ANNOUNCER 1: You're listening to *Brains On.* Where we're serious about being curious.

ANNOUNCER 2: *Brains On* is supported in part by a grant from the National Science Foundation.

BOB: Popsicles! Get your popsicles here!

MOLLY: Hi, Bob.

BOB: Oh, hello, Molly.

MOLLY: I didn't know you had a popsicle stand.

BOB: Oh, I just opened today. It's called Bob's Pops. You want to try one of my new flavors?

MOLLY: It's kind of cold out, but sure. Thanks.

BOB: Here you go.

MOLLY: [SLURPS]

BOB: What do you think? Can you guess the flavor?

MOLLY: Wow, it tastes like ice.

BOB: Yep, and?

MOLLY: And algae?

BOB: Ding ding, correct. This is my lake pop. It tastes just like a lake, doesn't it?

MOLLY: Uh, yeah, it does.

BOB: Well, it's got a lot more character than the stuff coming out of your tap. But here, I got another one for you. I'll give you a hint. It's also inspired by nature!

MOLLY: OK. [SLURPS]

Oh, whoa, it's brown and goopey.

BOB: And?

MOLLY: And gritty like dirt or mud.

BOB: Bingo! You've got a keen sense of taste, Molly. It's my mud pop. I figured there are mud pies, why not mud pops?

MOLLY: Oh, it's very unique. But mud pops aren't really my thing. Do you have anything that's a little lighter, maybe with less dirt?

BOB: Oh, not to worry. I've got the perfect pop for you.

MOLLY: You know what? I'm actually getting kind of full.

BOB: Really, really, this is my absolute favorite. Here.

MOLLY: But it's just a popsicle stick.

BOB: It may look like just a popsicle stick, but it's so much more. Give it a try.

MOLLY: [SLURPS] Mm, it's invisible, but there is something there. Whoa, it feels like my ears are popping, and I'm getting a touch of cloudiness with subtle notes of air.

BOB: [LAUGHING] You got it, Molly. Three out of three! This is my sky pop! It might not look like much, but boy, does it pack a punch, just like our big, beautiful sky. [LAUGHING]

[MUSIC PLAYING]

MOLLY: You're listening to *Brains On* from APM Studios. I'm Molly Bloom, and I'm here with Felix from Nashville, Tennessee. Hey, Felix.

FELIX: Hi, Molly.

MOLLY: So Felix, today we are talking about the sky. And you asked us a pretty big question about it.

FELIX: Yeah, I wanted to know, how heavy is the sky?

MOLLY: That's a really, really great question. So I'm curious, how did you come up with it?

FELIX: I was looking up at the sky and was like, has to weigh something, right?

MOLLY: What a great thought. I love that. So how do you define the sky?

FELIX: It's like an area above the trees but, like, not in outer space.

MOLLY: Hmm, very good. And what do you think about when you look up at the sky?

FELIX: Ooh, I think of it like a place where birds fly and planes soar.

MOLLY: Mm-hmm. Have you ever been up in the sky yourself?

FELIX: Yeah, I've been in a plane.

MOLLY: What did it feel like to be in a plane?

FELIX: When you first take off, it feels like you're soaring, but then you're normal.

MOLLY: Mm-hmm? yeah, your first takeoff, you feel it pushing on your body.

FELIX: Yeah, and your ears pop.

MOLLY: Yes. I don't want to jump at the sky though. It kind of just feels like you're just sitting there.

FELIX: Yeah, it just feels like you're-- I don't know-- in a car?

MOLLY: Mm-hmm, totally. Felix, what does the sky taste like, in your opinion?

FELIX: Coolness, like water but, like, fresh but not water. That's a really good question.

MOLLY: That's a good answer.

FELIX: What does it taste like?

MOLLY: Should we taste the air right now? Just kind of cool.

FELIX: Mm-hmm.

MOLLY: Mm-hmm, refreshing. Well, to figure out how heavy the sky is, first we have to answer, where does the sky start? And where does it end?

FELIX: Yeah, like, how big is it?

