Sidedoor (S10E20) – Cosmic Journey II: Voyage into the Abyss transcript

Lizzie Peabody: Hey there, Sidedoorables. This is part two of our space odyssey in search of black holes. If you haven't heard part one, I highly recommend going back and listening to that one first. It's a story of bitter rivalry among the scientists that helped us get this close to black holes.

Lizzie: This is Sidedoor, a podcast from the Smithsonian with support from PRX. I'm Lizzie Peabody.

*[**ARCHIVE CLIP, NASA:** T minus 15. 12 ...]*

Lizzie: In the summer of 1999, NASA packed some very special cargo aboard the space shuttle Columbia and prepared to blast it into space. It was a night launch.

*[**ARCHIVE CLIP, NASA:** We have a go for engine start. Zero ...]*

Lizzie: Think of ground shaking, your sky lights up like the daytime kind of thing.

*[**ARCHIVE CLIP, NASA:** We have booster ignition, and liftoff of Columbia. Reaching new heights for X-ray astronomy.]*

Lizzie: Kimberly Arcand of the Smithsonian Astrophysical Observatory had a lot riding on this mission.

Kim Arcand: *I remember being super nervous because it's just a lot to build this spacecraft the size of a school bus and, like, pack it in a rocket and then launch it up into space in this violent way, and then drop it off in that cold void and just hope everything works perfect.*

Lizzie: The school bus-sized cargo was NASA's Chandra X-ray Observatory—a space telescope. After nearly three decades of planning and preparation on the ground, Chandra was heading to space.

Kim Arcand: *It goes a third of the way to the moon, so there was no—there were no takesy backsies, right?*

Lizzie: *[laughs]*

Kim Arcand: *There were no second chances, right? There were no missions that could be run that far. It had to work perfect.*

Lizzie: Seven hours after the space shuttle Columbia left Earth, it opened its cargo bay and ejected the telescope into space. As Chandra floated away from the space ship, its jets ignited, it began its orbit ...

Kim Arcand: *And right out of the gate, it just performed incredibly.*

Lizzie: Kim let out a sigh of relief. Now the real work could begin: hunting black holes.

Lizzie: This time on Sidedoor, it's a journey of discovery that's out of this world, as we peer through the eyes of the Chandra X-ray Observatory, and seek out some of the most mysterious and misunderstood things in space: black holes! What are they for? Where do they come from? And what we still don't know.

Lizzie: We'll find answers. But let me just tell you, it gets weird! This episode might just make you question—well, everything. So take your protein pills and put your helmet on, because we're heading into deep space. That's coming up, after the break.

***

Lizzie: There's a common idea that black holes are sort of like the villains of the universe, the end of a vacuum hose, sucking up everything in its path.

Daryl Haggard: *So I actually have this public lecture that I give that is just called "Black Holes Don't Suck."*

Lizzie: *[laughs]*

Lizzie: Daryl Haggard would like to correct this misconception. She's a professor of physics at McGill University. She says black holes are like Earth in a sense—they also have a gravitational pull. So just like asteroids fall to Earth, things fall into black holes, too. It's just that sometimes these things can be entire planets or stars.

Daryl Haggard: *But it's just there's no pressure, there's no suction, there's no—slurp!—in the black hole. It just doesn't do that.*

Lizzie: It would be like if you were walking down a city street and came across an uncovered manhole. If you step into the manhole, you're gonna topple down into the sewer. But the manhole is not going to suck you off the sidewalk and slurp you down. So we know what a black is not, so what is it?

Daryl Haggard: *Everybody has—well, I guess scientists who study black holes each kind of have their own version of what is a black hole, but I will share with you my favorite description.*

Lizzie: Imagine you're holding a baseball, and you throw it up into the sky as hard as you can. There's a reason it doesn't keep going up until it hits the moon: the reason is gravity.

Daryl Haggard: *Every gravitating body, including our Earth, has a so-called escape velocity. That's how hard you have to throw the baseball to get it to go into orbit or even to escape the gravity of the planet.*

Lizzie: Earth's escape velocity is about 25,000 miles an hour, or seven miles per second. That is how fast you'd have to throw a baseball for it to escape Earth's gravity.

Daryl Haggard: *That's really fast. I can't throw a baseball that fast but, you know, a rocket can accelerate something that fast. And we know this is true because we send rockets out into space all the time.*

Lizzie: And if you think the Earth's escape velocity of seven miles per second is fast, then think about this: a black hole's escape velocity is 186,000 miles per second.

