or you can shoot a bunch of particles at it and wait till the end of the universe and see which ones escaped and which ones didn't.

So

Jorge: it's sort of a fuzzy boundary, I think is what you're saying.

Daniel: Exactly. And we're gonna have to keep that [00:38:00] definition in mind as we think about what happens when the event horizons get close to

Jorge: each other. All right. Yeah. So what happens? So I have a one black hole and I have another black hole in me in my hands and I'm swirling them and I'm bringing them together and they're swirling and swirling.

And at some point where the event horizon. Would be or where we think it is or fuzzily where it should be. They start to overlap. They

Daniel: start to overlap. And when people write to me about this, something they're confused about is like a black holes event. Horizon is a sphere, right? It's like centered around the singularity.

Now you have two black holes, both of which are spheres. What happens when they touch? Do you suddenly get a sphere at the center of the two? You know, does that mean the event horizon is like shrinking a little bit. What happens there? And so the answer is you can't have like discontinuities or the event horizon is in one place and then one instant later it's totally different.

It's a smooth transformation from having two blobs to one blob and a little bit, surprisingly, that means that the event horizon is not always spherical [00:39:00] in the transition between two black holes and one black hole. That results. It's a weird sort of peanut

Jorge: shape. Yeah, I'm imagining, I guess, you know, like if, if you take two ink plots, like two blobs of ink and you sort of bring them together, they're gonna sort of like touch maybe at the boundary and then sort of merge and, but just a little bit first, and then the blobs sort of merges together.

The two blobs become a peanut shape and then they sort of blob blob together. Is that sort of what happens?

Daniel: That's sort of what happens and to figure out exactly what the shape of the event horizon is. People do these numerical relativity calculations, where basically they shoot a bunch of particles near these two masses and they figure out where the no-go zones are, where if a particle passed through it, it ends up in the singularity, no matter what.

You know, they have to calculate the event horizon in this way to like figure out where the no-go zones are and they do these incredible simulations. And you can find these images online. If you wanna look for the video, we'll put a link into the show notes. And what happens is you have like two blobs and as they get closer to each other, there's like a [00:40:00] filament that forms between them.

Now the event horizon looks sort of like a dumbbell. It's like two big blobs with a very thin line between them. Then as they get closer and closer, that line grows and grows and grow. Eventually you have like a peanut and then a tic TAC and finally a

Jorge: sphere. wait, we skip past the peanut M have a whole bunch of other candies.

all right. Well, let's get into what actually is happening with that event horizon and where do all the gravitational waves come from? But first let's take another quick

Daniel: break.

Jorge: All right. We're talking about smashing two black holes together. And the scenario we're picturing is two black holes that came from a set of binary stars, and each star became a black hole. Now the black holes are swirling around each other, getting closer and closer and closer. And just as they're about to touch, they actually sort of [00:41:00] reach out and, and touch each other kind of in a way.

Daniel: Yeah, there become regions in space between the two black holes that are now effectively inside their event, horizon their combined event horizon. Because if you're in that place, you will not escape. So you could have been outside the event horizon just before, but now this filament has formed where if you were right between them and you're no longer have any chance to escape the black hole.

And to me, it's really fascinating. This moment when the event horizon is no longer a sphere. Because it's an opportunity to learn something, to know something about the history of the black hole what's going on inside, even from the outside. What do you mean?

Jorge: What, what can you learn or what could you hope to learn?

Well, if you

Daniel: come along a black hole and it's a perfect sphere, you have no idea what's inside. Is it bananas? Is it apples? Is it the result of a star collapsing or two stars collapsing? You have no idea about like the merger history of that black. But if you come along at the moment when the black holes are still merging, then you know, this must have come from two [00:42:00] mergers.

You know, that there are two singularities inside that event horizon, or, you know, something about the history of it more so than if you just come along to a spear. Right. So you know, a little bit about what's going on inside the event horizon.

Jorge: I see it. It, you're saying it tells you a little. About what happens when you change a black hole, right?

Because a, a non-changing black hole is sort of mysterious and impenetrable, but, uh, a black hole that's changing. Maybe you can tell something about whether, you know, all the stuff inside of it is concentrated in the middle or spread out evenly, things like that.

Daniel: Yeah. It's fascinating to me because black holes are like the most identical thing in the universe.

Remember this in theory, only three things to know about a block. Only three numbers that totally determine it. And two black holes that have the same mass spin and charge are totally equivalent. There's no way you could do experiments to tell them apart, except unless, and this is the crack in the Noha theorem.

