Lex Fridman Podcast #433 - Sara Walker: Physics of Life, Time, Complexity, and Aliens

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Lex Fridman
The following is a conversation with Sara Walker, her third time in this podcast. She is an astrobiologist and theoretical physicist interested in the origin of life and in discovering alien life on other worlds. She has written an amazing new upcoming book titled Life As No One Knows It: The Physics of Life's Emergence. This book is coming out on August 6th, so please go pre-order it now. It will blow your mind. This is the Lex Fridman Podcast. To support it, please check out our sponsors in the description. And now, dear friends, here's Sara Walker. You open the book, Life As No One Knows It: The Physics of Life's Emergence, with the distinction between the materialists and the vitalists. So what's the difference? Can you maybe define the two?

Sara Walker
I think the question there is about whether life can be described in terms of matter and physical things, or whether there is some other feature that's not physical that actually animates living things. So for a long time, people maybe have called that a soul. It's been really hard to pin down what that is. So I think the vitalist idea is really that it's a dualistic interpretation that there's sort of the material properties, but there's something else that animates life that is there when you're alive and it's not there when you're dead. And materialists don't think that there's anything really special about the matter of life and the material substrates that life is made out of, so they disagree on some really fundamental points.

Lex Fridman
Is there a gray area between the two? Maybe all there is is matter, but there's so much we don't know that it might as well be magic. Whatever that magic that the vitalists see, meaning there's just so much mystery that it's really unfair to say that it's boring and understood and as simple as "physics."

Sara Walker
Yeah, I think the entire universe is just a giant mystery. I guess that's what motivates me as a scientist. And so oftentimes, when I look at open problems like the nature of life or consciousness or what is intelligence or are there souls or whatever question that we have that we feel like we aren't even on the tip of answering yet, I think we have a lot more work to do to really understand the answers to these questions. So it's not magic, it's just the unknown. And I think a lot of the history of humans coming to understand the world around us has been taking ideas that we once thought were magic or supernatural and really understanding them in a much deeper way that we learn what those things are. And they still have an air of mystery even when we understand them. There's no bottom to our understanding.

Lex Fridman
So do you think the vitalists have a point that they're more eager and able to notice the magic of life?

Sara Walker
I think that no tradition, vitalists included, is ever fully wrong about the nature of the things that they're describing. So a lot of times when I look at different ways that people have described things across human history, across different cultures, there's always a seed of truth in them. And I think it's really important to try to look for those, because if there are narratives that humans have been telling ourselves for thousands of years, for thousands of generations, there must be some truth to them. We've been learning about reality for a really long time and we recognize the patterns that reality presents us. We don't always understand what those patterns are, and so I think it's really important to pay attention to that. So I don't think the vitalists were actually wrong. And a lot of what I talk about in the book, but also I think about a lot just professionally, is the nature of our definitions of what's material and how science has come to invent the concept of matter. And that some of those things actually really are inventions that happened in a particular time in a particular technology that could learn about certain patterns and help us understand them, and that there are some patterns we still don't understand. And if we knew how to measure those things or we knew how to describe them in a more rigorous way, we would realize that the material world matter has more properties than we thought that it did. One of those might be associated with the thing that we call life. Life could be a material property and still have a lot of the features that the vitalists thought were mysterious.

Lex Fridman
So we may still expand our understanding, what is incorporated in the category of matter, that will eventually incorporate such magical things that the vitalists have noticed, like life?

Sara Walker
Yeah. I always like to use examples from physics, so I'll probably do that. It's my go-to place. But in the history of gravitational physics, for example, in the history of motion, when Aristotle came up with his theories of motion, he did it by the material properties he thought things had. So there was a concept of things falling to earth because they were solid-like and things raising to the heavens because they were air-like and things moving around the planet because they were celestial-like. But then we came to realize that, thousands of years later and after the invention of many technologies that allowed us to actually measure time in a mechanistic way and track planetary motion and we could roll balls down inclined planes and track that progress, we realized that if we just talked about mass and acceleration, we could unify all motion in the universe in a really simple description. So we didn't really have to worry about the fact that my cup is heavy and the air is light. The same laws describe them if we have the right material properties to talk about what those laws are actually interacting with. And so I think the issue with life is we don't

know how to think about information in a material way, and so we haven't been able to build a unified description of what life is or the kind of things that evolution builds because we haven't really invented the right material concept yet.

Lex Fridman
So when talking about motion, the laws of physics appear to be the same everywhere out in the universe. You think the same is true for other kinds of matter that we might eventually include life in?

Sara Walker
I think life obeys universal principles. I think there is some deep underlying explanatory framework that will tell us about the nature of life in the universe and will allow us to identify life that we can't yet recognize because it's too different.

Lex Fridman
You're right about the paradox of defining life. Why does it seem to be so easy and so complicated at the same time?

Sara Walker
All the classic definitions people want to use just don't work. They don't work in all cases. So Carl Sagan had this wonderful essay on definitions of life where I think he talks about aliens coming from another planet. If they saw earth, they might think that cars were the dominant life form because there are so many of them on our planet. Humans are inside them, and you might want to exclude machines. But any definition, classic biology textbook definitions, would also include them. He wanted to draw a boundary between these kind of things by trying to exclude them, but they were naturally included by the definitions people want to give. And in fact, what he ended up pointing out is that all of the definitions of life that we have, whether it's life is a self-reproducing system or life eats to survive or life requires compartments, whatever it is, there's always a counterexample that challenges that definition. This is why viruses are so hard or why fire is so hard. And so we've had a really hard time trying to pin down from a definitional perspective exactly what life is.

Lex Fridman
Yeah, you actually bring up the zombie-ant fungus. I enjoyed looking at this thing as an example of one of the challenges. You mentioned viruses, but this is a parasite. Look at that.

Sara Walker
Did you see this in the jungle?

Lex Fridman
Infects ants. Actually, one of the interesting things about the jungle, everything is ephemeral. Everything eats everything really quickly. So if an organism dies, that organism disappears. It's a machine that doesn't have - I wanted to say it doesn't have a memory or a history, which is interesting given your work on history in defining a living being. The jungle forgets very quickly. It wants to erase the fact that you existed very quickly.

Sara Walker
Yeah, but it can't erase it. It's just restructuring it. And I think the other thing that is really vivid to me about this example that you're giving is how much death is necessary for life. So I worry a bit about notions of immortality and whether immortality is a good thing or not. So I have a broad conception that life is the only thing the universe generates that actually has even the potential to be immortal, but that's as the sort of process that you're describing where life is about memory and historical contingency and construction of new possibilities. But when you look at any instance of life, especially one as dynamic as what you're describing, it's a constant birth and death process. But that birth and death process is the way that the universe can explore what possibilities can exist. And not everything, not every possible human or every possible ant or every possible zombie ant or every possible tree, will ever live. So it's an incredibly dynamic and creative place because of all that death.

Lex Fridman
This is a parasite that needs the ant. So is this a living thing or is this not a living thing?

Sara Walker
Yeah.

Lex Fridman
It just pierces the ant.

Sara Walker
Right.

Lex Fridman
And I've seen a lot of this, by the way. Organisms working together in the jungle, like ants protecting a delicious piece of fruit. They need the fruit, but if you touch that fruit, the forces emerge. They're fighting you. They're defending that fruit to the death. Nature seems to find mutual benefits, right?

Sara Walker
Yeah, it does. I think the thing that's perplexing for me about these kind of examples is effectively the ant's dead, but it's staying alive now because piloted by this fungus. And so that gets back to this thing that we're talking about a few minutes ago about how the

boundary of life is really hard to define. So anytime that you want to draw a boundary around something and you say, "This feature is the thing that makes this alive, or this thing is alive on its own," there's not ever really a clear boundary. And these kind of examples are really good at showing that because it's like the thing that you would've thought is the living organism is now dead, except that it has another living organism that's piloting it. So the two of them together are alive in some sense, but they're now in this weird symbiotic relationship that's taking this ant to its death.

Lex Fridman
So what do you do with that in terms of when you try to define life?

Sara Walker
I think we have to get rid of the notion of an individual as being relevant. And this is really difficult because a lot of the ways that we think about life, like the fundamental unit of life is the cell, individuals are alive, but we don't think about how gray that distinction is. So for example, you might consider self-reproduction to be the most defining feature of life. A lot of people do, actually. That's one of these standard different definitions that a lot of people in my field like to use in astrobiology is life as a self-sustaining chemical system capable of Darwinian evolution, which I was once quoted as agreeing with, and I was really offended because I hate that definition. I think it's terrible, and I think it's terrible that people use it. I think every word in that definition is actually wrong as a descriptor of life.

Lex Fridman
Life is a self-sustaining chemical system capable of Darwinian evolution. Why is that? That seems like a pretty good definition.

Sara Walker
I know. If you want to make me angry, you can pretend I said that and believed it.

Lex Fridman
So self-sustaining, chemical system, Darwinian evolution. What is self-sustaining? What's so frustrating? Which aspect is frustrating to you, but it's also those are very interesting words.

Sara Walker
Yeah, they're all interesting words and together they sound really smart and they sound like they box in what life is. But you can use any of the words individually and you can come up with counterexamples that don't fulfill that property. The self-sustaining one is really interesting, thinking about humans. We're not self-sustaining dependent on societies. And so I find it paradoxical that it might be that societies, because they're self-sustaining units, are now more alive than individuals are. And that could be the case, but I still think we have some property associated with life. That's the thing that we're trying to describe, so that

one's quite hard. And in general, no organism is really self-sustaining. They always require an environment, so being self-sustaining is coupled in some sense to the world around you. We don't live in a vacuum, so that part's already challenging. And then you can go to chemical system. I don't think that's good either. I think there's a confusion because life emerges in chemistry that life is chemical. I don't think life is chemical. I think life emerges in chemistry because chemistry is the first thing the universe builds where it cannot exhaust all the possibilities, because the combinatorial space of chemistry is too large.

Lex Fridman
Well, but is it possible to have a life that is not a chemical system?

Sara Walker
Yes.

Lex Fridman
Well, there's a guy I know named Lee Cronin who's been on a podcast a couple of times who just got really pissed off listening to this.

Sara Walker
I know. What a coincidence.

Lex Fridman
He probably just got really pissed off hearing that. For people who somehow don't know, he's a chemist.

Sara Walker
Yeah, but he would agree with that statement.

Lex Fridman
Would he? I don't think he would. He would broaden the definition of chemistry until it'll include everything.

Sara Walker
Oh, sure.

Lex Fridman
Okay.

Sara Walker
Or maybe, I don't know.

Lex Fridman
But wait, but you said that universe, the first thing it creates is chemistry.

Sara Walker
Very precisely. It's not the first thing it creates. Obviously, it has to make atoms first, but it's the first thing. If you think about the universe originated, atoms were made in Big Bang nuclear synthesis, and then later in stars. And then planets formed and planets become engines of chemistry. They start exploring what kind of chemistry is possible. And the combinatorial space of chemistry is so large that even on every planet in the entire universe, you will never express every possible molecule. I like this example actually that Lee gave me, which is to think about Taxol. It has a molecular weight of about 853. It's got a lot of atoms, but it's not astronomically large. And if you try to make one molecule with that molecular formula and every three-dimensional shape you could make with that molecular formula, it would fill 1.5 universes in volume with one unique molecule. That's just one molecule. So chemical space is huge, and I think it's really important to recognize that because if you want to ask a question of why does life emerge in chemistry, well, life emerges in chemistry because life is the physics of how the universe selects what gets to exist. And those things get created along historically contingent pathways and memory and all the other stuff that we can talk about, but the universe has to actually make historically contingent choices in chemistry because it can't exhaust all possible molecules.

Lex Fridman
What kind of things can you create that's outside the combinatorial space of chemistry? That's what I'm trying to understand.

Sara Walker
Oh, if it's not chemical. So I think some of the things that have evolved on our biosphere I would call as much alive as chemistry, as a cell, but they seem much more abstract. So for example, I think language is alive, or at least life. I think memes are. I think -

Lex Fridman
You're saying language is life?

Sara Walker
Yes.

Lex Fridman
Language is alive. Oh boy, I'm going to have to explore that one.

Sara Walker
Life maybe. Maybe not alive, but actually I don't know where I stand exactly on that. I've been thinking about that a little bit more lately. But mathematics too, and it's interesting because

people think that math has this Platonic reality that exists outside of our universe, and I think it's a feature of our biosphere and it's telling us something about the structure of ourselves. And I find that really interesting because when you would internalize all of these things that we noticed about the world, and you start asking, well, what do these look like? If I was something outside of myself observing these systems that all embedded in, what would that structure look like? And I think we look really different than the way that we talk about what we look like to each other.

Lex Fridman
What do you think a living organism in math is? Is it one axiomatic system or is it individual theorems or is it individual steps of -

Sara Walker
I think it's the fact that it's open-ended in some sense. It's another open-ended combinatorial space, and the recursive properties of it allow creativity to happen, which is what you see with the revolution in the last century with Gödel's Theorem and Turing. And there's clear places where mathematics notices holes in the universe.

Lex Fridman
So it seems like you're sneaking up on a different kind of definition of life. Open-ended, large combinatorial space.

Sara Walker
Yeah.

Lex Fridman
Room for creativity.

Sara Walker
Definitely not chemical. Chemistry is one substrate.

Lex Fridman
Restricted to chemical. What about the third thing, which I think will be the hardest because you probably like it the most, is evolution or selection.

Sara Walker
Well, specifically it's Darwinian evolution. And I think Darwinian evolution is a problem. But the reason that that definition is a problem is not because evolution is in the definition, but because the implication that most people would want to make is that an individual is alive. And the evolutionary process, at least the Darwinian evolutionary process, most evolutionary processes, they don't happen at the level of individuals. They happen at the level of population. So again, you would be saying something like what we saw with the

self-sustaining definition, which is that populations are alive, but individuals aren't because populations evolve and individuals don't. And obviously maybe you are alive because your gut microbiome is evolving. But Lex is an entity right now is not evolving by canonical theories of evolution. In assembly theory, which is attempting to explain life, evolution is a much broader thing.

Lex Fridman
So an individual organism can evolve under assembly theory?

Sara Walker
Yes, you're constructing yourself all the time. Assembly theory is about construction and how the universe selects for things to exist.

Lex Fridman
What if you reformulate everything like a population is a living organism?

Sara Walker
That's fine too. But this again gets back to it. We can nitpick at definitions. I don't think it's incredibly helpful to do it. But the reason for me -

Lex Fridman
It's fun.

Sara Walker
Yeah, it is fun. It is really fun. And actually I do think it's useful in the sense that when you see the ways that they all break down, you either have to keep forcing in your conception of life you want to have, or you have to say, "All these definitions are breaking down for a reason. Maybe I should adopt a more expansive definition that encompasses all the things that I think and are life." And so for me, I think life is the process of how information structures matter over time and space, and an example of life is what emerges on a planet and yields an open-ended cascade of generation of structure and increasing complexity. And this is the thing that life is. And any individual is just a particular instance of these lineages that are structured across time. And so we focus so much on these individuals that are these short temporal moments in this larger causal structure that actually is the life on our planet, and I think that's why these definitions break down because they're not general enough, they're not universal enough, they're not deep enough, they're not abstract enough to actually capture that regularity.

Lex Fridman
Because we're focused on that little ephemeral thing and call it human life?

Sara Walker
Yeah. It's like Aristotle focusing on heavy things falling because they're earth-like, and things floating because they're air-like. It's the wrong thing to focus on.

Lex Fridman
What exactly are we missing by focusing on such a short span of time?

Sara Walker
I think we're missing most of what we are. One of the issues - I've been thinking about this really viscerally lately. It's weird when you do theoretical physics, because I think it literally changes the structure of your brain and you see the world differently, especially when you're trying to build new abstractions.

