Black Hole Theory Cosmology Part 2 with Dr. Ronald Gamble, Jr.
Ologies Podcast
February 28, 2024

Oh hey, it's once again your friend's dog with the snaggletooth, Alie Ward. We're back with Part 2 of Black Holes. Whoo! Do yourself a favor, do yourself an honor by listening to Part 1 for Black Holes 101. And once again, this ologist is a cosmic origins scientist in the Astrophysics Science Division at NASA's Goddard Space Flight Center in Maryland. We were introduced by a previous *Ologies* guest, Dr. Raven the Science Maven Baxter, and this was recorded in my home studio over a few cups of tea, with my geriatric poodle goblin at our feet.

But before we get into it, thank you so much to everyone at Patreon.com/Ologies who submitted questions about wormholes and dimensions and flim-flam. We're going to get into it. You can submit questions if you'd like, for a dollar a month. You can be a patron, or you can upgrade a tier and we may play your audio questions, your voice on the show. Also, thank you to everyone who is wearing *Ologies* merch from OlogiesMerch.com and who rates and leaves us a review so that I can read a freshie, like this one from Kikiwella who wrote in that they:

> *... woke up from a surgery and immediately recommended Ologies to the nurse who was in the OR with me lol I love the show.*

Kikiwella, I hope you're on the mend. Also, if you listened to the secrets at the end of last week's episode, Black Holes Part 1, you might already know that I myself am going in for some surgery on March 1st. Feel free to guess what it might be, but yeah, you're going to get a Field Trip out of it eventually with all the details but first, we've got to see how it goes.

Okay, speaking of blacking out, let's dive into the singularity of information and learn about time travel, multiverses, sizes of black holes, pop culture, visualizations, how to get in the field, problem-solving, some petty-ass scientists, what we know about black holes, what we don't know and why we don't it, with Theoretical Astrophysicist and Black Hole Theory Cosmologist, Dr. Ronald Gamble.

Alie: Can I ask you questions from listeners?

Dr. Gamble: Yes.

Alie: Okay. Because we have [*sings*] a looooot! [*Dr. Gamble laughs*] Oh my god, so many.

Aside: Straight out of the gate, patrons Audrey Hudak, Nicky Gevirtz, Lizzy Martinez, Ryan Marlow, Penny Loader, Sarah Meaden, Nicole Harper, and Matt Ceccato needed Dr. Gamble's pop cultural assessments, such as...

Alie: Rachel wants to know: "This is Rachel from Oregon and I want to know, of all of the movies that depict black holes in some form, which one does the best job, and which one does the worst job?"

Dr. Gamble: Okay, so this is actually a very easy question, and if you haven't seen this movie, shame on y'all. [*Alie laughs*] But the best movie that I have seen that depicts black holes is *Interstellar*.

Alie: Really?

Dr. Gamble: Yes. [*dramatic music "We must reach far beyond our own lifespans."*] Now, I haven't seen every single movie on black holes, y'all, so if there's an indie film that you want me to see, just send it to

me and I'll review it. But *Interstellar* did a very great job, as best they could, to depict black holes the way they actually look. So, Gargantua, that scene, how the light curved around the black hole, the disc, if you were to actually go to a black hole and you were that close, it may very well look like that. [*"Heading towards blackness." static sounds. "It's all black. TARS, you read me? It's all blackness."*]

Alie: Really?

Dr. Gamble: Now, of course, there would be a whole bunch of other things around it, we're talking about a supermassive black hole. Gargantua is bigger than our galaxy's black hole, so this thing is huge. Of course, there would be other things but if we're just talking about the black hole, that was very accurate.

Aside: So, the 2014 Matthew McConaughey and Jessica Chastain sci-fi spacetime-bending flick, *Interstellar*, was, of course, the most mentioned movie by patrons with folks Bálint Novák, Jani Rounds, Sydney Koenig, Nathan Marion, Olivia Coppin, Katy, Abraham Livingston and first-time question-asker, Joe: Wanted to know about accuracy and the time-dilation in the movie, as gravity slows time for the movie's space explorers so much that as one hour passes for them, seven years go by on Earth.

Dr. Gamble: The time they spent down on the planet compared to the time for the scientists still up on board, very accurate, that is exactly, probably, how it would be.

Alie: Did they have a good consultant, do you think?

Dr. Gamble: They did, they had Kip Thorne.

Alie: Oh, well there you go. [*laughs*]

Dr. Gamble: Yeah! I mean, yeah! You had Kip consulting you, yeah, you're going to get this right.

Aside: Okay, remember in Part 1 when we mentioned that huge 1973 textbook, *Gravitation,* and how it was co-authored by this Nobel Prize winner, Kip Thorne. That's him. Yeah, that's him. Also, the visual effects team of *Interstellar* innovated all these new ways to simulate black hole imagery and they actually published their findings in a 2015 study called, "Gravitational lensing by spinning black holes in astrophysics, and in the movie *Interstellar*." Who is a co-author on that paper? Kip Thorne. Again. He's 83, he lives a few miles away from me, one day I hope to run into him at Target, I know what he looks like, and I want to ask him, "Who decides on the names of black holes in movies?" But I'll do it politely.

Alie: How do you feel about the word Gargantua? Is it like Unobtainium in *Avatar* where you're like, "Little on the nose"?

Dr. Gamble: It's better than stupendously large. Stupendously large, I kid you not, is a technical term for the massive black holes that are [*Alie laughs*] I would say probably 50 to 100 billion times, 100 times larger than supermassive black holes. We had to create a new category of black holes and they're called stupendously large black holes. I kid you not. You heard it today. It's a real thing; you can google it, it's on Wikipedia and probably in somebody's paper somewhere. Yeah. [*laughs*]

Alie: Was there a 5-year-old with a place mat who got to name it? Like an actual, they're like, "Uh stupendously."

Dr. Gamble: Probably. [*laughs*] Somebody's kid named this. He's like, what do you call it? "Stupendous." Okay. Yeah. That'll work.

Alie: That works! And elsewhere, I had no– God, so many tattoos you could get.

Dr. Gamble: [*laughs*] Yes!

Aside: So, stupendously large, seems to have emerged as an official science term in 2020 via the paper, "Constraints on Stupendously Large Black Holes." But in order to qualify as one, you would have to be larger than 100 billion times the mass of our Sun. Also, we would call you a SLAB, which is another official term for Stupendously Large Black Holes. SLAB is a compliment, don't get upset.

Now, if you're wondering about teeny, teeny black holes, there are suspicions that they could be as tiny as one atom but weigh as much as a mountain, according to the NASA article, "What Is a Black Hole?" which notes that "This page was written for children Grades K-4" but... worked for me! So yeah, ask smart people stupendous questions because stupendous comes from a Latin word meaning "to marvel at something."

But between the teenies and the SLABs, there are also marvelous supermassive black holes, and we had questions from Iso Partee, Euan Munro, Alan Gross, Kate Noonan, Bill LaBranche, and...

> *"This is Liz Spanier from Metamora, Illinois and my question is: How do you tell the difference between a regular ol' black hole and a supermassive black hole? And also, are there any other types of black holes and does it really matter if there's a difference?"*

Alie: I guess there's stupendous. When it comes to a black hole and supermassive, is it just scale or it's also performance, what they do?

Dr. Gamble: It's just scale. So, we're talking about just one number and that's mass. So, a supermassive black hole, as of now, they have been found inside the center of galaxies.

Aside: Such as for example like ours such as.

