GIRL: You're listening to *BrainsOn,* where we are serious about being curious.

BOY: *Brains On* is supported in part by a grant from the National Science Foundation.

SANDEN TOTTEN: All right, Marc. Let's check this survival kit one more time. Goggles?

MARC SANCHEZ: Yep, a pair for you, Sanden, and a pair for me.

SANDEN TOTTEN: Snorkels?

MARC SANCHEZ: Got them.

SANDEN TOTTEN: Flashlights?

MARC SANCHEZ: Here.

SANDEN TOTTEN: Worm repellent?

MARC SANCHEZ: I really don't think there are actual worms in a space-time wormhole.

SANDEN TOTTEN: [CLEARS THROAT] I said worm repellent.

MARC SANCHEZ: OK, yes. I have the stuffed bird for scaring away worms.

SANDEN TOTTEN: Phew, good. I do not mess with a creature that you can cut in half and it still won't die. That's just wrong.

MOLLY BLOOM: Hey, guys. Going on a trip?

MARC SANCHEZ: Yeah, we're going to go get donut holes.

ANWEN WINTER: I think you're overpacking.

SANDEN TOTTEN: What he means is we're going to that new place, Black Hole Donuts.

MARC SANCHEZ: Yeah, you know that commercial. Donut hole so dense. You'll think they're made from collapsed stars.

SANDEN TOTTEN: The directions say take Highway 5, exit at Bergamot, and then go through the wormhole to find it.

ANWEN WINTER: Wait. You have to travel through an actual wormhole?

MOLLY BLOOM: I thought those were just theoretical, like maybe they exist, but no one has found one yet.

MARC SANCHEZ: Well, we thought so, too, but apparently, there's one just off the freeway. We have no idea what it's like to go through it, so we're packing to prepare for anything.

SANDEN TOTTEN: Yeah. Look, here's what I know. I need those donut holes. I've seen pictures on the internet, and they look amazing.

So if I have to travel through a theoretical portal linking to distant points based on complex equations from Einstein's field equations to get them, then so be it. Now let's finish this checklist.

MARC SANCHEZ: Roger that, buddy.

MOLLY BLOOM: Bring me back a chocolate one. Oh, and glazed.

MARC SANCHEZ: You got it.

SANDEN TOTTEN: OK, emergency flare?

MARC SANCHEZ: Got it.

SANDEN TOTTEN: Good. We'll need that if the worms attack. Cash?

MARC SANCHEZ: Check.

SANDEN TOTTEN: Nope, the site specifically says they don't take checks.

MARC SANCHEZ: No, no, no. I said check--

SANDEN TOTTEN: I can't cash a check. No, no, I need you to [INAUDIBLE] I don't have [INAUDIBLE]

[MUSIC PLAYING]

MOLLY BLOOM: You're listening to Brains On from American Public Media. I'm Molly Bloom. And here with me today is 13-year-old Anwen Winter from Duluth, Minnesota. Hi, Anwen.

ANWEN WINTER: Hello, Molly.

MOLLY BLOOM: Today we're talking about wormholes and black holes.

ANWEN WINTER: And donut holes.

MOLLY BLOOM: Apparently. So Anwen, what do you picture when I say black hole?

ANWEN WINTER: I picture this like black like circle that's like completely black, and then everything is just like swirling around it. And it's like all dark.

But like super cool. And it's like reading all this power and like craziness.

MOLLY BLOOM: Yes. So black holes are like these mysterious pits in the universe. Things fall into them and never come out. Not even light can escape.

ANWEN WINTER: They are totally bananas.

MOLLY BLOOM: Yes. Wormholes are more like tunnels that can take you across the universe. The idea is you'd enter in one place and come out somewhere totally different, maybe on the other side of town or maybe the other side of the galaxy.

ANWEN WINTER: Wormholes are also totally bananas.

MOLLY BLOOM: Too true. We know black holes exist because we've found some, but we haven't found any wormholes yet. Some scientists think they are possible and are looking for proof.

ANWEN WINTER: But since we don't know what it's like to go through one, your guess is as good as mine.

MOLLY BLOOM: And you all sent us some pretty amazing guesses.