MOLLY: That's a tricky question. When you look up at the sky on a clear day, it sort of feels like you're standing inside a snow globe, looking up at a bright blue dome. But even though it might look like there's an end to the sky, there is no sky ceiling. It just goes on and on until it fades into space.

FELIX: Right. But there is an imaginary line out there that scientists think of as the end of the sky.

MOLLY: Yes, and it's called-- [SUSPENSEFUL MUSIC]

ROBOTIC VOICE: The Karman line.

MOLLY: The Karman line is somewhere between 50 and 62 miles above the Earth's surface, which is actually pretty close. If you drove a car at freeway speed straight up into the sky, it only takes about an hour to get there.

FELIX: But once you got there, you wouldn't know it because the Karman line is invisible.

MOLLY: Yes. And it marks the point above the Earth's surface where planes can no longer fly because there isn't enough air to support them. And here's why, planes need lift to fly. Lift is a force created by a liquid or gas moving past an object. When a plane takes off, air rushes past its wings. And as it does, the air generates pressure that pushes those wings up, up, up, and away.

[AIRPLANE WHIRRING]

FELIX: So the lift created by the air rushing past the airplane's wings helps keep it aloft.

MOLLY: Yep. And at the Karman line, there isn't enough air left to create that lift.

FELIX: That's where something called orbital force takes over.

MOLLY: Orbital force is the energy that pushes objects like satellites and space junk in circles around the Earth.

FELIX: Those things are moving above the Karman line.

MOLLY: And everything below the Karman line is part of the sky.

FELIX: Which is where planes can fly.

MOLLY: So we'll say the sky ends at the--

[SUSPENSEFUL MUSIC]

ROBOTIC VOICE: The Karman line.

MOLLY: The next question is, where does the sky start?

FELIX: Right beneath our feet?

MOLLY: Yes, because the sky is made up of air and there is air beneath our feet. It's also in our stomachs, our lungs, our ears. It's everywhere. But because we can't see air most of the time, it's easy to forget about.

FELIX: But as soon as we start paying attention to our breaths-- [BREATHING DEEPLY]

MOLLY: Or the wind blowing outside our window.

[WIND BLOWING]

Or--

[FART]

FELIX: Oh, Molly!

MOLLY: Oh, sorry. My cat has no manners. But yes, even our farts remind us that air is everywhere.

FELIX: And air is made up of air molecules.

MOLLY: Molecules are the teeny, tiny building blocks that make up everything.

FELIX: You, me, my shoes, trees, the air, everything. Molecules are so small that we can't see them with our own eyes.

MOLLY: Should we get the zoom right and look at some air molecules up close?

FELIX: Yeah!

ROBOT: Zoom, zoom, zoom, zoom, zoom.

MOLECULE 1: Hi.

MOLECULE 2: Hello.

MOLECULE 1: We're air molecules.

MOLECULE 2: Hi.

FELIX: Hi, nice to meet you.

MOLLY: Hi. As you can see, air molecules are tiny blobs bouncing around in empty space.

[GIGGLING AND CHUCKLING]

MOLECULE 2: Yeah.

MOLLY: Up by the Karman line where there's less air, there are way fewer air molecules.

FELIX: And they're really far apart from each other.

MOLECULE 2: Hey, molecule, where'd you go?

MOLECULE 1: I'm over here! Miss you, buddy.

MOLLY: But whether you're way up there or down here, air molecules are all around you.

FELIX: Because they're the stuff that makes up the sky.

MOLLY: OK, so let's review. The sky begins beneath our feet and ends at the Karman line about 50 to 62 miles above the Earth's surface.

FELIX: And the sky is made up of air, which is made of air molecules.

MOLLY: Which brings us back to your question, Felix, how heavy is the sky? So we have all these air molecules from here to the Karman line pushing down on us.

FELIX: Even though they're tiny and we can't feel each one individually, altogether, they weigh a lot.

MOLLY: Yes. The average weight of the air pressing down on us is about 15 pounds for every square inch of the Earth's surface.

FELIX: That's like the weight of a bowling ball pressing down on every square inch of the planet.

MOLLY: Or the weight of a medium sized cat--

FELIX: Who farts.