Dr. Gamble: That doesn't mean they have to exist there. There could be one somewhere else and we probably wouldn't see it because it's black, which is very scary to have a billion solar mass thing out there that we can't see. [*"There's something out there, isn't there?"*] But it's just mass. So, black holes are probably the simplest things that you can study in the universe. You only need four numbers: mass, spin (which is angular momentum), the area of the event horizon, and we like to say a fourth one that is kind of geared toward the effect of the black hole or kind of like the luminosity of the black hole. Physicists would call that entropy or another term for it. Observational astronomers would call it flux or luminosity, or brightness. So...

Alie: Is that dependent on how many photons are getting sucked into it?

Dr. Gamble: Yes. That depends on how many are going in and how many are coming... Not coming out of the black hole, [*chuckles*] but irradiating away from the black hole. This is how we can actually see black holes.

Alie: Ohhh!

Dr. Gamble: The matter around the black hole radiates light.

Aside: So yeah, scientists study the mass, the spin (or the angular momentum), how big the event horizon is, and its brightness or entropy because they radiate light.

Alie: How does it do that?

Dr. Gamble: Very simply, if you take a charge and you accelerate it, it will radiate light. And depending on what energy scale it's at and depending on how much the energy changes depends on what spectrum of light you get between radio, gamma rays, microwaves, infrared, all of that. So, the light that's going into the black hole, we can't see. But there's light coming away from the black hole and that's how we observe them.

Alie: That's bonkers to me!

Dr. Gamble: Now, it's not escaping from inside the black hole. Again, theorists... [*chuckles softly*] Don't get picky. It's not escaping the black hole from inside. This is, again, we're outside. So, we're thinking the ergosphere and further out. There are objects that are coming off of black holes, and these are some of the things that I study at NASA, called relativistic jets. You can think of them as black hole lighthouses. They are quite literally fountains coming off, they're like black hole lasers.

Alie: Wow.

Dr. Gamble: I've already put that in a paper, people, so don't steal it. [*Alie laughs*]

Aside: You can see his 2022 paper, "Spin Tetrad Formalism Of Circular Polarization States In Relativistic Jets." And this is a 10-pager, it's full of equations and it concludes with the line, "There are still fundamental questions that continue to remain unresolved."

Alie: Or make it a terminology that everyone uses.

Dr. Gamble: Or yeah. As long as you cite me, please. [*both laugh*] There's a bunch of different things that we have coming away from a black hole but not necessarily coming from inside. Once you are inside, that's it, you are done, you can say goodbye to student loans [*Alie laughs*] and debt and taxes and everything else. It's done. Like, COVID doesn't exist inside of a black hole, you're done. You may not see anybody else, but you don't have anything else to...

Alie: Nothing to worry about.

Dr. Gamble: Nothing to worry about.

Alie: No worries!

Dr. Gamble: It's just you and your thoughts and God, maybe. [*laughs*]

Alie: No exes. Amazing. [*"Absolute... nothingness."*] Calm.

Okay, so many questions. Erica Smith and Lily, Valerie Bertha, Aileen Lands want to know, in Aileen's words: Do black holes have a lifespan? Is there any way to know how old it is?

Dr. Gamble: That's a very good question. The answer, short answer is yes, they do have a lifespan. The long answer is, we don't exactly know how to calculate that, entirely. Again, theorists, don't be picky. So, we have a really cool physicist, last name Hawking, first name Stephen.

Alie: Heard of him.

Dr. Gamble: He came up with a theory about evaporating black holes. So now, let's imagine this, I have a pair of particles, I will keep this brief. You have a pair of particles, you have one electron, and you have what's called a positron.

Alie: Okay.

Dr. Gamble: Okay. So, a positron is the antimatter pair of an electron.

Aside: So, the legendary British astrophysicist, Stephen Hawking, figures prominently in anything black hole-related. But this is some friction and some chafing because he may have been a bit dicey in his personal life, but his work is still deeply influential, of course. And this theory about evaporating black holes hinges on these pairs of matter and antimatter which have the same mass but opposite charges. So, the positron, which has a positive charge, can be the result of natural radioactive decay. And of course, the antimatter to a positron is the electron. Vice versa.

Dr. Gamble: Imagine them as just twins. If you throw one twin into the black hole but the other twin gets kicked out away from the black hole, the twin that left the black hole will take away some angular momentum and energy from the black hole. [*"I'm taking this with me."*] What do you do when you take angular momentum away from something that's spinning?

Alie: It slows a little.

Dr. Gamble: It slows down. If something slows down that means it lost energy.

Alie: Oh!

Dr. Gamble: Now, if something is that massive and we're talking about gravity and spacetime and light speed and relativity this and Einstein that, then that means it also lost mass.

Alie: Yeah, I was wondering! So, they get smaller...?

Dr. Gamble: So, it's going to get smaller. Now, that's just one particle. If I scale that up to a trillion trillion, over the course of, I would say, maybe billions of years, the black hole will eventually evaporate.

Alie: Aha! Billions of years.

Dr. Gamble: Billions of years, yes. Now, supermassive black holes, we don't know if they actually evaporate because that means the galaxy is gone.

Alie: Oh.

Dr. Gamble: Yeah, we've never seen a galaxy just randomly pop out of existence.

Alie: Mm? Okay.

Dr. Gamble: Which would be scary, actually because now physics is really broken. What happened? But stellar mass black holes, which are black holes that are the size of our Sun, they could evaporate.

Aside: So, particle by particle, things just evaporating. Imagine the gradual disappearance of a supermassive black hole, like Sagittarius A* at the center of the Milky Way. That is about 14.6 million miles or 23 million kilometers in diameter. 23 *million* kilometers. And it's 4.3 million times bigger than the Sun, which if our Sun were a purse, you could cram 1.3 million Earths in it.

But smaller black holes, are prone to that total evaporation, obviously in a shorter amount of time. But guess what, jerks? There was a 2023 paper titled, "Gravitational Pair Production and Black Hole Evaporation," which published calculations showing that anything with gravity – i.e., every object in the universe, including our faces, would eventually evaporate. Get silly. Time's a wastin'. Nothing matters.

Alie: And would it take a long time for that?

Dr. Gamble: It would still take a long time. So, you know, of course, our Sun is a few billion years old, the Earth is about 4.5 billion years old, maybe 3 billion, so it would still take a long time. But in terms of peering back further and further in time, the further we look out into space, the farther back in time we're actually seeing.

Alie: Which still boggles my mind.

Dr. Gamble: Blows my mind too and I study this. [*both laugh*]

Aside: And that's because the light takes billions of years to get to us so we're seeing events on a bit of a time delay, like how west coasters watch *Saturday Night Live*.

Dr. Gamble: But if we had telescopes that could look further and further back, we might be able to see a black hole evaporate.

Alie: Oh man.

Dr. Gamble: Which would be crazy. I know. So, fingers crossed... NASA. [*Alie laughs*] But that's like the holy grail, if we were to ever see one, what would it look like? Could we... Would we recognize it? Would be the first question. I don't know.

Alie: I wonder if anyone has seen one but just didn't know what it looked like.

Dr. Gamble: That's how we discovered comets.

Alie: [*gasps*] Really?

Dr. Gamble: Kind of, yeah. They were like, "What is this? this looks like a star but it's moving and has a tail."

Alie: When was this?

Dr. Gamble: Probably thousands of years ago.

Alie: 1975.

Dr. Gamble: 1975. Yeah.

Alie: [*laughs*] Someone's like, "What is that?"

Aside: So, people have been seeing comets for thousands and thousands of years, ever since things had eyes but, of course, they were once considered a terrible omen or just aliens coming to eat us, understandably. I'd think the same thing.

But one thing not fully understood by me and some of you is the Big Bang. So, patrons Kenn Lippert, Duckman's 9-year-old future astronaut son, Charlie, and...