GIRL: I think traveling through a wormhole is like being squished into a ball and sucks through a tube surrounded by slowly blinking lights.

BOY: Everything will be rotating, and you will be traveling super fast.

BOY: Everything would be blue, purple, and red all in different places.

BOY: I think you would be going faster than the speed of light lighting many colored blues passing by you like every second or two.

GIRL: And you would see a bunch of auroras and rainbows.

GIRL: I think when you're traveling through a wormhole, you would see rainbow Hula-Hoops all around you. And it feels like you're going down the giant waterslide

BOY: At the other side of the rainbow would be the end of the wormhole.

[MUSIC PLAYING]

MOLLY BLOOM: Those colorful wormhole depictions come to us from listeners Connor, Milo, Abe, Amina, Charlotte, Aiden, and Ian. We'll talk more about wormholes later. But first, Anwen, you wrote in to us with some questions about black holes. Do you remember what they were?

ANWEN WINTER: Yes, I do. They were what are black holes, who discovered them, how did they discover them, and where do things go when they go into a black hole?

MOLLY BLOOM: How did you get interested in black holes?

ANWEN WINTER: Well, I remember reading a book in like second grade, and I was like, wow, these are like stuff of legend. And I was like totally into them, and I just read everything I could.

And I didn't understand a lot of it, but I still found them quite inspiring.

MOLLY BLOOM: Are you still interested in them?

ANWEN WINTER: Oh, yeah.

MOLLY BLOOM: Are you interested in space in general or black holes in particular?

ANWEN WINTER: Both, really.

MOLLY BLOOM: So what is your favorite thing to think about space?

ANWEN WINTER: That everything might have like one cent-- it's like center. Everything might be working perfectly together in this crazy like space-time amazingness sort of thing. I don't know.

MOLLY BLOOM: No, that's amazing. It is really mind-blowing. It's really kind of hard to wrap your mind around but really fun to think about.

ANWEN WINTER: Yeah, it's kind of beautiful.

MOLLY BLOOM: Mm-hmm. Do you know what you want to be when you're an adult?

ANWEN WINTER: Well, I kind of want to be like a space scientist. Like well, just someone who likes observes or looks for something. Or I kind of want to be a professional harpist, which would be kind of awesome.

MOLLY BLOOM: So maybe you could do both.

ANWEN WINTER: Yeah, maybe I could.

MOLLY BLOOM: You could be an astrophysicist who plays the harp--

ANWEN WINTER: Yes.

MOLLY BLOOM: --can go on the road, and your tour just happens to go by all of the giant telescopes.

ANWEN WINTER: [CHUCKLES] That'd be awesome.

[HARP KEYS PLAYING]

MOLLY BLOOM: Well, let's see if we can shed some light on black holes. Black holes happen when you have a super huge, mega giant amount of stuff crammed into a super tiny, infinitely small amount of space.

ANWEN WINTER: We call that stuff mass. You have mass. I have mass. Trees have mass. But black holes have a lot of mass.

DARYL HAGGARD: So I'll tell you my very favorite analogy.

MOLLY BLOOM: Meet Daryl Haggard. She studies black holes at McGill University.

DARYL HAGGARD: If you were to take our whole entire Earth, all of the buildings; all of the people; all the plants, trees, animals, oceans and squished the whole thing down into the size of a sugar cube, our Earth would become a black hole.

ANWEN WINTER: Whoa, that is like one extreme sugar to you.

MOLLY BLOOM: Totally. When something has a lot of mass like this, we say it is very dense.

ANWEN WINTER: And the cause of black holes are super-duper intense dense.

MOLLY BLOOM: In fact, many have a mass that is 10 times greater than our own sun.

ANWEN WINTER: Others have the mass of like 100 suns or 1,000 suns or more.

MOLLY BLOOM: When something is that dense and has that much mass, you can bet it also has super gravitational powers, which brings us to this question.

ASHTON: Hi, I'm Ashton from Tampa, Florida, and my question is, how do black holes trap light?

DARYL HAGGARD: The reason we call it a black hole is that when you make things that compact, even light is like trapped in the gravitational pull of the black hole. So light can't get out.

MOLLY BLOOM: Light is made of these little packets called photons. And normally, those photons fly around as if gravity doesn't affect them.