Lex Fridman
Do you think it's possible if you're a theoretical physicist, that it's easy to fall off the cliff and descend into madness?

Sara Walker
I think you're always on the edge of it, but I think what is amazing about being a scientist and trying to do things rigorously is it keeps your sanity. So I think if I wasn't a theoretical physicist, I would be probably not sane. But what it forces you to do is you have to hold yourself to the fire of these abstractions in my mind have to really correspond to reality. And I have to really test that all the time. And so I love building new abstractions and I love going to those incredibly creative spaces that people don't see as part of the way that we understand the world now. But ultimately, I have to make sure that whatever I'm pulling from that space is something that's really usable and really relates to the world outside of me. That's what science is.

Lex Fridman
So we were talking about what we're missing when we look at a small stretch of time in a small stretch of space.

Sara Walker
Yeah, so the issue is we evolve perception to see reality a certain way. So for us, space is really important and time feels fleeting. And I had a really wonderful mentor, Paul Davies, most of my career. And Paul's amazing because he gives these little seed thought experiments all the time. Something he used to ask me all the time was when I was a postdoc, this is a random tangent, but was how much of the universe could be converted into technology if you were thinking about long-term futures and stuff like that. And it's a weird thought experiment, but there's a lot of deep things there. And I do think a lot about the fact that we're really limited in our interactions with reality by the particular architectures that we evolved, and so we're not seeing everything. And in fact, our

technology tells us this all the time because it allows us to see the world in new ways by basically allowing us to perceive the world in ways that we couldn't otherwise. And so what I'm getting at with this is I think that living objects are actually huge. They're some of the biggest structures in the universe, but they are not big in space. They're big in time. And we actually can't resolve that feature. We don't interact with it on a regular basis, so we see them as these fleeting things that have this really short temporal clock time without seeing how large they are. When I'm saying time here, really, the way that people could picture it is in terms of causal structure. So if you think about the history of the universe to get to you and you imagine that that entire history is you, that is the picture I have in my mind when I look at every living thing.

Lex Fridman
You have a tweet for everything. You tweeted-

Sara Walker
Doesn't everyone?

Lex Fridman
You have a lot of poetic, profound tweets. Sometimes -

Sara Walker
Thank you.

Lex Fridman
- they're puzzles that take a long time to figure out.

Sara Walker
Well, you know what it is? The reason they're hard to write is because it's compressing a very deep idea into a short amount of space, and I really like doing that intellectual exercise because I find it productive for me.

Lex Fridman
Yeah, it's a very interesting kind of compression algorithm though.

Sara Walker
Yeah, I like language. I think it's really fun to play with.

Lex Fridman
Yeah, I wonder if AI can decompress it. That'd be an interesting challenge.

Sara Walker
I would like to try this, but I think I use language in certain ways that are non-canonical and I do it very purposefully. And it would be interesting to me how AI would interpret it.

Lex Fridman
Yeah, your tweets would be a good Turing Test for super intelligence. Anyway, you tweeted that things only look emergent because we can't see time. So if we could see time, what would the world look like? You're saying you'll be able to see everything that an object has been, every step of the way that led to this current moment, and all the interactions that require to make that evolution happen. You would see this gigantic tail.

Sara Walker
The universe is far larger in time than it is in space, and this planet is one of the biggest things in the universe.

Lex Fridman
So the more complexity, the bigger the object -

Sara Walker
Yeah, I think the modern technosphere is the largest object in time in the universe that we know about.

Lex Fridman
And when you say technosphere, what do you mean?

Sara Walker
I mean the global integration of life and technology on this planet.

Lex Fridman
So all the technological things we've created?

Sara Walker
But I don't think of them as separate. They're very integrated with the structure that generated them. So you can almost imagine it like time is constantly bifurcating and it's generating new structures, and these new structures are locally constructing the future. And so things like you and I are very close together in time because we didn't diverge very early in the history of universe. It's very recent. And I think this is one of the reasons that we can understand each other so well and we can communicate effectively, and I might have some sense of what it feels like to be you. But other organisms bifurcated from us in time earlier. This is just the concept of phylogeny. But if you take that deeper and you really think about that as the structure of the physics that generates life and you take that very seriously, all of that causation is still bundled up in the objects we observe today. And so

you and I are close in this temporal structure, but we're so close because we're really big and we only are very different and the most recent moments in the time that's embedded in us. It's hard to use words to visualize what's in minds. I have such a hard time with this sometimes. Actually, I was thinking on the way over here, I was like, you have pictures in your brain and then they're hard to put into words. But I realized I always say I have a visual, but it's not actually I have a visual. I have a feeling, because oftentimes I cannot actually draw a picture in my mind for the things that I say, but sometimes they go through a picture before they get to words. But I like experimenting with words because I think they help paint pictures.

Lex Fridman
It's, again, some kind of compressed feeling that you can query to get a sense of the bigger visualization that you have in mind. It's just a really nice compression. But I think the idea of this object that in it contains all the information about the history of an entity that you see now, just trying to visualize that is pretty cool. Obviously, the mind breaks down quickly as you step seconds and minutes back in time.

Sara Walker
Yeah, for sure.

Lex Fridman
I guess it's just a gigantic object we're supposed to be thinking about.

Sara Walker
Yeah, I think so. And I think this is one of the reasons that we have such an ability to abstract as humans because we are so gigantic that the space that we can go back into is really large. So the more abstract you're going, the deeper you're going in that space.

Lex Fridman
But in that sense, aren't we fundamentally all connected?

Sara Walker
Yes. And this is why the definition of life cannot be the individual. It has to be these lineages because they're all connected, they're interwoven, and they're exchanging parts all the time.

Lex Fridman
Yeah, so maybe there are certain aspects of those lineages that can be lifelike. They can be characteristics. They can be measured with the sunbeam theory that have more or less life, but they're all just fingertips of a much bigger object.

Sara Walker
Yeah, I think life is very high dimensional. In fact, I think you can be alive in some dimensions and not in others. If you could project all the causation that's in you, in some features of you, very little causation is required, very little history. And in some features, a lot is. So it's quite difficult to take this really high-dimensional, very deep structure and project it into things that we really can understand and say, "This is the one thing that we're seeing," because it's not one thing.

Lex Fridman
It's funny we're talking about this now and I'm slowly starting to realize, one of the things I saw when I took Ayahuasca, afterwards actually, so the actual ceremony is four or five hours, but afterwards you're still riding whatever the thing that you're riding. And I got a chance to afterwards hang out with some friends and just shoot the shit in the forest, and I could see their faces. And what was happening with their faces and their hair is I would get this interesting effect. First of all, everything was beautiful and I just had so much love for everybody, but I could see their past selves behind them. I guess it's a blurring effect of where if I move like this, the faces that were just there are still there and it would just float like this behind them, which will create this incredible effect. But another way to think about that is I'm visualizing a little bit of that object of the thing they were just a few seconds ago. It's a cool little effect.

Sara Walker
That's very cool.

Lex Fridman
And now it's giving it a bit more profundity to the effect that was just beautiful aesthetically, but it's also beautiful from a physics perspective because that is a past self. I get a little glimpse at the past selves that they were. But then you take that to its natural conclusion, not just a few seconds ago, but just to the beginning of the universe. And you could probably get to that -

Sara Walker
Billions of years, yeah.

Lex Fridman
- get down that lineage.

Sara Walker
It's crazy that there's billions of years inside of all of us.

Lex Fridman
All of us. And then we connect obviously not too long ago.

Sara Walker
Yeah.

Lex Fridman
You mentioned just the technosphere, and you also wrote that the most, the live thing on this planet is our technosphere. Why is the technology we create a kind of life form? Why are you seeing it as life?

Sara Walker
Because it's creative. But with us, obviously. Not independently of us. And also because of this lineage view of life. And I think about life often as a planetary scale phenomena because the natural boundary for all of this causation that's bundled in every object in our biosphere. And so for me, it's just the current boundary of how far life on our planet has pushed into the things that our universe can generate, and so it's the furthest thing, it's the biggest thing. And I think a lot about the nature of life across different scales. And so we have cells inside of us that are alive and we feel like we're alive, but we don't often think about the societies that we're embedded in as alive or a global-scale organization of us in our technology on the planet as alive. But I think if you have this deeper view into the nature of life, which I think is necessary also to solve the origin of life, then you have to include those things.

Lex Fridman
All of them, so you have to simultaneously think about -

Sara Walker
Every scale.

Lex Fridman
- life at every single scale.

Sara Walker
Yeah.

Lex Fridman
The planetary and the bacteria level.

Sara Walker
Yeah. This is the hard thing about solving the problem of life, I think, is how many things you have to integrate into building a sort of unified picture of this thing that we want to call life. And a lot of our theories of physics are built on building deep regularities that explain a really broad class of phenomena, and I think we haven't really traditionally thought about life that way. But I think to get at some of these hardest questions like looking for life on other planets or the origin of life, you really have to think about it that way. And so most of my

professional work is just trying to understand every single thing on this planet that might be an example of life, which is pretty much everything, and then trying to figure out what's the deeper structure underlying that.

Lex Fridman
Yeah. Schrodinger wrote that living matter, while not eluding the laws of physics as established up to date, is likely to involve other laws of physics hitherto unknown. So to him -

Sara Walker
I love that quote.

Lex Fridman
- there was a sense that at the bottom of this, there are new laws of physics that could explain this thing that we call - new laws of physics that could explain this thing that we call life.

Sara Walker
Yeah. Schrodinger really tried to do what physicists try to do, which is explain things. And his attempt was to try to explain life in terms of non-equilibrium physics, because he thought that was the best description that we could generate at the time. And so he did come up with something really insightful, which was to predict the structure of DNA as an aperiodic crystal. And that was for a very precise reason, that was the only kind of physical structure that could encode enough information to actually specify a cell. We knew some things about genes, but not about DNA and its actual structure when he proposed that. But in the book, he tried to explain life is kind of going against entropy. And so some people have talked about it as like Schrodinger's paradox, how can life persist when the second law of thermodynamics is there? But in open systems, that's not so problematic. And really the question is, why can life generate so much order? And we don't have a physics to describe that. And it's interesting, generations of physicists have thought about this problem. Oftentimes, it's like when people are retiring, they're like, "Oh, now I can work on life." Or they're more senior in their career and they've worked on other more traditional problems. And there's still a lot of impetus in the physics community to think that non-equilibrium physics will explain life. But I think that's not the right approach. I don't think ultimately the solution to what life is there, and I don't really think entropy has much to do with it unless it's entirely reformulated.

Lex Fridman
Well, because you have to explain how interesting order, how complexity emerges from the soup.

Sara Walker
Yes. From randomness.

Lex Fridman
From randomness. Physics currently can't do that.

Sara Walker
No. Physics hardly even acknowledges that the universe is random at its base. We like to think we live in a deterministic universe and everything's deterministic. But I think that's probably an artifact of the way that we've written down laws of physics since Newton invented modern physics and his conception of motion and gravity, which he formulated laws that had initial conditions and fixed dynamical laws. And that's been sort of become the standard canon of how people think the universe works and how we need to describe any physical system is with an initial condition in a law of motion. And I think that's not actually the way the universe really works. I think it's a good approximation for the kind of systems that physicists have studied so far. And I think it will radically fail in the longterm at describing reality at its more basal levels. But I'm not saying there's a base, I don't think that reality has a ground, and I don't think there's a theory of everything, but I think there are better theories, and I think there are more explanatory theories, and I think we can get to something that explains much more than the current laws of physics do.

Lex Fridman
When you say theory of everything, you mean everything, everything?

Sara Walker
Yeah. In physics right now, it's really popular to talk about theories of everything. So string theory is supposed to be a theory of everything because it unifies quantum mechanics and gravity. And people have their different pet theories of everything. And the challenge with the theory of everything, I really love this quote from David Krakauer, which is, "A theory of everything is a theory of everything except those things that theorize."

Lex Fridman
Oh, you mean removing the observer from the thing?

Sara Walker
Yeah. But it's also weird because if a theory of everything explained everything, it should also explain the theory. So the theory has to be recursive and none of our theories of physics are recursive. So it's a weird concept.

Lex Fridman
But it's very difficult to integrate the observer into a theory.

Sara Walker
I don't think so. I think you can build a theory acknowledging that you're an observer inside the universe.

Lex Fridman
But doesn't it become recursive in that way? And you saying it's possible to make a theory that's okay with that?

Sara Walker
I think so. I mean, I don't think - there's always going to be the paradox of another meta level you could build on the meta level. So if you assume this is your universe and you're observe outside of it, you have some meta description of that universe, but then you need a meta description of you describing that universe. So this is one of the biggest challenges that we face being observers inside our universe. And also, why the paradoxes and the foundations of mathematics and any place that we try to have observers in the system or a system describing itself show up. But I think it is possible to build a physics that builds in those things intrinsically without having them be paradoxical or have holes in the descriptions. And so one place I think about this quite a lot, which I think can give you sort of a more concrete example, is the nature of what we call fundamental. So we typically define fundamental right now in terms of the smallest indivisible units of matter. So again, you have to have a definition of what you think material is and matter is, but right now what's fundamental are elementary particles. And we think they're fundamental because we can't break them apart further. And obviously, we have theories like string theory that if they're right would replace the current description of what's the most fundamental thing in our universe by replacing with something smaller. But we can't get to those theories because we're technologically limited. And so if you look at this from a historical perspective and you think about explanations changing as physical systems like us learn more about the reality in which they live, we once considered atoms to be the most fundamental thing. And it literally comes from the word indivisible. And then we realized atoms had substructure because we built better technology, which allowed us to "See the world better" and resolve smaller features of it. And then we built even better technology, which allowed us to see even smaller structure and get down to the standard model particles. And we think that there might be structure below that, but we can't get there yet with our technology. So what's fundamental, the way we talk about it in current physics is not actually fundamental, it's the boundaries of what we can observe in our universe, what we can see with our technology. And so if you want to build a theory that's about us and about what's inside the universe that we can observe, not what's at the boundary of it, you need to talk about objects that are in the universe that you can actually break apart to smaller things. So I think the things that are fundamental are actually the constructed objects. They're the ones that really exist, and you really understand their properties because you know how the universe constructed them because you can actually take them apart. You can understand the intrinsic laws that built them. But the things that the boundary are just at the boundary,

they're evolving with us, and we'll learn more about that structure as we go along. But really, if we want to talk about what's fundamental inside our universe, we have to talk about all these things that are traditionally considered emergent, but really just structures in time that have causal histories that constructed them and are really actually what our universe is about.

Lex Fridman
So we should focus on the construction methodology as the fundamental thing. Do you think there's a bottom to the smallest possible thing that makes up the universe?

Sara Walker
I don't see one.

Lex Fridman
It'll take way too long. It'll take longer to find that than it will to understand the mechanism that created life.

Sara Walker
I think so, yeah. I think for me, the frontier in modern physics, where the new physics lies is not in high energy particle physics, it's not in quantum gravity, it's not in any of these sort of traditionally sold, "This is going to be the newest deepest insight we have into the nature of reality." It is going to be in studying the problems of life and intelligence and the things that are sort of also our current existential crises as a civilization or a culture that's going through an existential trauma of inventing technologies that we don't understand right now.

Lex Fridman
The existential trauma and the terror we feel that that technology might somehow destroy us, us meaning living intelligently with organisms, and yet we don't understand what that even means.

Sara Walker
Well, humans have always been afraid of our technologies though. So it's kind of a fascinating thing that every time we invent something we don't understand, it takes us a little while to catch up with it.

Lex Fridman
I think also in part, humans kind of love being afraid.

Sara Walker
Yeah, we love being traumatized.