Alie: Matt Hirschl, Brian Schardt, C dB, John Salaun, Greg Lewis, TayBo33, Matt asked: What is the chance the Big Bang was our universe going through a black hole? Where does the Big Bang factor into black holes?

Dr. Gamble: Holy crap, okay.

Alie: Right?

Dr. Gamble: All right, so I'm going to try to... [*Alie laughs*] I'm going to try and keep this to 30 seconds. And... Go. [*"All right... Go."*] Okay. So, now the Big Bang... we have– I've already fucked up. [*Alie laughs*] The Big Bang... You have to think of, you have to go beyond our traditional normal, I would say, relativity. We now are extending into things like string theory, you have to go even further beyond that and start now talking about a multiverse of things. So now, mathematically, in terms of our physical theories, we call that braneworld theory or M-theory. Now, we're talking about, okay, well our universe is kind of like a bubble and another universe is another bubble. What happens when the bubbles both touch? [*drumroll*] Bang.

Alie: Oh!

Dr. Gamble: So, that's a theory.

Alie: Okay.

Dr. Gamble: Yeah. Was it a black hole? Don't know. Are black holes portals to somewhere else? Maybe. Mathematically, there is a symmetric half to the black hole called a white hole.

Alie: Reallllly?

Dr. Gamble: That instead of pulling everything in, it pushes everything out.

Alie: Whaaat?

Dr. Gamble: We need balance through the universe. [*Alie gasps*] The math admits what's called a white hole that spews everything out and doesn't pull anything in, that balances out our complete solution of black holes.

Aside: Again, my face just turned into rubber with the laxity of my jaw. Huh? And white holes are sometimes called black holes' neglected twins. Did you know that the supermodel Gisele Bündchen, she has a twin, she's named Patty, they're fraternal. I bet you didn't know about her.

Alie: Can we see or detect those at all?

Dr. Gamble: We would have no idea what those would look like.

Alie: They don't have photons coming out like a disco ball?

Dr. Gamble: We don't know what they would spew out because if you're pushing something out, where did it come from?

Alie: I don't know. The singularity?

Dr. Gamble: It wouldn't be a singularity if something is coming out of it.

Alie: Ohhh!

Dr. Gamble: Oh! So, now we have to talk about things like what's called an Einstein Rosen Bridge which is wormholes!

Alie: Oh, a wormhole!

Dr. Gamble: I was waiting for the right second to put that in.

Alie: I'm sure that we got a ton of questions, and I will list people in an aside.

Aside: Wormholes, wormholes, wormholes, wormholes. Let's go down one for patrons Mark Hewlette, Pavka34, Gemma, Felipe Jimenez, Tim Pfarr, Juliana, and first-time question-askers Ashley Marrs, and Jenna Congdon's husband Dan.

Alie: [*groans*] Let's talk about it.

Dr. Gamble: Okay. So, wormholes. If you connect a black hole and a white hole together, you'd have a tube. So now, what can you do with a tube? You can go through it. But you take one sheet of spacetime, and you fold it around another sheet, and you poke a hole through it, that's a wormhole.

Alie: How do you poke a hole in it?

Dr. Gamble: I don't know.

Alie: Okay.

Dr. Gamble: I say I don't know, but I do know, but it would take another three hours to explain. [*both laugh*] But you need exotic matter, and we say exotic matter, we're not talking about electrons, we're not talking about photons, we're not talking about antimatter or dark matter. We're talking about exotic, something that we don't even know exists yet, but it can't be our regular matter because it doesn't have the properties to actually hold a wormhole open. Now, *Interstellar*, again, was very good at describing and showing the wormhole as a sphere. If a black hole is a sphere, then one opening to the wormhole would be a sphere and the other opening to the wormhole would be another sphere.

Aside: And for more on wormhole portals, you can see the 2020 paper, "Multi-mouth Traversable Wormholes," which honestly starts off kind of like a chipper travel brochure reading, "Our

wormholes may be traversed between any pair of mouths." But then the paper continues kind of like a DIY video on building a spacetime tunnel saying:

> *Inserting a sufficiently small black hole into its throat preserves traversability between the original two mouths... Making the new wormhole traversable in a manner similar to the original two-mouth wormhole provides the desired causal connections.*

Is this paper sexy? I feel like it's sexy. I can't tell!

But let's hop into a hole and take us to the 2021 article by the American Physics Society. This is titled, maybe prematurely, "Wormholes Open for Transport," and it explains that previously, it was thought that wormholes could stay open with what's called exotic matter. Exotic matter is also known as "ghost matter" (I prefer that) but some researchers recently used a model of quantum entanglement to prop that sucker open.

Now, if you just cannot wait to get the hell away from your life, consider the 2021 paper, "Humanly traversable wormholes," or "Wormhole models that involve five-dimensional spacetime." I understand that a human being would experience about 20 Gs of survivable force, about twice what a fighter pilot is trained to take, but you could bop about the galaxy in under a second as all of your sad friends on Earth experience thousands of years of time waiting for you to return their "Hey, how is the wormhole?!" text. Ghosted? Ghost-mattered.

Moving on.

> *"Hi, this is Debra and I'm in Placentia, California and I kind of get how black holes affect space... I'm just wondering how black holes affect time? Thank you."*

Dr. Gamble: Because that's what the geometry, that's what the math tells us. These are two spheres, connected together through some bridge in spacetime.

Alie: Got it.

Dr. Gamble: Where do you go? You go into some intermediate hyperspace connecting one 4D space to another 4D space.

Alie: And that bridge is what we don't know?

Dr. Gamble: That bridge as well, we have no idea.

Alie: And that could be time travel?

Dr. Gamble: It could be time travel.

Alie: But not time travel like going back to, like, three months before you...

Dr. Gamble: No, you're not going back three months, you're going like... maybe a million light years somewhere else, and now you're figuring out, "Okay, well I hope the bridge behind me doesn't close because now, how do I get back?" [*laughs*]

Alie: Do you think one day we'll be able to do that? Like, we have people on the Moon here and there, we're sending cars to Mars.

Dr. Gamble: Listen, human ingenuity is undefeated, so I think, I give it another 10 to 1,000 years. That's a very wide range. [*laughs*]

Alie: Okay. That's a good timeframe.

Dr. Gamble: Good timeframe.

Alie: I might be alive for it, who knows! I might go pop through a wormhole and check it out. [*Dr. Gamble laughs*] Who knows? Okay, in talking about all this, a lot of people had questions about anxiety.

Aside: Including Alie Ward, Shannon O'Grady, TheDorkNextDoor, Alex W, and Britt Carpenter.

Alie: Bee wants to know: Why are they so terrifying? Marie-Michelle, first-time question-asker, wants to know: Do space scientists, when lying in bed at night and contemplating space and vastness, also experience that intense psychological vertigo? Does it... Is it anxiety-provoking for you in any way? Or how do people deal with the [*squirmy sounds*]?

Dr. Gamble: Okay, so I'm not going to lie here. We 100% absolutely lose our shit. [*Alie laughs*] And that's part of the reason why we're studying this in the first place, because we lost our shit and are like, "Wait a minute, that was cool. But let me not have this panic attack again and actually work the math." And then we panic again because we can't work the math, what am I doing? [*Alie laughs*] But yes, we do have some anxiety over discovering new things but then also figuring out, what does that actually mean? Because something brand, brand new that I've never seen before, we don't have any answers for. And scientists and theorists don't like to say, "I don't know." We don't like to say that. I say it sometimes. I said it in grad school one time, and it didn't work for my exams. [*both laugh*] "I don't know. We don't have an answer to this." And my professor was like, "Well, figure it out!" And I'm like, I don't have a Nobel Prize yet, I can't do it!