[CAT MEOWS AND FARTS]

MOLLY: Yes, a square inch is about the size of two postage stamps. Imagine squeezing the weight of a bowling ball or a medium sized cat who farts onto two postage stamps.

FELIX: That's a lot of weight pushing down on a very small amount of space.

MOLLY: Yeah. And there are 4,14,489,600 square inches in one square mile. Imagine that many medium sized cats--

FELIX: Ugh, who fart!

MOLLY: --each perching on two postage stamps all squeezed into one square mile.

[CATS MEOWING AND FARTING VIGOROUSLY]

FELIX: That's a lot of cats.

MOLLY: And a lot of farts.

FELIX: And a lot of weight in one square mile.

MOLLY: But get this, the Earth is 196,900,000 square miles. So imagine, 4,14,489,600 medium sized cats--

FELIX: Ugh, who fart.

MOLLY: --who fart--

FELIX: 196,900,000 times over.

[CATS MEOWING AND FARTING VIGOROUSLY]

MOLLY: And that is the weight of the sky.

FELIX: Whoa. So what is that number? Like, if the sky stepped on a scale, how heavy would it be?

MOLLY: Let's do a little math here. [TYPES ON KEYPAD] 14.7 pounds per square inch times 4,14,489,600-- whoa. Drum roll, please.

[DRUMROLL]

The sky weighs-- 5,000,000,000,000,000 tons.

FELIX: I don't even know how to imagine that.

MOLLY: Neither do I. What if we think about 5,000,000,000,000 tons in a different way? A ton is 2,000 pounds.

FELIX: Adult walruses weigh about a ton.

MOLLY: They do. OK, now imagine a billion walruses.

[WALRUSES GRUNTING]

Now imagine a billion walruses times a million.

[WALRUSES GRUNTING]

FELIX: That's a whole lot of walruses.

MOLLY: Yeah, and they sound so funny. Not sure that helps, but that's how heavy the sky is. It weighs--

BOTH: 5,000,000,000,000 walruses.

FELIX: Which feels like the name of an awesome band.

CORNELIA: It is.

MOLLY: Whoa! A walrus!

CORNELIA: Yep. The name is Cornelia. I'm the frontwoman of my band Five Million Billion Walruses. Want to hear our new hit single about the weight of the sky?

FELIX: Radical.

MOLLY: Yeah.

CORNELIA: All right, Wallies, hit it!

[MUSIC PLAYING]

(SINGING) We are the walruses of the sky. Five million billion flying high. Feel our breath. Feel our breeze. Hear us moving through the trees. Each 2,000 pounds of walrus love, circling round.

The howling wind is our sigh. Hop on our backs, come on, let's fly. Feel us slip. Feel is dive. Hear us sing, swing and dive. When the wind goes woo, just know a walrus loves you!

[WALRUS GRUNTS]

FELIX: Nice job.

MOLLY: Yeah, really beautiful work.

CORNELIA: Thanks, Felix. Thanks, Molly. Catch you on the flipper side.

FELIX: That was really cool.

MOLLY: Yeah, almost as cool as today's--

[SUSPENSEFUL FIZZ]

WHISPERING VOICE: Mystery sound.

MOLLY: Felix, are you ready to listen to the mystery sound?

FELIX: Yes, I am.

MOLLY: All right, let's hear it.

[CLUNKING AND GRINDING]

All right, Felix, what do you think?

FELIX: Sounds like someone pouring something into a bowl.

MOLLY: Hmm.

FELIX: Because, like, the spoon at the end--

MOLLY: Yes, definitely sounded like there were some cutlery, spoon, bowl sounds happening. What do you think might be being poured into a bowl?

FELIX: I don't know. It sounds like walnuts or something, something bigger. Not like cereal, but like that can make that type of clunk.

MOLLY: Very good listening. Well, we're going to hear it again and have another chance to guess after the credits.

FELIX: So stay with us.

[MUSIC PLAYING]

MOLLY: We're working on an episode all about bugs. They pollinate our plants, keep soil healthy, and lots end up as delicious meals for other animals. Some bugs even eat other bugs like how dragonflies eat mosquitoes. So we want to hear from you, what is your favorite bug? My favorite bug is probably a dragonfly. I love that they eat mosquitoes. They are super colorful. And they've been around a very, very long time. So record yourself telling us about your favorite bug, what it is, and why it's your favorite.