BOY: Hey, gravity. Can't touch this. Haha. (SINGING) Came through zip and zip, zip. Came through zip and zip. Zip?

GIRL: Hey, I'm stuck. What gives? I can't zip out of this hole.

MOLLY BLOOM: Black holes have super gravity powerful enough to trap even a photon of light.

DARYL HAGGARD: So we actually don't have any information coming back out of the black hole because the light is sort of trapped in there the same way we are sort of stuck down by gravity to our Earth.

ANWEN WINTER: Which actually brings up an interesting point.

DARYL HAGGARD: Black holes don't suck. They're not like a vacuum cleaner.

MOLLY BLOOM: You might think they suck. They're often drawn that way with swirls of stuff spiraling around them, like water going down a drain.

ANWEN WINTER: And stuff does swirl around a black hole's edge, like gases.

MOLLY BLOOM: We call that edge the event horizon, by the way.

ANWEN WINTER: Which is a totally awesome name.

MOLLY BLOOM: Right. Everything about them is so awesome. Anyway, the black hole isn't sucking things in so much as stuff is just being pulled by its gravity, like how you or I would be pulled down if we fell off something. And that gravity is so intense. Nothing gets out of a black hole.

ANWEN WINTER: No sights.

MOLLY BLOOM: No smells.

ANWEN WINTER: No sounds.

MOLLY BLOOM: Nada. What happens in black holes stays in black holes.

CHILDREN: *Brains On.*

MOLLY BLOOM: We'll talk more about black holes in a minute, but right now, let's hit pause and take a listen to the--

GIRL: Shh. Mystery sound.

MOLLY BLOOM: Are you ready, Anwen?

ANWEN WINTER: Yes.

MOLLY BLOOM: All right. Here it is.

[MYSTERY SOUND]

OK. Do you have any guesses?

ANWEN WINTER: Is it a rain forest waterfall?

MOLLY BLOOM: That's an excellent guess. There's a lot of like rushing--

ANWEN WINTER: Yeah, and there's like animal sounds in the background.

MOLLY BLOOM: Mm-hmm. Mm-hmm. Yes. Well, we are going to hear it again in just a little bit.

[MUSIC PLAYING]

Coming up, how are black holes made, and where are those donut holes we were promised?

ANWEN WINTER: We'll have answers. And hopefully, baked goods. So stay tuned.

[MUSIC PLAYING]

Do you have a question you'd like to have answered on *Brains On?*

MOLLY BLOOM: Or maybe you have a mystery sound or a drawing?

ANWEN WINTER: Send them our way.

MOLLY BLOOM: You can head to brainson.org/contact. That's what this listener did.

EMMA: Hi, my name is Emma. I'm from Redding, Connecticut, and I wonder why goat's pupils look like thin lines instead of circular balls like other mammals and animals.

MOLLY BLOOM: We'll have an answer to that during our Moment of Um at the end of the show and the most recent group of listeners to be added to the Brains Honor Roll.

ANWEN WINTER: Keep listening.

[MUSIC PLAYING]

MOLLY BLOOM: You're listening to *Brains On.* I'm Molly.

ANWEN WINTER: And I'm Anwen.

MOLLY BLOOM: And I am hungry for a donut. I hope Marc and Sanden survived that trip through the wormhole.

ANWEN WINTER: Me too. I mean, because they are our friends, not just for donut reasons.

MOLLY BLOOM: But also kind of for donut reasons.

ANWEN WINTER: Yeah.

MOLLY BLOOM: Hey, let's imagine their journey with the help of some more creative brainiacs. Let's hear what they think it's like in a wormhole.

[MUSIC PLAYING]

BOY: When you go through a wormhole, it's probably like a flash of light. And then it just blinds you because it's so fast.

BOY: Your eyes would just kind of stop working. And then you would go into it as you started twisting, really, really twisting.

BOY: You might be in a different world, and you might be a different thing. And then you're in a whole another place or a city.

GIRL: If I was traveling through a wormhole, it will be fun.

BOY: Wormholes, to me, feel like you're just floating in beds made out of tacos. Bye.