So yes, we panic sometimes. But we pick ourselves back up and we say okay, well I can figure this out. And if I don't figure it out then I'm going to publish a paper saying, "I didn't figure it out." And that's it. [*laughs*]

Alie: There's your answer, we don't know yet.

Dr. Gamble: We don't know yet. And then we go back to panicking like, "Oh, there's a black hole at the center of our galaxy." [*laughs*]

Aside: So, black holes, they're distant, they're giant, they're mysterious, but what do they mean for us, who are little ape people and nearby and we're small and we're transparent in our wants and desires?

> *"Hi, I am first-time question-asker Ivan Gonzalez. I am keen to explore the potential implications that the study of black holes may hold for humanity... and the insights we might gain about the origin of the universe through this exploration. Thank you."*

Alie: That is such a big part of our everyday lives that we don't think about, you know? That every single day, we're somehow, whether we're created by, influenced by, that a supermassive black hole figures into our day-to-day life, we don't think about.

Dr. Gamble: Our cell phones work because of gravity.

Alie: How so?

Dr. Gamble: GPS.

Alie: Ohhh! GPS, that's right.

Dr. Gamble: Yeah. Thank you, relativity. Yeah. We have 5G because of relativity even though 5G kind of sucks.

Alie: [*laughs*] Is there going to be 6G?

Dr. Gamble: I mean, if there is 6G just don't charge me more, that's all I care.

Alie: [*laughs*] Okay, so many people, Josh Waldman, first-time question-asker, wants to know: What's up with the idea that the Large Hadron Collider could create a black hole? Is this a real concern or just a weird conspiracy theory?

Aside: Others conCERNed with particle accelerator business are Timmy H, Greg H, Dave Cannon, Justina Vasiliauskas, Chris Allen, James Dean Cotton, Dirt Witch, Early of Greymalkin, and fellow first-time question-askers AubGoblin and Matchstick Merryweather. I'm seeing that over time more of you have weird names and I'm fine with that.

Dr. Gamble: Okay, so for our longtime listeners, first-time callers, no, the LHC is not creating black holes, it's not creating portals to somewhere else, we're not finding aliens or demons, or whatever conspiracy theories are out there. I've read them all and I'm like, "Whyyy y'all?" So no, they're not creating micro black holes and I know a lot of people are saying, "LHC is creating..." They're not creating black holes. That was a random thought by somebody that that actual conversation was probably never supposed to be public.

Alie: Oh no! Was that just like lunchroom chatter?

Dr. Gamble: It's kind of like lunchroom... Yeah. Because we think of these random theories– This is how some of these theories start. You have to think of something completely random, completely off the wall and I'm like, "Okay. Well, what if we actually did create a black hole and we threw some atoms together and they actually smashed but they didn't blow apart, but they crunched in?" I'm like, okay, maybe we don't do that. Is it actually going to happen? No. We know gravity doesn't behave that way, we know relativity doesn't behave that way, we know spacetime doesn't quite behave that way, we know black holes don't form that way. We're safe. [*laughs*]

Alie: Okay, good to know. Aren't there theories that we popped into a different, shittier universe when they turned that thing on? [*"There's no off switch." "There is an off switch."*] But I mean, things have always been a little...

Dr. Gamble: Things have already been shitty.

Alie: Yeah. There are so many universes where you're like, "How did that happen?"

Dr. Gamble: Okay so theorists, again, don't be picky, but I have to explain to the public. So, quantum mechanics, the essence of quantum mechanics is probability. Schrödinger's cat, or Schrödinger's poodle...

Aside: Dr. Gamble points to my nearby dog Gremmie so that we could ponder killing her with radioactive poison to simulate the superpositions of subatomic states of matter. We discussed this in Part 1 but with a hypothetical cat instead of my daughter.

Dr. Gamble: Which... pick your favorite. You are either alive or you're not, that was his thought experiment. You're either there or you're not. If you are there, then there's a probability that you're not quite there. Hmm. Now, if we are talking about, going back to events in spacetime now, an event could be there, or it could not be there. An event could be there and then another event could be there or it could not be there. Or another event could have been there, but it changed.

Aside: Okay. Don't be stoned right now because this is going to get weird.

Dr. Gamble: And now, instead of having one timeline of events, we have created a branch in a new timeline.

Alie: Aha!

Dr. Gamble: Ahhh. Now we call that causality. It's basically our theory version of cause and effect. If I have Event A that caused Event B, they're supposed to be after each other and they're supposed to be on the same timeline. If B changes timelines, I have created a new universe.

Alie: And that's multiverses.

Dr. Gamble: And it's kind of multiversal. Yeah. But if B is the cause of something else and it branches again, I now have what looks kind of like a tree graph.

Alie: Yeah. Fractals, almost?

Dr. Gamble: Fractals almost and now you can have an infinite number of universes according to quantum mechanics because you have an infinite number of possibilities of how that event transpired.

Alie: Because events are part of spacetime.

Dr. Gamble: Because events are part of spacetime. [*laughs*]

Alie: Oh fuck!

Dr. Gamble: Fucking fuck.

Alie: [*voice quivers*] Oh no-o-o!

Dr. Gamble: So, now it's like, am I actually here, or am I in Cleveland right now or something?

Alie: Does that ever make you think about different yous? What if you didn't go to that diner with a placemat? What if you didn't meet this person?

Dr. Gamble: This is the anxiety that we have. It's even worse because we know the math, or we're supposed to know the math, ha-ha! But we know the math and we know the physics and we think we know all the physics but then we say, "Um, well, I could have multiple versions of myself according to quantum mechanics and I could be inside of a box somewhere in Italy having scones or a croissant."

Alie: What do they have in Italy? Biscotti? I don't even know. I've never been to Italy either. [*laughs*]

Dr. Gamble: I've never been to Italy either so I'm sorry if I'm offending anybody. I assume they have croissants in Italy.

Alie: I'm sure they do.

Aside: Okay, just a side note, I investigated this for us, and the most popular Italian pastry is a horn-shaped thing of, just, flaky *bellissimo* and it's called a *sfogliatella,* I'd never heard of it before but I looked at a lot of pictures. I want the tourism board of Italy, if you are listening, please extend an invitation to your country so that I can record some Field Trip episodes and maybe move to the homeland of my people. *Grazie*. But yes, at this moment, I'm at my studio with Dr. Gamble, my very much alive poodle, thank you, and there are no Italian pastries.

Dr. Gamble: Or I could just be here on *Ologies*, having fun, drinking my Earl Grey tea, which is actually pretty good, [*Alie giggles*] or I could just not exist at all, or I could be green or I could be blue or I could have three arms or I could have three legs or I could have two brains. [*"I could be hurtful, I could be purple, I could be anything you like."*] Or I could fly, or we could actually meet aliens, or we could be the aliens in another universe.

Aside: For more on those topics, please see our Astrobiology episode with Dr. Kevin Hand, an actual NASA scientist looking for actual life on real, not-ours planets. We also have an episode on UFOs.

Dr. Gamble: There are too many possibilities and all it takes is one small, tiny change. If there's a universe that exists where we're wearing white shirts instead of black shirts, there's a universe that exists where we're sitting on the ceiling instead of the floor, this is quantum mechanics. This is Quantum Mechanics 101.

Alie: Do you take bigger risks in life because you're like, "Well, all I got is this timeline," and you know...

Dr. Gamble: I take so many more risks in life. [*laughs*]

Alie: Do you really?

Dr. Gamble: Because I'm like, okay well... I say... Okay, I only have this universe that I'm in. I know there are probably others that exist that are like me, but I've not met them yet, so I only have this universe to actually maximize in so I'm going to do the best. I'm going to maximize my time here. Yeah.