Lex Fridman
It's weird, the trauma -

Sara Walker
We want to learn more, and then when we learn more, it traumatizes us. I never thought about this before, but I think this is one of the reasons I love what I do, is because it traumatizes me all the time. That sounds really bad. But what I mean is I love the shock of realizing that coming to understand something in a way that you never understood it before. I think it seems to me when I see a lot of the ways other people react to new ideas that they don't feel that way intrinsically. But for me, that's why I do what I do. I love that feeling.

Lex Fridman
But you're also working on a topic where it's fundamentally ego destroying, is you're talking about life. It's humbling to think that we're not - the individual human is not special. And you're very viscerally exploring that.

Sara Walker
Yeah. I'm trying to embody that. Because I think you have to live the physics to understand it. But there's a great quote about Einstein. I don't know if this is true or not, that he once said that he could feel like beam in his belly. But I think you got to think about it though, right? If you're really deep thinker and you're really thinking about reality that deeply and you are part of the reality that you're trying to describe, you feel it, you really feel it.

Lex Fridman
That's what I was saying about, you're always walking along the cliff. If you fall off, you're falling into madness.

Sara Walker
Yes. It's a constant descent into madness.

Lex Fridman
The fascinating thing about physicists and madness is that you don't know if you've fallen off the cliff.

Sara Walker
Yeah, you don't don't know.

Lex Fridman
That's the cool thing about it.

Sara Walker
I rely on other people to tell me. Actually, this is very funny. Because I have these conversations with my students often, they're worried about going crazy. I have to reassure them that one of the reasons they'll stay sane is by trying to work on concrete problems.

Lex Fridman
I'm going crazy or waking up. I don't know which one it is.

Sara Walker
Yeah.

Lex Fridman
So what do you think is the origin of life on earth and how can we talk about it in a productive way?

Sara Walker
The origin of life is like this boundary that the universe can only cross if a structure that emerges can reinforce its own existence, which is self-reproduction, autocatalysis, things people traditionally talk about. But it has to be able to maintain its own existence against this sort of randomness that happens in chemistry, and this randomness that happens in the quantum world. And it's in some sense the emergence of a deterministic structure that says, "I'm going to exist and I'm going to keep going." But pinning that down is really hard. We have ways of thinking about it in assembly theory that I think are pretty rigorous. And one of the things I'm really excited about is trying to actually quantify in an assembly theoretic way when the origin of life happens. But the basic process I have in mind is a system that has no causal contingency, no constraints of objects, basically constraining the existence of other objects or forming or allowing the existence of other objects. And so that sounds very abstract, but you can just think of a chemical reaction can't happen if there's not a catalyst, for example. Or a baby can't be born if there wasn't a parent. So there's a lot of causal contingency that's necessary for certain things to happen. So you think about this sort of unconstrained random system, there's nothing that reinforces the existence of other things. So those sort of resources just get washed out in all of these different structures and none of them exist again, or they're not very complicated if they're in high abundance. And some random events allow some things to start reinforcing the existence of a small subset of objects. And if they can do that, just molecules basically recognizing each other and being able to catalyze certain reactions. There's this kind of transition point that happens where, unless you get a self-reinforcing structure, something that can maintain its own existence, it actually can't cross this boundary to make any objects in high abundance without having this sort of past history that it's carrying with us and maintaining the existence of that past history. And that boundary point where objects can't exist unless they have the selection and history in them, is what we call the origin of life. And pretty much everything beyond that boundary is holding on for dear life to all of the causation and

causal structure that's basically put it there, and it's carving its way through this possibility space into generating more and more structure. And that's when you get the open-ended cascade of evolution. But that boundary point is really hard to cross. And then what happens when you cross that boundary point and the way objects come into existence is also really fascinating dynamics, because as things become more complex, the assembly index increases. I can explain all these things. Sorry. You can tell me what you want to explain or what people will want to hear. This - sorry, I have a very vivid visual in my brain and it's really hard to articulate it.

Lex Fridman
Got to convert it to language.

Sara Walker
I know. It's so hard. It's like it's going from a feeling to a visual to language is so stifling sometimes.

Lex Fridman
I have to convert it from language to a visual to a feeling. I think it's working.

Sara Walker
I hope so.

Lex Fridman
I really like the self-reinforcement of the objects. Just so I understand, one way to create a lot of the same kind of object is make the self-reinforcing?

Sara Walker
Yes. So self-reproduction has this property. If the system can make itself, then it can persist in time because all objects decay, they all have a finite lifetime. So if you're able to make a copy of your self before you die, before the second law eats you or whatever people think happens, then that structure can persist in time.

Lex Fridman
So that's a way to sort of emerge out of a random soup, out of the randomness of soup.

Sara Walker
Right. But things that can copy themselves are very rare.

Lex Fridman
Yeah, very.

Sara Walker
And so what ends up happening is that you get structures that enable the existence of other things, and then somehow only for some sets of objects, you get closed structures that are self-reinforcing and allow that entire structure to persist.

Lex Fridman
So the object A reinforces the existence of object B, but object A can die. So you have to close that loop?

Sara Walker
Right. So this is the classic -

Lex Fridman
It's all very unlikely statistically, but that's sufficiently - so, you're saying there's a chance?

Sara Walker
There is a chance.

Lex Fridman
It's low probability, but once you solve that, once you close the loop, you can create a lot of those objects?

Sara Walker
And that's what we're trying to figure out, is what are the causal constraints that close the loop? So there is this idea that's been in the literature for a really long time that was originally proposed by Stuart Kauffman as really critical to the origin life called, autocatalytic sets. So autocatalytic set is exactly this property we have A makes B, B makes C, C makes A, and you get a closed system. But the problem with the theory of autocatalytic sets is incredibly brittle as a theory and it requires a lot of ad hoc assumptions. You have to assume function, you have to say this thing makes B. It's not an emergent property, the association between A and B. And so the way I think about it is much more general. If you think about these histories that make objects, it's kind of like the structure of the histories becomes, collapses in such a way that these things are all in the same sort of causal structure, and that causal structure actually loops back on itself to be able to generate some of the things that make the higher level structures. Lee has a beautiful example of this actually in molybdenum. It's like the first non-organic autocatalytic set. It's a self-reproducing molybdenum ring. But it's like molybdenum. And basically if you look at the molybdenum, it makes a huge molybdenum ring. I don't remember exactly how big it is. It might be like 150 molybdenum atoms or something. But if you think about the configuration space of that object, it's exponentially large how many possible molecules. So why does the entire system collapse on just making that one structure? If you start from molybdenum atoms that are maybe just a couple of them stuck together. And so what they see in this

system is there's a few intermediate stages. So there's some random events where the chemistry comes together and makes these structures. And then once you get to this very large one, it becomes a template for the smaller ones. And then the whole system just reinforces its own production.

Lex Fridman
How did Lee find this molybdenum closed loop?

Sara Walker
If I knew how Lee's brain work, I think I would understand a more about the universe. But I -

Lex Fridman
This is not an algorithm with discovery, it's a -

Sara Walker
No, but I think it goes to the deepest roots of when he started thinking about origins of life. So I mean, I don't know all his history, but what he's told me is he started out in crystallography. And there's some things that he would just - people would just take for granted about chemical structures that he was deeply perplexed about. Just like why are these really intricate, really complex structures forming so easily under these conditions? And he was really interested in life, but he started in that field. So he's just carried with him these sort of deep insights from these systems that seem like they're totally not alive and just like these metallic chemistries into actually thinking about the deep principles of life. So I think he already knew a lot about that chemistry. And he also, assembly theory came from him thinking about how these systems work. So he had some intuition about what was going on with this molybdenum ring.

Lex Fridman
The molybdenum might be able to be the thing that makes a ring?

Sara Walker
They knew about them for a long time, but they didn't know that the mechanism of why that particular structure form was all catalytic feedback. And so that's what they figured out in this paper. And I actually think that paper is revealing some of the mechanism of the origin life transition. Because really what you see the origin of life is basically like you should have a combinatorial explosion of the space of possible structures that are too large to exhaust. And yet you see it collapse on this really small space of possibilities that's mutually reinforcing itself to keep existing. That is the origin of life.

Lex Fridman
There's some set of structures that result in this autocatalytic feedback.

Sara Walker
Yeah.

Lex Fridman
And what is it? Tiny, tiny, tiny, tiny percent?

Sara Walker
I think it's a small space, but chemistry is very large. So there might be a lot of them out there, but we don't know.

Lex Fridman
And one of them is the thing that probably started life on earth?

Sara Walker
That's right.

Lex Fridman
Many, many starts and it keeps starting maybe.

Sara Walker
Yes. Yeah. I mean, there's also all kinds of other weird properties that happen around this kind of phase boundary. So this other project that I have in my lab is focused on the origin of chirality, which is thinking about - so, chirality is this property molecules that they can come in mirror image forms. So just like chirality means hand. So your left and right hand are what's called non-superimposable, because if you try to lay one on the other, you can't actually lay them directly on top of each other. And that's the property being a mirror image. So there's this sort of perplexing property of the chemistry of life that no one's been able to really adequately explain, that all of the amino acids in proteins are left-handed and all of the bases in RNA and DNA are right-handed. And yet the chemistry of these building block units, amino acids and nucleobases is the same for left. And so you have to have some kind of symmetry breaking where you go from these chemistries that seem entirely equivalent, to only having one chemistry takeover is the dominant form. And for a long time, I had been really - I actually did my PhD on the origin of chirality. I was working on it as a symmetry breaking problem in physics. This is how I got started in the origin of life. And then I left it for a long time because I thought it was one of the most boring problems in the origin of life, but I've come back to it. I think there's something really deep going on here related to this combinatorial explosion of the space of possibilities. But just to get to that point, this feature of this handedness has been the main focus. But people take for granted the existence of chiral molecules at all, that this property of having a handedness, and they just assume that it's just a generic feature of chemistry. But if you actually look at molecules, if you look at chemical space, which is the space of all possible molecules that people can generate, and you look at small molecules, things that have less than about seven to 11

heavy atoms. So things that are not hydrogen, almost every single molecule in that space is achiral, like doesn't have a chiral center. So it would be like a spoon. A spoon doesn't have, it's the same as its mirror image. It's not like a hand that's different than its mirror image. But if you get to this threshold boundary, above that boundary, almost every single molecule is chiral. So you go from a universe where almost nothing has a mirror image form, there's no mirror image universe of possibilities to this one where every single structure has pretty much a mirror image version. And what we've been looking at in my lab is that, it seems to be the case that the origin of life transition happens around the time when you start accumulating, you push your molecules to a large enough complexity that chiral molecules become very likely to form. And then there's a cascade of molecular recognition where chiral molecules can recognize each other. And then you get this sort of autocatalytic feedback and things self-reinforcing.

Lex Fridman
So is chirality in itself an interesting feature or just an accident of complexity?

Sara Walker
No, it's a super interesting feature. I think chirality breaks symmetry in time, not space. So we think of it as a spatial property, like a left and right hand. But if I choose the left hand, I'm basically choosing the future of that system for all time, because I've basically made a choice between the ways that that molecule can now react with every other object in its chemical universe.

Lex Fridman
Oh, I see.

Sara Walker
And so you're actually, when you have the splitting of making a molecule that now has another form it could have had by the same exact atomic composition, but now it's just a mirror image isometry, you're basically splitting the universe of possibilities every time.

Lex Fridman
Yeah. In two.

Sara Walker
In two, but molecules can have more than one chiral center, and that's not the only symmetry that they can have. So this is one of the reasons that Taxol fills 1.5 universes of space. It's all of these spatial permutations that you do on these objects that actually makes the space so huge. So the point of this sort of chiral transition that I am pointing out is, chirality is actually signature of being in a complex chemical space. And the fact that we think it's a really generic feature of chemistry and it's really prevalent is because most of the chemistry we study on earth is a product already of life. And it also has to do with this

transition in assembly, this transition in possibility spaces, because I think there's something really fundamental going on at this boundary, that you don't really need to go that far into chemical space to actually see life in terms of this depth in time, this depth in symmetries of objects, in terms of chiral symmetries or this assembly structure. But getting past this boundary that's not very deep in that space requires life. It's a really weird property, and it's really weird that so many abrupt things happen in chemistry at that same scale.

Lex Fridman
So would that be the greatest invention ever made on earth in its evolutionary history? I really like that formulation of it. Nick Lane has a book called Life Ascending, where he lists the 10 great inventions of evolution, the origin of life being first and DNA, the hereditary material that encodes the genetic instructions for all living organisms. Then photosynthesis, the process that allows organisms to convert sunlight into chemical energy, producing oxygen as a byproduct, the complex cell, eukaryotic cells, which contain in nucleus and organelles arose from simple bacterial cells. Sex, sexual reproduction. Movement, so just the ability to move under which you have the predation, the predators and ability of living organisms.

Sara Walker
I like that movement's in there. That's cool.

Lex Fridman
But a movement includes a lot of interesting stuff in there, like predator-prey dynamic, which not to romanticized a nature is metal. That seems like an important one. I don't know. It's such a computationally powerful thing to have a predator and prey.

Sara Walker
Well, it's efficient for things to eat other things that are already alive because they don't have to go all the way back to the base chemistry.

Lex Fridman
Well that, but maybe I just like deadlines, but it creates an urgency. You're going to get eaten.

Sara Walker
You got to live.

Lex Fridman
Yeah. Survival. It's not just the static environment you're battling against.

Sara Walker
Oh, I see.

Lex Fridman
You're like - the dangers against which you're trying to survive are also evolving. This is just a much faster way to explore the space of possibilities.

Sara Walker
I actually think it's a gift that we don't have much time.

Lex Fridman
Yes. Sight, the ability to see. So the increasing complexifying of sensory organisms. Consciousness and death, the concept of programmed cell death. These are all these inventions along the line.

Sara Walker
Yeah. I like invention as a word for them. I think that's good.

Lex Fridman
Which are the more interesting inventions to you with origin of life? Because you kind of are not glorifying the origin of life itself. There's a process -

Sara Walker
No, I think the origin of life is a continual process, that's why. I'm interested in the first transition and solving that problem, because I think it's the hardest, but I think it's happening all the time.

Lex Fridman
When you look back at the history of earth, what are you impressed happened?

Sara Walker
I like sight as an invention, because I think having sensory perception and trying to comprehend the world, to use anthropocentric terms, is a really critical feature of life. And I also, it's interesting the way that site has complexified over time. So if you think at the origin of life, nothing on the planet could see. So for a long time, life had no sight, and then photon receptors were invented. And then when multicellular evolved, those cells eventually grew into eyes and we had the multicellular eye. And then it's interesting when you get to societies like human societies, that we invent even better technologies of seeing, like telescopes and microscopes, which allow us to see deeper into the universe or at smaller scales. So I think that's pretty profound, the way that site has transformed the ability of life to literally see the reality in which it's existing in. I think consciousness is also obviously deeply interesting. I've gotten kind of obsessed with octopus. They're just so

weird. And the fact that they evolved complex nervous systems kind of independently seems very alien.

Lex Fridman
Yeah, there's a lot of alien organisms. That's another thing I saw in the jungle, just things that are like, "Oh, okay. They make one of those, huh?" It just feels like there's -

Sara Walker
Do you have any examples?

Lex Fridman
There's a frog that's as thin as a sheet of paper. And I was like, "What?" And it gets birthed through pores.

Sara Walker
Oh, I've seen videos of that. It's so gross when the babies come out. Did you see that in person? The baby's coming out?

Lex Fridman
Oh, no. I saw the without the -

Sara Walker
Have you seen videos of that? It's so gross. It's one of the grossest things I've ever seen.

