Black Hole Theory Cosmology (Part 1) with Dr. Ronald Gamble, Jr.
Ologies Podcast
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Oh hey, it's your friend's dog with the snaggletooth, Alie Ward. We're going to take a deep breath, all right? ... We got this. We got it. Let's get illuminated on the topic of black holes, shall we?

So, this ologist is a Theoretical Astrophysicist and a Cosmic Origins Scientist in the Astrophysics Science Division at NASA's Goddard Space Flight Center in Maryland. He got his bachelor's in physics, a master's in Condensed Matter Physics, and that deals with how matter arises, and then he just topped off those degrees with a casual PhD in Theoretical Astrophysics at North Carolina Agricultural and Technical State University.

So, we were introduced by *Ologies* fan-favorite guest, you love her, Dr. Raven the Science Maven Baxter, and I trust her taste in everything. So, I asked this NASA scientist to please meet me the next time he was in LA and to be prepared and steel himself for questions that a 6-year-old might ask about what is a black hole. He obliged and explained things so well, we're all going to learn enough to impress at least an 8-year-old, but also people who work in our office who are going to think that we're geniuses. So, he showed up, he was wearing the coolest boots I have ever seen – they were dressy, above the ankle with, like, embroidered gold floral motifs – and we headed to my home studio with two cups of tea and a small goblin named my dog.

But before we get into it, thank you so much to everyone at Patreon.com/Ologies who submitted questions about wormholes and dimensions and the singularity and so many terms we're going to talk about. You too can be a patron and submit questions for me to read, alongside your name. Thank you to everyone wearing our art on your bodies at OlogiesMerch.com. And of course, you can support the show and get it in more ears just by rating and leaving us a review. I read them every week, such as this hot one from Thvchhfdvbjfdvg, who, I think that was just fingers dancing on a keyboard, but they said:

> *Hit and run? More like hit and FUN! Yesterday, I was rear-ended while driving home from work and listening to Ologies. As I waited for 4 hours for an officer to make a police report on the side of a busy highway, Alie and her guests guided me through amazing topics and helped me calm down with fun and learning. I was even able to laugh during what was a stressful situation.*

Oh, Thvchhfdvbjfdvg, that sucks. That sucks so bad. Not for me though, because that was a nice review.

Okay. So, the ology for this one is Black Hole Theory Cosmology and it's a lot of words but it's heavy stuff, because a black hole, it's a spot in the universe where gravity and space and time go hog wild, things go bonkers, and it's so strong that nothing can wrestle out from it, not even light, or you. So, where are they? What are they? What's in the center of them? I don't know but this guest does and is going to fill us in.

So, get ready for a dazzling two-parter that starts with the 101 of black holes, absolute basics, busting of flim-flam, the major players in the history of the theories, what happens when they collide, how do we image them, what is the most giant, dense book you can buy about them, where do trad goths fit into this episode, does my dog exist, how many of me are there, the hows and how

manys of black holes, how astrophysics is like drawing, and the greatest gift he could give his mom with Theoretical Astrophysicist and Black Hole Theory Cosmologist, Dr. Ronald Gamble.

Dr. Gamble: Ron Gamble, he/him/his.

Alie: All right, let's get into it.

Dr. Gamble: My work is entirely focused on the theory of black holes. So, a lot of people work on just observing them and they're really looking at the matter around a black hole. I'm like, no. What is a black hole? How can we move or how can we get to one? Maybe. What's the theory around it? What's the math? Can I make new math to study a black hole? Do I need new math? Do I need to break my brain to study this?

Of course, you mentioned cosmology and that's a more, kind of, larger scale, like an esoteric almost, what's our place in the universe? Where did the universe come from? How many black holes are there? Was there a black hole at the beginning of the universe? Is there going to be a black hole at the end of the universe? Who knows? But nobody panic because that's a very long, long way away. [*laughs*]

Alie: [*laughs*] What about, is there one in... the middle of most solar systems? Let's pull back. Where exactly are we and what's in the center of the galaxy, our galaxy?

Dr. Gamble: So, if you look at the map of if you look at the map of a Milky Way, right – the Milky Way is a spiral galaxy – if you look at the arms of the spiral galaxy and you go kind of two-thirds, a little, maybe a third out, that's where we are. That's where the Solar System is. So, we're in, like, a very sweet spot in the galaxy. Earth is in a sweet spot in the Solar System. We are like, perfectly placed.

Aside: And just in case you're blanking, as far as we know, there's one universe. In that universe are up to 2 trillion galaxies and the Milky Way is just one of those 2 trillion. In the Milky Way, there are about 100 billion stars including our one little Sun, around which your planet revolves. So, we're up here, we're worried about things like nose hairs and how many likes our baby announcement got while living a very short life on a *tiny* speck, on a pinwheel arm, of a spiral galaxy, our ol' Milky Way.

Dr. Gamble: But at the center of the galaxy is a supermassive black hole. So, supermassive, meaning it's at least a billion times the mass of our Sun.

Alie: Oh my God.

Dr. Gamble: So, if you think a billion Suns, that is the mass of that black hole, and it's called Sagittarius A*, so now we named it, that's at the center of our galaxy. We've been studying it for a long, long time. Do we know any more than a few numbers? No. [*laughs*] We still need theory about it. But it's a very interesting object to think, you know, over a million billion years we're going to fall into a black hole.

Alie: Is it sucking things in as it goes? Is that why it's a spiral? Is it like a toilet going down?