Aside: And then listen next to the Quantum Ontology episode to become more convinced that you should do a daring haircut while you're alive because what's real? We're all going to die. Text your crush. More on that later.

Dr. Gamble: Text your crush. Yes. Please. DM them.

Alie: Works out sometimes... [*laughs*]

Dr. Gamble: Heyyy!

Aside: And yeah, I do promise more on that in a bit but first, let's take a break to donate to a charity of Dr. Gamble's choosing and for this episode and for Part 1, we'll be sending a donation for each of those to TheScienceHaven.org which is dedicated to democratizing science, fostering curiosity, bridging the gap between complex scientific concepts and the public, and making science accessible, engaging, and meaningful for all. They have telescope programs called Stellar Dreams, they have a public lecture series, a sci-comm fellowship, and also Dr. Raven Baxter's YouTube series called *Nerdy Jobs*. So, head to TheScienceHaven.org for more and they are linked in our show notes. That donation was made possible by sponsors of the show.

[Ad Break]

Okay, let's get back to your questions from patrons such as Aoife Holmes, June Eskridge, Brittney Corrigan, and our somewhat space-anxious friends, Kimberly Talbert, and Storm.

Alie: A lot of people, Alan Gross, Caro Young, Christine Pikstein want to know the closest known black hole. Is it the one in the center of our universe?

Dr. Gamble: No.

Aside: Okay, so fret not. Dr. Gamble mentioned that the closest one is called Gaia BH1 and it's about 1,500 lightyears away and M87, the one that was imaged a few years back that we talked about in Part 1 is 55 million lightyears away! So, by comparison, 1,500 light years away might as well be lounging on your back deck cracking a beer.

Dr. Gamble: But all right, it's not that close. [*Alie laughs*] It's not that close. We still can't travel to one. We're talking... One light year we're talking millions of miles away. We're talking millions of miles, millions of kilometers away. So, we're talking about 3.7 million, millions of miles away. We can't get there. Again, we can observe the matter around a black hole, right? And all the funky stuff that it does, probably having a part around a black hole. "This is the end of the world." No. [*Alie laughs*] We can see the effects that a black hole would have on other things, and we call that gravitational lensing.

Alie: Oh right. Okay. So, you're seeing light getting bent a bit.

Dr. Gamble: Yeah.

Alie: Okay.

Dr. Gamble: But that's it. And we can see mergers happen, right? But that's it. We can only see what the black hole does to other things but not directly the black hole itself. It's black for a reason. It probably doesn't want to be seen.

Alie: It doesn't blot out things behind it?

Dr. Gamble: It does, and that's one property of gravitational lensing and they're called Einstein Crosses. You can have a black hole in front of you, and you can have a star behind the black hole, but you won't see the black hole, but you'll see four points in the sky that look exactly the same, that's an Einstein Cross. That is the light from the star behind the black hole being lensed around the black hole like a prism in a funhouse, you're seeing multiple copies of the same thing but there's only one thing that exists. So, you're just seeing mirrored copies of the same thing. But if I were to actually travel to the black hole and go beyond it, there's only one star there.

Alie: Yeah, yeah.

Dr. Gamble: But there's this funhouse effect called lensing that does a whole bunch of weird things and of course, this is light so we can detect it. We see four stars there, but the four stars aren't actually there.

Alie: Yeah. So, that's evidence?

Dr. Gamble: That's evidence that some gravitational body is there, more than likely, we can't see it, it's a black hole. Sometimes dark matter does that and that's how we know dark matter is there.

Alie: Ooo-oo-oo.

Dr. Gamble: Yeah. [*laughs*]

Alie: You mentioned Einstein's Cross. What about Hawking radiation?

Aside: A surprising number of you asked this including Jason Holdren, Jason Rogers, Ryan Marlow, Leanna Shuster, Jessica Rudd, C dB, and first-time question-askers Valary Joly, Austin Thompson and...

Alie: Kate Noonan, first-time question-asker: Can Hawking radiation be used to measure the size of a black hole?... What is it?

Dr. Gamble: Yes, we can.

Alie: What is Hawking radiation?

Dr. Gamble: Hawking radiation is what we call quantum thermal fluctuations.

Alie: Okay. Quantum...

Dr. Gamble: Those are very big words, I know. So, what we mean by that is we are quite talking about heat coming off of a black hole on a quantum particle scale.

Aside: So, heat leaving a black hole by really, really very small, subatomic amounts, the smallest confetti you can imagine, just fluttering away from the dense piñata of a black hole. Smaller than atoms!

Dr. Gamble: So now, again, we're talking about quantum particles so we're talking about individual electrons, things like that. But again, if we scale it up to trillions and trillions, we can get radiation. Have we observed Hawking radiation yet? No. Have we tried? Yes. Do we have the right technology yet? No. [*laughs*]

Alie: What kind of technology do you need?

Dr. Gamble: You would need something that would...

Alie: You need 6G.

Dr. Gamble: We need 6G phones for it, yeah. [*laughs*] We don't know yet, actually. I'm trying to wrap my brain around what the actual spectra would look like, and we still don't know yet. We haven't worked that math out entirely yet to present an observable, something that we can actually measure, we don't have that yet. So, Hawking radiation, if you go read his papers, it is absolutely phenomenal. It's a *beautiful* theory. [*laughs*] We like to call it elegant. We actually say elegant theory. If you've seen *Theory of Everything*, his movie, we do actually say, "This is an elegant theory," because it's quite amazing.

Alie: Mm-hm. I love these terms. So many great terms. Stupendous, elegant, elsewhere. Just ridiculous. I love this. But we don't know yet.

Dr. Gamble: We don't know yet. [*Alie groans*] I know, a lot of unknowns.

Alie: I know. Well, speaking of unknowns, a lot of folks wanted to know if you can explain the information paradox. What is the information paradox?

Aside: Patrons Esohn, Tim McCollow, Vedant Patel, Guido Ferri, and Jani Rounds also needed information on the paradox of information and this elicited a string of good-natured swearing from the Doc.

Dr. Gamble: Sorry. Yeah, so the information paradox quite literally is... [*deep breath*] If I take something like a... Oh gosh. If I take a Rubik's cube, we know what that is, take a Rubik's cube, you've solved it obviously, because we're all geniuses, [*"Not me."*] and you toss it into a black hole, the collection of information that was compiled to comprise of that Rubik's cube, we're talking now a property of matter called entropy. Entropy is just a configuration of information. The more energy something has, the more entropy it's supposed to have. Naturally, we see that analogy.

Aside: But entropy can also mean the degradation of the matter and energy in the universe to this ultimate state of inert uniformity. And Merriam-Webster added, "Entropy is the general trend of the universe toward death and disorder," which is true. But like, Merriam, are you okay?

Dr. Gamble: Now, back to our Rubik's cube, if I toss that into the black hole and it did not come out, that means our universe lost information because I can't get the Rubik's cube back. But if I toss a star, a planet, a rock... the paper I'm supposed to be writing tonight, [*chuckles, Alie starts laughing*] your rejected publication, your homework, student loans, taxes, you'd throw that all into the black hole. [*Alie still laughing*] You're not getting those back. So, that's information from our universe that's lost. So, this is now what we call an irreversible process.

Some irreversible processes exist in nature that you probably didn't even think about. Fusion in the Sun is irreversible because it cascades, we can't stop it. There are other things you've seen in nature that are quite irreversible. Matter breaking apart, some of it is irreversible, you can't put it back together. But in terms of the fundamental physics, you toss something into a black hole, beyond the event horizon, we're not getting that back. There is a theory out there – it's pretty far out there – that says, what if my entire universe, there only existed one black hole and the rest of matter, if I were to somehow toss everything into the black hole, would I still have a universe left?

