The following is a conversation with Andrew Stromminger, theoretical physicist at Harvard, whose research seeks to shed light on the unification of fundamental laws of nature, the origin of the universe, and the quantum structure of black holes and event horizons.
And now, a quick viewset convention of your sponsor. Check them out in the description. It's the best way to support this podcast. We got aid sleep, for naps, rocket money, for saving out subscriptions, indeed, for hiring excellent teams and ExpressVPN for security and privacy on the internet. Choose wisely, my friends.
And now, onto the full ad reads. As always, no ads in the middle. I try to make this interesting, but if you skip them, please still check out our sponsors. I enjoy their stuff. Maybe you will too. And I should also mention that, as always, we're hiring folks to join our amazing team. And if you're interested, or know somebody who might be interested, go to lexfreedman.com slash hiring. This episode is brought to you by aid sleep, and it's new pod three mattress. Today is actually an example of a day where it's been a pretty rough one. I didn't get much sleep tonight. Before I didn't get much sleep tonight, I had to do a bunch of really difficult work, especially programming work and then reviewing
other people's code. I also had to record a podcast and also had to socialize, which is another kind of challenge altogether. And all of that combines to just this kind of mental state of maybe psychological, physical, all kinds of exhaustion. And it's kind of incredible how a short nap can fix so much of that. At least can fix the most important aspect, which is once you wake up, you see the world anew. That reinvigorated feeling of gratitude for being alive for the beauty of the world, for being able to experience the beauty of the world.
And a great nap, at least for me, does that just every single time. And in order to do a great nap, the best of the naps, you should do it on a sleep mattress. It keeps it cool, warm blanket, it's heaven. Check it out and get special savings when you go to 8sleep.com slash Lex.
This show is also brought to you by Rocket Money, a personal finance app that finds and cancels your unwanted subscriptions, monitors your spending and helps you lower your bills all in one place. It always cracks me up when people have something like a treadmill in their basement or in their apartment or wherever. And you could just tell that treadmill is not being used in months, if not years. And to me, from my life, I hate having that treadmill there because it's a kind of symbolic visceral reminder of promises to yourself that you have broken. Anyway, subscriptions
are kind of like that, except they also waste your money. It's like, I plan to consume this product or this service or to do this kind of reading or to do this kind of thing on the internet or whatever the subscription is. And then you realize, I'm actually not using that thing. So save the money by using Rocket Money. It's an easy service that helps you get rid of the unwanted subscriptions.
Anyway, go to rocketmoney.com slash Lex to cancel unwanted subscriptions and manage your money the
easy way. That's rocketmoney.com slash Lex. This show is also brought to you by, indeed, a hiring website. I should also mention that we're currently hiring. We're always hiring.
We have an amazing team of human beings that I'm truly proud of. I'm truly happy to stand and, besides, as we take on the challenges of creative work in this particular podcast and

beyond, basically capturing in video form, interesting ideas, interesting people, interesting concepts, whether it's educational, whether it's beyond maybe educational, almost like exploring the human condition, whether that's podcast or videos or all that kind of stuff. Anyway, it's an amazing team and we're always growing it. And to do so, you have to use the best tools for the job. Indeed, to me, is an incredible tool for hiring. They have all kinds of stuff, including instant match tool that helps you find quality candidates. That's the first step, the hardest step, and to do that fast is super cool. Indeed knows when you're growing your own business, every dollar counts. That's why with Indeed, you only pay for quality applications that match your job requirements. Visit indeed.com slash Lex to start hiring now. That's indeed.com slash Lex terms and conditions apply. This show is also brought to you by ExpressVPN.
I've used them for many years with a big red sexy button that I would press. And like Alice in Wonderland, escape into a world where nobody knows exactly where I am, but everybody is happy I'm
there. And that's useful for like Netflix for watching content that's geographically restricted. But it's also useful in a way that the journey that Alice takes in Wonderland is useful because it allows you to do all kinds of stuff on the internet where your privacy is sensitive. I mean, everybody should be using a VPN. And maybe I'm biased, but I don't think so. I think ExpressVPN is the best and you should use it. It works on any device. Again, I'm biased, but the best operating system Linux, it works on that works on your iPhone, Android, it works on Windows and Mac, everything, everything, everywhere. And I should also mention super fast, the most operating systems
too. Anyway, go to ExpressVPN.com slash Lex pod for an extra three months free.
This is the Lex Friedman podcast. To support it, please check out our sponsors in the description. And now dear friends, here's Andrew Strominger.
You are part of the Harvard black hole initiative, which has theoretical physicists, experimentalists, and even philosophers. So let me ask the big question, what is a black hole from a theoretical, from an experimental, maybe even from a philosophical perspective?
So a black hole is defined theoretically as a region of spacetime from which light can never escape. Therefore, it's black. Now, that's just the starting point. Many weird things follow from that basic definition, but that is the basic definition.
What is light? They can't escape from a black hole.
Well, light is the stuff that comes out of the sun, that stuff that goes into your eyes.
Light is one of the stuff that disappears when the lights go off. This is stuff that appears when the lights come on. Of course, I could give you a mathematical definition, or physical mathematical definition, but I think it's something that we will understand very intuitively what is light. Black holes, on the other hand, we don't understand intuitively. They're very weird. And one of the questions is about black holes, which I think you were alluding to, is why doesn't light get out, or how is it that there can be a region of spacetime from which light can't escape? It definitely happens. We've seen those regions. We have spectacular pictures, especially in the last several years of those regions. They're there. In fact, they're up in the sky, thousands or millions of them. We don't yet know how many. But the proper explanation of why light doesn't escape from a black hole is still a matter of some debate. And one explanation,

which perhaps Einstein might have given, is that light carries energy. You know it carries energy because we have photocells and we can take the light from the sun and collect it, turn it into electricity. So there's energy in light. And anything that carries energy is subject to a gravitational pull. Gravity will pull at anything with energy. Now, it turns out that the gravitational pull exerted by an object is proportional to its mass. And so if you get enough mass in a small enough region, you can prevent light from escaping. And let me flesh that out a little more. If you're on the Earth and you're on a rocket ship leaving the surface of the Earth and if we ignore the friction from the air, if your rocket accelerates up to 11 kilometers per second, that's escape velocity. And if there were no friction, it could just continue forever to the next galaxy. On the moon, which has less mass, it's only seven kilometers per second. But going in the other direction, if you have enough mass in one place, the escape velocity can become the speed of light. If you shine light straight up away from the Earth, it doesn't have too much trouble. It's going way above the escape velocity. But if you have enough mass there, even light can't escape the escape velocity. And according to Einstein's theory of relativity, there is an absolute speed limit in the universe, the speed of light, and nothing makes any sense. Nothing could be self-consistent if there were objects that could exceed light speed. And so in these very, very massive regions of space-time, even light cannot escape. And the interesting thing is Einstein himself didn't think that these objects we call the black holes could exist. But let me actually linger on this. Yeah, that's incredibly interesting. There's a lot of interesting things here. First of all, the speed limit. How wild is it to you, if you put yourself in the mind in the time of Einstein before him, to come up with a speed limit of that there is a speed limit, and that speed limit is the speed of light? How difficult of an idea is that? You said from a mathematical physics perspective, everything just kind of falls into place. But he wasn't perhaps maybe initially had the luxury to think mathematically, he had to come up with it intuitively, yes? So how common intuitive is this notion to you? Is it still crazy? No, no. It's a very funny thing in physics. The best discoveries seem completely obvious in retrospect. Even my own discoveries, which of course are far lesser than Einstein's, but many of my papers, many of my collaborators get all confused. We'll try to understand something. We say, we've got to solve this problem. We'll get all confused. Finally, we'll solve it. We'll get it all together. And then, all of a sudden, everything will fall into place. We'll explain it. And then we'll look back at our discussions for the preceding of months and literally be unable to reconstruct how confused we were and how we could ever have thought of it any other way. So not only can I not fathom how confused Einstein was before he, when he started thinking about the issues, I can't even reconstruct my own confusion from two weeks ago. So the really beautiful ideas in physics have this very hard to get yourself back into the mindset. Of course, Einstein was confused about many, many things. It doesn't matter if you're a physicist. It's not how many things you got wrong. It's not the ratio of how many you got wrong to how many you got right. It's the number that you got right. So Einstein didn't believe black holes existed, even though he predicted them. And I went and I read that paper, which he wrote. You know, Einstein wrote down his field equations in 1915 and Schwarzschild solved them and discovered the black hole solution three or four months later in very early 1916. And 25 years later, Einstein wrote a paper. So with 25 years to think about