Daryl Haggard: *The escape velocity is faster than the speed of light.*

Lizzie: Basically, nothing can escape the gravitational pull of a black hole—not even light. And that's why it's black. It's so dense that light cannot escape it. That makes it invisible. So as you can probably imagine, Chandra's job of looking for black holes is challenging. Not just because they're invisible, but because they're relatively small.

Lizzie: Some of the smallest black holes can have more than 2,000 times the mass of Earth packed into an area not much larger than Los Angeles. And these small black holes are known as 'stellar mass black holes.'

Daryl Haggard: *These black holes are born in supernova explosions.*

Lizzie: This is the type of black hole that is formed when a star dies.

Daryl Haggard: *The core, the hot, dense part in the middle, actually is left behind as a remnant, we would call it. And that remnant is either a neutron star or a stellar mass black hole.*

Lizzie: But these stellar mass black holes are still baby black holes, anywhere from a few to several hundred times the mass of our sun. On the other end of the spectrum are supermassive black holes.

Daryl Haggard: *These ones tend to be a million to a billion or several billions of times the mass of our sun.*

Lizzie: These supermassive black holes can be found smack dab in the middle of most galaxies. But even though they're supermassive they're still not that big! Take, for example, our friendly neighborhood black hole, Sagittarius A*. That's the black hole at the center of the Milky Way galaxy. It's a supermassive black hole with four million times the mass of our sun. And yet ...

Daryl Haggard: *All four million times the mass of our Sun in this black hole could be tucked into our own solar system in, you know, right around the sort of orbit of Mercury. These things are massive, but they are small, very small. And so it's hard to find small things at very large distances.*

Lizzie: But that's why Chandra is our secret weapon—or, well, tool—for finding black holes. See, Chandra has X-ray vision, and space is filled with X-ray light. Which, when astronomers first figured this out, was pretty perplexing.

Kim Arcand: *The original goal of Chandra was to understand the X-ray background. There was an amount of X-rays being found if you will, kind of all over, and astronomers weren't sure exactly what it was.*

Lizzie: The Smithsonian's Kim Arcand again. She says Chandra helped scientists figure where all these X-rays were coming from. And it turned out they weren't random, they were each coming from specific objects, like how the light in your house could come from a lamp, or the television or the clock on your microwave. But it has to come from somewhere. And I want to pause here because it might be helpful to understand what the heck X-rays actually are. Let me break it down for you.

Lizzie: We are surrounded by all sorts of electromagnetic radiation, but we can only see a fraction of it. To help you visualize this, picture a waveform moving up and down and up and down like a ping pong ball bouncing across a table. That's a radio wave. That's the widest frequency in the electromagnetic spectrum. Too wide for us to see. If we could, our house would be filled with the flickering light between our Bluetooth speakers and our phones, a glow coming from our FM radio.

Lizzie: Microwave and infrared waves are also on a frequency too wide for us to see, but as that frequency narrows, you get into the visible spectrum. This is where we can see stuff.

Lizzie: Now if the waveform gets even narrower ...

Kim Arcand: *Then we get into the energetic stuff, which is my favorite. I am biased. [laughs]*

Lizzie: The narrower the waveform, the more energy. And Kim says the next stage after the visible spectrum is ultraviolet light.

Kim Arcand: *Which probably most people know because, you know, we have to wear sunscreen on* *our skin to protect ourselves from the ultraviolet rays.*

Lizzie: This is why you can still get sunburned on cloudy days: we cannot see those UV rays. As you get towards the high end of energetic electromagnetic light, we finally get to X-rays. And this is how Chandra sees the world.

Kim Arcand: *The universe comes alive in, like, full color, right?*

Lizzie: *Hmm.*

Kim Arcand: *Pulsars, neutron stars, quasars, blazars, it's all—it sounds very fantastical, but ...*

Lizzie: *Blazars?*

Kim Arcand: *... there is a—yes. Yes! [laughs]*

Lizzie: I promise you blazars are a real thing, and I would try to explain them but you should probably just google it yourself. Now Chandra joins a whole team of stellar seers! There are telescopes orbiting the earth right now that can see in every form of light on the electromagnetic spectrum, from radio to visible light to X-rays and beyond.