If you have a black hole with that mass and that's spin in that charge, but it's still finishing its last merger. You [00:43:00] can know one little clue about that black hole. You can know that it came from this merger and that must mean that the INDs of the black hole haven't quite settled down yet. They haven't like formed the singularity or the quantum Fu ball or whatever's going on inside because the event horizon has a different shape.

It's the same mass, the same spin and the same charge, but a different shape of enter horizon hasn't yet collapsed into a

Jorge: sphere. Oh, I see. You're saying we can learn about the resulting black holes, but we, we don't really would know anything about the holes, the two holes that went into it. Right. Like they, those would still be a

Daniel: mystery.

Those would be a little bit of a mystery, but you could know something about their relative masses. For example, if two black holes that are equal in mass merge, then as they're merging, they look different than a black hole where one was like 99% of the final mass. And the other one was 1% because it's more asymmetric.

So you know something about what went into the black hole from the shape of the sort of peanut before it collapses into a. I just think that's fascinating, cuz it's a tiny little crack and any [00:44:00] crack to say, like I know something about what's going on past the evangelizing that's tantalizing because we know so little about what's inside.

Jorge: I see you're saying like a regular black wall by itself. It's inscrutable. But if you see what two of I'm joining together, you're like, Hey, I know a little bit about what happens in these extreme

Daniel: Condit. Yeah. You know, a little bit about the history of this black hole, whereas for other normal black hole, you know, literally zilch except for the mass, the spin and the charge.

And here you have like a little bit more information. Plus you get to describe these things in terms of a diagram that physicists call a pair of pants diagram. Which

Jorge: is a lot of fun. yeah. If you, I guess if you Google pants in black holes, you'll get a whole bunch of interesting images. I haven't tried it to me.

Maybe we should, uh, maybe we should have the adults in the audience check that

Daniel: first. The idea is that you have two patches of space time, which are sort of like the legs of the pants, and then they're merging and they form like the waist eventually. So if you draw that out with like [00:45:00] tubes of space, time connecting each other, you start with two, you end with one, it's sort of like a pair of pants.

Jorge: Mm. Yeah, I think it's gonna be hard to paint that picture, but I think the main point is that when the two black holes get together, they sort of reach out in the middle. They start merging. That's sort of, I guess, where your in scene would be in the pants and then they blop together. Right. Is that sort of what happens?

Like is that what this, at least that's what the simulation say that they just. Bloob together and become one big

Daniel: hole. Yeah. They bloob together and become one big hole. And in the process released an incredible amount of gravitational radiation. And we can learn something about that process from looking at the details of the wiggles of that

Jorge: radiation.

Right. And a lot of this energy comes from the angular momentum, right? Like maybe they're spinning around each other. Slowly when they're far apart, but then when, as the two black holes get together, they have to preserve the same angular momentum as not they're, by the time they get really, really close to each other, they're spinning at incredible speeds.

Right. Which makes for huge accelerations, which make for huge gravitational

Daniel: [00:46:00] waves. And that's why probably every black hole out there is spinning the simplest idea we have of a black hole. The short style black hole of a spear is in the event that the mass is not spinning. It's just sitting there, but because things fall into a black hole and they will always swirl around.

Before they fall in because otherwise they'd have to fall in directly to the center, like a perfectly online with the singularity, any deviation from that they're gonna fall in with a little bit of angular velocity, and so with momentum. And so they're gonna end up spinning. So the final black hole has to be spinning.

Every black hole out there in the universe is almost certainly spinning for that reason. And two black holes spinning around each other. You're absolutely right. How a lot of angular momentum and they're gonna generate a lot of gravitational radi.

Jorge: But the end result, the what ha ends up happening at the end is merge into one bigger black hole.

That's bigger than the two individual black holes, but maybe like not as big as if you just added the mass of the two black holes. Exactly.

Daniel: They lose some of that [00:47:00] mass. Right? What happens when you lose energy as a black hole, you lose mass. Just like if a black hole is radiating, Hawking radiation, it's shooting out particles, it's losing mass.

And so if therefore it's shrink. So black holes can evaporate. They can lose their mass through Hawking radiation and get smaller and smaller. If they also lose energy by gravitational radiation, they are also getting smaller. And so there's so much energy released in these collisions that sometimes they can lose a lot of mass, like as much mass is our sun.

Right.

Jorge: And this energy goes out as gravitational ways, but also I imagine a whole bunch of like light too, right? Like quasars have, you know, all that gas that was around each of 'em is, you know, going through these extreme velocities and smashing against each other. A lot of that must go out as basically light

Daniel: as well.