Lex Fridman
Well, gross is just the other side of beautiful, I think it's like, "Oh, wow. That's possible."

Sara Walker
I guess, if I was one of those frogs, I would think that was the most beautiful event I'd ever seen. Although, human childbirth is not that beautiful either.

Lex Fridman
Yeah. It's all a matter of perspective.

Sara Walker
Well, we come into the world so violently, it's just like, it's amazing.

Lex Fridman
I mean, the world is a violent place. So again, it's just another side of the coin.

Sara Walker
You know what? This actually makes me think of one that's not up there, which I do find really incredibly amazing, is the process of the germline cell in organisms. Basically, every living thing on this planet at some point in its life has to go through a single cell. And this whole issue of development, the developmental program is kind of crazy. How do you build you out of a single cell? How does a single cell know how to do that? Pattern formation of a multicellular organism, obviously evolves with DNA, but there's a lot of stuff happening there about when cells take on certain morphologies and things that people don't understand, like the actual shape formation mechanism. A lot of people study that, and there's a lot of advances being made now in that field. I think it's pretty shocking though that how little we know about that process. And often it's left off of people's lists, it's just kind of interesting. Embryogenesis is fascinating.

Lex Fridman
Yeah. Because you start from just one cell.

Sara Walker
Yeah. And the genes and all the cells are the same. So the differentiation has to be something that's much more about the actual expression of genes over time and how they get switched on and off, and also the physical environment of the cell interacting with other cells. And there's just a lot of stuff going on.

Lex Fridman
Yeah. The computation, the intelligence of that process -

Sara Walker
Yes.

Lex Fridman
- might be the most important thing to understand. And we just kind of don't really think about it.

Sara Walker
Right.

Lex Fridman
We think about the final product.

Sara Walker
Yeah.

Lex Fridman
Maybe the key to understanding the organism is understanding that process, not the final product.

Sara Walker
Probably, yes. I think most of the things about understanding anything about what we are embedded in time.

Lex Fridman
Well, of course you would say that.

Sara Walker
I know. So predictable. It's turning into a deterministic universe.

Lex Fridman
It always has been. Always was like the meme.

Sara Walker
Yeah, always was, but it won't be in the future.

Lex Fridman
Well, before we talk about the future, let's talk about the past. The assembly theory.

Sara Walker
Yes.

Lex Fridman
Can you explain assembly theory to me? I listened to Lee talk about it for many hours, and I understood nothing. No, I'm just kidding. I just wanted to take another - you've been already talking about it, but just what from a big picture view is the assembly theory way of thinking about our world, about our universe.

Sara Walker
Yeah. I think the first thing is the observation that life seems to be the only thing in the universe that builds complexity in the way that we see it here. And complexity is obviously a loaded term, so I'll just use assembly instead because I think assembly is more precise. But the idea that all the things on your desk here from your computer, to the pen, to us sitting here don't exist anywhere else in the universe as far as we know, they only exist on this planet and it took a long evolutionary history to get to us, is a real feature that we should take seriously as one that's deeply embedded in the laws of physics and the structure of the universe that we live in. Standard physics would say that all of that complexity traces back to the infinitesimal deviations and the initial state of the universe that there was some

order there. I find that deeply unsatisfactory. And what assembly theory says that's very different is that, the universe is basically constructing itself, and when you get to these combinatorial spaces like chemistry, where the space of possibilities is too large to exhaust them all, you can only construct things along historically contingent paths, like you basically have causal chains of events that happen to allow other things to come into existence. And that this is the way that complex objects get formed, is basically on scaffolding on the past history of objects, making more complex objects, making more complex objects. That idea in itself is easy to state and simple, but it has some really radical implications as far as what you think is the nature of the physics that would describe life. And so what assembly theory does formally is try to measure the boundary in the space of all things that chemically could exist. For example, like all possible molecules, where's the boundary above which we should say these things are too complex to happen outside of an evolutionary chain of events, outside of selection. And we formalize that with two observables. One of them is the copy number, the object. So - is that with two observables. One of them is the copy number of the object. How many of the object did you observe? And the second one is what's the minimal number of recursive steps to make it? If you start from elementary building blocks, like bonds for molecules, and you put them together, and then you take things you've made already and build up to the object, what's the shortest number of steps you had to take? And what Lee's been able to show in the lab with his team is that for organic chemistry, it's about 15 steps. And then you only see molecules that the only molecules that we observe that are past that threshold are ones that are in life. And in fact, one of the things I'm trying to do with this idea of trying to actually quantify the origin of life as a transition in - a phase transition and assembly theory is actually be able to explain why that boundary is where because I think that's actually the boundary that life must cross. The idea of going back to this thing we were talking about before about these structures that can reinforce their own existence and move past that boundary, 15 seems to be that boundary in chemical space. It's not a universal number. It will be different for different assembly spaces, but that's what we've experimentally validated so far. And then -

Lex Fridman
Literally 15, the assembly index is 15?

Sara Walker
It's 15 or so for the experimental data. Yeah.

Lex Fridman
That's when you start getting the self-reinforcing?

Sara Walker
When have to have that feature in order to observe molecules in high abundance in that space.

Lex Fridman
The copy number is the number of exact copies. That's what you mean by high abundance and assembly index or the complexity of the object is how many steps it took to create it. Recursive.

Sara Walker
Recursive. Yeah. You can think of objects in assembly theory as basically recursive stacks of the construction steps to build them. They're like, it's like you take this step and then you make this object and you make it this object and make this object, and then you get up to the final object. But that object is all of that history rolled up into the current structure.

Lex Fridman
What if you took the long way home with all of this?

Sara Walker
You can't take the long way.

Lex Fridman
Why not?

Sara Walker
The long way doesn't exist.

Lex Fridman
It's a good song though. What do you mean the long way doesn't exist? If I do a random walk from A to B, if I start at A, I'll eventually end up at B. And that random walk would be much longer than the short.

Sara Walker
It turns out, now if you look at objects - and so, we define something we call the assembly universe. And assembly universe is ordered in time. It's actually ordered in the causation, the number of steps to produce an object. And so, all objects in the universe are in some sense existed, a layer that's defined by their assembly index. And the size of each layer is growing exponentially. What you're talking about, if you want to look at the long way of getting to an object, as I'm increasing the assembly index of an object, I'm moving deeper and deeper into an exponentially growing space. And it's actually also the case that the typical path to get to that object is also exponentially growing with respect to the assembly index. And so, if you want to try to make a more and more complex object and you want to do it by a typical path, that's actually an exponentially receding horizon. And so most objects that come into existence have to be causally very similar to the things that exist because close by in that space, and they can actually get to it by an almost shortest path for that object.

Lex Fridman
Yeah. The almost shortest path is the most likely and by a lot.

Sara Walker
By a lot.

Lex Fridman
Okay. If you see a high copy number.

Sara Walker
Yeah, imagine yourself -

Lex Fridman
A copy number of greater than one.

Sara Walker
Yeah. I mean basically, the more complex we live in a space that is growing exponentially large. And the ways of getting to objects in the space are also growing exponentially large. And so, we're this recursively stacked structure of all of these objects that are clinging onto each other for existence. And then they grab something else and are able to bring that thing into existence similar to them.

Lex Fridman
But there is a phase transition.

Sara Walker
There is a transition.

Lex Fridman
There is a place where you would say, "Oh, that's life."

Sara Walker
I think it's actually abrupt. I've never been able to say that in my entire career before. I've always gone back and forth about whether the original life was gradual or abrupt. I think it's very abrupt.

Lex Fridman
Poetically, chemically, literally?

Sara Walker
Life snaps into existence.

Lex Fridman
With snaps. Okay. That's very beautiful.

Sara Walker
It snaps.

Lex Fridman
Okay. But -

Sara Walker
We'll be poetic today. But no, I think there's a lot of random exploration. And then the possibility space just collapses on the structure really fast that can reinforce its own existence because it's basically fighting against non-existence.

Lex Fridman
Yeah. You tweeted, "The most significant struggle for existence in the evolutionary process is not among the objects that do exist, but between the ones that do and those that never have the chance to. This is where selection does most of its causal work. The objects that never get a chance to exist, the struggle between the ones that never get a chance to exist and the ones that..." Okay, what's that line exactly?

Sara Walker
I don't know. We can make songs out of all of these.

Lex Fridman
What are the objects that never get a chance to exist? What does that mean?

Sara Walker
There was this website, I forgot what it was, but it's like a neural network that just generates a human face. And it's like this person does not exist. I think that's what it's called. You can just click on that all day and you can look at people all day that don't exist. All of those people exist in that space of things that don't exist.

Lex Fridman
Yeah. But there's the real struggle.

Sara Walker
Yeah. The struggle of the quote, the struggle for existence is that goes all the way back to Darwin's writing about natural selection. The whole idea of survival of the fittest is everything struggling to exist, this predator-prey dynamic. And the fittest survive. And so, the struggle for existence is really what selection is all about. And that's true. We do see things that do exist competing to continue to exist. But if you think about this space of

possibilities and each time the universe generates a new structure or an object that exists, generates a new structure along this causal chain. It's generating something that exists that never existed before. And each time that we make that kind of decision, we're excluding a huge piece of possibilities. And so actually, as this process of increasing assembly index, it's not just that the space that these objects exist in is exponentially growing, but there are objects in that space that are exponentially receding away from us. They're becoming exponentially less and less likely to ever exist. And so, existence excludes a huge number of things.

Lex Fridman
Just because of the accident of history, how it ended up?

Sara Walker
Yeah. It is in part an accident because I think some of the structure that gets generated is driven a bit by randomness. I think a lot of it. One of the conceptions that we have in assembly theory is the universe is random at its base. You can see this in chemistry, unconstrained chemical reactions are pretty random. And also, quantum mechanics, there's lots of places that give evidence for that. And deterministic structures emerge by things that can causally reinforce themselves and maintain persistence over time. And so, we are some of the most deterministic things in the universe. And so, we can generate very regular structure and we can generate new structure along a particular lineage. But the possibility space at the tips, the things we can generate next is really huge. There's some stochasticity in what we actually instantiate as the next structures that get built in the biosphere. It's not completely deterministic because the space of future possibilities is always larger than the space of things that exist now.

Lex Fridman
How many instantiations of life is out there, do you think? How often does this happen? What we see happen here on earth, how often is this process repeated throughout our galaxy, throughout the universe?

Sara Walker
I said before, right now, I think the origin of life is a continuous process on earth. I think this idea of combinatorial spaces that our biosphere generates not just chemistry, but other spaces often cross this threshold where they then allow themselves to persist with particular regular structure over time. Language is another one where the space of possible configurations of the 26 letters of the English alphabet is astronomically large, but we use with very high regularity, certain structures. And then we associate meaning to them because of the regularity of how much we use them. Meaning is an emergent property of the causation and the objects and how often they recur and what the relationship of the recurrence is to other objects.

Lex Fridman
Meaning is the emergent property. Okay, got it.

Sara Walker
Well, this is why you can play with language so much actually. Words don't really carry meaning, it's just about how you lace them together.

Lex Fridman
But from where does the language?

Sara Walker
But obviously as a speaker of a given language, you don't have a lot of room with a given word to wiggle, but you have a certain amount of room to push the meanings of words. And I do this all the time, and you have to do it with the kind of work that I do because if you want to discover an abstraction, like some keep concept that we don't understand yet, it means we don't have the language. And so, the words that we have are inadequate to describe the things. This is why we're having a hard time talking about assembly theory because it's a newly emerging idea. And so, I'm constantly playing with words in different ways to try to convey the meaning that is actually behind the words, but it's hard to do.

Lex Fridman
You have to wiggle within the constraints.

Sara Walker
Yes. Lots of wiggle.

Lex Fridman
The great orators are just good at wiggling.

Sara Walker
Do you wiggle?

Lex Fridman
I'm not a very good wiggler. No. This is the problem. This is part of the problem.

Sara Walker
No, I like playing with words a lot. It's very funny because I know you talked about this with Lee, but people were so offended by the writing of the paper that came out last fall. And it was interesting because the ways that we use words were not the way that people were interacting with the words. And I think that was part of the mismatch where we were trying to use words in a new way because we were trying to describe something that hadn't been described adequately before, but we had to use the words that everyone else uses for

things that are related. And so, it was really interesting to watch that clash play out in real time for me, being someone that tries to be so precise with my word usage, knowing that it's always going to be vague.

Lex Fridman
Boy, can I relate. What is truth? Is truth the thing you meant when you wrote the words or is truth the thing that people understood when they read the words?

Sara Walker
Oh, yeah.

Lex Fridman
I think that compression mechanism into language is a really interesting one. And that's why Twitter is a nice exercise.

Sara Walker
I love Twitter.

Lex Fridman
Because you get to write a thing and you think a certain thing when you write it. And then you get to see all these other people interpret it all kinds of different ways.

Sara Walker
Yeah. I use it as an experimental platform for that reason.

Lex Fridman
I wish there was a higher diversity of interpretation mechanisms applied to tweets, meaning all kinds of different people would come to it. Like some people that see the good in everything and some people that are ultra-cynical, a bunch of haters and a bunch of lovers and a bunch of -

Sara Walker
Maybe they could do better jobs with presenting material to people. How things - it's usually based on interest. But I think it would be really nice if you got 10% of your Twitter feed was random stuff sampled from other places. That'd be fun.

Lex Fridman
True. I also would love to filter just bin the response to tweets by the people that hate on everything.

Sara Walker
Oh, that would be fantastic.

Lex Fridman
The people that are super positive about everything. And they'll just, I guess, normalize the response because then it'd be cool to see if the people that you're usually positive about everything are hating on you or totally don't understand or completely misunderstood.

Sara Walker
Yeah, usually it takes a lot of clicking to find that out. Yeah, so it'd be better if it was sorted. Yeah.

Lex Fridman
The more clicking you do, the more damaging it is to the soul.

Sara Walker
Yeah. It's like instead of like, well, you could have the blue check. But you should have, are you a pessimist, an optimist?

Lex Fridman
Yeah. There's a lot of colors.

Sara Walker
Chaotic neutral. What's your personality?

Lex Fridman
Be a whole rainbow of checks. And then you realize there's more categories than we can possibly express in colors.

Sara Walker
Yeah. Of course. People are complex.

Lex Fridman
That's our best feature. I don't know how we got to the wiggling required given the constraints of language because I think we started about me asking about alien life. Which is how many different times did the phase transition happen elsewhere? Do you think there's other alien civilizations out there?

Sara Walker
This goes into the are you on the boundary of insane or not? But when you think about the structure of the physics of what we are, that deeply, it really changes your conception of things. And going to this idea of the universe being small in physical space compared to how big it is in time and how large we are. It really makes me question about whether there's any other structure that's this giant crystal in time, this giant causal structure, like our biosphere/technosphere is anywhere else in the universe.

Lex Fridman
Why not?

Sara Walker
I don't know.

Lex Fridman
Just because this one is gigantic doesn't mean there's no other gigantic spheres.

Sara Walker
But I think when the universe is expanding, it's expanding in space, but in assembly theory, it's also expanding in time. And actually that's driving the expansion in space. And expansion in time is also driving the expansion in the combinatorial space of things on our planet. That's driving the pace of technology and all the other things. Time is driving all of these things, which is a little bit crazy to think that the universe is just getting bigger because time is getting bigger. But the sort of visual that gets built in my brain about that is the structure that we're building on this planet is packing more and more time in this very small volume of space because our planet hasn't changed its physical size in 4 billion years, but there's a ton of causation and recursion and time, whatever word you want to use, information packed into this. And I think this is also embedded in the virtualization of our technologies or the abstraction of language and all of these things. These things that seem really abstract are just really deep in time. And so, what that looks like is you have a planet that becomes increasingly virtualized. And so it's getting bigger and bigger in time, but not really expanding out in space. And the rest of space is moving away from it. Again, it's a exponentially receding horizon. And I'm just not sure how far into this evolutionary process something gets if it can ever see that there's another such structure out there.

