Neil

So, I think I'm sitting in Toronto right now and I think you're sitting in Waterloo right now. And I know we're both in the same country right now, and we're on the same planet right now, but where are we planetarily speaking right now?

Katie

Yeah, so, well, so we're orbiting the sun, right? So, so our, our, the earth is, is orbiting the sun and gets around once a year. And then our sun is orbiting the center of the galaxy. And so the sun is moving at about 220 kilometers a second in the direction of the constellation of Cignas, if you ever were interested in that. So, you know, going around around the galaxy. And so

Neil

We're orbiting the sun, the sun's orbiting what?

Katie

The sun is orbiting the center of the galaxy.

Neil

So the galaxy, what's at the center of the galaxy, nothing what's at the center there?

Katie

Well, a lot of stuff. So, so the Milky Way Galaxy is a kind of disc shaped collection of stars and gas and dust and black holes and, and, you know, all kinds of things like that. And so if you, if you've seen , if you imagine a galaxy in your head, you probably imagine like a spiral galaxy with, you know, spiral arms. So our galaxy looks a lot like that. It's got a kind of bulge of stars in the center, and then it's flatter around the edges, it's sort of disc shaped and in the center and the bulge, there's a whole lot of stars. There's clusters of stars. There's just a lot of a lot of star formation and stuff happening there. There's a lot of gas and dust and there's a super massive black hole. It's about 4 million times as massive as the sun, we call it Sagittarius A star. So the star part is the it's part of the name. It's not actually a star, but it's Sagittarius A star. That's the, the name for it. And we've, we've recently obtained some really cool imagery of, Sagittarius A star, the event, horizon telescope, project produced

Neil

I saw your amazing geek out video on YouTube about it.

Katie

I, well, yeah. Yeah. Well, so there've been two. So the event horizon telescope produced images of two black holes, Sagittarius A star is the, is our black hole. And that image came out more recently. The first black hole picture they got was of a, a, a super mass black hole in the galaxy M 87 which is, which is a, a very massive galaxy kind of more distant. So anyway that's, that's where we are. And the other thing that's important to know about where we are is that the Milky Way Galaxy and the Andromeda galaxy, which is a big disc shaped galaxy you know, kind of relatively nearby as galaxies are concerned, we are moving toward each other. So the Andromeda galaxy is moving toward us at 110 kilometers a second from our perspective, and we're gonna merge in about 4 billion years. So that's where we are at the universe.

Neil

I read about that in your wonderful book. So, we are orbiting the sun, the sun and our solar system is orbiting the center of our galaxy called the Milky Way galaxy. This galaxy, is it orbiting something?

Katie

No, but it's, well, it it's part of the local group of galaxies, which is the creative name for the group of galaxies nearby. So it's the Andromeda galaxy, Triangulum, the large and small Mengelonic clouds. So we're in this little group of galaxies, so we're kind of gravitationally bound, but we're not in like steady orbits. We are moving toward Andromeda, Andromeda is moving toward us. We're gonna, when we get close, we'll probably loop around a little bit before colliding. And the Triangulum Galaxy's gonna do the same thing. But yeah, we're not, we're not an orbit on that scale. Exactly. We're just kind of moving around.

Neil

Okay. I got so many more questions, but I wanna, I wanna use them as a lever to talk to me about them through the discussion of your first book, which I believe is a book that you read as a child. Yes. Growing up in California. Yeah. It is called A Brief History of Time. Yes. I wanna describe it for our listeners so that they can pitch your holding it in a bookstore. Sure. And I'm gonna ask you to tell us about your relationship with it. A Brief History of Time from the big bang to black holes by Stephen Hawking was published in 1988 by Bantam Dell publishing. I am holding the Navy blue hard cover in my hand with a glossy jacket. Stephen Hawking, sitting in his wheelchair with a, I don't wanna say glum, but like a, a flat, like this is how it is kind of expression on his face with a bunch of stars behind them.

Neil

At the bottom. It says with an introduction by Carl Sagan book came out in 1988, sold 25 million copies with a was a Sunday times best seller for 237 straight weeks. Stephen Hawking was an English theoretical physicist, cosmologist and author best known for research surrounding relativity, quantum mechanics and black holes. Born 1942 in Oxford died 2018 and Cambridge. He was the professor of mathematics and later the director of research at the center for theoretical cosmology at the University of Cambridge. Stephen Hawking for those that don't know, also suffered from a motor neuron disease called ALS that gradually paralyzed him, including his speech in A Brief History of Time he talks about the structure, origin development and eventual fate of the universe, Dewey decimal heads file this one under 5, 2, 3 0.1 for natural sciences slash astronomy slash astrophysics slash universe. Katie, please tell us about your relationship with A Brief History of Time.

Katie

Yeah. So when I was, when I was a kid, I was really curious about all kinds of things. Right. And I was, I was the kind of kid who was like always sort of taking things apart and putting them back together. I was always trying to understand how everything worked. And at some point, you know, I kind of, I, I saw things like, I, I got interested in like science fiction. You know, those children's magazines that they, that they children's science magazines where sometimes they talk about like the big bang or planets or black holes or whatever. And so I guess it, it must have been just a year or two after it came out. I, I found A Brief History of Time. And and I, I remember reading that book and, and at the time, you know, I was 10 years old or something. I I didn't understand everything in the book. You know, it was, it was it's, it's still, still not, you know, it, it's a, it's a very popular book. It's not the most accessible book, I think in terms of like, it's, it's elegant, but it's not, I

Neil

I show it to a friend yesterday. He said, ah, the book everyone owns and no one has read. Yeah.

Katie

Yeah.

Neil

But, but the introduction, the first couple chapters are very accessible.

Katie

Yeah. Yeah. So, but it gets into some deep stuff. And so I remember that when I read it, I didn't understand everything in it, but I understood that this book is about, you know, the big bang about the biggest questions in the universe about black holes, about time. And when I, you know, am looking to the book, you know, it talks about the, the author is described as a cosmologist, right. And cosmologist is someone who studies the cosmos. And I was like, well, clearly this is what I wanna be. I want to be a cosmologist. I want to study the universe and how it works. And that was just, that was the most fascinating thing to me. The thing I, I could, I, I imagined like this would be the best way to spend my life is just thinking about these big questions, trying to understand the universe. So I, I wanted Stephen Hawking's job <laugh> as soon as I read that book,

Neil

You said you were a curious kid, but what about that job or the contemplation of the cosmos for the rest of your life was so appealing?