Alie: I was wondering the same thing.

Dr. Gamble: Question is... I don't know.

Alie: And then, if you don't have a universe then is it just all darkness or would we get spit out the other end from a white hole and then we'd just mishmash again?

Dr. Gamble: Does a universe with a white hole have maximal entropy? Because it's just spewing everything out.

Alie: Could that have been the Big Bang?

Dr. Gamble: Could have been.

Alie: I fixed it. I solved it.

Dr. Gamble: We need more people doing the math.

Alie: People get this math!

Dr. Gamble: People, calculus, please. For the love of god, don't skip out on calculus.

Alie: Arlo Kay wants to know: Is "Black Hole Sun" by Soundgarden a good song?

Dr. Gamble: Yes.

Alie: Okay.

Aside: So, the chorus to this 1994 hit goes, "Black hole sun, won't you come and wash away the rain?" And patron Linea Brink Andersen wanted to know: What is a black hole sun and WHY won't it come? So, I looked into this for us, and I found out that the late singer and lyricist, one Chris Cornell, had once explained that he wrote the song quickly, and that, "Lyrically, it's probably the closest to me just playing with words for words' sake." He added that "It worked for a lot of people who heard it, but I have no idea how you'd begin to take that literally." Patron Arlo Kay wrote in: Not really a question but "Black Hole Sun" by Soundgarden is a good song. Dave Brewer wanted Dr. Gamble to sing the song, but Erica Smith asked if Dr. Gamble had any other favorite black hole tunes? Are there any?

Alie: How about the album, Supermassive Black Hole by a band I can't remember. But it came out in the 2010s [*"Supermassive Black Hole," starts playing in the background*] and I reviewed it for the *LA Times* and now I can't remember who sings it. [*laughs*]

Dr. Gamble: Oh my god! No. That is um um um um um um... Oh my god. No, no, no. [*Alie laughs*] They are.... [*song continues to play*] "Supermassive Black Hole." Was that Pearl Jam?

Alie: No!

Dr. Gamble: Sorry.

Alie: I can't remember it either. You remember that one? I literally reviewed this for the *LA Times*.

Dr. Gamble: Um um uhhh! God!

Alie: It went into an information paradox. [*song continues to play*]

Dr. Gamble: It... quite, yeah.

Alie: I never look things up in between but I...

Dr. Gamble: I'm sorry, we're cheating.

Alie: We're cheating. You know what they did, they went into a wormhole. Muse. It was Muse! [*record scratch*]

Dr. Gamble: Dammit.

Alie: [*laughs*] It was Muse!

Dr. Gamble: That's what it was. That's what it was, Muse! That was my third guess.

Alie: it was my second and a half.

Dr. Gamble: Yes! Oh my god.

Aside: This 2006 hit bears the lyrics, "You set my soul alight, glaciers melting in the dead of night, and the superstar's sucked into the supermassive." I had to go back to my archives, 18 years, to find a piece that I wrote for the *LA Times* as a young journalist, and I had written: "The first single, Supermassive Black Hole," is a jaw-dropping departure for the band, boasting a baffling, Justin Timberlake-like falsetto, a bizarrely danceable beat, and infectious riffs." I actually still stand behind that. I was prepared to be very embarrassed, but I think that still holds true.

But according to interviews with Muse vocalist, Matthew Bellamy, the song is about how women are at the center of his galaxy and he's a bright giant star that gets sucked into their dark, powerful nothingness. Apparently, women are his muse... and *he* is Muse, so women are his him. Also, I didn't realize that this song was featured in the feature film, *Twilight*. And yeah, we have a Vampirology episode, and we discuss that film at length. But yes, it was Muse.

Dr. Gamble: I, yes. Yeah. I'm a Muse fan.

Alie: Okay! I mean, who else has an album about supermassive black holes?

Dr. Gamble: It would be Muse.

Alie: It would be Muse. You've got to meet them one day. You're like, "Let me Kip Thorne your next album."

Dr. Gamble: Can I Kip Thorne my way into your album? [*laughs*]

Alie: [*laughs*] I know someone in here and I don't know who asked about LIGO.

Aside: Adam Foote, first-time question-asker, Kate Noonan, and Grant Mildwaters. Grant asked: When we detected the gravitational waves from the black hole merger (GW190521), 9 suns worth of mass-energy was converted into the waves. How does mass 'dissolve' into warping of spacetime? Grant, this is not a not-smart question but let's try to wrangle the basics here.

Alie: Gravitational waves... Being able to like, measure, or detect two black holes colliding... Tell me about it. What happens?

Dr. Gamble: So, you take one black hole, let's just say it's mass 5. You take another black hole and let's say it's mass 3.

Alie: Okay.

Dr. Gamble: They will smash together, first they will rotate around each other, the event horizons of the two black holes will begin to smear. That is a very violent process.

Alie: I bet.

Dr. Gamble: Yeah, and you're probably too... Why are you so excited?

Alie: No, [*speaks quickly and gruffly*] because I'm thinking excited about it like, oh my god... Would it sound like anything, or no?

Dr. Gamble: Actually, they do.

Alie: Would it sound like... [*makes choppy grumbly noises*]

Dr. Gamble: No, it doesn't sound like that.

Alie: I picture like, you know when in a car in the junkyard, they put it through the thresher?

Dr. Gamble: LIGO actually, they sonified the data.

Alie: Magic.

Dr. Gamble: Let me see... Oh, I found it. All right, so this is the sound of two black holes colliding together and I think my phone might work. [*deep rumble followed by more static rumble with little blips*]

Aside: So, LIGO, the Laser Interferometer Gravitational-Wave Observatory is part of a collaboration between CalTech and MIT and each of the two sites involves this 10-foot wide, 12-foot-tall concrete tube. It's 2.5 miles long on each arm and it houses a laser that in the presence of a spacetime blip, will move the laser one one-thousandth of the diameter of a nucleus of an atom. According to LIGO, this first-ever detection "confirms a key prediction of Einstein's theory of general relativity and provides the first direct evidence that black holes merge."

Our Cosmology guest Dr. Katie Mack described the sound detected as "a rapid increase in the frequency and the amplitude of the gravitational radiation," which, when presented as a sound wave, sounds like a chirp or a little tiny, "Whoop." [*little blips, like a small bubble bursting*]

Alie: Why is it alternating like that?

Dr. Gamble: Because we are quite literally, they are measuring ripples in spacetime. So, that's what gravitational waves are. So, you can imagine if you tossed a rock into a pond and you see it ripple like that, that's like a gravitational wave. But again remember, spacetime isn't actually a physical thing that we can touch and feel but we measure the displacement or the deformation of things as the gravitational wave went by. LIGO is an interferometer.

Aside: It involves powerful lasers, which is cool.

Dr. Gamble: One arm is perpendicular to the other arm, you have two lasers, you can probably make one at home, I've made one before. [*Alie giggles*] Don't point it at your parents.

Alie: Have good insurance if you do.

Dr. Gamble: Get your insurance, please. [*laughs*] But one arm would shrink while the other arm would stretch and that's how we know a gravitational wave went by and we could measure the amplitude of that gravitational wave. So, that displacement, it's on the scale of like, 10^{-20} meters, it is *tiiiiiiny*. Tiny, tiny, tiny. But LIGO and advances LIGO, they've done such an incredible job calibrating this instrument, they could detect traffic miles away underground at LIGO.

Alie: Wow.

Dr. Gamble: There's one in Louisiana and there's another one in Washington, Hanford and Livingston. They could detect very, very sensitive things. This was back in 2015. The 2015 detection, I was in grad school at the time.

Alie: I was just going to ask where you were because I watched the livestream from a...