[MUSIC PLAYING]

MOLLY BLOOM: Since they are theoretical, wormholes can be anything, even bed's made out of tacos. Thanks to listeners Bear, Ian, Bradley, Ayana, Evan, Levi, and Frederick for sending in those wormhole thoughts.

ROBOT: Brains, brains, *Brains On.*

MOLLY BLOOM: OK, Anwen. Let's go back to that mystery sound again. And as you're listening, I'm just going to give you a little hint. It is worm-related.

ANWEN WINTER: It is?

MOLLY BLOOM: Mm-hmm. OK? So here it is.

[MYSTERY SOUND]

ANWEN WINTER: I still have no idea.

MOLLY BLOOM: [CHUCKLES]

ANWEN WINTER: Wow. Could it be like a worm colony watering their gardens? I have no idea.

MOLLY BLOOM: They have little tiny watering cans.

ANWEN WINTER: Yes [INAUDIBLE]

MOLLY BLOOM: I like the idea of that. It's a lot of worms together, though.

ANWEN WINTER: Yeah.

MOLLY BLOOM: All right. Here is the answer.

CAMERON: Hi, I'm Cameron from Port Macquarie, Australia. That was the sound of silkworms eating mulberry leaves.

ANWEN WINTER: Oh, that's really cool.

MOLLY BLOOM: [LAUGHS]

CAMERON: The sound reminds me of rain pattering on the window. They only eat leaves from the mulberry tree, so we had to find trees in our neighborhood to collect leaves from. They are very hungry and eat about 20 large leaves a day till they spend their silk into a cocoon before emerging as a moth. They are quite fascinating.

MOLLY BLOOM: And not a wormhole. I mean, they are making worm holes in the leaves.

ANWEN WINTER: In the leaves. [CHUCKLES] Worm hole.

MOLLY BLOOM: It's a kind of wormhole.

MAN: Ba, ba, ba, ba, ba, ba, ba, ba, ba, ba, ba, ba, *Brains On.*

MOLLY BLOOM: So today we've been hearing some mind-blowing facts about black holes.

ANWEN WINTER: But scientists didn't always know this much about them.

MOLLY BLOOM: In fact, it took centuries for us to start figuring out these mysterious space pits. Producer Menaka Wilhelm has some backstory for us.

MENAKA WILHELM: I hope you guys like puzzles as much as you like donuts because that's kind of what the history of black holes is like, a bunch of scientists building a big honking jigsaw puzzle without the box. No picture. At first, they didn't even know the puzzle they were building would lead to a black hole.

ANWEN WINTER: So like a 5,000-piece puzzle?

MENAKA WILHELM: I'm not sure exactly how many pieces this puzzle has. But so far, it's taken, well, 50 to 75, 200-- over 200 years and counting. I asked someone who's studying the history of black holes to give us the lowdown.

CARLA RODRIGUES ALMEIDA: Hi, my name is Carla Rodrigues Almeida.

MENAKA WILHELM: Carla says the story of this black hole puzzle starts way back in 1784, just a few years after America got its independence. When Hamilton wasn't a musical, he was just a real living person. Across the ocean in England, there was a curious thinker named John Michell.

JOHN MICHELL: How do you do? Care for some tea or perhaps four or five hours of me talking about my theories? I have many.

MENAKA WILHELM: Michell had ideas about earthquakes and gravity and stars. He was the first person who wrote about something like a black hole. The idea was part of this thought experiment.

JOHN MICHELL: I've been thinking. If you take a star and suppose it were roughly 500 times bigger than the sun-- do you follow-- then you can imagine--

CARLA RODRIGUES ALMEIDA: What Michell predicted was that there would be a star so massive

JOHN MICHELL: If so, then anything escaping the star would have to go faster than the speed of light. No light would ever leave.

[MUSIC PLAYING]

CARLA RODRIGUES ALMEIDA: And so they would appear to be black.

JOHN MICHELL: And [CHUCKLES] I've come up with a name for these objects as the opposite of light. I call them dark stars.

MENAKA WILHELM: But no one else really cared about Michell's idea.

CARLA RODRIGUES ALMEIDA: So the idea of dark stars was dropped.

MENAKA WILHELM: But Mitchell was right that a giant, dense star would trap all light. He just didn't have it totally figured out.