Katie

I just like, it was, it's the biggest questions, right? It's, it's the most fundamental questions in the universe. Like the, the question of where we came from, of how the universe works. Why is it here? How are, how does, you know, how does it all fit together? Where are we going? What's gonna happen to us? You know, all of those big, big questions were things that I just found utterly fascinating. And it just, it was an extension of my curiosity about everything. You know, I wanted to know how the TV remote control worked. I wanted to know how the bike gears worked. I wanted to know how black holes worked <laugh> and just like, I, I had this, this curiosity about everything, and I liked the idea of, you know, of spending my time, just thinking really hard about hard things, right. <Laugh> like, I liked math, you know, I liked I wasn't, I wasn't like a, a math prodigy or anything, but I, I liked thinking about things that are logical and where you can solve a puzzle, you know? And, and so cosmology was sort of the biggest puzzle and, and you solve it by, by learning these, these you know, rules about the universe and, and logically fitting everything together in a way that makes sense, that that kind of thinking that kind of working really appealed to me.

Neil

So this book is called A Brief History of Time. Time,. I wanna pause on that word time, page 16 of your book, you write, everything you see is in the past, as far as you're concerned, if you look up at the moon, you're seeing a little over a second to go, the sun is more than eight minutes in the past. And the stars you see in the night sky are in the deep past, I've even heard you go into detail about how two people in a room together are actually at occurring in their minds at different times. Yeah. So how do you define time?

Katie

<Laugh> so if you are, if you're a physicist, then time is one part of the coordinate system that you're using to sort of think about how things are happening in the universe, right? So, so you have three, three directions of space, right? You have sort of front back left right up down. And then you have time, which you can think of as another dimension, as another dimension, where on this sort of grid on, on which things happened. So like, if I said that, you know, if I said that, that I don't know a balloon pops, right. I can tell you where that happened. And I can tell you when that happened. And that's, that's those, those sort of four coordinates, right? There's X, Y, Z, and T, right? So X, Y, Z are telling you the spacial part of that coordinate system, and then T is telling you the time.

Katie

So that was an event that happened at a particular space at a particular time. Right? so generally in physics, we think of time as one part of that coordinate system that we use, when we're talking about how things occur in the universe, it gets complicated because how you move through space affects how you move through time. And that's, that's part of relativity. So if you're moving very, very quickly, then your experience of time is gonna be different from someone who's moving slowly. If you are very close to a large gravitating object, like a black hole, your experience of time is different from somebody who is not near a large gravitating object. And so we all kind of move through space and time in different ways. And so in the same way that, you know, if you're you're, you trace a path through the world, as you move through your life, you also trace a path through space, time through this, this sort of grid of space and time as you move through your life.

Katie

And the way you're moving through the time, part of that is dependent on how you're moving through the space. Part of that they're connected to each other. And so we are all tracing our own world lines. They're called world lines, these paths through space time. And sometimes those world lines meet when you have an event where you, you know, go and shake hands with someone you're at the same place at the same time. And sometimes they don't meet, you know, sometimes you're you pass by a, a street corner. Somebody else passed by, though, you know, 10 minutes before. So you're at the same place, but not at the same time. Sometimes you're, you know, you're 50 meters apart, across, away from someone else you're at the same time, but not at the same place. Like, so there's, it's, I think of time as being part of this sort of coordinate system of this space time fabric, essentially. And that fabric is malleable, which is the weird thing about relativity is that, that this space and time can bend in different ways depending on what you're doing. And what's, what's there.

Neil

Yeah. I'm trying to put my finger on that Einstein quote that you may know. And I don't about like the pretty girl and the oven burner.

Katie

I don't know that

Neil

One. Okay. Well, I won't, I won't try to do it, but he is like, you know, cuz I was the reason I wanted to use that quote was because it's like, why do our perceptions of time change all the time? Mm-Hmm <affirmative> like, why, how come you know a minute can feel like an hour in certain situations and an hour can feel like a minute in others. How come?

Katie

That's psychology though. That's that's that's human experience. That's based on how our brains process information and how we emotionally react to information in different circumstances. And some of that is because, you know, when, you know, we evolved from creatures who needed to think very, very quickly when they're under threat and you know, so there, there are different ways that we, that we experience time subjectively just based on our psychology based on our biology. But, but what I'm talking about is we experience time differently, physically. So if, if you were an astronaut for example, and you're orbiting the earth, you're gonna experience time slightly differently than someone who's at home. Not in a way that you can perceive. So you don't actually, it's, it's such a tiny difference. You would not notice it. But it's measurable. I mean, even I, then they've done experiments where they take a clock and they put it at the bottom of a tower and they take another clock and they put it at the top of a tower and they leave them there for, you know, a couple weeks or whatever. And you can tell that they're a little bit off afterward, right? Like they, yeah, like the time that, because the time is moving just a little bit slower on the surface of the earth than it is a hundred meters in the air.

Neil

See, okay, I'm gonna throw another thing at you on this time. I don't wanna pause this time thing cuz, cuz we also got this Gregorian calendar that we came up with 500 years ago and we used it blocked ourselves backwards, you know, to, to couple thousand years ago, but it's this annual cyclical kind of linear time. And then there's also, I've been reading a lot about the, the sort of more cyclical universal calendar that people have followed for many hundreds of thousands of years, the circle of life type thing and growth and regrowth and so on. How do either of those calendars that we think about maybe both of them fit into this concept of time that you're describing?

Katie

I mean that none, no calendars are really are really connected to the physical aspect in, so the interesting thing about time in, in physics is that while, while you can move in any direction you want in the three dimensions of space, you can only move in one direction in time. Now how quickly you move through that through time is dependent on, on what you're doing and where you are, but the direction you're moving through time is constant. You're only gonna move through toward the future. You cannot move toward the past physically. So there's no, there's no cycle in that sense. Like, you know, we, we started at the big bang and we're going toward the end of time, whatever that turns out to be, maybe there will be new universes born, in my book, I talk about some cyclic universe models where, you know, our universe ends and a new one comes up after it.