Lex Fridman
What do you mean by virtualized in that context?

Sara Walker
Virtual as a play on virtual reality and simulation theories. But virtual also in a sense of, we talk about virtual particles in particle physics, which they are very critical to doing calculations about predicting the properties of real particles, but we don't observe them directly. What I mean by virtual here is virtual reality for me, things that appear virtual, appear abstract are just things that are very deep in time in the structure of the things that we are. If you think about you as a 4 billion year old object, the things that are a part of you, like your capacity to use language or think abstractly or have mathematics are just very deep temporal structures. That's why they look like they're informational and abstract is because they're existing in this temporal part of you, but not necessarily spatial part.

Lex Fridman
Just because I have a 4 billion year old history, why does that mean I can't hang out with aliens?

Sara Walker
There's a couple ideas that are embedded here. One of them comes again from Paul. He wrote this book years ago about the eerie silence and why we're alone. And he concluded the book with this idea of quintelligence or something. But this idea that really advanced intelligence would basically just build itself into a quantum computer and it would want to operate in the vacuum of space, because that's the best place to do quantum computation. And it would just run out all of its computations indefinitely, but it would look completely dark to the rest of the universe. As typical, I don't think that's actually the right physics, but I think something about that idea as I do with all ideas is partially correct. And Freeman Dyson also had this amazing paper about how long life could persist in a universe that was exponentially expanding. And his conception was if you imagine analog life form, it could run slower and slower and slower and slower and slower as a function of time. And so, it would be able to run indefinitely, even against an exponentially expanding universe because it would just run exponentially slower. And so, I guess part of what I'm doing in my brain is putting those two things together along with this idea that, if you imagine with our technology, we're now building virtual realities, things we actually call virtual reality. Which required four billions years of history and a whole bunch of data to basically embed them in a computer architecture. Now you can put an Oculus headset on and think that you're in this world. And what you really are embedded in is in a very deep temporal structure. And so, it's huge in time, but it's very small in space. And you can go lots of places in the virtual space, but you're still stuck in your physical body and sitting in the chair. And so, part of it is it might be the case that sufficiently evolved biospheres virtualize themselves. And they internalize their universe in their temporal causal structure, and they close themselves off from the rest of the universe.

Lex Fridman
I just don't know if a deep temporal structure necessarily means that you're closed off.

Sara Walker
No, I don't either. that's my fear. I'm not sure I'm agreeing with what I say. I'm just saying this is one conclusion. And in my most, it's interesting, I don't do psychedelic drugs. But when people describe to me your thing with the faces and stuff, and I've had a lot of deep conversations with friends that have done psychedelic drugs for intellectual reasons and otherwise. But I'm always like, "Oh, it sounds like you're just doing theoretical physics. That's what brains do on theoretical physics." I live in these really abstract spaces most of the time. But there's also this issue of extinction. Extinction events are basically pinching off an entire causal structure. The one of these - I'm going to call them time crystals, I don't know what, but there's these very large objects in time. Pinching off that whole structure from

the rest of it. And so it's like, if you imagine that same thing in the universe, I once thought that sufficiently advanced technologies would look like black holes.

Lex Fridman
That would be just completely imperceptible to us.

Sara Walker
Yeah. there might be lots of aliens out there.

Lex Fridman
They all look like black holes.

Sara Walker
Maybe that's the explanation for all the singularities. They're all pinched off causal structures that virtualize their reality and broke off from us

Lex Fridman
Black holes in every way, so untouchable to us or unlikely be detectable by us with whatever sensory mechanisms we have.

Sara Walker
Yeah. But the other way I think about it is there is probably hopefully life out there. I do work on life detection efforts in the solar system and I'm trying to help with the Habitable Worlds Observatory mission planning right now and working with the biosignatures team for that to think about exoplanet biosignatures. I have some optimism that we might find things, but there are the challenges that we don't know the likelihood for life, which is what you were talking about. If I get to a more grounded discussion, what I'm really interested in doing is trying to solve the origin of life so we can understand how likely life is out there. I think that the problem of discovering alien life and solving the origin of life are deeply coupled and in fact are one in the same problem, and that the first contact with alien life will actually be in an origin of life experiment. But that part I'm super interested in. And then there's this other feature that I think about a lot, which is our own technological phase of development as what is this phase in the evolution of life on a planet? If you think about a biosphere emerging on a planet and evolving over billions of years and evolving into a technosphere. When a technosphere can move off planet and basically reproduce itself on another planet, now you have biospheres reproducing themselves. Basically they have to go through technology to do that. And so, there are ways of thinking about the nature of intelligent life and how it spreads in that capacity that I'm also really excited about and thinking about. And all of those things for me are connected. We have to solve the origin of life in order for us to get off planet because we basically have to start life on another planet. And we also have to solve the origin life in order to recognize other alien intelligence. All of these things are literally the same problem.

Lex Fridman
Right. Understanding the origin of life here on earth is a way to understand ourselves. And to understanding ourselves as a prerequisite from being able to detect other intelligent civilizations. I, for one, take it for what it's worth on Ayahuasca, one of the things I did is zoom out aggressively, like a spaceship. And it would always go quickly through the galaxy and from the galaxy to this representation of the universe. And at least for me from that perspective, it seemed like it was full of alien life. Not just alien life, but intelligent life.

Sara Walker
I like that.

Lex Fridman
And conscious life. I don't know how to convert it into words. It's more like a feeling. Like you were saying, a feeling converted to a visual to converted to words. I had a visual with it, but really it was a feeling that it was just full of this vibrant energy that I was feeling when I'm looking at the people in my life and full of gratitude. But that same exact thing is everywhere in the universe.

Sara Walker
Right. I totally agree with this, that visual I really love. And I think we live in a universe that generates life and purpose, and it's part of the structure of just the world. And so maybe this lonely view I have is, I never thought about it this way until you're describing that. I was like, I want to live in that universe. And I'm a very optimistic person and I love building visions of reality that are positive. But I think for me right now in the intellectual process, I have to tunnel through this particular way of thinking about the loneliness of being separated in time from everything else. Which I think we also all are, because time is what defines us as individuals.

Lex Fridman
Part of you is drawn to the trauma of being alone deeply in a physics-based sense.

Sara Walker
But also part of what I mean is you have to go through ideas you don't necessarily agree with to work out what you're trying to understand. And I'm trying to be inside this structure so I can really understand it. And I don't think I've been able to - I am so deeply embedded in what we are intellectually right now that I don't have an ability to see these other ones that you're describing, if they're there.

Lex Fridman
Well, one of the things you described that you already spoke to, you call it the great perceptual filter. There's the famous great filter, which is basically the idea that there's some really powerful moment in every intelligent civilization where they destroy

themselves. That explains why we have not seen aliens. And you're saying that there's something like that in the temporal history of the creation of complex objects, that at a certain point they become an island, an island too far to reach based on the perceptions?

Sara Walker
I hope not, but yeah, I worry about it. Yeah.

Lex Fridman
But that's basically meaning there's something fundamental about the universe where if the more complex you become, the harder it will be to perceive other complex creatures.

Sara Walker
I mean, just think about us with microbial life. We used to once be cells. And for most of human history, we didn't even recognize cellular life was there until we built a new technology, microscopes, that allowed us to see them. It's weird. Things that we -

Lex Fridman
And they're close to us.

Sara Walker
They're close, they're everywhere.

Lex Fridman
But also in the history of the development of complex objects, they're pretty close.

Sara Walker
Yeah, super close. Super close. Yeah. I mean, everything on this planet is - it's pretty much the same thing. The space of possibilities is so huge. It's like we're virtually identical.

Lex Fridman
How many flavors or kinds of life do you think are possible?

Sara Walker
I'm trying to imagine all the little flickering lights in the universe in the way that you were describing. That was kind of cool.

Lex Fridman
I mean, it was awesome to me. It was exactly that. It was like lights. The way you maybe see a city, but a city from up above. You see a city with the flickering lights, but there's a coldness to the city. You know that humans are capable of good and evil. And you could see there's a complex feeling to the city. I had no such complex feeling about seeing the lights of all the galaxies, whatever, the billions of galaxies.

Sara Walker
Yeah, this is cool. I'll answer the question in a second, but just maybe this idea of flickering lights and intelligence is interesting to me because we have such a human-centric view of alien intelligences that a lot of the work that I've been doing with my lab is just trying to take inspiration from non-human life on earth. And so, I have this really talented undergrad student that's basically building a model of alien communication based on fireflies. One of my colleagues, Orit Peleg, is she's totally brilliant. But she goes out with GoPro cameras and films in high resolution, all these firefly flickering. And she has this theory about how their signaling evolved to maximally differentiate the flickering pattern. She has a theory basically that predicts this species should flash like this. If this one's flashing like this, other one's going to do it at a slower rate so that they can distinguish each other living in the same environment. And so this undergrad's building this model where you have a pulsar background of all these giant flashing sources in the universe. And an alien intelligence wants to signal it's there so it's flashing a firefly. And I like the idea of thinking about non-human aliens so that was really fun.

Lex Fridman
The mechanism of the flashing unfortunately, is the diversity of that is very high, and we might not be able to see it. That's what -

Sara Walker
Yeah. Well, I think there's some ways we might be able to differentiate that signal. I'm still thinking about this part of it. One is if you have pulsars and they all have a certain spectrum to their pulsing patterns. And you have this one signal that's in there that's basically tried to maximally differentiate itself from all the other sources in the universe, it might stick out in the distribution. There might be ways of actually being able to tell if it's an anomalous pulsar, basically. But I don't know if that would really work or not. Still thinking about it.

Lex Fridman
You tweeted, "If one wants to understand how truly combinatorially and compositionally complex our universe is, they only need step into the world of fashion. It's bonkers how big the constructable space of human aesthetics is." Can you explain, can we explore the space of human aesthetics?

Sara Walker
Yeah. I don't know. I've been obsessed with the - I never know how to pronounce it. It's a Schiaparelli. They have ears and things. It's such a weird, grotesque aesthetic, but it's totally bizarre. But what I meant, I have a visceral experience when I walk into my closet. I have a lot of -

Lex Fridman
How big is your closet?

Sara Walker
It's pretty big. It's like I do assembly theory every morning when I walk in my closet because I really like a very large combinatorial diverse palette, but I never know what I'm going to build in the morning.

Lex Fridman
Do you get rid of stuff?

Sara Walker
Sometimes.

Lex Fridman
Or do you have trouble getting rid of stuff?

Sara Walker
I have trouble getting rid of some stuff. It depends on what it is. If it's vintage, it's hard to get rid of because it's hard to replace. It depends on the piece. Yeah.

Lex Fridman
You have, your closet is one of those temporal time crystals that they just, you get to visualize the entire history of the -

Sara Walker
It's a physical manifestation of my personality.

Lex Fridman
Right. Why is that a good visualization of the combinatorial and compositionally complex universe?

Sara Walker
I think it's an interesting feature of our species that we get to express ourselves through what we wear. If you think about all those animals in the jungle you saw, they're born looking the way they look, and then they're stuck with it for life.

Lex Fridman
That's true. I mean, it is one of the loudest, clearest, most consistent ways we signal to each other, is the clothing we wear.

Sara Walker
Yeah. It's highly dynamic. I mean, you can be dynamic if you want to. Very few people are - there's a certain bravery, but it's actually more about confidence, willing to play with style

and play with aesthetics. And I think it's interesting when you start experimenting with it, how it changes the fluidity of the social spaces and the way that you interact with them.

Lex Fridman
But there's also commitment. You have to wear that outfit all today.

Sara Walker
I know. I know. It's a big commitment. Do you feel like that every morning?

Lex Fridman
No. I wear, that's why -

Sara Walker
You're like "This is a life commitment."

Lex Fridman
All I have is suits and a black shirt and jeans.

Sara Walker
I know.

Lex Fridman
Those are the two outfits.

Sara Walker
Yeah. Well, see, this is the thing though. It simplifies your thought process in the morning. I have other ways I do that. I park in the same exact parking spot when I go to work on the fourth floor of a parking garage because no one ever parks on the fourth floor, so I don't have to remember where I park my car. But I really like aesthetics and playing with them. I'm willing to spend part of my cognitive energy every morning trying to figure out what I want to be that day.

Lex Fridman
Did you deliberately think about the outfit you were wearing today?

Sara Walker
Yep.

Lex Fridman
Was there backup options or were you going back and forth between some?

Sara Walker
Three or four, but I really like yellow.

Lex Fridman
Were they drastically different?

Sara Walker
Yes.

Lex Fridman
Okay.

Sara Walker
And even this one could have been really different because it's not just the jacket and the shoes and the hairstyle. It's like the jewelry and the accessories. Any outfit is a lot of small decisions.

Lex Fridman
Well, I think your current office has a lot of shades of yellow. There's a theme. It's nice. I'm grateful that you did that.

Sara Walker
Thanks.

Lex Fridman
Its like its it's own art form.

Sara Walker
Yeah. Yellow's my daughter's favorite color. And I never really thought about yellow much, but she's been obsessed with yellow. She's seven now. And I don't know, I just really love it.

Lex Fridman
I guess you can pick a color and just make that the constraint and then just go with it and understand the beauty.

Sara Walker
I'm playing with yellow a lot lately. This is not even the most yellow because I have black pants on, but I have -

Lex Fridman
You go all out.

Sara Walker
I've worn outfits that have probably five shades of yellow in them.

Lex Fridman
Wow. What do you think beauty is? We seem to - underlying this idea of playing with aesthetics is we find certain things beautiful. What is it that humans find beautiful? And why do we need to find things beautiful?

Sara Walker
Yeah, it's interesting. I mean, I am attracted to style and aesthetics because I think they're beautiful, but it's much more because I think it's fun to play with. And so, I will get to the beauty thing, but I guess I want to just explain a little bit about my motivation in this space, because it's really an intellectual thing for me. And Stewart Brand has this great infographic about the layers of human society. And I think it starts with the natural sciences and physics at the bottom, and it goes through all these layers and it's economics. And then fashion is at the top, is the fastest moving part of human culture. And I think I really like that because it's so dynamic and so short and it's temporal longevity. Contrasted with studying the laws of physics, which are the deep structure reality that I feel like bridging those scales tells me much more about the structure of the world that I live in.

Lex Fridman
That said, there's certain kinds of fashions. A dude in a black suit with a black tie seems to be less dynamic. It seems to persist through time.

Sara Walker
Are you embodying this?

Lex Fridman
Yeah, I think so. I think it just -

Sara Walker
I'd like to see you wear yellow, Lex.

Lex Fridman
I wouldn't even know what to do with myself. I would freak out. I wouldn't know how to act to know -

Sara Walker
You wouldn't know how to be you. Yeah. I know. This is amazing though, isn't it? Amazing, you have the choice to do it, but one of my favorite. Amazing. You have the choice to do it. But one of my favorite, just on the question of beauty, one of my favorite fashion designers of all time is Alexander McQueen. He was really phenomenal. But his early, and actually I

used what happened to him in the fashion industries, a coping mechanism with our paper. When the nature paper in the fall when everyone was saying it was controversial and how terrible that - but controversial is good. But when Alexander McQueen first came out with his fashion lines, he was mixing horror and beauty and people were horrified. It was so controversial. It was macabre. He had, it looked like there were blood on the models.

Lex Fridman
That was beautiful. We're just looking at some pictures here.

Sara Walker
Yeah, no, his stuff is amazing. His first runway line, I think was called Nihilism. I don't know if you could find it. He was really dramatic. He carried a lot of trauma with him. There you go, that's - yeah. Yeah.