Dr. Gamble: I watched the livestream, we were watching it in my department, I think there were maybe three of us excited about it. I was the only one studying gravitational waves along with my advisor and we were like "Okay, well we're going to nerd out while the rest of you are weird. You should be screaming like at a concert or something."

Aside: Again, a triumph for the space detectives working on the mystery of the universe. And a huge day for nerds.

Dr. Gamble: And we were like, "Oh, they did it." And we're like, "Okay, well what does this mean?" And now we're having anxiety attacks, we actually measured one. Okay, let's look at the data. I'm like, "Great, I will drink to this because now I can do the rest of my dissertation." [*laughs*]

Alie: So that helped you move on.

Dr. Gamble: It quite literally helped me prove one of the solutions in my dissertation.

Alie: No.

Dr. Gamble: One of the wave equations in my solutions, I based it off of that 2015 LIGO data set and recreated and got the partial waveform back again which told me that my theory actually worked. So, there are some kinks in there, of course, but getting known data back again... Yes! That is...

Alie: That's huge.

Dr. Gamble: That is truly huge.

Alie: I mean, the thing is when it's all theoretical and then when something experimental can prove your theory, that's...

Dr. Gamble: It is quite awesome, yeah.

Alie: That's everything coming together. I mean, augh! [*"We have detected gravitational waves. We did it." applause*]

Okay, last listener questions, Lee Wang, first-time question-asker: Would getting spaghettified hurt?

Dr. Gamble: Short answer is no because you wouldn't feel it.

Alie: You wouldn't feel it. Oh. Average_Pi wants to know: Will I turn into noodles or more like pancakes?

Dr. Gamble: Oooh... Huh! I've never had that question before. It's very interesting.

Alie: I mean, it's called spaghettification because what, you just stretch out?

Dr. Gamble: You're stretching. But... Huh! I guess you would flatten if you were rotating.

Alie: Like... [*makes spinning sound*]

Dr. Gamble: If you were spinning around and stretching toward the center, you would flatten out. [*Alie gasps*] That's interesting.

Alie: So, Average_Pi maybe just opened up a whole can of spaghetti.

Dr. Gamble: Okay, if I write this up in a paper, I'll cite you.

Alie: [*laughs*] Average_Pi. Oh my god, okay. I think we covered a lot. We can't cover everything. We can't cover everything. But okay...

Aside: Patrons Skella Borealis, Daniel White, and so many others I'm just going to list the first-time question-askers, E, Iso Partee, and Bender had questions relating to scale.

Alie: If you could measure a black hole, the average-sized black hole, how many millions of miles?

Dr. Gamble: It depends on what you're measuring. Are you talking about the accretion disc around a black hole or the actual size of the event horizon of a black hole?

Alie: Okay.

Dr. Gamble: If you're measuring the size of the event horizon of a black hole which we kind of dictate that's the actual size of a black hole, then those are actually... they're not as big as you think. So, say the size of our Sun, the event horizon would actually be quite small. We're not talking about the size of my cup small, but we're talking about possibly the radius of the Earth, small.

Alie: Really?

Dr. Gamble: Yeah. So, the distance between the event horizon and there are other surfaces in between the ergosphere, the very edge, where you would begin to feel the effects of gravity, and the event horizon, where you can't fall beyond or get out of. So now, if we're talking supermassive black hole, the event horizon is larger than our Solar System.

Alie: Oh my god.

Dr. Gamble: It would be huge.

Alie: There is a black hole, I kid you not, there is a black hole called TON 618. TON 618 is so huge, I think it's about a hundred times larger than Sag A* in our galaxy.

Aside: Patrons Michael Munene, Dave Langlinais, Dtl1of1, and Valerie Bertha wanted to hear more about this "radio-loud quasar and Lyman-alpha blob," which is a big boy, TON618.

Dr. Gamble: So, you can think of a black hole, here comes the stupendously large again. [*Alie laughs*] We love names. That's a hundred times the mass of the center of our galaxy. That event horizon is measured in light years.

Alie: It's that big.

Dr. Gamble: It is *huge*. It is huge. If you google "TON618, event horizon size," there are plenty of animations out there, those zoom-out animations, it will show you the scale that this black hole is, and it makes our Solar System look like a speck inside the event horizon.

Aside: Okay, I checked out the visuals on this meaty, meaty thing, TON 618. If TON 618 is a 150-pound capybara, our entire Milky Way is like a small bird on its head. It's huge!

Alie: [*softly*] Wow.

Dr. Gamble: That is what gives us anxiety. [*laughs*]

Alie: I bet... Unfathomable.

Dr. Gamble: It's unfathomably large and it's incredible that these things exist. It's even more incredible that there's so much space in the universe for these things to exist. We don't even know how big the universe is!

Alie: And the universe is expanding.

Dr. Gamble: It's accelerating.

Alie: Accelerating.

Dr. Gamble: The expansion is accelerating, yeah. So, it's like all gas, no brakes, just zooming off into nothingness.

Alie: What... I mean, okay. These are questions that we may never answer in our lifetime, or you may answer in five years.

Dr. Gamble: Yeah.

Alie: I mean... Does that ever keep you working too many hours?

Dr. Gamble: It keeps me quite literally up at night and I have a wall of chalkboards in my apartment [*Alie laughs*] with all these equations on there. In grad school I dreamed of equations, that's how deep I was in it. [*laughs*]

Alie: I love it.

Dr. Gamble: And that's how I wrote my dissertation and did my work. I'm like, "Okay, well I had a dream, and I moved this minus sign over to the outside and I factored this term and I integrated this. Okay, well, what would happen if I actually do that?" And so, I would write it on the chalkboard. I was like, [*mutters*] "Okay, well that doesn't look right. Well, let me change this term. I move that over there. Let me not integrate it. See what happens... Oh, okay. Well, I get a new equation that I've never seen before. Now I actually have to solve this thing and see if it works. "And that's how discoveries are made. That's quite literally how Einstein did some of his work. He just sat, he sat on the train, he rode his bike, he imagined, "What would I look like if I saw myself riding a train going by accelerating? What would I look like if I was standing still and doing that? What would I look like if I was on the train watching myself go by?"

Alie: So, a lot of it is imagination as well.

Dr. Gamble: These are what we call thought experiments in physics. Yes, it's imagination, but we call them thought experiments because we're trying to experiment the logic of the physics that we're actually trying to solve. So, we're talking philosophically, can this even, can I even imagine it? If I can imagine it correctly, then that means I can write an equation down for it.

Alie: Ha-ha!

Dr. Gamble: Ha! Cheat codes. So yeah, I do stay up at night and I have to force myself sometimes to go to sleep. I'm like, "Brain, turn off. Stop working."

Alie: You're like, "Put a pin in it, I'll get to you tomorrow!" What's the hardest thing about your job?

Dr. Gamble: Oh my gosh.

Alie: It can be anything.

Dr. Gamble: Gosh, I would say the hardest thing about my job is explaining new theories to old theorists.

Alie: Okay. [*laughs*]

Dr. Gamble: Another tie would be just explaining my science to the public. [*laughs*]

Alie: Well, soooorry!

Dr. Gamble: And telling them, "We don't know yet."

Alie: That's exciting though!

Dr. Gamble: It's actually pretty exciting.

Alie: It's so exciting because we didn't even know what germs were until recently.

Dr. Gamble: We don't. And I gave a talk last year, this is probably one of the only schools I would probably shout out, other than my alma mater, North Carolina A&T State University. Shout out to them. "Go Aggies!" Sorry, have to do that. But I gave a talk at a high school last year, this time last year, I was at a high school, St. Andrew's, Episcopal High School in, I think it was Middleton, Delaware. They know who they are. They're listening to this. They will probably find this episode. [*Alie laughs*] Those students were phenomenal, and they asked some of the best questions I ever got but they did not quite accept an, "I don't know."