Katie

That's, that's so many trillions and trillions of years in the future. We're, we're not, that's not really relevant to human experience. We make calendars to, to mark the passing of time just for our own reasons because we live on a, on a planet that has seasons and days and, and you know, these are important things to our, our experience and they're important to our biology. We have internal clocks that, that respond to just respond to the passive time. But from a physics perspective, we're just, we're moving toward the future. We're just moving at different rates in different ways, but we're all moving toward the future. And the, the, the, the most important clock in, in physics is the second law of thermodynamics. So this is the

Neil

Entropy, this is entropy

Katie

Yeah. So this is the idea that that disorder increases into the future. So whatever's happening, there's more entropy. Entropy is just disorder, essentially. There's more entropy as you go toward the future. And that determines in, in a sense the direction of, of time. Right? So, so the future is defined as the direction in which entropy is increasing. And so, and that's, you know

Neil

The future is the direction that entropy's increasing

Katie

Yeah. I mean, there, there are different ways to, to define things, but I think the sort of most, most sort of accepted way to think about the, the future versus the past is that the future is the direction in which entropy is increasing. So, you know, if you, if you you know, scramble an egg that's something that increases the entropy in that situation, you had a, a sort of very simple, very orderly egg, and then you scramble it. Now it's a mess. You can't really unscramble that egg. I mean, if you, if you tried to do that, if you tried to take every little egg molecule and put it back, you know, with very careful tweezers or whatever, and you had to, you you'd have to sort of undenature the proteins or whatever, move the move, the atoms around in principle, you could put the egg back together. If you were very, very careful, but you would expend so much energy in the process, you would get hot and sweaty, you would, you know, you'd have you would expel waste gases into the room. And so on the total entropy in the room you're in, is gonna be higher at the end, even if you put the egg back together

Neil

But what if you eat the egg in any form and it goes through your body mm-hmm <affirmative> and eventually it turns into food that a chicken eats and produces a new egg.

Katie

I mean, that that's, so that's something that happens over

Neil

Is the entropy declining?

Katie

There's always gonna be waste in that process. So, so there's always gonna be some kind of disorder that's that's the result of whatever process is occurring. So this is, this comes back to people, this comes, this is relevant to things like a perpetual motion machine. So if you, if you try and spin a wheel and keep it spinning forever, it's gonna eventually slow down. And the reason is that it's gonna lose a little bit of energy to friction. It's gonna make some heat, like there's gonna be some waste. So something's gonna break, like it's gonna decay a little bit. And so in the end, like it'll be more disordered. There'll be more heat. The, the wheel will stop spinning. And it's the same with, you know, you can try and put together some kind of cyclic thing for, for life, for food or whatever, but there's always gonna be more disorderer at the end than there was at the beginning.

Neil

Got it. I have, okay. I wanna, I wanna keep going on these rabbit holes and I want to keep moving through your books. By the way, there's a quote from Stephen Hawking in, in this book where he says if time travel is possible, where are the tourists from the future? Mm. And like that gets to the, do you believe in aliens question? <Laugh>?

Katie

I, I suppose I mean the question of time travel

Neil

Fermin paradox, I mean, the idea that if the universe is so vast, how can I be any other living things yet?

Katie

Yeah. Oh, that's a, that's a long conversation. <Laugh> so, I mean, the question of, of whether or not time travelers would've come back. Yeah, I mean, that's a good question. The physically, it seems that time travel into the past is probably impossible. There's you can, you can mess around with the equations and set up certain conditions in which technically you can have sort of a world line that bends back on itself. So you can go back to, to your own past, if you, if you mess up the equations in a particular way. But it doesn't seem to be actually possible in terms of practical you know

Neil

You can do it mathematically, you can't do it physically, just the same way that you say in your book, you can see the big bang, but we can't get to it.

Katie

Well, yeah. I mean, that's, that's a, I would call that a slightly different thing, but, but yeah, I mean, you so mathematically in the sense that, that if you, if you were able to manipulate space and time, however you wanted then you could set up a situation where the equations would admit the possibility of a cycle, what we call a closed timeline curve. So a, a, a world line that meets itself of, of travel into the past. But in practice, it, it, it, it seems to involve things that we don't think exist in the universe and ways of manipulating space and time that we don't think are possible. So probably it can't happen, but we don't.

Neil

What about your belief in aliens?

Katie

So the, so then the alien thing <laugh> so, so that's a whole other question because, I mean, yeah, so the Fermin paradox is this question of, you know, why, if there are aliens out there, why haven't they come to visit us? You know, and that's, that gets into whether or not you think that that aliens would want to come and visit us, or, or if alien life is gonna be the kind of technological life that can create spaceships and, and, you know, spread out through the galaxy. And then there's, there's a lot of questions around that.

Neil

Well, what about you personally?

Katie

Well, I think that, so my thinking about alien life is, you know, we have a reasonably good idea of how life originated on earth. I mean, we're not certain obviously there are some questions, but the, the best hypothesis we have is that there are certain chemicals that were present in the early earth. Those are chemicals that are very common in the, in the universe. We've seen traces of these things, amino acids and things on comets and, and other places in the universe. There were chemicals that were present and there were sources of energy, like like hydrothermal vents underneath the ocean. And over time, by chance, some chemicals kind of bounced off of each other. Chemical reactions occurred there was a source of energy. It, it sort of gradually evolved from chemistry to biology and the first single cell organisms appeared through just a very, very long time.

Katie

<Laugh>, you know, billions of years of, of sort of random, random sort of collisions of, of molecules. And then that led to biological evolution and then that led to life. So we think that that's probably what happened on earth. The thing about that, though, is that the conditions that were present on the early earth are not unique in the universe. You know, we know that there are moons of the gas giants yeah. In our own solar system, that, that seem to have hydrothermal vents underneath their, underneath their icy shell covering their oceans. And, and that suggests that, you know, probably they have the right chemicals, the right conditions that life, life could arise there, whether or not it has, we don't know, maybe it's pretty rare, but there are something like, you know, four hundred billion stars in our galaxy. Right. a lot of those probably have planets. We think, you know, somewhere around a planet per star is, is somewhere around the average. Some of those planets are probably the kinds of planets that can have these these conditions. So the idea that we're the

Neil

Did you say 400 billion?

Katie

Yeah. Somewhere around 400 billion,

Neil

400 billion stars just in our galaxy,

Katie

Just in our milk way

Neil

Like how many galaxies are there?

Katie

So there's something like 2 trillion galaxies in the observable universe, as far as we know. So, so the idea that, that, that, we're the only place in the universe where life has arisen seems, seems just shockingly unrealistic to me. I mean, and people will argue about this. You know, I get into arguments about this, where people are like, well, you know, but you don't know for sure, like, we don't know how common this stuff is, but the, I feel like the hypothesis that we are so special <laugh> that it's only happened here is, is such a low probability hypothesis that we might as well reject it.