Dr. Gamble: It depends on how the galaxy evolved. So, you have many different types of galaxies, and I don't want to go into the galaxy-ology here [*both laugh*] but you have spiral galaxies you have elliptical galaxies, you have globular galaxies that are kind of irregular and that is just how the stars, planets, rocks, dust accrued around the central object that's pulling them all in due to gravity. Could be a black hole, could be a larger or smaller galaxy at the center. Sometimes it is, most of the time it's a black hole because that's the only thing strong enough that can actually pull and hold a galaxy

together. And then, you have dark matter that's kind of squeezing everything in and holding a lot of things in place.

Aside: And for more on specifically dark matter, you can see our Scotohylology episode with Dr. Flip Tanedo to learn more about how it's everywhere, but we can't see it, we don't know what it does, maybe you're a ghost. We talk about that.

Dr. Gamble: So, do we know the connection between dark matter, dark energy, and black holes? Not yet. Come back and I'll tell you in 15 years... 20, 50 years. I don't know.

Aside: Just a quick question, what is gravity? Where is it coming from? [*"Good question."*]

Dr. Gamble: So, if I have flat spacetime, okay, we are talking about curvature now. So, now we're talking about spacetime curvature, that is the strength of gravity, right? So, gravity in and of itself, is the curvature of spacetime. It is a force, it's one of the four fundamental forces: electromagnetism, the strong and weak nuclear force, and then there's gravity. Gravity is always the one that eludes us because we still don't know how it behaves entirely. But we're going back to this flat sheet. If there's no gravity, spacetime is flat. As soon as I place anything with mass or energy, spacetime curves, and that creates gravity.

Aside: So, mass is mass, but gravity is spacetime bending to that mass. And we'll talk about spacetime in a bit but imagine a wire frame or a grid and it's stretching and warping around mass and energy.

Alie: Aha!

Dr. Gamble: Now, how can I curve spacetime? Do I just need a static object just sitting there? Yeah, it'll sit there, or it could spin.

Alie: What happens if it spins?

Dr. Gamble: Well, you're creating more gravity?

Alie: Why is the spinning creating more gravity?

Dr. Gamble: Because you're curving spacetime.

Alie: Oh! Because it's spinning so it's deforming spacetime a little bit more.

Dr. Gamble: Not only that, but if I spin faster, I'm getting more energy so I'm curving spacetime more, so I have more gravity. Again, how else can you curve something? Are donuts curved? Yeah, but they have a hole in the center. So, if I have something that's at the very center and it's like a ball, a black hole, and it's curving spacetime, we have gravity. But what if I also have something that's on the edge but it's more shaped like a donut or a disc with a hole in the center? We call that an annulus, but okay... [*"Donuts anyone?"*]

Aside: Just a side note, when you see an eclipse and there's a glowing ring, like a halo, from the Sun around the silhouette of the Moon, that's also called an annulus. And annulus comes from the root word for ring. And um, yeah... an annulus is related to the other hole that sounds like it that you're thinking about.

Dr. Gamble: Disc hole, [*laughs*] for now, and that has mass energy and it's rotating. Does that create gravity? Yeah. Now, if I keep going further and further out, observations tell me that hey, there's this extra mass that's sitting on the edge of galaxies. What the hell is that? Dark matter. Is dark matter creating gravity? Yes.

Alie: A lot of it? Or a little of it? Or all of it?

Dr. Gamble: Enough to keep... It creates enough of an effect or enough force to keep the galaxy spinning faster than it should at the edge. Now, does dark matter have gravity? Yeah. It *only* interacts with gravity and nothing else, that's why we can't see it. Are dark matter and dark energy and black holes made of the same thing? I have no idea. [*Alie groans*] Cliffhanger.

Alie: Interesting. [*Dr. Gamble laughs*] Oh my gosh... Love a cliffhanger. Okay so, do you think black holes then... Is one of the theories that black holes predated galaxies because they just started sucking in matter and that's kind of what made the galaxy gather there? That's kind of what's going on?

Dr. Gamble: Yeah. So, the term there, and I'm going to try and keep it super basic, is accreting matter. So, we're talking about accreting matter. We're talking about the black hole pulling things in and at the same time, if you pull something in and you're self-gravitating, you have a likelihood to rotate. So, you're not only pulling things in but you're also rotating around. So, it kind of creates that spiral look, that spiral geometry. But if you do it over millions and billions of years, then you're going to get more matter, more stars, planets. There are smaller nebulae, there are smaller systems inside the discs of galaxies.

Aside: A nebula is this huge blob of dust and gasses and part of your body, and your brain might be made up from stars that were made in a nebula. And no, I can't really handle that. But yeah, a black hole accretes and draws in all kinds of things like planets, and stars, and nebulae, and your car keys, and my sandwich.

Dr. Gamble: So, you can imagine... Like stellar mass black holes, which are black holes the size of our Sun, in the disc around a supermassive black hole, and there could be a thousand of them there.

Alie: [*softly*] Really?

Dr. Gamble: Because they're the size of stars. How many stars are in the Milky Way? [*"Couple of hundred billion."*] So, you can imagine, well, there's probably some black holes there, falling into another black hole, falling into another black hole that's a much larger black hole.

Aside: So, a supermassive black hole at the center of our galaxy but then sprinkled in there, a bunch of Sun-sized black holes, just dark voids that light and matter can't get out of. And I had a difficult time processing this and I think I may have dissociated for a moment.

Dr. Gamble: So, now it's like... yeah, your face. Like what the hell? [*laughs*]

Alie: Yeah, whaaat? Can black holes be tiny and in our Solar System? Is there a possibility that there's little pinpoints of black holes here and there around us? Or are black holes only gigantic?