what this solution means, wrote a paper in which he said that black holes didn't exist.
And I'm like, well, you know, if one of my students in my general relativity course wrote this,
you know, I wouldn't pass them. You get a C-minus. Oh, you wouldn't pass them. Okay.
Get a C-minus. Okay. Same thing with gravity waves. He didn't believe.
Oh, he didn't believe in gravitational waves either. He went back and forth,
but he wrote a paper in, I think, 34 saying that gravity waves didn't exist because
people were very confused about what a coordinate transformation is. And in fact,
this confusion about what a coordinate transformation is has persisted. And we actually think
we were on the edge of solving it 100 years later. 100 years later.
What is coordinate transformation as it was 100 years ago to today?
Let's imagine I want to draw a map with pictures of all the states and the mountains,
and then I want to draw the weather forecast, what the temperatures are going to be all over the
country. And I do that using one set of weather stations, and I number the weather stations,
and you have some other set of weather stations, and you do the same thing. So the coordinates
are the locations of the weather stations. They're how we describe where the things are.
At the end of the day, we should draw the same map. That is coordinate invariance. And if we're
if we're telling somebody, we're going to tell somebody at a real physical operation, we want you to
stay as dry as possible on your drive from here to California, we should give them exactly the same
route. No matter which weather stations we use or how we, it's a very trivial, it's the labeling
of points as an artifact and not in the real physics. So it turns out that that's almost true,
but not quite. There's some subtleties to it. The statement that you should always have the same,
give it the same kind of trajectory, the same kind of instructions no matter the weather states.
Yeah. There's some very delicate subtleties to that, which began to be noticed in the 50s.
It's mostly true, but when you have a space time with edges, it gets very tricky how you label the
edges. A space time in terms of space or in terms of time, in terms of everything, just space.
Either one, space or time. That gets very tricky. Einstein didn't have it right. In fact,
he had an earlier version of general relativity in 1914, which he was very excited about,
which was wrong. It wasn't fully coordinate invariant. It was only partially coordinate
invariant. It was wrong. It gave the wrong answer for bending light to the sun by a factor of two.
There was an expedition sent out to measure it during World War I. They were captured
before they could measure it. It gave Einstein four more years to clean his act up by which
time he'd gotten it right. It's a very tricky business, but once it's all laid out, it's clear.
Then why do you think Einstein didn't believe his own equations and didn't think that black holes are
real? Why was that such a difficult idea for him? Something very interesting happens in
Schwarzschild's solution of the Einstein equation.
I think his reasoning was ultimately wrong, but let me explain to you what it was.
At the center of the black hole behind the horizon in a region that nobody can
see and live to tell about it. As a center of the black hole, there's a singularity,
and if you pass the horizon, you go into the singularity, you get crushed, and that's the
end of everything. Now, the word singularity means that Einstein's equations break down.
They become infinite. You write them down. You put them on the computer. When the computer hits
that singularity, it crashes. Everything becomes infinite. There's two. The equations are just
no good there. Now, that's actually not a bad thing. It's a really good thing. Let me explain why.

It's an odd thing that Maxwell's theory and Newton's theory never exhibit this phenomenon. You write them down. You can solve them exactly. They're really Newton's theory of gravity. They're really very simple theories. You can solve them. Well, you can't solve the three-body problem, but you can certainly solve a lot of things about them. Nevertheless, there was never any reason, even though Maxwell and Newton perhaps fell for this trap, there were never any reason to think that these equations were exact. There's some equations that we've written down that we still think are exact. Some people still think are exact. My view is that there's no exact equation. Everything is an approximation. Everything is an approximation. You're trying to get as close as possible. You're saying objective truth doesn't exist in this world. The internet's going to be very mad at you. We could discuss that, but that's a different thing. We wouldn't say Newton's theory was wrong. It had very, very small corrections, incredibly small corrections. It's actually a puzzle why they're so small. If you watch the procession of Mercury's perihelia, this was the first indication of something going wrong. According to Newton's theory, Mercury has an elliptical orbit. The long part of it moves around as other planets come by and perturb it and so on. This was measured by Laverier in 1859. He compared theory and experiment. He found out that the perihelion process moves around the sun once every 233 centuries instead of every 231 centuries.
Now, this is the wonderful thing about science. Why was this guy? I mean, you don't get any idea how much work this is, but of course, he made one of the greatest discoveries in the history of science without even knowing what good it was going to be. That was the first sign that there was something wrong with Newton.
The corrections to Newton's law are very, very small, but they're definitely there.
The corrections to electromagnetism, the ones that we see are mostly coming from quantum effects. So the corrections for Maxwell's equations is when you get super tiny and then the corrections for Newton's law of gravity is when you get super big. That's when you require corrections. That's true, but I would phrase it as saying when it's super accurate. If you look at the Bohr atom, Maxwell electromagnetism is not a very good approximation to the force between the proton and the electron. If you didn't have quantum mechanics, the electron would spiral into the proton and the atom would collapse. So that's a huge correction there. So every theory gets corrected as we learn more. There'd just be no reason to suppose that it should be otherwise. How's this related to the singularity? Why the singularity?
So when you hit the singularity, you know that you need some improvement to Einstein's theory of gravity and that improvement, we understand what kind of things that improvement should involve. It should involve quantum mechanics, quantum effects become important there. It's a small thing. We don't understand exactly what the theory is, but there's no reason to think Einstein's theory was invented to describe weekly curved things, the solar system and so on. It's incredibly robust that we now see that it works very well near the horizons around black holes and so on. So it's a good thing that the theory drives itself, that it predicts its own demise. Newton's gravity had its demise. There were regimes in which it wasn't valid. Maxwell's electromagnetism had its demise. There were regimes in which quantum effects greatly modified the equations. But general relativity all on its own found a system which originally was fine would perversely wander off into a configuration in which Einstein's equations no longer applied. So to you, the edges of the theory are wonderful,

the failures of the theory. Edges are wonderful because that keeps us in business.
So one of the things you said, I think in your TED talk, that the fact that quantum mechanics and relativity don't describe everything and then they clash is wonderful. I forget the adjective you used, but it was something like this. So why is that? Why is that interesting?
Do you mean that same way that there's contradictions that create discovery?
There's no question in my mind, of course, many people would disagree with me, that now is the most
wonderful time to be a physicist. So people look back at, it's a classical thing to say among physicists, I wish it were 1920. Quantum mechanics had been just understood.
There was the periodic table. But in fact, that was such a rich thing that,
well, so that what a lot of exciting stuff happened around 1920. It took a whole century to sort out the new insights that we got. Especially adding some experimental stuff into the bunch, actually making observations. And the experimental thing.
All the computers also helped with visualizations and all that kind of stuff.
Yeah. It was all sort of wonderful century. I mean, the seed of general relativity was the incompatibility of Maxwell's theory of the electromagnetic field with Newton's laws of gravity. They were incompatible because if you look at Maxwell's theory,
there's a contradiction if anything goes faster than the speed of light.
But Newton's theory of gravity, the gravitational field, the gravitational force,
is instantaneously transmitted across the entire universe. If you had a friend in another galaxy with a very sensitive measuring device that could measure the gravitational field, they could just take this cup of coffee and move it up and down in Morse code and they could
get the message instantaneously over another galaxy. That leads to all kinds of contradictions.
It's not self-consistent. It was exactly in resolving those contradictions that Einstein came up with the general theory of relativity. And it's fascinating how this contradiction,
which seems like maybe it's kind of technical thing, led to a whole new vision of the universe. Now, let's not get fooled because lots of contradictions are technical things.
We haven't set up this. We run into other kinds of contradictions that are technical and they don't seem to... We understood something wrong. We made a mistake. We set up equations in the wrong
way. We didn't translate the formalisms. As opposed to revealing some deep mystery that's yet to be uncovered. We're never very sure which are the really important ones.
But to you, the difference between quantum mechanics and general relativity,
the tension, the contradiction there seems to hint at some deeper, deeper thing that's going to be discovered in the century. Yes, because that one has been understood since the 50s. Pauli was the first person to notice it and Hawking in the early 70s gave it a really much more visceral form. And people have been hurling themselves at it trying to reduce it to some technicality, but nobody has succeeded. The efforts to understand it have led to all kinds of interesting relations between quantum systems and applications to other fields and so on.
Well, let's actually jump around. We'll return to black holes. I have a million questions there, but let's go into this unification, the battle against the contradictions and the tensions between the theories of physics. What is quantum gravity? Maybe what is the standard model of physics? What is quantum mechanics? What is general relativity? What's quantum gravity?

What are all the different unification efforts? Again, five questions.
Yeah. It's a theory that describes everything with astonishing accuracy. It's the most accurate theory in the history of human thought. Theory and experiment have been then successfully compared to 16 decimal place. We have that stenciled on the door where I work. It's an amazing feat of the human mind. It describes the electromagnetic interaction, unifies the electromagnetic interaction with the so-called weak interaction, which you need some good tools to even view the weak interaction. Then there's the strong interaction, which binds the quarks into protons. The forces between them are mediated by something called Yang-Mills theory, which is a beautiful mathematical generalization of electromagnetism in which the analogues of the photons themselves carry charge. The final piece of this of the standard model, everything in the standard model has been observed. Its properties have been measured. The final particle to be observed was the Higgs particle. It served over a decade ago.
Higgs is already a decade ago. I think it is. Yeah.
Wow. But you better check me on that. That's true, but so much fun has been happening.
So much fun has been happening. That's all pretty well understood. There are some things that might
or might not around the edges of that. Dark matter, neutrino masses, some sort of fine points or things we haven't quite measured perfectly and so on, but it's largely a very complete theory, and we don't expect anything very new conceptually in the completion of that.
Anything contradictory by new? Anything contradictory.
I'll have some wild questions for you on that front, but yeah, anything that, yeah, because there's no gaps. It's so accurate, so precise in its predictions, it's hard to imagine.
It was all based on something called, let me not explain what it is, let me just throw out the buzz word, renormalizable quantum field theory. They all fall in the category of renormalizable quantum field theory. I'm going to throw that at a bar later to impress the girls.
Good luck. Thank you.
They all fall under that rubric. Gravity will not put that suit on. So the force of gravity cannot be tamed by the same renormalizable quantum field theory to which all the other forces so eagerly submit it. What is the effort of quantum gravity? What are the different efforts to have these two dance together effectively to try to unify the standard model and and general relativity, any kind of model of gravity? Sort of the one fully consistent model that we have that reconciles, that sort of tames gravity and reconciles it with quantum mechanics is string theory and its cousins. We don't know what or if in any sense, string theory describes the world, the physical world, but we do know that it is a consistent reconciliation of quantum mechanics and general relativity and moreover one which is able to incorporate particles and forces like the ones we see around us.
It hasn't been ruled out as an actual sort of unified theory of nature, but there also isn't a, in my view, some people would disagree with me, but there isn't a reasonable possibility that we would be able to do an experiment in the foreseeable future which would be sort of a yes or no to string theory. Okay. So you've been there from the early days of string theory. You've seen its developments. What are some interesting developments? What do you see as also the future of string theory? And what is string theory?
Well, the basic idea which emerged in the early 70s was that if you