Neil

4 billion stars in the galaxy

Katie

400 billion,

Neil

400 billion stars in the galaxy, let's hang out in the galaxy for a second as we talk about A Hitchhiker's Guide to the Galaxy by Douglas Adams published in 1979 by pan books, the cover depicts outer space with stars and planet scattered around. And one with a goofy facial expression, a tongue hanging out of an open mouth and flapping hands. Douglas Adams was born in 1952 in Cambridge, UK. You got a thing about Cambridge. Died in 2001, very sadly of a heart attack at age 49, English author, screenwriter, essayist, humorist satirist, and dramatist probably pronouncing those wrong whose most famous work is A Hitchhiker's Guide to the Galaxy, which sold over 15 million copies. What's it about? Seconds before the earth is demolished to make way for a, a galactic freeway, Arthur D is plucked off the planet by his friend Ford prefect, a researcher for the revised edition of the book called A Hitchhiker's Guide to the Galaxy, who for the last 15 years has been posing as an out of work actor. File this one under 8 2, 3 0.914 for 20th century fiction. Katie, tell us about your relationship with A Hitchhiker's Guide to the Galaxy?

Katie

So this is a book. I don't remember exactly how old I was when I first read it. I was pretty young. I, I enjoyed science fiction in general, and A Hitchhiker's Guide to the Galaxy was sort of the ultimate, the ultimate sort of funny science fiction novel. It was, I loved that. I loved that it was so witty, you know, I loved that this book had so many jokes and, and, you know, really amusing commentary about life and the universe and everything like just, it was, it was a hilarious book. It was well written. It was, it was fun ideas in science fiction. And it was, it was just, it was a joy, you know, to read and, and I, I carried it around with me. Like I would go, I would travel and I would keep it in my suitcase, just so I had something great to read if I needed to read something. I, I, for, for many years,

Neil

The backup book.

Katie

Yeah. It was my backup up book for a very long time. And it was kind of a, it was just something that was, that was pleasant and, and familiar. You know, I memorized passages of it. I, wow. I got, I just, it, for, to me, it was, it was such a, it was such a joy, you know, it was just playing with ideas about science playing with language. I really loved that.

Neil

The meaning of life is 42.

Katie

Yeah, yeah, yeah. Just like stuff like that, just absurdist, but, but also also just really fun, you know, really, and really, and sometimes very cutting in, in its commentary. And I, I really, really enjoyed that.

Neil

I feel like some of these words you've been describing, absurdist, fun, you know, you could describe your own Twitter feed with them today. You've got this joyous, fun absurdist, sometimes cutting. I've heard you talking about antimaskers and so on, on Twitter and at Astro Katie, for those that don't follow you, you've got half a million people you're talking to you're broadcasting to kind of on a regular basis, hanging out in the galaxy for a second. You know, there's people on the planet today who believe that we gotta, we gotta be like hitchhikers. We gotta be like Elon Musk. We gotta colonize space. We gotta settle on Mars. And yeah, we might put the, the sort of starting seeds of that in place today. And it won't happen for generations. What's your opinion on the whole colonizing other planets thing. And cuz it seems to be part of the sadness of being a theoretical astrophysicist that you can't go to all the places you're talking about. What's what, where do you net out on what Jeff Bezos was in Elon Musk are doing today?

Katie

Oh, well, okay. So <laugh>, that's, that's also a long conversation. I feel like I, first of all, there's, there's a lot of discussion in the sort of space community about the term colonization and how that's, that's the wrong sort of lens in which to view exploration of space because you know, obviously colonization on earth has a long and, and very very bad

Neil

Negative.

Katie

Yeah, yeah, yeah. And we don't want to approach space exploration in that way as, as sort of, you know, we're gonna go and we're gonna conquer flag

Neil

Flag planters

Katie

Yeah. Yeah. We don't want, that's not the right way to go about this. Right. I, I like the idea of going out.

Neil

T fascinating to me because of the fact that there's no life on the <laugh>, you know,

Katie

We dunno, we don't know. Right,

Neil

Right, right, right. We

Katie

We dunno for sure. Yeah. There could be microbes on Mars. There could be life on all, a lot of other, in a lot of other places in the,

Neil

Or forms of life we cannot see or even perceive.

Katie

Yeah. But, but even if it is, even if it is entirely lifeless, like it's, it's still a natural wonder that that should not be approached with avarice, you know? I, I just, I, I think that that's, that's, that's part of the, my problem with, with that, that sort of approach.

Neil

So your first, the first I asked you, so what are your thoughts on the subject? The first thing they thought was the, the word to describe it is wrong. It’s not colonizing planets. So then zoom into the, the act of taking our species off of just here.

Katie

Yeah. Well, I mean, so I think that, I mean, I wanna go to Mars, like I've, I've applied to the NASA astronaut program a couple of times. I, I made the first cut once. Like I wanna go into space. You know, I do, I do want to, well,

Neil

Don’t you think it'll take too long?

Katie

What do you mean?

Neil

To get there and to get back. I mean,

Katie

It'll take a long, I mean, it's a long trip to Mars, like you know, six to nine months probably. And that's part of the challenge of it's part of, one of the things that hasn't really been solved yet. How do you, how do you survive and survive with other people in a small space <laugh> and for that length of time, right. That's, that's part of the difficulty,

Neil

But then by the story that say this, but like, then why'd you want to go so bad?

Katie

Cause I, I just, I, I mean, I feel like I, I want, I wanna experience that, you know, I wanna experience another world. I want to see what it's like. I wanna feel what it's like there, I wanna experience the different gravity of another planet. The, the difference in where the horizon is, the, the, you know just the feel of being in a, in a place like that. I, I mean

Neil

What do you mean, difference of where the horizon is.

Katie

Well, cuz because the horizon, the distance to the horizon is based on, on the curvature of the planet. Right. So, so it's closer on the moon or on Mars than it is here.

Neil

Looks like the ground and the sky touching would look at a different place there

Katie

Yeah. I mean it, it might not be noticeable. I don't know. I wanna see <laugh> yeah. I wanna know what that looks like. Yeah. you know, so, so I wanna experience, I, I would love to experience, I love the idea of exploring. I mean, I love traveling on earth. I love going to different places and experiencing different settings. So I, I would love to go. And I think that there's a lot of scientific. There's a lot we can learn scientifically by, by going. Scientifically though, I think that the, the, the most efficient way to explore other worlds is through robots and satellites. I think that, that, you know, it's very expensive and very dangerous to send humans and a lot can go wrong and, and once you have a human on a planet, you've contaminated it. So if there was life there, then you've contaminated it.