Dr. Gamble: Short answer, and I have to say this is... No. Long answer is yes.

Alie: Okay.

Dr. Gamble: But we call them primordial black holes. So, those are black holes that are not like your traditional black hole, like, traditional meaning the center of the galaxy, that's our run-of-the-mill black hole. These are more geared toward much longer timescales. We're talking about cosmology, we're talking about cosmological times, we're talking going back near the Big Bang, and what did those black holes look like? And those are on the scales, those are tiny black holes. So, we're talking probably on the masses of like... maybe atoms, molecules, maybe up to the size of a planet. We're talking about micro black holes.

The mass of a black hole does not matter, the physics of the black hole is the same. Whether you have a supermassive black hole or a micro, tiny, primordial black hole, the black hole physics are the same, as we found out. Theory says that and theory has been correct so far. There are some holes... [*Alie laughs*] I'm working on it, but it's been pretty good so far. Thus far, it's been pretty

good. [*"Prettyyyy, pretty good."*] There's not a black hole that could just randomly pop up, guys, don't worry. There's not going to be one in Manhattan, you're going to see it in a movie only in movies.

Alie: [*laughs*] You're like, [*dramatic voice*] "Dr. Gamble had a bad day," a black hole opens up in a subway, coming to a theater near you. [*Dr.* Gamble laughs]

Okay, so we're going to talk about the structure of them, but I want to ask you about you. How does one go from a normal person who doesn't know shit about this to someone who is a theoretical astrophysicist studying the nature of black holes? Yeah, how did it happen?

Dr. Gamble: So first, you have to be 4 years old with a Solar System placemat in front of you. Pluto was a planet in 1995. [*Alie laughs*] Fuck that. And then you ask your mom, "Does the Sun have fire?" And that's where my story begins. [*laughs*]

Alie: Really?!

Dr. Gamble: At 4 years old and she was like, "Oh crap. Okay. I need to put him in something." Because she has a degree in biology, she was like, "Okay, I don't do space." [*both laugh*] So, she did that. So, all along through childhood, through college, high school, whatever, I would just ask myself, "Well, what if? Gravity's weird, but what does gravity actually do? What do black holes do? What's inside of a black hole?" So, I googled, I looked up what are the unanswered questions in physics, what do we not know yet? Dark matter was, like, at the top of the list. Dark energy. There's another weird thing that I'm probably not going to mention because it's going to take us another hour, segue.

Alie: [*small, squeaky voice*] What is it? What is it?

Dr. Gamble: It's called dark flow but I'm not going to even...

Alie: Oh my god, I've never even heard of it.

Dr. Gamble: It's a bunch of weird stuff.

Aside: It's a controversial hypothesis apparently, so we're just going to set that aside. But if you happen to Wikipedia it, don't get distracted by this italicized warning on the top of the page that says, "Not to be confused with dark energy, dark fluid, dark matter, or dark wave." And I was like, "Hm?" And I clicked the dark wave link, and it takes you to a page about the 1990s goth scene, which then took me to an external website where I learned that I would be considered an "elder trad goth." So, where were we? We were spiraling.

Dr. Gamble: And then of course, some other things that pertain to black holes and the Big Bang and others. I'm like, okay. So, and I looked up, "Well, why haven't we figured this out?" Oh, well we don't know yet. "Why can't I do this?"

So, fast forward to college, undergrad, I'm asking my advisor, like, okay, I want to study black holes. He's like, "Um, we don't have anybody here that does that." I'm like, okay, "Well, how do I do this? Math." And I look up... I open [*chuckles*], what we call "The Gravity Bible," which is Misner, Thorne, and Wheeler, *Gravity*. [*"That's heavy, man."*] Thank you, MTW for all the headache you've given me. [*both laugh*]

Aside: So, *Gravitation*, it's a 1,280-page high-level textbook. And yes, it is a religious text to astrophysicists. It was initially published, first came out in 1973 and the reviews for it still swoon saying things like "a pedagogic masterpiece." If there were a Rotten Tomatoes for physics books, this would be Certified Fresh. It was co-written by Charles Misner, Kip Thorne, and John Wheeler and Kip was a co-winner of the Nobel Prize for Physics. This book covers such topics as the Theory of Relativity, flat and curved spacetime, and black holes, gravitational collapse, gravitational waves,

cosmology, and so much more; like an infomercial for a manual of the universe. It's got this stark black cover with a white diagram of an apple, some sans serif font, and kind of a rebellious sense of Nixon-era futurism. And honestly, I saw it and I was like, this would be the perfect graphic for a dark wave album.

So, if you are ever set up on a date, let's say, someone sets you up on a date with an astrophysicist, and should want to marry them on that first date, just ask if they still have their copy of *Gravitation* lying around.

Dr. Gamble: And I look, I'm like, "Oh shit, there's a lot of math here," that I didn't know at the time. [*Alie laughs*] I'm like, what does this mean? What the hell is a metric tensor and all this? I'm like, "Okay, let me flip," and I go through the glossary and am like, "That's a lot of terms." And at the time, I had not taken Calculus III yet. So, I'm like, let me go back to my actual homework that's due tomorrow, finish this, then go back on, like, weekends or my own time and start taking notes. I started just rewriting things I saw in textbooks. I didn't know what they said, I didn't know what they meant but I knew I had to practice memorizing some of this so that when I actually went back and I learned the math now, became an expert in the math I was like, "Okay, I've seen this before, I've seen it a while now."