take the notion of a particle and you literally replace it by a little loop of string,
the strings are sort of softer than particles. What do you mean by softer?
Well, if you hit a particle, if there were a particle on this table, a big one and you hit it,
you might bruise yourself. But if there was a string on the table, you would probably just
push it around. And the source of the infinities in quantum field theories that would particles hit
each other, it's a little bit of a jarring effect. And I've never described it this way before,
but it's actually scientifically accurate. But if you throw strings at each other,
it's a little more friendly. One thing I can't explain is how wonderfully
precise will the mathematics is that goes into describing string theory. We don't just
wave our hands and throw strings around. There are some very compelling mathematical
equations that describe it. Now, what was realized in the early 70s is that if you replace
particles by strings, these infinities go away and you get a consistent theory of gravity without
the infinities. And that may sound a little trivial, but at that point it had already been
15 years that people had been searching around for any kind of theory that could do this. And it
was actually found kind of by accident. And there are a lot of accidental discoveries in this subject.
Now, at the same time, it was believed then that string theory was an interesting sort of toy model
for putting quantum mechanics and general relativity together on paper, but that it
couldn't describe some of the very idiosyncratic phenomena that pertain to our own universe,
in particular the form of so-called parity violation.
Oh, another term for the bar later tonight. Parity violation. So if you go to the bar and...
I already got the renormalizable quantum. And you look in the mirror across the bar.
Yes. The universe that you see in the mirror is not identical.
You would be able to tell if you show the lady in the bar a photograph that shows both the
mirror and you. There's a difference.
If she's smart enough, she'll be able to tell which one is the real world and which one is you.
Now, she would have to do some very precise measurements.
And if the photograph was too grainy, it might not be possible, but it principle is possible.
Why is this interesting? Does this mean that there is some
not perfect determinism? Or what does that mean? There's some uncertainty?
No, it's a very interesting feature of the real world that it isn't parity or invariant.
And string theory, it was thought, could not tolerate that.
And then it was learned in the mid-80s that not only could it tolerate that,
but if you did things in the right way, you could construct a world involving strings that
reconciled quantum mechanics and general relativity, which looked more or less like the world that
we live in. And now, that isn't to say that string theory predicted our world.
It just meant that it was consistent, that the hypothesis that string theory describes
our world can't be ruled out from the get-go. And it is also the only proposal for a complete
theory that would describe our world. Still, nobody will believe it until there's some kind of
direct experiment. And I don't even believe it myself.
Sure, which is a good place to be mentally as a physicist. Einstein didn't believe his own
equations with the black hole. Okay.
Well, then when he was wrong about that, he was wrong about that.
But you might be wrong too, right? So, do you think string theory is dead if you were to

bet all your money on the future of string theory?
I think it's a logical error to think that string theory is either right or wrong or dead or alive. What it is is a stepping stone. And an analogy I like to draw is Yang-Mills theory, which I mentioned a few minutes ago in the context of standard model.
Yang-Mills theory was discovered by Yang and Mills in the 50s.
And they thought that the symmetry of Yang and Mills theory described the relationship between the proton and the neutron. That's why they invented it.
But that turned out to be completely wrong. It does, however, describe everything else in the standard model. And it had a kind of inevitability. They had some of the right pieces, but not the other ones. They didn't have it quite in the right context. And it had an inevitability to it. And it eventually found its place. And it's also true of Einstein's theory of general relativity. He had the wrong version of it in 1914. And he was missing some pieces. And you wouldn't say that his early version was right or wrong. He'd understood the equivalence principle. He'd understood spacetime curvature. He just didn't have everything. I mean, technically, you would have to say it was wrong. And technically, you would have to say Yang and Mills were wrong. And I guess in that sense, I would believe just odds are we always keep finding new wrinkles. Odds are we're going to find new wrinkles in string theory. And technically, what we call string theory now isn't quite right. But we're always going to be wrong, but hopefully a little bit less wrong every time. Exactly. And I would bet the farm, as they say. Do you have a farm? You know, I say that much more seriously because not only do I have a farm, but we just renovated it. So before I renovated, better get the farm. My wife, I spent five years renovating it before. You were much, much looser with that statement, but now it really means something. Now it really means something. And I would bet the farm on the guess that 100 years from now, string theory will be viewed as a stepping stone towards a greater understanding of nature. And another thing that I didn't mention about string theory is, of course, we knew that it solved the infinities problem. And then we later learned that it also solved Hawking's puzzle about what's inside of a black hole. And you put in one assumption, you get five things out. Somehow you're doing something right. Probably not everything, but there's some good signposts. And there have been a lot of good signposts like that.
It is also a mathematical toolkit. And you've used it. You've used it with Kamran Vafa.
Maybe we can sneak our way back from string theory into black holes. What was the idea that you and Kamran Vafa developed with the holographic principle in string theory?
Were we able to discover through string theory about black holes or that connects us back to the reality of black holes? Yeah. So that is a very interesting story. I was interested in black holes before I was interested in string theory. I was sort of a reluctance string theorist in the beginning. I thought I had to learn it because people were talking about it. But once I studied it, I grew to love it. First, I did it in a sort of dutiful way. These people say they've claimed quantum gravity. I ought to read their papers, at least. And then the more I read them, the more interested I got. And I began to see, they phrased it in a very clumsy way. The description of string theory was very clumsy.
Mathematically clumsy or just the interpretation?
Mathematically clumsy. It was all correct, but mathematically clumsy. But it often happens that in all kinds of branches of physics that people start working on it really hard and they

sort of dream about it and live it and breathe it. And they begin to see inner relationships and they see a beauty that is really there. They're not deceived. They're really seeing something that exists. But if you just kind of look at it, you can't grasp it all in the beginning.
And so our understanding of string theory in 1985 was almost all about weakly coupled waves of strings colliding and so on. We didn't know how to describe a big thing like a black hole in string theory. Of course, we could show that strings in theory in some limit reproduced Einstein's theory of general relativity and corrected it. But we couldn't do any better with black holes than before my work with Cormorant, we couldn't do any better than Einstein and Schwarzschild had done. Now, one of the puzzles, if you look at the Hawking's headstone and also Boltzmann's headstone and you put them together, you get a formula for their really central equations in 20th century physics. I don't think there are many equations that made it to headstones.
They're really central equations and you put them together and you get a formula for the number of gigabytes in a black hole. Now, in Schwarzschild's description, the black hole is literally a hole in space and there's no place to store the gigabytes. It's not too hard to, and this really was Wheeler and Beckenstein and Hawking to come to the conclusion that if there isn't a sense in which a black hole can store some large number of gigabytes, that quantum mechanics and gravity can't be consistent. We've got to go there a little bit. So how is it possible, when we say gigabytes, that there's some information? So black holes can store information. How is this thing that sucks up all light and it's supposed to basically be super homogeneous and boring? How is that actually able to store information? Where does it store information? On the inside, on the surface, where? Where's, and what's information? I'm liking this ask five questions to see which one you actually answer. Oh, okay. So if you say that, I shouldn't try to memorize them and answer each one in order just to answer them. No, I don't know. I don't know what I'm doing. I'm desperately trying to figure it out as we go along here. So Einstein's black holes are short-circuit black hole. They can't store information. The stuff goes in there and it just keeps flying and it goes to the singularity and it's gone. However, Einstein's theory is not exact. It has corrections and string theory tells you what those corrections are.
And so you should be able to find some way of, some alternate way of describing the black hole that enables you to understand where the gigabytes are stored. So what Hawking and Beckenstein really did was they showed that physics is inconsistent unless a black hole can store a number of gigabytes proportional to its area divided by four times Newton's constant times Planck's constant. And that's another wild idea. You said area, not volume.
Exactly. And that's the holographic principle. The universe is so weird.
And that's the holographic principle. That's called the holographic principle, that it's the area. We're just jumping around. What is the holographic principle? What does that mean? Is there some kind of weird projection going on? What the heck?
Well, I was just before I came here writing an introduction to a paper and the first sentence was the as yet imprecisely defined holographic principle. Blah, blah, blah, blah. So nobody knows exactly what it is. But roughly speaking, it says just what we were alluding to, that really all the information that is in some volume of spacetime can be stored on the boundary of that region. So this is not just about black holes, it's about any area space? Any area space.