Katie

You've you've changed the ecosystem entirely. So there are a lot of reasons why from a scientific perspective, humans sending humans may not be the right choice depending on what your goals are. But I think that as humans, we like to explore, we, we are excited by new places and new experiences and we're inspired by that. You know, so many people were inspired by the moon landings inspired into going into science and, and, you know, and, and even, even just from the perspective of, if you go to another place, you have a different perspective on your home. Right.

Neil

That happens with the blue dot.

Katie

Yeah. Yeah. So like, yeah, the pale blue dot or, or the images of the earth from the Apollo missions were some would argue that that sort of was one of the things that kind of kickstarted the environmental movement was people for, for the first time, seeing their earth from far away and understanding how fragile and, and special our home is, you know, that that's another aspect of, of human space flight that I think is, is important and valuable.

Neil

I was just learning recently, cuz we interviewed Kevin Kelly for this show mm-hmm <affirmative> and he was the former editor of The Whole Earth Catalog. I was just learning recently that those images were actually not revealed to the public for a long period of time. Cause they were thought to be fraught.

Katie

Oh really

Neil

With some danger. Yeah. If you showed everybody where we actually are. Yeah. But I, I thought so. I, I see that you're kind of like venturing towards like the net positive side of this whole thing. Yeah. But I was thinking of it from a different perspective, which is that I just watched Don't Look Up right. Like that tongue in cheek movie about the asteroid coming and there's been endless asteroids hitting earth kind of stories over time. And I guess part of the fascination we have with that is that we gotta get somewhere else, like just in case, forget climate change for a second, just in case the whole planet, you know, we're to get struck by something. So how far in advance do we see stuff coming at us?

Katie

Well, okay. So, so I, I feel like that that's an argument I hear a lot and I think that that's not a good argument. <Laugh> okay. So yeah. So, okay. I think, I think exploring the universe is a great idea for a lot of reasons as a way to have a backup plan for humanity, I think it's a terrible idea. There, there is almost nothing you could do to the earth, there's almost nothing the universe could do to the earth that would make it less habitable than Mars is. Right. Right now. Okay. Ah, right. Like let's say that let's say a giant asteroid hits the earth and it's like a nuclear winter. It destroys you know, know it destroys our atmosphere in various ways. We, you know, we can't live on the surface. There's radiation. You can't live on the surface of Mars. There's radiation on Mars. There's there's no, you know that we don't, there's no protective magnetosphere or, or atmosphere to, to slow down the cosmic rays. Like Mars is a, is a really inhospitable place. There's no breathable atmosphere. You can't, I mean, there's a, a tiny, tiny amount of carbon dioxide and basically nothing else. So you can't breathe on Mars,

Neil

UV 10,000. UV is probably 10,000.

Katie

Yeah I mean it it's, it's a, you can't live on Mars. You'd be, if you go to Mars, you're living underground in like a lava tunnel or a cave to escape the radiation. You're you're bringing your own oxygen with you or you're making it through through with machines that can convert carbon dioxide to oxygen on the earth, on the planet. You're you're, you're taking, you're trying to extract ice from the, from the soil. Yeah. But then it's, it's contaminated with these toxic chemicals called perchlorate.

Neil

It's a great, it's a great point. You're saying, Hey, the, the worst that could happen here is that we'd be more like that anyway.

Katie

Yeah, exactly.

Neil

So how far I want, how far in advance do we see stuff coming at us? Because when you talk to Alie a few years ago, you said, hey, in the Southern south of the equator, we got pretty much nothing looking up.

Katie

Well, I think so. I think that, I think that some of those surveys have restarted since then. We don't see everything. We have pretty good coverage for the most dangerous stuff for, for things that can destroy a city. I think we, we see most of those things before they can get here. You know, so it depends like there's a, there's an element of luck. If something is coming from the, the wrong direction, it might be hard to see, we might miss it with our surveys. So I don't know the exact numbers in terms of how well we're, we're watching. There are some surveys that are coming up that are gonna do much better. So there are some surveys that are gonna look specifically for, for near earth objects. And then there's also the Ruben observatory, which is gonna be doing some some surveys that can find near earth objects. Some of those are gonna be made more difficult by the Starlink satellites because the Starlink satellites are just the kind of thing that make it harder to see to see near earth objects. And so our, our ability to protect ourselves from space rocks is gonna be damaged by the Starlink system. I don't know,

Neil

That’s Elon Musk’s thing, thing to get everybody faster internet

Katie

Yeah. So I, I don't know, you know, if you work out the sort of like net positive or negative <laugh> of his ventures on the earth is hard to say right now.

Neil

Yeah. Hey, I've been wondering where to stick this question, but it's been burning in my head since, before we chatted. And so my dad's an astrophysicist. He did his masters in astrophysics at the university of New Delhi in 1966. So he joked that the stuff he learned then is like what you'd learned in like 12th grade today, you know? But also he also is a deep believer in astrology to the point where he's had, you know, all of our charts written from when we were kids and it's the date and location place of your birth and what the alignment of the stars was. Then he talks to people who use little computer programs that say, you know, what's gonna happen in the, you know three month, six month, 12 month window of his life. And he, he, he's an astrophysicist who believes in astrology. Astrology is a pretty loaded term in our culture today. Where do you net on astrology? How do people think about navigating that from a very logical place?

Katie

Well I'm, I've never heard of another astrophysicist who, who puts any stock in it, so that's, that's interesting. Okay.

Neil

Yeah, and I, I shouldn't label my dad, so he was a high school physics teacher in Canada. Okay. That's that was the net out, but he, I wouldn't, he wasn't at the perimeter Institute or anything like that, but he, he did a degree in astrophysics back in the sixties in India.

Katie

Okay. Okay. Okay.

Neil

So let's move him down a few pigs to start with here.

Katie

<Laugh> okay.

Neil

He'd be fine with that.

Katie

<Laugh> so when, when I talk about astrology on Twitter, people yell at me because because a lot of people view it as a kind of a kind of cultural practice or a religious practice. And you know, I, it's not for me to tell people how to think about their spirituality, but

Neil

I want you to, but that's right.