And send it to us at brainson.org/contact. And while you're there, you can send us mystery sounds, drawings, and questions like this one.

KID: Why are clouds white when they are actually clear water vapor?

MOLLY: You can find an answer to that question on our*Moment of Um* podcast. It's a short dose of facts and fun every weekday. Find it wherever you listen to *Brains On.*

FELIX: And keep listening.

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

FELIX: And I'm Felix.

MOLLY: And today, we're answering the epic question--

FELIX: How heavy is the sky?

[THUNDER]

MOLLY: Before the break, we calculated that the sky weighs 5,000,000,000,000 tons.

FELIX: AKA 5,000,000,000,000 walruses.

MOLLY: But something we haven't talked about yet is why we don't notice the weight of the sky most of the time.

FELIX: And sometimes we do. Here to talk to us about some of those times is our friend Wanda Weather Woman. Hi, Wanda.

WANDA: Hi, Felix. Hi, Molly. Welcome to Wanda's Weather Hour.

[MUSIC PLAYING]

(SINGING) Where we walk the weather walk. Where we talk the weather talk. Where there is weather, we weather it better because we love the weather a lot.

MOLLY: Wow, great theme song.

WANDA: Thanks. I wrote it myself.

MOLLY: So we want to ask you a question about the weight of the sky. We figured out that it weighs 5,000,000,000,000 tons. But we want to know, why don't we usually notice how heavy it is?

WANDA: What a wonderful question, Molly. When I get big questions like this, I always consult my handy dandy everything almanac.

[FLIPS PAGES]

Here we go, the sky is real but it's hard to feel. Air moves around, pressing up, out, in, and down. So what that means is we usually don't notice the weight of the sky because the air outside our bodies is usually pushing in on us just as hard as the air inside our bodies is pressing out.

MOLLY: OK, got it. So the pressure is balanced inside and outside of our bodies?

WANDA: Most of the time, yes. Think about it this way, the sky is the stuff we swim in.

[WATER SPLASHES]

So we don't usually notice it until it starts moving and grooving around in unexpected ways. Now, if you'll excuse me, I'm just going to check my barometer here and see if I've got any weather updates to share.

FELIX: You mean that thing that looks like a big pocket watch?

WANDA: Yeah. Barometers are tools that measure how much air is swirling around us and how heavy or light it is. We call that atmospheric pressure or air pressure.

MOLLY: The atmosphere is all of the layers of air that surround the Earth.

WANDA: Yes. And the atmosphere is like a delicious, airy layer cake. The bottom layer, which is the one that surrounds us, is called the troposphere. It includes all the air we breathe and all the clouds in the sky.

MOLLY: Oh, and tropos means turn or change in Greek because the weather in this layer is always changing.

WANDA: And that's why I love it. The troposphere is where the weather happens. If the weather never changed, I wouldn't have a job! [LAUGHS] [SIGHS] Seriously, and you wouldn't notice the weight of the sky. So weather is a win-win.

FELIX: So when weather changes, that's when we feel the weight of the sky?

WANDA: Basically, yes. Take wind, for example. You can feel wind. And what you're feeling is the air and sky moving. My friend Deanna Henz describes how wind works in the most beautiful way. She says it's all about balance.

DEANNA: The wind happens because it's just the atmosphere trying to balance places where there's more air versus less air. And so it's moving that air from the places where there's more of it, what we know is a high pressure, towards places where there's less of it, and that's known as a low pressure.

WANDA: Couldn't have said it better myself. Deanna is an assistant professor of atmospheric science at the University of Illinois Urbana-Champaign and a huge fan of my show. I have her on as a guest all the time.

MOLLY: So wind is just the atmosphere trying to move air from places where there's lots of air to places where there's less air?

WANDA: Yes. And this is how all weather works, it's just air moving from high pressure to low pressure over and over again, getting mixed up with water along the way.