Aside: So, without knowing the full context, yeah, Dr. Gamble got familiar with the shapes of the equations and the patterns so that later, the figures were familiar, and he could jump into the hows and the whys of that what.

Dr. Gamble: I can now really explode my brain, right, and be like, okay well, let me come back to my art background, I'm a painter also. [*Alie exclaims*] So, I double-majored in art and physics in undergrad.

Alie: I did not know that! [*gasps*]

Dr. Gamble: Yes. Superpowers.

Alie: Did you make a lot of space painting?

Dr. Gamble: Honestly, I didn't actually. [*laughs*]

Alie: You're like, "This is a different part of my life."

Dr. Gamble: I did a lot of seascapes because I like the beach. So, that was one of my favorite things, I did a lot of portraits. But, ha-ha, you heard it here first, I am going to be doing a cubism black hole series in 2024.

Alie: Are you really?

Dr. Gamble: Yeah, I'll show you.

Aside: So, we will link Dr. Gamble's social media in the show notes in case you'd like to own a painting by someone whose brain comprehends beautifully terrifying things in the universe.

Dr. Gamble: That's the story of how I kind of... You've got to get interested in it, but you have to be really intimate with the theory, with the actual philosophy of black holes. What does a black hole mean? That's what I asked. So, I was like, "Let me learn everything I can while college is cheap in undergrad. [*both laugh*] I can just take an extra class because I have a scholarship here and just learn and ask questions." That's what I really did, I asked a lot of questions both to my professors, to myself, and then others who actually studied black holes. And then I just went and did it, I found the textbooks. Some of the math, I knew I had to learn a lot of math. So, I started my graduate thesis, my dissertation, two years before I got into grad school.

Alie: Oh wow!

Dr. Gamble: So, it was the summer before my junior year in undergrad, that's when I first started learning the math that I knew I would need for my PhD. So, it was kind of like a foresight.

Alie: And what was your PhD? What was the dissertation name?

Dr. Gamble: Oh my god. [*laughs*] Okay, so here are the words that I can't really ignore. My dissertation was on a nonlinear gravitational wave theory for rotating black holes with a positive cosmological constant...

Alie: Okay.

Dr. Gamble: ... under a viscoelastic interpretation.

Alie: Okay.

Aside: Once again that was, "On Gravitational Radiation: Nonlinear Wave Theory in Viscoelastic Kerr-Lambda Spacetime." Yep.

Dr. Gamble: So, what that means is, I quite literally created [*chuckles*] an extension to Einstein's theory of relativity that now interpreted spacetime as some elastic property.

Alie: Viscoelastic.

Dr. Gamble: Viscoelastic. So, if you think of elastic putty, that's how I envisioned spacetime to act around a rotating black hole, radiating gravitational waves away. So, I'm thinking, "Okay, this is weird, yes. But I know the math to put this together." So, the math literally, I was working with Legos at that point in grad school.

Alie: Literal Legos? Actual Legos?

Dr. Gamble: Sometimes yes.

Aw: Okay, oh my god.

Dr. Gamble: Because Legos are cool, and I had them.

Alie: [*laughs*] Why not?

Dr. Gamble: If you're a grad student, play with Legos. [*laughs*] But the math was like Legos, like building blocks. I could put an integral or derivative together and put tensors together and reconstruct them, break them down, and make new ones. And I made some new math, it's like fake new math but it's an operation that didn't exist before and I needed it to do my work. So, I was like, again, why doesn't this exist? If it's not there, then create it. So again, I was trained as an artist, I put the paintbrush down and picked up a piece of chalk for math. It used the same parts of your brain, that's what I used the whole time, the creative aspect of your brain. That's how I did my work.

Alie: So, can you explain where Einstein's calculations don't really apply to some of what's out there? I understand that [*Dr. Gamble laughs*] dark matter might not totally fit in with the theory of relativity. There's something where it's like "Uh-uh, this doesn't work here." What's going on there?

Dr. Gamble: So, okay. So, no. Einstein's field equations, which is the principle equation for general relativity.

Aside: And remember, general relativity is all about how mass affects the four dimensions of time and space, but not for all stuff. Things get really weird when you get to particles smaller than atoms.

Dr. Gamble: It doesn't quite work for dark matter or dark energy, we have a best guess, of course, we have some modified gravity equations... I'm going to leave it there because that's a whole other topic.

[*chuckles*] But if you go beyond the event horizon of a black hole, so it's kind of the outer surface, that's the point of no return, right? If you go inside that, relativity fails. [*Alie gasps softly*] We don't know what's going on, so we're kind of taking the equations and we're kind of smearing them closer and closer slowly, but it's not as simple as A+B=C. It's A+(a little change in A)+A+(another little change in A)+A. We're trying to sneak up on C or something and not try to use B, right, the full-fledged equation; we can only do that but so much. And then they fail right at the singularity, we have no idea what's going on. We would need something called quantum gravity... [*sighs and laughs*]

Aside: So, gravity theories that work with those subatomic particles, but that's not really happening yet. It's a mystery.

Dr. Gamble: But we would need an interpretation of gravity on a quantum scale now, which as of right now, we don't have a... I would say a consensus for what that theory should look like. We have a whole bunch of competing theories. One of them is loop quantum gravity, we have a bunch of other... string theory is another one, but you need at least seven dimensions to do that.

Alie: [*hushed tone*] Oh my god.

Dr. Gamble: It's madness, I know. But you know, we're working on very simple questions. Does gravity behave the same way for planets as it does atoms?

Alie: Aha! And that's where the quantum comes in.

Dr. Gamble: That's the quantum aspect. Is it the same? If it's not the same, well then, we need new physics.