However, we've made sense of the holographic principle for black holes. We've made sense of the holographic principle for something which could be called the anti-decider space, which could be thought of as a giant, as a black hole turned into a whole universe.
And we don't really understand how to talk about the holographic principle for either flat space, which we appear to live in, or asymptotically decider space, which astronomers tell us we actually live in as the universe continues to expand.
So it's one of the huge problems in physics is to apply or even formulate the holographic principle for more realistic, well, black holes are realistic, we see them, but in more general context, to give a more general statement of the holographic principle.
What's the difference between flat space and asymptotic decider space? So flat space is just an approximation of the world we live in. So a decider space, I wonder what that even means, meaning asymptotic over what? Okay. So for thousands of years, until the last half of the 20th century, we thought spacetime was flat.
Can you elaborate on flat? What do we mean by flat?
Well, like the surface of this table is flat. Let me just give an intuitive explanation.
Surface of the table is flat, but the surface of a basketball is curved. So the universe itself could be flat, like the surface of a table, or it could be curved like a basketball, which actually has a positive curvature. And then there's another kind of curvature called the negative curvature. And curvature can be even weirder because that kind of curvature I've just described is the curvature of space. But Einstein taught us that we really live in a spacetime continuum. So we can have curvature in a way that mixes up space and time.
And that's kind of hard to visualize. Because you have to step a couple of dimensions up.
You have to step a couple. But even if you have flat space and it's expanding in time, you know, we could imagine we're sitting here, this room, good approximation is flat, but imagine we suddenly start getting further and further apart. Then space is flat, but it's expanding, which means that spacetime is curved. Ultimately, it's about spacetime. Okay, so what's the sitter and you consider space? The three simplest spacetimes are flat spacetime, which we call Minkowski spacetime, and negatively curved spacetime, anti-decider space, and positively curved spacetime, the sitter space.
And so astronomers think that on large scales, even though for thousands of years we hadn't noticed it, beginning with Hubble, we started to notice that spacetime was curved. Spaces expanding
in time means that spacetime is curved. And the nature of this curvature is affected by the matter in it because matter itself causes the curvature of spacetime. But as it expands, the matter gets more and more diluted. And one might ask, when it's all diluted away, is spacetime still curved? And astronomers believe they've done precise enough measurements to determine this, and they believe that the answer is yes. The universe is now expanding. Eventually, all the matter in it will be expanded away, but it will continue to expand because, well, they would call it the dark energy. Einstein would call it a cosmological constant.
In any case, in the far future, matter will be expanded away and will be left with empty sitter space. Okay, so there's this cosmological, Einstein's cosmological constant that now hides this thing that we don't understand called dark energy. What's dark energy? What's your best guess at what

this thing is? Why do we think it's there? It's because it comes from the astronomers.
Dark energy is synonymous with positive cosmological constant. And we think it's there
because the astronomers have told us it's there, and they know what they're doing.
And we don't know what they're doing. It's a really, really hard measurement,
but they really know what they're doing. And we have no frigging idea why it's there.
Another big mystery. Another reason it's fun to be a physicist. And if it is there, why should it be
so small? Why should there be so little? Why should it have hid itself from us?
Why shouldn't there be enough of it to substantially curve the space between us and the moon?
Why did there have to be such a small amount that only the crazy best astronomers in the world
could
find it? Well, can't the same thing be said about all the constants? Can't that be said about
gravity? Can't that be said about the speed of light? Why is the speed of light so slow?
So fast. So slow. Relative to the size of the universe. Can't it be faster?
Well, the speed of light is a funny one because you could always choose units
in which the speed of light is one. We measure it in kilometers per second, and it's 186,000
or miles per second. It's 186,000 miles per second. But if we had used different units,
then we could make it one. But you can make dimensionless ratios. So you could say why is
the time scale set by the expansion of the universe so large compared to the time scale of a human
life or so large compared to the time scale for a neutron to decay? Yeah. I mean, ultimately,
the temporal reference frame here is a human life. Maybe.
Isn't that the important thing for us descendants of apes? Isn't that a really important aspects
of physics? Because we kind of experience the world. We intuit the world through the eyes of
these biological organisms. Absolutely. I mean, I guess mathematics helps you escape that for
a time. But ultimately, isn't that how you wonder about the world? Absolutely.
That like a human life at times only 100 years. Because if you think of everything,
if you're able to think in, I don't know, in billions of years,
then maybe everything looks way different. Maybe universes are born and die and maybe
all of these physical phenomena become much more intuitive that we see at the grand scale
of general relativity. Well, that is one of the little off the track here. But that certainly
is one of the nice things about being a physicist is you spend a lot of time thinking about insides
of black holes and billions of years in the future. And it sort of gets you away from the day to day
into another fantastic realm. But I was answering your question about
how there could be information in a black hole. So Einstein only gave us an approximate description.
And we now have a theory that corrects it, string theory. And now sort of was the moment of truth.
Well, when we first discovered string theory, we knew from the get go that string theory would
correct what Einstein said, just like Einstein corrected what Newton said. But we didn't understand
it well enough to actually compute the correction, to compute how many gigabytes there were. And
sometime in the early 90s, we began to understand the mathematics of string theory better and
better.
And it came to the point where it was clear that this was something we might be able to compute.
And it was a kind of moment of truth for string theory, because if it hadn't given the answer
that Beckenstein and Hawking said it had to give for consistency,
string theory itself would have been inconsistent and we wouldn't be doing this interview.

Wow. That's a very dramatic statement. That's not the most, that's not the most dramatic thing. I mean, okay, that's very life and death. You mean like, that be because string theory was centered till you work at that time? Is that what you mean? Well, string theory would have been inconsistent. Yeah, okay. So string theory would have been inconsistent. But those inconsistencies can give birth to other theories, like you said. The inconsistency, right, something else could have happened. It would have been a major change in the way we think about string theory. And it was a good thing that one supposition that the world has made of strings solves two problems, not one. It solves the infinity problem and it solves the Hawking's problem. And also the way that it did it was very beautiful. It gave an alternate description. So alternate description thing of things are very common. I mean, we could, to take a simple example, this bottle of water here is 90% full. I could say it's 90% full. I could also say it's 10% empty. Those are obviously the same statement. And it's trivial to see that they're the same. But there are many statements that can be made in mathematics and mathematical physics that are equivalent, but might take years
to understand that they're equivalent and might take the invention or discovery of whole new fields of mathematics to prove they're equivalent. And this was one of those. We found an alternate description of certain black holes in string theory, which we could prove was equivalent.
And it was a description of the black hole as a hologram that can be thought of a holographic plate that could be thought of as sitting on the surface of the black hole. And the interior of the black hole itself sort of arises as a projection, or the near horizon region of the black hole arises as a projection of that holographic plate. So the two descriptions were the hologram, the three-dimensional image, and the holographic plate. And the hologram is what Einstein discovered,
and the holographic plate is what we discovered. And this idea that you could describe things very, very concretely in string theory in these two different languages, of course, took off and was applied to many different contexts within string theory.
So you mentioned the infinity problem and the Hawking problem,
which Hawking problem? That the black hole destroys information or which Hawking problem we're talking about? Well, there's really two Hawking problems. They're very closely related. One is, how does the black hole store the information? And that is the one that we solved in some cases.
So it's sort of like your smartphone. How does it store at 64 gigabytes? Well, you rip the cover off and you count the chips and there's 64 gigabytes. And that's the one that we solved in some cases. 64 gigabytes, well, you rip the cover off and you count the chips and there's 64 of them, each with a gigabyte. And you know there's 64 gigabytes. But that does not solve the problem of how you get information in and out of your smartphone. You have to understand a lot more about the Wi-Fi and the internet and the cellular. That's where Hawking radiation, this prediction starts. That's where Hawking radiation comes in. And that problem of how the information gets in and out, you couldn't have explained how information gets in and out of an iPhone without first explaining how it's stored in the first place.
So just to clarify, the storage is on the plate, on the holographic plate, and then it projects somehow inside the... The bulk, the space time is the hologram.
The hologram. But man, I mean, do you have any intuitive when you sit late at night and you

stare at the stars, do you have any intuitive understanding what a holographic plate is?
Like that there's two dimensions, no projections that store information?
How a black hole could store information on a holographic plate?
I think we do understand in great mathematical detail and also intuitively. And it's very much like an ordinary hologram where you have a holographic plate and it contains all the information, you shine a light through it, and you get an image which looks three-dimensional.
Yeah, but why should there be a holographic plate?
Why should there be? Yeah, why?
That is the great thing about being a theoretical physicist is anybody can very quickly stump you with a going to the next level of wise. Yeah, so if you're asking, you could just keep asking and it won't take you very long to.
So the trick in being a theoretical physics is finding the questions that you can answer.
So the questions that we think we might be able to answer now, and we've partially answered, is that there is a holographic explanation for certain kinds of things in string theory.
We've answered that. Now we'd like to take what we've learned and that's what I've mostly been doing for the last 15, 20 years. I haven't really been working so much on string theory proper.
I've been sort of taking the lessons that we learned in string theory and trying to apply them to the real world, assuming only what we know for sure about the real world.
So on this topic, you co-authored a paper with Stephen Hawking called Soft Hair on Black Holes that makes the argument against Hawking's original prediction that black holes destroy information. Can you explain this paper and the title?
Okay, so first of all, the hair on black holes is a word that was coined by the greatest phrase master in the history of physics, John Wheeler, invented the word black hole, and he also said that he made the statement that black holes have no hair. That is, every black hole in the universe is described just by its mass and spin. They can also rotate as was later shown by Kerr. This is very much unlike a star. Every star of the same mass is different in a multitude of different ways, different chemical compositions, different motions of the individual molecules. Black holes, every star in the universe, even of the same mass, is different in many, many different ways. Black holes are all the same, and that means when you throw some in Einstein's description of them, which we think must be corrected, and if you throw something into a black hole, it gets sucked in. If you throw in a red book or a blue book, the black hole gets a little bigger, but there's no way within Einstein's theory of telling how they're different.
That was one of the assumptions that Hawking made in his 1974-75 papers in which he concluded that black holes destroy information. You can throw encyclopedias, thesis defenses, the Library of Congress.
It doesn't matter. It's going to behave exactly the same uniform way.
Yeah. What Hawking and I showed, and also Malcolm Perry, is that one has to be very careful about what happens at the boundary of the black hole. This gets back to something I mentioned earlier about when two things which are related by a coordinate transformation are and are not equivalent.
What we showed is that there are very subtle imprints when you throw something into a black hole.
There are very subtle imprints left on the horizon of the black hole, which you can read off at least partially what went in. This invalidates Stephen's original argument that the information is destroyed. That's the soft hair.