Kim Arcand: *And each chunk of light offers you just a different perspective.*

Lizzie: And being able to see in every form of light helps us track down those invisible black holes. Since we can't see them, we have to look for clues in the universe, signs that their massive gravitational pull is bending light, or that a star may have disappeared. To get a sense of this search within the galaxy for black holes, imagine you're wearing a set of goggles that can see in every form of electromagnetic light.

Lizzie: Let's say you're looking at a spiral galaxy. It looks like a cluster of stars swirling outwards like a pinwheel or a cinnamon roll. If you switch your goggles to X-ray light ...

Kim Arcand: *You're gonna see these bright spots of light, things like exploding stars and X-ray binaries, which are just like pairs of stars, and some, like, diffuse clouds of hot gas.*

Lizzie: But if you turn your goggles onto ultraviolet light ...

Kim Arcand: *Now you're gonna see some of the slightly younger stars, and you'll see larger populations of those stars. And you'll start to see a little bit more of the spiral structure of the arms of the galaxy.*

Lizzie: Now let's say you take your goggles off and look at the galaxy in the visible spectrum.

Kim Arcand: *Now you're seeing, like, that true sort of classic view of a spiral galaxy with all of the bright pricks of light, and those dusty lanes that make up those spiral arms.*

Lizzie: But once you put the goggles back on and switch them to infrared ...

Kim Arcand: *Now you're kind of peering down to, like, the bones of the galaxy, all that, like, cool dust that you're seeing. Each different type of light really brings something different to the table, and you have all of them and it adds up, you know, something more.*

Lizzie: By seeing the galaxy in full color, you can start to see the signs of a black hole like little arrows pointing in their direction. Chandra has helped us discover that gasses in space, stars, and planets get trapped in black holes' massive gravitational pull. As these objects orbit the black hole they crash into each other, heating up and creating a glowing ring around the black hole.

Kim Arcand: *That immediately makes them more visible, right? These invisible objects become some of the brightest objects that we have in our universe when that happens.*

Lizzie: Now that we know what to look for when searching for black holes, it's time to see one up close and personal—and maybe even find out what happens if you get too close. Still to come, we climb aboard a very special vehicle and head directly toward the center of a black hole. Not only will we peer into the cosmic abyss, but we'll get to hear what a black hole sounds like. That's coming up after the break.

***

Lizzie: We're back, hunting for black holes, which we now know is like looking for a needle in a very very very very very very very big haystack. An invisible needle. But now that we've found some black holes, I have new questions. Like, what happens when we get close to one?

Lizzie: Let's say we're moving through space in a magic school ... van. And I'm your teacher, Miss Lizzle. Seatbelts everyone!

Lizzie: Since we're looking for a supermassive black hole and they're found at the center of galaxies, we're headed to the center of our galaxy, the Milky Way galaxy. And the black hole there is Sagittarius

A*. Say it with me, class. "Sagittarius A Star." Very good.

Lizzie: As we get closer to the center of the galaxy in our magic school van, we start to see swirling clouds of gas and dust.

Daryl Haggard: *That gas and dust starts to sort of spin and spiral in toward the black hole.*

Lizzie: Again, black holes don't suck, but they do have a strong gravitational pull, so things get stuck in their orbit. Gas and stars and all that stuff are orbiting around Sagittarius A like satellites orbit around Earth. But it's a lot of stuff. Imagine a NASCAR race with all those cars speeding around in a circle, but it's like Los Angeles traffic congestion on the race course.

Lizzie: And as we move closer, that spinning gas starts to flatten out into a disk. Or maybe picture a donut in space.

Daryl Haggard: *And the whole thing is sort of spinning, so you can imagine like a spinning donut in the kind of outer regions near the black hole. And as you get in closer and closer to the black hole, the energies are getting higher and higher and higher.*

Lizzie: As we look out the windows of the van, we can see the swirling gas speeding up as it circles the black hole, like water spinning around a drain. And the swirling gas is getting hot and starting to glow.

Lizzie: As we approach the black hole, gravity starts to pull on the Magic School Van. The laws of physics start to bend. Since the magic school van's headlights and hood are closest to the black hole, they're getting pulled in faster than the rest of the van. It's getting stretched out!