Lex Fridman
Wow.

Sara Walker
But he changed the fashion industry. His stuff became very popular.

Lex Fridman
That's a good outfit to show up to a party in.

Sara Walker
Right, right. But this gets at the question, is that horrific or is it beautiful? I think he ended up committing suicide and actually he left his death note on the descent of man, so he was a really deep person.

Lex Fridman
Great fashion certainly has that kind of depth to it.

Sara Walker
Yeah, it sure does. I think it's the intellectual pursuit. This is very highly intellectual and I think it's a lot how I play with language. It's the same way that I play with fashion or the same way that I play with ideas in theoretical physics, there's always this space that you can just push things just enough so they look like something someone thinks is familiar, but they're not familiar. I think that's really cool.

Lex Fridman
It seems like beauty doesn't have much function, but it seems to also have a lot of influence on the way we collaborate with each other.

Sara Walker
It has tons of function. What do you mean it doesn't have function?

Lex Fridman
I guess sexual selection incorporates beauty somehow. But why? Because beauty is a sign of health or something. I don't even -

Sara Walker
Oh, evolutionarily? Maybe. But then beauty becomes a signal of other things. It's really not - then beauty becomes an adaptive trait, so it can change with different, maybe some species would think, well, you thought the frog having babies come out of its back was beautiful and I thought it was grotesque. There's not a universal definition of what's beautiful. It is something that is dependent on your history and how you interact with the world. I guess what I like about beauty, like any other concept is when you turn it on its head. Maybe the traditional conception of why women wear makeup and they dress certain ways is because they want to look beautiful and pleasing to people. I just like to do it because a confidence thing, it's about embodying the person that I want to be and about owning that person. Then the way that people interact with that person is very different than if I wasn't using that attribute as part of - obviously, that's influenced by the society I live and what's aesthetically pleasing things. But it's interesting to be able to turn that around and not have it necessarily be about the aesthetics, but about the power dynamics that the aesthetics create.

Lex Fridman
But you're saying there's some function to beauty in that way, in the way you're describing and the dynamic it creates in the social interaction.

Sara Walker
Well, the point is you're saying it's an adaptive trait for sexual selection or something. I'm saying that the adaptation that beauty confers is far richer than that. Some of the adaptation is about social hierarchy and social mobility and just playing social dynamics. Why do some people dress goth? It's because they identify with a community and a culture associated with that and get, and that's a beautiful aesthetic. It's a different aesthetic. Some people don't like it.

Lex Fridman
It has the same richness as does language.

Sara Walker
Yes.

Lex Fridman
It's the same kind of -

Sara Walker
Yes. I think too few people think about the aesthetics they build for themselves in the morning and how they carry it in the world and the way that other people interact with that because they put clothes on and they don't think about clothes as carrying function.

Lex Fridman
Let's jump from beauty to language. There's so many ways to explore the topic of language. You called it, you said that language, parts of language or language in itself or the mechanism of language is a kind of living life form. You've tweeted a lot about this in all kinds of poetic ways. Let's talk about the computation aspect of it. You tweeted, " The world is not a computation, but computation is our best current language for understanding the world. It is important we recognize this so we can start to see the structure of our future languages that will allow us to see deeper than the computation allows us." What's the use of language in helping us understand and make sense of the world?

Sara Walker
I think one thing that I feel like I notice much more viscerally than I feel like I hear other people describe is that the representations in our mind and the way that we use language are not the things - actually, this is an important point going back to what Godel did, but also this idea of signs and symbols and all kinds of ways of separating them. There's the word and then there's what the word means about the world. We often confuse those things. What I feel very viscerally, I almost sometimes think I have some synesthesia for language or something, and I just don't interact with it the way that other people do. But for me, words are objects and the objects are not the things that they describe. They have a different ontology to them. They're physical things and they carry causation and they can create meaning, but they're not what we think they are. Also, the internal representations in our mind, the things I'm seeing about this room are probably - they're small projection of the things that are actually in this room. I think we have such a difficult time moving past the way that we build representations in the mind and the way that we structure our language to realize that those are approximations to what's out there and they're fluid, and we can play around with them and we can see deeper structure underneath them that I think we're missing a lot.

Lex Fridman
But also the life of the mind is, in some ways, richer than the physical reality. Sure. What's going on in your mind might be a projection.

Sara Walker
Right.

Lex Fridman
Actually here, but there's also all kinds of other stuff going on there.

Sara Walker
Yeah, for sure. I love this essay by Poincare about mathematical creativity where he talks about this sort of frothing of all these things and then somehow you build theorems on top of it and they become concrete. I also think about this with language. It's like there's a lot of stuff happening in your mind, but you have to compress it in this few sets of words to try to convey it to someone. It's a compactification of the space and it's not a very efficient one. I think just recognizing that there's a lot that's happening behind language is really important. I think this is one of the great things about the existential trauma of large language models, I think is the recognition that language is not the only thing required. There's something underneath it, not by everybody.

Lex Fridman
Can you just speak to the feeling you have when you think about words? What's the magic of words, to you? Do you feel, it almost sometimes feels like you're playing with it?

Sara Walker
Yeah, I was just going to say it's like a playground.

Lex Fridman
But you're almost like, I think one of the things you enjoy, maybe I'm projecting, is deviating using words in ways that not everyone uses them, slightly deviating from the norm a little bit.

Sara Walker
I love doing that in everything I do, but especially with language.

Lex Fridman
But not so far that it doesn't make sense.

Sara Walker
Exactly.

Lex Fridman
You're always tethered to reality to the norm, but are playing with it basically fucking with people's minds a little bit, and in so creating a different perspective on another thing that's been previous explored in a different way.

Sara Walker
Yeah. It's literally my favorite thing to do.

Lex Fridman
Yeah. Use as words as one way to make people think.

Sara Walker
Yeah. A lot of my, what happens in my mind when I'm thinking about ideas is I've been presented with this information about how people think about things, and I try to go around to different communities and hear the ways that different, whether it's hanging out with a bunch of artists, or philosophers, or scientists thinking about things. They all think about it different ways. Then I just try to figure out how do you take the structure of the way that we're talking about it and turn it slightly so you have all the same pieces that everybody sees are there, but the description that you've come up with seems totally different. They can understand that they understand the pattern you're describing, but they never heard the structure underlying it described the way that you describe it.

Lex Fridman
Is there words or terms you remember that disturbed people the most? Maybe the positive sense of disturbed, is assembly theory, I suppose, is one.

Sara Walker
Yeah. The first couple sentences of that paper disturbed people a lot, and I think they were really carefully constructed in exactly this kind of way.

Lex Fridman
What was that? Let me look it up.

Sara Walker
Oh, it was really fun. But I think it's interesting because I do sometimes I'm very upfront about it. I say I'm going to use the same word in probably six different ways in a lecture, and I will.

Lex Fridman
You write, "Scientists have grappled with reconciling biological evolution with immutable laws of the universe defined by physics. These laws underpin life's origin, evolution, and the..."

Sara Walker
- with me when he was here, too.

Lex Fridman
"The development of human culture." Well, he was, I think your love for words runs deeper than these.

Sara Walker
Yeah, for sure. This is part of the brilliant thing about our collaboration is complimentary skill sets. I love playing with the abstract space of language, and it's a really interesting playground when I'm working with Lee because he thinks at a much deeper level of abstraction than can be expressed by language. The ideas we work on are hard to talk about for that reason.

Lex Fridman
What do you think about computation as a language?

Sara Walker
I think it's a very poor language. A lot of people think is a really great one, but I think it has some nice properties. But I think the feature of it that is compelling is this kind of idea of universality, that if you have a language, you can describe things in any other language.

Lex Fridman
Well, for me, one of the people who revealed the expressive power of computation, aside from Alan Turing, is Stephen Wolfram through all the explorations of cellular automata type of objects that he did in a New Kind of Science and afterwards. What do you get from that? The computational worlds that are revealed through even something as simple as cellular automata. It seems like that's a really nice way to explore languages that are far outside our human languages and do so rigorously and understand how those kinds of complex systems can interact with each other, can emerge, all that kind of stuff.

Sara Walker
I don't think that they're outside our human languages. I think they define the boundary of the space of human languages. They allow us to explore things within that space, which is also fantastic. But I think there is a set of ideas that takes, and Stephen Wolfram has worked on this quite a lot and contributed very significantly to it. I really like some of the stuff that Stephen's doing with his physics project, but don't agree with a lot of the foundations of it. But I think the space is really fun that he's exploring. There's this assumption that computation is at the base of reality, and I see it at the top of reality, not at the base, because I think computation was built by our biosphere. It's something that happened after many billion years of evolution. It doesn't happen in every physical object. It only happens in some of them. I think one of the reasons that we feel like the universe is computational is because it's so easy for us as things that have the theory of computation in our minds. Actually, in some sense it might be related to the functioning of our minds and how we build languages to describe the world and sets of relations to describe the world. But it's easy for us to go out into the world and build computers and then we mistake our ability to do that with assuming that the world is computational. I'll give you a really simple example. This one came from John Conway. I one time had a conversation with him, which was really delightful. He was really fun. But he was pointing out that if you string lights in a

barn, you can program them to have your favorite one dimensional CA and you might even be able to make them do a be capable of universal computation. Is universal computation a feature of the string lights?

Lex Fridman
Well, no.

Sara Walker
No, it's probably not. It's a feature of the fact that you as a programmer had a theory that you could embed in the physical architecture of the string lights. Now, what happens though is we get confused by this distinction between us as agents in the world that actually can transfer things that life does onto other physical substrates with what the world is. For example, you'll see people studying the mathematics of chemical reaction networks and saying, "Well, chemistry is turning universal," or studying the laws of physics and saying, "The laws of physics are turning universal." But anytime that you want to do that, you always have to prepare an initial state. You have to constrain the rule space, and then you have to actually be able to demonstrate the properties of computation. All of that requires an agent or a designer to be able to do that.

Lex Fridman
But it gives you an intuition if you look at a 1D or two cellular automata, it allows you to build an intuition of how you can have complexity emerge from very simple beginnings, very simple initial conditions -

Sara Walker
I think that's the intuition that people have derived from it. The intuition I get from cellular automata is that the flat space of an initial condition in a fixed dynamical law is not rich enough to describe an open-ended generation process. The way I see cellular automata is they're embedded slices in a much larger causal structure. If you want to look at a deterministic slice of that causal structure, you might be able to extract a set of consistent rules that you might call a cellular automata, but you could embed them as much larger space that's not dynamical and is about the causal structure and relations between all of those computations. That would be the space cellular automata live in. I think that's the space that Stephen is talking about when he talks about his ruliad and these hypergraphs of all these possible computations. But I wouldn't take that as my base reality because I think again, computation itself, this abstract property computation, is not at the base of reality.

Lex Fridman
Can we just linger on that ruliad?

Sara Walker
Yeah. One ruliad to rule them all.

Lex Fridman
Yeah. This is part of Wolfram's physics project. It's what he calls the entangled limit of everything that is computationally possible. What's your problem with the ruliad?

Sara Walker
Well, it's interesting. Stephen came to a workshop we had in the Beyond Center in the fall, and the workshop theme was Mathematics, Is It Evolved or Eternal? He gave a talk about the ruliad, and he was talking about how a lot of the things that we talk about in the Beyond Center, like "Does reality have a bottom.If it has a bottom, what is it?"

Lex Fridman
I need to go to -

Sara Walker
We'll have you to one sometime.

Lex Fridman
This is great. Does reality have a bottom?

Sara Walker
Yeah. We had one that was, it was called Infinite turtles or Ground Truth. It was really just about this issue. But the thing that was interesting, I think Stephen was trying to make the argument that fundamental particles aren't fundamental, gravitation is not fundamental. These are just turtles. Computation is fundamental. I remember pointing out to him, I was like, "Well, computation is your turtle. I think it's a weird turtle to have."

Lex Fridman
First of all, isn't it okay to have a turtle?

Sara Walker
It's totally fine to have a turtle. Everyone has a turtle. You can't build a theory without a turtle. It depends on the problem you want to describe. Actually, the reason I can't get behind Stephen's ontology is I don't know what question he's trying to answer. Without a question to answer, I don't understand why you're building a theory of reality.

Lex Fridman
The question you're trying to answer is -

Sara Walker
What life is.

Lex Fridman
What life is, which another simpler way of phrasing that is how did life originate?

Sara Walker
Well, I started working in the origin of life, and I think what my challenge was there was no one knew what life was. You can't really talk about the origination of something if you don't know what it is. The way I would approach it is if you want to understand what life is, then proving that physics is solving the origin of life. There's the theory of what life is, but there's the actual demonstration that that theory is an accurate description of the phenomena you aim to describe. Again, they're the same problem. It's not like I can decouple origin life from what life is. It's like that is the problem. The point, I guess, I'm making about having a question is no matter what slice of reality you take, what regularity of nature you're going to try to describe, there will be an abstraction that unifies that structure of reality, hopefully. That will have a fundamental layer to it. You have to explain something in terms of something else. If I want to explain life, for example, then my fundamental description of nature has to be something I think that has to do with time being fundamental. But if I wanted to describe, I don't know the interactions of matter and light, I have elementary particles be fundamental. If I want to describe electricity and magnetism in the 18 hundreds, I have to have waves be fundamental. Right? You are in quantum mechanics. It's a wave function that's fundamental because the explanatory paradigm of your theory. I guess I don't know what problem saying computation is fundamental solves.

Lex Fridman
Doesn't he want to understand how does the basic quantum mechanics and general relativity emerge?

Sara Walker
Yeah.

Lex Fridman
And cause time.

Sara Walker
Right.

Lex Fridman
Then that doesn't really answer an important question for us?

Sara Walker
Well, I think that the issue is general relativity and quantum mechanics are expressed in mathematical languages, and then computation is a mathematical language. You're basically saying that maybe there's a more universal mathematical language for describing

theories of physics that we already know. That's an important question. I do think that's what Stephen's trying to do and do well. But then the question becomes, does that formulation of a more universal language for describing the laws of physics that we know now tell us anything new about the nature of reality? Or is it a language?

Lex Fridman
To you, languages can't be fundamental?

Sara Walker
The language itself is never the fundamental thing. It's whatever it's describing.

Lex Fridman
One of the possible titles you were thinking about originally for the book is The Hard Problem of Life, reminiscent of the hard problem of consciousness. You are saying that assembly theory is supposed to be answering the question about what is life. Let's go to the other hard problems. You also say that's the easiest of the hard problems is the hard problem of life. What do you think is the nature of intelligence and consciousness? Do you think something like assembly theory can help us understand that?

Sara Walker
I think if assembly theory is an accurate depiction of the physics of life, it should shed a lot of light on those problems. In fact, I sometimes wonder if the problems of consciousness and intelligence are at all different than the problem of life, generally. I'm of two minds of it, but I in general try to - the process of my thinking is trying to regularize everything into one theory, so pretty much every interaction I have is like, "Oh, how do I fold that into..." I'm just building this giant abstraction that's basically trying to take every piece of data I've ever gotten in my brain into a theory of what life is. Consciousness and intelligence are obviously some of the most interesting things that life has manifest. I think they're very telling about some of the deeper features about the nature of life.

Lex Fridman
It does seem like they're all flavors of the same thing. But it's interesting to wonder at which stage does something that we would recognize as life in a canonical silly human way and something that we would recognize as intelligence, at which stage does that emerge? At which assembly index does that emerge? Which assembly index is a consciousness something that you would canonically recognize as consciousness?

Sara Walker
Right. Is this the use of flavors the same as you meant when you were talking about flavors of alien life?