Most of the energy is radiated as gravitational radiation. It can be like 5% of the mass of the system is lost. Due to gravitational radiation, [00:48:00] there can also be light emitted. And this is sort of an open question. People have only seen a couple examples where they have seen flashes of light, perfectly coincident with black hole collisions.

And so something they're excited to study. This is an era of multi messenger astronomy, where you can see the same thing in electromagnetic, radiation light, as you can in gravitational radiation. And so you can study it much more deeply. Uh, it's not something we've seen many examples of, so it's not something that's very well

Jorge: understood.

So stay tuned as we get more samples of these coalitions. But I guess one big question, it kind of goes back to what you were saying before, which is that, you know, time slows down near a black hole. So if you're, if I'm near a black hole, my time is frozen basically, or it's super slow motion. So how do these, but, but now if you get black hole next to the other one, isn't one of 'em slowing time down for the other one and wouldn't, they just.

Look to us, like they're frozen in

Daniel: time. Yeah. You might wonder, like, why do black holes ever collide? Don't they slow each other's time down so much that they basically just get [00:49:00] frozen before they merge. Right. Remember that a black hole is not a single point in space. So really what we're talking about is the merger of their event horizons.

And so while the two singularities may orbit each other for a long time slowing down because of the timed. Their event horizons can merge before the singularities come together. Right.

Jorge: But still like the times should be slowing down. Almost to a standstill near the edge of each black hole. So as they start to merge wouldnt things kind of freeze

Daniel: in time.

So things sort of do freeze in time in the sense that they get slowed down. Like what are we seeing? When we see black holes merge, we see a pattern of gravitational radiation. That comes from the black hole and we see it speed up and go faster and faster and faster. Now, when you look at that, you might wonder, like, why isn't that slowed down?

Why doesn't it get like spread out and slowed down? Why don't we see the gravitational radiation get slower and slower? The answer is that we are, we are seeing the effects of that time [00:50:00] dilation already. Like if there wasn't time dilation, then that gravitational radiation just bore the collision would be going insanely.

So we are seeing the effects of time dilation already sort of build in. When we see black holes collide, it would look different without the time dilation.

Jorge: Oh, I see. You're saying like, things are so extreme. Things are moving so fast around these collisions. And gravitational waves are being emitted so quickly.

And so intensely that even with almost freezing time, they still come out and they seem at a sort of a, a certain frequency for us.

Daniel: Exactly. That's built into those calculations. And when we do the numerical relativity to figure out like what's happening and where is the event horizon? How much gravitational radiation is emitted?

That's of course taken into account. And so we're seeing just what we expect time dilated, slowed down collision, but still generating these gravitational waves. So it's not slowed down

Jorge: to zero. I see. So if you were like near one of these black holes as an observer, like it would be like [00:51:00] insane, right? It would just like happen in a flash.

Daniel: Yes, exactly. It would happen much more quickly if you were very close to the event horizons of these black holes as they were happening. So you had sort of the same clock as they would, you would see something very D. Just the same way. If you see somebody fall into a black hole from far away, you see their time getting slowed down, but they don't see that.

Right. They experience time. Normally they just fall in and end up hitting the singularity. If you look very, very different, if you were in the neighborhood of the black hole.

Jorge: Mm. So that's pretty convenient, right? Like usually when you wanna observe something colliding really fast, you have to use a high speed camera, or you have to somehow slow down.

Or sample it super fast. So you get a good picture of what's going on, but this one has sort of like a, a built in slowmo

Daniel: setting. yeah, exactly. When the most interesting thing happens in the universe, it automatically goes slowmo, just like in special effects in the movies. Right. Just like in

Jorge: Marvel movies.

where like the bad guy shoots at the good guy and it's like time slows down so

Daniel: they can Dodge it. Yeah, exactly. Just like in the matrix [00:52:00] so they can make those crazy bends and Dodge, those. All

Jorge: right. Well, I guess then that's what happens when you collide to black holes, they sort of slowly reach out to each other.

They start to merge, you get a peanut shape, black hole, I guess. And then that eventually BLOS into a bigger black hole

Daniel: and some folks write and ask questions like. Is it possible for particles to escape the black hole during the murder? Because they've heard that black holes shrink a little bit, they radiate this energy away.

And so like maybe when the black holes are combining, something can like sneak out the back. Right. Which is a fun idea. But unfortunately, no black holes do not leak out any of this information when they. And the key thing to understand is that even though the mass of the two black holes is smaller than there's some, a volume of a black hole grows very quickly with its mass.