Alie: Ahh!

Dr. Gamble: Yeah. I was like, okay guys, we have to at some point end this. But they asked, "Okay, well if you don't know, then why don't you don't know?" And I'm like, "Uhhh, that's a very good question. Why don't I, don't know. How come... Hmm." So, and I'm up on a stage and I'm giving a talk and they're, you know, their auditorium. I'm like, "That's a very great question. I will try to figure that out." And

so that is, that's probably the hardest part, explaining to someone why you don't know something that they think you should know.

Alie: I have no expectations of people knowing that yet. I'm like, we are barely... [*Dr. Gamble laughs*] We've only had the internet for like 20 years or something. Fax machines came out in the '80s!

Dr. Gamble: Yeah, I remember dial-up.

Alie: The fact that we know any of this is *amazing*.

Dr. Gamble: It's truly amazing.

Alie: That there are brains like yours working on this, that understand this is *so* incomprehensible to me. So, the idea that we know anything and even know what to look for is absolutely bonkers to me.

Dr. Gamble: Yeah, and we write code trying to solve this too.

Alie: Yeah. I mean, just think that scientists used to have to send letters back and forth. [*laughs*] They're like, "What do you think of this?" Delivered by pony, you know.

Dr. Gamble: I'm glad we don't deliver by pony anymore but if you go and look up some of these letters, you will see scientists trashing each other and they will send a letter, they used to send letters, "Hey, I read your paper. I don't agree with your terms here and I think you're wrong, but you could do better. But add me on the next paper if you want it published. And it'll be better." Send. And they'll get it like a week or two later, they'll read it. "No! Hawking or Planck, what are you talking about? No. Why are you rude?" They send another letter back. And this is how they published rebuttals.

Aside: Oh, I love petty bullshit when it doesn't involve me or this century, and apparently, the American physicist and X-ray researcher, Dayton Miller, wrote a letter to friend and fellow physicist, who was a photon scattering researcher, Robert Shankland. The year? 1935. And Miller had just attended a talk at Carnegie Tech by some visiting physicist and he thought it sucked and he wrote to his friend, "The lecture was unimpressive, and Professor Birkhoff told me that he thought the theory is on its way out and in a few years will have been forgotten."

The talk was titled "An Elementary Proof of the Theorem Concerning the Equivalence of Mass and Energy," about the theory of relativity and the speaker was, um, Einstein... Ahh!... They were wrong. And the theory of relativity was not on its way out in a few years. What is the core lesson other than relativity? Sweat not your haters, keep moving.

Dr. Gamble: It was a war out there. [*laughs*] This is how they published rebuttals. What a time to be a scientist.

Alie: Yeah. I love the idea that Twitter is nothing compared to some of these scathing private longhand letters back and forth. [*laughs*]

Dr. Gamble: Oh my god, no! And some, they will get on review committees just so Einstein's paper doesn't get accepted because they didn't like it, or they didn't like the terms they used.

Alie: Pettiness.

Dr. Gamble: Super petty. [*laughs*]

Alie: Okay, the best thing. The best thing about black holes. What do you love the most about them?

Dr. Gamble: Okay so, I'm probably unique in stating that, and I might be contradicting myself, but the worst things, we've covered that, is what we don't know, but also one of the best things is what we don't know. That's one of the things that drew me to black holes, the mystery of black holes. We know enough to put a couple cute equations together, we can calculate some things and get it wrong and

then we can assume that we know some things. And then arrogance plays in like, "Yeah, I won a Nobel Prize." Okay, but we still don't know. Do more. [*laughs*] Win two Nobel Prizes. [*Alie laughs*]

Why does something in our universe exist to the point where you can put something inside of it and never get it back again? That simple question blows my mind. Something like that actually exists. We have the Sun, we have Earth. Yeah, we have tangible things, yeah. But a black hole? Dark matter? Why did... God you bein' funny right now. [*Alie laughs*] What's going on here? You just playing games, or do you actually want us to figure this out? Because if you do we need... We need some cheat codes, some lifelines.

Alie: [*laughs*] I mean just memorizing functions and math and just... I mean, you must be amazing at Sudoku.

Dr. Gamble: I crush Sudoku.

Alie: I bet you do, I bet you do. What's the one that my husband plays it... It's on his iPad, it's like...

Dr. Gamble: 2048?

Alie: Yes!

Dr. Gamble: Oh my god. [*deep groan*] Yes!

Alie: So, advice to people who want to try to crack the code of black holes. Any advice that you wish you knew coming up?

Dr. Gamble: Oh man. I would say, one, if you think you know all the math, learn some more. I'm still learning new math and I've been doing this for a lot of years. The other thing is, you have to stay creative. So, one thing about studying black holes, especially if you want to go into theory, field theory theory but mathematical theory, you have to be creative. You have to continuously think, not outside the box but smear the edges of the box and make a circle and do it again, make a triangle, make a hexagon, a decagon, an octagon, whatever-gon, and keep doing that and see what works. And then remember everything that you did because there are some pieces that didn't work then that might work with a new theory.

Alie: Oh!

Dr. Gamble: That you tossed out before, yeah. So, that is what I'm currently going through in my work. I'm going back to old notes that I had in grad school, which was like 10 years ago and I'm like, why did I write this down? That was a weird idea but now it's like, I was onto something back then! Okay, yeah, keep doing it, keep at it.

Alie: And keep your notes.

Dr. Gamble: Oh my god, for the love of god, please keep all your notes.

Aside: Oh, do you remember I had some simmering romantic news? Turns out that Dr. Gamble taking more chances in life led to a text to a crush, led to a now Instagram-official relationship with Dr. Raven the Science Maven Baxter. Two supermassive science stars, emitting space lasers of brilliance.

Dr. Gamble: I coined us the Jay-Z and Beyonce of science.

Alie: [*laughs*] Yes. That's accurate. [*Dr. Gamble laughs*] That's correct. Very much.

So, ask the brilliant people the dimmest questions because that's the only way to shed light on black holes folks. You can find Dr. Ron Gamble on social media and say hi; his handles are linked in the

show notes. As well as a link to The Science Haven and other episodes of ours you might like, including Dr. Raven Baxter's, and others on Cosmology, and aliens, and everything else.

We also have shorter episodes that are classroom friendly, those are called *Smologies,* and they are linked in the show notes as well as our social media. We're @Ologies on Instagram and Twitter, I'm @AlieWard all over the place. To become a patron and submit your questions and maybe hear your name, including audio questions we may play on the show, sign up at Patreon.com/Ologies. *Ologies* merch, you can wear us on your body, that's available at *Ologies* Merch is available at OlogiesMerch.com.

Thank you, Erin Talbert, for adminning the *Ologies* Podcast Facebook group. Aveline Malek makes our professional transcripts. The wonderful Noel Dilworth is our scheduling producer. Susan Hale is our managing director and also does fact-checking, a little extra research. Kelly R Dwyer does the website, Nick Thorburn wrote the theme music. And our TON 618 of editing and producing is Mercedes Maitland of Maitland Audio.

And if you stick around until the end of the episode, I tell you a secret and right now it's that I can hear my alarm clock going off in the other room but it's a gentle, lovely alarm clock and so I don't think it's picking up on the microphone, but I keep hearing it and I'm like, "I know, I'm awake! I'm awake!" So, if you hear dreamy spa music way in the background, that's what that is. I think you can't hear it. Anyway, berbye.

Transcribed by Aveline Malek at TheWordary.com

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"Grace Kelly" (I could be brown, I could be blue) cover by Sarah Cothran

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