That's the soft hair. Soft is the word that is used in physics for things which have very low energy. These things actually carry no energy. There are things in the universe which carry no energy. You said, I think to Sean Carroll, by the way, everyone should go check out Sean Carroll's Mindscape Podcast. It's incredible. Sean Carroll is an incredible person. I think you said there, maybe in a paper, I have a quote. You said that a soft particle is a particle that has zero energy, just like you said now. When the energy goes to zero because the energy is proportioned to the wavelength, it's also spread over an infinitely large distance. If you like, it's spread over the whole universe. It somehow runs off to the boundary. What we learned from that is that if you add a zero energy particle to the vacuum, you get a new state. There are infinitely many vacuum, plural for vacuum, which can be thought of as being different from one another by the addition of soft photons or soft gravitons. Can you elaborate on this wild idea? If you like, it spreads over the whole universe. When the energy goes to zero because the energy is proportioned
to the wavelength, it also spreads over an infinitely large distance. If you like,
it's spread over the whole universe. Can you explain these soft gravitons and photons?
Yeah. The soft gravitons and photons have been known about since the 60s,
but exactly what we're supposed to do with them or how we're supposed to think about them,
I think, has been well understood only recently. In quantum mechanics, the energy of a particle is proportional to Planck's constant times its wavelength. When the energy goes to zero, the wavelength goes to infinity. Now, if something has zero energy and it's spread all over the universe, in what sense is it actually there? That's been the confusing thing, to make a precise statement about when something is and isn't there.
Now, the simplest way of seeing, people might have taken the point of view that if it has zero energy and it's spread all over the universe, it's not there. We can ignore it.
But if you do this, you'll get into trouble. One of the ways that you'll get into trouble is that even though it has zero energy, it doesn't have zero angular momentum.
If it's a photon, it always has angular momentum one. If it's a graviton, it's angular momentum two. You can't say that the state of the system with the zero energy photon should be identified without the zero energy photon, that we can just ignore them because then you will conclude that angular momentum is not conserved. If angular momentum is not conserved, things won't be consistent. Of course, you can have a lot of these things.
Typically, you do get a lot of them. When you can actually do a calculation that shows that every time you scatter two particles, you create an infinite number of them.
Infinite number of the soft photons. Of the zero energy ones.
And they're somehow everywhere, but they're also contained information or they're able to store information. And they're able to store information. They're able to store an arbitrary large amount of information. What we pointed out is what these things really do, one way of thinking of them is they rush off to the edges of the universe. Spreading out all over the space is like saying they rush off to the energy edge of the universe. And that includes, if the interior of the black hole is not considered part of the universe, that includes the edge of the black hole.
So we need to set up our description of physics so that all the things that are conserved are still conserved in the way that we're describing them. And that will not be true if we ignore these things. We have to keep a careful track of these things. And people had

been sloppy about that. And we learned how to be very precise and careful about it.
And once you're being precise, you can actually answer this very problematic thing that Hawking suggested that black holes destroy information. Well, what we showed is that there's an error in the argument that all black holes are the same because they hadn't kept track of these very subtle things. And whether or not this is the key error in the argument remains to be seen or whether this is a technical point. Yes. But it is an error.
It is an error. And Hawking obviously agreed with it.
Hawking agreed with it. And he was sure that this was the critical error.
That this was the critical error and that understanding this would get us the whole story.
And that could well be. What was it like working with Stephen Hawking on this particular problem because it's kind of a whole journey, right? Well, I love the guy. He's so passionate about physics. He just, yeah, his oneness with the problem.
And I mean, it's... So his mind is all occupied by the world that's...
Yeah. And let me tell you, there's a lot of other things with his illness and with his celebrity and a lot of other things. A lot of distractions pulling at his mind. He's still there. He's still there. That's right. I remember him turning down tea with Lady Gaga so we could spend another hour on paper.
But that, my friends, is dedication. What did you learn about physics?
What did you learn about life from having worked with Stephen Hawking?
Well, he was one of my great teachers. Of course, he's older than me and I was reading his textbooks in graduate school. And I learned a lot about relativity from him. I learned about passion for a problem. I learned about not caring what other people think.
I mean, physics is an interesting culture. Even if you make a great discovery, like Hawking did, people don't believe everything you say. In fact, people love to disagree.
It's a culture that cherishes disagreement. And so he kept ahead with what he believed in and sometimes he was right and sometimes he was wrong. Do you feel pressure from the community?
So for example, with string theory, it was very popular for a time. There's a bit of criticism or it's less popular now. Do you feel the forces of the community as it moves in and out of different fields or do you try to stay? How difficult is it to stay intellectually and mathematically independent from the community? Personally, I'm lucky. I'm well equipped for that. When I started out in graduate school, the problem of quantum gravity was not considered interesting. You still did it anyway. I still did it anyway. I'm a little bit of a contrarian, I guess, and I think that has served me well. And people are always sort of disagreeing with me and they're usually right, but I'm right enough. And like you said, the contradiction ultimately paves the path for discovery. Let me ask you just on this tension, we've been dancing between physics and mathematics. What to you is an interesting line you can draw between the two? You have done some very complicated mathematics in your life to explore the laws of nature. What's the difference between physics and mathematics to you?
Well, I love math. I think my first love is physics and the math that I've done, because it was needed. In service of physics.
In service of physics, but then of course, in the heat of it, it has its own appeal.
In the heat of it, I like it. Sure.
It has its own appeal and I certainly enjoyed it. Ultimately, I would like to think, I wouldn't

say I believe, but I would like to think that there's no difference between physics and mathematics that all mathematics is realized in the physical world and all physics has a firm mathematical basis that they're really the same thing. Why would there be math that had no physical manifestation? It seems a little odd, right? You have two kinds of math, some that are relevant to the real world. Well, they don't have to be contradictory, but can you not have mathematical objects that are not at all connected to the physical world?
I mean, this is to the question of, is math discovered or invented? To you, math is discovered and there's a deep linkage between the two. Do you find it all compelling, these ideas, something like Max Tagmark, where our universe is actually a fundamentally mathematical object that our universe is mathematical, fundamentally mathematical in nature?
Yeah. My expertise is, a physicist doesn't add anything to that. Physics is, I was once very interested in philosophy and physics. I like questions that can be answered. It's not obvious what the answer is and that you can find an answer to the question and everybody will agree what the answer is and that there's an algorithm for getting there.
Not that these other questions aren't interesting and they don't somehow have a way of presenting themselves, but to me, the interesting thing is motion in what we know is learning more and understanding things that we didn't understand before, things that seemed totally confusing, having them seem obvious. That's wonderful. I think that those questions are there. I mean, I would even go further. The whole multiverse, I don't think there's too much concrete we're ever going to be able to say about it.
This is fascinating because you spend so much time in string theory, which is devoid from a connection to the physical world for a long time. Not devoid, but it travels in a mathematical world that seems to be beautiful and consistent and seems to indicate that it could be a good model of the laws of nature, but it's still traveling independently because it's very difficult to experiment to verify, but there's a promise laden in it in the same way multiverse or you can have a lot of very far out there questions where your gut instinct and intuition says that maybe in 50, 100, 200 years, you'll be able to actually have strong experimental validation.
Right? I think that with string theory, I don't think it's likely that we could measure it, but we could get lucky. In other words, just to take an example, about 10 or 20 years ago, it was thought that they had seen a string in the sky, and that it was seen by doubled stars that were gravitationally lensed around the gravitational field produced by some long string. There was a line of double lens.
Now, the signal went away, but people were hoping that they'd seen a string, and it could be a fundamental string that had somehow gotten stretched, and that would be some evidence for string theory. There was also biseptu, which the experiment was wrong, but it could have happened.
It could have happened that we got lucky, and this experiment was able to make direct measurements.
Certainly, it would have been measurements of quantum gravity if not string theory.
It's a very logical possibility that we could get experimental evidence from string.
That is a very different thing than saying, do this experiment. Here's a billion dollars, and after you do it, we'll know whether or not strings are real.
But I think it's a crucial difference. It's measurable in principle, and we don't see how to

get from here to there. If we see how to get from here to there, in my eyes, it's boring. When I was a graduate student, they knew how to measure the Higgs boson. Took 40 years, but they didn't. Not to say that stuff is boring. I don't want to say that stuff is boring. But when Magellan said out, he didn't know he could get around the world. There was no map. I don't know how we're going to connect in a concrete way all these ideas of string theory to the real world. When I started out in graduate school, I said, what is the most interesting problem that there might be, the deepest, most interesting problem that there might be progress on in 60 years? I think it could be in another 30 years that maybe we'll learn that we have understood how black holes store information. That doesn't seem wild. That we're able to abstract what we learned from string theory and show that it's operative. When Bose and Einstein predicted it, when was that? The 30s, maybe early 30s. There were 20 orders of magnitude that were needed in order to improve it, in order to measure it, and they did 50 years later. You couldn't have guessed how that had happened, how they could have gotten that. It could happen that we, I don't think we're going to like see the had erotic string spectrum at an accelerator, but it could be that things come around in an interesting way and somehow it comes together. The fact that we can't see to the end isn't a reason not to do it. What did they do when they were trying to find the Pacific? They just took every route. They just tried everything, and that's what we're doing. I'm taking the one that my nose tells me is the best. Other people are taking other ones, and that's good, because we need every person taking every route. If somebody on another route finds something that looks really promising, I'm going to make a portage over the mountain and get on their stream. The fact that you don't see the experiment now isn't to me a reason to give up on what I view as the most fundamental paradox in present physics, 2021 century physics. Absolutely. You can see that it's possible. You just don't know the way, but that's what I mean why some of the philosophical questions could be formulated in a way that's explorable scientifically. Some of the stuff we've talked about, but for example, this topic that's become more okay to talk about, which is the topic of consciousness. To me, as an artificial intelligence person, that's a very practically interesting topic, but there's also philosophers. Sean Carroll loves to argue against them, but there's philosophers that are panpsychists. I'm not against philosophers. It's just not as fun. I don't... It's not a fun. All right. They start a little flame of a fire going that some of those flames, I think, eventually become physics. Having them around is really important because you'll discover something by modeling and exploring black holes that's really weird and having these ideas around, like the ideas of panpsychists that consciousness could be a fundamental force of nature. Just even having that crazy idea, swimming around in the background, could really spark something where you were missing something completely. That's where the philosophy done right, I think, is very useful. That's where even these thought experiments, which is very fun in the tech sci-fi world that we live in a simulation, that taking a perspective of the universe as a computer, as a computational system that processes information, which is a pretty intuitive notion, but you can just even reframing it that way for yourself, could really open up some different way of thinking. Could be. And then you have, I don't know if you're familiar with Stephen Wolfram's work of cellular automata and complexity. Yeah. I did a podcast with Stephen.