Katie

So my, my, my thoughts on that are that if it is, if it is an aspect of spirituality, you know, I, I don't have much to say about that. There is, there is no science to it. There, there are a lot of science terms in it. You know, people talk about you know, orbits and ephemeries, and like, like all of these charts and everything, and, and you can, you can plot things out when astrology was first being done in the world. It was being done by people who were taking very detailed observations of the night sky. And a lot of those observations led to actual scientific discoveries. Yeah. But astrology, as a, as a way of connecting the apparent positions of objects in the night sky to human experience has no signs behind it at all.

Neil

So why the, why the, why the industry?

Katie

I don't know. I mean, I think that, I think that there are a lot of people who have figured out that that a large segment of the public does not understand how physics and astronomy work and finds, you know, spiritual connection to the universe. And so there are a lot of people who exploit that, who try to convince people that, that there is some, you know, science behind the, the positions of the stars and, and, and for a lot of people that feels very intuitive. Some people, you know, a lot of people think, well, of course the planets, the positions of the planets should connect to how I live my life, because, you know, we're all connected in the universe.

Neil

Well the date and place of my birth is some ..., like, I feel like there's more stuff coming up now in the science, on the side of fatalism versus free will. Like, I feel like I've always been a free will kind of guy. And as I listen to more and more to Sam Harris, or I listen to more and more, you know, these guys, I just saw you roll your eyes. <Laugh>, I'm hearing a little more on the fatalist side these days from the sciencey people. Are you, are you not hearing this? Am I misreading the

Katie

I mean, there are, there are interesting discussions to be had about about how our experiences in our brain brain chemistry and our, our backgrounds affect how we live our lives. And, and, you know, you can, you can, you can dig down deep into that rabbit hole, but in any event, whether or not it looks like mercury is moving east or west in the sky has nothing to do with it. You know, I mean, most people don't even see mercury, right? Like it's actually kind of hard to observe the planet mercury because it's quite, quite close to the sun. And so, you know, it's not like, it's not like you're walking down the street and you look up and you see that mercury is moving the wrong way, and it totally throws you off for the day. That's not, that's not how that works, but yet, and yet you talk about talk to people who are into astrology and they're like, oh, no, mercury is in retrograde. It's, you know, I, you know, my whole life is messed up. Right. And that's has nothing to, it has nothing to do with, you know, the, the, the, the positions, the apparent direction that mercury is moving through the sky just has no effect on anything on earth. <Laugh> like, it's just, it's an optical illusion.

Neil

And, and why, sorry, can I say why the eye roll?

Katie

Oh, about Sam Harris.

Neil

<Laugh> yeah.

Katie

<Laugh> there's, there's a, there's a group of, of there's a group of people who are there's this whole, like new atheist movement kind of thing. And, and a lot of what a lot of what they do and talk about is stuff that I think is unhelpful in the world, but I don't wanna get into, I don't want to get into that. <Laugh>

Neil

Okay. It's interesting though, that you brought atheism though. Cause I was interested that the very last sentence of A Brief History of Time, the very last of the entire book Uhhuh is I wanna just pull open the book so I can actually read the last sentence. I'll just read the last paragraph so that it has some context. However, if we do discover a complete theory, it should in time be understandable in broad principle by everyone, not just a few scientists. Then we shall all philosophers scientists and just ordinary people be able to take part in the discussion of the question of why it is that we and the universe exist. Mm. If we find the answer to that, it would be the ultimate triumph of human reason for then we would know the mind of God. Mm. I was very surprised that the very last sentence of this whole book was God, I was, I was caught off guard.

Katie

I, I would, I would guess that he was using that in a more sort of metaphorical way. Talking about God as a sort of unifying principle of the universe, rather than

Neil

as a, as a metaphor for everything.

Katie

That's, I would guess

Neil

Chapter 44 with Pete Holmes, we talked about that he, he's a big proponent of Ram Dass and Be Here Now kind of spiritual idea. And he was a former deeply passionate Christian growing up, evangelical and he's like, I, I just now recognize the word God to be kind of everything around us.

Katie

Yeah.

Neil

Okay. Okay, cool. Now your third and final formative book was read a little bit later than the sort of 9, 10, 11 year period that you read the first two and it is called Rosencrantz and Gildenstern Are Dead by Tom Stoppard, a play that premiered at the Edinburg Fringe festival in 1966. I got the cover right in front of me. It's a dull gray, two sets of feet coming out of two barrels laying on the ground. A coiled noose is hanging down from the top, right? The cover's in like a gold art deco kind of font, the author's name in red. The New York Times says this is a remarkable play. Very funny, very brilliant, very chilling. Tom Stoppard born 1937 in the present day Czech Republic. Alive today. He is a British playwright and screenwriter whose family fled Czechoslovakia during the Nazi regime.

Neil

What's it about? Well, it claimed as a modern dramatic masterpiece Rosencrantz and Gildenstern Are Dead is the fabulously inventive tale of a Hamlet as told from the worms eye view of the bewildered Rosencrantz and Gildenstern, two minor characters in Shakespeare's play in Tom Stoppard's best known work, the Shakespearean Laurel and Hardy finally get a chance to take the lead role, but do so in a world where echoes of Waiting for Godot resound, where reality and illusion intermix and where fate leads our two heroes to a tragic, but inevitable end. File this under 1 8 2 2 0.914 for English dramas of the 20th century. Katie, tell us about your relationship with the play Rosencrantz and Gildenstern Are Dead by Tom Stoppard.

Katie

So I first encountered this because my, my sister had to, had to watch the movie of it for class when she was, I guess, Junior, she was in high school or something. She's seven years older than me, and she was a drama major and everything. And so she,

Neil

I love that. She's like a drama. I love that you guys are so different. Well,

Katie

Well yeah, so she was a drama major and she spent a number of years as an actor just like doing Shakespeare and such around LA, but it turned out that she was one of, you know, a million tall blonde actresses in LA and it just like, that's, it is hard to get a break. So now she's actually a math teacher. So anyway she's great. So anyway, so she, she had this, this play to read this movie to watch and I watched the film and I was just enthralled. It was, it was such an interesting approach to telling a story. And the, the main characters, at least in the film version, they go around kind of accidentally discovering sort of weird things about physics. <Laugh> and then, but, but like, yeah, but like with coin play

Neil

Opens with them flipping a coin heads 92 times in a row.

Katie

Yeah, yeah. Stuff like that. So, so weird sort of physics discussions with a little geeky things sort of sprinkled throughout and and it, it just, it had, they had so much fun with language. And so, so I loved all the word play, you know all of, and it's just, it's just full of these, these really clever turns of phrase, these, these puns and, and and interesting ways of speaking. And I, and I, you know, by the time I was reading this, this play, I mean, I watched the film, I read the play by the time I was into this, I was also reading a bunch of Shakespeare, you know, I, I liked, I liked that. And my sister being a, a drama major, like she, you know, also helped expose me to a lot of, a lot of Shakespeare.