JOHN MICHELL: Ugh, drat. I thought surely I'd cracked that one.

MENAKA WILHELM: Michell's problem was that he was trying to put together this big puzzle. And he didn't have all the pieces. Some of the pieces he was missing were the rules of the universe that we know now.

Michell knew about density and mass, but scientists still had a lot to learn about the way gravity and light work. The other missing pieces were equipment and machines that would be able to search the cosmos and pick up distant signals. In Michell's day, there weren't many ways to actually measure those things in space. So let's fast-forward to the 1960s.

There are TVs.

MAN: Recorded in front of a live studio audience.

MENAKA WILHELM: And cars now.

[ENGINE STARTING]

And giant slow computers, like computers as big as a room. More of the pieces of the black hole puzzle are coming together. Physicists have figured out more of the rules about gravity and light, some of those missing puzzle pieces. And they've put those rules into equations.

An equation is a math formula, like a times b equals c. They've developed lots of equations that explain the laws of physics. There are also better machines to help measure and understand stuff we discover in space, those other missing pieces.

And when scientists put all those new puzzle pieces together, they started discovering really, really, really big stars.

WOMAN: I never thought we'd find such a dense object out in space.

MAN: This is denser than anything we've ever seen before.

WOMAN: So dense, right?

MAN: The densest. Oh, wait. Is that one over there even denser?

MENAKA WILHELM: And they had questions about those giant, dense stars.

CARLA RODRIGUES ALMEIDA: Why are they so heavy?

MENAKA WILHELM: To find out, they were using these machines to pick up signals from very far away radio telescopes.

CARLA RODRIGUES ALMEIDA: And also computer simulations.

MENAKA WILHELM: The computer simulations are kind of like *Fortnite,* an entire world inside a computer. And physicists could use these simulations to watch how stars and galaxies form and change according to the rules of the universe.

CARLA RODRIGUES ALMEIDA: The computer said that black holes could happen.

MENAKA WILHELM: And so between the computer simulations and the very dense stars found by radio telescopes, some physicists were pretty sure that black holes were out there. But they were calling them completely collapsed objects, zero points for style on that one.

WOMAN: It's so dense. It must be a completely collapsed object.

MENAKA WILHELM: Not everyone was on board.

MAN: Have you lost your mind? We don't know that.

WOMAN: Are you dense? What else could it be? Also, are we ever going to get a better name for these things? Completely collapsed object doesn't just roll off the tongue.

MAN: Why do we need a better name for an object that isn't real?

WOMAN: I don't think you are real.

MAN: We don't make stuff up. We take notes.

JOHN MICHELL: Completely collapsed object?

WOMAN: [INAUDIBLE] write home about.

JOHN MICHELL: That's far worse than dark star. You'd think nearly 200 years would improve the name, not make it worse.

MENAKA WILHELM: Don't worry, John Michell. A different guy named John-- the physicist John Wheeler helped change the name in the late '60s. He just got tired of saying completely collapsed object.

CARLA RODRIGUES ALMEIDA: Someone suggested black holes, and he liked it. And everybody started using it.

[MUSIC PLAYING]

MENAKA WILHELM: So by 1970, black holes finally had their new name. That same year, scientists Stephen Hawking and Roger Penrose also put an important piece of the black hole puzzle together. They checked how well black holes followed the rules of the universe and came up with a theory that said that black holes do exist. They're just hiding behind their event horizons, that edge around a black hole.

CARLA RODRIGUES ALMEIDA: They came and said yeah, this is it. And there's no other way.

MENAKA WILHELM: So that was a big deal. Scientists had been putting more and more puzzle pieces together over the past 200 years. And the picture was really starting to take shape. But something was still missing.

The strongest proof of black holes arrived in 2015 when a machine called LIGO made a big discovery. LIGO has one name, but it's actually two giant detectors. One is in Washington State, and the other is in Louisiana. The detectors have arms that are 2.5 miles long. And together, they measured gravitational waves from two black holes colliding.

This was huge for the black hole puzzle. LIGO's measurements were actual proof. Score one for space science. Still, it took hundreds of years and tons of scientists all over the world working to find this proof.