With Stephen? That's awesome. To me, forget physics, forget all that. Cellular automata make no sense. They're so beautiful. They're so... They're from simple rules you can create complexity. I just don't think... He wrote a book on new kind of science that's basically hinting at, which a lot of people have hinted at, is we don't have a good way to talk about these objects. We can't figure out what is happening here. These simple, these trivial rules can create incredible complexity. He's totally right about that. And physicists, I guess, don't know what to do with that. Don't know what to do with cellular automata. Because you can describe the simple rules that will govern the system with how complexity can emerge, like incredible complexity. Yeah. Of course, Wolfram's version of that is that physicists will never be able to describe it. Right. Yeah. Exactly. He tries to prove that it's impossible. What do you make of that? What do you make about the tension of being a physicist and potentially not being able to... It's like Freud or somebody that maybe, Sigmund Freud, that maybe you'll never be able to actually describe the human psyche. Is that a possibility for you? That you will never be able to get to the core fundamental description of the laws of nature?

Yeah. So I had this conversation with Weinberg.

Yeah. How'd it go?

So Weinberg has this book called Dreams of a Final Theory.

And I had this conversation with him. I said, why do you think there's ever going to be a final theory? Why should there ever be a final theory? I mean, what does that mean? Do physics departments shut down? We've solved everything. Doesn't it seem that every time we answer some old questions, we'll just find new ones and that it will just keep going on forever and ever?

He said, well, that's what they used to say about the Nile. They were never going to find the end. Then one day they found it. Yeah. So I don't know.

String theory doesn't look like a candidate to me for a final theory.

As it stands now, it doesn't get to the bottom of the world to the size and to the whole...

Yeah. It seems to me that even if we kind of solved it and we did experiments, there still would be more questions like why are there four dimensions instead of six? It doesn't seem to have anything in it that would explain that. You can always hope that there's something that we don't know about string theory that will explain it. But it still doesn't look like it's going to answer every question. And why is there one time, not two? It doesn't seem like it's... I don't even know what it would mean to answer every question.

Well, to answer every question, obviously, so when you refer to the theory of everything, you'll be able to have a... If it exists, it would be a theory that allows you to predict precisely the behavior of objects in the universe and their movement, right? What about them? Their movement, like precisely no matter the object? Right. That's true. So that would be a really interesting state of affairs if we could predict everything but not necessarily understand everything. So for example, let's just forget about gravity. I mean, we're not too far from that situation. If we forget about gravity, the standard model in principle, given a big enough computer, predicts almost everything. But if you look at the standard model, it's kind of a laundry list with neutrino masses and all that stuff. There are hundreds of free parameters. Where do they come

from? Is there an organizing principle? Is there some further unification? Sure. So being able to predict everything is not the only goal that physicists have. So on the way to trying to predict, you're trying to understand. That's actually probably the goal to understand.
Yeah. Right. We're more interested in understanding than actually doing the predictions.
But the predictions are more focusing on how to make predictions is a good way to improve your understanding because you know you've understood it if you could do the predictions.
Yeah. One of the interesting things that might come to a head with is artificial intelligence.
There's an increasing use of AI in physics. We might live in a world where AI would be able to predict perfectly what's happening. As physicists, you'll have to come to the fact that you're actually not that interested in prediction. I mean, it's very useful, but you're interested in really understanding the deep laws of nature versus a perfect predictor. Like you want to play chess. But even within AI, AI people are trying to understand what it is that the AI bots have learned in order to produce whatever they produce. For sure. But you still don't understand deeply, especially because they're getting, especially language models, if you're paying attention, the systems that are able to generate text, they're able to have conversations, chat GPTs, the recent manifestation of that. They just seem to know everything.
They're trained on the internet. They seem to be very, very good at something that looks like reasoning. They're able to generate, you can ask them questions, they can answer questions. It just feels like this thing is intelligent. I could just see that being possible with physics. You ask any kind of physical question, and it'll be able to be very precise about a particular star system or a particular black hole. You'll say, well, these are the numbers. It'll perfectly predict. Then sure, you can understand how the neural network is, the architecture is structured. Actually, for most of them now, they're very simple.
You can understand what data is trained on, huge amount of data. You're giving a huge amount of data from a very nice telescope or something. But it seems to predict everything perfectly.
How a banana falls when you throw it. Everything is perfectly predicted. You still don't have a deep understanding of what governs the whole thing. Maybe you can ask it a question. It'll be some kind of hitchhiker's guide to the galaxy type answer. It's a funny world we live in. Of course, it's also possible that there's no such deep, simple governing laws of nature behind the whole thing. There's something in us humans that wants it there to be, but doesn't have to be. Again, you're betting, you already bet the farm, but if you were to have a second farm, do you think there is a theory of everything that we might get at? Simple laws that govern the whole thing.
Honestly, I don't know, but I'm pretty confident that if there is, we won't get to it in my lifetime.
I don't think we're near it. But doesn't it feel like the fact that we have the laws we do, they're relatively simple already? That's kind of incredible.
There seems to be simple laws that govern things.
By theory of everything, you mean a theory of everything, an algorithm to predict everything.
But a simple algorithm.
A relatively simple algorithm to predict everything. For me, it would be a sad day if we arrived at that without answering some deeper questions.
Sure, of course. But the question, yes, but one of the questions before we arrive there,

we can ask, does such a destination even exist? Because asking the question and the possible answers and the process of trying to answer that question is in itself super interesting.
Is it even possible to get there where there's an equals empty square type of,
there's a function? Okay, you can have many parameters, but a finite number of parameter function that can predict a lot of things about our universe.
But just to throw one thing in, in order to answer every question,
we would need a theory of the origin of the universe. And that is a huge task.
The fact that the universe seems to have a beginning defies everything we know and love.
Because one of the basic principles of physics is determinism, that the past follows from,
the present follows from the past, the future follows from the present, so on.
But if you have the origin of the universe, if you have a big bang, that means before that,
there was nothing. You can't have a theory in which something follows from nothing.
So somehow... Sounds like you don't like singularities.
Well, I thought for somebody that works with black holes, you would get used to them by now.
No, no, I like this because it's so hard to understand. I like it because it's hard to understand, but it's really challenging. It's not a, I don't think we're close to solving that problem. And string theory has basically had nothing, there's been almost nothing interesting said about that in the last many decades.
So string theory hasn't really looked at the big bang. It hasn't really tried to get to the origin.
Not successfully. There aren't compelling papers that lots of people have read that
people have taken it up and tried to go at it, but there aren't compelling.
String theory doesn't seem to have a trick that helps us with that puzzle.
Do you think we'll be able to sneak up to the origin of the universe, like reverse engineer it,
from experimental, from theoretical perspective? Okay, if we can, what would be the trajectory?
You've already gotten yourself in trouble because you used the word reverse engineer.
Sure. So if you're going to reverse engineer, that means you forward engineering means that you take the present and determine the future. Reverse engineering means that you take the present and determine the past. Yeah. But estimate the past. But yes, sure. But if the past was nothing, how are you ever going to reverse engineer to nothing? That's hard to do.
Run up against then nothing, right? Until have mathematical models that break down nicely
to where you can actually start to infer things.
Let's work on it. No, but do you think that that...
Maybe, but it is people have tried to do things like that, but it's not something that we're getting A pluses in. Sure. Let's pretend we live in a world where in 100 years, we have an answer to that. Yeah. What would that answer look like? What department is that from? What fields led us there? Not what fields, what set of ideas in theoretical physics? Is it experimental? Is it theoretical? What can you imagine possibly could have possibly led us there? Is it through gravitational waves and some kind of observations there? Is it investigation of black holes? Is it simulation of universes? Is it maybe you start creating black holes somehow? I don't know.
Maybe some kind of high energy physics type of experiments.
Well, I have some late night ideas about that that aren't really ready for prime job.
Okay, sure. But you have some ideas. Yeah. But many people do. It could be that some of the advances in quantum information theory are important in that they go beyond taking quantum