Katie

And I loved, you know, I loved Hamlet and I loved the comedies and everything. And, and, and this was a, it was kind of a take on that, but, but from this, this sort of weird absurdist perspective of, of two minor characters and I, I I had, I just had so much fun with it. I mean, Shakespeare has some, some interesting comedy, you know, there's a lot of, lot of word play and Shakespeare, especially in the comedies. But but this was just kind of taking it up a notch and, and building the entire, the entire story around that. And and I, I, I just loved it. I thought it was so much fun.

Neil

I love that. I feel, I feel like there's more and more discussions today about the limiting nature of language. Mm. Like, I, I grew up just, you know, I, I was not aware of what language was, you know, growing up, but I'm hearing more and more conversations that are coming into the consciousness about how limiting language is as a communications device, how we're all forced to compartmentalize the vastness of our, you know, emotional experience into these tiny compartments called words.

Katie

But, but you can do so much. I mean, there's, I, you could be so creative with language. You can, you can create such beautiful and, and thrilling things through, through playing around with words. I mean, I think, you know, I mean, I'm, I'm, I'm obviously a scientist, but I'm also I'm also somebody who just has such a love for words, for language, for, for literature, for, for speech, like just interesting ways of, of, of playing with words to, to, to get across a feeling or, or a, a change of perspective. You know, or that,

that sort of, that thrill of, of hearing something put in just the right way or a new way, or, or a new, yeah. A new perspective on, on anything because of, of clever wordplay. I, I, I love that experience so much.

Neil

I totally agree with you. And this is kind of the thing about narrative voice, like how astounding is that, that you can actually feel the author's emotional energy, even though that energy isn't directly communicated through the words. I was so shocked when my very first book came out and so many people said, I almost could tell that you're going through a divorce or hard time, it was true I was, but I didn't talk about that at all. And the words, somehow the energy was communicated through the words and, you know, we always hear this phrase, like it's about what's reading between the lines, you know, that, that classic cliche, how does that work?

Katie

<Laugh> I mean, I, I mean, I don't know, that's the, again, we're getting into sort of human psychology, but but it's, it's, it's amazing. Like, I love the idea that you can, you can create an emotion in another person just by the way that you're using words, you know? I, I used to do a lot of, I used to write a lot of poetry when I was younger and I, I loved the idea that you could, you could use words in a way to, to make someone feel something it, it be it, you know, sadness or delight or, or amusement or, or whatever, and, and, and I,

Neil

And dizziness

Katie

Yeah.

Neil

To quote the first line of your wonderful poem on, on your website. I want to, I want to make you feel dizzy.

Katie

Yeah. Yeah. I mean, yeah. I love

Neil

I'll put a link to that poem in the show notes. So for those wondering, we're talking about Katie has an incredible poem that just communicates the vastness of the universe on her website, and I've shared it with my community, but I'll put it in the show notes here as well.

Katie

Thank you.

Neil

I was thinking about asking you to read it for us today about, oh, <laugh>,

Katie

I mean, there's a recording online. You could just, you can play that.

Neil

Okay. Embarrassed about it. You, you, this is absurdist, right? This plays absurdist, absurdist absurdist. In your book, you say the universe is far more strange than we ever realized. What do you mean? What do you mean by that?

Katie

I mean, that, that yeah, it's, there are things about the universe about the largest scales or the smallest scales that are so there's so contradictory to our daily experience like that. They seem absurd to us that they, they seem impossible.

Neil

Give us a few tid tidbits on that. Well,

Katie

Well so, so I mean, on the, on the small scales, on the quantum scales, we know that things act in very strange ways, right. We know that that you know, a a particle can move through tooth places at once, apparently that, that, you know, that, that

Neil

Schrodringer's cat.

Katie

Yeah. That, yeah, superposition this idea that, that something is neither this or this until you, until you take a measurement until you collapse the wave function, there's all these sort of weird things that happen on the small scales, even quantum tunneling, where you can put a particle on one side of a wall and it'll just appear on the other side eventually without going through or we've seen this happen around. Oh yeah. That happens all the time. Quantum tunneling is, is part, is built into our technology. I mean you know, you've ever heard of the scanning scanning tunneling microscopes. So this is the idea of there are certain kinds of microscopes where the idea is they wanna, they wanna hit the target with electrons very, very slowly to kind of trace out the, the shape of something and the

Neil

What's an electron microscope.

Katie

Yeah. But yeah, but what they use as the valve to drip, those electrons on is quantum tunneling. They actually create a barrier that the electrons can't get through, but occasionally they do. And that's, that's how the microscope puts the electrons onto the surface is they, they make the use, make use of the quantum tunneling. They make it impossible for the, the electrons to go through in a classical way. And they just quantumly appear on the other side. And that's how, that's how they regulate the, the flow of electrons.Yeah. I mean, we

Neil

We don't, we don't really know why that happens.

Katie

I mean, it has to do like, we, we have mathematical models for why it happens, where if you, if you say that every particle is not really a solid object, but a kind of wave function, a sort of a sort of cloud of probability in a region instead of at a single point, then it makes sense and you can do the calculations and you can work out the transmission probability based on that way function, but,

Neil

Okay. Okay. But it's not,

Katie

It's not a solid object

Neil

And that's on the smallest scales. You gave us one tidbit. Now go to the, go to the upper edge. Okay. Zoom, zoom out. I mean, we, we got as far as galaxies and with 400 billion stars in us and nearby galaxy kind of having tourists, that'll crash into us in 4 billion years, but you know, zoom out to the highest possible level. I'd love, I'd love a, I've been waiting to ask it. I would love a, a metaphor for how me walking down the street can think of the size of the universe. I, okay. I'm struggling for one of these physical metaphors. And I figure, feel like you have one, like a grain of sand. No,

Katie

I mean, whatever mean there's, you know, I, you can, you can come up with, you can come up with lots of things like that, but none of them mean anything. I mean, I mean, to your own experience, you know, you can give, you can talk about, you know, how many, how many school buses you'd have to line up between here and the moon in order to, you know, to cover that distance. But it doesn't, you know, at some point your brain is just like, oh, that's a lot

Neil

Possibly contemplate the size. No, I'm asking you though. Seriously. How, how do we think about the size of the thing?