FELIX: How do some places end up with more or less air than other places? How does high and low pressure happen?

WANDA: Well, one way is the temperature. Temperature affects the movement of air big time. Let's think about low pressure areas or places where there's less air. It can happen when the air heats up. Here's Deanna's take.

DEANNA: As air gets more energy, say, from the sun heating it up, it starts to get what I think about as zoomies.

MOLLY: Zoomies? Fun! Let's zoom in on those air molecules again so we can watch them zoomie around.

ROBOT: Zoom, zoom, zoom, zoom, zoom, zoom, zoom, zoom.

MOLECULE 1: Woohoo!

MOLECULE 2: Hoohoo!

MOLECULE 1: Mole-cool? More like mole-hot! [CHUCKLES]

MOLECULE 2: Wee!

FELIX: They're moving so fast.

WANDA: Yes, and here's a fun fact.

DEANNA: It's the actual speed of the molecules hitting us-- is what registers as being hot or cold, depending on how fast it's going.

FELIX: Whoa!

WANDA: I know. So when air molecules hit you, you absorb some of their energy. And if the air molecules are hot and supercharged with energy and zooming around, they're going to bounce into you a ton and transfer their energy to you in the form of heat.

MOLECULE 2: Wee! Look how fast I'm going!

MOLECULE 1: Hi, Mom!

MOLLY: Those molecules are really moving. I can feel the heat right now.

WANDA: Yes! (SINGING) It's getting hot in here. But you know, another funny thing happens when air molecules heat up.

DEANNA: As those zoomies happen, the air molecules move further and further apart. But they don't have much of anything to stop them from just expanding, expanding, expanding further away from each other. And as they do so, they become less and less and less dense.

WANDA: Another way to say this is that there's less air in the same space since the air is so spread out.

FELIX: Oh, so that would be lower pressure, less air. Hotter air means fewer air molecules in an area.

WANDA: Right. And as those hot air molecules are moving apart, getting less dense and lower in pressure, they rise.

FELIX: Right, hot air rises like in a hot air balloon.

WANDA: Exactly. But as the air molecules rise away from Earth and get farther and farther apart, they start to slow down. And as they slow down, they get colder.

DEANNA: Cold air on the other hand, it's kind of getting more cozy with its buddies, becomes more and more dense and it starts to condense. If there's water, then it will start to condense that water into clouds.

WANDA: Those clouds might cool down the area or even rain on it. This cycle of hot air zooming around, rising, expanding, getting colder, and then condensing, this is what makes the weather.

[THUNDER AND RAIN]

Including my favorite, the rain.

MOLLY: My great aunt Honey always said she could tell when the rain was coming because she felt it in her joints.

WANDA: Ah, yes, there's a bit about that phenomenon in my handy-dandy-everything almanac. When it's going to rain, creaky elbows feel pain, right, because rainy weather comes with low pressure and this low pressure means there is less air around and less weight on our joints. So your joints can react by swelling up a bit and feeling achy.

MOLLY: So cool. But what happens if the weather changes and you're already up in the air like a bird?

WANDA: Hmm, well, let me consult the almanac section about birds and weather. [HUMS] Ah, here we go. When pressure goes from high to low, a robin knows it's time to go.

[BIRD CHIRPS]

MOLLY: So birds can sense air pressure dropping before the rain comes?

WANDA: Yes. It also says here, hawks flying high means a clear sky. Hawks flying low means a storm's going to blow.

[HAWK SQUAWKING]

It also says that scientists aren't quite sure exactly how birds sense changes in air pressure, but it seems like they're very sensitive to it. Looks like there are some other rhymes written in the margins here. If birds are singing in the rain, a fair weather will soon come again.

[BIRD CHIRPS]

MOLLY: Oh, because they can feel increasing air pressure, so they know the rain is on its way out.

WANDA: Yes. And here, when seagulls huddle close to shore, it's not a beach day anymore.

[SEAGULLS CHIRPING]

FELIX: Oh, they can sense bad weather so they can avoid the open ocean? That makes sense.

WANDA: Aha. Hmm, if your chickens will not roost, their self esteem might need a boost.