systems and just replicating themselves, but combining them with others. Do you think
since you highlighted the issue with time and the origin of the universe,
do you think time is fundamental or emergent? I think ultimately it has to be emergent.
Yeah. What does it mean for time to be emergent?
Well, let's review what it means for space to be emergent.
Yes. What it means for space to be emergent is that you have a holographic plate
and you shine some light that's moving in space and it produces an image
which contains an extra spatial dimension and time just goes along for the ride.
So what we'd like to do, and indeed there is some rather concrete work in this direction,
though again I would say even within our stringing community we're not getting A pluses on these
efforts. What we'd like to do is to see examples in which the extra space-time dimension is time.
In other words, usually what we understand very well mathematically is how to take systems
in some number of space-time dimensions and rewrite them as a plate in fewer space dimensions.
What we'd like to do is to take systems with one time in some number of space dimensions
and to rewrite them as a system that had only space dimensions in it, had no time evolution.
And there are some fairly concrete ideas about how to do that but they're not
universally accepted even within the stringy community.
But isn't it wild to you to be emergent? How do we intuit these kinds of ideas as human beings
for whom space and time seems as fundamental as apples and oranges?
They're both illusions, even time.
You co-authored a paper titled Photon Rings Around Warped Black Holes. First of all,
whoever writes your paper titles, you like the soft hair and the term black hole and the big
bang, you're very good at coming up with titles yourself. Anyway, you co-authored a paper titled
Photon Rings Around Warped Black Holes. In it, you write, quote, recent work has identified a
number of emergent symmetries related to the intricate self-similar structure of the photon ring.
So what are photon rings? What are some interesting characteristics of a photon ring?
So that was a paper with Dan Kopitz and Alex Lipsaska that just came out.
And this paper is kind of a wonderful example of what happens when you start to talk to people who
are way out of your comfort zone of no different stuff and look at the world a different way.
And some two or three years ago, I'm part of the black hole initiative. I'm also part of this
event horizon telescope collaboration that took the famous, though I had nothing to do with the
experiment, that took the famous picture of the doughnut of M87. And through conversations with
them, which started out in an effort to understand the image that they'd seen. So it's a great thing
for somebody like me, a theoretical physicist, seemingly lost in stringland to be presented
with an actual picture of a black hole and to be asked, what can we learn from this? So
with some help from Michael Johnson and Alex Lipsaska and a bunch of other people
at the Venturizing Collaboration, we came up with a fantastic, beautiful answer using Einstein's
theory
that is both shaping the future of now it is shaping the future of improved black hole photographs.
What do you want to concentrate on in the photograph? You just pointed at the sky and
click. No, you don't do that. You optimize for various features. And it's both shaping that and
in the process of talking to them and thinking about how light behaves around a black hole,
black holes just have so many magic tricks and they do so many weird things. And the photon ring

is among the weirdest of them. We understood the photon ring and in the process of this, we said, hey, this photon ring has got to be telling us something about the puzzle of where the holographic plate is outside of an ordinary astrophysical black hole. I mean, we nailed it for the stringy black holes, but they have a somewhat different character.
What's a stringy black hole? The black holes that describe us?
The black holes that are contained in string theory and they have different structure in them.
Sure. Well, actually, can we start back? So what was the light in the image taken in 2019?
Okay. Well, not taken in 2019, presented in 2000. So here's the puzzle. What they really saw, so the black holes tend to gather stuff that swirls around it. Yeah. And they don't know what that stuff is made of. They don't know what its temperature is. They don't know what kind of magnetic fields there are around there. So the form of the image has a lot of unknowns in it that it's dependent on many other things other than the geometry of the black hole. So most of what you're learning is about the stuff. Now, the stuff, the swirling stuff, the hot swirling stuff is interesting as hell, but it's not as interesting as the black hole, which are the most, in my view, the most interesting things in the universe. So you don't want to just learn about the stuff. You want to learn about the black hole that is swirling around. So at the very first step at the very primitive level, this is just a big lead for human civilization to be able to see a black hole and the way you can see it is because there's stuff around it. But you don't get to learn much about the black hole, but you get to learn more about the stuff just from the image. Yeah. But you're not going to learn about the details before you've even seen it. Because there's too many parameters. There's too many variables that govern the stuff. Yeah. So then we found a very wonderful way to learn about the black hole. And here's how it works. A black hole is a mirror. And the way it's a mirror is if light, a photon bounces off your face towards the black hole and it goes straight to the black hole, just falls in, you never see it again. But if it just misses the black hole, it'll swing around the back and come back to you. And you see yourself from the photon that went around the back of the black hole. But not only can that happen, the black hole, the photon can swing around twice and come back. So you actually see an infinite number of copies of yourself. Like with a little bit of a delay.
With a little bit of a delay, right? This is awesome. Yeah. And in fact, I mean, we're not used to an object that bends light like that, right? Yeah.
So you're going to get some trippy effects. Yeah. And in fact, one of my students has made a really awesome computer animation of this, which I'm going to show in a public lecture in a couple of weeks where the audience will see infinitely many copies of themselves swirling around the black hole. So it's, a black hole is like a hall of mirrors, you know, like in a department store where you go and there's the three mirrors and you see infinitely many copies of yourself. Yeah. So think of the black hole as the mirror. You know, and you go in there with your clothes. If you want to know about your clothes, you just look at the direct image. You're not learning anything about the configuration of mirrors. But the relation of the image you see in front of you to the one you see at the side and the next one and then so on depends only on the mirrors. It doesn't matter what clothes you're wearing. So you can go there a thousand times wearing different clothes, but each time, there will be the same relation between the subsequent images. And that is how

we're going to learn about the black holes. We're going to take the stuff that is swirling around and we're going to tease out the subsequent images and look at their relation. And there's some very beautiful, really beautiful mathematics, which we were surprised to realize with the volumes
and volumes of papers on black holes and their properties. This particular, because it was a physical question that had never been asked in exactly this way. So basically you're looking at the... The relation between the subsequent images. The relation, but those are ultimately formed by photons that are swirling around. Photons that are orbiting. So the photon ring
are the photons that orbit around. And beyond. So orbit and lose orbit.
Wow. And that starts to give you, what can you possibly figure out mathematically about the black hole? Did geometry of it, does the spin of it? The geometry, the spin. And you can verify things behaving... We have never seen a region of spacetime with such high curvature. I mean, the region around a black hole is crazy. It's not like in this room. The curvature is everything. You spend probably enough time with the math and the photons. Can you put yourself in that space? So we're having a conversation in pretty peaceful, comfortable, flat space. Are you able to put yourself in the place around a black hole? Yeah, I'm able to imagine that kind of thing. Yeah. So for example, and actually there's a wonderful movie in her stellar. And in that movie, Kip Thorne, of course, is a great theoretical physicist, experimental, who later won the Nobel Prize for LIGO. And that movie is very accurate scientifically. And there's some funny statements in there that of the hundred million people who saw that movie, there can't be more than 10 or 20 understood about why Matthew McConaughey is ejecting the trash in a certain direction in order to... But for example, if I were a spinning black hole right here, if I was spinning fast enough, you wouldn't be able to stay still there. You'd have to be orbiting around like that. You'd have to have your microphone on a roof.
But I wonder what the actual experience is because space itself is curved.
Well, if space gets very curved, you get crushed.
You know, body gets ripped apart because the forces are different on different parts.
Sure. Okay, so that would be... But if it can be less curved so that the curvature is very noticeable, but you're not ripped apart. The fact that this was just nonchalantly stated is just beautiful. Like two biological systems discussing which level of curvature is required to rip apart said biological system. Very well. So you propose in the paper that a photon ring of a warped black hole is indeed part of the black hole hologram. A photon ring of a warped black hole is indeed part of the black hole hologram. So what can you intuit about the hologram? And the holographic plate from looking at the photon rings?
Well, this paper is exploring a new idea. It's not making a new discovery, so to speak. It's exploring an idea and the ins and outs of it and what might work and what might not. And this photon ring, somehow everybody always thought that the holographic plate sat at the horizon of the black hole and that the quantum system that describes the black hole is inside the horizon. And in fact, we think it's plausible and we give some evidence in some soluble examples. In this case, in an example in one lower dimension where we can handle the equations better, that the quantum system that describes the black hole should correspond to a region of spacetime, which includes the photon ring. So it's bigger.
So that would be the holographic plate?

That would be the holographic plate.
All of that.
We didn't prove this. We put it out there. It hadn't really been considered previously.
We put it out there and it does seem more plausible than the idea that it sits literally at the horizon. And it is a big outstanding problem of how you have a holographic reconstruction of black holes like M87.
Do you think there could be further experimental data that helps explore some of these ideas that you have for photon rings and holographic plates through imaging and through high and high resolution images and also just more and more data?
I wish so, but I don't think so. But what I think already has happened and will continue to happen is that there are many different ways that theorists and observers can interact. The gold standard is the theorist makes a prediction, the observer measures it and confirms it, or the observer makes a discovery and the theorist explains it. But there's a lot less than that, which is really the bread and butter. Those are dramatic moments when that happens. Those are once-in-a-lifetime moments when that happens. But the bread and butter is more when it has already happened. They came to us and said, what is the interesting theoretical things we can understand in this swirl around the black hole? We gave an answer and then that in turn jogged us to think about the holographic principle in the context of M87 a little bit differently. In the same vein, it's useful to talk to the philosophers and it's useful to talk to the mathematicians. We don't know where we're going. We just got to do everything. Let me ask you another philosophical type of question, but not really actually. It's not just mathematics that makes progress in theoretical physics, but thought experiments do. They did for Einstein as well. They did for a lot of great physicists throughout history. How's your ability to generate thought experiments or just your intuition about some of these weird things like quantum mechanics or string theory or quantum gravity or even general relativity? How's your intuition improved over the years? Have you been able to make progress? The hard part in physics is most problems are either doable. Most problems, the theoretical calculation that a theoretical physicist would do, there's no end of problems whose answer is uninteresting, can be solved, but the answer is uninteresting. There's also no end of problems that are very interesting, some of which you've asked me, but we don't have a clue how to solve them.
When first presented with a problem, almost every problem is one or the other.
It's the jackpot when you find one that isn't one or the other.
Seems like there's a gray area between the two, right? That's where you should be looking.
Well, I wouldn't describe it as a gray area. I would describe it as a knife edge.
So it's a very small area. There isn't a huge area with a sign, here lie problems that are doable and people want to know the answer.
In some deep sense, that's where timing is everything, with physics, with science, with discovery. With timing. I think earlier in my career, I aired more on the side of problems that were not solvable. The ambition of youth.
What made you fall in love with physics at first, if you can go back to the early days?
You said black holes were there in the beginning. Do you remember what really made you fall in love?