Lex Fridman
Yeah, sure. Yeah. It's the same as the flavors of ice cream and the flavors of fashion.

Sara Walker
But we were talking about in terms of colors and very nondescript, but the way that you just talked about flavors now was more in the space of consciousness and intelligence. It was much more specific.

Lex Fridman
It'd be nice if there's a formal way of expressing -

Sara Walker
Quantifying flavors.

Lex Fridman
Quantifying flavors.

Sara Walker
Yeah.

Lex Fridman
It seems like I would order it life, consciousness, intelligence probably as the order in which things emerge. They're all just, it's the same.

Sara Walker
They're the same.

Lex Fridman
We're using the word life differently here. Life when I'm talking about what is a living versus non-living thing at a bar with a person, I'm already four or five drinks in, that kind of thing.

Sara Walker
Just that.

Lex Fridman
We're not being too philosophical, like "Here's the thing that moves, and here's the thing that doesn't move," but maybe consciousness precedes that. It's a weird dance there, is life precede consciousness or consciousness precede life. I think that understanding of what life is in the way you're doing will help us disentangle that.

Sara Walker
Depending on what you want to explain, as I was saying before, you have to assume something's fundamental. Because people can't explain consciousness, there's a temptation for some people to want to take consciousness as fundamental and assume everything else is derived out of that. Then you get some people that want to assume consciousness preceded life. I don't find either of those views particularly illuminating because I don't want to assume a feminology before I explain a thing. What I've tried really hard to do is not assume that I think life is anything except hold on to the patterns and structures that seem to be the sort of consistent ways that we talk about this thing. Then try to build a physics that describes that. I think that's a really different approach than saying, "Consciousness is this thing we all feel and experience about things." I would want to understand irregularities associated with that and build a deeper structure underneath that and build into it. I wouldn't want to assume that thing and that I understand that thing, which is usually how I see people talk about it,

Lex Fridman
The difference between life and consciousness, which comes first.

Sara Walker
Yeah. I think if you're thinking about this thinking about living things as these giant causal structures or these objects that are deep in time or whatever language we end up using to describe it seems to me that consciousness is about the fact that we have a conscious experience is because we are these temporally extended objects. Consciousness and the abstraction that we have in our minds is actually a manifestation of all the time that's rolled up in us. It's just because we're so huge that we have this very large inner space that we're experiencing that's not, and it's also separated off from the rest of the world because we're the separate thread in time. Our consciousness is not exactly shared with anything else because nothing else occupies the same part of time that we occupy. But I can understand something about you maybe being conscious because you and I didn't separate that far in the past in terms of our causal histories. In some sense, we can even share experiences with each other through language because of that overlap in our structure.

Lex Fridman
Well, then if consciousness is merely temporal separateness, then that comes before life.

Sara Walker
It's not merely temporal separateness. It's about the depth in that time.

Lex Fridman
Yes.

Sara Walker
The reason that my conscious experience is not the same as yours is because we're separated in time. The fact that I have a conscious experience is because I'm an object that's super deep in time, so I'm huge in time. That means that there's a lot that I am basically, in some sense, a universe onto myself because my structure is so large relative to the amount of space that I occupy.

Lex Fridman
But it feels like that's possible to do before you get anything like bacteria.

Sara Walker
I think there's a horizon, and I don't know how to articulate this yet, it's a little bit like the horizon at the origin of life where the space inside a particular structure becomes so large that it has some access to a space that doesn't feel as physical. It's almost like this idea of counterfactuals. I think the past history of your horizon is just much larger than can be encompassed in a small configuration of matter. You can pull this stuff into existence. This property is maybe a continuous property, but there's something really different about human-level physical systems and human-level ability to understand reality. I really love David Deutsch's conception of universal explainers, and that's related to theory of universal computation. I think there's some transition that happens there. But maybe to describe that a little bit better, what I can also say is what intelligence is in this framework. You have these objects that are large in time. They were selected to exist by constraining the possible space of objects to this particular, all of the matter is funneled into this particular configuration of object over time. These objects arise through selection, but the more selection that you have embedded in you, the more possible selection you have on your future. Selection and evolution, we usually think about in the past sense where selection happened in the past, but objects that are high density configurations of matter that have a lot of selection in them are also selecting agents in the universe. They actually embody the physics of selection and they can select on possible futures. I guess what I'm saying with respect to consciousness and the experience we have is that something very deep about that structure and the nature of how we exist in that structure that has to do with how we're navigating that space and how we generate that space and how we continue to persist in that space.

Lex Fridman
Is there shortcuts we can take to artificially engineering, living organisms, artificial life, artificial consciousness, artificial intelligence? Maybe just looking pragmatically at the LLMs we have now, do you think those can exhibit qualities of life, qualities of consciousness, qualities of intelligence in the way we think of intelligence?

Sara Walker
I think they already do, but not in the way I hear popularly discussed. They're obviously signatures of intelligence and a part of a ecosystem of intelligence system of intelligent systems. But I don't know that individually I would assign all the properties to them that people have. It's a little like, so we talked about the history of eyes before and how eyes scaled up into technological forms. Language has also had a really interesting history and got much more interesting I think once we started writing it down and then inventing books and things. But every time that we started storing language in a new way where we were existentially traumatized by it. The idea of written language was traumatic because it seemed like the dead were speaking to us even though they were deceased. Books were traumatic because suddenly there were lots of copies of this information available to everyone and it was going to somehow dilute it. Large language models are interesting because they don't feel as static. They're very dynamic. But if you think about language in the way I was describing before, as language is this very large in time structure. Before it had been something that was distributed over human brains as a dynamic structure. Occasionally, we store components of that very large dynamic structure in books or in written language. Now, we can actually store the dynamics of that structure in a physical artifact, which is a large language model. I think about it almost like the evolution of genomes in some sense, where there might've been really primitive genes in the first living things and they didn't store a lot of information or they were really messy. Then by the time you get to the eukaryotic cell, you have this really dynamic genetic architecture that's read writable and has all of these different properties. I think large language models are kind of like the genetic system for language in some sense, where it's allowing an archiving that's highly dynamic. I think it's very paradoxical to us because obviously in human history, we haven't been used to conversing anything that's not human. But now we can converse basically with a crystallization of human language in a computer that's a highly dynamic crystal because it's a crystallization in time of this massive abstract structure that's evolved over human history and is now put into a small device.

Lex Fridman
I think crystallization implies that a limit on its capabilities.

Sara Walker
I think there's not, I mean it very purposefully because a particular instantiation of a language model trained on a particular data set becomes a crystal of the language at that time it was trained, but obviously we're iterating with the technology and evolving it.

Lex Fridman
I guess the question is, when you crystallize it, when you compress it, when you archive it, you're archiving some slice of the collective intelligence of the human species.

Sara Walker
Yes. That's right.

Lex Fridman
The question is how powerful is that?

Sara Walker
Right. It's a societal level technology. We've actually put collective intelligence in a box.

Lex Fridman
Yeah. How much smarter is the collective intelligence of humans versus a single human? That's the question of AGI versus human level intelligence, superhuman level intelligence versus human level intelligence. How much smarter can this thing, when done well, when we solve a lot of the computation complexities, maybe there's some data complexities and how to really archive this thing, crystallize this thing really well, how powerful is this thing going to be? What's your thought?

Sara Walker
Actually, I don't like the language we use around that, and I think the language really matters. I don't know how to talk about how much smarter one human is than another. Usually, we talk about abilities or particular talents someone has, and going back to David Deutsch's idea of universal explainers, adopting the view that where the first kinds of structures are biosphere has built that can understand the rest of reality. We have this universal comprehension capability. He makes an argument that basically we're the first things that actually are capable of understanding anything. It doesn't mean - things that actually are capable of understanding anything. It doesn't mean an individual understands everything, but we have that capability. And so there's not a difference between that and what people talk about with AGI. In some sense, AGI is a universal explainer, but it might be that a computer is much more efficient at doing, I don't know, prime factorization or something, than a human is. But it doesn't mean that it's necessarily smarter or has a broader reach of the kind of things that can understand than a human does. And so I think we really have to think about is it a level shift or is it we're enhancing certain kinds of capabilities humans have in the same way that we enhanced eyesight by making telescopes and microscopes? Are we enhancing capabilities we have into technologies and the entire global ecosystem is getting more intelligent? Or is it really that we're building some super machine in a box that's going to be smart and kill everybody? It's not even a science fiction narrative. It's a bad science fiction narrative. I just don't think it's actually accurate to any of the technologies we're building or the way that we should be describing them. It's not even how we should be describing ourselves.

Lex Fridman
So the benevolence stories, there's a benevolent system that's able to transform our economy, our way of life by just 10Xing the GDP of countries -

Sara Walker
Well, these are human questions. Right? I don't think they're necessarily questions that we're going to outsource to an artificial intelligence. I think what is happening and will continue to happen is there's a co-evolution between humans and technology that's happening, and we're coexisting in this ecosystem right now and we're maintaining a lot of the balance. And for the balance to shift to the technology would require some very bad human actors, which is a real risk, or some sort of - I don't know, some sort of dynamic that favors - I just don't know how that plays out without human agency actually trying to put it in that direction.

Lex Fridman
It could also be how rapid the rate -

Sara Walker
The rapid rate is scary. So I think the things that are terrifying are the ideas of deepfakes or all the kinds of issues that become legal issues about artificial intelligence technologies, and using them to control weapons or using them for child pornography or faking out that someone's loved one was kidnapped or killed. There's all kinds of things that are super scary in this landscape and all kinds of new legislation needs to be built and all kinds of guardrails on the technology to make sure that people don't abuse it need to be built and that needs to happen. And I think one function of the artificial intelligence doomsday part of our culture right now is it's our immune response to knowing that's coming and we're over scaring ourselves. So we try to act more quickly, which is good, but it's about the words that we use versus the actual things happening behind the words. I think one thing that's good is when people are talking about things in different ways, it makes us think about them. And also, when things are existentially threatening, we want to pay attention to those. But the ways that they're existentially threatening and the ways that we're experiencing existential trauma, I don't think that we're really going to understand for another century or two, if ever. And I certainly think they're not the way that we're describing them now.

Lex Fridman
Well, creating existential trauma is one of the things that makes life fun, I guess.

Sara Walker
Yeah. It's just what we do to ourselves.

Lex Fridman
It gives us really exciting, big problems to solve.

Sara Walker
Yeah, for sure.

Lex Fridman
Do you think we will see these AI systems become conscious or convince us that they're conscious and then maybe we'll have relationships with them, romantic relationships?

Sara Walker
Well, I think people are going to have romantic relationships with them, and I also think that some people would be convinced already that they're conscious, but I think in order - what does it take to convince people that something is conscious? I think that we actually have to have an idea of what we're talking about. We have to have a theory that explains when things are conscious or not, that's testable. Right? And we don't have one right now. So I think until we have that, it's always going to be this gray area where some people think it hasn't, some people think it doesn't because we don't actually know what we're talking about that we think it has.

Lex Fridman
So do you think it's possible to get out of the gray area and really have a formal test for consciousness?

Sara Walker
For sure.

Lex Fridman
And for life, as you were -

Sara Walker
For sure.

Lex Fridman
As we've been talking about for assembly theory?

Sara Walker
Yeah.

Lex Fridman
Consciousness is a tricky one.

Sara Walker
It is a tricky one. That's why it's called the hard problem of consciousness because it's hard. And it might even be outside of the purview of science, which means that we can't

understand it in a scientific way. There might be other ways of coming to understand it, but those may not be the ones that we necessarily want for technological utility or for developing laws with respect to, because the laws are the things that are going to govern the technology.

Lex Fridman
Well, I think that's actually where the hard problem of consciousness, a different hard problem of consciousness, is that I fear that humans will resist. That's the last thing they will resist is calling something else conscious.

Sara Walker
Oh, that's interesting. I think it depends on the culture though, because some cultures already think everything's imbued with a life essence or kind of conscious.

Lex Fridman
I don't think those cultures have nuclear weapons.

Sara Walker
No, they don't. They're probably not building the most advanced technologies.

Lex Fridman
The cultures that are primed for destroying the other, constructing very effective propaganda machines of what the other is the group to hate are the cultures that I worry would -

Sara Walker
Yeah, I know.

Lex Fridman
Would be very resistant to label something to acknowledge the consciousness latent in a thing that was created by us humans.

Sara Walker
And so what do you think the risks are there, that the conscious things will get angry with us and fight back?

Lex Fridman
No, that we would torture and kill conscious beings.

Sara Walker
Oh, yeah. I think we do that quite a lot anyway without - it goes back to your - and I don't know how to feel about this, but we talked already about the predator-prey thing that in

some sense, being alive requires eating other things that are alive. And even if you're a vegetarian or try to have - you're still eating living things.

Lex Fridman
So maybe part of the story of earth will involve a predator-prey dynamic between humans -

Sara Walker
That's struggle for existence.

Lex Fridman
And human creations, and all of that is part of the chemosphere.

Sara Walker
But I don't like thinking our technologies as a separate species because this again goes back to this sort of levels of selection issue. And if you think about humans individually alive, you miss the fact that societies are also alive. And so I think about it much more in the sense of an ecosystem's not the right word, but we don't have the right words for these things of - and this is why I talk about the technosphere. It's a system that is both human and technological. It's not human or technological. And so this is the part that I think we are really good, and this is driving in part a lot of the attitude of, "I'll kill you first with my nuclear weapons." We're really good at identifying things as other. We're not really good at understanding when we're the same or when we're part of an integrated system that's actually functioning together in some kind of cohesive way. So even if you look at the division in American politics or something, for example. It's important that there's multiple sides that are arguing with each other because that's actually how you resolve society's issues. It's not like a bad feature. I think some of the extreme positions and the way people talk about are maybe not ideal, but that's how societies solve problems. What it looks like for an individual is really different than the societal level outcomes and the fact that there is - I don't want to call it cognition or computation. I don't know what you call it, but there is a process playing out in the dynamics of societies that we are all individual actors in, and we're not part of that. It requires all of us acting individually, but this higher level structure is playing out some things and things are getting solved for it to be able to maintain itself. And that's the level that our technologies live at. They don't live at our level. They live at the societal level, and they're deeply integrated with the social organism, if you want to call it that. And so I really get upset when people talk about the species of artificial intelligence. I'm like, you mean we live in an ecosystem of all these intelligent things and these animating technologies that were in some sense helping to come alive. We are generating them, but it's not like the biosphere eliminated all of its past history when it invented a new species. All of these things get scaffolded, and we're also augmenting ourselves at the same time that we're building technologies. I don't think we can anticipate what that system's going to look like.

Lex Fridman
So in some fundamental way, you always want to be thinking about the planet as one organism?

Sara Walker
The planet is one living thing.

Lex Fridman
What happens when it becomes multi-planetary? Is it still just -

Sara Walker
Still the same causal chain.

Lex Fridman
Same causal chain?

Sara Walker
It's like when the first cell split into two. That's what I was talking about. When a planet reproduces itself, the technosphere emerges enough understanding. It's like this recursive, the entire history of life is just recursion. Right? So you have an original life event. It evolves for 4,000,000,000 years, at least on our planet. It evolves the technosphere. The technologies themselves start to become having this property we call life, which is the phase we're undergoing now. It solves the origin of itself, and then it figures out how that process all works, understands how to make more life and then can copy itself onto another planet so the whole structure can reproduce itself. And so the origin of life is happening again right now on this planet in the technosphere with the way that our planet is undergoing another transition. Just like at the origin of life, when geochemistry transitioned to biology, which is the global - for me, it was a planetary scale transition. It was a multiscale thing that happened from the scale of chemistry all the way to planetary cycles. It's happening now, all the way from individual humans to the internet, which is a global technology and all the other things. There's this multiscale process that's happening and transitioning us globally, and it's a dramatic transition. It's happening really fast and we're living in it.