Alie: Mm-hm. Oh boy.

Dr. Gamble: How do we test for new physics? We have no idea. [*chuckles*] I don't know. [*laughs*]

Alie: Can you walk me through the anatomy of a black hole? Because what I understand is there's the event horizon which is where everything is burning up around the edges and then where is the singularity? And from what I picture, it's like a big butterfly net that tapers into something massive. But how wrong am I?

Dr. Gamble: I cringe whenever I see that.

Alie: I'm so sorry. [*both laugh*] I just picture the wireframe illustrations. [*laughs*] I'm sorry.

Dr. Gamble: I try not to kill people for it but it's like, okay, that's the best mathematical representation we could draw. I'm like, "Okay guys, do better. We can..." [*Alie still laughing*] Okay, so it's not a funnel.

Alie: Okay.

Aside: Hang onto your hats, people.

Dr. Gamble: So, a black hole is actually a sphere.

Alie: [*softly*] Whaaat?

Dr. Gamble: Yeah, it's actually a sphere. So, not only is it a sphere but because the black hole is rotating, it squishes along the poles so it's an oblate spheroid.

Alie: Wow.

Dr. Gamble: The Earth is an oblate spheroid, it's not a perfect sphere because it rotates.

Alie: Like an M&M or like a...

Dr. Gamble: Exactly.

Alie: Not-as-squished M&M.

Dr. Gamble: Not as squished M&M. A fat M&M. So, if you think a fat M&M, that's what a black hole is. [*"Oh my god, it looks like a huge M&M."*] And that's edge-on, right? So now, if we're looking bird's eye view down, down the pole, you're going to see a perfect circle.

Alie: Okay.

Dr. Gamble: Because it has what we call, circular, equatorial symmetry. So, it's perfectly circular along the equator but as you kind of go up toward the poles, it changes. It's not a perfect sphere. So now, that's the outside of a black hole, right?

Aside: So, along the middle, perfectly round toward the top and bottom, less so. And around the black hole is a corona, and that's apparently a billion degrees Celsius, which Americans, that would be 1.8 billion-and-32 degrees Fahrenheit, in case you're getting close to one. But yeah, inward from the corona but before the event horizon is a hot nightlife spot called Ergosphere.

Dr. Gamble: Before we go inside, there's another area right outside the black hole that's called the ergosphere. Ergosphere meaning "work sphere," or "work region." The essence of the ergosphere is that spacetime itself, not you, not just the black hole, but spacetime itself is being dragged around. So, it is quite, quite impossible for you to stay still in the ergosphere.

Alie: Because it's getting dragged around.

Dr. Gamble: Because it's being dragged around the black hole with the blast. The black hole spins, spacetime is being dragged around. So, not being dragged around like a merry-go-round. So, you can imagine if you're on a merry-go-round and you took a picture, a long exposure picture, and you went around the merry-go-round, your image would smear, right?

Alie: Mm-hm.

Dr. Gamble: That's what you would see around a black hole in the ergosphere. You could see the back of your own head.

Alie: Nooo!

Dr. Gamble: Because the light would be dragged all the way around and hit your eyeballs. Yes.

Alie: Okay, spacetime. [*Dr. Gamble laughs*] In a nutshell, dragging spacetime is so hard to grasp for someone who is like, "Today is Wednesday, tomorrow is Thursday, dah-dah-dah-dah-dah, I'm this years old." What is spacetime in the aspect that it can be dragged?

Dr. Gamble: We're sitting in this studio, I can clock your time, I can figure out your position in 3D, in 4D. But is that actually spacetime? No. We are talking about events now, not just points. We have to go to 4D instead of 3D. So, XYZ and time. 4D, we're talking about events in spacetime now.

Aside: So, if some cosmic object were flat, it would occupy two dimensions on an X and a Y-axis. But when something is three-dimensional it has the added dimension of depth, and we exist in a three-dimensional world. So, I toss a sock at your face and that goes through three dimensions. But according to Einstein time is not only money, it's also the fourth dimension... Woooo!

Dr. Gamble: So, spacetime doesn't... They're going to kill me for this. [*Alie laughs*] Spacetime doesn't exist without events. Okay?

Alie: Okay. Got it. Like plotting points, sort of?

Dr. Gamble: Almost like plotting points. So, you can imagine the graph itself, like graph paper, if you could imagine you put your dog on graph paper. [*"Okay." "All right."*] And now, you can't see the graph paper.

Alie: Because you're looking at the dog.

Dr. Gamble: Because you're looking at the dog. But you know that the dog exists at some point on the graph paper.

Aside: So, we're looking at mass and events but can't forget that underneath it all, space and time are affected and doing all kinds of mysterious things.

Dr. Gamble: That is spacetime. [*Alie groans*] Yeah. It is there and there may be some quantum interpretation of it that we haven't figured out yet on a very, very small, we call it the Planck scale, we're talking 10^{-35} meters, *tiny*, tiny, tiny. Spacetime, in essence, turns into what is called a quantum foam.

Aside: Yep. It's actually called, I looked this up, quantum foam or spacetime foam.

Dr. Gamble: So, now it's terms of just like, a flat, or the graph paper analogy, now you're talking about something like whipped cream. So, you're talking about foam on top of a latte, in terms of not just events existing but events popping in and out of existence. So now, okay, your dog might be there, or it might not be.

Alie: Is that superposition, or no? That's totally different.

Dr. Gamble: That is superposition.

Alie: Ha-ha!

Dr. Gamble: Yes!