Daryl Haggard: *All of my German colleagues have this amazing term for this. They refer to it as 'Spaghettification.'*

Lizzie: *Oh my gosh!*

Kim Arcand: *It's kind of like spaghetti on your fork.*

Lizzie: *Oh!*

Kim Arcand: *But molecular.*

Lizzie: *Molecular spaghetti.*

Kim Arcand: *[laughs]*

Lizzie: And while molecular spaghetti is kind of a fun image, it's not too great if it actually happens to you.

Daryl Haggard: *You're definitely for sure dying. For sure. Just so people know.*

Lizzie: Good thing your parents signed those permission slips! But this is a *magic* school van, so we'll be okay. But as the gravity of the black hole pulls on the van, it's basically taking it ...

Daryl Haggard: *And just, you know, stretching it into a long piece of pasta as it orbits around the black hole.*

Lizzie: Okay. So now we are long strands of linguine swirling around in space and approaching the final boundary of the black hole: the event horizon. This is like the rim of the uncovered manhole, the point of no return.

Lizzie: Now let's say we're standing at this point of no return, and there's a little star next to us. And we just oh, kick it in.

Daryl Haggard: *It might just go bloop, just like a hole in one. If you shoot the star straight in the black hole, it will just go straight in.*

Lizzie: *Oh!*

Daryl Haggard: *If you kick it slightly, you know, kind of like going down the drain in the bathtub, if you kick the star a little bit off perfect, that's when it gets shredded and makes a kind of more interesting energetic encounter.*

Lizzie: The abyss on the other side of the event horizon is the black hole. In astrophysics, it's called the singularity. And what happens inside the singularity is a complete and utter mystery.

Daryl Haggard: *There are probably 800,000 theories about what happens to things behind the event horizon, but it's hidden.*

Lizzie: But let's say one of the passengers on the Magic School Van is an astrophysicist from Yale named Priyamvada Natarajan. And she really wants to know what happens inside the singularity, so she jumps out of the van and into the blackness.

Priyamvada Natarajan: *I think it would be fair to say that if I was falling, I wouldn't materially exist at that point.*

Lizzie: Priya says all of the molecules and atoms that she's made of would technically still exist ...

Priyamvada Natarajan: *But they will no longer be in the form that is recognizable as Priya, or even dismembered Priya, right? It would be smithereened Priya.*

Lizzie: Remember how the laws of physics bent as we approached the singularity? Well, once something enters it ...

Priyamvada Natarajan: *There's a point where all known laws of physics break down. Like, we don't have a description of what really happens either to light or to matter.*

Lizzie: So it's a mystery what happens to all the stuff that falls into a black hole. Scientists call it 'the informational paradox.'

Priyamvada Natarajan: *Stephen Hawking had a very nice analogy. Suppose you have an Encyclopedia Britannica, and I look up and read up everything about New Haven, you know, inhabitants, 120,000 people, blah, blah, blah. All the kind of entry on New Haven. Then I put the Encyclopedia Britannica in a box, in a closed, tight box, and I burn it down. And all the ashes are still inside that box. They've not left. They are right there, okay?` But we no longer know how the description of New Haven is actually saved in those ashes. And we also no longer know how to retrieve it, but clearly that is there somehow, somewhere, in some form.*

Lizzie: There are certain thresholds beyond which we as humans just cannot see.

Lizzie: But supermassive black holes aren't just devouring stars and planets, consuming their energy and becoming all powerful. They give back to the cosmic community in the form of things we call 'relativistic jets.'

Priyamvada Natarajan: *This, if you will, is like the spit of black holes.*

Lizzie: *[laughs]*

Priyamvada Natarajan: *Well, it's more energetic than the spit because spit doesn't have the, you know, the fire hose, if you will, of the black holes.*

Lizzie: And while spitting on the universe doesn't sound all that charitable—it actually sounds downright rude—this 'spit' is actually a good example of how black holes don't suck. In fact, they play a really important role in our universe.

Priyamvada Natarajan: *So it turns out that black holes also generate and push matter and energy out. So you can think of a black hole now as a kind of piston that is kind of pushing energy into the centers of galaxies. And so now we realize, in fact, that they are a key ingredient now in modulating the formation of all the visible stars that we see in the universe and galaxy.*

Lizzie: Priya says this is a relatively new finding.