Lex Fridman
You think this technosphere that created this increasingly complex technosphere will spread to other planets?

Sara Walker
I hope so. I think so.

Lex Fridman
Do you think we'll become a type two Kardashev civilization?

Sara Walker
I don't really like the Kardashev scale, and it goes back to I don't like a lot of the narratives about life because they're very like survival of the fittest, energy consuming, this, that and the other thing. It's very, I don't know, old world conqueror mentality.

Lex Fridman
What's the alternative to that exactly?

Sara Walker
I think it does require life to use new energy sources in order to expand the way it is, so that part's accurate. But I think this process of life being the mechanism that the universe creatively expresses itself, generates novelty, explores the space of the possible is really the thing that's most deeply intrinsic to life. And so these energy-consuming scales of technology, I think is missing the actual feature that's most prominent about any alien life that we might find, which is that it's literally our universe, our reality, trying to creatively express itself and trying to find out what can exist and trying to make it exist.

Lex Fridman
See, but past a certain level of complexity, unfortunately, maybe you can correct me, but all complex life on earth is built on a foundation of that predator-prey dynamic.

Sara Walker
Yes.

Lex Fridman
And so I don't know if we can escape that.

Sara Walker
No, we can't. But this is why I'm okay with having a finite lifetime. And one of the reasons I'm okay with that actually, goes back to this issue of the fact that we're resource bound. We have a finite amount of material, whatever way you want to define material. For me, material is time, material is information, but we have a finite amount of material. If time is a generating mechanism, it's always going to be finite because the universe is - it's a resource that's getting generated, but it has a size, which means that all the things that could exist don't exist. And in fact, most of them never will. So death is a way to make room in the universe for other things to exist that wouldn't be able to exist otherwise. So if the universe over its entire temporal history wants to maximize the number of things - wants is a hard word, maximize is a hard word, all these things are approximate, but wants to maximize the number of things that can exist, the best way to do it is to make recursively embedded

stacked objects like us that have a lot of structure and a small volume of space. And to have those things turn over rapidly so you can create as many of them as possible.

Lex Fridman
So that for sure is a bunch of those kinds of things throughout the universe.

Sara Walker
Hopefully. Hopefully our universe is teaming with life.

Lex Fridman
This is like early on in the conversation. You mentioned that we really don't understand much. There's mystery all around us.

Sara Walker
Yes.

Lex Fridman
If you had to bet money on it, what percent? So say 1,000,000 from now, the story of science and human understanding that started on earth is written, what chapter are we on? Is this 1%, 10%, 20%, 50%, 90%? How much do we understand, like the big stuff, not the details of - big important questions and ideas?

Sara Walker
I think we're in our 20s and -

Lex Fridman
20% of the 20?

Sara Walker
No, age wise, let's say we're in our 20s, but the lifespan is going to keep getting longer.

Lex Fridman
You can't do that.

Sara Walker
I can. You know why I use that though? I'll tell you why, why my brain went there, is because anybody that gets an education in physics has this trope about how all the great physicists did their best work in their 20s, and then you don't do any good work after that. And I always thought it was funny because for me, physics is not complete, it's not nearly complete, but most physicists think that we understand most of the structure of reality. And so I think I put this in the book somewhere, but this idea to me that societies would discover everything while they're young is very consistent with the way we talk about physics right

now. But I don't think that's actually the way that things are going to go, and you're finding that people that are making major discoveries are getting older in some sense than they were, and our lifespan is also increasing. So I think there is something about age and your ability to learn and how much of the world you can see that's really important over a human lifespan, but also over the lifespan of societies. And so I don't know how big the frontier is. I don't actually think it has a limit. I don't believe in infinity as a physical thing, but I think as a receding horizon, I think because the universe is getting bigger, you can never know all of it.

Lex Fridman
Well, I think it's about 1.7%.

Sara Walker
1.7? Where does that come from?

Lex Fridman
And It's a finite - I don't know. I just made it up, but it's like -

Sara Walker
That number had to come from somewhere.

Lex Fridman
Certainly. I think seven is the thing that people usually pick

Sara Walker
7%?

Lex Fridman
So I wanted to say 1%, but I thought it would be funnier to add a point. So inject a little humor in there. So the seven is for the humor. One is for how much mystery I think there is out there.

Sara Walker
99% mystery, 1% known?

Lex Fridman
In terms of really big important questions.

Sara Walker
Yeah.

Lex Fridman
Say there's going to be 200 chapters, the stuff that's going to remain true.

Sara Walker
But you think the book has a finite size?

Lex Fridman
Yeah.

Sara Walker
And I don't. Not that I believe in infinities, but I think this size of the book is growing.

Lex Fridman
Well, the fact that the size of the book is growing is one of the chapters in the book.

Sara Walker
Oh, there you go. Oh, we're being recursive.

Lex Fridman
I think you can't have an ever-growing book.

Sara Walker
Yes, you can.

Lex Fridman
I don't even - Because then -

Sara Walker
Well, you couldn't have been asking this at the origin of life because obviously you wouldn't have existed at the origin of life. But the question of intelligence and artificial general - those questions did not exist then. And they in part existed because the universe invented a space for those questions to exist through evolution.

Lex Fridman
But I think that question will still stand 1,000 years from now.

Sara Walker
It will, but there will be other questions we can't anticipate now that we'll be asking.

Lex Fridman
Yeah, and maybe we'll develop the kinds of languages that we'll be able to ask much better questions.

Sara Walker
Right. Or the theory of gravitation, for example. When we invented that theory, we only knew about the planets in our solar system. And now, many centuries later, we know about all these planets around other stars and black holes and other things that we could never have anticipated. And then we can ask questions about them. We wouldn't have been asking about singularities and can they really be physical things in the universe several 100 years ago? That question couldn't exist.

Lex Fridman
Yeah, but it's not - I still think those are chapters in the book. I don't get a sense from that -

Sara Walker
So do you think the universe has an end, if you think it's a book with an end?

Lex Fridman
I think the number of words required to describe how the universe works as an end, yes. Meaning I don't care if it's infinite or not.

Sara Walker
Right.

Lex Fridman
As long as the explanation is simple and it exists.

Sara Walker
Oh, I see.

Lex Fridman
And I think there is a finite explanation for each aspect of it, the consciousness, the life. Very probably, there's some - the black hole thing, it's like, what's going on there? Where's that going? What are they what? And then why the Big Bang?

Sara Walker
Right.

Lex Fridman
It's probably, there's just a huge number of universes, and it's like universes inside -

Sara Walker
You think so? I think universes inside universes is maybe possible.

Lex Fridman
I just think every time we assume this is all there is, it turns out there's much more.

Sara Walker
The universe is a huge place.

Lex Fridman
And we mostly talked about the past and the richness of the past, but the future, with many worlds interpretation of quantum mechanics.

Sara Walker
Oh, I'm not a many worlds person.

Lex Fridman
You're not?

Sara Walker
No. Are you? How many Lexes are there?

Lex Fridman
Depending on the day. Well -

Sara Walker
Do some of them wear yellow jackets?

Lex Fridman
The moment you asked the question, there was one. At the moment I'm answering it, there's now near infinity, apparently. The future is bigger than the past. Yes?

Sara Walker
Yes.

Lex Fridman
Okay. Well, there you go. But in the past, according to you, it's already gigantic.

Sara Walker
Yeah. But yeah, that's consistent with many worlds, right? Because there's this constant branching, but it doesn't really have a directionality to it. I don't know. Many worlds is weird. So my interpretation of reality is if you fold it up, all that bifurcation of many worlds, and you just fold it into the structure that is you, and you just said you are all of those many worlds and your history converged on you, but you're actually an object exists that was selected to exist, and you're self-consistent with the other structures. So the quantum mechanical

reality is not the one that you live in. It's this very deterministic, classical world, and you're carving a path through that space. But I don't think that you're constantly branching into new spaces. I think you are that space.

Lex Fridman
Wait, so to you, at the bottom, it's deterministic? I thought you said the universe is just a bunch of random -

Sara Walker
No, it's random at the bottom. Right? But this randomness that we see at the bottom of reality that is quantum mechanics, I think people have assumed that that is reality. And what I'm saying is all those things you see in many worlds, all those versions of you, just collect them up and bundle them up and they're all you. And what has happened is elementary particles, they don't live in a deterministic universe, the things that we study in quantum experiments. They live in this fuzzy random space, but as that structure collapsed and started to build structures that were deterministic and evolved into you, you are a very deterministic macroscopic object. And you can look down on that universe that doesn't have time in it, that random structure. And you can see that all of these possibilities look possible, but they're not possible for you because you're constrained by this giant causal structural history. So you can't live in all those universes. You'd have to go all the way back to the very beginning of the universe and retrace everything again to be a different you.

Lex Fridman
So where's the source of the free will for the macro object?

Sara Walker
It's the fact that you're a deterministic structure living in a random background. And also, all of that selection bundled in you allows you to select on possible futures. So that's where your will comes from. And there's just always a little bit of randomness because the universe is getting bigger. And this idea that the past and the present is not large enough yet to contain the future, the extra structure has to come from somewhere. And some of that is because outside of those giant causal structures that are things like us, it's fucking random out there, and it's scary, and we're all hanging onto each other because the only way to hang on to each other, the only way to exist is to clinging on to all of these causal structures that we happen to coinhabitate existence with and try to keep reinforcing each other's existence.

Lex Fridman
All the selection bundled in.

Sara Walker
In us, but free will's totally consistent with that.

Lex Fridman
I don't know what I think about that. That's complicated to imagine. Just that little bit of randomness is enough. Okay.

Sara Walker
Well, it's not just the randomness. There's two features. One is the randomness helps generate some novelty and some flexibility, but it's also that because you're the structure that's deep in time, you have this combinatorial history that's you. And I think about time and assembly theory, not as linear time, but as combinatorial time. So if you have all of the structure that you're built out of, in principle, your future can be combinations of that structure. You obviously need to persist yourself as a coherent you. So you want to optimize for a future in that combinatorial space that still includes you, most of the time for most of us. And then that gives you a space to operate in, and that's your horizon where your free will can operate, and your free will can't be instantaneous. So for example, I'm sitting here talking to you right now. I can't be in the UK and I can't be in Arizona, but I could plan, I could execute my free will over time because free will is a temporal feature of life, to be there tomorrow or the next day if I wanted to.

Lex Fridman
But what about the instantaneous decisions you're making like, I don't know, to put your hand on the table?

Sara Walker
I think those were already decided a while ago. I don't think free will is ever instantaneous.

Lex Fridman
But on a longer time horizon, there's some kind of steering going on? Who's doing the steering?

Sara Walker
You are.

Lex Fridman
And you being this macro object that encompasses -

Sara Walker
Or you being Lex, whatever you want to call it.

Lex Fridman
There you are assigning words to things once again.

Sara Walker
I know.

Lex Fridman
Why does anything exist at all?

Sara Walker
Ah, I don't know.

Lex Fridman
You've taken that as a starting point.

Sara Walker
Yeah.

Lex Fridman
That it exists.

Sara Walker
Yeah, I think that's the hardest question.

Lex Fridman
Isn't it just hard questions stacked on top of each other?

Sara Walker
It is.

Lex Fridman
Wouldn't it be the same kind of question of what is life?

Sara Walker
It is the same. Well, that's like I try to fold all of the questions into that question because I think that one's really hard, and I think the nature of existence is really hard.

Lex Fridman
You think actually answering what is life will help us understand existence? Maybe it's turtles all the way down. Understanding the nature of turtles will help us march down even if we don't have the experimental methodology of reaching before the Big Bang.

Sara Walker
Right. Well, I think there's two questions embedded here. I think the one that we can't answer by answering life is why certain things exist and others don't? But I think the

ultimate question, the prime mover question of why anything exists, we will not be able to answer.

Lex Fridman
What's outside the universe?

Sara Walker
Oh, there's nothing outside the universe. So I am the most physicalist that anyone could be. So for me, everything exists in our universe. And I like to think everything exists here. So even when we talk about the multiverse, to me, it's not like there's all these other universes outside of our universe that exist. The multiverse is a concept that exists in human minds here, and it allows us to have some counterfactual reasoning to reason about our own cosmology, and therefore, it's causal in our biosphere to understanding the reality that we live in and building better theories, but I don't think that the multiverse is something - and also, math. I don't think there's a Platonic world that mathematical things live in. I think mathematical things are here on this planet. I don't think it makes sense to talk about things that exist outside of the universe. If you're talking about them, you're already talking about something that exists inside the universe and is part of the universe and is part of what the universe is building.

Lex Fridman
It all originates here. It all exists here in some -

Sara Walker
I mean - what else would there be?

Lex Fridman
There could be things you can't possibly understand outside of all of this that we call the universe.

Sara Walker
Right. And you can say that, and that's an interesting philosophy. But again, this is pushing on the boundaries of the way that we understand things. I think it's more constructive to say the fact that I can talk about those things is telling me something about the structure of where I actually live and where I exist.

Lex Fridman
Just because it's more constructive doesn't mean it's true.

Sara Walker
Well, it may not be true. It may be something that allows me to build better theories I can test to try to understand something objective.

Lex Fridman
And in the end, that's a good way to get to the truth.

Sara Walker
Exactly.

Lex Fridman
Even if you realize -

Sara Walker
So I can't do experiments -

Lex Fridman
You were wrong in the past?

Sara Walker
Yeah. So there's no such thing as experimental Platonism, but if you think math is an object that emerged in our biosphere, you can start experimenting with that idea. And that to me, is really interesting. Well, mathematicians do think about math sometimes as an experimental science, but to think about math itself as an object for study by physicists rather than a tool physicists use to describe reality, it becomes the part of reality they're trying to describe, to me, is a deeply interesting inversion.

Lex Fridman
What to you is most beautiful about this kind of exploration of the physics of life that you've been doing?

Sara Walker
I love the way it makes me feel.

Lex Fridman
And then you have to try to convert the feelings into visuals and the visuals into words?

Sara Walker
Yeah. I love the way it makes me feel to have ideas that I think are novel, and I think that the dual side of that is the painful process of trying to communicate that with other human beings to test if they have any kind of reality to them. And I also love that process. I love trying to figure out how to explain really deep abstract things that I don't think that we understand and trying to understand them with other people. And I also love the shock value of this idea we were talking about before, of being on the boundary of what we understand. And so people can see what you're seeing, but they haven't ever saw it that way before. And I love the shock value that people have, that immediate moment of recognizing

that there's something beyond the way that they thought about things before. And being able to deliver that to people, I think is one of the biggest joys that I have, is just - maybe it's that sense of mystery to share that there's something beyond the frontier of how we understand and we might be able to see it.

Lex Fridman
And you get to see the humans transformed, like no idea?

Sara Walker
Yes. And I think my greatest wish in life is to somehow contribute to an idea that transforms the way that we think. I have my problem I want to solve, but the thing that gives me joy about it is really changing something and ideally getting to a deeper understanding of how the world works and what we are.

Lex Fridman
Yeah, I would say understanding life at a deep level is probably one of the most exciting problems, one of the most exciting questions. So I'm glad you're trying to answer just that and doing it in style.

Sara Walker
It's the only way to do anything.

Lex Fridman
Thank you so much for this amazing conversation. Thank you for being you, Sara. This was awesome.

Sara Walker
Thanks, Lex.

Lex Fridman
Thanks for listening to this conversation with Sara Walker. To support this podcast, please check out our sponsors in the description. And now, let me leave you with some words from Charles Darwin. "In the long history of humankind, and animal kind too, those who learn to collaborate and improvise most effectively have prevailed." Thank you for listening and hope to see you next time.