[CHICKEN CLUCKS]

Huh? A nightingale who will not sing might benefit from counseling? Oh, whoops, I flipped too far. That was the bird therapy section. Back to us humans. One of the times we definitely notice shifts in air pressure is when our ears pop. If you go way up high in a building or climb up a mountain--

FELIX: Or fly on an airplane?

WANDA: Yes, you know what that feels like. There can be lots of pressure behind your eardrum. You have to yawn, chew gum. That's air pressure in action Deanna explains it like this.

DEANNA: And what's happening there is that your body has air bubbles inside of it, especially in some of these things in your faces. They're known as sinuses. Once you are moving to an environment where there's less air, again, that air is going to want to move from where this higher pressure, which is inside your head, to the outside where there's less air. And so that change in pressure is what we experience as our ears popping.

WANDA: So before the air moves from one side of your eardrum to the other, it puts lots of pressure on your eardrums, which makes them hurt.

FELIX: It's like all the air behind your eardrum is begging to get out.

WANDA: And when you go on a plane and you're changing how much air pressure is around you very quickly, you notice it a lot. Oh, goodness, I have to hop on a 5 o'clock flight to Tulsa for my next broadcast of *Wanda's Weather Hour.* The TSA security lines are always 5,000,000,000,000 people long. Bye!

MOLLY: Bye, Wanda!

[MUSIC PLAYING]

The sky starts below our feet and ends at the Karman line around 50 to 62 miles above the Earth's surface.

FELIX: And the sky is made up of a bunch of air molecules--

MOLLY: Which are constantly moving from high pressure to low pressure.

FELIX: And this cycle of air movement creates the weather.

MOLLY: That's it for this episode of *Brains On.*

FELIX: This episode was written by Rose DuPont and Anna Goldfield and produced by Molly Bloom, Ruby Guthrie, and Anna Weggle, Arham Wildeslazi, Nico Gonzalez Wisler, and Mark Sanchez.

MOLLY: Our editors are Shahla Farzan and Sanden Totten. This episode was sound designed by Rachel Breeze. And we had engineering help from David Walton and Michael Osborne. Beth Perlman is our executive producer. The executives in charge of APM Studios are Chandra Kavati, Alex Shaffer, and Joanne Griffith. Special thanks to Brant Miller, Jenny Adams, and Alex Adams.

FELIX: *Brains On* is a nonprofit public radio program.

MOLLY: There are lots of ways to support the show. You can subscribe to our Smarty Pass, buy our books, or tell your friends about us.

FELIX: And you can submit questions, fan art, and mystery sounds. Head to brainson.org.

MOLLY: All right, Felix, are you ready to go back to the mystery sound?

FELIX: Yep.

MOLLY: Wonderful. Here it is again.

[CLUNKING AND GRINDING]

All right, any new thoughts?

FELIX: Ooh, it's hard.

MOLLY: It is a hard one.

FELIX: It kind of sounds like if you were to drop potatoes on something, like, in a bowl. I don't know.

MOLLY: Hmm. You're hearing food though. You're hearing, like, a food-related sound.

FELIX: Yeah, because, like, that plate.

MOLLY: Yes, that plate sound is very familiar. Just hard to know what food is happening there exactly. Are you ready for the answer?

FELIX: Yes, I am.

MOLLY: All right.

SHAUN: Hello. My name is Shaun.

KEPLER: Hey. My name is Kepler.

SHAUN: That was the sound of my dad cutting kernels off of a corn cob.

FELIX: What?

MOLLY: [CHUCKLES] I know, I know. Yes, cutting corn off a cob.

FELIX: Wow.

MOLLY: Yeah, it's a really hard one. But you know what? I'm giving you definitely at least, like, 75% credit for that one because--

FELIX: Whoo!

MOLLY: --you got the food and you got the plate and you got the utensils. So well done. Very good job.

[CLUNKING AND GRINDING]

Now it's time for the brains honor roll. These are the kids who keep the show going with their questions, ideas, mystery sounds, drawings, and high fives.

[LISTING HONOR ROLL]

We'll be back next week with more answers to your questions.

FELIX: Thanks for listening.