Priyamvada Natarajan: *Suddenly these sort of invisible entities now start to play a very important role in determining how many visible things we're gonna actually see, how many stars you can actually form.*

Kim Arcand: *And now it's kind of taken for granted that most of these normal galaxies have a supermassive black hole powering them at the core. That was not really a thing when I started working for Chandra back in 1998, right? That was not necessarily known.*

Lizzie: And a lot of this information has come to us from the Chandra X-ray Observatory.

Priyamvada Natarajan: *Chandra has played a very, very important role in establishing the starring role of supermassive black holes.*

Lizzie: Over the past 25 years, Chandra has used its X-ray vision to peer deeper into the galaxy than any other X-ray telescope. Let's drive our Magic School Van back down to Earth, hop on I-95 and head towards Harvard to visit the Smithsonian Astrophysical Observatory. From there, we can see what Chandra sees. Let's take this image, for example.

Kim Arcand: *The Chandra Deep Field South. It's the deepest image ever created. Chandra looked at this patch of the sky for, like, 40 days and 40 nights.*

Lizzie: *[laughs] How biblical!*

Kim Arcand: *I know, it really is! Seven million seconds looking at this one patch of the sky. And the resulting image, well, it's beautiful to an X-ray astrophysicist.*

Lizzie: Looking at this patch of space you see a black rectangle dotted with multicolored spots, tiny and scattered. Nothing in particular stands out, but what you're actually looking at ...

Kim Arcand: *The spots, the dots that you're seeing, they aren't stars. They're actually black holes. So it's the highest concentration of black holes ever captured.*

Lizzie: About 5,000 black holes in an area of sky you could cover with your thumb! Not only are you seeing thousands of black holes at once, but you're looking back in time.

Kim Arcand: *And really what it does is it gives us our best look yet at the growth of these black holes, like, over billions of years. And some of those pretty soon after the Big Bang.*

Lizzie: If you've got your phone, you can pull up this image of the Chandra Deep Field South. But even if you can't see it, you can HEAR it. You're hearing it right now, actually. Kim made this sonification of the Chandra Deep Field South.

Kim Arcand: *I had been inspired by a dear friend and colleague, Dr. Wanda Diaz. She is an astronomer and a computer scientist who became blind when she was a teenager.*

Lizzie: Kim started by assigning each celestial object a specific note or pitch.

Kim Arcand: *Based on its color, its energy. Where there was low energy, it was a lower sound. Where there was higher energy, it had a higher sound. So as you're scanning through this field of thousands of black holes, it's done in stereo, and you can kind of feel—I don't know, just a population of black holes around you.*

Lizzie: And you might be thinking, "Well, this isn't actually what a black hole or a star or a supernova sounds like." And you're right.

Kim Arcand: *Yeah, so it's not holding up a giant microphone to the sky, right? Instead, it's another representation.*

Lizzie: Think about it: most images you see of space are actually representations, since we can't see most of the types of light in the universe.

Kim Arcand: *So, like, the images from these telescopes that are in light we can't see, we have to translate that data into something we can see. But it's still invisible light, right? So X-ray light, we can't see. So instead of changing it just into something you can see, you can translate it into something you can hear.*

Lizzie: Now the galaxy is alive in both sight *and* sound. Let's use Chandra to listen to the supermassive black hole at the center of the Perseus Galaxy Cluster.

Kim Arcand: *Quite a few years ago, using Chandra, scientists found that the black hole was sort of burping out into the hot gas around it, and that was causing pressure waves—which are sound waves.*

Lizzie: *Huh!*

Kim Arcand: *And those waves were actually detected in the image from Chandra. And so they did some very clever math, and were able to determine that it was a B flat about 57 octaves below middle C.*

Lizzie: *Oh my gosh!*

Kim Arcand: *So very low.*

Lizzie: That's way too low for humans to hear.

Kim Arcand: *What we did is we brought that note back up into the range of human hearing so that those sound waves could be heard in a unique kind of way.*

Lizzie: That's what you're hearing right now.

[audio]

Lizzie: *Oh my gosh, it sounds like a space monster.*

Kim Arcand: *[laughs] Yeah. Yep. We get that a lot.*

Lizzie: *I mean, I know you've said it's not a cosmic Roomba, but it sounds kind of like a cosmic Roomba.*

Kim Arcand: *[laughs] All right. It does sound like it, but I don't think it is.*

Lizzie: Behold, a black hole in all its glory! But not all black holes look—or sound—alike. For example, M87, the first black hole we ever took a picture of ...