Alie: Okay. So, that's Schrödinger's dog sort of.

Dr. Gamble: That is, yes. [*laughs*]

Alie: Okay. Schrödinger's Gremmie.

Dr. Gamble: That's where you would start.

Aside: Just a little head's up, the thought experiment of a cat in a box exposed to a 50-50 chance of dying from radioactive poison inside the box is 50% a bummer but it was a way for Schrödinger, who was a founder of quantum mechanics, to highlight that superposition is an absurdity when it's scaled up. But superposition (that means something that can exist in multiple states until it's observed) has been validated experimentally via photons. And we're going to talk more about that in a second but first, we're going to take a break for sponsors of the show.

We always donate to a cause of the ologist's choosing thanks to sponsors of the show. And I'll be really honest, I realized that I didn't get the cause that Dr. Gamble wants this to go to but it's okay because we're back next week for Part 2, we'll donate on behalf of this episode and next episode. Next week we'll tell you all about it. But yeah, oops! That's how fresh these episodes are. I record this today; you get them tonight. Anyway, thanks, sponsors.

[Ad break]

Okay, so for more on that superposition too you can see the Quantum Ontology episode with Dr. Adam Becker. But back to black holes and what is happening on the inside to affect the outside?

Alie: So, the event horizon is sort of that equatorial mishmash of things going around. Where is singularity?

Dr. Gamble: It's at the very, very center. Now, again, because the black hole is spherical, the event horizon is actually a sphere.

Alie: Oh. Oh! Oh! The whole thing is a sphere.

Dr. Gamble: It's a sphere, yes! Now, here's the thing, here's the caveat. We have four different classifications of black holes; we have a non-rotating, non-charged black hole which is a Schwarzschild black hole, cool. We have a rotating black hole that's uncharged, Kerr black holes, those are your astrophysical ones. We have charged, non-rotating. And then we have rotating, charged.

Alie: Okay.

Dr. Gamble: Okay. So, that's our little black hole Punnett square.

Aside: Okay, so think of charged being caffeinated and rotating being the churning stomach of lactose. So, there's an oat milk decaf (noncharged, nonrotating), a whole milk decaf one (rotating but uncharged), a full-caff oat milk (charged, nonrotating), and lastly, a rotating charged, whole milk, full caffeine. And I guess you can get any of those with spacetime foam, depending on how good your barista is.

Dr. Gamble: If you have a non-rotating black hole, the singularity is a point, so it's an infinitely small point where all our lines, all our paths in spacetime point and you can't get out, they all point down to the center. As soon as you rotate that thing, it turns from a point into a ring. So, an astrophysical black hole, because we assume they're all rotating, right, it would have a ring singularity, not a point, it would be a ring at the very center.

Alie: And still tiny, tiny?

Dr. Gamble: And still very tiny, tiny.

Alie: What's in the middle of the ring? [*drumroll*]

Dr. Gamble: We don't know yet.

Alie: Blahhh!

Dr. Gamble: So, now you can imagine, instead of you going from a point, you're now going to something that is kind of like a ring, a little surface, so you can think of like, a disc that spacetime ceases to exist on [*Alie gasps*] and at the very edge of that disc is our event horizon, that's that ring. Anything inside that singularity is what we call elsewhere. [*slowed and repeated, "Elsewhere."*]

Alie: Elsewhere? Is that actually the term?

Dr. Gamble: It's the actual technical term.

Alie: No way.

Dr. Gamble: It is the actual technical term. [*Alie laughs*] We have the past, of course, we have the future. Past and future, and if you look at an XYZ plot, if I'm pointing up, vertical on the plot, my axis would be like time, and the horizontal axis would be space, cool. A trajectory that's exactly at 45 degrees, would be like traveling at the speed of light.

Alie: ... In that tiny of an area? Sort of?

Dr. Gamble: In that regard, yes. So again, we have to think abstractly here. If I am moving faster than light, I'm moving closer and closer toward that spatial axis.

Aside: So, the speed of light cuts right through space and time on a graph, which is just a tiny sliver of where it lands. But that angle would change if you're beating light on the speed axis.

Dr. Gamble: Which means time doesn't really pass that much, which means time is getting slower and slower and slower, but I'm covering more and more space... elsewhere.

Alie: No.

Dr. Gamble: So, we have the future, that's directly up top; the past that's at the bottom of the axes; and then on the sides, left and right, we have what's called elsewhere.

Alie: Bonkers.

Dr. Gamble: Bonkers, right?

Alie: So, time is... That viscoelasticity, that is partly, like, time expanding?

Dr. Gamble: In a sense, yes.

Alie: Okay.

Dr. Gamble: But that was a new term that I came up with in grad school so it's not very popular. It's out there, you can go read my dissertation if you want nightmares. [*laughs*]

Alie: I imagine there's a lot of math in it.

Dr. Gamble: There are 200 pages of math.

Alie: Oh my god. And then if something gets, say, sucked into a black hole... So, from what I understand, it's gravity condenses in that singularity? Sort of? It's just pulling it into it?

Dr. Gamble: Sort of. So now, you can imagine, we go back to the putty, right? It's the best analogy I can probably give you. Go back to the putty, you hold it in your hand, right? Imagine your hand being spacetime but the putty is an atom of some kind. If you keep squeezing your hand around the putty, you are simulating spacetime shrinking and shrinking and shrinking.

Alie: Ohhh!

Dr. Gamble: What happens to the putty? The putty has to condense also. But the putty cannot overcome that force, which is gravity, shrinking things down. So, now you have no choice but to fall all the way towards the singularity. Well, how long is that going to take? An infinite amount of time because the duration of time becomes slower and slower and slower.