And it never would have happened if it weren't for all those other pieces falling into place first.

ANWEN WINTER: Wow. Thanks for the background, Menaka.

MENAKA WILHELM: You are totally welcome. Here's the crazy thing, more puzzle pieces are still coming together. At this point, scientists have found multiple kinds of black holes.

MOLLY BLOOM: We are going to get into other kinds of black holes in a bit. But first, we have a message from a new sponsor.

GRIFF JENKINS: What's better than donuts? Donut holes. What's better than donut holes? Nothing.

Hey everyone. It's me, celebrity chef, extreme baker, and spiky hair hatter, Griff Jenkins.

BENNY: And I'm Benny, Griff's assistant. I also have hair.

GRIFF JENKINS: We love donuts, but most shops leave out the best part, the hole. That's why we opened up Griff and Benny's Black Hole Donuts.

BENNY: Because black holes are cool, and so are donut holes.

GRIFF JENKINS: Using my patented technique of baking with extreme righteousness--

BENNY: He means whole wheat flour.

GRIFF JENKINS: --I've managed to make donut holes so dense. They're like a singularity in your mouth.

BENNY: We've got plenty of flavors, too, like double fudge cosmic cocoa bomb--

GRIFF JENKINS: Extreme chocolate--

BENNY: Vanilla peanut butter bacon saturn swirl--

GRIFF JENKINS: Gnarly flavor combo with custard filling--

BENNY: Plain donuts--

GRIFF JENKINS: Righteously unadventurous--

BENNY: And my favorite, spring lavender and wild honey.

GRIFF JENKINS: The floral notes are intense. So come on down. Black Hole Donut Hole, so dense. No light can escape.

MAN: Donuts will not collapse all nearby matter. Light can actually escape them. Floral notes are not actually intense but rather beautifully understated and refreshing. Find us just off Bergamot Drive, straight through the wormhole.

MOLLY BLOOM: So how do scientists find black holes? Dr. Chung-Pei Ma is here to help us.

ANWEN WINTER: She's an astrophysicist and a black hole Hunter from UC Berkeley. Welcome, Chung-Pei.

CHUNG-PEI MA: Hi.

ANWEN WINTER: So I have a few questions here. And my first one is, how do black holes form?

CHUNG-PEI MA: Black holes form when gravity become so great that the opposing force cannot resist it anymore. So something like a ball of gas, like a very, very big sun. When the force at the center of the sun starts to be overwhelmed by the gravitational pull, then it collapses onto itself and into a point. And that's when a black hole forms.

ANWEN WINTER: Oh, that's super cool. Wow.

You've discovered supermassive black holes. How big are they, and how far away are they?

CHUNG-PEI MA: We call these supermassive black holes because they are super massive. And by that, we mean we like to compare the mass to the mass of the sun, our own star, which is by itself already very, very big. And we like to use a solar mass, the mass of the sun, as a unit, like how you would use a pound as a unit to weigh ourselves.

So in the unit of the sun, these black holes are the biggest ones that I have found. They have a mass about 20 billion times that of the sun. And they are at a distance of millions and millions of light-years away from the Earth.

So a light-year is a distance light can travel in one year. And that's many hundreds of thousands of miles. And these are at millions and millions of light-years away. So they are pretty far, but given the size of the universe, is still pretty close to our home.

ANWEN WINTER: It makes you feel small

[LAUGHTER]

So why are some black holes bigger than others?

CHUNG-PEI MA: That's a great question. And why are some kids bigger than other kids? Bigger parents tend to make bigger kids, but that's not always true. That's nature.

And there's also nurture, right? The more candy bars you eat, you may get a little bigger than your friends. More spinach you eat, you may get a little taller than your friends.

Same thing for black holes. We are not sure, but there's nurture and there is nature. So for the nature part, we think some black holes may have been formed from-- there's a collapse end product of a bigger, more massive gas cloud.

This is like bigger parents. But then some black holes are more voracious than others as they grew. And black holes grow by gobbling up gas. Just a lot of--

ANWEN WINTER: Yum, yum, yum.