Lizzie: *M87 is beautiful. It's much more kind of melodic.*

Kim Arcand: *Yeah.*

Lizzie: And the supermassive blackhole at the center of our galaxy, Sagittarius A* ...

Sidedoor (S10E20) – Cosmic Journey II: Voyage into the Abyss transcript

Lizzie: *Oh, this is very different!*

Kim Arcand: *Yeah.*

Lizzie: *This is more like a jet taking off.*

Kim Arcand: *Yeah. Yeah.*

Lizzie: *And then—but it's got a wavelike surf from a great distance.*

Kim Arcand: *Yep. So it's the data, right? The data and, like, that scientific information that's captured in that—that image is really driving the sonification.*

Lizzie: All right class, let's turn our Magic School Van back home towards the Smithsonian in DC.

Lizzie: Over the course of our journey, we've learned that black holes don't suck. They live at the center of most galaxies eating planets and stars, but also pumping matter back out into space, playing a vital role in the regulation of the universe. They may sound like monsters or vacuum cleaners, but they can also sound sort of enchanting.

Lizzie: Our journey to find black holes has been a long one, but in just a hundred years, we've made the seemingly impossible possible.

Lizzie: Albert Einstein opened the door to their existence in 1915, although he himself couldn't fathom something like this actually existing. Subrahmanyan Chandrasekhar showed them to be mathematically possible in 1930—and nobody believed him. In the 1960s, we discovered the first black hole: Cygnus X-1. And then finally, in 2019, the world laid eyes on a black hole. This enigma of the cosmos was there in plain sight, a reality we could see.

Lizzie: Thanks to the Chandra X-ray Observatory and its quest to find black holes, we've gazed deeper into the universe than ever before, and have discovered questions we can't answer—at least, not yet.

Lizzie: Daryl says it's an exciting time to be a scientist. Chandra has opened our eyes to see how space is both beautifully simple and wildly complex. All from the comfort of our home planet.

Daryl Haggard: *We've learned so much about the universe without being able to travel into it. And I think that we could take kind of a combination of humility from that and also hope because it's so endlessly exciting and interesting just to be here and to do this.*

Lizzie: You've been listening to Sidedoor, a podcast from the Smithsonian with support from PRX. To learn more about the Chandra X-ray Observatory and the Smithsonian Astrophysical Observatory, check out our newsletter. You can subscribe at SI.edu/Sidedoor. We'll include links to Kim's sonifications of black holes and other space stuff, too. They are pretty cool.

Lizzie: And you can join the Smithsonian this summer for a cosmic journey. We'll travel from our closest star, the sun, to the far reaches of the universe, with events and virtual resources from across the Smithsonian. Visit our website, SI.edu/cosmicjourney, for the full event schedule. And you can also follow along on social media @Smithsonian. If you follow us @sidedoorpod, we'll share plenty of stuff there as well.

Lizzie: For help with this episode, we want to thank Kim Arcand, Priyamvada Natarajan and Daryl Haggard.

Lizzie: Our podcast is produced by James Morrison and me, Lizzie Peabody. Our associate producer is Nathalie Boyd. Executive producer is Ann Conanan. Our editorial team is Jess Sadeq and Sharon Bryant.

Lizzie: Tami O'Neill writes our newsletter. Russell Gragg writes our transcripts. Episode artwork is by Dave Leonard. Extra support comes from PRX. Our show is mixed by Tarek Fouda. Our theme song and episode music are by Breakmaster Cylinder.

Lizzie: If you have a pitch for us, send us an email at Sidedoor(@)si.edu. And if you want to sponsor our show, please email sponsorship(@)prx.org.

Lizzie: I'm your host, Miss Lizzle. Thanks for listening—and coming on the Magic School Van.

Daryl Haggard: *Wow. I apologize if any of your other experts listen to this and they're like, "Oh, Daryl. She's so full of [bleep].*

Lizzie: *What?*

Daryl Haggard: *[laughs] Yeah. Just the theorists who are like, "I have an idea of what's happening inside there!" Including my brother who is a theorist. I'm sure some will be like, "We have lots of ideas," but I mean, the truth is that we can't test them, so I'm an empiricist.*

Lizzie: *I want to be at your Thanksgiving dinner table.*

Daryl Haggard: *No, you really don't. [laughs]*

-30-