Alie: Ohhh!

Dr. Gamble: But you're covering more and more space.

Aside: So, putty is matter and your hand would represent the squish of gravity as spacetime condenses. So, this matter, the putty, gets slowly condensed toward a tiny point, it's like a cosmic stress ball on a Zoom call that feels like it's never going to end.

Dr. Gamble: Space will stretch out, time will contract.

Alie: Nuts.

Dr. Gamble: So, when do you reach the singularity?

Alie: You could maybe...

Dr. Gamble: Never.

Alie: Never? Oh my gosh. [*gasps*]

Dr. Gamble: Never. Now, according to... Other theorists are going to listen to this, according to our theories, never. But we need new science, we need physics, we need quantum gravity. Quantum gravity is probably going to be the buzzword for this. [*laughs*] Yeah, we need quantum gravity.

Alie: And there are innumerable black holes out there?

Dr. Gamble: There are probably trillions of black holes out there.

Alie: Trillions of black holes! And when you're studying them, so much of this is theory based on what kind of math can work. What about things like LIGO and things like the imaging of the event horizon that came out a couple years ago that looked kind of like a glowing orange disc?

Aside: Okay, so for one of my other jobs, a TV job, *Innovation Nation* on CBS, I got to interview one of the data scientists imaging this event horizon of the black hole M87 and her name is Dr. Katie Bouman. Let's roll the tape.

[*clip of Alie narrating on Innovation Nation*]

> *The event horizon of a black hole is its surface, a sort of point of no return. And therein lies the name of the project of which Katie was a part, the Event Horizon Telescope, an international collaboration capturing images of black holes using a global array of eight telescopes.*

Dr. Gamble: So, the glowing orange disc is called a photon ring. You are watching the very extreme matter as it's falling into the black hole. We are quite literally taking an image of the edge of spacetime. If you were to take a picture of the last thing a photon would see before it fell in, that's probably it. We are trying to get even closer. So, now I am on a mission concept team to kind of extend that Event Horizon Telescope concept into space so we can look even deeper. So, we're trying to peer right on the very edge of the event horizon. What does that look like? What radiation can we collect? What do the photons look like? How are we going to collect weird matter? Do we see anything else there? Is that where aliens exist?

Alie: Yeah!

Dr. Gamble: I don't know. [*laughs*]

Alie: How far away do you have to go to keep looking at those? And how far away was the photon ring that was imaged?

Dr. Gamble: The popular images that you see are both of Sgr A*. Our Milky Way's supermassive black hole, and another supermassive black hole called M87. So, of course, these are catalog names and astronomers love cataloging things. Yikes. We have very weird names for shit, and I don't understand why. [*Alie laughs*] Just pick one system and stick to it. Anyways, M87 presents itself as a very unique and very energetic black hole; it's at the right perfect angle for observing, it's got a lot of activity around the disc, it's rotating very rapidly and we like that, it's emitting in all types of spectra across the electromagnetic spectrum between radio, through gamma rays, cosmic rays, X-rays, infrared, all of them.

Aside: And for more on X-rays, we have a Radiology episode, as well as an Invisible Photology episode with an expert physicist on this about invisibility cloaks. And yeah, we're going to link those in the show notes.

Yeah, so this black hole, M87, it's got a nice variety of rays and we're like, "Ooh, thank you. We can use these. We like you."

Dr. Gamble: So, it's a very nice, well-behaved, as I like to say, black hole. [*Alie laughs*] There are others that are out there that are misbehaving, I'm like, why are you doing this? Stop it. Stay still. Stop merging. [*Alie laughs*] You don't need to merge again after you've merged a first time.

Aside: And yeah, if black holes can't escape each other's gravity, they can swallow each other, like two cell phone providers that suddenly merge and you're like, where do I even pay you bastards?

Dr. Gamble: So, that's what we're trying to see. Are photon rings that are the same around every black hole? Are there other photon rings that we haven't seen? Are there different types of photon rings? Can we catch photon rings in two different directions? What happens? So, there's a lot of new science, a lot of new things that are out there. Have we figured them out yet? No. That's why we send stuff to space and observe. [*laughs*]

Alie: And now, you work with NASA.

Dr. Gamble: Yeah.

Alie: And NASA Goddard. How long have you been with NASA? What was that like?

Dr. Gamble: So, I started August 2021. They kind of found me. Of course, everybody applies to NASA, and you send your application out and you're like, "Okay, I didn't get picked, I'm going to move on." But then they said, "Hey, do you want to interview?" I was like, "The fuck? Yes. Are you spamming me?" [*Alie laughs*] And this was the Deputy Director, my current boss. I'm like, you've got to be fu... You've got to be kidding me. Are you real? Okay."

Alie: Did you check the email address to make sure it wasn't like, NASA44445@hotmail. [*laughs*]

Dr. Gamble: I checked it four times.

Alie: Yeah. [*laughs*]

Dr. Gamble: So, I put together like 30 slides of the work I was doing post-grad school. It was unfunded, it was unsupported, I was just doing it on the side. I was like, "One day, I'm going to present this to somebody and they're going to like it." Turns out it was NASA.

Alie: Oh my god.

Dr. Gamble: Which got me my job now. [*laughs*] They loved it. And were like "You were doing this... Who did you collaborate with?" I'm like, "Nobody." "Oh, did you... So, how were you supported?" I'm like, I didn't have funding for this, I just did it because I liked it. And they were so impressed by it.

Alie: That's got to be so gratifying.