Katie

I mean, I don't, I don't, I don't try to, I don't try to envision it all in my head. I, I use I mean, I do, what other scientists do we use? We use scientific notation, right? So, so 10 to the one is, is 10, 10 to the two is 100, 10 to the three is a thousand. And so, you know, I, I deal with things that are on the scale of 10 to the 18 meters. I mean, this is like, that's, that's just too huge a distance to contemplate to, to really hold in your head. You can, you can try to kind of zoom out in, in powers of 10, you know? So there's, this

Neil

That’s even, that's even just the observable universe.

Katie

Yeah. Yeah. That's just the observable universe

Neil

So there's unobservable after that

Katie

Potentially

Neil

And then what's after what's after that?

Katie

I mean, we don't know. We dunno, we, we have no information about anything beyond the observable universe.

Neil

Okay. Well, gimme something strange about, about the, about the big universe and then I guess,

Katie

So here's my favorite one and it's, it's freaky. Okay. So, so you know how, if, if something is far away, it looks smaller, right? Yeah. Like, so just, you know

Neil

I'm with you so far.

Katie

Okay, great. <Laugh> yeah.

Neil

Okay.

Katie

If you had a galaxy, if you, if you if you have a, a galaxy of a particular size, right. Just a normal size galaxy, there's some physical, say a scale of that galaxy. If it is if you, if it's farther away, it looks smaller up to a point. And beyond that point, if it's farther away, it looks bigger. And the reason for that, <laugh> the reason for that is that the universe is expanding, which means that it was much, much smaller in the past. And the most distant things we see right now are the things that are so far away, that their light has taken billions and billions of years to reach us. And so there are some things that we can see that are so far away, that the light has taken so long to reach us that when the light left those things, they were actually very close to us because the universe was smaller and then the universe expanded. And now they're very far away, but the light from them is coming to us from a closer point. And so that means that they look bigger on the sky because they actually were taking up more of the sky, cuz they were closer when the light left them.

Neil

But if they were then why are, are they now?

Katie

Well now, well now they're really far away because the universe has expanded since the light left them and the, and the expansion, the universe carried them away from us.

Neil

So I'm, I'm, I'm not following. It's something that, so it's, it's everything further away from us looks smaller and smaller up to a point. And then it looks bigger. Yes. Because the light left it so long ago that it was from a point in the universe when the universe was constricted, like the universe was, you know, fit into a thimble or whatever,

Katie

Because yeah. The universe was a lot smaller.

Neil

So, but it was a lot smaller. It's not a lot smaller now. So why is it?

Katie

No. So it's like, okay. So imagine, imagine that well

Neil

I'm not challenging you and wanna make that clear. I just, just don’t understand

Katie

No, no, no. It's, it's, it's extreme. This is, this is the point. It's extremely counterintuitive. It's very hard to understand. Imagine that that I don't know. I I shout something to you and then I run away. Okay. and let's say I run extraordinarily fast, whatever. You will hear what I said to you. It'll be loud because I was close to you when I said it, but by the time you hear it, I'm very, very far away. And if I shouted from there, you wouldn't be able to hear it. Cuz it was, it would be too quiet. Right. so, so and somebody else you know, they, they are far away and they, you know, they shout to you and then they move a little bit farther away, but they haven't moved very much farther away. And they, you know, whether you hear from them is a little bit quieter than what you heard from me. Cuz when I shouted at you, I was very, very close. And then I ran away very quickly. When the light, when, when the universe was smaller, a galaxy, you know, the light left some galaxy and then the universe expanded and that Galaxy's really, really far away from us now. But that light has been traveling to us since that time. And the, the amount of sky that, that image took up when the light left, it is the amount of sky that the image takes up when we see it.

Neil

Wow.

Katie

But the, the Galaxy's really far away, but a, a, a galaxy that's you know, that's,

Neil

I, I, I think I kind of get it now.

Katie

Okay. Yeah. It's, it's really like, you'd have to draw diagrams. It's really hard to explain. Even I taught a general relativity class last, last semester when I was still at NC state and, and I, I was explaining this to my students and I was drawing the diagrams and they, and it was the end of the semester. They'd already learned all of general relativity and they're still looking at me, like, what are you saying? Like it's really counterintuitive.

Neil

Well, this is part of what you have, an amazing gift of right. You are taking the vastness of the cosmos that we all stare into and wonder about. And the extra steps of knowledge you have, your translating them back for us. And it's so appreciated. Maybe to close this conversation off, which has been a real gift. I really mean that like it's you scratching an itch inside us all that we have in our soul to wonder and know more about where we are and what this thing even is. How, how may we I'll I'll ask you for, take a pause and close us off with how might we go through our life with a little bit more cosmological awareness?

Katie

That's an interesting question. I, I mean, I think that, I think that what we can do is

Katie

I think that a lot of, a lot of people think about physics and astronomy and mathematics and think that's for science people. I'm not a science person. I don't understand that stuff. Right. and people think, oh, I'm not smart enough for that. I don't know. And I think that that's wrong. I think that there is, there are things that we can all understand and appreciate about the universe. We can all look into the night sky and wonder, and we can all try to try to get some glimpse of, of this beautiful universe we live in. And there are people, you know, like me who are out there working to make this stuff accessible. And I think that one thing we can do those of us who are not scientists, one thing we can do is to, you know, to, to actually trust that, that, that we do have the capacity to understand some things about the universe and to, you know, to think about it and to contemplate it and to, to seek out sources who will walk us through these very difficult questions and give us some, some of that insight, not everybody is gonna talk down to you.

Katie

Not everybody is going to you know, be you know, condescending because they understand things that you don't understand. There are people out there who, who just wanna share understanding and love of the universe. And if, if you can find those people, if you can find those sources, then you can have that experience of, of understanding something new and, and learning something about the universe. And it's such an amazing experience to have. And I experience that every day in my work, I learn something new about the universe and I, I it's, it's a wonderful thing. And I think that we should all have that have that experience.

Neil

Thank you so much, Katie, on page 180, one of your book, you say, we don't know how to, how to connect dark matter or dark energy, which constitute 95% of the universe to fundamental physics. So in that sense, we don't understand anything at all. We don't know how far it goes. We don't know what's passive observable, and we don't know what's outside of it. Mm-Hmm <affirmative> but you have given us a little bit of light in the darkness today. Thank you so much for coming on three books and thank you so much for the gift of your time.

Katie

Thank you. Thank you for having me. It was a fun conversation.