So even though the final mass is not just the sum of the incoming mass, the final volume can be like eight times the original black hole volume. So the event horizon is smaller than it [00:53:00] would've been. If it hadn't radiated gravitational radiation, but it's still bigger than either of the two black.

Combined. Mm.

Jorge: But you're saying, I think some things do sort of escape, right. Some information escapes, right? Like even if it's in, in different form in the form of gravitational waves, I think you were saying earlier that, you know, you can learn a little bit of the it's history as stuff escapes, right.

That's information, right? Yeah.

Daniel: The gravitational waves contain information about the mass of the black hole and its location. And. Velocity. It doesn't tell you anything about what's going on inside, but you're right from the shape of the event horizon, you can tell a little bit about the history of this black hole and you're right.

That's also encoded in the gravitational waves, but if something was

Jorge: just like at the edge of the black hole, as it was merging, could somehow, you know, Get lucky. And somehow, you know, as these things are merging, it maybe pools on the event horizon in such a way that somehow it gives you a little bit of a window for like one particle to like shoot out.

Daniel: no, unfortunately [00:54:00] not. That's what the event horizon means. The event horizon is not a physical surface. It's just like. The location past, which no information ever actually gets out. So you can't ask, like, is it possible for something to get out? Well, that's like by definition, that's what the event horizon is.

It's the point where nothing ever escapes, no information leaks out. That's how we figure out where the event horizon is for these things. At any given moment, we look into the future history of these black holes in our simulation and say, where's the point past? Which nothing ever escape.

Jorge: Right, right. I guess I'm thinking like, you know, like if you're accelerating the black hole really fast, isn't it possible for something to escape?

You know, like if I accelerate it to earth really fast, the things on one side would be squish against the earth, but maybe the things on the other side of the earth, Might fly off and get left behind. It's certainly

Daniel: true that if you did that to the earth, you would cause incredible damage. And I like the way you're thinking about really destructive experiments, just to learn about the nature of the universe, kudos there nearly becoming a physicist.

But if you did that to a [00:55:00] black hole, you would, nothing would leak out of the event. Horizon that black hole is enough curvature that even photons moving at the speed of light can't escape. And by accelerating the black hole, can't make anything travel faster than the

Jorge: speed of light. All right. Seems like it's plausible.

Well, but I think, uh, the main question is what happens when two black holes collide and they sort of don't collide, right? They sort of S smush together, I guess, is the, the simple answer. Mm-hmm

Daniel: they sort of grow to meet each other. And for a few moments there, you have a black hole that doesn't have a spherical event horizon, which is kind of an incredible revealing moment for the black hole.

Yeah.

Jorge: You get a peanut, I guess a peanut black hole. All right. Well, I think this really kind of points to some of the amazing things that can happen out there in the universe. You know, situations where that are not just extreme, but it's like you take two extreme situations and you smash 'em together.

You get like extra

Daniel: extreme. The thing that amazes me is that we can do these calculations. People perform these simulations, using numerical relativity tools. [00:56:00] They describe these incredible bonkers things that's happening. And then we can actually look out there in the universe and we see them, it really happens.

And that makes you wonder, like, is this what's really going on out there? If I could fly out to the black hole and like, watch it with my eyeballs, is this what I would see? You know? And I hope that one day eventually we can travel the universe and we don't have to just see these black holes from billions of light years away.

We could see these collisions

Jorge: close up. Yeah. Just make sure you bring some peanuts to snack. While you watch

Daniel: and smash your peanuts together with a chocolate bar and boom, you invented chocolate. M and Ms. that's too

Jorge: extreme. Daniel.

Daniel: extreme snacking with Daniel and

Jorge: Jorge. All right. Well, we hope you enjoyed that.

And, um, think about all the amazing things that are happening right now in the universe. Who's, you know, echoes. We are hearing right now that are washing through you right now, and maybe telling you about what happened in that C. Think

Daniel: about all the things that are happening in the universe and sending us information that we don't even know about, that we are ignoring that future generations of scientists will [00:57:00] discover and will use to learn incredible things about the universe.

Yeah.

Jorge: I mean, there must have been hundreds or thousands or hundreds of thousands of black hole collisions whose crash, whose smush sounds washed over humanity, but we

never

Daniel: even knew. We see a tiny, tiny fraction of the universe and we understand even less of it. Thanks

Jorge: for joining us. See you next time.

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