Dr. Gamble: It was so gratifying. Now, it gets even better. I tell my mom this and she's like, "Shut up." I'm like, "Yeah, Mom. NASA." She's like, "When are you starting? Did you get your job?" I'm like, they haven't offered me anything yet, don't jinx it. It was a four-month process. Another interview, that's when my official offer came in. And I was like, okay, do I leave my current job and work for NASA? Or do I make more money here? My mom was like, "Why are you thinking about this? [*Alie laughs*] What are you doing?" I'm like okay, yeah, I'm being stupid. Sure, I'm going to accept.

My very first day at my dream job at NASA was the day of my mom's birthday, August 16, 2021. So, I gave her, [*laughs*] my job acceptance to NASA for her birthday, that was her birthday gift. I was like, "Mom, I finally got to NASA." So, we both were like, on the phone like, "I know! I'm crying too!" It was yes, it was truly amazing, and I had to get her T-shirts and I still probably owe her NASA T-shirts, even though she has three.

Alie: And it all started with a, "Is the Sun on fire?"

Dr. Gamble: It all started with, "Is the Sun on fire?" Yeah.

Alie: Did you ever find that placemat? What restaurant was it?

Dr. Gamble: I have no idea where it's at now. Mom, if you still have it, keep it because it's probably gold. [*Alie laughs*] Pluto is on there and they don't make those anymore.

Alie: Yeah, it's a collector's item either way.

Dr. Gamble: It's truly a collector's item.

Alie: Can I ask you questions from listeners?

Dr. Gamble: Yes.

Alie: Okay, because we have [*sings*] a looooooot. Oh my god, so many. Okay.

So, next week, we will ask Dr. Ron Gamble, a smart person, all kinds of not-smart and very smart questions in the thrilling and the heavy conclusion of black holes, including all of your questions from Patreon. Meanwhile, we've linked his work and social media in the show notes along with a ton of related episodes that you might love and get cosmic vertigo from.

We also have shorter episodes that are classroom-friendly, they're okay for kids and those are called *Smologies* and those 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 your voice on the show, sign up at Patreon.com/Ologies; it's just a dollar to get in there. *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, the dark matter that holds us all together. Kelly R Dwyer does the website, Nick Thorburn wrote the theme music, and our supermassive editor swirling this all together into an episode is Mercedes Maitland of Maitland Audio.

And if you stick around until the end of the episode, I tell you a secret. You're going to get three today, can you believe it? Okay, number 1, those boots that I mentioned up top, I'm not going to gate-keep those, they're made by TAFT, and I only know that because I looked on Dr. Gamble's Instagram and I was like, "Oooh, what are those boots?" after he wore them to my house. They're lovely boots, I just want to let you know. Take a gander, gorgeous. They are not a sponsor of this show at all, I'm just shouting them out.

Two, I recorded a bunch of this voice-over already and then I went to go edit it and realized that my mic hadn't been on... [*drawn out horn sound*] It happens infrequently but when it does, I want to take something wet and floppy, like an alive jellyfish, and I want to hit myself in the face with it. But it's okay, we got to the end.

The least casual secret I'm going to tell you is that on March 1st, I'm having some surgery. What am I having done? Is it elective? Is it cosmetic? Is it urgent? Are they going to know I'm a fake redhead and not give me too much anesthetic? Should I do an Anesthesiology episode, groggily? I might see if they let me take my whole kit into the operating room, I don't know if that's a violation of my own HIPAA laws. Anyway, I won't tell you quite what it is yet, we'll wait to get a little more information. But I'm going to try my best in early March to recover okay, we'll see what we can crank out during that recovery and yeah, we'll learn some stuff from it, eventually. But yeah, March should be interesting. Next week obviously, we'll be back with the thrilling conclusion of Black Holes Part 2. Stay tuned. Okay, berbye.

Links to things we discussed:

Milky Way Galaxy - Imagine the Universe!

Hubble Reveals Observable Universe Contains 10 Times More Galaxies Than Previously Thought

Astronomers Reveal First Image of the Black Hole at the Heart of Our Galaxy

Galaxy Types

The four fundamental forces of nature

Annulus (mathematics) - Wikipedia

What's an Accretion Disk?

The physics of accretion: How the universe pulled itself together

Types of Black Holes

Has Anyone Created a Black Hole on Earth?

Gravitation textbook

Gravitation textbook on Bookshop.org

Spin Tetrad Formalism Of Circular Polarization States In Relativistic Jets

Quantum Gravity

Black Hole Anatomy

Ergosphere and shadow of a rotating regular black hole

General Relativity & Curved Spacetime Explained!

Spot the difference: Imaging Sagittarius A* and M87

NASA made memory foam

The Universe Is Made of Tiny Bubbles Containing Mini-Universes, Scientists Say

Ronald Gamble: Astrophysicist Inspiring Others to Follow Their Dreams

Luminiferous aether

Trad Goths

Goth makeup through the decades

Spacetime Diagram

The First Image of a Black Hole Explained | The Henry Ford's Innovation Nation

Other episodes you may enjoy:

Scotohylology (DARK MATTER)

Cosmology (THE UNIVERSE)

Quantum Ontology (WHAT IS REAL?)

UFOlogy (UNEXPLAINED AERIAL PHENOMENA)

Astrobiology (ALIENS)

Abstract Mathematology (UH, IS MATH REAL?)

Futurology (THE FUTURE)

Eschatology (THE APOCALYPSE)

Radiology (X-RAY VISION)

Invisible Photology (INVISIBILITY CLOAKS)

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