I wanted to reach Nirvana and I realized that wasn't going to happen.
Then after that, I wanted to know the meaning of life. I realized I probably wasn't going to figure that out and then I wanted to understand justice and socialism and world things and couldn't figure those out either. Smaller and smaller problems.
Smaller and smaller problems. I mean, most of this stuff, I'm talking about adolescence.
But it was the biggest problem that I thought that there was a prospect of,
but not 100% and I was definitely ready to spend my life in the wilderness
knocking my head against the wall. I haven't solved them, but I've said enough interesting things that you're interviewing me. So I'm not in the wilderness, but yeah.
Do you remember the early days? Do you feel nostalgic when you think back to the ideas,
the circumstances that led you down the path towards black holes, towards theoretical physics, towards the tools of physics, towards this really fascinating world of theoretical physics?
Well, I wouldn't add nostalgia to it because
it's not like a summer in Italy or something. It's like there's
results that are there that people are, and that's what's so gratifying.
I mean, of course one's name disappears from these things, unless you're Einstein or Newton or something. People are not going to remember my name in 50 years.
Well, basically every name will be forgotten in hundreds of years. Are you able to, by the way, love the exploration of ideas themselves without the names, the recognition?
Yeah, that's what I'm saying. So I have not, I hope someday, but I have not.
There are some experiments now to verify some of my predictions about properties of gravity and so on, but I have not. Most of what I've done is, it could happen still. It's still a logical possibility that everything having to do with string theory. As we mentioned, I'm betting the farm that it's not, but it is indeed a logical possibility that people always say,
can you believe Lex Fridman interviewed Elon Musk in Kenya West? And
then he interviewed Strominger, who was working on this theory that just completely went into the toilet. I'm going to make, I'm going to get, with a wife I don't have, I'm going to make a public statement. She'll be on stage. I'll say, I'm really sorry. I made a giant mistake of platforming this wild-eyed physicist that believed for decades in the power of theoretical physics. Yes. No, like you said. So that could happen. It could happen. It could happen. It's in the, and of course, if that couldn't happen, it wouldn't be real exploration, right? Absolutely.
And so, but I do take a lot of satisfaction that some of the things I discovered are at the minimum mathematical truths and they're still, so you don't have that sort of nostalgic feeling of it being something that was
gone and I'm still making discoveries now that I'm as excited about, we'll see if they hold the test of time that stand the test of time that these other ones did, but that I'm as excited about as I was about those when I made them. I am easily excitable, as my friends will tell you. Well, one interesting thing about you is- And I have been very excited about things which turned out to be completely wrong, you know? Well, that's the, the excitement is a precondition for breakthroughs, but you're also somebody like just like you said,
you don't have a cynical view of the modern state of physics. No. So there's a lot of people that glorify like the early days of string theory and that, you know, all the, you know, all the things that were made in the 20th century. But you're saying like this, this to you might be one

of, if not the most exciting times to be a theoretical physicist, like when the alien civilizations 500 years from now that visit Earth will look back those that think the 21st century, some of the biggest discoveries ever were made in the 21st century. Yeah, I mean when they have a, when they have a measurement of string theory, the fun's over. Then we have to go on to something new, you know? No, there's deep, there's, there's going to be, the fun is over. Oh man.
But there is an end to the Nile, right? I mean, there, that there's- Is there?
Who told you? Some whiteboard guy. Let me, let me ask you another trippy out there question. So again, perhaps unanswerable from a physics perspective, but do you wonder about alien civilizations? Do you wonder about other intelligent beings out there, making up their own math and physics, trying to figure out the world? Do you think they're, they're out there? It is hard to understand why there would, given that there's so many planets and of course there's Drake's formula and we don't exactly know what the, but I mean, I think Fermi's paradox that, you know, is a real paradox. And I, I think there, there probably are. And I think it's very exciting that, you know, we might, you know, find some, it's, it's a logical possibility that we could learn about it.
I mean, to me, it's super interesting to think about aliens from a perspective of physics, because so any intelligent civilization is going to be contending with the ideas that you're trying to understand the world around it. So I think that the alien, I think that the universe is filled with alien civilizations. So they're all have their physicists, right? They're all have their, they're all trying to understand the world around them. And it's just interesting to me to imagine all these different perspectives, all these different Einstein's, like trying to make sense of like, though they might be more different than we think, they might be different in a way that we haven't even thought of, like smarter or different, just, just different. Something that we don't even, we're not even able to describe now. We just haven't thought of it, you know, me. Yeah. Yeah. This, this is a really frustrating thing when we think from me as an AI person, you start to think about what is intelligence, which is consciousness. And you start to, sometimes again, like evening thoughts is how little we understand, how narrow our thinking is about these concepts. Yeah. Yeah. That, that it could be intelligence, could be something could be intelligent and be very different, intelligent in a very different way. They won't be able to detect because we're not keeping an open mind, open enough mind. And that's kind of sad because to me, there's also just a strong possibility that aliens or something like alien intelligence or some fascinating, beautiful physical phenomena are all around us. And we're too down to see it for now, or too closed-minded to see it. There's something we're just deeply missing, whether it's like fundamental limitations or like fundamental limitations of our cognitive abilities, or just because our tools are too primitive right now. Or like the way we, it's like you said, like the idea seemed trivial once you figured it all out, looking back. Yeah. But that kind of makes me sad because there's could be so much beauty in the world we're not seeing. Because we're too dumb.
There surely is. And that's, I guess the process of science and physics is to keep exploring, to keep exploring, to find the thing that will in a century seem obvious.
Well, something we know for sure. I mean, the brain we don't really understand. And that's got to be some fabulously beautiful story. I'm hoping some of that story will be written through the process of trying to build a brain. So the process of engineering intelligence, not just the

neuroscience
perspective of just looking at the brain, but trying to create it. But yeah, that story hasn't been written almost at all. Or just the early days of figuring that one out. But see, like you said that math is discovered. So aliens should at least have the same math as us, right?
I think so. Maybe different symbols. Oh, well, they might have discovered different.
They might have discovered it differently. And they might have had a different idea of what a proof is. Sure. Yeah. We're very black and white with the proof thing.
Yeah. Maybe they're looser. Right. So you can know something is true. First of all, first of all, you never know something is true with 100% uncertainty. I mean, you might have had a blackout. It's never 100%, right? You might have had a momentary lapse of consciousness, a key step in the proof, and nobody read it and whatever. Okay. So you never know for sure. But you can have a preponderance of evidence. And preponderance of evidence is not accepted very much in mathematics. And that was sort of how the famous Ramanujan work worked. He had formulas which he guessed at, and then he gathered a preponderance of evidence
that he was sure they were true. So there might be or something completely different.
They might function in a very different way. Let me ask you a kind of a heavy question for physicists. But one on nuclear weapons, just in general, what do you think about nuclear weapons where, like philosophical level, where brilliant physicists and brilliant engineering leads to thing that can destroy human civilization? Sort of like some of the ideas that you're working on have power when engineered into machines, into systems. Is there some aspect of you that worries about that? Well, first of all, I don't know what the brilliant had to do with it, because of course, Oppenheimer and all that, okay, they did it really fast. But if you didn't have Oppenheimer, I mean, would all have happened anyway? It had a reality of its own. The possibility
of making a nuclear, it didn't depend on the fact that the physicists who built it were brilliant. Maybe that sped it up by a year or two years. But by now, we'd have nuclear weapons. It's something that- So the ideas have momentum and that they're unstoppable.
Right. The possibility of making nuclear weapons was discovered. It was there before, we didn't, it's not like somebody made it. Without Picasso, there would never have been a Guernica, but without Oppenheimer, there would surely have still been an atom bomb.
But timing matters, right? Timing's very important. There's a guy who must have-
Of course, of course, of course, of course, the timing mattered there.
But I, yeah, okay, I mean, you could try to make a case for stopping-
No, no, no, it's the case of carrying the burden of the responsibility of the power of ideas when manifested through systems. So it's not a game. It's not just a game of fun mathematics. Just same with artificial intelligence. You have this, a lot of people in AI, in the AI community, it's a fascinating, fun puzzle how to make systems more and more intelligent, how to, you have a bunch of benchmarks. You're trying to make them perform better and better and better. And all of a sudden, you have a system that's able to outsmart people. It's now able to be used in geopolitics. It's able to create super intelligent bots that are able to, at scale, control the belief of a population of people. And now you can have world wars. You can have a lot of really risky instabilities- They're incredible. They really are incredible.

And so there's some responsibility. This is not sort of, it's a beauty and a power and a terror to these ideas. Yeah. At that moment, it was certainly a question for Oppenheimer and everybody who participated in that. What is the responsible way to serve society when you're sort of accidentally in this position of being at the forefront of a development that has a huge impact on society? I don't see my work a likelihood of having a huge impact on the development of society itself. But if I were you working on AI, I think that there is a possibility there. And that it is as a responsible scientist that it's really not a good thing to say, I'm just the scientist here and I'm figuring out what's possible because you're in a role where you have more of a podium to influence things than other people and it's your responsibility as a citizen of the planet. Or let me phrase it a little less shoddy. You have an opportunity as a citizen of the planet to make the world a better place, which it would be sad to bypass. Yes, a nice world without going. It'd be nice to keep it going for a little bit longer. Andrew, I'm really honored that you sit down with me. Thank you for your work. Thank you for your time. Well, it was a really great conversation. I really enjoyed it. You really covered a lot. I can't believe you're able to discuss at this level on so many different topics. It's a pleasure. It was super fun. Thank you. Thanks for listening to this conversation with Andrew Stromiger. To support this podcast, please check out our sponsors in the description. And now, let me leave you with some words from Warner Heisenberg. Not only is the universe stranger than we think, it is stranger than we can think. Thank you for listening and hope to see you next time.