CHUNG-PEI MA: Yum, yum, yum gas, like Oreo cookies. So in some parts of the universe, it seems like they're just more Oreo cookies. So these black holes, they may have started out being small. But as they grew, they got billions of years to grow to get big.

And some of them ate a lot of spinach or Oreo cookies, whichever way. And they ended up big. And some may just be big because they started off big.

And this is a very important question we're trying to answer, nature versus nurture. And we think both matter.

ANWEN WINTER: So how do you get interested in black holes?

CHUNG-PEI MA: I was just always fascinated by the nice sky and the universe when I was around your age. I really liked to just [INAUDIBLE] looking out. And then I also really, really liked math.

I just enjoy how I could get it and answer. That's either right or wrong. It's very clear-cut.

And then later on when I was about 12 or 13, I realized that I was taking biology, chemistry, physics but really liked physics because I felt I could use math as a language to understand the physical, the universe around me. And that's when I decided I wanted to become an astrophysicist when I was about 12 or 13.

ANWEN WINTER: Well, thanks, Chung-Pei. This is really awesome. And thank you for taking your time to talk to us.

CHUNG-PEI MA: No problem. Yeah. If you ever have any other questions about the black hole, about the universe, you know where to find me.

[MUSIC PLAYING]

MOLLY BLOOM: We've been hearing throughout the episode "Your Wormhole Travel Dreams." But just like black holes used to be, they are totally theoretical.

ANWEN WINTER: There is no proof that wormholes exist in our universe.

MOLLY BLOOM: But they are mathematically possible, given our understanding of the laws of physics.

ANWEN WINTER: And this all has to do with the fabric of space-time. Imagine a stretchy sheet of fabric, like a big stretchy blanket.

MOLLY BLOOM: This is how scientists sometimes imagine the universe. There are three dimensions for physical space. Those are the three dimensions that we can move in.

ANWEN WINTER: Forward and backwards, left and right, up and down.

MOLLY BLOOM: And then a fourth dimension, time. These dimensions make up the fabric of space-time.

ANWEN WINTER: So first, let's talk about what a black hole does to our blanket of space-time.

MOLLY BLOOM: Black holes are like putting something very dense on this fabric. Let's imagine a bowling ball. What would happen to this fabric if we set a big heavy bowling ball on it?

ANWEN WINTER: Well, either it would like sink down or smash through.

MOLLY BLOOM: [CHUCKLES] Exactly. So in the case of space-time, it sinks down, and it makes a big dip or a hole in the fabric. That's why things fall into a black hole.

OK, so let's take this bowling ball off the fabric. Now imagine folding this fabric like the way you fold a blanket to put it away. Suddenly, two blanket corners that were on opposite ends of the blanket before are right on top of each other now.

So what if there was a hole or tunnel connecting one layer of fabric to the other? That's what a wormhole is. So that tunnel can make a shortcut between two spots on the fabric that are normally very far apart.

Cool, right? But alas, they remain theoretical.

ANWEN WINTER: And there are some reasons why traveling through one of these theoretical space-time tunnels might not work.

MOLLY BLOOM: First of all, scientists have never found the kind of matter that would be needed to hold open the wormhole. We don't know if it can be found anywhere in the universe.

ANWEN WINTER: And no one knows if they'd be stable. Even if you could find the right matter to make one, the smallest jiggle might make it collapse.

MOLLY BLOOM: Scientists are still exploring the idea of wormholes. And until they're proven to exist, we can let our imaginations run wild just like many science fiction writers have done and our listeners.

[MUSIC PLAYING]

GIRL: I think traveling through a wormhole would look like blue and purple galaxy slime all around. I think everything would be in sort of a slow motion, and you would feel rubbery, like when you touch to your skin.

BOY: And then you would still feel a lot of tickling. And you might come out just looking different than you were.

GIRL: I think it would smell like burning metal and rubber because that's not a pleasant smell.

BOY: And then you would go at hyperspeed, and then you would fall back into a blob of space.

GIRL: I think you might see things that it had swallowed, like stars and space drone.

BOY: I think it's like just like a swirl through existence and then just go to a different place in time.

GIRL: I feel like it would spin you upside down in slow mo but you would be floating because you were in space.

[MUSIC PLAYING]

MOLLY BLOOM: Special thanks to Elle, Dillon, Frederick, and Will for sending in those wormhole word pictures to us. OK. Well, that's it for this--

MARC SANCHEZ: Hey, hey, wait. We made it back with donuts.

ANWEN WINTER: The donuts survived. I mean, you guys survived. Nice job.

MARC SANCHEZ: Yeah. It turns out there was no space-time wormhole at all. Black hole donuts was just a pop up donut stand at the back of a bake shop called The Wormhole.

MOLLY BLOOM: That is a very strange place for a donut stand.

MARC SANCHEZ: Cheap rent, I guess. Anyway, dig in, everybody.

ANWEN WINTER: Sanden, you're not eating?

SANDEN TOTTEN: I've lost my appetite. The horrors I saw, worms, so many worms everywhere. And you never know which end's their butt and which end's their mouth. I mean, how can you trust a creature like that?

I don't think I'll ever eat a-- oh, wait. Is that a strawberry one over there? Actually, can I just take one little bite of that?

MARC SANCHEZ: I'll take a twist.

SANDEN TOTTEN: Oh, and save me that chocolate. Oh, and definitely the lemon fireball squirrel.

MARC SANCHEZ: I don't even care--

MOLLY BLOOM: [INAUDIBLE] one.

ANWEN WINTER: [GASPS] Can I have that? No, I want--

MOLLY BLOOM: [INAUDIBLE]

ANWEN WINTER: Oh, thank you.

MOLLY BLOOM: You can have it.

Black holes are spots in the universe filled with super dense materials.

ANWEN WINTER: They have so much gravity that nothing can escape them, not even light.

MOLLY BLOOM: The idea of a black hole was proposed over 200 years ago. But it was only recently we were able to get proof of them.

ANWEN WINTER: And wormholes are theoretical tunnels in the fabric of space-time that haven't been proven to exist.

MOLLY BLOOM: Black holes are spots in the universe filled with super dense materials. They are formed when stars collapse. That's it for this episode of *Brains On.*

ANWEN WINTER: *Brains On* is produced by Molly Bloom, Marc Sanchez, and Sanden Totten.

MOLLY BLOOM: A special hello to our fellow Menaka Wilhelm. We had production help from Caroline Champlin and engineering help from Corey Schreppel and Veronica Rodriguez. Special thanks to [INAUDIBLE] Sarah Winter, [INAUDIBLE] Winter, John Miller, Eric Ringham, Chris Greenspon, and Lisa Brenner.

ANWEN WINTER: *Brains On* is a nonprofit public radio podcast, and your support helps keep the show going.

MOLLY BLOOM: You can donate and see our cool thank you gifts at brainson.org/donate.

ANWEN WINTER: Now before we go, it's time for our Moment of Um.

[MOMENT OF UM]

BOY: I wonder why goat's pupils look like thin lines instead of circular balls, like other mammals and animals.

[MUSIC PLAYING]

MARTIN BANKS: So with a horizontal pupil that allows the goat to see more widely in front of them to the side of them and behind them along the ground. And that's useful because that's where an animal that might be hunting them would be likely to come from. Hi, I'm Martin Banks. I'm a professor of optometry and vision science at UC Berkeley.

The horizontal pupil like a line is actually pretty common among mammals, particularly common among mammals that are herbivorous, that is that they live on the ground and they eat plants. Cows sheep, goats, horses all have the horizontal line pupil. It's predators, the mammalian predators that tend to have circular pupils or vertical line pupils-- there are other pupils that we just find kind of interesting and bizarre in the animal kingdom.

The octopus and related animals have a W-shaped pupil. And there are some reptiles like the gecko that when its pupil stops down, closes down to either three or four small holes-- those are really interesting pupil shapes. So we just don't have a really good idea about why they have that shape.

[MOMENT OF UM]

MOLLY BLOOM: My eyes are focused on this list of names in front of me. These are the amazing listeners who are about to be added to the Brains Honor Roll. They keep the show going by sending us their brilliant ideas, questions, mystery sounds, and drawings.

[MUSIC PLAYING]

[LISTING HONOR ROLL]

ROBOT: Brains Honor Roll. Bye. Bye.

ANWEN WINTER: Thanks for listening.